ETSI GS F5G 023 V1.1.1 (2024-09)

Fifth Generation Fixed Network (F5G); F5G Advanced Technology Requirements and Gap Analyses; Release 3

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Reference

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Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group (ISG) Fifth Generation Fixed Network (F5G).

Modal verbs terminology

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1 Scope

The present document specifies the technology requirements for F5G-A use cases release 3 and explores existing technologies from related SDOs. The present document performs gap analyses between the technologies required by the use cases and those that are available. The identification of the relevant SDOs is based on their existing projects.

2 References

2.1 Normative 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.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference.

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The following referenced documents are necessary for the application of the present document.

[1] Recommendation ITU-T G.709/Y.1331: "Interfaces for the optical transport network".

[2] Recommendation ITU-T G.709.20: "Overview of fine grain OTN".

[3] ETSI GS F5G 014: "Fifth Generation Fixed Network (F5G); F5G Network Architecture Release 2".

[4] IEEE 802.11k™: "IEEE Standard for Information technology -- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Radio Resource Measurement of Wireless LANs".

[5] IEEE 802.11v™: "IEEE Standard for Information technology -- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 8: IEEE 802.11 Wireless Network Management".

[6] IEEE 802.11r™: "IEEE Standard for Information technology -- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 2: Fast Basic Service Set (BSS) Transition".

[7] Recommendation ITU-T G.9940 (2023): "High speed fibre-based in-premises transceivers - system architecture".

[8] Recommendation ITU-T G.9941 (2024): "High speed fibre-based in-premises transceivers - physical layer specification".

[9] Recommendation ITU-T G.9942 (2024): "High speed fibre-based in-premises transceivers - Data link layer".

[10] Recommendation ITU-T G.988 (2022): "ONU management and control interface (OMCI) specification".

[11] ETSI GS F5G 013: "Fifth Generation Fixed Network (F5G); F5G Technology Landscape Release 2".

[12] Recommendation ITU-T G.709.1: "Flexible OTN common elements", consented in the ITU-T SG15 Plenary Meeting, 20 November - 1 December, 2023.

[13] Recommendation ITU-T G.709.3: "Flexible OTN B100G long-reach interfaces".

[14] Recommendation ITU-T G.709.5: "Flexible OTN short-reach interfaces".

[15] Recommendation ITU-T G.709.6: "Flexible OTN B400G long-reach interfaces".

[16] Recommendation ITU-T G.872: "Architecture of the optical transport network".

[17] IEEE P2893™-2023: "IEEE Approved Draft Standard for Flexible Optical Service Unit (OSUFlex) of Optical Transport Network (OTN) in Power Systems", published, 14 July, 2023.

[18] Recommendation ITU-T G.823: "The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy.

[19] Recommendation ITU-T G.825: "The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH).

[20] Recommendation ITU-T G.874 (2020.10): "Management aspects of optical transport network elements".

[21] ETSI GS F5G 015 (V1.2.1): "Fifth Generation Fixed Network (F5G); F5G Residential Services Quality Evaluation and Classification Release 2".

[22] ETSI GS F5G 017 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Measurement Specification for Residential Services Quality Evaluation".

[23] ETSI GS F5G 026 (V1.1.1): "Fifth Generation Fixed Network (F5G); Architecture and data models for residential service quality monitoring".

[24] ISO/IEC 14496-10:2022: "Information technology -- Coding of audio-visual objects -- Part 10: Advanced video coding".

[25] Recommendation ITU-T G.698.2: "Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces".

[26] IEEE 802.3™-2022: "IEEE standards for Ethernet".

[27] OIF-400ZR-01.0 March 10th 2020: "Implementation Agreement 400ZR".

[28] IEEE 802.3ct™-2021: "IEEE Standard for Ethernet Amendment 13: Physical Layers and Management Parameters for 100 Gb/s Operation over DWDM Systems".

[29] Recommendation ITU-T G.672: "Characteristics of multi-degree reconfigurable optical add/drop multiplexers".

[30] Recommendation ITU-T G.7044/Y.1347: "Hitless adjustment of ODUflex (GFP)".

[31] Recommendation ITU-T G.698.4 (2023): "Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces".

[32] ETSI GS F5G 006: "Fifth Generation Fixed Network (F5G); End-to-End Management and Control; Release #1".

[33] IEEE 802.3df™-2024: "IEEE Standard for Ethernet Amendment 9: Media Access Control Parameters for 800 Gb/s and Physical Layers and Management Parameters for 400 Gb/s and 800 Gb/s Operation".

[34] Recommendation ITU-T G.9804.3: "50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification".

[35] Recommendation ITU-T G.987 series: "10-Gigabit-capable passive optical networks (XG-PON)".

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 GR F5G 020 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Use Cases; Release 3".

[i.2] IETF RFC 3945: "Generalized Multi-Protocol Label Switching (GMPLS) Architecture".

[i.3] IETF RFC 7138: "Traffic Engineering Extensions to OSPF for GMPLS Control of Evolving G.709 Optical Transport Networks".

[i.4] IETF RFC 7139: "GMPLS Signalling Extensions for Control of Evolving G.709 Optical Transport Networks".

[i.5] IETF RFC 9376: "Applicability of GMPLS for beyond 100 Gbit/s Optical Transport Network".

[i.6] draft-ietf-ccamp-otn-topo-yang: "A YANG Data Model for Optical Transport Network Topology".

[i.7] draft-ietf-ccamp-otn-tunnel-model: "OTN Tunnel YANG Model".

[i.8] draft-ietf-ccamp-otn-path-computation-yang: "A YANG Data Model for requesting Path Computation in an Optical Transport Network (OTN)".

[i.9] draft-ietf-ccamp-l1csm-yang: "A YANG Data Model for L1 Connectivity Service Model (L1CSM)".

[i.10] draft-ietf-ccamp-client-signal-yang: "A YANG Data Model for Transport Network Client Signals.

[i.11] ITU-T draft G.9943: "High speed fibre-based in-premises transceivers - management".

[i.12] ITU-T draft G.wmci: "WLAN management control interface (WMCI) for in-premises network".

[i.13] IEEE 802.11bn™: "IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment: Enhancements for Ultra High Reliability".

[i.14] BBF oneM2M TR-069: "CPE WAN Management Protocol (CWMP)".

[i.15] BBF oneM2M TR-369: "User Services Platform (USP)".

[i.16] ITU-T draft G.dfos: "Distributed fibre optic sensing".

[i.17] ITU-T draft G.Sup.CMAFP: "Coordinated management of access and fibre on premises networks".

[i.18] ETSI DGS/F5G-0025: "Fifth Generation Fixed Network (F5G); Architecture of computing collaboration in PON network".

[i.19] IETF draft-gstk-ccamp-actn-optical-transport-mgmt: "Integrating YANG Configuration and Management into an Abstraction and Control of TE Networks (ACTN) System for Optical Networks".

[i.20] BBF oneM2M TR-383: "Common YANG Modules for Access Networks".

[i.21] BBF oneM2M TR-385: "ITU-T PON YANG Modules".

[i.22] WT-411i2: "Definition of interfaces between Cloud CO Functional Modules".

[i.23] WT-454i2: "YANG Modules for Network Map & Equipment Inventory".

[i.24] ETSI GR F5G 021 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Generation Definition".

[i.25] IEEE 802.11ad™: "Telecommunications and Information Exchange between Systems Local and metropolitan area networks--Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band".

[i.26] IEEE 802.11aj™: "Telecommunications and Information Exchange between Systems Local and metropolitan area networks--Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput to Support Chinese Millimetre Wave Frequency Bands (60 GHz and 45 GHz)".

[i.27] IEEE 802.11ay™: "Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks--Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 2: Enhanced Throughput for Operation in License-exempt Bands above 45 GHz".

[i.28] ITU-T draft G.vhsp: "Very High Speed PON".

[i.29] IEEE 802.3bq™-2024: "IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment: Enhancements for Integrated mmWave (IMMW) WLAN".

[i.30] IEEE 802.3cw™-2021: "IEEE standards for 400Gbps over DWDM System". Editor's Note: this is reference is to the IEEE task force.

[i.31] IEEE 802.3dj™-2021: "IEEE standards for 200Gbps, 400Gbps, 800Gbps, 1.6Gbps Ethernet.

[i.32] ROS: "Robot Operating System".

[i.33] Object Management Group (OMG): "Data Distribution Service (DDS) Version 1.4", April 2014.

[i.34] The Linux® Foundation Projects CAMARA website.

NOTE: Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

[i.35] ETSI GS F5G 011 (V1.1.1): "Fifth Generation Fixed Network (F5G); Telemetry Framework and Requirements for Access Networks".

[i.36] Recommendation ITU-T G.808.4: "Linear protection for fine grain Metro Transport Network (fgMTN) and fine grain Optical Transport Network (fgOTN)".

[i.37] ITU-T Recommendation G.798 Amendment 1: "Characteristics of optical transport network hierarchy equipment functional blocks".

[i.38] ITU-T Recommendation G.8251 Amendment 1: "The control of jitter and wander within the optical transport network (OTN)".

