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Satellite Earth Stations & Systems (SES); DVB-S2x/RCS2 versus 3GPP New Radio protocol technical comparison for broadband satellite systems

Reference

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

Modal verbs terminology

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Introduction

In view of the recent extension of 3GPP defined New Radio (NR) to support Non-Terrestrial Networks (NTN) operating in the Ka- and Ku-band allocated satellite services, it is necessary to understand the merits and limitations of this access technology in comparison with the long-established satellite access technology defined by the DVB forum as 'DVB-S2x/RCS2'.

The present document includes a qualitative and quantitative comparison of both access technologies in the context of broadband satellite networks, based on GSO space segment operating in above 10 GHz frequencies. The quantitative analysis is leveraging link- and system level simulation methodologies typically adopted in 3GPP.

Clause 2 provides the references. Clause 3 provides the definitions of terms, explains symbols and expands abbreviations. Clause 4 provides qualitative technology analysis on functional, operational, performance, and other non-technical aspects. Clause 5 provides a comprehensive quantitative link level analysis, including the simulation configuration and results. Clause 6 provides a system level comparison with simulation configurations and results, leveraging the link level results. Clause 7 concludes the technical comparison.

1 Scope

The present document contains a technical comparison of DVB-S2x/RCS2 and 3GPP New Radio (NR) Non Terrestrial Networks (NTN) radio interface/access technology for broadband satellite communication systems operating above 10 GHz for fixed satellite services. Possible enhancements (e.g. Peak-to-Average Power Ratio (PAPR) mitigation) for NR taking into account backward compatibility aspects and 3GPP specification impacts are identified and assessed.

Applicability of the study to frequencies below 10 GHz is not considered.

NOTE 1: The comparison analysis considered both Single SFPB and MFPB (with BFN) payload architectures.

NOTE 2: The GEO scenario is considered.

NOTE 3: The same carrier bandwidth is considered for the comparison between DVB and NR.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 302 307-2: "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 2: DVB-S2 Extensions (DVB-S2X)".

[i.2] ETSI EN 302 307-1: "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 1: DVB-S2".

[i.3] ETSI EN 301 545-2: "Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 2: Lower Layers for Satellite standard".

[i.4] ETSI TS 138 214: "5G; NR; Physical layer procedures for data (3GPP TS 38.214)".

[i.5] 3GPP TR 38.886 (V16.3.0) (03-2021): "V2X Services based on NR; User Equipment (UE) radio transmission and reception (Release 16)".

[i.6] 3GPP TR 38.821: "Solutions for NR to support non-terrestrial networks (NTN)".

[i.7] 3GPP TR 38.811: "Study on New Radio (NR) to support non-terrestrial networks".

[i.8] Recommendation ITU-R P.1853-2: "Time Series synthesis of tropospheric impairments", Geneva, August 2019.

[i.9] 3GPP TR 36.889: "Study on Licensed-Assisted Access to Unlicensed Spectrum".

[i.10] ETSI TR 101 545-4: "Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 4: Guidelines for Implementation and Use of EN 301 545-2".

[i.11] ETSI TR 103 297: "Satellite Earth Stations and Systems (SES); SC-FDMA based radio waveform technology for Ku/Ka band satellite service".

[i.12] IEEE 802.1ad™: "IEEE Standard for Local and Metropolitan Area Networks -- Virtual Bridged Local Area Networks -- Amendment 4: Provider Bridges".

[i.13] IEEE 802.1ah™: "IEEE Standard for Local and metropolitan area networks -- Virtual Bridged Local Area Networks -- Amendment 7: Provider Backbone Bridges".

[i.14] IETF RFC 3135: "Performance Enhancing Proxies Intended to Mitigate Link-Related Degradations".

[i.15] ETSI TS 122 261: "5G; Service requirements for the 5G system (3GPP TS 22.261)".

[i.16] ETSI TS 123 501: "5G; System architecture for the 5G System (5GS) (3GPP TS 23.501)".

[i.17] ETSI TS 101 545-1: "Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 1: Overview and System Level specification".

[i.18] Void.

[i.19] ETSI TS 138 104: "5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104)".

[i.20] ETSI TS 138 101-5: "5G; NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements (3GPP TS 38.101-5)".

[i.21] 3GPP R1-2005311: "Considerations on PAPR requirements for NR NTN downlink transmission", Thales.

[i.22] ETSI TS 138 101-2 (V18.0.0): "5G; NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone (3GPP TS 38.101-2 version 18.8.0 Release 18)".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

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

ARQ	Automatic ReQuest
BAP	Backhaul Adaptation Protocol
BHTP	Beam Hopping Time Plan
BTP	Burst Time Plan
CMT	Correction Message Table
CSI	Channel State Information
DL	Down Link
DVB	Digital Video Broadcasting
FDD	Frequency Division Duplexing
GEO	Geostationary
GSE	Generic Stream Encapsulation
HARQ	Hybrid Automatic ReQuest

IBO	Input Back-Off
LLC	Logical Link Control
MAC	Medium Access Control
NCR	Network Clock Reference
NR	New Radio
OBO	Output Back-Off
PDCP	Packet Data Convergence Protocol
PEP	Performance-Enhancing Proxy
PRB	Physical Resource Block
PTRS	Phase Tracking Reference Signal
RLC	Radio Link Control
RLE	Return Link Encapsulation
SCS	Sub Carrier Spacing
SDAP	Service Data Adaptation Protocol
TIM	Terminal Information Message
Tput	Throughput
UL	Up Link

4 DVB and NR Radio protocols for SatCom

4.1 General characteristics of the radio protocols

Table 1 provides in synthetic table comparing the radio protocol stacks of both radio protocols: DVB-S2x/DVB-RCS2 and 3GPP NR with NTN enhancements.

Table 1: Protocol stacks of the candidate Radio protocols for the service link

	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
Sources	DVB forum. Published via ETSI TC BROADCAST. Down-link (DL): ETSI EN 302 307-1 [i.1] & 2 [i.2]. Uplink (UL): ETSI EN 301 545-2 [i.3].	www.3gpp.org Pre-standard: 3GPP TR 38.811 [i.7] & 3GPP TR 38.821 [i.6]. Standard: 3GPP TS 38.XXX series with Change Request defined by 3GPP work items "NR_NTN_solutions", "NR_NTN_enh" and "NR_NTN_ph3".
Physical layer (Waveform)	Down-link (DL): M-ary APSK TDM (S2x). Uplink (UL): M-ary PSK, 16QAM or CPM MF-TDMA (RCS2).	Down-link (DL): M-ary QAM CP-OFDM. Uplink (UL): M-ary QAM CP-OFDM or DFT-s-OFDM.
Access layer	User plane: MAC (Medium Access Control), LLC (Logical Link Control). Downlink: GSE (Generic Stream Encapsulation). Uplink: RLE (Return Link Encapsulation).	User plane: MAC, Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), Service Data Adaptation Protocol (SDAP). Control plane: RRC, PDCP, RLC, MAC and PHY sub-layers (terminated in UE and gNB); NAS protocol (terminated in the UE and the AMF).
Network layer	IPv4/IPv6. For backhaul: IEEE 802.1ad [i.12] / 802.1ah [i.13].	IPv4/IPv6. For backhaul: Backhaul Adaptation Protocol (BAP).
Transport layer	TCP, UDP, Performance Enhancing Proxy (PEP - IETF RFC 3135 [i.14]) is possible to mitigate latency with GEO satellites.	TCP, UDP, Performance Enhancing Proxy (PEP - IETF RFC 3135 [i.14]) is possible to mitigate latency with GEO satellites only.

Overall both protocols feature a similar stack structure. However, NR has been designed to optimize mobile broadband and low latency communications, while DVB has been designed for fixed broadband communications re-using the DVB-S2x video broadcast channel.

This leads to some differences between the radio protocols with respect to a number of key technical operational, functional, performance as well as non-technical requirements as identified in the next paragraphs.

Although NR can operate in FR1 (frequency range) 410 MHz to 7 125 MHz, FR2 (24 250 MHz to 52 600 MHz) and soon in frequency bands beyond 52,6 GHz which are being studied in 3GPP Release 17, the comparison below will be mainly focused on Ku and Ka band Satcoms since DVB applies to bands allocated to satellite services above 3,4 GHz.

4.2 Functional aspects

Table 2 hereunder compares both radio protocols with respect to different functional criteria.

Table 2: Functional characteristics of DVB-S2x/DVB-RCS2 and of 3GPP NR with NTN enhancements

	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
QoS management	Multi-CoS specific to SatCom.	Multi-CoS: 3GPP defined 5QI classes (see ETSI TS 122 261 [i.15] and ETSI TS 123 501 [i.16]).
Terminal states from radio access point of view once registered	(Not) Connected mode.	Idle, Inactive, Connected mode.
Terminal mobility	Connected mode (hand-over).	Idle and inactive mode (cell (re)selection) connected mode (hand-over).
Hand-over	Make before break (with dual reception chain) and break before make supported.	Make before break supported (with single reception chain).
Data transmission principles	DL: DVB-S2X: Continuous transmission of medium to large data blocks (FECFrame of typically 64 800 bits). UL: DVB-RCS2: Discontinuous transmission of small to medium data blocks (Burst length: [304 bits; 4 792 bits]).	DL & UL: Discontinuous or continuous transmission of small to medium data blocks (Code-block size range dependent [24 bits; 8 424 bits], see ETSI TS 138 214 [i.4]).
Contention channel	For initial access. For short data transmission (CRDSA Access with replicate suppression).	1) During initial access: Contention based: UEs randomly select preamble, More than 1 UE may select same preamble (collision). 2) For hand-over: Non-contention based: gNB dedicates preamble to UE, No collision possible. 3) For short burst transmission: grant free access may be considered as part of a future release.
System architecture context	The access network is designed to connect to the IP network.	The 5G NR protocol is part of a 3GPP defined system architecture including 5GC, NG-RAN and UE, API interfaces to 3rd party service providers, interface to network management system.
Inter system mobility (with 4G/5G system)	No.	Natively supported.
Support of 5G Core network	Via an Inter Working Function. DVB forum plans to define this feature.	Natively supported.
Multi connectivity satellite / 5G cellular access	No.	At core network level (Traffic Steering Switching Splitting). At radio access level (to be defined in future 3GPP releases).
Multi connectivity NGSO satellite / GEO satellite access	Possibly at service level through proprietary scheme.	At core network level (Traffic Steering Switching Splitting). At radio access level (to be defined in future 3GPP releases).
Terminal Location service	Not supported.	embedded GNSS receiver in the UE + other network based methods.
Use of GNSS for operation	Not necessary.	Yes.
Trusted location of terminal (i.e. network verified/provided)	Not supported.	RAN-based NTN NR positioning solutions via 3GPP defined LCS framework for LEO.
Reliability (see note)	Yes with automatic request at access layer.	Yes with automatic request at both physical (Hybrid Automatic Repeat Request = HARQ) and access layer RLC/PDCP (Automatic Repeat Request = ARQ).

	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
Energy saving	No scheme defined in the standard. Proprietary scheme can be implemented.	Idle and inactive mode defined in the standard with all the radio protocol signalling. Management aspects of RAN and CN elements are also defined in the standard including all the related metrics (at Network side and UE side).
Synchronization	DL: Continuous synchronization except in beam hoping mode. UL: Burst synchronization.	DL/UL: Burst synchronization in DL and Timing Advance (TA) mechanism for UL synchronization.
Network slicing	Not supported in the standard. However, a satellite radio link (hub - terminal) can be statically configured to support VPNs that can be considered as slices. Dynamic control of radio resources to support the different slices can be achieved through proprietary implementation and appropriate interface exposure.	E2E network slicing across RAN is natively supported. Support of dynamic control of radio resources to support the different slices.
Cellular backhaul service	Support with static and quasi dynamic control of the backhaul connection irrespective of the traffic variation of the connection. Backhauling service may be implemented by IEEE 802.1ad [i.12] / 802.1ah [i.13] technics. Requires specific mapping of 3GPP QoS to DVB QoS.	Support with dynamic control of the backhaul connection in terms of Radio Resource Management adapted to the traffic variation of the connection. Support the 5G security architecture and the 3GPP defined QoS framework.
Spectrum sharing (Adjacent channel coexistence) of SatCom with terrestrial system (Mobile, microwave links)	Un coordinated only approach between independent satcom and the terrestrial systems.	Through uncoordinated or coordinated approach between satcom and the terrestrial systems. The coordinated approach can leverage existing techniques used for the spectrum coexistence between Macro and Femto cells.
Security framework	Security aspects are described in ETSI TS 101 545-1 [i.17] and ETSI TR 101 545-4 [i.10] Guidelines (DVB-RCS2). In practice the security framework of DVB system is proprietary and specific for each SatCom vendor. It can be adapted to meet specific European requirements.	3GPP has specified a 5G security architecture supporting user authentication, secured communications. Leveraging this 5G security framework, further additional security features can be developed to meet specific European requirements.
NOTE: Reliability is defined in ETSI TS 122 261 [i.15] as "in the context of network layer packet transmissions, percentage value of the amount of sent network layer packets successfully delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets". The relation of communication service availability and reliability is explained in Annex C (informative) of the same document.		

Compared to DVB-S2x/RCS2, the NR protocol is best suited to support:

- mobility procedures and energy saving features at both idle and connected modes;
- slicing including at RAN level;
- QoS management in 5G system including RAN and core network;
- mobility/multi connectivity across satellite/cellular access technology though integration of satellite networks in 5G system at different levels including RAN;
- backhaul service thanks to dynamic control of radio resources and the integrity of the 5G E2E security framework.

Beam hopping, both NR and DVB can in theory support Traffic-Driven Beam Hopping capability on the downlink with Beam Hopping Time Plan (BHTP):

- for DVB-S2x: See ETSI EN 302 307-1 [i.18];
- for NR, the flexibility of radio resource block allocation in both time and frequency domain and bandwidth part adaptations can be used to implement an equivalent beam hopping scheme.

4.3 Operational aspects

Table 3 hereunder compares both radio protocols with respect to operational criteria.

Table 3: Operational characteristics of DVB-S2x/DVB-RCS2 and of 3GPP NR with NTN enhancements

	DVB-S2x/RCS2	**3GPP NR radio protocol with NTN enhancements**
Spectrum supported	In theory all bands allocated to satellite services above 3,4 GHz.	FR1: (frequency range) 410 - 7 125 MHz. FR2: 24 250 - 52 600 MHz + frequency bands beyond 52,6 GHz are being studied in 3GPP Release 17.
Space segment supported	GEO and NGSO.	GEO and NGSO.
Min channel bandwidth requirements (DL/UL) for traffic	DL: 1 MHz carrier. UL: 64 kHz carrier in practice.	DL: 5 MHz in FR1, 50 MHz for FR2. UL: 5 MHz in FR1, 50 MHz for FR2. For UL transmissions, minimum size is one physical resource block (PRB, bandwidth 12* Subcarrier Spacing = 12* [15, 30, 60, 120 kHz]).
Min log-on burst signal bandwidth requirements (UL)	Same as carrier bandwidth.	1,08 MHz with 1,25 kHz SCS (FR1, Long PRACH formats). 8,64 MHz with 60 kHz SCS (FR2, Short PRACH formats). 17,28 MHz with 120 kHz SCS (FR2, Short PRACH formats).
Max channel bandwidth capability	DL: 500 MHz in practice (state of the art). UL: 167 MHz as per standard. Higher channel bandwidth is possible on DL only through channel bonding scheme.	DL & UL: 100 MHz in FR1, 400 MHz in FR2. Multiple channels (set of sub- carriers can be aggregated to achieve up to 6,4 GHz of transmission bandwidth through carrier aggregation scheme.
Duplex mode supported	FDD. TDD made possible with DVB-S2X Beam Hopping and RCS2 (though not defined as such in the technical specifications).	FDD and TDD.
Radio resource allocation flexibility	DL: Frame structure dependent on symbol rate hence creating variable size of data blocks. One frame can be allocated to several UEs. UL: Single frame is allocated to one UE. Allocation can be volume or rate based.	DL & UL: Allocation per UE is one PRB at a time or on a continuous periodical basis.
Min radio resource granularity assigned by the scheduler to a UE	On DL: typically a normal FECFrame of [64 800 bits], but also possible a short FECFrame [16 200 bits]. On UL: very short bursts of 266 symbols (QPSK 5/6 to 16QAM 5/6).	On both DL & UL: Min radio resource corresponds to one PRB (Physical Resource Block) mapped over 12 sub-carriers. The slot duration is 14 OFDM symbols and depends on Sub Carrier Spacing (SCS) configuration (1 ms with 15 kHz sub-carrier spacing; 0,250 ms with 60 kHz SCS, 0,125 ms with 120 kHz sub-carrier spacing). 1 frame is always 1 ms duration and the number of slot per frame depends on SCS. The useful OFDM symbol size is inversely proportional with the SCS.

	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
Radio resource allocation efficiency	DL: Combination of Multi UE allocation and ACM scheme applied to one BB frame create the risk of resource waste since some BB frames are not usable by all UEs. UL: High risk of mismatch between allocated resource and traffic load creating waste of resource usage.	DL/UL: The granularity can be extremely small (On the order of 1 symbol) that risk of mismatch between allocated resource and traffic load creating waste of resource usage is low.
Radio resource management flexibility	Beam hoping **and** fractional frequency re-use supported.	Beam hoping **and** fractional frequency re-use supported.
Robustness to payload's phase noise	DL: phase noise can be tracked using pilot symbols in case of continuous transmission. For burst transmission (beam hoping), super framing structure help to handle phase noise and synchro issues. UL: phase noise can be tracked using pilot symbols.	Configurable Phase Tracking Reference Signal (PTRS) is a low density pilot sequence sent at regular time interval, it used to enable tracking of phase noise in both UL/DL.
Robustness to the payload's Group Delay	Sensitive for carriers with hundreds of Mega Symbol per seconds partially mitigated by wide-band equalizers.	Not sensitive.

Both radio protocols are able to support LEO and GEO systems operating in Ku and Ka bands and are able to support the same operational constraints.

Frequency Division Duplexing (FDD) mode is required by Regulations (space-earth & earth-space paired bands allocated).

4.4 General performance aspects

Table 4 hereunder compares both radio protocols with respect to different performance criteria.

Table 4: Performance characteristics of DVB-S2x/DVB-RCS2 and of 3GPP NR with NTN enhancements

	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
PAPR on UL (at terminal level)	Reference performance which is based on the 20 % roll-off as per standard.	3GPP defines SC-FDMA (DFT-s-OFDM) mode for UL. Standard assumes 2,5 % of guard band (ETSI TS 138 104 [i.19] and ETSI TS 138 101 [i.20]). In terms of OBO, ETSI has demonstrated that NR Uplink performs comparably to DVB-RCS2 (see ETSI TR 103 297 [i.11] "SC-FDMA based radio waveform technology for Ku/Ka band satellite service".
PAPR on DL (at satellite level)	Mono carrier per amplifier: ~0 dB in QPSK (for broadcast payload) => not relevant for broadband. Multi carrier (> 3) per amplifier/active antenna: See note 1.	See note 1.
Overhead due to access layer in user plane (number of UE dependent)	DL: between 2 and 4 % (first order) mainly due to allocation tables + to a lower extent GSE encapsulation. UL: 2,1 % to 3,93 % mainly due to RLE encapsulation.	DL & UL: up to 4 % (due to MAC, RLC, PDCP + control plane signalling).

	DVB-S2x/RCS2	**3GPP NR radio protocol with NTN enhancements**
Overhead due to physical layer (modulation and coding dependent)	DL: 5 % to 10 % (main due to Roll off and to a lower extent Physical Layer framing including CRC). UL: up to 20 % (main due to Roll off and to a lower extent guard times and CRC).	Depending on Frequency Range: DL: Up to 18 % (mainly due to SSB, DL reference signals and DCI signalling). Note that the DL overhead can be optimized to 8,25 % to 12 % (through configuration of the reference signals and related MIMO layers). UL: Up to 10 % (Mainly due to PRACH, Sounding reference signal and demodulation reference signal).
Min spectral efficiency/Max modcod	DL: 0,1 bit/symbol @ BPSK-S 1/5 SF5 (VL-SNR mode for traffic). UL: 0,25 bit/symbol @ BPSK 1/3 (for traffic). UL: 0,02 bit/symbol @ π/2 BPSK with code rate 1/3 and SF 16.	DL: From 0,0586 bit/symbol @ QPSK 30/1 024 (for traffic). UL: From 0,0586 bit/symbol @ π/2-BPSK 30/1 024 or QPSK 30/1 024 (for traffic).
Highest spectral efficiency (and related modcod) but link budget dependent	DL: Up to 5,9 bits/symbol @ 256APSK 135/180 (also called 3/4). UL: Up to 3 bits/symbol @ 16 QAM 5/6.	DL: Up to 7,4063 bits/symbol @ 256QAM 948/1 024. UL: Up to 5,5547 bits/symbol @ 64QAM 948/1 024.
User plane latency (note 2)	DL: 7ms (at least 100 MHz bandwidth). UL:1ms (at least 5 MHz bandwidth).	DL & UL: < 4 ms (at least 5 MHz bandwidth) for eMBB service category Latencies depend on the selected QoS classes (see ETSI TS 123 501 [i.16]).
Control plane latency (note 2)	Not applicable.	10 ms.
Throughput versus SNR	Comparable performances can be expected thanks to similar coding techniques (LDPC based for the traffic) for a given error rate.	
Min required SNR performance	ModCod type and frame type (2 options) dependent. Target PER is 10E-5 for typically SatCom operation.	ModCod, Transport block size, HARQ, pilot density configuration, 5QI (target BLER) dependent.
Min Signal to Noise Ratio for synchronization on DL	DVB-S2X supports down to -9,90 dB (VL-SNR: Very Low SNR). (Makes use of specific π/2-BPSK MODCOD).	SNR = -9,20 dB (on PSS/SSS burst).
Min Signal to Noise Ratio for traffic on DL	DVB-S2X supports down to -9,90 dB @ BPSK-S 1/5 (VL-SNR: Very Low SNR) for FER 1E-5 (AWGN condition). See table 20c in clause "Error performance" of ETSI EN 302 307-1 [i.2]. SNR = -2,85 dB @QPSK 2/9 for FER 1E-5 (AWGN condition).	SNR = -12,2 dB @ QPSK 30/1 024 and for BLER = 1E-02 or 1 %. Lower BLER can be achieved thanks to HARQ.
Min Signal to Noise Ratio for log on burst on UL (initial access)	SNR = -0,27dB Es/N0 @FER 1E-3 (AWGN condition). SNR = -14 dB @BPSK 1/3 SF=16 for PER = 1E-05 and under AWGN Ideal synchronization. Possible lower SNR with spreading down to factor of 16.	PRACH: -8,5 dB @false detection 1E-3.
Min Signal to Noise Ratio for traffic on UL	SNR = -3,51 dB @BPSK 1/3, for PER = 1E-05 and under AWGN Ideal synchronization. SNR = -0,80 dB @QPSK 1/3, for PER = 1E-03 and AWGN channel. SNR = -2,35 dB @QPSK 1/3, for PER = 1E-07 and under AWGN channel. Possible lower SNR with spreading down to factor of 16. SNR = -11 dB @BPSK 1/3 SF = 8 for PER = 1E-05 and under AWGN Ideal synchronization. SNR = -14 dB @BPSK 1/3 SF = 16 for PER = 1E-05 and under AWGN Ideal synchronization .	SNR = -12,2 dB @ QPSK 30/1 024 and for BLER = 1E-02 or 1 %. Using an even more robust modcod, a lower SNR can be achieved: -13 dB @ π/2-BPSK 30/1 024 (with precoding enabled) and for BLER = 1E-04 or 0,01 % (for both control and data). Lower BLER can be achieved thanks to HARQ, at the expense of the throughput.

	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
NOTE 1: In 3GPP R1-2005311 [i.21]. NOTE 2: User plane latency refers to the time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor Base Station reception is restricted by DRX. Scheduling delay is excluded. Control plane latency refers to the time to move from a battery efficient state (e.g. IDLE) to start of continuous data transfer (e.g. ACTIVE).		

Compared to DVB-S2x/RCS2, the NR protocol performs slightly worse on the DL and slightly better on the UL in terms of overhead at both access and physical layer. Further assessment is need taking into account detailed use case (e.g. user traffic profile, number of UE served, mean spectral efficiency per beam, …).

In terms of link level degradation arising with PAPR, almost no performance degradation is expected on the UL if SC-FDMA is considered (see ETSI TR 103 297 [i.11]). As per DL, the performance degradation at low to moderate spectral efficiency is expected to be similar for satellite with multi carrier per amplifier/active antenna payload configuration.

4.5 Other aspects

Table 5 compares both radio protocols with respect to additional non-technical criteria.

Table 5: Respective non-technical characteristics of DVB-S2x/DVB-RCS2 and of 3GPP NR with NTN enhancements

Comparison criteria	DVB-S2x/RCS2	3GPP NR radio protocol with NTN enhancements
Multi-vendor interoperability	On a case by case basis. No interoperability tests are defined.	3GPP defined interoperability tests allowing multi vendors interoperability across the radio protocol as well as across several interface of the satellite enabled 5G system.
Support of national regulated services (e.g. lawful intercept, emergency calls, public warning, charging)	Implemented through proprietary scheme.	Yes (key requirements taken into account in the protocol design).
Forward compatibility towards B5G/6G	Can be defined (specific for each SatCom system) once the first specs on 6G will be available.	Natively supported.
Carbon footprint impact	No specific energy saving enabling features are defined in DVB specifications. Some proprietary schemes are typically implemented.	Leveraging a continuous effort of more than 20 years on enabling energy saving technology and features (at both UE and network infrastructure level) based on Life cycle assessment methodology/studies.

5 Link level performance comparison

5.1 Reference scenario description

The reference scenario is based on a single GSO satellite system offering broadband services through a multi-beam service coverage. The satellite payload is transparent in the sense that it does not have signal regeneration capabilities. The payload architecture on the service link is based on an active antenna.

Table 6: Summary of the reference scenario

Orbit Type	Payload Type	Frequency Plan		Waveform	
		FWD	**RTN**	**FWD**	**RTN**
GEO	Transparent multi-beam payload architecture based on active antenna (user link)	Ka band Feeder uplink: 27,5 - 29,5 GHz Service downlink: 19,8 - 20,2 GHz	Ka band Service uplink: 29,6 - 30,0 GHz Feeder downlink: 17,7 - 19,7 GHz	DVB-S2X NR PDSCH	DVB-RCS2 NR PUSCH

5.2 Channel and impairments models for LLS

5.2.1 Frequency Plan

It is assumed as baseline that the feeder links and service links are all operated in Ka band:

- Feeder link frequency plan:
    - Uplink: 27,5 GHz to 29,5 GHz
    - Downlink: 17,7 GHz to 19,7 GHz
- Service link frequency plan:
    - Uplink: 29,6 GHz to 30,0 GHz
    - Downlink: 19,8 GHz to 20,2 GHz

5.2.2 Propagation channel

5.2.2.0 General

For the link level simulations, the propagation channel on both service and feeder links is considered as a LOS, non-frequency selective and non-time variant channel. This is justified by the assumption related to the fixed directive terminal type considered in the study.

