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Contents

Intellectual Property Rights	2
Legal Notice	2
Modal verbs terminology.....	2
Foreword.....	14
Introduction	15
1 Scope	16
2 References	16
3 Definitions of terms, symbols and abbreviations	20
3.1 Terms.....	20
3.2 Symbols.....	21
3.3 Abbreviations	21
4 Overview of video codec capabilities in 3GPP services in Release 17	23
4.1 Introduction	23
4.2 TV Video Profiles	23
4.3 VR Video Profiles	24
4.4 5G Media Streaming	25
4.4.1 Introduction.....	25
4.4.2 5GMS Downlink Streaming default profile	25
4.4.2.1 H.264 (AVC).....	25
4.4.2.2 H.265 (HEVC)	25
4.4.2.3 Encapsulation format	25
4.4.3 5GMS Uplink Streaming default profile.....	26
4.4.3.1 H.265 (HEVC)	26
4.4.3.2 Encapsulation format	26
4.4.4 5GMS Television (TV) profile.....	26
4.4.4.1 H.264 (AVC).....	26
4.4.4.2 H.265 (HEVC)	26
4.4.4.3 Encapsulation format	26
4.4.5 5GMS Downlink 360 Virtual Reality (VR) profile	26
4.4.5.1 H.264 (AVC).....	26
4.4.5.2 H.265 (HEVC)	26
4.4.5.3 Encapsulation format	27
4.5 Multimedia Telephony Services over IMS.....	27
4.5.1 Introduction.....	27
4.5.2 H.264 (AVC)	27
4.5.3 H.265 (HEVC).....	27
4.5.4 Encapsulation format	27
4.6 Messaging Services	27
4.7 Screen Content Coding.....	28
5 Test and Characterization Framework for Video Codecs	28
5.1 Overview	28
5.2 Reference Sequences	29
5.3 Anchors	29
5.4 Reference Software Tools	30
5.5 Metrics.....	31
5.5.1 General.....	31
5.5.2 Bitrate	31
5.5.3 Quality Metrics - General	32
5.5.4 SDR Quality Metrics	32
5.5.4.1 Overview	32
5.5.4.2 Structural similarity metric MS-SSIM	32
5.5.5 HDR Quality Metrics.....	34

5.5.6	Anchor Tuple Metrics Reporting	34
5.5.7	Reference computation of SDR metrics.....	36
5.5.8	Reference computation of HDR metrics	36
5.6	General encoding constraints	37
5.7	Tests	37
5.8	Characterization	38
5.9	Verification.....	42
5.9.1	Principles	42
5.9.2	Documentation.....	43
6	Relevant Scenarios	44
6.1	Introduction	44
6.2	Scenario 1: Full HD Streaming	45
6.2.1	Motivation.....	45
6.2.2	Description of the Anticipated Application	45
6.2.3	Source Format Properties.....	46
6.2.4	Encoding and Decoding Constraints.....	46
6.2.5	Performance Metrics.....	47
6.2.6	Interoperability Considerations.....	47
6.2.7	Reference Sequences	48
6.2.8	Anchor Definition	48
6.2.8.1	Overview	48
6.2.8.2	H.264/AVC Anchors.....	48
6.2.8.2.1	Overview	48
6.2.8.2.2	S1-JM-01	49
6.2.8.3	H.265/HEVC Anchors	50
6.2.8.3.1	Overview	50
6.2.8.3.2	Common Parameters and Settings	50
6.2.8.3.3	S1-HM-01: SDR Settings	51
6.2.8.3.4	S1-HM-02: HDR PQ Settings	51
6.2.9	Anchor Results.....	51
6.2.9.1	H.264/AVC Anchors.....	51
6.2.9.2	H.265/HEVC Anchors	52
6.3	Scenario 2: 4K-TV	52
6.3.1	Motivation.....	52
6.3.2	Description of the Anticipated Application	53
6.3.3	Source Format Properties.....	54
6.3.4	Encoding and Decoding Constraints.....	54
6.3.5	Performance Metrics.....	54
6.3.6	Interoperability Considerations.....	55
6.3.7	Reference Sequences	55
6.3.8	Anchor Definition	56
6.3.8.1	Overview	56
6.3.8.2	H.264/AVC Anchors.....	56
6.3.8.3	H.265/HEVC Anchors	56
6.3.8.3.1	Overview	56
6.3.8.3.2	Common Parameters and Settings	56
6.3.8.3.3	S2-HM-01: SDR Settings	57
6.3.8.3.4	S2-HM-02: HDR PQ Settings	57
6.3.9	Anchor Results.....	57
6.3.9.1	H.264/AVC Anchors.....	57
6.3.9.2	H.265/HEVC Anchors	57
6.4	Scenario 3: Screen Content Scenario.....	58
6.4.1	Motivation.....	58
6.4.2	Description of the Anticipated Application	59
6.4.3	Source Format Properties.....	59
6.4.4	Encoding and Decoding Constraints.....	59
6.4.5	Performance Metrics.....	60
6.4.6	Interoperability Considerations.....	60
6.4.7	Reference Sequences	60
6.4.8	Anchor Definition	61
6.4.8.1	Overview	61

6.4.8.2	H.264/AVC Anchors.....	61
6.4.8.2.1	Overview	61
6.4.8.2.2	Common Parameters	61
6.4.8.2.3	S3-JM-01: no random access.....	62
6.4.8.2.3	S3-JM-02: fixed Intra every second	62
6.4.8.3	H.265/HEVC Anchors	63
6.4.8.3.1	Overview	63
6.4.8.3.2	Common Settings	64
6.4.8.3.3	S3-HM-01 and S3-HM-03: Main 10 Profile with no fixed Intra	65
6.4.8.3.4	S3-HM-02 and S3-HM-04: Main 10 Profile with fixed Intra every second	65
6.4.8.3.5	S3-SCC-01 and S3-SCC-03: Screen Content Profile with no fixed Intra.....	65
6.4.8.3.6	S3-SCC-02 and S3-SCC-04: Screen Content Profile with fixed Intra every second	65
6.4.9	Anchor Results.....	66
6.4.9.1	H.264/AVC Anchors.....	66
6.4.9.2	H.265/HEVC Anchors	66
6.4.10	Additional information and external performance data	70
6.5	Scenario 4: Messaging and Social Sharing.....	70
6.5.1	Motivation.....	70
6.5.2	Description of the Anticipated Application	71
6.5.3	Source Format Properties.....	73
6.5.4	Encoding and Decoding Constraints.....	73
6.5.5	Performance Metrics	74
6.5.6	Interoperability Considerations.....	74
6.5.7	Reference Sequences	74
6.5.8	Anchor Definition	75
6.5.8.1	Overview	75
6.5.8.2	H.264/AVC Anchors.....	75
6.5.8.2.1	Overview	75
6.5.8.2.2	Common Parameters	75
6.5.8.2.3	S4-JM-01: no random access.....	76
6.5.8.2.4	S4-JM-02: random access near 1 sec.....	76
6.5.8.3	H.265/HEVC Anchors	76
6.5.8.3.1	Overview	76
6.5.8.3.2	Common Parameters	77
6.5.8.3.4	S4-HM-02: Intra	77
6.5.9	Anchor Results.....	78
6.5.9.1	H.264/AVC Anchors.....	78
6.5.9.2	H.265/HEVC Anchors	78
6.6	Scenario 5: Online Gaming	79
6.6.1	Motivation.....	79
6.6.2	Description of the Anticipated Application	80
6.6.3	Source Format Properties.....	80
6.6.3.1	Introduction	80
6.6.3.2	Category A: Low/medium dynamicity with low/medium complexity.....	81
6.6.3.3	Category B: games with high dynamicity and low/medium complexity.	81
6.6.3.4	Category C: games with high dynamicity and high complexity.	81
6.6.3.5	Category D: photo-realistic games or games based on natural images/video.	81
6.6.3.6	Category E: XR game content.....	81
6.6.3.7	Summary	81
6.6.4	Encoding and Decoding Constraints.....	82
6.6.5	Performance Metrics	83
6.6.6	Interoperability Considerations.....	83
6.6.7	Reference Sequences	83
6.6.8	Anchor Definition	84
6.6.8.1	Overview	84
6.6.8.2	H.264/AVC Anchors.....	84
6.6.8.2.1	Overview	84
6.6.8.2.2	Common Parameters	84
6.6.8.2.3	S5-JM-01: no random access.....	85
6.6.8.2.4	S5-JM-02: random access near 1 sec.....	85
6.6.8.3	H.265/HEVC Anchors	85
6.6.8.3.1	Overview	85

6.6.8.3.2	Common Parameters	86
6.6.8.3.3	S5-HM-01: Main 10 Profile with no fixed random access	87
6.6.8.3.4	S5-HM-02: Main 10 Profile with fixed random access near 1 sec	87
6.6.8.3.5	S5-SCC-01: Screen Content Profile with no fixed random access	87
6.6.8.3.6	S5-SCC-02: Screen Content Profile with random access near 1 sec	87
6.6.9	Anchor Results.....	88
6.6.9.1	H.264/AVC Anchors.....	88
6.6.9.2	H.265/HEVC Anchors	89
7	Characterization Framework	90
7.1	Introduction	90
7.2	Characterization against 3GPP Anchor Codecs	91
7.3	H.265/HEVC Characterization against H.264/AVC	93
7.3.1	Introduction	93
7.3.2	H.265/HEVC HM against H.264/AVC	93
7.3.2.1	Overview	93
7.3.2.2	Scenario 1: Full HD	93
7.3.2.3	Scenario 3: Screen Content	94
7.3.2.4	Scenario 4: Messaging and Social Sharing	96
7.3.2.5	Scenario 5: Online Gaming	98
7.3.2.6	Summary	100
7.3.3	H.265/HEVC SCC against H.264/AVC	101
7.3.3.1	Overview	101
7.3.3.2	Scenario 3: Screen Content	101
7.3.3.3	Scenario 5: Online Gaming	103
7.3.3.4	Summary	105
7.4	Characterization of different HEVC modes	106
7.4.1	Introduction	106
7.4.2	H.265/HEVC SCC against H.265/HEVC HM	106
7.4.2.1	Introduction	106
7.4.2.2	Scenario 3: Screen Content	106
7.4.2.3	Scenario 5: Online Gaming	108
7.4.2.4	Summary	110
7.5	External Characterization Results	111
7.5.1	Introduction.....	111
7.5.2	H.265/HEVC Characterization against H.264/AVC.....	111
8	Initial Information on new Codecs	112
8.1	Introduction	112
8.2	Versatile Video Coding (VVC)	112
8.2.1	Overview	112
8.2.2	Test Configurations and Results for VTM.....	113
8.2.2.1	Introduction.....	113
8.2.2.2	Scenario 1: Full HD Streaming.....	113
8.2.2.2.1	Overview	113
8.2.2.2.2	Common Parameters and Settings	113
8.2.2.2.3	SDR Settings: S1-VTM-01.....	114
8.2.2.2.4	HDR PQ Settings: S1-VTM-02	114
8.2.2.2.5	Test Results	114
8.2.2.3	Scenario 2: 4K-TV	115
8.2.2.3.1	Overview	115
8.2.2.3.2	Common Parameters and Settings	115
8.2.2.3.3	SDR Settings: S2-VTM-01.....	116
8.2.2.3.4	HDR PQ Settings: S2-VTM-02	116
8.2.2.3.5	Test Results	116
8.2.2.4	Scenario 3: Screen Content Scenario	117
8.2.2.4.1	Overview	117
8.2.2.4.2	Test Model and Configurations	118
8.2.2.4.2.1	Common Parameters	118
8.2.2.4.2.2	S3-VTM-01/03: Main 10 Profile with no fixed Intra.....	118
8.2.2.4.2.3	S3-VTM-02/04: Main 10 Profile with fixed Intra every second.....	119
8.2.2.4.3	Test Results	119

8.2.2.5	Scenario 4: Messaging and Social Sharing	120
8.2.2.5.1	Overview	120
8.2.2.5.2	Test Model and Configurations	121
8.2.2.5.2.1	Common Parameters	121
8.2.2.5.2.2	S5-VTM-01: Main 10 Profile with no fixed Intra	121
8.2.2.5.2.3	S5-VTM-02: Main 10 Profile with fixed Intra every second	121
8.2.2.5.3	Test Results	121
8.2.2.6	Scenario 5: Online Gaming	122
8.2.2.6.1	Overview	122
8.2.2.6.2	Test Model and Configurations	122
8.2.2.6.2.1	Common Parameters	122
8.2.2.6.2.2	S5-VTM-01: Main 10 Profile with no fixed Intra	123
8.2.2.6.2.3	S5-VTM-02: Main 10 Profile with fixed Intra every second	123
8.2.2.6.3	Test Results	123
8.2.3	H.266/VVC Characterization against H.264/AVC	124
8.2.3.1	Overview	124
8.2.3.2	Scenario 1: Full HD	124
8.2.3.3	Scenario 3: Screen Content	124
8.2.3.4	Scenario 4: Messaging and Social Sharing	125
8.2.3.5	Scenario 5: Online Gaming	125
8.2.3.6	Summary	125
8.2.4	H.266/VVC Characterization against H.265/HEVC HM	125
8.2.4.1	Overview	125
8.2.4.2	Scenario 1: Full HD	125
8.2.4.3	Scenario 2: 4K TV	127
8.2.4.4	Scenario 3: Screen Content	129
8.2.4.5	Scenario 4: Messaging and Social Sharing	131
8.2.4.6	Scenario 5: Online Gaming	133
8.2.4.7	Summary	135
8.2.5	H.266/VVC against H.265/HEVC SCC	136
8.2.5.1	Introduction	136
8.2.5.2	Scenario 3: Screen Content	136
8.2.5.3	Scenario 5: Online Gaming	139
8.2.5.4	Summary	141
8.2.6	External subjective tests results	142
8.3	Essential Video Coding (EVC)	143
8.3.1	Overview	143
8.3.2	Test Configurations and Results for EVC	144
8.3.2.1	Introduction	144
8.3.2.2	Scenario 1: Full HD Streaming	144
8.3.2.2.1	Overview	144
8.3.2.2.2	Test Model and Configurations	145
8.3.2.2.2.1	S1-ETM-01: SDR Configuration	145
8.3.2.2.2.2	S1-ETM-02: HDR Configuration	145
8.3.2.2.3	Test Results	146
8.3.2.3	Scenario 2: 4K-TV	146
8.3.2.3.1	Overview	146
8.3.2.3.2	Test Model and Configurations	147
8.3.2.3.2.1	S2-ETM-01: SDR Configuration	147
8.3.2.3.2.2	S2-ETM-02: HDR Configuration	147
8.3.2.3.3	Test Results	147
8.3.2.4	Scenario 3: Screen Content Scenario	148
8.3.2.4.1	Overview	148
8.3.2.4.2	Test Model and Configurations	149
8.3.2.4.2.1	S3-ETM-01: no fixed random access	149
8.3.2.4.2.2	S3-ETM-02: fixed random access every second	149
8.3.2.4.3	Test Results	150
8.3.2.5	Scenario 4: Messaging and Social Sharing	151
8.3.2.5.1	Overview	151
8.3.2.5.2	Test Model and configurations	152
8.3.2.5.2.1	S4-ETM-01: no random access	152
8.3.2.5.2.2	S4-ETM-02: fixed random access every second	152

8.3.2.5.3	Test Results	152
8.3.2.6	Scenario 5: Online Gaming	153
8.3.2.6.1	Overview	153
8.3.2.6.2	Test Model and configurations	153
8.3.2.6.2.1	S5-ETM-01: no random access	153
8.3.2.6.2.2	S5-ETM-02: fixed random access every second	154
8.3.2.6.3	Test Results	154
8.3.3	EVC Characterization against H.264/AVC	155
8.3.3.1	Overview	155
8.3.3.2	Scenario 1: Full HD	155
8.3.3.3	Scenario 3: Screen Content	155
8.3.3.4	Scenario 4: Messaging and Social Sharing	156
8.3.3.5	Scenario 5: Online Gaming	156
8.3.3.6	Summary	156
8.3.4	EVC ETM Characterization against H.265/HEVC HM	156
8.3.4.1	Overview	156
8.3.4.2	Scenario 1: Full HD	156
8.3.4.3	Scenario 2: 4K TV	158
8.3.4.4	Scenario 3: Screen Content	160
8.3.4.5	Scenario 4: Messaging and Social Sharing	162
8.3.4.6	Scenario 5: Online Gaming	164
8.3.4.7	Summary	166
8.3.5	EVC Characterization against H.265/HEVC SCC	167
8.3.5.1	Introduction	167
8.3.5.2	Scenario 3: Screen Content	167
8.3.5.3	Scenario 5: Online Gaming	169
8.3.5.4	Summary	172
8.4	AOMedia Video 1 (AV1)	173
8.4.1	Overview	173
8.4.2	Test Configurations and Results for AV1	173
8.4.2.1	Introduction	173
8.4.2.2	Scenario 1: Full HD Streaming	175
8.4.2.2.1	Overview	175
8.4.2.2.2	Common Parameters and Settings	175
8.4.2.2.3	S1-AV1-01: SDR Settings	175
8.4.2.2.4	S1-AV1-02: HDR PQ Settings	176
8.4.2.2.5	AV1 Test Results	176
8.4.2.3	Scenario 2: 4K-TV	177
8.4.2.3.1	Overview	177
8.4.2.3.2	Common Parameters and Settings	177
8.4.2.3.3	S2-AV1-01: SDR Settings	178
8.4.2.3.4	S2-AV1-02: HDR PQ Settings	178
8.4.2.3.5	AV1 Test Results	178
8.4.2.4	Scenario 3: Screen Content Scenario	179
8.4.2.4.1	Overview	179
8.4.2.4.3	S3-AV1-01 and S3-AV1-03: Main 10 Profile with no fixed random access	180
8.4.2.4.4	S3-AV1-02 and S3-AV1-04: Main 10 Profile with fixed random access every second	181
8.4.2.4.5	S3-AV1-SCC-01 and S3-AV1-SCC-03: Screen Content Profile with no fixed random access	181
8.4.2.4.6	S3-AV1-SCC-02 and S3-AV1-SCC-04: Screen Content Profile with fixed random access every second	182
8.4.2.4.7	AV1 Test Results	182
8.4.2.5	Scenario 4: Messaging and Social Sharing	183
8.4.2.5.1	Overview	183
8.4.2.5.2	Common Parameters and Settings	183
8.4.2.5.3	S4-AV1-01: no random access	183
8.4.2.5.4	S4-AV1-02: Intra	183
8.4.2.5.5	Test Results	184
8.4.2.6	Scenario 5: Online Gaming	184
8.4.2.6.1	Overview	184
8.4.2.6.2	Common Parameters and Settings	185
8.4.2.6.3	S5-AV1-01: Main 10 Profile with no fixed Random access	185
8.4.2.6.4	S5-AV1-02: Main 10 Profile with fixed Random access every second	186

8.4.2.6.5	S5-SCC-01: Screen Content Profile with no fixed Random access.....	186
8.4.2.6.6	S5-SCC-02: Screen Content Profile with fixed Random access.....	187
8.4.2.6.7	Test Results	187
8.4.3	AV1 Characterization against H.264/AVC.....	189
8.4.3.1	Overview	189
8.4.3.2	Scenario 1: Full HD	189
8.4.3.3	Scenario 3: Screen Content	189
8.4.3.4	Scenario 4: Messaging and Social Sharing	189
8.4.3.5	Scenario 5: Online Gaming.....	189
8.4.3.6	Summary	189
8.4.4	AV1 libaom Characterization against H.265/HEVC HM	190
8.4.4.1	Overview	190
8.4.4.2	Scenario 1: Full HD	190
8.4.4.3	Scenario 2: 4K TV	191
8.4.4.4	Scenario 3: Screen Content	193
8.4.4.5	Scenario 4: Messaging and Social Sharing	195
8.4.4.6	Scenario 5: Online Gaming	197
8.4.4.7	Summary	199
8.4.5	AV1 against H.265/HEVC SCC	200
8.4.5.1	Introduction	200
8.4.5.2	Scenario 3: Screen Content	200
8.4.5.3	Scenario 5: Online Gaming	203
8.4.5.4	Summary	205
8.4.6	AV1-SCC against H.265/HEVC.....	206
8.4.7	AV1-SCC against H.265/HEVC SCC	206
9	Gaps and Optimization Potential.....	206
9.1	Identified Gaps and Deficiencies with Existing Codecs.....	206
9.2	Potential Requirements for New Codecs.....	206
10	Conclusions and Proposed Next Steps	206
Annex A:	Scenario Template	208
A.1	Introduction	208
A.2	Template.....	208
Annex B:	Data Formats and Metrics	210
B.1	Introduction	210
B.2	Raw Video Sequences	210
B.2.1	Overview	210
B.2.2	JSON Schema	211
B.2.3	Example	215
B.3	Encoded Video Sequences	215
B.3.1	Overview	215
B.3.2	JSON Schema	216
B.3.3	Example	216
B.4	Verification	217
B.4.1	Overview	217
B.4.2	JSON Schema	217
B.4.3	Example	217
B.4.4	Cross-check Report.....	218
Annex C:	Reference Sequences.....	220
C.1	Introduction	220
C.2	Gaming Test Sequences	220
C.2.1	Overview	220
C.2.2	AOV	221
C.2.2.1	Introduction.....	221

C.2.2.2	Sequence properties	222
C.2.2.3	Copyright and license information.....	222
C.2.3	Baolei-Man.....	222
C.2.3.1	Introduction.....	222
C.2.3.2	Sequence properties	223
C.2.3.3	Copyright and license information.....	223
C.2.4	Baolei-Woman	223
C.2.4.1	Introduction.....	223
C.2.4.2	Sequence properties	224
C.2.4.3	Copyright and license information.....	224
C.2.5	Baolei-Balloon	224
C.2.5.1	Introduction.....	224
C.2.5.2	Sequence properties	225
C.2.5.3	Copyright and license information.....	225
C.2.6	Baolei-Yard	225
C.2.6.1	Introduction.....	225
C.2.6.2	Sequence properties	226
C.2.6.3	Copyright and license information.....	226
C.2.7	Jianling-Temple.....	226
C.2.7.1	Introduction.....	226
C.2.7.2	Sequence properties	227
C.2.7.3	Copyright and license information.....	227
C.2.8	Jianling-Beach	227
C.2.8.1	Introduction.....	227
C.2.8.2	Sequence properties	228
C.2.8.3	Copyright and license information.....	228
C.2.9	Heroes of the Storm.....	228
C.2.9.1	Introduction.....	228
C.2.9.2	Sequence properties	229
C.2.9.3	Copyright and license information.....	229
C.2.10	Project CARS	229
C.2.10.1	Introduction.....	229
C.2.10.2	Sequence properties	230
C.2.10.3	Copyright and license information.....	230
C.2.11	World of Warcraft: WoW.....	230
C.2.11.1	Introduction.....	230
C.2.11.2	Sequence properties	231
C.2.11.3	Copyright and license information.....	231
C.2.12	Minecraft	231
C.2.12.1	Introduction.....	231
C.2.12.2	Sequence properties	232
C.2.12.3	Copyright and license information.....	232
C.2.13	CS:GO	232
C.2.13.1	Introduction.....	232
C.2.13.2	Sequence properties	233
C.2.13.3	Copyright and license information.....	233
C.2.14	StarCraft	233
C.2.14.1	Introduction.....	233
C.2.14.2	Sequence properties	234
C.2.14.3	Copyright and license information.....	234
C.3	4K-TV Sequences	234
C.3.1	SDR Category	234
C.3.1.1	Candidate Test Sequences	234
C.3.1.1.1	Introduction.....	234
C.3.1.1.2	Ultra Video Group Sequences.....	235
C.3.1.1.3	JVET Sequences	235
C.3.1.1.4	Netflix Sequences	235
C.3.1.1.5	EBU Sequences.....	236
C.3.1.1.6	SVT Sequences	236
C.3.1.1.7	4ever Sequences.....	236
C.3.1.1.8	CableLabs Sequences.....	237

C.3.1.2	Test Sequence Selection Process	238
C.3.1.2.1	Introduction	238
C.3.1.2.2	x265 Encoding	238
C.3.1.2.3	SI-TI Metrics.....	240
C.3.1.2.4	SDR Sequence Selection.....	242
C.3.1.3	Selected Sequences	244
C.3.1.3.1	Brest-Sedof.....	244
C.3.1.3.2	Rain Fruits.....	246
C.3.1.3.3	Park Joy.....	247
C.3.1.3.4	Soccer.....	248
C.3.1.3.5	Tunnel Flag	249
C.3.1.3.6	Boat	250
C.3.1.3.7	Fountain	251
C.3.1.3.8	Riverbank.....	252
C.3.2	HDR Category	253
C.3.2.1	HDR Candidate Test Sequences	253
C.3.2.1.1	Introduction	253
C.3.2.1.2	AOM Sequences	253
C.3.2.1.3	CableLabs Sequences.....	254
C.3.2.2	Selected Test Sequences	255
C.3.2.2.1	Introduction	255
C.3.2.2.2	x265 Encoding	255
C.3.2.2.3	SI-TI Metrics.....	258
C.3.2.2.4	Codewords distribution	260
C.3.2.2.5	HDR Sequence Selection	263
C.3.2.3	Selected Sequences	265
C.3.2.3.1	Life Untouched	265
C.3.2.3.2	Meridian.....	266
C.3.2.3.3	Sol Levante	267
C.3.2.3.4	Cosmos.....	268
C.3.2.3.5	Elevator	269
C.3.2.3.6	Sparks.....	270
C.3.2.3.7	Nocturne.....	271
C.3.3	HFR Category	272
C.4		HD Test
	Sequences	272
C.4.1	Overview	272
C.5		Messaging
	Sequences	273
C.5.1	Overview	273
C.5.1.1	Candidate Sequences	273
C.5.1.2	x265 encodings	273
C.5.2	Powder.....	274
C.5.2.1	Introduction.....	274
C.5.2.2	Sequence properties	275
C.5.2.3	Copyright and license information.....	275
C.5.3	Vertical Bees	276
C.5.3.1	Introduction.....	276
C.5.3.2	Sequence properties	276
C.5.3.3	Copyright and license information.....	277
C.5.4	Vertical Walking	277
C.5.4.1	Introduction.....	277
C.5.4.2	Sequence properties	277
C.5.4.3	Copyright and license information.....	278
C.5.5	Neon 4K	278
C.5.5.1	Introduction.....	278
C.5.5.2	Sequence properties	278
C.5.5.3	Copyright and license information.....	279
C.5.6	Skater 4K.....	279
C.5.6.1	Introduction.....	279

C.5.6.2	Sequence properties	279
C.5.6.3	Copyright and license information.....	279
C.6	 Screen Content Test	
	Sequences	280
C.6.1	Overview	280
C.6.2	Moving Text 2	280
C.6.2.1	Introduction.....	280
C.6.2.2	Source sequence properties.....	280
C.6.2.3	Copyright information	281
C.6.3	Text Mix Transitions	281
C.6.3.1	Introduction.....	281
C.6.3.2	Source sequence properties.....	281
C.6.3.3	Copyright information	282
C.6.4	Graphics Mix Simple.....	282
C.6.4.1	Introduction.....	282
C.6.4.2	Source sequence properties.....	282
C.6.4.3	Copyright information	283
C.6.5	Graphics Mix Transition	283
C.6.5.1	Introduction.....	283
C.6.5.2	Source sequence properties.....	283
C.6.5.3	Copyright information	284
C.6.6	Mission Control.....	284
C.6.6.1	Introduction.....	284
C.6.6.2	Source sequence properties.....	284
C.6.6.3	Copyright information	285

Annex D Data Management and Hosting.....286

D.1	Introduction	286
D.2	Reference Sequences	286
D.2.1	Hosting	286
D.2.2	Uploading	286
D.2.3	Downloading	286
D.3	Anchors and Tests	287
D.3.1	Hosting	287
D.3.2	Uploading	288
D.3.3	Downloading	288
D.4	Verification.....	288

Annex E: Software Package 289

E.1	Introduction	289
E.2	README: Video codec characterization scripts	290
E.2.1	Overview.....	290
E.2.3	installation	291
E.2.3.1	cloning	291
E.2.3.2	working directory.....	291
E.2.3.3	download content from server	291
E.2.4	vcc.py script usage	292
E.2.4.1	Overview	292
E.2.4.2	processing all QPs of an anchor.....	292
E.2.4.3	processing a single QP for an anchor.....	292
E.2.4.4	process all anchors for a given encoder config	292
E.2.4.4.1	general.....	292
E.2.4.4.2	common options	292
E.2.4.4.3	encode	292
E.2.4.4.4	decode	293
E.2.4.4.5	convert.....	293
E.2.4.4.6	metrics.....	293

E.2.4.4.6.1	storage	293
E.2.4.4.6.2	image quality metrics	293
E.2.4.4.6.3	bitrate / bitstream size	294
E.2.4.4.6.4	metrics csv export	294
E.2.5	characterization, rd curves plots, bd rate	294
E.2.6	using the scripts for metrics verification	295
E.2.6.1	General	295
E.2.6.2	working directory	295
E.2.6.3	download bitstreams for verification	295
E.2.6.4	reconstruction and metrics	296
E.2.6.4.1	generate reconstruction of bitstreams	296
E.2.6.4.2	format conversion before metrics computation	296
E.2.6.4.3	compute metrics	297
E.2.6.4.4	export metrics from .json to .csv	297
E.2.6.5	generate verification report	297
E.2.6.5.1	general	297
E.2.6.5.2	download the original metrics	297
E.2.6.5.3	metrics verification	298
E.2.7	docker usage	298
E.2.7.1	General	298
E.2.7.2	building the docker images	298
E.2.7.3	using the worker image	298
E.2.7.4	using docker-compose	299
Annex F:	Attachments	300
Annex G:	Non-verified results	301
Annex <X> (informative):	Change history	302
History		303

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

- x the first digit:
 - 1 presented to TSG for information;
 - 2 presented to TSG for approval;
 - 3 or greater indicates TSG approved document under change control.
- y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.
- z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

- shall** indicates a mandatory requirement to do something
- shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

- should** indicates a recommendation to do something
- should not** indicates a recommendation not to do something
- may** indicates permission to do something
- need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

- can** indicates that something is possible
- cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

- will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document
- will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document
- might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

might not indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

is (or any other verb in the indicative mood) indicates a statement of fact

is not (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

Introduction

Predictions on mobile video consumption are ever increasing. Different studies point to dominance of video traffic in 5G networks reaching from 65% total traffic in the short-term all the way to 90% by the end of the decade. Video is expected to be integral for services such as enhanced mobile media (such as mobile streaming services), home broadband and TV (for example in the context of 5G fixed wireless access services), immersive and interactive media in the context of eXtended Realities (XR) and cloud gaming as well as new media services from new verticals. This indicates that the user experience and efficiency of 5G networks will be heavily impacted by the quality of video compression technologies that are used with 5G services. Efficient video compression and decompression technologies required dedicated hardware for power and resource efficient real-time execution but are at the same time complex and costly in terms of implementation on integrated platforms. Hence, typically state-of-the-art video compression technologies last for several years and are used as generic service enablers for different applications and services, including traditional streaming and conversational services, but also new media services. This document analyzes the currently defined 3GPP-defined video compression technologies for their suitability for existing and emerging services in the context of 5G and identifies gaps and optimization potentials that would warrant the introduction of new video compression technologies.

1 Scope

The present technical report documents relevant interoperability requirements, performance characteristics and implementation constraints of video codecs in 5G services, and characterizes video codecs, in particular 3GPP defined codecs H.264/AVC and H.265/HEVC in order to have a benchmark for the addition of potential future video codecs. For this purpose, the document:

- Collects a summary of the video coding capabilities in 3GPP services.
- Collects a subset of relevant scenarios for video codecs in 5G-based services and applications, including video formats (resolution, frame rates, colour space, etc.), encoding and decoding requirements, adaptive streaming requirements.
- Collects relevant and exemplary test conditions and material for such scenarios, including test sequences.
- Defines performance metrics for such scenarios with focus on objective performance metrics.
- Collects relevant interoperability functionalities and enabling elements for video codecs in different 5G services such as MTSI and Telepresence (i.e. RTP based conversational communications), or 5G media streaming (e.g. based on DASH/CMAF) supporting the identified scenarios.
- Collects relevant criteria and key performance indicators for the integration of video codecs in 5G processing platforms, taking into account factors such as encoding and decoding complexity in the context of the defined scenarios.
- Provides anchors for the existing codecs H.264/AVC and H.265/HEVC in the context of the above scenarios and document the findings in a consistent manner and characterizes H.265/HEVC against H.264/AVC
- Provides initial information on EVC video codec developed in ISO/IEC SC29 WG 4 and H.266/VVC video codec developed in JVET (ITU-T SG16 Q6 and ISO/IEC SC29 WG 5) in the context of the above scenarios, including test streams and characterization results.
- Provides initial information AV1 video codec developed by the Alliance for Open Media in the context of the above scenarios, including test streams and characterization results.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

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3 Definitions of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

3GPP codec: a video codec defined in a 3GPP specification.

Anchor: combination of a reference sequence, a reference software of 3GPP codec and codec configuration to provide a baseline for codec testing and characterization.

Anchor Bitstream: a bitstream resulting from the encoding of a reference sequence with a reference software and a codec configuration assigned to an anchor.

Anchor Tuple: several anchors that differentiate only by one parameter in the codec configuration to change the bitrate/quality.

BD-Rate Gain: a measure of the bitrate reduction in percentage offered by a codec or codec feature under test compared to an anchor coded, while maintaining the same quality as measured by objective metrics.

Characterization: comparison of a codec under test with a 3GPP codec based on selected metrics.

Metric: A single number to provide a measurable quality of an anchor.

Test: combination of tools to test a codec for comparison with anchor, i.e. same reference sequence and comparable codec configuration.

Test Bitstream: a bitstream resulting from the encoding of a reference sequence with a reference software and a codec configuration assigned to a test.

Test Tuple: several tests that differentiate only by one parameter in the codec configuration to change the bitrate/quality.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

MSE_Y	Mean Square Error of the luma component
PSNRy	Peak-Signal to Noise Ratio of the luma component
PSNRu	Peak-Signal to Noise Ratio of the chroma u component
PSNRv	Peak-Signal to Noise Ratio of the chroma v component
PSNRyuv	Average PSNR over all colour components
MS_SSIM	Multi-Scale Structural Similarity Index Metric

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

AAC	Advanced Audio Coding
AAP	Alternative Approval Process
ABR	Adaptive BitRate
AOM	Alliance for Open Media
AOV	Arena Of Valor
ATSC	Advanced Television Systems Committee
AV1	AOMedia Video 1
AVC	Advanced Video Coding
AVCHD	AVC High Definition
AVI	Audio Video Interleave
BD	Bjöntegard-Delta
BDR	BD Rate
BMFF	Based Media File Format
CABAC	Context-Adaptive Binary Arithmetic Coding
CAE	Content Aware Encoding
CBP	Constrained Baseline Profile
CBR	Constant BitRate
CGI	Computed Generated Imaginary
CHP	Constrained High Profile
CMAF	Common Media Application Format
CRA	Clean Random Access
CSV	Comma-Separated Values
CTC	Common Test Conditions
CTU	Coding Tree Unit
DASH	Dynamic Adaptive Streaming over HTTP
DVB	Digital Video Broadcasting
EBU	European Broadcast Union
EFS	Effective File Size
EPZS	Enhanced Predictive Zonal Search
ERP	Equi-Rectangular Projection
EVC	Essential Video Coding
EXR	EXtended Range
FHD	Full HD (i.e. 1080p)
FPS	Frames Per Second
GOP	Group-Of-Pictures
HDMI	High-Definition Multimedia Interface
HDR	High Dynamic Range
HDTV	High Definition TeleVision
HEVC	High-Efficiency Video Coding
HFR	High Frame Rate

HLG	Hybrid Log-Gamma
HLS	HTTP Live Streaming
HMD	Head-Mounted Display
HRD	Hypothetical Reference Decoder
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
IDR	Instantaneous Decoder Refresh
JCT-VC	Joint Collaborative Team on Video Coding
JSON	JavaScript Object Notation
JVET	Joint Video Experts Team
MCTF	Motion-Compensated Temporal Filtering
MIME	Multipurpose Internet Mail Extensions
MKV	MatrosKa Video
MMO	Massive Multiplayer Online
MMORPG	MMO Role-Playing Game
MMS	Multimedia Messaging Service
MOBA	Multiplayer Online Battle Arena
MOS	Mean Opinion Score
MPD	Media Presentation Description
MPEG	Moving Pictures Expert Group
MS-SSIM	Multi-Scale Structural Similarity Index
MSE	Mean Square Error
MTSI	Multimedia Telephony Service over IMS
OBS	Open Broadcaster Software
PSNR	Peak Signal to Noise Ratio
RA	Random Access
RAP	Random Access Point
RCS	Rich Communication Services
RDPCM	Residual Differential Pulse Code Modulation
RGB	Red Green Blue
RPG	Role-Playing Game
RTMP	Real-Time Messaging Protocol
RTP	Realtime Transport Protocol
RTS	RealTime Strategy
SCC	Screen Content Coding
SCM	Screen Content coding Model
SDK	Software Development Kit
SDR	Standard Definition Range
SEI	Supplemental Enhancement Information
SI	Spatial perceptual Information
SSIM	Structural Similarity Index Measure
SVOD	Subscription Video On Demand
TI	Temporal perceptual Information
TIFF	Tagged Image File Format
UDP	User Datagram Protocol
UHD	Ultra High Definition
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
UVG	Ultra Video Group
VBR	Variable BitRate
VBS	Visual Basic Script
VCL	Video Coding Layer
VMAF	Video Multimethod Assessment Fusion
VSEI	Versatile Supplemental Enhancement Information
VTM	VVC Test Model
VVC	Versatile Video Coding
WCG	Wide Colour Gamut

4 Overview of video codec capabilities in 3GPP services in Release 17

4.1 Introduction

This clause summarizes the video coding capabilities in relevant existing 5G services as of Release-16. Video codecs introduced in this clause are referred to as 3GPP video codecs.

In Release 17, two video codecs are prominently referenced and available, namely H.264 (AVC) [7] and H.265 (HEVC) [8].

Both codecs are defined as part of the TV Video Profiles in 3GPP TS 26.116 [3] and are also the foundation of the VR Video Streaming Profiles in 3GPP TS 26.118 [4]. The highest defined profile/level combinations are:

- H.264 (AVC) Progressive High Profile Level 5.1 [7] with the following additional restrictions and requirements:
 - o the maximum VCL Bit Rate is constrained to be 120Mbps with `cpbBrVclFactor` and `cpbBrNALFactor` being fixed to be 1250 and 1500, respectively.
 - o the bitstream does not contain more than 10 slices per picture
- H.265 (HEVC) Main 10 Profile Main Tier Level 5.1 [8] without any restrictions

Both codecs are also defined for other 3GPP-based services. More details on the codec capabilities and the necessary interoperability requirements for different services are collected in the remainder of this clause.

4.2 TV Video Profiles

The TV Video Profiles in TS 26.116 [3] address coded representations of TV distribution signals up to UHD-1 phase 2. Table 4.2-1 provides an overview of the TV relevant formats considered in the context of 3GPP TV Video Profiles.

In the context of TV Video Profiles, the following aspect are defined:

- **Bitstream:** A media bitstream that conforms to a video encoding format and certain Operation Point.
- **Operation Point:** A collection of discrete combinations of different content formats including spatial and temporal resolutions, colour mapping, transfer functions, etc. and the encoding format.
- **Receiver:** A receiver that can decode and render any bitstream that is conforming to a certain Operation Point.

Table 4.2-1: TV over 3GPP services Video Profile Operation Points (TS 26.116 [3])

Operation Point name	Resolution format	Picture aspect ratio	Scan	Max. frame rate	Chroma format	Chroma sub-sampling	Bit depth	Colour space format	Transfer Characteristics
H.264/AVC 720p HD	1280 × 720	16:9	Progressive	30	Y'CbCr	4:2:0	8	BT.709	BT.709
H.265/HEVC 720p HD	1280 × 720	16:9	Progressive	30	Y'CbCr	4:2:0	8	BT.709	BT.709
H.264/AVC Full HD	1920 × 1080	16:9	Progressive	60	Y'CbCr	4:2:0	8	BT.709	BT.709
H.265/HEVC Full HD	1920 × 1080	16:9	Progressive	60	Y'CbCr	4:2:0	8; 10	BT.709; BT.2020	BT.709; BT.2020
H.265/HEVC UHD	3840 × 2160	16:9	Progressive	60	Y'CbCr	4:2:0	10	BT.2020	BT.2020
H.265/HEVC Full HD HDR	1920 × 1080	16:9	Progressive	60	Y'CbCr	4:2:0	10	BT.2020	BT.2100 PQ
H.265/HEVC UHD HDR	3840 × 2160	16:9	Progressive	60	Y'CbCr	4:2:0	10	BT.2020	BT.2100 PQ
H.265/HEVC Full HD HDR HLG	1920 × 1080	16:9	Progressive	60	Y'CbCr	4:2:0	10	BT.2020	BT.2100 HLG
H.265/HEVC UHD HDR HLG	3840 × 2160	16:9	Progressive	60	Y'CbCr	4:2:0	10	BT.2020	BT.2100 HLG

Each one of the Operation Points is associated with a video coding specification and a particular Profile, Level, and Tier (for HEVC). The combination of a specific profile, level, and tier indicate the maximum decoding capabilities, such as chroma format, resolution, frame rate, and bit depth, that can be supported by a decoder conforming to such combination of parameters. An operation point is also associated with additional bitstream constraints defined in TS 26.116 [3], clause 4. Table 4.2-2 summarizes the video coding specification profile, tier, and level associated with each operation point.

Table 4.2-2: Operation point video codec Profile/Tier/Level

Operation Point name	Video Codec	Profile	Tier	Level
H.264/AVC 720p HD	AVC	High	-	3.1
H.265/HEVC 720p HD	HEVC	Main	Main	3.1
H.264/AVC Full HD	AVC	High	-	4.2
H.265/HEVC Full HD	HEVC	Main 10	Main	4.1
H.265/HEVC UHD	HEVC	Main 10	Main	5.1
H.265/HEVC Full HD HDR	HEVC	Main 10	Main	4.1
H.265/HEVC UHD HDR	HEVC	Main 10	Main	5.1
H.265/HEVC Full HD HDR HLG	HEVC	Main 10	Main	4.1
H.265/HEVC UHD HDR HLG	HEVC	Main 10	Main	5.1

For TV Video profiles, interoperability with ISO BMFF based systems and the DASH Streaming is of most relevance. Hence, for a codec to be used in the context of TV Video Profiles, the following is defined in terms of interoperability:

1. The receiver requirements on elementary stream level
2. The encapsulation of an elementary stream into an ISO Base Media File Format track
3. The provisioning of the media as part of the DASH Adaptation Set to support seamless switching
4. All MPD-level signalling for the codec to support capability discovery

For details, refer to TS 26.116 [3], clause 4 and clause 5.

4.3 VR Video Profiles

The VR profiles for streaming applications defined in TS 26.118 [4] address the coded representation of 360 VR distribution signals. Table 4.3-1 provides an overview of the 360 VR relevant formats considered in the context of

3GPP VR profiles. The VR profiles follow the same logic as the TV Video profiles, they represent a list of interoperability points that are amended by the 3GPP services such as 5G Media Streaming (5GMS) described in the following clause.

Table 4.3-1: High-level Summary of Operation Points

Operation Point name	Decoder	Bit depth	Typical Original Spatial Resolution	Frame Rate	Colour space format	Transfer Characteristics	Projection	RWP	Stereo
Basic H.264/AVC	H.264/AVC HP@L5.1	8	Up to 4k	Up to 60 Hz	BT.709	BT.709	ERP w/o padding	No	No
Main H.265/HEVC	H.265/HEVC MP10@L5.1	8, 10	Up to 6k in mono and 3k in stereo	Up to 60 Hz	BT.709 BT.2020	BT.709	ERP w/o padding	Yes	Yes
Flexible H.265/HEVC	H.265/HEVC MP10@L5.1	8, 10	Up to 8k in mono and 3k in stereo	Up to 120 Hz	BT.709 BT.2020	BT.709, BT.2100 PQ	ERP w/o padding CMP	Yes	Yes
Main 8K H.265/HEVC	H.265/HEVC MP10@L6.1	10	Up to 8k in mono and 6k in stereo	Up to 60 Hz for 8K and 120 Hz for 4k	BT.709 BT.2020	BT.709, BT.2100 PQ,	ERP w/o padding	Yes, but restricted to coverage	Yes

4.4 5G Media Streaming

4.4.1 Introduction

5G Media Streaming (5GMS) services are associated with a series of 5GMS profiles, each of which contains a set of capability requirements associated with a service scenario. Default profiles (for downlink and uplink streaming) are also defined in case no other profile is claimed to be supported. The detailed requirements for 5G Media Streaming profiles and their associated codec requirements are defined in 3GPP TS 26.511 [13]. The following clauses focus on video codec requirements and recommendations in 5GMS specification as well as the encapsulation format.

NOTE: In some profiles the HD-HDR capability is used as the ability for a UE to present video signals with all the following features: at least Full-HD resolution, bit depth of at least 10, at least 60 frames per second, Wide Colour Gamut and High Dynamic Range.

4.4.2 5GMS Downlink Streaming default profile

4.4.2.1 H.264 (AVC)

TS 26.511 [13] requires the support of H.264 (AVC) Progressive High Profile Level 3.1 [7] decoding, with the maximum VCL Bit Rate constrained to be 14 Mbps.

If the 5GMS client supports the reception of video and HD-HDR capabilities, then TS 26.511 [13] requires the support of H.264 (AVC) Progressive High Profile Level 4.0 [7] decoding.

4.4.2.2 H.265 (HEVC)

TS 26.511 [13] recommends the support of H.265 (HEVC) Main Profile, Main Tier, Level 3.1 [8] decoding with no interlace support.

If the 5GMS client supports the reception of video and HD-HDR capabilities, then TS 26.511 [13] requires the support of H.265 (HEVC) Main10 Profile, Main Tier, Level 4.1 [8] decoding with no interlace support.

4.4.2.3 Encapsulation format

TS 26.511 [13] requires the support of Common Media Application Format (CMAF) encapsulation as defined in ISO/IEC 23000-19 [30].

4.4.3 5GMS Uplink Streaming default profile

4.4.3.1 H.265 (HEVC)

TS 26.511 [13] requires the support of H.265 (HEVC) Main10 Profile, Main Tier, Level 4.1[8] encoding with no interlace support.

4.4.3.2 Encapsulation format

TS 26.511 [13] requires the support of Common Media Application Format (CMAF) as defined in ISO/IEC 23000-19 [30].

4.4.4 5GMS Television (TV) profile

4.4.4.1 H.264 (AVC)

TS 26.511 [13] requires the support of H.264/AVC 720p HD as specified in TS 26.116 [3], clause 4.4.2.6.

TS 26.511 [13] recommends the support of H.264/AVC Full HD as specified in TS 26.116 [3], clause 4.4.3.6.

NOTE: Associated codec profiles and levels are listed in Table 4.2-2 of the present document.

4.4.4.2 H.265 (HEVC)

TS 26.511 [13] recommends the support of H.265/HEVC 720p HD, H.265/HEVC Full HD, H.265/HEVC, H.265/HEVC Full HD, H.265/HEVC UHD HDR, H.265/HEVC Full HD HDR HLG and H.265/HEVC UHD HDR HLG as specified in TS 26.116 [3].

If the 5GMS client supports the Television (TV) profile and HD-HDR capabilities, TS 26.511 [13] requires the support of H.265/HEVC Full HD as specified in TS 26.116 [3].

NOTE: Associated codec profiles and levels are listed in Table 4.2-2 of the present document.

4.4.4.3 Encapsulation format

TS 26.511 [13] requires the support of DASH as defined in 3GPP TS 26.116 [3], clause 5.

NOTE: Full alignment between DASH support in TS 26.116 [3] and CMAF support in TS 26.511 is still to be investigated.

4.4.5 5GMS Downlink 360 Virtual Reality (VR) profile

4.4.5.1 H.264 (AVC)

TS 26.511 [13] requires the support of the Basic H.264/AVC Operation Point as defined in 3GPP TS 26.118 [4], clause 5.1.4.

NOTE: Associated codec profiles and levels are listed in Table 4.3-1 of the present document.

4.4.5.2 H.265 (HEVC)

TS 26.511 [13] recommends the support of the Main H.265/HEVC Operation Point as defined in TS 26.118 [4], clause 5.1.5.

TS 26.511 [13] indicates that the Flexible H.265/HEVC Operation Point as defined in TS 26.118 [4], clause 5.1.6, may be supported.

TS 26.511 [13] indicates that the Main 8K H.265/HEVC Operation Point as defined in TS 26.118 [4], clause 5.1.7, may be supported.

NOTE: Associated codec profiles and levels are listed in Table 4.3-1 of the present document.

4.4.5.3 Encapsulation format

TS 26.511 [13] requires the support of DASH as defined in 3GPP TS 26.118 [4], clause 5.2.

NOTE: Full alignment between DASH support in TS 26.116 [3] and CMAF support in TS 26.511 is still to be investigated.

4.5 Multimedia Telephony Services over IMS

4.5.1 Introduction

The Multimedia Telephony Services over IMS (MTSI) specification 3GPP TS 26.114 [2] covers the media aspects of 3GPP conversational services. For MTSI services the UE is associated with both encoder and decoder requirements. Therefore, the support for a given video codec with its profile and level is interpreted as the ability to:

- encode any video input which characteristics fit in the level limits and produce a bitstream conformant with the codec profile.
- decode any bitstream in the codec/profile/level configuration.

NOTE: Additional constraints related to conversational services such as decoding process, location of the parameter sets are defined in TS 26.114 [2], clause 5.2.2.

4.5.2 H.264 (AVC)

TS 26.114 [2], in clause 5.2.2 requires the support of H.264 (AVC) [7] Constrained Baseline Profile (CBP) Level 1.2.

TS 26.114 [2], in clause 5.2.2 also recommends H.264 (AVC) [7] Constrained High Profile (CHP) Level 3.1.

4.5.3 H.265 (HEVC)

TS 26.114 [2] requires the support of H.265 (HEVC) [8] Main Profile, Main Tier, Level 3.1 except for constrained terminals for which it is only recommended.

4.5.4 Encapsulation format

MTSI is built upon the Real Time Protocol (RTP) for which the payload formats are specified in TS 26.114 [2], clause 7.4.3.

4.6 Messaging Services

3GPP TS 26.140 [32] specifies the media types, formats and codecs for the MMS within the 3GPP system. The document extends to codecs for speech, audio, video, still images, bitmap graphics, and other media in general, as well as scene description, multimedia integration and synchronization schemes.

Specifically, for video, the following capabilities are defined:

- TS 26.140 [32] requires the support of H.264 (AVC) [7] Constrained Baseline Profile (CBP) Level 1.3.
- TS 26.140 [32] recommends the support of H.264 (AVC) [7] High Profile Level 3.1 with `frame_mbs_only_flag=1` by MMS clients supporting HDTV video content at a resolution of 1280x720 (720p) with progressive scan at 30 frames per second.
- TS 26.140 [32] also recommends the support of H.265 (HEVC) [8] Main Profile, Main Tier, Level 3.1.

NOTE: The specification has not been updated since 2014.

4.7 Screen Content Coding

3GPP TS 26.223 [35] specifies a client for the IMS-based telepresence service supporting conversational speech, video and text transported over RTP. Telepresence is defined as a conference with interactive audio-visual communications experience between remote locations, where the users enjoy a strong sense of realism and presence between all participants (i.e. as if they are in same location) by optimizing a variety of attributes such as audio and video quality, eye contact, body language, spatial audio, coordinated environments and natural image size.

As specified in 3GPP TS 26.223 [35] clause 5.2, telepresence UEs are required to support:

- H.264 (AVC) [7] Constrained High Profile (CHP), Level 3.1,
- H.264 (AVC) [7] Constrained Baseline Profile (CBP), Level 1.2 (for interworking with MTSI clients),
- H.265 (HEVC) [8] Main Profile, Main Tier, Level 4.1.

As specified in 3GPP TS 26.223 [35], Telepresence UEs are also recommended to support dedicated HEVC extensions defined specifically for such types of content:

- H.265 (HEVC) [8] Screen-Extended Main, Main Tier, Level 4.1,
- H.265 (HEVC) [8] Screen-Extended Main 4:4:4, Main Tier, Level 4.1.

5 Test and Characterization Framework for Video Codecs

5.1 Overview

This clause defines the characterization framework for video codecs for relevant 3GPP scenarios. For this purpose, the following is applied:

- A set of relevant scenarios is defined. The scenarios reflect a typical application for video codecs in 5G systems and networks. The scenarios are introduced in clause 6 and may be extended in future versions of this document.
- For each scenario, one or several reference sequences are defined that serve as the baseline for anchor generation.
- For each test scenario, one or several anchors are defined and generated. For details on anchors, please refer to clause 5.3. For anchor generation, reference software tools are used as introduced in clause 5.4. Anchors for specific scenarios follow certain general encoding constraints documented in clause 5.6.
- For each of the anchors, metrics are provided. Metrics are documented in detail in clause 5.5.
- Tests for new codecs can be developed and generated. They are equivalent to anchor generation, but possibly for other codecs. Tests are introduced in clause 5.7.
- Codecs are to be characterized against anchors. Characterization is documented in terms of expected bitrate savings for a codec, and may include additional comparison parameters such as complexity increase, etc. The basic characterization framework is introduced in clause 5.8.
- Verification of the provided anchors and tests is needed. A process for verification is introduced in clause 5.9.

An overview of the anchor generation framework and the anchor metrics is provided in Figure 5.1-1. An integral part of this Technical Report is the following information:

- Formats to store reference and anchor sequences
- Reference sequences for each of the defined scenarios
- Reference software encoders
- Anchor configuration files

- Anchor bitstreams in a well-defined anchor bitstream format
- A anchor metric computation based on a reference sequence, anchor bitstream and an anchor sequence.
- Conforming decoders to generate an anchor sequence from an anchor bitstream
- Anchor metrics in a well-defined storage format.

NOTE: as the anchor sequences can be generated by conforming decoders, anchor sequences are not included in this document.

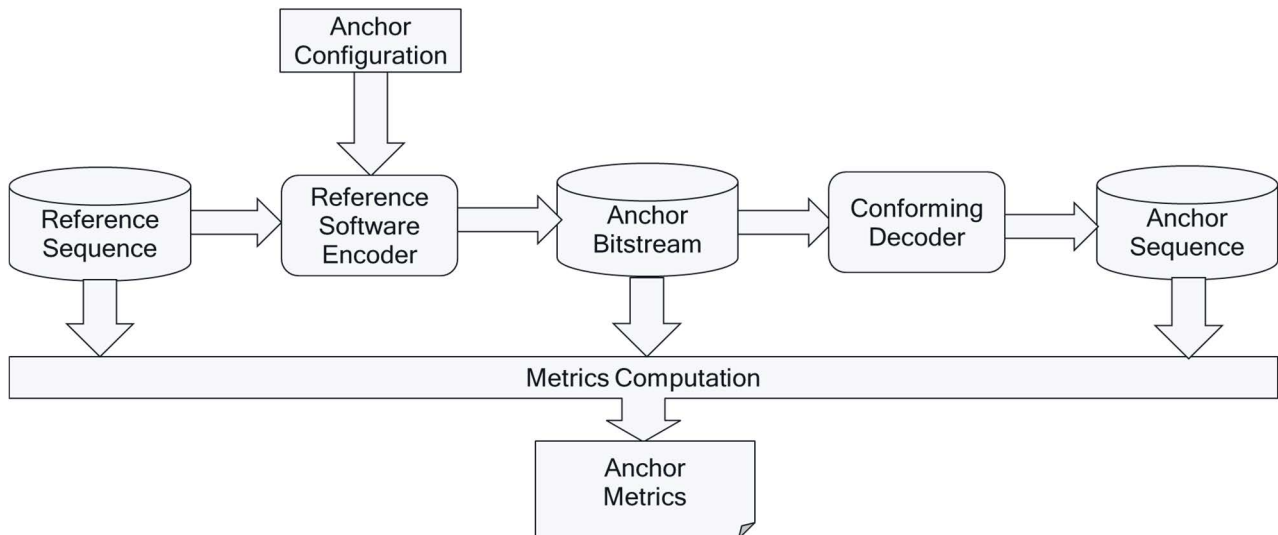


Figure 5.1-1 Anchor Generation Framework and Anchor Metrics Generation

5.2 Reference Sequences

This document provides reference sequences that are used to generate anchors and are also made available in order to generate test bitstreams for other codecs. Reference sequences are selected to be representative for a scenario.

Reference sequences are described in Annex C of this document along with their properties and their licenses. A format for raw reference sequences based on a JSON schema is defined in clause B.2.

Annex D describes how to upload new proposed reference sequences and how to download the reference sequences.

5.3 Anchors

Anchors provide a baseline that a tested method can be compared against. Anchors defined in this specification use a codec/profile/level that exists in an existing 3GPP specification as introduced in clause 4.

Anchor tuples are collected to address different qualities and bitrates that can then be used for evaluation over a larger set of operation points.

The following principles apply to anchor definitions:

- Each scenario typically has several well-defined anchors
- An anchor is a combination of:
 - Explanation on anchor relevance
 - Reference sequence
 - Reference encoder
 - Encoder configuration matching scenario requirements

- Encoding complexity estimation, if available
- Variable encoder configuration to create multiple quality/bitrate variants (using for example QP variations or other bitrate/quality evaluation tools).
- Anchor tuples creating multiple variants, each including
 - Anchor bitstream
 - Anchor Metrics
- Additional recommended anchor information includes
 - MD5 check sum of the complete reconstructed yuv file (anchor sequence)
 - Output picture log from reference encoder
 - Output picture log from reference decoder

Anchors and anchor tuples are an integral part of this document.

Anchor tuples should be created over a wide range of parameters to provide sufficient data and overlap with expected test results to support the generation of characterization results (see clause 5.7).

The workflow for the generation of anchor tuples is shown in Figure 5.3-1.

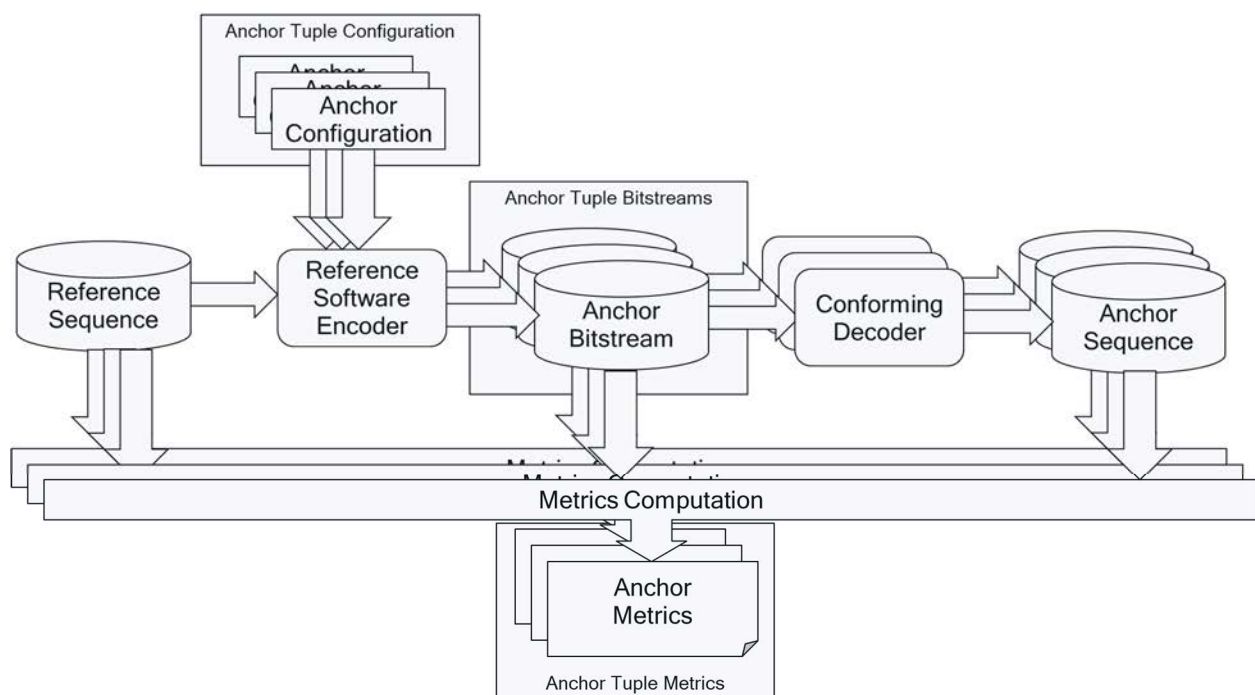


Figure 5.3-1: Anchor Tuple Generation Framework and Anchor Tuple Metrics Generation

Anchors are provided according to the format as defined in Annex B.3.

5.4 Reference Software Tools

Anchors bitstreams for each anchor codec are generated with their corresponding reference software. Reference software and reference configurations are documented in each scenario under clause 6 to permit repeatability of the anchor generation.

For H.264/AVC generated anchor bitstreams, H.264/AVC reference software (AVC Joint Model) has been used.

AVC reference software implementing H.264 (AVC) High Profile called JM and its versions can be downloaded from in the repository <http://iphome.hhi.de/suehring/tml/download/>. To generate the anchor bitstreams, JM19 is used with

JM19 tag: <https://vcgit.hhi.fraunhofer.de/jvet/JM/-/commit/aab15e2e0315eca92368048170f1f546e357f328>. The software is referred to as JM19.

For H.265/HEVC generated anchor bitstreams, H.265/MPEG-H HEVC reference software (HEVC Test Model) has been used.

HEVC reference software implementing H.265 (HEVC) Main Profile and H.265 (HEVC) Main 10 Profile called HM and its versions can be downloaded from in the repository <https://vcgit.hhi.fraunhofer.de/jct-vc/HM-/tags/>.

HEVC reference software implementing H.265 (HEVC) Screen-Extended Main 10 Profile is called SCC (Screen Content Coding Model) software and is available from <https://vcgit.hhi.fraunhofer.de/jct-vc/HM/-/tags/HM-16.21+SCM-8.8>.

Test bitstreams for tested codecs are generated with their corresponding reference software. Test reference software and configurations are documented in clause 8.

5.5 Metrics

5.5.1 General

Each anchor bitstream gets assigned multiple performance metrics, in particular:

- the bitrate as defined in clause 5.5.2,
- If Standard Dynamic Range (SDR) is used, then the quality metrics in clause 5.5.4 apply.
- If High Dynamic Range (HDR) is used, then the quality metrics in clause 5.5.5 apply.

An overview of the metrics is provided below. These metrics are implemented in software scripts defined in Annex E. This software is used to compute and report all the metrics. The detailed configuration for the software is provided in clause 5.5.7 for SDR metrics and clause 5.5.8 for HDR metrics.

A detailed reporting schema for metrics is provided in clause 5.5.6.

Metrics for test streams are expected to follow the same principles.

Subjective evaluation of anchors and test streams is not considered in this report.

5.5.2 Bitrate

Anchors and test streams are provided as bitstream files generated by reference software encoders. The file size of the bitstream provides a reasonable measure for the efficiency of codec in terms of compression efficiency, together with a distortion/quality metrics as defined in clauses 5.5.3 and 5.5.4. However, in some cases the bitstream includes information that is irrelevant for the reconstruction but may be useful for example for debug and cross-check issues. An example for such information is the md5 hash for each reconstructed frame. While such information is useful, it is expected to be not counted when evaluating the compression efficiency.

In order to define a meaningful and comparable value for the size of the bitstream, the effective file size *EFS* is defined as the size of the encapsulated bitstream

- including all information that is needed for reconstruction of the anchor sequence,
- excluding all information that is not needed for reconstruction of the anchor sequence.

Each reference encoder or even each scenario may define an EFS. Note that the EFS is always expressed in octets.

Furthermore, in order to normalize the results, the compression efficiency is most suitably expressed by dividing the *EFS* by the duration of the encoded reference sequence, referred to *duration* in seconds.

Based on these considerations, the bitrate *Bitrate* of an anchor or test stream is defined as:

$$\text{Bitrate} = 8 * \text{EFS} / (1000 * \text{duration}) \text{ in kbit/s} \quad (5.5.2-1)$$

5.5.3 Quality Metrics - General

For quality metrics, a set of well-established metrics are re-used. All defined metrics define a single number when comparing the sample values of the original reference sequence $orig(x, y, t, c)$ and reconstructed and decoded sequence $dec(x, y, t, c)$. In this case for each colour component $c=(Y,U,V)$ and each frame of the video sequence $t=1, \dots, N$, describe the sample positions within a luma image of width W_Y and height H_Y , as well as within a chroma image of width $W_U = W_V = W_Y/2$ and height $H_U = H_V = H_Y/2$ and the reconstructed anchor or test sequence.

For all metrics, it is assumed that the original sequence and the decoded sequence have 10 bit precision, i.e. the range of the values is between 0 and 1023. Should a sequence have less than 10 bit, i.e. 8 bit, then the metric is computed by applying an 8 bit to 10 bit conversion by appending 2 trailing 0s.

The following basic metrics per frame are defined. For an individual frame t and each colour component c , the mean square error $MSE(t, c)$ is calculated for colour component channel $dec(t, Y)$ of the decoded output image and the colour component channel $orig(t, Y)$ of the original image according to

$$MSE(t, c) = \frac{1}{W*H} \sum_{y=0}^{H-1} \sum_{x=0}^{W-1} (dec(x, y, t, c) - orig(x, y, t, c))^2, \quad (5.5.3-1)$$

where W and H are the width and height of the colour component, respectively. The PSNR value for the frame t and each colour component c is then calculated as:

$$PSNR(t, c) = \min \left[10 * \log_{10} \left(\frac{1020^2}{MSE(t, c)} \right), 999.99 \right] \text{ in dB} \quad (5.5.3-2)$$

Then the PSNR for each bitstream is computed as the sum of all individual frame PSNR values divided by the number of frames in the sequence, i.e.

$$PSNR(c) = \frac{1}{N} \sum_{t=1}^N PSNR(t, c) \text{ in dB} \quad (5.5.3-3)$$

This definition follows the definition of PSNR in [44].

5.5.4 SDR Quality Metrics

5.5.4.1 Overview

Based on the introduction in clause 5.5.3, for standard dynamic range (SDR) sequences, the following metrics are used:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as defined in clause 5.5.3,
- Peak-Signal to Noise Ratio $PSNR(U)$ of chroma component U as defined in clause 5.5.3,
- Peak-Signal to Noise Ratio $PSNR(V)$ of chroma component V as defined in clause 5.5.3,
- Average colour component PSNR, $PSNR$ over all colour components $PSNR$:

$$PSNR = (6*PSNR(Y) + PSNR(U) + PSNR(V))/8$$

- Multi-Scale Structural Similarity Metric MS -SSIM, as specified in [54], [55] and [56] and defined in clause 5.5.4.2
- Video Multimethod Assessment Fusion (VMAF) $VMAF$, as specified in [57]. See clause 5.5.7 on the use of the associated software implementation [59] to compute VMAF.

The exact definition for all SDR quality metrics is based on the software scripts as defined in clause 5.5.7. A reporting scheme for SDR metrics is defined in clause 5.5.6.

5.5.4.2 Structural similarity metric MS-SSIM

The multi-scale SSIM method is illustrated in Figure 5.5.4-1. Taking the original reference sequence $orig(x, y, t, c)$ and reconstructed and decoded sequence $dec(x, y, t, c)$ image signals as the input (referred to as $\mathbf{x}$ and $\mathbf{y}$ in Figure 5.5.4-1), the system iteratively applies a low-pass filter and downsamples the filtered image by a factor of 2. The original image is indexed as scale 1, and the highest scale as scale M , which is obtained after $M-1$ iterations. At the j -th scale, the contrast and structure components are calculated and denoted as $C_j(\mathbf{x}, \mathbf{y})$ and $S_j(\mathbf{x}, \mathbf{y})$, respectively. The luma

component (inappropriately named as the luma component in the references) is computed only at scale $j=M$ and is denoted as $l_M(\mathbf{x}, \mathbf{y})$. The overall metric for each frame is obtained by combining the measurement at different scales.

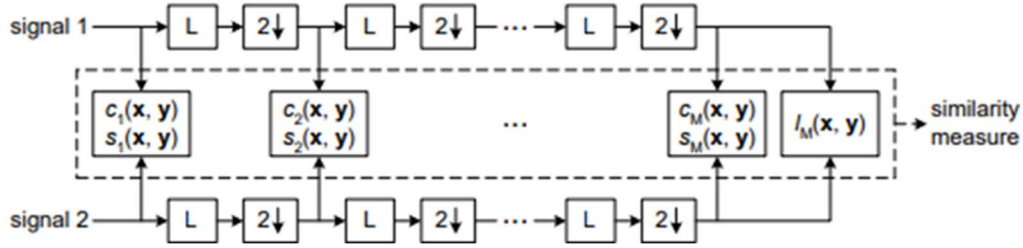


Figure 5.5.4-1: Multi-scale structural similarity measurement system (L: low-pass filter, 2↓: downsampling by 2)

The MS-SSIM between the original image, I , and the reconstructed image component, I' , is calculated as:

$$MS\_SSIM(I, I') = \frac{1}{N} \sum_{k=1}^N \left([L_M(I_k, I'_k)]^{\alpha_M} \prod_{j=1}^M [C_j(I_k, I'_k)]^{\beta_j} [S_j(I_k, I'_k)]^{\gamma_j} \right)$$

$$L(I_k, I'_k) = \frac{2\mu_{I_k}\mu_{I'_k} + C_1}{\mu_{I_k}^2 + \mu_{I'_k}^2 + C_1}$$

$$C(I_k, I'_k) = \frac{2\sigma_{I_k}\sigma_{I'_k} + C_2}{\sigma_{I_k}^2 + \sigma_{I'_k}^2 + C_2}$$

$$S(I_k, I'_k) = \frac{\sigma_{I_k I'_k} + C_3}{\sigma_{I_k} \sigma_{I'_k} + C_3}$$

where I_k, I'_k are pixels of original and reconstructed frames, N is the number of pixels per frame, $\alpha_M, \beta_j, \gamma_j, C_1, C_2, C_3$ are the constants:

$$\beta_1 = \gamma_1 = 0.0448, \beta_2 = \gamma_2 = 0.2856, \beta_3 = \gamma_3 = 0.3001, \beta_4 = \gamma_4 = 0.2363, \text{ and } \alpha_5 = \beta_5 = \gamma_5 = 0.1333.$$

$$C_1 = (K_1 * \text{maxValue})^2$$

$$C_2 = (K_2 * \text{maxValue})^2$$

$$C_3 = C_2/2,$$

$$K_1 = 0.01, K_2 = 0.03, \text{maxValue} = (1 < \text{bitDepth}) - 1, \text{ and } M = 5.$$

As bitDepth is set to 10, the maxValue is set to 1020.

Average values $\mu_{I_k}, \mu_{I'_k}$ at pixels I_k and I'_k are computed as weighted sum of 11×11 neighbors with Gaussian weights. $\sigma_{I_k}, \sigma_{I'_k}$ represent the variance at pixels I_k and I'_k . $\sigma_{I_k I'_k}$ is covariance of these two pixels.

The MS_SSIM value for each bitstream is computed as the sum of all individual frame MS_SSIM values divided by the number of frames in the sequence.

See clause 5.5.7, on the use of [59] for computation of MS_SSIM .

It is quite common to convert the MS_SSIM numbers to a dB representation since that representation can be more easily interpreted and is somewhat similar to the PSNR representation. Such computation also has an impact in the BD-rate numbers since the resulting points end up having more similar properties to the PSNR ones for the BD-rate computation. Both HDRTTools and VMAF support this conversion, using:

$$\log\_MS\_SSIM = (-10.0 * \log_{10}(1 - MS\_SSIM)) \text{ in dB};$$

The MS_SSIM value for each bitstream is computed as the sum of all individual frame $\log\_MS\_SSIM$ values divided by the number of frames in the sequence. A reporting scheme for SDR metrics is defined in clause 5.5.6.

5.5.5 HDR Quality Metrics

For high dynamic range (HDR) sequences, the following Metrics as defined in clause 5.5.3 are used:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as specified in [44],
- Peak-Signal to Noise Ratio $PSNR(U)$ of chroma component U,
- Peak-Signal to Noise Ratio $PSNR(V)$ of chroma component V,
- Average colour component PSNR, $PSNR$ over all colour components $PSNR$.

In addition, a weighted Peak-Signal To Noise Ratio metric for each colour components $wPSNR(c)$ is used, which aims to compensate for a different distribution of codewords in HDR content:

- $wPSNR(Y)$, $wPSNR(U)$, $wPSNR(V)$, as specified in [44] and [58],
- Average colour component weighted PSNR, $wPSNR$ over all colour components $wPSNR$.

In addition, HDR specific quality metrics are reported. For this purpose, the YUV sequences, both original reference sequence and reconstructed sequences are transformed first from YUV 4:2:0 to 4:4:4 and then to floating point RGB to obtain 32-bit EXR floating point representation. The output is then used in the next step to compute

- $PSNRL100$, as specified in [44] and [58],
- $DE100$, as specified in [44] and [58].

The basic approach to generate HDR metrics is shown in Figure 5.5.5-1.

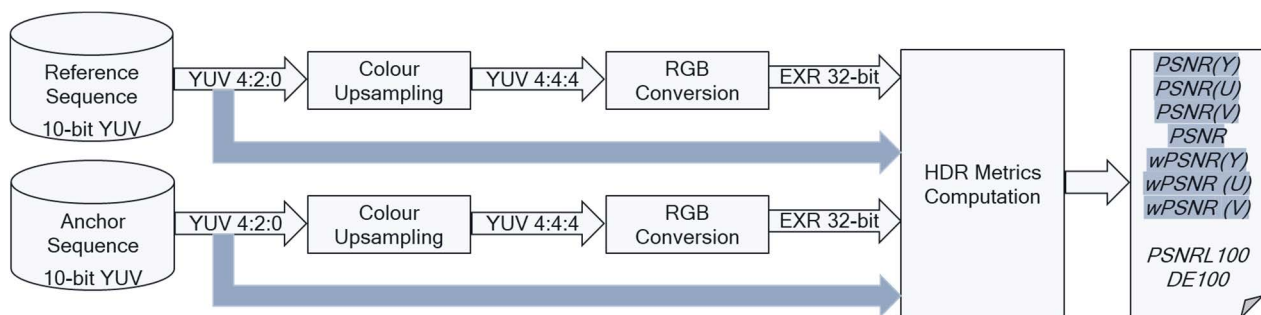


Figure 5.5.5-1: Basic approach for HDR metrics generation

The exact definition for all HDR quality metrics is based on the software scripts as referenced in clause 5.5.8. A reporting scheme for HDR metrics is defined in clause 5.5.6.

5.5.6 Anchor Tuple Metrics Reporting

For each anchor tuple, the Metrics are reported in a single csv file as defined in IETF RFC 4180 [60].

Additional metrics may be reported, for example encoding times, etc.

Table 5.5.6-1 provides the result format for SDR/HLG.

Table 5.5.6-1 Metrics result format for SDR/HLG

Name	Type	Semantics
parameter	BIGINT	the associated variation parameter as defined for the anchor, for example the QP
bitrate	DOUBLEPRECISION	The <i>Bitrate</i> as defined in Equation (5.5.2-1) based on the effective file size and normalized to kbit/s as defined in clause 5.5.2 with 2 decimal digits accuracy.
y_psnr	DOUBLEPRECISION	Peak signal to noise ratio for Y planes in dB as defined as $PSNR(Y)$ in clause 5.5.4 with 3 decimal digits accuracy.

u_psnr	DOUBLEPRECISION	Peak signal to noise ratio for U planes in dB as defined as $PSNR(U)$ in clause 5.5.4 with 3 decimal digits accuracy.
v_psnr	DOUBLEPRECISION	Peak signal to noise ratio for V planes in dB as defined as $PSNR(V)$ in clause 5.5.4 with 3 decimal digits accuracy.
psnr	DOUBLEPRECISION	Average colour component PSNR, $PSNR$ over all colour components $PSNR$ as defined as $PSNR$ in clause 5.5.4 with 3 decimal digits accuracy.
ms_ssim	DOUBLEPRECISION	structural similarity for Y planes in dB as defined in clause 5.5.4 with 2 decimal digits accuracy.
vmaf	DOUBLEPRECISION	Video Multimethod Assessment Fusion (VMAF) as defined in clause 5.5.4 with 3 decimal digits accuracy.
bitrate_log	DOUBLEPRECISION	The bitrate as documented by the encoder log. If not known, it is set to 0.
encode_time	DOUBLEPRECISION	Total time spent to encode the sequence with reference encoder in seconds. If not known, it is set to 0.
decode_time	DOUBLEPRECISION	Total time spent to decode the sequence with reference decoder in seconds. If not known, it is set to 0.

Table 5.5.6-2 provides the result format for HDR.

Table 5.5.6-2 Metrics result format for HDR

Name	Type	Semantics
Parameter	BIGINT	the associated variation parameter as defined for the anchor, for example the QP
Bitrate	DOUBLEPRECISION	The <i>Bitrate</i> as defined in Equation (5.5.2-1) based on the effective file size and normalized to kbit/s as defined in clause 5.5.2 with 3 decimal digits accuracy.
y_psnr	DOUBLEPRECISION	Peak signal to noise ratio for Y planes in dB as defined as $PSNR(Y)$ in clause 5.5.5 with 3 decimal digits accuracy.
u_psnr	DOUBLEPRECISION	Peak signal to noise ratio for U planes in dB as defined as $PSNR(U)$ in clause 5.5.5 with 3 decimal digits accuracy.
v_psnr	DOUBLEPRECISION	Peak signal to noise ratio for V planes in dB as defined as $PSNR(V)$ in clause 5.5.5 with 3 decimal digits accuracy.
psnr	DOUBLEPRECISION	Average colour component PSNR, $PSNR$ over all colour components $PSNR$ defined as $PSNR$ in clause 5.5.5 with 3 decimal digits accuracy.
y_wpsnr	DOUBLEPRECISION	Weighted peak signal to noise ratio for Y planes in dB as defined as $wPSNR(Y)$ in clause 5.5.5 with 3 decimal digits accuracy.
u_wpsnr	DOUBLEPRECISION	Weighted peak signal to noise ratio for U planes in dB as defined as $wPSNR(U)$ in clause 5.5.5 with 3 decimal digits accuracy.
v_wpsnr	DOUBLEPRECISION	Weighted peak signal to noise ratio for V planes in dB as defined as $wPSNR(V)$ in clause 5.5.5 with 3 decimal digits accuracy.
wpsnr	DOUBLEPRECISION	Average colour component weighted PSNR, $wPSNR$ over all colour components $wPSNR$ as defined as $PSNR$ in clause 5.5.5 with 3 decimal digits accuracy.
psnr_l100	DOUBLEPRECISION	PSNRL100 as defined in clause 5.5.5 with 3 decimal digits accuracy.
de100	DOUBLEPRECISION	DE100 as defined in clause 5.5.5 with 3 decimal digits accuracy.
bitrate_log	DOUBLEPRECISION	The bitrate as documented by the encoder log. If not known, it is set to 0.
encode_time	DOUBLEPRECISION	Total time spent to encode the sequence with reference encoder in seconds. If not known, it is set to 0.
decode_time	DOUBLEPRECISION	Total time spent to decode the sequence with reference decoder in seconds. If not known, it is set to 0.

5.5.7 Reference computation of SDR metrics

Clause 5.5.3 specifies that all metrics are computed with 10-bit precision. 8-bit to 10 bit up-conversion is performed with `HDRConvert` tool [67] using the attached script `HDRConvert_8bto10b.cfg`. Note that `ScaleOnly` is set to 1 to address sequences with pixel values that are not within standard video range.

Computation of $PSNR(Y)$, $PSNR(U)$ and $PSNR(V)$ metrics as defined in clause 5.5.3 is performed with `HDRMetrics` tool as included in `HDRTools` version 0.23 [67] with the following parameters specified:

- `EnablePSNR=1`
- `EnableJVETPSNR=1`
- `MaxSampleValue=1020.0`

Computation of MS-SSIM metric as defined in clause 5.5.4 is performed with `HDRMetrics` tool with the following parameters specified:

- `EnableJVETMSSSIM=1`
- `MaxSampleValue=1020.0`

NOTE: An issue was discovered for the `HDRMetrics` tool with fractional frame rate. The bug is reported and expected to be fixed in a future version of `HDRMetrics` tool. For the purpose of this report, integer frame rates have been used for HDR metrics computation as metrics are independent of the frame rate. The bitrate is still measured based on the fractional frame rate.

For the computation of VMAF, the C++ executable "vmafossesec" [59], open source provided by Netflix is used (<https://github.com/Netflix/vmaf/releases/tag/v2.1.1>).

Here is the command line:

```
vmafossesec $VMAF_FMT $WIDTH $HEIGHT ref.yuv test.yuv $VMAFMODEL --thread 1 -
-log metrics.vmaf

$VMAF_FMT: describe yuv subsampling (yuv420p10le as all metrics are computed in 10 bit domain)

$VMAFMODEL: vmaf_v0.6.1.pkl

thread: 1 (no threads used)
```

Additional `libvmaf` parameters `phone_model` and `enable_transform` are set to 0.

5.5.8 Reference computation of HDR metrics

Computation of $wPSNR(Y)$, $wPSNR(U)$ and $wPSNR(V)$ metrics as defined in clause 5.5.5 is performed with `HDRMetrics` tool version 0.23 [67] with reference config file `HDRMetrics_wtPSNR.cfg` and `hdrTable.txt` attached to this report.

The following `HDRMetrics` parameters are specified:

- `EnablePSNR=1`
- `EnableJVETPSNR=0`
- `MaxSampleValue=1023.0`

Computation of ΔE_{100} and $PSNR_{L100}$ metrics requires conversion from YUV to linear light RGB data which is performed with the use of `HDRConvert` tool [67] and the reference config file `HDRConvertYCbCr420ToEXR2020.cfg` as attached. After the conversion for reference and decoded video clips is done, computation of ΔE_{100} and $PSNR_{L100}$ metrics as defined in clause 5.5.5 is performed with `HDRMetrics` tool version 0.23 [67] with reference config file `HDRMetrics_deltaE100.cfg` as attached.

5.6 General encoding constraints

This clause defines general encoding constraints for encoders that are used in scenarios and configurations in order to ensure a fair comparison between the anchor and the test stream. These encoding constraints may for example address latency requirements, encoding complexity restrictions, functional properties or data management considerations.

Given how the anchors are produced (see clause 6 for details), it is expected that the test encoders should follow similar configuration settings, which would enable similar functionality as per the defined applications.

The following general encoder configurations are defined:

- *Single-pass encoding*: Only fixed periodic (temporal) QP and coding structures (e.g. GOP order, coding order) are permitted, without the use of any lookahead multi pass encoding of a current picture or multiple pictures ahead encoding that would alter encoding, rate-distortion optimization processes, coding tools settings, the QP or coding structures (e.g. GOP order, coding order) dynamically per content. For HDR content, the QP settings may be adjusted within a frame as a function of the local, average luma and chroma values. QP and coding structures may differ from those used by the anchors, but such differences should be consistent for all content in a given scenario and should be described. Preprocessing in the form of Motion-Compensated Temporal Filtering (MCTF) and residual energy/distortion-based decisions that can adapt the coding type of the current frame are allowed.
- *Multiple QP variants*: several encoder operational points to create multiple quality/bitrate variants, where different variants are generated by changing only the QP, but no other parameters.
- *Random Access Functionality*: When decoding a bitstream from a specific bitstream position, i.e. a random access point, the resulting output pictures are identical as if the bitstream would be decoded from the beginning.
- *Random Access Period*: For a given scenario the random-access period of the test encoders matches the random access period of the anchors exactly to ensure the same number of Intra frames in the anchor and test bitstreams.
- *Low-Delay*: encoding configuration that is defined to produce a bitstream only containing pictures with decoding order matching the presentation order.
- *Low-Delay P*: Low-delay encoding configuration that is defined such that the encoding process includes performing a constrained prediction of the current block, where all samples within the block are predicted using a single hypothesis.

NOTE: This configuration illustrates the most largely deployed service configurations observed at the time of producing this report.

- *Low-Delay B*: Low-delay encoding configuration that is defined as a Low-delay configuration such that the encoding process may perform an unrestricted prediction of the current block.

NOTE: This configuration is intended to reflect the full capabilities of the video codec to be characterized.

5.7 Tests

Tests may be executed to compare codecs not yet in 3GPP specifications against anchors already defined in 3GPP specification. Tests, equivalently to anchors, are collected in tuples to address different quality and bitrates that can then be used for evaluation over a larger set of operation points.

A test is developed against an anchor and is a combination of:

- The corresponding anchor, which includes
 - Scenario
 - Reference Sequence
- Test encoder

- Test encoder configuration that provides an equivalent setting to the anchor configuration based on the general encoding constraints in clause 5.6.
- Test tuples creating multiple variants, each including
 - Test bitstream
 - Test Metrics
- Additional recommended test information includes
 - MD5 check sum of the complete reconstructed yuv file (reconstructed test sequence)
 - Output picture log for reference encoder
 - Output picture log for reference decoder
- Tests are an integral part of the Technical Report

The generation of test tuples is shown in Figure 5.7-1.

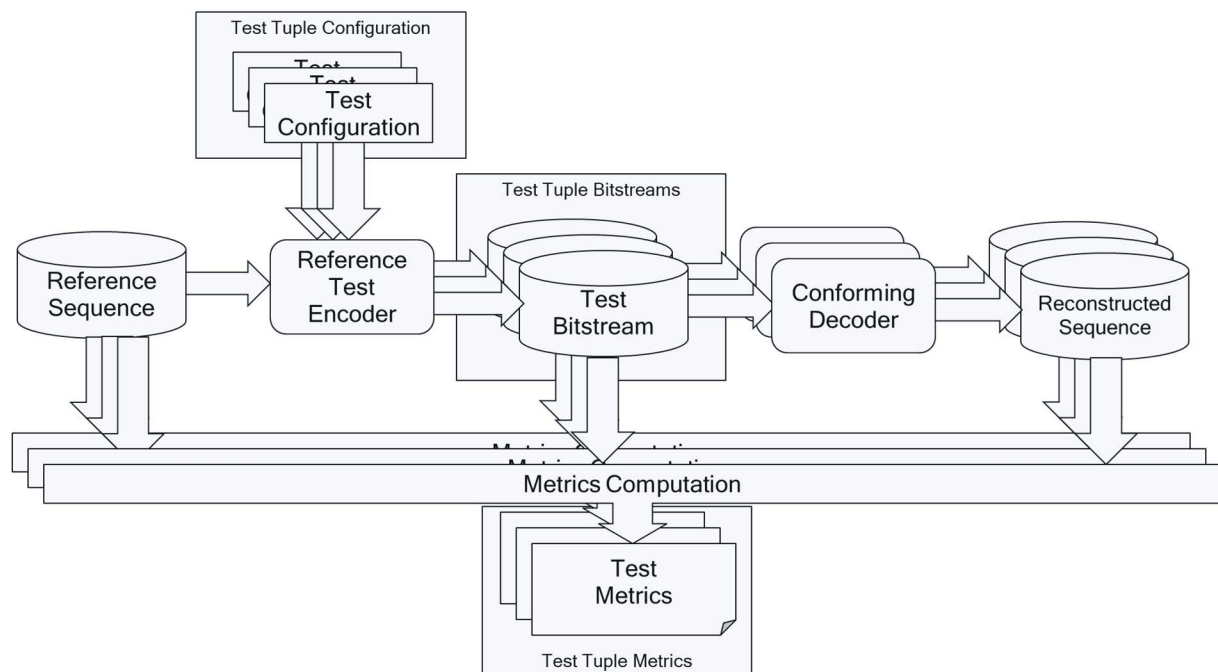


Figure 5.7-1: Test Tuple Generation Framework and Test Tuple Metrics Generation

For any coding technology being characterized in the study and reported in this document

- the evaluation is conducted consistently with the framework and test designs defined for the anchors as defined in clauses 5.5 and 6.
- technical documentation to conduct the study is available and provided. Such information includes normative specification text, reference software and description of configuration files, and codec description.
- additional data such as subjective test results (with description of test methodology and conditions) not conducted as part of this study item, encoding tool and configuration file description is also important information that could be provided

5.8 Characterization

Characterization is the comparison of a codec under test with an anchor based on the framework introduced in this clause. Characterization in this report is based on Bjöntegard-Delta (BD)-rate information according to [44].

Characterization is expected to provide a summary of the expected gains a codec under test would provide, compared to a reference codec. For characterization, the metric results in this Technical Report are used to derive summary numbers. It is important for a codec to understand the performance for individual scenarios, for individual configurations within a scenario, but also for individual reference sequences. At the same time, a summary comparison is beneficial to provide an overview of the overall performance. A summary based on averages of selected sequences as an example can only provide indication of the performance if the reference sequences would be fully representative. However, it is also of interest to understand maximum and minimum gains.

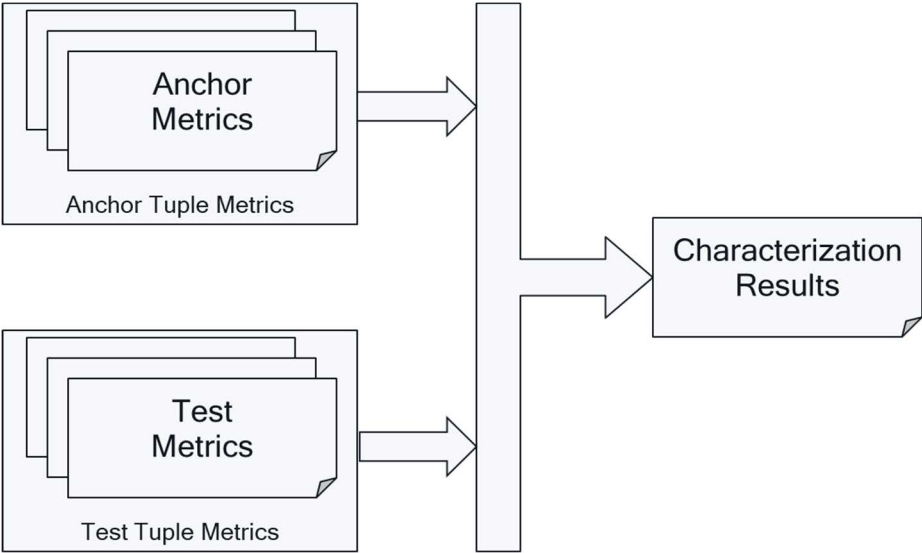


Figure 5.8-1: Characterization Framework

Based on this, a full characterization of a codec for a scenario against a 3GPP codec is expected to provide at least the following metrics

- The *BD-Rate Gain* (for a given metric and a given anchor codec) for each reference sequence in the test configuration. The *BD-Rate gain* for a given metrics is documented as *BDR-<metric>* in percentage.
- The minimum, maximum and average *BD-Rate Gain* (for a given metric and a given anchor codec) across all reference sequences in the test configuration.
- this typically results in the following results for a codec under test. For each scenario and for each configuration, a table is provided to compare against each anchor codec
- where the row header documents the reference sequence for the test, e.g. *S5-R<i>* to the specific configuration.
- where the column header documents the key of the metric
- that documents in the cell with *BD-Rate Gain* using a single digit
- the above is extended with three summary rows, where the column header documents average, minimum and maximum gain

An example is provided in Table 5.8-1.