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:

ACTN	Abstraction and Control of Traffic Engineering Networks
AFC	Automatic Fare Collection
AGGN	Aggregation Network
AI	Artificial Intelligence
AP	Access Point
API	Application Programming Interface
BBF	BroadBand Forum
BE	Best Effort
BK	Background
BSS	Basic Service Set
BSSID	Basic Service Set ID
CBR	Constant Bit Rate
CCSA	China Communications Standards Association
CPE	Customer Premise Equipment
CPN	Customer Premise Network
CPU	Central Processing Unit
DBA	Dynamic Bandwidth Allocation
DC	Data Centre
DCI	Data Centre Interconnect
DCPS	Data-Centric Publish-Subscribe
DDS	Data Distribution Service
DFOS	Distributed Fibre Optic Sensing
DL	Data Link
DLL	Data Link Layer
DR	Disaster Recovery
DWDM	Dense Wavelength Division Multiplexing
E2E	End To End
EMF	Equipment Management Function
EML	Element Management Layer
E-ONU	Edge ONU
FCAPS	Fault, Configuration, Accounting, Performance and Security
fgODU	fine grain Optical Data Unit
fgOTN	fine grain Optical Transport Network
FMCI	Fibre Management & Control Interface
FOADM	Fixed Optical Add/Drop Multiplexer
FTTR	Fibre to the Room
FTTx	Fibre To The (x = Room, Home, Machine, Office
GE	Gigabit Ethernet
GIS	Geographic Information System
GMP	Generic Mapping Procedure
GMPLS	Generalized Multi-Protocol Label Switching
GPON	Gigabit Passive Optical Network
GPU	Graphics Processing Unit
HDMI	High-Definition Multimedia Interface
ID	Identification
IMMW	Integrate mmWave
IMP	Idle Mapping Procedure
IoT	Internet of Things
IP	Internet Protocol
IPTV	Internet Protocol Television
KQI	Key Quality Indicators
L2	Layer 2
LAN	Local Area Network

LR/ZR	Long Range / Data Rate optic series
M&C	Management and Control
MAC	Medium Access Control
MD-ROADM	Multi-Dimensional Reconfigurable Optical Add/Drop Multiplexer
ME	Management Entities
M-FTR	G.fin transceiver in the Main Fibre Unit
MFU	Main FTTR Unit
MGWS	Multiple Gigabit Wireless System
MIMO	Multiple Input Multiple Output
MMW	mmWave
MOS	Mean Opinion Score
MPEG	Moving Pictures Experts Group
MSOTN	Multi-Service OTN
MSTP	Multi-Service Transport Platform
NaaS	Network as a Service
NAS	Network Attached Storage
NE	Network Element
NPU	Network Processing Unit
NTP	Network Time Protocol
O&M	Operation and Maintenance
OADM	Optical Add/Drop Multiplexer
OAM	Operation Administration and Maintenance
ODN	Optical Distribution Network
ODUk	Optical Data Unit k =0, 1, 2, 3, 4, flex
OFDM	Orthogonal Frequency Division Multiplexing
OIF	Optical Internetworking Forum
OLT	Optical Line Termination
OMCI	Optical Management and Control Interface
ONU	Optical Network Unit
ONU/AP	Optical Network Unit / Access Point
OPEX	Operational expense
OPGW	Optical Ground Wire
OS	Operating System
OSNR	Optical Signal to Noise Ratio
OSPF	Open Short Path First
OSU	Optical Service Unit
OSUFlex	Flexible Optical Service Unit
OTN	Optical Transport Network
OXC	Optical Cross Connect
P2MP	Point to MultiPoint
P2P	Peer-to-Peer
PCM	Pulse Code Modulation
PCS	Physical Coding Sublayer
PDH	Plesiochronous Digital Hierarchy
PHY	PHYsical (as in physical layer of a protocol)
PIS	Passenger Information System
PKT	Packet
PLOAM	Physical Layer Operation Administration and Maintenance
PMA	Physical Medium Attachment sublayer
PMD	Physical Medium Dependent sublayer
PON	Passive Optical Network
P-ONU	Primary ONU
QAM	Quadrature Amplitude Modulation
QoD	Quality on Demand
QoE	Quality of Experience
QoS	Quality of Service
RaaS	Robotics as a Service
RF	Radio Frequency
ROADM	Reconfigurable Optical Add/Drop Multiplexer
ROS	Robotics Operating System
RTT	Round Trip Time
RUC	Requirement Use csae

SA	Standards Association
SDH	Synchronous Digital Hierarchy
SDN	Software Defined Networking
SDO	Standards Development Organisation
S-FTR	G.fin transceiver in an Sub Fibre Unit
SFU	Sub FTTR Unit
SG	Study Group
SINR	Signal to Interference and Noise Ratio
SLA	Service Level Agreement
SME	Small Medium Enterprise
SNR	Signal to Noise Ratio
SOP	State Of Polarization
SR/DR	Short Range / Data Rate optic series
STA	Station
STM	Synchronous Transport Module
SU	Single User
TDM	Tine Division Multiplexing
TE	Traffic Engineering
TV	TeleVision
UC	Use Case
UHD	Ultra-High Definition
UHV	Ultra-High Voltage
VBR	Variable Bit Rate
VC	Virtual Container
VI	Video
VO	Voice
VoIP	Voice over Internet Protocol
VR	Virtual Reality
WDM	Wavelength Division Multiplexing
WFA	Wi-Fi® Alliance
WLAN	Wireless Local Area Network
WMCI	WLAN Management & Control Interface
WP3	Working party 3 (ITU-T - Study Group 15)
WT	Working Text
XGS	10 G Symmetric
XGSPON	10 Gigabit Symmetric Passive Optical Network
YANG	Yet Another Next Generation data modelling language

4 Technology requirements and landscape

4.1 Overview

4.1.1 Introduction

This clause is reliant on the use cases as defined in ETSI GR F5G 020 [i.1] and specifies per use case the technology requirements, describes the gaps in technology to implement those use cases and the current available related standards.

NOTE: Some clauses define requirements, standards, and gaps for several similar use cases together.

The following use cases are included in the present document, refer to ETSI GR F5G 020 [i.1] for a detailed description of the use cases. In the following, only use case titles are given for reference:

- UC#1: Premium private line service automation: clause 4.2.
- UC#2: Stable & reliable Wi-Fi® connection over on-premises networking: clause 4.3.
- UC#3: Computing collaboration in PON network: clause 4.4.
- UC#4: Intelligent power grid: clause 4.5.

- UC#5: Railway perimeter inspection: clause 4.6.
- UC#6: Naked-eye 3D display: clause 4.7.
- UC#7: Unified access and on-premises network: clause 4.8.
- UC#8: OTN intelligent fault management: clause 4.9.
- UC#9: Evaluation and assurance of user service experience: clause 4.10.
- UC#10: Cloud Desktop: clause 4.11.
- UC#11: Dynamically digitalized ODN: clause 4.12.
- UC#12: F5G-A: On-premises Millimetre-Wave (mmWave) WLAN: clause 4.13.
- UC#13: Wavelength-shared WDM aggregation network (AGGN): clause 4.14.
- UC#14: Robotics as a Service: clause 4.15.
- UC#15: All-optical base for urban rail transit communication network: clause 4.16.
- UC#16: Optical Fibre Sensing for telecom operators: clause 4.17.
- UC#17: QoD App-Flow service provisioning: clause 4.18.

4.1.2 Document structure overview

The remainder of clause 4 covers the use case itemized in clause 4.1.1. The structure of each use case is:

- Brief use case overview.
- Technology related to the use cases and associated requirements.
- Gaps in standards to meet the requirements.
- Current standards relevant to the use case.

The order of the use cases match that of those defined in ETSI GR F5G 020 [i.1] and the requirements are structured as [RUC#-xx] where UC# is the use case number defined in ETSI GR F5G 020 [i.1] and xx is the sequence number of the requirements. The Gaps have a similar structure [GapUC#-yy] and again UC# is the use case number defined in ETSI GR F5G 020 [i.1] and yy is the sequence number of the gaps. Ideally there should be a one to one correspondence between the requirements and the gaps, however it is possible that a given requirement may have multiple gaps and this will be accommodated in the present document. If the requirements are already satisfied by current standards then the gap is labelled 'None' to indicate there is no gap.

NOTE: There is an offset of one between the use case number and the clause number in the present document due to the inclusion of a clause on the present document overview in clause 4.1.1.

4.2 Premium private line service automation

4.2.1 Use Case Briefing

OTN / fine grain OTN (fgOTN) based premium private line services are widely used in many scenarios such as government institutions, financial organizations, medical organizations and large enterprises. In F5G-A, the automation capabilities of the premium private line services, such as CPE Plug-and-play, automatic service provisioning and SLA information visualization, need to be improved, to enable the evolution towards a higher-level autonomous optical network. See Use Case # 1 in ETSI GR F5G 020 [i.1] for more details.

4.2.2 Technology Requirements and Gap Analyses

4.2.2.1 General

Private line service automation capabilities are developed based on key features including of private line SLA evaluation before provisioning, E2E automatic configuration of both the customer's CPEs and the operator's OTN NEs for service provisioning, flexible bandwidth adjustment, and SLA information visualization.

4.2.2.2 Automatic evaluation of private line SLA before provisioning

The premium private line service provisioning system needs to be aware of the OTN resource information (including link bandwidth, latency and availability) in real-time, for both the electrical layer and the optical layer resources. Such information is the basic inputs for the service path computation and SLA evaluation.

[R1-1] The OTN electrical and optical layer resource information shall be reported to the premium private line service provisioning system in real-time.

The OTN control plane protocols, including the routing protocols, are defined by IETF. The new extensions to the OTN routing protocols supporting Recommendation ITU-T G.709/Y.1331 [1], including fgOTN, need to be supported in IETF.

[Gap1-1] Real-time resource discovery of fgOTN resources is currently not supported.

4.2.2.3 Agile service provisioning

The premium private line service provisioning system needs to automatically compute the service route, evaluate whether the calculated path can satisfy the SLA, and create the path for the service. If the OTN electrical layer has insufficient resources to support the service, it shall compute and create the new optical layer paths, to form the new electrical layer link resources for the requested service.

[R1-2] Computing and creating of both the OTN electrical and the optical layer paths shall be supported for private line service.

IETF develops the YANG data models for the electrical layer and the optical layer path computation and tunnel creation respectively. But currently there is no data model for computing and creating both the OTN electrical and optical layer paths for private line services.

YANG data models for fgOTN service provisioning have not been discussed yet.

[Gap1-2] Standardized YANG data models for computing and creating both the OTN electrical and optical layer paths for private line services are currently not supported.