5.2.2.1 Doppler

The Doppler impact in the frequency and time domain has been considered negligible in the scenarios under study since the terminals are considered fixed on the ground and the GEO satellite on-orbit velocity is usually inferior to 1,5 m/s.

5.2.3 Impairments

5.2.3.1 Gain flatness and group delay

The end-to-end profiles to be taken into consideration for the FWD and RTN links is obtained from the aggregation of three type of sub-profiles (linear, parabolic and sinusoidal ripple) defined in Table 7.

Table 7: Gain flatness and group delay profiles

Profiles	Gain flatness profile	Group delay profile
Linear f_0: channel center frequency	GF = $\frac{\Delta G}{\Delta F} \times (f - f_0)$ [dB] $\frac{\Delta G}{\Delta F}$ = [0,25 dB/MHz] (worst case local slope) $\frac{\Delta G}{\Delta F}$ = [-0,0085 dB/MHz] (typical slope observed on channel bandwidth)	GD = $\frac{\Delta T}{\Delta F} * (f - f_0)$ [ns] $\frac{\Delta T}{\Delta F}$ = [2 ns/MHz] (worst case local slope) $\frac{\Delta T}{\Delta F}$ = [0,0080 ns/MHz] (typical slope observed on channel bandwidth)
Parabolic f_0 :channel center frequency B: channel bandwidth	GF = $4\Delta G \times (f - f_0)^2/B^2$ [dB] $\Delta G = [2{,}4\ \mathrm{dB}]$ for B = 500 MHz	GD = $4\Delta T \times (f - f_0)^2/B^2$[ns] $\Delta T = [20\ \mathrm{ns}]$ for B = 500 MHz
Sinusoidal ripple Δf: ripple period f_0 : channel center frequency	GF= $\Delta G\ \cos(\frac{2\pi(f-f_0)}{\Delta f})$ [dB] within 90 % of the band ΔG =[0,3 dB] Δf = 15 MHz; 30 MHz; 75 MHz	GD=$\Delta T\ \cos(\frac{2\pi(f-f_0)}{\Delta f})$ [ns] within 90 % of the band ΔT= [1,5 ns] Δf = 15 MHz; 30 MHz; 75 MHz

From Table 7, several end-to-end filter profiles can be calculated and considered as reference for link level simulations.

GF GD profile A

A 500 MHz channel bandwidth with a central frequency f0 = 0 is considered.

The end-to-end gain response is derived as follows:

- The gain response includes:
  - A parabolic response, with minimum relative gain of -2,4 dB at the edge of the channel.
  - A sinusoidal ripple with 0,3 dB amplitude and 30 MHz period is added within 90 % of the bandwidth.
  - A smooth slope of -0,0085 dB/MHz within all the channel bandwidth.
- The total response is the addition (in dB) of above 3 contributions.

The end-to-end group delay response is derived as follows:

- The group delay response includes:
  - A parabolic response, with maximum value of 20 ns at the edge of the channel.
  - A sinusoidal ripple with 1,5 ns amplitude and 30 MHz period is added within 90 % of the bandwidth.
  - A smooth slope of 0,0080 ns/MHz within all the channel bandwidth.
- The total response is the addition (in ns) of above 3 contributions.

This GF GD profile A has been defined in coherence with the baseline frequency plan.

The resulting end-to-end GF GD profile is presented in Figure 1 and Figure 2.

For the purpose of profile illustration, the following normalization have been assumed:

- The response is normalized so that the maximum gain is 0 dB.
- The response is normalized so that the minimum group delay is 0 ns.

This profile can be considered representative for both FWD and RTN links.

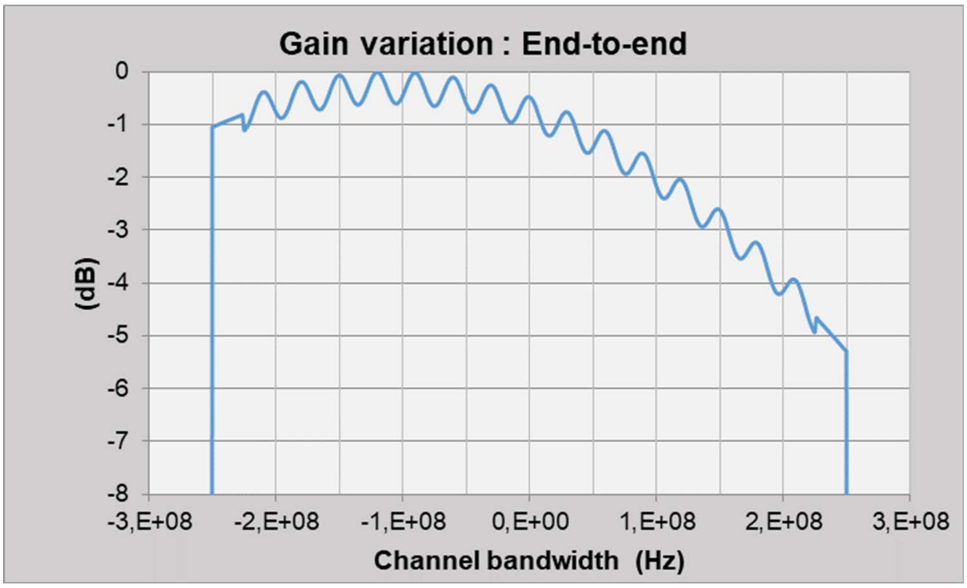

Figure 1: Aggregated gain variation for Profile A

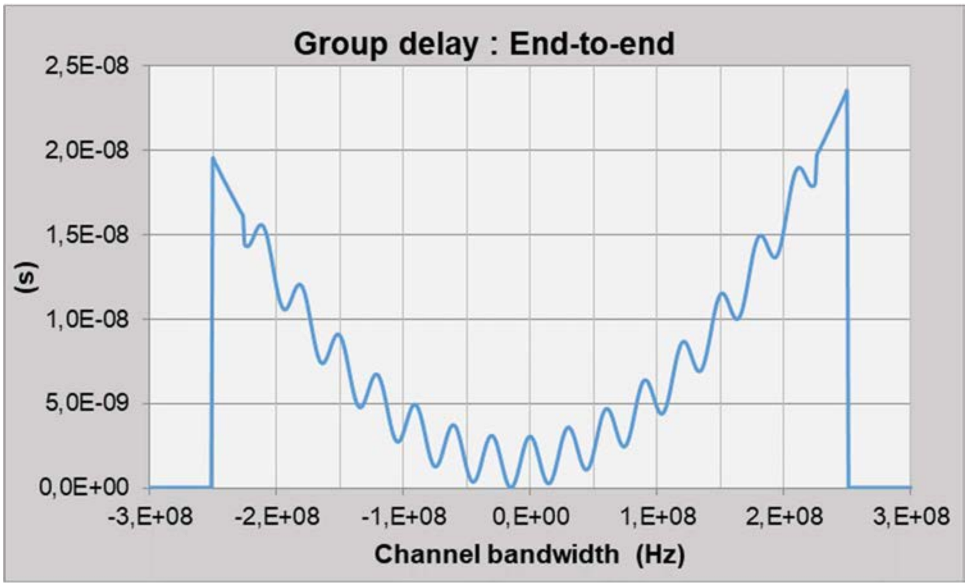

Figure 2: Aggregated group delay for Profile A

In theory, the carrier frequency, noted f_c, may be located anywhere within the channel bandwidth. Several configurations for f_c values can be defined:

- Typical case: $f_c = f_0$;
- Worst case: $f_c = f_0 + B/2 - b/2$ where B denotes the channel bandwidth and b denotes the carrier bandwidth.

5.2.3.2 Phase Noise

The phase noise profiles presented in Table 8 and Table 9 have been defined in coherence with the baseline frequency plan.

Table 8: Single sideband aggregated FWD phase noise profile

Offset from Carrier Frequency	Forward link (dBc/Hz)
10 Hz	NA
100 Hz	-25
1 kHz	-50
10 kHz	-73
100 kHz	-92
1 MHz	-102
10 MHz	-113
100 MHz	-116
NOTE: The values proposed in the table above have been obtained from [i.1], Table H.1.	

Table 9: Single sideband aggregated RTN phase noise profile

Offset from Carrier Frequency	Return link (dBc/Hz)
10 Hz	-36
100 Hz	-58
1 kHz	-69
10 kHz	-79
100 kHz	-87
1 MHz	-104
10 MHz	-109
100 MHz	-109

5.2.4 Non Linear Amplifier

5.2.4.0 General

The memory effects associated to the nonlinear amplification are not modelled in the present document.

5.2.4.1 Satellite Amplifier

The amplifier model used as reference to simulate the NL amplification impact is presented in Table 10.

Table 10: AM/AM and AM/PM CW amplifier response for Ka-Band amplifier model TYPE L-TWTA with active antenna

IBO (dB)	OBO dB	Phase [deg]
24,0000	19,4586	0,0000
23,0000	18,4133	0,0494
22,0000	17,4173	0,0472
21,0000	16,3591	0,0039
20,0000	15,3424	0,0360
19,0000	14,2954	0,1162
18,0000	13,2556	0,3809
17,0000	12,1685	0,6286
16,0000	11,0851	1,0183
15,0000	10,0238	1,7616
14,0000	8,9305	2,4184
13,0000	7,8286	3,0863
12,0000	6,7142	3,5320
11,0000	5,6247	3,9221
10,0000	4,5469	3,6716
9,0000	3,5644	3,3587
8,0000	2,6731	2,5310
7,0000	1,9102	1,2108
6,0000	1,2843	-0,2491
5,0000	0,7780	-1,7629
4,0000	0,4070	-3,3148
3,0000	0,1673	-5,0580
2,0000	0,0383	-6,3400
1,0000	-0,0060	-7,5836
0,0000	0,0000	-8,2804
-1,0000	0,0385	-8,7388
-2,0000	0,0874	-8,9858
-3,0000	0,1332	-9,0843
-4,0000	0,1723	-9,0998
-5,0000	0,2042	-9,1005
-6,0000	0,2292	-9,1417
-7,0000	0,2485	-9,2263
-8,0000	0,2636	-9,3428
-9,0000	0,2756	-9,4911
-10,0000	0,2854	-9,6615
-11,0000	0,2935	-9,7920
-12,0000	0,3002	-9,8313
-13,0000	0,3058	-9,8170
-14,0000	0,3101	-9,8128
-15,0000	0,3128	-9,8984
-16,0000	0,3135	-10,1349
NOTE: The amplifier saturation power: 70 W. The Amplifier Bandwidth: 2 GHz.		

5.2.4.2 Terminal Amplifier

To derive a terminal HPA model, the specifications of Ka-Band GaAs Amplifier are proposed. This amplifier bandwidth is 27 - 33,5 GHz. The saturated Output Power is about 33 dBm. The associated AM/AM AM/PM models are presented in Table 11.

Table 11: AM/AM and AM/PM CW amplifier response for Ka-Band UT amplifier model TYPE GaAs (@29,5 GHz)

IBO [dB]	OBO [dB]	Phase [deg]
40,35	40	0
39,35	39	0
38,35	38	0
37,35	37	0
36,35	36	0
35,35	35	0
34,35	34	0
33,35	33	0
32,35	32	0
31,35	31	0
30,35	30	0
29,35	29	0
28,35	28	0
27,35	27	0
26,35	26	0
25,35	25	0
24,35	24	0
23,35	23	0
22,35	22	0,023
21,35	21	0,046
20,35	20,02	0,092
19,35	19,02	0,161
18,35	18,02	0,23
17,35	17,01	0,299
16,35	16	0,3795
15,35	14,99	0,46
14,35	13,98	0,56
13,35	12,95	0,69
12,35	11,92	0,85
11,35	10,89	1
10,35	9,84	1,2
9,35	8,79	0,52
8,35	7,74	2
7,35	6,7	2,5
6,35	5,66	3,1
5,35	4,64	3,9
4,35	3,65	5
3,35	2,7	6,15
2,35	1,81	7,4
1,35	1	8,2
0,35	0,29	9,2
-0,65	-0,31	10,2
-1,65	-0,75	11,8
-2,65	-1,01	13
-3,65	-1,07	13,5

5.2.5 Channel types definition

The different channel types considered in the study are defined in Table 12.

Table 12: Channel types definition

Channel Types	**Impairments**			**Non Linear Amplifier**		**Propagation Channel**
	Phase Noise		**Gain Flatness & Group Delay**			
AWGN	No Phase Noise		No Gain Flatness and Group Delay Variations	No amplifier		Propagation channel: LOS, non-frequency selective and non-time variant No Doppler AWGN
Type A	FWD	RTN	Gain Flatness Group Delay Profile A: • Channel Bandwidth B = 500 MHz • Carrier Frequency Location $f_c = f_0$ with $f_0 = 0$ Hz	FWD	RTN	Propagation channel: LOS, non-frequency selective and non-time variant No Doppler AWGN
	Table 8	Table 9		Table 10 Working OBO configuration specified in SLS section (see clause 6.3)	Table 11 Working configuration specified in SLS section (see clause 6.3)	

5.3 NR PDSCH/PUSCH and DVB-S2X/DVB-RCS2 waveform configurations

5.3.1 DVB-S2X waveform configurations

Table 13: DVB-S2X Waveform and Receiver Configuration

DVB-S2X waveform and receiver configuration	
Parameter name	**Parameter value / description**
Carrier bandwidth	210 MHz
Roll-Off	5 %
FECFRAME size	Normal
Pilot	Enabled
Number of maximal LDPC decoder iterations	50
MODCOD	See Table 14
Receiver architecture	Continuous Frame Demodulation Every frame is used to feed loop based acquisition and tracking algorithms.

Table 14: Selected DVBS2X MODCOD list

Canonical MODCOD name	Modulation	Code rate	Spectral efficiency [bit/symbol]
QPSK_2s9	QPSK	2/9	0,46
QPSK_1s4	QPSK	1/4	0,49
QPSK_13s45	QPSK	13/45	0,57
QPSK_1_3	QPSK	1/3	0,66
QPSK_2s5	QPSK	2/5	0,79
QPSK_9s20	QPSK	9/20	0,89
QPSK_1s2	QPSK	1/2	0,99
QPSK_11s20	QPSK	11/20	1,09
QPSK_3s5	QPSK	3/5	1,19
QPSK_2s3	QPSK	2/3	1,33
QPSK_3s4	QPSK	3/4	1,49
QPSK_4s5	QPSK	4/5	1,59
QPSK_5s6	QPSK	5/6	1,66
8PSK_3s5	8PSK	3/5	1,79
8PSK_23s36	8PSK	23/36	1,91
8PSK_2s3	8PSK	2/3	1,99
8PSK_25s36	8PSK	25/36	2,07
8PSK_13s18	8PSK	13/18	2,16
16APSK_26s45	16APSK	26/45	2,30
16APSK_3s5	16APSK	3/5	2,39
16APSK_28s45	16APSK	28/45	2,48
16APSK_23s36	16APSK	23/36	2,54
16APSK_2s3	16APSK	2/3	2,66
16APSK_25s36	16APSK	25/36	2,77
16APSK_13s18	16APSK	13/18	2,88
16APSK_3s4	16APSK	3/4	2,99
16APSK_7s9	16APSK	7/9	3,10
16APSK_4s5	16APSK	4/5	3,19
16APSK_5s6	16APSK	5/6	3,32
32APSK_32s45	32APSK	32/45	3,54
32APSK_11s15	32APSK	11/15	3,65
32APSK_7s9	32APSK	7/9	3,87
NOTE 1: The modcod list proposed is a down selection from Table 1 in [i.1] and Table 13 in [i.2]. NOTE 2: The spectral efficiencies expressed in bits/symbol (also referred as MODCOD rates) are calculated taking into account only the BCH/LDPC effective code rate and the modulation order.			

5.3.2 DVB-RCS2 waveform configurations

Table 15: DVB-RCS2 Waveform and Receiver Configuration

Parameters	Values	Description
Burst Transmission Bandwidth	0,24 MHz 2,4 MHz 24 MHz	0,24 MHz is a typical value for LOGON and control transmissions. 2,4 MHz is a typical value for traffic transmissions. 24 MHz is a typical upper bound for traffic transmission bandwidth.
Roll-Off	20 %	Typical for DVB-RCS2 transmissions.
Max Turbo Decoder Iteration	8	To match the assumptions used to evaluate the DVB-RCS2 performance presented in clause 10.2.1 of [i.5].
Burst ID	-	See Table 16.
Receiver architecture	-	Slot per Slot Demodulation. Each slot is demodulated independently w/o knowledge about previous slots demodulation.

Table 16: Selected DVB-RCS2 reference waveform IDs

Waveform Id	Burst Length (symbols)	Payload length (bytes; symbols)	Mapping Scheme	Code-Rate	Spectral Efficiency (bits/symbol)
2	262	14; 168	QPSK	1/3	0,667
3	536	38; 456	QPSK	1/3	0,667
13	1 616	123; 1 476	QPSK	1/3	0,667
14	1 616	188; 1 504	QPSK	1/2	1,000
15	1 616	264; 1 584	QPSK	2/3	1,333
16	1 616	298; 1 590	QPSK	3/4	1,499
17	1 616	333; 1 599	QPSK	5/6	1,666
18	1 616	355; 1 420	8PSK	2/3	2,000
19	1 616	400; 1 423	8PSK	3/4	2,249
20	1 616	444; 1 422	8PSK	5/6	2,498
21	1 616	539; 1 438	16QAM	3/4	2,999
22	1 616	599; 1 438	16QAM	5/6	3,332

NOTE 1: The burst format selection is a down selection of the reference formats presented in Table A-1 from [i.3]. The waveform IDs 2 and 3 are selected to be representative of control and logon message transmissions. The rest of the waveform IDs are selected to be representative of traffic message transmissions.

NOTE 2: The spectral efficiencies are calculated taking into account only the code rate and the modulation order.

5.3.3 NR PDSCH waveform configurations

Table 17: NR PDSCH and receiver configuration

NR PDSCH configuration	
Parameter name	**Parameter value**
NR Carrier bandwidth	200 MHz
NR Duplex Mode	FDD
NRB	132
Subcarrier Spacing	120 kHz
HARQ	Disabled
PRB Set	See Table 19
Symbol Allocation	14 per slot
Mapping Type	A
VRB To PRB Interleaving	Disabled
Number of Layer	1
Number of TX Antennas	1
Number of RX Antennas	1
Number of Code Word per Transport Block	1
MCS Index	Table 18
Maximum LDPC Iteration Count	50
Receiver architecture	Slot per Slot Demodulation. Each slot is demodulated independently w/o knowledge about previous slots demodulation and periodical pilots (e.g. SSB, CSI-RS). This might lead to some implementation loss.

Table 18: Selected NR PDSCH MCS

MCS Index IMCS	Modulation Order Qm	Target code Rate R x [1024]	Spectral Efficiency [bit/symbol]
0	2	30	0,0586
1	2	40	0,0781
2	2	50	0,0977
3	2	64	0,1250
4	2	78	0,1523
5	2	99	0,1934
6	2	120	0,2344
7	2	157	0,3066
8	2	193	0,3770
9	2	251	0,4902
10	2	308	0,6016
11	2	379	0,7402
12	2	449	0,8770
13	2	526	1,0273
14	2	602	1,1758
15	4	340	1,3281
16	4	378	1,4766
17	4	434	1,6953
18	4	490	1,9141
19	4	553	2,1602
20	4	616	2,4063
21	6	438	2,5664
22	6	466	2,7305
23	6	517	3,0293
24	6	567	3,3223
25	6	616	3,6094
26	6	666	3,9023
27	6	719	4,2129
28	6	772	4,5234

NOTE 1: The modulation order and the target code rate proposed are extracted from Table 5.1.3.1-3 in [i.4].

NOTE 2: The spectral efficiencies presented are also extracted from Table 5.1.3.1-3 in [i.4]. They only reflect the performance of the coding scheme. Any other source of overhead has not been considered.

Contrary to DVBS2X frames which have the same size after FEC encoding in terms of transmitted bits, the number of PDSCH transmitted bits after encoding depends on:

- The frequency and time PDSCH allocations for this transmission (PRB set, symbol allocation within a slot, number of layers).
- The PDSCH configuration parameters which drive the number of REs allocated for data transmission within one PRB.
- The modulation and target code rate given by the MCS index considered for the DL transmission.

These elements can be used to derive the transport block size in terms of information bits which can be transmitted.

From there, the number of coded bits transmitted can be derived based on:

- The transport block size in terms of information bits.
- The rate matching operation.

As a consequence, the number of information bits and coded bits associated to a given PDSCH transmissions is not straightforward.

However, one can reasonably assume that, for broadband services in FR2, a large number of information bits can be transmitted in each transport block because the traffic is going to be dense and the number of UEs served by the scheduler per slot (= 0,125 ms) can be considered as relatively low. As a consequence, it is expected that large transport blocks will be used and code block segmentation will be performed.

In these conditions, the code block sizes can be expected to be at least equal to the maximum block size K_{cb} divided by 2 with:

- $K_{cb} = 8\ 448$ for LDPC base graph 1
- $K_{cb} = 3\ 840$ for LDPC base graph 2

LDPC base graph 2 is used if transport block size ≤ 292, or if transport block size ≤ 3 824 and coding rate ≤ 2/3, or if coding rate ≤ 1/4. Otherwise, LDPC base graph 1 is used.

Therefore, it is proposed to configure PDSCH allocation such that the transport block size is very close to $K_{cb}/2$ before channel coding. However, for the lowest MCS indexes (based on base graph 2) it is not possible to achieve a transport block size close to this value even when the 132 PRBs are allocated. As consequence, a lower code block size will be considered when required.

The PDSCH PRB set allocations and the associated code block sizes to be considered for each MCS index are presented in Table 19.

Table 19: MCS indexes, PRB Set allocations and Transport/Code Block size associations

MCS Index I_{MCS}	PDSCH PRB Set length [number of PRB]	PDSCH DMRS configuration	PDSCH PTRS configuration	Transport Block Size / Code Block Size [information bits]
0	132	0	0	1 224/1 240
1	132	0	0	1 608/1 624
2	123	0	0	1 928/1 944
3	96	0	0	1 928/1 944
4	79	0	0	1 928/1 944
5	63	0	0	1 928/1 944
6	52	0	0	1 928/1 944
7	40	0	0	1 928/1 944
8	32	0	0	1 928/1 944
9	25	0	0	1 928/1 944
10	45	0	0	4 224/4 248
11	37	0	0	4 224/4 248
12	31	0	0	4 224/4 248
13	27	0	0	4 352/4 376
14	23	0	0	4 224/4 248
15	21	0	0	4 352/4 376
16	19	0	0	4 352/4 376
17	16	0	0	4 224/4 248
18	15	0	0	4 480/4 504
19	13	0	0	4 352/4 376
20	12	0	0	4 480/4 504
21	11	0	0	4 352/4 376
22	10	0	0	4 224/4 248
23	9	0	0	4 224/4 248
24	9	0	0	4 608/4 632
25	8	0	0	4 480/4 504
26	7	0	0	4 224/4 248
27	7	0	0	4 608/4 632
28	6	0	0	4 224/4 248
NOTE 1: The transport block size is computed assuming a time domain allocation of 14 OFDM symbols per slot in accordance with Table 17. NOTE 2: In order to keep the transmit power constant from one MCS configuration to the other, the unused PRB can be stuffed with dummy symbols. NOTE 3: For each slot, the PRBs are allocated contiguously. The first allocated PRB index is defined from a uniform random discreet distribution ranging from 0 to NPRB - PRB Set length.				

Table 20: PDSCH DMRS Configuration 0

Parameters	Values
DMRS Type A Position	2
DMRS Length	1
DMRS Additional Position	0
DMRS Configuration Type	1
Num CDM Groups Without Data	1

Table 21: PDSCH PTRS Configuration 0

Parameters	Values
Enable PTRS	Enabled
Time Density	Not present when I_{MCS} < ptrs-MCS1 4 when ptrs-MCS1 ≤ I_{MCS} < ptrs-MCS2 2 when ptrs-MCS2 ≤ I_{MCS} < ptrs-MCS3 1 when ptrs-MCS3 ≤ I_{MCS} < ptrs-MCS4 The considered threshold values are 10, 15, 20 and 29 for ptrs-MCS1, ptrs-MCS2, ptrs-MCS3, and ptrs-MCS4, respectively.
Frequency Density	Not present when $N_{RB} < N_{RB0}$ 2 when $N_{RB0} \le N_{RB} < N_{RB1}$ 4 when $N_{RB1} \le N_{RB}$ The considered threshold values are 3 and 66 for N_{RB0} and N_{RB1}, respectively.

5.3.4 NR PUSCH waveform configurations

Numerology 2 was selected for the PUSCH configuration to achieve a reasonable CBS considering a transmission bandwidth of 2,8 MHz. This bandwidth is closest to the typical transmission bandwidth of DVB-RCS2 which is 2,4 MHz.

Table 22: NR PUSCH and receiver configuration

NR PUSCH configuration	
Parameter name	**Parameter value**
NR Carrier bandwidth	200 MHz
NR Duplex Mode	FDD
Subcarrier Spacing	60 kHz
NRB	264
HARQ	Disabled
Transform precoding	Enabled
PRB Set	4 and 40
Symbol Allocation	14 per slot
Mapping Type	A
Number of Layer	1
Number of TX Antennas	1
Number of RX Antennas	1
MCS Index	Table 23
Maximum LDPC Iteration Count	50
Receiver architecture	Slot per Slot Demodulation. Each slot is demodulated independently w/o knowledge about previous slots demodulation.