Table 5.8-1 *BD-Rate Gain* example table for an example scenario SX with 4 reference sequences, a given codec under test, a given anchor codec and given test configuration

Reference sequence	psnr	y_psnr	vmaf	ms_ssim
SX-R01				
SX-R02				
SX-R03				
SX-R04				
Average				
Minimum				
maximum				

BD-Rate Gain is computed according to the Common Test Condition (CTC) method used in JVET and specified in [44]. According to the IETF draft on "Video Codec Testing and Quality Measurement" [70], clause 4.2, the *BD-Rate Gain* is defined as a measure of the bitrate reduction offered by a codec or codec feature, while maintaining the same quality as measured by objective metrics. The rate change is computed as the average percent difference in rate over a range of qualities. Metric score ranges are not static - they are calculated either from a range of bitrates of the reference codec, or from quantizers of a third, anchor codec. Given an anchor codec and test codec, the *BD-Rate Gain* values are calculated as follows:

1. Rate/quality points are calculated for the anchor and test code as $(Q_{\text{anchor}}[i], R_{\text{anchor}}[i]), i=1, \dots, N_{\text{anchor}}$ and $(Q_{\text{test}}[i], R_{\text{test}}[i]), i=1, \dots, N_{\text{test}}$
 - At least four points need to be computed, i.e. $N_{\text{test}} \geq 4$ and $N_{\text{test}} \geq 4$. These points should be the same quantizers when comparing two versions of the same codec.
 - Additional points outside of the range should be discarded.
2. The rates $R_{\text{anchor}}[i]$ and $R_{\text{test}}[i]$ are converted into logarithmic scale.
3. A piecewise cubic hermite interpolating polynomial is fit to the points for each codec to produce functions of log-rate in terms of quality measure. Interpolation functions require that two quality values are different. Hence, if provided data does have identical quality values, the higher rate point is adjusted to a slightly higher value that is withing the rounding error of the identical value, for example if twice 23.24 is reported, value 1 is set to 23.240 and the second value is set to 23.241.
4. Quality ranges are chosen by the maximum of the minimum value of any of the two codecs and the minimum of the maximum value of any of the two codecs, i.e.
 - $\text{min\_range} = \max(\min(Q_{\text{anchor}}[i]), \min(Q_{\text{test}}[i]))$
 - $\text{max\_range} = \min(\max(Q_{\text{anchor}}[i]), \max(Q_{\text{test}}[i]))$
5. The log-rate is numerically integrated over the metric range for each curve, using at least 1000 samples and trapezoidal integration.
6. The resulting integrated log-rates are converted back into linear rate, and then the percent difference is calculated from the anchor to the test codec. This difference is reported as the *BD-Rate Gain*.
7. The plot is provided in linear scale for bitrate and for quality metric, and the "gain" of test against anchor is shown in green, where as if there would be a loss, a loss would be shown in "red". The points in the linear domain are plotted also using piecewise cubic hermite polynomial interpolation.

As described in [44], the PSNR ranges of two curves generally do not overlap completely, and the current practice is to avoid measuring the part of the area between curves that are extrapolated rather than interpolated, which can give unpredictable results if the non-overlapping parts are large. Therefore, the area between the two curves is only measured in the region where there is an overlap. If two curve overlap is only in a very small region, the BD-rate will be calculated using only a small (and possibly atypical) part of the available data. Therefore, it is important that the overlap is substantial for the BD-rate value to be meaningful.

With the availability of *quality* data for the anchor and the test, *Overlap* is defined as follows:

$$\text{Overlap} = 100 \cdot \frac{\min\left(\max_i(Q_{\text{anchor}}[i]), \max_i(Q_{\text{test}}[i])\right) - \max\left(\min_i(Q_{\text{anchor}}[i]), \min_i(Q_{\text{test}}[i])\right)}{\max\left(\max_i(Q_{\text{anchor}}[i]), \max_i(Q_{\text{test}}[i])\right) - \min\left(\min_i(Q_{\text{anchor}}[i]), \min_i(Q_{\text{test}}[i])\right)}$$

The characterization of the codecs in the framework is documented when the overlap is substantial.

An example for BD-rate computation and the associated values is provided in Figure 5.8-2.

NOTE: For consistency, the JVET excel files have been extended in the Random-Access and low delay tabs to contain new columns for the new metrics: VMAF and MS-SSIM, in the SDR case only. The “SA4 extended excel files” for SDR and HDR are attached as S4-template-HDR.xlsx and S4-template-SDR.xlsx, but are not considered to be used for BD-Rate computation.

In addition, the code permits to provide the Overlap using the following command:

Usage: `python3 compare.py -c --overlap <key anchor configuration> <key test configuration>`

Example: `python3 compare.py -c --overlap S1-JM-01 S1-HM-01`

The data is written into a csv file in the directory Characterization of the codec under test with the naming convention:

`<anchor configuration>.<test configuration>.overlap.csv`

Example: `S1-JM-01.S1-HM-01.overlap.csv`

5.9 Verification

5.9.1 Principles

Submissions of anchors, tests and associated metrics are based on 3GPP member input. However, such input to be considered valid is expected of to be verified. Verification in the context of this document includes the following according to Figure 5.9.1-1:

- 1) Anchor bitstream verification: Anchor bitstreams are correct. By using a defined reference sequence, an anchor configuration as well as a reference encoder, two different executions of this process result in the same anchor bitstream.
- 2) Anchor reconstruction is correct. By using a verified anchor bitstream, a reference decoder in two different implementations results
 - a. in the same anchor sequence,
 - b. in the same quality metrics.

The equivalent process is applied for tests.

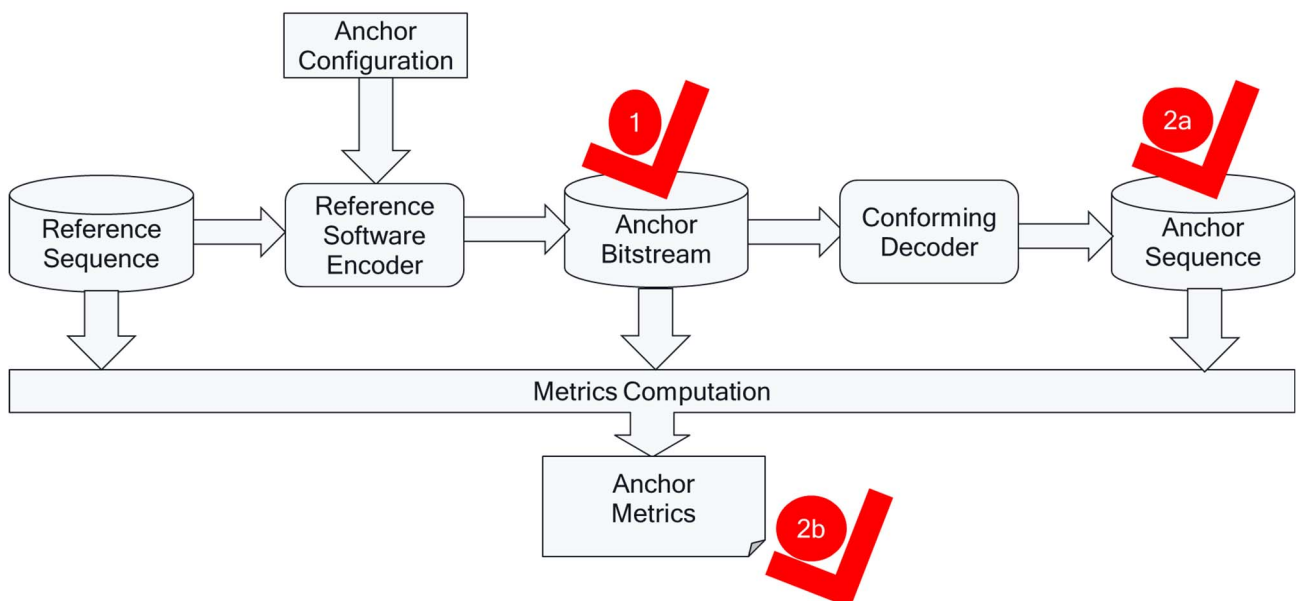


Figure 5.9.1-1: Verification and cross-check processes

Verification is primarily supported by cross-checks from independent members who carry out the execution of the same process and done by the initial submitter of the anchors/tests. Whereas process 2 is deemed to be of manageable complexity, process 1 is of significantly higher complexity. Based on this it is expected that anchor reconstruction (process 2a) and anchor metrics (process 2b) are cross-checked and verified for every anchor, whereas anchor bitstreams are only cross-checked and verified for one anchor of the entire anchor tuple.

A successful cross-check is defined as follows:

- 1) Anchor bitstream verification: Initial run and cross-check result in the same size and md5 for the anchor bitstream
- 2) Anchor reconstruction verification. By using a verified anchor bitstream, a reference decoder in two different implementations results in the same md5 for the anchor sequence.
- 3) Anchor metrics verification. By using a verified anchor bitstream, a reference decoder in two different implementations results in the same quality metrics with a maximum deviation of 0.01 for all metrics that are required for characterization.

This technical report includes verified metrics in the main body of the text (i.e. successful completion of stage 3). Verified metrics are agreed to be correct and have been sufficiently cross-checked.

This technical report may also include non-verified anchors, tests and metrics in the Annex G. In this case, the reason for the lacking verification is explained.

5.9.2 Documentation

In order to track initial submission, cross-checking and verification, the anchor/test documentation adds the following information. The anchor/test stream gets assigned verification data as follows

- **status-bitstream**: status of bitstream verification (see 1 in Figure 5.9.1-1 and 1) in clause 5.9.1)
 - **successful**: cross-checks were successful
 - **missing**: cross-checks are missing
 - **failed**: cross-checks were done, but were not successful
 - **ambiguous**: there are successful and unsuccessful cross-checks
- **status-reconstruction**: status of reconstruction verification (see 2a in Figure 5.9.1-1 and 2) in clause 5.9.1)
 - **successful**: cross-checks were successful
 - **missing**: cross-checks are missing
 - **failed**: cross-checks were done, but were not successful
 - **ambiguous**: there are successful and unsuccessful cross-checks
- **status-metrics**: status of reconstruction verification (see 2b in Figure 5.9.1-1 and 3) in clause 5.9.1)
 - **successful**: cross-checks were successful
 - **missing**: cross-checks are missing
 - **failed**: cross-checks were done, but were not successful
 - **ambiguous**: there are successful and unsuccessful cross-checks
- **none, one or multiple cross-check reports**:
 - contact of the cross-check

- type
 - **bitstream**: the anchor/test bitstream was cross-checked
 - **reconstruction**: the anchor/test reconstruction cross-check is done
 - **metrics**: the anchor/test metrics cross-check is done
- the status of the cross-check
 - **successful**: cross-check was successful
 - **failed**: cross-check failed
 - **missing**: cross-check still missing
- reference to a cross-check report providing possibly the issues

A detailed reporting cross-check scheme is provided in Annex B.4.

For every scenario, a csv file and table are provided that documents the verification status of each anchor and test stream for bitstream (B), reconstruction (R) and Metrics (M) according to Table 5.9.2-1 with S for successful, F for failed, and an empty cell for missing. A summary is provided that combines the verification status of each anchor based on the principles introduced in clause 5.9.1.

Table 5.9.2-1: Example for Verification Status Report

Anchor + Key Verification Type	Summary			Parameter 1			Parameter 2			Parameter 3			Parameter 4		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S1-A01-Codec	S	S	S		S	S		S	S		S	S	S	S	S
S1-A02-Codec		S	S		S	S	F		S		F		F	F	
S1-A02-Codec		S	S		S	S		S	S		S	S		S	S

A detailed verification report scheme is provided in Annex B.5.

6 Relevant Scenarios

6.1 Introduction

This clause collects relevant scenarios based on the template defined in Annex A. It also defines the anchors for each scenario based on the existing 3GPP codecs and profiles defined in clause 4. For each scenario, the following information is provided:

- **Motivation**: provides a context for the scenario, why it is relevant for 5G video services.
- **Description of the Anticipated Application**: This provides an overview on how the service may be done technically in a 5G system. It summarizes where encoders and decoders reside, what codecs are in use today and how the end-to-end system is working.
- **Source format properties**: Provides an overview of relevant video source formats in terms of spatial and temporal resolutions, colour spaces, etc.
- **Encoding and Decoding Constraints**: provides details on encoder settings and configurations for each of the 3GPP codecs mapped to the scenario.
- **Performance Metrics**: Documents the relevant performance metrics for this scenario
- **Interoperability Considerations**: Documents relevant interoperability requirements for a codec when used in the scenario, based on the known applications and protocols.

- Reference Sequences: defines the reference sequences that are selected for this scenario in order to create anchors and anchor metrics. A justification is provided, why this sequence is selected.
- Anchor Definition: provides details on how to generate the anchors for the scenario for each 3GPP codec using the selected reference sequences, the reference software and the codec configuration.
- Anchor Results: provides the results for each anchor.
- Additional information and performance data: provides additional information and performance data available externally.

6.2 Scenario 1: Full HD Streaming

6.2.1 Motivation

The 2020 Mobile Internet Phenomena Report from Sandvine [9] shows that mobile video downstream traffic accounts for more than 65% of the global application category traffic share.

According to Ericsson mobility report [10], video traffic in mobile networks is forecast to grow by around 30 percent annually through 2025 to account for three-quarters of mobile data traffic, from slightly more than 60 percent in 2019. The video traffic growth is driven by the increase of embedded video in many online applications, growth of video-on-demand (VoD) streaming services in terms of both subscribers and viewing time per subscriber, and the evolution toward higher screen resolutions on smart devices. All of these factors have been influenced by the increasing penetration of video-capable smart devices.

Furthermore, while UHD and 4K are trendy formats, the main application for mobile streaming is Full HD with 1080p at 50 or 60 frames per second and is expected to be the format of choice for mobile streaming at scale. The distribution version may be down-sampled to support adaptive bitrate streaming, possibly with High Dynamic Range (HDR) support. For detailed discussion please refer to the presentation at the DASH-IF Workshop Dec 2019 [11].

In terms of distribution, while in the past, streaming video was delivered primarily via RTMP or RTP, fewer and fewer devices support these aging protocols each year. Instead, the latest web standards support built-in video playback and HTML5 is now by far the preferred method for video playback. And adaptive bitrate protocols dominate the distribution. According to the developer report [12], adaptive bitrate streaming through HLS/DASH, using the CMAF/DASH based segment formats, provide vast majority for streaming video. The distribution is used for On-Demand and Live Streaming.

6.2.2 Description of the Anticipated Application

In the context of 3GPP services, 5G Media Streaming [13] as well as the TV Video Profiles [3] are specifications addressing this streaming scenario. Both, 5G Media Streaming [13] and TV Video Profiles [3] builds on CMAF-based Segment formats and DASH distribution. From TS 26.116, the following operation points may be considered in scope of the Full HD Streaming Scenario (pending availability of appropriate test content):

- H.265/HEVC Full HD HDR, see TS26.116 [3] clause 4.5.3.
- H.264/AVC Full HD, see TS26.116 [3] clause 4.4.3.
- H.265/HEVC Full HD, see TS26.116 [3] clause 4.5.5.
- H.265/HEVC Full HD HDR HLG, see TS26.116 [3] clause 4.5.7.

These operation points are further informed by relevant operational experience with commercially available encoders and decoders.

The considered scenario is the distribution of content through DASH/CMAF based streaming. Important aspects that are expected to be considered when evaluating a codec in the context of this:

- Quality and Coding Efficiency:
 - High and uninterrupted visual quality, taking into account the service constraints.

- Any savings can provide significant benefits due to the expected large volume of the traffic either in quality or network utilization.
- Adaptive Bitrate streaming:
 - Multiple bit rates are provided, typically with a ladder of 30–50% to permit bandwidth adaptation. The use of constant bit rate (CBR) encoding maximises reuse of a common ladder of encoded representations across multiple distribution networks. The use of capped variable bit rate (VBR) encoding allows the bit rate to be varied according to the difficulty of the source material while maintaining the ability to distribute the encoded representations through distribution networks with fixed capacity. This also maximises reuse of a common ladder across multiple distribution networks.
 - CMAF Fragments of size typically in the range of 1–6s to permit seamless switching for bit rate adaptation.
 - Regular Random Access, typically every 1–2 seconds according to TS 26.116 [3]. To achieve clean switching in both sound and picture when moving between different encoded representations in the ladder, 3.84 seconds enables video segment boundaries to be aligned with an integer number of audio Access Units, if a 50fps video signal and 48kHz audio signal is used.
- Encoding in this scenario is typically done as
 - Live and On-Demand distribution and encoding
 - Server and Cloud-based Encoding
- No specific encoding latency constraints

6.2.3 Source Format Properties

Table 6.2.3-1 provides an overview of the different source signal properties following the information from TS 26.116 [3]. This information is used to select proper test sequences.

Table 6.2.3-1 Source Format Properties for different operation point

Source Format Properties	H.264/AVC Full HD	H.265/HEVC Full HD	H.265/HEVC Full HD HDR	H.265/HEVC Full HD HLG
Spatial resolutions	1920 × 1080 (Permitted Distribution formats: 1920 × 1080, 1600 × 900, 1280 × 720, 960 × 540, 854 × 480, 640 × 360, 426 × 240)			
Chroma Format	Y'CbCr			
Chroma Subsampling	4:2:0			
Picture Aspect ratios	16:9			
Frame rates	24; 25; 30; 50; 60; 24/1.001; 30/1.001; 60/1.001 Hz			
Bit Depth	8	8, 10	10	10
Colour space formats	BT.709 [14]	BT.709 [14]; BT.2020 [15]	BT.2020 [15]	BT.2020 [15]
Transfer Characteristics	BT.709 [14]	BT.709 [14]; BT.2020 [15]	BT.2100 [16] PQ	BT.2100 [16] HLG

6.2.4 Encoding and Decoding Constraints

Table 6.2.4-1 provides an overview of encoding and decoding constraints for H.264/AVC Full HD and H.265/HEVC Full HD Profiles. This will support the definition of detailed test conditions.

Table 6.2.4-1 Encoding and Decoding Configurations

Encoding and Decoding Constraints	H.264/AVC Full HD	H.265/HEVC Full HD
Relevant Codec and Codec Profile/Levels according to TS26.116 and TS26.511.	H.264/AVC Progressive High Profile Level 4.2 [7]	HEVC/H.265 Main 10 Profile Main Tier Level 4.1 [8]
Random access frequency	1 second, 3.84 seconds	1 second, 3.84 seconds
Error resiliency requirements	None	None
Bit rate parameters (CBR, VBR, CAE, HRD parameters)	Fixed QP CBR 8–12 Mbit/s VBR capped at 12 Mbit/s others	Fixed QP CBR 5–8 Mbit/s VBR capped at 12 Mbit/s others
ABR encoding requirements (switching frequency, etc.)	1 second ABR through multiple QPs	1 second ABR through multiple QPs
Latency requirements and specific encoding settings	No latency requirements beyond RAP so picture reordering is allowed	No latency requirements beyond RAP so picture reordering is allowed
Encoding complexity context	real-time encoding, cloud-based encoding, offline encoding, etc.	real-time encoding, cloud-based encoding, offline encoding, etc.
Required decoding capabilities	H.264/AVC Progressive High Profile Level 4.2 [7]	HEVC/H.265 Main 10 Profile Main Tier Level 4.1 [8]

6.2.5 Performance Metrics

All metrics as defined in clause 5.5 are expected to be reported.

For BD-Rate computation and SDR, only the following metrics are expected to be provided:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as defined in clause 5.5.3,
- Average colour component PSNR, $PSNR$ over all colour components $PSNR$ as defined in clause 5.5.3,
- Structural similarity metric $MS-SSIM$ as defined in clause 5.5.4.2,
- Video Multimethod Assessment Fusion (VMAF) $VMAF$ as defined in clause 5.5.3.

For BD-Rate computation and HDR, only the following metrics are expected to be provided:

- the weighted Peak-Signal-To-Noise Ratio metric for the luma colour components $wPSNR(Y)$, as specified in clause 5.5.4 and 5.5.8,
- Average colour component weighted PSNR, $wPSNR$ over all colour components $wPSNR(Y)$, as specified in clause 5.5.4 and 5.5.8,
- the $PSNRL100$ metric as specified in clause 5.5.4 and 5.5.8,
- $DE100$ metric as specified in clause 5.5.4 and 5.5.8.

6.2.6 Interoperability Considerations

In order to use a codec in the context of 5G Media Streaming services in TS 26.511 and for TV Video profiles in TS 26.116, the following list provides a set of potentially relevant interoperability aspects for Full HD Streaming:

1. The receiver requirements on elementary stream level, in particular the profile/level and additional considerations.
2. The encapsulation of an elementary stream into an ISO Base Media File Format track
3. The definition of a CMAF media profile.
4. The static mapping of parameters to a DASH MPD, in particular to the MPD parameters, such as @mimeType, @codecs, etc
5. The dynamic mapping of parameters to a DASH MPD from a CMAF Principal Header, in particular to the MPD parameters, such as @width, @height, etc.
6. All MPD-level signalling for the codec to support capability discovery

7. Encryption requirements and recommendations.
8. Capability discovery options, for example mapping to HTML-5, MSE and media capability APIs.
9. Source Buffer Initialization Requirements.
10. Playback Requirements, for example by referencing CTA WAVE Specifications
11. Relation to other specifications, such as in DVB, ATSC, MPEG, ETSI, etc.

For additional details, please refer to TS 26.116 and TS 26.511.

6.2.7 Reference Sequences

Table 6.2.7-1 provides the selected SDR reference sequences for this scenario and Table 6.2.7-2 provides the HDR sequences. Keys are defined to refer to the sequences in the context of the scenario. The sequences are named and a reference to the details of the sequence is provided.

The applied sequences are the subsampled versions of selected 4K-TV sequences as defined in clause 6.3.7. Subsampling is done with HDRConvert based on the configuration provided in the attachment.

Table 6.2.7-1 SDR Reference Sequences for FullHD scenario

Key	Name	Reference	Resolution	Frame rate	Colour Gamut	Number of Frames	Scene Cut
S1-R01	Brest-Sedof-FHD	Annex C.3.1.3.1	1920 x 1080	60	BT.709	300	0
S1-R02	Rain Fruits-FHD	Annex C.3.1.3.2	1920 x 1080	50	BT.709	500	0
S1-R03	Park Joy-FHD	Annex C.3.1.3.3	1920 x 1080	50	BT.709	500	0
S1-R04	Soccer-FHD	Annex C.3.1.3.4	1920 x 1080	23.98	BT.709	385	4
S1-R05	Tunnel Flag-FHD	Annex C.3.1.3.5	2048 x 1080	59.94	BT.709	600	0
S1-R06	Boat-FHD	Annex C.3.1.3.6	2048 x 1080	59.94	BT.709	300	0
S1-R07	Fountain-FHD	Annex C.3.1.3.7	2048 x 1080	59.94	BT.709	600	0
S1-R08	Riverbank-FHD	Annex C.3.1.3.8	1920 x 1080	50	BT.709	600	0

Table 6.2.7-2 HDR Reference Sequences for FullHD scenario

Key	Name	Reference	Resolution	Frame rate	Colour Gamut	Number of Frames	Scene Cut
S1-R11	Life-Untouched-FHD	Annex C.3.2.3.1	1920 x 1080	59.94	BT.2020	450	0
S1-R12	Meridian-FHD	Annex C.3.2.3.2	1920 x 1080	59.94	BT.2020	327	0
S1-R13	Sol-Levante-FHD	Annex C.3.2.3.3	1920 x 1080	24	BT.2020	145	0
S1-R14	Cosmos-FHD	Annex C.3.2.3.4	1920 x 1080	24	BT.2020	182	0
S1-R15	Elevator-FHD	Annex C.3.2.3.5	2048 x 1080	59.94	BT.2020	432	0
S1-R16	Sparks-FHD	Annex C.3.2.3.6	2048 x 1080	59.94	BT.2020	261	0
S1-R17	Nocturne-FHD	Annex C.3.2.3.7	1920 x 1080	60	BT.2020	370	0

6.2.8 Anchor Definition

6.2.8.1 Overview

This clause provides details on how to generate the anchors for the Full HD Scenario.

6.2.8.2 H.264/AVC Anchors

6.2.8.2.1 Overview

Table 6.2.8.2.1-1 provides an overview of the H.264/AVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario1-FullHD/264/streams.csv>.

Table 6.2.8.2.1-1 Anchor Tuple generation with H.264/AVC for Full HD Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S1-A01-264	6.2.8.2.2	S1-R01	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A01-264-<QP>
S1-A02-264	6.2.8.2.2	S1-R02	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A02-264-<QP>
S1-A03-264	6.2.8.2.2	S1-R03	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A03-264-<QP>
S1-A04-264	6.2.8.2.2	S1-R04	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A04-264-<QP>
S1-A05-264	6.2.8.2.2	S1-R05	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A05-264-<QP>
S1-A06-264	6.2.8.2.2	S1-R06	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A06-264-<QP>
S1-A07-264	6.2.8.2.2	S1-R07	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A07-264-<QP>
S1-A08-264	6.2.8.2.2	S1-R08	JM19	S1-JM-01	QP = [22,27,32,37]	S1-A08-264-<QP>

6.2.8.2.2 S1-JM-01

To generate the anchor bitstreams, JM19 is used.

However, as the test sequences are 10 bit sequences, 8 bit version of S1 SDR reference sequences are generated with `HDRConvert` and the attached `HDRConvert` config `HDRConvert_10bto8b.cfg`. These sequences are used to generate the H.264/AVC anchors for S1. To generate the metrics, the 8 bit output is converted to 10 bit using `HDRConvert` and the attached `HDRConvert` config `HDRConvert_8bto10b.cfg`.

In order to verify the proper down scaling from 10 to 8 bit, a csv file is provided with the md5 of the 8 bit downconverted reference sequences here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario1-FHD/264/md5-8bit.csv>.

- Profile H.264/AVC Progressive High-Profile Level 4.2 [7]
- Random access and switching at 1 second interval
- `LevelIDC` = 50
- `NumberBFrames` = 15
- `BReferencePictures` = 2
- Quantization parameters are set as according to Table 6.2.8.2.2-1
- Picture based multipass coding disabled
- `IDRPeriod` = 0, i.e. open GOP structure are used in case of intra.

Table 6.2.8.2.2-1: Quantization parameters settings for H.264/AVC Anchor definition

QP	QPSlice	QPPSlice	QPBSlice	ExplicitHierarchyFormat
22	19	23	23	B7r0B3r3B1r4b0e6b2e6B5r4b4e6b6e6B11r3B9r4b8e6b10e6B13r4b12e6b14e6
27	24	28	28	B7r1B3r4B1r6b0e8b2e8B5r6b4e8b6e8B11r4B9r6b8e8b10e8B13r6b12e8b14e8
32	29	33	33	B7r2B3r5B1r7b0e8b2e8B5r7b4e8b6e8B11r5B9r7b8e8b10e8B13r7b12e8b14e8
37	34	38	38	B7r3B3r6B1r7b0e8b2e8B5r7b4e8b6e8B11r6B9r7b8e8b10e8B13r7b12e8b14e8

The settings are defined in the attached configuration file `s1-jm-01.cfg`.

The source sequence `InputFile` as well as the `FrameRate` needs to be set accordingly.

The following parameters need to be adapted for each sequence as follows using the JSON parameters of the reference sequence:

- `IntraPeriod`: Intra Period aligned with `GOPSize` such that approximately 1 second is achieved, i.e.
- `"frameRate"`: 23.98 or 24.0 or 25 or 30 => `IntraPeriod` set to 32,

- "frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64

6.2.8.3 H.265/HEVC Anchors

6.2.8.3.1 Overview

Table 6.2.8.3.1-1 provides an overview of the H.265/HEVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario1-FullHD/265/streams.csv>.

Table 6.2.8.3.1-1 Anchor Tuple generation with H.265/HEVC for FullHD Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S1-A01-265	6.3.8.3.3	S1-R01	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A01-265-<QP>
S1-A02-265	6.3.8.3.3	S1-R02	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A02-265-<QP>
S1-A03-265	6.3.8.3.3	S1-R03	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A03-265-<QP>
S1-A04-265	6.3.8.3.3	S1-R04	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A04-265-<QP>
S1-A05-265	6.3.8.3.3	S1-R05	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A05-265-<QP>
S1-A06-265	6.3.8.3.3	S1-R06	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A06-265-<QP>
S1-A07-265	6.3.8.3.3	S1-R07	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A07-265-<QP>
S1-A08-265	6.3.8.3.3	S1-R08	HM.16.24	S1-HM-01	QP: [22,27,32,37]	S1-A08-265-<QP>
S1-A11-265	6.3.8.3.4	S1-R11	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A11-265-<QP>
S1-A12-265	6.3.8.3.4	S1-R12	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A12-265-<QP>
S1-A13-265	6.3.8.3.4	S1-R13	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A13-265-<QP>
S1-A14-265	6.3.8.3.4	S1-R14	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A14-265-<QP>
S1-A15-265	6.3.8.3.4	S1-R15	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A15-265-<QP>
S1-A16-265	6.3.8.3.4	S1-R16	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A16-265-<QP>
S1-A17-265	6.3.8.3.4	S1-R17	HM.16.24	S1-HM-02	QP: [22,27,32,37]	S1-A17-265-<QP>

6.2.8.3.2 Common Parameters and Settings

To generate the anchor bitstreams, HM.16.24 is used:

- HM.16.24 https://hevc.hhi.fraunhofer.de/svn/svn_HEVCSoftware/tags/HM-16.24/

The common parameters are as follows:

- Profile: main10 (Main 10 Profile)
- DecodingRefreshType: 1 (CRA)
- SearchRange: 384
- InternalBitDepth: 10 (codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits)
- SEIMasteringDisplayColourVolumeSEI is not added. If it would be added, then the metadata in the json file may be used.

The following parameters need to be adapted for each sequence as follows using the JSON parameters of the reference sequence:

- IntraPeriod: Intra Period aligned with GOPSize such that approximately 1 second is achieved, i.e.
 - "frameRate": 23.98 or 24.0 or 25 or 30 => IntraPeriod set to 32,
 - "frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64

The following parameters are variables and triggered through updates of the config-file.

- QP: [22,27,32,37]

In cases where the anchor uses temporal filtering and the codec being tested does not, additional results may be included for information to show the comparison with temporal filtering turned off for the anchor. Alternatively, an external document, which details the improvement due to temporal filtering for the anchor, may be referenced.

6.2.8.3.3 S1-HM-01: SDR Settings

The common parameters as defined in 6.2.8.3.2 apply.

In addition, the following parameters apply:

- VuiParametersPresent: 0 (VUI absent)
- SEIDecodedPictureHash: 0 (md5 checksum absent)

The settings are defined in the attached configuration file `s1-hm-01.cfg`.

6.2.8.3.4 S1-HM-02: HDR PQ Settings

The common parameters as defined in 6.2.8.3.2 apply.

In addition, the following parameters apply:

- VuiParametersPresent: 1 (VUI present)
- ColourPrimaries: 9
- TransferCharacteristics: 16
- MatrixCoefficients: 9
- ChromaLocInfoPresent: 1
- ChromaSampleLocTypeTopField: 2
- ChromaSampleLocTypeBottomField: 2
- SEIDecodedPictureHash: 0 (md5 checksum absent)

The settings are defined in the attached configuration file `s1-hm-02.cfg`.

6.2.9 Anchor Results

6.2.9.1 H.264/AVC Anchors

AVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/264/>

AVC anchor results are provided with the appropriate keys as defined in Table 6.2.8.2.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/264/Metrics/>

Note that the results provided for H.264/AVC are impacted not only by the encoding distortion, but also by the 10 to 8 bit conversion prior to encoding, in particular when used as anchor and compared with 10 bit encoding.

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/264/cross-check.csv>.

Based on these cross-check results, the verification status for the H.264/AVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/264/verification.csv> and Table 6.2.9.1-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.2.9.1-1 Verification status of H.264/AVC anchors for Full HD Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S1-A01-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A02-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A03-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A04-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A05-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A06-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A07-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A08-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.2.9.2 H.265/HEVC Anchors

HEVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/265/>

HEVC anchor results are provided with the appropriate keys as defined in Table 6.2.8.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/265/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/265/cross-check.csv>.

Based on these cross-check results, the verification status for the H.265/HEVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/265/verification.csv> and Table 6.2.9.2-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.2.9.2-1 Verification status of H.265/HEVC anchors for Full HD Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S1-A01-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A02-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A03-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A04-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A05-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A06-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A07-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A08-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A11-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A12-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A13-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A14-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A15-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A16-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-A17-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.3 Scenario 2: 4K-TV

6.3.1 Motivation

Streaming towards mobile devices is undoubtedly the first natural use-case expected for 5G-media streaming. However, consumption of video services on fixed receivers (e.g. TV sets) remains a preferable way of experiencing the high-quality content, whether it is for on-demand (e.g., blockbuster movies) or live services (e.g., sport events). Recent reports from largest VOD platforms such as Netflix confirm that assumption and show that the primary way of

watching content remains fixed TV screens, covering 70% of devices 6 months after subscription [17]. In the same way, YouTube indicates that service usage on fixed TV set remains an inevitable way of accessing the content, with 250M of hours viewed per day on TV screens [18]. As 5G media streaming targets a wide range of connected devices and is expected to be able to deliver video streams to many compatible high-resolution receivers, (e.g. 5G-HDMI-sticks, 5G-StB/5G-MediaGateway or even 5G-TV sets) the inclusion of 4K TV Scenarios for 5G Video codec evaluation is important.

First, the 4K-TV set is currently the most established way of displaying premium quality services using latest technology improvements for video content, including High-Dynamic-Range (HDR) and Wide-Colour-Gamut (WCG). Latest statistics from the Ultra-HD forum indicate that 148 UHD services are currently on-air, 74% being linear, 45% of those using HDR [19]. In addition, a large number of SVOD operators propose 4K access in their subscription packages (e.g. Netflix™ and Amazon Prime™). All these services may eventually take advantage of 5G-network capabilities to increase the device reach and enlarge audiences. This scenario is also endorsed by strong shipment forecasts, as indicated in the latest IHS 4K-TV UHD bluebook [20].

6.3.2 Description of the Anticipated Application

In the context of 3GPP services, 5G Media Streaming [13] as well as the TV Video Profiles [3] are specifications addressing this 4K-TV scenario. Both, 5G Media Streaming [13] and TV Video Profiles [3] build on CMAF-based Segment formats and DASH distribution. From 3GPP TS 26.116, the following operation points may be considered in scope of the 4K-TV Streaming Scenario (pending availability of appropriate test content):

- H.265/HEVC UHD, see 3GPP TS 26.116 [3] clause 4.5.4.
- H.265/HEVC UHD HDR, see 3GPP TS 26.116 [3] clause 4.5.6.
- H.265/HEVC UHD HDR HLG, see 3GPP TS 26.116 [3] clause 4.5.8.

This scenario is based on CMAF (including LL-DASH and HLS-LL) distribution of UHD-TV video services over 5G networks to 5G/non-5G capable devices. This includes 5G-equipped devices (e.g. smartphone, tablets, ...) but also other devices gateway (e.g. TV sets, HDMI-Stick...) accessing services through a “5G-gateway” which can be a mobile phone or a home gateway. As multiple linear services will be delivered in parallel (news, sport, talk show...) in a similar manner as traditional TV services in a multiplex (potentially using multicast/broadcast delivery over 5G). In certain environments, High Frame Rate (HFR) beyond 60 fps is considered, e.g. in DVB and ATSC broadcast specifications. 3GPP does not have any HFR TV video profiles yet.

Important aspects that are expected to be considered when evaluating a codec in the context of this 4K-TV scenario are:

- Quality and Coding Efficiency:
 - High and uninterrupted visual quality, considering the service constraints.
 - Any savings can provide significant benefits due to the expected large volume of the traffic either in quality or network utilization.
- Adaptive Bitrate streaming:
 - Multiple bit rates are provided, typically with a ladder of 30–50% to permit bandwidth adaptation. The use of constant bit rate (CBR) encoding maximises reuse of a common ladder of encoded representations across multiple distribution networks. The use of capped variable bit rate (VBR) encoding allows the bit rate to be varied according to the difficulty of the source material while maintaining the ability to distribute the encoded representations through distribution networks with fixed capacity. This also maximises the usage of a common ladder across multiple distribution networks.
 - CMAF Fragments of size typically in the range of 1–6s to permit seamless switching for bit rate adaptation.
 - Regular Random Access, typically every 1–2 seconds according to 3GPP TS 26.116 [3]. To achieve clean switching in both sound and picture when moving between different encoded representations in the ladder, 3.84 seconds enables video segment boundaries to be aligned with an integer number of audio Access Units, if a 50fps video signal and 48kHz audio signal is used.
- Encoding in this scenario is typically done as
 - Live and On-Demand distribution and encoding

- Server and Cloud-based Encoding
- Capable of encoding multiple services at variable bitrate, inside a fixed dedicated resource (statistical multiplexing).

6.3.3 Source Format Properties

Table 6.3.3-1 provides an overview of the different source signal properties for 4K-TV. This information is used to select proper test sequences.

Table 6.3.3-1 4K-TV source format properties

Source format properties	4K-TV
Spatial resolution	3840 × 2160 (Permitted distribution formats: 2560 × 1440, 1920 × 1080, 1600 × 900, 1280 × 720)
Chroma format	Y'CbCr
Chroma subsampling	4:2:0
Picture aspect ratio	16:9
Frame rates	24; 50; 60; 24/1.001; 60/1.001; [100; 120] Hz
Bit depth	10
Colour space formats	BT.2020 [15]
Transfer characteristics	BT.2020 [15], BT.2100 [16] (PQ & HLG)

NOTE: High Frame Rate (HFR) is not supported by 3GPP TV Video profiles defined in 3GPP TS 26.116 [3] in release 16. However, HFR is introduced in this clause for consideration on the video codec performances.

6.3.4 Encoding and Decoding Constraints

Table 6.3.4-1 provides an overview of encoding and decoding constraints for 4K-TV category using legacy codec HEVC. This will support the definition of detailed test conditions. It is noted that no relevant profiles exist in TS26.116 and TS26.511 for HFR 4K-TV content.

Table 6.3.4-1 Encoding and Decoding Configurations for 4K-TV with legacy HEVC codec

Encoding and Decoding Constraints	H.265/HEVC 4K-TV	H.265/HEVC 4K-TV HFR
Relevant Codec and Codec Profile/Levels according to TS26.116 and TS26.511.	H.265/HEVC Main 10 Profile Level 5.1 [8]	No relevant 3GPP profiles, should be aligned with H.265/HEVC Main 10 Profile Level 5.2 [8]
RAP period	3.84sec, 1sec	3.84sec, 1sec
Bit rate parameters (CBR, VBR, CAE, HRD parameters)	QPs see below B = {10,20,30,40} Mbps [49] CBR and capped-VBR	QP are tbd B = {10,20,30,40} Mbps [49] CBR and capped-VBR
Latency requirements and specific encoding settings	No latency requirements beyond RAP so picture reordering allowed	No latency requirements beyond RAP so picture reordering allowed
Encoding complexity context	real-time encoding, cloud-based encoding, offline encoding, etc.	real-time encoding, cloud-based encoding, offline encoding, etc.
Required decoding capabilities	H.265/HEVC Main 10 Profile Level 5.1 [8]	H.265/HEVC Main 10 Profile Level 5.2 [8]

6.3.5 Performance Metrics

Performance is assessed using BD-Rate computation, with PSNR, SSIM and VMAF metrics as objective quality criterion. Regarding complexity considerations, encoding/decoding runtime is provided.

All metrics as defined in clause 5.5 are expected to be reported.

For BD-Rate computation and SDR, only the following metrics are expected to be provided:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as defined in clause 5.5.3,
- Average colour component PSNR, $PSNR$ over all colour components $PSNR(i)$ as defined in clause 5.5.3,

- Structural similarity metric *MS-SSIM* as defined in clause 5.5.4.2,
- Video Multimethod Assessment Fusion (VMAF) *VMAF* as defined in clause 5.5.3.

For BD-Rate computation and HDR, only the following metrics are expected to be provided:

- the weighted Peak-Signal-To-Noise Ratio metric for the luma colour components $wPSNR(Y)$, as specified in clause 5.5.4 and 5.5.8,
- Average colour component weighted PSNR, $wPSNR$ over all colour components $wPSNR(i)$, as specified in clause 5.5.4 and 5.5.8,
- the *PSNRL100* metric as specified in clause 5.5.4 and 5.5.8,
- *DE100* metric as specified in clause 5.5.4 and 5.5.8.

6.3.6 Interoperability Considerations

In order to use a codec in the context of 5G Media Streaming services in 3GPP TS 26.511 [13] and for TV Video profiles in 3GPP TS 26.116 [3], the same considerations for interoperability as for FullHD according to clause 6.2.6 apply.

For additional details, please refer to 3GPP TS 26.116 [3] and 3GPP TS 26.511 [13].

6.3.7 Reference Sequences

Table 6.3.7-1 provides the selected reference sequences for this scenario for SDR and Table 6.3.7-2 provides the selected reference sequences for this scenario for HDR. Keys are defined to refer to the sequences in the context of the scenario. The sequences are named and a reference to the details of the sequence is provided. Annex C.3 describes in detail the selection process conducted to build the test sequences considered for this scenario, the outcome of this process is reported in the table below.

Table 6.3.7-1 SDR Reference Sequences for 4K-TV scenario

Key	Name	Reference	Resolution	Frame rate	Colour Gamut	Number of Frames	Scene Cut
S2-R01	Brest-Sedof	Annex C.3.1.3.1	3840 x 2160	60	BT.709	300	0
S2-R02	Rain Fruits	Annex C.3.1.3.2	3840 x 2160	50	BT.709	500	0
S2-R03	Park Joy	Annex C.3.1.3.3	3840 x 2160	50	BT.709	500	0
S2-R04	Soccer	Annex C.3.1.3.4	3840 x 2160	23.98	BT.709	385	4
S2-R05	Tunnel Flag	Annex C.3.1.3.5	4096 x 2160	59.94	BT.709	600	0
S2-R06	Boat	Annex C.3.1.3.6	4096 x 2160	59.94	BT.709	300	0
S2-R07	Fountain	Annex C.3.1.3.7	4096 x 2160	59.94	BT.709	600	0
S2-R08	Riverbank	Annex C.3.1.3.8	3840 x 2160	50	BT.709	600	0

Table 6.3.7-2 HDR Reference Sequences for 4K-TV scenario

Key	Name	Reference	Resolution	Frame rate	Colour Gamut	Number of Frames	Scene Cut
S2-R11	Life-Untouched	Annex C.3.2.3.1	3840 x 2160	59.94	BT.2100 PQ	450	0
S2-R12	Meridian	Annex C.3.2.3.2	3840 x 2160	59.94	BT.2100 PQ	327	0
S2-R13	Sol-Levante	Annex C.3.2.3.3	3840 x 2160	24	BT.2100 PQ	145	0
S2-R14	Cosmos	Annex C.3.2.3.4	3840 x 2160	24	BT.2100 PQ	182	0
S2-R15	Elevator	Annex C.3.2.3.5	4096 x 2160	59.94	BT.2100 PQ	432	0
S2-R16	Sparks	Annex C.3.2.3.6	4096 x 2160	59.94	BT.2100 PQ	261	0
S2-R17	Nocturne	Annex C.3.2.3.7	3840 x 2160	60	BT.2100 PQ	370	0

6.3.8 Anchor Definition

6.3.8.1 Overview

This clause provides details on how to generate the anchors for the 4K-TV scenario.

No H.264/AVC Anchors are defined.

H.265/HEVC Anchors are defined in clause 6.3.8.3.

6.3.8.2 H.264/AVC Anchors

No H.264/AVC Anchors are defined for this scenario.

6.3.8.3 H.265/HEVC Anchors

6.3.8.3.1 Overview

Table 6.3.8.3.1-1 provides an overview of the H.265/HEVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/265/streams.csv>.

Table 6.3.8.3.1-1 Anchor Tuple generation with H.265/HEVC for 4K-TV Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S2-A01-265	6.3.8.3.3	S2-R01	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A01-265-<QP>
S2-A02-265	6.3.8.3.3	S2-R02	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A02-265-<QP>
S2-A03-265	6.3.8.3.3	S2-R03	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A03-265-<QP>
S2-A04-265	6.3.8.3.3	S2-R04	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A04-265-<QP>
S2-A05-265	6.3.8.3.3	S2-R05	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A05-265-<QP>
S2-A06-265	6.3.8.3.3	S2-R06	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A06-265-<QP>
S2-A07-265	6.3.8.3.3	S2-R07	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A07-265-<QP>
S2-A08-265	6.3.8.3.3	S2-R08	HM.16.24	S2-HM-01	QP: [22,27,32,37]	S2-A08-265-<QP>
S2-A11-265	6.3.8.3.4	S2-R11	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A11-265-<QP>
S2-A12-265	6.3.8.3.4	S2-R12	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A12-265-<QP>
S2-A13-265	6.3.8.3.4	S2-R13	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A13-265-<QP>
S2-A14-265	6.3.8.3.4	S2-R14	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A14-265-<QP>
S2-A15-265	6.3.8.3.4	S2-R15	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A15-265-<QP>
S2-A16-265	6.3.8.3.4	S2-R16	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A16-265-<QP>
S2-A17-265	6.3.8.3.4	S2-R17	HM.16.24	S2-HM-02	QP: [22,27,32,37]	S2-A17-265-<QP>

6.3.8.3.2 Common Parameters and Settings

To generate the anchor bitstreams, HM.16.24 is used:

- HM.16.24 https://hevc.hhi.fraunhofer.de/svn/svn_HEVCSoftware/tags/HM-16.24/

The common parameters are as follows:

- **Profile:** main10 (Main 10 Profile)
- **DecodingRefreshType:** 1 (CRA)
- **SearchRange:** 384
- **InternalBitDepth:** 10 (codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits)
- **SEIMasteringDisplayColourVolumeSEI** is not added. If it would be added, then the metadata in the json file may be used.

The following parameters need to be adapted for each sequence as follows using the JSON parameters of the reference sequence:

- **IntraPeriod**: Intra Period aligned with GOPSize such that approximately 1 second is achieved, i.e.
 - `"frameRate": 23.98 or 24.0 or 25 or 30 => IntraPeriod set to 32,`
 - `"frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64`

The following parameters are variables and triggered through updates of the config-file.

- **QP**: [22,27,32,37]

In cases where the anchor uses temporal filtering and the codec being tested does not, additional results may be included for information to show the comparison with temporal filtering turned off for the anchor. Alternatively, an external document, which details the improvement due to temporal filtering for the anchor, may be referenced.

6.3.8.3.3 S2-HM-01: SDR Settings

The common parameters as defined in 6.3.8.3.2 apply.

In addition, the following parameters apply:

- **VuiParametersPresent**: 0 (VUI absent)
- **SEIDecodedPictureHash**: 0 (md5 checksum absent)

The settings are defined in the attached configuration file `s2-hm-01.cfg`.

6.3.8.3.4 S2-HM-02: HDR PQ Settings

The common parameters as defined in 6.3.8.3.2 apply.

In addition, the following parameters apply:

- **VuiParametersPresent**: 1 (VUI present)
- **ColourPrimaries**: 9
- **TransferCharacteristics**: 16
- **MatrixCoefficients**: 9
- **ChromaLocInfoPresent**: 1
- **ChromaSampleLocTypeTopField**: 2
- **ChromaSampleLocTypeBottomField**: 2
- **SEIDecodedPictureHash**: 0 (md5 checksum absent)

The settings are defined in the attached configuration file `s2-hm-02.cfg`.

6.3.9 Anchor Results

6.3.9.1 H.264/AVC Anchors

No H.264/AVC anchors are provided.

6.3.9.2 H.265/HEVC Anchors

HEVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/265/>

HEVC anchor results are provided with the appropriate keys as defined in Table 6.3.8.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/265/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/265/cross-check.csv>.

Based on these cross-check results, the verification status for the H.265/HEVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/265/verification.csv> and Table 6.2.9.1-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.3.9.2-1 Verification status of H.265/HEVC anchors for 4K TV Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S2-A01-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A02-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A03-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A04-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A05-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A06-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A07-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A08-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A11-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A12-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A13-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A14-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A15-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A16-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-A17-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.4 Scenario 3: Screen Content Scenario

6.4.1 Motivation

This scenario mostly motivates cases for which content goes beyond videographic content, and in particular includes computer generated imagery (CGI). Several application spaces rely on screen content types such as videoconferencing and webinars with presentation slides displayed, or remote desktop applications for demos or remote assistance. These services include massive online videoconferencing systems and telepresence systems both being particularly popular with remote collaboration.

For telepresence with screen-sharing applications, some information related to video is collected in the following:

- MS Teams™ [26] as of end of 2019.
 - o There are several formats supported for video. Two key properties of a video format are its frame size and colour format. Supported frame sizes include 640x360 ("360p"), 1280x720 ("720p"), and 1920x1080 ("1080p"). Supported colour formats include NV12 (12 bits per pixel) and RGB24 (24 bits per pixel).
 - o A "720p" video frame contains 921,600 pixels (1280 times 720). In the RGB24 colour format, each pixel is represented as 3 bytes (24-bits) comprised of one byte each of red, green, and blue colour components. Therefore, a single 720p RGB24 video frame requires 2,764,800 bytes of data (921,600 pixels times 3 bytes/pixel). At a frame rate of 30fps, sending 720p RGB24 video frames means processing approximately 80 MB/s of content (which is substantially compressed by the H.264 video codec before network transmission).
- Other tools are for further study.

As an example of hardware implementation, the Intel Xe LP™ chipset supports HEVC screen content profile (see slide 101 of [41]).

6.4.2 Description of the Anticipated Application

3GPP until now has very restricted set of services but based on the considerations in clause 6.4.1, the following encoding benchmark capabilities are considered for decoding:

- H.264 (AVC) YUV 4:2:0, YUV 4:4:4, 8 bit, Max Resolution 1920x1080
- H.265 (HEVC) YUV 4:2:0, YUV 4:4:4, 10 bit, Max Resolution 4096 x 2048

The considered scenario is low-latency streaming or conversational. Important aspects that are expected to be considered when evaluating a codec in the context of this:

- Quality and Coding Efficiency:
 - The ability to compress computer-generated content. Typically, it means the ability to have non perceptible intra refreshes and the ability to maintain stability on low frequency areas (such as uniform backgrounds) as well as maintaining details on high frequencies (particularly for text)
 - The ability compress YUV 4:2:0 and 4:4:4 content.
- Considered settings for encoding:
 - Low-latency settings
 - No specific error resilience mechanisms
- Encoding in this scenario is typically done as
 - Real-time encoding

6.4.3 Source Format Properties

Table 6.4.3-1 provides an overview of the different source signal properties for Screen Content Sharing. This information is used to select proper test sequences.

Table 6.4.3-1 Screen Content Sharing source properties

Source format properties	Screen Content
Spatial resolution	1920 x 1080, 3840 x 2160
Chroma format	Y'CbCr, RGB
Chroma subsampling	4:2:0, 4:4:4
Picture aspect ratio	16:9
Frame rates	25, 30, 50, 60 Hz
Bit depth	8, 10
Colour space formats	BT.709
Transfer characteristics	BT.709

6.4.4 Encoding and Decoding Constraints

Table 6.4.4-1 provides an overview of the different codec tools per profile that may be suitable for coding screen content sequences for the AVC and HEVC codecs.

Table 6.4.4-1 Screen Content Tools per Profile

Screen content tools	AVC	HEVC
main profile	Not applicable	Transform skip
range extension profile	not applicable	Residual Differential Pulse Code Modulation (RDPCM) (implicit intra/explicit inter),
screen content profile	Not applicable	Intra Block Copy (full frame or less), Palette, Adaptive Colour Transform

Table 6.4.4-2 provides an overview of encoding and decoding constraints for Screen Content scenario

- - general constraints

- - using H.264/AVC codecs operating points,
- - using H.265/HEVC codecs operating points.

These configurations support the definition of detailed test conditions. The configuration files for HEVC are used as the reference configurations for other codecs.

Table 6.4.4-2 Encoding and Decoding Configurations for Screen Content

Encoding and Decoding Constraints	General	H.264/AVC	H.265/HEVC
Relevant Codec and Codec Profile/Levels according to TS26.116 and TS26.511.	Profiles suitable for screen content Levels to meet the above frame rates	H.264/AVC Progressive High Profile Level 4.2, 5.2	H.265/HEVC Main 10 Profile H.265/HEVC Screen-Extended Main 10 profile Level 4.1, 5.1, 6.1
Random access frequency	1 second, no RA	1 second, no RA	1 second, no RA
Error resiliency tools	none	none	none
Bit rate parameters (CBR, VBR, CAE, HRD parameters)	Constant quality	Fixed QP for I and P slices	Fixed QP for I and P slices
Bit rates and quality configuration	Covering a range of relevant bitrates and qualities	QP variations between 22 and 42	QP variations between 22 and 42
Latency requirements and specific encoding settings	Encoding adds no latency	Low-delay P	Low-delay P
Encoding complexity context	Real-time encoding is possible	Settings for search ranges, set to 256	Settings for search ranges, set to 64
Required decoding capabilities	Profiles suitable for screen content Levels to meet the above frame rates	H.264/AVC Progressive High Profile Level 4.2, 5.2	H.265/HEVC Main 10 Profile H.265/HEVC Screen-extended Main 10 profile Level 4.1, 5.1, 6.1

NOTE: A Random access frequency No RA means only the first frame is intra coded.

6.4.5 Performance Metrics

All SDR Metrics as defined in clause 5.5.2 may be reported. However, VMAF and MS-SSIM may not be adequate for screen content sequences and PSNR is the main SDR metric to consider.

Based on this, for BD-Rate computation and SDR, only the following metrics are provided:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as defined in clause 5.5.3,
- Average colour component $PSNR$, PSNR over all colour components PSNR as defined in clause 5.5.3.

6.4.6 Interoperability Considerations

For screen content, RTP-based communication is expected.

6.4.7 Reference Sequences

Table 6.4.7-1 provides the selected reference sequences for this scenario. Keys are defined to refer to the sequences in the context of the scenario. The sequences are named and a reference to the details of the sequence is provided. A justification is provided, why this sequence is selected.

Reference sequences illustrating the screen content scenario are described in Annex C. They contain either synthetic content from a presentation such as a slide deck with text and graphics.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/reference-sequence.csv>.

Table 6.4.7-1 Reference Sequences for Screen Content Scenario

Key	Name	Reference
S3-R01	MovingText2-4K-10bit	Annex C.6.2
S3-R02	MovingText2-4K-8bit	Annex C.6.2
S3-R03	MovingText2-FullHD-10bit	Annex C.6.2
S3-R04	MovingText2-FullHD-8bit	Annex C.6.2
S3-R05	TextMixTransitions-4K-10bit	Annex C.6.3
S3-R06	TextMixTransitions-4K-8bit	Annex C.6.3
S3-R07	TextMixTransitions-FullHD-10bit	Annex C.6.3
S3-R08	TextMixTransitions-FullHD-8bit	Annex C.6.3
S3-R09	GraphicsMixSimple-4K-10bit	Annex C.6.4
S3-R10	GraphicsMixSimple-4K-8bit	Annex C.6.4
S3-R11	GraphicsMixSimple-FullHD-10bit	Annex C.6.4
S3-R12	GraphicsMixSimple-FullHD-8bit	Annex C.6.4
S3-R13	GraphicsMixTransitions-4K-10bit	Annex C.6.5
S3-R14	GraphicsMixTransitions-4K-8bit	Annex C.6.5
S3-R15	GraphicsMixTransitions-FullHD-10bit	Annex C.6.5
S3-R16	GraphicsMixTransitions-FullHD-8bit	Annex C.6.5
S3-R17	Mission-Control	Annex C.6.6

6.4.8 Anchor Definition

6.4.8.1 Overview

This clause provides details on how to generate the anchors for the Screen Content scenario.

The screen content configuration relies on low delay encoding modes with the optional use of Screen Content encoding tools when possible (for HEVC).

6.4.8.2 H.264/AVC Anchors

6.4.8.2.1 Overview

Table 6.4.8.2.1-1 provides an overview of the H.264/AVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario. Note that only the 8-bit sequences are used.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/264/streams.csv>.

Table 6.4.8.2.1-1 Anchor Tuple generation with H.264/AVC for Screen Content Scenario

Key	Clause	Reference Sequence	Reference Encoder	Config	Variations	Anchor Key
S3-A02-264	6.4.8.2.3	S3-R02	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A02-264-<QP>
S3-A04-264	6.4.8.2.3	S3-R04	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A04-264-<QP>
S3-A06-264	6.4.8.2.3	S3-R06	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A06-264-<QP>
S3-A08-264	6.4.8.2.3	S3-R08	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A08-264-<QP>
S3-A10-264	6.4.8.2.3	S3-R10	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A10-264-<QP>
S3-A12-264	6.4.8.2.3	S3-R12	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A12-264-<QP>
S3-A14-264	6.4.8.2.3	S3-R14	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A14-264-<QP>
S3-A16-264	6.4.8.2.3	S3-R16	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A16-264-<QP>
S3-A18-264	6.4.8.2.3	S3-R17	JM19	S3-JM-01	QP=[22,27,32,37,42]	S3-A18-264-<QP>
S3-A20-264	6.4.8.2.3	S3-R02	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A20-264-<QP>
S3-A22-264	6.4.8.2.4	S3-R04	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A22-264-<QP>
S3-A24-264	6.4.8.2.4	S3-R06	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A24-264-<QP>
S3-A26-264	6.4.8.2.4	S3-R08	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A26-264-<QP>
S3-A28-264	6.4.8.2.4	S3-R10	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A28-264-<QP>
S3-A30-264	6.4.8.2.4	S3-R12	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A30-264-<QP>
S3-A32-264	6.4.8.2.4	S3-R14	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A32-264-<QP>
S3-A34-264	6.4.8.2.4	S3-R16	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A34-264-<QP>
S3-A65-264	6.4.8.2.4	S3-R17	JM19	S3-JM-02	QP=[22,27,32,37,42]	S3-A65-264-<QP>

6.4.8.2.2 Common Parameters

To generate the anchor bitstreams, JM19 is used.

The common parameters are as follows:

- ProfileIDC = 100 (High Profile)
- IDRPeriod = IntraPeriod
- NumberOfReferenceFrames = 4
- PList0References = 4 (P slice List 0 reference override)
- I16RD0pt = 1 (rd-optimized mode decision for Intra 16x16 MB)
- SearchMode = 3 Enhanced Predictive Zonal Search (EPZS)
- SearchRange = 256;
- Picture based multipass coding disabled

The following parameters are variables and triggered through updates of the config-file.

- QP: [22,27,32,37,42]

Note that the MaxMvsPer2Mb restriction is not matching the used level requirement from H.264/AVC due to use of inter 4x4 subpartitions. While a strictly conforming decoder may fail, this is not considered a limiting factor in today's implementations.

6.4.8.2.3 S3-JM-01: no random access

The common parameters as defined in 6.4.8.2.2 apply.

In addition, the following parameters apply:

- LevelIDC = 42 or 52 (depending on resolution)
- IntraPeriod = 0 (no random access)
- NumberBFrames = 4
- Quantization parameters are set according to Table 6.4.8.2.3-1.

Table 6.4.8.2.3-1 Quantization Parameters for S3-JM-01

QP	QPISlice	QPPSlice	QPBSlice	ExplicitHierarchyFormat
22	21	24	N/A	P0r3P1r2P2r3P3r2
27	26	29	N/A	P0r5P1r4P2r5P3r4
32	31	34	N/A	P0r6P1r5P2r6P3r5
37	36	39	N/A	P0r6P1r5P2r6P3r5
42	41	44	N/A	P0r6P1r5P2r6P3r5

The settings are defined in the attached configuration file s3-jm-01.cfg.

6.4.8.2.3 S3-JM-02: fixed Intra every second

The common parameters as defined in 6.4.8.2.2 apply.

In addition, the following parameters apply:

- LevelIDC = 42 or 52 (depending on resolution)
- IntraPeriod such that exactly 1 second is achieved (i.e. IntraPeriod value equal to the sequence fps value)
- SearchRange = 256
- QPISlice = QPPSlice = QP

- NumberBFrames = 0

The settings are defined in the attached configuration file `s3-jm-02.cfg`.

6.4.8.3 H.265/HEVC Anchors

6.4.8.3.1 Overview

Table 6.4.8.3.1-1 provides an overview of the H.265/HEVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/streams.csv>.

Table 6.4.8.3.1-1 Anchor Tuple generation with H.265/HEVC for Screen Content Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S3-A01-265	6.4.8.3.3	S3-R01	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A01-265-<QP>
S3-A02-265	6.4.8.3.3	S3-R02	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A02-265-<QP>
S3-A03-265	6.4.8.3.3	S3-R03	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A03-265-<QP>
S3-A04-265	6.4.8.3.3	S3-R04	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A04-265-<QP>
S3-A05-265	6.4.8.3.3	S3-R05	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A05-265-<QP>
S3-A06-265	6.4.8.3.3	S3-R06	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A06-265-<QP>
S3-A07-265	6.4.8.3.3	S3-R07	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A07-265-<QP>
S3-A08-265	6.4.8.3.3	S3-R08	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A08-265-<QP>
S3-A09-265	6.4.8.3.3	S3-R09	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A09-265-<QP>
S3-A10-265	6.4.8.3.3	S3-R10	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A10-265-<QP>
S3-A11-265	6.4.8.3.3	S3-R11	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A11-265-<QP>
S3-A12-265	6.4.8.3.3	S3-R12	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A12-265-<QP>
S3-A13-265	6.4.8.3.3	S3-R13	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A13-265-<QP>
S3-A14-265	6.4.8.3.3	S3-R14	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A14-265-<QP>
S3-A15-265	6.4.8.3.3	S3-R15	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A15-265-<QP>
S3-A16-265	6.4.8.3.3	S3-R16	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A16-265-<QP>
S3-A17-265	6.4.8.3.4	S3-R01	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A17-265-<QP>
S3-A18-265	6.4.8.3.4	S3-R02	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A18-265-<QP>
S3-A19-265	6.4.8.3.4	S3-R03	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A19-265-<QP>
S3-A20-265	6.4.8.3.4	S3-R04	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A20-265-<QP>
S3-A21-265	6.4.8.3.4	S3-R05	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A21-265-<QP>
S3-A22-265	6.4.8.3.4	S3-R06	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A22-265-<QP>
S3-A23-265	6.4.8.3.4	S3-R07	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A23-265-<QP>
S3-A24-265	6.4.8.3.4	S3-R08	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A24-265-<QP>
S3-A25-265	6.4.8.3.4	S3-R09	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A25-265-<QP>
S3-A26-265	6.4.8.3.4	S3-R10	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A26-265-<QP>
S3-A27-265	6.4.8.3.4	S3-R11	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A27-265-<QP>
S3-A28-265	6.4.8.3.4	S3-R12	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A28-265-<QP>
S3-A29-265	6.4.8.3.4	S3-R13	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A29-265-<QP>
S3-A30-265	6.4.8.3.4	S3-R14	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A30-265-<QP>
S3-A31-265	6.4.8.3.4	S3-R15	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A31-265-<QP>
S3-A32-265	6.4.8.3.4	S3-R16	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A32-265-<QP>
S3-A33-265	6.4.8.3.5	S3-R01	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A33-265-<QP>
S3-A34-265	6.4.8.3.5	S3-R02	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A34-265-<QP>
S3-A35-265	6.4.8.3.5	S3-R03	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A35-265-<QP>
S3-A36-265	6.4.8.3.5	S3-R04	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A36-265-<QP>
S3-A37-265	6.4.8.3.5	S3-R05	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A37-265-<QP>
S3-A38-265	6.4.8.3.5	S3-R06	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A38-265-<QP>
S3-A39-265	6.4.8.3.5	S3-R07	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A39-265-<QP>
S3-A40-265	6.4.8.3.5	S3-R08	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A40-265-<QP>
S3-A41-265	6.4.8.3.5	S3-R09	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A41-265-<QP>
S3-A42-265	6.4.8.3.5	S3-R10	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A42-265-<QP>
S3-A43-265	6.4.8.3.5	S3-R11	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A43-265-<QP>
S3-A44-265	6.4.8.3.5	S3-R12	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A44-265-<QP>
S3-A45-265	6.4.8.3.5	S3-R13	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A45-265-<QP>
S3-A46-265	6.4.8.3.5	S3-R14	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A46-265-<QP>
S3-A47-265	6.4.8.3.5	S3-R15	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A47-265-<QP>
S3-A48-265	6.4.8.3.5	S3-R16	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A48-265-<QP>
S3-A49-265	6.4.8.3.6	S3-R01	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A49-265-<QP>
S3-A50-265	6.4.8.3.6	S3-R02	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A50-265-<QP>
S3-A51-265	6.4.8.3.6	S3-R03	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A51-265-<QP>
S3-A52-265	6.4.8.3.6	S3-R04	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A52-265-<QP>
S3-A53-265	6.4.8.3.6	S3-R05	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A53-265-<QP>
S3-A54-265	6.4.8.3.6	S3-R06	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A54-265-<QP>
S3-A55-265	6.4.8.3.6	S3-R07	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A55-265-<QP>
S3-A56-265	6.4.8.3.6	S3-R08	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A56-265-<QP>
S3-A57-265	6.4.8.3.6	S3-R09	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A57-265-<QP>
S3-A58-265	6.4.8.3.6	S3-R10	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A58-265-<QP>
S3-A59-265	6.4.8.3.6	S3-R11	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A59-265-<QP>
S3-A60-265	6.4.8.3.6	S3-R12	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A60-265-<QP>
S3-A61-265	6.4.8.3.6	S3-R13	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A61-265-<QP>
S3-A62-265	6.4.8.3.6	S3-R14	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A62-265-<QP>
S3-A63-265	6.4.8.3.6	S3-R15	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A63-265-<QP>
S3-A64-265	6.4.8.3.6	S3-R16	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A64-265-<QP>
S3-A65-265	6.4.8.3.3	S3-R17	HM16.22	S3-HM-03	QP = [22,27,32,37,42]	S3-A65-265-<QP>
S3-A66-265	6.4.8.3.4	S3-R17	HM16.22	S3-HM-04	QP = [22,27,32,37,42]	S3-A66-265-<QP>
S3-A67-265	6.4.8.3.5	S3-R17	SCM8.8	S3-SCC-03	QP = [22,27,32,37,42]	S3-A67-265-<QP>
S3-A68-265	6.4.8.3.6	S3-R17	SCM8.8	S3-SCC-04	QP = [22,27,32,37,42]	S3-A68-265-<QP>
S3-A69-265	6.4.8.3.3	S3-R17	HM16.22	S3-HM-01	QP = [22,27,32,37,42]	S3-A69-265-<QP>
S3-A70-265	6.4.8.3.4	S3-R17	HM16.22	S3-HM-02	QP = [22,27,32,37,42]	S3-A70-265-<QP>
S3-A71-265	6.4.8.3.5	S3-R17	SCM8.8	S3-SCC-01	QP = [22,27,32,37,42]	S3-A71-265-<QP>
S3-A72-265	6.4.8.3.6	S3-R17	SCM8.8	S3-SCC-02	QP = [22,27,32,37,42]	S3-A72-265-<QP>

6.4.8.3.2 Common Settings

Each source sequence is encoded with:

- QP: [22, 27, 32, 37, 42]

- `InternalBitDepth` is 10 # codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits.
- `SEIDecodedPictureHash`=1

As the `SEIDecodedPictureHash` is set to 1, the effective file size (EFS) needs to take into account the removal of this SEI message when computing the bitrate metric as defined in clause 5.5.2. For all anchors, a modified bitstream is provided with ‘*.bis’ suffix, for which the SEI removal is applied. This file is used for bitrate computation.

6.4.8.3.3 S3-HM-01 and S3-HM-03: Main 10 Profile with no fixed Intra

To generate the anchor bitstreams, HM16.22 is used.

The settings are defined in the attached configuration file `s3-hm-01.cfg` and `s3-hm-03.cfg`.

Each source sequence is encoded with:

- The settings defined in 6.4.8.3.2.
- `IntraPeriod` with no fix interval
- `GOPSize` is equal to 8. Each P picture refers to up to 4 preceding pictures in display order

6.4.8.3.4 S3-HM-02 and S3-HM-04: Main 10 Profile with fixed Intra every second

To generate the anchor bitstreams, HM16.22 is used.

The settings are defined in the attached configuration file `s3-hm-02.cfg` and `s3-hm-04.cfg`.

Each source sequence is encoded with:

- The settings defined in 6.4.8.3.2.
- `IntraPeriod` such that exactly 1 second is achieved (i.e. `IntraPeriod` value equal to the sequence fps value)
- `DecodingRefreshType`: (2) IDR
- `IntraQPoffset` and `QPoffsets` are set equal to 0
- Each P picture refers to immediately preceding pictures in display order.

6.4.8.3.5 S3-SCC-01 and S3-SCC-03: Screen Content Profile with no fixed Intra

To generate the anchor bitstreams SCM-8.8 is used.

The settings are defined in the attached configuration file `s3-scc-01.cfg` and `s3-scc-03.cfg`.

Each source sequence is encoded with:

- The settings defined in 6.4.8.3.2.
- `IntraPeriod` with no fix interval
- `GOPSize` is equal to 8. Each P picture refers to up to 4 preceding pictures in display order within the GOP

6.4.8.3.6 S3-SCC-02 and S3-SCC-04: Screen Content Profile with fixed Intra every second

To generate the anchor bitstreams SCM-8.8 is used.

The settings are defined in the attached configuration file `s3-scc-02.cfg` and `s3-scc-04.cfg`.

Each source sequence is encoded with:

- The settings defined in 6.4.8.3.2.

- IntraPeriod such that exactly 1 second is achieved (i.e. IntraPeriod value equal to the sequence fps value)
- DecodingRefreshType: (2) IDR
- IntraQPOffset and P pictures QPoffsets are set equal to 0
- Each P picture refers to immediately preceding pictures in display order.

6.4.9 Anchor Results

6.4.9.1 H.264/AVC Anchors

AVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/264/>

AVC anchor results are provided with the appropriate keys as defined in Table 6.4.8.2.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/264/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/264/cross-check.csv>.

Based on these cross-check results, the verification status for the H.264/AVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/264/verification.csv> and Table 6.4.9.1-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.4.9.1-1 Verification status of H.264/AVC test streams for Screen Content Scenario

Anchor + Key Verification Type	Summary			22			27			32			37			42		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S3-A02-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A04-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A06-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A08-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A10-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A12-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A14-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A16-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A18-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A20-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A22-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A24-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A26-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A28-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A30-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A32-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A34-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A65-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A65-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.4.9.2 H.265/HEVC Anchors

HEVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/>

HEVC anchor results are provided with the appropriate keys as defined in Table 6.4.8.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/cross-check.csv>.

Based on these cross-check results, the verification status for the H.265/HEVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/verification.csv> and Table 6.4.9.2-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.4.9.2-1 Verification status of H.265/HEVC anchors for Screen Content Scenario

Anchor + Key	Summary			22			27			32			37			42		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S3-A01-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A02-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A03-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A04-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A05-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A06-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A07-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A08-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A09-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A10-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A11-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A12-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A13-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A14-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A15-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A16-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A17-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A18-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A19-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A20-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A21-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A22-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A23-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A24-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A25-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A26-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A27-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A28-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A29-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A30-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A31-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A32-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A33-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A34-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A35-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A36-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A37-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A38-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A39-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A40-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A41-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A42-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A43-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A44-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A45-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A46-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A47-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A48-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A49-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A50-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A51-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A52-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A53-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A54-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A55-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A56-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A57-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A58-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A59-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

S3-A60-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A61-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A62-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A63-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A64-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A65-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A66-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A67-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A68-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A69-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A70-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A71-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-A72-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.4.10 Additional information and external performance data

In JCTVC-AA1006 [40], verification test report for HEVC screen content coding extensions, “the coding performance of HEVC screen content model (SCM) reference software with the SCC extensions enabled is compared with that of HEVC test model (HM) without the SCC extensions, as well as with the AVC joint model (JM) reference software in both lossy and mathematically lossless compression modes using All-Intra (AI), Random Access (RA), and Low-delay B (LB) encoding structures and using similar encoding rate-distortion optimization techniques.

BD-rate savings of SCM over JM and SCM-w/o-SCC for RGB, YUV 4:4:4, and YUV 4:2:0 colour sampling formats were calculated by using the actual 648 test points that were used in the subjective testing across 6 JCT-VC sequences.

The document contains details on sequences, test parameters and configuration files, as well as subjective results. In the context of this study, only the objective results for lossy Low-delay B are reported in Table 6.4.10-1.

Table 6.4.10-1: BD-rate savings of SCM over JM and HM for LB coding configuration

	Low Delay					
	SCC vs. JM			SCC vs. HM		
	G/Y	B/U	R/V	G/Y	B/U	R/V
RGB, text & graphics with motion, 1080p	-90.1%	-87.7%	-87.8%	-71.0%	-66.4%	-67.9%
RGB, mixed content, 1080p	-35.6%	-61.4%	-60.4%	-31.9%	-23.4%	-21.1%
YUV4:4:4, text & graphics with motion, 1080p	-86.2%	-86.2%	-43.0%	-66.9%	-70.3%	-70.6%
YUV4:4:4, mixed content, 1080p	-53.2%	-61.4%	-60.4%	-17.4%	-25.8%	-25.2%
YUV4:2:0, text & graphics with motion, 1080p	-80.3%	-77.7%	-79.6%	-54.3%	-51.7%	-50.8%
YUV4:2:0, mixed content, 1080p	-50.8%	-46.1%	-48.6%	-14.6%	-15.9%	-17.6%

6.5 Scenario 4: Messaging and Social Sharing

6.5.1 Motivation

According to the 2020 Mobile Internet Phenomena Report from Sandvine [9] Video traffic continues to grow worldwide, and the increasing popularity of mobile consumers sharing video has not only caused growth in downstream traffic, but also in upstream traffic as well. Instagram TM grew in the upstream as more consumers share images and videos. TikTok TM, Snapchat TM (video), FaceTime TM, and even Facebook TM Live were all in the top 50 applications worldwide on the upstream that are video-sharing-centric. Messaging applications, especially on the upstream, continue to become a critical part of the mobile experience, replacing old style text messaging, and increasingly are video-based. Four of the top 20 applications on the upstream are messaging apps.

Some typical examples and restrictions in April 2020 are provided in the following:

1. WhatsAppTM [25]
 - a. The maximum size of the video that you can share is 16 MB.

- b. Various container formats that are supported by include MP4, MKV, AVI, 3GP, and MOV. H.264/AVC video codec and AAC audio codec are needed today.
2. YouTube™ [26]
- a. H.264/AVC is the recommended codec with the following settings
 - i. Progressive scan
 - ii. High Profile
 - iii. 2 consecutive B frames
 - iv. Closed GOP. GOP of half the frame rate.
 - v. CABAC
 - vi. Variable bitrate. No bitrate limit required, though we offer recommended bit rates below for reference
 - vii. Chroma subsampling: 4:2:0
 - b. Resolution Formats: 360p, 480p, 720p, 1080p, 1440p, 2160p
 - c. Both SDR and HDR are possible
 - d. The standard aspect ratio is 16:9
3. Facebook Live™ [27]. To live stream on Facebook™, these video format guidelines are provided:
- a. Recommended max bit rate is 4000 Kbps (4 mbps).
 - b. Max: 1080p (1920x1080) resolution, at 60 frames per second.
 - c. An I-frame (keyframe) must be sent at least every 2 seconds throughout the stream.
 - d. H264 encoded video.
4. TikTok™ [28], some video restrictions
- a. Upload from Android, up to 72 MB at most. upload videos from iOS up to 287.6 MB.
 - b. Video dimensions should be 1080 x 1920
 - c. MP4 or MOV file format. Video should be H.264/AVC encoded
5. Snapchat™ [25][2], The latest information from 2018
- a. Recommended size: 1080 by 1920 pixels (9:16 aspect ratio)
 - b. Recommended specs: .MP4 or MOV, H.264 encoded, maximum file size 1GB

According to Sandvine's report [9], sharing and uploading content as part of social sharing is predominantly pictures and videos that uploaded directly into a cloud and uploaded to one or many social networks, and then discussed (or shared again) over messaging networks. The relevant quality-of-experience factors include the quality of shared content, the time it takes to upload, the costs associated with the upload and also the processing and battery consumption requirements on the device to prepare the content for upload.

In another activity, three large operators released a 5G messaging white paper [31] to promote enhanced messaging services based on Rich Communication Services (RCS). This also shows the relevance of operator-based messaging services. Generally, uplink resources are even more precious and costly in 5G network operation and hence efficient technologies are vital for mass-scale services. This aspect is also considered by GSMA RCS Universal Profile specification, promoted as the industry standard for RCS Business Messaging, ensuring the telecoms industry remains at the centre of digital communications [34].

6.5.2 Description of the Anticipated Application

In the context of 3GPP services, 5G Media Streaming [13] provides the following encoding benchmark capabilities:

- HEVC-FullHD-Enc: the capability to encode a video signal with
 - up to 133,693,440 luma samples per second, and
 - up to a luma picture size of 2,228,224 samples, and
 - up to 240 frames per second, and
 - the Chroma format being 4:2:0, and
 - the bit depth being either 8 or 10 bit,

to a bitstream that is decodable by a decoder that is HEVC-FullHD-Dec capable as defined in clause 4.2.2.1 of TS26.511 and defined as the capability to decode H.265 (HEVC) Main10 Profile, Main Tier, Level 4.1 [3] bitstreams that have `general_progressive_source_flag` equal to 1, `general_interlaced_source_flag` equal to 0, `general_non_packed_constraint_flag` equal to 1, and `general_frame_only_constraint_flag` equal to 1.

Based on the considerations in clause 6.5.1, it is also recommended to take into account the AVC-FullHD-Enc capabilities as defined in TS26.511 [13]:

- AVC-FullHD-Enc: the capability to encode a video signal with
 - up to 245,760 macroblocks per second, and
 - up to a frame size of 8,192 macroblocks, and
 - up to 240 frames per second, and
 - the Chroma format being 4:2:0, and
 - the bit depth being 8 bit,

to a bitstream that is decodable by a decoder that is AVC-HD-Dec capable as defined in clause 4.2.1.1 of TS26.511 and defined as the capability to decode H.264 (AVC) Progressive High Profile Level 4.0 [2] bitstreams.

Based on future expectations of higher quality uploads, it is also recommended to take into account the HEVC-UHD-Enc capabilities as defined in TS 26.511 [13]:

- HEVC-UHD-Enc: the capability to encode a video signal with
 - up to 534,773,760 luma samples per second, and
 - up to a luma picture size of 8,912,896 samples, and
 - up to 480 frames per second, and
 - the Chroma format being 4:2:0, and
 - the bit depth being either 8 or 10 bit,

to a bitstream that is decodable by a decoder that is HEVC-UHD-Dec capable as defined in clause 4.2.2.1 of TS26.511 and defined as the capability the capability to decode H.265 (HEVC) Main10 Profile, Main Tier, Level 5.1[3] bitstreams that have `general_progressive_source_flag` equal to 1, `general_interlaced_source_flag` equal to 0, `general_non_packed_constraint_flag` equal to 1, and `general_frame_only_constraint_flag` equal to 1.

The considered scenario is the uploading and uplink streaming into the ISO/BMFF and CMAF container formats. Important aspects that are expected to be considered when evaluating a codec in the context of this:

- Quality and Coding Efficiency:
 - The ability to compress a video sequence targeting the maximum file size and maintaining high quality.
 - The ability to compress a video stream in real time to the available uplink streaming resources.

- Considered settings for encoding:
 - Regular random access at least every 2 seconds, preferably more often
 - No specific encoding latency constraints are applicable
- Encoding in this scenario is typically done as
 - Real-time encoding for social sharing
 - Offline encoding for messaging
 - UE-based Encoding

6.5.3 Source Format Properties

Table 6.5.3-1 provides an overview of the different source signal properties for Social Sharing and Messaging. This information is used to select proper test sequences.

Table 6.5.3-1 Source Format Properties for Social sharing scenario

Source format properties	Social Sharing
Spatial resolution	3840x2160, 1920 x 1080, 1080x1920
Chroma format	Y'CbCr
Chroma subsampling	4:2:0
Picture aspect ratio	16:9, 9:16
Frame rates	24, 25, 30 Hz 50, 60 Hz (Full HD only)
Bit depth	8, 10
Colour space formats	BT.709, BT.2020
Transfer characteristics	BT.709, BT.2100 (HDR)

6.5.4 Encoding and Decoding Constraints

Table 6.5.4-1 provides an overview of encoding and decoding constraints for H.264/AVC Full HD and H.265/HEVC for Social Sharing and Messaging scenario. This information supports the definition of detailed anchor conditions.

Table 6.5.4-1 Encoding and Decoding Configurations

Encoding and Decoding Constraints	General	H.264/AVC	H.265/HEVC
Relevant Codec and Codec Profile/Levels	Profile suitable for messaging content, no specific requirements. Levels to meet the above formats	H.264/AVC Progressive High Profile Level 4.2, 5.2	H.265/HEVC Main 10 Profile Level 4.1, 5.1
Random access frequency	1 second and 10 seconds	1 and 10 seconds	1 and 10 seconds
Bit rates and quality configuration	Capped-VBR (social sharing) and VBR (messaging) Fixed QP	B = {5, 10,15, 20} Mbps Capped-VBR (social sharing) and VBR (messaging) Fixed QP	B = {2.5, 5, 7.5,10} Mbps Capped-VBR (social sharing) and VBR (messaging) Fixed QP
Bit rate parameters (CBR, VBR, CAE, HRD parameters)	Covering a range of relevant bitrates and qualities	No latency requirements beyond RAP so picture reordering allowed	No latency requirements beyond RAP so picture reordering allowed
Latency requirements and specific encoding settings	No latency requirements	No specific requirements	No specific requirements
Encoding complexity context	real-time encoding (social sharing), offline encoding (messaging) on mobile device, single path	see General	see General
Required decoding capabilities	Profile suitable for messaging content, no specific requirements. Levels to meet the above formats	H.264/AVC Progressive High Profile Level 4.2, 5.2	H.265/HEVC Main 10 Profile Level 4.1, 5.1

6.5.5 Performance Metrics

All metrics as defined in clause 5.5 are expected to be reported.

For BD-Rate computation and SDR, only the following metrics are expected to be provided:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as defined in clause 5.5.3,
- Average colour component PSNR, $PSNR$ over all colour components $PSNR$ as defined in clause 5.5.3,
- Structural similarity metric $MS-SSIM$ as defined in clause 5.5.4.2,
- Video Multimethod Assessment Fusion (VMAF) $VMAF$ as defined in clause 5.5.3.

6.5.6 Interoperability Considerations

Social sharing and messaging applications require that the content is included in a packaging and file format.

6.5.7 Reference Sequences

Table 6.5.7-1 provides the selected reference sequences for this scenario. Keys are identified to refer to the sequences in the context of the scenario. The sequences are named and a reference to the details of the sequence is provided. A justification is provided, why this sequence is selected.

Table 6.5.7-1 Reference Sequences for Social sharing and messaging

Key	Name	Reference	Justification/Comment
S4-R01	Vertical-Bees	Annex C.5.2	Full-HD, portrait Stationary sequence with graphic overlays. Easy.
S4-R02	Vertical-Walking	Annex C.5.3	Difficult content, Full-HD Portrait.
S4-R03	Neon-4K	Annex C.5.4	4K difficult sequence, dark and noisy.
S4-R04	Skater-4K	Annex C.5.5	4K Especially good on the face close-up.

6.5.8 Anchor Definition

6.5.8.1 Overview

This clause provides details on how to generate the anchors for the social sharing and messaging scenario.

The Social sharing and messaging scenario relies on relaxed delay encoding modes with limited encoding complexity.

6.5.8.2 H.264/AVC Anchors

6.5.8.2.1 Overview

Table 6.5.8.2.1-1 provides an overview of the H.264/AVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/264/streams.csv>.

Table 6.5.8.2.1-1 Anchor Tuple generation with H.264/AVC for social sharing and messaging

Key	Clause	Reference Sequence	Reference Encoder	Config	Variations	Anchor Key
S4-A01-264	6.5.8.2.3	S4-R01	JM19	S4-JM-01	QP=[22,27,32,37]	S4-A01-264-<QP>
S4-A02-264	6.5.8.2.3	S4-R02	JM19	S4-JM-01	QP=[22,27,32,37]	S4-A02-264-<QP>
S4-A03-264	6.5.8.2.4	S4-R03	JM19	S4-JM-01	QP=[22,27,32,37]	S4-A03-264-<QP>
S4-A04-264	6.5.8.2.4	S4-R04	JM19	S4-JM-01	QP=[22,27,32,37]	S4-A04-264-<QP>
S4-A05-264	6.5.8.2.5	S4-R01	JM19	S4-JM-02	QP=[22,27,32,37]	S4-A05-264-<QP>
S4-A06-264	6.5.8.2.5	S4-R02	JM19	S4-JM-02	QP=[22,27,32,37]	S4-A06-264-<QP>
S4-A07-264	6.5.8.2.6	S4-R03	JM19	S4-JM-02	QP=[22,27,32,37]	S4-A07-264-<QP>
S4-A08-264	6.5.8.2.6	S4-R04	JM19	S4-JM-02	QP=[22,27,32,37]	S4-A08-264-<QP>

6.5.8.2.2 Common Parameters

To generate the anchor bitstreams, JM19 is used.

To generate the anchor bitstreams, JM19 is used.

The common parameters are as follows:

- ProfileIDC = 100 (High Profile)
- IDRPeriod = IntraPeriod
- NumberOfReferenceFrames = 4
- PList0References = 4 (P slice List 0 reference override)
- I16RD0pt = 1 (rd-optimized mode decision for Intra 16x16 MB)
- SearchMode = 3 (Enhanced Predictive Zonal Search (EPZS))
- SearchRange = 256;
- Picture based multipass coding disabled

The following variable triggers updates to the config-file depending on the test scenario.

- QP: [22,27,32,37]

Note that the MaxMvsPer2Mb restriction is not matching the used level requirement from H.264/AVC due to use of inter 4x4 subpartitions. While a strictly conforming decoder may fail, this is not considered a limiting factor in today's implementations.

6.5.8.2.3 S4-JM-01: no random access

In addition, the following parameters apply:

- LevelIDC = 52
- IntraPeriod = 0 (no random access)
- NumberBFrames = 4
- BReferencePictures = 2
- Quantization parameters are set as according to Table 6.5.8.2.3-1

Table 6.5.8.2.3-1 Quantization Parameters for S4-JM-01

QP	QPISlice	QPPSlice	QPBSlice	ExplicitHierarchyFormat
22	21	24	24	B0r3B1r2B2r3B3r2
27	26	29	29	B0r5B1r4B2r5B3r4
32	31	34	34	B0r6B1r5B2r6B3r5
37	36	39	39	B0r6B1r5B2r6B3r5

The settings are defined in the attached configuration file s4-jm-01.cfg.

6.5.8.2.4 S4-JM-02: random access near 1 sec

The common parameters as defined in 6.5.8.2.2 apply.

In addition, the following parameters apply:

- IntraPeriod and IDRPeriod = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences
- NumberBFrames = 0
- BReferencePictures = 2
- QPISlice = QPPSlice = QPBSlice = QP

The settings are defined in the attached configuration file s4-jm-02.cfg.

6.5.8.3 H.265/HEVC Anchors

6.5.8.3.1 Overview

Table 6.5.8.3.1-1 provides an overview of the H.265/HEVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/265/streams.csv>.

Table 6.5.8.3.1-1 Anchor Tuple generation with H.265/HEVC for Social sharing and messaging

Key	Clause	Reference Sequence	Reference Encoder	Config	Variations	Anchor Key
S4-A01-265	6.5.8.3.3	S4-R01	HM16.22	S4-HM-01	QP = [22,27,32,37]	S4-A01-265-<QP>
S4-A02-265	6.5.8.3.3	S4-R02	HM16.22	S4-HM-01	QP = [22,27,32,37]	S4-A02-265-<QP>
S4-A03-265	6.5.8.3.4	S4-R03	HM16.22	S4-HM-01	QP = [22,27,32,37]	S4-A03-265-<QP>
S4-A04-265	6.5.8.3.4	S4-R04	HM16.22	S4-HM-01	QP = [22,27,32,37]	S4-A04-265-<QP>
S4-A05-265	6.5.8.3.5	S4-R01	HM16.22	S4-HM-02	QP = [22,27,32,37]	S4-A05-265-<QP>
S4-A06-265	6.5.8.3.5	S4-R02	HM16.22	S4-HM-02	QP = [22,27,32,37]	S4-A06-265-<QP>
S4-A07-265	6.5.8.3.6	S4-R03	HM16.22	S4-HM-02	QP = [22,27,32,37]	S4-A07-265-<QP>
S4-A08-265	6.5.8.3.6	S4-R04	HM16.22	S4-HM-02	QP = [22,27,32,37]	S4-A08-265-<QP>

6.5.8.3.2 Common Parameters

To generate the anchor bitstreams, HM16.22 is used.

Each source sequence is encoded with:

- QP: [22, 27, 32, 37]
- InternalBitDepth is 10 # codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits.
- SEIDecodedPictureHash=1

As the SEIDecodedPictureHash is set to 1, the effective file size (EFS) needs to take into account the removal of this SEI message when computing the bitrate metric as defined in clause 5.5.2.

6.5.8.3.3 S4-HM-01: no random access

Each source sequence is encoded with the following changes:

- The common parameters as defined in clause 6.6.8.3.3
- IntraPeriod with no fix interval
- GOPSize is equal to 8. Each B picture refers to up to 4 preceding pictures in display order within the GOP
- IntraQPOffset is -1. B picture QP offsets are IntraQPOffset is -1. B picture QP offsets are adjusted based on the base QP and on the QPmod, QPoffset, QPoffsetModelScale and QPoffsetModelOff.

The settings are defined in the attached configuration file s4-hm-01.cfg.

6.5.8.3.4 S4-HM-02: Intra

Each source sequence is encoded with the following changes:

- The common parameters as defined in clause 6.6.8.3.3
- IntraPeriod = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences
- DecodingRefreshType: (2) IDR
- IntraQPOffset and B pictures QPoffsets are set equal to 0
- Each B picture refers to immediately preceding pictures in display order.

The settings are defined in the attached configuration file s4-hm-02.cfg.

6.5.9 Anchor Results

6.5.9.1 H.264/AVC Anchors

AVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/264/>

AVC anchor results are provided with the appropriate keys as defined in Table 6.5.8.2.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/264//Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/264/cross-check.csv>.

Based on these cross-check results, the verification status for the H.264/AVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/264/verification.csv> and Table 6.5.9.1-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.5.9.1-1 Verification status of H.264/AVC test streams for Messaging Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S4-A01-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A02-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A03-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A04-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A05-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A06-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A07-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A08-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.5.9.2 H.265/HEVC Anchors

HEVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/265/>

HEVC anchor results are provided with the appropriate keys as defined in Table 6.5.8.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/265/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/265/cross-check.csv>.

Based on these cross-check results, the verification status for the H.265/HEVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/265/verification.csv> and Table 6.5.9.2-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.5.9.2-1 Verification status of H.265/HEVC anchors for Messaging Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S4-A01-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A02-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A03-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A04-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A05-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A06-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A07-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-A08-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.6 Scenario 5: Online Gaming

6.6.1 Motivation

According to the 2020 Mobile Internet Phenomena Report from Sandvine [9] gaming is continuing to grow on mobile network. The improved performance of 4G and the coming promise of 5G will continue to drive at least casual gamers to mobile networks.

For games rendered on 2D displays such as smart phones, typical characteristics of rasterized frames produced by the game engine are:

- Resolution of 720p, 1080p or 4K
- Framerate of 30fps, 60fps or 120 fps

Typical colour bit depth of 8bits (RGB frames) but higher bit depth may be offered for HDR compatible games.