4.2.2.4 CPE plug-and-play

The OTN CPEs are deployed on the customer's premises. In the scenario of automatic provisioning of premium private line services, once the CPE is connected to the operator's network through fibres, it should go online automatically, and the premium private line services are automatically configured on the CPE.

[R1-3] The network management and control system should support automatic discovery and automatic configuration of the OTN CPEs.

The CPE discovery and automatic configuration includes control channel creation, resource information discovery, service configuration, and alarm and performance management. Currently there is no related standard describing the procedure for how to discover and manage a CPE.

[Gap1-3] CPE plug-and-play is currently not supported.

4.2.2.5 Bandwidth on Demand

The premium private line service customer may request a temporarily or permanent increase of the service bandwidth for a certain major event or higher bandwidth demand. In the temporary scenario once the event is over, the service bandwidth needs to revert to the original bandwidth. In the case of the permanent increase it will remain unless the customer requests it to revert.

[R1-4] The OTN shall support hitless bandwidth adjustment of an OTN connection.

[R1-5] The OTN shall support instant bandwidth adjustment of an OTN connection.

In the OTN Data Plane, OTN Recommendation ITU-T G.709/Y.1331 [1] supports an ODUflex container with a bandwidth of approximately N × 1,25 Gbps. OTN also supports fgOTN with a bandwidth of approximately N × 10,4 Mbps. Hitless bandwidth adjustment of both ODUflex and fgOTN is supported.

[Gap1-4] None.

In the OTN Control Plane, the YANG data models for the northbound interface of the Optical Transport Controller for fgOTN service modification have not been discussed yet.

[Gap1-5] Standardized YANG data models for bandwidth adjustment of an fgOTN connection is currently not supported.

4.2.2.6 Real-time visualization of private line SLAs

The network operators need to provide the private line network view and related open network APIs to the customers, so that the customers can monitor the private line SLAs (including, latency and availability) from their own perspectives.

The premium private line service provisioning system should support monitoring the SLA information of the private line service, and generating alarms when the SLA cannot be satisfied.

[R1-6] The premium private line service provisioning system shall support SLA information query and alarm report APIs.

Currently there are no standard APIs for the OTN management and control system to report the private line SLA information including service latency, traffic bandwidth, and availability to the customer. The alarm reporting for SLA degrade is also not supported.

[Gap1-6] Standardized APIs and YANG data models for SLA information query and alarm report are currently not supported.

4.2.3 Current related standard specifications

4.2.3.1 ITU-T

ITU-T SG15 Q11 has standardized the OTN series of Recommendations. Which includes:

- Recommendation ITU-T G.709/Y.1331 [1] defines the requirements for the OTN interface signals, including the OTN hierarchy, frame structures, bit rates and formats for mapping client signals.
- Recommendation ITU-T G.709.20 [2] provides an overview of functions provided by the fgOTN layer network.

ITU-T SG15 Q12 and Q14 are working together to define the management and control of the Optical Transport Network, including Automatically Switched Optical Networks (ASONs) and Software Defined Networking (SDN). Q12 focuses on the Optical Transport Network architecture including the operational network aspects, while Q14 focuses on the management and control of the Optical Transport systems and equipment.

4.2.3.2 IETF

IETF has defined the GMPLS architecture for the control plane for different types of transport networks, and has added protocol extensions to support the control of the OTN:

- IETF RFC 3945 [i.2] which defines the architecture of the GMPLS.
- IETF RFC 7138 [i.3] which specifies the OSPF-TE routing protocol extensions to support GMPLS control of OTN specified in Recommendation ITU-T G.709/Y.1331 [1] as published in 2012.
- IETF RFC 7139 [i.4] which provide extensions to GMPLS signalling to control the full set of OTN features specified in Recommendation ITU-T G.709/Y.1331 [1] as published in 2012, including ODU0, ODU4, ODU2e, and ODUflex.
- IETF RFC 9376 [i.5] which examines the applicability of using existing GMPLS routing and signalling mechanisms to set up ODU connections over ODUCn links as defined in Recommendation ITU-T G.709/Y.1331 [1] published in 2020.

NOTE: The Recommendation ITU-T G.709/Y.1331 published in 2012 and 2020 are older versions of Recommendation ITU-T G.709/Y.1331 [1].

IETF is now developing a set of YANG data models for the TE networks, and the augmentation of these YANG data models for OTN:

- Draft-ietf-ccamp-otn-topo-yang [i.6], which defines the YANG data model to describe the topologies of the OTN.
- Draft-ietf-ccamp-otn-tunnel-model [i.7], which defines the YANG data model for tunnels in OTN TE networks.
- Draft-ietf-ccamp-otn-path-computation-yang [i.8], which defines the YANG data model for requesting path computation in OTN.
- Draft-ietf-ccamp-l1csm-yang [i.9], which provides a YANG data model for Layer 1 Connectivity Service Model (L1CSM).
- Draft-ietf-ccamp-client-signal-yang [i.10], which provides a YANG data model for transport network client signals.

IETF has still not defined the control protocols and YANG models for the latest version of OTN (Recommendation ITU-T G.709/Y.1331 [1]), especially for the support of fgOTN.

4.3 Stable & reliable Wi-Fi® connection over on-premises networking

4.3.1 Use Case Briefing

The stability and reliability of the Wi-Fi® connection is essential for good end user QoE. Compared to the traditional multiple AP networking, which acts as independent cascaded backhaul links for the Wi-Fi® fronthaul link, a stable and reliable Wi-Fi® connection requires coordination between the different AP (including P-ONU and E-ONU) to avoid potential collisions. This requires dynamic coordination between the fibre link and the Wi-Fi® link for an FTTR on-premises network. A stable and reliable Wi-Fi® connection could provide benefits for the on-premises scenarios, including support for Gigabit/multi-Gigabit coverage, controlled latency boundary, seamless roaming, and stable IoT control. See Use Case # 2 in ETSI GR F5G 020 [i.1] for more details.

4.3.2 Technology Requirements and Gap Analyses

4.3.2.1 General

For the FTTR on-premises fibre network, a stable & reliable Wi-Fi® connection needs a centralized coordination architecture [3], facilitating a series of functions, including QoS identification, data collection, control messaging, module configuration. Based on the dynamic service requirements and Wi-Fi® channel sensing status, the centralized controller should make the correct decision and convey the control messages to each network devices for them to take timely actions.

Although the coordination architecture has been mentioned in different document from a number of SDOs, including ETSI ISG F5G and ITU-T SG15 Q3. There are still a number of gaps that need to be resolved before the practical implementation is achieved.

4.3.2.2 Service type identification and adaptation

The first step in deciding the allocation of network resources is to understand the QoS requirement by identifying the service type. In general, different network services can run in parallel within a single FTTR network. Mechanisms should be supported in the on-premises fibre network to differentiate the QoS flows in terms of network capability, including throughput, latency, packet loss rate, and packet jitter. The controller uses the QoS requirements to derive the dynamic scheduling for the dedicated packet flows under investigation (including the data buffer queue waiting time, the volume of data packets, and the Wi-Fi® air interface channel condition). The identification could be achieved by analysing the data flow behaviour, and recognizing the QoS indicators in the Ethernet frame or high-level protocols.

[R2-1] The fibre-based on-premises network shall support network application identification and the corresponding QoS mechanisms.

The fibre-based on-premises network needs an on-premises centralized controller dynamically supporting the data flow scheduling and configuration of each network device in the FTTR network.

[R2-2] The fibre-based on-premises network shall support an on-premises network centralized controller.

The current system uses Ethernet QoS identifiers to map the different QoS queues in the on-premises network system (such as Best Effort (BE), Background (BK), Video (VI), and Voice (VO) in Wi-Fi®). However, there may be several data stream from different service types using the same indicators. Improving the allocation of the network resources to the dedicated network services is required based on the identified QoS requirements. It is required that the system should identify the QoS requirements for each network service so that the scheduling procedure is specifically targeted to these network service data flows.

[Gap2-1] A dynamic and quantitative QoS indication scheme for practical data flows is currently not available.

[Gap2-2] None.

4.3.2.3 Wi-Fi® interference recognition and avoidance

Wi-Fi® interference exists when the neighbouring APs are working in overlapping channels. Especially for high-speed connection, spectrum limitation may lead to fewer number of channel with large bandwidth (160 MHz or 320 MHz). The detection of interference is necessary for the controller to understand the need for AP coordination in specific APs. This will require the controller to request and collect the interference information in real time from the peer APs or to allow the peer APs to regularly report such information.

Furthermore, in order to avoid interference, the Wi-Fi® transmission of each Wi-Fi® AP should be configured by the controller. Accordingly, interference mitigation can be achieved through the time-domain, the frequency-domain or the spatial domain. The fibre-based on-premises network shall support dynamically collecting Wi-Fi® channel information (including channel bandwidth and frequency, corresponding signal strength, channel duty cycle) so as to identify the neighbour's interference and the link quality of the end user device.

[R2-3] The fibre-based on-premises network shall support real time Wi-Fi® channel information collection.

[R2-4] The fibre-based on-premises network shall support continuous real time Wi-Fi® transmission behaviour configuration of each Wi-Fi® AP.

To achieve interference recognition the controller needs to understand the channel information in real time. On-time tuning requires fast decision making by the centralized controller, fast control message delivery and fast AP re-configuration. This process needs on-premises system level coordination from module to module of the network devices.

[Gap2-3] The messaging mechanism and data model for Wi-Fi® channel monitoring between different APs and end user devices over the fibre link are currently not available.

[Gap2-4] The messaging mechanism and data model for Wi-Fi® transmission coordination over the fibre link are currently not available.

4.3.2.4 Provide latency sensitive transmission mechanism

Wi-Fi® transmission delay is in the range tens of microseconds to a few milliseconds. To support latency sensitive packets (including control messages or data packets) needs a dedicated controller messaging channel to transport the control information. This is the key to guaranteeing on time packet scheduling. In addition, an efficient control messaging procedure is necessary to reduce any redundancy during the control process.