Table 23: Selected NR PUSCH MCS

MCS Index IMCS	Modulation Order Qm	Target code Rate R x [1024]	MCS rate
0	q	60/q	0,0586
1	q	80/q	0,0781
2	q	100/q	0,0977
3	q	128/q	0,1250
4	q	156/q	0,1523
5	q	198/q	0,1934
6	2	120	0,2344
7	2	157	0,3066
8	2	193	0,3770
9	2	251	0,4902
10	2	308	0,6016
11	2	379	0,7402
12	2	449	0,8770
13	2	526	1,0273
14	2	602	1,1758
15	2	679	1,3262
16	4	378	1,4766
17	4	434	1,6953
18	4	490	1,9141
19	4	553	2,1602
20	4	616	2,4063
21	4	658	2,5703
22	4	699	2,7305
23	4	772	3,0156
24	6	567	3,3223
25	6	616	3,6094
26	6	666	3,9023
27	6	772	4,5234

NOTE 1: The modulation order and the target code rate proposed are extracted from Table 6.1.4.1-2 in [i.4].
NOTE 2: The MCS rate presented are also extracted from Table 6.1.4.1-2 in [i.4]. They only reflect the performance of the target coding scheme. Any other source of overhead has not been considered.
NOTE 3: It can be assumed that higher layer parameter tp-pi2BPSK is not configured. Then $q = 2$ is assumed.

As a reminder, with NR PDSCH configuration, the allocation of PRBs varied for each MCS index. This approach aimed to maintain the transport block size around Kcb/2 for all MCS indexes. Regarding NR PUSCH configuration, all MCS indexes are allocated the same number of PRBs, resulting in a substantial amount of information bits in a transport block for the most efficient MCS indexes (see TBS in Table 24). In this case, segmentation is performed on the transport block to set the CBS between Kcb/2 and Kcb. The CBS of each MCS index is presented in Table 24.

Table 24: Code Block size of each NR PUSCH MCS Indexes

MCS Index	Allocated RB = 4		Allocated RB = 40	
	TBS	**CBS**	**TBS**	**CBS**
0	32	32	368	368
1	48	48	480	480
2	56	56	608	608
3	72	72	808	808
4	88	88	948	948
5	120	120	1 224	1 224
6	144	144	1 480	1 480
7	184	184	1 928	1 928
8	240	240	2 408	2 408
9	304	304	3 104	3 104
10	368	368	3 752	3 752
11	456	456	4 608	4 608
12	552	552	5 504	5 504
13	640	640	6 400	6 400
14	736	736	7 296	7 296
15	848	848	8 192	8 192
16	928	928	9 224	4 612
17	1 064	1 064	10 504	5 252
18	1 192	1 192	12 040	6 020
19	1 352	1 352	13 576	6 788
20	1 544	1 544	15 112	7 556
21	1 608	1 608	16 136	8 068
22	1 736	1 736	16 896	8 448
23	1 928	1 928	18 960	6 320
24	2 088	2 088	20 496	6 832
25	2 280	2 280	22 536	7 512
26	2 472	2 472	24 576	8 192
27	2 856	2 856	28 168	7 042

Table 25: PUSCH DMRS Configuration 0

Parameters	Values
DMRSTypeAPosition	2
DMRSLength	1
DMRSAdditionalPosition	0
DMRSConfigurationType	1

Table 26: PUSCH PTRS Configuration CONFIG 0

Parameters	Values
EnablePTRS	Enable
TimeDensity	2
Higher layer parameters sampleDensity	NRB0 = 0 NRB1 = 16 NRB2 = 24 NRB3 = 32 NRB4 = 64
NumPTRSSamples	See Table 27
NumPTRSGroups	See Table 27

Table 27: PT-RS group pattern as a function of scheduled bandwidth [i.4]

Scheduled bandwidth	Number of PT-RS groups	Number of samples per PT-RS group
NRB0 ≤ NRB < NRB1	2	2
NRB1 ≤ NRB < NRB2	2	4
NRB2 ≤ NRB < NRB3	4	2
NRB3 ≤ NRB < NRB4	4	4
NRB4 ≤ NRB	8	4

5.4 Link Level Simulation Results

5.4.1 Demodulation performance

5.4.1.0 General

In the comparison of the demodulation performance of both access technologies, two efficiency metrics are considered:

- the MODCOD/MCS Rate [bit/Symbol] which takes into account the modulation order and the effective coding rate;
- the spectral efficiency [bit/s/Hz] which takes also into account signalling overhead.

5.4.1.1 DVB-S2X

Table 28: DVB-S2X Demodulation performance

MODCOD	Waveform Configurations	Spectral efficiency [bits/symbol]	Spectral efficiency [bits/s/Hz]	Specified E_s/N_0 [dB] - Channel Type AWGN (notes 1, 2, 3 and 5)		E_s/N_0 [dB] - Channel Type AWGN (notes 1, 2 and 3)		E_s/N_0 [dB] - Channel Type A without Non Linear Amplifier (note 1)	
				FER = 1e-3	FER = 1e-5	FER = 1e-3	FER = 1e-5	FER = 1e-3	FER = 1e-5
QPSK_2s9	Table 16	0,46	0,40		-2,85	-2,88	-2,76	-1,99	-1,89
QPSK_1s4		0,49	0,45		-2,35	-2,47	-2,33	-1,62	-1,32
QPSK_13s45		0,57	0,52		-2,03	-2,06	-1,96	-1,22	-0,91
QPSK_1_3		0,66	0,60		-1,24	-1,28	-1,18	-0,57	-0,45
QPSK_2s5		0,79	0,72		-0,30	-0,45	-0,38	0,22	0,32
QPSK_9s20		0,89	0,81		0,22	0,18	0,24	0,80	0,89
QPSK_1s2		0,99	0,90		1,00	0,90	0,97	1,48	1,57
QPSK_11s20		1,09	0,99		1,45	1,40	1,46	1,95	2,04
QPSK_3s5		1,19	1,08		2,23	2,11	2,17	2,65	2,78
QPSK_2s3		1,33	1,21		3,10	3,05	3,10	3,55	3,65
QPSK_3s4		1,49	1,36		4,03	3,98	4,07	4,47	4,57
QPSK_4s5		1,59	1,45		4,68	4,62	4,70	5,10	5,20
QPSK_5s6		1,66	1,51		5,18	5,11	5,19	5,60	5,70
8PSK_3s5		1,79	1,63		5,50	5,43	5,50	6,00	6,12
8PSK_23s36		1,91	1,73		6,12	6,06	6,13	6,66	6,79
8PSK_2s3		1,99	1,81		6,62	6,49	6,60	7,06	7,31
8PSK_25s36		2,07	1,88		7,02	6,96	7,06	7,57	7,71
8PSK_13s18		2,16	1,96		7,49	7,34	7,43	8,07	8,22
16APSK_26s45		2,30	2,08		7,51	7,43	7,54	8,00	8,16
16APSK_3s5		2,39	2,16		7,80	7,72	7,79	8,34	8,51
16APSK_28s45		2,48	2,24		8,10	8,04	8,15	8,68	8,88
16APSK_23s36		2,54	2,30		8,38	8,31	8,39	8,97	9,21
16APSK_2s3		2,66	2,41		8,97	8,88	9,00	9,75	9,97
16APSK_25s36		2,77	2,51		9,27	9,14	9,27	9,97	10,27
16APSK_13s18		2,88	2,61		9,71	9,64	9,72	10,44	10,69
16APSK_3s4		2,99	2,71		10,21	10,12	10,19	10,97	11,24
16APSK_7s9		3,10	2,81		10,65	10,57	10,65	11,53	11,88
16APSK_4s5		3,19	2,89		11,03	10,93	11,00	11,84	12,12
16APSK_5s6		3,32	3,01		11,61	11,51	11,57	12,49	12,79
32APSK_32s45		3,54	3,21		11,75	11,69	11,76	12,93	13,43
32APSK_11s15		3,65	3,31		12,17	12,11	12,20	13,46	13,97
32APSK_7s9		3,87	3,51		13,05	12,96	13,04	14,75	15,53

MODCOD	Waveform Configurations	Spectral efficiency [bits/symbol]	Spectral efficiency [bits/s/Hz]	Specified E_s/N_0 [dB] - Channel Type AWGN (notes 1, 2, 3 and 5)		E_s/N_0 [dB] - Channel Type AWGN (notes 1, 2 and 3)		E_s/N_0 [dB] - Channel Type A without Non Linear Amplifier (note 1)	
				FER = 1e-3	FER = 1e-5	FER = 1e-3	FER = 1e-5	FER = 1e-3	FER = 1e-5

NOTE 1: The Es/N_0 values provided correspond to the minimum Es/N_0 value for which a certain criteria on the FER performance is respected, A FER target for DVB-S2X transmissions of 1e-3 and 1e-5 has been considered.
NOTE 2: The yellow Es/N0 values are extrapolated values based on FER measurements below the target.
NOTE 3: It is assumed the receiver is capable of perfect carrier synchronization recovery for simulations in Channel Type AWGN.
NOTE 4: The spectral efficiencies expressed in bits/symbol are calculated taking into account the BCH/LDPC code rate and the modulation order.
NOTE 5: The specified Es/No values are extracted from [i.1] and [i.2].

5.4.1.2 DVB-RCS2

Table 29: DVB-RCS2 Demodulation performance

Waveform Id	Waveform Configuration	Symbol rate [Mbd]	Spectral Efficiency [bits/symb]	E_s/N_0 [dB] - Channel Type AWGN (notes 1 and 5)		E_s/N_0 specified [dB] - Channel Type AWGN (notes 1 and 3)		E_s/N_0 [dB] - Channel Type A Without Non Lienar Amplifier (note 1)	
				PER = 1e-3	PER = 1e-5	PER = 1e-3	PER = 1e-5	PER = 1e-3	PER = 1e-5
2	Table 15	0,2	0,67	0,44	1,28	0,5	1,29	1,32	3,39
3		0,2	0,67	-0,33	0,17	-0,27	0,22	-0,11	1,45
13		2	0,67	-0,92	-0,56	-0,8	-0,51	-0,72	-0,36
14		2	1,00	1,34	1,60	1,49	1,71	1,54	1,82
15		2	1,33	3,37	3,63	3,46	3,69	3,42	3,68
16		2	1,50	4,41	4,70	4,5	4,73	4,46	4,75
17		2	1,67	5,60	6,00	5,64	5,94	5,66	6,15
18		2	2,00	7,29	7,49	7,29	7,49	7,42	7,66
19		2	2,25	8,49	8,72	8,56	8,77	8,65	8,89
20		2	2,50	9,91	10,21	10,02	10,23	10,10	10,40
21		2	3,00	10,48	10,67	10,55	10,72	10,60	10,80
22		2	3,33	11,80	12,01	11,86	12,04	11,96	12,18

NOTE 1: The Es/N_0 values provided correspond to the minimum Es/N_0 value for which a certain criteria on the PER performance is respected, A PER target for DVB-RCS2 transmissions of 1e-3 and 1e-5 has been considered.
NOTE 2: The Es/No specified are extracted from [i.6].
NOTE 3: It is assumed the receiver is capable of perfect carrier synchronization recovery for simulations in Channel Type AWGN.
NOTE 4: The spectral efficiencies expressed in bits/symbol are calculated taking into account the code rate and the modulation order of the reference burst.

DVB-RCS2: Channel Model and Symbol Rate Impact on demodulation performance

Figure 3 presents the impact of the symbol rate and the channel type on demodulation performance of ID13 to ID22 considering a target PER of 1e-5. One can observe that the symbol rate has no impact on demodulation performance, regardless of the type of channel considered. Therefore, the subsequent analyses of DVB-RCS2 will focus on the 20 Mbd symbol rate.

The demodulation performance in AWGN conditions is also compared with the demodulation performance in channel Type A conditions assuming a practical receiver implementation in Figure 3. The degradation induced by the implementation losses and the impairments ranges between 0,05 dB and 0,25 dB and is about 0,15 dB in average. The largest degradations are observed for the most efficient MODCODs (ID18 to ID22) which are more sensible to the amplitude and phase variations.

Table 20 illustrates the impact of the target PER by comparing the demodulation performance of ID13 to ID22 between two different PER targets in channel Type A conditions. The degradation gap induced by a target PER of 1e-5 compared to a target PER of 1e-3 ranges between 0,2 dB and 0,5 dB. The same gap is observed when considering an AWGN channel.

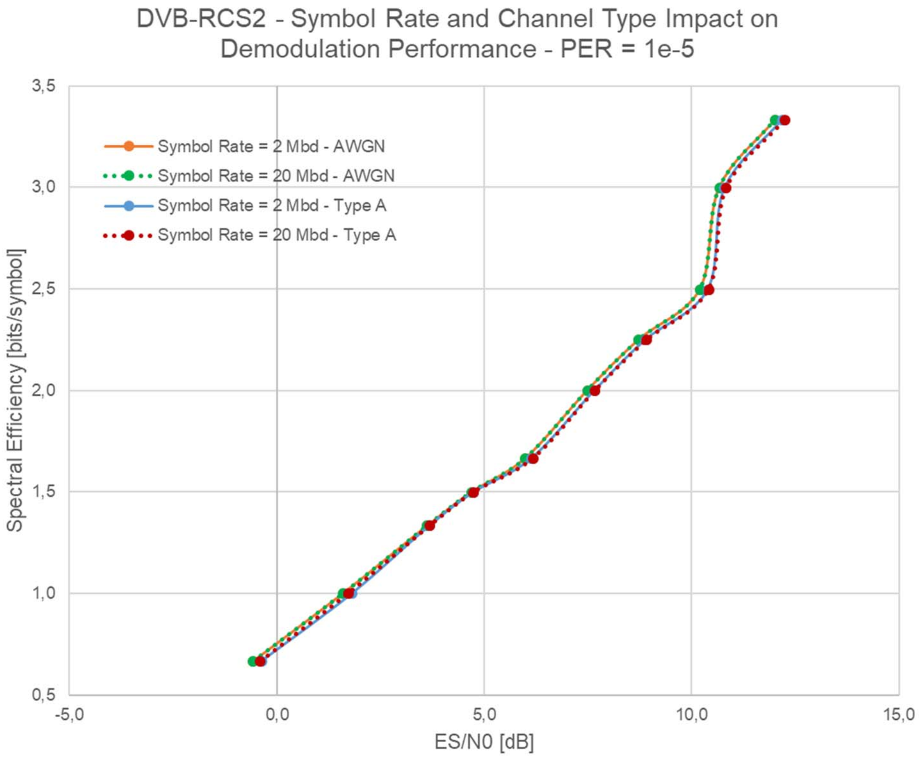

Figure 3: DVB-RCS2 - Symbol Rate and Channel Type Impact on Demodulation Performance - PER = 1e-5

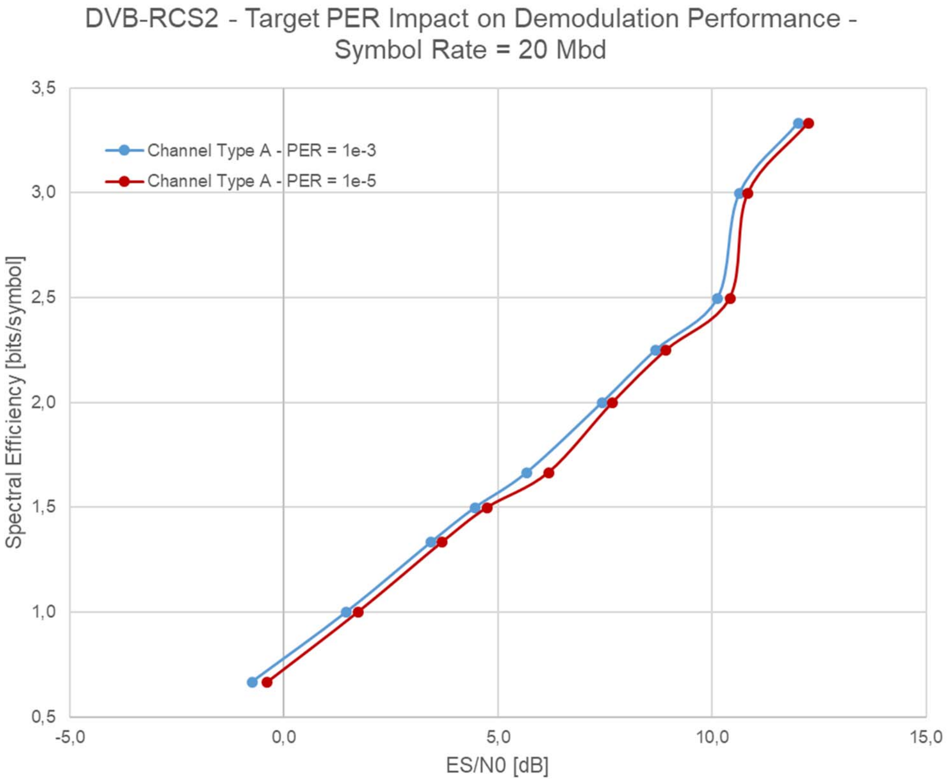

Figure 4: DVB-RCS2 - Target PER Impact on Demodulation Performance in Channel Type A - Symbol Rate = 20 Mbd

5.4.1.3 NR PDSCH

Table 30: NR PDSCH Demodulation performance

MCS Index	Waveform Configuration	Spectral efficiency [bits/symb]	E_s/N_0 [dB] - Channel Type AWGN (notes 1 and 3)		E_s/N_0 [dB] - Channel Type A without Non Linear Amplifier (note 1)	
			BLER = 1e-3	BLER = 1e-5	BLER = 1e-3	BLER = 1e-5
0	Table 17 DMRS: Table 20 PTRS: Table 21	0,06	-12,2	-11,7	-9,5	-8,98
1		0,08	-11,2	-10,8	-8,9	-8,44
2		0,10	-10,1	-9,7	-8,2	-7,74
3		0,13	-9,1	-8,8	-7,3	-6,85
4		0,15	-8,2	-7,9	-6,7	-6,14
5		0,19	-7,2	-7,0	-5,8	-5,30
6		0,23	-6,4	-5,9	-5,1	-4,59
7		0,30	-5,0	-4,6	-4,0	-3,45
8		0,38	-4,3	-4,0	-3,2	-2,57
9		0,48	-3,0	-2,6	-1,9	-1,24
10		0,58	-2,1	-1,4	-1,0	-0,34
11		0,71	-1,1	-0,5	-0,1	0,56
12		0,85	-0,1	0,9	1,0	1,65
13		1,00	1,0	1,7	2,0	2,69
14		1,14	1,9	2,5	3,1	3,78
15		1,29	3,7	4,2	4,7	5,08
16		1,42	4,4	4,9	5,4	5,85
17		1,64	5,5	6,2	6,7	7,24
18		1,85	6,2	7,2	7,5	8,12
19		2,08	7,2	8,3	8,5	9,23
20		2,32	7,8	9,0	9,5	9,97
21		2,46	9,0	10,2	10,5	11,43
22		2,62	9,7	10,8	11,2	12,02
23		2,91	10,5	11,7	12,3	13,12
24		3,18	11,4	12,3	13,1	13,68
25		3,48	12,3	13,2	14,2	14,74
26		3,75	13,1	13,9	15,2	15,83
27		4,08	14,2	15,1	16,4	17,30
28		4,37	15,1	16,1	17,7	19,45

NOTE 1: The E_S/N_0 values provided correspond to the minimum E_S/N_0 value for which a certain criteria on the BLER performance is respected. A BLER target for NR PDSCH transmissions of 1e-3 and 1e-5 has been considered.

NOTE 2: The spectral efficiencies expressed in bits/symbol only reflect the performance of the effective coding scheme. Any other source of overhead has not been considered.

NOTE 3: It is assumed the receiver is capable of perfect synchronization and channel estimation for simulations in Channel Type AWGN.

5.4.1.4 NR PUSCH

Table 31: NR PUSCH Demodulation performance considering 4 allocated PRBs

LLS simulation results for NR PUSCH transmissions considering 4 allocated PRBs						
MCS Index	**Waveform Configuration**	**MCS rate [bits/symb]**	**E_s/N_0 [dB] - Channel Type AWGN (notes 1 and 3)**		**E_s/N_0 [dB] - Channel Type A without Non Linear Amplifier (note 1)**	
			BLER = 1e-3	**BLER = 1e-5**	**BLER = 1e-3**	**BLER = 1e-5**
0	Table 22 DMRS: Table 25 PTRS: Table 26	0,05	-8,56	-7,33		
1		0,08	-7,66	-6,56		
2		0,09	-7,28	-6,30		
3		0,12	-6,59	-5,61		
4		0,14	-6,00	-5,14		
5		0,19	-5,10	-4,27		
6		0,23	-4,58	-3,73		
7		0,30	-3,70	-2,88		
8		0,39	-2,67	-2,04		
9		0,49	-1,68	-1,02		
10		0,59	-0,84	-0,12		
11		0,73	0,16	0,90		
12		0,89	1,14	1,87		
13		1,03	1,99	2,51		
14		1,18	2,93	3,53		
15		1,36	3,97	4,50		
16		1,49	5,26	6,06		
17		1,71	6,00	6,98		
18		1,91	6,76	7,61		
19		2,17	7,65	8,28		
20		2,47	8,80	9,48		
21		2,58	9,21	10,20		
22		2,78	10,02	10,56		
23		3,09	11,18	11,90		
24		3,35	12,09	13,39		
25		3,65	13,02	13,90		
26		3,96	14,18	15,48		
27		4,58	16,09	17,26		

NOTE 1: The E_S/N_0 values provided correspond to the minimum E_S/N_0 value for which a certain criteria on the BLER performance is respected. A BLER target for NR PUSCH transmissions of 1e-3 and 1e-5 has been considered.

NOTE 2: The spectral efficiencies expressed in bits/symbol only reflect the performance of the effective coding scheme. Any other source of overhead has not been considered.

NOTE 3: It is assumed the receiver is capable of perfect synchronization and channel estimation for simulations in Channel Type AWGN.

Table 32: NR PUSCH Demodulation performance considering 40 allocated PRBs

LLS simulation results for NR PUSCH transmissions considering 40 allocated PRBs						
MCS Index	**Waveform Configuration**	**MCS rate [bits/symb]**	**E_s/N_0 [dB] - Channel Type AWGN (notes 1 and 3)**		**E_s/N_0 [dB] - Channel Type A without Non Linear Amplifier (note 1)**	
			BLER = 1e-3	**BLER = 1e-5**	**BLER = 1e-3**	**BLER = 1e-5**
0	Table 22 DMRS: Table 25 PTRS: Table 26	0,06	-11,35	-10,74	-8,75	-7,61
1		0,08	-10,45	-9,94	-8,27	-7,31
2		0,10	-9,53	-8,98	-7,72	-6,94
3		0,13	-8,43	-7,96	-7,01	-6,26
4		0,16	-7,63	-7,18	-6,53	-5,85
5		0,20	-6,84	-6,34	-5,90	-5,27
6		0,24	-6,08	-5,70	-5,35	-4,82
7		0,31	-4,91	-4,46	-4,46	-3,98
8		0,39	-4,10	-3,81	-3,79	-3,33
9		0,50	-2,81	-2,43	-2,64	-2,29
10		0,60	-1,96	-1,27	-0,81	-0,04
11		0,74	-0,93	-0,33	0,12	0,83
12		0,88	0,16	1,13	1,07	1,60
13		1,03	1,21	1,76	1,83	2,42
14		1,17	2,20	2,48	2,74	3,30
15		1,31	3,16	3,36	3,59	4,06
16		1,48	4,65	5,14	5,00	5,47
17		1,68	5,76	6,68	6,01	6,96
18		1,93	6,53	7,48	6,92	7,91
19		2,18	7,42	8,50	7,72	8,78
20		2,42	8,14	8,98	8,63	9,47
21		2,59	8,72	9,55	9,24	10,10
22		2,71	9,39	10,05	9,88	10,62
23		3,04	10,52	11,27	11,22	11,99
24		3,29	11,75	12,57	12,18	12,82
25		3,61	12,60	13,45	13,24	13,73
26		3,94	13,56	14,66	14,49	15,12
27		4,51	15,38	16,28	17,51	18,85

NOTE 1: The E_S/N_0 values provided correspond to the minimum E_S/N_0 value for which a certain criteria on the BLER performance is respected. A BLER target for NR PUSCH transmissions of 1e-3 and 1e-5 has been considered.

NOTE 2: The spectral efficiencies expressed in bits/symbol only reflect the performance of the effective coding scheme. Any other source of overhead has not been considered.

NOTE 3: It is assumed the receiver is capable of perfect synchronization and channel estimation for simulations in Channel Type AWGN.

NR PUSCH: Number of allocated PRBs Impact on demodulation performance

Figure 5 illustrates the impact of the number of allocated PRBs on demodulation performance assuming a target BLER of 1e-5. In AWGN conditions, better demodulation performance can be observed with 40 allocated PRBs than with 4 allocated PRBs. The performance gap in favour of 40 allocated PRBs over 4 allocated PRBs ranges from 0,1 dB to 3,4 dB, with an average of about 1,27 dB. This performance gap is solely linked to the size of the code block. Therefore, the largest gaps are observed for the most robust MCS (MCS0 to MCS8) which have very low code block size (see Table 24) with 4 allocated PRBs. Furthermore, it can be observed that the performance gap decreases for MCS indices greater than 15. This trend is explained by the fact that the transport block associated with these MCS indices is composed of multiple code blocks due to segmentation. When segmentation is performed, the target BLER is no longer associated with a single code block but rather with the transport block composed of N code blocks. In reality, the target BLER of 1e-5 for these MCS indices is significantly lower than 1e-5, hovering around 5e-6 when the transport block is formed by two code blocks.

Figure 6 illustrates the impact of the target BLER by comparing the demodulation performance between two different BLER targets in AWGN conditions. The degradation gap induced by a target BLER of 1e-5 compared to a target BLER of 1e-3 ranges between 0,2 dB and 1,1 dB and is about of 0,6 dB in average.