Rasterized frames are directly passed to a video encoder (typically H.264 but H.265 may be used in a few environments) and content is live encoded to fit target quality. As an example, the following quality categorization may be done:

- High Quality: 4k at 60/120fps with an average throughput of 60/100 Mbps
- Main Quality: 1080p at 60/120fps with an average throughput of 30/40 Mbps
- Low Quality: 720p/1080p at 30fps with an average throughput of 10/12 Mbps

Online gaming for HMD-based consumption was discussed and introduced in detail in TR 26.928 [6]. At least the following use cases are in context of Online gaming:

- Use Case 5: Untethered Immersive Online Gaming
- Use Case 6: Immersive Game Spectator Mode

For raster-based split rendering, according to TR 26.928, clause 4.4, rasterized 3D scenes available in frame buffers are provided by the XR engine and need to be encoded, distributed, and decoded. According to clause 4.2.1, relevant formats for frame buffers are 2k by 2k per eye, potentially even higher. Frame rates are expected to be at least 60fps, potentially higher up to 90 fps. The formats of frame buffers are regular texture video signals that are then directly rendered. As the processing is graphics centric, formats beyond commonly used 4:2:0 signals and YUV signals may be considered. It is known from experiments that with H.264/AVC the bitrates are in the order of 50 Mbps per eye buffer. It is expected that this can be reduced to lower bitrates with improved compression tools as for example available for H.265/HEVC. For use case 5 from above and split rendering, encoding is required to be done in low-latency based on the considerations in TR 26.928. For the spectator mode, higher latency may be acceptable.

As an example, a comprehensive set of APIs including high-performance tools, samples and documentation for hardware accelerated video encode and decode on Windows and Linux for NVIDIA™ Video Codec SDK is available [N]. As another example, in a game recording and streaming scenario like streaming to Twitch.tv using Open Broadcaster Software (OBS), encoding being completely offloaded to NVENC makes the graphics engine bandwidth fully available for game rendering. As of May 2020, the following formats are supported for hardware-based encoding as documented on the high-end Turing encoding:

- H.264 (AVC) YUV 4:2:0, YUV 4:4:4, and Lossless, all 8 bit, Max Resolution 4096 x 4096;
- H.265 (HEVC) YUV 4:2:0, YUV 4:4:4, and Lossless, all 10 bit, Max Resolution 8192 x 8192;

In typical cloud gaming environments, the game server produces rasterized frames at a fixed resolution, framerate and colour bit depth which are negotiated with the player client. Negotiation takes into account game capabilities, player choices and eventually bandwidth constraints.

6.6.2 Description of the Anticipated Application

3GPP until now has very restricted set of services but based on the considerations in clause 6.6.1, the following encoding benchmark capabilities are considered for decoding 2D displays:

- H.264 (AVCHD) YUV 4:2:0, YUV 4:4:4, 8 bit, Max Resolution 1920x1080 and 4096 x 2048
- H.265 (HEVC) YUV 4:2:0, YUV 4:4:4, 10 bit, Max Resolutions 4096 x 2048, 8192 x 4096

The considered online gaming scenario is low-latency streaming, typically using UDP/IP based distribution to minimize protocol latencies. Important aspects that are expected to be considered when evaluating a codec in the context of this:

- Quality and Coding Efficiency:
 - The ability to compress traditional computer-generated content.
 - The ability to compress photorealistic computer-generated content.
 - The ability to compress YUV 4:2:0 and 4:4:4 content
- Considered settings for encoding:
 - Ultra low latency and Low-latency settings
 - No specific error resilience mechanisms
- Encoding in this scenario is typically done as
 - Real-time encoding
 - Cloud-based encoding

6.6.3 Source Format Properties

6.6.3.1 Introduction

Video games have different characteristics that are important to take into account when encoding the rasterized frames produced by the game engine. In TR 26.928 [6], clause 4.2.2, a few different types of games and their interaction delay tolerance are documented. However, TR 26.928 [6] does not differentiate the characteristics of the content. This aspect is addressed in the following.

In particular, the following characteristics are important:

- Dynamicity of content: how frequent rasterized frames change when compared to previous frame
- Complexity of content: how much content changes between frames and how complex such changes are
- Type of content: traditional CGI, photo-realistic CGI or natural images/video

Depending on these characteristics as well as the interaction delay tolerance, video games can be organized into different categories as document in the remainder of this clause.

6.6.3.2 Category A: Low/medium dynamicity with low/medium complexity.

This category includes games such as board games, turn-by-turn strategy games, management/simulation games or non-realtime role-playing games (RPG) in which content may not change over several consecutive frames and changes are typically limited.

This category also includes games such as adventure games, casual games, or platform games in which although content may change at every single frame, changes are limited to animation of sprites or simple global movements of the content.

The common characteristics of the games in this category is that their playability can support longer interaction delay tolerance (500 – 1000ms according to TR 26.928 [6]) and their content is typically considered to video encode.

6.6.3.3 Category B: games with high dynamicity and low/medium complexity.

This category includes games such as fighting games, racing games, real-time strategy (RTS) games or real-time RPGs in which content is very dynamic but changes are either limited or simple transforms.

The common characteristics of the games in this category is that their playability requires shorter interaction delay tolerances (100ms according to TR 26.928 [6]) while their content is still considered simple to video encode (with high benefits from prediction coding).

6.6.3.4 Category C: games with high dynamicity and high complexity.

This category includes games such as first-person shooters (FPS), Massive Multiplayer Online (MMO) games and racing games in which content is very dynamic with possibly very significant changes regularly in the content.

The common characteristics of the games in this category is that their playability requires shorter interaction delay tolerances (100ms according to TR 26.928) and their content is typically considered as complex content to video encode.

6.6.3.5 Category D: photo-realistic games or games based on natural images/video.

The main characteristics of the games in this category is that their content is typically considered as more complex content to video encode.

6.6.3.6 Category E: XR game content

For a detailed analysis, please refer to clause 6.6.1 and TR 26.928, clause 4.4.

6.6.3.7 Summary

Table 6.6.3.7-1 provides an overview of the different source signal properties for Online Gaming. This information is used to select proper test sequences.

Table 6.6.3.7-1 Online Gaming source properties

Source format properties	Category A low/med dynamicity & low/med complexity games	Category B high dynamicity & low/med complexity games	Category C high dynamicity & high complexity games	Category D photo-realistic or natural video games	Category E XR games
Spatial resolution	1280x720, 1920x1080, 3840x2160	1280x720, 1920x1080, 3840x2160	1280x720, 1920x1080, 3840x2160	1280x720, 1920x1080, 3840x2160	1920x1080, 2048x1024, 3840x2160, 4096x2048, 8192x4096
Chroma format	Y'CbCr	Y'CbCr	Y'CbCr	Y'CbCr	Y'CbCr
Chroma subsampling	4:2:0, 4:4:4	4:2:0, 4:4:4	4:2:0, 4:4:4	4:2:0, 4:4:4	4:2:0, 4:4:4
Picture aspect ratio	16:9	16:9	16:9	16:9	16:9; 2:1
Frame Buffers	1	1	1	1	2 (1 per eye)
Frame rates	30, 50, 60 Hz	30, 50, 60, 90, 120 Hz	30, 50, 60, 90, 120 Hz	30, 50, 60, 90, 120 Hz	30, 50, 60, 90, 120 Hz
Bit depth	8	8	8, 10	8, 10	8, 10
Colour space formats	BT.709, BT.2020	BT.709, BT.2020	BT.709, BT.2020	BT.709, BT.2020	BT.709, BT.2020
Transfer characteristics	N/A	N/A	BT.709 (SDR) BT.2100 (HDR)	BT.709 (SDR) BT.2100 (HDR)	BT.709 (SDR) BT.2100 (HDR)

6.6.4 Encoding and Decoding Constraints

For photo-realistic games (Category D), certain "screen content" tools may not provide much benefits for this type of game content and would need to be tested.

Table 6.6.4-2 provides an overview of encoding and decoding constraints for H.264/AVC Full HD and H.265/HEVC for online gaming. This information supports the definition of detailed anchor conditions. The configuration files for HEVC are used as the reference configurations for other codecs.

Table 6.6.4-2 Encoding and Decoding Configurations for Online Gaming

Encoding and Decoding Constraints	AVC	HEVC
Relevant Codec and Codec Profile/Levels according to TS26.116 and TS26.511.	H.264/AVC Progressive High Profile Level 4.0 [7]	H.265/HEVC Main 10 Profile H.265/HEVC Screen-Extended Main 10 profile Level 4.1, Level 5.1, Level 6.1
RAP period	Near 1 second, infinite	Near 1 second, infinite
Bit rate parameters (CBR, VBR, CAE, HRD parameters)	Similar to HEVC configurations.	See configuration files in section 6.6.8.3
Latency requirements and specific encoding settings	Low-latency requirements Low-delay B configuration without use of future reference frames	Low-latency requirements, Low-delay-B configuration without use of future reference frames.
Encoding complexity context	real-time encoding	real-time encoding.
Required decoding capabilities	H.264/AVC Main Profile Level 4.0 [7]	H.265/HEVC Main 10 Profile H.265/HEVC Screen-Extended Main 10 profile Level 4.1, 5.1, 6.1 [8]
NOTE: Depending on the type of game (First person, Massive Multi-Player Online Role Play Game, Strategy) the latency requirements differs, usually ranging from less than 50ms to more than 200ms, thus leading to different encoding constraints and configuration.		

Table 6.6.5-2 provides an overview of latency constraints for each game category and identifies which coding tools are applicable and potentially useful for each category.

Table 6.6.5-2 Latency constraints tools for different game categories

Latency Constraints	Category A	Category B	Category C	Category D	Category E
Low latency requirement	optional	Yes	Yes	Yes/No	Yes
Low delay P	optional	required	required	optional	required
Low delay B	optional	required	required	optional	required
Use of future reference frames	optional	No	No	optional	No

6.6.5 Performance Metrics

All SDR Metrics as defined in clause 5.5.2 may be reported. However, VMAF and MS-SSIM may not be adequate for online gaming sequences and PSNR should be the main SDR metric to consider.

Based on this, for BD-Rate computation and SDR, only the following metrics are expected to be provided:

- Peak-Signal to Noise Ratio $PSNR(Y)$ of luma component as defined in clause 5.5.3,
- Average colour component PSNR, $PSNR$ over all colour components $PSNR$ as defined in clause 5.5.3.

6.6.6 Interoperability Considerations

For online gamine, RTP-based communication is expected.

6.6.7 Reference Sequences

Reference sequences illustrating the Online Gaming scenario should ideally contain synthetic content with detailed textures and realistic movements. This should include FPS, RPG and Strategy games. For candidate test sequences, please refer to Annex C.2.

Table 6.6.7-1 provides the selected reference sequences for this scenario. Keys are identified to refer to the sequences in the context of the scenario. The sequences are named and a reference to the details of the sequence is provided. A justification is provided, why this sequence is selected.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/reference-sequence.csv>.

Table 6.6.7-1 Reference Sequences for Online Gaming

Key	Name	Reference	Justification/Comment
S5-R01	AOV	Annex C.2.2	FullHD Sequence at 60fps
S5-R02	Baolei-Man	Annex C.2.3	FullHD Sequence at 60fps
S5-R03	Baolei-Woman	Annex C.2.4	FullHD Sequence at 60fps
S5-R04	Baolei-Balloon	Annex C.2.5	4K Sequence at 60fps
S5-R05	Baolei-Yard	Annex C.2.6	4K Sequence at 60fps
S5-R06	Jianling-Temple	Annex C.2.7	FullHD Sequence at 60fps
S5-R07	Jianling-Beach	Annex C.2.8	FullHD Sequence at 60fps
S5-R08	Heroes-of-the-Storm	Annex C.2.9	FullHD Sequence at 30fps
S5-R09	Project-CARS	Annex C.2.10	FullHD Sequence at 30fps
S5-R10	World-of-WarCraft	Annex C.2.11	FullHD Sequence at 30fps
S5-R11	MineCraft	Annex C.2.12	FullHD Sequence at 60fps
S5-R12	CS-GO	Annex C.2.13	FullHD Sequence at 60fps
S5-R13	StarCraft	Annex C.2.14	FullHD Sequence at 60fps

6.6.8 Anchor Definition

6.6.8.1 Overview

This clause provides details on how to generate the anchors for the Online gaming scenario.

6.6.8.2 H.264/AVC Anchors

6.6.8.2.1 Overview

Table 6.6.8.2.1-1 provides an overview of the H.264/AVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/264/streams.csv>.

Table 6.6.8.2.1-1 Anchor Tuple generation with H.264/AVC for Online Gaming Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S5-A01-264	6.6.8.2.3	S5-R01	JM19	S5-JM-01	[22,27,32,37]	S5-A01-264-<QP>
S5-A02-264	6.6.8.2.3	S5-R02	JM19	S5-JM-01	[22,27,32,37]	S5-A02-264-<QP>
S5-A03-264	6.6.8.2.3	S5-R03	JM19	S5-JM-01	[22,27,32,37]	S5-A03-264-<QP>
S5-A04-264	6.6.8.2.3	S5-R04	JM19	S5-JM-01	[22,27,32,37]	S5-A04-264-<QP>
S5-A05-264	6.6.8.2.3	S5-R05	JM19	S5-JM-01	[22,27,32,37]	S5-A05-264-<QP>
S5-A06-264	6.6.8.2.3	S5-R06	JM19	S5-JM-01	[22,27,32,37]	S5-A06-264-<QP>
S5-A07-264	6.6.8.2.3	S5-R07	JM19	S5-JM-01	[22,27,32,37]	S5-A07-264-<QP>
S5-A08-264	6.6.8.2.3	S5-R08	JM19	S5-JM-01	[22,27,32,37]	S5-A08-264-<QP>
S5-A09-264	6.6.8.2.3	S5-R09	JM19	S5-JM-01	[22,27,32,37]	S5-A09-264-<QP>
S5-A10-264	6.6.8.2.3	S5-R10	JM19	S5-JM-01	[22,27,32,37]	S5-A10-264-<QP>
S5-A11-264	6.6.8.2.3	S5-R11	JM19	S5-JM-01	[22,27,32,37]	S5-A11-264-<QP>
S5-A12-264	6.6.8.2.3	S5-R12	JM19	S5-JM-01	[22,27,32,37]	S5-A12-264-<QP>
S5-A13-264	6.6.8.2.3	S5-R13	JM19	S5-JM-01	[22,27,32,37]	S5-A13-264-<QP>
S5-A14-264	6.6.8.2.4	S5-R01	JM19	S5-JM-02	[22,27,32,37]	S5-A14-264-<QP>
S5-A15-264	6.6.8.2.4	S5-R02	JM19	S5-JM-02	[22,27,32,37]	S5-A15-264-<QP>
S5-A16-264	6.6.8.2.4	S5-R03	JM19	S5-JM-02	[22,27,32,37]	S5-A16-264-<QP>
S5-A17-264	6.6.8.2.4	S5-R04	JM19	S5-JM-02	[22,27,32,37]	S5-A17-264-<QP>
S5-A18-264	6.6.8.2.4	S5-R05	JM19	S5-JM-02	[22,27,32,37]	S5-A18-264-<QP>
S5-A19-264	6.6.8.2.4	S5-R06	JM19	S5-JM-02	[22,27,32,37]	S5-A19-264-<QP>
S5-A20-264	6.6.8.2.4	S5-R07	JM19	S5-JM-02	[22,27,32,37]	S5-A20-264-<QP>
S5-A21-264	6.6.8.2.4	S5-R08	JM19	S5-JM-02	[22,27,32,37]	S5-A21-264-<QP>
S5-A22-264	6.6.8.2.4	S5-R09	JM19	S5-JM-02	[22,27,32,37]	S5-A22-264-<QP>
S5-A23-264	6.6.8.2.4	S5-R10	JM19	S5-JM-02	[22,27,32,37]	S5-A23-264-<QP>
S5-A24-264	6.6.8.2.4	S5-R11	JM19	S5-JM-02	[22,27,32,37]	S5-A24-264-<QP>
S5-A25-264	6.6.8.2.4	S5-R12	JM19	S5-JM-02	[22,27,32,37]	S5-A25-264-<QP>
S5-A26-264	6.6.8.2.4	S5-R13	JM19	S5-JM-02	[22,27,32,37]	S5-A26-264-<QP>

6.6.8.2.2 Common Parameters

To generate the anchor bitstreams, JM19 is used.

The common parameters are as follows:

- ProfileIDC = 100 (High Profile)
- IDRPeriod = IntraPeriod
- NumberOfReferenceFrames = 4
- PList0References = 4 (P slice List 0 reference override)
- I16RDOpt = 1 (rd-optimized mode decision for Intra 16x16 MB)

- SearchMode = 3 (Enhanced Predictive Zonal Search (EPZS))
- SearchRange = 256;
- Picture based multipass coding disabled

The following variable triggers updates to the config-file depending on the test scenario.

- QP: [22,27,32,37]

Note that the MaxMvsPer2Mb restriction is not matching the used level requirement from H.264/AVC due to use of inter 4x4 subpartitions. While a strictly conforming decoder may fail, this is not considered a limiting factor in today's implementations.

6.6.8.2.3 S5-JM-01: no random access

The common parameters as defined in 6.6.8.2.2 apply.

In addition, the following parameters apply:

- LevelIDC = 52
- IntraPeriod = 0 (no random access)
- NumberBFrames = 4
- BReferencePictures = 2
- Quantization parameters are set as according to Table 6.6.8.2.3-1

Table 6.6.8.2.3-1 Quantization Parameters for S5-JM-01

QP	QPISlice	QPPSlice	QPBSlice	ExplicitHierarchyFormat
22	21	24	24	B0r3B1r2B2r3B3r2
27	26	29	29	B0r5B1r4B2r5B3r4
32	31	34	34	B0r6B1r5B2r6B3r5
37	36	39	39	B0r6B1r5B2r6B3r5

The settings are defined in the attached configuration file `s5-jm-01.cfg`.

6.6.8.2.4 S5-JM-02: random access near 1 sec

The common parameters as defined in 6.6.8.2.2 apply.

In addition, the following parameters apply:

- IntraPeriod and IDRPeriod = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences
- NumberBFrames = 0
- BReferencePictures = 2
- QPISlice = QPPSlice = QPBSlice = QP

The settings are defined in the attached configuration file `s5-jm-02.cfg`.

6.6.8.3 H.265/HEVC Anchors

6.6.8.3.1 Overview

Table 6.6.8.3.1-1 provides an overview of the H.265/HEVC anchor tuples. Keys are identified to refer to the anchors in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/streams.csv>.

Table 6.5.8.3.1-1 Anchor Tuple generation with H.265/HEVC for Online Gaming Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S5-A01-265	6.6.8.3.3	S5-R01	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A01-265-<QP>
S5-A02-265	6.6.8.3.3	S5-R02	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A02-265-<QP>
S5-A03-265	6.6.8.3.3	S5-R03	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A03-265-<QP>
S5-A04-265	6.6.8.3.3	S5-R04	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A04-265-<QP>
S5-A05-265	6.6.8.3.3	S5-R05	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A05-265-<QP>
S5-A06-265	6.6.8.3.3	S5-R06	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A06-265-<QP>
S5-A07-265	6.6.8.3.3	S5-R07	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A07-265-<QP>
S5-A08-265	6.6.8.3.3	S5-R08	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A08-265-<QP>
S5-A09-265	6.6.8.3.3	S5-R09	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A09-265-<QP>
S5-A10-265	6.6.8.3.3	S5-R10	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A10-265-<QP>
S5-A11-265	6.6.8.3.3	S5-R11	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A11-265-<QP>
S5-A12-265	6.6.8.3.3	S5-R12	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A12-265-<QP>
S5-A13-265	6.6.8.3.3	S5-R13	HM16.22	S5-HM-01	[22, 27, 32, 37]	S5-A13-265-<QP>
S5-A14-265	6.6.8.3.4	S5-R01	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A14-265-<QP>
S5-A15-265	6.6.8.3.4	S5-R02	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A15-265-<QP>
S5-A16-265	6.6.8.3.4	S5-R03	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A16-265-<QP>
S5-A17-265	6.6.8.3.4	S5-R04	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A17-265-<QP>
S5-A18-265	6.6.8.3.4	S5-R05	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A18-265-<QP>
S5-A19-265	6.6.8.3.4	S5-R06	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A19-265-<QP>
S5-A20-265	6.6.8.3.4	S5-R07	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A20-265-<QP>
S5-A21-265	6.6.8.3.4	S5-R08	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A21-265-<QP>
S5-A22-265	6.6.8.3.4	S5-R09	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A22-265-<QP>
S5-A23-265	6.6.8.3.4	S5-R10	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A23-265-<QP>
S5-A24-265	6.6.8.3.4	S5-R11	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A24-265-<QP>
S5-A25-265	6.6.8.3.4	S5-R12	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A25-265-<QP>
S5-A26-265	6.6.8.3.4	S5-R13	HM16.22	S5-HM-02	[22, 27, 32, 37]	S5-A26-265-<QP>
S5-A27-265	6.6.8.3.5	S5-R01	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A27-265-<QP>
S5-A28-265	6.6.8.3.5	S5-R02	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A28-265-<QP>
S5-A29-265	6.6.8.3.5	S5-R03	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A29-265-<QP>
S5-A30-265	6.6.8.3.5	S5-R04	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A30-265-<QP>
S5-A31-265	6.6.8.3.5	S5-R05	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A31-265-<QP>
S5-A32-265	6.6.8.3.5	S5-R06	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A32-265-<QP>
S5-A33-265	6.6.8.3.5	S5-R07	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A33-265-<QP>
S5-A34-265	6.6.8.3.5	S5-R08	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A34-265-<QP>
S5-A35-265	6.6.8.3.5	S5-R09	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A35-265-<QP>
S5-A36-265	6.6.8.3.5	S5-R10	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A36-265-<QP>
S5-A37-265	6.6.8.3.5	S5-R11	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A37-265-<QP>
S5-A38-265	6.6.8.3.5	S5-R12	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A38-265-<QP>
S5-A39-265	6.6.8.3.5	S5-R13	SCC8.8	S5-SCC-01	[22, 27, 32, 37]	S5-A39-265-<QP>
S5-A40-265	6.6.8.3.6	S5-R01	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A40-265-<QP>
S5-A41-265	6.6.8.3.6	S5-R02	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A41-265-<QP>
S5-A42-265	6.6.8.3.6	S5-R03	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A42-265-<QP>
S5-A43-265	6.6.8.3.6	S5-R04	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A43-265-<QP>
S5-A44-265	6.6.8.3.6	S5-R05	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A44-265-<QP>
S5-A45-265	6.6.8.3.6	S5-R06	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A45-265-<QP>
S5-A46-265	6.6.8.3.6	S5-R07	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A46-265-<QP>
S5-A47-265	6.6.8.3.6	S5-R08	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A47-265-<QP>
S5-A48-265	6.6.8.3.6	S5-R09	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A48-265-<QP>
S5-A49-265	6.6.8.3.6	S5-R10	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A49-265-<QP>
S5-A50-265	6.6.8.3.6	S5-R11	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A50-265-<QP>
S5-A51-265	6.6.8.3.6	S5-R12	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A51-265-<QP>
S5-A52-265	6.6.8.3.6	S5-R13	SCC8.8	S5-SCC-02	[22, 27, 32, 37]	S5-A52-265-<QP>

6.6.8.3.2 Common Parameters

Each source sequence is encoded with:

- QP: [22, 27, 32, 37]
- InternalBitDepth is 10 # codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits.
- SEIDecodedPictureHash=1

As the `SEIDecodedPictureHash` is set to 1, the effective file size (EFS) needs to take into account the removal of this SEI message when computing the bitrate metric as defined in clause 5.5.2. For all anchors, a modified bitstream is provided with ‘*.bis’ suffix, for which the SEI removal is applied. This file is used for bitrate computation.

6.6.8.3.3 S5-HM-01: Main 10 Profile with no fixed random access

The common parameters as defined in 6.6.8.3.2 apply.

To generate the anchor bitstreams, HM16.22 is used.

Each source sequence is encoded with the following changes:

- `IntraPeriod` with no fix interval
- `GOPSize` is equal to 8. Each B picture refers to up to 4 preceding pictures in display order within the GOP
- `IntraQPOffset` is -1. B picture QP offsets are `IntraQPOffset` is -1. B picture QP offsets are adjusted based on the base QP and on the `QPmod`, `QPoffset`, `QPoffsetModelScale` and `QPoffsetModelOff`.

The settings are defined in the attached configuration file `s5-hm-01.cfg`.

6.6.8.3.4 S5-HM-02: Main 10 Profile with fixed random access near 1 sec

The common parameters as defined in 6.6.8.3.2 apply.

To generate the anchor bitstreams, HM16.22 is used.

Each source sequence is encoded with the following changes:

- `IntraPeriod` = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences
- `DecodingRefreshType`: (2) IDR
- `IntraQPOffset` and B pictures `QPoffsets` are set equal to 0
- Each B picture refers to immediately preceding pictures in display order.

The settings are defined in the attached configuration file `s5-hm-02.cfg`.

6.6.8.3.5 S5-SCC-01: Screen Content Profile with no fixed random access

The common parameters as defined in 6.6.8.3.2 apply.

To generate the anchor bitstreams SCM-8.8 is used.

Each source sequence is encoded with the following changes:

- `IntraPeriod` with no fix interval
- `GOPSize` is equal to 8. Each P picture refers to up to 4 preceding pictures in display order within the GOP
- `IntraQPOffset` is -1. B picture QP offsets are `IntraQPOffset` is -1. B picture QP offsets are adjusted based on the base QP and on the `QPmod`, `QPoffset`, `QPoffsetModelScale` and `QPoffsetModelOff`.

The settings are defined in the attached configuration file `s5-scc-01.cfg`.

6.6.8.3.6 S5-SCC-02: Screen Content Profile with random access near 1 sec

The common parameters as defined in 6.6.8.3.2 apply.

To generate the anchor bitstreams SCM-8.8 is used.

Each source sequence is encoded with the following changes:

- `IntraPeriod` = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences
- `DecodingRefreshType`: (2) IDR
- `IntraQPoffset` and B pictures `QPoffsets` are set equal to 0
- Each B picture refers to immediately preceding pictures in display order.

The settings are defined in the attached configuration file `s5-scc-02.cfg`.

6.6.9 Anchor Results

6.6.9.1 H.264/AVC Anchors

AVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/264/>

AVC anchor results are provided with the appropriate keys as defined in Table 6.6.8.2.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/264/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/264/cross-check.csv>.

Based on these cross-check results, the verification status for the H.264/AVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/264/verification.csv> and Table 6.6.9.1-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.6.9.1-1 Verification status of H.264/AVC test streams for Gaming Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S5-A01-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A02-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A03-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A04-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A05-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A06-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A07-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A08-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A09-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A10-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A11-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A12-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A13-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A14-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A15-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A16-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A17-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A18-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A19-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A20-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A21-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A22-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A23-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A24-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A25-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A26-264	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

6.6.9.2 H.265/HEVC Anchors

HEVC anchor streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/>

HEVC anchor results are provided with the appropriate keys as defined in Table 6.6.8.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/cross-check.csv>.

Based on these cross-check results, the verification status for the H.265/HEVC anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/verification.csv> and Table 6.6.9.2-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 6.6.9.2-1 Verification status of H.265/HEVC test streams for Gaming Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S5-A01-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A02-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A03-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A04-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A05-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A06-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A07-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A08-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A09-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A10-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A11-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A12-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A13-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A14-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A15-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A16-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A17-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A18-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A19-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A20-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A21-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A22-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A23-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A24-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A25-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A26-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A27-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A28-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A29-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A30-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A31-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A32-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A33-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A34-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A35-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A36-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A37-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A38-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A39-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A40-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A41-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A42-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A43-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A44-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A45-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A46-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A47-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A48-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A49-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A50-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A51-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A52-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

7 Characterization Framework

7.1 Introduction

This clause provides a characterization of existing codecs. This serves pre-dominantly as an example to introduce the characterization framework.

7.2 Characterization against 3GPP Anchor Codecs

7.2.1 Characterization against H.264/AVC

For a codec to be fully characterized against H.264/AVC, the following information should be provided:

1. For scenario 1:
 - a) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S1-JM-01 as defined in clause 6.2.8.2 with a comparable configuration and all SDR metrics defined clause 6.2.5.
2. For scenario 2 no characterization possible.
3. For scenario 3:
 - a) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S3-JM-01 and S3-JM-02 as defined in clause 6.4.8.2 with a comparable configuration and all SDR metrics defined clause 6.4.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S3-JM-03 and S3-JM-04 as defined in clause 6.4.8.2 with a comparable configuration and all SDR metrics defined clause 6.4.5.
4. For scenario 4:
 - a) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S4-JM-01 as defined in clause 6.5.8.2 with a comparable configuration and all SDR metrics defined clause 6.5.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S4-JM-02 as defined in clause 6.5.8.2 with a comparable configuration and all SDR metrics defined clause 6.5.5.
5. For scenario 5:
 - a) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S5-JM-01 as defined in clause 6.6.8.2 with a comparable configuration and all SDR metrics defined clause 6.6.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.264/AVC reference sequences and configuration S5-JM-02 as defined in clause 6.6.8.2 with a comparable configuration and all SDR metrics defined clause 6.6.5.

Additional information such as Rate-Quality plots may be provided if considered insightful.

Partial characterization may be conducted as well.

7.2.2 Characterization against H.265/HEVC HM

For a codec to be fully characterized against H.265/HEVC HM (Main 10 profile), the following information should be provided:

1. For scenario 1:
 - a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S1-HM-01 as defined in clause 6.2.8.3 with a comparable configuration and all SDR metrics defined clause 6.2.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S1-HM-02 as defined in clause 6.2.8.3 with a comparable configuration and all HDR metrics defined clause 6.2.5.
2. For scenario 2:

- a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S2-HM-01 as defined in clause 6.3.8.3 with a comparable configuration and all SDR metrics defined clause 6.3.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S2-HM-02 as defined in clause 6.3.8.3 with a comparable configuration and all HDR metrics defined clause 6.3.5.
3. For scenario 3:
- a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-HM-01 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-HM-02 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
 - c) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-HM-03 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
 - d) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-HM-04 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
4. For scenario 4:
- a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S4-HM-01 as defined in clause 6.5.8.3 with a comparable configuration and all SDR metrics defined clause 6.5.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S4-HM-02 as defined in clause 6.5.8.3 with a comparable configuration and all SDR metrics defined clause 6.5.5.
5. For scenario 5:
- a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S5-HM-01 as defined in clause 6.6.8.3 with a comparable configuration and all SDR metrics defined clause 6.6.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S5-HM-02 as defined in clause 6.6.8.3 with a comparable configuration and all SDR metrics defined clause 6.6.5.

Additional information such as Rate-Quality plots may be provided if considered insightful.

Partial characterization may be conducted as well.

7.2.3 Characterization against H.265/HEVC SCC

For a codec to be fully characterized against H.265/HEVC SCC (Screen-Extended Main 10 profile), the following information should be provided:

- 1. For scenario 1 no characterization possible.
- 2. For scenario 2 no characterization possible.
- 3. For scenario 3:
 - a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-SCC-01 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.

- b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-SCC-02 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
 - c) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-SCC-03 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
 - d) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S3-SCC-04 as defined in clause 6.4.8.3 with a comparable configuration and all SDR metrics defined clause 6.4.5.
4. For scenario 4 no characterization possible.
5. For scenario 5:
- a) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S5-HM-01 as defined in clause 6.6.8.3 with a comparable configuration and all SDR metrics defined clause 6.6.5.
 - b) *BD-Rate Gain* table as defined in clause 5.8 for all H.265/HEVC reference sequences and configuration S5-HM-02 as defined in clause 6.6.8.3 with a comparable configuration and all SDR metrics defined clause 6.6.5.

Additional information such as Rate-Quality plots may be provided if considered insightful.

Partial characterization may be conducted as well.

7.3 H.265/HEVC Characterization against H.264/AVC

7.3.1 Introduction

This clause provides characterization results for H.265/HEVC against H.264/AVC for different scenarios and metrics.

The clause 7.3.2 provides the results for H.265/HEVC Main 10 profile (referred as H.265/HEVC HM) and clause 7.3.3 provides the results for H.265/HEVC Screen-Extended Main 10 profile (referred as H.265/HEVC SCC) compared to H.264/AVC Progressive High-Profile or High Profile (referred as H.264/AVC JM).

7.3.2 H.265/HEVC HM against H.264/AVC

7.3.2.1 Overview

This clause provides a full characterization of H.265/HEVC HM against H.264/AVC JM according to clause 7.2.1. The results provided in clause 6 are used for the characterization.

7.3.2.2 Scenario 1: Full HD

This clause provides characterization of H.265/HEVC HM mode configurations against H.264/AVC JM for Scenario 1 Full HD. In particular, Table 7.3.2.2-1 provides the BD rate gain of H.265/HEVC HM with S1-HM-01 against H.264/AVC HM with configuration S1-JM-01, i.e. with the Full HD SDR scenario reference sequences.

Table 7.3.2.2-1 BD rate gain of H.265/HEVC HM with S1-HM-01 against H.264/AVC JM with configuration S1-JM-01, i.e. with the Full HD SDR scenario reference sequences

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S1-R01	Brest-Sedof-FHD	68.7	70.9	57.6	46.2
S1-R02	Rain Fruits-FHD	47.0	48.1	46.4	44.8
S1-R03	Park Joy-FHD	22.3	20.8	28.2	25.2
S1-R04	Soccer-FHD	56.7	56.6	55.7	54.8
S1-R05	Tunnel Flag-FHD	45.9	44.5	47.1	48.0
S1-R06	Boat-FHD	32.2	32.0	35.3	31.8
S1-R07	Fountain-FHD	21.6	21.5	28.1	21.4
S1-R08	Riverbank-FHD	37.6	34.2	36.0	29.3
Minimum		21.6	20.8	28.1	21.4
Maximum		68.7	70.9	57.6	54.9
Average		41.5	41.1	41.8	37.7

As an example, Figure 7.3.2.2-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.265/HEVC HM with S1-JM-01 against H.264/AVC JM with configuration S1-JM-01 for reference sequence S1-R04.

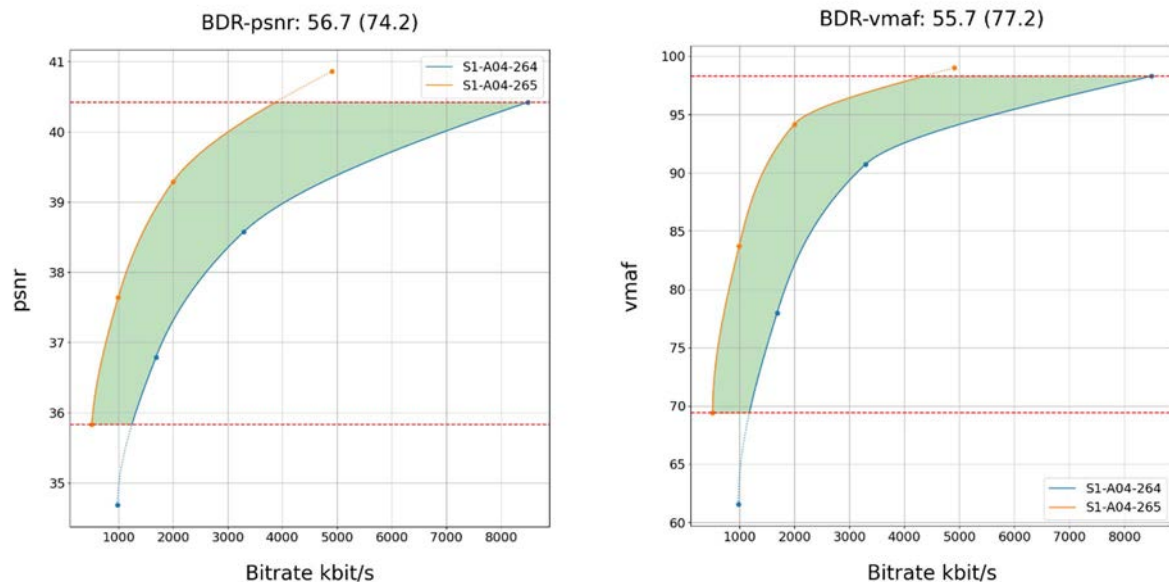


Figure 7.3.2.2-1 Rate-Quality curves and BD rate gain for psnr and vmaf of H.265/HEVC HM with S1-HM-01 against H.264/AVC JM with configuration S1-JM-01 for reference sequence S1-R04

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/265/Characterization/>.

7.3.2.3 Scenario 3: Screen Content

This clause provides characterization of H.265/HEVC HM mode configurations against H.264/AVC JM for Scenario 3 Screen Content. In particular,

- Table 7.3.2.3-1 provides the BD rate gain of H.265/HEVC HM with S3-HM-01 against H.264/AVC JM with configuration S3-JM-01, i.e. with the screen content scenario reference sequences and no RA.
- Table 7.3.2.3-2 provides the BD rate gain of H.265/HEVC HM with S3-HM-02 against H.264/AVC JM with configuration S3-JM-02, i.e. with the screen content scenario reference sequences with fixed Intra every second.

Table 7.3.2.3-1 BD rate gain of H.265/HEVC HM with S3-HM-01 against H.264/AVC JM with configuration S3-JM-01, i.e. with the screen content scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S3-R02	MovingText2-4K-8bit	61.7	61.5
S3-R04	MovingText2-FullHD-8bit	63.9	64.6
S3-R06	TextMixTransitions-4K-8bit	55.8	51.8
S3-R08	TextMixTransitions-FullHD-8bit	42.3	40.0
S3-R10	GraphicsMixSimple-4K-8bit	57.5	56.7
S3-R12	GraphicsMixSimple-FullHD-8bit	40.5	39.8
S3-R14	GraphicsMixTransitions-4K-8bit	62.7	61.5
S3-R16	GraphicsMixTransitions-FullHD-8bit	54.7	53.5
S3-R17	Mission-Control	32.5	31.7
Minimum		32.5	31.7
Maximum		63.9	64.6
Average		52.4	51.2

Table 7.3.2.3-2 BD rate gain of H.265/HEVC HM with S3-HM-02 against H.264/AVC JM with configuration S3-JM-02, i.e. with the screen content scenario reference sequences with fixed Intra every second

Reference sequence	Name	psnr	y_psnr
S3-R02	MovingText2-4K-8bit	53.0	51.9
S3-R04	MovingText2-FullHD-8bit	51.5	51.8
S3-R06	TextMixTransitions-4K-8bit	49.1	44.1
S3-R08	TextMixTransitions-FullHD-8bit	33.0	31.1
S3-R10	GraphicsMixSimple-4K-8bit	47.6	46.2
S3-R12	GraphicsMixSimple-FullHD-8bit	34.6	33.4
S3-R14	GraphicsMixTransitions-4K-8bit	55.3	54.0
S3-R16	GraphicsMixTransitions-FullHD-8bit	46.7	45.4
S3-R17	Mission-Control	27.0	26.7
Minimum		27.0	26.7
Maximum		55.3	54.0
Average		44.2	42.7

As an example, Figure 7.3.2.3-1 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC HM with S3-HM-01 against H.264/AVC JM with configuration S3-JM-01 for reference sequences S3-R02 and S3-R17.

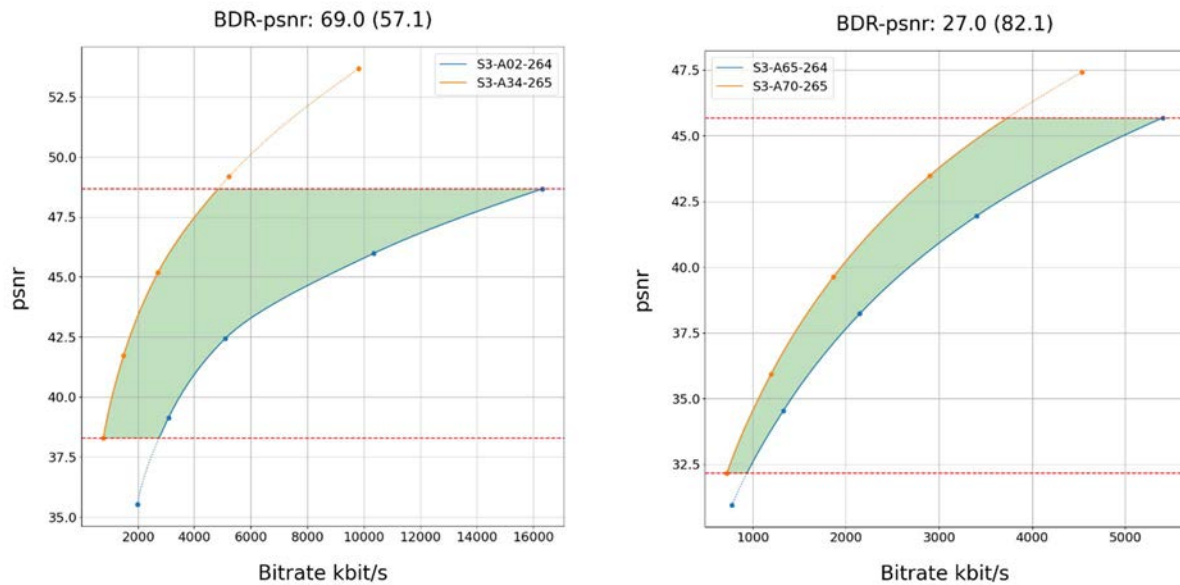


Figure 7.3.2.3-1 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC HM with S3-HM-01 against H.264/AVC JM with configuration S3-JM-01 for reference sequence S3-R02 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/Characterization/>.

7.3.2.4 Scenario 4: Messaging and Social Sharing

This clause provides characterization of H.265/HEVC HM mode configurations against H.264/AVC JM for Scenario 4 Messaging and Social Sharing. In particular,

- Table 7.3.2.4-1 provides the BD rate gain of H.265/HEVC HM with S4-HM-01 against H.264/AVC JM with configuration S4-JM-01, i.e. with the messaging and social sharing scenario reference sequences and no RA.
- Table 7.3.2.4-2 provides the BD rate gain of H.265/HEVC HM with S4-HM-02 against H.264/AVC JM with configuration S4-JM-02, i.e. with the messaging and social sharing scenario reference sequences with fixed Intra every second.

Table 7.3.2.4-1 BD rate gain of H.265/HEVC HM with S4-HM-01 against H.264/AVC JM with configuration S4-JM-01, i.e. with the messaging and social sharing scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	60.2	60.0	62.2	64.1
S4-R02	Vertical-Walking	26.0	25.7	30.4	27.4
S4-R03	Neon-4K	33.5	31.8	37.7	34.4
S4-R04	Skater-4K	71.6	70.8	68.4	71.3
Minimum		26.0	25.7	30.4	27.4
Maximum		71.6	70.8	68.4	71.3
Average		47.8	47.1	49.7	49.3

Table 7.3.2.4-2 BD rate gain of H.265/HEVC HM with S4-HM-02 against H.264/AVC JM with configuration S4-JM-02, i.e. with the messaging and social sharing scenario reference sequences and fixed Intra every second

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	42.2	43.7	47.4	47.7
S4-R02	Vertical-Walking	19.6	19.2	22.9	19.9
S4-R03	Neon-4K	24.0	22.8	34.4	26.6
S4-R04	Skater-4K	63.4	63.9	60.9	63.2
Minimum		19.6	19.2	22.9	19.9
Maximum		63.4	63.9	60.9	63.2
Average		37.3	37.4	41.4	39.3

As an example, Figure 7.3.2.4-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.265/HEVC HM with S4-HM-01 against H.264/AVC JM with configuration S4-JM-01 for reference sequence S4-R01.

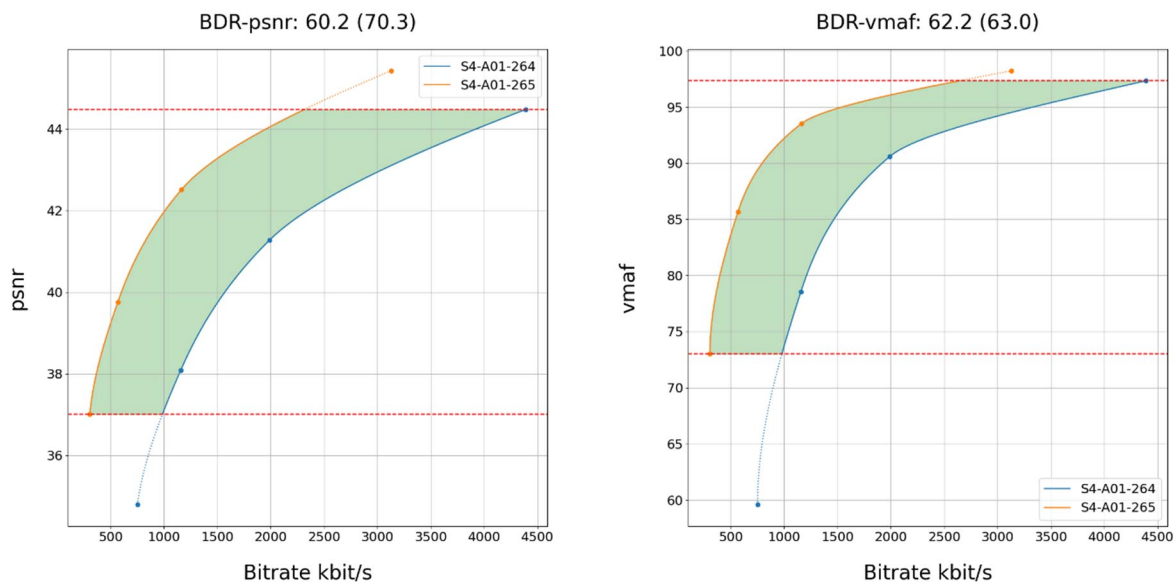


Figure 7.3.2.4-1 Rate-Quality curves and BD rate gain for psnr and vmaf of H.265/HEVC HM with S4-HM-01 against H.264/AVC JM with configuration S4-JM-01 for reference sequence S4-R01

As another example, Figure 7.3.2.4-2 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.265/HEVC HM with S4-HM-02 against H.264/AVC JM with configuration S4-JM-02 for reference sequence S4-R01.

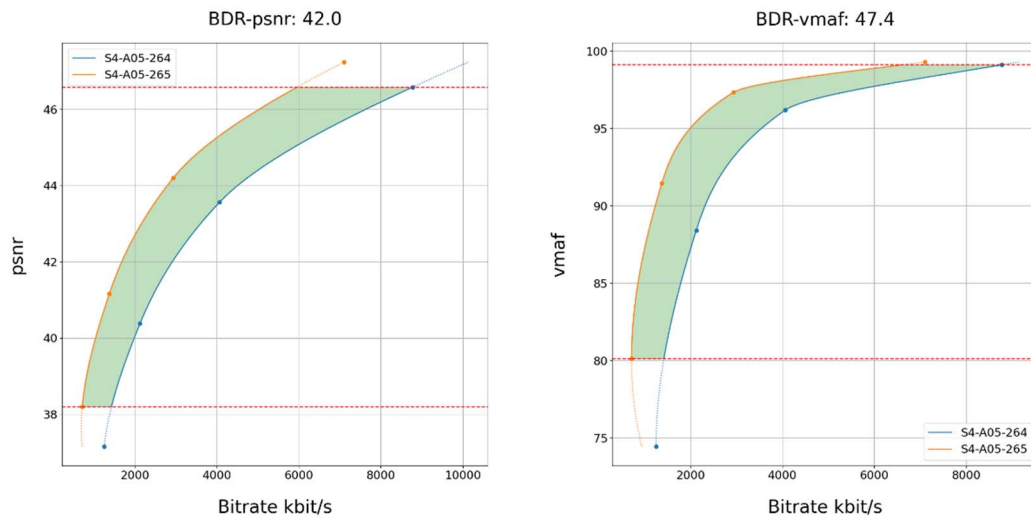


Figure 7.3.2.4-2 Rate-Quality curves and BD rate gain for psnr and vmaf of H.265/HEVC HM with S4-HM-02 against H.264/AVC JM with configuration S4-JM-02 for reference sequence S4-R01

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/265/Characterization/>.

7.3.2.5 Scenario 5: Online Gaming

This clause provides characterization of H.265/HEVC HM mode configurations against H.264/AVC fJM or Scenario 5 Online Gaming. In particular,

- Table 7.3.2.5-1 provides the BD rate gain of H.265/HEVC HM with S5-HM-01 against H.264/AVC JM with configuration S5-JM-01, i.e. with the online gaming scenario reference sequences and no RA.
- Table 7.3.2.5-2 provides the BD rate gain of H.265/HEVC HM with S5-HM-02 against H.264/AVC JM with configuration S5-JM-02, i.e. with the online gaming scenario reference sequences with fixed Intra every second.

Table 7.3.2.5-1 BD rate gain of H.265/HEVC HM with S5-HM-01 against H.264/AVC JM with configuration S5-JM-01, i.e. with the online gaming scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	45.2	44.8
S5-R02	Baolei-Man	36.5	35.3
S5-R03	Baolei-Woman	44.7	44.0
S5-R04	Baolei-Balloon	52.3	52.3
S5-R05	Baolei-Yard	48.2	48.1
S5-R06	Jianling-Temple	23.4	23.0
S5-R07	Jianling-Beach	37.0	34.9
S5-R08	Heroes-of-the-Storm	31.9	31.8
S5-R09	Project-CARS	40.5	37.9
S5-R10	World-of-WarCraft	49.1	48.4
S5-R11	MineCraft	28.3	25.8
S5-R12	CS-GO	52.6	49.3
S5-R13	StarCraft	44.9	43.4
Minimum		23.4	23.0
Maximum		52.6	52.3
Average		41.1	39.9

Table 7.3.2.5-2 BD rate gain of H.265/HEVC HM with S5-HM-02 against H.264/AVC JM with configuration S5-JM-02, i.e. with the online gaming scenario reference sequences and fixed RA, fixed QP every second

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	32.4	32.7
S5-R02	Baolei-Man	27.0	26.8
S5-R03	Baolei-Woman	33.7	33.9
S5-R04	Baolei-Balloon	42.6	43.5
S5-R05	Baolei-Yard	41.3	42.1
S5-R06	Jianling-Temple	20.8	20.9
S5-R07	Jianling-Beach	23.6	23.3
S5-R08	Heroes-of-the-Storm	20.9	21.3
S5-R09	Project-CARS	31.2	31.8
S5-R10	World-of-WarCraft	37.0	36.4
S5-R11	MineCraft	25.9	24.9
S5-R12	CS-GO	36.3	35.6
S5-R13	StarCraft	29.9	29.3
Minimum		20.8	20.9
Maximum		42.6	43.5
Average		31.0	31.0

As an example,

- Figure 7.3.2.5-1 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC HM with S5-HM-01 against H.264/AVC JM with configuration S5-JM-01 for reference sequences S5-R01 and S5-R04
- Figure 7.3.2.5-2 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC HM with S5-HM-02 against H.264/AVC JM with configuration S5-JM-02 for reference sequences S5-R01 and S5-R04

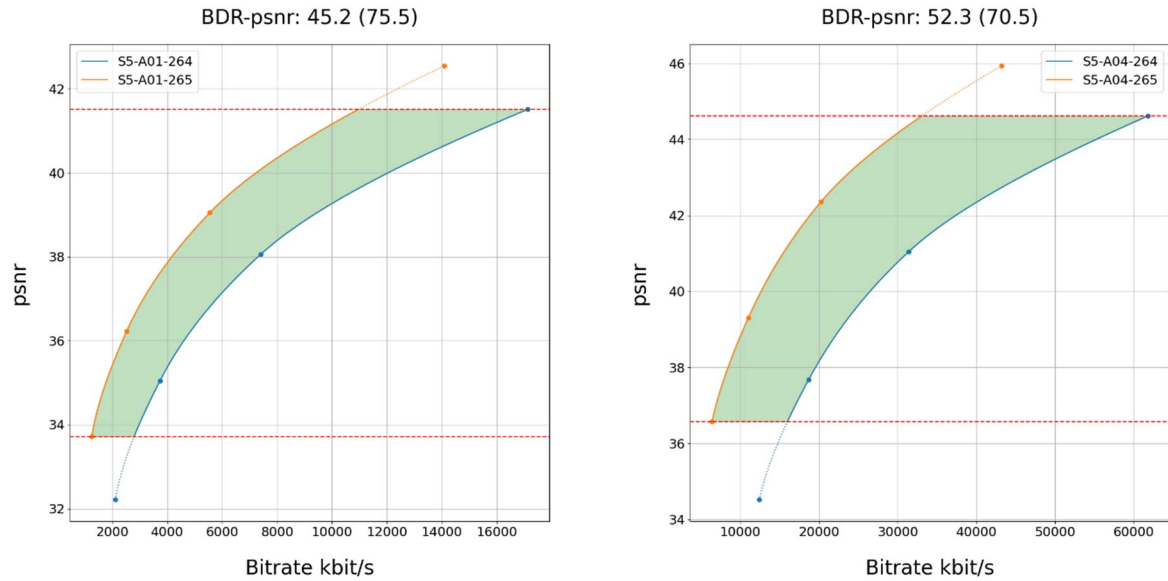


Figure 7.3.2.5-1 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC HM with S5-HM-01 against H.264/AVC JM with configuration S5-JM-01 for reference sequences S5-R01 and S5-R04

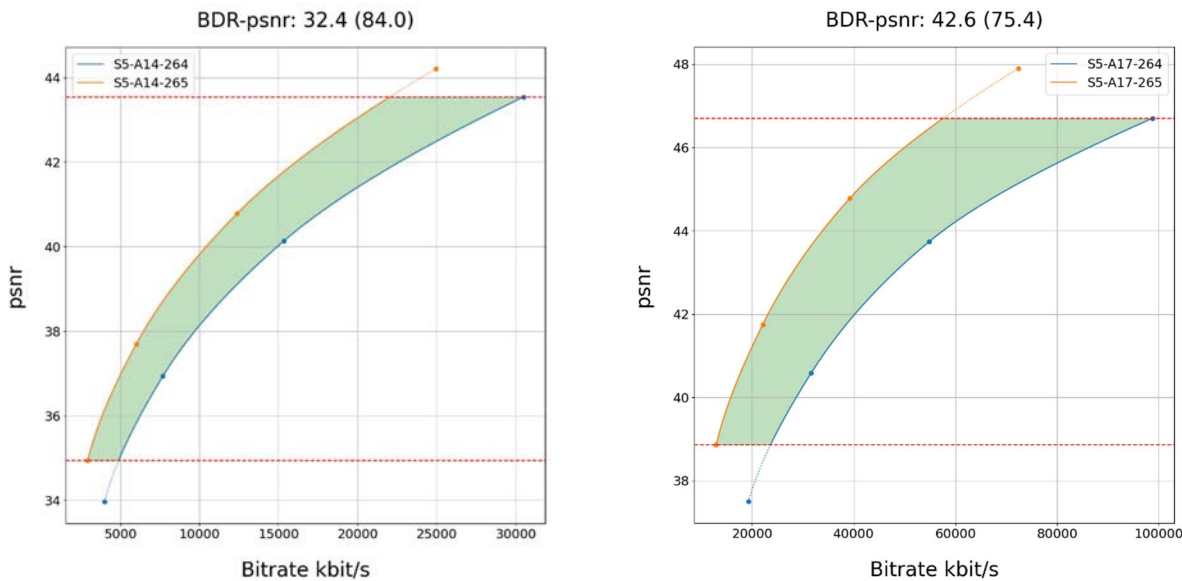


Figure 7.3.2.5-2 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC HM with S5-HM-02 against H.264/AVC JM with configuration S5-JM-02 for reference sequences S5-R01 and S5-R04

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/Characterization/>.

7.3.2.6 Summary

Table 7.3.2.6-1 provides a summary of BD rate gain in psnr and vmf of H.265/HEVC HM against H.264/AVC JM for different scenarios and configurations.

Table 7.3.2.6-1 Summary of BD rate gain in psnr and vmaf of H.265/HEVC HM against H.264/AVC JM for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr	average vmaf	min vmaf	max vmaf
S1	41.5	21.5	68.7	41.8	28.1	57.6
S3 no RA	52.4	32.5	63.9	n/a	n/a	n/a
S3 RA, fixed QP	44.2	27.0	55.3	n/a	n/a	n/a
S4 no RA	46.7	21.7	71.5	49.8	30.4	68.4
S4 RA, fixed QP	36.2	15.9	63.2	41.5	23.2	60.8
S5 no RA	41.1	23.4	52.6	n/a	n/a	n/a
S5 RA, fixed QP	31.0	20.8	42.6	n/a	n/a	n/a
Minimum	31.0	15.9	42.6	41.5	23.2	57.6
Maximum	52.4	32.5	71.5	49.8	30.4	68.4

7.3.3 H.265/HEVC SCC against H.264/AVC

7.3.3.1 Overview

This clause provides a partial characterization of H.265/HEVC SCC against H.264/AVC JM according to clause 7.2.1. The results provided in clause 6 are used for the characterization.

7.3.3.2 Scenario 3: Screen Content

This clause provides characterization of H.265/HEVC SCC mode configurations against H.264/AVC JM for Scenario 3 Screen Content. In particular,

- Table 7.3.3.2-1 provides the BD rate gain of H.265/HEVC SCC with S3-SCC-01 against H.264/AVC JM with configuration S3-JM-01, i.e. with the screen content scenario reference sequences and no RA.
- Table 7.3.3.2-2 provides the BD rate gain of H.265/HEVC SCC with S3-SCC-02 against H.264/AVC JM with configuration S3-JM-02, i.e. with the screen content scenario reference sequences with fixed Intra every second.

Table 7.3.3.2-1 BD rate gain of H.265/HEVC SCC with S3-SCC-01 against H.264/AVC JM with configuration S3-JM-01, i.e. with the screen content scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S3-R02	MovingText2-4K-8bit	69.0	67.8
S3-R04	MovingText2-FullHD-8bit	67.5	67.7
S3-R06	TextMixTransitions-4K-8bit	72.3	68.3
S3-R08	TextMixTransitions-FullHD-8bit	56.1	51.8
S3-R10	GraphicsMixSimple-4K-8bit	75.7	74.8
S3-R12	GraphicsMixSimple-FullHD-8bit	56.5	55.1
S3-R14	GraphicsMixTransitions-4K-8bit	68.3	66.8
S3-R16	GraphicsMixTransitions-FullHD-8bit	58.3	56.4
S3-R17	Mission-Control	55.3	54.9
Minimum		55.3	51.8
Maximum		75.7	74.8
Average		64.3	62.6

Table 7.3.3.2-2 BD rate gain of H.265/HEVC SCC with S3-SCC-02 against H.264/AVC JM with configuration S3-JM-02, i.e. with the screen content scenario reference sequences with fixed Intra every second

Reference sequence	Name	psnr	y_psnr
S3-R02	MovingText2-4K-8bit	62.2	60.6
S3-R04	MovingText2-FullHD-8bit	57.3	57.0
S3-R06	TextMixTransitions-4K-8bit	72.3	68.4
S3-R08	TextMixTransitions-FullHD-8bit	54.1	50.8
S3-R10	GraphicsMixSimple-4K-8bit	72.6	71.3
S3-R12	GraphicsMixSimple-FullHD-8bit	55.1	53.2
S3-R14	GraphicsMixTransitions-4K-8bit	67.4	65.9
S3-R16	GraphicsMixTransitions-FullHD-8bit	55.8	53.8
S3-R17	Mission-Control	53.8	53.8
Minimum		53.8	50.8
Maximum		72.6	71.3
Average		61.2	59.4

As an example,

- Figure 7.3.3.2-1 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-01 against H.264/AVC JM with configuration S3-JM-01 for reference sequences S3-R02 and S3-R17
- Figure 7.3.3.2-2 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-02 against H.264/AVC JM with configuration S3-JM-02 for reference sequences S3-R02 and S3-R17

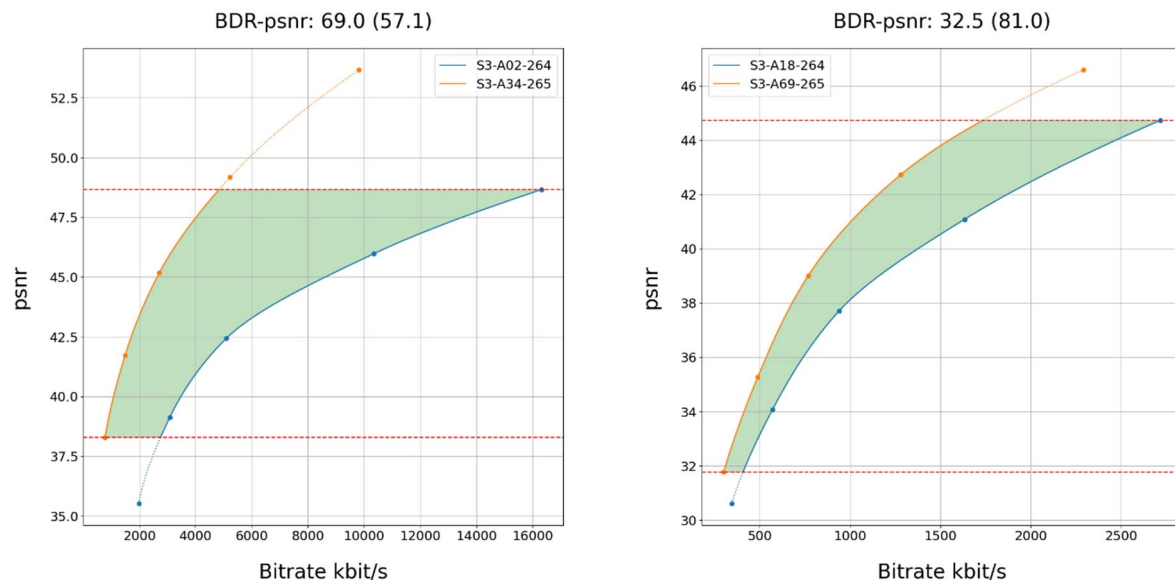


Figure 7.3.3.2-1 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-01 against H.264/AVC JM with configuration S3-JM-01 for reference sequences S3-R02 and S3-R17

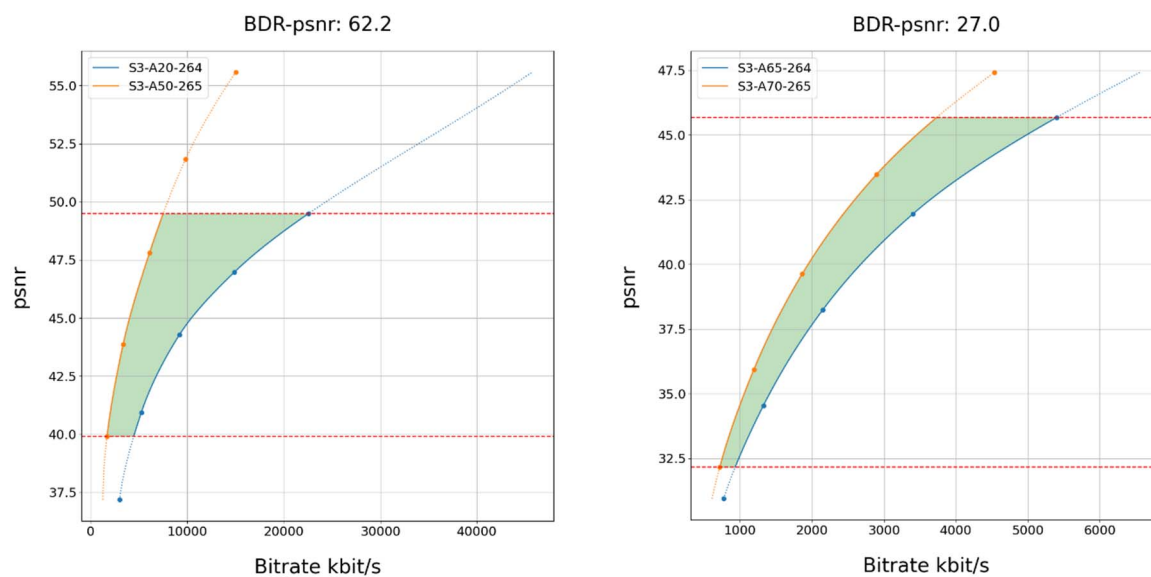


Figure 7.3.3.2-2 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-02 against H.264/AVC JM with configuration S3-JM-02 for reference sequences S3-R02 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/Characterization/>.

7.3.3.3 Scenario 5: Online Gaming

This clause provides characterization of H.265/HEVC SCC mode configurations against H.264/AVC for Scenario 5 Online Gaming. In particular,

- Table 7.3.3.3-1 provides the BD rate gain of H.265/HEVC SCC with S5-SCC-01 against H.264/AVC JM with configuration S5-JM-01, i.e. with the online gaming scenario reference sequences and no RA.
- Table 7.3.3.3-2 provides the BD rate gain of H.265/HEVC SCC with S5-SCC-02 against H.264/AVC JM with configuration S5-JM-02, i.e. with the online gaming scenario reference sequences with fixed Intra every second.

Table 7.3.3.3-1 BD rate gain of H.265/HEVC SCC with S5-SCC-01 against H.264/AVC JM with configuration S5-JM-01, i.e. with the online gaming scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	45.2	44.7
S5-R02	Baolei-Man	36.7	35.2
S5-R03	Baolei-Woman	45.2	44.4
S5-R04	Baolei-Balloon	52.7	52.7
S5-R05	Baolei-Yard	48.3	48.1
S5-R06	Jianling-Temple	25.4	24.6
S5-R07	Jianling-Beach	39.3	36.7
S5-R08	Heroes-of-the-Storm	33.5	33.2
S5-R09	Project-CARS	42.2	39.1
S5-R10	World-of-WarCraft	49.8	48.7
S5-R11	MineCraft	39.3	34.2
S5-R12	CS-GO	56.5	52.4
S5-R13	StarCraft	46.8	44.5
Minimum		25.4	24.6
Maximum		56.5	52.7
Average		43.1	41.4

Table 7.3.3.3-2 BD rate gain of H.265/HEVC SCC with S5-SCC-02 against H.264/AVC JM with configuration S5-JM-02, i.e. with the online gaming scenario reference sequences and fixed RA every second and fixed QP

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	33.2	33.3
S5-R02	Baolei-Man	28.0	27.5
S5-R03	Baolei-Woman	35.4	35.4
S5-R04	Baolei-Balloon	43.1	43.9
S5-R05	Baolei-Yard	41.4	42.1
S5-R06	Jianling-Temple	22.9	22.7
S5-R07	Jianling-Beach	28.8	27.8
S5-R08	Heroes-of-the-Storm	24.4	24.6
S5-R09	Project-CARS	33.8	33.7
S5-R10	World-of-WarCraft	40.4	39.4
S5-R11	MineCraft	38.3	35.0
S5-R12	CS-GO	43.5	41.5
S5-R13	StarCraft	34.5	32.9
Minimum		22.9	22.7
Maximum		43.5	43.9
Average		34.4	33.8

As an example,

- Figure 7.3.3.3-1 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-01 against H.264/AVC JM with configuration S5-JM-01 for reference sequences S5-R01 and S5-R04
- Figure 7.3.3.3-2 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-02 against H.264/AVC JM with configuration S5-JM-02 for reference sequences S5-R01 and S5-R04

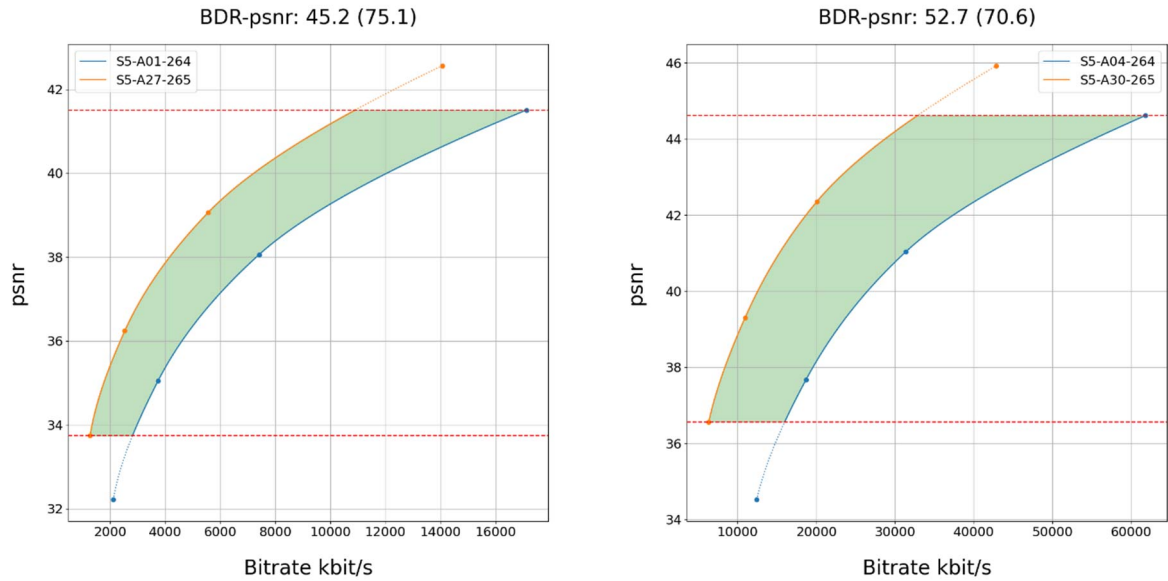


Figure 7.3.3.3-1 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-01 against H.264/AVC JM with configuration S5-JM-01 for reference sequences S5-R01 and S5-R04

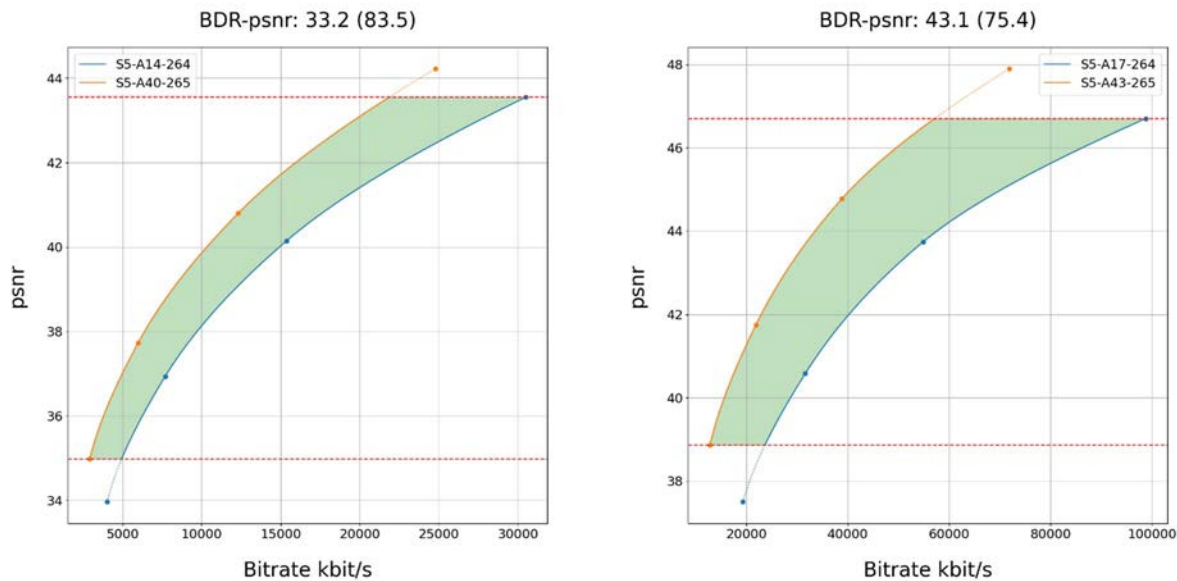


Figure 7.3.3.3-2 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-02 against H.264/AVC JM with configuration S5-JM-02 for reference sequences S5-R01 and S5-R04

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/Characterization/>.

7.3.3.4 Summary

Table 7.3.3.4-1 provides a summary of BD rate gain in psnr and vmaf of H.265/HEVC SCC against H.264/AVC JM for different scenarios and configurations.

Table 7.3.3.4-1 Summary of BD rate gain in psnr of H.265/HEVC SCC against H.264/AVC JM for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr
S3 no RA	64.3	55.3	75.7
S3 RA, fixed QP	61.2	53.8	72.6
S5 no RA	43.1	25.4	56.5
S5 RA, fixed QP	34.4	22.9	43.5
Minimum	34.4	22.9	43.5
Maximum	64.3	55.3	75.7

7.4 Characterization of different HEVC modes

7.4.1 Introduction

This clause provides characterization results of different H.265/HEVC modes for different scenarios and metrics.

7.4.2 H.265/HEVC SCC against H.265/HEVC HM

7.4.2.1 Introduction

This clause provides characterization results H.265/HEVC Screen-Extended Main 10 profile (referred as H.265/HEVC SCC) against H.265/HEVC Main 10 profile (referred as H.265/HEVC HM) for different scenarios and metrics.

7.4.2.2 Scenario 3: Screen Content

This clause provides characterization of H.265/HEVC SCC mode configurations against H.265/HEVC HM for Scenario 3 Screen Content. In particular,

- Table 7.4.2.2-1 provides the BD rate gain of H.265/HEVC SCC with S3-SCC-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no RA.
- Table 7.4.2.2-2 provides the BD rate gain of H.265/HEVC SCC with S3-SCC-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences fixed Intra every second.

Table 7.4.2.2-1 BD rate gain of H.265/HEVC SCC with S3-SCC-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	18.9	16.5
S3-R02	MovingText2-4K-8bit	18.7	16.2
S3-R03	MovingText2-FullHD-10bit	10.0	8.6
S3-R04	MovingText2-FullHD-8bit	10.4	9.0
S3-R05	TextMixTransitions-4K-10bit	36.6	33.9
S3-R06	TextMixTransitions-4K-8bit	37.4	34.1
S3-R07	TextMixTransitions-FullHD-10bit	22.6	19.0
S3-R08	TextMixTransitions-FullHD-8bit	23.2	19.3
S3-R09	GraphicsMixSimple-4K-10bit	43.4	42.5
S3-R10	GraphicsMixSimple-4K-8bit	43.5	42.5
S3-R11	GraphicsMixSimple-FullHD-10bit	27.1	25.8
S3-R12	GraphicsMixSimple-FullHD-8bit	27.4	26.1
S3-R13	GraphicsMixTransitions-4K-10bit	14.6	13.5
S3-R14	GraphicsMixTransitions-4K-8bit	14.7	13.4
S3-R15	GraphicsMixTransitions-FullHD-10bit	7.3	5.7
S3-R16	GraphicsMixTransitions-FullHD-8bit	8.1	6.3
S3-R17	Mission-Control	32.7	32.8
Minimum		7.3	5.7
Maximum		43.5	42.5
Average		23.3	21.5

Table 7.4.2.2-2 BD rate gain of H.265/HEVC SCC with S3-SCC-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences fixed Intra every second

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	17.6	15.7
S3-R02	MovingText2-4K-8bit	17.5	15.5
S3-R03	MovingText2-FullHD-10bit	11.6	10.6
S3-R04	MovingText2-FullHD-8bit	11.8	10.6
S3-R05	TextMixTransitions-4K-10bit	45.8	43.9
S3-R06	TextMixTransitions-4K-8bit	46.1	43.9
S3-R07	TextMixTransitions-FullHD-10bit	31.4	28.4
S3-R08	TextMixTransitions-FullHD-8bit	31.4	28.5
S3-R09	GraphicsMixSimple-4K-10bit	47.6	47.0
S3-R10	GraphicsMixSimple-4K-8bit	47.5	46.6
S3-R11	GraphicsMixSimple-FullHD-10bit	31.5	30.3
S3-R12	GraphicsMixSimple-FullHD-8bit	31.5	30.1
S3-R13	GraphicsMixTransitions-4K-10bit	26.3	25.5
S3-R14	GraphicsMixTransitions-4K-8bit	26.3	25.1
S3-R15	GraphicsMixTransitions-FullHD-10bit	16.6	15.1
S3-R16	GraphicsMixTransitions-FullHD-8bit	17.0	15.2
S3-R17	Mission-Control	35.6	35.7
Minimum		11.6	10.6
Maximum		47.6	47.0
Average		29.0	27.5

As an example,

- Figure 7.4.2.2-1 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-03 against H.265/HEVC HM with configuration S3-HM-03 for reference sequences S3-R01 and S3-R17
- Figure 7.4.2.2-2 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-04 against H.265/HEVC HM with configuration S3-HM-04 for reference sequences S3-R01 and S3-R17

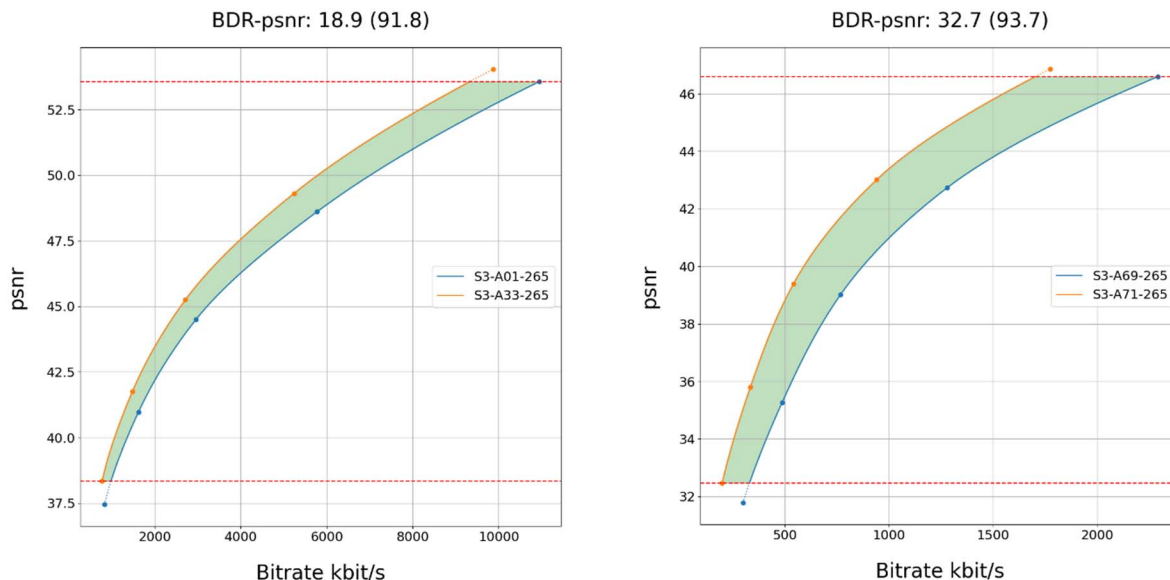


Figure 7.4.2.2-1 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-03 against H.265/HEVC HM with configuration S3-HM-03 for reference sequences S3-R01 and S3-R17

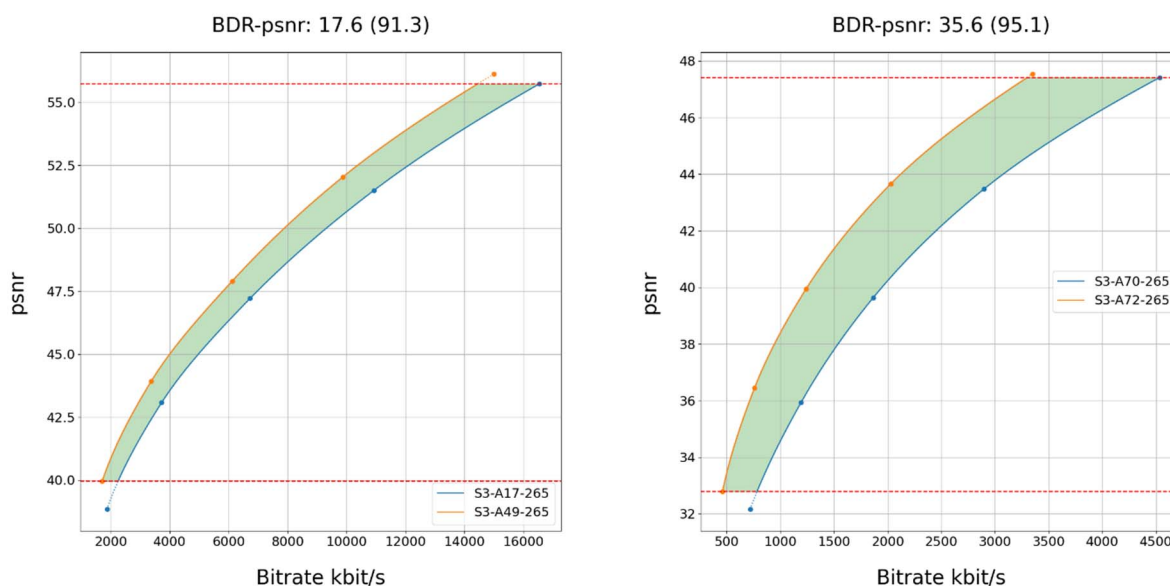


Figure 7.4.2.2-2 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S3-SCC-04 against H.265/HEVC HM with configuration S3-HM-04 for reference sequences S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/Characterization/>.

7.4.2.3 Scenario 5: Online Gaming

This clause provides characterization of H.265/HEVC SCC mode configurations against H.265/HEVC HM for Scenario 5 Online Gaming. In particular,

- Table 7.4.2.3-1 provides the BD rate gain of H.265/HEVC SCC with S5-SCC-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no RA.

- Table 7.4.2.3-2 provides the BD rate gain of H.265/HEVC SCC with S5-SCC-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences and fixed RA every second and fixed QP.

Table 7.4.2.3-1 BD rate gain of H.265/HEVC SCC with S5-SCC-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	0.2	-0.1
S5-R02	Baolei-Man	0.4	-0.1
S5-R03	Baolei-Woman	1.1	0.8
S5-R04	Baolei-Balloon	0.8	0.7
S5-R05	Baolei-Yard	0.2	0.1
S5-R06	Jianling-Temple	2.6	2.2
S5-R07	Jianling-Beach	4.1	3.1
S5-R08	Heroes-of-the-Storm	2.4	2.0
S5-R09	Project-CARS	3.1	2.2
S5-R10	World-of-WarCraft	1.8	0.8
S5-R11	MineCraft	16.4	12.3
S5-R12	CS-GO	8.6	6.4
S5-R13	StarCraft	3.8	2.2
Minimum		0.2	-0.1
Maximum		16.4	12.3
Average		3.5	2.5

Table 7.4.2.3-2 BD rate gain of H.265/HEVC SCC with S5-SCC-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences and fixed RA every second and fixed QP

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	1.1	0.8
S5-R02	Baolei-Man	1.4	1.0
S5-R03	Baolei-Woman	2.6	2.2
S5-R04	Baolei-Balloon	0.9	0.8
S5-R05	Baolei-Yard	0.2	0.1
S5-R06	Jianling-Temple	2.6	2.2
S5-R07	Jianling-Beach	6.8	5.7
S5-R08	Heroes-of-the-Storm	4.3	4.0
S5-R09	Project-CARS	3.9	2.9
S5-R10	World-of-WarCraft	5.5	4.9
S5-R11	MineCraft	17.1	13.9
S5-R12	CS-GO	11.4	9.1
S5-R13	StarCraft	6.5	5.1
Minimum		0.2	0.1
Maximum		17.1	13.9
Average		4.9	4.1

As an example,

- Figure 7.4.2.3-1 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequences S5-R04 and S5-R11
- Figure 7.4.2.3-2 provides Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11

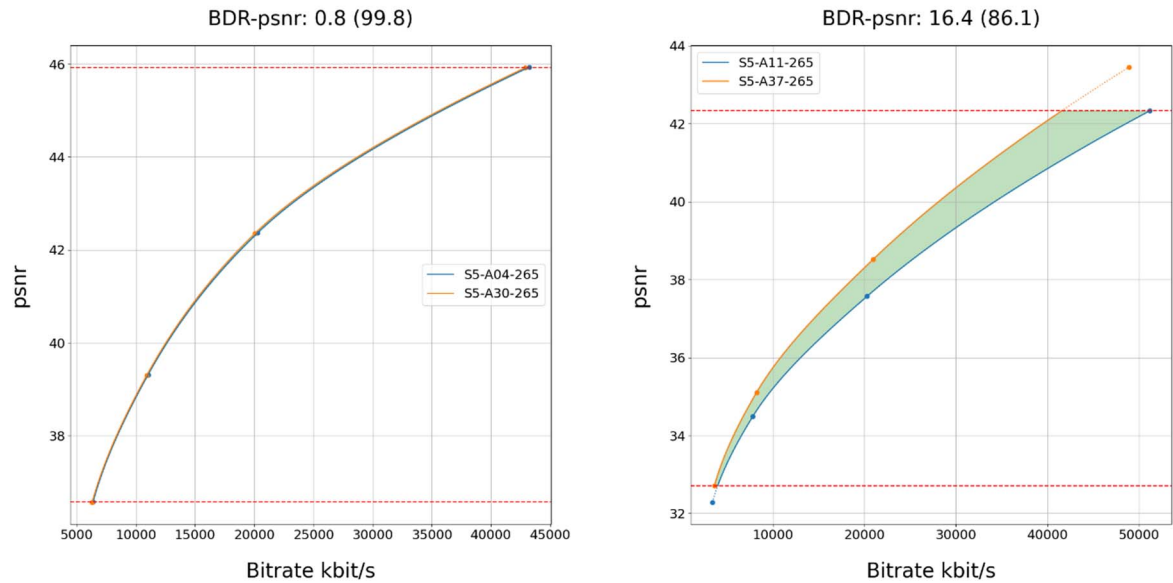


Figure 7.4.2.3-1 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequence s S5-R04 and S5-R11

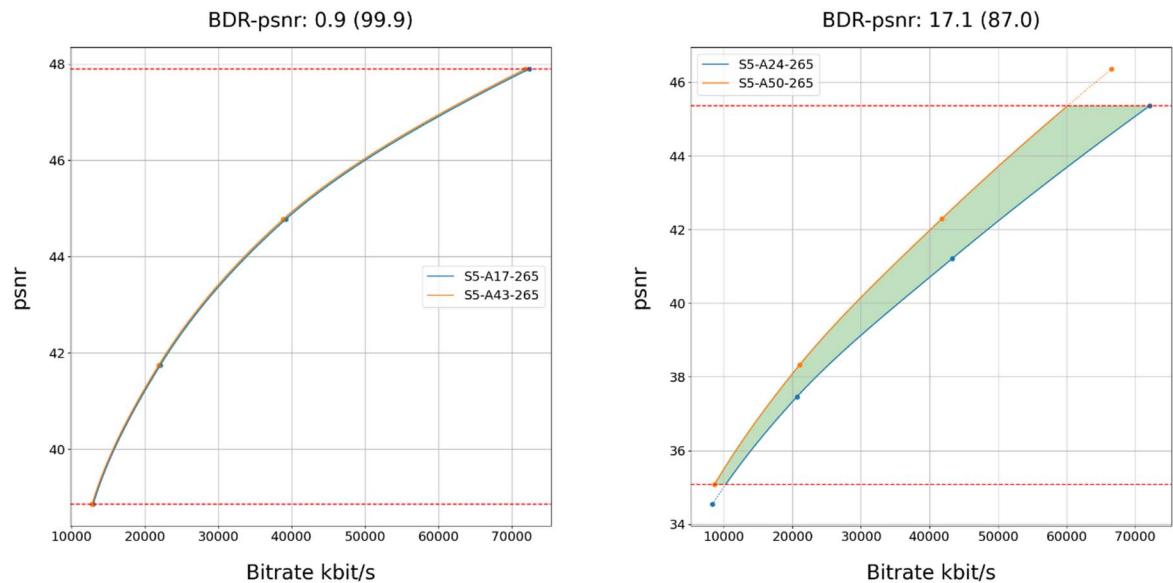


Figure 7.4.2.3-2 Rate-Quality curves and BD rate gain for psnr of H.265/HEVC SCC with S5-SCC-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/265/Characterization/>.

7.4.2.4 Summary

Table 7.4.2.4-1 provides a summary of BD rate gain in psnr of H.265/HEVC SCC against H.265/HEVC HM for different scenarios and configurations.

Table 7.4.2.4-1 Summary of BD rate gain in psnr of H.265/HEVC SCC against H.265/HEVC HM for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr
S3 no RA	23.3	7.3	43.5
S3 RA, fixed QP	29.0	11.6	47.6
S5 no RA	3.5	0.2	16.4
S5 RA, fixed QP	4.9	0.2	17.1
Minimum	3.5	0.2	16.4
Maximum	29.0	11.6	47.6

7.5 External Characterization Results

7.5.1 Introduction

This clause introduces external characterization results that have been conducted in a similar fashion as introduced in clause 5.8 but are not based on the metrics developed in this report.

7.5.2 H.265/HEVC Characterization against H.264/AVC.

In JCTVC-Q1011 [65] the JCTVC verification test reports that the HEVC standard achieves a substantial improvement in compression capability relative to its predecessor, the AVC standard, in accordance with the “HEVC verification test plan” in JCTVC-P1011 [65]. The precise performance results reported are a consequence of the specific configurations and software used.

The verification test was conducted for the HEVC Main profile and the AVC High profile using the HM12.1 (reference HEVC codec) and JM18.5 (reference AVC codec). Four picture resolutions UHD, 1080p, 720p and 480p were tested. Each resolution was represented by 5 test sequences, giving a total of 20 test sequences. For each test sequence 4 test points were chosen.

A bit depth of 8 bits for 480p, 720p and 1080p sequence and of 8 & 10 bits for 4K sequences was used. The coding structure was a combination of Random Access (RA) with an Intra refresh period at approximately 1 second intervals with picture reordering allowed and Low Delay (LD) with no intra refresh and no picture reordering.

A subjective evaluation was conducted comparing the same twenty test sequences.

Analysis of the subjective test results show that the HEVC bitstreams, generated at half or less than half the bit rate of the AVC reference bitstreams, were found to achieve comparable quality in 86% of the cases. This can be seen equivalently as the HEVC Main profile bitstreams requiring on average 59% fewer bits compared to the AVC reference bitstreams, to achieve the same subjective quality.

Figure 7.6.2-1 provides an overview of the results.

The bit rate savings are similar for the different resolutions tested, with higher resolution sequences having slightly more savings. The average bit rate savings for the test sequences with UHD, 1080p, 720p and 480p resolutions are estimated at approximately 64%, 62%, 56% and 52%, respectively.

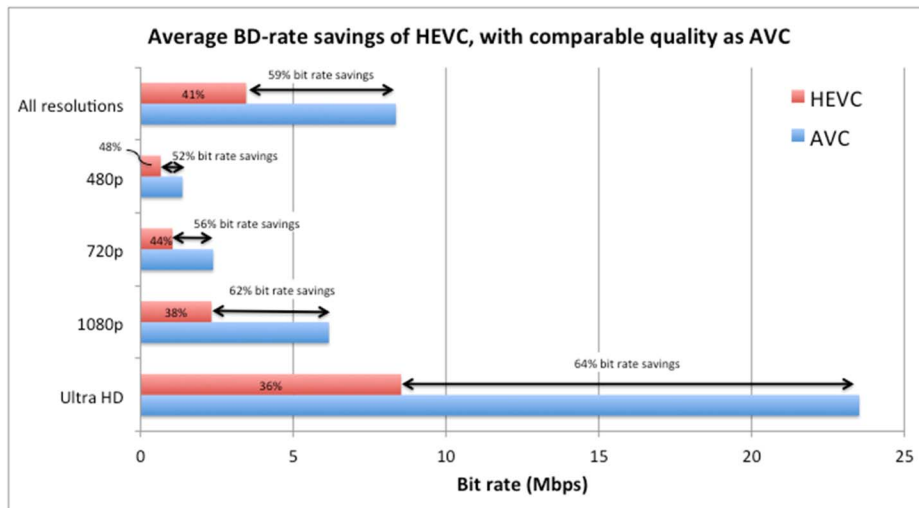


Figure 7.6.2-1: Average bit rate savings (measured by BD-Rate) of the conducted HEVC tests compared to corresponding AVC tests. The average of highest bit rate points over all sequences in each resolution was used in this illustration.

8 Initial Information on new Codecs

8.1 Introduction

This clause collects initial information on how new codecs under development in ISO/IEC SC29 WG 4/WG 5 (MPEG Video/JVET) - (in particular including VVC and EVC) and by the Alliance for Open Media (AV1), may meet the above criteria based on the characterization results provided, for example, by such organizations.

8.2 Versatile Video Coding (VVC)

8.2.1 Overview

ITU-T SG 16 informed that the development of the new Versatile Video Coding (VVC) standard has been completed for Consent at the June-July 2020 meeting of ITU-T SG16 and is also thereafter undergoing final approval in ISO/IEC JTC 1/SC 29/WG 11 (MPEG). After final approval, the dual reference to the jointly developed VVC standard will be Rec. ITU-T H.266 | ISO/IEC 23090-3 [38].