The latency sensitive channel could further be utilized for low latency packet transmission, which is identified and recognized by the system.

[R2-5] The fibre-based on-premises network shall support a low latency control channel with a 64 µs round trip time between the M-FTR and the S-FTR.

NOTE: The M-FTR is part of the P-ONU and the S-FTR is part of the E-ONU and are defined in Recommendation ITU-T G.9940 [7]. The M-FTR is the optical transceiver of the P-ONU while the S-FTR is the optical transceiver of E-ONU.

[R2-6] The fibre-based on-premises network shall support a control messaging procedure with bounded latency as required by the identified QoS.

G.fin is based on a P2MP infrastructure, in which the dynamic time allocation is applied for both downstream and upstream. To achieve low latency message transmission for the fibre and the wireless coordination, the on-premises fibre-based network should provide a protocol level mechanism to guarantee the transmission and reception of the messages. A dedicated message exchanging procedure needs to be defined over the latency sensitive channel for different technical features, including seamless handover.

[Gap2-5] The low latency control channel with less than 64 µs round trip time is currently not available in the fibre DL.

[Gap2-6] Dedicated message exchange procedures for different technical features, including seamless handover are currently not available.

4.3.2.5 Enable seamless connection switching

User mobility causes Wi-Fi® signal variation. To maintain a good quality connection within the fibre-based on-premises network, link selection between the end user device and dedicated AP is important. This requires link switching between network devices. In this case, seamless handover is essential. Completion of connection switching in handover can be achieved by traditional protocols, defined in IEEE 802.11k [4], 802.11v [5], 802.11r [6]. The protocol is based on L2+ transmission and is transparent to the fibre link and wireless link. The transmission of the handover packets is affected by scheduling of the fibre link and channel quality of the Wi-Fi® link. Any packet loss due to signal variation by user mobility or Wi-Fi® collision can result in switching delay or even failure.

A stable and reliable Wi-Fi® connection needs to provide a mechanism to achieve seamless switching for end user devices. The complex switching protocol may be simplified or discarded. Ideally, the handover process should be imperceptible to the end user device at the service level.

[R2-7] The fibre-based on-premises network shall provide a reliable handover message transmission channel with deterministic latency.

To develop a full handover procedure, each step of the message transmission should be transmitted as high priority and no collision/retransmission should take place. A robust messaging channel and corresponding data model are forthcoming.

[Gap2-7] Same as [Gap2-4], [Gap2-5], and [Gap2-6].

4.3.3 Current related standard specifications

4.3.3.1 ITU-T

The majority of FTTR specification development has been focused on P2MP systems. The standardization is being developed in Recommendation ITU-T G.994x series [7] to [9] and [i.11]. Recommendation ITU-T G.9940 [7] specifies the system architecture and requirements. In particular, a centralized fibre and wireless coordination architecture has been defined, as shown in Figure 1. The MFU (same as P-ONU in F5G) contains controller(s) that dynamically collect the network service QoS and characteristics (data buffer status, traffic priority, latency requirements, etc.), identify the network environment (such as channel status between the MFU and the SFU(s) (same as E-ONU in F5G), interferences, etc.) and creates a strategy to coordinate the behaviour of the different networks connected to it. Based on the coordinator(s), fast network operation and control, including ordered medium access, global handover, real-time link visibility, etc. can be achieved. The interface between the controller/coordinator and Wi-Fi® APs is expected to be considered in the Wi-Fi® specification.

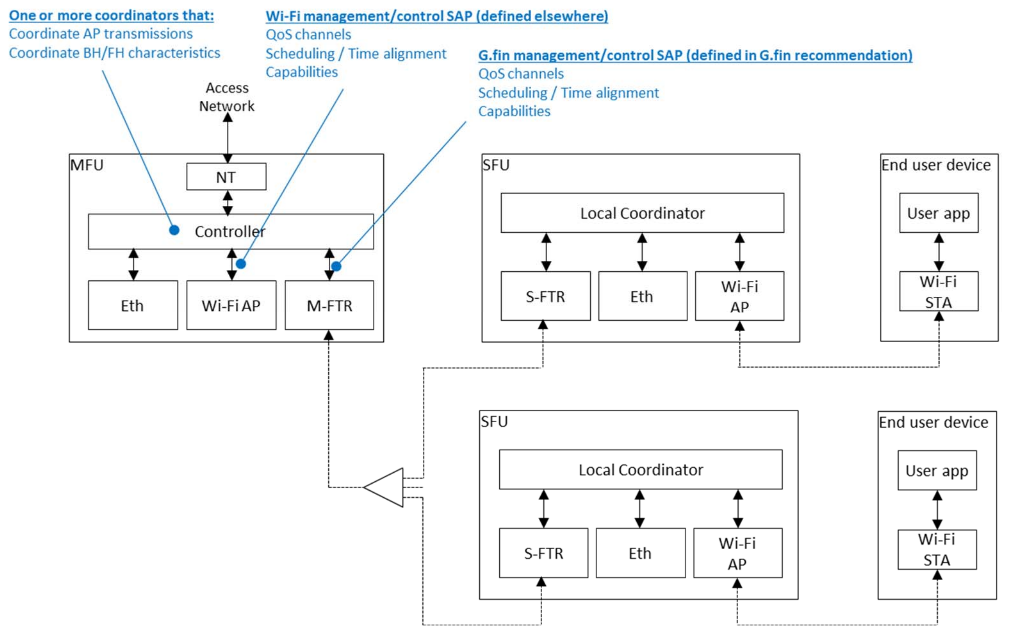

Figure 1: Centralized fibre and wireless coordination architecture (Source: Recommendation ITU-T G.9940 [7])

Recommendation ITU-T G.9941 [8] specifies the Physical layer (PHY) for P2MP G.fin systems. There are two speeds of interest: 2,5 Gbps symmetrical (the near term goal), and 10 Gbps symmetrical (the future goal). In this context, the PHY includes the Physical Medium Dependent (PMD) sublayer, the Physical Medium Attachment (PMA) sublayer, and the Physical Coding Sublayer (PCS). In the PMD, the transmitted power, the receiver sensitivity and overload, the wavelengths of operation, and more are defined. The PMA includes the functions such as forward error correction, scrambling, and control of the physical layer upstream bursting. The PCS includes functions like the transmission frame assembly, bandwidth map creation, the PLOAM channel protocol, and the frame delineation.

Recommendation ITU-T G.9942 [9] specifies the Data Link Layer (DLL) for P2MP G.fin systems. The basic protocol stack of the DLL is shown in Figure 2. A dedicated L1/L2 control channel "WLAN Management & Control Interface" (WMCI [i.12]) is defined to convey the Wi-Fi® control messages. A new recommendation called G.wmci [i.12] was initiated in 2023 ITU-T November plenary to define the protocol and corresponding data model.

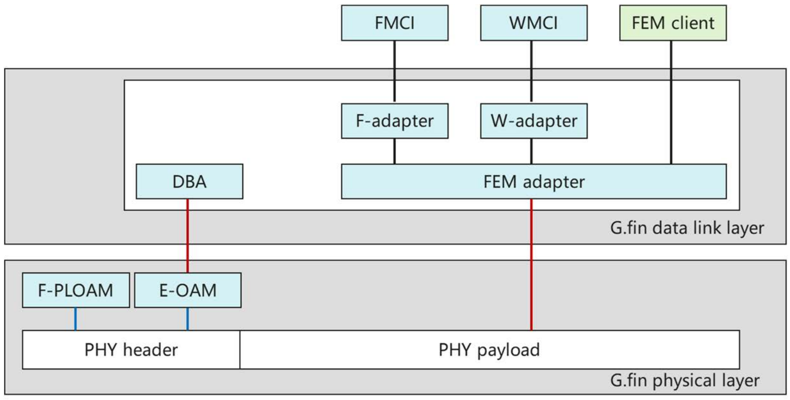

Figure 2: Protocol stack of G.fin DLL
(Source: Recommendation ITU-T G.9942 [9])

4.3.3.2 IEEE

IEEE 802.11bn [i.13] was started in 2023. This amendment of the IEEE 802.11 standard defines modifications to both the physical layer and medium access control layer that enhances the WLAN reliability:

1) Increase throughput, as measured at the MAC data service Access Point, at different Signal to Interference and Noise Ratio (SINR) levels (Rate-vs-Range), compared to extremely high throughput MAC/PHY operation.

2) Improve the tail of the latency distribution and packet jitter compared to extremely high throughput MAC/PHY operation, with mobility between BSSs.

3) Improve efficient use of the medium compared to extremely high throughput MAC/PHY operation.

IEEE 802.11bn [i.13] provides mechanisms for enhanced power savings for both the Access Point (AP) (including mobile AP) and the non-AP stations with improved Peer-to-Peer (P2P) operation compared to extremely high throughput MAC/PHY operation.

IEEE 802.11bn [i.13] applies to carrier frequencies operation between 1 GHz and 7,250 GHz. This amendment shall ensure backward compatibility and coexistence with legacy IEEE 802.11 devices in the 2,4 GHz, 5 GHz and 6 GHz unlicensed bands.

One of the core features under development in IEEE 802.11bn [i.13] is multi-AP coordination, in which a coordination scheme is deployed in the air interface to share the commonly used transmission opportunities. This helps to avoid collision through coordination.

4.4 Computing collaboration in PON network

4.4.1 Use Case Briefing

The computing collaboration of various network element in the E2E Optical access Network (PON) will make better use of the heterogeneous capabilities of dedicated devices to enable improved quality and higher efficiency for delivering network services. For example, to improve the QoE for communication, the network needs to identify the service type, the related QoS requirement, assign network scheduling to the dedicated network element, and coordinate with each by exchanging network status information. For the computing services, the image storage takes place in a Network Attached Storage (NAS) device, image editing takes place in the mobile device and image rendering takes place in the P-ONU. The collaboration procedure may be very diverse, depending on the service demand. Therefore, computing collaboration is necessary to be adapted for the different applications, dynamically organizing the necessary resources. See Use Case # 3 in ETSI GR F5G 020 [i.1] for more details.