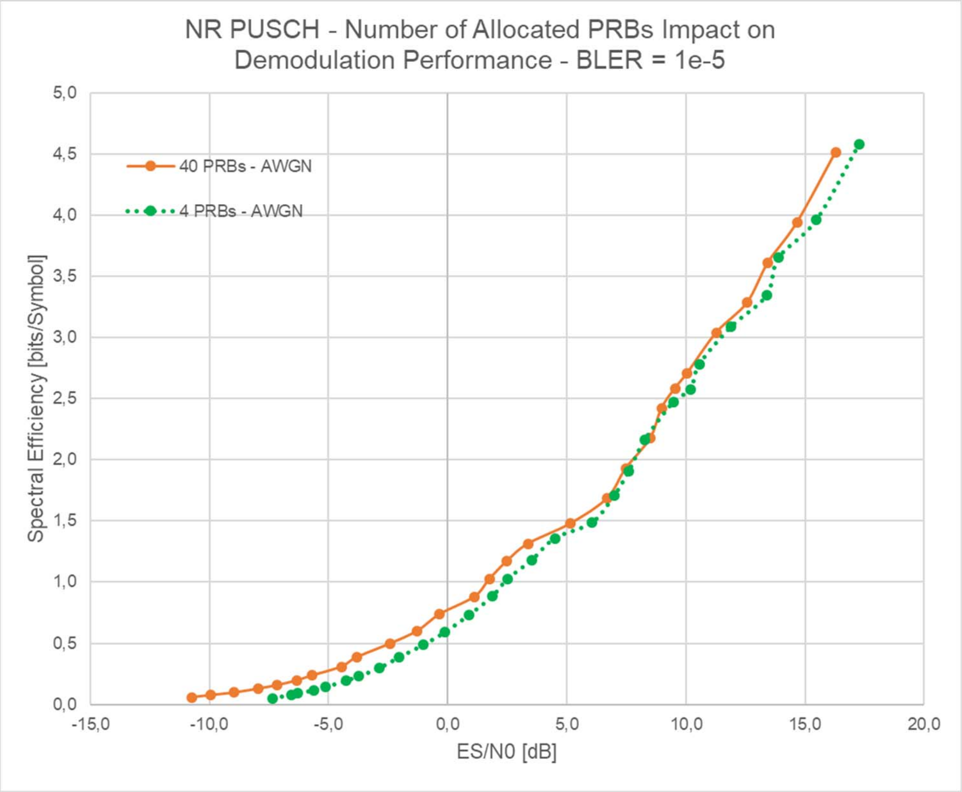

Figure 5: NR PUSCH - Number of Allocated PRBs Impact on Demodulation Performance - BLER = 1e-5

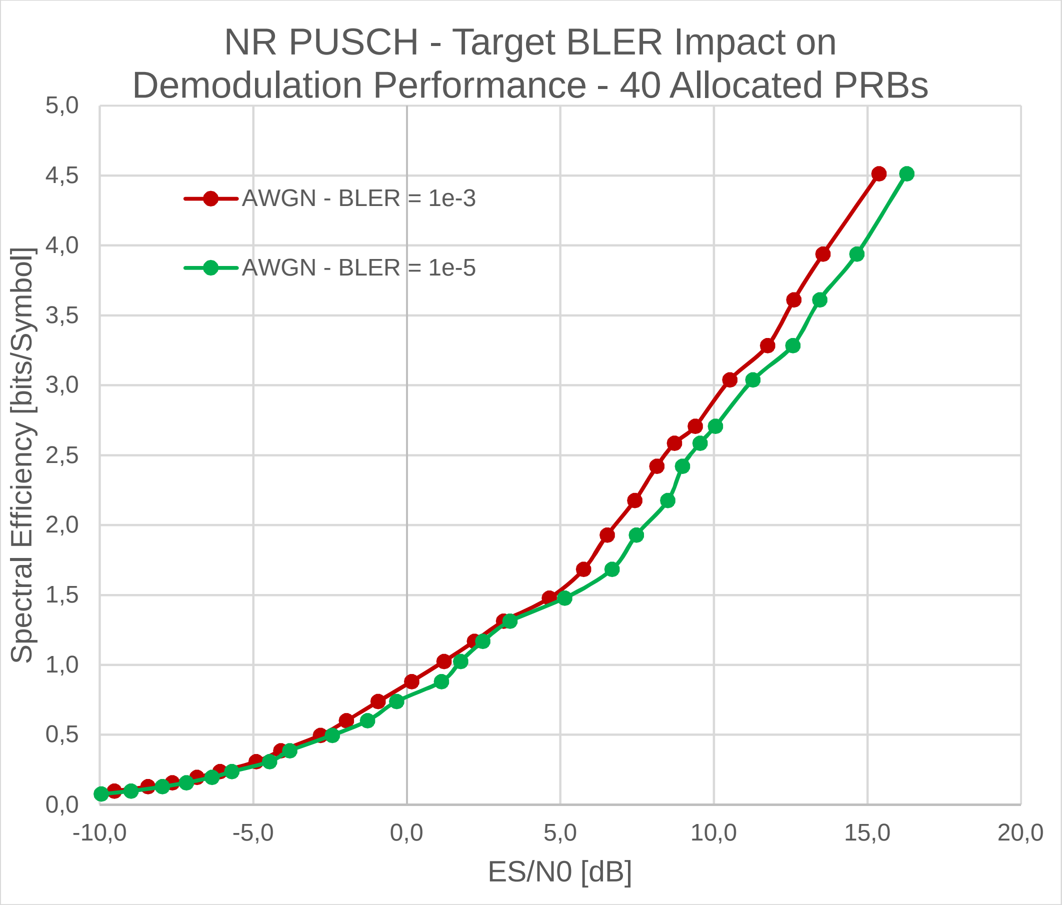

Figure 6: NR PUSCH - Target BLER Impact on Demodulation Performance in AWGN conditions - Number of Allocated PRBs = 40

NR PUSCH: Channel Model Impact on demodulation performance with 40 allocated PRBs

The demodulation performance in AWGN conditions are compared with the demodulation performance in channel Type A conditions assuming a practical receiver implementation in Figure 7. The degradation induced by the implementation losses and the impairments ranges between 0,2 dB and 2,6 dB and is about 0,9 dB in average. The largest gaps are observed for the most robust MCS indexes (MCS0 to MCS3) with the exception of MCS27. One can assume that the main contributor in terms of degradation in the channel Type A is phase noise since the GF/GD variations do not have a significant impact on the demodulation performances. This can be explained by the fact that the channel can be considered almost constant over one subcarrier.

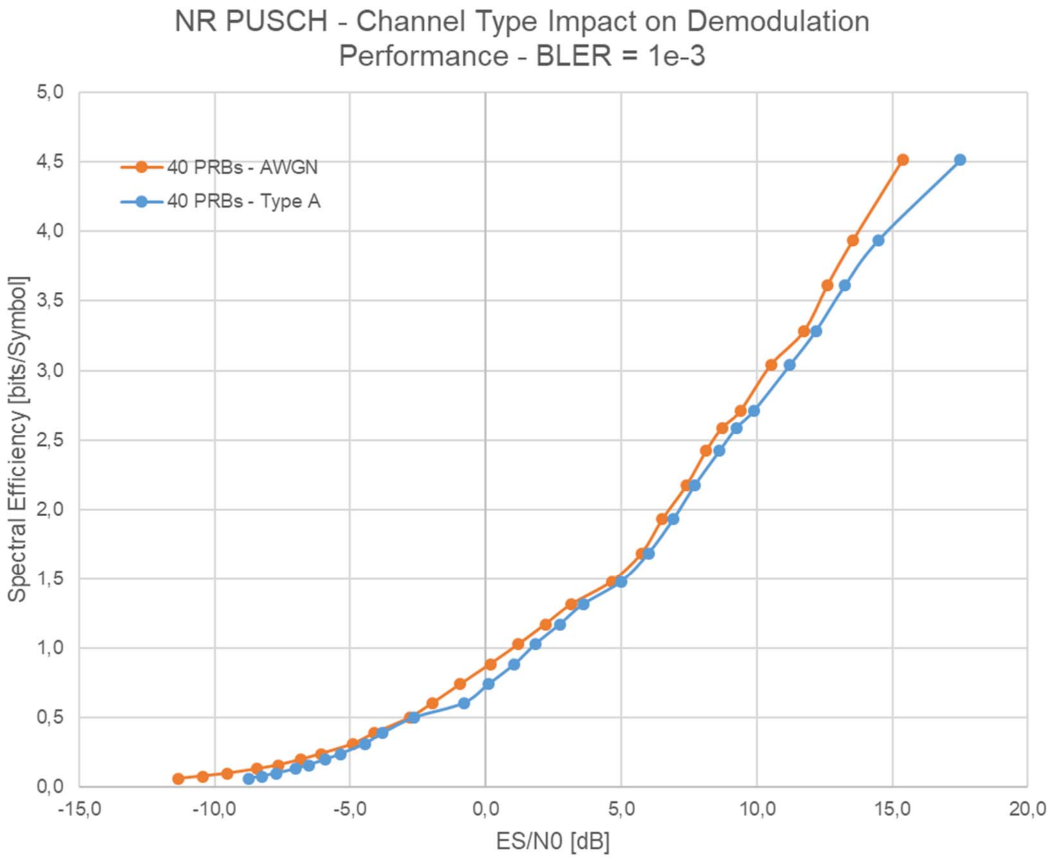

Figure 7: NR PUSCH - Channel Type Impact on Demodulation Performance - BLER = 1e-3

5.4.2 Peak To Average Power Ratio and C/Im

5.4.2.1 DVB-S2X

5.4.2.1.1 PAPR

The PAPR CCDF distributions have been analysed for DVB-S2X based transmissions assuming:

- a single carrier in the same HPA, 5 adjacent carriers in the HPA, 10 adjacent carriers in the HPA, or 32 overlapping carriers in the HPA;
- different type of modulations;
- no PAPR reduction techniques have been applied.

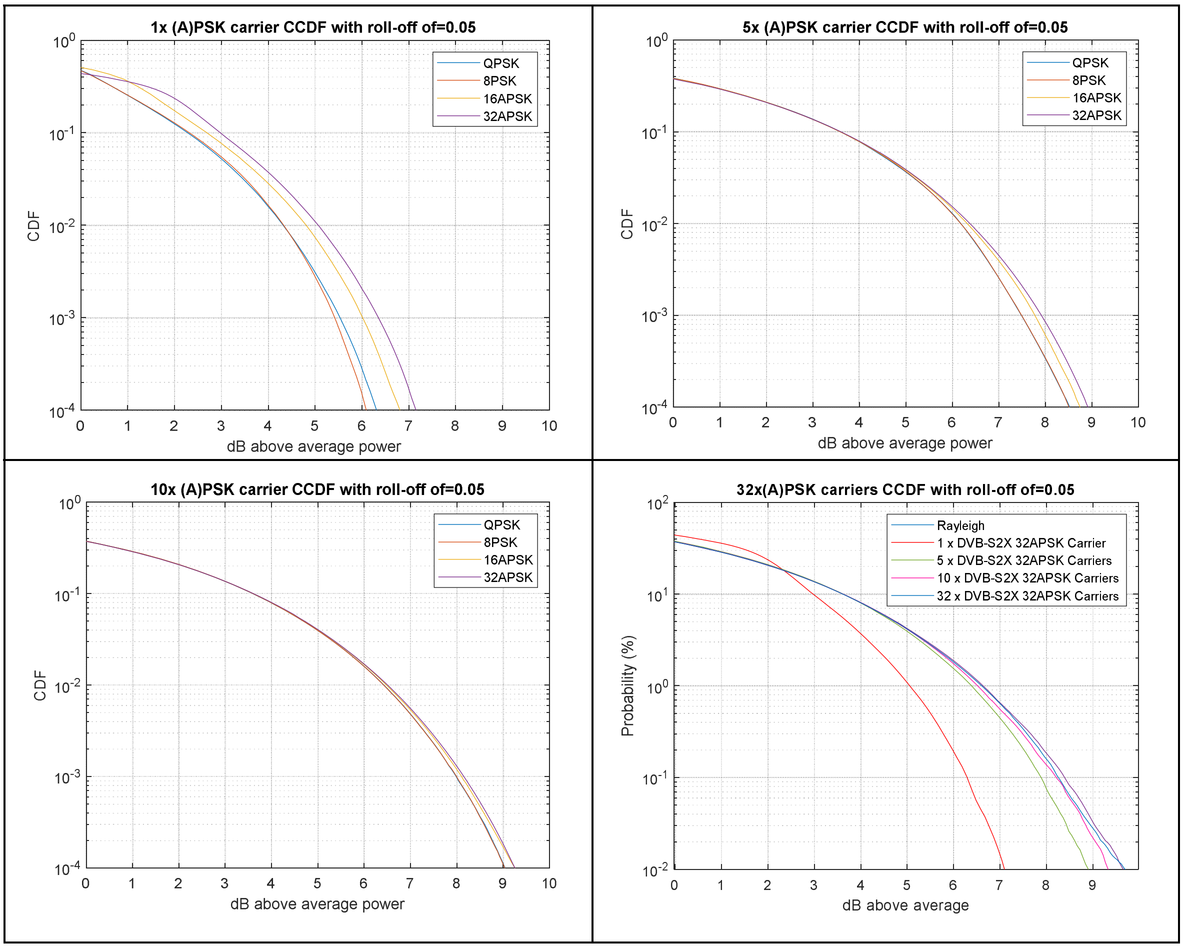

Figure 8: PAPR distributions for several amplifier load configurations in terms of number of DVB based carriers

The following observations are made:

- PAPR < 5,5 dB to 6,5 dB for 99,9 % of the time for the single carrier scenario depending on the modulation order.
- PAPR < 7,5 dB to 8 dB for 99,9 % of the time with 5 carriers depending on the modulation order.
- PAPR < 8 dB to 8,2 dB for 99,9 % of the time with 5 carriers depending on the modulation order.

The PAPR values with 5 TDM carriers increase drastically compared to the single-carrier scenario. Moreover, in the 5-carriers scenario the modulation order has a marginal impact on the PAPR level contrary to what can be observed for the single carrier scenario. The PAPR increases slightly in the 10 TDM carriers scenario w.r.t the 5-carriers scenario.

Finally, one can observe that when the number of carriers in the same HPA increases, the input signal power fluctuation distribution tends to match the distribution of a white Gaussian noise (Rayleigh).

5.4.3.1.2 C/Im

The achievable performance in terms of conducted C/Im assuming the satellite HPA characteristics have been evaluated for different points of operation. The input signal is composed of 32 DVB-S2X carriers of the same size overlapping in the frequency domain.

Due to the satellite antenna architecture and the multi beam coverage assumptions, it is assumed that a gain of 5 dB can be expected between conducted and radiated C/Im. The exact offset value may change depending on the number of beams in the satellite coverage, the beamforming laws considered, and so on. The 5 dB value is rather conservative.

The simulation results are summarized in Figure 9 and Table 33.

One can observe that for an OBO of 0,5 dB, a conducted C/Im of 12,8 dB has been measured.

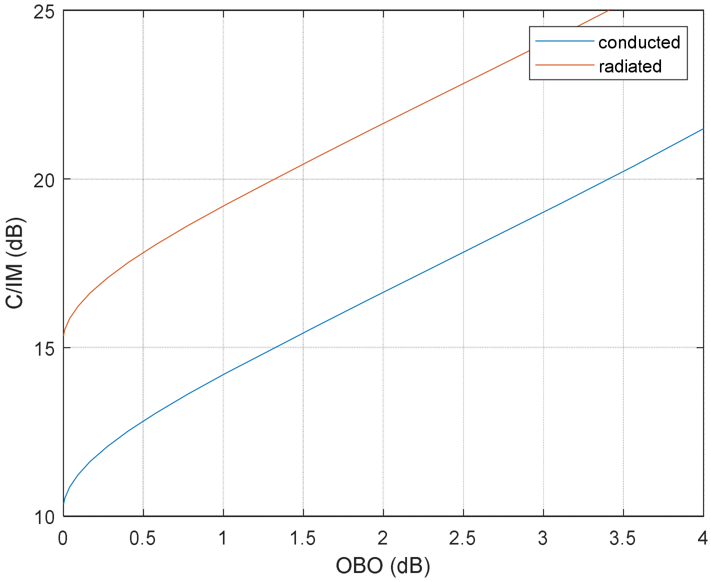

Figure 9: C/Im vs OBO performance assuming DVB-S2X based signal transmission (32 carriers)

Table 33: Conducted C/Im performance depending on HPA OBO assuming DVB-S2X based signal transmission (32 carriers)

OBO [dB]	C/Im (conducted) [dB]
-0,0060	10,2363
0,0087	10,5340
0,0383	10,8626
0,0908	11,2242
0,1673	11,6212
0,2723	12,0562
0,4070	12,5319
0,5759	13,0511
0,7780	13,6173
1,0151	14,2340
1,2843	14,9054
1,5815	15,6358
1,9102	16,4306
2,2751	17,2956
2,6731	18,2375
3,1048	19,2636
3,5644	20,3823
4,0441	21,6021
4,5469	22,9310

For the purpose of comparison, the conducted C/Im evaluation has been also performed assuming an input signal composed of 5 non-overlapping DVB-S2X carriers and the results are compared in Figure 10.

One can observe that for an OBO of 0,5 dB, a conducted C/Im of 13,3 dB has been measured with the configuration with only 5 carriers which is an increase offset of 0,5 dB with respect to the performance obtained with 32 carriers.

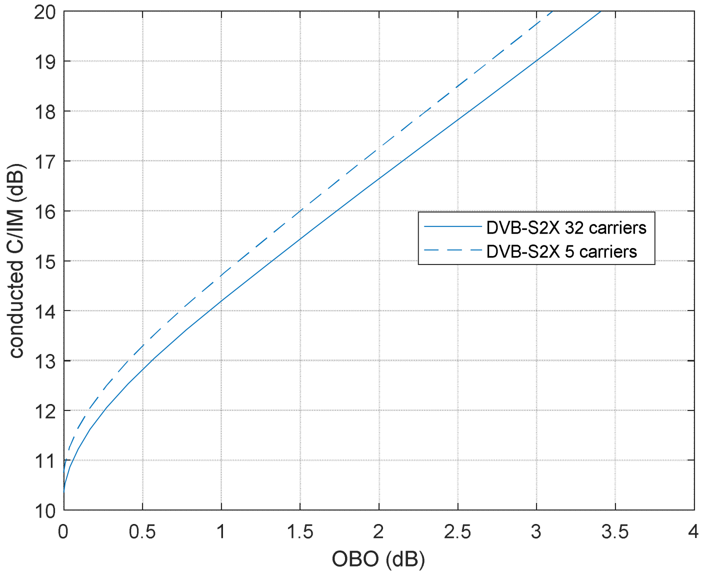

Figure 10: C/Im vs OBO performance assuming DVB-S2X based signal transmission (32 carriers & 5 carriers)

5.4.2.2 DVB-RCS2

5.4.2.2.1 PAPR

The PAPR CCDF distributions have been analysed for DVB-RCS2 based transmissions assuming:

- a single carrier amplified in the terminal HPA;
- different type of modulations (APSK or QAM);
- no PAPR reduction techniques have been applied.

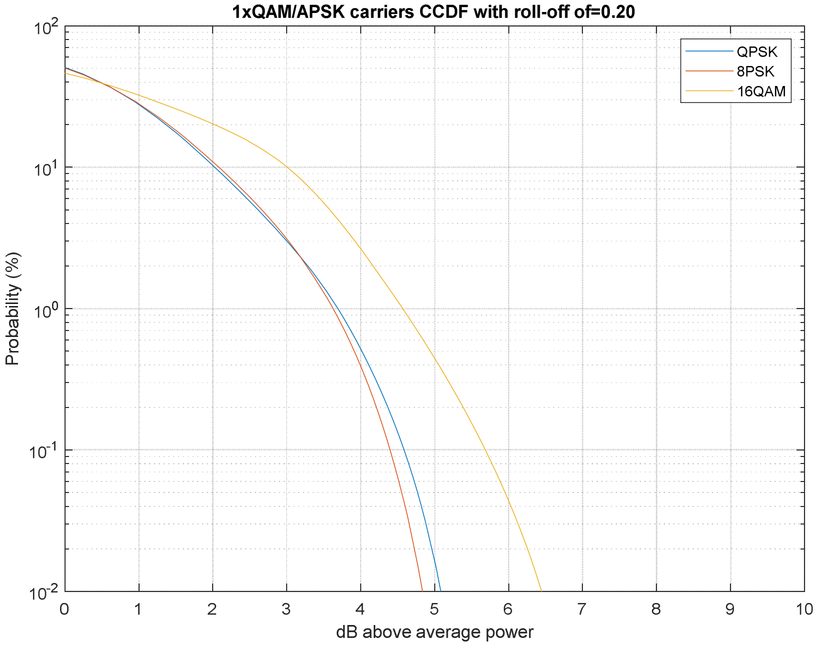

Figure 11: PAPR distribution in case of single carrier transmission with a roll-off of 0,20 and different modulations

The PAPR distributions of single carrier transmissions based on QPSK 8APSK and 16QAM modulations assuming a roll-off factor of 0,2 are presented in Figure 11. The following observations are made:

- PAPR < 4,6 dB for 99,9 % of the time for the single carrier scenario based on QPSK and 8PSK.
- PAPR < 5,7 dB for 99,9 % of the time for the single carrier scenario based on 16QAM.
- The PAPR distribution for 8PSK and QPSK are very similar.
- The power envelope fluctuation for 16-QAM is increased due to the amplitude variation from one symbol to the next.

5.4.2.2.2 C/Im

The achievable performance in terms of conducted C/Im assuming the User Terminal HPA characteristics have been evaluated for different points of operation. The input signal is composed of a DVB-RCS2 single carrier based on three different modulation configurations:

- QPSK.
- 8PKS.
- 16QAM.

The results are summarized in Figure 12.

One can observe that the results for QPSK and 8PSK are very similar. The PAPR CDF are very similar for both QPSK and 8PSK since both modulations design enforce constant amplitude symbols. Therefore, obtaining very similar intermodulation curves is not surprising.

One can observe a significant C/IM degradation of 4,5 dB for 16QAM with respect to QPSK/8PSK for the same point of operation. This is explained by the higher PAPR performance observed with 16QAM.

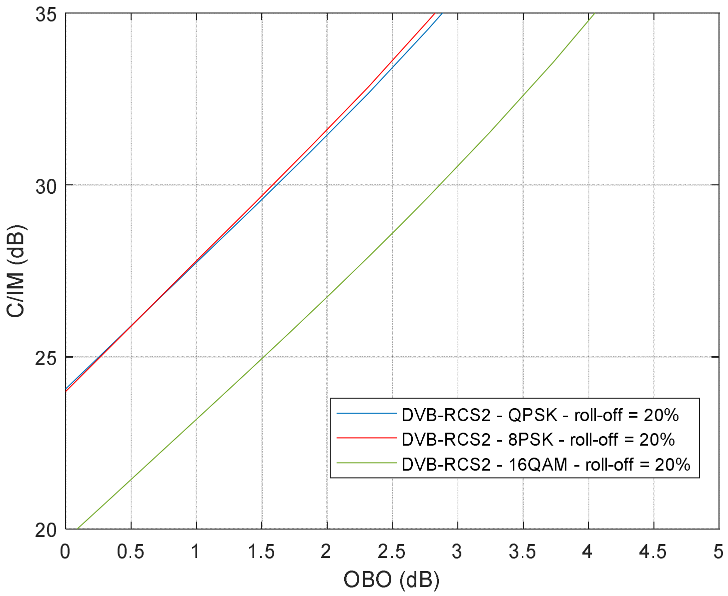

Figure 12: C/Im vs OBO performance assuming Single Carrier DVB-RCS2 based signal transmission with a roll-off of 20 %

Table 34: C/Im performance depending on HPA OBO assuming Single Carrier DVB-RCS2 based signal transmission with a roll-off of 20 %

OBO [dB]	C/Im [dB]		
	QPSK	8PSK	16QAM
0	24,0656	23,9925	19,6964
0,3228	25,2528	25,2247	20,8173
0,6742	26,5401	26,5559	22,0398
1,0486	27,9186	27,9765	23,3570
1,4507	29,3868	29,4856	24,7688
1,8719	30,9607	31,1023	26,2783
2,3147	32,6609	32,8489	27,8972
2,7722	34,5175	34,7572	29,6389
3,2458	36,5611	36,8629	31,5227
3,7294	38,8333	39,2084	33,5635
4,2233	41,3575	41,8039	35,7753

5.4.2.3 NR PDSCH

5.4.2.3.1 PAPR

The PAPR CCDF distributions have been analysed for NR PDSCH based transmissions assuming:

- A single NR carrier transmission but with different number of allocated PRBs in the same NR carrier.
- QPSK modulation for every subcarriers.
- no PAPR reduction techniques have been applied.

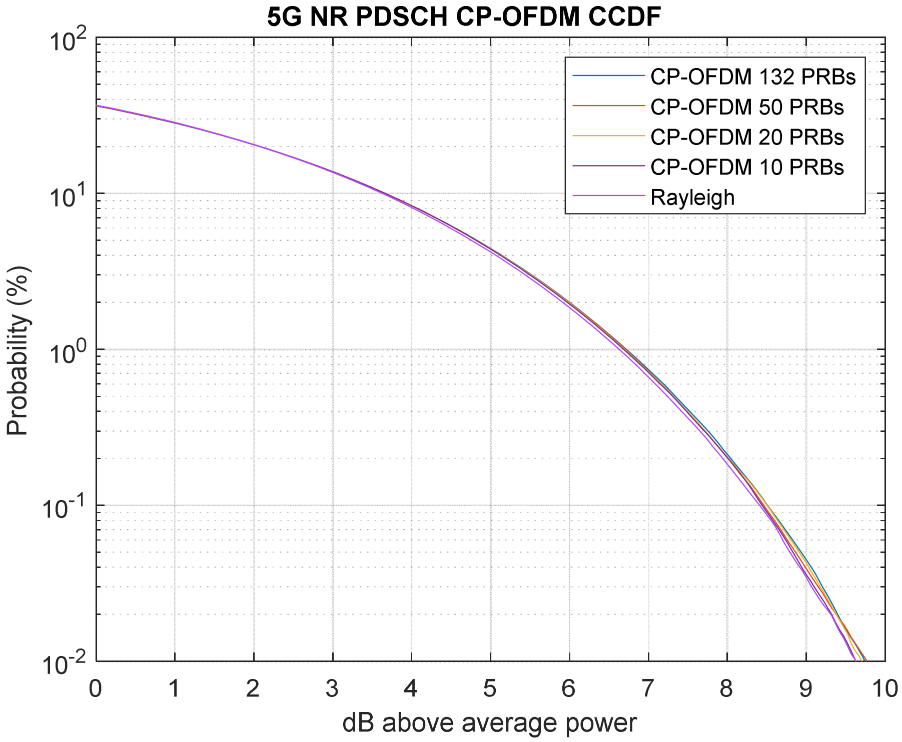

Figure 13: PAPR distribution in case of CP-OFDM transmission for different PRBs configurations

The following observation is made:

- PAPR < 8,5 dB for 99,9 % of the time for all the configurations.

Finally, one can observe that the signal power fluctuation distributions for all the 5G NR CP-OFDM is very much aligned with the distribution of a white Gaussian noise (Rayleigh).

5.4.2.3.2 C/Im

The achievable performance in terms of conducted C/Im assuming the satellite HPA characteristics have been evaluated for different points of operation. The input signal is composed of several hundreds of NR CP-OFDM subcarriers.

When the payload architecture embeds an active antenna and the multi beam coverage assumptions are adopted, it is assumed that a gain of 5 dB can be expected between conducted and radiated C/Im (same offset as for DVB-S2X analysis).