VVC is the latest in a series of such jointly developed ITU-T Recommendations and International Standards for video coding, and is the direct successor to HEVC (Rec. ITU-T H.265 | ISO/IEC 23008-2) [8] and AVC (Rec. ITU-T H.264 | ISO/IEC 14496-10) [7]. VVC provides significant coding efficiency improvements over HEVC. Plans are underway to conduct a verification test with formal subjective testing to confirm that VVC achieves about a 50% bit rate reduction vs. HEVC for equal subjective video quality. Test results demonstrate that VVC provides about a 40% bit rate reduction for 4K/UHD test sequences using objective metrics. Application areas especially targeted for the use of VVC include ultra-high definition 4K and 8K video, video with a high dynamic range and wide colour gamut, and video for immersive media applications such as 360° omnidirectional video, as well as conventional standard-definition and high-definition video content. In addition to improving coding efficiency, VVC also provides highly flexible syntax supporting such use cases as subpicture bitstream extraction, bitstream merging, and layered coding scalability.

The VVC standard includes the specification of a "Main 10" profile that supports 8- and 10-bit 4:2:0 video, a "Main 10 4:4:4" profile with 4:4:4 and 4:2:2 format support, corresponding "Multilayer Main 10" and "Multilayer Main 10 4:4:4" profiles with support for layered coding, and "Main 10 Still Picture" and "Main 10 4:4:4 Still Picture" profiles for still image coding employing the same coding tools as in the corresponding video profiles.

ITU-T also announced AAP Consent for Rec. ITU-T H.274 “Versatile supplemental enhancement information for coded video bitstreams” (VSEI), developed jointly as twin text with ISO/IEC JTC 1/SC 29/WG 11 as ISO/IEC 23002-7 [39]. VSEI specifies the syntax and semantics of video usability information (VUI) parameters and supplemental enhancement information (SEI) messages for use with coded video bitstreams. VSEI is particularly intended for use with VVC, although it is drafted in a manner intended to be sufficiently generic that it may also be used with other types of coded video bitstreams.

8.2.2 Test Configurations and Results for VTM

8.2.2.1 Introduction

This clause provides test setups, configurations and results for VVC.

The reference software for H.266/MPEG-I VVC is called VTM (VVC Test Model). The VTM software is maintained and can be downloaded from the repository: https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM.

The VVC implementation provided for the tests depends on the scenario and is documented individually for each scenario.

8.2.2.2 Scenario 1: Full HD Streaming

8.2.2.2.1 Overview

Table 8.2.2.2.1-1 provides an overview of the H.266/VVC test tuples. For provided bitstreams, reference H.266/VVC software implementation VTM available on the https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM branch, SHA 8159a6c72a770792b0bab4fee7445aa444821584 has been used. Utilized encoder configuration files are provided.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/streams.csv>.

Table 8.2.2.2.1-1 Test Tuple generation with H.266/VVC for FullHD Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S1-T01-VTM	8.2.2.2.3	S1-R1	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T01-VTM-<QP>
S1-T02-VTM	8.2.2.2.3	S1-R2	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T02-VTM-<QP>
S1-T03-VTM	8.2.2.2.3	S1-R3	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T03-VTM-<QP>
S1-T04-VTM	8.2.2.2.3	S1-R4	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T04-VTM-<QP>
S1-T05-VTM	8.2.2.2.3	S1-R5	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T05-VTM-<QP>
S1-T06-VTM	8.2.2.2.3	S1-R6	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T06-VTM-<QP>
S1-T07-VTM	8.2.2.2.3	S1-R7	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T07-VTM-<QP>
S1-T08-VTM	8.2.2.2.3	S1-R8	VTM	S1-VTM-01	QP: [22,27,32,37]	S1-T08-VTM-<QP>
S1-T11-VTM	8.2.2.2.4	S1-R11	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T11-VTM-<QP>
S1-T12-VTM	8.2.2.2.4	S1-R12	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T12-VTM-<QP>
S1-T13-VTM	8.2.2.2.4	S1-R13	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T13-VTM-<QP>
S1-T14-VTM	8.2.2.2.4	S1-R14	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T14-VTM-<QP>
S1-T15-VTM	8.2.2.2.4	S1-R15	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T15-VTM-<QP>
S1-T16-VTM	8.2.2.2.4	S1-R16	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T16-VTM-<QP>
S1-T17-VTM	8.2.2.2.4	S1-R17	VTM	S1-VTM-02	QP: [22,27,32,37]	S1-T17-VTM-<QP>

8.2.2.2.2 Common Parameters and Settings

To generate the VVC bitstreams, VTM is used:

The common parameters are as follows:

- Profile: main10 (Main 10 Profile)
- DecodingRefreshType: 1 (CRA)
- SearchRange: 384
- InternalBitDepth: 10

The following parameters need to be adapted for each sequence as follows using the JSON parameters of the reference sequence:

- IntraPeriod: Intra Period aligned with GOPSize such that approximately 1 second is achieved, i.e.
 - "frameRate": 23.98 or 24.0 or 25 or 30 => IntraPeriod set to 32,
 - "frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64
- LastValidFrame: Parameter value set to be equal to the number of coded frames minus 1.

The following parameters are variables and triggered through updates of the config-file.

- QP: [22,27,32,37]

8.2.2.2.3 SDR Settings: S1-VTM-01

The common parameters as defined in 8.2.2.2.2 apply.

In addition, the following parameters apply:

- VuiParametersPresent: 0 (VUI absent)
- SEIDecodedPictureHash: 0 (md5 checksum absent)

The complete settings (to be adapted for each sequence) are defined in the attached configuration file `s1-vtm-01.cfg`.

8.2.2.2.4 HDR PQ Settings: S1-VTM-02

The common parameters as defined in 8.2.2.2.2 apply.

In addition, the following parameters apply:

- VuiParametersPresent: 1 (VUI present)
- SEIDecodedPictureHash: 0 (md5 checksum absent)

The complete settings are defined in the attached configuration file `s1-vtm-02.cfg`.

8.2.2.2.5 Test Results

VVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/>

VVC test metrics are provided with the appropriate keys as defined in Table 8.2.2.2.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/cross-check.csv>.

Based on these cross-check results, the verification status for the VVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/verification.csv> and Table 8.2.2.2.5-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.2.2.2.5-1 Verification status of VVC test streams for FullHD Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S1-T01-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T02-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T03-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T04-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T05-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T06-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T07-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T08-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T11-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T12-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T13-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T14-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T15-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T16-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T17-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.2.2.3 Scenario 2: 4K-TV

8.2.2.3.1 Overview

Table 8.2.2.3.1-1 provides an overview of the H.266/VVC test tuples. For provided bitstreams, reference H.266/VVC software implementation VTM available on the https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM branch, SHA 8159a6c72a770792b0bab4fee7445aa444821584 has been used. Utilized encoder configuration files are provided.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/VTM/streams.csv>.

Table 8.2.2.3.1-1 Anchor Tuple generation with H.266/VVC for 4K-TV Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S2-T01-VTM	8.2.2.3.3	S2-R1	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T01-VTM-<QP>
S2-T02-VTM	8.2.2.3.3	S2-R2	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T02-VTM-<QP>
S2-T03-VTM	8.2.2.3.3	S2-R3	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T03-VTM-<QP>
S2-T04-VTM	8.2.2.3.3	S2-R4	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T04-VTM-<QP>
S2-T05-VTM	8.2.2.3.3	S2-R5	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T05-VTM-<QP>
S2-T06-VTM	8.2.2.3.3	S2-R6	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T06-VTM-<QP>
S2-T07-VTM	8.2.2.3.3	S2-R7	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T07-VTM-<QP>
S2-T08-VTM	8.2.2.3.3	S2-R8	VTM	S2-VTM-01	QP: [22,27,32,37]	S2-T08-VTM-<QP>
S2-T11-VTM	8.2.2.3.4	S2-R11	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T11-VTM-<QP>
S2-T12-VTM	8.2.2.3.4	S2-R12	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T12-VTM-<QP>
S2-T13-VTM	8.2.2.3.4	S2-R13	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T13-VTM-<QP>
S2-T14-VTM	8.2.2.3.4	S2-R14	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T14-VTM-<QP>
S2-T15-VTM	8.2.2.3.4	S2-R15	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T15-VTM-<QP>
S2-T16-VTM	8.2.2.3.4	S2-R16	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T16-VTM-<QP>
S2-T17-VTM	8.2.2.3.4	S2-R17	VTM	S2-VTM-02	QP: [22,27,32,37]	S2-T17-VTM-<QP>

8.2.2.3.2 Common Parameters and Settings

To generate the VVC bitstreams, VTM is used:

The common parameters are as follows:

- Profile: main10 (Main 10 Profile)
- DecodingRefreshType: 1 (CRA)
- SearchRange: 384
- InternalBitDepth: 10

The following parameters need to be adapted for each sequence as follows using the JSON parameters of the reference sequence:

- IntraPeriod: Intra Period aligned with GOPSize such that approximately 1 second is achieved, i.e.
- "frameRate": 23.98 or 24.0 or 25 or 30 => IntraPeriod set to 32,
- "frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64
- LastValidFrame: Parameter value set to be equal to the number of coded frames minus 1.

The following parameters are variables and triggered through updates of the config-file.

- QP: [22,27,32,37]

8.2.2.3.3 SDR Settings: S2-VTM-01

The common parameters as defined in 8.2.2.3.2 apply.

In addition, the following parameters apply:

- VuiParametersPresent: 0 (VUI absent)
- SEIDecodedPictureHash: 0 (md5 checksum absent)

The complete settings (to be adapted for each sequence) are defined in the attached configuration file `s2-vtm-01.cfg`.

8.2.2.3.4 HDR PQ Settings: S2-VTM-02

The common parameters as defined in 8.2.2.3.2 apply.

In addition, the following parameters apply:

- VuiParametersPresent: 1 (VUI present)
- SEIDecodedPictureHash: 0 (md5 checksum absent)

The complete settings are defined in the attached configuration file `s2-vtm-02.cfg`.

8.2.2.3.5 Test Results

VVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4k/VTM/>

VVC test metrics are provided with the appropriate keys as defined in Table 8.2.2.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4k/VTM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/VTM/cross-check.csv>.

Based on these cross-check results, the verification status for the VVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/VTM/verification.csv> and Table 8.2.2.3.5-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.2.2.3.5-1 Verification status of VVC test streams for 4K TV Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S2-T01-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T02-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T03-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T04-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T05-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T06-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T07-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T08-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T11-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T12-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T13-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T14-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T15-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T16-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T17-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.2.2.4 Scenario 3: Screen Content Scenario

8.2.2.4.1 Overview

Table 8.2.2.4.1-1 provides an overview of the H.266/VVC test tuples. For provided bitstreams, reference H.266/VVC software implementation VTM available on the https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM branch, SHA 8159a6c72a770792b0bab4fee7445aa444821584 has been used. Utilized encoder configuration files are provided.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/streams.csv>.

Table 8.2.2.4.1-1 Test Tuple generation with H.266/VVC for Screen Content Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S3-T01-VTM	8.2.2.4.2.2	S3-R01	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T01-VTM-<QP>
S3-T02-VTM	8.2.2.4.2.2	S3-R02	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T02-VTM-<QP>
S3-T03-VTM	8.2.2.4.2.2	S3-R03	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T03-VTM-<QP>
S3-T04-VTM	8.2.2.4.2.2	S3-R04	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T04-VTM-<QP>
S3-T05-VTM	8.2.2.4.2.2	S3-R05	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T05-VTM-<QP>
S3-T06-VTM	8.2.2.4.2.2	S3-R06	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T06-VTM-<QP>
S3-T07-VTM	8.2.2.4.2.2	S3-R07	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T07-VTM-<QP>
S3-T08-VTM	8.2.2.4.2.2	S3-R08	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T08-VTM-<QP>
S3-T09-VTM	8.2.2.4.2.2	S3-R09	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T09-VTM-<QP>
S3-T10-VTM	8.2.2.4.2.2	S3-R10	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T10-VTM-<QP>
S3-T11-VTM	8.2.2.4.2.2	S3-R11	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T11-VTM-<QP>
S3-T12-VTM	8.2.2.4.2.2	S3-R12	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T12-VTM-<QP>
S3-T13-VTM	8.2.2.4.2.2	S3-R13	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T13-VTM-<QP>
S3-T14-VTM	8.2.2.4.2.2	S3-R14	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T14-VTM-<QP>
S3-T15-VTM	8.2.2.4.2.2	S3-R15	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T15-VTM-<QP>
S3-T16-VTM	8.2.2.4.2.2	S3-R16	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T16-VTM-<QP>
S3-T17-VTM	8.2.2.4.2.3	S3-R01	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T17-VTM-<QP>
S3-T18-VTM	8.2.2.4.2.3	S3-R02	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T18-VTM-<QP>
S3-T19-VTM	8.2.2.4.2.3	S3-R03	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T19-VTM-<QP>
S3-T20-VTM	8.2.2.4.2.3	S3-R04	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T20-VTM-<QP>
S3-T21-VTM	8.2.2.4.2.3	S3-R05	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T21-VTM-<QP>
S3-T22-VTM	8.2.2.4.2.3	S3-R06	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T22-VTM-<QP>
S3-T23-VTM	8.2.2.4.2.3	S3-R07	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T23-VTM-<QP>
S3-T24-VTM	8.2.2.4.2.3	S3-R08	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T24-VTM-<QP>
S3-T25-VTM	8.2.2.4.2.3	S3-R09	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T25-VTM-<QP>
S3-T26-VTM	8.2.2.4.2.3	S3-R10	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T26-VTM-<QP>
S3-T27-VTM	8.2.2.4.2.3	S3-R11	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T27-VTM-<QP>
S3-T28-VTM	8.2.2.4.2.3	S3-R12	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T28-VTM-<QP>
S3-T29-VTM	8.2.2.4.2.3	S3-R13	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T29-VTM-<QP>
S3-T30-VTM	8.2.2.4.2.3	S3-R14	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T30-VTM-<QP>
S3-T31-VTM	8.2.2.4.2.3	S3-R15	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T31-VTM-<QP>
S3-T32-VTM	8.2.2.4.2.3	S3-R16	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T32-VTM-<QP>
S3-T33-VTM	8.2.2.4.2.2	S3-R17	VTM	S3-VTM-03	QP=[22, 27, 32, 37, 42]	S3-T33-VTM-<QP>
S3-T34-VTM	8.2.2.4.2.3	S3-R17	VTM	S3-VTM-04	QP=[22, 27, 32, 37, 42]	S3-T34-VTM-<QP>
S3-T35-VTM	8.2.2.4.2.3	S3-R17	VTM	S3-VTM-01	QP=[22, 27, 32, 37, 42]	S3-T35-VTM-<QP>
S3-T36-VTM	8.2.2.4.2.3	S3-R17	VTM	S3-VTM-02	QP=[22, 27, 32, 37, 42]	S3-T36-VTM-<QP>

8.2.2.4.2 Test Model and Configurations

8.2.2.4.2.1 Common Parameters

To generate the anchor bitstreams, the following is applied:

- VTM Main 10 in low delay P configuration is used with screen content tools enabled. In addition, to enable screen content tools, the following settings are set to 1: IBC, HashME, BDPCM.
- `InternalBitDepth` is 10 # codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits.
- Each source sequence is encoded with the following parameters: QP: [22, 27, 32, 37, 42]
- `SEIDecodedPictureHash`=1
- `CIIP`=0

As the `SEIDecodedPictureHash` is set to 1, the effective file size (EFS) needs to take into account the removal of this SEI message when computing the bitrate metric as defined in clause 5.5.2. For all teststreams, a modified bitstream is provided with ‘*.bis’ suffix, for which the SEI removal is applied. This file is used for bitrate computation.

8.2.2.4.2.2 S3-VTM-01/03: Main 10 Profile with no fixed Intra

Each source sequence is encoded with the following configurations:

- The common parameters defined in clause 8.2.2.4.2.1.

- IntraPeriod with no fix interval
- GOPSize is equal to 8. Each P picture refers to up to 4 preceding pictures in display order within the GOP

The detailed settings are defined in the attached configuration file `s3-vtm-01/03.cfg`.

8.2.2.4.2.3 S3-VTM-02/04: Main 10 Profile with fixed Intra every second

Each source sequence is encoded with the following configurations:

- The common parameters defined in clause 8.2.2.4.2.1.
- IntraPeriod such that 1 second is achieved
- DecodingRefreshType: (2) IDR
- IntraQPoffset and QPoffsets are set equal to 0
- Each P picture refers to immediately preceding pictures in display order.

The detailed settings are defined in the attached configuration file `s3-vtm-02/04.cfg`.

8.2.2.4.3 Test Results

VVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/>

VVC test metrics are provided with the appropriate keys as defined in Table 8.2.2.4.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/cross-check.csv>.

Based on these cross-check results, the verification status for the VVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/verification.csv> and Table 8.2.2.4.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.2.2.4.3-1 Verification status of VVC test streams for Screen Content Scenario

Anchor + Key Verification Type	Summary			22			27			32			37			42		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S3-T01-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T02-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T03-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T04-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T05-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T06-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T07-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T08-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T09-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T10-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T11-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T12-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T13-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T14-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T15-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T16-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T17-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T18-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T19-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T20-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T21-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T22-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T23-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T24-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T25-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T26-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T27-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T28-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T29-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T30-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T31-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T32-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T33-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T34-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T35-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S3-T36-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.2.2.5 Scenario 4: Messaging and Social Sharing

8.2.2.5.1 Overview

Table 8.2.2.5.1-1 provides an overview of the H.266/VVC test tuples. For provided bitstreams, reference H.266/VVC software implementation VTM available on the https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM branch, SHA 8159a6c72a770792b0bab4fee7445aa444821584 has been used. Utilized encoder configuration files are provided.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/VTM/streams.csv>.

Table 8.2.2.5.1-1 Test Tuple generation with H.266/VVC for messaging and social sharing scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S4-T01-VTM	8.2.2.5.2.2	S4-R01	VTM	S4-VTM-01	QP=[22, 27, 32, 37]	S4-T01-VTM-<QP>
S4-T02-VTM	8.2.2.5.2.2	S4-R02	VTM	S4-VTM-01	QP=[22, 27, 32, 37]	S4-T02-VTM-<QP>
S4-T03-VTM	8.2.2.5.2.2	S4-R03	VTM	S4-VTM-01	QP=[22, 27, 32, 37]	S4-T03-VTM-<QP>
S4-T04-VTM	8.2.2.5.2.2	S4-R04	VTM	S4-VTM-01	QP=[22, 27, 32, 37]	S4-T04-VTM-<QP>
S5-T05-VTM	8.2.2.5.2.2	S4-R01	VTM	S4-VTM-02	QP=[22, 27, 32, 37]	S4-T05-VTM-<QP>
S5-T06-VTM	8.2.2.5.2.2	S4-R02	VTM	S4-VTM-02	QP=[22, 27, 32, 37]	S4-T06-VTM-<QP>
S5-T07-VTM	8.2.2.5.2.2	S4-R03	VTM	S4-VTM-02	QP=[22, 27, 32, 37]	S4-T07-VTM-<QP>
S5-T08-VTM	8.2.2.5.2.2	S4-R04	VTM	S4-VTM-02	QP=[22, 27, 32, 37]	S4-T08-VTM-<QP>

8.2.2.5.2 Test Model and Configurations

8.2.2.5.2.1 Common Parameters

To generate the anchor bitstreams, the following is applied:

- VTM Main 10 in low delay B configuration is used with screen content tools enabled. In addition, to enable screen content tools, the following settings are set to 1: IBC, HashME, BDPCM.
- `InternalBitDepth` is 10 # codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits.
- Each source sequence is encoded with the following parameters: QP: [22, 27, 32, 37]

8.2.2.5.2.2 S5-VTM-01: Main 10 Profile with no fixed Intra

Each source sequence is encoded with the following configurations:

- The common parameters defined in clause 8.2.2.5.2.1.
- `IntraPeriod` with no fix interval
- `GOPSize` is equal to 8. Each B picture refers to up to 4 preceding pictures in display order within the GOP

The detailed settings are defined in the attached configuration file `s4-vtm-01.cfg`.

8.2.2.5.2.3 S5-VTM-02: Main 10 Profile with fixed Intra every second

Each source sequence is encoded with the following configurations:

- The common parameters defined in clause 8.2.2.5.2.1.
- `IntraPeriod` such that 1 second is achieved
- `DecodingRefreshType`: (2) IDR
- `IntraQPoffset` and `QPoffsets` are set equal to 0
- Each B picture refers to immediately preceding pictures in display order.

The detailed settings are defined in the attached configuration file `s4-vtm-02.cfg`.

8.2.2.5.3 Test Results

VVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Social/VTM/>

VVC test metrics are provided with the appropriate keys as defined in Table 8.2.2.5.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Social/VTM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/VTM/cross-check.csv>.

Based on these cross-check results, the verification status for the VVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/VTM/verification.csv> and Table 8.2.2.3.5-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.2.2.5.3-1 Verification status of VVC test streams for Sharing Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S4-T01-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T02-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T03-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T04-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T05-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T06-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T07-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S4-T08-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.2.2.6 Scenario 5: Online Gaming

8.2.2.6.1 Overview

Table 8.2.2.6.1-1 provides an overview of the H.266/VVC test tuples. For provided bitstreams, reference H.266/VVC software implementation VTM available on the https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM branch, SHA 8159a6c72a770792b0bab4fee7445aa444821584 has been used. Utilized encoder configuration files are provided.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/streams.csv>.

Table 8.2.2.6.1-1 Test Tuple generation with H.266/VVC for Online Gaming Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S5-T01-VTM	8.2.2.6.2.2	S5-R01	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T01-VTM-<QP>
S5-T02-VTM	8.2.2.6.2.2	S5-R02	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T02-VTM-<QP>
S5-T03-VTM	8.2.2.6.2.2	S5-R03	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T03-VTM-<QP>
S5-T04-VTM	8.2.2.6.2.2	S5-R04	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T04-VTM-<QP>
S5-T05-VTM	8.2.2.6.2.2	S5-R05	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T05-VTM-<QP>
S5-T06-VTM	8.2.2.6.2.2	S5-R06	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T06-VTM-<QP>
S5-T07-VTM	8.2.2.6.2.2	S5-R07	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T07-VTM-<QP>
S5-T08-VTM	8.2.2.6.2.2	S5-R08	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T08-VTM-<QP>
S5-T09-VTM	8.2.2.6.2.2	S5-R09	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T09-VTM-<QP>
S5-T10-VTM	8.2.2.6.2.2	S5-R10	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T10-VTM-<QP>
S5-T11-VTM	8.2.2.6.2.2	S5-R11	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T11-VTM-<QP>
S5-T12-VTM	8.2.2.6.2.2	S5-R12	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T12-VTM-<QP>
S5-T13-VTM	8.2.2.6.2.2	S5-R13	VTM	S5-VTM-01	QP=[22, 27, 32, 37]	S5-T13-VTM-<QP>
S5-T14-VTM	8.2.2.6.2.3	S5-R01	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T14-VTM-<QP>
S5-T15-VTM	8.2.2.6.2.3	S5-R02	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T15-VTM-<QP>
S5-T16-VTM	8.2.2.6.2.3	S5-R03	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T16-VTM-<QP>
S5-T17-VTM	8.2.2.6.2.3	S5-R04	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T17-VTM-<QP>
S5-T18-VTM	8.2.2.6.2.3	S5-R05	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T18-VTM-<QP>
S5-T19-VTM	8.2.2.6.2.3	S5-R06	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T19-VTM-<QP>
S5-T20-VTM	8.2.2.6.2.3	S5-R07	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T20-VTM-<QP>
S5-T21-VTM	8.2.2.6.2.3	S5-R08	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T21-VTM-<QP>
S5-T22-VTM	8.2.2.6.2.3	S5-R09	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T22-VTM-<QP>
S5-T23-VTM	8.2.2.6.2.3	S5-R10	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T23-VTM-<QP>
S5-T24-VTM	8.2.2.6.2.3	S5-R11	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T24-VTM-<QP>
S5-T25-VTM	8.2.2.6.2.3	S5-R12	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T25-VTM-<QP>
S5-T26-VTM	8.2.2.6.2.3	S5-R13	VTM	S5-VTM-02	QP=[22, 27, 32, 37]	S5-T26-VTM-<QP>

8.2.2.6.2 Test Model and Configurations

8.2.2.6.2.1 Common Parameters

To generate the anchor bitstreams, the following is applied:

- VTM Main 10 in low delay B configuration is used with screen content tools enabled. In addition, to enable screen content tools, the following settings are set to 1: IBC, HashME, BDPCM.
- `InternalBitDepth` is 10 # codec operating bit-depth where all sequences (including 8 bit sequences) are coded with an internal bitdepth of 10 in accordance with [44] and metrics are calculated in 10 bits.
- Each source sequence is encoded with the following parameters: QP: [22, 27, 32, 37]
- `SEIDecodedPictureHash`=1

As the `SEIDecodedPictureHash` is set to 1, the effective file size (EFS) needs to take into account the removal of this SEI message when computing the bitrate metric as defined in clause 5.5.2. For all teststreams, a modified bitstream is provided with ‘*.bis’ suffix, for which the SEI removal is applied. This file is used for bitrate computation.

8.2.2.6.2.2 S5-VTM-01: Main 10 Profile with no fixed Intra

Each source sequence is encoded with the following configurations:

- The common parameters defined in clause 8.2.2.6.2.1.
- `IntraPeriod` with no fix interval
- `GOPSize` is equal to 8. Each B picture refers to up to 4 preceding pictures in display order within the GOP

The detailed settings are defined in the attached configuration file `s5-vtm-01.cfg`.

8.2.2.6.2.3 S5-VTM-02: Main 10 Profile with fixed Intra every second

Each source sequence is encoded with the following configurations:

- The common parameters defined in clause 8.2.2.6.2.1.
- `IntraPeriod` such that 1 second is achieved
- `DecodingRefreshType`: (2) IDR
- `IntraQPOffset` and `QPoffsets` are set equal to 0
- Each B picture refers to immediately preceding pictures in display order.

The detailed settings are defined in the attached configuration file `s5-vtm-02.cfg`.

8.2.2.6.3 Test Results

VVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/>

VVC test metrics are provided with the appropriate keys as defined in Table 8.2.2.6.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/cross-check.csv>.

Based on these cross-check results, the verification status for the VVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/verification.csv> and Table 8.2.2.6.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.2.2.6.3-1 Verification status of VVC test streams for Gaming Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S5-T01-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T02-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T03-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T04-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T05-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T06-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T07-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T08-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T09-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T10-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T11-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T12-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T13-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T14-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T15-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T16-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T17-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T18-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T19-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T20-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T21-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T22-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T23-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T24-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T25-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-T26-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.2.3 H.266/VVC Characterization against H.264/AVC

8.2.3.1 Overview

This clause provides information related to the characterization of H.266/VVC VTM against H.264/AVC JM according to clause 7.2.1. The results provided in clauses 6 and 8.2.2 are considered for the characterization.

Analysis of the PSNR ranges provided in the clause 6 for H.264/AVC and in sub-clauses 8.2.2 of the H.266/VVC shows that their rate distortion curves exhibit an average overlap of 61% across scenarios. As a consequence, the aggregation of results for all rate points for all sequences in each scenario is not substantial enough and do not provide an accurate representation for codec characterisation. BD rate gain are not reported in this clause.

A way to obtain a substantial overlap for accurate estimation of BD rate gain estimates would be to adjust QP values of AVC for better alignments with the ones of HEVC and VVC.

8.2.3.2 Scenario 1: Full HD

This clause provides information related to the characterization of H.266/VVC VTM mode configurations against H.264/AVC JM for Scenario 1 Full HD.

For this scenario, the PSNR ranges of the curves between H.266/VVC and H.264/AVC overlaps at an average of 59% and can be as low as 29%. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/Characterization/>.

8.2.3.3 Scenario 3: Screen Content

This clause provides information related to the characterization of H.266/VVC VTM mode configurations against H.264/AVC JM for Scenario 3 Screen Content.

For this scenario, the PSNR ranges of the curves between H.266/VVC and H.264/AVC overlaps at an average of 43% and can be as low as 33 % in the non-RA configuration and an average of 42 % and can be as low as 24% in the RA configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/Characterization/>.

8.2.3.4 Scenario 4: Messaging and Social Sharing

This clause provides information related to the characterization of H.266/VVC VTM mode configurations against H.264/AVC for Scenario 4 Messaging and Social Sharing.

For this scenario, the PSNR ranges of the curve between H.266/VVC and H.264/AVC in no overlaps at an average of 69% and can be as low as 48% in the non-RA configuration and an average of 76% and can be as low as 55% in the RA configuration.

Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/VTM/Characterization/>.

8.2.3.5 Scenario 5: Online Gaming

This clause provides information related to the characterization of H.266/VVC VTM mode configurations against H.264/AVC JM for Scenario 5 Online Gaming.

For this scenario, the PSNR ranges of the curves between H.266/VVC and H.264/AVC overlaps at an average of 67% and can be as low as 54% in the non-RA configuration and an average of 71% and can be as low as 61% in the RA configuration.

Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming//VTM/Characterization/>.

8.2.3.6 Summary

No characterization results are provided due to the lack of substantial overlap of H.264/AVC and H.266/VVC characterization results.

8.2.4 H.266/VVC Characterization against H.265/HEVC HM

8.2.4.1 Overview

This clause provides a full characterization of H.266/VVC VTM against H.265/HEVC HM according to clause 7.2.1. The results provided in clauses 6 and 8.2.2 are used for the characterization.

8.2.4.2 Scenario 1: Full HD

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC HM for Scenario 1 Full HD. In particular,

- Table 8.2.4.2-1 provides the BD rate gain of H.266/VVC VTM with S1-VTM-01 against H.265/HEVC HM with configuration S1-HM-01, i.e. with the Full HD SDR scenario reference sequences
- Table 8.2.4.2-2 provides the BD rate gain of H.266/VVC VTM with S1-VTM-02 against H.265/HEVC HM with configuration S1-HM-02, i.e. with the Full HD HDR scenario reference sequences

Table 8.2.4.2-1 BD rate gain of H.266/VVC VTM with S1-VTM-01 against H.265/HEVC HM with configuration S1-HM-01, i.e. with the Full HD SDR scenario reference sequences

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S1-R01	Brest-Sedof-FHD	37.4	33.4	43.8	30.6
S1-R02	Rain Fruits-FHD	35.4	30.6	39.8	33.9
S1-R03	Park Joy-FHD	26.3	24.4	30.8	28.9
S1-R04	Soccer-FHD	37.9	37.0	37.1	36.5
S1-R05	Tunnel Flag-FHD	53.9	49.1	52.7	51.8
S1-R06	Boat-FHD	32.7	25.2	30.0	27.1
S1-R07	Fountain-FHD	22.9	21.1	20.9	18.7
S1-R08	Riverbank-FHD	39.8	26.2	29.5	28.9
Minimum		22.9	21.1	20.9	18.7
Maximum		53.9	49.1	52.7	51.8
Average		35.8	30.8	35.6	32.0

Table 8.2.4.2-2 BD rate gain of H.266/VVC VTM with S1-VTM-02 against H.265/HEVC HM with configuration S1-HM-02, i.e. with the Full HD HDR scenario reference sequences

Reference sequence	Name	wpsnr	y_wpsnr	psnr100	de100
S1-R11	Life-Untouched-FHD	38.5	33.1	35.7	59.5
S1-R12	Meridian-FHD	36.1	29.8	31.0	51.2
S1-R13	Sol-Levante-FHD	41.9	32.7	38.6	59.1
S1-R14	Cosmos-FHD	36.6	23.7	30.4	65.7
S1-R15	Elevator-FHD	46.8	41.3	41.6	61.3
S1-R16	Sparks-FHD	40.5	31.5	29.6	57.4
S1-R17	Nocturne-FHD	40.3	34.8	35.9	52.7
Minimum		36.1	23.7	29.6	51.2
Maximum		46.2	40.8	41.6	65.7
Average		39.5	31.8	34.7	58.1

As an example, Figure 8.2.4.2-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S1-VTM-01 against H.265/HEVC HM with configuration S1-HM-01 for reference sequence S1-R01.

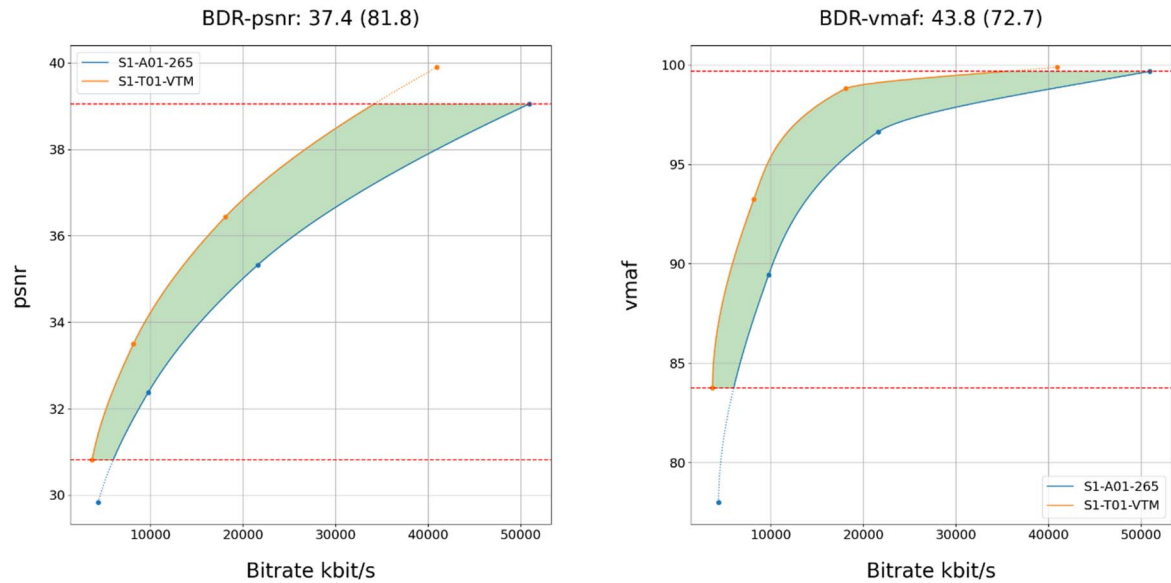


Figure 8.2.4.2-1 Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S1-VTM-01 against H.265/HEVC HM with configuration S1-HM-01 for reference sequence S1-R01

As another example, Figure 8.2.4.2-2 provides Rate-Quality curves and BD rate gain for wpsnr and de100 of H.266/VVC VTM with S1-VTM-02 against H.265/HEVC HM with configuration S1-HM-02 for reference sequence S1-R11.

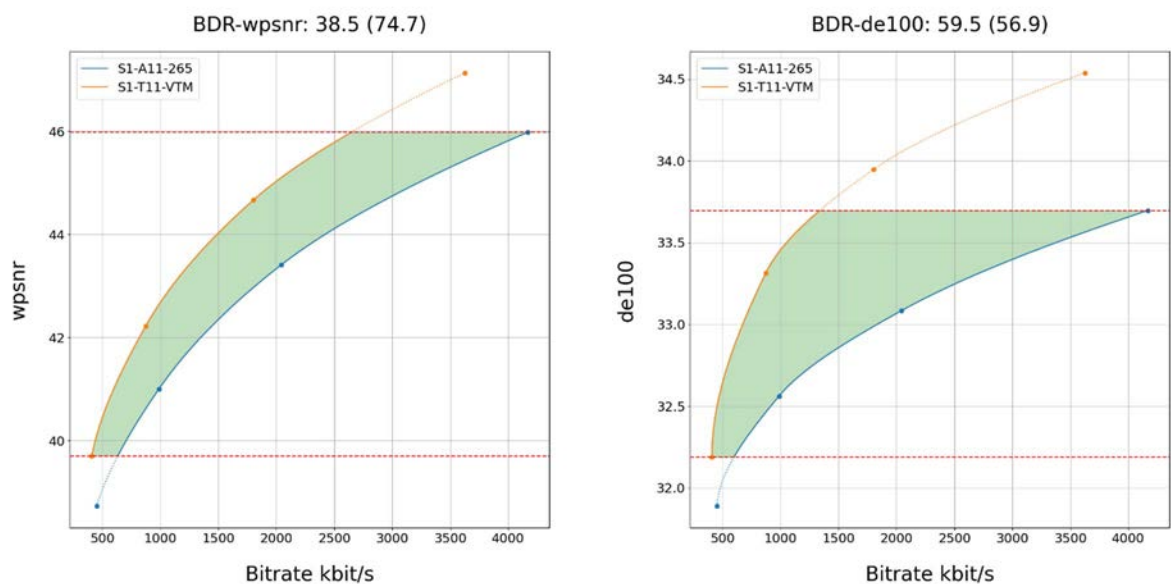


Figure 8.2.4.2-2 Rate-Quality curves and BD rate gain for wpsnr and de100 of H.266/VVC VTM with S1-VTM-02 against H.265/HEVC HM with configuration S1-HM-02 for reference sequence S1-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/Characterization/>.

8.2.4.3 Scenario 2: 4K TV

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC HM for Scenario 2 4K TV. In particular,

- Table 8.2.4.3-1 provides the BD rate gain of H.266/VVC VTM with S2-VTM-01 against H.265/HEVC HM with configuration S2-HM-01, i.e. with the 4K TV SDR scenario reference sequences
- Table 8.2.4.3-2 provides the BD rate gain of H.266/VVC VTM with S2-VTM-02 against H.265/HEVC HM with configuration S2-HM-02, i.e. with the 4K TV HDR scenario reference sequences

Table 8.2.4.3-1 BD rate gain of H.266/VVC VTM with S2-VTM-01 against H.265/HEVC HM with configuration S2-HM-01, i.e. with the 4K TV SDR scenario reference sequences

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S2-R01	Brest-Sedof	38.9	33.8	45.2	31.5
S2-R02	Rain Fruits	38.7	33.2	41.3	34.6
S2-R03	Park Joy	29.7	28.3	33.5	29.3
S2-R04	Soccer	38.6	39.8	39.8	38.3
S2-R05	Tunnel Flag	52.3	48.7	53.2	52.9
S2-R06	Boat	34.9	29.4	36.1	29.4
S2-R07	Fountain	23.1	22.1	23.7	19.9
S2-R08	Riverbank	37.7	27.2	31.2	27.0
Minimum		23.1	22.1	23.7	19.9
Maximum		52.3	48.7	53.2	52.9
Average		36.7	32.8	38.0	32.9

Table 8.2.4.3-2 BD rate gain of H.266/VVC VTM with S2-VTM-02 against H.265/HEVC HM with configuration S2-HM-02, i.e. with the 4K TV HDR scenario reference sequences

Reference sequence	Name	wpsnr	y_wpsnr	psnr100	de100
S2-R11	Life-Untouched	37.5	33.9	36.9	56.6
S2-R12	Meridian	32.8	29.6	29.3	42.6
S2-R13	Sol-Levante	45.6	37.3	42.9	62.1
S2-R14	Cosmos	35.2	25.4	30.1	62.7
S2-R15	Elevator	45.7	40.8	42.0	61.5
S2-R16	Sparks	39.7	32.3	31.6	61.7
S2-R17	Nocturne	37.0	33.6	34.9	47.5
Minimum		32.8	25.4	29.3	42.2
Maximum		45.7	40.8	42.9	62.7
Average		39.1	33.3	35.4	56.4

As an example, Figure 8.2.4.3-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S2-VTM-01 against H.265/HEVC HM with configuration S2-HM-01 for reference sequence S2-R01.

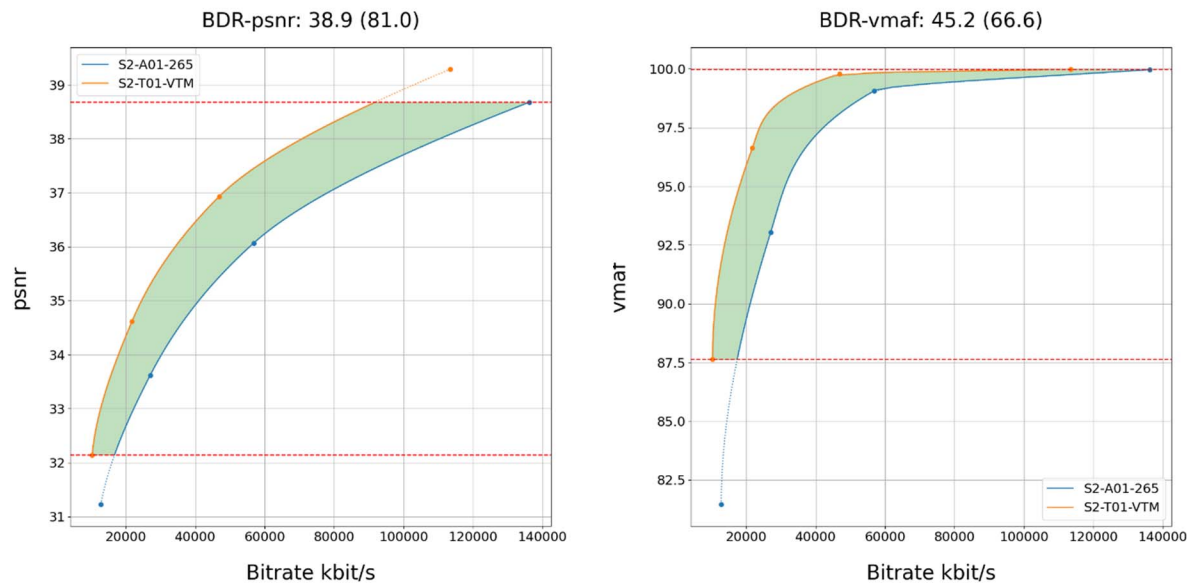


Figure 8.2.4.3-1 Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S2-VTM-01 against H.265/HEVC HM with configuration S2-HM-01 for reference sequence S2-R01

As another example, Figure 8.2.4.3-2 provides Rate-Quality curves and BD rate gain for wpsnr and de100 of H.266/VVC VTM with S2-VTM-02 against H.265/HEVC HM with configuration S2-HM-02 for reference sequence S2-R11.

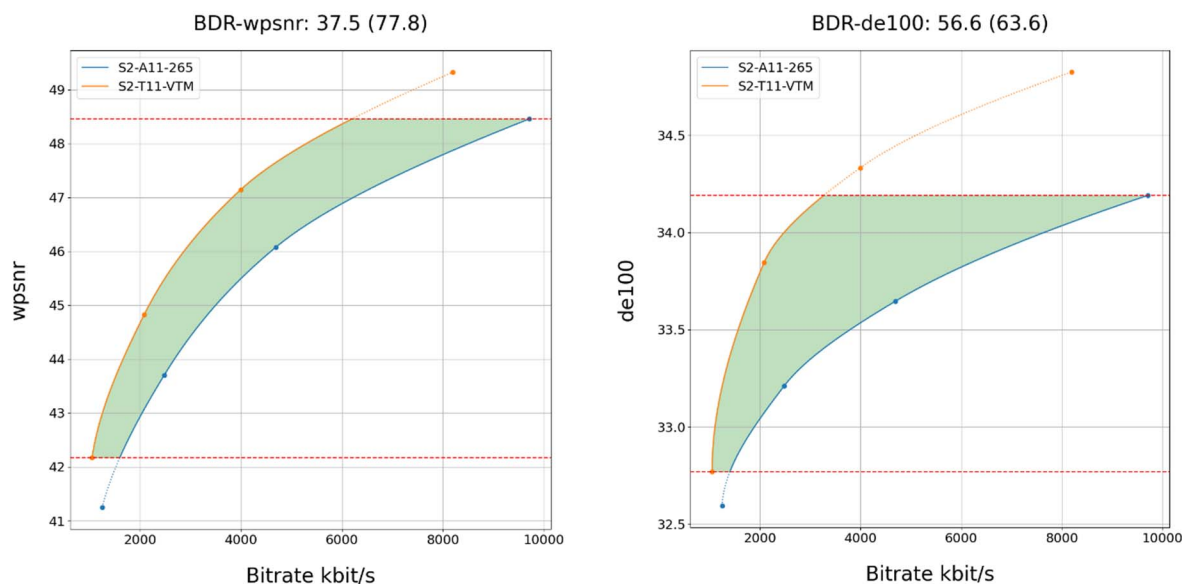


Figure 8.2.4.3-2 Rate-Quality curves and BD rate gain for wpsnr and de100 of H.266/VVC VTM with S2-VTM-02 against H.265/HEVC HM with configuration S2-HM-02 for reference sequence S2-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/VTM/Characterization/>.

8.2.4.4 Scenario 3: Screen Content

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC HM for Scenario 3 Screen Content. In particular,

- Table 8.2.4.4-1 provides the BD rate gain of H.266/VVC VTM with S3-VTM-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no RA.
- Table 8.2.4.4-2 provides the BD rate gain of H.266/VVC VTM with S3-VTM-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences with fixed Intra every second.

Table 8.2.4.4-1 BD rate gain of H.266/VVC VTM with S3-VTM-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no RA

Reference sequence	Name	psnr	y psnr
S3-R01	MovingText2-4K-10bit	52.2	50.5
S3-R02	MovingText2-4K-8bit	52.1	50.4
S3-R03	MovingText2-FullHD-10bit	57.6	57.0
S3-R04	MovingText2-FullHD-8bit	57.7	57.2
S3-R05	TextMixTransitions-4K-10bit	62.1	58.3
S3-R06	TextMixTransitions-4K-8bit	62.7	59.3
S3-R07	TextMixTransitions-FullHD-10bit	58.4	54.2
S3-R08	TextMixTransitions-FullHD-8bit	59.1	54.4
S3-R09	GraphicsMixSimple-4K-10bit	57.1	55.2
S3-R10	GraphicsMixSimple-4K-8bit	56.9	55.1
S3-R11	GraphicsMixSimple-FullHD-10bit	48.1	45.9
S3-R12	GraphicsMixSimple-FullHD-8bit	48.3	46.1
S3-R13	GraphicsMixTransitions-4K-10bit	59.0	57.6
S3-R14	GraphicsMixTransitions-4K-8bit	58.7	57.2
S3-R15	GraphicsMixTransitions-FullHD-10bit	53.6	51.9
S3-R16	GraphicsMixTransitions-FullHD-8bit	54.1	52.3
S3-R17	Mission-Control	52.2	51.9
Minimum		48.1	45.9
Maximum		62.7	59.3
Average		55.9	53.8

Table 8.2.4.4-1 BD rate gain of H.266/VVC VTM with S3-VTM-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences fixed Intra every second

Reference sequence	Name	psnr	y psnr
S3-R01	MovingText2-4K-10bit	49.3	46.8
S3-R02	MovingText2-4K-8bit	49.0	46.6
S3-R03	MovingText2-FullHD-10bit	58.3	56.3
S3-R04	MovingText2-FullHD-8bit	58.3	56.3
S3-R05	TextMixTransitions-4K-10bit	56.6	53.1
S3-R06	TextMixTransitions-4K-8bit	57.9	55.3
S3-R07	TextMixTransitions-FullHD-10bit	56.4	51.8
S3-R08	TextMixTransitions-FullHD-8bit	56.0	51.8
S3-R09	GraphicsMixSimple-4K-10bit	57.3	55.1
S3-R10	GraphicsMixSimple-4K-8bit	57.2	55.0
S3-R11	GraphicsMixSimple-FullHD-10bit	50.5	48.1
S3-R12	GraphicsMixSimple-FullHD-8bit	50.3	48.0
S3-R13	GraphicsMixTransitions-4K-10bit	57.9	55.5
S3-R14	GraphicsMixTransitions-4K-8bit	57.8	55.3
S3-R15	GraphicsMixTransitions-FullHD-10bit	52.6	50.1
S3-R16	GraphicsMixTransitions-FullHD-8bit	52.6	50.2
S3-R17	Mission-Control	48.7	48.0
Minimum		48.7	46.6
Maximum		58.3	56.3
Average		54.5	52.0

As an example, Figure 8.2.4.4-1 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S3-VTM-01 against H.265/HEVC HM with configuration S3-HM-01 for reference sequences S3-R01 and S3-R17

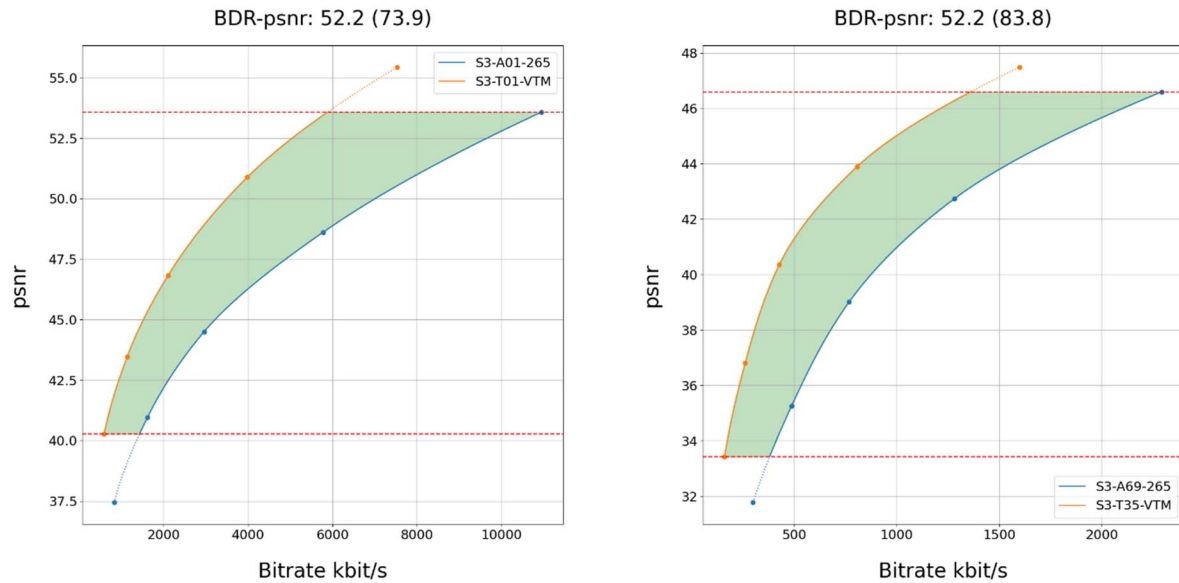


Figure 8.2.4.4-1 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S3-VTM-01 against H.265/HEVC HM with configuration S3-HM-01 for reference sequences S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/Characterization/>.

8.2.4.5 Scenario 4: Messaging and Social Sharing

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC HM for Scenario 4 Messaging and Social Sharing. In particular,

- Table 8.2.4.5-1 provides the BD rate gain of H.266/VVC VTM with S4-VTM-01 against H.265/HEVC HM with configuration S4-HM-01, i.e. with the messaging and social sharing scenario reference sequences and no RA.
- Table 8.2.4.5-2 provides the BD rate gain of H.266/VVC VTM with S4-VTM-02 against H.265/HEVC HM with configuration S4-HM-02, i.e. with the messaging and social sharing scenario reference sequences with fixed Intra every second.

Table 8.2.4.5-1 BD rate gain of H.266/VVC VTM with S4-VTM-01 against H.265/HEVC HM with configuration S4-HM-01, i.e. with the messaging and social sharing scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	23.0	25.9	25.4	24.1
S4-R02	Vertical-Walking	25.2	27.2	27.3	24.2
S4-R03	Neon-4K	26.6	27.9	31.7	30.0
S4-R04	Skater-4K	39.4	40.7	38.1	40.2
Minimum		23.0	25.9	25.4	24.1
Maximum		39.4	40.7	38.1	40.2
Average		28.6	30.4	30.6	29.6

Table 8.2.4.5-2 BD rate gain of H.266/VVC VTM with S4-VTM-02 against H.265/HEVC HM with configuration S4-HM-02, i.e. with the messaging and social sharing scenario reference sequences and fixed Intra every second

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	21.9	24.5	24.7	23.0
S4-R02	Vertical-Walking	20.6	22.7	26.6	19.7
S4-R03	Neon-4K	20.9	21.7	29.8	24.2
S4-R04	Skater-4K	35.7	35.8	34.3	34.2
Minimum		20.6	21.7	24.7	19.7
Maximum		35.7	35.8	34.3	34.2
Average		24.8	26.2	28.8	25.3

As an example, Figure 8.2.4.5-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S4-VTM-01 against H.265/HEVC HM with configuration S4-HM-01 for reference sequence S4-R01.

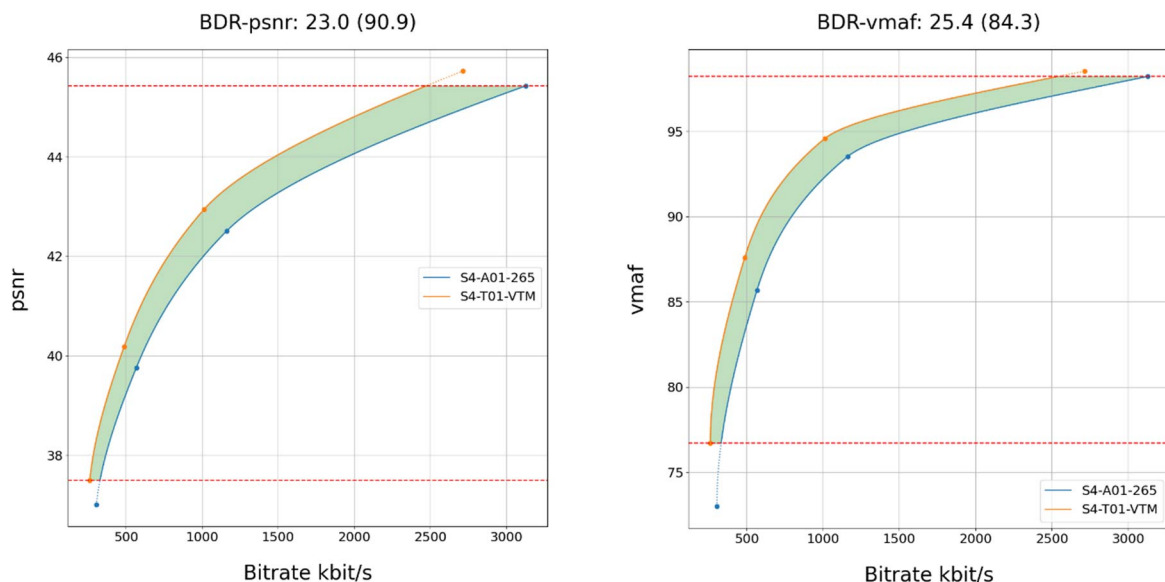


Figure 8.2.4.5-1 Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S4-VTM-01 against H.265/HEVC HM with configuration S4-HM-01 for reference sequence S4-R01

As another example, Figure 8.2.4.5-2 provides Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S4-HM-02 against H.265/HEVC HM with configuration S4-HM-02 for reference sequence S4-R01.

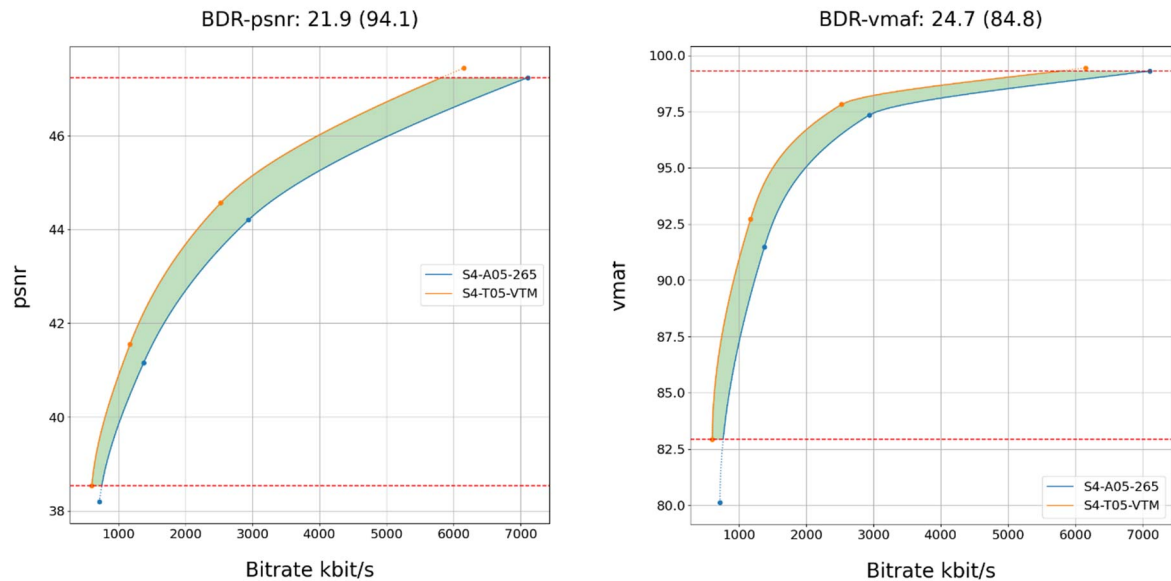


Figure 8.2.4.5-2 Rate-Quality curves and BD rate gain for psnr and vmaf of H.266/VVC VTM with S4-VTM-02 against H.265/HEVC HM with configuration S4-HM-02 for reference sequence S4-R01

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/VTM/Characterization/>.

8.2.4.6 Scenario 5: Online Gaming

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC HM for Scenario 5 Online Gaming. In particular,

- Table 8.2.4.6-1 provides the BD rate gain of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no RA.
- Table 8.2.4.6-2 provides the BD rate gain of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences with fixed Intra every second.

Table 8.2.4.6-1 BD rate gain of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no RA

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	27.7	29.9
S5-R02	Baolei-Man	25.4	26.4
S5-R03	Baolei-Woman	31.3	33.0
S5-R04	Baolei-Balloon	45.1	46.7
S5-R05	Baolei-Yard	33.3	34.7
S5-R06	Jianling-Temple	25.5	25.4
S5-R07	Jianling-Beach	25.2	24.6
S5-R08	Heroes-of-the-Storm	30.1	29.0
S5-R09	Project-CARS	31.8	32.0
S5-R10	World-of-WarCraft	38.0	36.9
S5-R11	MineCraft	39.2	36.6
S5-R12	CS-GO	50.2	50.0
S5-R13	StarCraft	28.9	28.5
Minimum		25.2	24.6
Maximum		50.2	50.0
Average		33.2	33.4

Table 8.2.4.6-2 BD rate gain of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences and fixed RA every second and fixed QP

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	26.2	26.9
S5-R02	Baolei-Man	23.9	24.0
S5-R03	Baolei-Woman	28.6	29.7
S5-R04	Baolei-Balloon	39.0	40.8
S5-R05	Baolei-Yard	30.9	32.2
S5-R06	Jianling-Temple	21.3	20.9
S5-R07	Jianling-Beach	23.9	22.3
S5-R08	Heroes-of-the-Storm	29.1	27.3
S5-R09	Project-CARS	29.9	28.0
S5-R10	World-of-WarCraft	36.2	34.4
S5-R11	MineCraft	36.5	34.2
S5-R12	CS-GO	47.9	46.1
S5-R13	StarCraft	28.8	27.4
Minimum		21.3	20.9
Maximum		47.9	46.1
Average		30.9	30.3

As an example,

- Figure 8.2.4.6-1 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequences S5-R04 and S5-R11.
- Figure 8.2.4.6-2 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11.

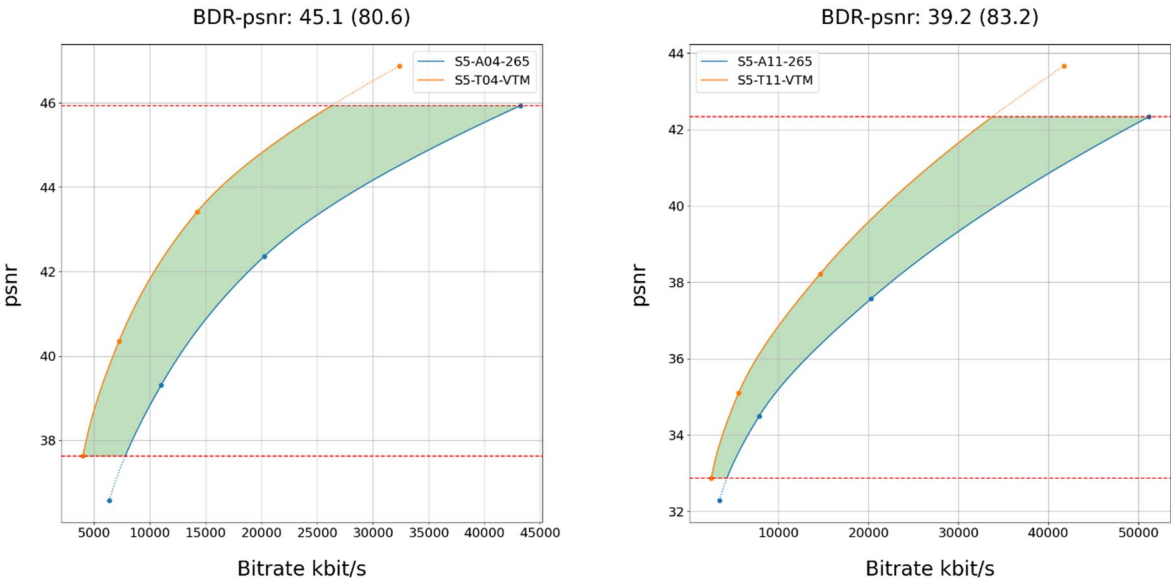


Figure 8.2.4.6-1 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequences S5-R04 and S5-R11.

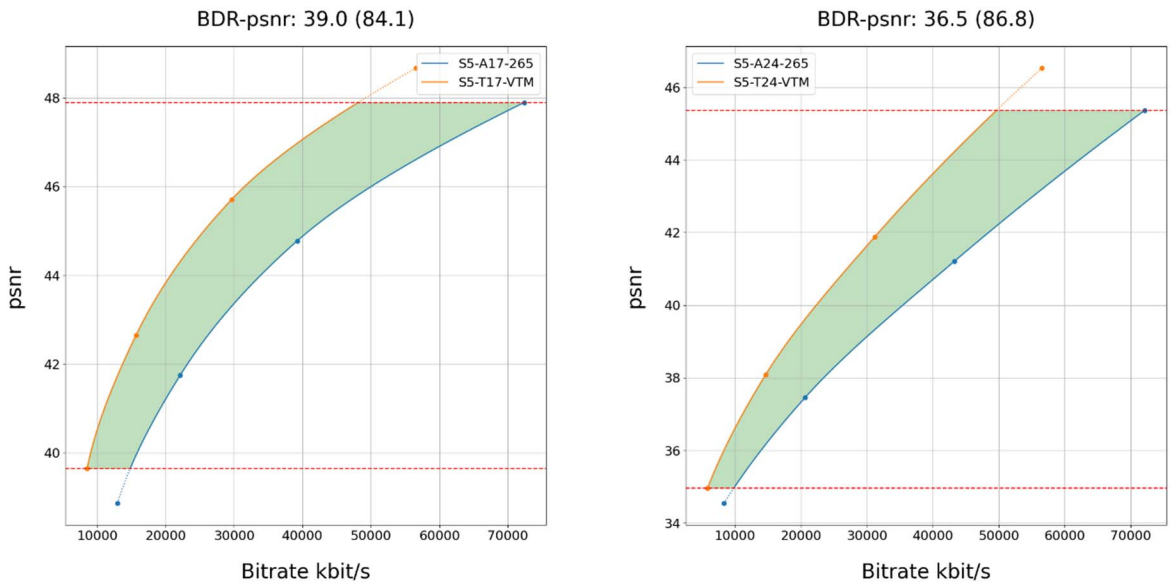


Figure 8.2.4.6-2 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11.

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/Characterization/>.

8.2.4.7 Summary

Table 8.2.4.6-1 provides a summary of BD rate gain in psnr and vmaf for SDR and wpsnr and de100 for HDR of H.266/VVC VTM against H.265/HEVC HM for different scenarios and configurations.

Table 8.2.4.7-1 Summary of BD rate gain in psnr and vmaf for SDR and wpsnr and de100 for HDR of H.266/VVC VTM against H.265/HEVC HM for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr	average vmaf	min vmaf	max vmaf
S1 SDR	35.8	22.9	53.9	35.6	20.9	52.7
S2	36.7	23.1	52.3	38.0	23.7	53.2
S3 no RA	55.9	48.1	62.7	n/a	n/a	n/a
S3 RA, fixed QP	54.5	48.7	58.3	n/a	n/a	n/a
S4 no RA	28.6	23.0	39.4	30.6	25.4	38.1
S4 RA, fixed QP	24.8	20.6	35.7	28.8	24.7	34.3
S5 no RA	33.2	25.2	50.2	n/a	n/a	n/a
S5 RA, fixed QP	30.9	21.3	47.9	n/a	n/a	n/a
Minimum	24.8	20.6	35.7	28.8	20.9	34.3
Maximum	55.9	48.7	62.7	38.0	25.4	53.2
	average wpsnr	min wpsnr	max wpsnr	average de100	min de100	max de100
S1 HDR	39.5	36.1	46.2	58.1	51.2	65.7
S2 HDR	39.14	32.81	45.7	56.4	42.2	62.7

8.2.5 H.266/VVC against H.265/HEVC SCC

8.2.5.1 Introduction

This clause provides a partial characterization of H.266/VVC VTM against H.265/HEVC SCC according to clause 7.2.1. The results provided in clause 6 and 8.2.2 are used for the characterization.

8.2.5.2 Scenario 3: Screen Content

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC SCC for Scenario 3 Screen Content. In particular,

- Table 8.2.5.2-1 provides the BD rate gain of H.266/VVC VTM with S3-VTM-01/03 against H.265/HEVC SCC with configuration S3-SCC-01/03, i.e. with the screen content scenario reference sequences and no fixed random access.
- Table 8.2.5.2-2 provides the BD rate gain of H.266/VVC VTM with S3-VTM-02/04 against H.265/HEVC SCC with configuration S3-SCC-02/04, i.e. with the screen content scenario reference sequences fixed random access every second.

Table 8.2.5.2-1 BD rate gain of H.266/VVC VTM with S3-VTM-01/03 against H.265/HEVC SCC with configuration S3-SCC-01/03, i.e. with the screen content scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	41.2	40.9
S3-R02	MovingText2-4K-8bit	41.3	41.0
S3-R03	MovingText2-FullHD-10bit	53.0	53.1
S3-R04	MovingText2-FullHD-8bit	52.9	53.1
S3-R05	TextMixTransitions-4K-10bit	39.9	36.0
S3-R06	TextMixTransitions-4K-8bit	39.5	37.4
S3-R07	TextMixTransitions-FullHD-10bit	46.6	43.4
S3-R08	TextMixTransitions-FullHD-8bit	46.9	43.4
S3-R09	GraphicsMixSimple-4K-10bit	22.3	20.0
S3-R10	GraphicsMixSimple-4K-8bit	21.7	19.7
S3-R11	GraphicsMixSimple-FullHD-10bit	27.8	26.0
S3-R12	GraphicsMixSimple-FullHD-8bit	27.8	26.1
S3-R13	GraphicsMixTransitions-4K-10bit	52.0	50.8
S3-R14	GraphicsMixTransitions-4K-8bit	51.6	50.5
S3-R15	GraphicsMixTransitions-FullHD-10bit	49.9	48.9
S3-R16	GraphicsMixTransitions-FullHD-8bit	50.0	49.0
S3-R17	Mission-Control	29.3	28.8
Minimum		21.7	19.7
Maximum		53.0	53.1
Average		40.8	39.3

Table 8.2.5.2-2 BD rate gain of H.266/VVC VTM with S3-VTM-02/04 against H.265/HEVC SCC with configuration S3-SCC-02/04, i.e. with the screen content scenario reference sequences fixed random access every second

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	39.1	37.6
S3-R02	MovingText2-4K-8bit	38.7	37.5
S3-R03	MovingText2-FullHD-10bit	53.3	51.5
S3-R04	MovingText2-FullHD-8bit	53.2	51.6
S3-R05	TextMixTransitions-4K-10bit	19.0	15.3
S3-R06	TextMixTransitions-4K-8bit	20.7	18.8
S3-R07	TextMixTransitions-FullHD-10bit	36.6	32.5
S3-R08	TextMixTransitions-FullHD-8bit	36.2	32.4
S3-R09	GraphicsMixSimple-4K-10bit	16.7	13.5
S3-R10	GraphicsMixSimple-4K-8bit	16.8	13.9
S3-R11	GraphicsMixSimple-FullHD-10bit	27.1	24.7
S3-R12	GraphicsMixSimple-FullHD-8bit	27.0	24.9
S3-R13	GraphicsMixTransitions-4K-10bit	42.6	39.9
S3-R14	GraphicsMixTransitions-4K-8bit	42.4	39.9
S3-R15	GraphicsMixTransitions-FullHD-10bit	43.1	41.0
S3-R16	GraphicsMixTransitions-FullHD-8bit	42.9	41.1
S3-R17	Mission-Control	20.8	19.7
Minimum		16.7	13.5
Maximum		53.3	51.6
Average		33.9	31.5

As an example,

- Figure 8.2.5.2-1 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S3-VTM-03 against H.265/HEVC SCC with configuration S3-SCC-03 for reference sequences S3-R01 and S3-R17.
- Figure 8.2.5.2-2 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S3-VTM-04 against H.265/HEVC SCC with configuration S3-SCC-04 for reference sequences S3-R01 and S3-R17.

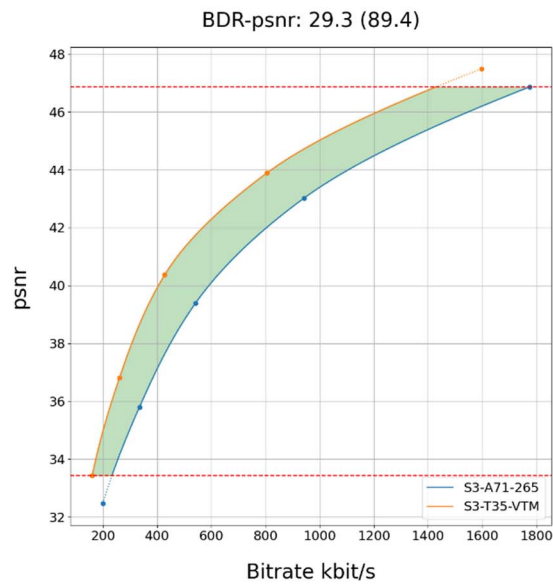
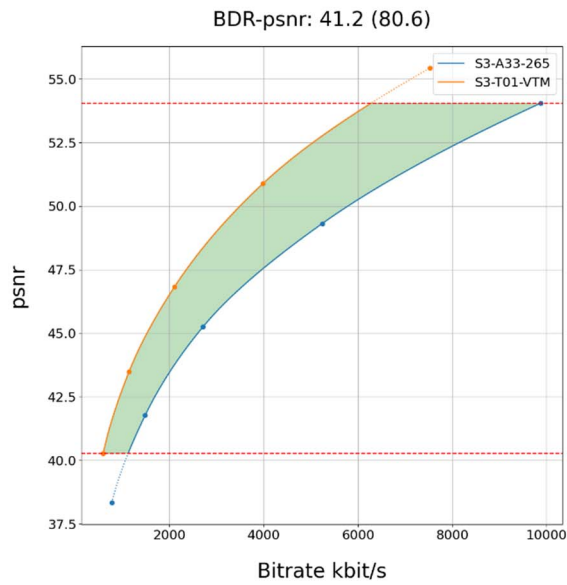


Figure 8.2.5.2-1 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S3-SCC-03 against H.265/HEVC SCC with configuration S3-SCC-03 for reference sequence s S3-R01 and S3-R17

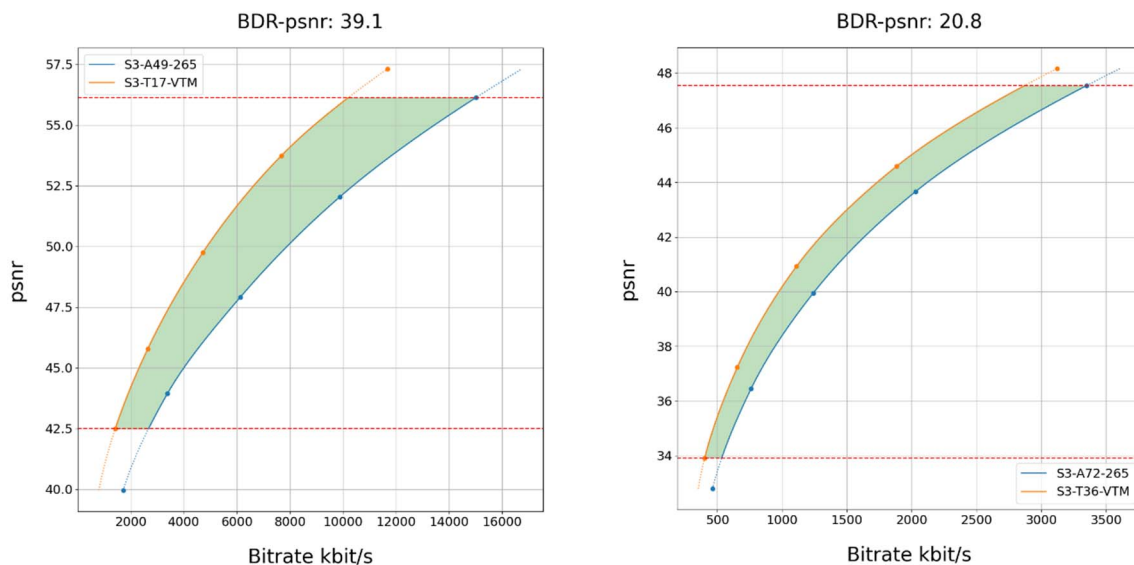


Figure 8.2.5.2-2 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S3-VTM-04 against H.265/HEVC SCC with configuration S3-SCC-04 for reference sequence s S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/VTM/Characterization/>.

8.2.5.3 Scenario 5: Online Gaming

This clause provides characterization of H.266/VVC VTM mode configurations against H.265/HEVC SCC for Scenario 5 Online Gaming. In particular,

- Table 8.2.5.3-1 provides the BD rate gain of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC SCC with configuration S5-SCC-01, i.e. with the online gaming scenario reference sequences and no fixed random access.
- Table 8.2.5.3-2 provides the BD rate gain of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC SCC with configuration S5-SCC-02, i.e. with the online gaming scenario reference sequences and fixed random access every second.

Table 8.2.5.3-1 BD rate gain of VTM with S5-VTM-01 against H.265/HEVC SCC with configuration S5-SCC-01, i.e. with the online gaming scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	27.6	29.9
S5-R02	Baolei-Man	25.1	26.4
S5-R03	Baolei-Woman	30.6	32.5
S5-R04	Baolei-Balloon	44.6	46.4
S5-R05	Baolei-Yard	33.1	34.7
S5-R06	Jianling-Temple	23.5	23.8
S5-R07	Jianling-Beach	22.0	22.2
S5-R08	Heroes-of-the-Storm	28.4	27.5
S5-R09	Project-CARS	29.6	30.3
S5-R10	World-of-WarCraft	36.8	36.3
S5-R11	MineCraft	26.2	26.8
S5-R12	CS-GO	45.5	46.6
S5-R13	StarCraft	26.0	26.8
Minimum		22.0	22.2
Maximum		45.5	46.6
Average		30.7	31.6

Table 8.2.5.3-2 BD rate gain of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC SCC with configuration S5-SCC-02, i.e. with the online gaming scenario reference sequences and fixed random access every second

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	25.4	26.3
S5-R02	Baolei-Man	22.8	23.3
S5-R03	Baolei-Woman	26.7	28.2
S5-R04	Baolei-Balloon	38.4	40.3
S5-R05	Baolei-Yard	30.7	32.2
S5-R06	Jianling-Temple	19.2	19.2
S5-R07	Jianling-Beach	18.5	17.8
S5-R08	Heroes-of-the-Storm	26.0	24.3
S5-R09	Project-CARS	27.1	25.9
S5-R10	World-of-WarCraft	32.5	31.2
S5-R11	MineCraft	22.8	23.1
S5-R12	CS-GO	41.4	41.1
S5-R13	StarCraft	23.9	23.7
Minimum		18.5	17.8
Maximum		41.4	41.1
Average		27.3	27.4

As an example,

- Figure 8.2.5.3-1 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC SCC with configuration S5-SCC-01 for reference sequences S5-R01 and S5-R04.
- Figure 8.2.5.3-2 provides Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC SCC with configuration S5-SCC-02 for reference sequences S5-R01 and S5-R04

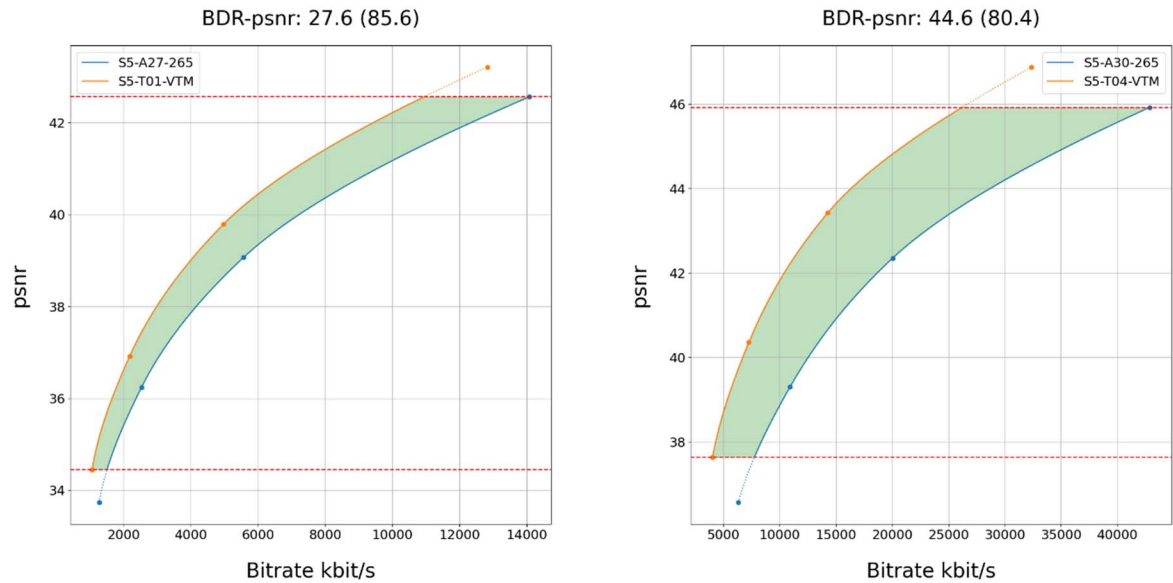


Figure 8.2.5.3-1 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-01 against H.265/HEVC SCC with configuration S5-SCC-01 for reference sequences S5-R01 and S5-R04

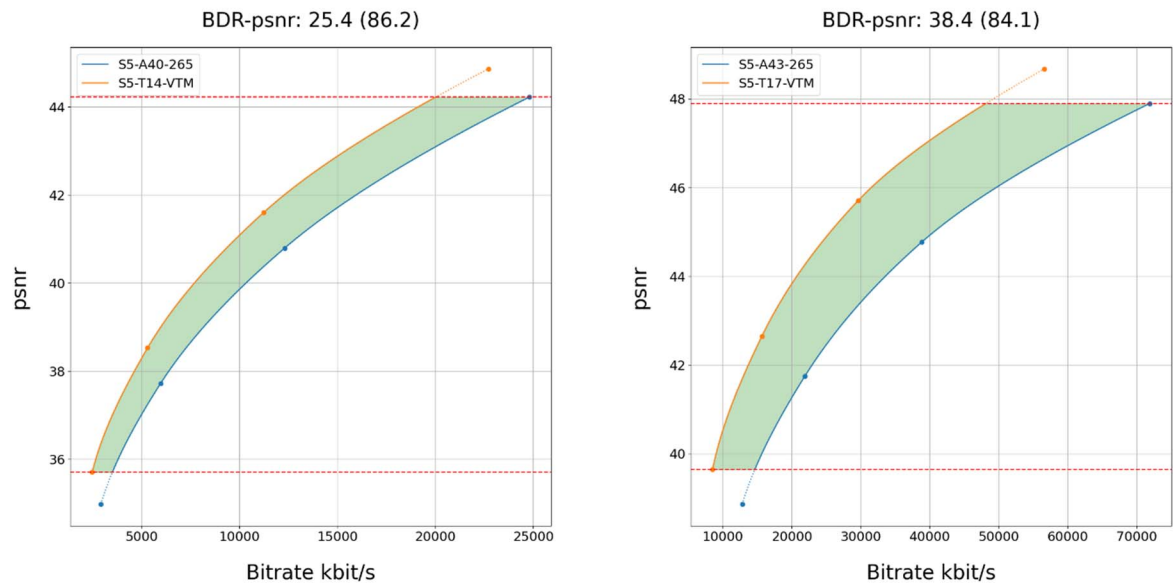


Figure 8.2.5.3-2 Rate-Quality curves and BD rate gain for psnr of H.266/VVC VTM with S5-VTM-02 against H.265/HEVC SCC with configuration S5-SCC-02 for reference sequences S5-R01 and S5-R04

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/VTM/Characterization/>.

8.2.5.4 Summary

Table 8.2.5.4-1 provides a summary of BD rate gain in psnr of H.266/VVC VTM against H.265/HEVC SCC for different scenarios and configurations.

Table 8.2.5.4-1 Summary of BD rate gain in psnr of H.266/VVC VTM against H.265/HEVC SCC for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr
S3 no RA	40.8	21.7	53.0
S3 RA, fixed QP	33.9	16.7	53.3
S5 no RA	30.7	22.0	45.5
S5 RA, fixed QP	27.4	18.5	41.4
Minimum	27.4	18.5	41.4
Maximum	40.8	22.0	53.3

8.2.6 External subjective tests results

The document [61] reports verification test results comparing VVC to its predecessor HEVC on ultra high definition (UHD, a.k.a. 4K, 3840×2160) standard dynamic range (SDR) video content using formal subjective visual quality assessment testing. The purpose of the verification test was to confirm that the coding efficiency objective for the VVC standard has been met achieving a substantial bit-rate reduction for the same level of *subjective* visual quality relative to the HEVC Main Profile. As anticipated in the test plan, in addition to using the HM reference software encoder for HEVC and the VTM reference software encoder for VVC, which used essentially the same rate-distortion optimization encoding techniques, another VVC encoder that uses alternative techniques for subjective quality optimization and faster encoding had also become available for study and was included in the test – namely the VVenC open-source VVC encode [62]. The VVenC encoder, although still a preliminary implementation produced only two months following the completion of the standard, was used to represent an example of practical encoding as may be found in product implementations and is reported to be more than 100 times faster than the VTM encoder [63]. The compression performance of the HEVC reference software HM-16.22, the VVC reference software VTM-10.0, and the open-source VVC implementation VVenC-0.1.0, were compared for UHD SDR content using a random-access (RA) configuration suitable for streaming or broadcast applications.

The testing used the degradation category rating (DCR) test method (as in ITU-T P.910) [64] with an 11-point impairment scale (as in Rec. ITU-R BT.500). The results of a visual assessment of VVC compared to HEVC by naïve test subjects are reported. The assessment included five test sequences encoded in a random-access configuration with a random-access interval of 1.07 seconds. The measured mean opinion score (MOS) figures indicate a significant improvement of VVC relative to HEVC for both VVC implementations, VTM-10.0 and VVenC-0.1.0, resulting in overall average bit-rate savings estimates of 43% and 49%, respectively.

The SDR UHD subjective test was carried out at the following test sites:

- GBTech, Rome, IT
- RWTH Aachen University, Aachen, DE

The arrangements for the two test sites are shown in Table 8.2.4-1.

Table 8.2.4-1 Arrangements for VVC subjective test sites

Test Site	GBTech	RWTH Aachen University
Display, size (resolution setting)	LG 65" CX6LA (3840x2160)	Sony PVM X550, 55" (3840x2160)
Viewing distance	2 viewers at 1.5H	1 viewer at 1.5H
Viewing angle	60° (30° from screen center)	90° (at screen center)
Total number of viewers	16 (7 females, 9 males; age 18-24), all screened for visual acuity and normal colour vision.	24 (5 females, 19 males, age 16-34), all screened for visual acuity and normal colour vision.

Additional verification tests for HDR UHD, SDR HD and 360° omnidirectional video were performed in JVET.

UHD HDR video verification test results are reported in the JVET-W2020 document [71]:

- Test was performed using 10 UHD, with 3840x2160 resolution, HDR sequences. 5 sequences were in Hybrid-Log Gamma (HLG) HDR format and 5 were in Perceptual Quantizer (PQ) HDR format.
- Encoders were configured using random access settings.

- VVC (using VTM-12.0 encoder) resulted in overall average bit-rate saving of 49% for HLG content and of 51% for PQ content over HEVC (using HM-16.23 encoder).

VVC verification test results for random access HD SDR video are reported in the JVET-V2020 document [72].

- Test was performed using 4 HD (1920x1080) resolution, SDR sequences.
- Encoders were configured with random access settings.
- VVC (using VTM-11.0 encoder) resulted in overall average bit-rate saving of 49% over HEVC (using HM-16.22 encoder) and 52% bitrate saving using Fraunhofer HHI VVenC-0.3 encoder (execution run-times were reported to be 100x faster compared with the VTM encoder).

VVC verification test results for low delay HD SDR video are reported in the JVET-V2020 document [72]:

- Test was performed using 6 HD, with 1920x1080 resolution, SDR sequences. 3 sequences were representative of conversational applications and 3 were representative of online-gaming applications.
- Encoders were configured with low-delay settings.
- VVC (using VTM-11.0 encoder) resulted in overall average bit-rate saving of 37% over HEVC (using HM-16.22 encoder).

VVC verification test results for 360° omnidirectional video are reported in the JVET-V2020 document [72]:

- Test was performed using 4 360° omnidirectional SDR video sequences with 4K (4320x2160), 6K (6144x3072) and 8K (8192x4096) input resolutions.
- Encoders were configured with random access settings.
- VVC bitstreams were coded with padded equirectangular projection (PERP) and generalized cubemap projection (GCMP). HEVC bitstreams were coded with PERP and padded cubemap projection (PCMP) respectively.
- VVC (using VTM-11.0 encoder) resulted in overall average bit-rate saving of 51% for PERP, and of 56% for GCMP/PCMP, over HEVC (using HM-16.22 encoder).

8.3 Essential Video Coding (EVC)

8.3.1 Overview

The development of the MPEG-5 Essential Video Coding (EVC) standard is completed, and its specification has been published in October 2020 as ISO/IEC 23094-1 [50].

The main goal of the EVC standard is to provide significantly improved compression capability over previous generation of video coding standards with timely publication of commercial terms. The EVC standard has been developed to provide a video codec for emerging delivery protocols and networks, such as 5G, enabling the delivery of high-quality video services to an ever-growing audience by providing improved coding performance.

The MPEG-5 EVC defines two important profiles, "Baseline" profile and "Main" profile. It was the design objective that the "Baseline" profile contains only technologies that are older than 20 years. The "Main" profile includes additional tools, each of which can be either cleanly disabled or switched to the corresponding baseline tool on an individual basis. Additionally, for still image coding, "Main Still Picture" and "Baseline Still Picture" profiles, which employ the same coding tools as in the corresponding video profiles, are defined.

MPEG has completed the EVC verification tests for HDR and SDR content with formal subjective testing showing that for equal subjective video quality, the EVC reference encoder using the EVC Main profile can achieve significant bit-rate reduction compared to the HEVC reference encoder using the HEVC Main 10 profile. These tests also demonstrated that the EVC reference encoder using the EVC Baseline profile can achieve similar bit-rate reduction compared to the AVC reference encoder using the AVC Progressive High 10 profile. Such analysis was performed using MOS BD-rate calculations.

The verification test conditions and results for SDR content are reported in [52]. The average bitrate savings for the EVC reference encoder using the EVC Main profile compared to the HEVC reference encoder using the HEVC Main

10 profile are approximately 39% for UHD SDR content, encoded using the random access configuration, and approximately 41% for HD SDR content, encoded using the low delay configuration. The average bit rate savings for the EVC reference encoder using the EVC Baseline profile compared to the AVC reference encoder using the AVC Progressive High 10 profile are approximately 39% for the UHD SDR content, encoded using the random access configuration, and approximately 34% for HD SDR content, encoded using the low delay configuration.

The verification test conditions and results for HDR content are reported in [53]. For random access configuration, the EVC reference encoder using the EVC Main profile provides around 36% bitrate reduction for HDR content at UHD resolution and 35% bitrate reduction for HDR content at HD resolution compared to the HEVC reference encoder with HDR/WCG encoder optimizations enabled, using the HEVC Main 10 profile, for equal subjective video quality.

Application areas especially targeted for the use of EVC include ultra-high definition 4K and 8K video, video with a high dynamic range and wide colour gamut, and video for immersive media applications such as 360° omnidirectional video, as well as conventional standard-definition and high-definition video content.

8.3.2 Test Configurations and Results for EVC

8.3.2.1 Introduction

This clause provides test setups, configurations and results for EVC.

The reference software for MPEG-5 EVC is called ETM (EVC Test Model). The ETM software is maintained and can be downloaded from the repository: <https://github.com/MPEGGroup/MPEG-EVC-ETM>.

ETM configuration parameters have been chosen to closely match those used by the corresponding HM configuration files. More specifically,

1. The output bit-depth is always set to 10 so that the metrics calculation can be performed at bit-depth of 10.
2. The per frame QP values are specified to be aligned with the settings of the HM anchor.
3. The reference frames are specified to be aligned with the settings of the HM anchor.

Details that are specific to a particular scenario are described in the corresponding sections. The proposed EVC configuration files are attached to this document.

8.3.2.2 Scenario 1: Full HD Streaming

8.3.2.2.1 Overview

Table 8.3.2.2.1-1 provides an overview of the EVC test tuples provided for this scenario. For provided bitstreams, reference EVC software implementation ETM7.5.1 has been used.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/streams.csv>.

Table 8.3.2.2.1-1 Test Tuple generation with EVC for FullHD Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S1-T01-ETM	8.2.2.2.3	S1-R1	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T01-ETM-<QP>
S1-T02-ETM	8.2.2.2.3	S1-R2	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T02-ETM-<QP>
S1-T03-ETM	8.2.2.2.3	S1-R3	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T03-ETM-<QP>
S1-T04-ETM	8.2.2.2.3	S1-R4	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T04-ETM-<QP>
S1-T05-ETM	8.2.2.2.3	S1-R5	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T05-ETM-<QP>
S1-T06-ETM	8.2.2.2.3	S1-R6	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T06-ETM-<QP>
S1-T07-ETM	8.2.2.2.3	S1-R7	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T07-ETM-<QP>
S1-T08-ETM	8.2.2.2.3	S1-R8	ETM7.5.1	S1-ETM-01	QP: [22,27,32,37]	S1-T08-ETM-<QP>
S1-T11-ETM	8.2.2.2.4	S1-R11	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T11-ETM-<QP>
S1-T12-ETM	8.2.2.2.4	S1-R12	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T12-ETM-<QP>
S1-T13-ETM	8.2.2.2.4	S1-R13	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T13-ETM-<QP>
S1-T14-ETM	8.2.2.2.4	S1-R14	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T14-ETM-<QP>
S1-T15-ETM	8.2.2.2.4	S1-R15	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T15-ETM-<QP>
S1-T16-ETM	8.2.2.2.4	S1-R16	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T16-ETM-<QP>
S1-T17-ETM	8.2.2.2.4	S1-R17	ETM7.5.1	S1-ETM-02	QP: [22,27,32,37]	S1-T17-ETM-<QP>

8.3.2.2.2 Test Model and Configurations

8.3.2.2.2.1 S1-ETM-01: SDR Configuration

Prediction structure:

- GOP size is equal to 16.
- Hierarchical QP structure is used.
- temporal filtering is disabled (`temporal_filter = 1`)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- The random access period is set to approximately 1 second (closest multiple of GOP size that is greater than or equal to the frame rate).