4.4.2 Technology Requirements and Gap Analyses

4.4.2.1 General

For computing collaboration in the PON network, there are multiple network elements involved, including a cloud platform (traditionally providing management functions, big data analysis could also be enable there), an OLT (close to the end user and could have large computing resources for edge computing), a P-ONU (the network terminal, to schedule the network resources and take part in distributed computing using spare CPU/GPU capability), and an E-ONU (the access point to control the quality for the last-meter connection and sensing the behaviour of the end user). These network elements will require dedicated computing functionality in the different devices, and efficient communication and coordination between the devices.

4.4.2.2 Heterogeneous computing capability

To facilitate the computing function in the network elements for diverse service and dynamic computing, additional computing capability is needed. Dedicated computing hardware including CPU/GPU/NPU should be integrated at the system level, such as the OLT or the P-ONU. Therefore, independent computing oriented software or applications can be run without affecting the normal data transmission. Additional computing oriented hardware or modules need to be supported in the PON network elements (including the OLT, the P-ONU and the E-ONU) to support computing functions and collaboration.

[R3-1] The PON network elements shall support additional computing oriented hardware or modules.

The traditional optical access network is designed mainly for data transmission. The typical computing module in the PON network is DBA, which calculates the data transmission requirements and grant transmission opportunities in the time domain to schedule upstream transmission for the connected ONUs. It is also similar for the P-ONU in the FTTR network.

[Gap3-1] Additional computing oriented hardware or modules in the current PON network elements, including the OLT, the P-ONU and the E-ONU are currently not available.

4.4.2.3 Identification of service flow & corresponding demand

The goal for computing collaboration is to satisfy the service flow SLA requirements. This is similar to the requirements in Use Case # 2 clause 5.2 of ETSI GR F5G 020 [i.1]. The PON network shall be capable of identifying the service flows and understand the corresponding requirements. This can be done by the PON network itself or managed by an external entitle such as the cloud platform. The PON shall also identify the corresponding QoS requirements, including throughput, latency, and packet jitter.

[R3-2] The PON network shall support service flow identification and identification of the corresponding QoS requirements.

Traditionally, the data priority is identified by the Ethernet QoS indicators, which do not provide quantitative requirements to inform the network how to achieve dynamic scheduling or collaboration.

[Gap3-2] A dynamic and quantitative QoS indication scheme for practical data flows for the PON network are currently not available.

4.4.2.4 Dynamic collaboration between the PON network elements and the computing elements

Dynamic collaboration takes place between multiple network elements, including the cloud platform, the OLT, the P-ONU and the E-ONU. The interfaces between the different network elements are the key to collecting collaboration data and forwarding the configuration. The algorithm for computing collaboration is based on the status of the collection and sensing.

[R3-3] The cloud platform shall support the enabling or disabling computing collaboration of the OLT, the P-ONU or the E-ONU.

[R3-4] The cloud platform shall be capable of collecting the computing capability information and utilization of the OLT, the P-ONU or the E-ONU computing resources.

[R3-5] The OLT shall support a computing collaboration information and configuration exchange interface with the P-ONU and the E-ONU.

NOTE 1: This interface is protected by a secure mechanism.

[R3-6] The on-premises network P-ONU shall support a computing information and configuration exchange interface with the E-ONU.

NOTE 2: This interface is protected by a secure mechanism.

Information and configuration exchanges are at the core for the coordination between multiple network elements. Protocol design and a data model to support this collaboration is necessary. Extensions to the current protocols or a new protocols are needed to be considered according to the computing collaboration requirements.

[Gap3-3] A Collaboration function is not defined in the current E2E system.

[Gap3-4] A Data model for computing collaboration is currently not available in BBF oneM2M TR-069 [i.14] and oneM2M TR-369 [i.15].

[Gap3-5] A Data model for computing collaboration is currently not available in OMCI [10].

[Gap3-6] A Data model for computing collaboration is currently not available in FMCI [i.11] or WMCI [i.12] for the on-premises network.

4.4.3 Current related standard specifications

4.4.3.1 ITU-T

ITU-T SG15 defines interfaces for PON and FTTR networks:

1) Between the OLT and the P-ONU based on OMCI [10].

2) Between the P-ONU and the E-ONU based on FMCI [i.11].

ITU-T SG15 Q2 defined the Optical Management & Control Interface (OMCI) [10] for P-ONU management by the OLT, shown as the I2 interface in Figure 3. This interface is a layer 2 management interface, having higher transmission priority in an independent logic channel.

ITU-T SG15 Q3 defined the Fibre Management & Control Interface (FMCI [i.11]) and WLAN Management & Control Interface (WMCI [i.12]) to exchange management or control information for the fibre link and the Wi-Fi® link.

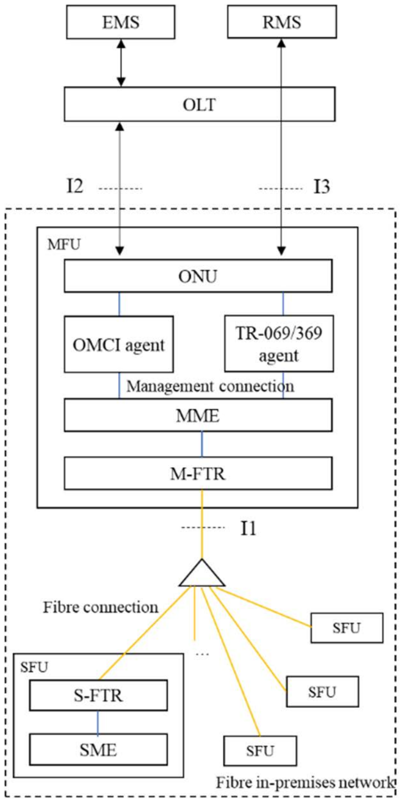

Figure 3: An example of management scheme of FTTR (Source: Recommendation ITU-T G.9940 [7])

Computing collaboration information may be defined based on the current protocol stack. In this case, an additional data model should be considered.

4.4.3.2 BBF

BBF defined oneM2M TR-069 [i.14] for P-ONU management by a cloud platform. An evolution of BBF oneM2M TR-069 [i.14] was developed to enable information exchanged between any network element in the form of "controller" and "agent" For details, refer to clause 4.5.3.3 of ETSI GS F5G 013 [11].

4.5 Intelligent power grid

4.5.1 Use Case Briefing

The current power grid communication network uses multiple transmission technologies such as OTN, SDH, PDH and PON to provide a secure and reliable communication infrastructure for the power grid relay protection system, security stability system, and power grid automation system, including dispatching automation, transmission and transformation automation, and distribution automation. It also provides information services for power grid headquarters, the branches and the operation centres. The transition from the current power grid communication network to an intelligent power grid communication network is driven by the need for intensive substations, unmanned substations, distributed new energy grid connectivity, and Ultra High Voltage (UHV) grid deployment. See Use Case # 4 in ETSI GR F5G 020 [i.1] for more details.

4.5.2 Technology Requirements and Gap Analyses

4.5.2.1 General

The current power communications network needs to be upgraded to the new intelligent power grid communication network so that it can provide an end-to-end high-quality connectivity infrastructure to meet the needs of the intelligent and cloud-based power grid.

For the data centre communication network of the intelligent power grid, an optical transport network with higher capacity up to 800 G is needed for intra-city Data Centre Interconnect (DCI).

For the backbone communication network of the intelligent power grid, needs to support ultra-large State Of Polarization (SOP) and an ultra-long single-span transmission network, 10 Gbps and 100 Gbps or beyond coexisting transmission network, which meets the power grid requirements, including Optical Ground Wire (OPGW) cables, long distance between sites, and smooth flexible bandwidth updatability.

For the substation communication network of the intelligent power grid, requires a new fine grain Time-Division Multiplexing (TDM) technology to replace the legacy and end of life SDH/PDH technology. The fine grain TDM technology can be used in the power distribution access network and the substation campus access network, to provide the multiple services transport capabilities as well as providing the end-to-end high quality connections across the power grid communication network.

4.5.2.2 High capacity optical transport network

For the data centre communication network of the intelligent power grid, the interconnection bandwidth between Data Centres (DCs) and Disaster Recovery (DR) centres, the interconnection bandwidth between the DC and the headquarters, and the access bandwidth between the DC and the branches are increasing rapidly. A higher capacity optical transport network is needed to provide higher bandwidth and more connections.

[R4-1] The DCI network of the intelligent power grid shall support up to 800 Gbps per wavelength up to 80 km.

In the backbone transport network, there is a need for ultra-large State Of Polarization (SOP) for Optical Ground Wire (OPGW) cables and ultra-long single-span for 500 km long distances between sites. At the same time, the backbone transport network is being updated from 10 Gbps to 100 Gbps or beyond per wavelength, so 10 Gbps and 100 Gbps or beyond coexisting is required in the same fibre.

[R4-2] The backbone transport network of the intelligent power grid shall support ultra-large State Of Polarization (SOP) with at least 8 M rad/s.

[R4-3] The backbone transport network of the intelligent power grid shall support ultra-long single-span of at least 500 km.

[R4-4] The backbone transport network of the intelligent power grid shall support 10 G and 100 G coexisting on the same fibre.

However, for the DCI network of the current power grid, the interconnection bandwidth between data centres is mainly 100 Gbps or 200 Gbps per wavelength, there are a number of 400 Gbps wavelengths. The 800 Gbps interface for DCI/Metro applications is specified in other SDOs, such as ITU-T SG15 and OIF. It can meet the demands of the intelligent power grid communication network.

[Gap4-1] None.

SOP with at least 8 M rad/s and 10 Gbps and 100 Gbps or beyond coexisting on the same fibre technology is currently available. But ultra-long single-span with at least 500 km technology is not mature.

[Gap4-2] None.