One can observe that for an OBO of 0,5 dB, a conducted C/Im of 12,7 dB has been measured.

The results are summarized in Figure 14 and Table 35.

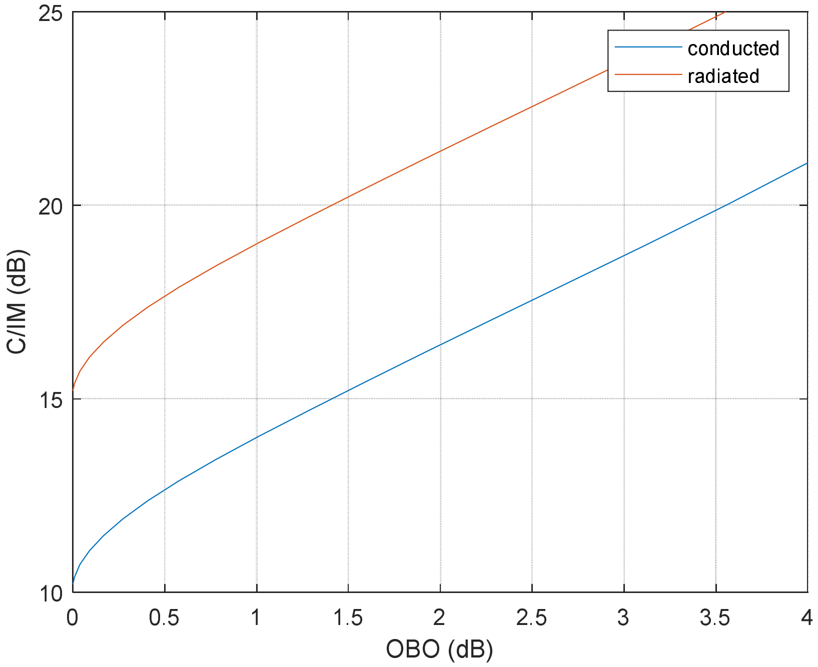

Figure 14: C/Im vs OBO performance assuming NR CP-OFDM input signal (hundreds of subcarriers)

Table 35: Conducted C/Im performance depending on HPA OBO assuming NR CP-OFDM based signal transmission (hundreds of subcarriers)

OBO [dB]	C/Im [dB]
-0,0060	10,0930
0,0087	10,3900
0,0383	10,7168
0,0908	11,0756
0,1673	11,4686
0,2723	11,8983
0,4070	12,3673
0,5759	12,8783
0,7780	13,4346
1,0151	14,0395
1,2843	14,6970
1,5815	15,4112
1,9102	16,1870
2,2751	17,0300
2,6731	17,9462
3,1048	18,9427
3,5644	20,0269
4,0441	21,2066
4,5469	22,4892

5.4.2.4 NR PUSCH

5.4.2.4.1 PAPR

The PAPR distributions of NR PUSCH transmissions are presented in Figure 15. Several configurations are explored with NR PUSCH transmissions either based on CP-OFDM or DFT-OFDM with different adjacent PRB allocation lengths and assuming a single NR carrier amplified in the terminal HPA. No PAPR reduction techniques have been applied.

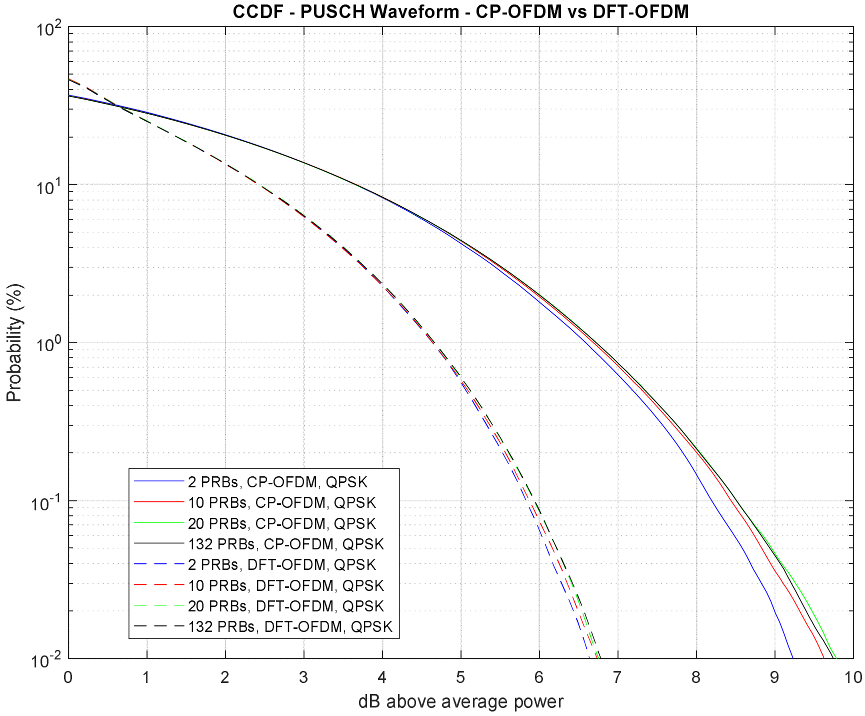

Figure 15: Comparison of NR PUSCH transmissions PAPR distribution in case of CP-OFDM and DFT-OFDM

The following observations are made:

- PAPR < 6 dB for 99,9 % of the time for the DFT-OFDM based transmissions.
- PAPR < 8,5 dB for 99,9 % of the time for the CP-OFDM based transmissions.
- The PAPR distributions are mainly driven by the usage of CP-OFDM vs DFT-OFDM.

The influence of the number of allocated PRB is much less significant especially for DFT-OFDM transmissions.

These results show the benefit to use DFT-OFDM in terms of power envelope fluctuation reduction.

Additional PAPR distributions of NR PUSCH transmissions are presented in Figure 16. Several configurations are explored with NR PUSCH transmissions based on DFT-OFDM with different adjacent PRB allocation lengths and for different modulations.

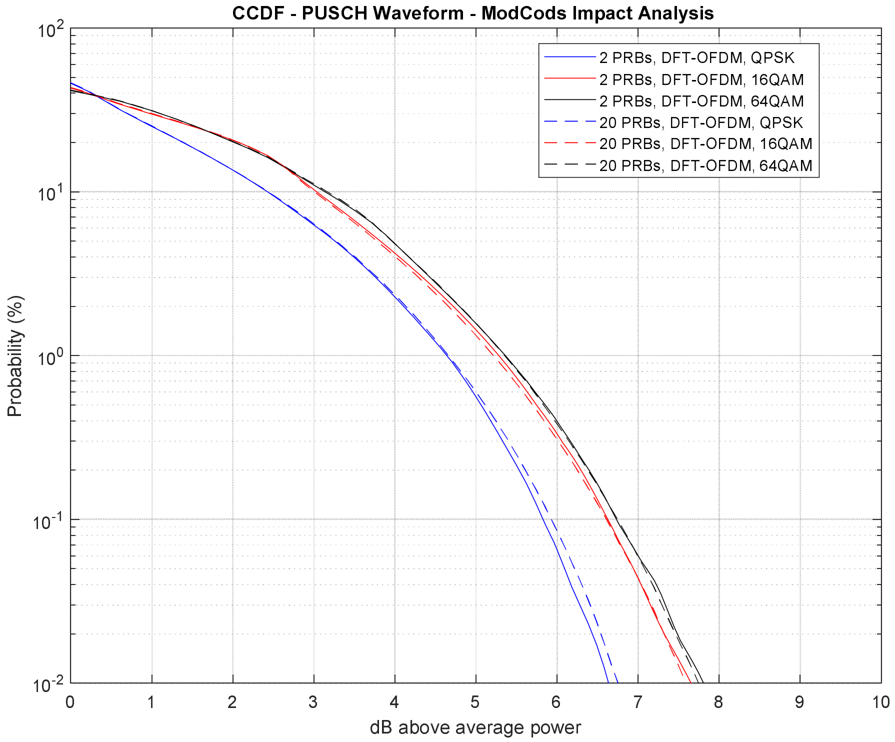

Figure 16: Influence of the number PRB and the modulation on the DFT-OFDM based NR PUSCH transmissions PAPR distribution

The following observations are made:

- PAPR < 6 dB for 99,9 % of the time for the DFT-OFDM based transmissions in QPSK.
- PAPR < 6,7 dB for 99,9 % of the time for the DFT-OFDM based transmissions in 16QAM or 64QAM.
- The PAPR distributions are mainly driven by the modulation by the usage of constant amplitude modulation (QPSK) or variable amplitude modulation (16QAM, 64 QAM).
- The PAPR distributions for 16QAM and 64QAM modulation are very similar.
- The influence of the number of allocated PRB is much less significant.

5.4.2.4.2 C/Im

The achievable performance in terms of conducted C/Im assuming the User Terminal HPA characteristics have been evaluated for different points of operation. The input signal is DFTsOFDM based NR PUSCH transmission based three different modulation configurations:

- QPSK.
- 16QAM.
- 64QAM.

Note that the number of transmitted PRB has been fixed to 40 but this parameter does not impact significantly the results.

The results are summarized in Figure 17 and Table 36.

One can observe a significant C/IM degradation of 2,6 dB for 16QAM with respect to QPSK for the same point of operation. This is explained by the higher PAPR performance observed with 16QAM in the previous clause.

One can observe a less significant C/IM degradation of 0,7 dB for 64QAM with respect to 16QAM for the same point of operation. This is explained by the lower PAPR performance gap observed between the two configurations in the previous clause.

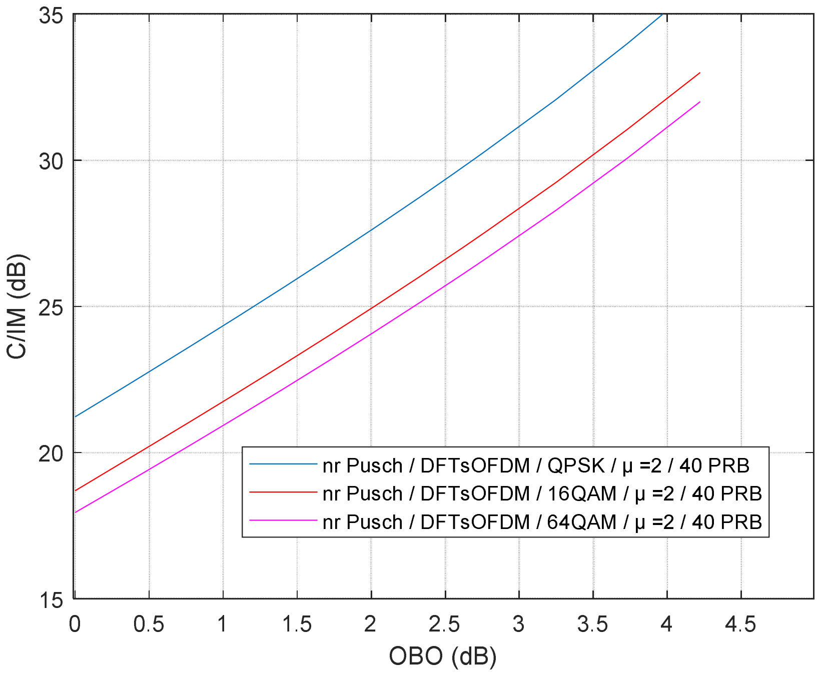

Figure 17: C/Im vs OBO performance assuming DFTsOFDM based NR PUSCH signal transmission

Table 36: C/Im vs OBO performance assuming DFTsOFDM based NR PUSCH signal transmission

OBO [dB]	C/Im [dB]		
	QPSK	16QAM	64QAM
0	21,2239	18,6888	17,9425
0,3228	22,2173	19,6721	18,8951
0,6742	23,3078	20,7424	19,9414
1,0486	24,4970	21,9041	21,0809
1,4507	25,7875	23,1612	22,3137
1,8719	27,1823	24,5169	23,6455
2,3147	28,6868	25,9761	25,0797
2,7722	30,3110	27,5450	26,6228
3,2458	32,0697	29,2321	28,2819
3,7294	33,9809	31,0465	30,0701
4,2233	36,0614	32,9965	31,9973

5.5 Spectral Efficiencies Evaluation

5.5.1 DVB-S2X Spectral Efficiencies

Table 14 presents the MODCOD rates that is the number of information bits transmitted per symbol taking into account only the effective code rate and the modulation order. However, it is necessary to derive a spectral efficiency metric defined in terms of information bits per second per Hertz for the sake of comparison. To do so, it is necessary to take into account the waveform specificities as well as other considerations such as:

- BB framing efficiency taking into account the BB header overhead.
- PL framing efficiency taking into account the pilots and the PL header overhead.
- Carrier roll-off which characterizes the spectral occupancy of the carrier.
- Guard bands which are often required between adjacent DVB-S2X carriers due to operational constraints.

The assumptions and the resulting spectral efficiencies are presented in Table 37.

Note that additional effects can also impact significantly the over-all spectral efficiency:

- In-band control plane signalling loss is difficult to estimate and may change significantly from one implementation to another and from one scenario to the next (mobility, channel conditions, traffic, QoS management). The control plane information includes but may not be limited to Broadcast Network Clock Reference (NCR), Broadcast System tables, Burst Time Plan (BTP), multicast Correction Message Table (CMT), Terminal Information Message (TIM).
- Scheduling efficiency is difficult to estimate and may change from one implementation to another as it results from a trade-off between spectral efficiency, user fairness and scheduler induced latency. In particular, it integrates:
    - The multiuser multiplexing efficiency when the data of multiple users experiencing different radio conditions is multiplexed in the same BB frame.
    - The BB padding loss when there is no enough relevant data to fill up the BB frame.

However, it has been decided to ignore these effects in the PHY layer spectral efficiency calculation since their impact can vary significantly from one higher layer implementation to another and may negatively affect the comparison between the two technologies by hiding the native waveforms performance within other implementation dependent and very roughly estimated spectral efficiency loss contributions. Such effects are taken into account (at least partially) in the SLS evaluation.

Table 37: DVB-S2X Spectral Efficiencies

				Waveform framing efficiency		Waveform spectral occupancy		
MODCOD	**Mod. [Bit/Symb]**	**Coding Rate**	**MODCOD rate [bits/symb]**	**BB Framing Efficiency Loss (note 1)**	**PL Framing Efficiency Loss (note 2)**	**Carrier Roll-off [% of symbol rate]**	**Guard Band (note 3) [% of symbol rate]**	**Spectral Efficiency [bit/s/Hz]**
QPSK_2s9	2	0,231	0,462	0,56 %	7,52 %	5,00 %	2,00 %	0,397
QPSK_1s4	2	0,247	0,494	0,50 %	2,65 %	5,00 %	2,00 %	0,447
QPSK_13s45	2	0,286	0,572	0,43 %	2,65 %	5,00 %	2,00 %	0,518
QPSK_1_3	2	0,330	0,661	0,37 %	2,65 %	5,00 %	2,00 %	0,599
QPSK_2s5	2	0,397	0,794	0,31 %	2,65 %	5,00 %	2,00 %	0,720
QPSK_9s20	2	0,447	0,894	0,28 %	2,65 %	5,00 %	2,00 %	0,811
QPSK_1s2	2	0,497	0,994	0,25 %	2,65 %	5,00 %	2,00 %	0,902
QPSK_11s20	2	0,547	1,094	0,23 %	2,65 %	5,00 %	2,00 %	0,993
QPSK_3s5	2	0,597	1,194	0,21 %	2,65 %	5,00 %	2,00 %	1,084
QPSK_2s3	2	0,664	1,328	0,19 %	2,65 %	5,00 %	2,00 %	1,206
QPSK_3s4	2	0,747	1,494	0,17 %	2,65 %	5,00 %	2,00 %	1,357
QPSK_4s5	2	0,797	1,594	0,15 %	2,65 %	5,00 %	2,00 %	1,448
QPSK_5s6	2	0,831	1,662	0,17 %	2,65 %	5,00 %	2,00 %	1,509
8PSK_3s5	3	0,597	1,791	0,15 %	2,68 %	5,00 %	2,00 %	1,627
8PSK_23s36	3	0,636	1,908	0,21 %	2,68 %	5,00 %	2,00 %	1,732
8PSK_2s3	3	0,664	1,993	0,19 %	2,68 %	5,00 %	2,00 %	1,809
8PSK_25s36	3	0,691	2,074	0,19 %	2,68 %	5,00 %	2,00 %	1,883
8PSK_13s18	3	0,719	2,158	0,18 %	2,68 %	5,00 %	2,00 %	1,959
16APSK_26s45	4	0,575	2,299	0,17 %	2,91 %	5,00 %	2,00 %	2,083
16APSK_3s5	4	0,597	2,388	0,21 %	2,91 %	5,00 %	2,00 %	2,162
16APSK_28s45	4	0,619	2,477	0,21 %	2,91 %	5,00 %	2,00 %	2,243
16APSK_23s36	4	0,636	2,544	0,20 %	2,91 %	5,00 %	2,00 %	2,303
16APSK_2s3	4	0,664	2,657	0,19 %	2,91 %	5,00 %	2,00 %	2,406
16APSK_25s36	4	0,691	2,766	0,19 %	2,91 %	5,00 %	2,00 %	2,505
16APSK_13s18	4	0,719	2,877	0,18 %	2,91 %	5,00 %	2,00 %	2,606
16APSK_3s4	4	0,747	2,988	0,17 %	2,91 %	5,00 %	2,00 %	2,707
16APSK_7s9	4	0,775	3,099	0,16 %	2,91 %	5,00 %	2,00 %	2,808
16APSK_4s5	4	0,797	3,188	0,15 %	2,91 %	5,00 %	2,00 %	2,888
16APSK_5s6	4	0,831	3,323	0,15 %	2,91 %	5,00 %	2,00 %	3,011
32APSK_32s45	5	0,708	3,541	0,17 %	2,83 %	5,00 %	2,00 %	3,210
32APSK_11s15	5	0,730	3,652	0,17 %	2,83 %	5,00 %	2,00 %	3,311
32APSK_7s9	5	0,775	3,874	0,16 %	2,83 %	5,00 %	2,00 %	3,512

NOTE 1: BB framing efficiency is calculated taking into account the BB header overhead.
NOTE 2: PL framing efficiency is calculated taking into account the pilots and the PL header overhead.
NOTE 3: Typically, operational constraints enforce minimal guard bands between adjacent DVB-S2X carriers.

5.5.2 DVB-RCS2 Spectral Efficiencies

Table 15 presents the number of information bits transmitted per symbol taking into account only the code rate and the modulation order. However, it is necessary to derive a spectral efficiency metric defined in terms of information bits per second per Hertz for the sake of comparison. To do so, it is necessary to take into account the waveform specificities as well as other additional considerations such as:

- Frame PDU CRC which may induce significant loss in the burst ID with the smallest size in terms of number of information bits.
- Burst framing efficiency taking into account the pilots, preamble and postamble overhead.
- Guard Times which are necessary to avoid inter-user interference between successive transmissions and maintain the close time synchronization loop between the baseband demodulator and the user terminals. The guard time sizing is specific to each scenario (GSO/NGSO, user mobility, user terminal synchronization capabilities). To cover the scenario under study, a typical guard time value has been proposed for both TRF and CTRL burst.
- Carriers roll-off which characterizes the spectral occupancy of the MF-TDMA burst transmission.
- Guard bands between adjacent burst in the same DVB-RCS2 frame are typically not required. However, it does not preclude defining guard bands for other operational reasons between two adjacent channels supporting two independent MF-TDMA systems.

These assumptions and the resulting spectral efficiencies are presented in Table 38.

Note that additional effects can also impact significantly the over-all spectral efficiency:

- In-band control plane signalling loss is difficult to estimate and may change significantly from one implementation to another and from one scenario to the next (mobility, channel conditions, type of traffic, QoS targets). The control plane information includes but may not be limited to Logon PDU allowing a user terminal to request network access and Control PDU allowing to establish and maintain synchronization, send measurements reports, make traffic request.
- Scheduling efficiency is difficult to estimate and may change from one implementation to another as it results from a trade-off between spectral efficiency, user fairness and scheduler induced latency. In particular, it integrates:
    - The optimization of the scheduler allocation based on the DVB-RCS2 frame format.
    - The flexibility to allocate different carrier sizes to different users transmitting in the same frame.

However, it has been decided to ignore these effects in the PHY layer spectral efficiency calculation since their impact can vary significantly from one implementation to another and may negatively affect the comparison between the two technologies by hiding the native waveforms performance within other implementation dependent and very roughly estimated spectral efficiency loss contributions. Such effects are taken into account (at least partially) in the SLS evaluation.

Table 38: DVB-RCS2 Spectral Efficiencies

							Waveform framing efficiency			Waveform spectral occupancy		
Waveform Id	**Burst length [Symb]**	**Payload length [Bytes]**	**Payload length [Symb]**	**Mod [Bit/Symb]**	**Code rate**	**Modcod rate [Bit/Symb]**	**Frame PDU CRC efficiency Loss**	**Burst framing efficiency Loss**	**Guard Time framing efficiency Loss (note 1)**	**Carrier Roll-off [% of symbol rate]**	**Guard Band (note 2) [% of symbol rate]**	**Spectral Efficiency [bits/s/Hz]**
2	262	14	168	2	0,333	0,667	0,143	0,359	0,092	0,20	0,02	0,273
3	536	38	456	2	0,333	0,667	0,053	0,149	0,045	0,20	0,02	0,421
13	1 616	123	1 476	2	0,333	0,667	0,033	0,087	0,007	0,20	0,02	0,479
14	1 616	188	1 504	2	0,500	1,000	0,021	0,069	0,007	0,20	0,02	0,741
15	1 616	264	1 584	2	0,667	1,333	0,015	0,020	0,007	0,20	0,02	1,047
16	1 616	298	1 590	2	0,750	1,499	0,013	0,016	0,007	0,20	0,02	1,184
17	1 616	333	1 599	2	0,833	1,666	0,012	0,011	0,007	0,20	0,02	1,325
18	1 616	355	1 420	3	0,667	2,000	0,011	0,121	0,007	0,20	0,02	1,414
19	1 616	400	1 423	3	0,750	2,249	0,010	0,119	0,007	0,20	0,02	1,595
20	1 616	444	1 422	3	0,833	2,498	0,009	0,120	0,007	0,20	0,02	1,772
21	1 616	539	1 438	4	0,750	2,999	0,007	0,110	0,007	0,20	0,02	2,155
22	1 616	599	1 438	4	0,833	3,332	0,007	0,110	0,007	0,20	0,02	2,396

NOTE 1: The required guard time sizing is specific to each scenario (i.e. GSO/NGSO, user mobility and synchronization requirements).

NOTE 2: The guard bands between adjacent burst in the same DVB-RCS2 frame are typically not required. However, it does not preclude defining guard bands for other operational reasons between two adjacent channels supporting two independent MF-TDMA systems.

5.5.3 NR PDSCH Spectral Efficiencies

To make a fair comparison between the DVB-S2X and the NR PDSCH, the spectral efficiency is expressed in bits per second per Hertz. To do so, it is necessary to take into account the considered waveform configuration such as:

- PDSCH DMRS and PTRS occupancy which are essential to the receiver for synchronization and demodulation.
- The cyclic prefix which is an essential feature of NR to deal with multipath channel and enable one tap equalization.
- The guard band which has been defined in the standard to enable good co-existence conditions between two systems operating in adjacent channel carriers.

Note that to be consistent with DVB-S2X frame which includes a preamble, it would be fair to take also into account the NR PSS/SSS included in SSB occupancy. However, due to the low broadcast periodicity (typically between 10 and 40 ms) and low resource occupation of SSS/PSS, the efficiency loss is expected to be inferior to 0,03 % and therefore has not been considered in the calculation.

The resulting spectral efficiencies are presented in Table 39.

Note that additional effects can also impact significantly the over-all spectral efficiency:

- Control plane overhead which can be modelled as:
    - PDCCH CORESET occupancy: The PDCCH is essential to transmit the control plane information to the UE. The associated spectral efficiency loss depends to the possible configurations to address a GSO-based broadband system for fixed user in FR2.
    - Higher layer signalling loss through PDSCH: Some of the control plane signalling can also be delivered through PDSCH. The associated spectral efficiency loss is very implementation and scenario dependent.
    - PBCH occupancy: The PBCH broadcast is essential for the UE cell acquisition procedure.
- Other PHY signals occupancy:
    - CSI-RS occupancy: The CSI-RS are essential to perform channel measurements and potentially perform precoding.
    - TRS occupancy: The TRS are reference signals used to assist the terminal in tracking and compensating variations in time and frequency that can be optionally enabled.
- Scheduling efficiency is difficult to estimate and may change from one implementation to another as it results from a trade-off between spectral efficiency, user fairness and scheduler induced latency. In particular, it integrates:
    - The allocation per user which may be flexibly sized in terms of bits and resource by the scheduler.
    - The dependence between the scheduler allocation and the code block size and its impact on the demodulation performance.
    - The flexibility to transmit data to multiple users at the same instant over different channel bandwidths at different spectral power density levels.

However, it has been decided to ignore these effects in the PHY layer spectral efficiency calculation since their impact can vary significantly from one higher layer implementation and network configuration to another and may negatively affect the comparison between the two technologies by hiding the native waveforms performance within other implementation dependent and very roughly estimated spectral efficiency loss contributions. Such effects are taken into account (at least partially) in the SLS evaluation.