The detailed settings are defined in the attached configuration file `S1-ETM-01.cfg`.

8.3.2.2.2.2 S1-ETM-02: HDR Configuration

Prediction structure:

- GOP Size is equal to 16.
- Hierarchical QP structure is used.
- temporal filtering is disabled (`temporal_filter = 0`)

ETM HDR settings specified for MPEG Verification Testing, output document ISO/IEC JTC 1/SC 29/WG 04 N0030 [53].

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- The random access period is set to approximately 1 second (closest multiple of GOP size that is greater than or equal to the frame rate).

The detailed settings are defined in the attached configuration file S1-ETM-02.cfg.

8.3.2.2.3 Test Results

EVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/>

EVC test metrics are provided with the appropriate keys as defined in Table 8.3.2.2.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/cross-check.csv>.

Based on these cross-check results, the verification status for the EVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/verification.csv> and Table 8.3.2.2.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.3.2.2.3-1 Verification status of EVC test streams for FullHD Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S1-T01-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T02-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T03-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T04-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T05-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T06-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T07-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T08-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T11-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T12-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T13-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T14-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T15-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T16-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T17-ETM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.3.2.3 Scenario 2: 4K-TV

8.3.2.3.1 Overview

Table 8.3.2.3.1-1 provides an overview of the EVC test tuples provided for this scenario. For provided bitstreams, reference EVC software implementation ETM7.5.1 has been used.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/ETM/streams.csv>.

Table 8.3.2.3.1-1 Anchor Tuple generation with EVC for 4K-TV Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S2-T01-ETM	8.3.2.3.2.1	S2-R1	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T01-ETM-<QP>
S2-T02-ETM	8.3.2.3.2.1	S2-R2	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T02-ETM-<QP>
S2-T03-ETM	8.3.2.3.2.1	S2-R3	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T03-ETM-<QP>
S2-T04-ETM	8.3.2.3.2.1	S2-R4	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T04-ETM-<QP>
S2-T05-ETM	8.3.2.3.2.1	S2-R5	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T05-ETM-<QP>
S2-T06-ETM	8.3.2.3.2.1	S2-R6	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T06-ETM-<QP>
S2-T07-ETM	8.3.2.3.2.1	S2-R7	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T07-ETM-<QP>
S2-T08-ETM	8.3.2.3.2.1	S2-R8	ETM7.5.1	S2-ETM-01	QP: [22,27,32,37]	S2-T08-ETM-<QP>
S2-T11-ETM	8.3.2.3.2.2	S2-R11	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T11-ETM-<QP>
S2-T12-ETM	8.3.2.3.2.2	S2-R12	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T12-ETM-<QP>
S2-T13-ETM	8.3.2.3.2.2	S2-R13	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T13-ETM-<QP>
S2-T14-ETM	8.3.2.3.2.2	S2-R14	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T14-ETM-<QP>
S2-T15-ETM	8.3.2.3.2.2	S2-R15	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T15-ETM-<QP>
S2-T16-ETM	8.3.2.3.2.2	S2-R16	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T16-ETM-<QP>
S2-T17-ETM	8.3.2.3.2.2	S2-R17	ETM7.5.1	S2-ETM-02	QP: [22,27,32,37]	S2-T17-ETM-<QP>

8.3.2.3.2 Test Model and Configurations

8.3.2.3.2.1 S2-ETM-01: SDR Configuration

Prediction structure:

- GOP size is equal to 16.
- Hierarchical QP structure is used.
- temporal filtering is enabled (`temporal_filter = 1`)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- The random access period is set to approximately 1 second (closest multiple of GOP size that is greater than or equal to the frame rate).

The detailed settings are defined in the attached configuration file `S2-ETM-01.cfg`.

8.3.2.3.2.2 S2-ETM-02: HDR Configuration

Prediction structure:

- GOP Size is equal to 16.
- Hierarchical QP structure is used.
- temporal filtering is disabled (`temporal_filter = 0`)

ETM HDR settings specified for MPEG Verification Testing, output document ISO/IEC JTC 1/SC 29/WG 04 N0030 [53].

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- The random access period is set to approximately 1 second (closest multiple of GOP size that is greater than or equal to the frame rate).

The detailed settings are defined in the attached configuration file `S2-ETM-02.cfg`.

8.3.2.3.3 Test Results

EVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4k/ETM/>

EVC test metrics are provided with the appropriate keys as defined in Table 8.3.2.3.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4k/ETM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/ETM/cross-check.csv>.

Based on these cross-check results, the verification status for the EVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/ETM/verification.csv> and Table 8.3.2.3.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.3.2.3.3-1 Verification status of EVC test streams for 4K TV Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S2-T01-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T02-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T03-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T04-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T05-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T06-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T07-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T08-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T11-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T12-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T13-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T14-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T15-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T16-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T17-VTM	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.3.2.4 Scenario 3: Screen Content Scenario

8.3.2.4.1 Overview

Table 8.3.2.4.1-1 provides an overview of the EVC test tuples provided for this scenario. For provided bitstreams, reference EVC software implementation ETM7.5 and corresponding encoder configuration have been used.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/streams.csv>.

Table 8.3.2.4.1-1 Test Tuple generation with EVC for Screen Content Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S3-T01-ETM	8.2.2.4.2.1	S3-R01	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T01-ETM-<QP>
S3-T02-ETM	8.2.2.4.2.1	S3-R02	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T02-ETM-<QP>
S3-T03-ETM	8.2.2.4.2.1	S3-R03	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T03-ETM-<QP>
S3-T04-ETM	8.2.2.4.2.1	S3-R04	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T04-ETM-<QP>
S3-T05-ETM	8.2.2.4.2.1	S3-R05	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T05-ETM-<QP>
S3-T06-ETM	8.2.2.4.2.1	S3-R06	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T06-ETM-<QP>
S3-T07-ETM	8.2.2.4.2.1	S3-R07	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T07-ETM-<QP>
S3-T08-ETM	8.2.2.4.2.1	S3-R08	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T08-ETM-<QP>
S3-T09-ETM	8.2.2.4.2.1	S3-R09	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T09-ETM-<QP>
S3-T10-ETM	8.2.2.4.2.1	S3-R10	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T10-ETM-<QP>
S3-T11-ETM	8.2.2.4.2.1	S3-R11	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T11-ETM-<QP>
S3-T12-ETM	8.2.2.4.2.1	S3-R12	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T12-ETM-<QP>
S3-T13-ETM	8.2.2.4.2.1	S3-R13	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T13-ETM-<QP>
S3-T14-ETM	8.2.2.4.2.1	S3-R14	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T14-ETM-<QP>
S3-T15-ETM	8.2.2.4.2.1	S3-R15	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T15-ETM-<QP>
S3-T16-ETM	8.2.2.4.2.1	S3-R16	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T16-ETM-<QP>
S3-T17-ETM	8.2.2.4.2.2	S3-R17	ETM7.5	S3-ETM-01	QP=[22, 27, 32, 37, 42]	S3-T17-ETM-<QP>
S3-T18-ETM	8.2.2.4.2.2	S3-R01	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T18-ETM-<QP>
S3-T19-ETM	8.2.2.4.2.2	S3-R02	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T19-ETM-<QP>
S3-T20-ETM	8.2.2.4.2.2	S3-R03	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T20-ETM-<QP>
S3-T21-ETM	8.2.2.4.2.2	S3-R04	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T21-ETM-<QP>
S3-T22-ETM	8.2.2.4.2.2	S3-R05	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T22-ETM-<QP>
S3-T23-ETM	8.2.2.4.2.2	S3-R06	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T23-ETM-<QP>
S3-T24-ETM	8.2.2.4.2.2	S3-R07	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T24-ETM-<QP>
S3-T25-ETM	8.2.2.4.2.2	S3-R08	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T25-ETM-<QP>
S3-T26-ETM	8.2.2.4.2.2	S3-R09	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T26-ETM-<QP>
S3-T27-ETM	8.2.2.4.2.2	S3-R10	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T27-ETM-<QP>
S3-T28-ETM	8.2.2.4.2.2	S3-R11	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T28-ETM-<QP>
S3-T29-ETM	8.2.2.4.2.2	S3-R12	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T29-ETM-<QP>
S3-T30-ETM	8.2.2.4.2.2	S3-R13	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T30-ETM-<QP>
S3-T31-ETM	8.2.2.4.2.2	S3-R14	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T31-ETM-<QP>
S3-T32-ETM	8.2.2.4.2.2	S3-R15	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T32-ETM-<QP>
S3-T33-ETM	8.2.2.4.2.2	S3-R16	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T33-ETM-<QP>
S3-T34-ETM	8.2.2.4.2.2	S3-R17	ETM7.5	S3-ETM-02	QP=[22, 27, 32, 37, 42]	S3-T34-ETM-<QP>
S3-T35-ETM	8.2.2.4.2.1	S3-R17	ETM7.5	S3-ETM-03	QP=[22, 27, 32, 37, 42]	S3-T35-ETM-<QP>
S3-T36-ETM	8.2.2.4.2.2	S3-R17	ETM7.5	S3-ETM-04	QP=[22, 27, 32, 37, 42]	S3-T36-ETM-<QP>

8.3.2.4.2 Test Model and Configurations

8.3.2.4.2.1 S3-ETM-01: no fixed random access

Prediction structure:

- Hierarchical QP structure is used.
- GOP size is equal to 8. Each P picture refers to up to 4 preceding pictures in display order.
- temporal filtering is disabled (temporal_filter = 0)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37, 42].
- Only the first picture is random access, the rest of the pictures are of type P.

The detailed settings are defined in the attached configuration file S3-ETM-01.cfg.

8.3.2.4.2.2 S3-ETM-02: fixed random access every second

Prediction structure:

- The QP value for each frame is constant (equal to the nominal QP value). Each P picture refers to immediately preceding pictures in display order.
- temporal filtering is disabled (temporal_filter = 0)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37, 42].
- The random access period is set to exactly 1 second (i.e. random access period is equal to the sequence fps value).

The detailed settings are defined in the attached configuration file S3-ETM-02.cfg.

8.3.2.4.3 Test Results

EVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/>

EVC test metrics are provided with the appropriate keys as defined in Table 8.3.2.4.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/cross-check.csv>.

Based on these cross-check results, the verification status for the EVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/verification.csv> and Table 8.3.2.4.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.3.2.4.3-1 Verification status of EVC test streams for Screen Content Scenario

Anchor + Key Verification Type	Summary			22			27			32			37			42		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S3-T01-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T02-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T03-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T04-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T05-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T06-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T07-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T08-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T09-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T10-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T11-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T12-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T13-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T14-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T15-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T16-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T17-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T18-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T19-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T20-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T21-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T22-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T23-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T24-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T25-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T26-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T27-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T28-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T29-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T30-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T31-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T32-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T33-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T34-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T35-ETM		S	S		S	S		S	S		S	S		S	S		S	S
S3-T36-ETM		S	S		S	S		S	S		S	S		S	S		S	S

8.3.2.5 Scenario 4: Messaging and Social Sharing

8.3.2.5.1 Overview

Table 8.3.2.5.1-1 provides an overview of the EVC test tuples provided for this scenario. For provided bitstreams, reference EVC software implementation ETM7.5 has been used.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/streams.csv>.

Table 8.3.2.5.1-1 Test Tuple generation with EVC for Social sharing and messaging

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S4-T01-ETM	8.3.2.5.2.1	S4-R01	ETM7.5	S4-ETM-01	QP = [22,27,32,37]	S4-T01-ETM-<QP>
S4-T02-ETM	8.3.2.5.2.1	S4-R02	ETM7.5	S4-ETM-01	QP = [22,27,32,37]	S4-T02-ETM-<QP>
S4-T03-ETM	8.3.2.5.2.1	S4-R03	ETM7.5	S4- ETM-01	QP = [22,27,32,37]	S4-T03-ETM-<QP>
S4-T04-ETM	8.3.2.5.2.1	S4-R04	ETM7.5	S4- ETM-01	QP = [22,27,32,37]	S4-T04-ETM-<QP>
S4-T05-ETM	8.3.2.5.2.2	S4-R01	ETM7.5	S4-ETM-02	QP = [22,27,32,37]	S4-T05-ETM-<QP>
S4-T06-ETM	8.3.2.5.2.2	S4-R02	ETM7.5	S4-ETM-02	QP = [22,27,32,37]	S4-T06-ETM-<QP>
S4-T07-ETM	8.3.2.5.2.2	S4-R03	ETM7.5	S4-ETM-02	QP = [22,27,32,37]	S4-T07-ETM-<QP>
S4-T08-ETM	8.3.2.5.2.2	S4-R04	ETM7.5	S4-ETM-02	QP = [22,27,32,37]	S4-T08-ETM-<QP>

8.3.2.5.2 Test Model and configurations

8.3.2.5.2.1 S4-ETM-01: no random access

Prediction structure:

- Hierarchical QP structure is used.
- GOP size is equal to 8. Each B picture refers to up to 4 preceding pictures in display order.
- temporal filtering is disabled (temporal_filter = 0)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- Only the first picture is random access, the rest of the pictures are of type B.

The detailed settings are defined in the attached configuration file S4-ETM-01.cfg.

8.3.2.5.2.2 S4-ETM-02: fixed random access every second

Prediction structure:

- The QP value for each frame is constant (equal to the nominal QP value).
- Each B picture (in L0 and L1) refers to immediately preceding pictures in display order.
- temporal filtering is disabled (temporal_filter = 0)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- The random access period of approximately 1 second is achieved (32 for 30fps sequences and 64 for 60fps sequences).

The detailed settings are defined in the attached configuration file S4-ETM-02.cfg.

8.3.2.5.3 Test Results

EVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/>

EVC test metrics are provided with the appropriate keys as defined in Table 8.3.2.5.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/cross-check.csv>.

Based on these cross-check results, the verification status for the EVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/verification.csv> and Table 8.3.2.5.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.3.2.5.3-1 Verification status of EVC test streams for Messaging Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S4-T01-VTM		S	S		S	S		S	S		S	S		S	S
S4-T02-VTM		S	S		S	S		S	S		S	S		S	S
S4-T03-VTM		S	S		S	S		S	S		S	S		S	S
S4-T04-VTM		S	S		S	S		S	S		S	S		S	S
S4-T05-VTM		S	S		S	S		S	S		S	S		S	S
S4-T06-VTM		S	S		S	S		S	S		S	S		S	S
S4-T07-VTM		S	S		S	S		S	S		S	S		S	S
S4-T08-VTM		S	S		S	S		S	S		S	S		S	S

8.3.2.6 Scenario 5: Online Gaming

8.3.2.6.1 Overview

Table 8.3.2.6.1-1 provides an overview of the EVC test tuples provided for this scenario. For provided bitstreams, reference EVC software implementation ETM7.5 has been used.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/streams.csv>.

Table 8.3.2.6.1-1 Test Tuple generation with EVC for Online Gaming Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S5-T01-ETM	8.3.2.6.2.1	S5-R01	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T01-ETM-<QP>
S5-T02-ETM	8.3.2.6.2.1	S5-R02	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T02-ETM-<QP>
S5-T03-ETM	8.3.2.6.2.1	S5-R03	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T03-ETM-<QP>
S5-T04-ETM	8.3.2.6.2.1	S5-R04	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T04-ETM-<QP>
S5-T05-ETM	8.3.2.6.2.1	S5-R05	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T05-ETM-<QP>
S5-T06-ETM	8.3.2.6.2.1	S5-R06	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T06-ETM-<QP>
S5-T07-ETM	8.3.2.6.2.1	S5-R07	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T07-ETM-<QP>
S5-T08-ETM	8.3.2.6.2.1	S5-R08	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T08-ETM-<QP>
S5-T09-ETM	8.3.2.6.2.1	S5-R09	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T09-ETM-<QP>
S5-T10-ETM	8.3.2.6.2.1	S5-R10	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T10-ETM-<QP>
S5-T11-ETM	8.3.2.6.2.1	S5-R11	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T11-ETM-<QP>
S5-T12-ETM	8.3.2.6.2.1	S5-R12	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T12-ETM-<QP>
S5-T13-ETM	8.3.2.6.2.1	S5-R13	ETM7.5	S5-ETM-01	QP=[22, 27, 32, 37]	S5-T13-ETM-<QP>
S5-T14-ETM	8.3.2.6.2.2	S5-R01	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T14-ETM-<QP>
S5-T15-ETM	8.3.2.6.2.2	S5-R02	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T15-ETM-<QP>
S5-T16-ETM	8.3.2.6.2.2	S5-R03	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T16-ETM-<QP>
S5-T17-ETM	8.3.2.6.2.2	S5-R04	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T17-ETM-<QP>
S5-T18-ETM	8.3.2.6.2.2	S5-R05	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T18-ETM-<QP>
S5-T19-ETM	8.3.2.6.2.2	S5-R06	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T19-ETM-<QP>
S5-T20-ETM	8.3.2.6.2.2	S5-R07	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T20-ETM-<QP>
S5-T21-ETM	8.3.2.6.2.2	S5-R08	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T21-ETM-<QP>
S5-T22-ETM	8.3.2.6.2.2	S5-R09	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T22-ETM-<QP>
S5-T23-ETM	8.3.2.6.2.2	S5-R10	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T23-ETM-<QP>
S5-T24-ETM	8.3.2.6.2.2	S5-R11	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T24-ETM-<QP>
S5-T25-ETM	8.3.2.6.2.2	S5-R12	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T25-ETM-<QP>
S5-T26-ETM	8.3.2.6.2.2	S5-R13	ETM7.5	S5-ETM-02	QP=[22, 27, 32, 37]	S5-T26-ETM-<QP>

8.3.2.6.2 Test Model and configurations

8.3.2.6.2.1 S5-ETM-01: no random access

Prediction structure:

- Hierarchical QP structure is used.
- GOP size is equal to 8. Each B picture refers to up to 4 preceding pictures in display order.

- temporal filtering is disabled (temporal_filter = 0)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- Only the first picture is random access, the rest of the pictures are of type B.

The detailed settings are defined in the attached configuration file S5-ETM-01.cfg.

8.3.2.6.2.2 S5-ETM-02: fixed random access every second

Prediction structure:

- The QP value for each frame is constant (equal to the nominal QP value).
- Each B picture (in L0 and L1) refers to immediately preceding pictures in display order.
- temporal filtering is disabled (temporal_filter = 0)

Additional settings (to be specified on the command line):

- QP: [22, 27, 32, 37].
- The random access period of approximately 1 second is achieved (32 for 30fps sequences and 64 for 60fps sequences).

The detailed settings are defined in the attached configuration file S5-ETM-02.cfg.

8.3.2.6.3 Test Results

EVC test streams are provided according to the key system here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/>

EVC test metrics are provided with the appropriate keys as defined in Table 8.3.2.5.1-1

- in the attached csv files
- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/cross-check.csv>.

Based on these cross-check results, the verification status for the EVC test stream is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/verification.csv> and Table 8.3.2.6.3-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.3.2.6.3-1 Verification status of EVC test streams for Gaming Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S5-T01-ETM		S	S		S	S		S	S		S	S		S	S
S5-T02-ETM		S	S		S	S		S	S		S	S		S	S
S5-T03-ETM		S	S		S	S		S	S		S	S		S	S
S5-T04-ETM		S	S		S	S		S	S		S	S		S	S
S5-T05-ETM		S	S		S	S		S	S		S	S		S	S
S5-T06-ETM		S	S		S	S		S	S		S	S		S	S
S5-T07-ETM		S	S		S	S		S	S		S	S		S	S
S5-T08-ETM		S	S		S	S		S	S		S	S		S	S
S5-T09-ETM		S	S		S	S		S	S		S	S		S	S
S5-T10-ETM		S	S		S	S		S	S		S	S		S	S
S5-T11-ETM		S	S		S	S		S	S		S	S		S	S
S5-T12-ETM		S	S		S	S		S	S		S	S		S	S
S5-T13-ETM		S	S		S	S		S	S		S	S		S	S
S5-T14-ETM		S	S		S	S		S	S		S	S		S	S
S5-T15-ETM		S	S		S	S		S	S		S	S		S	S
S5-T16-ETM		S	S		S	S		S	S		S	S		S	S
S5-T17-ETM		S	S		S	S		S	S		S	S		S	S
S5-T18-ETM		S	S		S	S		S	S		S	S		S	S
S5-T19-ETM		S	S		S	S		S	S		S	S		S	S
S5-T20-ETM		S	S		S	S		S	S		S	S		S	S
S5-T21-ETM		S	S		S	S		S	S		S	S		S	S
S5-T22-ETM		S	S		S	S		S	S		S	S		S	S
S5-T23-ETM		S	S		S	S		S	S		S	S		S	S
S5-T24-ETM		S	S		S	S		S	S		S	S		S	S
S4-T25-ETM		S	S		S	S		S	S		S	S		S	S
S4-T26-ETM		S	S		S	S		S	S		S	S		S	S

8.3.3 EVC Characterization against H.264/AVC

8.3.3.1 Overview

This clause provides information related to the characterization of EVC against H.264/AVC according to clause 7.2.1. The results provided in clauses 6 and 8.3.2 are considered for the characterization.

Analysis of the PSNR ranges provided in the clause 6 for H.264/AVC and in sub-clauses 8.3.2 of the EVC shows that their rate distortion curves exhibit an average overlap of 70% across scenarios. As a consequence, the aggregation of results for all rate points for all sequences in each scenario is not substantial enough and do not provide an accurate representation for codec characterisation. BD rate gain are not reported in this clause.

A way to obtain a substantial overlap for accurate estimation of BD rate gain estimates would be to adjust QP values of AVC for better alignments with the ones of HEVC and EVC.

8.3.3.2 Scenario 1: Full HD

This clause provides information related to the characterization of EVC ETM mode configurations against H.264/AVC JM for Scenario 1 Full HD.

For this scenario, the PSNR ranges of the curves between EVC and H.264/AVC overlaps at an average of 69% and can be as low as 35%. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/Characterization/>.

8.3.3.3 Scenario 3: Screen Content

This clause provides information related to the characterization of EVC ETM mode configurations against H.264/AVC JM for Scenario 3 Screen Content.

For this scenario, the PSNR ranges of the curves between EVC and H.264/AVC overlaps at an average of at 69 % and can be as low as 53 % in the non-RA configuration and an average of 69 % and can be as low as 59 % in the RA

configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/Characterization/>.

8.3.3.4 Scenario 4: Messaging and Social Sharing

This clause provides information related to the characterization of EVC ETM mode configurations against H.264/AVC JM for Scenario 4 Messaging and Social Sharing.

For this scenario, the PSNR ranges of the curves between EVC and H.264/AVC overlaps at an average of at 69% and can be as low as 49% in the non-RA configuration and an average of 74% and can be as low as 55% in the RA configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/Characterization/>.

8.3.3.5 Scenario 5: Online Gaming

This clause provides information related to the characterization of EVC ETM mode configurations against H.264/AVC JM for Scenario 5 Online Gaming.

For this scenario, the PSNR ranges of the curves between EVC and H.264/AVC overlaps at an average of at 73% and can be as low as 63% in the non-RA configuration and an average of 79% and can be as low as 69% in the RA configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/Characterization/>.

8.3.3.6 Summary

No characterization results are provided due to the lack of substantial overlap of H.264/AVC and EVC characterization results.

8.3.4 EVC ETM Characterization against H.265/HEVC HM

8.3.4.1 Overview

This clause provides a full characterization of EVC ETM against H.265/HEVC HM according to clause 7.2.1. The results provided in clauses 6 and 8.3.2 are used for the characterization.

8.3.4.2 Scenario 1: Full HD

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC HM for Scenario 1 Full HD. In particular,

- Table 8.3.4.2-1 provides the BD rate gain of EVC ETM with S1-ETM-01 against H.265/HEVC HM with configuration S1-HM-01, i.e. with the Full HD SDR scenario reference sequences
- Table 8.3.4.2-2 provides the BD rate gain of EVC ETM with S1-ETM-02 against H.265/HEVC HM with configuration S1-HM-02, i.e. with the Full HD HDR scenario reference sequences

Table 8.3.4.2-1 BD rate gain of EVC ETM with S1-ETM-01 against H.265/HEVC HM with configuration S1-HM-01, i.e. with the Full HD SDR scenario reference sequences

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S1-R01	Brest-Sedof-FHD	17.6	16.9	29.9	16.2
S1-R02	Rain Fruits-FHD	16.5	16.5	29.7	17.9
S1-R03	Park Joy-FHD	12.2	12.9	20.6	15.3
S1-R04	Soccer-FHD	22.0	22.2	24.1	21.1
S1-R05	Tunnel Flag-FHD	34.9	34.1	40.3	36.1
S1-R06	Boat-FHD	12.8	13.1	20.6	13.1
S1-R07	Fountain-FHD	13.8	13.4	14.1	11.9
S1-R08	Riverbank-FHD	15.0	12.3	20.6	12.4
Minimum		12.2	12.3	14.1	11.9
Maximum		34.9	34.1	40.3	36.1
Average		18.1	17.7	25.0	18.0

Table 8.3.4.2-2 BD rate gain of EVC ETM with S1-ETM-02 against H.265/HEVC HM with configuration S1-HM-02, i.e. with the Full HD HDR scenario reference sequences

Reference sequence	Name	wpsnr	y_wpsnr	psnr100	de100
S1-R11	Life-Untouched-FHD	15.1	16.8	18.0	10.6
S1-R12	Meridian-FHD	12.9	12.4	12.5	18.9
S1-R13	Sol-Levante-FHD	25.7	20.3	27.5	41.5
S1-R14	Cosmos-FHD	25.8	16.6	25.3	60.8
S1-R15	Elevator-FHD	23.4	22.5	19.7	20.2
S1-R16	Sparks-FHD	18.2	16.1	14.5	28.4
S1-R17	Nocturne-FHD	27.4	27.4	21.3	22.0
Minimum		12.9	12.4	12.5	10.6
Maximum		27.4	27.4	27.5	60.8
Average		21.2	18.9	19.8	28.9

As an example, Figure 8.3.4.2-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of ETM with S1-ETM-01 against H.265/HEVC HM with configuration S1-HM-01 for reference sequence S1-R01.

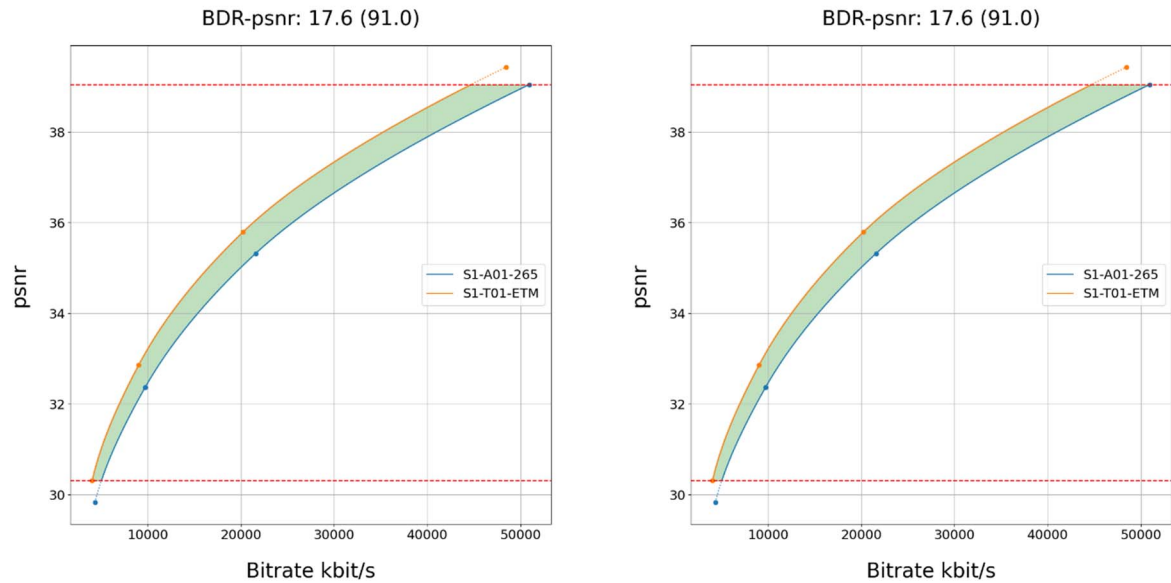


Figure 8.3.4.2-1 Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S1-ETM-01 against H.265/HEVC HM with configuration S1-HM-01 for reference sequence S1-R01

As another example, Figure 8.3.4.2-2 provides Rate-Quality curves and BD rate gain for wpsnr of EVC ETM with S1-ETM-02 against H.265/HEVC HM with configuration S1-HM-02 for reference sequence S1-R11.

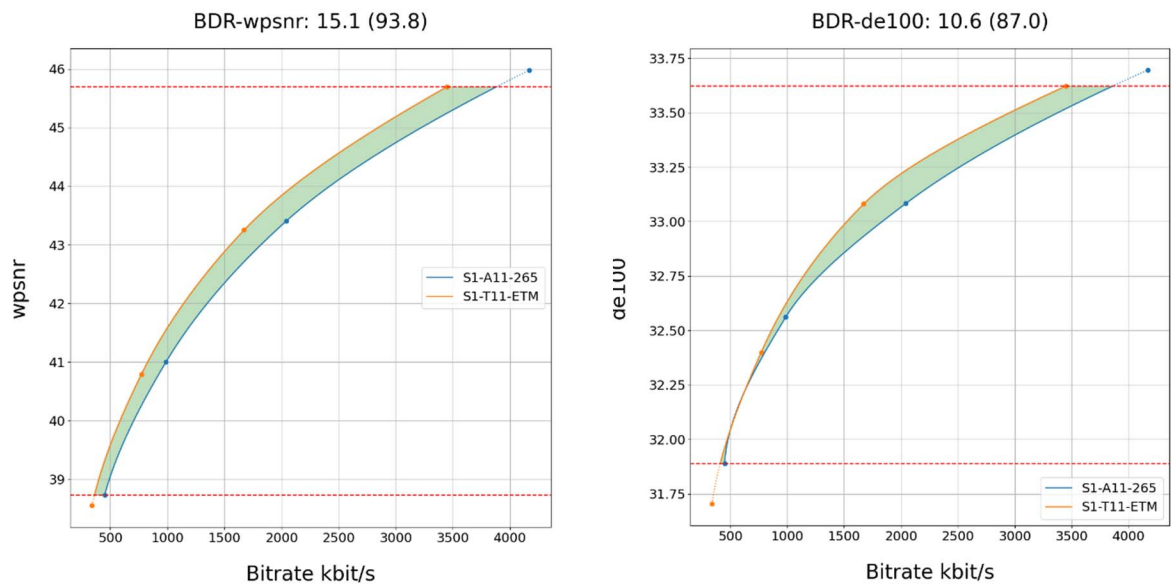


Figure 8.3.4.2-2 Rate-Quality curves and BD rate gain for wpsnr of EVC ETM with S1-ETM-02 against H.265/HEVC HM with configuration S1-HM-02 for reference sequence S1-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/ETM/Characterization/>.

8.3.4.3 Scenario 2: 4K TV

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC HM for Scenario 2 4K TV. In particular,

- Table 8.3.4.3-1 provides the BD rate gain of EVC ETM with S2-ETM-01 against H.265/HEVC HM with configuration S2-HM-01, i.e. with the 4K TV SDR scenario reference sequences

- Table 8.3.4.3-2 provides the BD rate gain of EVC ETM with S2-ETM-02 against H.265/HEVC HM with configuration S2-HM-02, i.e. with the 4K TV HDR scenario reference sequences

Table 8.3.4.3-1 BD rate gain of EVC ETM with S2-ETM-01 against H.265/HEVC HM with configuration S2-HM-01, i.e. with the 4K TV SDR scenario reference sequences

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S2-R01	Brest-Sedof	19.9	18.8	32.6	18.4
S2-R02	Rain Fruits	19.7	20.0	31.1	20.3
S2-R03	Park Joy	16.8	18.0	24.5	17.2
S2-R04	Soccer	24.1	25.2	25.7	23.3
S2-R05	Tunnel Flag	36.2	35.4	41.8	38.5
S2-R06	Boat	16.4	17.0	26.1	15.5
S2-R07	Fountain	13.4	13.9	14.4	12.1
S2-R08	Riverbank	16.7	15.3	21.6	14.1
Minimum		13.4	13.9	14.4	12.1
Maximum		36.2	35.4	41.8	38.5
Average		20.4	20.4	27.2	19.9

Table 8.3.4.3-2 BD rate gain of EVC ETM with S2-ETM-02 against H.265/HEVC HM with configuration S2-HM-02, i.e. with the 4K TV HDR scenario reference sequences

Reference sequence	Name	wpsnr	y_wpsnr	psnr100	de100
S2-R11	Life-Untouched	16.8	18.4	19.3	10.8
S2-R12	Meridian	12.9	12.2	11.5	18.8
S2-R13	Sol-Levante	31.4	25.8	32.7	48.2
S2-R14	Cosmos	26.4	19.5	27.3	59.6
S2-R15	Elevator	24.7	22.9	22.0	25.7
S2-R16	Sparks	21.2	17.9	16.8	35.6
S2-R17	Nocturne	29.5	28.7	26.3	27.2
Minimum		12.9	11.	11.5	10.8
Maximum		31.4	28.7	32.7	59.6
Average		23.3	20.8	22.3	32.3

As an example, Figure 8.3.4.3-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S2-ETM-01 against H.265/HEVC HM with configuration S2-HM-01 for reference sequence S2-R01.

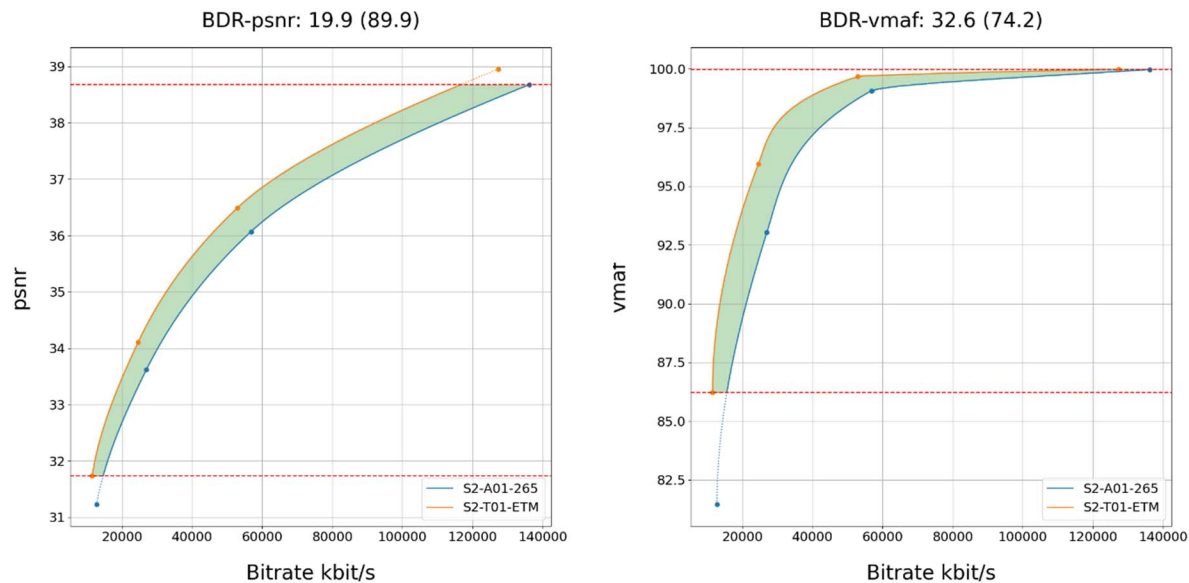


Figure 8.3.4.3-1 Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S2-ETM-01 against H.265/HEVC HM with configuration S2-HM-01 for reference sequence S2-R01

As another example, Figure 8.3.4.3-2 provides Rate-Quality curves and BD rate gain for wpsnr and de100 of EVC ETM with S2-ETM-02 against H.265/HEVC HM with configuration S2-HM-02 for reference sequence S2-R11.

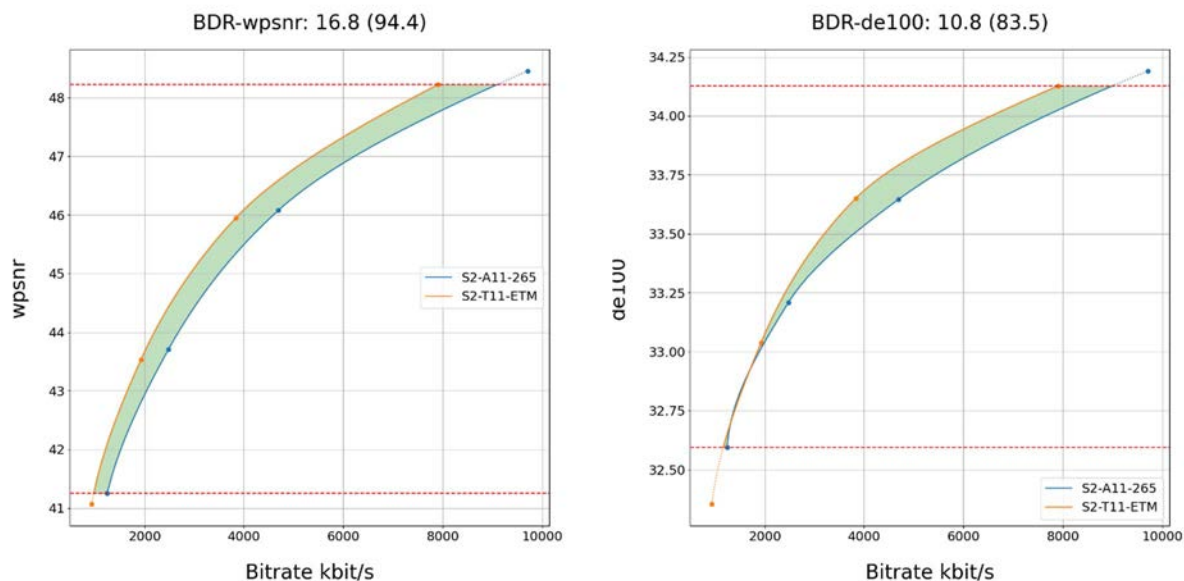


Figure 8.3.4.3-1 Rate-Quality curves and BD rate gain for wpsnr and de100 of EVC ETM with S2-ETM-02 against H.265/HEVC HM with configuration S2-HM-02 for reference sequence S2-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/ETM/Characterization/>.

8.3.4.4 Scenario 3: Screen Content

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC HM for Scenario 3 Screen Content. In particular,

- Table 8.3.4.4-1 provides the BD rate gain of EVC ETM with S3-ETM-01 against H.265/HEVC HM with configuration S3-HM-01, i.e. with the screen content scenario reference sequences and no fixed random access.

- Table 8.3.4.4-2 provides the BD rate gain of EVC ETM with S3-ETM-02 against H.265/HEVC HM with configuration S3-HM-02, i.e. with the screen content scenario reference sequences with fixed random access every second.

Table 8.3.4.4-1 BD rate gain of EVC ETM with S3-ETM-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	23.8	25.1
S3-R02	MovingText2-4K-8bit	24.1	25.5
S3-R03	MovingText2-FullHD-10bit	29.4	33.2
S3-R04	MovingText2-FullHD-8bit	29.6	33.1
S3-R05	TextMixTransitions-4K-10bit	14.8	11.9
S3-R06	TextMixTransitions-4K-8bit	13.2	11.7
S3-R07	TextMixTransitions-FullHD-10bit	19.8	19.7
S3-R08	TextMixTransitions-FullHD-8bit	20.1	19.8
S3-R09	GraphicsMixSimple-4K-10bit	21.5	20.9
S3-R10	GraphicsMixSimple-4K-8bit	21.5	21.0
S3-R11	GraphicsMixSimple-FullHD-10bit	16.7	16.6
S3-R12	GraphicsMixSimple-FullHD-8bit	18.6	18.6
S3-R13	GraphicsMixTransitions-4K-10bit	28.1	27.8
S3-R14	GraphicsMixTransitions-4K-8bit	28.0	27.7
S3-R15	GraphicsMixTransitions-FullHD-10bit	28.0	28.6
S3-R16	GraphicsMixTransitions-FullHD-8bit	28.5	29.1
S3-R17	Mission-Control	27.8	27.8
Minimum		13.2	11.7
Maximum		29.6	33.2
Average		23.1	23.4

Table 8.3.4.4-2 BD rate gain of EVC ETM with S3-ETM-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences fixed random access every second

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	19.6	19.1
S3-R02	MovingText2-4K-8bit	19.8	19.4
S3-R03	MovingText2-FullHD-10bit	27.9	30.1
S3-R04	MovingText2-FullHD-8bit	28.2	30.4
S3-R05	TextMixTransitions-4K-10bit	11.2	7.4
S3-R06	TextMixTransitions-4K-8bit	10.5	7.5
S3-R07	TextMixTransitions-FullHD-10bit	20.3	19.5
S3-R08	TextMixTransitions-FullHD-8bit	19.7	19.1
S3-R09	GraphicsMixSimple-4K-10bit	24.5	24.2
S3-R10	GraphicsMixSimple-4K-8bit	24.5	24.4
S3-R11	GraphicsMixSimple-FullHD-10bit	23.6	24.0
S3-R12	GraphicsMixSimple-FullHD-8bit	24.0	24.5
S3-R13	GraphicsMixTransitions-4K-10bit	24.1	23.8
S3-R14	GraphicsMixTransitions-4K-8bit	24.2	24.2
S3-R15	GraphicsMixTransitions-FullHD-10bit	25.3	25.9
S3-R16	GraphicsMixTransitions-FullHD-8bit	25.4	26.1
S3-R17	Mission-Control	27.5	27.1
Minimum		10.5	7.4
Maximum		28.2	30.4
Average		22.4	22.2

As an example, Figure 8.3.4.4-1 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S3-ETM-01 against H.265/HEVC HM with configuration S3-HM-01 for reference sequences S3-R01 and S3-R17.

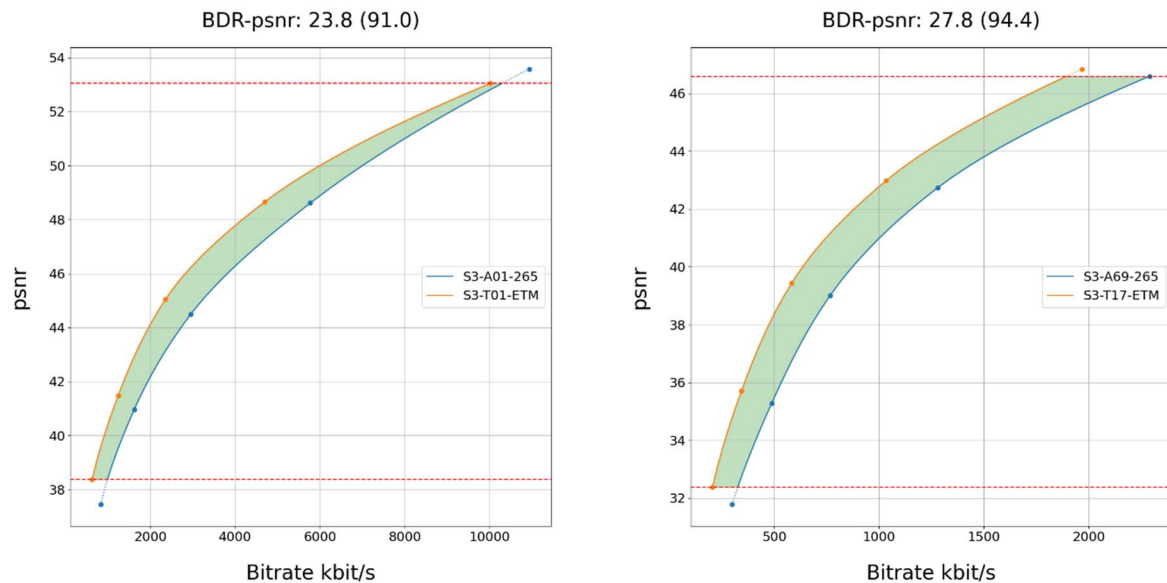


Figure 8.3.4.4-1 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S3-ETM-01 against H.265/HEVC HM with configuration S3-HM-01 for references sequence S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/Characterization/>.

8.3.4.5 Scenario 4: Messaging and Social Sharing

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC HM for Scenario 4 Messaging and Social Sharing. In particular,

- Table 8.3.4.5-1 provides the BD rate gain of EVC ETM with S4-ETM-01 against H.265/HEVC HM with configuration S4-HM-01, i.e. with the messaging and social sharing scenario reference sequences and no fixed random access.
- Table 8.3.4.5-2 provides the BD rate gain of EVC ETM with S4-ETM-02 against H.265/HEVC HM with configuration S4-HM-02, i.e. with the messaging and social sharing scenario reference sequences with fixed random access every second.

Table 8.3.4.5-1 BD rate gain of EVC ETM with S4-ETM-01 against H.265/HEVC HM with configuration S4-HM-01, i.e. with the messaging and social sharing scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	17.0	17.8	17.7	15.6
S4-R02	Vertical-Walking	16.5	17.9	20.5	15.4
S4-R03	Neon-4K	17.8	17.7	22.3	17.7
S4-R04	Skater-4K	31.4	31.7	29.0	31.2
Minimum		16.5	17.7	17.7	15.4
Maximum		31.4	31.7	29.0	31.2
Average		20.7	21.3	22.4	20.0

Table 8.3.4.5-2 BD rate gain of EVC ETM with S4-ETM-02 against H.265/HEVC HM with configuration S4-HM-02, i.e. with the messaging and social sharing scenario reference sequences and fixed random access every second

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	16.4	17.0	18.0	15.2
S4-R02	Vertical-Walking	13.2	14.0	20.0	11.3
S4-R03	Neon-4K	14.6	13.2	19.3	12.7
S4-R04	Skater-4K	28.7	27.5	27.2	25.6
Minimum		13.2	13.2	18.0	11.3
Maximum		28.7	27.5	27.2	25.6
Average		18.2	17.9	21.1	16.2

As an example, Figure 8.3.4.5-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S4-ETM-01 against H.265/HEVC HM with configuration S4-HM-01 for reference sequence S4-R01.

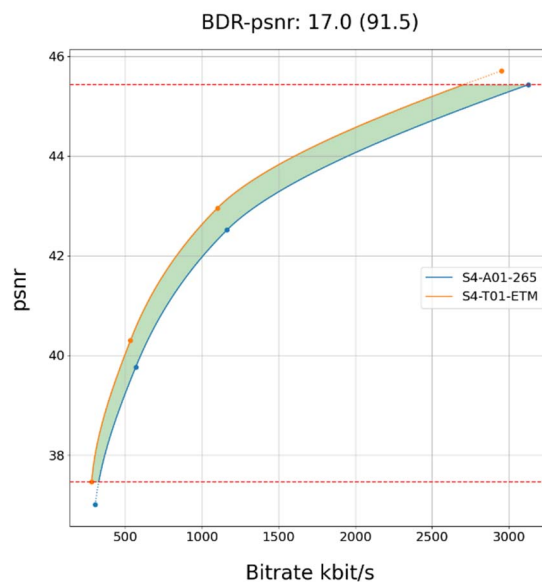


Figure 8.3.4.5-1 Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S4-ETM-01 against H.265/HEVC HM with configuration S4-HM-01 for reference sequence S4-R01

As another example, Figure 8.3.4.5-2 provides Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S4-HM-02 against H.265/HEVC HM with configuration S4-HM-02 for reference sequence S4-R01.

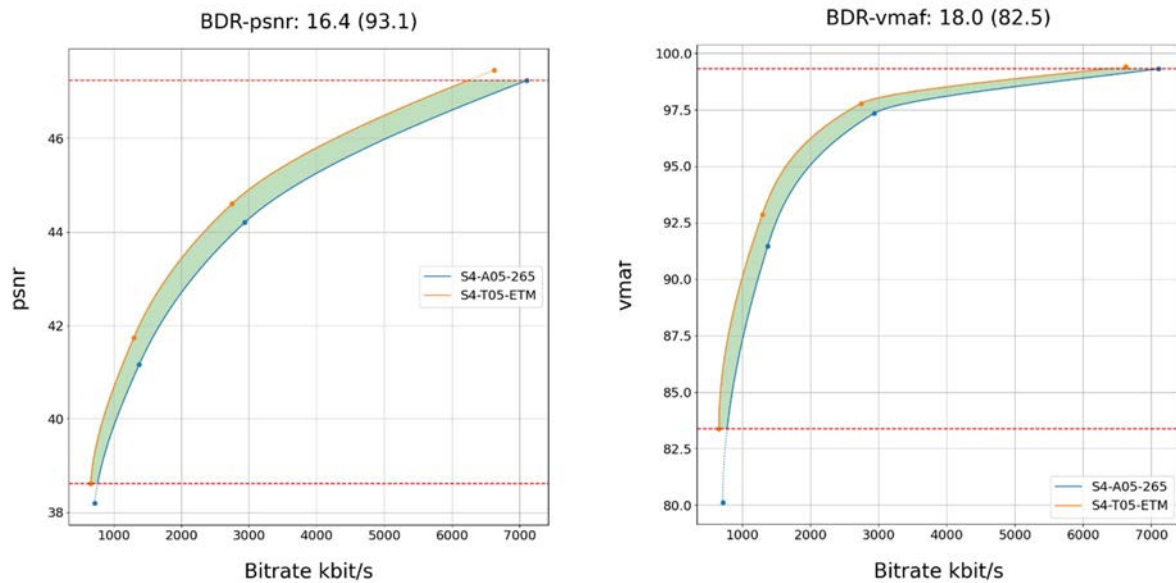


Figure 8.3.4.5-2 Rate-Quality curves and BD rate gain for psnr and vmaf of EVC ETM with S4-ETM-02 against H.265/HEVC HM with configuration S4-HM-02 for reference sequence S4-R01

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/ETM/Characterization/>.

8.3.4.6 Scenario 5: Online Gaming

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC HM for Scenario 5 Online Gaming. In particular,

- Table 8.3.4.6-1 provides the BD rate gain of EVC ETM with S5-ETM-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no fixed random access.
- Table 8.3.4.6-2 provides the BD rate gain of EVC ETM with S5-ETM-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences with fixed random access every second.

Table 8.3.4.6-1 BD rate gain of EVC ETM with S5-ETM-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	17.0	16.7
S5-R02	Baolei-Man	15.1	15.8
S5-R03	Baolei-Woman	20.3	20.7
S5-R04	Baolei-Balloon	27.5	28.3
S5-R05	Baolei-Yard	21.9	22.6
S5-R06	Jianling-Temple	5.7	5.6
S5-R07	Jianling-Beach	13.0	11.6
S5-R08	Heroes-of-the-Storm	15.2	14.6
S5-R09	Project-CARS	20.1	20.0
S5-R10	World-of-WarCraft	20.2	20.0
S5-R11	MineCraft	14.5	14.6
S5-R12	CS-GO	22.0	24.8
S5-R13	StarCraft	15.7	14.6
Minimum		5.7	5.6
Maximum		27.5	28.3
Average		17.6	17.7

Table 8.3.4.6-2 BD rate gain of EVC ETM with S5-ETM-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences and fixed random access every second

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	15.5	15.2
S5-R02	Baolei-Man	13.4	13.6
S5-R03	Baolei-Woman	18.1	18.2
S5-R04	Baolei-Balloon	25.5	26.2
S5-R05	Baolei-Yard	20.9	21.3
S5-R06	Jianling-Temple	2.8	3.0
S5-R07	Jianling-Beach	11.6	10.3
S5-R08	Heroes-of-the-Storm	12.0	11.7
S5-R09	Project-CARS	17.9	16.0
S5-R10	World-of-WarCraft	20.2	20.0
S5-R11	MineCraft	10.2	10.5
S5-R12	CS-GO	26.8	26.8
S5-R13	StarCraft	13.5	13.2
Minimum		2.8	3.0
Maximum		26.8	26.8
Average		16.0	15.8

As an example,

- Figure 8.3.4.6-1 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequences S5-R04 and S5-R11
- Figure 8.3.4.6-2 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11

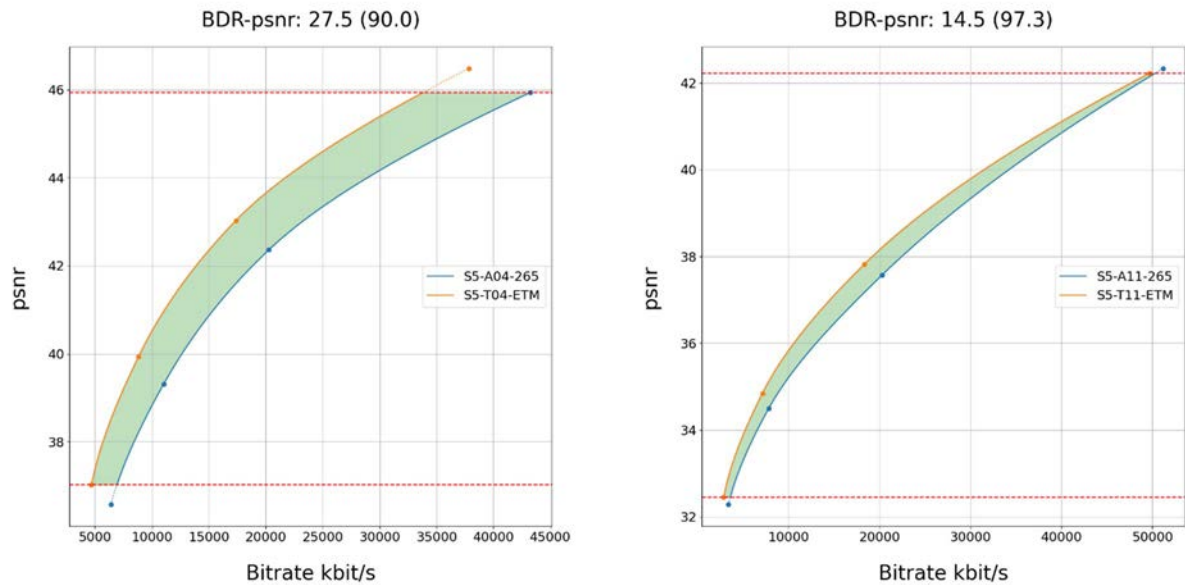


Figure 8.3.4.6-1 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-01 against H.265/HEVC HM with configuration S5-HM-01 for sequences S5-R04 and S5-R11

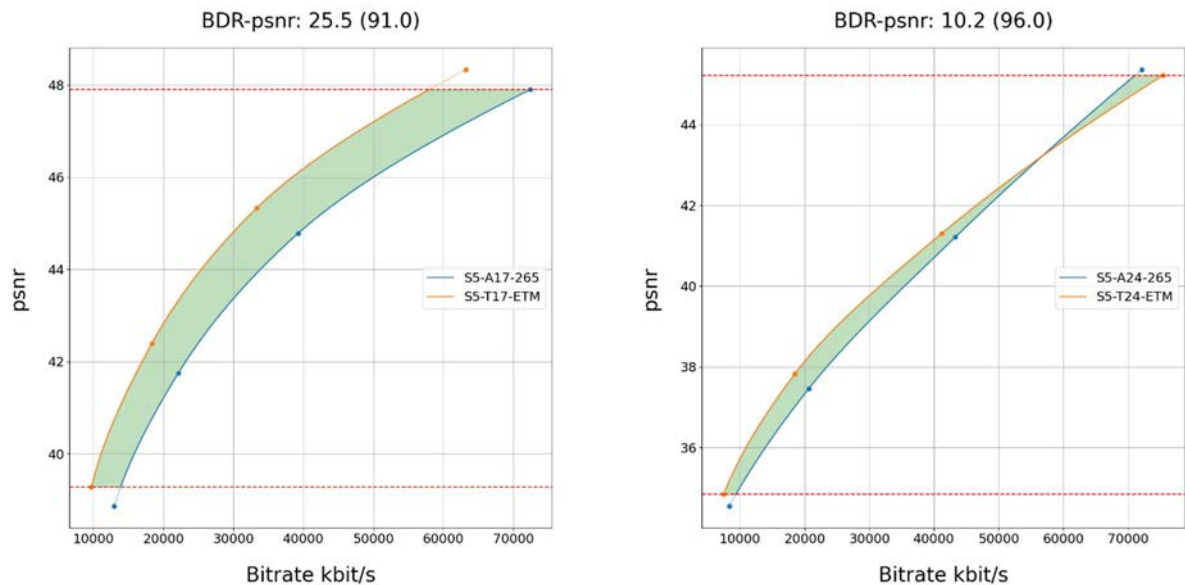


Figure 8.3.4.6-2 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/Characterization/>.

8.3.4.7 Summary

Table 8.3.4.6-1 provides a summary of BD rate gain in psnr and vmaf for SDR and wpsnr and de100 for HDR of EVC ETM against H.265/HEVC HM for different scenarios and configurations.

Table 8.3.4.7-1 Summary of BD rate gain in psnr and vmaf for SDR and wpsnr and de100 for HDR of EVC ETM against H.265/HEVC HM for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr	average vmaf	min vmaf	max vmaf
S1 SDR	18.1	12.2	34.8	25.0	14.1	40.3
S2 SDR	20.4	13.4	36.2	27.2	14.4	41.8
S3 no RA	23.4	13.2	29.6	n/a	n/a	n/a
S3 RA, fixed QP	22.4	10.5	28.2	n/a	n/a	n/a
S4 no RA	20.7	16.5	31.4	22.4	17.7	29.0
S4 RA, fixed QP	18.2	13.2	28.7	21.1	18.0	27.2
S5 no RA	17.6	5.7	27.5	n/a	n/a	n/a
S5 RA, fixed QP	16.0	2.8	26.8	n/a	n/a	n/a
Minimum	16.0	2.8	26.8	21.1	10.7	27.2
Maximum	23.4	16.5	36.2	27.2	18.0	41.8
	average wpsnr	min wpsnr	max wpsnr	average de100	min de100	max de100
S1 HDR	21.21	12.95	27.4	28.9	10.67	60.8
S2 HDR	23.32	12.95	31.4	32.32	10.89	59.6

8.3.5 EVC Characterization against H.265/HEVC SCC

8.3.5.1 Introduction

This clause provides a partial characterization of EVC ETM against H.265/HEVC SCC according to clause 7.2.1. The results provided in clause 6 and 8.3.2 are used for the characterization.

8.3.5.2 Scenario 3: Screen Content

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC SCC for Scenario 3 Screen Content. In particular,

- Table 8.3.5.2-1 provides the BD rate gain of EVC ETM with S3-ETM-01/03 against H.265/HEVC SCC with configuration S3-SCC-01/03, i.e. with the screen content scenario reference sequences and no fixed random access.
- Table 8.3.5.2-2 provides the BD rate gain of EVC ETM with S3-ETM-02/04 against H.265/HEVC SCC with configuration S3-SCC-02/04, i.e. with the screen content scenario reference sequences fixed random access every second.

Table 8.3.5.2-1 BD rate gain of EVC ETM with S3-ETM-01/03 against H.265/HEVC SCC with configuration S3-SCC-01/03, i.e. with the screen content scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	5.8	10.3
S3-R02	MovingText2-4K-8bit	6.6	11.2
S3-R03	MovingText2-FullHD-10bit	21.5	26.8
S3-R04	MovingText2-FullHD-8bit	21.3	26.5
S3-R05	TextMixTransitions-4K-10bit	-35.2	-32.6
S3-R06	TextMixTransitions-4K-8bit	-38.8	-33.3
S3-R07	TextMixTransitions-FullHD-10bit	-3.6	0.8
S3-R08	TextMixTransitions-FullHD-8bit	-4	0.6
S3-R09	GraphicsMixSimple-4K-10bit	-39.1	-38.5
S3-R10	GraphicsMixSimple-4K-8bit	-39.3	-38.4
S3-R11	GraphicsMixSimple-FullHD-10bit	-15.1	-13.4
S3-R12	GraphicsMixSimple-FullHD-8bit	-12.9	-11.1
S3-R13	GraphicsMixTransitions-4K-10bit	15.9	16.5
S3-R14	GraphicsMixTransitions-4K-8bit	15.6	16.5
S3-R15	GraphicsMixTransitions-FullHD-10bit	22.3	24.2
S3-R16	GraphicsMixTransitions-FullHD-8bit	22.2	24.2
S3-R17	Mission-Control	-7.5	-7.6
Minimum		-39.3	-38.5
Maximum		22.3	26.8
Average		-3.8	-1.0

Table 8.3.5.2-2 BD rate gain of EVC ETM with S3-ETM-02/04 against H.265/HEVC SCC with configuration S3-SCC-02/04, i.e. with the screen content scenario reference sequences fixed random access every second

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	2.4	4.4
S3-R02	MovingText2-4K-8bit	2.8	4.9
S3-R03	MovingText2-FullHD-10bit	18.7	22.1
S3-R04	MovingText2-FullHD-8bit	18.9	22.6
S3-R05	TextMixTransitions-4K-10bit	-63.9	-63.6
S3-R06	TextMixTransitions-4K-8bit	-65.9	-63.7
S3-R07	TextMixTransitions-FullHD-10bit	-16.1	-12.5
S3-R08	TextMixTransitions-FullHD-8bit	-17.0	-13.2
S3-R09	GraphicsMixSimple-4K-10bit	-44.9	-44.1
S3-R10	GraphicsMixSimple-4K-8bit	-44.6	-42.8
S3-R11	GraphicsMixSimple-FullHD-10bit	-12.1	-9.8
S3-R12	GraphicsMixSimple-FullHD-8bit	-11.3	-8.7
S3-R13	GraphicsMixTransitions-4K-10bit	-3.1	-2.5
S3-R14	GraphicsMixTransitions-4K-8bit	-2.9	-1.5
S3-R15	GraphicsMixTransitions-FullHD-10bit	10.3	12.5
S3-R16	GraphicsMixTransitions-FullHD-8bit	10.1	12.7
S3-R17	Mission-Control	-12.8	-13.3
Minimum		-65.9	-63.7
Maximum		18.9	22.6
Average		-13.6	-11.6

As an example,

- Figure 8.3.5.2-1 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S3-ETM-03 against H.265/HEVC SCC with configuration S3-SCC-03 for reference sequences S3-R01 and S3-R17
- Figure 8.3.5.2-2 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S3-ETM-04 against H.265/HEVC SCC with configuration S3-SCC-04 for reference sequences S3-R01 and S3-R17

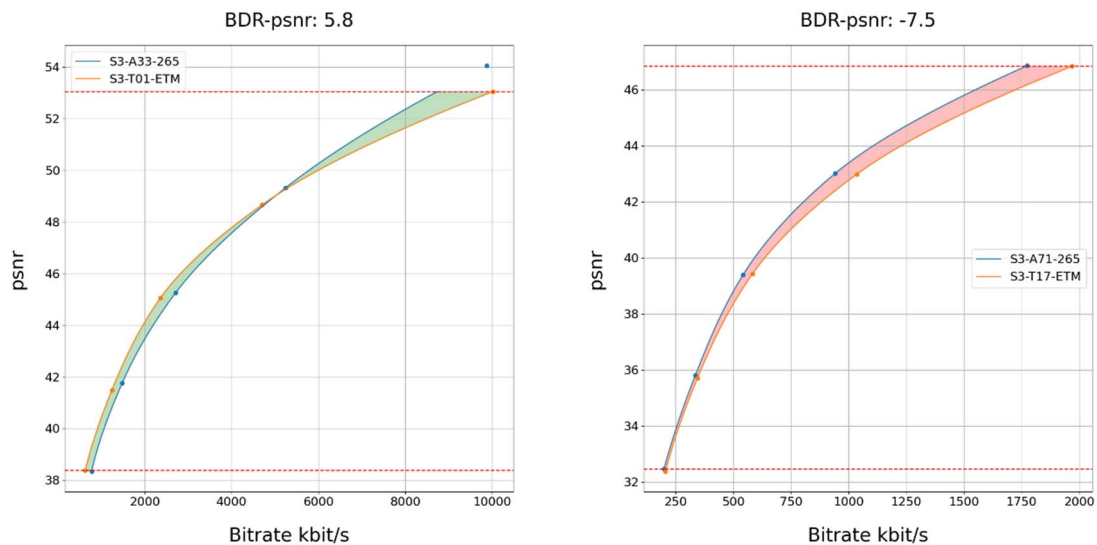


Figure 8.3.5.2-1 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S3-SCC-03 against H.265/HEVC SCC with configuration S3-SCC-03 for reference sequences S3-R01 and S3-R17

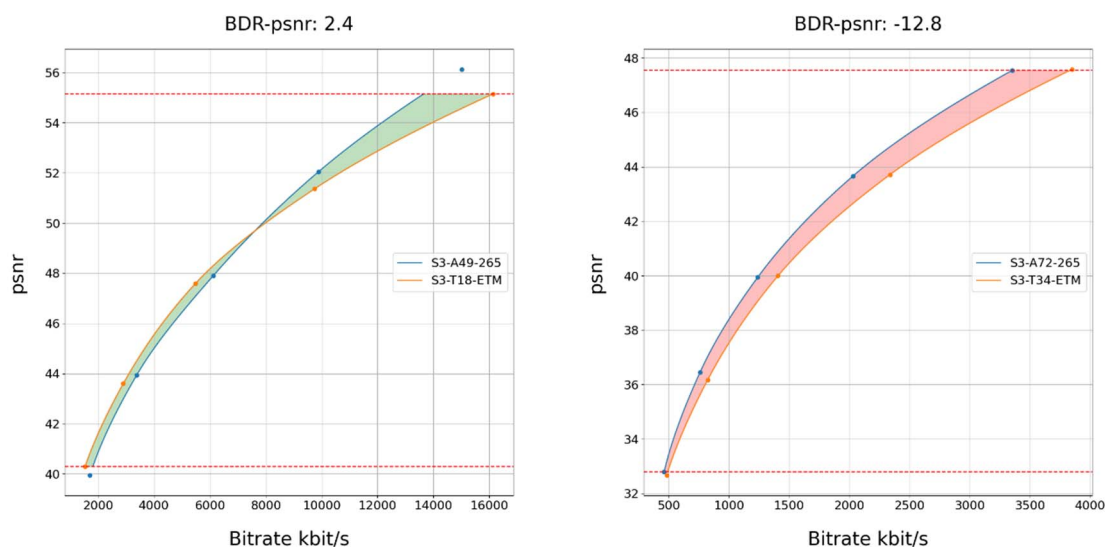


Figure 8.3.5.2-2 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S3-ETM-04 against H.265/HEVC SCC with configuration S3-SCC-04 for reference sequences S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/ETM/Characterization/>.

8.3.5.3 Scenario 5: Online Gaming

This clause provides characterization of EVC ETM mode configurations against H.265/HEVC SCC for Scenario 5 Online Gaming. In particular,

- Table 8.3.5.3-1 provides the BD rate gain of EVC ETM with S5-ETM-01 against H.265/HEVC SCC with configuration S5-SCC-01, i.e. with the online gaming scenario reference sequences and no fixed random access.
- Table 8.3.5.3-2 provides the BD rate gain of EVC ETM with S5-ETM-02 against H.265/HEVC SCC with configuration S5-SCC-02, i.e. with the online gaming scenario reference sequences and fixed random access every second.

Table 8.3.5.3-1 BD rate gain of EVC ETM with S5-ETM-01 against H.265/HEVC SCC with configuration S5-SCC-01, i.e. with the online gaming scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	16.8	16.8
S5-R02	Baolei-Man	14.8	15.8
S5-R03	Baolei-Woman	19.5	20.0
S5-R04	Baolei-Balloon	26.9	27.8
S5-R05	Baolei-Yard	21.7	22.5
S5-R06	Jianling-Temple	3.1	3.5
S5-R07	Jianling-Beach	9.2	8.7
S5-R08	Heroes-of-the-Storm	13.1	12.8
S5-R09	Project-CARS	17.4	18.1
S5-R10	World-of-WarCraft	18.7	19.3
S5-R11	MineCraft	-2.5	2.6
S5-R12	CS-GO	14.6	19.6
S5-R13	StarCraft	12.3	12.6
Minimum		-2.5	2.6
Maximum		26.9	27.8
Average		14.3	15.4

Table 8.3.5.3-2 BD rate gain of EVC ETM with S5-ETM-02 against H.265/HEVC SCC with configuration S5-SCC-02, i.e. with the online gaming scenario reference sequences and fixed random access every second

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	14.6	14.5
S5-R02	Baolei-Man	12.2	12.8
S5-R03	Baolei-Woman	15.9	16.4
S5-R04	Baolei-Balloon	24.8	25.6
S5-R05	Baolei-Yard	20.7	21.3
S5-R06	Jianling-Temple	0.1	0.8
S5-R07	Jianling-Beach	5.1	4.9
S5-R08	Heroes-of-the-Storm	8.0	8.0
S5-R09	Project-CARS	14.5	13.5
S5-R10	World-of-WarCraft	15.5	15.9
S5-R11	MineCraft	-8.6	-4.0
S5-R12	CS-GO	16.9	19.4
S5-R13	StarCraft	7.5	8.6
Minimum		-8.6	-4.0
Maximum		24.8	25.6
Average		11.3	12.1

As an example,

- Figure 8.3.5.3-1 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-01 against H.265/HEVC SCC with configuration S5-SCC-01 for reference sequences S5-R01 and S5-R04
- Figure 8.3.5.3-2 provides Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-02 against H.265/HEVC SCC with configuration S5-SCC-02 for reference sequences S5-R01 and S5-R04

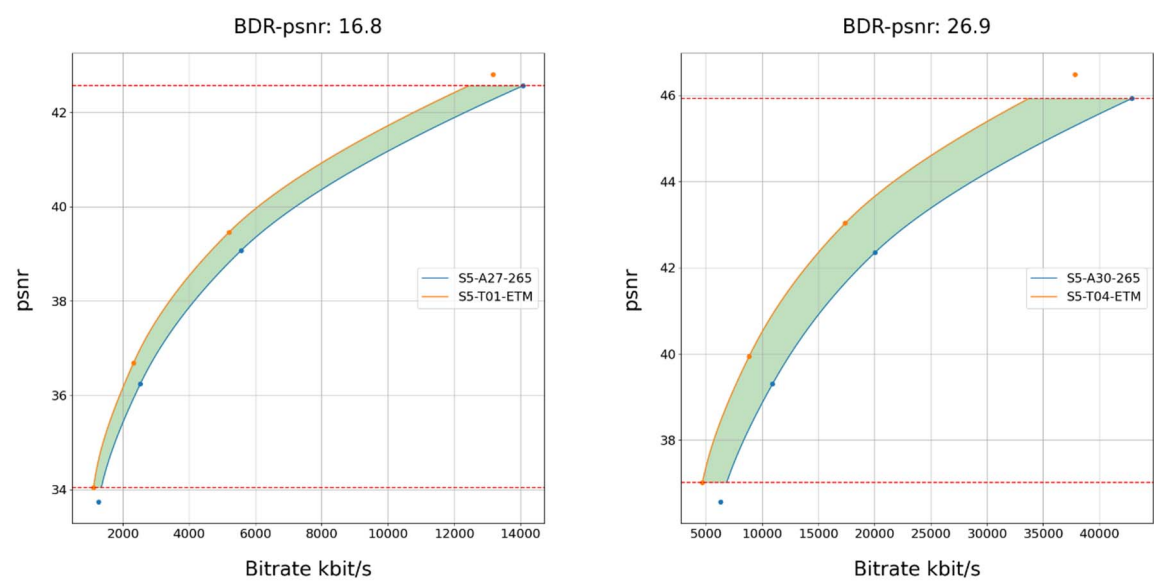


Figure 8.3.5.3-1 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-01 against H.265/HEVC SCC with configuration S5-SCC-01 for reference sequences S5-R01 and S5-R04

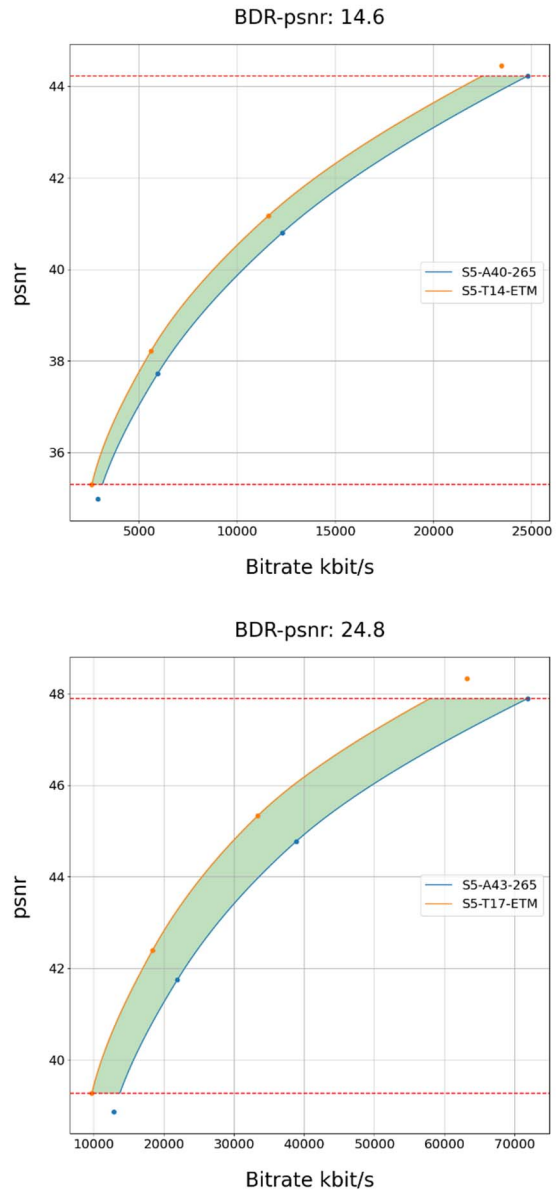


Figure 8.3.5.3-2 Rate-Quality curves and BD rate gain for psnr of EVC ETM with S5-ETM-02 against H.265/HEVC SCC with configuration S5-SCC-02 for reference sequences S5-R01 and S5-R04

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/ETM/Characterization/>.

8.3.5.4 Summary

Table 8.3.5.4-1 provides a summary of BD rate gain in psnr of EVC ETM against H.265/HEVC SCC for different scenarios and configurations.

Table 8.3.5.4-1 Summary of BD rate gain in psnr of EVC ETM against H.265/HEVC SCC for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr
S3 no RA	-3.8	-39.3	22.3
S3 RA, fixed QP	-13.6	-65.9	18.9
S5 no RA	14.3	-2.5	26.9
S5 RA, fixed QP	11.3	-8.6	24.8
Minimum	-13.6	-65.9	18.9
Maximum	14.3	-2.5	26.9

8.4 AOMedia Video 1 (AV1)

8.4.1 Overview

AV1 (AOMedia Video 1) [68] is a video coding format developed by the Alliance for Open Media (AOMedia). AOMedia is a consortium founded in 2015 that, in July 2021, includes 47 companies from across the web media ecosystem, including semiconductor developers, video on demand providers, video content producers, software development companies and web browser vendors. In addition to the AV1 bitstream specification, AOMedia makes available a reference software implementation of the AV1 video codec [69].

AV1 is used today to implement some of the relevant 5G video service scenarios listed in clause 6. Some of the references documenting motivation for the 4K-TV scenario (clause 6.3.1 [17] [18] [19] [20]) and the Screen Content Scenario (clause 6.4.1 [26] [41]) discuss implementations that support AV1 today.

AV1 was designed to support features required by real-time applications, including high resolutions, high dynamic range, wide colour gamut formats and high frame rates. It fully supports the ITU-R BT.2100 recommendation [16], as well as static and dynamic metadata for HDR applications, such as the HDR10+ format. It can also support up to 12 bits of precision per colour sample as well as the 4:4:4 chroma sampling format.

AV1 defines three profiles for decoders. The “Main”, “High” and “Professional” profiles, specified in Annex A of [68]. The “Main” profile allows for a bit depth of 8 bits or 10 bits per sample with 4:0:0 (greyscale) and 4:2:0 (quarter) chroma sampling. The “High” profile further adds support for 4:4:4 chroma sampling (no subsampling). The “Professional” profile extends capabilities to fully support 4:0:0, 4:2:0, 4:2:2 (half) and 4:4:4 chroma sub-sampling with 8-, 10-, and 12-bit colour depths.

8.4.2 Test Configurations and Results for AV1

8.4.2.1 Introduction

The reference software for AV1 is built from the AV1 codec library (libaom). It is used to build two applications – aomenc and aomdec. General instructions for building libaom can be found here:

<https://aomedia.googlesource.com/aom#building-the-library-and-applications>

The AV1 codec library has multiple configuration options. These come in two varieties - build system configuration options and codec configuration options. Both option types are set at built time. The configurations to be used for 3GPP testing are:

```
-DCMAKE_BUILD_TYPE=Release
-DCONFIG_DOCS=0
-DCONFIG_SHARED=0
-DENABLE_TESTS=0
-DCONFIG_UNIT_TESTS=0
-DCONFIG_AV1_HighbitDepth=1
```

The `libaom` implementation provided for the tests depends on the scenario and is documented individually for each scenario.

Several changes had to be introduced to the `libaom` reference software to match the requirements and needs of 3GPP and for this test. A specific release of that software containing these changes, which should be used for the 3GPP testing, can be found by using the following git release tag:

`3gpp-2021-10-15-4`

The AV1 encoder that is built using the AV1 libraries is `aomenc`. Command line options are used to configure the encoding performed by `aomenc`. A complete description of all command line options used to generate the bitstreams referenced in this technical report can be found here [74].

Depending on the testing scenario, `libaom` needs to be configured differently with appropriate command line configuration settings [73]. Such configuration settings are documented individually and provided in independent Linux shell script files for convenience. These attached configuration scripts take arguments to generate the tuples. For example, `S1-AV1-01.sh`, `S5-AV1-SCC-01.sh`, etc. Arguments to be used with each configuration script are listed in the sections, below.

Note that based on the general configuration restrictions in clause 5.6 and the permitted use of residual energy/distortion-based decisions that can adapt the coding type of the current frame, overlay frames in AV1 are permitted.

Table 8.4.2.1-1 provides the common command line options used by all of AV1 configuration file scripts, along with an explanation of their use.

Table 8.4.2.1-1 Common command line options used by all of AV1 configuration file scripts, along with an explanation of their use

<code>--cpu-used=0</code>	Instruct the encoder to use settings to achieve the best compression efficiency.
<code>--enable-keyframe-filtering=0</code>	Disable temporal filtering for Key frame
<code>--enable-tpl-model=0</code>	disable RDO based temporal layer model so that fixed hierarchy is used.
<code>--end-usage=q</code>	Instruct encoder to use the constant quality mode
<code>--frame-parallel=0</code>	disable the support for parallel decoding, to achieve the best compression efficiency.
<code>--gf-min-pyr-height=5</code> <code>--gf-max-pyr-height=5</code>	set the number of hierarchical layers to be 6 [0-5]
<code>--passes=1</code>	Use single pass encoding
<code>--tile-columns=0</code>	disable column tiles, so that the entire frame is encoded as a single tile to achieve the best compression efficiency.
<code>--codec=av1</code>	Specify that the Alliance for Open Media codec version to be used is AV1
<code>--verbose, -v</code>	display encoding parameters for information only.
<code>--psnr</code>	enabled encoder to calculate PSNR using a reconstructed frame after encoding. This is for information only.
<code>--i420</code>	all input video is in 420 color format
<code>--input-bit-depth=10</code>	specifies the bit depth of the input video
<code>--bit-depth=10</code>	specifies the bit depth of the encoded video to be 10 bit. since all input videos specified by 3GPP are converted to 10 bit before encoding, so both input bit depth and encoding bit depth are specified to be 10 bit.
<code>--threads=1</code>	using single threading mode for encoding to achieve the best compression efficiency.
<code>--obu</code>	Open Bitstream Unit (OBU) container format is used as the output bitstream container format.
<code>--fps</code>	Specifies the frame rate of the input video. Frame rate value is represented as rational number as "numerator/denominator". For example, if the frame rate is 29.97, 30000/1001 should be used. If frame rate is 59.94, 60000/1001 should be used. If frame rate is 30, 30000/1000 should be used.
<code>--disable-kf</code>	disable scene cut detection, which was enabled by default by the encoder when command line option <code>lag-in-frames > 19</code>

8.4.2.2 Scenario 1: Full HD Streaming

8.4.2.2.1 Overview

Table 8.4.2.2.1-1 provides an overview of the AV1 test tuples. For provided bitstreams, the AV1 encoder aomenc is built from the libaom libraries using the tag provided in the introduction. Keys are identified to refer to the bitstreams in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1/streams.csv>.

Table 8.4.2.2.1-1 Test Tuple generation with AV1 for Full HD Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S1-T01-AV1	8.4.2.2.3	S1-R1	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T01-AV1-<QP>
S1-T02-AV1	8.4.2.2.3	S1-R2	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T02-AV1-<QP>
S1-T03-AV1	8.4.2.2.3	S1-R3	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T03-AV1-<QP>
S1-T04-AV1	8.4.2.2.3	S1-R4	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T04-AV1-<QP>
S1-T05-AV1	8.4.2.2.3	S1-R5	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T05-AV1-<QP>
S1-T06-AV1	8.4.2.2.3	S1-R6	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T06-AV1-<QP>
S1-T07-AV1	8.4.2.2.3	S1-R7	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T07-AV1-<QP>
S1-T08-AV1	8.4.2.2.3	S1-R8	aomenc <tag>	S1-AV1-01	QP: [27,39,49,59]	S1-T08-AV1-<QP>
S1-T11-AV1	8.4.2.2.4	S1-R11	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T11-AV1-<QP>
S1-T12-AV1	8.4.2.2.4	S1-R12	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T12-AV1-<QP>
S1-T13-AV1	8.4.2.2.4	S1-R13	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T13-AV1-<QP>
S1-T14-AV1	8.4.2.2.4	S1-R14	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T14-AV1-<QP>
S1-T15-AV1	8.4.2.2.4	S1-R15	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T15-AV1-<QP>
S1-T16-AV1	8.4.2.2.4	S1-R16	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T16-AV1-<QP>
S1-T17-AV1	8.4.2.2.4	S1-R17	aomenc <tag>	S1-AV1-02	QP: [27,39,49,59]	S1-T17-AV1-<QP>

8.4.2.2.2 Common Parameters and Settings

For both SDR and HDR the common Scenario 1 command line options are provided in Table 8.4.2.2.2-1.

Table 8.4.2.2.2-1 Common Scenario 1 command line options

--auto-alt-ref=1	parameter to specify how alternative reference frames are determined in random access configuration. only 1 is supported.
--lag-in-frames=35	This parameter is typically set to be the sub-GOP size + 3. Since sub-GOP size for random access is 32, this parameter is set to be 35. This command line argument to the configuration script represents the maximum number of input frames to buffer or look ahead.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--fwd-kf-dist=<IntraPeriod>	This command line argument to the configuration script is only used in open GOP scenarios. It sets the distance between successive forward keyframes. Hierarchical prediction is enabled when sub-GOP size and hierarchical layers are specified through other parameters.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32 for random-access content.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

IntraPeriod: Intra Period aligned with GOPSize such that approximately 1 second is achieved, i.e.

- "frameRate": 23.98 or 24.0 or 25 or 30 => IntraPeriod set to 32,
- "frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64

8.4.2.2.3 S1-AV1-01: SDR Settings

For SDR content the following command line option is used.

--deltaq-mode=0

disable block based adaptive quantization, so all blocks within a frame use the same quantization parameter

The following command line is used for all SDR encodes:

S1-AV1-01.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input>
<output>

8.4.2.2.4 S1-AV1-02: HDR PQ Settings

For SDR content the following command line option is used.

--deltaq-mode=5

enable chroma QP offset adjustment for HDR video. Only frame level chroma QP offset is enabled.

--chroma-sample-position=colocated

specify chroma sample position to be colocated

The following command line is used for all HDR encodes:

S1-AV1-02.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input>
<output>

8.4.2.2.5 AV1 Test Results

AV1 test streams are provided according to the key system here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1>

AV1 test metrics are provided with the appropriate keys as defined in Table 8.4.2.2.1-1. The csv files are located here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1/cross-check.csv>.

Based on these cross-check results, the verification status for the AV1 test streams is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1/verification.csv> and Table 8.4.2.2.5-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.4.2.2.5-1 Verification status of AV1 test streams for Full HD Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S1-T01-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T02-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T03-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T04-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T05-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T06-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T07-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T08-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T11-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T12-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T13-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T14-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T15-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T16-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S1-T17-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.4.2.3 Scenario 2: 4K-TV

8.4.2.3.1 Overview

Table 8.4.2.3.1-1 provides an overview of the AV1 test tuples. For provided bitstreams, the AV1 encoder `aomenc` is built from the `libaom` libraries using the tag provided in the introduction. Keys are identified to refer to the bitstreams in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/AV1/streams.csv>.

Table 8.4.2.3.1-1 Test Tuple generation with AV1 for 4K-TV Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S2-T01-AV1	8.4.2.3.3	S2-R1	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T01-AV1-<QP>
S2-T02-AV1	8.4.2.3.3	S2-R2	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T02-AV1-<QP>
S2-T03-AV1	8.4.2.3.3	S2-R3	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T03-AV1-<QP>
S2-T04-AV1	8.4.2.3.3	S2-R4	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T04-AV1-<QP>
S2-T05-AV1	8.4.2.3.3	S2-R5	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T05-AV1-<QP>
S2-T06-AV1	8.4.2.3.3	S2-R6	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T06-AV1-<QP>
S2-T07-AV1	8.4.2.3.3	S2-R7	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T07-AV1-<QP>
S2-T08-AV1	8.4.2.3.3	S2-R8	aomenc <tag>	S2-AV1-01	QP: [27,39,49,59]	S2-T08-AV1-<QP>
S2-T11-AV1	8.4.2.3.4	S2-R11	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T11-AV1-<QP>
S2-T12-AV1	8.4.2.3.4	S2-R12	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T12-AV1-<QP>
S2-T13-AV1	8.4.2.3.4	S2-R13	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T13-AV1-<QP>
S2-T14-AV1	8.4.2.3.4	S2-R14	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T14-AV1-<QP>
S2-T15-AV1	8.4.2.3.4	S2-R15	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T15-AV1-<QP>
S2-T16-AV1	8.4.2.3.4	S2-R16	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T16-AV1-<QP>
S2-T17-AV1	8.4.2.3.4	S2-R17	aomenc <tag>	S2-AV1-02	QP: [27,39,49,59]	S2-T17-AV1-<QP>

8.4.2.3.2 Common Parameters and Settings

For both SDR and HDR the following common Scenario 2 command line options are provided in Table 8.4.2.3.2-1.

Table 8.4.2.3.2-1 Common Scenario 2 command line options

--auto-alt-ref=1	parameter to specify how alternative reference frames are determined in random access configuration. only 1 is supported.
--lag-in-frames=35	This parameter is typically set to be the sub-GOP size + 3. Since sub-GOP size for random access is 32, this parameter is set to be 35. This command line argument to the configuration script represents the maximum number of input frames to buffer or look ahead.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--fwd-kf-dist=<IntraPeriod>	This command line argument to the configuration script is only used in open GOP scenarios. It sets the distance between successive forward keyframes. Hierarchical prediction is enabled when sub-GOP size and hierarchical layers are specified through other parameters.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32 for all random-access content.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

IntraPeriod: Intra Period aligned with GOPSize such that approximately 1 second is achieved, i.e.

- "frameRate": 23.98 or 24.0 or 25 or 30 => IntraPeriod set to 32,
- "frameRate": 50.0 or 59.94 or 60 => IntraPeriod set to 64

8.4.2.3.3 S2-AV1-01: SDR Settings

For SDR content the following command line option is used.

```
--deltaq-mode=0           disable block based adaptive quantization, so all blocks within a frame use the same
                           quantization parameter
```

The following command line is used for all SDR encodes:

```
S2-AV1-01.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input>
<output>
```

8.4.2.3.4 S2-AV1-02: HDR PQ Settings

For SDR content the following command line option is used.

```
--deltaq-mode=5           enable chroma QP offset adjustment for HDR video. Only frame level chroma QP offset is
                           enabled.
--chroma-sample-position=colocated specify chroma sample position to be colocated
```

The following command line is used for all HDR encodes

```
S2-AV1-02.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input>
<output>
```

8.4.2.3.5 AV1 Test Results

AV1 test streams are provided according to the key system here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/AV1>

AV1 test metrics are provided with the appropriate keys as defined in Table 8.4.2.3.1-1. The csv files are located here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/AV1/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/AV1/cross-check.csv>.

Based on these cross-check results, the verification status for AV1 test streams is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/AV1/verification.csv> and Table 8.4.2.3.5-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.4.2.3.5-1 Verification status of AV1 test streams for 4K TV Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S2-T01-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T02-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T03-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T04-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T05-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T06-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T07-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T08-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T11-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T12-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T13-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T14-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T15-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T16-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S2-T17-AV1	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.4.2.4 Scenario 3: Screen Content Scenario

8.4.2.4.1 Overview

Table 8.4.2.4.1-1 provides an overview of the AV1 test tuples. For provided bitstreams, the AV1 encoder aomenc is built from the libaom libraries using the tag provided in the introduction. Keys are identified to refer to the bitstreams in the context of the scenario.

The details are also provided here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/streams.csv>.