[Gap4-3] Ultra-long single-span with at least 500 km technology is currently unavailable.

[Gap4-4] None.

4.5.2.3 Fine grain optical transport network

In the current substation communication network, legacy and end of life SDH as a TDM technology, is still used to carry power grid production services, including relay protection services, security stability services and dispatching automation services, which require hard isolation, deterministic low latency, high reliability, and high security.

As the power grid is evolving to an intelligent power grid, the intensive substations and unmanned substations are driving the bandwidth increase from 2 Mbps to 20 Mbps or even 50 Mbps. The number of connections to the primary substations is increasing from hundreds to thousands for dispatching automation and the new services such as video services and IoT services. The current substation transport network cannot meet the growing demand for the increased bandwidth and larger number of connections. A new fine grain TDM technology is required as an alternative to SDH technology once SDH equipment is obsoleted. This new technology needs to support equivalent properties as SDH including hard isolation, low latency, low latency variation and efficiently support carrying a large number of sub 1 G services. N by 10 Mbps tributary slots for $N \leq 119$ will allow for substations bandwidth growth.

[R4-5] The substation transport network of the intelligent power grid shall support fine granularity with 10 Mbps tributary slots.

[R4-6] The substation transport network of the intelligent power grid shall support hard isolation, low latency, low latency variation, Operation, Administration and Maintenance (OAM).

[R4-7] F5G advanced network of the intelligent power grid should support migration of legacy SDH networks.

Timing transparency is essential for this new fine grain technology in order to replace the SDH synchronous network in particular for Constant Bit Rate (CBR) services such as E1 and STM-n.

[R4-8] The substation transport network of the intelligent power grid shall support timing transparent transmission for CBR services.

In addition to CBR traffic, this new fine grain technology needs to be flexible and support hitless bandwidth adjustment capabilities for Variable Bit Rate (VBR) packet services such as IP/Ethernet services.

[R4-9] The substation transport network of the intelligent power grid shall support agile and hitless bandwidth adjustment capabilities.

OTN is a TDM technology that provides guaranteed bandwidth and latency performance. However, the minimum rate of the current ODUk connection is ODU0 with approximate 1,25 Gbps bitrate, and the minimum granularity of the current ODUk connection is 1,25 Gbps, which cannot efficiently map sub 1 G services or support a large number of fine granularity sub 1 G services. The fine grain OTN technology is specified in ITU-T SG15 WP3. Flexible optical service unit (OSUFlex) of the Optical Transport Network (OTN) in power systems was specified in IEEE P2893 [17] in parallel. With the standardization of fgOTN and OSU, these new technologies can well serve the demands of the intelligent power grid once SDH is obsoleted, and provide fine granularity, low latency, low latency variation, efficiently carrying a large number of sub 1 G services.

[Gap4-5] None.

[Gap4-6] None.

[Gap4-7] None.

[Gap4-8] None.

[Gap4-9] None.

4.5.2.4 End-to-end high quality connection

The access network for the power distribution and the substation campus needs to differentiate service types and provide different QoS, including real-time and non-real-time production control services for dispatching automation, distribution automation, video surveillance services, IoT terminal connection services, and power consumption data services. All the services in different security zones are transmitted on the same physical network. Hard isolation and multi-service transport capabilities are needed. In particular, for the key priority services, the end-to-end high quality hard isolation connections across the distribution access network and substation transport network should provide guaranteed bandwidth and latency performance.

[R4-10] The communication network of the intelligent power grid shall support an end-to-end high quality hard isolated connections.

In addition, optical transport network services are the foundation of the emerging intelligent power grid. For the flexible scheduling requirements of the intelligent network, a multi-level flexible scheduling mechanism based on Optical Cross-Connect (OXC), Optical Data Unit (ODU), and fgOTN needs to be constructed to implement intelligent coordinated scheduling at the wavelength, channel, and service levels, and meet the high quality connections.

[R4-11] The communication network of the intelligent power grid shall support a multi-level flexible scheduling mechanism at the wavelength, ODU as channel, and fgOTN as service levels.

However, in the current power grid communication network, the services need to be demapped from one connection in the power distribution access network or the substation campus access network, and then mapped to another connection in the substation transport network and the backbone transport network. An end-to-end high quality hard isolated connection across the power grid communication network is currently unavailable.

[Gap4-10] An end-to-end high quality hard isolated connection across the communication network of the intelligent power grid is currently unavailable.

[Gap4-11] None.

4.5.3 Current related standard specifications

4.5.3.1 ITU-T

Over the past 30 years, ITU-T has driven the standardization of OTN, with the line rate of OTN increasing from 1,25 Gbps to 400 Gbps and beyond. Currently, OTN technology is evolving to the next generation in two directions. The first direction is beyond 400 G OTN technology, which is standardized by ITU-T [1], [12], [13], [14], and [15] in order to support 800 GE clients mapping and up to 800 Gbps flexible OTN interface. The second direction is fine-grain OTN with 10 Mbps bandwidth granularity, which is standardized by Recommendation ITU-T G.709.20 [2], Recommendation ITU-T G.709/Y.1331 [1] annexes M and O, and Recommendation ITU-T G.872 [16] in order to efficiently support a large number of high-quality sub 1 G services and the migration of legacy SDH networks, increasing the value of OTN to meet the future communication demands. Figure 4 illustrates the overview of the OTN structure from Recommendation ITU-T G.872 [16].

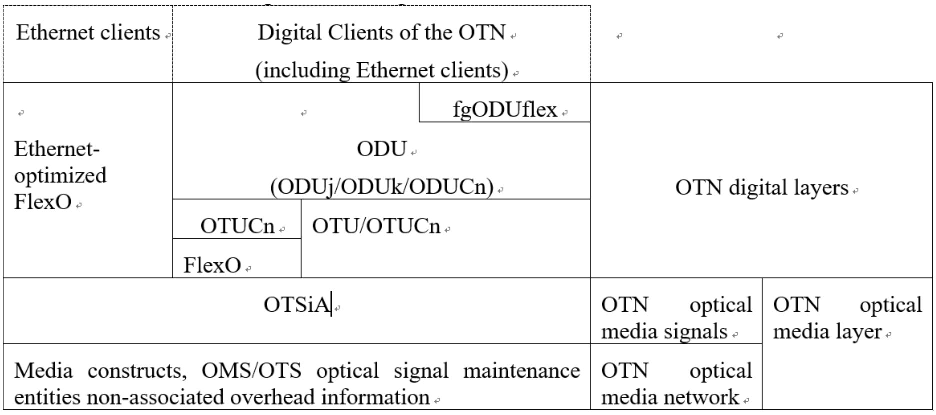

Figure 4: Overview of the OTN structure

SDH and OTN are Time-Division Multiplexing (TDM) technologies that provide guaranteed bandwidth and latency performances. As the next generation TDM technology after SDH, fgOTN is expected to provide fine granularity, high-quality TDM connections for Constant Bite Rate (CBR) services once SDH networks are obsoleted from the transport network, where the multi-layer network structure of OTN+SDH will be simplified to a unified OTN network including fgOTN. In addition, the fgOTN connections need to support Variable Bit Rate (VBR) services such as Ethernet Packet (PKT) services with agile and hitless bandwidth adjustment capabilities. Figure 5 shows the overview of the fgOTN layer network inside OTN. The fgOTN complements the existing OTN with an additional fgOTN layer network that efficiently and reliably carries the sub 1 G services as an optimal alternative to the SDH technology.

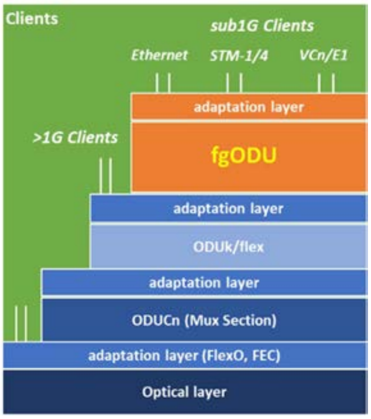

Figure 5: Overview of the fgOTN layer network inside OTN

Figure 6 shows the information structure for fgOTN layer network with the key functions and capabilities as follows:

- The fgOTN supports mapping the client service into fgODU path layer, including Ethernet services (p × 10 M, p = 1 to 119) via IMP, CBR services (STM-1, STM-4, VC-n, E1) via GMP.
- The fgOTN supports multiplexing multiple fgODU paths into ODU0/1/2/flex. The bandwidth granularity is 10 Mbps.
- The fgOTN supports fgODU 1+1 protection.
- The fgOTN supports timing transparent transport for CBR services, meeting the jitter and wander requirements defined in Recommendations ITU-T G.823 [18] and G.825 [19].
- The fgOTN supports fgODU hitless bandwidth adjustment function for packet services.

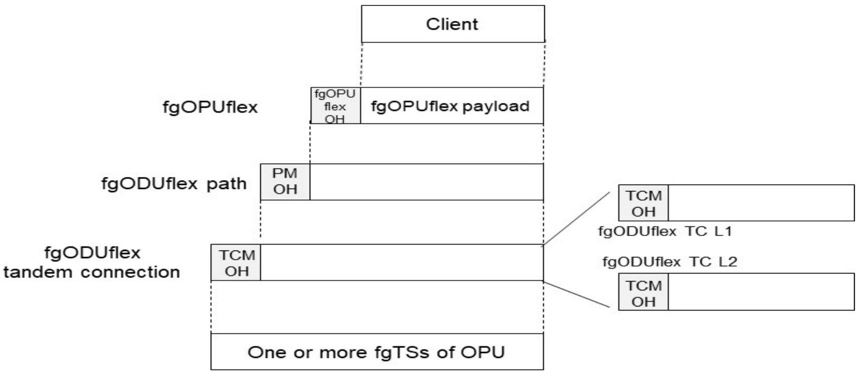

Figure 6: The information structure of the fgOTN layer network

The first set of four core fgOTN recommendations have been consented, including Recommendation ITU-T G.709.20 [2] on fgOTN overview, Recommendation ITU-T G.709/Y.1331 [1], Annex M on fgOTN interface, Annex O on fgOTN hitless bandwidth adjustment, and Recommendation ITU-T G.872 [16], Annex A on fgOTN path layer network architecture, in the ITU-T SG15 Plenary Meeting held during November 20th to December 1st, 2023 in Geneva. The remaining fgOTN recommendations were consented in ITU-T SG15 Plenary Meeting held during July 1st to 12th 2024 in Montreal, including Recommendation ITU-T G.808.4 [i.36] on fgOTN protection, Recommendation ITU-T G.798 amendment 1 [i.37] on fgOTN equipment and Recommendation ITU-T G.8251 amendment 1 [i.38] on fgOTN synchronization.