Table 39: NR PDSCH Spectral efficiencies

					PDSCH framing efficiency				**Waveform spectral occupancy**	
MCS Index	**Mod. [Bit/ Symb]**	**Coding Rate**	**Effective Coding Rate (note 1)**	**MCS rate [bits/symb]**	**TB CRC Framing efficiency loss (note 2)**	**PDSCH DMRS Framing efficiency loss (note 3)**	**PDSCH PTRS Framing efficiency loss (note 4)**	**Cyclic Prefix Framing Efficiency Loss (note 5)**	**Guard Band (note 6) [% Symbol Rate]**	**Spectral Efficiency [bit/s/Hz]**
0	2	0,03	0,03	0,06	1,29 %	2,38 %	0,00 %	7,14 %	5,16 %	0,05
1	2	0,04	0,04	0,08	0,99 %	2,38 %	0,00 %	7,14 %	5,16 %	0,06
2	2	0,05	0,05	0,10	0,82 %	2,38 %	0,00 %	7,14 %	5,16 %	0,08
3	2	0,06	0,06	0,13	0,82 %	2,38 %	0,00 %	7,14 %	5,16 %	0,11
4	2	0,08	0,08	0,15	0,82 %	2,38 %	0,00 %	7,14 %	5,16 %	0,13
5	2	0,10	0,10	0,19	0,82 %	2,38 %	0,00 %	7,14 %	5,16 %	0,16
6	2	0,12	0,12	0,23	0,82 %	2,38 %	0,00 %	7,14 %	5,16 %	0,20
7	2	0,15	0,15	0,30	0,82 %	2,38 %	0,00 %	7,14 %	5,16 %	0,26
8	2	0,19	0,19	0,38	0,82 %	2,38 %	0,89 %	7,14 %	5,16 %	0,32
9	2	0,25	0,24	0,48	0,82 %	2,38 %	0,93 %	7,14 %	5,16 %	0,41
10	2	0,30	0,29	0,58	0,56 %	2,38 %	0,91 %	7,14 %	5,16 %	0,49
11	2	0,37	0,35	0,71	0,56 %	2,38 %	0,92 %	7,14 %	5,16 %	0,60
12	2	0,44	0,42	0,85	0,56 %	2,38 %	0,92 %	7,14 %	5,16 %	0,72
13	2	0,51	0,50	1,00	0,55 %	2,38 %	0,93 %	7,14 %	5,16 %	0,85
14	2	0,59	0,57	1,14	0,56 %	2,38 %	0,93 %	7,14 %	5,16 %	0,97
15	4	0,33	0,32	1,29	0,55 %	2,38 %	1,87 %	7,14 %	5,16 %	1,08
16	4	0,37	0,36	1,42	0,55 %	2,38 %	1,88 %	7,14 %	5,16 %	1,20
17	4	0,42	0,41	1,64	0,56 %	2,38 %	1,79 %	7,14 %	5,16 %	1,38
18	4	0,48	0,46	1,85	0,53 %	2,38 %	1,90 %	7,14 %	5,16 %	1,56
19	4	0,54	0,52	2,08	0,55 %	2,38 %	1,92 %	7,14 %	5,16 %	1,75
20	4	0,60	0,58	2,32	0,53 %	2,38 %	3,87 %	7,14 %	5,16 %	1,91
21	6	0,43	0,41	2,46	0,55 %	2,38 %	4,22 %	7,14 %	5,16 %	2,01
22	6	0,46	0,44	2,62	0,56 %	2,38 %	3,87 %	7,14 %	5,16 %	2,16
23	6	0,50	0,49	2,91	0,56 %	2,38 %	4,30 %	7,14 %	5,16 %	2,39
24	6	0,55	0,53	3,18	0,52 %	2,38 %	4,30 %	7,14 %	5,16 %	2,60
25	6	0,60	0,58	3,48	0,53 %	2,38 %	3,87 %	7,14 %	5,16 %	2,86
26	6	0,65	0,62	3,75	0,56 %	2,38 %	4,42 %	7,14 %	5,16 %	3,07
27	6	0,70	0,68	4,08	0,52 %	2,38 %	4,42 %	7,14 %	5,16 %	3,34
28	6	0,75	0,73	4,37	0,56 %	2,38 %	3,87 %	7,14 %	5,16 %	3,60

					PDSCH framing efficiency				Waveform spectral occupancy	
MCS Index	**Mod. [Bit/ Symb]**	**Coding Rate**	**Effective Coding Rate (note 1)**	**MCS rate [bits/symb]**	**TB CRC Framing efficiency loss (note 2)**	**PDSCH DMRS Framing efficiency loss (note 3)**	**PDSCH PTRS Framing efficiency loss (note 4)**	**Cyclic Prefix Framing Efficiency Loss (note 5)**	**Guard Band (note 6) [% Symbol Rate]**	**Spectral Efficiency [bit/s/Hz]**

NOTE 1: Effective Coding rate is the ratio of the transport block size plus the CRC size and the number of coded bits at 5G NR encoder output.

NOTE 2: CRC loss is the ratio of the CRC size and the transport block size plus the CRC size assuming TB segmentation is not required.

NOTE 3: PDSCH DMRS loss is calculated taking into account the time density and the frequency density of the DRMS in the PDSCH resource grid. Based on the simulated PDSCH waveform configuration, the PDSCH DRMS loss has the same value for each MCS index.

NOTE 4: PDSCH PTRS loss is also calculated taking into account the time density and the frequency density of the PTRS in the PDSCH grid. Since the PTRS configuration is a function of the MCS index and the allocated PDSCH resource blocks, the PDSCH PTRS loss is also a function of these two parameters. In consequence, there are different values of the PDSCH PTRS loss according to the MCS index and the allocated PDSCH resource blocks.

NOTE 5: Cyclic Prefix loss is the ratio of the Cyclic Prefix time duration and the symbol time duration. The Cyclix Prefix time duration of the long symbols is combined to the Cyclic Prefix time duration of the classic symbols in the Cyclix Prefix time duration calculation.

NOTE 6: Guardband loss is calculated using the minimum guard bands specified in Table 5.3.3-1 of ETSI TS 138 101-2 [i.22] and the channel bandwidth.

5.5.4 NR PUSCH Spectral Efficiencies

To make a fair comparison between the DVB-RCS2 and the NR PUSCH, the spectral efficiency is expressed in bits per second per Hertz. To do so, it is necessary to take into account the considered waveform configuration such as:

- PUSCH DMRS and PTRS occupancy which are essential to the receiver for synchronization and demodulation.
- The cyclic prefix which is an essential feature of NR to deal with multipath channel and enable one tap equalization.
- Standardized guard band which have been defined in the standard to enable good co-existence conditions between two systems operating in adjacent channel carriers.

The resulting spectral efficiencies are presented in Table 40 which correspond to the spectral efficiencies considering numerologies 2 and 3, respectively.

Note that additional effects can also impact significantly the over-all spectral efficiency:

- Control plane overhead which can be modelled as:
  - PUCCH occupancy: The PUCCH is used by the device to send hybrid-ARQ acknowledgments, indicating to the gNB whether the downlink transport block(s) was successfully received or not, to send channel-state reports aiding downlink channel-dependent scheduling, and for requesting resources to transmit uplink data upon. The associated spectral efficiency loss depends to the possible configurations to address a GSO-based broadband system for fixed user in FR2.
  - PRACH occupancy: The PRACH carries random access preambles used to initiate the random access procedures.
- Other PHY signals occupancy:
  - SRS occupancy: The SRS helps the gNB to obtain the Channel State Information (CSI) for each user.

However, it has been decided to ignore these effects in the PHY layer spectral efficiency calculation since their impact can vary significantly from one higher layer implementation and network configuration to another and may negatively affect the comparison between the two technologies by hiding the native waveforms performance within other implementation dependent and very roughly estimated spectral efficiency loss contributions. Such effects are taken into account (at least partially) in the SLS evaluation.

Table 40: 5G NR PUSCH Spectral efficiencies

							PUSCH framing efficiency						**Waveform spectral occupancy**			
MCS Index	**Mod. [Bit/Symb]**	**Coding Rate**	**Effective Coding Rate (note 1)**		**MCS rate [bits/symb]**		**TB CRC framing efficiency loss (note 2)**		**PUSCH PTRS framing efficiency loss (note 3)**		**PUSCH DMRS framing efficiency loss (note 4)**	**Cyclic Prefix Framing Efficiency Loss (note 5)**	**Guard Band (note 6) [% Symbol Rate]**	**Spectral Efficiency [bit/s/Hz]**	**Spectral Efficiency [bit/s/Hz]**
			NRBs = 4	**NRBs = 40**	**NRBs = 4**	**NRBs = 40**	**NRBs = 4**	**NRBs = 40**	**NRBs = 4**	**NRBs = 40**				**NRBs = 4**	**NRBs = 40**
0	2	0,03	0,026	0,029	0,051	0,059	50,00 %	4,35 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,021	0,046
1	2	0,04	0,038	0,038	0,077	0,077	33,33 %	3,33 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,042	0,061
2	2	0,05	0,045	0,049	0,090	0,097	28,57 %	2,63 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,053	0,078
3	2	0,06	0,058	0,065	0,115	0,129	22,22 %	1,98 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,074	0,104
4	2	0,08	0,071	0,079	0,141	0,158	18,18 %	1,69 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,095	0,127
5	2	0,10	0,096	0,098	0,192	0,196	13,33 %	1,31 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,137	0,159
6	2	0,12	0,115	0,119	0,231	0,237	11,11 %	1,08 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,168	0,192
7	2	0,15	0,147	0,154	0,295	0,309	8,70 %	0,83 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,221	0,251
8	2	0,19	0,192	0,193	0,385	0,386	6,67 %	0,66 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,294	0,314
9	2	0,25	0,244	0,249	0,487	0,497	5,26 %	0,52 %	0,00 %	0,00 %	7,14 %	7,14 %	5,19 %	0,378	0,406
10	2	0,30	0,295	0,301	0,590	0,601	4,35 %	0,43 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	0,445	0,483
11	2	0,37	0,365	0,369	0,731	0,738	3,51 %	0,52 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	0,556	0,593
12	2	0,44	0,442	0,441	0,885	0,882	2,90 %	0,44 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	0,677	0,709
13	2	0,51	0,513	0,513	1,026	1,026	2,50 %	0,38 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	0,788	0,825
14	2	0,59	0,590	0,585	1,179	1,169	2,17 %	0,33 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	0,910	0,941
15	2	0,66	0,679	0,656	1,359	1,313	1,89 %	0,29 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	1,051	1,057
16	4	0,37	0,372	0,370	1,487	1,478	1,72 %	0,78 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	1,152	1,184
17	4	0,42	0,426	0,421	1,705	1,683	1,50 %	0,69 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	1,324	1,349
18	4	0,48	0,478	0,482	1,910	1,929	1,34 %	0,60 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	1,486	1,548
19	4	0,54	0,542	0,544	2,167	2,176	1,18 %	0,53 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	1,688	1,747
20	4	0,60	0,619	0,605	2,474	2,422	1,04 %	0,48 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	1,930	1,945
21	4	0,64	0,644	0,646	2,577	2,586	1,00 %	0,45 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	2,011	2,078
22	4	0,68	0,696	0,677	2,782	2,708	0,92 %	0,43 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	2,173	2,176
23	4	0,75	0,772	0,760	3,090	3,038	0,83 %	0,51 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	2,415	2,440
24	6	0,55	0,558	0,547	3,346	3,285	0,77 %	0,47 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	2,617	2,639
25	6	0,60	0,609	0,602	3,654	3,612	0,70 %	0,43 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	2,860	2,903
26	6	0,65	0,660	0,656	3,962	3,938	0,65 %	0,39 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	3,102	3,166
27	6	0,75	0,763	0,752	4,577	4,514	0,56 %	0,43 %	3,57 %	1,43 %	7,14 %	7,14 %	5,19 %	3,587	3,628

							PUSCH framing efficiency						Waveform spectral occupancy		
MCS Index	Mod. [Bit/Symb]	Coding Rate	Effective Coding Rate (note 1)		MCS rate [bits/symb]		TB CRC framing efficiency loss (note 2)		PUSCH PTRS framing efficiency loss (note 3)		PUSCH DMRS framing efficiency loss (note 4)	Cyclic Prefix Framing Efficiency Loss (note 5)	Guard Band (note 6) [% Symbol Rate]	Spectral Efficiency [bit/s/Hz]	Spectral Efficiency [bit/s/Hz]
			NRBs = 4	NRBs = 40	NRBs = 4	NRBs = 40	NRBs = 4	NRBs = 40	NRBs = 4	NRBs = 40				NRBs = 4	NRBs = 40

NOTE 1: Effective Coding rate is the ratio of the transport block size plus the CRC size and the number of coded bits at 5G NR encoder output.

NOTE 2: TB CRC framing efficiency loss is the ratio of the CRC size and the transport block size plus the CRC size.

NOTE 3: PUSCH PTRS framing efficiency loss is also calculated taking into account the time density and the frequency density of the PTRS in the PUSCH grid. Since the PTRS configuration is a function of the allocated PUSCH resource blocks when performing DFT-s-OFDM, the PUSCH PTRS loss is also a function of this parameter. In consequence, there are different values of the PUSCH PTRS loss according to the allocated PUSCH resource blocks.

NOTE 4: PUSCH DMRS framing efficiency loss is calculated taking into account the time density and the frequency density of the DRMS in the PUSCH resource grid. Based on the simulated PUSCH waveform configuration, the PUSCH DRMS loss has the same value for each MCS index.

NOTE 5: Cyclic Prefix framing efficiency loss is the ratio of the Cyclic Prefix time duration and the symbol time duration. The Cyclix Prefix time duration of the long symbols is combined to the Cyclic Prefix time duration of the classic symbols in the Cyclix Prefix time duration calculation.

NOTE 6: Guardband loss is calculated using the minimum guard band specified in Table 5.3.3-1 of ETSI TS 138 101-2 V18.0.0 [i.22] and the channel bandwidth.

5.6 Link Level Comparison

5.6.1 DVB-S2X vs NR PDSCH demodulation performance comparison

5.6.1.1 General

Figure 18 presents a comparison between DVB-S2X spectral efficiencies (expressed in terms of bits/symbol) and demodulation performance with respect to NR PDSCH spectral efficiencies (expressed in terms of bit/symbol) and demodulation performance in AWGN conditions without impairments and considering a perfectly synchronized receiver. Therefore, these curves are the results of the modulation and coding scheme performance of both technologies.

When considering a FER/BLER target of 1e-3, a degradation of SNR ranging from 0 dB to 1 dB in disfavour of 5G NR is observed to achieve the same level of spectral efficiency. This becomes evident for spectral efficiency greater than 2,5 bits/symbol.

The degradation in SNR observed in disfavour of 5G NR varies from 0 dB to 2,2 dB when considering a FER/BLER target of 1e-5. This demonstrates a significant increase in the gap of up to 1,2 dB when moving from a FER/BLER target of 1e-3 to 1e-5. This becomes evident for spectral efficiency greater than 1,5 bits/symbol.

It appears that FER/BLER vs SNR FEC curve are much more steep for DVB-S2X than for 5G NR PDSCH. Therefore, when the required SNR remains almost at the same level for DVB-S2X between a FER target of 1e-3 and 1e-5, a significant SNR increase is observed in case of 5G NR PDSCH.

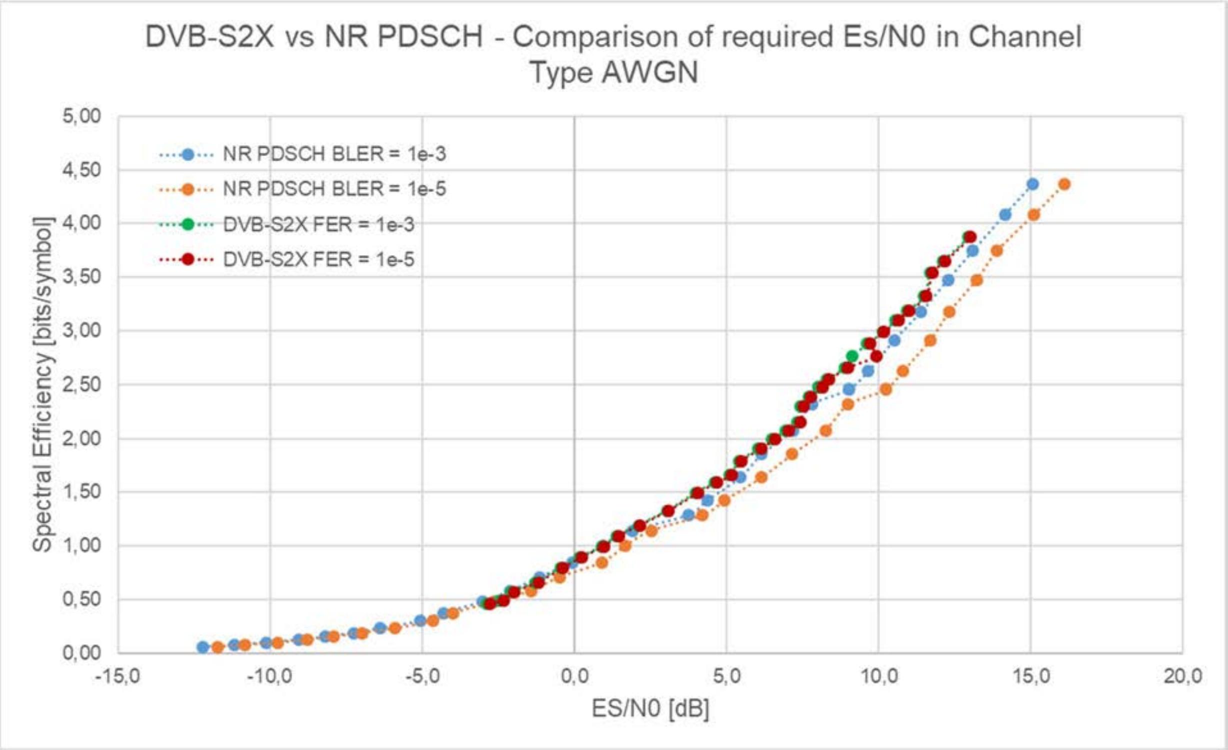

Figure 18: DVB-S2X vs NR PDSCH - Comparison of required Es/N0 in Channel Type AWGN

Figure 19 presents a comparison between DVB-S2X spectral efficiencies (expressed in terms of bits/symbol) and demodulation performance with respect to NR PDSCH spectral efficiencies (expressed in terms of bit/symbol) and demodulation performance in AWGN conditions with impairments (Channel Type A). Therefore, **these curves reflect the additional impact of implementation losses and impairments degradations on both technologies**.

In channel Type A conditions without Non Linear Amplifier, the performance gap remains in disfavour of 5G NR with an additional degradation of few tenths of dB.

The degradation in SNR observed to achieve the same level of spectral efficiency varies from 0 dB to 2,1 dB for a FER/BLER target of 1e-3 and from 0 dB to 2,6 dB for a FER/BLER target of 1e-5.

Finally, one can observe that the impairments of the channel Type A excluding the impact of Non Linear Amplifier increase the performance gap between DVB-S2X and 5G NR meaning that implementation losses and impairments sensitivity are higher for NR. This results from the selection of the 5G NR channel estimation methodology as explained in the next clause.

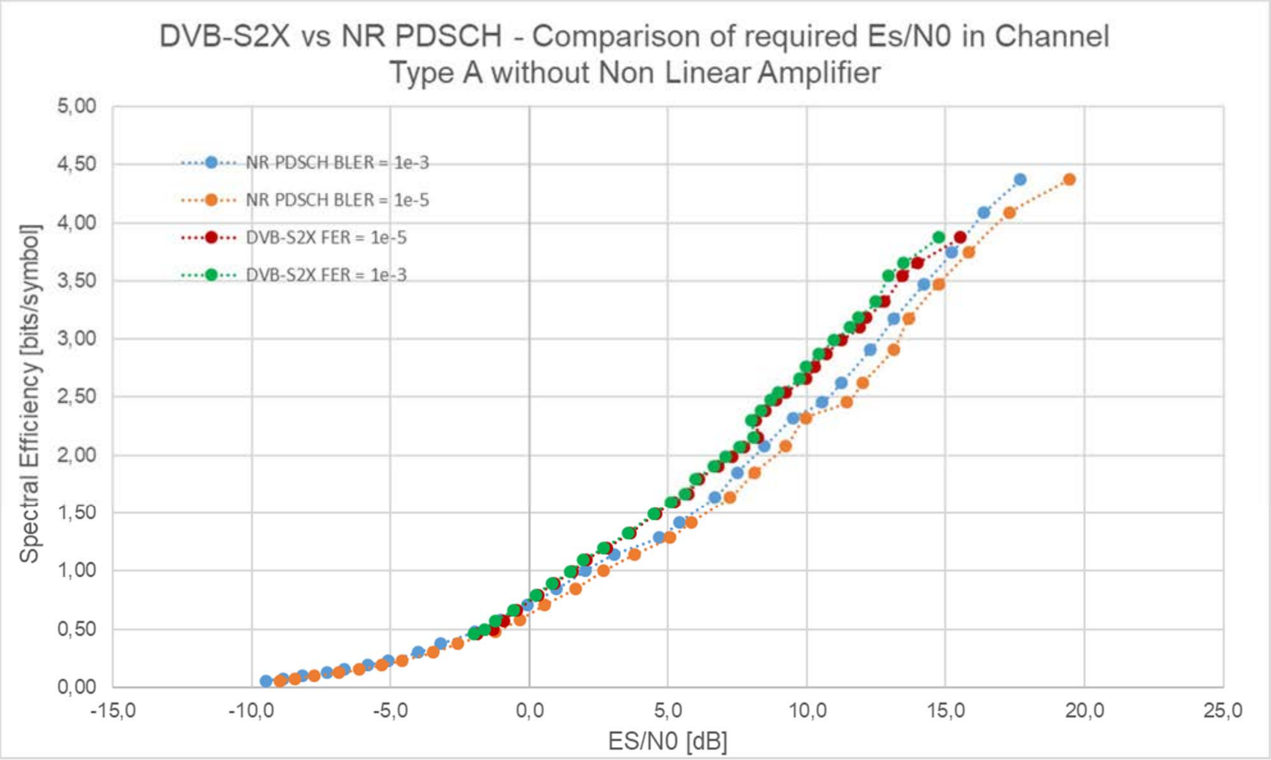

Figure 19: DVB-S2X vs NR PDSCH - Comparison of required Es/N0 in Channel Type A conditions without Non Linear Amplifier

The comparison is carried out by using spectral efficiencies expressed in terms of bits/s/Hz and taking into account the spectral occupancy and the framing efficiency of both technologies. Figure 20 and Figure 21 present a comparison between DVB-S2X spectral efficiencies (expressed in terms of bits/s/Hz) and demodulation performance with respect to NR PDSCH spectral efficiencies (expressed in terms of bits/s/Hz) and demodulation performance in AWGN conditions without impairments (see Figure 20) and in channel Type A without Non Linear Amplifier (see Figure 21). **These curves reflect the additional impacts of spectral occupancy and framing efficiency** (pilots overhead, encapsulation loss, …).

In AWGN conditions, the observed SNR degradation in disfavour of 5G NR to achieve the same level of spectral efficiency expressed in terms of bits/s/Hz varies from 0 dB to 2 dB for a FER/BLER target of 1e-3, and from 0 dB to 2,5 dB for a FER/BLER target of 1e-5. This increased loss has been magnified by the higher physical layer overhead of the 5G NR waveform with respect to the DVB-S2X technology.

The performance gap remains in disfavour of 5G NR when considering the channel Type A without Non Linear Amplifier. The observed SNR degradation to achieve the same level of spectral efficiency expressed in bits/s/Hz varies from 0 dB to 3 dB for a FER/BLER target of 1e-3, and from 0 dB to 3,2 dB for a FER/BLER target of 1e-5.

Therefore, the impact of spectral occupancy and framing efficiency tend to increase the performance gap between both technologies.

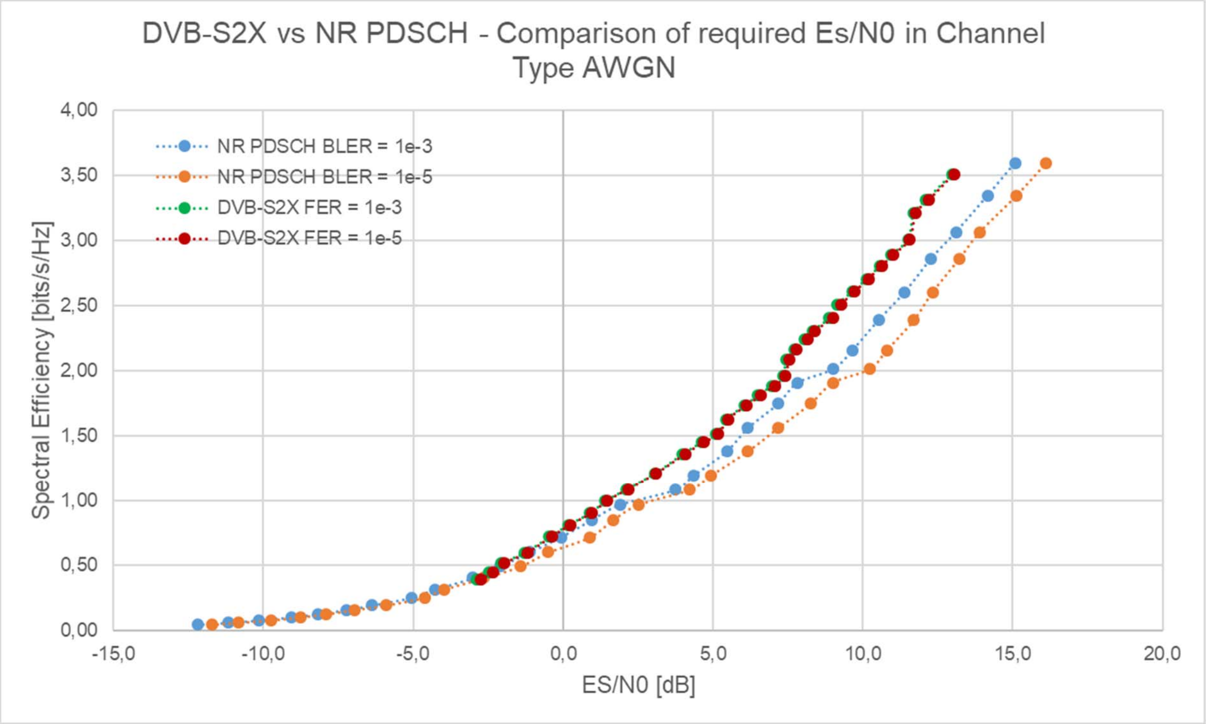

Figure 20: DVB-S2X vs NR PDSCH - Comparison of required Es/N0 in Channel Type AWGN - Spectral efficiency in bits/s/Hz

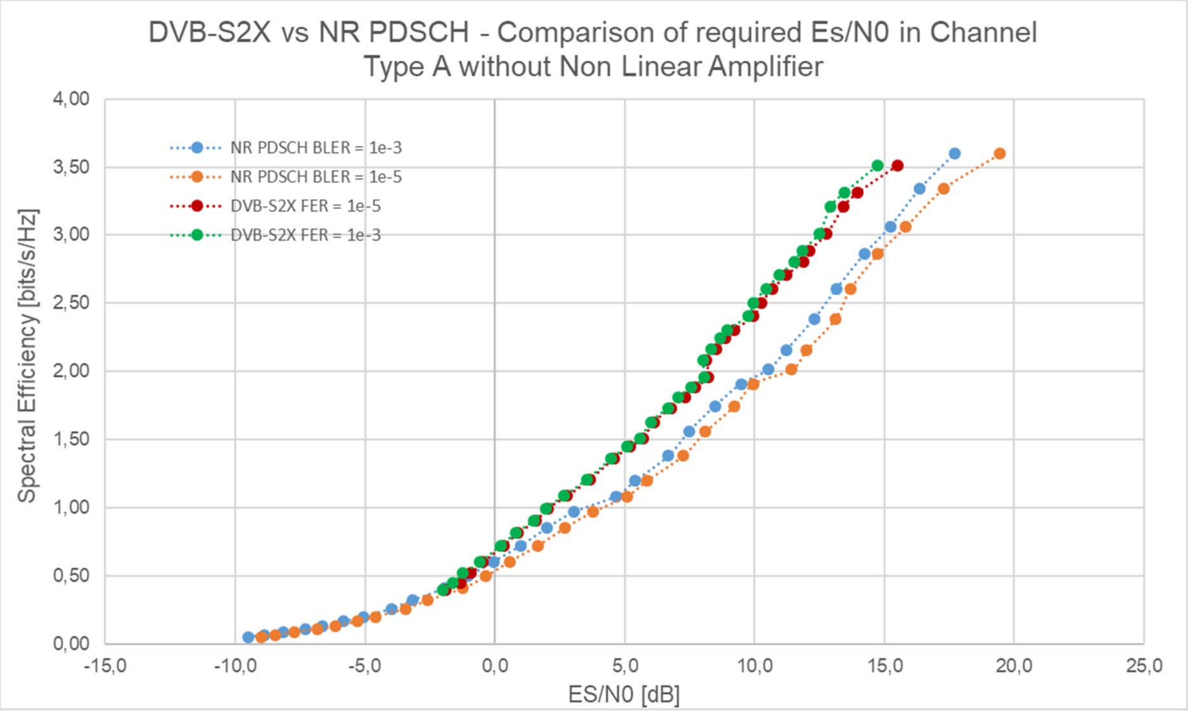

Figure 21: DVB-S2X vs NR PDSCH - Comparison of required Es/N0 in Channel Type A conditions without Non Linear Amplifier - Spectral efficiency in bits/s/Hz

5.6.1.2 DVB-S2X vs NR PDSCH demodulation performance comparison summary

The observed performance gaps in favour of DVB-S2X are mainly explained by the following factors:

- The lower performance of the NR LDPC coding scheme especially at low FER/BLER targets:
    - This is explained by the fact that NR was not primarily designed to reach such low BLER targets in a single transmission and therefore does not implement concatenated coding scheme unlike DVB-S2X.
    - This is also due to the lower number of information bits per LDPC code block in case of NR transport block transmissions which varies approximatively from 1 200 bits to 4 000 bits depending on the MCS index considered (see Table 19) w.r.t. the number of information bits inside a DVB-S2X NORMAL BBFRAME which varies approximatively from 15 000 bits to 55 000 bits depending on the MODCOD considered.
- The NR lower framing efficiency due to higher reference symbol overhead specifically for the high MCS indexes for which the PTRS overhead may become significant as well as CP related efficiency loss. Indeed, when comparing in bits/symbol (i.e. without the impact of the physical layer overhead), it can be observed that Figure 18 and Figure 19 show a reduced gap between the two technologies. As a reminder, the MODCOD/MCS rate are expressed in terms of bits per symbol and only integrate the modulation order and the effective coding rate effects.
- The higher impairments sensitivity and implementation losses for NR. This seems to be the factor with the least impact on the performance gap:
    - This is probably mainly explained by the nature of the receiver architecture. The NR receiver is based on a slot per slot demodulation process depending on the network grants. Each slot is demodulated independently w/o knowledge about previous slots demodulation. The DVB-S2X receiver is based on a continuous frame demodulation process. Every frame is used to feed loop based acquisition and tracking algorithms.