Table 8.4.2.4.1-1 Test Tuple generation with AV1 for Screen Content Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S3-T01-AV1	8.4.2.4.3	S3-R01	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T01-AV1-<QP>
S3-T02-AV1	8.4.2.4.3	S3-R02	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T02-AV1-<QP>
S3-T03-AV1	8.4.2.4.3	S3-R03	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T03-AV1-<QP>
S3-T04-AV1	8.4.2.4.3	S3-R04	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T04-AV1-<QP>
S3-T05-AV1	8.4.2.4.3	S3-R05	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T05-AV1-<QP>
S3-T06-AV1	8.4.2.4.3	S3-R06	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T06-AV1-<QP>
S3-T07-AV1	8.4.2.4.3	S3-R07	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T07-AV1-<QP>
S3-T08-AV1	8.4.2.4.3	S3-R08	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T08-AV1-<QP>
S3-T09-AV1	8.4.2.4.3	S3-R09	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T09-AV1-<QP>
S3-T10-AV1	8.4.2.4.3	S3-R10	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T10-AV1-<QP>
S3-T11-AV1	8.4.2.4.3	S3-R11	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T11-AV1-<QP>
S3-T12-AV1	8.4.2.4.3	S3-R12	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T12-AV1-<QP>
S3-T13-AV1	8.4.2.4.3	S3-R13	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T13-AV1-<QP>
S3-T14-AV1	8.4.2.4.3	S3-R14	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T14-AV1-<QP>
S3-T15-AV1	8.4.2.4.3	S3-R15	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T15-AV1-<QP>
S3-T16-AV1	8.4.2.4.3	S3-R16	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T16-AV1-<QP>
S3-T17-AV1	8.4.2.4.4	S3-R01	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T17-AV1-<QP>
S3-T18-AV1	8.4.2.4.4	S3-R02	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T18-AV1-<QP>
S3-T19-AV1	8.4.2.4.4	S3-R03	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T19-AV1-<QP>
S3-T20-AV1	8.4.2.4.4	S3-R04	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T20-AV1-<QP>
S3-T21-AV1	8.4.2.4.4	S3-R05	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T21-AV1-<QP>
S3-T22-AV1	8.4.2.4.4	S3-R06	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T22-AV1-<QP>
S3-T23-AV1	8.4.2.4.4	S3-R07	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T23-AV1-<QP>
S3-T24-AV1	8.4.2.4.4	S3-R08	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T24-AV1-<QP>
S3-T25-AV1	8.4.2.4.4	S3-R09	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T25-AV1-<QP>
S3-T26-AV1	8.4.2.4.4	S3-R10	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T26-AV1-<QP>
S3-T27-AV1	8.4.2.4.4	S3-R11	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T27-AV1-<QP>
S3-T28-AV1	8.4.2.4.4	S3-R12	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T28-AV1-<QP>
S3-T29-AV1	8.4.2.4.4	S3-R13	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T29-AV1-<QP>
S3-T30-AV1	8.4.2.4.4	S3-R14	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T30-AV1-<QP>
S3-T31-AV1	8.4.2.4.4	S3-R15	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T31-AV1-<QP>
S3-T32-AV1	8.4.2.4.4	S3-R16	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T32-AV1-<QP>
S3-T33-AV1	8.4.2.4.5	S3-R01	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T33-AV1-<QP>
S3-T34-AV1	8.4.2.4.5	S3-R02	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T34-AV1-<QP>
S3-T35-AV1	8.4.2.4.5	S3-R03	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T35-AV1-<QP>
S3-T36-AV1	8.4.2.4.5	S3-R04	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T36-AV1-<QP>
S3-T37-AV1	8.4.2.4.5	S3-R05	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T37-AV1-<QP>
S3-T38-AV1	8.4.2.4.5	S3-R06	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T38-AV1-<QP>
S3-T39-AV1	8.4.2.4.5	S3-R07	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T39-AV1-<QP>
S3-T40-AV1	8.4.2.4.5	S3-R08	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T40-AV1-<QP>
S3-T41-AV1	8.4.2.4.5	S3-R09	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T41-AV1-<QP>
S3-T42-AV1	8.4.2.4.5	S3-R10	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T42-AV1-<QP>
S3-T43-AV1	8.4.2.4.5	S3-R11	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T43-AV1-<QP>
S3-T44-AV1	8.4.2.4.5	S3-R12	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T44-AV1-<QP>
S3-T45-AV1	8.4.2.4.5	S3-R13	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T45-AV1-<QP>
S3-T46-AV1	8.4.2.4.5	S3-R14	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T46-AV1-<QP>
S3-T47-AV1	8.4.2.4.5	S3-R15	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T47-AV1-<QP>
S3-T48-AV1	8.4.2.4.5	S3-R16	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T48-AV1-<QP>
S3-T49-AV1	8.4.2.4.6	S3-R01	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T49-AV1-<QP>
S3-T50-AV1	8.4.2.4.6	S3-R02	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T50-AV1-<QP>
S3-T51-AV1	8.4.2.4.6	S3-R03	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T51-AV1-<QP>
S3-T52-AV1	8.4.2.4.6	S3-R04	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T52-AV1-<QP>
S3-T53-AV1	8.4.2.4.6	S3-R05	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T53-AV1-<QP>
S3-T54-AV1	8.4.2.4.6	S3-R06	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T54-AV1-<QP>
S3-T55-AV1	8.4.2.4.6	S3-R07	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T55-AV1-<QP>
S3-T56-AV1	8.4.2.4.6	S3-R08	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T56-AV1-<QP>

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S3-T57-AV1	8.4.2.4.6	S3-R09	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T57-AV1-<QP>
S3-T58-AV1	8.4.2.4.6	S3-R10	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T58-AV1-<QP>
S3-T59-AV1	8.4.2.4.6	S3-R11	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T59-AV1-<QP>
S3-T60-AV1	8.4.2.4.6	S3-R12	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T60-AV1-<QP>
S3-T61-AV1	8.4.2.4.6	S3-R13	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T61-AV1-<QP>
S3-T62-AV1	8.4.2.4.6	S3-R14	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T62-AV1-<QP>
S3-T63-AV1	8.4.2.4.6	S3-R15	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T63-AV1-<QP>
S3-T64-AV1	8.4.2.4.6	S3-R16	aomenc	S3-AV1-SCC-02	[27,39,49,59, 63]	S3-T64-AV1-<QP>
S3-T65-AV1	8.4.2.4.3	S3-R17	aomenc	S3-AV1-03	[27,39,49,59, 63]	S3-T65-AV1-<QP>
S3-T66-AV1	8.4.2.4.4	S3-R17	aomenc	S3-AV1-04	[27,39,49,59, 63]	S3-T66-AV1-<QP>
S3-T67-AV1	8.4.2.4.5	S3-R17	aomenc	S3-AV1-SCC-03	[27,39,49,59, 63]	S3-T67-AV1-<QP>
S3-T68-AV1	8.4.2.4.6	S3-R17	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T68-AV1-<QP>
S3-T69-AV1	8.4.2.4.3	S3-R17	aomenc	S3-AV1-01	[27,39,49,59, 63]	S3-T69-AV1-<QP>
S3-T70-AV1	8.4.2.4.4	S3-R17	aomenc	S3-AV1-02	[27,39,49,59, 63]	S3-T70-AV1-<QP>
S3-T71-AV1	8.4.2.4.5	S3-R17	aomenc	S3-AV1-SCC-01	[27,39,49,59, 63]	S3-T71-AV1-<QP>
S3-T72-AV1	8.4.2.4.6	S3-R17	aomenc	S3-AV1-SCC-04	[27,39,49,59, 63]	S3-T72-AV1-<QP>

8.4.2.4.2 Common Parameters and Settings

The following common Scenario 3 command line options are provided in Table 8.4.2.4.2-1.

Table 8.4.2.4.2-1 Common Scenario 3 command line options

--lag-in-frames=0	No future frame is used as reference in low delay configuration. Key-frame-filtering is a motion compensated temporal filtering. It is only enabled in random access configuration. When --lag-in-frames=0, key frames will not be filtered.
--deltaq-mode=0	disable block based adaptive quantization, so all blocks within a frame use the same quantization parameter
--enable-onesided-comp=0	disable compound prediction for low delay content. Unidirectional prediction Inter frame, only.
--max-reference-frames=4	restrict number of reference frames to 4.
--enable-obmc=0	Disable OBMC
--enable-dist-wtd-comp=0	Disable distance weighted inter compound prediction
--enable-diff-wtd-comp=0	Disable difference weighted inter compound prediction
--enable-interintra-comp=0	Disable inter/intra compound prediction
--enable-interinter-wedge=0	Disable wedge-based inter compound prediction
--enable-interintra-wedge=0	Disable wedge-based inter/intra compound prediction
--enable-masked-comp=0	Disable mask based inter compound prediction
--enable-smooth-interintra=0	Disable smooth inter/intra compound prediction

8.4.2.4.3 S3-AV1-01 and S3-AV1-03: Main 10 Profile with no fixed random access

For these clips the following additional command line options are provided in Table 8.4.2.4.3-1.

Table 8.4.2.4.3-1 Additional Scenario 3 command line options for S3-AV1-01/03

--kf-min-dist=9999 --kf-max-dist=9999	Only the first frame is encoded as Intra (Key) frame. --kf-min/max-dist are used only in closed GOP cases to specify the Intra Period. When kf-min-dist and kf-max-dist have the same value, the key frame is only inserted at a fixed interval.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--min-gf-interval=8 --max-gf-interval=8	Set the GOPSize to 8.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

The following command line is used for all encodes:

S3-AV1-01/03.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <input> <output>

8.4.2.4.4 S3-AV1-02 and S3-AV1-04: Main 10 Profile with fixed random access every second

For these clips the following additional command line options are used provided in Table 8.4.2.4.4-1.

Table 8.4.2.4.4-1 Additional Scenario 3 command line options for S3-AV1-02/04

--min-q=<cq-level> --max-q=>cq-level>	Specifies min/max q equal to the cq-level to make sure all frames use the same QP
--disable-warning-prompt	This parameter is used to bypass the warning prompt that min-q and max-q are set to be the same value.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32. Note: Flat QP. GOP Size does not alter QP.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

IntraPeriod such that exactly 1 second is achieved (i.e., IntraPeriod value equal to the sequence fps value rounded to the nearest integer).

The following command line is used for all encodes:

S3-AV1-02/04.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input> <output>

8.4.2.4.5 S3-AV1-SCC-01 and S3-AV1-SCC-03: Screen Content Profile with no fixed random access

For these clips the following additional command line options are used. provided in Table 8.4.2.4.5-1.

Table 8.4.2.4.5-1 Additional Scenario 3 command line options for S3-AV1-SCC-01/03.

--kf-min-dist=9999 --kf-max-dist=9999	Only the first frame is encoded as Intra (Key) frame. --kf-min/max-dist are used only in closed GOP cases to specify the random access Period. When kf-min-dist and kf-max-dist have the same value, the key frame is only inserted at a fixed interval.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--tune-content=screen	specify content type to be screen content. In AV1, screen content coding tools are enabled in all profiles. The encoder internally has an algorithm to detect if the input video is screen content or not. By default, if the encoder detects the input video is screen content, it will enable the screen content coding tool. When tune-content is set to screen, the encoder will bypass the screen content detection and assume the input video is screen content and enable screen content coding tools. Note that the encoder has an internal algorithm to detect if the input video is classified as screen content. When --tune-content=screen is enabled, the internal detection algorithm is bypassed, and the screen content coding tool will always be enabled.
--min-gf-interval=8 --max-gf-interval=8	Set the GOPSize to 8.

The following command line is used for all encodes:

S3-AV1-SCC-01/03.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <input> <output>

8.4.2.4.6 S3-AV1-SCC-02 and S3-AV1-SCC-04: Screen Content Profile with fixed random access every second

For these clips the following additional command line options are used, provided in Table 8.4.2.4.6-1.

Table 8.4.2.4.6-1 Additional Scenario 3 command line options for S3-AV1-SCC-02/04.

--min-q=<cq-level> --max-q=>cq-level>	Specifies min/max q equal to the cq-level to make sure all frames use the same QP
--disable-warning-prompt	This parameter is used to bypass the warning prompt that min-q and max-q are set to be the same value.
--tune-content=screen	specify content type to be screen content. In AV1, screen content coding tools are enabled in all profiles. The encoder internally has an algorithm to detect if the input video is screen content or not. By default, if the encoder detects the input video is screen content, it will enable the screen content coding tool. When tune-content is set to screen, the encoder will bypass the screen content detection and assume the input video is screen content and enable screen content coding tools. Note that the encoder has an internal algorithm to detect if the input video is classified as screen content. When --tune-content=screen is enabled, the internal detection algorithm is bypassed, and the screen content coding tool will always be enabled.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32. Note: Flat QP. GOP Size does not alter QP.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

IntraPeriod such that exactly 1 second is achieved (i.e., IntraPeriod value equal to the sequence fps value rounded to the nearest integer).

The following command line is used for all encodes:

```
S3-AV1-SCC-02/04.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level>
<intra_preiod> <input> <output>
```

8.4.2.4.7 AV1 Test Results

AV1 test streams are provided according to the key system here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1>

AV1 test metrics are provided with the appropriate keys as defined in Table 8.4.2.4.1-1. The csv files are located here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/cross-check.csv>.

Based on these cross-check results, the verification status for the AV1 test streams is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/verification.csv> and Table 8.4.2.4.7-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.4.2.4.7-1 Verification status of AV1 test streams for Screen Content Scenario

8.4.2.5 Scenario 4: Messaging and Social Sharing

8.4.2.5.1 Overview

Table 8.4.2.5.1-1 provides an overview of the AV1 test tuples. For provided bitstreams, the AV1 encoder aomenc is built from the libaom libraries using the tag provided in the introduction. Keys are identified to refer to the bitstreams in the context of the scenario.

Table 8.4.2.5.1-1 Test Tuple generation with AV1, Messaging and Social Sharing Scenario

Key	Clause	Reference Sequence	Reference Encoder	Config	Variations	Anchor Key
S4-T01-AV1	8.4.2.5.3	S4-R01	aomenc <tag>	S4-AV1-01	QP=[27,39,49,59]	S4-T01-AV1-<QP>
S4-T02-AV1	8.4.2.5.3	S4-R02	aomenc <tag>	S4-AV1-01	QP=[27,39,49,59]	S4-T02-AV1-<QP>
S4-T03-AV1	8.4.2.5.3	S4-R03	aomenc <tag>	S4-AV1-01	QP=[27,39,49,59]	S4-T03-AV1-<QP>
S4-T04-AV1	8.4.2.5.3	S4-R04	aomenc <tag>	S4-AV1-01	QP=[27,39,49,59]	S4-T04-AV1-<QP>
S4-T05-AV1	8.4.2.5.4	S4-R01	aomenc <tag>	S4-AV1-02	QP=[27,39,49,59]	S4-T05-AV1-<QP>
S4-T06-AV1	8.4.2.5.4	S4-R02	aomenc <tag>	S4-AV1-02	QP=[27,39,49,59]	S4-T06-AV1-<QP>
S4-T07-AV1	8.4.2.5.4	S4-R03	aomenc <tag>	S4-AV1-02	QP=[27,39,49,59]	S4-T07-AV1-<QP>
S4-T08-AV1	8.4.2.5.4	S4-R04	aomenc <tag>	S4-AV1-02	QP=[27,39,49,59]	S4-T08-AV1-<QP>

8.4.2.5.2 Common Parameters and Settings

The following common Scenario 4 command line options are provided in Table 8.4.2.5.2-1.

Table 8.4.2.5.2-1 Common Scenario 4 command line options

--lag-in-frames=0	No future frame is used as reference in low delay configuration. Key-frame-filtering is a motion compensated temporal filtering. It is only enabled in random access configuration. When --lag-in-frames=0, key frames will not be filtered.
--deltaq-mode=0	disable block based adaptive quantization, so all blocks within a frame use the same quantization parameter
--max-reference-frames=4	restrict number of reference frames to 4
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

8.4.2.5.3 S4-AV1-01: no random access

For these clips the following additional command line options are provided in Table 8.4.2.5.3-1.

Table 8.4.2.5.3-1 Additional Scenario 4 command line options for S4-AV1-01

--kf-min-dist=9999 --kf-max-dist=9999	Only the first frame is encoded as Intra (Key) frame. --kf-min/max-dist are used only in closed GOP cases to specify the Random access Period. When kf-min-dist and kf-max-dist have the same value, the key frame is only inserted at a fixed interval.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--min-gf-interval=8 --max-gf-interval=8	Set the GOPSize to 8.

The following command line is used for all encodes:

S4-AV1-01.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <input> <output>

8.4.2.5.4 S4-AV1-02: Intra

For these clips the following additional command line options are provided in Table 8.4.2.5.4-1.

Table 8.4.2.5.4-1 Additional Scenario 4 command line options for S4-AV1-02

--min-q=<cq-level> --max-q=>cq-level>	Specifies min/max q equal to the cq-level to make sure all frames use the same QP
--disable-warning-prompt	This parameter is used to bypass the warning prompt that min-q and max-q are set to be the same value.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32. Note: Flat QP. GOP Size does not alter QP.

IntraPeriod = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences.

The following command line is used for all encodes:

```
S4-AV1-02.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input>
<output>
```

8.4.2.5.5 Test Results

AV1 test streams are provided according to the key system here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/AV1/>

AV1 test metrics are provided with the appropriate keys as defined in Table 8.4.2.5.1-1. The csv files are located here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/AV1/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/AV1/cross-check.csv>.

Based on these cross-check results, the verification status for the AV1 anchors is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/AV1/verification.csv> and Table 8.4.2.5.5-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.4.2.5.5-1 Verification status of AV1 test streams for Messaging Scenario

Anchor + Key Verification Type	Summary			22			27			32			37		
	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S4-A01-265															
S4-A02-265															
S4-A03-265															
S4-A04-265															
S4-A05-265															
S4-A06-265															
S4-A07-265															
S4-A08-265															

8.4.2.6 Scenario 5: Online Gaming

8.4.2.6.1 Overview

Table 8.4.2.6.1-1 provides an overview of the AV1 test tuples. For provided bitstreams, the AV1 encoder **aomenc** is built from the libaom libraries using the tag provided in the introduction. Keys are identified to refer to the bitstreams in the context of the scenario.

Table 8.4.2.6.1-1 Test Tuple generation with AV1, Online Gaming Scenario

Key	Clause	Reference Sequence	Reference Encoder	Configuration	Variations	Anchor Key
S5-T01-AV1	8.4.2.6.3	S5-R01	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T01-AV1-<QP>
S5-T02-AV1	8.4.2.6.3	S5-R02	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T02-AV1-<QP>
S5-T03-AV1	8.4.2.6.3	S5-R03	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T03-AV1-<QP>
S5-T04-AV1	8.4.2.6.3	S5-R04	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T04-AV1-<QP>
S5-T05-AV1	8.4.2.6.3	S5-R05	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T05-AV1-<QP>
S5-T06-AV1	8.4.2.6.3	S5-R06	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T06-AV1-<QP>
S5-T07-AV1	8.4.2.6.3	S5-R07	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T07-AV1-<QP>
S5-T08-AV1	8.4.2.6.3	S5-R08	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T08-AV1-<QP>
S5-T09-AV1	8.4.2.6.3	S5-R09	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T09-AV1-<QP>
S5-T10-AV1	8.4.2.6.3	S5-R10	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T10-AV1-<QP>
S5-T11-AV1	8.4.2.6.3	S5-R11	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T11-AV1-<QP>
S5-T12-AV1	8.4.2.6.3	S5-R12	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T12-AV1-<QP>
S5-T13-AV1	8.4.2.6.3	S5-R13	aomenc <tag>	S5-AV1-01	QP=[27,39,49,59]	S5-T13-AV1-<QP>
S5-T14-AV1	8.4.2.6.4	S5-R01	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T14-AV1-<QP>
S5-T15-AV1	8.4.2.6.4	S5-R02	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T15-AV1-<QP>
S5-T16-AV1	8.4.2.6.4	S5-R03	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T16-AV1-<QP>
S5-T17-AV1	8.4.2.6.4	S5-R04	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T17-AV1-<QP>
S5-T18-AV1	8.4.2.6.4	S5-R05	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T18-AV1-<QP>
S5-T19-AV1	8.4.2.6.4	S5-R06	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T19-AV1-<QP>

S5-T20-AV1	8.4.2.6.4	S5-R07	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T20-AV1-<QP>
S5-T21-AV1	8.4.2.6.4	S5-R08	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T21-AV1-<QP>
S5-T22-AV1	8.4.2.6.4	S5-R09	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T22-AV1-<QP>
S5-T23-AV1	8.4.2.6.4	S5-R10	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T23-AV1-<QP>
S5-T24-AV1	8.4.2.6.4	S5-R11	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T24-AV1-<QP>
S5-T25-AV1	8.4.2.6.4	S5-R12	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T25-AV1-<QP>
S5-T26-AV1	8.4.2.6.4	S5-R13	aomenc <tag>	S5-AV1-02	QP=[27,39,49,59]	S5-T26-AV1-<QP>
S5-T27-AV1	8.4.2.6.5	S5-R01	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T27-AV1-<QP>
S5-T28-AV1	8.4.2.6.5	S5-R02	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T28-AV1-<QP>
S5-T29-AV1	8.4.2.6.5	S5-R03	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T29-AV1-<QP>
S5-T30-AV1	8.4.2.6.5	S5-R04	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T30-AV1-<QP>
S5-T31-AV1	8.4.2.6.5	S5-R05	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T31-AV1-<QP>
S5-T32-AV1	8.4.2.6.5	S5-R06	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T32-AV1-<QP>
S5-T33-AV1	8.4.2.6.5	S5-R07	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T33-AV1-<QP>
S5-T34-AV1	8.4.2.6.5	S5-R08	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T34-AV1-<QP>
S5-T35-AV1	8.4.2.6.5	S5-R09	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T35-AV1-<QP>
S5-T36-AV1	8.4.2.6.5	S5-R10	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T36-AV1-<QP>
S5-T37-AV1	8.4.2.6.5	S5-R11	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T37-AV1-<QP>
S5-T38-AV1	8.4.2.6.5	S5-R12	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T38-AV1-<QP>
S5-T39-AV1	8.4.2.6.5	S5-R13	aomenc <tag>	S5-AV1-SCC-01	QP=[27,39,49,59]	S5-T39-AV1-<QP>
S5-T40-AV1	8.4.2.6.6	S5-R01	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T40-AV1-<QP>
S5-T41-AV1	8.4.2.6.6	S5-R02	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T41-AV1-<QP>
S5-T42-AV1	8.4.2.6.6	S5-R03	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T42-AV1-<QP>
S5-T43-AV1	8.4.2.6.6	S5-R04	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T43-AV1-<QP>
S5-T44-AV1	8.4.2.6.6	S5-R05	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T44-AV1-<QP>
S5-T45-AV1	8.4.2.6.6	S5-R06	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T45-AV1-<QP>
S5-T46-AV1	8.4.2.6.6	S5-R07	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T46-AV1-<QP>
S5-T47-AV1	8.4.2.6.6	S5-R08	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T47-AV1-<QP>
S5-T48-AV1	8.4.2.6.6	S5-R09	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T48-AV1-<QP>
S5-T49-AV1	8.4.2.6.6	S5-R10	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T49-AV1-<QP>
S5-T50-AV1	8.4.2.6.6	S5-R11	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T50-AV1-<QP>
S5-T51-AV1	8.4.2.6.6	S5-R12	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T51-AV1-<QP>
S5-T52-AV1	8.4.2.6.6	S5-R13	aomenc <tag>	S5-AV1-SCC-02	QP=[27,39,49,59]	S5-T52-AV1-<QP>

8.4.2.6.2 Common Parameters and Settings

The following common Scenario 5 command line options are provided in Table 8.4.2.6.2-1.

Table 8.4.2.6.2-1 Common Scenario 5 command line options

--lag-in-frames=0	No future frame is used as reference in low delay configuration. Key-frame-filtering is a motion compensated temporal filtering. It is only enabled in random access configuration. When --lag-in-frames=0, key frames will not be filtered.
--deltaq-mode=0	disable block based adaptive quantization, so all blocks within a frame use the same quantization parameter
--max-reference-frames=4	restrict number of reference frames to 4

8.4.2.6.3 S5-AV1-01: Main 10 Profile with no fixed Random access

For these clips the following additional command line options are provided in Table 8.4.2.6.3-1.

Table 8.4.2.6.3-1 Additional Scenario 5 command line options for S5-AV1-01.

--kf-min-dist=9999 --kf-max-dist=9999	Only the first frame is encoded as Intra (Key) frame. --kf-min/max-dist are used only in closed GOP cases to specify the Random access Period. When kf-min-dist and kf-max-dist have the same value, the key frame is only inserted at a fixed interval.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--min-gf-interval=8 --max-gf-interval=8	Set the GOPSize to 8.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

The following command line is used for all encodes:

S5-AV1-01.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <input> <output>

8.4.2.6.4 S5-AV1-02: Main 10 Profile with fixed Random access every second

For these clips the following additional command line options are provided in Table 8.4.2.6.4-1.

Table 8.4.2.6.4-1 Additional Scenario 5 command line options for S5-AV1-02.

--min-q=<cq-level> --max-q=>cq-level>	Specifies min/max q equal to the cq-level to make sure all frames use the same QP
--disable-warning-prompt	This parameter is used to bypass the warning prompt that min-q and max-q are set to be the same value.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32. Note: Flat QP. GOP Size does not alter QP.
--enable-intrabc=0	Disable the intra block copy prediction mode.
--enable-palette=0	Disable the palette prediction mode.

IntraPeriod = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences

The following command line is used for all encodes:

S5-AV1-02.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_period> <input> <output>

8.4.2.6.5 S5-SCC-01: Screen Content Profile with no fixed Random access

For these clips the following additional command line options are provided in Table 8.4.2.6.5-1.

Table 8.4.2.6.5-1 Additional Scenario 5 command line options for S5-AV1-SCC-01.

--kf-min-dist=9999 --kf-max-dist=9999	Only the first frame is encoded as Intra (Key) frame.
--use-fixed-qp-offsets=1	use fixed ratios to determine the QP for frames at different hierarchical layers. In av1 encoder, cq-level specified is only used for the frames at the highest temporal layer (non-reference frames), for Key frames and Inter frames at other layers, a fixed ratio is used to determine the quantization parameter.
--tune-content=screen	specify content type to be screen content. In AV1, screen content coding tools are enabled in all profiles. The encoder internally has an algorithm to detect if the input video is screen content or not. By default, if the encoder detects the input video is screen content, it will enable the screen content coding tool. When tune-content is set to screen, the encoder will bypass the screen content detection and assume the input video is screen content and enable screen content coding tools. Note that the encoder has an internal algorithm to detect if the input video is classified as screen content. When --tune-content=screen is enabled, the internal detection algorithm is bypassed, and the screen content coding tool will always be enabled.
--min-gf-interval=8 --max-gf-interval=8	Set the GOPSize to 8.

The following command line is used for all encodes:

S5-AV1-SCC-01.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <input> <output>

8.4.2.6.6 S5-SCC-02: Screen Content Profile with fixed Random access

For these clips the following additional command line options are provided in Table 8.4.2.6.6-1.

Table 8.4.2.6.6-1 Additional Scenario 5 command line options for S5-AV1-SCC-02.

ss	Specifies min/max q equal to the cq-level to make sure all frames use the same QP
--disable-warning-prompt	This parameter is used to bypass the warning prompt that min-q and max-q are set to be the same value.
--tune-content=screen	specify content type to be screen content. In AV1, screen content coding tools are enabled in all profiles. The encoder internally has an algorithm to detect if the input video is screen content or not. By default, if the encoder detects the input video is screen content, it will enable the screen content coding tool. When tune-content is set to screen, the encoder will bypass the screen content detection and assume the input video is screen content and enable screen content coding tools. Note that the encoder has an internal algorithm to detect if the input video is classified as screen content. When --tune-content=screen is enabled, the internal detection algorithm is bypassed, and the screen content coding tool will always be enabled.
--min-gf-interval=32 --max-gf-interval=32	Set the GOPSize to 32. Note: Flat QP. GOP Size does not alter QP.

IntraPeriod = power of 2 value that is greater than or equal to the frame rate (fps), such that near 1 second is achieved: 32 for 30fps sequences and 64 for 60fps sequences.

The following command line is used for all encodes:

```
S5-AV1-SCC-02.sh <num_frame> <fps_norm> <fps_denom> <width> <height> <cq-level> <intra_preiod>
<input> <output>
```

8.4.2.6.7 Test Results

AV1 test streams are provided according to the key system here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Others/CandidateSubmission/Bitstreams/Scenario-5-Gaming/AV1/>

AV1 test metrics are provided with the appropriate keys as defined in Table 8.4.2.6.1-1. The csv files are located here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Others/CandidateSubmission/Bitstreams/Scenario-5-Gaming/AV1/Metrics/>

Cross-checks have been conducted and are documented here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/AV1/cross-check.csv>.

Based on these cross-check results, the verification status for the AV1 test streams is provided in <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/AV1/verification.csv> and Table 8.4.2.6.7-1 with S for successful and F for failed. Empty cells indicate missing verification.

Table 8.4.2.6.7-1 Verification status of AV1 test streams for Gaming Scenario

Anchor + Key	Summary			22			27			32			37		
Verification Type	B	R	M	B	R	M	B	R	M	B	R	M	B	R	M
S5-A01-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A02-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A03-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A04-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A05-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A06-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A07-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A08-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A09-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A10-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A11-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A12-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A13-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A14-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A15-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A16-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A17-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A18-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A19-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A20-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A21-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A22-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A23-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A24-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A25-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A26-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A27-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A28-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A29-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A30-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A31-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A32-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A33-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A34-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A35-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A36-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A37-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A38-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A39-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A40-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A41-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A42-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A43-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A44-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A45-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A46-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A47-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A48-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A49-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A50-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A51-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S5-A52-265	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

8.4.3 AV1 Characterization against H.264/AVC

8.4.3.1 Overview

This clause provides information related to the characterization of AV1 against H.264/AVC according to clause 7.2.1. The results provided in clauses 6 and 8.4.2 are considered for the characterization.

The results in clause 6 for the anchor are not verified.

Analysis of the PSNR ranges provided in the clause 6 for H.264/AVC and in sub-clauses 8.2.2 of the AV1 shows that their rate distortion curves exhibit an average overlap of 50% across scenarios. As a consequence, the aggregation of results for all rate points for all sequences in each scenario is not substantial enough and do not provide an accurate representation for codec characterisation. BD rate gain are not reported in this clause.

A way to obtain a substantial overlap for accurate estimation of BD rate gain estimates would be to adjust QP values of AVC and AV1 for better alignments with the ones of HM.

8.4.3.2 Scenario 1: Full HD

This clause provides information related to the characterization of AV1 libaom mode configurations against H.264/AVC JM for Scenario 1 Full HD.

For this scenario, the PSNR ranges of the curves between AV1 and H.264/AVC overlaps at an average of at 53% and can be as low as 21%. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1/Characterization/>.

8.4.3.3 Scenario 3: Screen Content

This clause provides information related to the characterization of AV1 libaom mode configurations against H.264/AVC JM for Scenario 3 Screen Content.

For this scenario, the PSNR ranges of the curves between AV1 and H.264/AVC overlaps at an average of at 34 % and can be as low as 29 % in the non-RA configuration and an average of 77 % and can be as low as 69 % in the RA configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/Characterization/>.

8.4.3.4 Scenario 4: Messaging and Social Sharing

This clause provides information related to the characterization of AV1 libaom mode configurations against H.264/AVC JM for Scenario 4 Messaging and Social Sharing.

For this scenario, the PSNR ranges of the curves between AV1 and H.264/AVC overlaps at an average of at 46% and can be as low as 30% in the non-RA configuration and an average of 57% and can be as low as 51% in the RA configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/AV1/Characterization/>.

8.4.3.5 Scenario 5: Online Gaming

This clause provides information related to the characterization of AV1 libaom mode configurations against H.264/AVC JM for Scenario 5 Online Gaming.

For this scenario, the PSNR ranges of the curve between AV1 and H.264/AVC overlaps at an average of at 40% and can be as low as 25% in the non-RA configuration and an average of 59% and can be as low as 54% in the RA configuration. Details on overlap values can be found here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/AV1/Characterization/>.

8.4.3.6 Summary

No characterization results are provided due to the lack of substantial overlap of H.264/AVC and AV1 characterization results.

8.4.4 AV1 libaom Characterization against H.265/HEVC HM

8.4.4.1 Overview

This clause provides a full characterization of AV1 against H.265/HEVC according to clause 7.2.1. The results provided in clauses 6 and 8.4.2 are used for the characterization.

8.4.4.2 Scenario 1: Full HD

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC HM for Scenario 1 Full HD. In particular,

- Table 8.4.4.2-1 provides the BD rate gain of AV1 libaom with S1-AV1-01 against H.265/HEVC HM with configuration S1-HM-01, i.e. with the Full HD SDR scenario reference sequences
- Table 8.4.4.2-2 provides the BD rate gain of AV1 libaom with S1-AV1-02 against H.265/HEVC HM with configuration S1-HM-02, i.e. with the Full HD HDR scenario reference sequences

Table 8.4.4.2-1 BD rate gain of AV1 libaom with S1-AV1-01 against H.265/HEVC HM with configuration S1-HM-01, i.e. with the Full HD SDR scenario reference sequences

Reference sequence	Name	psnr	y psnr	vmaf	ms ssim
S1-R01	Brest-Sedof-FHD	24.2	18.1	34.5	10.6
S1-R02	Rain Fruits-FHD	19.2	10.5	20.0	16.5
S1-R03	Park Joy-FHD	14.4	10.6	17.7	15.4
S1-R04	Soccer-FHD	15.8	13.8	14.0	12.4
S1-R05	Tunnel Flag-FHD	28.3	19.2	22.9	22.0
S1-R06	Boat-FHD	15.8	7.9	14.2	9.0
S1-R07	Fountain-FHD	10.7	11.0	8.3	9.8
S1-R08	Riverbank-FHD	24.8	11.7	16.5	12.6
Minimum		10.7	7.9	8.3	9.0
Maximum		28.3	19.2	34.5	22.0
Average		19.1	12.9	18.5	13.5

Table 8.4.4.2-2 BD rate gain of AV1 libaom with S1-AV1-02 against H.265/HEVC HM with configuration S1-HM-02, i.e. with the Full HD HDR scenario reference sequences

Reference sequence	Name	wpsnr	y wpsnr	psnr100	de100
S1-R11	Life-Untouched-FHD	13.8	15.2	17.8	-3.5
S1-R12	Meridian-FHD	4.5	10.1	13.6	-13.8
S1-R13	Sol-Levante-FHD	22.9	26.6	23.7	13.8
S1-R14	Cosmos-FHD	10.3	18.1	7.5	-15.0
S1-R15	Elevator-FHD	23.9	25.2	26.6	18.5
S1-R16	Sparks-FHD	18.0	20.0	20.7	8.4
S1-R17	Nocturne-FHD	10.9	18.6	10.7	0.4
Minimum		4.5	10.1	7.5	-15.0
Maximum		23.9	26.6	26.6	18.5
Average		14.9	19.1	17.2	1.3

As an example, Figure 8.4.4.2-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S1-AV1-01 against H.265/HEVC HM with configuration S1-HM-01 for reference sequence S1-R01.

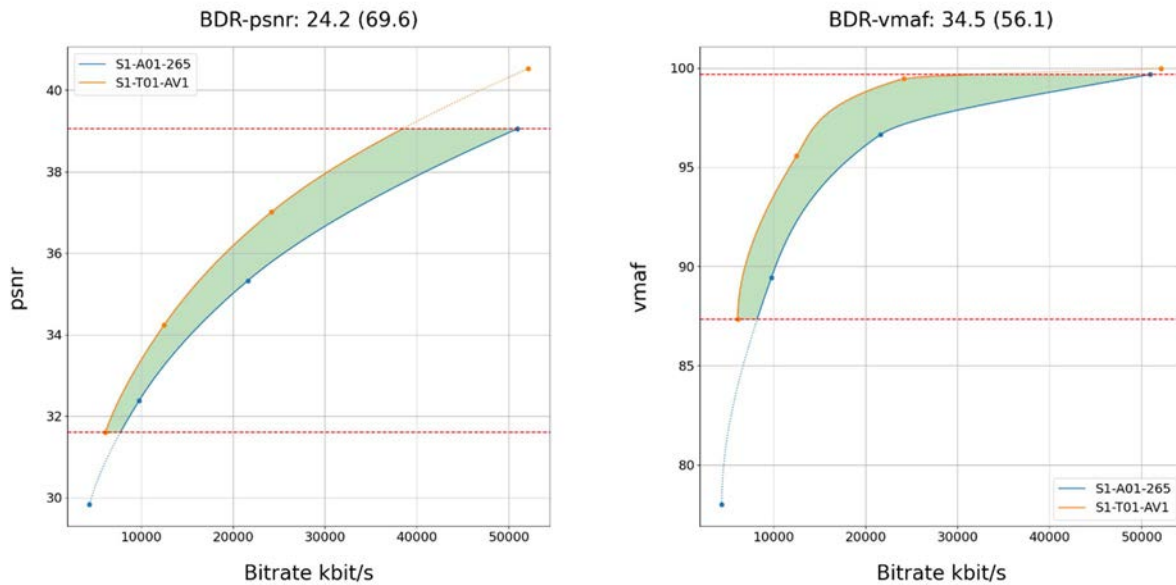


Figure 8.4.4.2-1 Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S1-AV1-01 against H.265/HEVC HM with configuration S1-HM-01 for reference sequence S1-R01

As another example, Figure 8.4.4.2-2 provides Rate-Quality curves and BD rate gain for wpsnr and de100 of AV1 libaom with S1-AV1-02 against H.265/HEVC HM with configuration S1-HM-02 for reference sequence S1-R11.

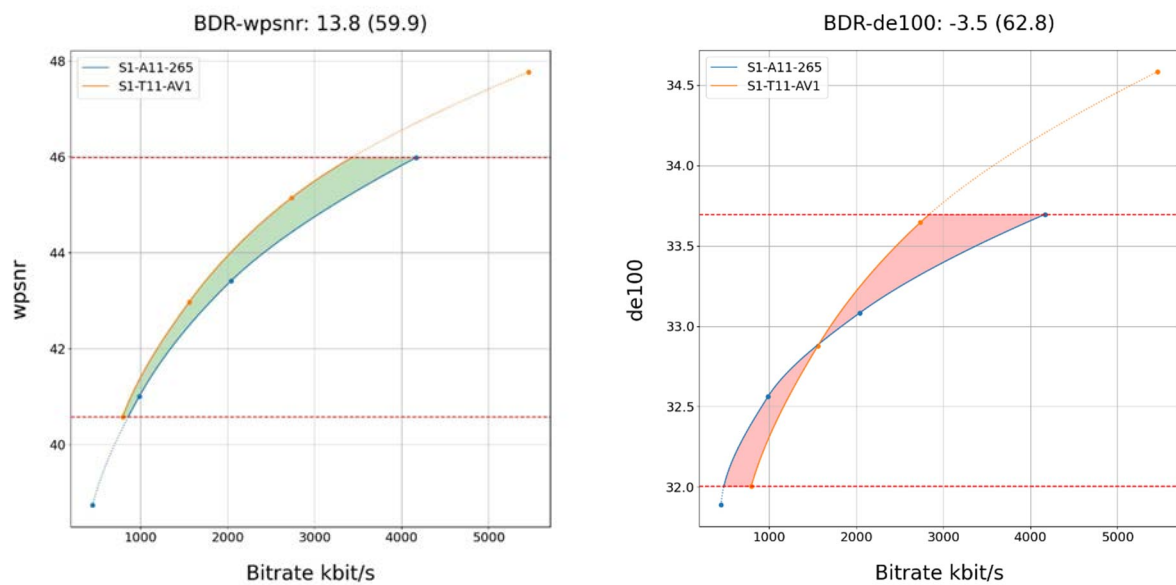


Figure 8.4.4.2-1 Rate-Quality curves and BD rate gain for wpsnr and de100 of AV1 libaom with S1-AV1-02 against H.265/HEVC HM with configuration S1-HM-02 for reference sequence S1-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/AV1/Characterization/>.

8.4.4.3 Scenario 2: 4K TV

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC HM for Scenario 2 4K TV. In particular,

- Table 8.4.4.3-1 provides the BD rate gain of AV1 libaom with S2-AV1-01 against H.265/HEVC HM with configuration S2-HM-01, i.e. with the 4K TV SDR scenario reference sequences

- Table 8.4.4.3-2 provides the BD rate gain of AV1 libaom with S2-AV1-02 against H.265/HEVC HM with configuration S2-HM-02, i.e. with the 4K TV HDR scenario reference sequences

Table 8.4.4.3-1 BD rate gain of AV1 with S2-AV1-01 against H.265/HEVC HM with configuration S2-HM-01, i.e. with the 4K TV SDR scenario reference sequences

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S2-R01	Brest-Sedof	18.7	11.5	28.9	9.3
S2-R02	Rain Fruits	21.8	9.6	14.9	16.2
S2-R03	Park Joy	14.0	12.0	17.2	13.2
S2-R04	Soccer	14.1	12.9	7.1	10.6
S2-R05	Tunnel Flag	28.4	19.8	20.7	25.2
S2-R06	Boat	17.8	9.2	14.5	9.3
S2-R07	Fountain	10.1	11.1	9.3	9.7
S2-R08	Riverbank	21.0	11.9	16.7	15.0
Minimum		10.1	9.2	7.1	9.3
Maximum		28.4	19.8	28.9	25.2
Average		18.2	12.2	16.2	13.6

Table 8.4.4.3-2 BD rate gain of AV1 libaom with S2-AV1-02 against H.265/HEVC HM with configuration S2-HM-02, i.e. with the 4K TV HDR scenario reference sequences

Reference sequence	Name	wpsnr	y_wpsnr	psnr100	de100
S2-R11	Life-Untouched	15.0	16.1	20.1	-2.1
S2-R12	Meridian	4.5	8.1	9.1	-11.2
S2-R13	Sol-Levante	24.6	30.0	25.2	10.0
S2-R14	Cosmos	16.7	21.8	14.1	-4.9
S2-R15	Elevator	20.6	22.7	24.0	14.1
S2-R16	Sparks	18.2	20.3	20.3	11.1
S2-R17	Nocturne	18.0	21.6	17.5	8.4
Minimum		4.9	8.1	9.1	-11.2
Maximum		24.6	30.0	25.2	14.1
Average		16.9	20.1	18.6	3.6

As an example, Figure 8.4.4.3-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S2-AV1-01 against H.265/HEVC HM with configuration S2-HM-01 for reference sequence S2-R01.

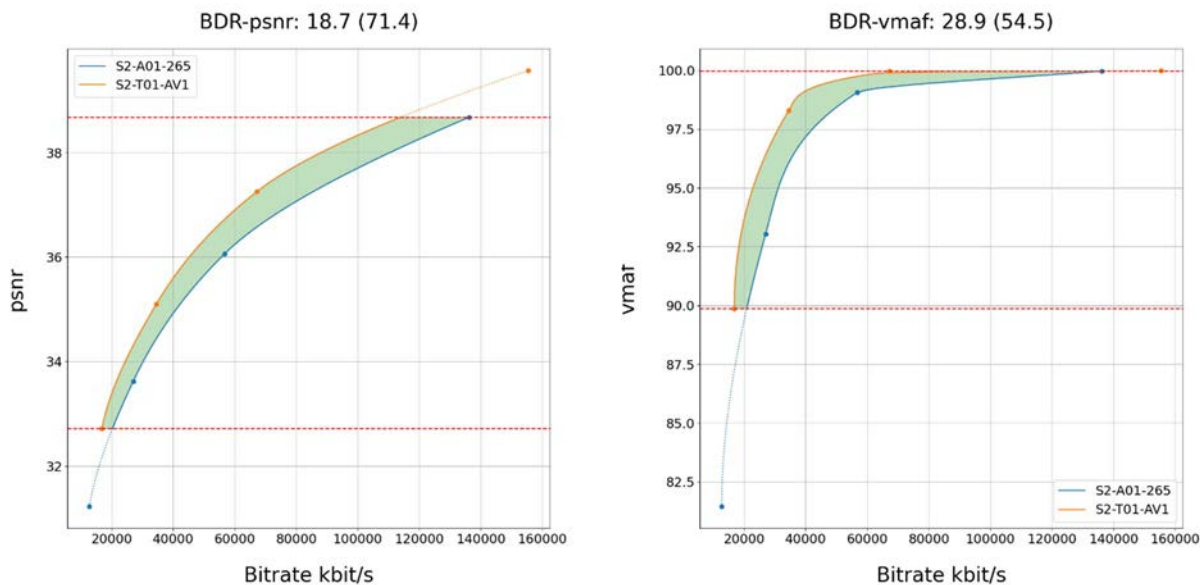


Figure 8.4.4.3-1 Rate-Quality curves and BD rate gain for psnr and vmaf of libaom AV1 with S2-AV1-01 against H.265/HEVC HM with configuration S2-HM-01 for reference sequence S2-R01

As another example, Figure 8.4.4.3-2 provides Rate-Quality curves and BD rate gain for wpsnr and de100 of libaom AV1 with S2-AV1-02 against H.265/HEVC HM with configuration S2-HM-02 for reference sequence S2-R11.

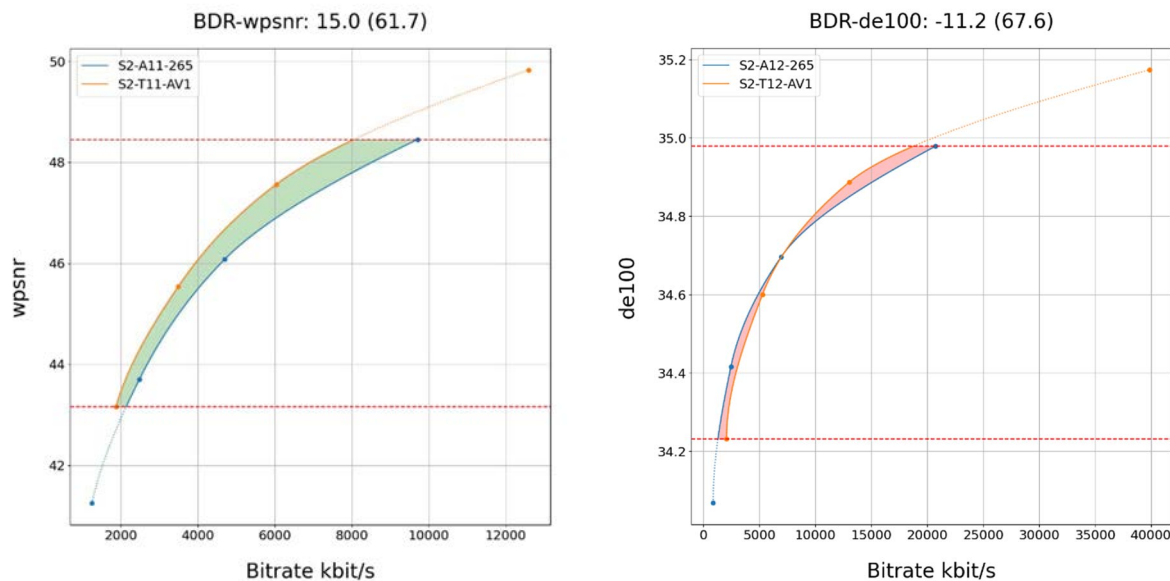


Figure 8.4.4.3-1 Rate-Quality curves and BD rate gain for wpsnr and de100 of AV1 libaom with S2-AV1-02 against H.265/HEVC HM with configuration S2-HM-02 for reference sequence S2-R11

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-2-4K/AV1/Characterization/>.

8.4.4.4 Scenario 3: Screen Content

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC HM for Scenario 3 Screen Content. In particular,

- Table 8.4.4.4-1 provides the BD rate gain of AV1 libaom with S3-AV1-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no fixed random access.
- Table 8.4.4.4-2 provides the BD rate gain of AV1 libaom with S3-AV1-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences with fixed Random access every second.

Table 8.4.4.4-1 BD rate gain of AV1 libaom with S3-AV1-01/03 against H.265/HEVC HM with configuration S3-HM-01/03, i.e. with the screen content scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	35.6	32.0
S3-R02	MovingText2-4K-8bit	34.8	31.4
S3-R03	MovingText2-FullHD-10bit	39.1	37.0
S3-R04	MovingText2-FullHD-8bit	39.1	37.0
S3-R05	TextMixTransitions-4K-10bit	39.7	35.3
S3-R06	TextMixTransitions-4K-8bit	40.3	35.5
S3-R07	TextMixTransitions-FullHD-10bit	35.1	30.7
S3-R08	TextMixTransitions-FullHD-8bit	35.3	30.8
S3-R09	GraphicsMixSimple-4K-10bit	28.7	25.9
S3-R10	GraphicsMixSimple-4K-8bit	28.6	25.8
S3-R11	GraphicsMixSimple-FullHD-10bit	24.8	22.3
S3-R12	GraphicsMixSimple-FullHD-8bit	24.9	22.5
S3-R13	GraphicsMixTransitions-4K-10bit	42.9	40.4
S3-R14	GraphicsMixTransitions-4K-8bit	43.0	40.4
S3-R15	GraphicsMixTransitions-FullHD-10bit	39.5	37.2
S3-R16	GraphicsMixTransitions-FullHD-8bit	39.9	37.7
S3-R17	Mission-Control	32.1	31.2
Minimum		24.8	22.3
Maximum		43.0	40.4
Average		35.5	32.5

Table 8.4.4.4-2 BD rate gain of AV1 libaom with S3-AV1-02/04 against H.265/HEVC HM with configuration S3-HM-02/04, i.e. with the screen content scenario reference sequences with fixed Random access every second

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	44.9	44.1
S3-R02	MovingText2-4K-8bit	44.7	44.0
S3-R03	MovingText2-FullHD-10bit	43.5	43.9
S3-R04	MovingText2-FullHD-8bit	43.5	43.9
S3-R05	TextMixTransitions-4K-10bit	25.8	20.5
S3-R06	TextMixTransitions-4K-8bit	25.7	20.6
S3-R07	TextMixTransitions-FullHD-10bit	26.4	22.0
S3-R08	TextMixTransitions-FullHD-8bit	26.5	22.3
S3-R09	GraphicsMixSimple-4K-10bit	28.6	27.2
S3-R10	GraphicsMixSimple-4K-8bit	28.6	27.2
S3-R11	GraphicsMixSimple-FullHD-10bit	26.5	25.1
S3-R12	GraphicsMixSimple-FullHD-8bit	26.6	25.3
S3-R13	GraphicsMixTransitions-4K-10bit	35.0	33.6
S3-R14	GraphicsMixTransitions-4K-8bit	35.2	33.7
S3-R15	GraphicsMixTransitions-FullHD-10bit	32.6	31.2
S3-R16	GraphicsMixTransitions-FullHD-8bit	32.8	31.5
S3-R17	Mission-Control	27.0	26.9
Minimum		25.7	20.5
Maximum		44.9	44.1
Average		32.6	30.8

As an example, Figure 8.4.4.4-1 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S3-AV1-01 against H.265/HEVC HM with configuration S3-HM-01 for reference sequences S3-R01 and S3-R17

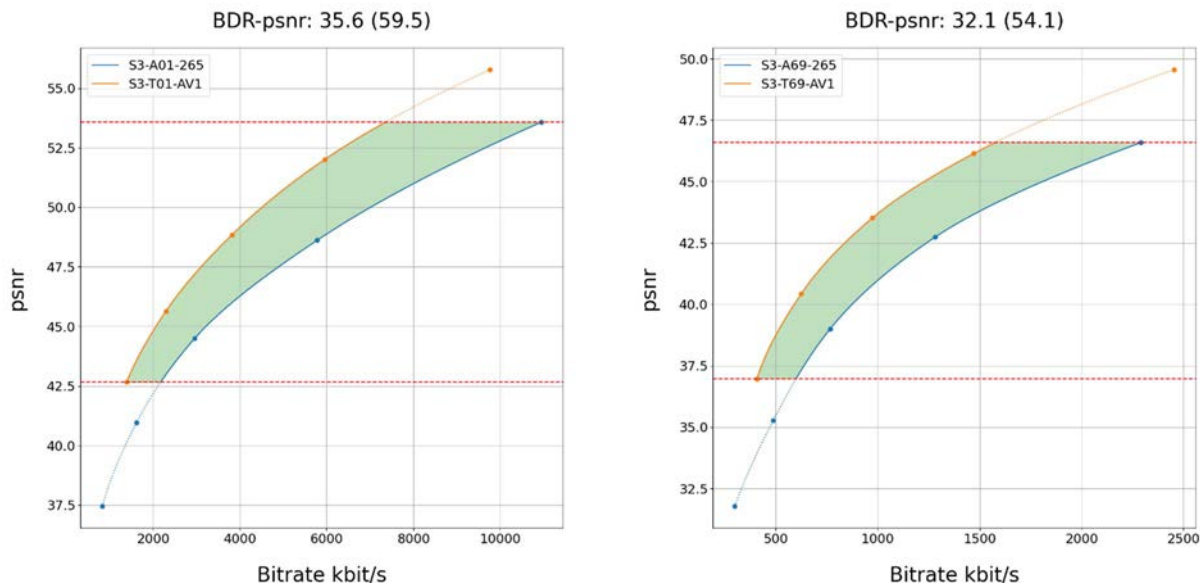


Figure 8.4.4.4-1 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S3-AV1-01 against H.265/HEVC HM with configuration S3-HM-01 for reference sequences S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/Characterization/>.

8.4.4.5 Scenario 4: Messaging and Social Sharing

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC HM for Scenario 4 Messaging and Social Sharing. In particular,

- Table 8.4.4.5-1 provides the BD rate gain of AV1 libaom with S4-AV1-01 against H.265/HEVC HM with configuration S4-HM-01, i.e. with the messaging and social sharing scenario reference sequences and no fixed random access.
- Table 8.4.4.5-2 provides the BD rate gain of AV1 libaom with S4-AV1-02 against H.265/HEVC HM with configuration S4-HM-02, i.e. with the messaging and social sharing scenario reference sequences with fixed Random access every second.

Table 8.4.4.5-1 BD rate gain of AV1 with S4-AV1-01 against H.265/HEVC HM with configuration S4-HM-01, i.e. with the messaging and social sharing scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	8.8	4.0	1.7	4.2
S4-R02	Vertical-Walking	7.2	3.3	-11.0	4.5
S4-R03	Neon-4K	7.7	6.8	0.2	7.0
S4-R04	Skater-4K	12.2	6.1	-7.2	11.2
Minimum		7.2	3.3	-11.0	3.9
Maximum		12.2	6.8	1.7	11.2
Average		9.0	5.2	-4.1	6.7

Table 8.4.4.5-2 BD rate gain of AV1 libaom with S4-AV1-02 against H.265/HEVC HM with configuration S4-HM-02, i.e. with the messaging and social sharing scenario reference sequences and fixed Random access every second

Reference sequence	Name	psnr	y_psnr	vmaf	ms_ssim
S4-R01	Vertical-Bees	11.6	11.9	9.1	8.5
S4-R02	Vertical-Walking	16.4	16.3	17.2	12.5
S4-R03	Neon-4K	16.8	15.6	12.1	14.8
S4-R04	Skater-4K	22.7	20.7	12.3	19.6
Minimum		11.6	11.9	9.1	8.5
Maximum		22.7	20.7	17.2	19.6
Average		16.9	16.1	12.7	13.8

As an example, Figure 8.4.4.5-1 provides Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S4-AV1-01 against H.265/HEVC HM with configuration S4-HM-01 for reference sequence S4-R01.

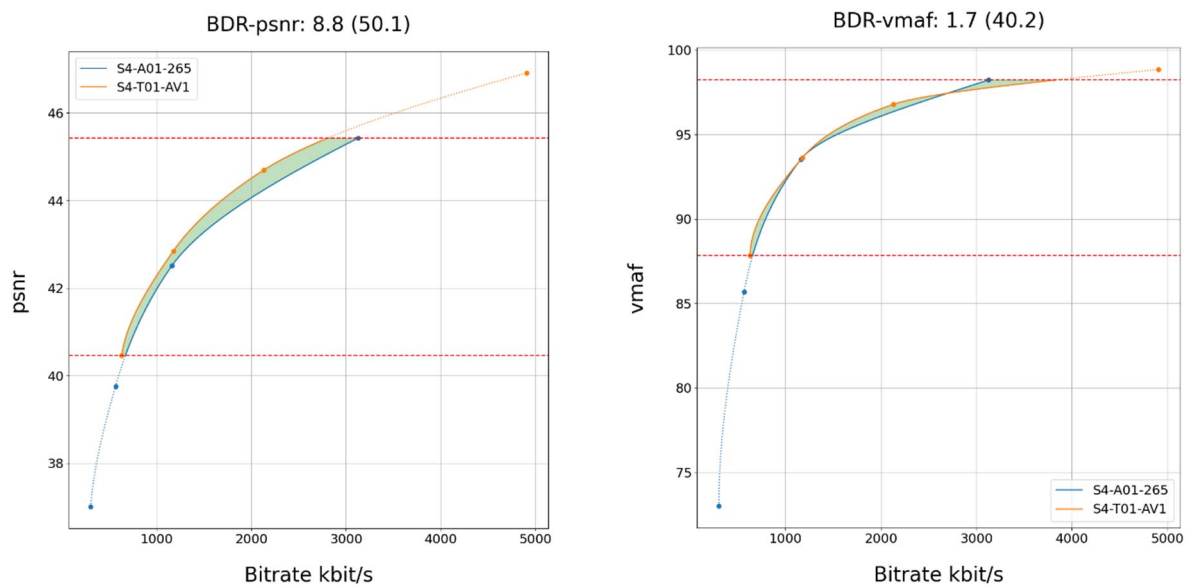


Figure 8.4.4.5-1 Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S4-AV1-01 against H.265/HEVC HM with configuration S4-HM-01 for reference sequence S4-R01

As another example, Figure 8.4.4.5-2 provides Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S4-HM-02 against H.265/HEVC HM with configuration S4-HM-02 for reference sequence S4-R01.

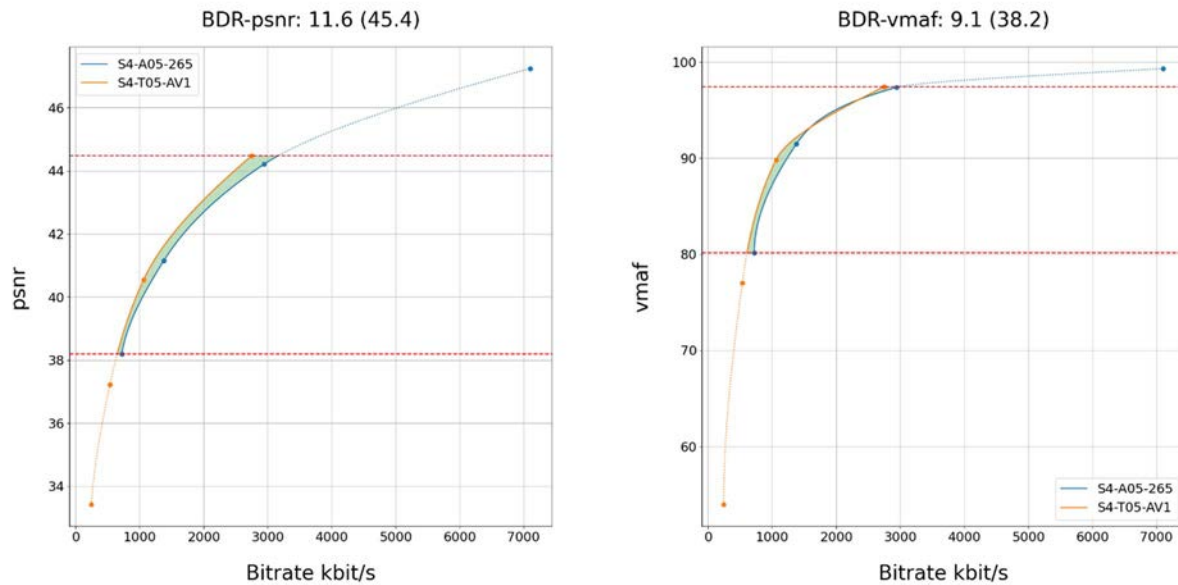


Figure 8.4.4.5-2 Rate-Quality curves and BD rate gain for psnr and vmaf of AV1 libaom with S4-AV1-02 against H.265/HEVC HM with configuration S4-HM-02 for reference sequence S4-R01.

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-4-Sharing/AV1/Characterization/>.

8.4.4.6 Scenario 5: Online Gaming

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC HM for Scenario 5 Online Gaming. In particular,

- Table 8.4.4.6-1 provides the BD rate gain of AV1 libaom with S5-AV1-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no fixed random access.
- Table 8.4.4.6-2 provides the BD rate gain of AV1 libaom with S5-AV1-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences with fixed Random access every second.

Table 8.4.4.6-1 BD rate gain of AV1 libaom with S5-AV1-01 against H.265/HEVC HM with configuration S5-HM-01, i.e. with the online gaming scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	17.8	15.2
S5-R02	Baolei-Man	16.1	10.9
S5-R03	Baolei-Woman	20.3	16.8
S5-R04	Baolei-Balloon	19.9	17.3
S5-R05	Baolei-Yard	15.5	12.3
S5-R06	Jianling-Temple	15.8	11.6
S5-R07	Jianling-Beach	17.8	12.4
S5-R08	Heroes-of-the-Storm	17.9	13.2
S5-R09	Project-CARS	17.4	10.9
S5-R10	World-of-WarCraft	20.4	15.3
S5-R11	MineCraft	28.8	24.1
S5-R12	CS-GO	42.0	36.8
S5-R13	StarCraft	31.0	26.4
Minimum		15.5	10.9
Maximum		42.0	36.8
Average		21.6	17.2

Table 8.4.4.6-2 BD rate gain of AV1 libaom with S5-AV1-02 against H.265/HEVC HM with configuration S5-HM-02, i.e. with the online gaming scenario reference sequences and fixed random access every second

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	17.7	17.0
S5-R02	Baolei-Man	17.3	15.3
S5-R03	Baolei-Woman	20.8	20.0
S5-R04	Baolei-Balloon	24.5	24.5
S5-R05	Baolei-Yard	19.9	19.3
S5-R06	Jianling-Temple	13.3	11.4
S5-R07	Jianling-Beach	17.7	14.7
S5-R08	Heroes-of-the-Storm	19.5	16.0
S5-R09	Project-CARS	20.1	18.3
S5-R10	World-of-WarCraft	23.5	18.8
S5-R11	MineCraft	28.7	26.8
S5-R12	CS-GO	35.5	32.6
S5-R13	StarCraft	19.1	14.3
Minimum		13.3	11.4
Maximum		35.5	32.6
Average		21.4	19.2

As an example,

- Figure 8.4.4.6-1 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequences S5-R04 and S5-R11.
- Figure 8.4.4.6-2 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11.

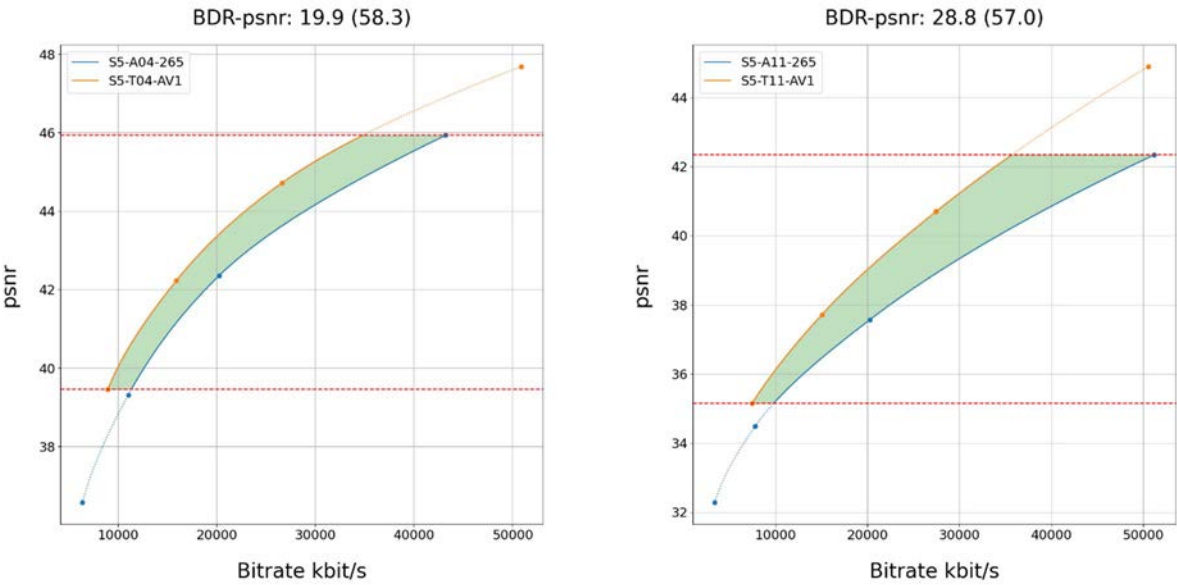


Figure 8.4.4.6-1 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-01 against H.265/HEVC HM with configuration S5-HM-01 for reference sequences S5-R04 and S5-R11.

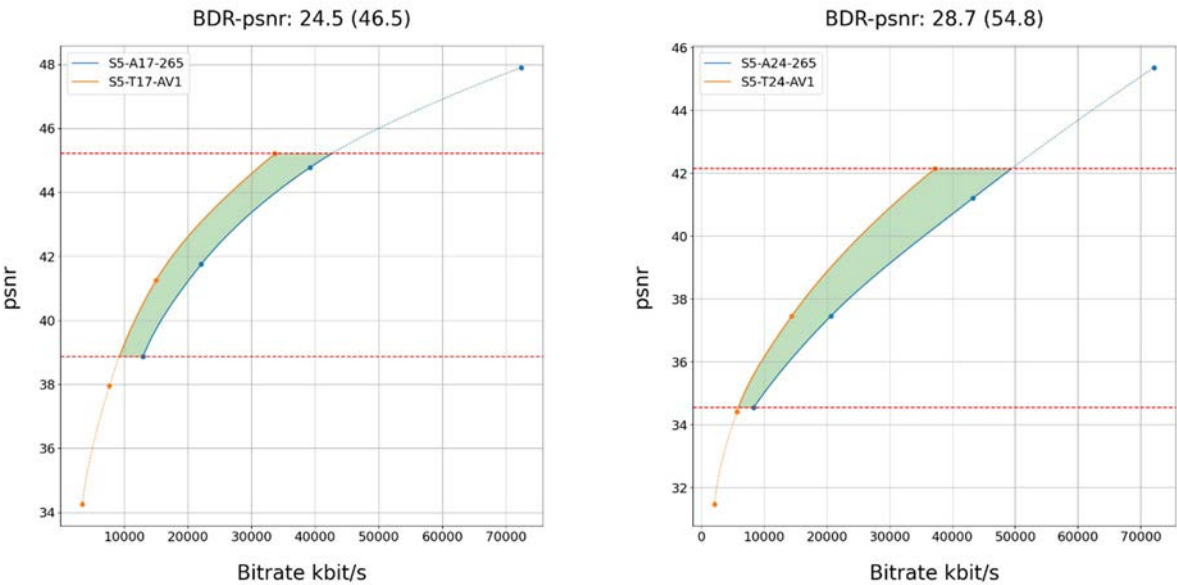


Figure 8.4.4.6-2 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-02 against H.265/HEVC HM with configuration S5-HM-02 for reference sequences S5-R04 and S5-R11.

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/AV1/Characterization/>.

8.4.4.7 Summary

Table 8.4.4.6-1 provides a summary of BD rate gain in psnr and vmaf for SDR and wpsnr and de100 for HDR of AV1 libaom against H.265/HEVC HM for different scenarios and configurations.

Table 8.4.4.7-1 Summary of BD rate gain in psnr and vmaf for SDR and wpsnr and de100 for HDR of AV1 libaom against H.265/HEVC HM for different scenarios and configurations

Scenario	av psnr	min psnr	max psnr	av vmaf	min vmaf	max vmaf
S1 SDR	19.1	10.7	28.3	18.5	8.3	34.5
S2 SDR	18.2	10.1	28.4	16.2	7.1	28.9
S3 no RA	35.5	24.8	43.0	n/a	n/a	n/a
S3 RA, fixed QP	32.6	25.7	44.9	n/a	n/a	n/a
S4 no RA	9.0	7.2	12.2	-4.1	-11.0	1.7
S4 RA, fixed QP	16.9	11.6	22.7	12.7	9.1	17.2
S5 no RA	21.6	15.5	42.0	n/a	n/a	n/a
S5 RA, fixed QP	21.4	13.3	35.5	n/a	n/a	n/a
Minimum	9.0	7.2	12.2	-4.1	-11.0	1.7
Maximum	35.5	25.7	44.9	18.5	9.1	34.5
	av wpsnr	min wpsnr	max wpsnr	av de100	min de100	max de100
S1 HDR	14.9	4.5	23.9	1.3	-15.0	18.5
S2 HDR	16.9	4.9	24.6	3.6	-11.2	14.1

8.4.5 AV1 against H.265/HEVC SCC

8.4.5.1 Introduction

This clause provides a partial characterization of AV1 against H.265/HEVC SCC according to clause 7.2.1. The results provided in clause 6 and 8.4.2 are used for the characterization.

8.4.5.2 Scenario 3: Screen Content

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC SCC for Scenario 3 Screen Content. In particular,

- Table 8.4.5.2-1 provides the BD rate gain of AV1 libaom with S3-AV1-01/03 against H.265/HEVC SCC with configuration S3-SCC-01/03, i.e. with the screen content scenario reference sequences and no fixed random access.
- Table 8.4.5.2-2 provides the BD rate gain of AV1 libaom with S3-AV1-02/04 against H.265/HEVC SCC with configuration S3-SCC-02/04, i.e. with the screen content scenario reference sequences fixed Random access every second.

Table 8.4.5.2-1 BD rate gain of AV1 libaom with S3-AV1-01/03 against H.265/HEVC SCC with configuration S3-SCC-01/03, i.e. with the screen content scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	21.4	19.3
S3-R02	MovingText2-4K-8bit	20.7	18.9
S3-R03	MovingText2-FullHD-10bit	32.8	31.6
S3-R04	MovingText2-FullHD-8bit	32.5	31.4
S3-R05	TextMixTransitions-4K-10bit	4.8	0.1
S3-R06	TextMixTransitions-4K-8bit	3.4	-0.1
S3-R07	TextMixTransitions-FullHD-10bit	17.8	15.0
S3-R08	TextMixTransitions-FullHD-8bit	16.9	14.5
S3-R09	GraphicsMixSimple-4K-10bit	-32.6	-36.5
S3-R10	GraphicsMixSimple-4K-8bit	-33.2	-36.6
S3-R11	GraphicsMixSimple-FullHD-10bit	-6.1	-8.2
S3-R12	GraphicsMixSimple-FullHD-8bit	-6.0	-7.9
S3-R13	GraphicsMixTransitions-4K-10bit	33.0	30.5
S3-R14	GraphicsMixTransitions-4K-8bit	33.2	30.9
S3-R15	GraphicsMixTransitions-FullHD-10bit	34.6	33.0
S3-R16	GraphicsMixTransitions-FullHD-8bit	34.4	32.9
S3-R17	Mission-Control	2.4	1.1
Minimum		-33.2	-36.6
Maximum		34.6	33.0
Average		12.4	10.0

Table 8.4.5.2-2 BD rate gain of AV1 with S3-AV1-02/04 against H.265/HEVC SCC with configuration S3-SCC-02/04, i.e. with the screen content scenario reference sequences fixed Random access every second

Reference sequence	Name	psnr	y_psnr
S3-R01	MovingText2-4K-10bit	32.0	32.4
S3-R02	MovingText2-4K-8bit	32.0	32.5
S3-R03	MovingText2-FullHD-10bit	35.4	36.4
S3-R04	MovingText2-FullHD-8bit	35.4	36.4
S3-R05	TextMixTransitions-4K-10bit	-34.7	-38.7
S3-R06	TextMixTransitions-4K-8bit	-36.2	-38.8
S3-R07	TextMixTransitions-FullHD-10bit	-7.6	-9.0
S3-R08	TextMixTransitions-FullHD-8bit	-7.6	-8.8
S3-R09	GraphicsMixSimple-4K-10bit	-35.5	-36.7
S3-R10	GraphicsMixSimple-4K-8bit	-35.2	-35.8
S3-R11	GraphicsMixSimple-FullHD-10bit	-6.5	-6.6
S3-R12	GraphicsMixSimple-FullHD-8bit	-6.3	-5.8
S3-R13	GraphicsMixTransitions-4K-10bit	11.4	10.2
S3-R14	GraphicsMixTransitions-4K-8bit	11.5	10.8
S3-R15	GraphicsMixTransitions-FullHD-10bit	19.1	19.0
S3-R16	GraphicsMixTransitions-FullHD-8bit	18.9	19.2
S3-R17	Mission-Control	-16.9	-17.3
Minimum		-36.2	-38.8
Maximum		35.4	36.4
Average		0.5	0.0

As an example,

- Figure 8.4.5.2-1 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S3-AV1-03 against H.265/HEVC SCC with configuration S3-SCC-03 for reference sequences S3-R01 and S3-R17.
- Figure 8.4.5.2-2 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S3-AV1-04 against H.265/HEVC SCC with configuration S3-SCC-04 for reference sequences S3-R01 and S3-R17.

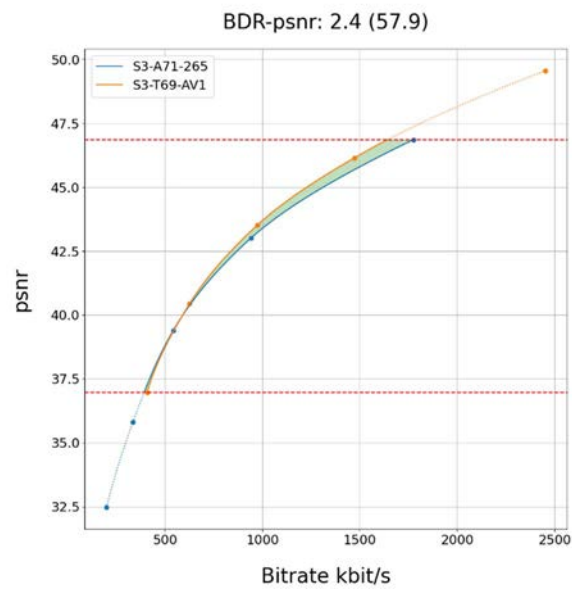
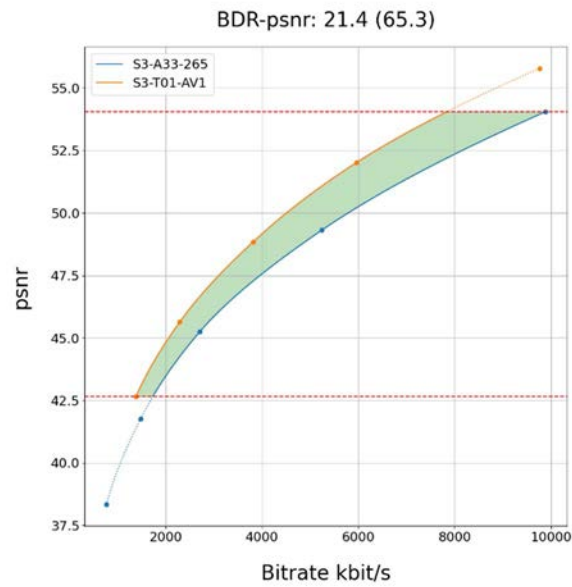


Figure 8.4.5.2-1 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S3-SCC-03 against H.265/HEVC SCC with configuration S3-SCC-03 for reference sequence s S3-R01 and S3-R17

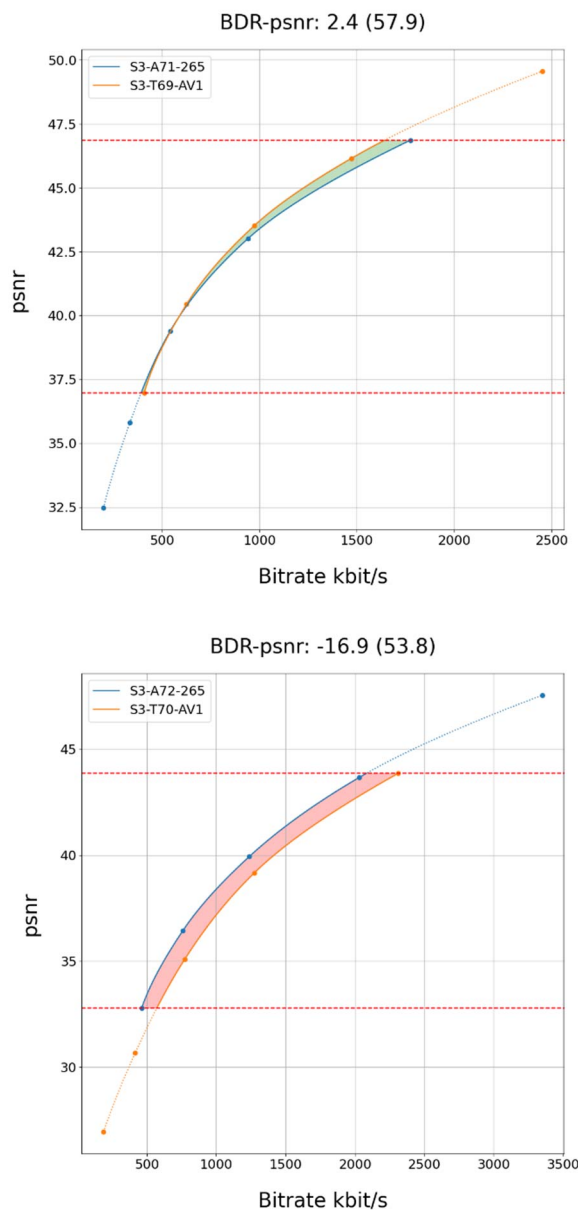


Figure 8.4.5.2-2 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S3-AV1-04 against H.265/HEVC SCC with configuration S3-SCC-04 for reference sequence s S3-R01 and S3-R17

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/AV1/Characterization/>.

8.4.5.3 Scenario 5: Online Gaming

This clause provides characterization of AV1 libaom mode configurations against H.265/HEVC SCC for Scenario 5 Online Gaming. In particular,

- Table 8.4.5.3-1 provides the BD rate gain of AV1 libaom with S5-AV1-01 against H.265/HEVC SCC with configuration S5-SCC-01, i.e. with the online gaming scenario reference sequences and no fixed random access.

- Table 8.4.5.3-2 provides the BD rate gain of AV1 libaom with S5-AV1-02 against H.265/HEVC SCC with configuration S5-SCC-02, i.e. with the online gaming scenario reference sequences and fixed random access every second.

Table 8.4.5.3-1 BD rate gain of AV1 libaom with S5-AV1-01 against H.265/HEVC SCC with configuration S5-SCC-01, i.e. with the online gaming scenario reference sequences and no fixed random access

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	17.5	15.2
S5-R02	Baolei-Man	15.8	11.0
S5-R03	Baolei-Woman	19.4	16.1
S5-R04	Baolei-Balloon	19.2	16.7
S5-R05	Baolei-Yard	15.3	12.1
S5-R06	Jianling-Temple	13.8	9.7
S5-R07	Jianling-Beach	14.5	9.8
S5-R08	Heroes-of-the-Storm	15.9	11.4
S5-R09	Project-CARS	14.6	8.5
S5-R10	World-of-WarCraft	18.9	14.3
S5-R11	MineCraft	13.7	12.1
S5-R12	CS-GO	37.3	33.4
S5-R13	StarCraft	28.2	24.5
Minimum		13.7	8.5
Maximum		37.3	33.4
Average		18.8	15.0

Table 8.4.5.3-2 BD rate gain of AV1 libaom with S5-AV1-02 against H.265/HEVC SCC with configuration S5-SCC-02, i.e. with the online gaming scenario reference sequences and fixed random access every second

Reference sequence	Name	psnr	y_psnr
S5-R01	AOV	16.6	16.2
S5-R02	Baolei-Man	15.8	14.1
S5-R03	Baolei-Woman	18.2	17.8
S5-R04	Baolei-Balloon	23.8	23.9
S5-R05	Baolei-Yard	19.7	19.2
S5-R06	Jianling-Temple	10.4	9.0
S5-R07	Jianling-Beach	10.9	8.6
S5-R08	Heroes-of-the-Storm	15.5	12.0
S5-R09	Project-CARS	16.6	15.8
S5-R10	World-of-WarCraft	18.7	14.3
S5-R11	MineCraft	14.0	15.6
S5-R12	CS-GO	25.2	23.6
S5-R13	StarCraft	12.7	8.9
Minimum		10.4	8.6
Maximum		25.2	23.9
Average		16.8	15.3

As an example,

- Figure 8.4.5.3-1 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-01 against H.265/HEVC SCC with configuration S5-SCC-01 for reference sequences S5-R01 and S5-R04.
- Figure 8.4.5.3-2 provides Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-02 against H.265/HEVC SCC with configuration S5-SCC-02 for reference sequences S5-R01 and S5-R04

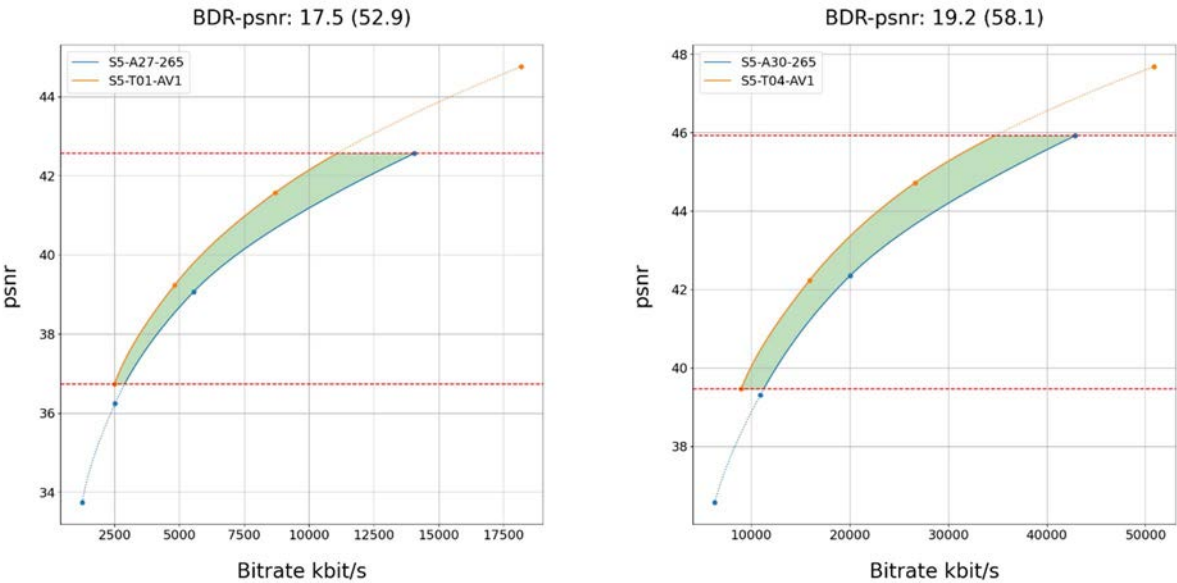


Figure 8.4.5.3-1 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-01 against H.265/HEVC SCC with configuration S5-SCC-01 for reference sequences S5-R01 and S5-R04

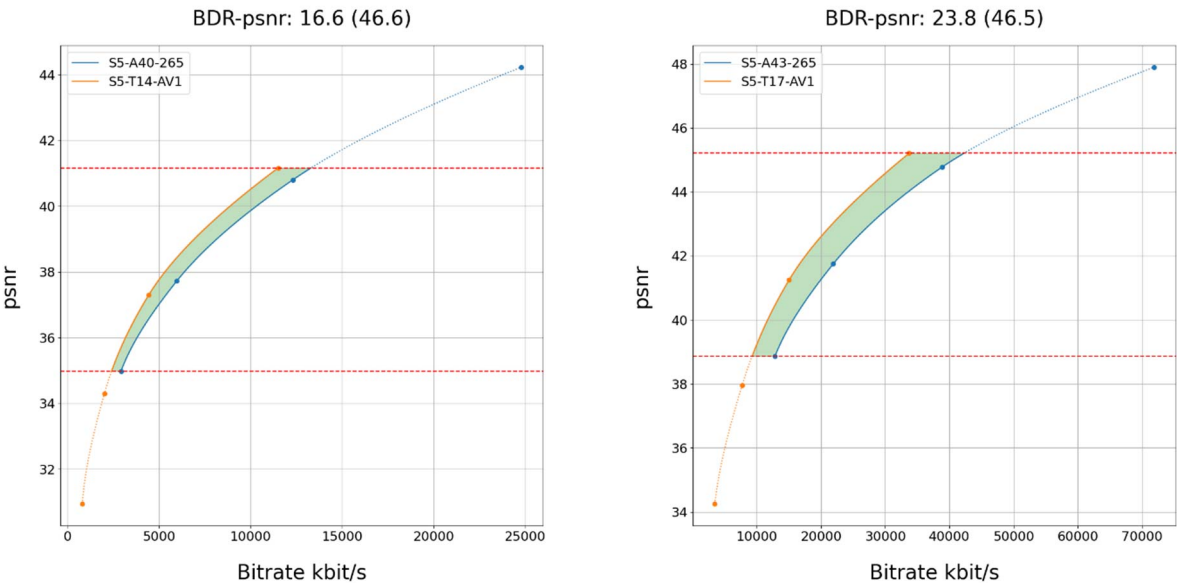


Figure 8.4.5.3-2 Rate-Quality curves and BD rate gain for psnr of AV1 libaom with S5-AV1-02 against H.265/HEVC SCC with configuration S5-SCC-02 for reference sequences S5-R01 and S5-R04

All Rate-Quality curves and BD rate gain plots are provided in the attachment as well as online here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-5-Gaming/AV1/Characterization/>.

8.4.5.4 Summary

Table 8.4.5.4-1 provides a summary of BD rate gain in psnr of AV1 libaom against H.265/HEVC SCC for different scenarios and configurations.

Table 8.4.5.4-1 Summary of BD rate gain in psnr of AV1 libaom against H.265/HEVC SCC for different scenarios and configurations

Scenario	average psnr	min psnr	max psnr
S3 no RA	12.4	-33.2	34.6
S3 RA, fixed QP	0.5	-36.2	35.4
S5 no RA	18.8	13.7	37.3
S5 RA, fixed QP	16.8	10.4	25.2
Minimum	0.5	-36.2	25.2
Maximum	18.8	13.7	35.4

8.4.6 AV1-SCC against H.265/HEVC

Characterization of AV1-SCC against H.265/HEVC HM is for further study.

8.4.7 AV1-SCC against H.265/HEVC SCC

Characterization of AV1-SCC against H.265/HEVC SCC is for further study.

9 Gaps and Optimization Potential

9.1 Identified Gaps and Deficiencies with Existing Codecs

Based on the scenarios that were defined in this Technical Report, the existing 3GPP codecs H.264/AVC and H.265/HEVC have been benchmarked and evaluated.

H.264/AVC is still widely used in services and due to its install base and ubiquity remains a fallback solution for basic use cases. However, H.264/AVC clearly lacks compression efficiency and flexibility to address more advanced use cases, such as HDR, gaming sequences and screen content sharing.

H.265/HEVC provides, at least for the considered scenarios, a full feature set and is broadly and versatily applicable. As H.265/HEVC is part of 3GPP specifications since quite some time, its install base has matured and is almost ubiquitous.

Based on this, a successor to H.264/AVC or H.265/HEVC would be interesting if it provides greater flexibility and feature set coverage with improved compression efficiency over H.265/HEVC.

The performance of H.265/HEVC for higher spatial resolutions, such as 8K, has not been evaluated.

9.2 Potential Requirements for New Codecs

From the collected scenarios, no explicit new requirements for new codecs have been identified.

However, flexibility to different applications, feature coverage and compression efficiency are key functionalities for a codec in 3GPP. A new codec is expected to differentiate from H.265/HEVC in at least one, preferably several dimensions.

It is encouraged to study in more details on potential requirements for new codecs.

10 Conclusions and Proposed Next Steps

The Technical Report provides a full characterization framework for video codecs in the context of 5G services. This framework permits the evaluation of the performance of existing 3GPP codecs, and also permits the identification of potential benefits of new codecs.

The framework fulfils the following aspects:

- A comprehensive set of scenarios relevant to 3GPP services is described in clause 6. For each scenario the anchor(s), the version of the reference software for the anchor(s), and their configuration(s) are defined.
- A set of reference sequences is identified per scenario and each sequence is described in more details in Annex C.
- For each scenario, one or more performance metrics are defined. Each metric is described in more details in clause 5.5
- The overall characterization framework process is defined in clause 5 and in Annex B, D, E, F, and G.
- New codecs are identified in clause 8. For each scenario, a version of their respective reference software is identified and configurations as close as possible to the anchor configurations are defined.

The framework clearly has some limitations; for example, encoder configurations for each scenario may have not been stringent enough in the definition, leading to results that may not be fully comparable. Further, the encoders used for the evaluation of the various codecs have different maturity and features. Results in this document should always be considered with caution, and the reader should understand how these results were derived. The framework does not include subjective evaluation; it is purely based on objective metrics.

Results are complete for 3GPP codecs - H.264/AVC and H.265/HEVC - for all scenarios.

One important outcome of the work documented in this Technical Report is the characterization and evaluation of H.265/HEVC against relevant scenarios and its characterization against H.264/AVC. Also, a first understanding of H.265/HEVC performances versus new codecs was developed. From the scenarios and results in this Technical Report it is observed that:

- H.265/HEVC does not show any functional deficiencies or gaps, nor does it lack any relevant features.
- In terms of compression efficiency, H.265/HEVC, evaluated based on the HM, performs sufficiently well for all the scenarios in this technical report.

Providing consistent HEVC-based interoperability in 3GPP services, for traditional and new scenarios, is definitely beneficial. It is recommended that 3GPP consider upgrading specifications to support profiles, levels, and possibly features available in HEVC. Features may include better support for screen content and computer-generated content, XR/AR type of services, as well as low and very low latency services.

The framework and the initial results for new codecs, while demonstrating coding performance improvements over H.265/HEVC, are not mature enough to support concrete recommendations.

The potential addition of any new codec in 3GPP services and specifications requires diligent preparation, including the identification of needs and requirements for different scenarios, as well as a complete characterization against existing codecs. The information in this TR, as well as any new developments in 3GPP with respect to codecs in latest specifications, could serve as a baseline for future work. Such an effort may lead to conclusions on the potential addition of any new codec in 3GPP services and specifications. However, no immediate need has been identified to initiate such follow-up work.

Annex A: Scenario Template

A.1 Introduction

This annex provides a proposed template to introduce a Scenario for 5G Video. This template has been used to collect the scenarios in this report.

A.2 Template

The following aspects are considered to be important for a scenario

1. Scenario name <give the scenario a catchy name>
2. Motivation for the scenario: Why is the scenario relevant for 5G and video? What is the expected traffic?
3. Description of the scenario: This provides a description of the scenario addressing potentially the relation to a service 5G-based services and applications, including video formats (resolution, frame rates, colour space, etc.), encoding and decoding requirements, adaptive streaming requirements, predominantly based on scenarios defined for 5G media streaming as well as for TR 26.925 and TR 26.928
4. Supporting companies and 3GPP members:
 - a. This documents the 3GPP members that support this scenario in terms of providing the information, test material, test requirements and the characterization for the tests. For each of the identified necessities, a tick box is created in the template.
 - b. Preferably several 3GPP members are included in the support, and in addition a video service provider may be included (not necessarily a 3GPP member).
 - c. Cross-verification is preferably done by the supporters of the scenario
5. Source format properties: This defines a clear range of the considered and relevant source formats, including the signal properties, but also the characteristics of the content. As an example, the source formats as defined in TS26.116 may be used which include:
 - a. Spatial resolutions
 - b. Chroma Format
 - c. Chroma Subsampling
 - d. Aspect ratios
 - e. Frame rates
 - f. Colour space formats
 - g. Transfer Characteristics
 - h. Bit depth
 - i. Other signal properties
6. Encoding and decoding constraints and settings: Typical encoding constraints and settings such as
 - a. Relevant Codec and Codec Profile/Levels according to TS26.116 and TS26.511.
 - b. Random access frequency
 - c. Error resiliency requirements
 - d. Bitrates and quality requirements

- e. Bitrate parameters (CBR, VBR, CAE, HRD parameters)
 - f. ABR encoding requirements (switching frequency, etc.)
 - g. Latency requirements and specific encoding settings
 - h. Encoding context: real-time encoding, on device encoding, cloud-based encoding, offline encoding, etc.
 - i. Required decoding capabilities
7. Performance Metrics and Requirements:
- a. A clear definition on how the performance needs to be evaluated including metrics, etc addressing the main KPIs of the scenario.
 - b. Objective measures such as PSNR, VMAF, etc, may be used.
 - c. Subjective evaluation is not excluded and may be done, but needs commitment
8. Interoperability Considerations for the application
- a. Streaming with DASH/HLS/CMAF
 - b. RTP based delivery
9. Test Sequences
- a. A set of selected test sequences that are provided by the proponents in order to do the evaluation. They should cover a set of source format properties
10. Detailed test conditions:
- a. Provides a proposal for detailed test conditions, for example based on a reference software together with the sequences and configuration parameters.
11. External Performance data
- a. References to external performance data that can be added, for example other SDOs, public documents and so on.
12. Additional Information

Annex B: Data Formats and Metrics

B.1 Introduction

This Annex provides a detailed overview on data formats and their usage for metrics computation.

B.2 Raw Video Sequences

B.2.1 Overview

For a raw video sequence used in the context of this Technical Report, the following metadata is expected to be provided:

- 1) Spatial Resolution width
- 2) Spatial Resolution height
- 3) Chroma Format
- 4) Chroma Sub-Sampling
- 5) Picture Aspect ratio
- 6) Frame rate
- 7) Bit depth
- 8) Colour space format (default is 1 for BT.709)
- 9) Transfer characteristics (default is 1 for BT.709)
- 10) Frame count (and optionally the duration)
- 11) HDR Metadata

In addition, the following aspects were collected that should be added:

- 12) Video storage format
- 13) MD5 of raw video
- 14) Reference to bitstream (URL to weblink where the original sequence is available)
- 15) Copyright statement
- 16) Contact Person
- 17) packing and storage format
- 18) thumbnail preview
- 19) mp4 preview
- 20) Name of sequence
- 21) Sequence key
- 22) Some background information
- 23) Information on how the sequence had been generated.
- 24) md5-10 documenting the md5 of the 10 bit version after conversion

Some information may be optional, others may be optionally defaulted.