With the full TDM characteristics, fgOTN is an ideal TDM technology to serve as the next-generation TDM technology replacing SDH, and provide fine granularity, hard isolation, low latency, and low latency variation. The fgOTN technology efficiently carrying a large number of sub 1 G services, supports synchronized connections for CBR services, as well as agile and hitless bandwidth adjustment capabilities for VBR services.

4.5.3.2 IEEE

IEEE P2893 [17] has been approved in 2023. This standard specifies a communication layer, Flexible Optical Service Unit (OSUFlex) to provide small service channels in optical transport networks. The main features of the OSUflex communication layer provide a large number of OSUflex connections to directly carry power services into an optical transport network, enabling the flexible bandwidth and hitless bandwidth adjustment for each OSUflex connection, direct mapping of services into OSUflex with the capabilities of high-bandwidth efficiency, low latency, low latency jitter and high-precision clock synchronization for power system applications.

4.6 Railway perimeter inspection

4.6.1 Use Case Briefing

As the main means of transportation and an important infrastructure, the railway system plays an important role in the economic and social development. For railway transportation, safety is the highest priority, but factors including illegal intrusion onto the railway tracks, illegal destruction or crossing the railway fence, rock fall, landslide, and other factors threaten the train's safety. With the growth and expanse of the railway system, continuing to rely upon personnel patrolling the railway perimeter is becoming less efficient and time consuming. New technologies need to be explored to further strengthen the perimeter inspection capability along the railway track.

Vegetation, animals, pedestrians, vehicles, wind, rain, snow, fog and other complex weather and environment conditions pose serious challenges to the reliability, adaptability and stability of the perimeter inspection system. With the rapid development of sensing technologies, the optical fibre sensing technology provides full coverage, all-weather, and all-intelligence technology for the railway perimeter inspection. Vibrating optical fibre is easy to deploy and is cost-effective. The optical fibre sensing technology is suitable for detecting human intrusion along irregular and sheltered long-fence distances. The optical fibre sensing technology is an important technical defence measure for railway perimeters inspection. See Use Case # 5 in ETSI GR F5G 020 [i.1] for more details.

4.6.2 Technology Requirements and Gap Analyses

4.6.2.1 General

The technical capability of the perimeter inspection system along the railway track needs to be an efficient mechanism to prevent human intrusion and physical damage. Up to now, the security of important facilities along the railway tracks, such as communication stations, substations and other facilities mainly relies on manual patrols by railway protection personnel on sites or remote patrols via the existing video surveillance system. Due to the lack of technical prevention mechanisms, capabilities, and the limitation of the perimeter patrol in terms of patrol range, none real-time, and efficiency, human intrusions and foreign object intrusions occur frequently on the perimeter of the railway tracks. This results in a large amount of property loss or damage, especially on the high-speed railway line. High-speed trains need a longer braking distance to respond to an emergency situation. The safety of the high-speed railway line operating environment has been the main challenge of the railway safety operation. The occurrence of the railway perimeter security risk is sudden, hidden and complex. These malicious acts or potential dangers are a serious safety risk to railway transportation. These shortcomings are overcome by deploying an optical fibre sensing railway perimeter inspection system.

4.6.2.2 Fibre sensing performance

Railway perimeter inspection fibre sensing technology needs to support the following functions and capabilities:

The maximum distance between the communication stations is up to 100 km, so the unidirectional coverage range shall be at least 50 km to cover the full range.

[R5-1] Unidirectional coverage range shall be greater than 50 km.

[Gap5-1] Standards which support unidirectional coverage range greater than 50 km are currently unavailable.

The perimeter intrusion event detection system needs to improve the detection rate of the true intrusion events and reduce the number of missed intrusion events as much as possible. The detection rate needs to be greater than 99,9 %.

The detection rate is the detected number of true intrusion events divided by the actual number of true intrusion events:

$$\text{Detection rate} = \frac{\text{Detected number of true intrusion events}}{\text{Actual number of true intrusion events}}$$

[R5-2] The detection rate of true intrusion events shall be greater than 99,9 %.

[Gap5-2] Standards which support the detection rate greater than 99,9 % are currently unavailable.

The perimeter intrusion event system needs to reduce the false intrusion event detection as much as possible, the frequency of such false intrusion events per month period needs to be less than 0,002 events/km/hour on average.

[R5-3] The frequency of false intrusion events shall be less than 0,002 events/km/hour on average.

[Gap5-3] Standards which support the frequency of false intrusion events less than 0,002 events/km/hour on average are currently unavailable.

The position accuracy of the perimeter intrusion event detection system needs to be less than 10 m.

[R5-4] The position accuracy of the true intrusion event detection shall be less than 10 m.

[Gap5-4] Standards which support the position accuracy less than 10 m are currently unavailable.

The perimeter intrusion event detection system needs to support real-time response. Within the monitoring range of the detection sensor, the response time from the start of an intrusion event to the time reported by the monitoring centre needs to be less than 5 s.

[R5-5] Intrusion event identification time shall be less than 5 s.

[Gap5-5] Standards which support intrusion event identification time less than 5 s are currently unavailable.

4.6.3 Current related standard specifications

4.6.3.1 ITU-T

ITU-T SG15 Q6 is defining a standard named G.dfos [i.16] (distributed fibre optic sensing) to specify the fibre sensing system for monitoring fibre cable.

4.7 Naked-eye 3D display

4.7.1 Use Case Briefing

Naked-eye 3D display provides 3D visual sensing from the human eye to the brain without the need for external objects on the human body, such as 3D glasses, helmet, etc. It can be applied in a wide range of application, for sport broadcasting, variety show, live news, education & training, gaming, etc. A high end naked-eye 3D display provides high resolution video streaming and multiple viewpoints with sensing functionality for eyeball tracking, voice interaction or gesture recognition. See Use Case # 6 in ETSI GR F5G 020 [i.1] for more details.

4.7.2 Technology Requirements and Gap Analyses

4.7.2.1 General

Due to the high resolution video streaming in 3D and the multiple viewpoints to support visual imaging for multiple customers simultaneously, the high end naked-eye 3D display requiring extremely high throughput [i.1]. For example, a typical 4K display over H.265 compression with 36 viewpoints requires 1,14 Gbps while an 8K display over H.265 compression with 84 viewpoints requires 10,68 Gbps (see Table 2 of ETSI GR F5G 020 [i.1]). Moreover, the imaging content should adapt to the human's position or commands for interaction activities (like gaming). This requires latency restrictive transmission for small control or information feedback package.

4.7.2.2 Extremely high throughput

The naked-eye 3D display is initially deployed for business application for advertisement. This requiring high throughput in the downstream direction. On another hand, for live applications, the uplink collection of 3D data is necessary while the content is processed remotely in the cloud and then sent for display as downlink. Therefore, bilateral high throughput is needed. In the future, it will evolve to residential applications over mobile phone, laptop, tablets or TV. The F5G-A E2E network shall support 10 Gbps for the end user. In particular, the optical access network and the on-premises network shall enable 10 Gbps throughput.

[R6-1] The F5G-A access network shall provide symmetric 10 Gbps data rate for each subscriber.

[R6-2] The FTTR on-premises network shall provide symmetric 10 Gbps data rate.

It is necessary to evolve the traditional F5G network to have support for naked-eye 3D display for excellent user experience. XGSPON and 2,5 G FTTR may not be sufficient in this case. ITU-T SG15 Q2 has completed the 50 GPON standardization while 10 G FTTR is still in its infancy.

[Gap6-1] None.

[Gap6-2] Symmetric 10 G FTTR technology is currently not available.

4.7.2.3 Latency restricted transmission

The latency requirements come from the interaction activities from dedicated use case, like gaming, 2D to 3D switching. Since the processing is located in the cloud and the naked-eye 3D display is exposing the content to the user, which is very similar to the Cloud VR use case (in which Cloud VR phase 3 and phase 4 requirements in Table 1 of ETSI GS F5G 013 [11], requires 8 ms to 10 ms E2E RTT), for this real-time interactive application.

[R6-3] The E2E F5G-A network shall support < 10 ms RTT.

To have an aggregated RTT through the E2E F5G-A network, the different network segments shall coordinate with each other to satisfy the quality demand of latency.

[Gap6-3] The unified E2E latency control is not specified yet. E2E coordination mechanism is still currently not available.

4.8 Unified access and on-premises network

4.8.1 Use Case Briefing

A cooperative DBA mechanism in data transmission between the F5G-A access network and the on-premises network achieves control of network QoS. Through a wider view of the service type, the buffering status, the network resource, etc., dynamic optimization can be achieved in terms of different network performance demands (i.e. throughput, latency, and packet jitter). Additionally, a coordinated management scheme provides accurate diagnostic of network issues, fast service provisioning, optimization of the network configuration, asset monitoring, etc. In the F5G-A access networks, it is important to provide optimized resources allocation, asset monitoring, energy saving, etc. See Use Case # 7 in ETSI GR F5G 020 [i.1] for more details.