However, several NR PDSCH optimizations are recommended to reduce the performance gap observed at the physical layer level w.r.t. DVB-S2X:

- Further optimize the DMRS and PTRS configuration for each MCS to find the best compromise between the induced overhead and the level of degradation due to impairments and channel estimation inaccuracy.
- Enhance the NR receiver in order to take advantage of the past PDSCH demodulations and the periodical broadcast of reference signal (SSB, CSI-RS, …).
- Adjust the NR PDSCH allocation to target a higher number of information bits per code block. In a high traffic scenario, it should be possible to be closer to Kcb than Kcb/2.

Finally, this PHY layer comparison of NR PDSCH and DVB-S2X is carried out through SLS evaluation by taking into consideration higher layer aspects such as control plane overhead and achievable scheduling efficiency for both technologies.

5.6.2 DVB-S2X vs NR PDSCH: PAPR and C/Im Comparison

5.6.2.1 Peak To Average Power Ratio

With the active antenna payload architecture and the multi beam coverage assumptions, it is reasonable to assume that each satellite amplifier amplifies tens of carriers in case of DVB-S2X based transmissions or thousands of OFDM subcarriers in case of 5G NR based transmissions. Moreover, since the payload design is based on an active antenna and satellite beamforming capabilities, the carriers amplified within the same amplifier will even share the same frequency resources when they have been applied different beamforming coefficients.

Furthermore, the power envelope fluctuation to cope with at the amplifier input is very similar for OFDM based signal and multi DVB-S2X carriers based signal as soon as the number of uncorrelated DVB-S2X carriers in the amplified bandwidth is higher than ten as illustrated in Figure 22.

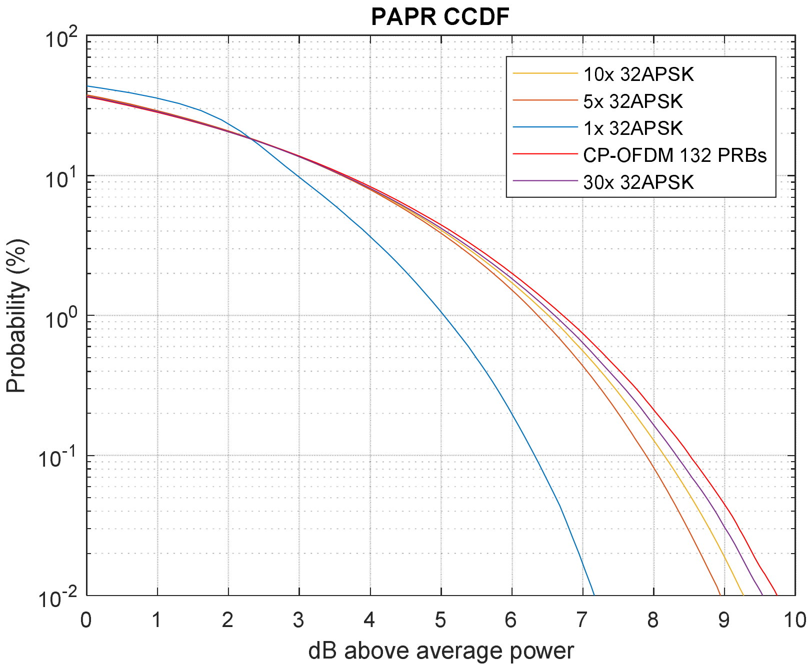

Figure 22: Comparison of PAPR distribution of CP-OFDM transmission and single or multi DVB-S2X carriers transmissions

In conclusion, the power envelope fluctuation to cope with at the high power amplifier chain input is waveform agnostic in case of satellite payload designs based on active antenna. Therefore, the performance in terms of intermodulation noise level at the HPA output is expected to be very similar for both DVB-S2X and NR PDSCH.

However, for the use cases for which the number of carriers (NR or DVB-S2X) per satellite amplifier is lower, then the PAPR is going to be lower for DVB-S2X with respect to NR. In these conditions, depending on how the amplifier is operated, one can expect less nonlinear distortions and/or better power efficiency in Favor of DVB-S2X.

5.6.2.2 C/IM vs IBO/OBO

The achievable performance in terms of conducted C/Im assuming the satellite HPA characteristics have been evaluated for different points of operation. The input signal is either composed of several hundreds of NR CP-OFDM subcarriers or 32 DVB-S2X carriers.

Due to the satellite active antenna architecture and the multi beam coverage assumptions, it is assumed that a gain of 5 dB can be expected between conducted and radiated C/Im.

The results are summarized in Figure 23.

One can observe that the C/Im performance are very similar for both cases with small gain of 0,1 dB to 0,3 dB in favour of DVB-S2X. It is expected that increasing the number of DVB carriers in the amplifier will make this gain disappear.

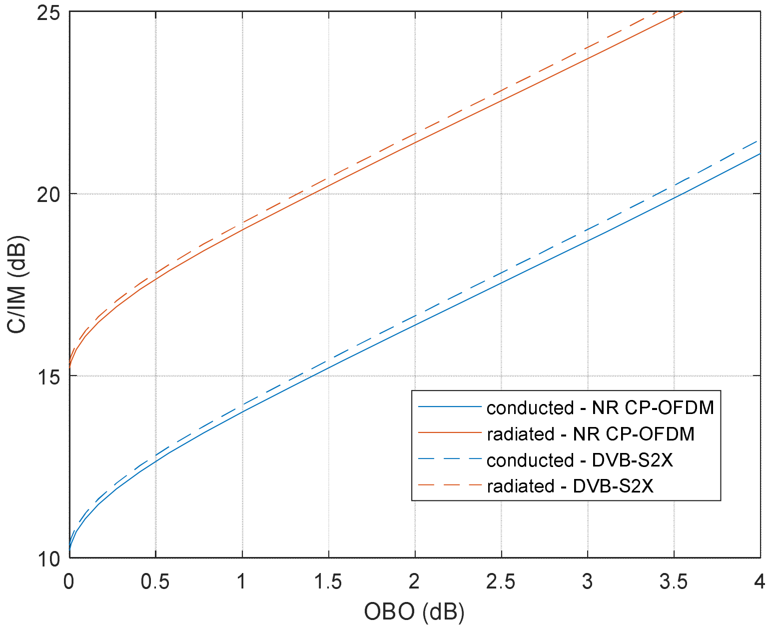

Figure 23: C/Im vs OBO performance comparison between NR CP-OFDM and DVB-S2X

5.6.3 DVB-RCS2 vs NR PUSCH demodulation performance comparison

5.6.3.1 Allocated bandwidth of 28 MHz

Figure 24 presents a comparison between DVB-RCS2 spectral efficiencies (expressed in terms of bit/symbol) and demodulation performance with respect to NR PUSCH spectral efficiencies (expressed in terms of bit/symbol) and demodulation performance in AWGN conditions without impairments and considering a perfectly synchronized receiver. Therefore, these curves are the results of the modulation and coding scheme performance of both technologies.

When considering a PER/BLER target of 1e-3, a degradation of SNR ranging from 0,1 dB to 1,2 dB in favour of NR PUSCH is observed to achieve the same level of spectral efficiency expressed in terms of bit/symbol. Considering a PER/BLER target of 1e-5, there is no significant difference between DVB-RCS2 and NR PUSCH for spectral efficiencies below 1,5 bits/symbol. However, one can observe a degradation of SNR ranging from 0,1 dB to 0,6 dB in disfavour of NR PUSCH for spectral efficiencies greater than 1,5 bits/symbol, except for DVB-RCS2 ID20.

It appears that PER/BLER vs SNR FEC curve are more steep for DVB-RCS2 than for NR PUSCH. Therefore, when the maximum SNR deviation is around 0,5 dB for DVB-RCS2 between a PER target of 1e-3 and 1e-5, an increase in SNR is observed in case of NR PUSCH up to 1,1 dB between a BLER target of 1e-3 and 1e-5.

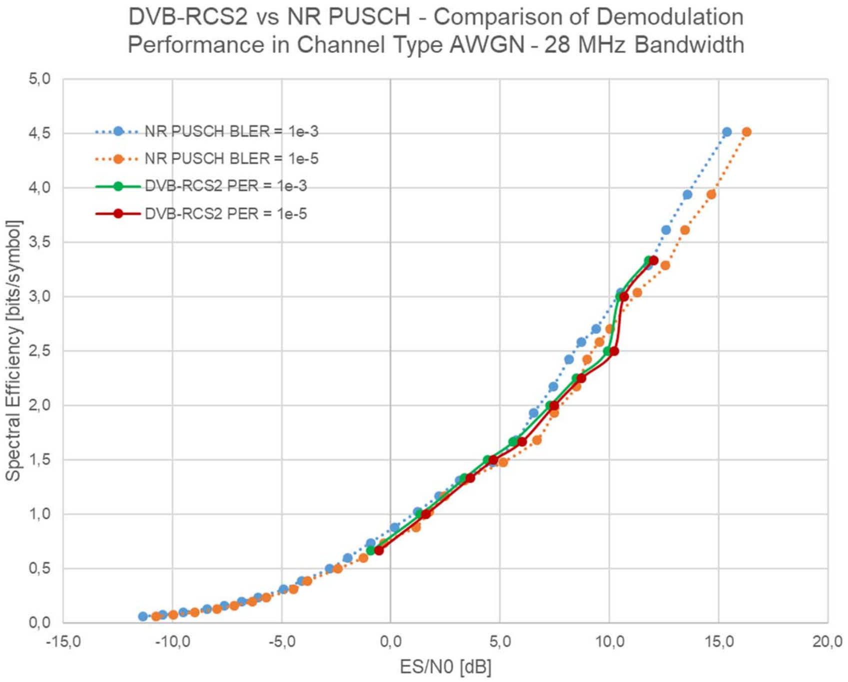

Figure 24: DVB-RCS2 vs NR PUSCH - Comparison of required Es/N0 in Channel Type AWGN - 28 MHz Allocated Bandwidth

Figure 25 presents a comparison between DVB-RCS2 spectral efficiencies (expressed in terms of bits/symbol) and demodulation performance with respect to NR PUSCH spectral efficiencies (expressed in terms of bit/symbol) and demodulation performance in channel Type A conditions. Therefore, **these curves reflect the additional impact of implementation losses and impairments degradations on both technologies**.

In channel Type A conditions without Non Linear Amplifier, there is no significant difference DVB-RCS2 and NR PUSCH considering a FER/BLER target of 1e-3. However, the DVB-RCS2 shows a better demodulation performance when considering a FER/BLER target of 1e-5. The performance gap in favour of DVB-RCS2 ranges from 0,1 dB to 1,0 dB to achieve the same spectral efficiency.

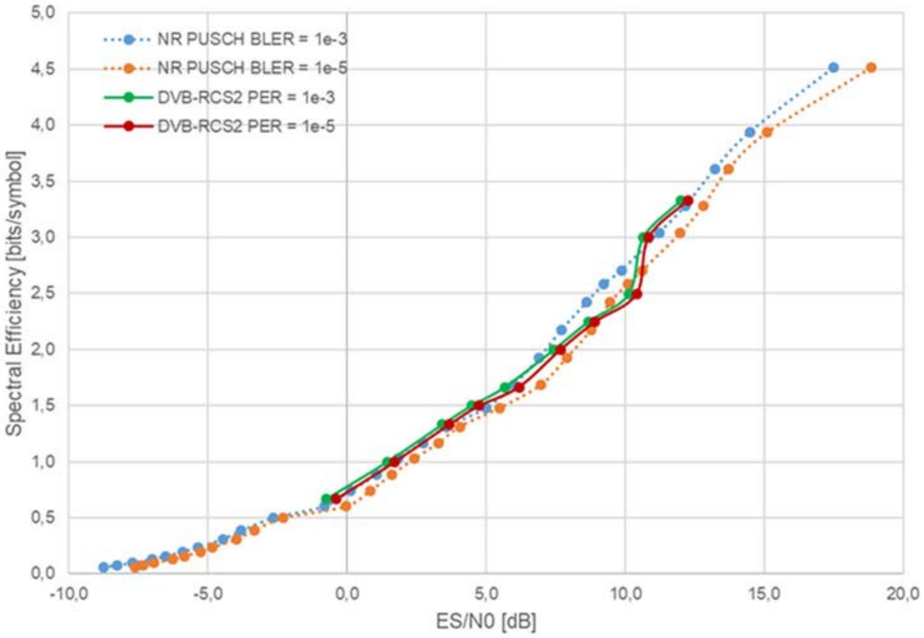

Figure 25: DVB-RCS2 vs NR PUSCH - Comparison of required Es/N0 in Channel Type A - 28 MHz allocated Bandwidth

The comparison is carried out by using spectral efficiencies expressed in terms of bits/s/Hz and taking into account the spectral occupancy and the framing efficiency of both technologies. Figure 26 presents a comparison between DVB-RCS2 spectral efficiencies (expressed in terms of bits/s/Hz) and demodulation performance with respect to NR PUSCH spectral efficiencies (expressed in terms of bits/s/Hz) and demodulation performance in AWGN conditions. **These curves reflect the additional impacts of spectral occupancy and framing efficiency** (pilots overhead, encapsulation loss, …).

In AWGN conditions, the observed SNR degradation in disfavour of DVB-RCS2 to achieve the same level of spectral efficiency expressed in terms of bits/s/Hz varies from 0 dB to 2,5 dB for a PER/BLER target of 1e-3, and from 0 dB to 1,7 dB for a PER/BLER target of 1e-5. The gap between the two technologies is amplified by the higher physical layer overhead of the DVB-RCS2 waveform with respect to the NR PUSCH waveform.

The performance gap remains generally in favour of NR PUSCH when considering the channel Type A without Non Linear Amplifier (see Figure 27). One can observe the same performance between the two technologies for spectral efficiencies below 1,4 bits/s/Hz. For spectral efficiencies above 1,4 bits/s/Hz, a better performance of NR PUSCH compared to DVB-RCS2 is observed. The induced SNR degradation to achieve the same level of spectral efficiency expressed in bits/s/Hz varies from 0,5 dB to 2,2 dB for a BLER target of 1e-3, and from 0,1 dB to 1,6 dB for a BLER target of 1e-5.

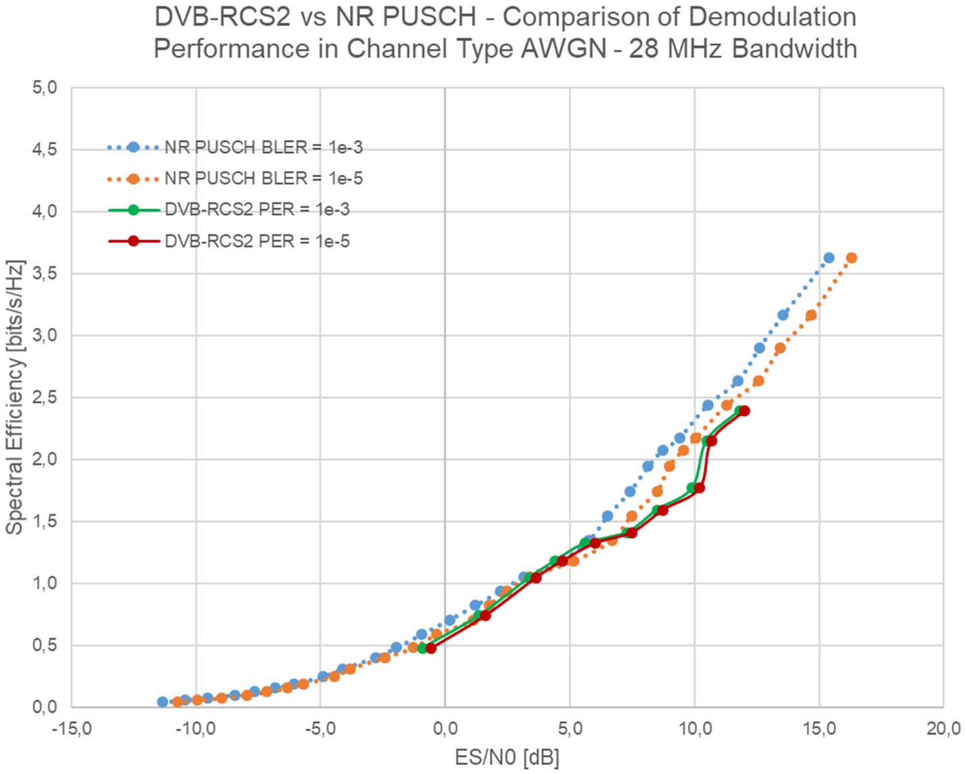

Figure 26: DVB-RCS2 vs NR PUSCH - Comparison of required Es/N0 in Channel Type AWGN - 28 MHz Allocated Bandwidth - Spectral Efficiency in Bits/s/Hz

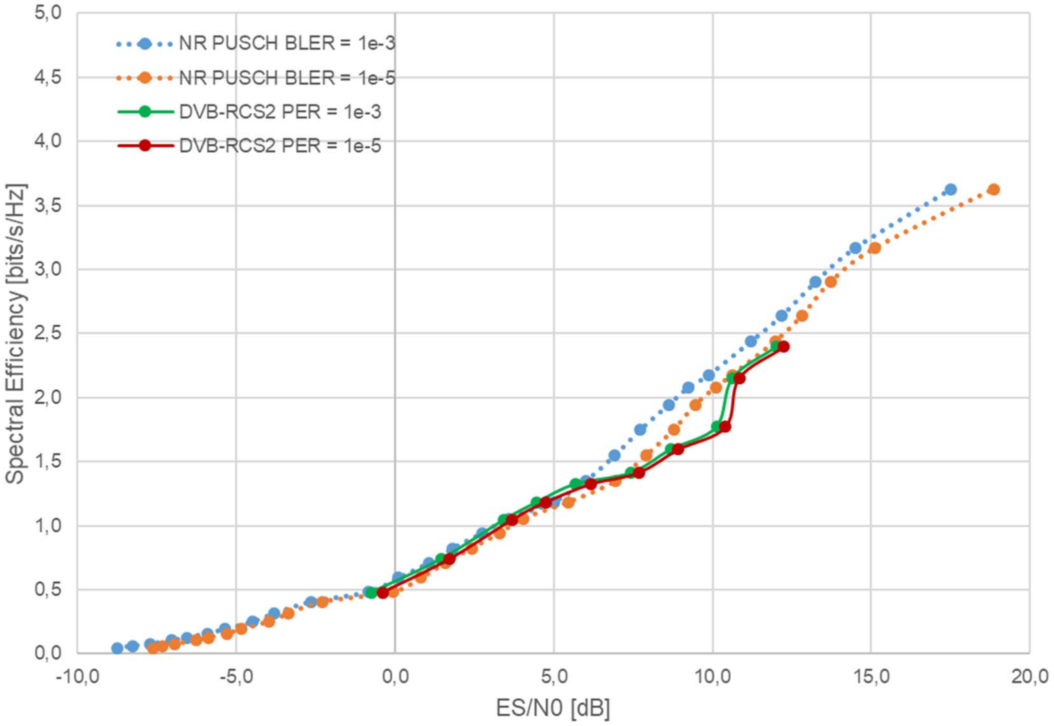

Figure 27: DVB-RCS2 vs NR PUSCH - Comparison of required Es/N0 in Channel Type A - 28 MHz Allocated Bandwidth - Spectral Efficiency in Bits/s/Hz

5.6.3.2 DVB-RCS2 vs NR PUSCH demodulation performance in AWGN conditions comparison summary

The observed performance gaps between DVB-RCS2 and NR PUSCH are mainly explained by the following factors:

- Allocated bandwidth of 28 MHz:
  - Spectral efficiency in bit/symbol:
    - The better FEC performance of the NR PUSCH with respect to DVB-RCS2 when considering a PER/BLER target of 1e-3 as illustrated by Figure 24.
    - No significant difference in terms of FEC performance between DVB-RCS2 and NR PUSCH for a PER/BLER target of 1e-5 as illustrated by Figure 24.
    - Same demodulation performance in channel Type A conditions between DVB-RCS2 and NR PUSCH for a PER/BLER target of 1e-3. However, the DVB-RCS2 shows a better demodulation performance when considering a PER/BLER target of 1e-5.
  - Spectral efficiency in bit/s/Hz:
    - Better FEC performance of NR PUSCH due to the DVB-RCS2 lower framing efficiency especially the higher roll-off overhead as illustrated by Figure 26.
    - Same demodulation performance in channel Type A conditions between the two technologies for spectral efficiencies below 1,4 bits/s/Hz as illustrated by Figure 27.
    - Better demodulation performance in channel Type A conditions of the NR PUSCH with respect to DVB-RCS2 for spectral efficiencies above 1,4 bits/s/Hz as illustrated by Figure 27.

Finally, this PHY layer comparison of NR PUSCH and DVB-RCS2 is carried out through SLS evaluation by taking into consideration higher layer aspects such as control plane overhead and achievable scheduling efficiency for both technologies.

Note that the overhead of DVB-RCS2 may be penalized when considering 20 % roll-off given that DVB forum is currently defining an improved roll off of 5 %.

5.6.4 DVB-RCS2 vs NR PUSCH: PAPR and C/Im Comparison

5.6.4.1 Peak To Average Power Ratio

The PAPR distributions of NR PUSCH transmissions and single DVB-RCS2 carrier transmissions are compared in Figure 28.

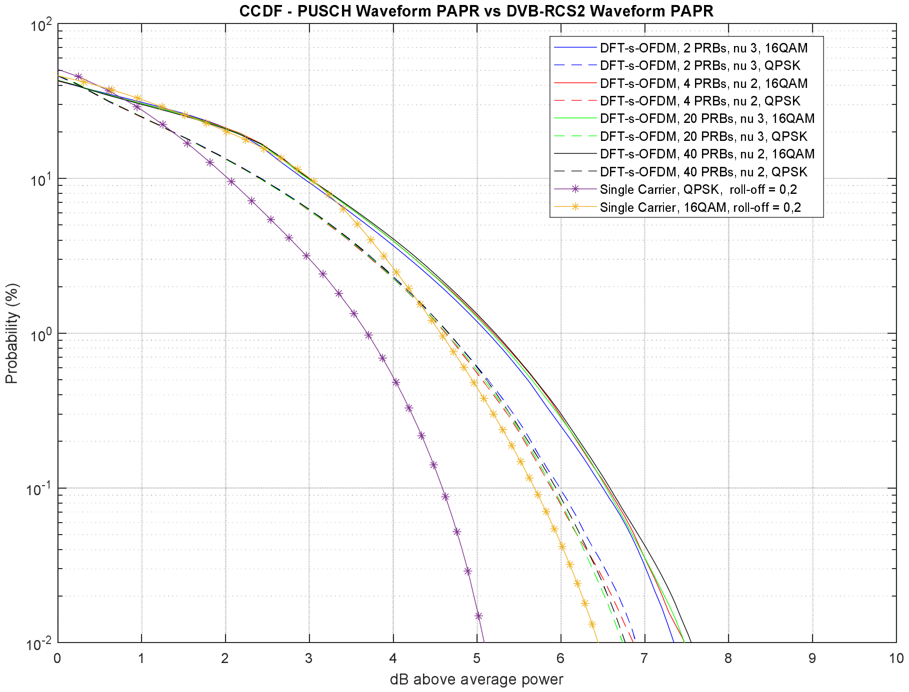

Figure 28: Comparison of DFT-OFDM based NR PUSCH transmissions and single carrier transmissions PAPR distribution

The following observations are made:

- PAPR < 4,7 dB for 99,9 % of the time for the single carrier transmissions in QPSK.
- PAPR < 6 dB for 99,9 % of the time for the DFT-OFDM based transmissions in QPSK.
- PAPR < 5,7 dB for 99,9 % of the time for the single carrier transmissions in 16QAM.
- PAPR < 6,6 dB for 99,9 % of the time for the DFT-OFDM based transmissions in 16QAM.