A JSON schema is defined in clause B.2.2 for this matter. An example is provided in clause B.2.3.

B.2.2 JSON Schema

JSON schema for the raw format is here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/raw-schema.json>

```
{
  "$schema": "http://json-schema.org/draft-07/schema",
  "$id": "https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/raw-schema.json",
  "type": "object",
  "title": "The root schema",
  "description": "Schema for raw sequences.",
  "default": {},
  "required": ["Sequence", "Properties", "copyRight", "Contact"],
  "properties": {
    "Sequence": {
      "$id": "#/properties/Sequence",
      "type": "object",
      "title": "Schema for the Sequence",
      "description": "Includes all information about the sequence",
      "default": {},
      "required": ["Name", "Background", "Scenario", "URI", "md5", "size", "md5-10"],
      "properties": {
        "Name": {
          "$id": "#/properties/Sequence/properties/Name",
          "type": "string",
          "title": "The Name schema",
          "description": "Provides a unique name of the sequence."
        },
        "Background": {
          "$id": "#/properties/Sequence/properties/Background",
          "type": "string",
          "title": "The Background schema",
          "description": "Provides some background information on the sequence."
        },
        "Scenario": {
          "$id": "#/properties/Sequence/properties/Scenario",
          "type": "string",
          "title": "The Scenario schema",
          "description": "Provides information to which Scenario this sequence relates."
        },
        "Key": {
          "$id": "#/properties/Sequence/properties/Key",
          "type": "string",
          "title": "The Key schema",
          "description": "Provides the key used in TR 26.955.",
          "examples": ["S5-R5"]
        },
        "URI": {
          "$id": "#/properties/Sequence/properties/URI",
          "type": "uri",
          "title": "The URI schema",
          "description": "Provides a reference/URL to the raw video data."
        },
        "md5": {
          "$id": "#/properties/Sequence/properties/md5",
          "type": "string",
          "title": "The md5 schema",
          "description": "Provides the md5 of the raw sequence.",
          "examples": ["d055a94f35f7594776186fc5d09a9fa4"]
        },
        "md5-10": {
          "$id": "#/properties/Sequence/properties/md5-10",
          "type": "string",
          "title": "The md5-10 schema",
          "description": "documents the md5 of the 10 bit version after conversion.",
          "examples": ["d055a94f35f7594776186fc5d09a9fa4"]
        },
        "thumbnail": {
          "$id": "#/properties/Sequence/properties/thumbnail",
          "type": "uri",

```



```

        "title": "The thumbnail schema",
        "description": "Provides a reference/URL to a typical frame of the video."
    },
    "preview": {
        "$id": "#/properties/Sequence/properties/preview",
        "type": "uri",
        "title": "The preview schema",
        "description": "Provides a reference/URL to an mp4 encoded video."
    },
    "TR26.955": {
        "$id": "#/properties/Sequence/properties/TR26.955",
        "type": "string",
        "title": "The TR26.955 schema",
        "description": "An explanation about the purpose of this instance.",
        "default": "",
        "examples": ["Annex C.3.2.3.2"]
    },
    "size": {
        "$id": "#/properties/Sequence/properties/size",
        "type": "integer",
        "title": "The size schema",
        "description": "The size of the raw video in octets."
    },
    },
    "additionalProperties": true
},
"Properties": {
    "$id": "#/properties/Properties",
    "type": "object",
    "title": "The Properties schema",
    "description": "the properties of the raw video."
},
"required": ["width", "height", "bitDepth", "frameRate", "colourPrimaries",
"transferCharacteristics", "matrixCoefficients", "sampleAspectRatio", "duration", "frameCount"],
"properties": {
    "width": {
        "$id": "#/properties/Properties/properties/width",
        "type": "integer",
        "title": "The width schema",
        "description": "width in pixels.",
        "examples": [3840]
    },
    "height": {
        "$id": "#/properties/Properties/properties/height",
        "type": "integer",
        "title": "The height schema",
        "description": "height in pixels.",
        "examples": [2160]
    },
    "format": {
        "$id": "#/properties/Properties/properties/format",
        "type": "string",
        "title": "The format schema",
        "description": "raw video format",
        "default": "yuv",
        "examples": ["yuv"]
    },
    "packing": {
        "$id": "#/properties/Properties/properties/packing",
        "type": "string",
        "title": "The packing schema",
        "description": "packing of the raw video.",
        "default": "planar",
        "examples": ["planar"]
    },
    "scan": {
        "$id": "#/properties/Properties/properties/scan",
        "type": "string",
        "title": "The scan schema",
        "description": "scan schema of the raw video.",
        "default": "progressive",
        "examples": ["progressive"]
    },
    "subsampling": {
        "$id": "#/properties/Properties/properties/subsampling",
        "type": "string",
        "title": "The subsampling schema",
        "description": "colour subsampling.",

```

```

        "default": "420",
        "examples": ["420"]
    },
    "bitDepth": {
        "$id": "#/properties/Properties/properties/bitDepth",
        "type": "integer",
        "title": "The bitDepth schema",
        "description": "bitdepth of the video.",
        "default": 0,
        "examples": [10]
    },
    "frameRate": {
        "$id": "#/properties/Properties/properties/frameRate",
        "type": "number",
        "title": "The frameRate schema",
        "description": "Framerate of the video."
    },
    "colourPrimaries": {
        "$id": "#/properties/Properties/properties/colourPrimaries",
        "type": "string",
        "title": "The colourPrimaries schema",
        "description": "Colour Primaries according to ISO/IEC 23091-3.",
        "examples": ["1", "9"]
    },
    "transferCharacteristics": {
        "$id": "#/properties/Properties/properties/transferCharacteristics",
        "type": "string",
        "title": "The transferCharacteristics schema",
        "description": "Transfer Characteristics according to ISO/IEC 23091-3.",
        "examples": ["1", "14", "16", "18"]
    },
    "matrixCoefficients": {
        "$id": "#/properties/Properties/properties/matrixCoefficients",
        "type": "string",
        "title": "The matrixCoefficients schema",
        "description": "Matrix Coefficients according to ISO/IEC 23091-3.",
        "examples": ["1", "9"]
    },
    "sampleAspectRatio": {
        "$id": "#/properties/Properties/properties/sampleAspectRatio",
        "type": "string",
        "title": "The sampleAspectRatio schema",
        "description": "Sample Aspect Ratio according to ISO/IEC 23091-3.",
        "examples": ["1"]
    },
    "duration": {
        "$id": "#/properties/Properties/properties/duration",
        "type": "number",
        "title": "The duration schema",
        "description": "Duration of the sequence in seconds.",
        "examples": [5.46]
    },
    "frameCount": {
        "$id": "#/properties/Properties/properties/frameCount",
        "type": "integer",
        "title": "The frameCount schema",
        "description": "The number of frames in the sequence.",
        "examples": [327]
    },
    "startFrame": {
        "$id": "#/properties/Properties/properties/startFrame",
        "type": "integer",
        "title": "The startFrame schema",
        "description": "The first frame in the sequence that is to be used starting
from 1.",
        "default": 1,
        "examples": [1]
    },
    "videoFullRangeFlag": {
        "$id": "#/properties/Properties/properties/videoFullRangeFlag",
        "type": "string",
        "title": "The videoFullRangeFlag schema",
        "description": "The fullRange video flag according to ISO/IEC 23091-3.",
        "default": "1",
        "examples": ["0", "1"]
    },
    "chromaSampleLocType": {
        "$id": "#/properties/Properties/properties/chromaSampleLocType",

```

```

        "type": "string",
        "title": "The chromaSampleLocType schema",
        "description": "The chroma sample location according to ISO/IEC 23091-3.",
        "default": "0",
        "examples": ["0", "2"]
      },
      "HDRmasterDisplay": {
        "$id": "#/properties/Properties/properties/HDRmasterDisplay",
        "type": "string",
        "title": "The HDRmasterDisplay schema",
        "description": "HDR Master Display metadata.",
        "examples":
["G(13250,34500)B(7500,3000)R(34000,16000)WP(15635,16450)L(40000000,47)"]
      },
      "HDRmaxCLL": {
        "$id": "#/properties/Properties/properties/HDRmaxCLL",
        "type": "string",
        "title": "The HDRmaxCLL schema",
        "description": "HDRmaxCLL information.",
        "examples": ["4000"]
      },
      "HDRmaxFALL": {
        "$id": "#/properties/Properties/properties/HDRmaxFALL",
        "type": "string",
        "title": "The HDRmaxFALL schema",
        "description": "HDRmaxFALL schema.",
        "examples": ["0"]
      }
    },
    "additionalProperties": true
  },
  "copyRight": {
    "$id": "#/properties/copyRight",
    "type": "string",
    "title": "The copyRight schema",
    "description": "Copyright statement."
  },
  "Contact": {
    "$id": "#/properties/Contact",
    "type": "object",
    "title": "The Contact schema",
    "description": "A contact for the sequence."
  },
  ],
  "required": ["Name"],
  "properties": {
    "Name": {
      "$id": "#/properties/Contact/properties/Name",
      "type": "string",
      "title": "The Name schema",
      "description": "The name of a person."
    },
    "Company": {
      "$id": "#/properties/Contact/properties/Company",
      "type": "string",
      "title": "The Company schema",
      "description": "Company."
    },
    "e-mail": {
      "$id": "#/properties/Contact/properties/e-mail",
      "type": "string",
      "title": "The e-mail schema",
      "description": "e-mail or web page link."
    },
    "generation": {
      "$id": "#/properties/Contact/properties/generation",
      "type": "string",
      "title": "The generation schema",
      "description": "Information on how the data was generated"
    }
  },
  "additionalProperties": true
},
"additionalProperties": true
}

```

B.2.3 Example

```
{
  "Sequence": {
    "Name": "Meridian",
    "Background": "The Meridian test sequence is tbd.",
    "Scenario": "4K-TV",
    "Key": "S5-R5",
    "URI": "meridian.yuv",
    "md5": "d055a94f35f7594776186fc5d09a9fa4",
    "md5-10": "d055a94f35f7594776186fc5d09a9fa4",
    "thumbnail": "./meridian.png",
    "preview": "./meridian.mp4",
    "TR26.955": "Annex C.3.2.3.2",
    "size": 8136806400
  },
  "Properties": {
    "width": 3840,
    "height": 2160,
    "format": "yuv",
    "packing": "planar",
    "scan": "progressive",
    "subsampling": "420",
    "bitDepth": 10,
    "frameRate": 59.94,
    "colourPrimaries": "9",
    "transferCharacteristics": "16",
    "matrixCoefficients": "9",
    "sampleAspectRatio": "1",
    "duration": 5.46,
    "frameCount": 327,
    "startFrame": 1,
    "videoFullRangeFlag": "0",
    "chromaSampleLocType": "2",
    "HDRmasterDisplay":
      "G(13250,34500)B(7500,3000)R(34000,16000)WP(15635,16450)L(40000000,47)",
    "HDRmaxCLL": "4000",
    "HDRmaxFALL": "0"
  },
  "copyright": "Copyright \u00c2\u00a9 The video sequence provided above and all intellectual
property rights therein remain the property of Netflix Inc. This video sequence is licensed under
the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view a
copy of this license, visit http://creativecommons.org/licenses/by-nc-nd/4.0/ ",
  "Contact": {
    "Name": "Thomas Stockhammer",
    "Company": "Qualcomm",
    "e-mail": "tsto@qti.qualcomm.com",
    "generation": "The original sequences can be accessed here
https://media.xiph.org/video/derf/"
  }
}
```

B.3 Encoded Video Sequences

B.2.1 Overview

For encoded video sequences used in the context of this Technical Report, the following metadata is expected to be provided:

- 1) Explanation what this anchor is important for
- 2) Reference sequence
- 3) Reference encoder
- 4) Encoder configuration
- 5) Reference to bitstream
- 6) MD5 of bitstream

- 7) Metrics
- 8) MD5 of reconstructed sequence
- 9) Encoder log
- 10) Copyright statement
- 11) Contact Person

Some information may be optional, others may be optionally defaulted.

A JSON scheme is defined in clause B.2.2 for this matter. An example is provided in clause B.2.3.

B.3.2 JSON Schema

JSON schema for the encoded format is here: <https://github.com/haudioebe/5G-Video-Content/blob/main/3gpp-bin-schema.json>.

B.3.3 Example

```
{
  "Bitstream": {
    "URI": ". /S3-A01-265_22.bin",
    "key": "S3-A01-265_22",
    "md5": "36d42a42c4f1096e6a6fe5d01cae9edf",
    "size": 13709661
  },
  "Contact": {
    "Company": "3GPP",
    "e-mail": "3GPP_TSG_SA_WG4_VIDEO@LIST.ETSI.ORG"
  },
  "Generation": {
    "config-file": "HM-01.cfg",
    "encoder": "HM16.22",
    "key": "S3-R01",
    "log-file": "encoder_S3-A01-265_22.log",
    "sequence": "MovingText2-4K-10bit.json",
    "variant": "-qp 22"
  },
  "Metrics": {
    "Bitrate": "10967.73",
    "BitrateLog": "10940.37",
    "DecodeTime": "119.08",
    "EncodeTime": "51116.6",
    "MS_SSIM": "0.9978",
    "UPSNR": "52.96",
    "VMAF": "100.0",
    "VPSNR": "54.97",
    "YPSNR": "53.44",
    "PSNR": "53.57"
  },
  "Reconstruction": {
    "decoder": "HM16.22",
    "log-file": "decoder_S3-A01-265_22.log",
    "md5": "unknown"
  },
  "Verification": {
    "date": "na",
    "verified": "false"
  },
  "copyright": "The MovingText2 video sequence has been produced for the purpose of this study on the characterization of video codecs in 3GPP."
}
```

B.4 Verification

B.4.1 Overview

In order to track verification, a verification field is added to the json document for each anchor as documented in B.4.2. An example document is provided in clause B.4.3. In order to report cross-check results, a csv file is preferably submitted.

B.4.2 JSON Schema

JSON schema for the encoded format is here: <https://github.com/haudiobe/5G-Video-Content/blob/main/3gpp-bin-schema.json>.

B.4.3 Example

```
{
  "Bitstream": {
    "URI": "https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/S3-A01-265/S3-A01-265-22.bin",
    "md5": "36d42a42c4f1096e6a6fe5d01cae9edf",
    "size": 13709661,
    "key": "S3-A01-265-22",
    "date": "Thu Feb 25 01:47:12 2021"
  },
  "Generation": {
    "sequence": "https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/MovingText2-4K-10bit/MovingText2-4K-10bit.json",
    "key": "S3-R01",
    "encoder": "HM16.22",
    "config-file": "S3-HM-03.cfg",
    "variant": "-qp 22",
    "log-file": ""
  },
  "Reconstruction": {
    "decoder": "HM16.22",
    "log-file": "",
    "md5": "unknown"
  },
  "Metrics": {
    "Bitrate": "10940.369",
    "YPSNR": "53.439",
    "UPSNR": "52.960",
    "VPSNR": "54.966",
    "PSNR": "53.570",
    "MS_SSIM": "26.576",
    "VMAF": "100.000",
    "BitrateLog": "10940.369",
    "EncodeTime": "51116.600",
    "DecodeTime": "119.080"
  },
  "Verification": {
    "bitstream": {
      "status": "missing"
    },
    "metrics": {
      "status": "successful",
      "Reports": [
        {
          "type": "metrics",
          "status": "successful",
          "orig-date": "Thu Feb 25 01:47:12 2021",
          "info": "[('bitrate', 10940.368), ('y_psnr', 53.439), ('u_psnr', 52.96), ('v_psnr', 54.966), ('psnr', 53.57)]",
          "orig-info": "[('bitrate', 10940.369), ('y_psnr', 53.439), ('u_psnr', 52.96), ('v_psnr', 54.966), ('psnr', 53.57)]",
          "company": "Qualcomm",
          "e-mail": "tsto@qti.qualcomm.com",
          "tdoc": "Mon Mar 21 13:10:38 2022"
        }
      ]
    }
  }
}
```

```

    },
    "reconstruction": {
      "status": "missing"
    }
  },
  "copyRight": "The MovingText2 video sequence has been produced for the purpose of this study on
the characterization of video codecs in 3GPP.",
  "Contact": {
    "Company": "3GPP",
    "e-mail": "3GPP_TSG_SA_WG4_VIDEO@LIST.ETSI.ORG"
  }
}

```

B.4.4 Cross-check Report

In order to verify results, cross-check reports may be submitted. Table B.4.4-1 provides a reporting format for cross-checks in CSV.

Table B.4.4-1 Reporting format for cross-checks.

Name	Type	Semantics	Examples
key	STRING	Provides the key of the anchor/test stream	S3-A01-265_22
file	STRING	Provides the reference to the anchor json file	\$root/BitstreamsScenario-3-Screen/265/S3-A01-265/S3-A01-265-22.json
origdate	STRING	Provides the date of the upload of the binary file as documented in the json file	Thu Feb 25 01:47:12 2021
type	STRING	Provides the type of cross-check, bitstream, reconstruction or metrics.	reconstruction
orig-info	STRING	Provides - For bitstream: the md5 of the binary file as documented in the json file - For reconstruction: the md5 of the reconstructed sequence as documented in the json file - For metrics: a list of key value pairs of the metrics required for characterization.	36d42a42c4f1096e6a6fe5d01cae9edf [(bitrate,3547301),(psnr,37.313), (y_psnr, 36.218)]
information	STRING	Provides - For bitstream: the md5 of the binary file - For reconstruction: the md5 of the reconstructed sequence - For metrics: a list of key value pairs of the metrics computed metrics needed for characterization.	1788f44fbd64ead28b7ebf21b7f47fef [(bitrate,3547301),(psnr,37.313), (y_psnr, 36.218)]
status	STRING	Provides the status of the cross check which can be successful, pending, or failed	successful

document	STRING	Provides the SA4 document number in which this was submitted	S4-210xxx
vdate	STRING	Provides the date of the cross-check	Thu May 13 01:47:12 2021
company	STRING	Provides the name of the company that did the cross-check	Example LLC
e-mail	STRING	Provides the e-mail of a contact person that did the cross-check	mustermann@example.com

Annex C: Reference Sequences

C.1 Introduction

This annex provides a summary of candidate reference sequences that were discussed to be potentially suitable for one or multiple of the scenarios introduced in clause 6 of this Technical Report. For each candidate reference sequence, at least the following information is provided.

- A summary of the sequence characteristics
- A screenshot of the sequence
- Source sequence properties
- Information where the source sequence is hosted
- Copyright and license information

The content is provided in JSON files here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequence>. The format of the reference sequences follows the proposed format in Annex B.2.

The sequences are summarized here: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/sequences.csv>.

C.2 Gaming Test Sequences

C.2.1 Overview

A set of gaming sequences is described in this sub-clause C.2.

Table C.2.1-1 proposes a summary of the gaming sequences according to the categories defined in section 6.6.3.

Table C.2.1-1, Gaming sequences categorization

Sequence description			Categories				
Game sequence title	Game type	Sequences Characteristics	A	B:	C:	D:	E:
Arena of Valor (AOV) (Tencent)	multiplayer online battle arena	fix + Smooth travelling. Small incrustation. Stable at 90%. One pop-up incrustation.	X				
Baolei-Man (Tencent)	online multiplayer first person shooter	Pursuit. Some irregular camera traveling. Small incrustation. Stable at 99%		X			
Baloei-Balloon 4k (Tencent)	online multiplayer first person shooter	Pursuit. Some irregular camera traveling. Small incrustation. Stable at 90%		X			
Baolei-Woman (Tencent)	online multiplayer first person shooter	Pursuit. Lots of irregular camera traveling. Small incrustation. Stable at 90%			X		
Baolei-Yard 4K (Tencent)	online multiplayer first person shooter	Pursuit. Some irregular camera traveling. Small incrustation. Stable at 99%			X		
Jianling-Temple (Tencent)	massive multiplayer online role-playing	Battle/pursuit. Lots of irregular camera traveling. Stable at 90% One small pop-up incrustation			X		
Jianling-Beach (Tencent)	massive multiplayer online role-playing	Battle/pursuit. Dark scene. Irregular camera traveling. Small incrustation. Stable at 99%		X			
Heroes of the Storm part 1 (kingston)	a crossover multiplayer online battle arena	Fix, plus 2 smooth small travelling	X				
Project CARS part 1 (kingston)	Car racing game	Realistic rendering. Constant smooth movement. Small incrustation. Stable at 90%				X	
WoW part 2 (kingston)	multiplayer online role play	Dark scene, irregular camera traveling. Small incrustation. Stable at 90%	X				
Minecraft (twitch)	Casual game sandbox, brick construction	Graphic : Lots of irregular camera traveling. Very small incrustation. Stable at 100%	X				
CS:GO (twitch)	a multiplayer first-person shooter	1/ first half of sequence is dark (300pict) 2/ fade (15 pict) 3/ action : first-person shooter	X (first part)		X (3 rd part)		
StarCraft (twitch)	Real Time Strategy game	fix + smooth travelling Small incrustation stable at 90%.		X			

C.2.2 AOV

C.2.2.1 Introduction

Arena of Valor (AOV) ©Tencent Games – is a 3D MOBA (multiplayer online battle arena) game. Within a limited size map 2 groups of 5 vs 5 or 3 vs 3 players take part of a battle for which each player chooses a hero with particular power and abilities. The figure C.2.2-1 illustrates the gameplay of AOV with a screenshot of the AOV test sequence.



Figure C.2.2-1: Screenshot of AOV test sequence

C.2.2.2 Sequence properties

The AOV test sequence properties are provided in Table C.2.2.2-1.

Table C.2.2.2-1 AOV sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/AOV/AOV.json>

C.2.2.3 Copyright and license information

The AOV video sequence is made available under the following copyright disclaimer.

Copyright © 1998 - 2018 Tencent. All Rights Reserved.

This sequence and all intellectual property rights therein remain the property of Shenzhen Tencent Computer System Co. Ltd. and Tencent America LLC. This sequence may only be used for the purpose of developing, testing and promulgating technology standards (the Purpose). Shenzhen Tencent Computer System Co. Ltd. and Tencent America LLC. make no warranties with respect to this sequence and expressly disclaim any warranties regarding its fitness for any purpose. This disclaimer shall remain attached to this sequence except when this sequence is used for the Purpose.

C.2.3 Baolei-Man

C.2.3.1 Introduction

The *Baolei-Man* test sequence is an extract from a famous online multiplayer game in which many players play in a battle royale mode meaning that in survival mode, the last standing one is the winner. The figure C.2.3-1 shows a screenshot of the *Baolei-Man* test sequence.



Figure C.2.3-1: Screenshot of Baolei-Man test sequence

C.2.3.2 Sequence properties

The Baolei-Man test sequence is available in fullHD with the following properties specified hereafter in Table C.2.3.2-1.

Table C.2.3.2-1 Baolei-Man sequence properties

Parameter	Value fullHD
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Baolei-Man/Baolei-Man.json>

C.2.3.3 Copyright and license information

The Baolei-Man video sequence is made available under the following copyright disclaimer.

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C.2.4 Baolei-Woman

C.2.4.1 Introduction

The Baolei-Woman test sequence is also an extract from the same game as for Balei-Man. The figure C.2.4-1 shows a screenshot of the Baolei-Woman test sequence.



Figure C.2.4-1: Screenshot of Baolei-Woman test sequence

C.2.4.2 Sequence properties

Similarly to the Baolei-Man test sequence, Baolei-Woman is also available in FullHD with the following properties specified hereafter in Table C.2.4.2-1.

Table C.2.4.2-1 Baolei-Woman sequences properties

Parameter	Value FullHD
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Baolei-Woman/Baolei-Woman.json>

C.2.4.3 Copyright and license information

The Baolei-Woman video sequence is made available under the following copyright disclaimer.

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C.2.5 Baolei-Balloon

C.2.5.1 Introduction

The *Baolei-Balloon* test sequence is also an extract from the same game as for Balei-Man. The figure C.2.5-1 shows a screenshot of the *Baolei-Balloon* test sequence.



Figure C.2.5-1: Screenshot of Baolei-Balloon test sequence

C.2.5.2 Sequence properties

The Baolei-Balloon test sequence is available in 4K with the following properties specified hereafter in Table C.2.5.2-1.

Table C.2.5.2-1 Baolei-Balloon sequence properties

Parameter	Value 4K
Resolution	4096x2160
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Baolei-Balloon/baolei-balloon.json>

C.2.5.3 Copyright and license information

The *Baolei-Balloon* video sequence is made available under the following copyright disclaimer.

Copyright © 1998 - 2020 Tencent. All Rights Reserved.

This sequence and all intellectual property rights therein remain the property of Shenzhen Tencent Computer System Co. Ltd.. This sequence may only be used for the purpose of developing, testing and promulgating technology standards (the Purpose). Shenzhen Tencent Computer System Co. Ltd. make no warranties with respect to this sequence and expressly disclaim any warranties regarding its fitness for any purpose. This disclaimer shall remain attached to this sequence except when this sequence is used for the Purpose.

C.2.6 Baolei-Yard

C.2.6.1 Introduction

The *Baolei-Yard* test sequence is also an extract from the same game as for Balei-Man. The figure C.2.6-1 shows a screenshot of the Baolei-Yard test sequence.



Figure C.2.6-1: Screenshot of Baolei-Yard test sequence

C.2.6.2 Sequence properties

Similarly to the Baolei-Balloon test sequence, Baolei-Yard is also available in 4K with the following properties specified hereafter in Table C.2.6.2-1.

Table C.2.4.2-1 Baolei-Yard sequences properties

Parameter	Value 4K
Resolution	4096x2160
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Baolei-Yard/Baolei-Yard.json>

C.2.6.3 Copyright and license information

The Baolei-Yard video sequence is made available under the following copyright disclaimer.

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C.2.7 Jianling-Temple

C.2.7.1 Introduction

The Jianling-Temple test sequence is an extract from another famous massive multiplayer online role-playing game (MMORPG) having two gameplay modes Player-versus-Environment (PvE) and Player-versus-player (PvP). The figure C.2.7-1 is a screenshot of the Jianling-Temple test sequence.



Figure C.2.7-1: Screenshot of Jianling-Temple test sequence

C.2.7.2 Sequence properties

The Jianling-Temple test sequence properties are provided in Table C.2.7.2-1.

Table C.2.7.2-1 Jianling-Temple sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Jianling-Temple/jianling-temple.json>

C.2.7.3 Copyright and license information

The Jianling-Temple video sequence is made available under the following copyright disclaimer.

Copyright © 1998 - 2020 Tencent & NCSOFT. All Rights Reserved.

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C.2.8 Jianling-Beach

C.2.8.1 Introduction

The *Jianling-Beach* test sequence is another extract from the same MMORPG game as the Jianling-Temple sequence. The figure C.2.8-1 is a screenshot of the Jianling-Beach test sequence.



Figure C.2.8-1: Screenshot of Jianling-Beach test sequence

C.2.8.2 Sequence properties

The Jianling-Beach test sequence properties are provided in Table C.2.8.2-1.

Table C.2.8.2-1 Jianling-Beach sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Jianling-Beach/jianling-beach.json>

C.2.8.3 Copyright and license information

The Jianling-Beach video sequence is made available under the following copyright disclaimer.

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C.2.9 Heroes of the Storm

C.2.9.1 Introduction

Heroes of the Storm is a crossover multiplayer online battle arena video game developed and published by Blizzard Entertainment. The figure C.2.9.1-1 illustrates the gameplay of Heroes of the Storm with a screenshot of the test sequence provided by Kingston University, London and Technical University, Berlin. [42] [43].



Figure C.2.9.1-1: Screenshot of Heroes of the Storm test sequence

C.2.9.2 Sequence properties

The Heroes of the Storm test sequence properties are provided in Table C.2.9.2-1.

Table C.2.2.2-1 Heroes of the Storm sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	30 fps
Bit Depth	8
Length	900 frames (30s), but only first 300 frames to be used
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The Heroes of the Storm video sequence part 1 provided by Kingston University, London and Technical University, Berlin is available at this location:

- <https://kingston.app.box.com/v/GamingVideoSET.Part2>.

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Heroes-of-the-Storm/Heroes-of-the-Storm.json>

C.2.9.3 Copyright and license information

The Heroes of the Storm video sequence provided by Kingston University, London and Technical University, Berlin is made available under the following copyright disclaimer.

<https://kingston.app.box.com/v/GamingVideoSET/file/289578680253>

C.2.10 Project CARS

C.2.10.1 Introduction

Project CARS is a racing video game series developed by Slightly Mad Studios and published by Bandai Namco Entertainment. The figure C.2.10.1-1 illustrates the gameplay of Project CARS with a screenshot of the test sequence provided by Kingston University, London and Technical University, Berlin. [42] [43].



Figure C.2.10.1-1: Screenshot of Project CARS test sequence

C.2.10.2 Sequence properties

The Project CARS test sequence properties are provided in Table C.2.10.2-1.

Table C.2.10.2-1 Project CARS sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	30 fps
Bit Depth	8
Length	900 frames (30s), but only first 300 frames to be used
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The Project CARS video sequence part 1 provided by Kingston University, London and Technical University, Berlin is available at this location:

<https://kingston.app.box.com/v/GamingVideoSET>. Part 2

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Project-CARS/Project-CARS.json>

C.2.10.3 Copyright and license information

The Project CARS video sequence provided by Kingston University, London and Technical University, Berlin is made available under the following copyright disclaimer:

<https://kingston.app.box.com/v/GamingVideoSET/file/289578680253>

C.2.11 World of WarCraft: WoW

C.2.11.1 Introduction

WoW is a multiplayer online role play developed and published by Blizzard Entertainment where players control a character avatar within a game world in third- or first-person view, exploring the landscape, fighting various monsters, completing quests, and interacting with non-player characters or other players. The figure C.2.11.1-1 illustrates the gameplay of WoW with a screenshot of the test sequence, which is a dark scene, provided by Kingston University, London and Technical University, Berlin. [42] [43].



Figure C.2.11.1-1: Screenshot of World of Warcraft: WoW test sequence

C.2.11.2 Sequence properties

The WoW test sequence part 2, provided by Kingston University, London and Technical University, Berlin, sequence properties are provided in Table C.2.11.2-1.

Table C.2.11.2-1 World of Warcraft sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	30 fps
Bit Depth	8
Length	900 frames (30s), but only first 300 frames to be used
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The WoW video sequence part 2 provided by Kingston University, London and Technical University, Berlin is available at this location:

[https://kingston.app.box.com/v/GamingVideoSET. Part 2](https://kingston.app.box.com/v/GamingVideoSET.Part2)

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/World-of-WarCraft/World-of-WarCraft.json>

C.2.11.3 Copyright and license information

The WoW video sequence provided by Kingston University, London and Technical University, Berlin is made available under the following copyright disclaimer:

<https://kingston.app.box.com/v/GamingVideoSET/file/289578680253>

C.2.12 Minecraft

C.2.12.1 Introduction

The Minecraft test sequence is an extract from a famous a sandbox video game developed by Mojang Studios in which players explore a blocky, procedurally-generated 3D world with infinite terrain, and may discover and extract raw materials, craft tools and items, and build structures or earthworks. The figure C.2.12.1-1 shows a screenshot of the Minecraft test sequence provided by DERF_TWITCH.



Figure C.2.12.1-1: Screenshot of Minecraft test sequence

C.2.12.2 Sequence properties

The Minecraft test sequence properties are provided in Table C.2.12.2-1.

Table C.2.12.2-1 Minecraft sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The Minecraft sequence provided by DERTF-Twitch can be downloaded in y4m format at following URL: <https://media.xiph.org/video/derf/twitch/y4m/> and can be converted into YUV format with ffmpeg by using the following exemplary command line: `ffmpeg -i Minecraft.y4m Minecraft.yuv`.

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/MineCraft/MineCraft.json>

C.2.12.3 Copyright and license information

The copyright under which the Minecraft video sequence from DERF_Twitch is made available on that link:

<https://media.xiph.org/video/derf/twitch/copyright.txt>

C.2.13 CS:GO

C.2.13.1 Introduction

The CS:GO test sequence from Twitch is an extract from a is a multiplayer first-person shooter video game developed by Valve and Hidden Path Entertainment where two opposing teams, known as the Terrorists and the Counter-Terrorists, compete in game modes to complete objectives, such as securing a location to plant or defuse a bomb and rescuing or guarding hostages. The figure C.2.13.1-1 shows a screenshot of the CS:GO test sequence provided by DERF-TWITCH.



Figure C.2.13.1-1: Screenshot of CS:GO test sequence

C.2.13.2 Sequence properties

The CS:GO test sequence properties are provided in Table C.2.13.2-1.

Table C.2.13.2-1 CS:GO sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The CS:GO sequence provided by DERF-Twitch can be downloaded in y4m format at following URL: <https://media.xiph.org/video/derf/twitch/y4m/> and can be converted into YUV format with ffmpeg by using the following exemplary command line: `ffmpeg -i CSGO.y4m CSGO.yuv`.

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/CS-GO/CS-GO.json>

C.2.13.3 Copyright and license information

The copyright under which the CS:GO video sequence provided by DERF-Twitch is made available can be found on that link:

<https://media.xiph.org/video/derf/twitch/copyright.txt>.

C.2.14 StarCraft

C.2.14.1 Introduction

The StarCraft test sequence from Twitch is an extract from a famous Real Time Strategy game developed and published by Blizzard Entertainment where players enter a tournament of 5 games and chose to play one of three alien categories with distinct characteristic and abilities. The figure C.2.12.1-1 shows a screenshot of the StarCraft test sequence provided by DERF-Twitch.



Figure C.2.14.1-1: Screenshot of StarCraft test sequence

C.2.14.2 Sequence properties

The StarCraft test sequence properties are provided in Table C.2.14.2-1.

Table C.2.14.2-1 StarCraft sequence properties

Parameter	Value
Resolution	1920x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	8
Length	600 frames (10s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The StarCraft sequence provided by Derf-Twitch can be downloaded in y4m format at following URL: <https://media.xiph.org/video/derf/twitch/y4m/> and can be converted into YUV format with ffmpeg by using the following exemplary command line: `ffmpeg -i StartCraft.y4m Startcraft.yuv`.

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/StarCraft/StarCraft.json>

C.2.14.3 Copyright and license information

The copyright under which the StarCraft video sequence provided by DERF-Twitch is made available can be found on that link: <https://media.xiph.org/video/derf/twitch/copyright.txt>.

C.3 4K-TV Sequences

C.3.1 SDR Category

C.3.1.1 Candidate Test Sequences

C.3.1.1.1 Introduction

In this Annex, a wide range of SDR test material is reported. The candidate sequences are extracted from test material used in video processing community. The following sections describe the test material in terms of format characteristics and copyright.

C.3.1.1.2 Ultra Video Group Sequences

The Ultra Video Group (UVG) sequences are publicly available and can be used under CC BY-NC 3.0 license. The sequences are available for download at <https://github.com/ultravideo/UVG-4K-Dataset> and an overview is provided in Table C.3.1.1.2-1.

Table C.3.1.1.2-1: UVG test material description

Name	Resolution	Frame Rate	Colour Gamut	Duration
CityAlley	3840 x 2160	50	BT.709	12s
FlowerFocus	3840 x 2160	50	BT.709	12s
FlowerKids	3840 x 2160	50	BT.709	12s
FlowerPan	3840 x 2160	50	BT.709	12s
RaceNight	3840 x 2160	50	BT.709	12s
RiverBank	3840 x 2160	50	BT.709	12s
SunBath	3840 x 2160	50	BT.709	6s
Twilight	3840 x 2160	50	BT.709	12s

C.3.1.1.3 JVET Sequences

The JVET test material for UHD SDR sequences is composed by six sequences described in Table C.3.1.1.3-1. The licensing information referenced in the table is described below:

1. CC BY-NC-ND 4.0
2. Our dataset is available for free and academic research only, no commercial use. Please cite our paper (L. Song, X. Tang, W. Zhang, X. Yang, P. Xia, The SJTU 4K Video Sequence Dataset, the Fifth International Workshop on Quality of Multimedia Experience (QoMEX2013), Klagenfurt, Austria, July 3rd-5th, 2013) in any published work if you use those video sequences.
3. Please note that this test material remains the property of the Institute of Research & Technology b<>com and is solely provided “as is” to ITU-T SG16 Q6 and ISO/IEC JTC1/SC29/WG11, on a non-transferable and non-exclusive basis, and solely for the purpose of development, testing and promulgation of video coding standards. Any disclosure to third parties, exhibition, broadcast, distribution, public display or other exploitation of the test material is strictly prohibited.
4. The proposed test sequences in this document and all intellectual property rights therein remain the property of Huawei Technologies Co., Ltd., and National Engineering Research Center.

Table C.3.1.1.3-1: JVET test material description

Name	Resolution	Frame Rate	Colour Gamut	Number of frames	License
Tango2	3840 x 2160	60	BT.709	294	See 1.
FoodMarket4	3840 x 2160	60	BT.709	300	See 1.
Campfire	3840 x 2160	30	BT.709	300	See 2.
Catrobots1	3840 x 2160	60	BT.709	300	See 3.
Daylightroad2	3840 x 2160	60	BT.709	300	See 4.
Parkrunning3	3840 x 2160	50	BT.709	300	See 4.

C.3.1.1.4 Netflix Sequences

The Netflix dataset is composed by eighteen 4K sequences described in Table C.3.1.1.4-1. The sequences can be used under the CC BY-NC-ND 4.0 license restriction.

Table C.3.1.1.4-1: Netflix test material description

Name	Resolution	Frame Rate	Colour Gamut	Number of frames
Netflix_Aerial	4096 x 2160	59.94	BT.709	1199
Netflix_DinnerScene	4096 x 2160	59.94	BT.709	1199
Netflix_RollerCoaster	4096 x 2160	59.94	BT.709	1199
Netflix_DrivingPOV	4096 x 2160	59.94	BT.709	1199
Netflix_BarScene	4096 x 2160	59.94	BT.709	1199
Netflix_ToddlerFountain	4096 x 2160	59.94	BT.709	1199
Netflix_Dancers	4096 x 2160	59.94	BT.709	1199
Netflix_PierSeaside	4096 x 2160	59.94	BT.709	1199
Netflix_WindAndNature	4096 x 2160	59.94	BT.709	1199
Netflix_Boat	4096 x 2160	59.94	BT.709	300
Netflix_FoodMarket	4096 x 2160	59.94	BT.709	600
Netflix_Tango	4096 x 2160	59.94	BT.709	294
Netflix_BoxingPractice	4096 x 2160	59.94	BT.709	254
Netflix_Narrator	4096 x 2160	59.94	BT.709	300
Netflix_TunnelFlag	4096 x 2160	59.94	BT.709	600
Netflix_RitualDance	4096 x 2160	59.94	BT.709	600
Netflix_FoodMarket2	4096 x 2160	59.94	BT.709	300
Netflix_SquareAndTimelapse	4096 x 2160	59.94	BT.709	600
Netflix_Aerial	4096 x 2160	59.94	BT.709	1199
Netflix_DinnerScene	4096 x 2160	59.94	BT.709	1199
Netflix_RollerCoaster	4096 x 2160	59.94	BT.709	1199

C.3.1.1.5 EBU Sequences

The EBU dataset is composed by two sequences described in Table C.3.1.1.5-1. The sequences can be used under the CC BY-NC-ND 4.0 license restriction.

Table C.3.1.1.5-1: EBU test material description

Name	Resolution	Frame Rate	Colour Gamut	Number of frames
Rain_fruits	3840 x 2160	50	BT.709	600
Lupo_candlelight	3840 x 2160	50	BT.709	600

C.3.1.1.6 SVT Sequences

The SVT dataset is composed by five sequences described in Table C.3.1.1.6-1. The sequences can be used under the license available at <https://tech.ebu.ch/webdav/site/tech/shared/hdtv/svt-multiformat-conditions-v10.pdf>.

Table C.3.1.1.6-1: SVT test material description

Name	Resolution	Frame rate	Colour Gamut	Number of frames
CrowdRun	3840 x 2160	50	BT.709	500
ParkJoy	3840 x 2160	50	BT.709	500
DucksTakeOff	3840 x 2160	50	BT.709	500
IntoTree	3840 x 2160	50	BT.709	500
OldTownCross	3840 x 2160	50	BT.709	500

C.3.1.1.7 4ever Sequences

The 4ever dataset is composed by two sequences described in Table C.3.1.1.7-1. The sequences can be used under the license described below:

The proposed test sequences Brest_Sedof_3840x2160p60_10b.yuv and Paris_Montmartre_3840x2160p60_10b, and all intellectual property rights therein remain the property of 4EVER consortium partners: Orange, AMP Visual TV, ATEME, France Télévisions, GlobeCast, InterDigital, Highlands Technologies Solutions, INSA Rennes, TeamCast and Télécom ParisTech

- The following uses are allowed for the proposed sequences:
 - Can be published in technical papers, played at technology research and development events.
 - Can be used in 3GPP SA4.
- The following use is not allowed for the proposed sequences:
 - Do not publish snapshots in product brochures.
 - Do not redistribute video with a commercial product.

Table C.3.1.1.7-1: 4ever test material description

Name	Resolution	Frame Rate	Colour Gamut	Number of frames
4EVER_Brest_Sedof	3840 x 2160	60	BT.2020	600
4EVER_Paris_Montmartre	3840 x 2160	60	BT.2020	600

C.3.1.1.8 CableLabs Sequences

The CableLabs dataset is composed by eight sequences described in the Table C.3.1.1.8-1. The sequences can be used under the CC BY-NC-ND 3.0 license restriction.

Table C.3.1.1.8-1: CableLabs test material description

Name	Resolution	Frame Rate	Colour Gamut	Duration	Comment on selected intervals
Lifting Off	3840 x 2160	24/1.001	BT.709	3:21	Nice colored pictures, som burned in text, scene cuts (2)
Seconds that count	3840 x 2160	24/1.001	BT.709	5:22	Not critical
Unspoken Friend	3840 x 2160	24/1.001	BT.709	4:17	Not critical
Indoor Soccer	3840 x 2160	24/1.001	BT.709	4:12	Fast motion, scene cuts (4)
Skateboarding	3840 x 2160	24/1.001	BT.709	4:36	Not critical
Eldorado	3840 x 2160	24/1.001	BT.709	3:02	Panning up/down on a tree (oak), no scene cut
Moment of Intensity	3840 x 2160	60/1.001	BT.709	3:10	Skate board, no scene cuts
Ancient Thought	3840 x 2160	24/1.001	BT.709	3:08	Not critical

All of the sequences are not of interest for compression evaluation. A selection of some critical time intervals have been conducted based on experience on compression. Especially intervals with fast or complex motion, some including scene cuts, representative of TV contents have been selected. Static pictures, or pictures with artistic intent with few spatial details have been discarded. To remain in the scope of the scenario, the following sub sequences have been selected as final candidates:

- Lifting off: from 00:05 to 00:22
- Indoor Soccer: from 01:07 to 01:23 (385 frames)
- Eldorado: from 01:33 to 01:50
- Moment of intensity: from 01:33 to 01:50

The extraction of subpart from original ProRes sequences is realized with FFmpeg release 4.3.1 using the following command line:

```
./ffmpeg.exe -i $IN.mov -vcodec rawvideo -ss $START_TIME -t $DURATION -
  pix_fmt yuv420p10le $OUT.yuv
```

Where \$IN and \$OUT are respectively the input and output sequences, \$START_TIME and \$DURATION respectively the start time and duration in hh:mm:ss format.

C.3.1.2 Test Sequence Selection Process

C.3.1.2.1 Introduction

In order to decide which sequences should be used in this specification, the following process has been used:

1. Run informative encoding using x265 on the candidate sequences
2. Run SI-TI metrics computation on the candidate sequences
3. Select two diverse datasets based on R-D and SI-TI information.

C.3.1.2.2 x265 Encoding

To represent candidate sequences in the R-D plane, fixed QP encodings are carried out for QPs [12, 17, 22, 27, 32, 37, 42] using ffmpeg release 4.3.1, with the following command line:

```
./ffmpeg.exe -pix_fmt yuv420p10le -s $Wx$H -framerate $FR -i $IN -vcodec  
libx265 -qp $QP -preset fast -x265-params "psnr=1:ssim=1" $OUT.mp4
```

Where W and H are respectively the sequence width and height, FR the sequence frame rate, QP the selected quantization parameter. IN and OUT are respectively the input and output files.

From the obtained log, the overall bitrate and PSNR are extracted to be used for plotting. The encoding result are presented below:

- Figure 3.1.2.2-1 provides the R-D curves for the UVG dataset,
- Figure 3.1.2.2-2 provides the R-D curves for the JVET dataset,
- Figure 3.1.2.2-3 provides the R-D curves for the Netflix dataset,
- Figure 3.1.2.2-4 provides the R-D curves for the EBU, SVT and 4ever dataset,
- Figure 3.1.2.2-5 provides the R-D curves for the CableLabs dataset.

All sequences being represented in the targeted [10-40] Mbps range (red box).

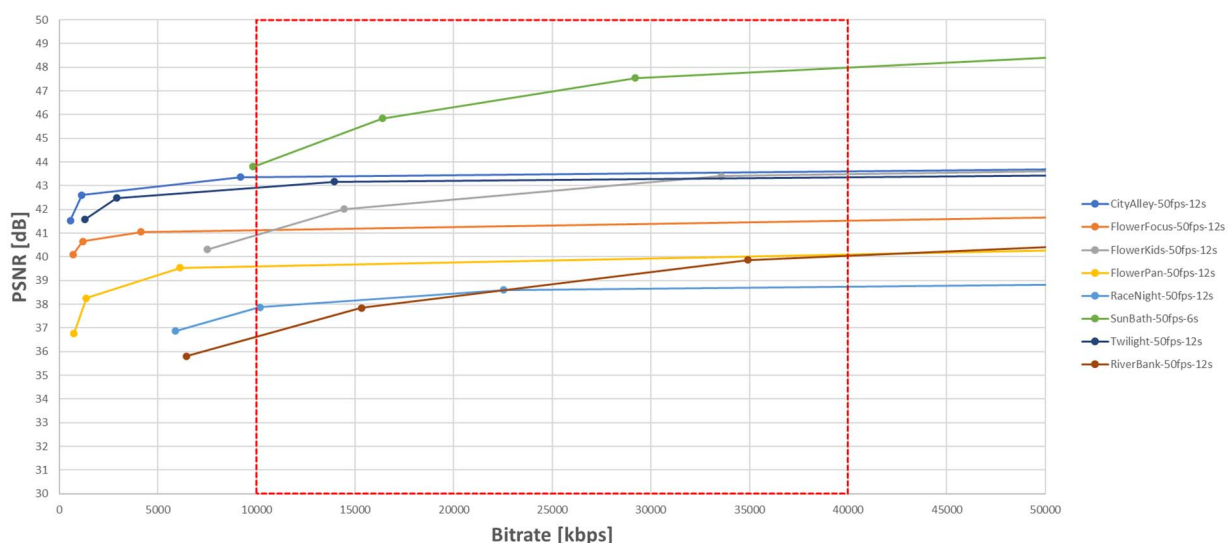


Figure C. 3.1.2.2-1: R-D curves for the UVG dataset

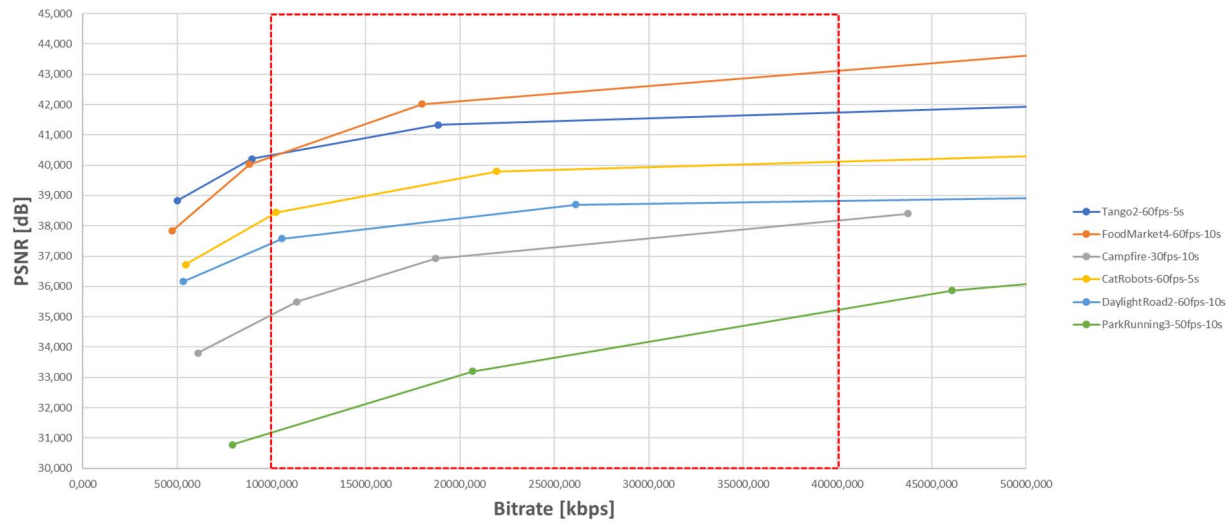


Figure C. 3.1.2.2-2: R-D curves for the JVET dataset

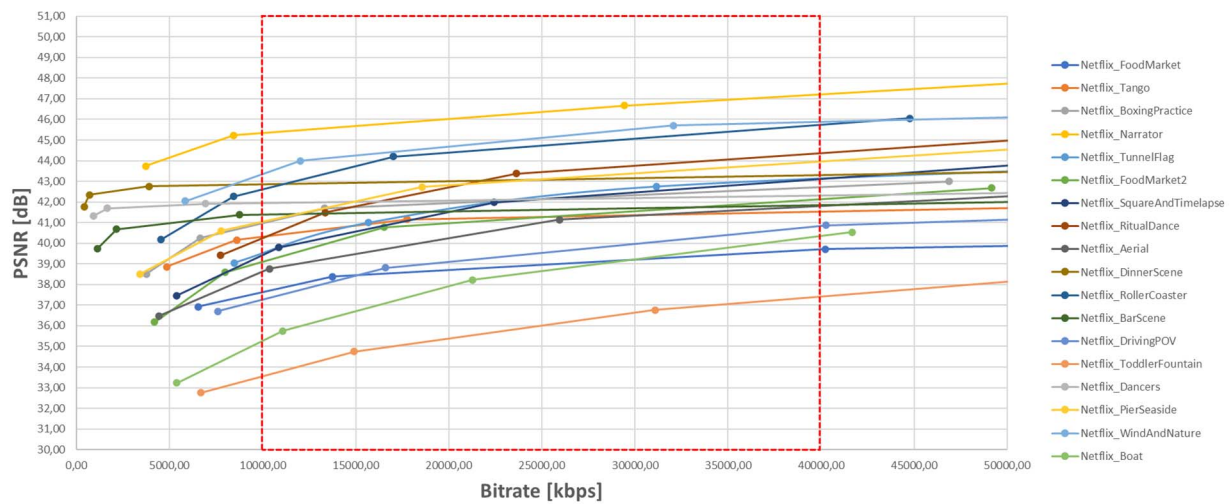


Figure C. 3.1.2.2-3: R-D curves for the Netflix dataset

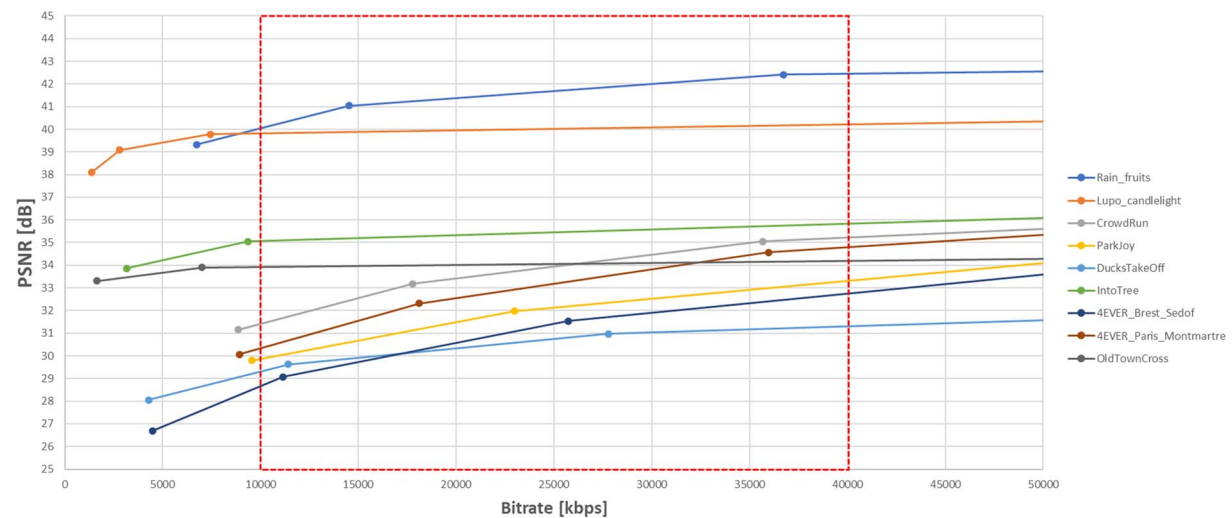


Figure C. 3.1.2.2-4: R-D curves for the EBU, SVT and 4ever datasets

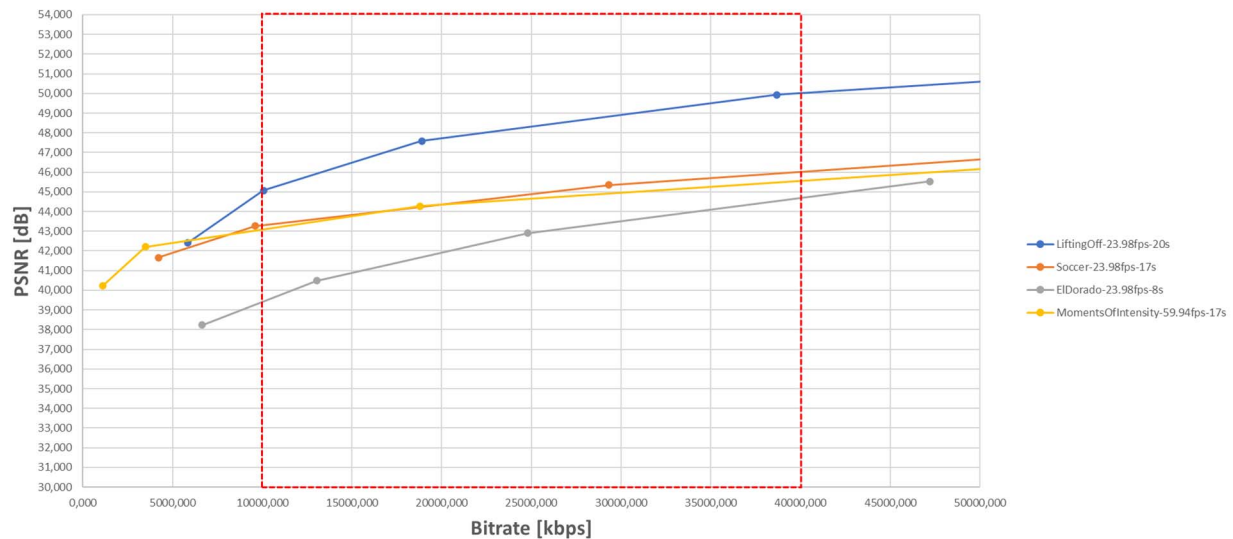


Figure C. 3.1.2.2-5: R-D curves for the CableLabs dataset

C.3.1.2.3 SI-TI Metrics

The analysis is based on spatial perceptual information (SI) and temporal perceptual information (TI) metrics calculated as defined in ITU-P.910 recommendation [40]. In order to reduce the bias introduced by scene-cuts in TI metric computation, the TI at scene-cut boundaries are removed from computation.

From the obtained log, the SI and TI metrics are presented below:

- Figure 3.1.2.3-1 provides the SI-TI plots for the UVG dataset,
- Figure 3.1.2.3-2 provides the SI-TI plots for the JVET dataset,
- Figure 3.1.2.3-3 provides the SI-TI plots for the Netflix dataset,
- Figure 3.1.2.3-4 provides the SI-TI plots for the EBU, SVT, 4ever and CableLabs dataset.

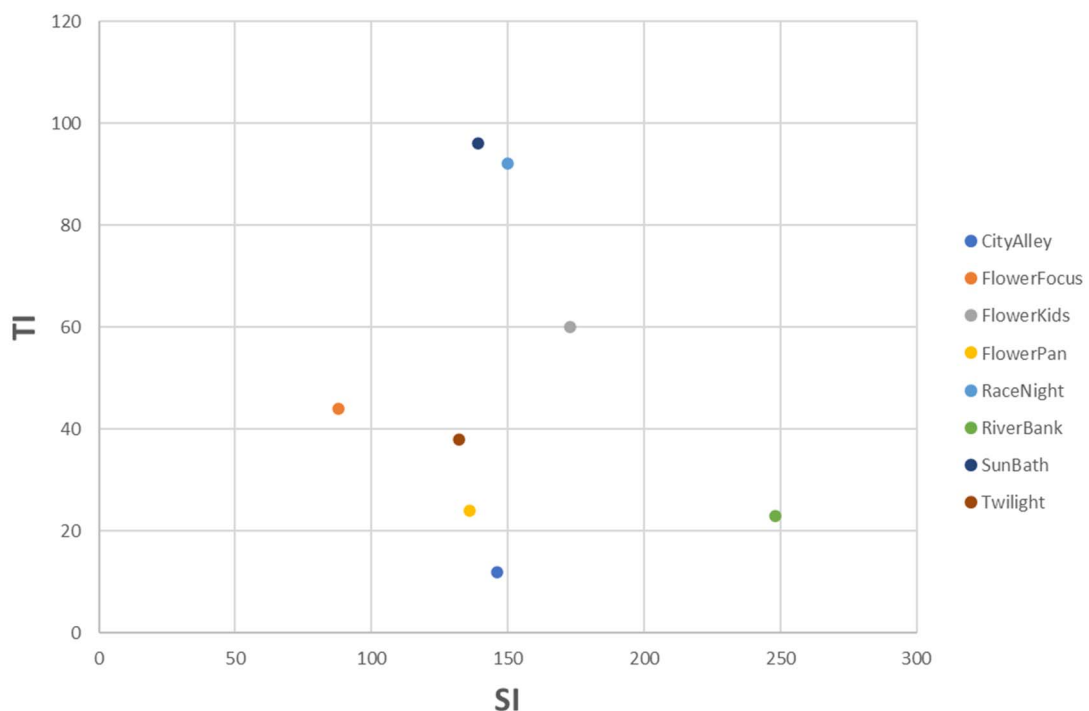


Figure C.3.1.2.3-1: SI-TI for the UVG dataset

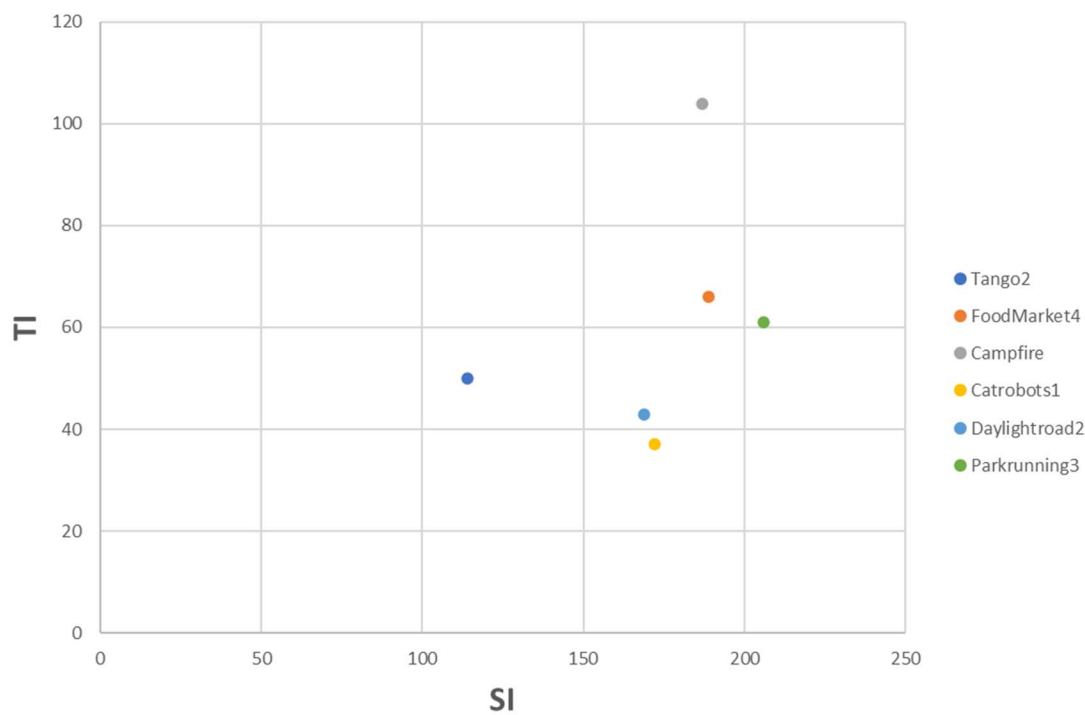


Figure C.3.1.2.3-2: SI-TI for the JVET dataset

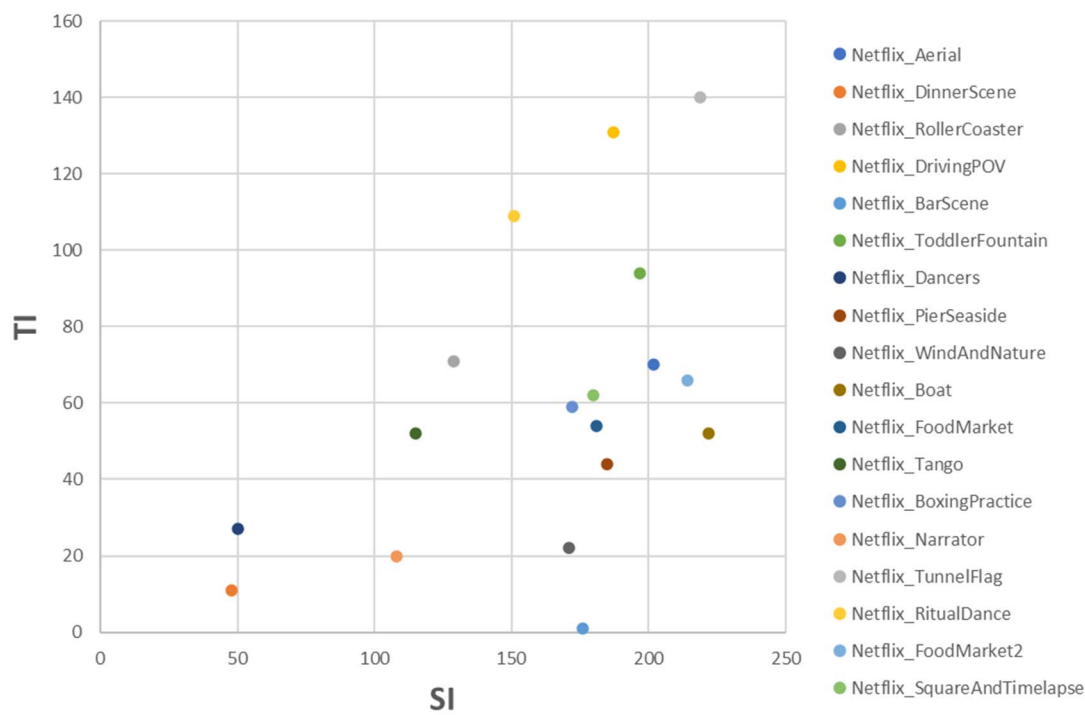


Figure C.3.1.2.3-3: SI-TI for the Netflix dataset

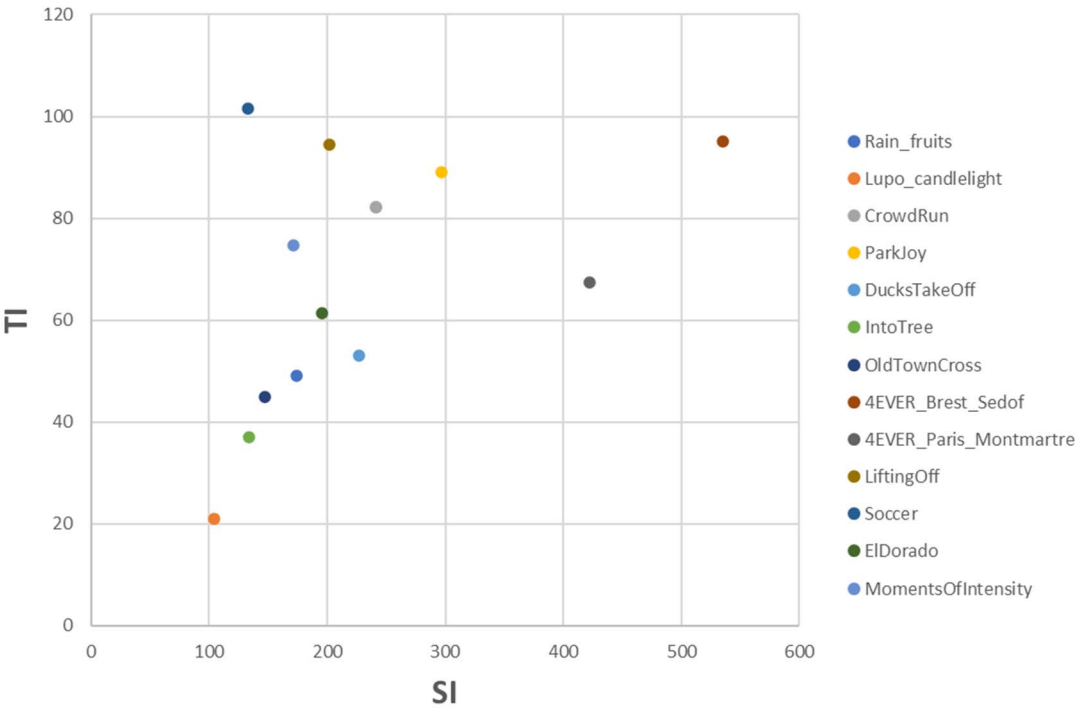


Figure C.3.1.2.3-4: SI-TI for the EBU, SVT, 4ever and CableLabs dataset

C.3.1.2.4 SDR Sequence Selection

The first step consists in classifying the sequences in two categories: easy and challenging. This reflects the complexity of the sequences from an encoding perspective. Based on the R-D data, the QP points covering the application range [10-40] Mbps are identified. For the lower (10Mbps) and higher (40Mbps) boundaries, a linear interpolation is achieved between the two closest QP points to estimate the distortion at the boundaries: D_10 and D_40. If the distortion difference $D\_DIFF=(D_{40}-D_{10})$ is less than or equal to a threshold $Thr=1.5$, then the sequence is classified as follows:

- Low-dynamic: the PSNR dynamic on the application bitrate range is limited
- High-dynamic: the PSNR dynamic on the application bitrate range is high

The results of this first classification step are reported in Table C.3.2.1.4-1.

Table C.3.2.1.4-1: SDR sequence classification based on R-D information in the [10-40] Mbps range, Thr=1.5

	Name	D_10	D_40	D_DIFF	Dynamic
JVET	Tango2	40.33	41.44	1.12	Low
	FoodMarket4	40.28	42.37	2.09	High
	Campfire	35.06	37.29	2.23	High
	Catrobots1	38.36	39.85	1.50	Low
	Daylightroad2	37.42	38.61	1.19	Low
	Parkrunning3	31.17	33.65	2.48	High
UVG	CityAlley	43.37	43.49	0.12	Low
	FlowerFocus	41.13	41.33	0.20	Low
	FlowerKids	40.92	42.78	1.86	High
	FlowerPan	39.60	39.85	0.25	Low
	RaceNight	37.82	38.62	0.79	Low
	RiverBank	36.62	38.84	2.22	High
	SunBath	43.85	46.98	3.13	High
Netflix	Twilight	42.92	43.24	0.33	Low
	Netflix_Aerial	38.62	41.00	2.37	High
	Netflix_DinnerScene	42.85	43.08	0.23	Low
	Netflix_RollerCoaster	42.61	44.73	2.11	High
	Netflix_DrivingPOV	37.27	39.54	2.27	High
	Netflix_BarScene	41.39	41.62	0.23	Low
	Netflix_ToddlerFountain	33.56	36.01	2.45	High
	Netflix_Dancers	41.96	42.14	0.18	Low
	Netflix_PierSeaside	41.05	43.10	2.06	High
	Netflix_WindAndNature	43.35	45.09	1.75	High
	Netflix_Boat	35.27	38.64	3.37	High
	Netflix_FoodMarket	37.62	38.95	1.32	Low
	Netflix_Tango	40.31	41.27	0.97	Low
	Netflix_BoxingPractice	40.97	42.14	1.17	Low
	Netflix_Narrator	45.33	46.36	1.03	Low
	Netflix_TunnelFlag	39.47	42.06	2.59	High
	Netflix_RitualDance	40.25	43.46	3.21	High
	Netflix_FoodMarket2	39.11	41.27	2.16	High
	Netflix_SquareAndTimelapse	39.43	42.15	2.72	High
EBU	Rain_fruits	40.04	41.69	1.65	High
	Lupo_candlelight	39.81	40.01	0.20	Low
SVT	CrowdRun	31.41	33.94	2.53	High
	ParkJoy	29.86	32.13	2.27	High
	DucksTakeOff	29.31	30.75	1.44	Low
	IntoTree	35.06	35.45	0.39	Low
	OldTownCross	33.93	34.06	0.13	Low
4ever	4EVER_Brest_Sedof	28.66	31.42	2.76	High
	4EVER_Paris_Montmartre	30.33	33.19	2.86	High
CableLabs	LiftingOff	45.01	48.31	3.30	High
	Soccer	43.31	44.89	1.58	High
	ElDorado	39.41	44.29	4.88	High
	MomentsOfIntensity	43.09	44.66	1.57	High

It is observed that 26 sequences are classified as "High" while 19 are "Low". In order to keep sequences that are relevant for a codec characterization, the low-dynamic sequences are removed. Then, the next step consists in removing sequences having some similarities, using SI-TI information computed in clause C.3.1.2.3. The sequences are represented below in the SI-TI plane with a k-means clustering to help the decision.

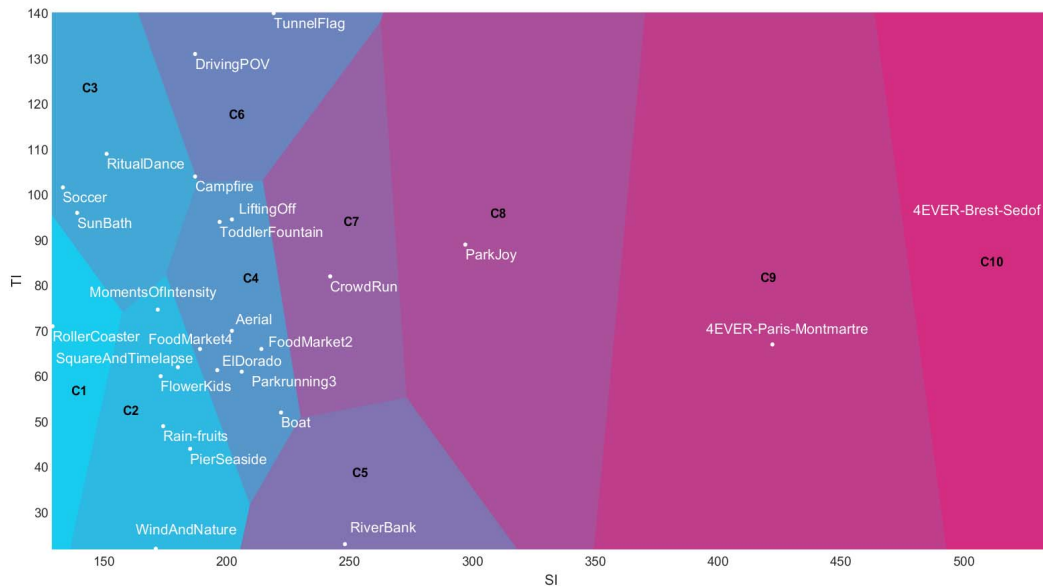


Figure C.3.1.2.4-1: SI-TI clustering for the Challenging sequences (10 clusters)

In order to remain representative in the sense of sources origin, format, and SI-TI values, the following approach was taken:

- 1 sequence (out of 6) from the C2 cluster (EBU: Rain-fruits)
- 1 sequence (out of 4) from the C3 cluster (CableLabs: Soccer)
- 2 sequences (out of 8) from the C4 cluster (Netflix: ToddlerFountain, Boat)
- 1 sequence (out of 1) from the C5 cluster (UVG: Riverbank)
- 1 sequence (out of 2) from the C6 cluster (Netflix: TunnelFlag)
- 1 sequence (out of 1) from the C8 cluster (SVT: ParkJoy)
- 1 sequence (out of 1) from the C10 cluster (4ever: Brest-Sedof)

The following eight sequences are selected:

- 1 From 4ever: Brest-Sedof (3840x2160p 60fps)
- 1 From EBU: RainFruits (3840x2160p 50fps)
- 1 From SVT: ParkJoy (3840x2160p 50fps)
- 1 From CableLabs: Soccer (3840x2160p 23.98fps)
- 3 From Netflix: TunnelFlag, Boat and Toddlerfountain (4096x2160p 59.94fps)
- 1 From UVG: RiverBank (3840x2160p 50fps)

C.3.1.3 Selected Sequences

C.3.1.3.1 Brest-Sedof

The Brest-Sedof test sequence is made of a panning on a stationary large sailboat (Sedof), and a moving small one in Brest harbour.

Figure C.3.1.3.1-1 shows a screenshot of the Brest-Sedof test sequence.



Figure C.3.1.3.1-1: Screenshot of Brest-Sedof test sequence

The Brest-Sedof test sequence properties are provided in Table C.3.1.3.1-1.

Table C.3.1.3.1-1 Brest-Sedof sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	60
Bit Depth	10
Length	300 frames
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Brest-Sedof/Brest-Sedof.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Brest-Sedof/Brest-Sedof-FHD.json>

The Brest-Sedof test sequence is made available under the following copyright disclaimer.

The proposed test sequence Brest_Sedof_3840x2160p60_10b.yuv, and all intellectual property rights therein remain the property of 4EVER consortium partners: Orange, AMP Visual TV, ATEME, France Télévisions, GlobeCast, InterDigital, Highlands Technologies Solutions, INSA Rennes, TeamCast and Télécom ParisTech. The following uses are allowed for the proposed sequences: (i) Can be published in technical papers, played at technology research and development events (ii) Can be used in 3GPP SA4. The following use is not allowed for the proposed sequences: (i) Do not publish snapshots in product brochures. (ii) Do not redistribute video with a commercial product.

C.3.1.3.2 Rain Fruits

The Rain Fruits test sequence is captured by a steady camera on a turning basket of fruits.

Figure C.3.1.3.2-1 shows a screenshot of the Rain Fruits test sequence.



Figure C.3.1.3.2-1: Screenshot of Rain Fruits test sequence

The Rain Fruits test sequence properties are provided in Table C.3.1.3.2-1.

Table C.3.1.3.2-1 Rain Fruits sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	50
Bit Depth	10
Length	500 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Rain-Fruits/Rain-Fruits.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Rain-Fruits/Rain-Fruits-HD.json>

The original sequence is available at EBU FTP server (https://tech.ebu.ch/EBU_SVT_Public_Test_Sequences) in 10 bit RGB dpx format. Details of the Rain Fruits sequence format are available in https://tech.ebu.ch/docs/testmaterial/ebu_test_sequences_tech_info_170315.pdf

In the first step, ffmpeg was used to convert dpx into tiff format:

```

FFMPEG -i $INPUT.dpx -compression_algo raw -pix_fmt rgb48le $OUTPUT.tiff

```


In the second step, conversion from 16 bit RGB to ITU-T BT. 709 10 bit 4:2:0 was performed with the use of HDRConvert (HDRConvert EBU_RainFruits_TIFFtoYUV.cfg).

The Rain Fruits test sequence is made available under the following copyright disclaimer.

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C.3.1.3.3 Park Joy

The Park Joy test sequence is shot by a camera tracking a group of people moving on a river bank.

Figure C.3.1.3.3-1 shows a screenshot of the Park Joy test sequence.



Figure C.3.1.3.3-1: Screenshot of Park Joy test sequence

The Park Joy test sequence properties are provided in Table C.3.1.3.3-1.

Table C.3.1.3.3-1 Park Joy sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	50
Bit Depth	8
Length	500 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Park-Joy/Park-Joy.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Park-Joy/Park-Joy-FHD.json>

The original sequence is available at EBU FTP server (https://tech.ebu.ch/EBU_SVT_Public_Test_Sequences) in 16 bit SGI format. In the first step, ffmpeg was used to convert sgi into tiff format:

```
FFMPEG -i $INPUT.sgi -compression_algo raw $OUTPUT.tiff
```

In the second step, conversion from 16 bit RGB to ITU-T BT. 709 10 bit 4:2:0 was performed with the use of HDRConvert (HDRConvert SVT_ParkJoy_TIFFtoYUV.cfg).

The Park Joy test sequence is made available under the following copyright disclaimer.

The EBU & SVT Public Test Sequences are licensed by the EBU under a Creative Commons Licence (BY-NC-ND - <http://creativecommons.org/licenses/by-nc-nd/4.0/legalcode>).

C.3.1.3.4 Soccer

The Soccer test sequence is an indoor soccer game with three cuts.

Figure C.3.1.3.4-1 shows a screenshot of the Soccer test sequence.



Figure C.3.1.3.4-1: Screenshot of Soccer test sequence

The Soccer test sequence properties are provided in Table C.3.1.3.4-1.

Table C.3.1.3.4-1 Soccer sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	24/1.001
Bit Depth	10
Length	385 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Soccer/Soccer.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Soccer/Soccer-FHD.json>

The Soccer test sequence is made available under the following copyright disclaimer.

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C.3.1.3.5 Tunnel Flag

The Tunnel Flag test sequence is shot from a train in an aerial tunnel.

Figure C.3.1.3.5-1 shows a screenshot of the Tunnel Flag test sequence.



Figure C.3.1.3.5-1: Screenshot of Tunnel Flag test sequence

The Tunnel Flag test sequence properties are provided in Table C.3.1.3.5-1.

Table C.3.1.3.5-1 Tunnel Flag sequence properties

Parameter	Value
Resolution	4096 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	600 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Tunnel-Flag/Tunnel-Flag.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Tunnel-Flag/Tunnel-Flag-FHD.json>

The Tunnel Flag test sequence is made available under the following copyright disclaimer.

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C.3.1.3.6 Boat

The Boat test sequence is scene on a moving float carnival.

Figure C.3.1.3.6-1 shows a screenshot of the Boat test sequence.



Figure C.3.1.3.6-1: Screenshot of Boat test sequence

The Boat test sequence properties are provided in Table C.3.1.3.6-1.

Table C.3.1.3.6-1 Boat sequence properties

Parameter	Value
Resolution	4096 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	300 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Boat/boat.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Boat/boat-FHD.json>

The Boat test sequence is made available under the following copyright disclaimer.

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C.3.1.3.7 Fountain

The Fountain test sequence is shot by a camera following a young boy running under water jets.

Figure C.3.1.3.7-1 shows a screenshot of the Fountain test sequence.



Figure C.3.1.3.7-1: Screenshot of Fountain test sequence

The Fountain test sequence properties are provided in Table C.3.1.3.7-1.

Table C.3.1.3.7-1 Fountain sequence properties

Parameter	Value
Resolution	4096 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	600 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Fountain/Fountain.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Fountain/Fountain-FHD.json>

The Fountain test sequence is made available under the following copyright disclaimer.

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C.3.1.3.8 Riverbank

The Riverbank test sequence is is a panning on a river.

Figure C.3.1.3.8-1 shows a screenshot of the Riverbank test sequence.



Figure C.3.1.3.8-1: Screenshot of Riverbank test sequence

The Riverbank test sequence properties are provided in Table C.3.1.3.8-1.

Table C.3.1.3.8-1 Riverbank sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	50
Bit Depth	10
Length	600 frames
YUV format	4:2:0
Colour components	ITU-T BT.709
Colour space	SDR

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Riverbank/Riverbank.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Riverbank/Riverbank-FHD.json>

The Riverbank test sequence is made available under the following copyright disclaimer.

Copyright © This sequence and all intellectual property rights therein remain the property of Digiturk. You may use this sequence according to Creative Commons Attribution-NonCommercial 3.0 Unported (http://creativecommons.org/licenses/by-nc/3.0/deed.en_US). Please cite the following paper for any usage of the dataset: A. Mercat, M. Viitanen, and J. Vanne, "UVG dataset: 50/120fps 4K sequences for video codec analysis and development," in Proc. ACM Multimedia Syst. Conf., Istanbul, Turkey, June 2020.

C.3.2 HDR Category

C.3.2.1 HDR Candidate Test Sequences

C.3.2.1.1 Introduction

In this Annex, a wide range of HDR test material is reported. The candidate sequences are extracted from test material used in video processing community. The following sections describe the test material in terms of format characteristics and copyright.

C.3.2.1.2 AOM Sequences

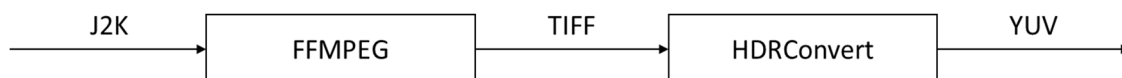
The Alliance for Open Media (AOM) sequences are used for the purpose of AOM codec development. The sequences are available for download at <https://media.xiph.org/video/av2/> and an overview is provided in the Table C.3.2.1.2-1. The following copyrights are applicable:

- Sparks : <http://creativecommons.org/licenses/by-nc-nd/4.0/>
- Meridian : <https://creativecommons.org/licenses/by-nc-nd/4.0/>
- Sol Levante : <https://creativecommons.org/licenses/by-nc-nd/4.0/>
- Cosmos Laundromat : <https://creativecommons.org/licenses/by/3.0/>
- Nocturne : <https://creativecommons.org/licenses/by-nc-nd/4.0/>

Table C.3.2.1.2-1: AOM test material description

Name	Resolution	Frame Rate	Colour Gamut	TF	duration
sparks_aom_30-511	4096 x 2160	59.94	P3-D65	PQ	481
sparks_aom_2024-2455	4096 x 2160	59.94	P3-D65	PQ	431
sparks_aom_5363-5763	4096 x 2160	59.94	P3-D65	PQ	400
sparks_aom_5764-6024	4096 x 2160	59.94	P3-D65	PQ	260
sparks_aom_6026-6502	4096 x 2160	59.94	P3-D65	PQ	476
sparks_aom_8396-8941	4096 x 2160	59.94	P3-D65	PQ	545
sparks_aom_9774-10071	4096 x 2160	59.94	P3-D65	PQ	297
sparks_aom_11198-11570	4096 x 2160	59.94	P3-D65	PQ	372
meridian_aom_1782-2163	3840 x 2160	59.94	P3-D65	PQ	381
meridian_aom_11872-12263	3840 x 2160	59.94	P3-D65	PQ	391
meridian_aom_12264-12745	3840 x 2160	59.94	P3-D65	PQ	481
meridian_aom_15932-16309	3840 x 2160	59.94	P3-D65	PQ	377
meridian_aom_20988-21412	3840 x 2160	59.94	P3-D65	PQ	424
meridian_aom_22412-22738	3840 x 2160	59.94	P3-D65	PQ	324
meridian_aom_24058-24550	3840 x 2160	59.94	P3-D65	PQ	492
sol_levante_aom_289-453	3840 x 2160	24	P3-D65	PQ	164
sol_levante_aom_519-649	3840 x 2160	24	P3-D65	PQ	130
sol_levante_aom_2268-2412	3840 x 2160	24	P3-D65	PQ	144
sol_levante_aom_3282-3874	3840 x 2160	24	P3-D65	PQ	592
sol_levante_aom_4123-4545	3840 x 2160	24	P3-D65	PQ	422
cosmos_aom_1573-1749	3840 x 2160	24	P3-D65	PQ	176
cosmos_aom_8686-8826	3840 x 2160	24	P3-D65	PQ	176
cosmos_aom_9561-9789	3840 x 2160	24	P3-D65	PQ	228
cosmos_aom_11589-11752	3840 x 2160	24	P3-D65	PQ	163
cosmos_aom_12025-12075	3840 x 2160	24	P3-D65	PQ	50
cosmos_aom_12149-12330	3840 x 2160	24	P3-D65	PQ	181
cosmos_aom_12916-13078	3840 x 2160	24	P3-D65	PQ	162
cosmos_aom_13446-13649	3840 x 2160	24	P3-D65	PQ	203
nocturne_aom_2370-2539	3840 x 2160	60	P3-D65	PQ	169
nocturne_aom_8540-9009	3840 x 2160	60	P3-D65	PQ	469
nocturne_aom_9010-9349	3840 x 2160	60	P3-D65	PQ	339
nocturne_aom_17140-17709	3840 x 2160	60	P3-D65	PQ	569
nocturne_aom_18013-18315	3840 x 2160	60	P3-D65	PQ	302
nocturne_aom_23820-24322	3840 x 2160	60	P3-D65	PQ	502
nocturne_aom_27740-28109	3840 x 2160	60	P3-D65	PQ	369
nocturne_aom_32660-32799	3840 x 2160	60	P3-D65	PQ	139

The clip cosmos_aom_12025-12075 being fifty frames duration, it is removed from the selection process and is not considered. In order to use these sequences for the selection process, a conversion into the appropriate format is conducted using FFmpeg and HDRTools [67] software v0.21. The conversion according to Figure C.3.2.1.2-1 conducted:

**Figure C.3.2.1.2-1: Processing pipeline for AOM sequence conversion**

In the first step FFMPEG was used to decode JPEG 2000 sequences and store in uncompressed TIFF format. The following command line was used:

```
FFMPEG -i $INPUT.j2k -compression_algo raw -pix_fmt rgb48le $OUTPUT.tiff
```

HDRConvert was used to convert the sequences from P3-D65 RGB 12 bit to Rec. BT.2100 10 bit YCbCr 4:2:0. HDRConvert config file used for this process is attached to this contribution.

C.3.2.1.3 CableLabs Sequences

The CableLabs dataset is composed by one HDR sequence described in Table C.3.2.1.3-1. The sequence can be used under the CC BY-NC-ND 3.0 license restriction.

Table C.3.2.1.3-1: Cable Labs HDR test material description

Name	Resolution	Frame rate	Colour Gamut	TF	duration
Life Untouched	3840 x 2160	59.94	P3-D65	PQ	5:20

For this sequence, a selection of some critical time intervals have been conducted based on experience on compression. Especially intervals with fast or complex motion, representative of TV contents have been selected. Static pictures, or pictures with artistic intent with few spatial details have been discarded. To remain in the scope of the scenario, the following section have been selected:

- Life Untouched 1: 0.5s-8s

The extraction of subpart from original ProRes sequences is realized with FFmpeg release 4.3.1 using the following command line:

```
./ffmpeg.exe -i $IN.mov -vcodec rawvideo -ss $START_TIME -t $DURATION -pix_fmt yuv444p12le $OUT.yuv
```

Where \$IN and \$OUT are respectively the input and output sequences, \$START_TIME and \$DURATION respectively the start time and duration in hh:mm:ss format.

In order to map the colour into a BT.2020 colour container, HDRTools v2.1 has been used. In the first step conversion from YCbCr 4:4:4 to RGB color space was performed. In the second step conversion from P3-D65 RGB to 10-bit YCbCr 4:2:0 was performed. Both configuration files for HDRTools are attached to this report.

C.3.2.2 Selected Test Sequences

C.3.2.2.1 Introduction

In order to decide which sequences should be used in this specification a similar process as the SDR one is used. The following process is conducted:

1. Run informative encoding using x265 on the converted candidate sequences
2. Run SI-TI metrics computation on the converted candidate sequences
3. Run codeword histogram computation on the converted candidate sequences
4. Select diverse datasets based on R-D, SI-TI and codewords distribution.

C.3.2.2.2 x265 Encoding

To represent candidate sequences in the R-D plane, fixed QP encodings are carried out for QPs [12, 17, 22, 27, 32, 37, 42, 51] using ffmpeg release 4.3.1, with the following command line:

```
./ffmpeg.exe -pix_fmt yuv420p10le -s $Wx$H -framerate $FR -i $IN -vcodec libx265 -qp $QP -preset fast -x265-params "psnr=1:ssim=1" $OUT.mp4
```

Where \$W and \$H are respectively the sequence width and height, \$FR the sequence frame rate, \$QP the selected quantization parameter. \$IN and \$OUT are respectively the input and output files.

From the obtained log, the overall bitrate and PSNR are extracted to be used for plotting. The encoding result are presented in

- Figure C.3.2.2.2-1 R-D curves for the AOM dataset (Nocturne clips),
- Figure C.3.2.2.2-2 R-D curves for the AOM dataset (Meridian clips),
- Figure C.3.2.2.2-3 R-D curves for the AOM dataset (Cosmos clips),
- Figure C.3.2.2.2-4 R-D curves for the AOM dataset (Sparks clips),
- Figure C.3.2.2.2-5 R-D curves for the AOM dataset (SolLevante clips), and
- Figure C.3.2.2.2-6 R-D curves for the Cable Labs dataset.

All sequences being represented in the targeted [10-40] Mbps range (red box).