In conclusion, these results show that the power envelope fluctuation is approximately 0,9 dB to 1,3 dB higher in case of DFT-based transmissions with respect to single carrier transmission with a roll-off factor of 0,2 depending on the modulation considered.

Therefore, it is expected that the terminal amplifier IBO should be increased in case of NR PUSCH transmission to get the same intermodulation noise level at the amplifier output. It will result in the terminal effective EIRP reduction. The other way around, if the same IBO configuration is applied for both waveforms, then the non-linear distortion impact on the signal will be higher in case of NR PUSCH transmissions w.r.t. DVB-RSC2.

5.6.4.2 C/Im vs IBO/OBO

The achievable performance in terms of conducted C/Im assuming the User Terminal HPA characteristics have been evaluated for different points of operation. The input signal is either composed of several hundreds of NR subcarriers assuming DFTsOFDM precoding is used or a single DVB-RCS2 carriers. Several configurations of modulations are compared.

Assuming a point of operation with an OBO of 0 dB (which has been analysed as the optimal configuration for both technologies assuming a required SNR inferior to 12 dB), the following observations are made:

- DVB-RCS2 QPSK and 8PSK C/Im equals 24 dB.
- DVB-RCS2 16QAM C/Im equals 19,7 dB.
- NR DFTsOFDM QPSK C/Im equals 21,2 dB that is a degradation of 2,8 dB with respect to DVB-RCS2 QPSK.
- NR DFTsOFDM 16QAM C/Im equals 18,7 dB that is a degradation of 5,3 dB with respect to DVB-RCS2 8PSK and a degradation of 1 dB with respect to DVB-RCS2 16QAM.
- NR DFTsOFDM 64QAM C/Im equals 17,95 dB that is a degradation of 1,75 dB with respect to DVB-RCS2 16QAM.

The impact of such considerations on the comparison are addressed in the SLS output results since the SLS integrates the C/IM vs OBO/IBO curves resulting from the LLS analysis and compute the link budgets accordingly.

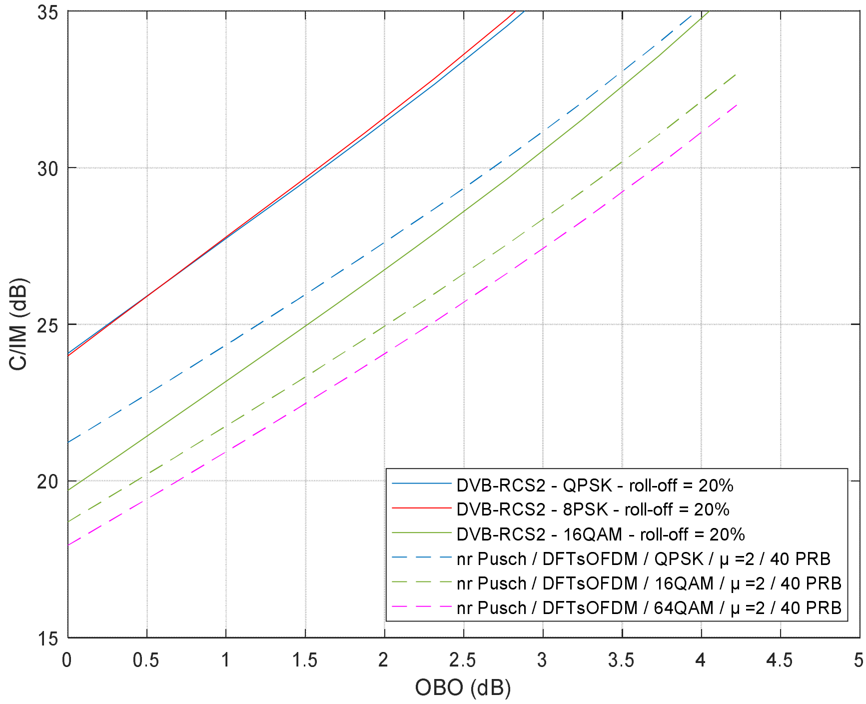

Figure 29: C/Im vs OBO performance comparison between NR DFTsOFDM and DVB-RCS2

6 System level performance comparison

6.1 Reference scenario description

6.1.0 General

Table 41 presents the general parameters for the system level simulation evaluation of DVB and NR.

Table 41: Reference scenario description

Parameter	Value
Simulation duration	5 seconds per simulated drop.
Satellite & beam layout	GEO satellite with one reference beam for collecting the statistics (i.e. $C1_0$) + 1 or 2 tiers of surrounding, interfering beams of same colour. Central beam elevation angle 45 deg.
Frequency re-use factor	2+2 (Option 3 of Table 6.1.1.1-5 in [i.3] with single simulated colour.
User terminals per beam (per drop)	50 (in the statistics beam; interfering beams can be optionally simplified).
Interference sources	Neighbour beams of same colour and PA intermodulation interference.

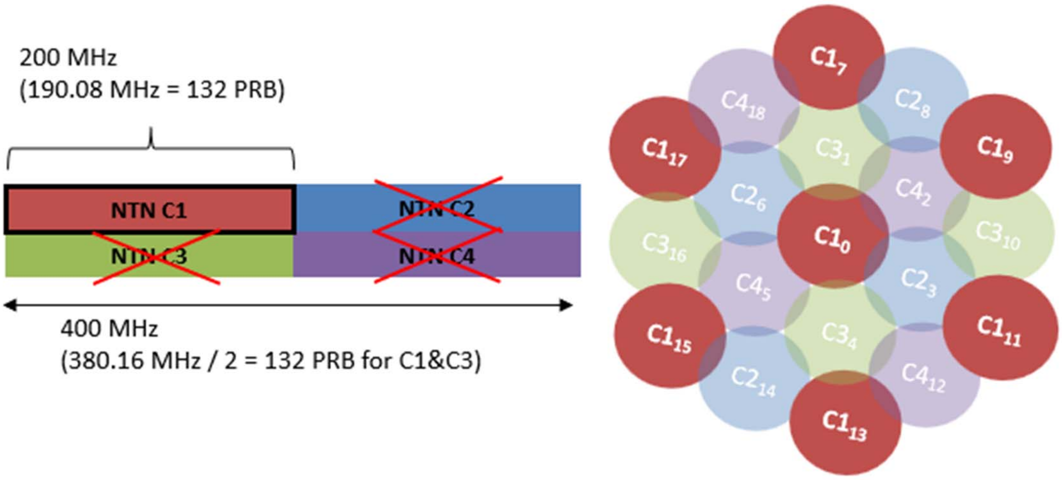

Figure 30: Example beam layout with one tier of surrounding, interfering beams

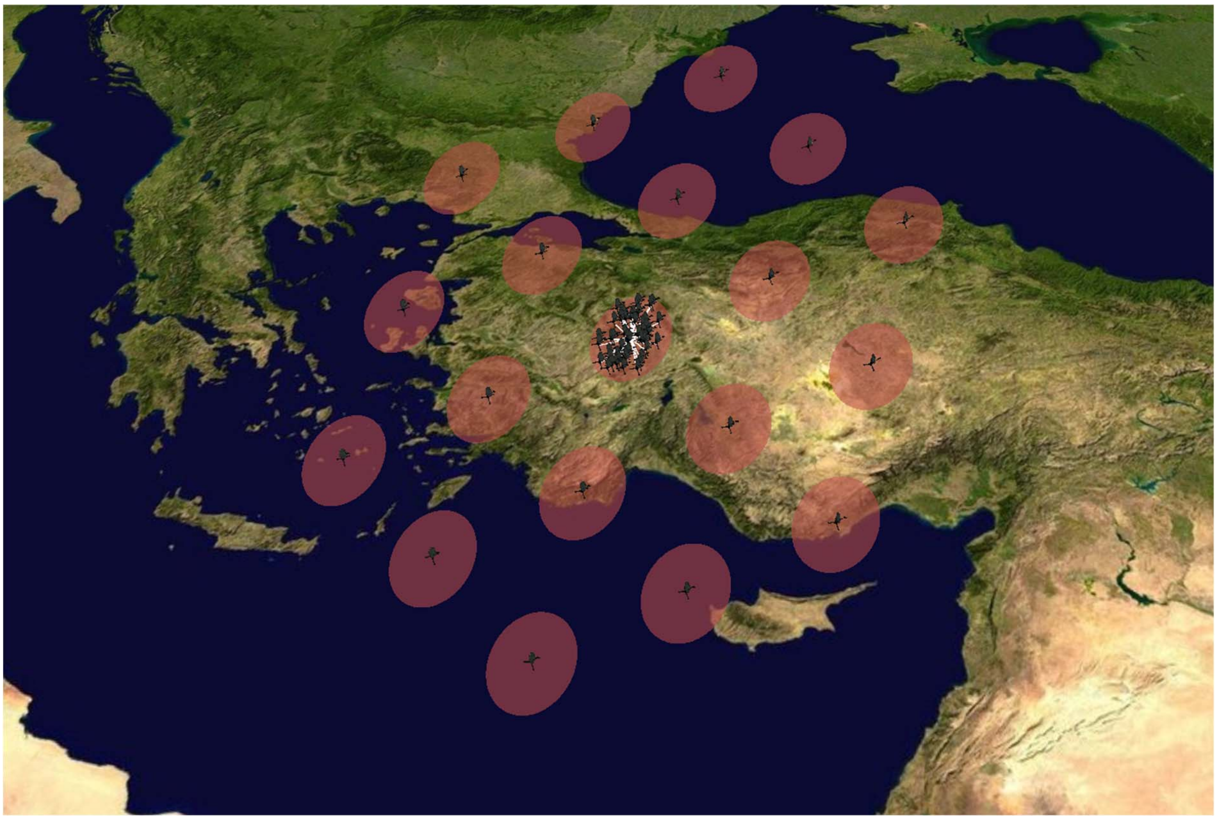

Figure 31: GEO Ka-band Set-1 scenario visualization

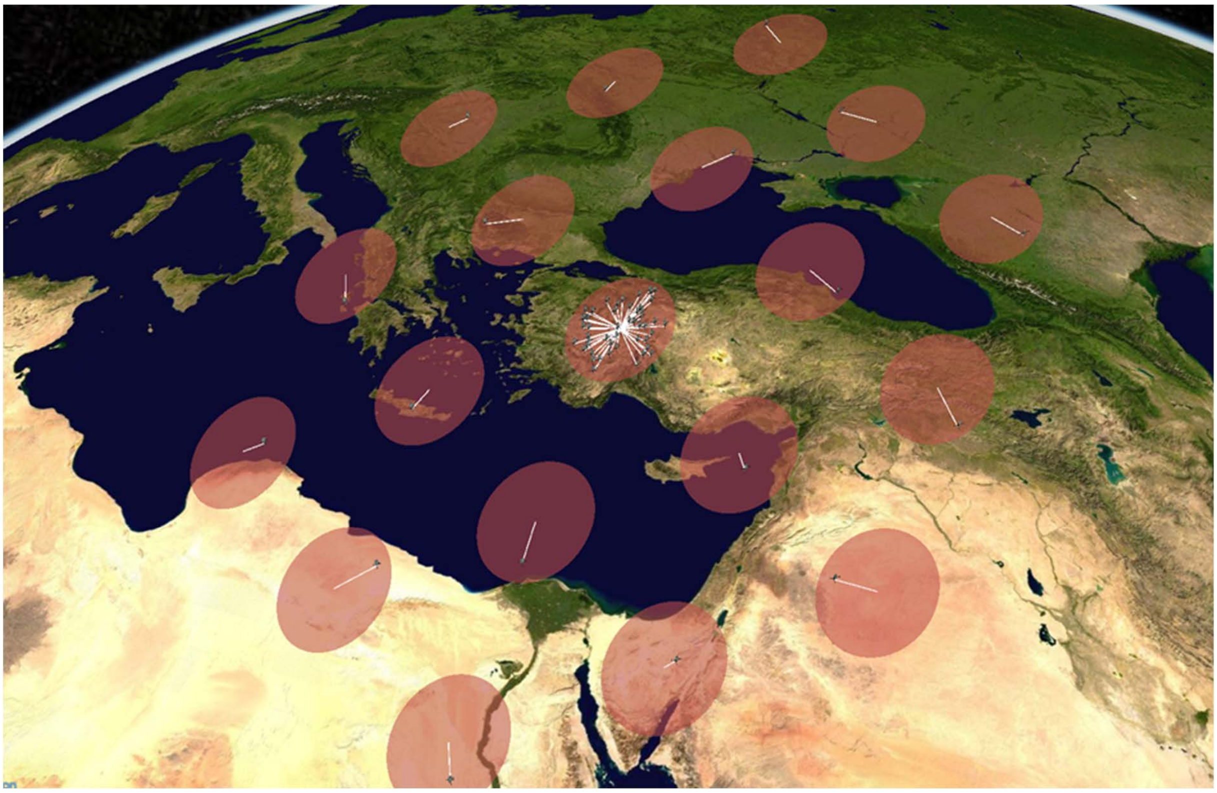

Figure 32: GEO Ka-band Set-2 scenario visualization

6.1.1 Space segment

Table 42: Space segment

Characteristics	Value
Orbit	Geostationary (GEO)
Number of satellites	1
Beam pattern	FRF2+2 (Option 3 of Table 6.1.1.1-5 in [i.3])
EIRP per beam	40 dBW per MHz (Set-1 in Table 6.1.1.1-1 of [i.3]) (Optional: 32 dBW per MHz, Set-2 in Table 6.1.1.1-2 of [i.3])
G/T	28 dB K^{-1} (Set-1 in Table 6.1.1.1-1 of [i.3]) (Optional: 20 dB K^{-1} per MHz, Set-2 in Table 6.1.1.1-2 of [i.3])
Maximum bandwidth per beam (DL + UL)	200 MHz on DL + 200 MHz on UL
Payload	Transparent
Transponder characteristics (AM/PM conversion)	TBA
Frequency range	Ka-band

6.1.2 User terminal types

6.1.2.1 Technical Objective

In Geostationary Satellite communication Systems (GEO), configurations with a single terminal type may present a limited SINR range. This constraint often restricts the usage to one or at most two MODCODs when calculating system level throughput. To overcome this limitation, the introduction of three types of terminals proves to be a clever strategy. The primary objective of this approach is to expand the available SINR range. Indeed, with multiple terminals, each optimized to operate within a specific SINR range, the aggregated system level throughput of the three terminals provides a more accurate representation of the technology's performance.

6.1.2.2 Terminal Characteristics

The user terminals are assumed to be fixed on the ground and to have directive antenna pointing in the satellite direction. The characteristics of the three types of user terminal are summarized in Table 43, and the default VSAT antenna (also specified in ETSI EN 301 545-2 [i.3]) is prioritized.

Table 43: User terminal characteristics

Characteristics	VSAT low capability	VSAT (default)	VSAT high capability
Frequency band	Ka band (i.e. 30 GHz UL and 20 GHz DL)	Ka band (i.e. 30 GHz UL and 20 GHz DL)	Ka band (i.e. 30 GHz UL and 20 GHz DL)
Antenna type and configuration	Directional with 46 cm equivalent aperture diameter	Directional with 60 cm equivalent aperture diameter	Directional with 180 cm equivalent aperture diameter
Polarization	circular	circular	circular
Rx Antenna gain	36,7 dBi	39,7 dBi	53,2 dBi
Antenna temperature	150 K	150 K	150 K
Noise figure	1,2 dB	1,2 dB	1,2 dB
Tx transmit power	1 W (30 dBm)	2 W (33 dBm)	2 W (33 dBm)
Tx antenna gain	40,4 dBi	43,2 dBi	50,1 dBi

6.1.3 Channel Model

The channel models are configured identically in both simulators, consisting of LOS-only free space path loss channel coupled with 3GPP TR 38.811 [i.7] antenna gain models and without additional effects, such as shadowing. Optionally, the channel model can be complemented with Recommendation ITU-R P.1853-2 [i.8] weather attenuation models.

6.2 Comparison criteria

Comparison statistics:

- Coupling loss
- SNR
- SIR
- SNR
- User throughput
- File throughput (for FTP3 traffic model [i.3])
- Beam throughput (for Full buffer traffic model)
- Beam spectral efficiency (for Full buffer traffic model)
- Error rate

6.3 Simulation assumptions

Table 44: General simulation parameters

Parameter	Value
Frequency configuration	Ka-band: - 20 GHz on DL/FWD link. - 30 GHz on UL/RTN link. 200 MHz single beam bandwidth per link direction. DVB-S2X: 1 TDM carrier per beam (roll-off = 0,05, carrier spacing 0,02). DVB-RCS2: Static 10 x 20 MHz and 40 x 5 MHz carriers, 12,456 ms super frame duration, waveforms 13-22 (roll-off = 0,20, carrier spacing 0,02). NR: Numerology 3, 132 PRBs.
Adaptive coding and modulation	Enabled. MCS Table 18 and Table 23 - for NR.
ARQ/HARQ	Disabled.
Control channel and signalling	Ideal signalling with delay, no control channel overhead modelled.
Physical layer overheads	DVB-S2X: BB frame PL header, pilots. NR: DMRS, PTRS, code block CRCs. DVB-RCS2: Waveform and burst overheads. NR: DMRS, PTRS, TB overheads (CRC, code rate).
Non-linear power amplifier	DVB-S2X/NR PDSCH: - Input back-off (IBO) = 5,0 dB. - Output back-off (OBO) = 0,8 dB. - Carrier-to-intermodulation noise ratio (radiated) (C/Im) = 18,6 dB for DVB-S2X, 18,4 dB for NR. NR PUSCH and DVB-RCS2: - OBO and associated C/Im depend on the used modulation and coding scheme and uplink power control. Exact settings TBA.
Scheduler	DVB-S2X/NR PDSCH: - Proportional fair (α = 0, β = 1). NR PUSCH and DVB-RCS2: - Round robin (NR) / Resource-fair. (NR: Dynamic multi-user scheduling, UEs multiplexed in the same slot).
Power control	Enabled. DVB-RCS2 E_s/N_0 and NR PUSCH SNR targets set at e.g. 15 dB or other scenario-dependent, optimized values. (DVB-RCS2: E_s/N_0 target per transmission [i.3], NR PUSCH: CLx-ile power control of [i.5]).
Channel model	Free-space path loss, LOS only. (Optional) Spatially correlated weather attenuation (Recommendation ITU-R P.1853-2 [i.8]).
Channel estimation (NR PUSCH and DVB-RCS2)	- C/N_0 and CQI reporting every configured interval e.g. 100 ms. - Minimum SINR value in a moving window with duration of configured period e.g. 500 ms used as basis for C/N_0 and CQI estimation.
User terminals per beam (per drop)	50 per beam (for realistic scheduling effects) in the beam(s) with statistics collection. Interfering beams can be simplified, if possible.
Traffic model	- Full buffer (RLC for NR, LLC for DVB). - FTP3 [i.9].
FTP3 parameters	Mean file inter-arrival time: 100 ms (Poisson distribution). Poisson interval upper bound: 1 s. File size: configurable, e.g. 5 kB, 10 kB, 15 kB, 30 kB or 60 kB can be considered to demonstrate different system load situations, e.g. 10 %, 50 %.

6.4 Simulation results

6.4.0 General

Based on system-level assumptions described in this clause, the results presented in Table 45 and Table 47 have been obtained for forward and return link, respectively, in three different sub-scenarios concerning user terminal types and their traffic models:

- Full buffer (default VSAT terminals).
- Finite buffer, i.e. 3GPP FTP3 (60 kB files on forward link and 15 kB files on return link with average inter--arrival times of 100 ms).
- Multiple terminal types + Full buffer (three different terminal categories, 3GPP Set-2 selected as baseline).

Moreover, the beam average spectral efficiencies and throughputs in full load scenarios have been presented in Table 46 and Table 48 for forward and return links, respectively.

6.4.1 NR PDSCH vs. DVB-S2X

Table 45: NR PDSCH vs. DVB-S2X user SINR and throughput summary

Sub-scenario	Technology	SINR 5th %-ile [dB]	SINR 50th %-ile [dB]	SINR 95th %-ile [dB]	SINR average [dB]	5th %-ile user tput [kbps]	50th %-ile user tput [kbps]	95th %-ile user tput [kbps]	User tput average [kbps]	Tput average gain (over other)
Full buffer (see note 1)	NR PDSCH	7,4	7,9	8,1	7,8	6 389,8	6 389,8	6 389,8	6 390,6	-24,7 %
	DVB-S2X	7,4	7,9	8,1	7,8	8 331,3	8 458,4	8 830,1	8 489,2	+32,8 %
Finite buffer (see note 2)	NR PDSCH	8,4	9,5	10,9	9,5	1 485,3	1 692,8	1 760,5	1 676,8	-4,7 %
	DVB-S2X	8,3	8,5	8,7	8,5	1 745,9	1 761,3	1 764,3	1 759,3	+4,9 %
Multiple terminal types (Set-2) + Full buffer 2)	NR PDSCH	0,3	3,1	9,0	3,6	3 719,1	4 055,1	4 865,0	4 235,6	-17,8 %
	DVB-S2X	0,2	3,4	9,0	4,2	4 798,2	5 165,0	5 330,3	5 155,9	+21,7 %
All summarized results are based on AWGN receiver performance and have BLER/FER target = 1e-5. NOTE 1: 2 interfering tiers of beams. NOTE 2: 1 interfering tier of beams.										

Table 46: NR PDSCH vs. DVB-S2X beam spectral efficiency and throughput summary

Sub-scenario	Technology	Average beam PHY spectral efficiency over system bandwidth (400 MHz) [bps/Hz]	Average beam PHY spectral efficiency (200 MHz) [bps/Hz]	Average beam throughput (on RLC/LLC) [Mbps]	Tput average gain
Full buffer	NR PDSCH	0,799	1,598	319,5	-24,7 %
	DVB-S2X	1,062	2,124	424,5	+32,9 %
Multiple terminal types (Set-2) + Full buffer	NR PDSCH	0,530	1,060	211,8	-17,2 %
	DVB-S2X	0,640	1,280	255,8	+20,8 %

6.4.2 NR PUSCH vs. DVB-RCS2

Table 47: NR PUSCH vs. DVB-RCS2 user SINR and throughput summary

Sub-scenario	Technology	SINR 5th %-ile [dB]	SINR 50th %-ile [dB]	SINR 95th %-ile [dB]	SINR average [dB]	5th %-ile user tput [kbps]	50th %-ile user tput [kbps]	95th %-ile user tput [kbps]	User tput average [kbps]	Throughput average gain
Full buffer (see note 1)	NR PUSCH	9,1	9,6	10,4	9,6	6 781,7	7 538,1	8 191,5	7 466,6	+25,0 %
	DVB-RCS2 (see note 3)	8,8	10,4	12,3	10,5	5 521,6	6 174,7	6 339,0	5 970,3	-20,0 %
Finite buffer (see note 2)	NR PUSCH	9,0	9,9	12,3	10,2	219,9	385,3	432,7	359,5	+30,3 %
	DVB-RCS2 (see note 4)	11,1	13,3	14,8	13,2	150,3	273,0	415,8	275,8	-23,3 %
Multiple terminal types (Set-2) + Full buffer (see note 2)	NR PUSCH	5,7	9,6	11,2	9,2	956,2	4 661,6	14 731,4	6 872,6	+17,4 %
	DVB-RCS2 (see note 3)	2,3	9,0	14,6	8,8	1 876,7	5 532,8	9 523,1	5 851,7	-14,9 %

All summarized results are based on AWGN receiver performance and assume 1 interfering tier of beams.
NOTE 1: BLER/FER target = 1e-3.
NOTE 2: BLER/FER target = 1e-5.
NOTE 3: Static frame configuration 40 x 5 MHz.
NOTE 4: Static frame configuration 10 x 20 MHz.

Table 48: NR PUSCH vs. DVB-RCS2 beam spectral efficiency and throughput summary

Sub-scenario	Technology	Average beam PHY spectral efficiency over system bandwidth (400 MHz) [bps/Hz]	Average beam PHY spectral efficiency (200 MHz) [bps/Hz]	Average beam throughput (on RLC/LLC) [Mbps]	Tput average gain
Full buffer	NR PUSCH	0,954	1,908	373,3	+25,1 %
	DVB-RCS2	0,747	1,494	298,5	-20,0 %
Multiple terminal types (Set-2) + Full buffer	NR PUSCH	0,872	1,744	343,6	+17,4 %
	DVB-RCS2	0,732	1,464	292,6	-14,8 %

7 Conclusion

Comparing DVB-S2x/RCS2 and 3GPP NR NTN access technologies in the context of a broadband access network, based on GSO space segment operating in over 10 GHz frequencies, the following observations can be made:

Link level simulations: The results are overall consistent with the qualitative analysis:

- On one hand, DVB-S2x outperforms NR PDSCH, due to slightly worse coding scheme, lower framing efficiency and potentially higher observed PAPR in NR, especially when there are low number of carriers per amplifier.
- On the other hand, NR PUSCH performs equally compared to DVB-RCS2.
- The results are, however, very dependent on the deployment scenario considered.

System level simulations: The results mostly reflect the link level results, although the effects of system level aspects, such as the multi-user scenario, varying traffic patterns, fixed geometry and radio resource management decisions, were observable in the results:

- On one hand, DVB-S2x outperforms NR PDSCH especially under full system load. This gap diminishes with reduced system load.
- On the other hand, NR PUSCH offers better or near equal performance overall, compared to DVB-RCS2. NR PUSCH could utilize the spectrum more efficiently, especially when the target PER/BLER was increased (see clause 5.6.3.2).
- Similarly, to link level analysis, the results are highly dependent on the chosen scenario and configurations.

Several recommendations (see clause 5.6.1.1) have been identified, which are expected to further reduce the performance gaps between NR PDSCH and DVB-S2x.

NOTE: Further study would be needed to compare both access technologies in the context of broadband satellite networks, based on NGSO space segment operating in frequencies above 10 GHz frequencies.

History

Document history		
V1.1.1	March 2025	Publication