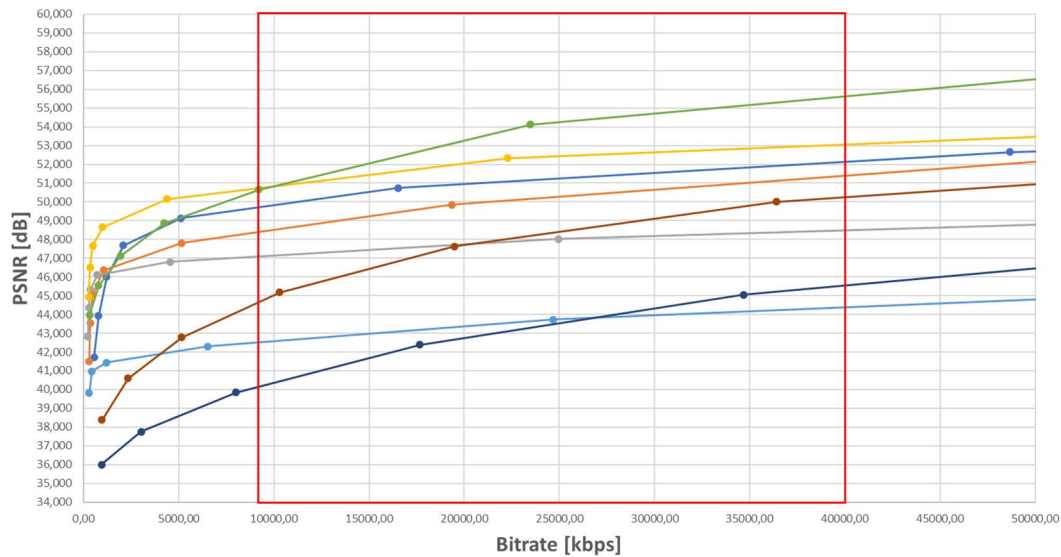


Figure C.3.2.2-1: R-D curves for the AOM dataset (Nocturne clips)

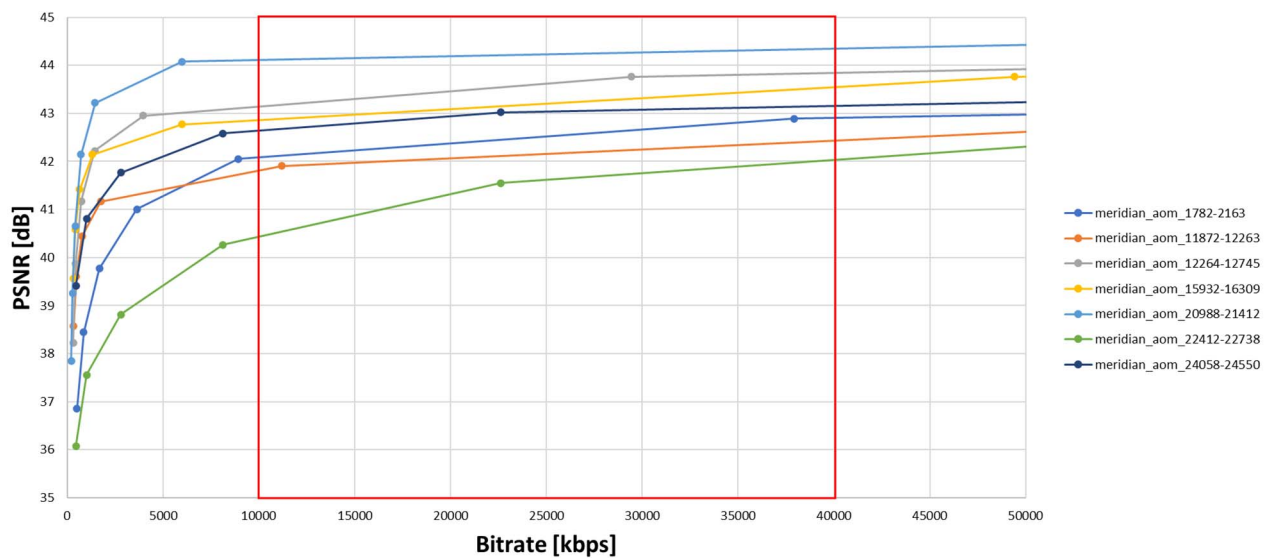


Figure C.3.2.2-2: R-D curves for the AOM dataset (Meridian clips)

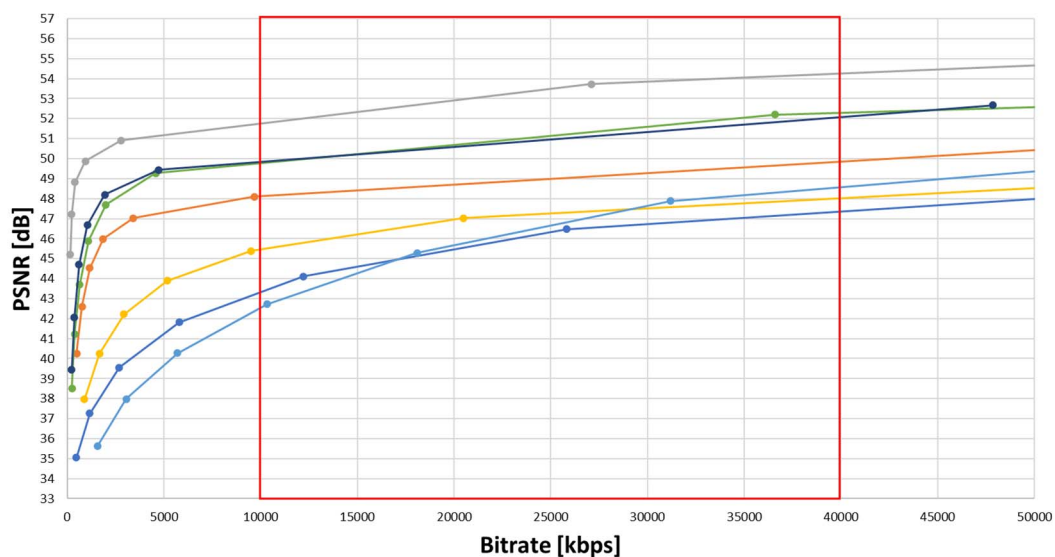


Figure C.3.2.2.2-3: R-D curves for the AOM dataset (Cosmos clips)

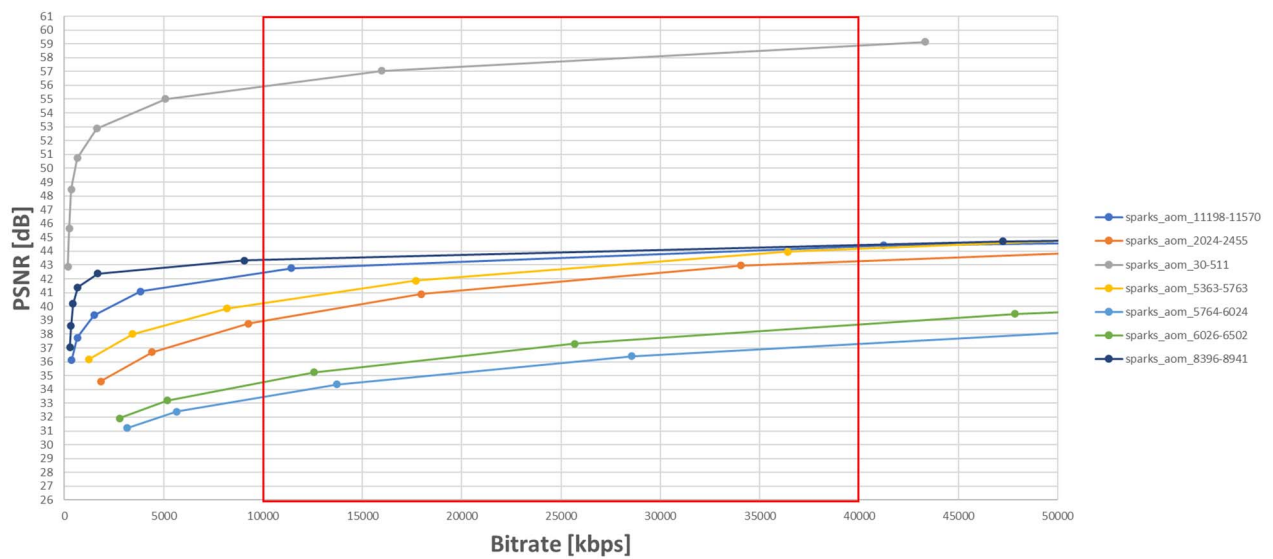


Figure C.3.2.2.2-4: R-D curves for the AOM dataset (Sparks clips)

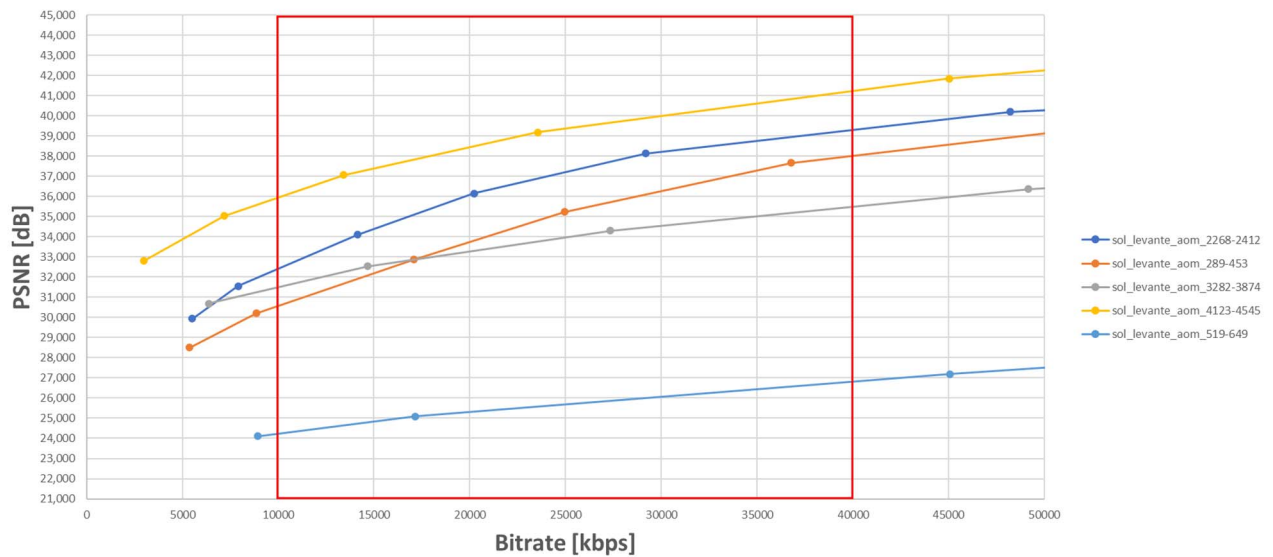


Figure C.3.2.2.2-5: R-D curves for the AOM dataset (SolLevante clips)

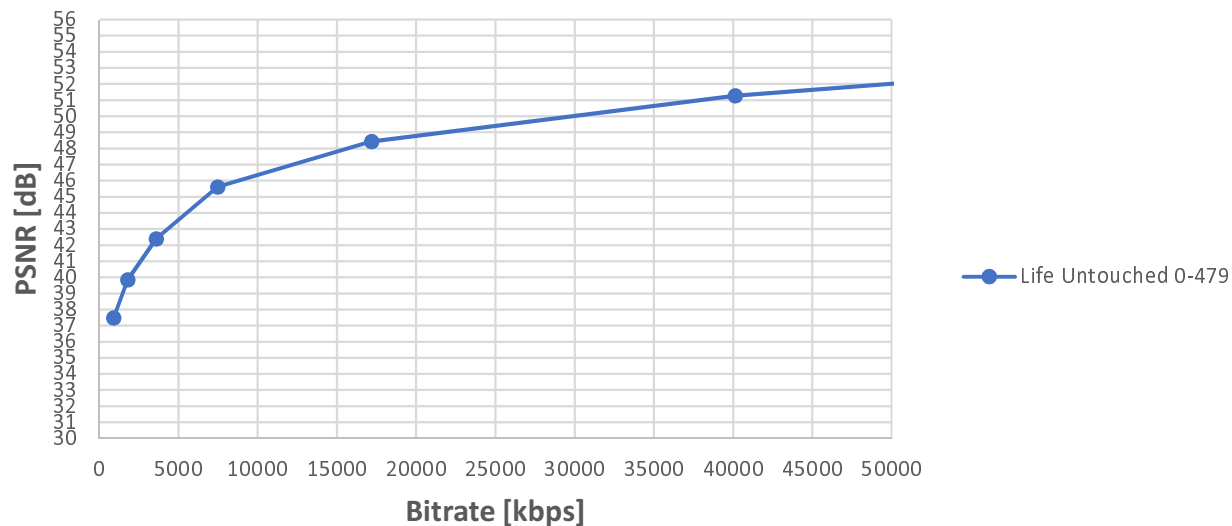


Figure C.3.2.2.2-6: R-D curves for the Cable Labs Life Untouched sequence.

C.3.2.2.3 SI-TI Metrics

The analysis is based on spatial perceptual information (SI) and temporal perceptual information (TI) metrics calculated as defined in ITU-P.910 recommendation [40]. In order to reduce the bias introduced by scene-cuts in TI metric computation, the TI at scene-cut boundaries are removed from computation.

The TI metrics are presented in

- Figure C.3.2.2.3-1 SI-TI for the AOM dataset (Nocturne clips),
- Figure C.3.2.2.3-2 R SI-TI for the AOM dataset (Meridian clips),
- Figure C.3.2.2.3-3 SI-TI for the AOM dataset (Cosmos clips),
- Figure C.3.2.2.3-4 SI-TI for the AOM dataset (Sparks clips), and
- Figure C.3.2.2.3-5 SI-TI for the AOM dataset (SolLevante clips) and CableLabs dataset.

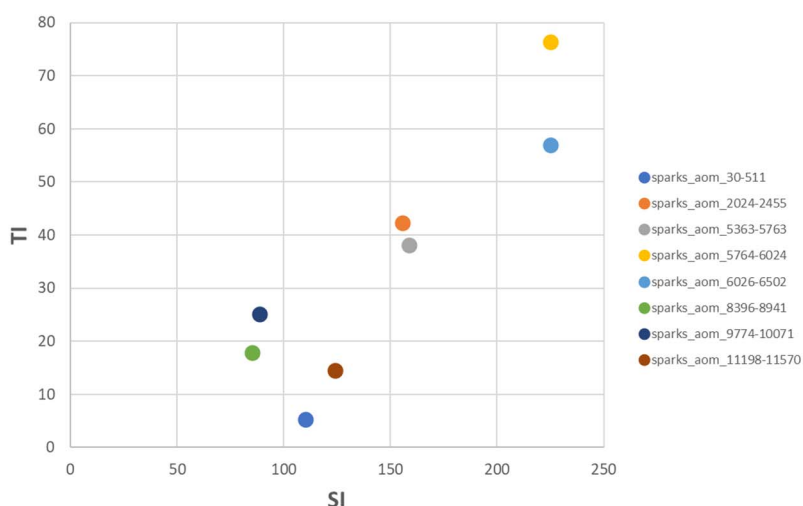


Figure C.3.2.2.3-1: SI-TI for the AOM dataset (Sparks clips)

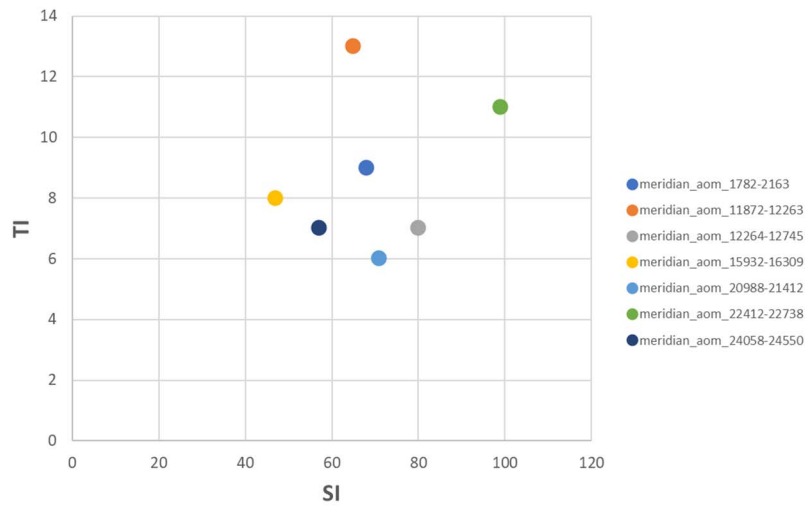


Figure C.3.2.2.3-2: SI-TI for the AOM dataset (Meridian clips)

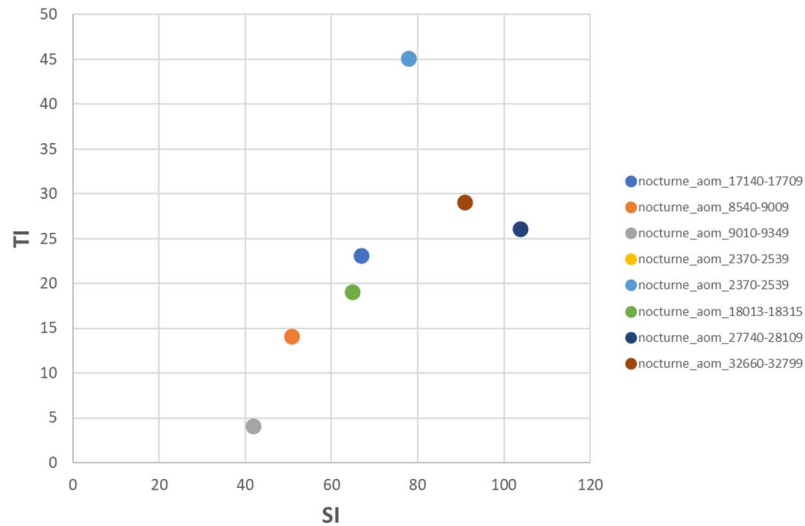


Figure C.3.2.2.3-3: SI-TI for the AOM dataset (Nocturne clips)

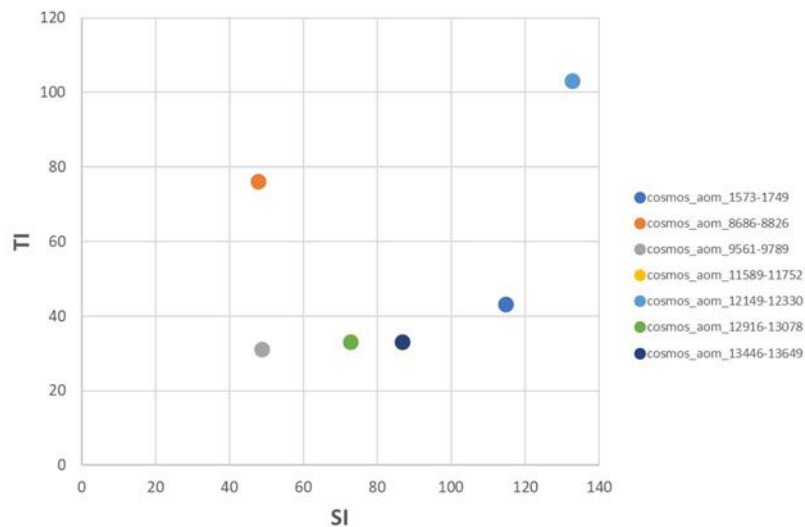


Figure C.3.2.2.3-4: SI-TI for the AOM dataset (Cosmos clips)

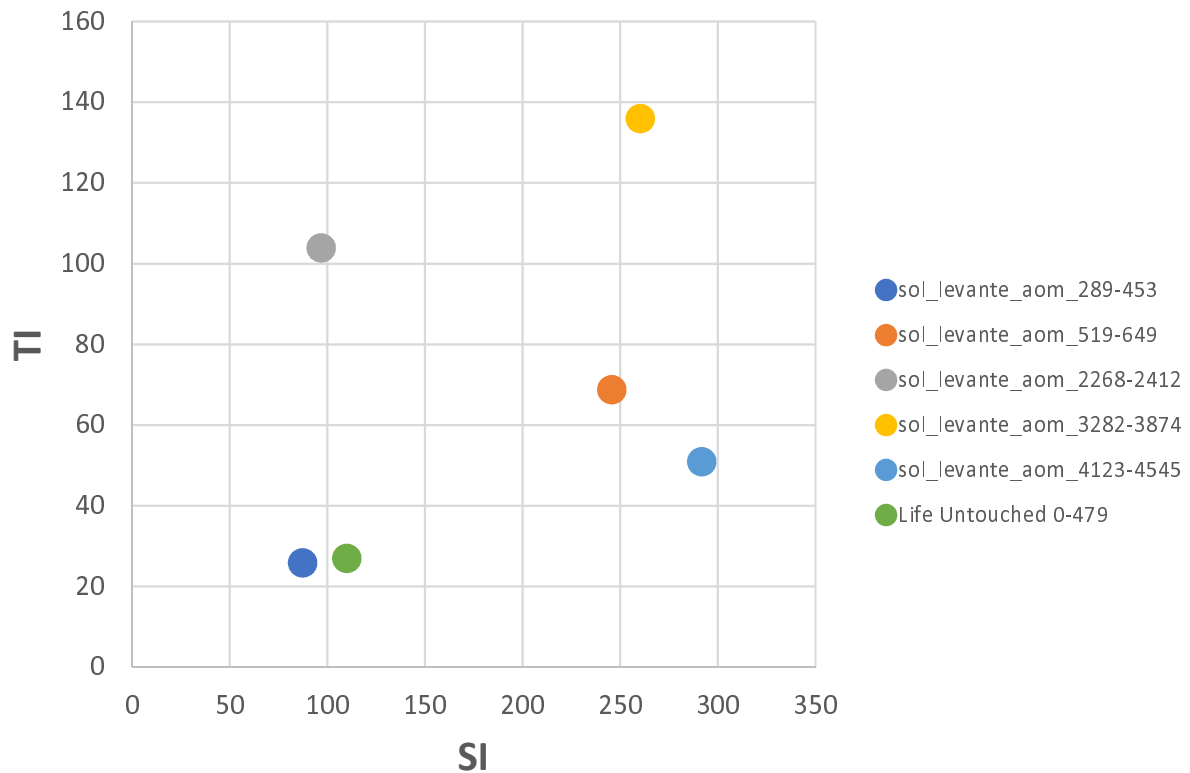


Figure C.3.2.2.3-5: SI-TI for the AOM (SolLevante) and CableLabs (Life Untouched) dataset

C.3.2.2.4 Codewords distribution

For the HDR case, the distribution of codewords into the sequence is also taken into account in the decision process. The obtained histograms are provided in

- Figure C.3.2.2.4-1 Codewords distribution for the AOM dataset (Nocturne clips),
- Figure C.3.2.2.4-2 Codewords distribution for the AOM dataset (Meridian clips),
- Figure C.3.2.2.4-3 Codewords distribution for the AOM dataset (Cosmos clips),
- Figure C.3.2.2.4-4 Codewords distribution for the AOM dataset (Sparks clips),
- Figure C.3.2.2.4-5 Codewords distribution for the AOM dataset (SolLevante clips), and
- Figure C.3.2.2.4-6 Codewords distribution for the Cable Labs dataset.

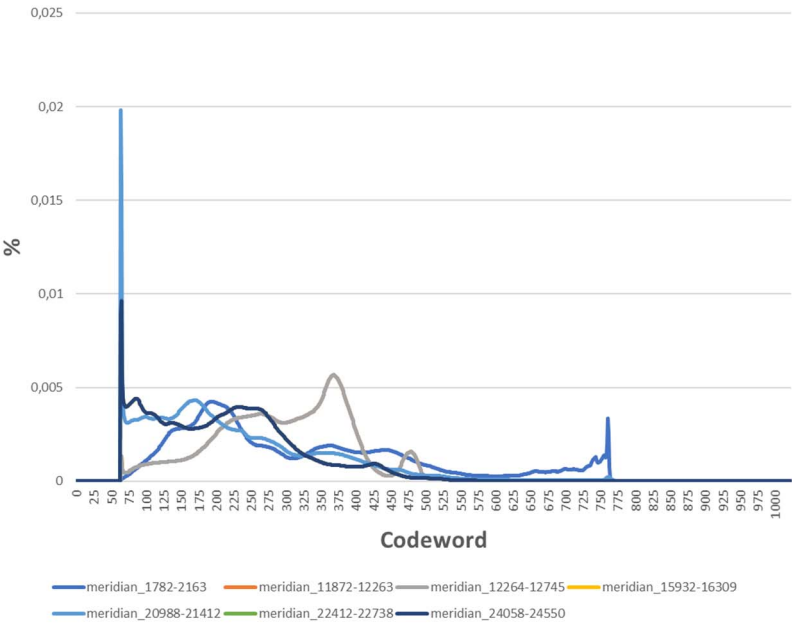


Figure C.3.2.2.4-1: Codewords distribution for AOM dataset (Meridian clips)

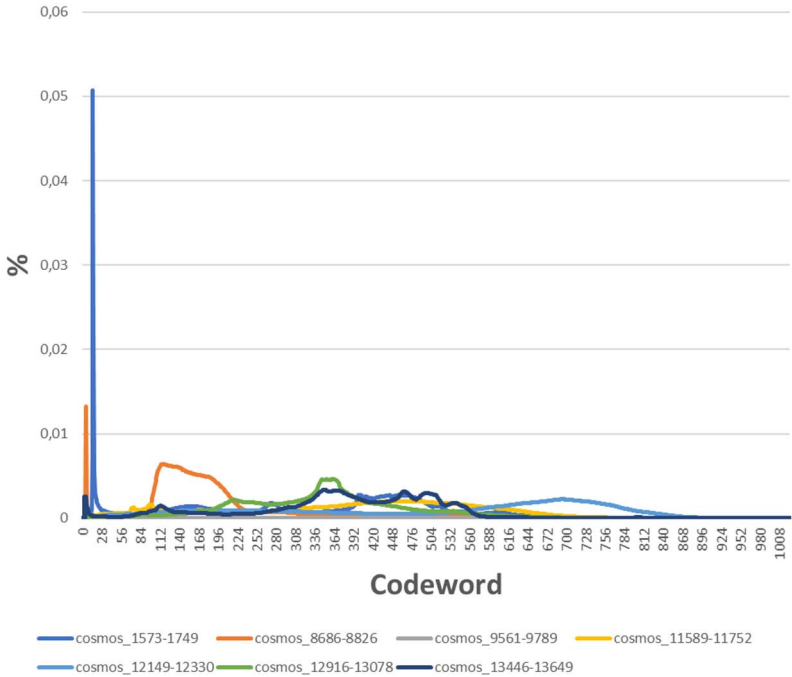


Figure C.3.2.2.4-2: Codewords distribution for AOM dataset (Cosmos clips)

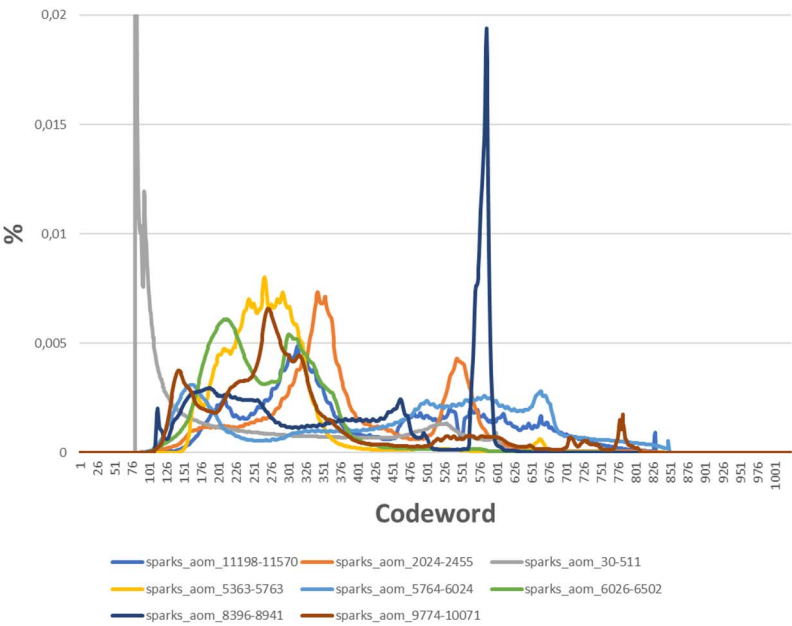


Figure C.3.2.2.4-3: Codewords distribution for AOM dataset (Sparks clips)

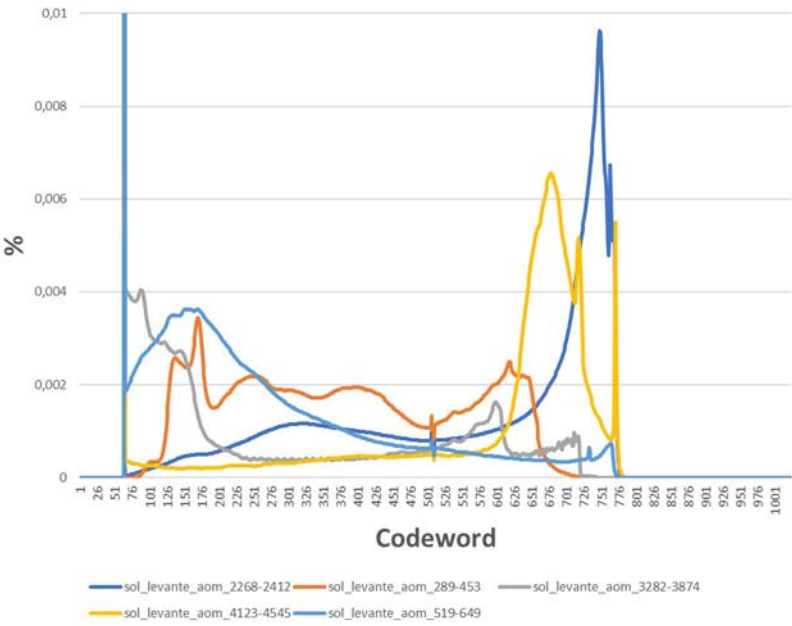


Figure C.3.2.2.4-4: Codewords distribution for AOM dataset (SolLevante clips)

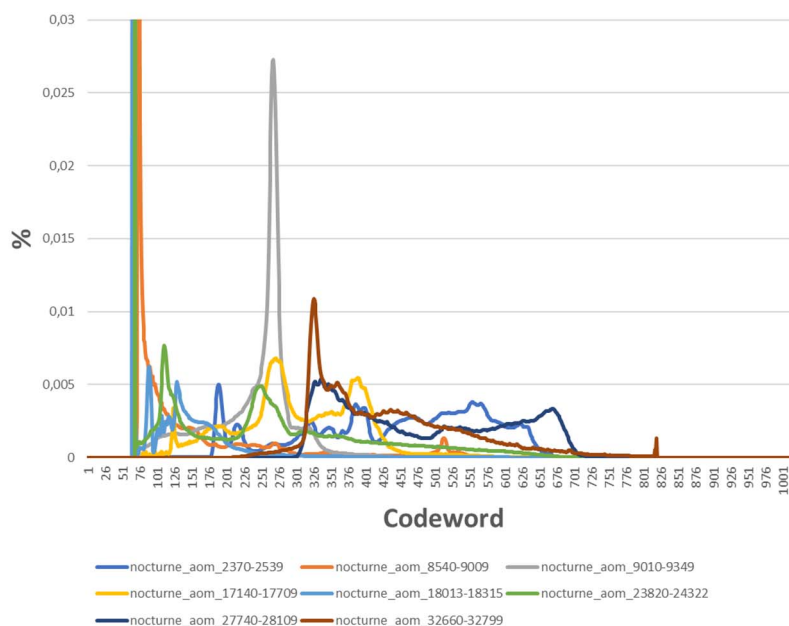


Figure C.3.2.2.4-5: Codewords distribution for AOM dataset (Nocturne clips)

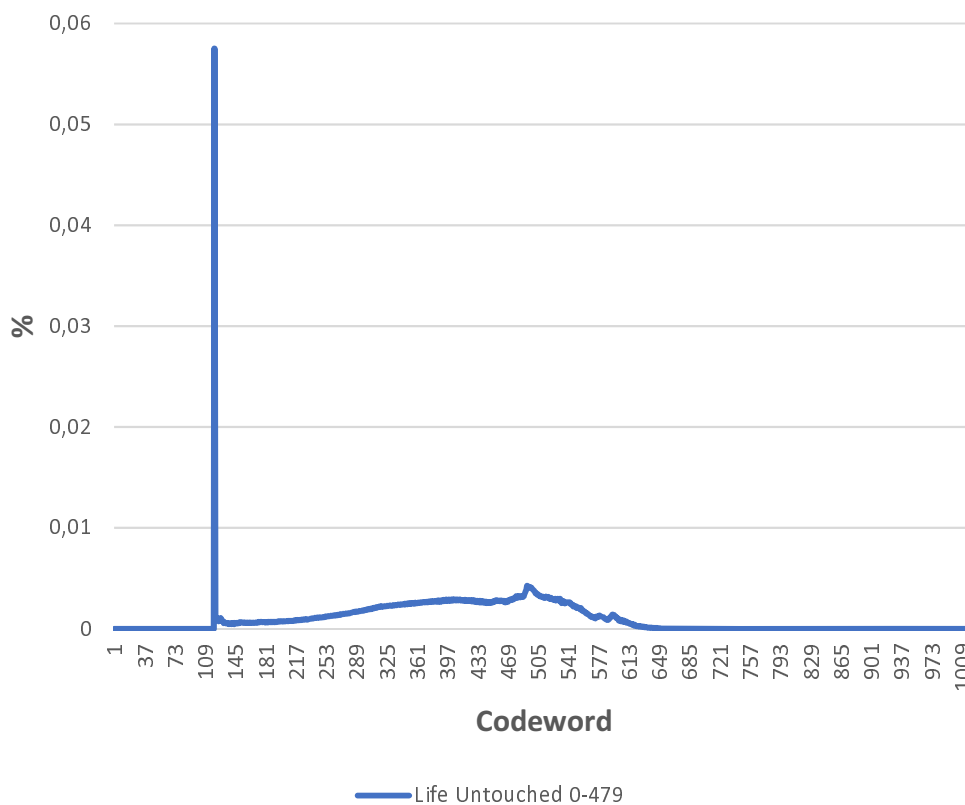


Figure C.3.2.2.4-6: Codewords distribution for Life Untouched sequence (frames 0-479).

C.3.2.2.5 HDR Sequence Selection

The first step consists in classifying the sequences in two categories: easy and challenging. This reflects the complexity of the sequences from an encoding perspective. Based on the R-D data, the QP points covering the application range [10-40] Mbps are identified. For the lower (10Mbps) and higher (40Mbps) boundaries, a linear interpolation is achieved between the two closest QP points to estimate the distortion at the boundaries: D_{10} and D_{40} . If the distortion difference $D\_DIFF = (D_{40} - D_{10})$ is less than or equal to a threshold $Thr = 3$, then the sequence is classified as follows:

- Low-dynamic: the PSNR dynamic on the application bitrate range is limited
- High-dynamic: the PSNR dynamic on the application bitrate range is high

The results of this first classification step is reported in the Table C.3.2.2.5-1.

Table C.3.2.2.5-1: HDR sequence classification based on R-D information in [10-40] Mbps range, Thr=3

	Name	D_10	D_40	D_DIFF	Complexity
Sparks	sparks_aom_30-511	55.93	58.88	2.95	Low
	sparks_aom_2024-2455	38.95	43.28	4.33	High
	sparks_aom_5363-5763	40.24	44.16	3.92	High
	sparks_aom_5764-6024	33.45	37.29	3.84	High
	sparks_aom_6026-6502	34.54	38.69	4.16	High
	sparks_aom_8396-8941	43.35	44.46	1.10	Low
	sparks_aom_9774-10071	47.15	48.89	1.74	Low
	sparks_aom_11198-11570	42.45	44.36	1.91	Low
Nocturne	nocturne_aom_2370-2539	49.81	52.14	2.33	Low
	nocturne_aom_8540-9009	48.50	51.39	2.89	Low
	nocturne_aom_9010-9349	48.50	51.39	2.89	Low
	nocturne_aom_17140-17709	50.83	53.05	2.23	Low
	nocturne_aom_18013-18315	42.57	44.37	1.80	Low
	nocturne_aom_23820-24322	50.84	55.62	4.78	High
	nocturne_aom_27740-28109	40.37	45.54	5.17	High
	nocturne_aom_32660-32799	45.04	50.25	5.22	High
Meridian	meridian_aom_1782-2163	42.08	42.91	0.83	Low
	meridian_aom_11872-12263	41.81	42.44	0.62	Low
	meridian_aom_12264-12745	43.15	43.85	0.70	Low
	meridian_aom_15932-16309	41.81	42.44	0.62	Low
	meridian_aom_20988-21412	44.11	44.34	0.24	Low
	meridian_aom_22412-22738	40.43	42.03	1.60	Low
	meridian_aom_24058-24550	43.35	43.57	0.22	Low
SolLevante	sol_levante_aom_289-453	30.57	38.02	7.45	High
	sol_levante_aom_519-649	24.23	26.81	2.58	Low
	sol_levante_aom_2268-2412	32.42	39.30	6.89	High
	sol_levante_aom_3282-3874	31.50	39.30	7.81	High
	sol_levante_aom_4123-4545	35.95	41.22	5.27	High
Cosmos	cosmos_aom_1573-1749	43.32	47.37	4.04	High
	cosmos_aom_8686-8826	48.12	49.85	1.73	Low
	cosmos_aom_9561-9789	51.75	54.25	2.50	Low
	cosmos_aom_11589-11752	45.46	48.02	2.56	Low
	cosmos_aom_12149-12330	42.55	47.49	4.93	High
	cosmos_aom_12916-13078	49.76	52.29	2.53	Low
	cosmos_aom_13446-13649	49.84	52.09	2.25	Low
CableLabs	Life Untouched 0-479	46.34	51.26	4.91	High

It is observed that 14 sequences are classified as "High" while 23 are "Low". In order to keep sequences that are relevant for a codec characterization, the low-dynamic sequences are removed. To select a data set having different sources, LifeUntouched_1 is automatically selected since it is the only complex one in CableLabs set. Similarly, the sequence meridian_aom_22412-22738 from Meridian which is most challenging from an encoding perspective is selected.

Then, the next step consists in selecting a subset of remaining sequences in order to end up with a reasonable number of sequences, from diverse sources and having different characteristics. With the target of selecting the same number of sequences as SDR, the remaining set of sequences are clustered into the SI-TI plane, using k-mean clustering to identify sequences having same spatial and temporal features. Since two sequences have already been selected, and given that eight sequences are targeted, six clusters are identified in the figure below.

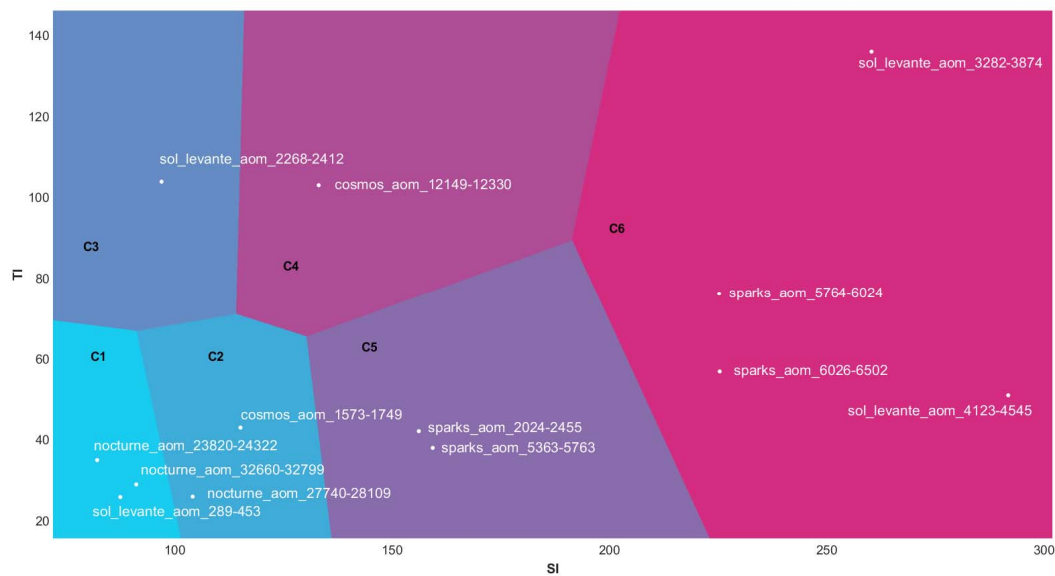


Figure C.3.2.2.5-1: SI-TI clustering for the challenging HDR sequences (6 clusters)

It is observed that clusters C3 and C4 only contain one sequence each, which are automatically selected since they present interesting codewords distribution and content. For other clusters, the codeword histograms are used to help deciding which sequence should be selected.

For C5, sparks_aom_2024-2455 is selected since it presents interesting codewords distribution compared to what is already included in the figure above.

For C1, sol_levante_aom_289-453 is rejected since it is similar to the cosmos sequence. In the two remaining sequences, nocturne_aom_32660-32799 is too short in duration while nocturne_aom_23820-24322 does not present particular interest due to a static long dark transition part in the middle. Thus, no sequences are selected from C1.

For C6, sol_levante sequences are removed since two computer-generated sequences are already selected. sparks_aom_5764-6024 is selected to make the dataset more diverse in terms of codeword distributions.

For C2, cosmos_aom_1573-1749 is removed since two computer-generated sequences are already selected. For the sake of having diverse sources, nocturne_aom_27740-28109 is selected since two sparks sequences are already selected.

Eventually, the selected sequences are summarized below:

- LifeUntouched1 (0-479)
- meridian_aom_22412-22738
- sol_levante_aom_2268-2412
- cosmos_12149-12330
- sparks_aom_2024-2455
- sparks_aom_5764-6024
- nocturne_aom_27740-28109

C.3.2.3 Selected Sequences

C.3.2.3.1 Life Untouched

The Life Untouched test sequence shows nature scenes. The selected part starts from fade from black and includes camera tilt.

Figure C.3.2.3.1-1 shows a screenshot of the Life Untouched test sequence.



Figure C.3.2.3.1-1: Screenshot of Life Untouched test sequence

The Life Untouched test sequence properties are provided in Table C.3.2.3.1-1.

Table C.3.2.3.1-1 Life Untouched sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	450
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Life-Untouched/Life-Untouched.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Life-Untouched/Life-Untouched-FHD.json>

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C.3.2.3.2 Meridian

The Meridian test sequence is (meridian_aom_22412-22738).

Figure C.3.2.3.2-1 shows a screenshot of the Meridian test sequence.



Figure C.3.2.3.2-1: Screenshot of Meridian test sequence

The Meridian test sequence properties are provided in Table C.3.2.3.2-1.

Table C.3.2.3.2-1 Meridian sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	327
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Meridian/Meridian.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Meridian/Meridian-FHD.json>

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C.3.2.3.3 Sol Levante

The Sol Levante test sequence is (sol_levante_aom_2268-2412).

Figure C.3.2.3.3-1 shows a screenshot of the Sol Levante test sequence.



Figure C.3.2.3.3-1: Screenshot of Sol Levante test sequence

The Sol Levante test sequence properties are provided in Table C.3.2.3.3-1.

Table C.3.2.3.3-1 Sol Levante sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	24
Bit Depth	10
Length	145
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Sol-Levante/Sol-Levante.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Sol-Levante/Sol-Levante-FHD.json>

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C.3.2.3.4 Cosmos

The Cosmos test sequence is (cosmos_12149-12330).

Figure C.3.2.3.4-1 shows a screenshot of the Cosmos test sequence.

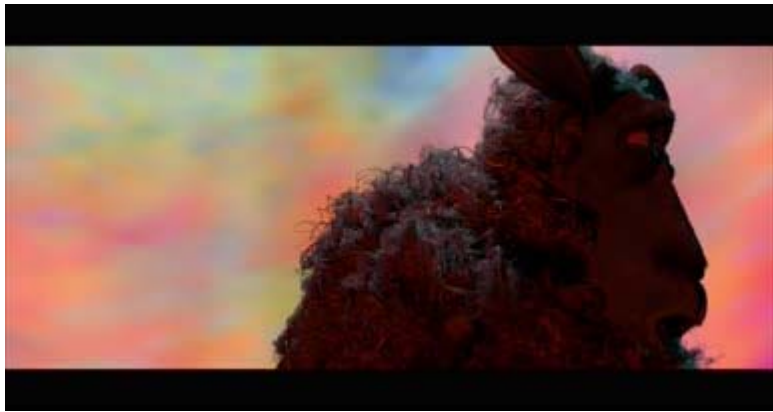


Figure C.3.2.3.4-1: Screenshot of Cosmos test sequence

The Cosmos test sequence properties are provided in Table C.3.2.3.4-1.

Table C.3.2.3.4-1 Cosmos sequence properties

Parameter	Value
Resolution	3840 x 2160
Scan	progressive
Frame Rate	24
Bit Depth	10
Length	182
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Cosmos/Cosmos.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Cosmos/Cosmos-FHD.json>

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C.3.2.3.5 Elevator

The Elevator test sequence is (sparks_aom_2024-2455).

Figure C.3.2.3.5-1 shows a screenshot of the Elevator test sequence.



Figure C.3.2.3.5-1: Screenshot of Elevator test sequence

The Elevator test sequence properties are provided in Table C.3.2.3.5-1.

Table C.3.2.3.5-1 Elevator sequence properties

Parameter	Value
Resolution	4096 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	432
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Elevator/Elevator.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Elevator/Elevator-FHD.json>

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C.3.2.3.6 Sparks

The Sparks test sequence is (sparks_aom_5764-6024).

Figure C.3.2.3.6-1 shows a screenshot of the Sparks test sequence.



Figure C.3.2.3.6-1: Screenshot of Sparks test sequence

The Sparks test sequence properties are provided in Table C.3.2.3.6-1.

Table C.3.2.3.6-1 Sparks sequence properties

Parameter	Value
Resolution	4096 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	261
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Sparks/Sparks.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Sparks/Sparks-FHD.json>

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C.3.2.3.7 Nocturne

The Nocturne test sequence is (nocturne_aom_27740-28109).

Figure C.3.2.3.7-1 shows a screenshot of the Nocturne test sequence.



Figure C.3.2.3.7-1: Screenshot of Nocturne test sequence

The Nocturne test sequence properties are provided in Table C.3.2.3.7-1.

Table C.3.2.3.7-1 Nocturne sequence properties

Parameter	Value
Resolution	4096 x 2160
Scan	progressive
Frame Rate	60/1.001
Bit Depth	10
Length	370
YUV format	4:2:0
Colour components	ITU-T BT.2020
Colour space	HDR PQ

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Nocturne/Nocturne.json>

The Full HD version of the sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Nocturne/Nocturne-FHD.json>

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C.3.3 HFR Category

No test sequences are yet defined.

C.4 HD Test Sequences

C.4.1 Overview

For FullHD test sequences, downsampled versions of the 4K Sequences as introduced in C.3.1 and C.3.2 are used.

C.5 Messaging Sequences

C.5.1 Overview

C.5.1.1 Candidate Sequences

Several candidate sequences have been checked from: <https://media.xiph.org/video/av2/>. This clause provides an overview on the characteristics of the selected sequences in Annex C.5.2 to Annex C.5.5. Original sequences are available in y4m format which stores uncompressed YCbCr data. Conversion from y4m to YCbCr 4:2:0 is done using the following ffmpeg command (sequences are SDR therefore chroma downsampling is performed in ffmpeg):

```
./ffmpeg.exe -i $IN -vcodec rawvideo -video_size $Wx$H -pix_fmt yuv420p $OUT.yuv
```

Where \$W and \$H are respectively the sequence width and height, and \$IN and \$OUT are respectively the input and output files.

C.5.1.2 x265 encodings

To represent candidate sequences in the R-D plane, fixed QP encodings are carried out for QPs [12, 17, 22, 27, 32, 37, 42, 47] using ffmpeg release 4.3.1, with the following command line:

```
./ffmpeg.exe -pix_fmt yuv420p -s $Wx$H -framerate $FR -i $IN -vcodec libx265  
-qp $QP -preset fast -x265-params "psnr=1:ssim=1" $OUT.mp4
```

Where \$W and \$H are respectively the sequence width and height, \$FR the sequence frame rate, \$QP the selected quantization parameter. \$IN and \$OUT are respectively the input and output files.

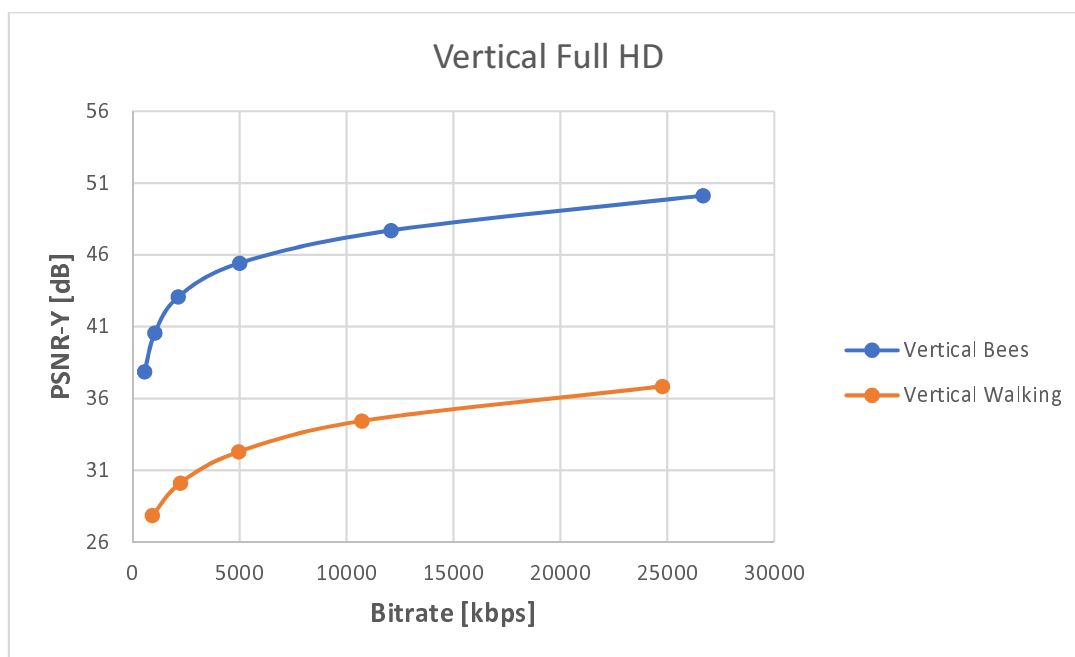


Figure C. 5.1.2-1: R-D curves for Vertical Full HD sequences.

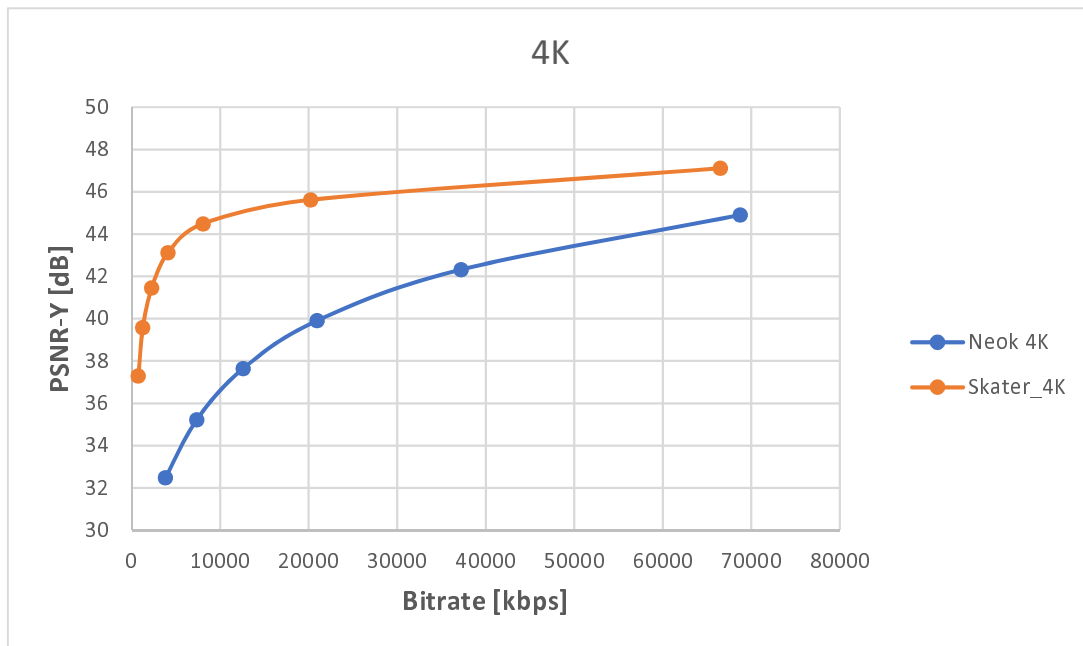


Figure C. 5.1.3-2: R-D curves for 4K sequences.

C.5.1.3 Visual analysis

Visual analysis of the sequences was performed to check quality of the sources in terms of compression artefacts from previous compression stages. For the selected sequences no obvious compression artifacts were noticed. Analysis of compressed bitstreams was performed to assert that quality degradation is introduced with decreasing bitrates.

It was noticed that Vertical Walking sequence was very noisy, and this had an impact on resulting bitrates. In addition, the sequence suffered from jerkiness at the beginning on the sequence (presumably due to man walking) and a strange lighting artifact towards the end of the sequence. Therefore, it is recommended to use an extract from the middle of the clip (between 9th and 14th second) which does not suffer from those impairments.

For the Neon 4K sequence it was noticed that there was fairly constant movement in the captured scene therefore it is recommended to use an extract of 5 seconds (first 5 seconds) to reduce codec simulation time.

C.5.2 Powder

C.5.2.1 Introduction

A donated sequence with outdoor filming <https://photos.app.goo.gl/6QrmTTMoizVtxAoQA>



Figure C.5.2.1-1: Screenshot of Powder sequence

C.5.2.2 Sequence properties

The Powder test sequence properties are provided in Table C.5.2.2-1.

Table C.5.2.2-1 Powder test sequence

Parameter	POWDER -01
Resolution	1920x1080
Scan	Progressive
Frame Rate	30 fps
Bit Depth	8
Length	3600 frames (60s)
YUV format	YUV 4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

C.5.2.3 Copyright and license information

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C.5.3 Vertical Bees

C.5.3.1 Introduction

The sequence is a camera close-up on bees around a thistle. Graphics overlays pop-up during the sequence. For this report a whole 5 seconds long clip was selected.

Figure C.5.3.1-1 shows a screenshot of the Vertical-Bees test sequence.

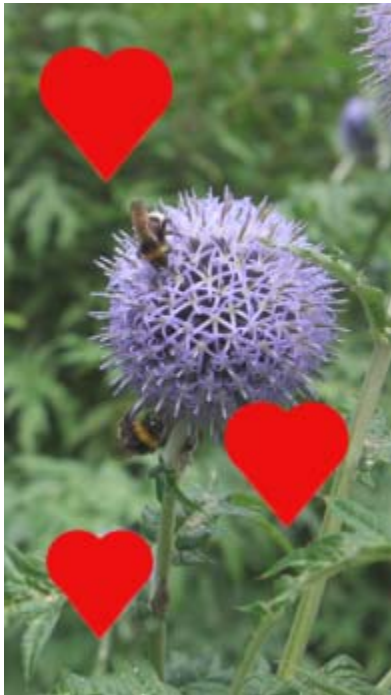


Figure C.5.3.1-1: Screenshot of Vertical-Bees test sequence

C.5.3.2 Sequence properties

The Vertical-Bees test sequence properties are provided in Table C.5.3.2-1.

Table C.5.3.2-1 Vertical-Bees sequence properties

Parameter	Value
Resolution	1080x1920
Scan	Progressive
Frame Rate	30/1.001
Bit Depth	8
Length	150 (5 seconds)
YUV format	4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Vertical-Bees/Vertical-Bees.json>

C.5.3.3 Copyright and license information

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C.5.4 Vertical Walking

C.5.4.1 Introduction

The sequence is a selfie shot by a walking man. For this report 5 seconds long clip was extracted (between 9th and 14th second) from the original sequence.

Figure C.5.4.1-1 shows a screenshot of the Vertical-Walking test sequence.



Figure C.5.4.1-1: Screenshot of Vertical Walking test sequence

C.5.4.2 Sequence properties

The Vertical-Walking test sequence properties are provided in Table C.5.4.2-1.

Table C.5.4.2-1 Vertical Walking sequence properties

Parameter	Value
Resolution	1080x1920
Scan	Progressive
Frame Rate	30
Bit Depth	8
Length	150 (5 seconds)
YUV format	4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Vertical-Walking/Vertical-Walking.json>

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C.5.5 Neon 4K

C.5.5.1 Introduction

The sequence captures dancing people dressed in neon-covered clothings in a disco/club hall. For this report 5 seconds long clip was extracted (first 5 seconds) from the original sequence.

Figure C.5.5.1-1 shows a screenshot of the Neon-4K test sequence.



Figure C.5.5.1-1: Screenshot of Neon 4K test sequence

C.5.5.2 Sequence properties

The Neon-4K test sequence properties are provided in Table C.5.5.2-1.

Table C.5.5.2-1 Neon 4K sequence properties

Parameter	Value
Resolution	3840x2160
Scan	Progressive
Frame Rate	30/1.001
Bit Depth	8
Length	150 (5 seconds)
YUV format	4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Neon-4K/Neon-4K.json>

C.5.5.3 Copyright and license information

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C.5.6 Skater 4K

C.5.6.1 Introduction

The sequence is a recording of a skater passing by. Includes camera pan following the skater. For this report a whole 10 seconds long clip was selected.

Figure C.5.6.1-1 shows a screenshot of the Skater-4K test sequence.



Figure C.5.6.1-1: Screenshot of Skater 4K test sequence

C.5.6.2 Sequence properties

The Skater-4K test sequence properties are provided in Table C.5.6.2-1.

Table C.5.6.2-1 Skater 4K sequence properties

Parameter	Value
Resolution	3840x2160
Scan	Progressive
Frame Rate	30
Bit Depth	8
Length	300 (10 seconds)
YUV format	4:2:0
Colour components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Skater-4K/Skater-4K.json>

C.5.6.3 Copyright and license information

The original content Skater227 was authored by Jim Skinner and made available at https://media.xiph.org/video/av2/y4m/SmoothSkaterP5_3840x2160_30fps.y4m under Creative Commons 4.0 license <https://creativecommons.org/licenses/by-sa/4.0/>.

C.6 Screen Content Test Sequences

C.6.1 Overview

Screen content test sequences have been generated for the purpose of this study with the objective to illustrate commonly encountered situations during videoconferences, particularly when sharing presentation slides. Some critical configurations are part of this test set such as moving text at different speeds and various transitions between the slides.

C.6.2 Moving Text 2

C.6.2.1 Introduction

The sequence *MovingText2* is composed of several lines of text horizontally scrolling at different speeds over a gradation of background colours. The sequence has been generated in 4K resolution at 60 frames per second with an authoring tool and exported into Apple ProRes 422 before being converted into YUV4:2:0. The figure C.6.2.1-1 is a screenshot of the *MovingText2* test sequence.



Figure C.6.2.1-1: Screenshot of MovingText2 test sequence

C.6.2.2 Source sequence properties

The *MovingText2* test sequence properties are provided in Table C.6.2.2-1.

Table C.6.2.2-1 Moving Text 2 test sequences

Parameter	MT2-01	MT2-02	MT2-03	MT2-04
Resolution	3840 x 2160	3840 x 2160	1920 x1080	1920 x1080
Scan	Progressive	Progressive	Progressive	Progressive
Frame Rate	60 fps	60 fps	60 fps	60 fps
Bit Depth	10	8	10	8
Length	600 frames (10s)	600 frames (10s)	600 frames (10s)	600 frames (10s)
YUV format	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0
Colour components	Y'CbCr	Y'CbCr	Y'CbCr	Y'CbCr
Colour space	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709

The original version as well as subsampled ones are available here:

- FullHD 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/MovingText2-FullHD-8bit/>
- FullHD 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/MovingText2-FullHD-10bit/>

- 4K 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/MovingText2-4K-8bit/>
- 4K 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/MovingText2-4K-10bit/>

C.6.2.3 Copyright information

The *MovingText2* video sequence has been produced for the purpose of this study on the characterization of video codecs in 3GPP.

C.6.3 Text Mix Transitions

C.6.3.1 Introduction

The sequence *TextMixTransitions* is composed of 2 slides containing fixed text at different sizes. Those 2 slides appear twice each during 2.5s. 1s long transitions are inserted in between (fade, slide, turning page). The sequence has been generated in 4K resolution at 60 frames per second with an authoring tool and exported into Apple ProRes 422 before being converted into YUV4:2:0. The figure C.6.3.1-1 is a screenshot of the *TextMixTransitions* test sequence.



Figure C.6.3.1-1: Screenshot of *TextMixTransitions* test sequence

C.6.3.2 Source sequence properties

The *TextMixTransitions* test sequence properties are provided in Table C.6.3.2-1.

Table C.6.3.2-1 *TextMixTransitions* test sequences

Parameter	TMT-01	TMT-02	TMT-03	TMT-04
Resolution	3840 x 2160	3840 x 2160	1920 x1080	1920 x1080
Scan	Progressive	Progressive	Progressive	Progressive
Frame Rate	60 fps	60 fps	60 fps	60 fps
Bit Depth	10	8	10	8
Length	600 frames (10s)	600 frames (10s)	600 frames (10s)	600 frames (10s)
YUV format	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0
Colour components	Y'CbCr	Y'CbCr	Y'CbCr	Y'CbCr
Colour space	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709

The original version as well as subsampled ones are available here:

- FullHD 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/TextMixTransitions-FullHD-8bit/>
- FullHD 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/TextMixTransitions-FullHD-10bit/>

- 4K 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/TextMixTransitions-4K-8bit/>
- 4K 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/TextMixTransitions-4K-10bit/>

C.6.3.3 Copyright information

The *TextMixTransitions* video sequence has been produced for the purpose of this study on the characterization of video codecs in 3GPP.

C.6.4 Graphics Mix Simple

C.6.4.1 Introduction

The sequence *GraphicsMixSimple* is composed of 3 slides containing different types of graphics. Those 3 slides appear once each during 3.33s. Transitions are simple scene cut in between. The sequence has been generated in 4K resolution at 60 frames per second with an authoring tool and exported into Apple ProRes 422 before being converted into YUV4:2:0. The figure C.6.4.1-1 is a screenshot of each of the 3 scenes contained in the *GraphicsMixSimple* test sequence.

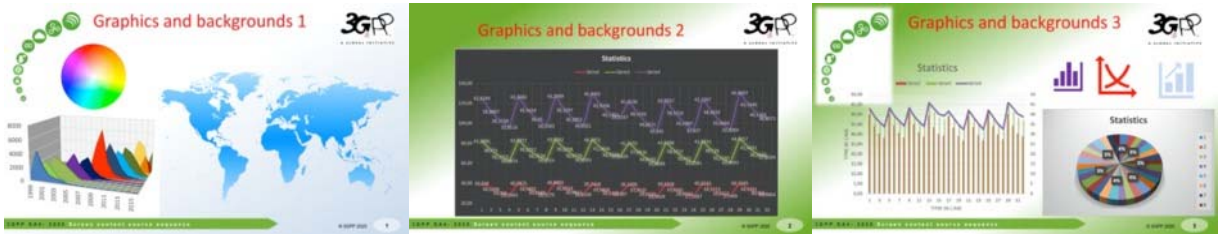


Figure C.6.4.1-1: Screenshot of the 3 scenes in GraphicsMixSimple test sequence

C.6.4.2 Source sequence properties

The *GraphicsMixSimple* test sequence properties are provided in Table C.6.4.2-1.

Table C.6.4.2-1 GraphicsMixSimple test sequences

Parameter	GMS-01	GMS-02	GMS-03	GMX-04
Resolution	3840 x 2160	3840 x 2160	1920 x1080	1920 x1080
Scan	Progressive	Progressive	Progressive	Progressive
Frame Rate	60 fps	60 fps	60 fps	60 fps
Bit Depth	10	8	10	8
Length	600 frames (10s)	600 frames (10s)	600 frames (10s)	600 frames (10s)
YUV format	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0
Colour components	Y'CbCr	Y'CbCr	Y'CbCr	Y'CbCr
Colour space	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709

The original version as well as subsampled ones are available here:

- FullHD 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixSimple-FullHD-8bit/>
- FullHD 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixSimple-FullHD-10bit/>
- 4K 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixSimple-4K-8bit/>

- 4K 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixSimple-4K-10bit/>

C.6.4.3 Copyright information

The *GraphicsMixSimple* video sequence has been produced for the purpose of this study on the characterization of video codecs in 3GPP.

C.6.5 Graphics Mix Transition

C.6.5.1 Introduction

The sequence *GraphicsMixTransition* is the same sequence as *GraphicsMixSimple* described in clause C.6.4, except the fact that 1s long transitions have been inserted composed of 3 slides containing different types of graphics. The 3 slides appear once each during 3.33s. Transitions are fading and page turning in between. The sequence has been generated in 4K resolution at 60 frames per second with an authoring tool and exported into Apple ProRes 422 before being converted into YUV4:2:0. The figure C.6.5.1-1 is a screenshot of each of the 3 scenes contained in the *GraphicsMixTransition* test sequence.



Figure C.6.5.1-1: Screenshot of the 2 transitions in GraphicsMixTransitions test sequence

C.6.5.2 Source sequence properties

The *GraphicsMixTransitions* test sequence properties are provided in Table C.6.5.2-1.

Table C.6.5.2-1 GraphicsMixTransitions test sequences

Parameter	GMT-01	GMT-01	GMT-03	GMT-04
Resolution	3840 x 2160	3840 x 2160	1920 x1080	1920 x1080
Scan	Progressive	Progressive	Progressive	Progressive
Frame Rate	60 fps	60 fps	60 fps	60 fps
Bit Depth	10	8	10	8
Length	600 frames (10s)	600 frames (10s)	600 frames (10s)	600 frames (10s)
YUV format	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0	YUV 4:2:0
Colour components	Y'CbCr	Y'CbCr	Y'CbCr	Y'CbCr
Colour space	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709	ITU-R BT.709

The original version as well as subsampled ones are available here:

- FullHD 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixTransitions-FullHD-8bit/>
- FullHD 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixTransitions-FullHD-10bit/>
- 4K 8bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixTransitions-4K-8bit/>
- 4K 10bit: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/GraphicsMixTransitions-4K-10bit/>

C.6.5.3 Copyright information

The *GraphicsMixTransitions* video sequence has been produced for the purpose of this study on the characterization of video codecs in 3GPP.

C.6.6 Mission Control

C.6.6.1 Introduction

The sequence *Mission-Control* combines natural video with synthetic content. Figure C.6.6.1-1 is a screenshot of each of the 3 scenes contained in the *Mission-Control* test sequence.

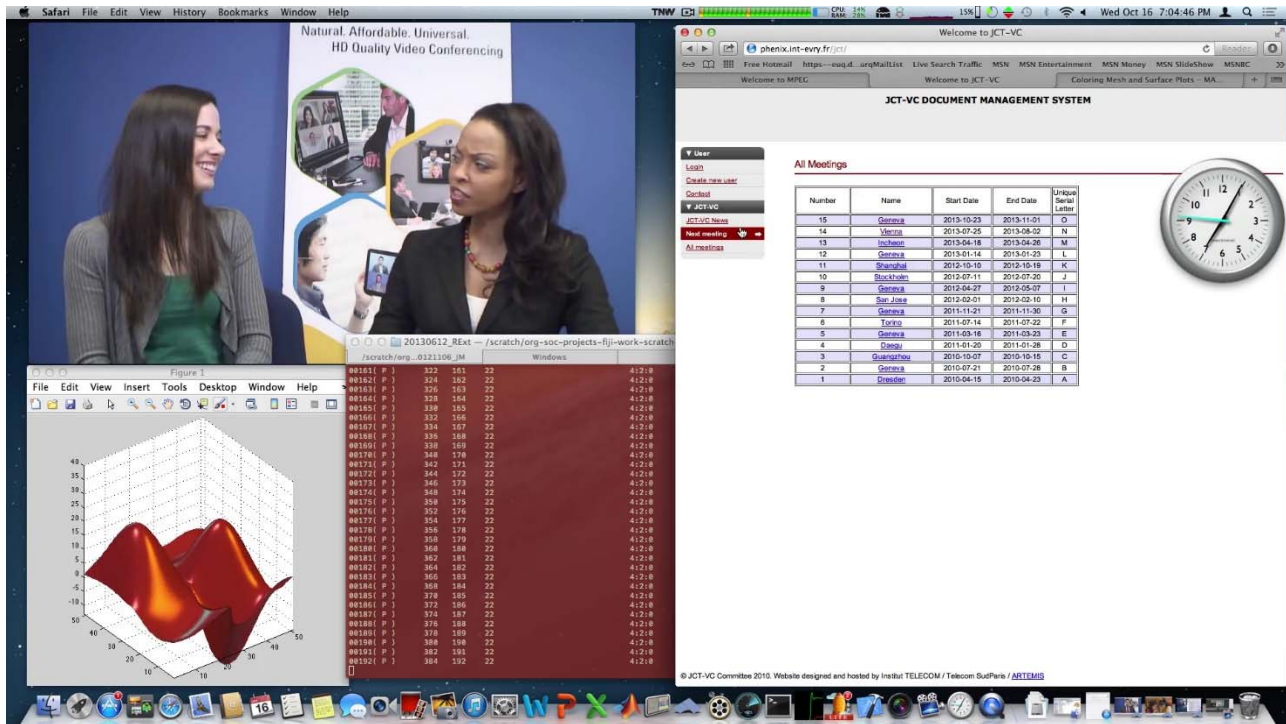


Figure C.6.6.1-1: Screenshot of Mission-Control test sequence

C.6.6.2 Source sequence properties

The *Mission-Control* test sequence properties are provided in Table C.6.6.2-1.

Table C.6.6.2-1 Mission-Control test sequence

Parameter	GMT-03
Resolution	1920 x1080
Scan	Progressive
Frame Rate	60 fps
Bit Depth	10
Length	600 frames (10s)
YUV format	YUV 4:2:0
Color components	Y'CbCr
Colour space	ITU-R BT.709

The sequence can be accessed here:

- <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/Mission-Control/Mission-Control.json>

C.6.6.3 Copyright information

*The test sequence and all intellectual property rights therein remain the property of their respective copyright holders. This material can only be used for the purpose of academic research and development of standards. This material cannot be distributed with charge. The owner makes no warranties with respect to the material and expressly disclaims any warranties regarding its fitness for any purpose.
Owners of this sequence: Apple Inc.*

Production: Apple Inc.

The sequence Kristen and Sara included in this video is property of Vidyo, Inc.

Annex D Data Management and Hosting

D.1 Introduction

All reference sequences and all anchors are hosted on a publicly accessible web-server here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo>

A frontend is provided here:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/index.html>.

NOTE: this frontend still needs to be implemented. Volunteers welcome.

In order to address reference sequences with different raw formats and to maintain consistency, a json file is added to describe the properties of the file.

D.2 Reference Sequences

D.2.1 Hosting

All reference sequences are hosted at

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/ReferenceSequences/>

Below this folder, for each reference sequence a dedicated folder is created. The folder includes at least the following information:

- JSON file for raw video according to schema in clause B.1.2.

In addition, the folder may include the following information

- the raw video sequence, if hosted on the server,
- a preview file,
- a thumbnail image.

D.2.2 Uploading

For uploading a new reference sequence, please create a new issue here

- https://github.com/haudio5e/5G-Video-Content/issues/new?assignees=&labels=request&template=reference_sequence.md&title=

Please specify all information that needs to be added to the JSON file for raw video sequences as defined in clause B.2.

D.2.3 Downloading

Sequences can be downloaded from the above folders. Licensing terms must be obeyed. Downloaded files should be MD5 verified.

On Windows

Open Command Prompt.

Open your downloads folder by typing `cd Downloads. ...`

Type `certutil -hashfile` followed by the `file name` and then MD5.

Check that the value returned matches the value the MD5 file you downloaded from the json.

On Mac

Open Terminal.

Type `md5` and hit the SPACE button.

Drag the file you have downloaded into the Terminal Window. ...

Hit Enter.

You should now see the MD5 Checksum so you can compare it to the string you have been given in json.

On Linux

Open Terminal.

Type `md5` and add `file name` – hit enter

Verify the json provided MD5.

D.3 Anchors and Tests

D.3.1 Hosting

All anchor test bitstreams are hosted at:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/>.

Below this folder, a hierarchy is created

- Scenario
 - Codec
 - Metrics (contains all metrics)
 - Characterization (contains all characterization results)
 - CFG (contains all cfgs)
 - streams.csv (Documents the streams and generation)
 - crosscheck.csv (documents all cross-check results)
 - verification.csv (documents all verification results)
 - Anchor/Test Tuple
 - Anchor/Test Bitstream

The folder includes at least the following information:

- JSON file for binary video according to schema in clause B.3.2.
- binary video bitstream
- Potentially log files

The basic structure is as follows

Anchors

Scenario-1-HD/	05-May-2021 19:06	-
Scenario-2-4K/	05-May-2021 19:07	-
Scenario-3-Screen/	10-May-2021 21:18	-
Scenario-4-Sharing/	05-May-2021 19:07	-
Scenario-5-Gaming/	06-May-2021 00:38	-

D.3.2 Uploading

For uploading anchors and tests, please create a new issue here

- https://github.com/haudio/be/5G-Video-Content/issues/new?assignees=&labels=request&template=anchor_tuple.md&title=

Please specify all required information that needs to be added to the JSON file for encoded video sequences as defined in clause B.3.

D.3.3 Downloading

Anchors and tests can be downloaded for free from the above folders. Licensing terms must be obeyed. Downloaded files should be MD5 verified. Please check the software in Annex E for intelligent batch download.

D.4 Verification

Verification Reports are for example hosted at:

<https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-3-Screen/265/verification.csv>

Annex E: Software Package

E.1 Introduction

The development of anchors, tests and metrics is supported by a software package provided here:
<https://github.com/haudiobe/5GVideo>. The software packager permits the following functionalities:

1. to produce anchors and test bitstreams.
 - a) Input
 - a reference sequence csv according to the format in this document. It includes the key and the reference to the online repository
 - a stream csv file according to the format provided in this document. It includes the tuple key, the reference sequence, the reference encoder, the configuration files, the variations and the anchor keys.
 - b) Output
 - the set of anchors in an anchor tuple in json according to the agreed naming convention
2. to produce metrics. The following information is needed.
 - a) Input
 - a reference sequence csv according to the format in this document. It includes the key and the reference to the online repository
 - a stream csv file according to the format provided in this document. It includes the tuple key, the reference sequence, the reference encoder, the configuration files, the variations and the anchor keys.
 - the set of anchors in an anchor tuple in json according to the agreed naming convention
 - b) Output
 - a metrics json file for each anchor tuple according to the definition in clause 5.5.
3. to verify reconstruction and metrics. The following information is needed.
 - a) Input
 - a reference sequence csv according to the format in this document. It includes the key and the reference to the online repository
 - a stream csv file according to the format provided in this document. It includes the tuple key, the reference sequence, the reference encoder, the configuration files, the variations and the anchor keys.
 - the set of anchors in an anchor tuple in json according to the agreed naming convention
 - b) Output
 - a list of verification report entries according to the definition in Annex B.4.
4. to verify bitstreams. The following information is needed.
 - a) Input
 - a reference sequence csv according to the format in this document. It includes the key and the reference to the online repository
 - a stream csv file according to the format provided in this document. It includes the tuple key, the reference sequence, the reference encoder, the configuration files, the variations and the anchor keys.
 - the set of anchors in an anchor tuple in json according to the agreed naming convention

b) Output

- a list of verification report entries according to the definition in Annex B.4.

5. to create characterization results. The following information is needed.

a) Input

- the configuration of the anchor and the test
- the metrics for which characterization is done.

b) Output

- Characterization reports.
- Plots for the characterizations

E.2 README: Video codec characterization scripts

E.2.1 Overview

These script can be used to produce / verify specific encoders and scenarios according to this TR.

- video codec characterization scripts
 - installation
 - working directory
 - download content from server
 - vcc.py script usage
 - processing all QPs of a an anchor
 - processing a single QP for an anchor
 - process all anchors for a given encoder config
 - encode, decode, convert, metrics subcommands
 - common options
 - encode
 - decode
 - convert
 - metrics
 - image quality metrics
 - bitrate / bitstream size
 - metrics csv export
 - characterization, rd curves plots, bd rate
 - using the scripts for metrics verification
 - working directory
 - download bitstreams for verification
 - reconstruction and metrics

- generate reconstruction of bitstreams
 - format conversion before metrics computation
 - compute metrics
 - export metrics from .json to .csv
- generate verification report
 - download the original metrics
 - metrics verification
- docker usage
 - building the docker images
 - using the worker image
 - using docker-compose

E.2.3 installation

E.2.3.1 cloning

```
git clone https://github.com/haudiobe/5GVideo
cd 5GVideo
```

Please use a [python virtual environment](#) to install dependencies and run the scripts.

install python dependencies:

```
pip3 install -r src/requirements.txt
```

E.2.3.2 working directory

The scripts assume you have a local directory where content has been downloaded from: <https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/> or follows that structure.

No default value is provided for the path to the working directory, it must be supplied explicitly by one of these 2 means: - the scripts accept a `--working-dir` argument to supply the path. - the `VCC_WORKING_DIR` environment variable is used to configure the location of that directory

E.2.3.3 download content from server

to download anchors, bitstreams, metrics, encoder configs, & reference sequence list for a given scenario:

```
python3 src/download.py streams https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/264/streams.csv $VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/264
```

to download anchors reference sequences for a csv list:

```
python3 src/download.py sequences $VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/reference-sequences.csv $VCC_WORKING_DIR/ReferenceSequences
```


E.2.4 vcc.py script usage

E.2.4.1 Overview

`src/vcc.py` provides the commands to encode, decode, and compute metrics.

All the commands described below have a common usage pattern.

E.2.4.2 processing all QPs of an anchor

```
python3 src/vcc.py [--dry-run] -s S1-A01-264 decode
```

the script parses `-s S1-A01-264`, finds `Scenario-1-FHD/265/streams.csv`, and processes **all QPs** listed for S1-A01-264.

E.2.4.3 processing a single QP for an anchor

```
python3 src/vcc.py [--dry-run] -s S1-A01-264-22 decode
```

the script works as described above, but will only process a **single QP** - in this case: **22**.

E.2.4.4 process all anchors for a given encoder config

E.2.4.4.1 general

```
python3 src/metrics.py [--dry-run] -c S1-JM-01 decode
```

the script parses `-c S1-JM-01`, finds `Scenario-1-FHD/264/streams.csv`, then processes **all QPs**, for **all anchors** where the encoder config is S1-JM-01.

`encode`, `decode`, `convert`, `metrics` subcommands follow

E.2.4.4.2 common options

- `--dry-run`: does not execute the subprocesses, but instead prints the corresponding commands to stdout.
- `--queue`: advanced - pushes the commands as tasks to a worker queue using the celery framework, instead of processing sequentially. This option is meant to be used with the sample `docker-compose.yml` stack. See *Docker usage > Using docker-compose*.

E.2.4.4.3 encode

```
JM19_0_ENCODER=~/.deps/JM/bin/lencod_static
```

```
python3 src/vcc.py -s S1-A01-264 encode
```

dry-run mode prints the command used to encode to stdout but doesn't run it, but it does compute existing bitstream md5.

E.2.4.4.4 decode

```
JM19_0_DECODER=~/.deps/JM/bin/ldecod_static
```

```
python3 src/vcc.py -s S1-A01-264 decode
```

dry-run mode prints the command used to encode to stdout but doesn't run it, but it does compute existing reconstruction md5.

E.2.4.4.5 convert

```
HDRCONVERT_TOOL=~/.deps/HDRTools/build/bin/HDRConvert
```

```
python3 src/vcc.py -s S1-A01-264 decode --reference
```

```
python3 src/vcc.py -s S1-A01-264 decode --reconstructions
```

Performs conversion needed before metrics computation using HDRTools' HDRConvert.

when `--reconstructions` is specified, the reconstructions for all QPs are processed. when `--reference` is specified, the reference sequence is processed instead.

Conversion is either be 8 to 10 bit YUV, or YUV to EXR. **When conversion is not needed for a given sequence, the script does nothing.**

The converted sequences are stored in a tmp subfolder for each anchor.

dry-run mode prints the command used to convert to stdout but doesn't run it.

E.2.4.4.6 metrics

E.2.4.4.6.1 storage

when running the metrics command, the result is stored in the json file.

E.2.4.4.6.2 image quality metrics

```
HDRMETRICS_TOOL=~/.deps/HDRTools/build/bin/HDRMetrics
```

```
VMAF_EXE=~/.deps/vmaf/libvmaf/build/tools/vmafossxec
```

```
VMAF_MODEL=/home/.deps/vmaf/model/vmaf_v0.6.1.json
```

```
python3 src/vcc.py -s S1-A01-264 metrics
```

Computes metrics for the given sequence. This step also computes bitrate after removing SEI.

HDRTOOLS or VMAF can be enabled / disabled through environment variables.

```
DISABLE_HDRMETRICS=1
```

```
DISABLE_VMAF=1
```

This step is meant to run after successful conversion. It uses the converted sequence where appropriate, and raise an error if it doesn't exist.

dry-run mode doesn't run HDRTools or vmaf, but it parses existing logs if any.

E.2.4.4.6.3 bitrate / bitstream size

Bitstream size / bitrate is always computed when running metrics. It can be computed explicitly as a separate step.

```
python3 src/vcc.py -s S1-A01-264-22 bitrate
```

First, SEI_REMOVAL_APP is used if implemented by the encoder class. Then bitrate is computed based on the resulting bitstream size, and the json metadata are updated with the result.

E.2.4.4.6.4 metrics csv export

Metrics are saved on the anchors JSON file. A script can be used to export them to .csv:

```
python3 src/metrics.py -s S1-A01-264 csv-metrics
python3 src/metrics.py -c S1-HM-02 csv-metrics
```

For the above commands, the metrics .csv files can then be found in:
\$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/265/Metrics

E.2.5 characterization, rd curves plots, bd rate

The characterization script is meant to compare test data to an anchor. For instance, to compare sequences JM and HM for Scenario-1-FHD, you should have the following data:

```
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/264/S1-A01-264.json
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/264/streams.csv
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/264/Metrics/S1-A01-264.csv
[...]
```

```
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/264/S1-A01-265.json
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/265/streams.csv
$VCC_WORKING_DIR/Bitstreams/Scenario-1-FHD/265/Metrics/S1-A01-264.csv
[...]
```

To compare and plot psnr, y_psnr, and ms_ssim for these 2 sequences:

```
python3 src/compare.py --plot -s S1-A01-264 S1-A01-265 psnr y_psnr ms_ssim
```

Assuming you have all the anchors for encoder config S1-JM-01 and S1-HM-01, you can process them at once:

```
python3 src/compare.py --plot -c S1-JM-01 S1-HM-01 psnr y_psnr ms_ssim
```

E.2.6 using the scripts for metrics verification

E.2.6.1 General

This guide provides step by step instructions to process with reconstruction and metrics verifications.

E.2.6.2 working directory

In this guide, /data will be the directory where reference content is downloaded. All subsequent verification steps assume the VCC_WORKING_DIR environment variable is set to /data.

E.2.6.3 download bitstreams for verification

1. download bitstreams and metadata for a given scenario

```
python3 src/download.py streams --bitstream https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/streams.csv /data/Bitstreams/Scenario-1-FHD/VTM
```

```
/data
├── Bitstreams
│   └── Scenario-1-FHD
│       ├── reference-sequence.csv
│       └── VTM
│           ├── streams.csv
│           ├── CFG
│           ├── Metrics
│           └── S1-T11-VTM
│               ├── S1-T11-VTM-22
│               │   ├── S1-T11-VTM-22.json
│               │   └── S1-T11-VTM-22.bin
│               ├── S1-T11-VTM-27
│               ├── S1-T11-VTM-32
│               └── S1-T11-VTM-37
│   [...]
│   └── S1-T17-VTM
```

2. download reference sequences for that scenario

```
python3 src/download.py sequences /data/Bitstreams/Scenario-1-FHD/reference-sequence.csv /data/ReferenceSequences
```

```
/data
├── ReferenceSequences
│   └── Life-Untouched
│       ├── Life-Untouched-FHD.json
│       └── Life-Untouched-FHD.yuv
```

E.2.6.4 reconstruction and metrics

E.2.6.4.1 generate reconstruction of bitstreams

reconstruct QP 22 for S1-T11-VTM

```
python3 src/vcc.py decode -s S1-T11-VTM-22 decode
```

```
/data/Bitstreams/Scenario-1-FHD
└─ S1-T11-VTM
   └─ S1-T11-VTM-22
      S1-T11-VTM-22.yuv
      S1-T11-VTM-22.dec.log
```

E.2.6.4.2 format conversion before metrics computation

In some cases, must process conversion from one representation to another before. This 8 to 10 bit, 10 to 8 bit, and YUV to RGB444.

In the case of S1-T11-VTM, YUV to RGB444 needs to be performed on the reference sequence as well as on the reconstructions to compute HDR metrics using HDRTools.

Convert the reconstructions of the test scenario:

```
python3 src/vcc.py -s S1-T11-VTM-22 convert --reconstructions
```

```
/data/Bitstreams/Scenario-1-FHD
└─ S1-T11-VTM
   └─ S1-T11-VTM-22
      │ S1-T11-VTM-22.yuv
      │ S1-T11-VTM-22.yuv.json
      └─ tmp
         S1-T11-VTM-22_2020_444_%05d.json
         S1-T11-VTM-22_2020_444_000000.exr
         S1-T11-VTM-22_2020_444_000000.exr
         S1-T11-VTM-22_2020_444_000001.exr
         ...
         S1-T11-VTM-22_2020_444_%05d.hdrconvert.log
      ...
```

Convert the reference sequence used to encode S1-T11-VTM:

```
python3 src/vcc.py -s S1-T11-VTM convert --sequences
```

```
/data/ReferenceSequences
└─ Life-Untouched
   │ Life-Untouched-FHD.yuv
   │ Life-Untouched-FHD.json
   └─ tmp
      Life-Untouched-FHD_2020_444_%05d.json
      Life-Untouched-FHD_2020_444_000000.exr
```

```

    Life-Untouched-FHD_2020_444_000001.exr
    ...
    Life-Untouched-FHD_2020_444_%05d.hdrconvert.log
    ...

```

E.2.6.4.3 compute metrics

Run metrics computations, and updates the json metadata.

```
python3 src/vcc.py -s S1-T11-VTM-22 metrics
```

```

/data/Bitstreams/Scenario-1-FHD
├── S1-T11-VTM
│   └── S1-T11-VTM-22
│       ├── S1-T11-VTM-22.metrics.log
│       ├── S1-T11-VTM-22.json
│       ├── ...
│       └── tmp
│           ├── S1-T11-VTM-22_2020_444_%05d.metrics.log
│           └── ...

```

E.2.6.4.4 export metrics from .json to .csv

When computing metrics, results are stored in json metadata. After computing metrics for all anchors of a given encoder configuration, the metrics are exported to the appropriate csv format.

this is conveniently done for a set of all anchors with a given encoder config:

```
python3 src/metrics.py -c S1-VTM-02 csv-metrics
```

```

/data/Bitstreams/Scenario-1-FHD/Metrics
├── ...
└── S1-VTM-02.csv

```

but can also be done for individual anchor:

```

python3 src/metrics.py -s S1-T11-VTM csv-metrics
/data/Bitstreams/Scenario-1-FHD/Metrics
├── S1-T11-VTM.csv

```

E.2.6.5 generate verification report

E.2.6.5.1 general

to generate a verification report, we compare the local reconstruction and metrics computed in the working directory, to the original data downloaded from the server.

E.2.6.5.2 download the original metrics

create the directory /data/Origin/Scenario-1-FHD/VTM and download the reference metrics there:

```
python3 src/download.py streams --metrics https://dash-large-files.akamaized.net/WAVE/3GPP/5GVideo/Bitstreams/Scenario-1-FHD/VTM/streams.csv /data/Origin/Scenario-1-FHD/VTM
```

E.2.6.5.3 metrics verification

to generate a verification `verify-metrics` command of the `metrics.py` script.

the following options are needed: `-o` : the path to the directory containing the original data to which locally computed results will be compared `-r` : the resulting report path is specific with

the metrics key on which the verification report should run are specified as the last arguments. eg `psnr y_psnr` the following metrics keys are implemented: `psnr, y_psnr, u_psnr, v_psnr, ms_ssim, vmaf, bitrate, bitrate_log, wpsnr, y_wpsnr, u_wpsnr, v_wpsnr, psnr100, de100`

```
python3 ./src/metrics.py -c S1-VTM-01 verify-metrics
-o /data/origin
-r /data/origin/s1-vtm-01-verification-report.csv
--doc - --email foo@corp.com --company corp
y_psnr psnr
```

E.2.7 docker usage

E.2.7.1 General

All the dependencies in a single docker image.

E.2.7.2 building the docker images

on linux: `./build.sh` (should work on mac as well) on windows: `.\build.ps1`

the build script builds several docker images: `vcc:base` used as provides common build environment, and metrics dependencies : HDRTools, vmaf. `vcc:jm`, `vcc:hm`, `vcc:etm`, `vcc:ctm`, `vcc:aom` builds the respective reference encoders, decoders, and sei removal executable. `vcc:worker` copies pre-built binaries from the above images, supplies the appropriate environment variables, adds the scripts & config folders.

build a specific image : `docker image ls` list docker images on your machine: `docker image ls` remove a specific docker image: `docker image rm vcc:worker` remove all docker image: `docker image rm vcc`

E.2.7.3 using the worker image

The worker image is configured with `/data` as the root directory for all the ReferenceSequences and Bitstreams directories. When running the worker image; bitstreams and reference sequences must be mounted to the container `/data` directroy, eg. using docker's `--mount` option.

```
docker run -it --mount type=bind,source=/path/to/local/vcc_working_dir,target=/data vcc:workers vcc.py -s S1-A01-264 decode
```

local Bitstreams and ReferenceSequences data may be organized arbitrarily and mounted to the appropriate directory:

```
docker run -it \  
  --mount type=bind,source=/path/to/local/bitstreams_dir,target=/data/Bitstreams" \  
  --mount type=bind,source=/path/to/local/sequences_dir,target=/data/ReferenceSequences" \  
  vcc:workers vcc.py -s S1-A01-264 decode
```

E.2.7.4 using docker-compose

A sample docker-compose is provided. It starts a background worker and a redis queue. The `--queue` option of the `vcc.py` script can be used to add jobs to the queue. The initial concurrency is set to 2 simultaneous jobs. Too high value for concurrency may not be suitable for all tasks (eg. 4K encodes).

to use it, first configure local directories to mount using environment variables: linux

```
export VCC_BITSTREAMS_DIR=/path/to/local/bitstreams_dir  
export VCC_REFERENCES_DIR=/path/to/local/sequences_dir
```

windows

```
$env:VCC_BITSTREAMS_DIR="c:\path\to\local\bitstreams_dir"  
$env:VCC_REFERENCES_DIR="c:\path\to\local\sequences_dir"
```

build workers:

```
docker-compose build workers
```

then start the stack:

```
docker-compose up -d
```

verify that all services are running:

```
docker-compose ps
```

the queue can be monitored with a web browser at <http://localhost:8888/>

queue some tasks, eg. decode all anchors encoded with s1-jm-01.cfg:

```
docker-compose exec worker python3 vcc.py --queue -c S1-JM-01 decode
```

Annex F: Attachments

The attachments to this document are provided in 26955-Attachments.zip.

The attachment includes all information from the online repository from the folders:

- ReferenceSequences folder except yuv, mp4, jpg and png files
- Bitstreams folder except the binary anchors, log files as well pngs of the characterization results.
- HDRConvert folder with relevant HDR Tool configs

Annex G: Non-verified results

All results were verified, hence this Annex is empty.

Annex <X> (informative): Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2020-04	SA4#108	S4-200661				Initial Version	0.0.1
2020-04	SA4#108	S4-200666				Version agreed at SA4#108-e	0.1.0
2020-05	SA4#109	S4-200891				Version agreed at SA4#109-e	0.2.0
2020-08	SA4#110	S4-201243				Version agreed at SA4#110-e	0.3.0
2020-11	SA4#111	S4-201515				Version agreed at SA4#111-e	0.4.0
2021-02	SA4#112	S4-210207				Version agreed at SA4#112-e	0.5.0
2021-03	SA4#112	S4aV200662				Version agreed to be sent to SA plenary for information. The SA4#112-e had given special provision to the group to work on S4-210207 version of the report after the said meeting in order to submit an updated version at the SA plenary.	0.6.0
2021-03	#91-e	SP-210051				Version submitted to SA plenary for information.	1.0.0
2021-04	SA4#113	S4-210555				Version agreed at SA4#113-e	1.1.0
2021-05	SA4#114	S4-210871				Version agreed at SA4#114-e	1.2.0
2021-08	SA4#115	S4-211187				Version agreed at SA4#115-e	1.3.0
2021-11	SA4#116	S4-211553				Version agreed at SA4#116-e	1.4.0
2022-02	SA4#117	S4-220206				Version agreed at SA4#117-e	1.5.0
2022-04	SA4#118	S4-220493				Version agreed at SA4#118-e	1.6.0
2022-05	SA4#119	S4-220750				Version agreed at SA4#119-e	1.7.0
2022-05	SA4#119	S4-220879				Version agreed to be sent to SA plenary for approval. The SA4#119-e had given special provision to the group to work on S4-220879 version of the report after the said meeting in order to submit an updated version at the SA plenary.	1.8.0
2022-06	SA#96	SP-220607				Version sent to plenary for Approval	2.0.0
2022-06	SA#96	SP-220607				Under Change Control	17.0.0
2022-09	SA#97-e	SP-220762	000 1		F	Miscellaneous Corrections	17.1.0
2024-03	-	-	-	-	-	Update to Rel-18 version (MCC)	18.0.0
2025-10	-	-	-	-	-	Update to Rel-19 version (MCC)	19.0.0

History

Document history		
V19.0.0	October 2025	Publication