4.8.2 Technology Requirements and Gap Analyses

4.8.2.1 General

A unified F5G-A access network and on-premises network enhances the network performance and reduces the network management complexity of the control and management plane, respectively (OMCI between OLT and P-ONU, WMCI [i.12]/FMCI [i.11] between P-ONU and E-ONU). There is no requirement to change the physical topology, instead make a logical cooperation of the packet scheduling and management methodologies. A wider packet scheduling view can reduce the E2E transmission latency & packet jitter, optimize the data buffer, and enable network slicing. This is beneficial for the QoE of the end users. Utilizing the computing power of the device in central office (OLT) to provide a more accurate data transmission strategy. A coordinated management provides a global map of the device status enabling improved utilization of the network resources (time/spatial/spectrum) as well as perform asset monitoring.

4.8.2.2 Provide unified control of data transmission

Global control by the OLT to coordinate the F5G-A access network segment and the on-premises network segment will enable unified control. This requires an accurate and timely control signalling and deterministic scheduling. A protocol with a bounded latency is a necessity for message exchange. A L1 or L2 lower layer protocol like OMCI [10] or enhanced OMCI might be necessary. Control device (OLT, P-ONU, and E-ONU) data models should be defined.

[R7-1] The OLT shall be capable of requesting and receiving transmission status (including data buffer, communication environment) from any device in the F5G-access network and the on-premises network, including the P-ONU and the E-ONU.

The OLT shall be capable of configuring the transmission behaviour of any device including the optical transmission parameters in the optical F5G-A access network and the on-premises network, or the air interface of the LAN (WLAN).

[R7-2] The OLT shall be capable of configuring the transmission behaviour of any device in the F5G-A access network and the on-premises network.

[R7-3] The P-ONUs shall be capable of providing local control for the E-ONUs and the corresponding end user devices through a centralized control mechanism.

One way to achieve unified control of the data transmission in both the F5G-A access network segment and the on-premises network segment, is to enable the OLT with direct control of each E-ONU by using OMCI extensions. Alternatively the P-ONU acts as an OMCI proxy or the use of upper layer protocols from the OLT to control the E-ONUs while the on-premises fibre network uses WMCI [i.12] and FMCI [i.11] between P-ONU and E-ONU for management and control.

[Gap7-1] The OLT direct collection of the E-ONU's transmission status is currently not available.

[Gap7-2] The OLT support for the direct configuration of each E-ONU is currently not available.

[Gap7-3] None.

4.8.2.3 Provide unified management of the whole system

The management of the F5G-A access devices and the on-premises devices can be achieved through different methodologies. The ONU is managed and configured through OMCI based on the PON connection. The ONU or P-ONU could also be managed through IP based protocol like BBF oneM2M TR-069 [i.14] or BBF oneM2M TR-369 [i.15]. Proprietary solutions are also used to manage the E-ONU through the P-ONU. The coexistence of multiple protocols adds complexity to achieving global optimization in terms of management.

The F5G-A optical access network and the on-premises network shall support an extension of the OMCI management interface to enable global management of any device in the F5G-A access network and the on-premises network.

[R7-4] The F5G-A optical access network and the on-premises network shall support an extension of the OMCI management interface.

[R7-5] The unified management system shall support the management coordination between OLT and P-ONUs.

[R7-6] The unified management system shall support a single management protocol for both the F5G-A access network devices and the on-premises network devices.

[R7-7] The unified management shall support the collection of device information from the different network elements once they are connected by optical fibre.

The unified management shall provide visualization of the logical link for the different service flows, to enable a clean mapping between service flows and scheduling strategy.

[R7-8] The unified management shall provide visualization of the logical links for the different service flows.

One way to achieve unified management of both the F5G access network segment and the on-premises network segment, is to enable the OLT with direct management of each E-ONU by using an extended OMCI. Alternatively the P-ONU acts as an OMCI proxy of the OLT to manage the E-ONUs. In this case, additional Management Entities (MEs) need to be defined in the P-ONU.

[Gap7-4] The extended OMCI management interface to enable global management of any device in the F5G access network and the on-premises network is currently not supported by the OLT.

[Gap7-5] The unified management system between the OLT, the P-ONUs and E-ONUs is currently not supported.

[Gap7-6] The protocol for device information collection based on a single protocol is currently not available.

The current OLT can only directly collect device information from P-ONUs through OMCI, the direct collection of device information for both the P-ONU and E-ONUs is not supported.

[Gap7-7] The direct collection of device information for both the P-ONU and E-ONUs is currently not supported.

[Gap7-8] The management system providing visualization of the logical link for the different service flows via the OLT OMCI is currently not supported.

4.8.3 Current related standard specifications

4.8.3.1 ITU-T SG15

In order to study control and management for a unified access and on-premises network, a joint project ITU-T draft G.Sup.CMAFP [i.17] was initiated in the 2023 ITU-T SG15 December plenary. This new project intends to study use cases, requirements, network architectures, and technical solutions together with protocols for a coordinated management system that covers both the access and the on-premises fibre networks. Capabilities for fibre on-premises control and management are expected to be provided, with enhancement to the current solutions. This project acts as a guideline to realize a better integrated PON and on-premises management system.

Future standard activity may result from this supplement document for access (PON recommendations, such OMCI) or on-premises (FTTR recommendations, like management specification of G.fin or WMCI [i.12]).

4.8.3.2 ETSI ISG F5G

To have QoE on-demand networks, accurate determination for dynamically allocating or assigning network resource is important. The work item on computing collaboration in ETSI DGS/F5G-0025 [i.18].

ETSI DGS/F5G-0025 [i.18] will specify the architecture framework for computing collaboration in the PON network. It will also specify the requirements of computing collaboration in the PON network, the key computing functions and the capabilities of each component in the PON network.

4.9 OTN intelligent fault management

4.9.1 Use Case Briefing

Fault management is one of the most important operation tasks for the network operators. Traditional OTN networks use an alarm-based fault management approach. A single network fault may result in a large number of alarms, which produces a large number of complex manual operations. The root cause analysis of the fault condition is required before the true fault can be determined and repaired.

In F5G-A, the incident-based intelligent fault management approach is used, to automatically analyse the alarm information, determine the actual network fault and generate the necessary recovery procedure. See Use Case # 8 in ETSI GR F5G 020 [i.1] for more details.

4.9.2 Technology Requirements and Gap Analyses

4.9.2.1 General

In the OTN intelligent fault management scenario, when receiving alarms from the OTN Network Elements (NEs), the OTN intelligent fault management system will determine the root alarm from among the multiple correlated alarms, and perform fault diagnosis to identify the root cause which generated the root alarm and the multiple correlated alarms. Such root alarm and the correlated alarms triggered by the same root cause are aggregated as an incident. See Figure 7 below, which is from ETSI GR F5G 020 [i.1].

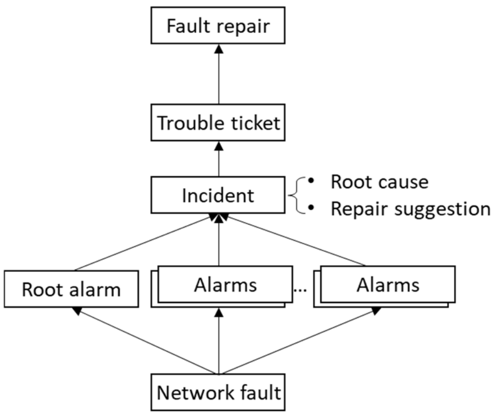

Figure 7: Incident-based fault management (Source: ETSI GR F5G 020 [i.1])

Furthermore, the OTN intelligent fault management system analyses the impact on the OTN by the identified incident, and provides fault repair recommendations to the network administrator.

The OTN intelligent fault management system reports the identified incident information to the network administrator.

4.9.2.2 OTN alarm aggregation

When a failure occurs in the OTN, the OTN intelligent fault management system shall receive alarms from each of the NEs that are affected by the fault.

The OTN intelligent fault management system shall support the identification of an incident from a set of correlated alarms. The OTN fault management system will perform the alarm aggregation to identify the root alarm that triggered the other correlated alarms.

[R8-1] The OTN intelligent fault management system shall support collecting alarm information from the OTN NEs.

[R8-2] The OTN intelligent fault management system shall support root alarm identification from the received alarms.

Recommendation ITU-T G.874 [20] defines the management aspects of NEs in the OTN, including the OTN fault management which allows the NEs in OTN to report fault information to the Element Management Layer (EML) Operations System (OS).

Currently there is no related standards describing the identification of the root alarm when receiving a set of correlated OTN alarms.

[Gap8-1] None.

[Gap8-2] Root alarm identification from the aggregated alarm reporting is currently not supported.

4.9.2.3 Troubleshooting

Based on the root alarm information, the OTN intelligent fault management system shall perform fault diagnosis to identify the root cause which led to the occurrence of a set of correlated alarms.

The OTN intelligent fault management system should provide fault repair recommendations, which can be used to guide the network administrators to handle the network faults.

[R8-3] The OTN intelligent fault management system shall support OTN root cause analysis based on a set of correlated alarms.

[R8-4] The OTN intelligent fault management system should support providing fault repair recommendations.

The OTN root cause analysis and fault repair recommendations are currently not specified in OTN related standards.

[Gap8-3] OTN root cause analysis is currently not supported.

[Gap8-4] The provisioning of OTN fault repair recommendations is currently not supported.

4.9.2.4 Fault impact analysis

Once the root cause is identified, the OTN intelligent fault management system shall analyse its impact on the OTN, including the OTN link resources and the OTN connection services which are affected by the faults.

When multiple faults occur in parallel, the OTN intelligent fault management system should provide the fault handling priorities based on the severity of the impact on the network. This is used to guide the network administrators about the best sequence for handling multiple faults.

[R8-5] The OTN intelligent fault management system shall support fault impact analysis.

[R8-6] The OTN intelligent fault management system should support providing fault handling priorities.

The OTN fault impact analysis and fault handling priorities are not specified in the current OTN related standards.

[Gap8-5] OTN fault impact analysis is currently not supported.

[Gap8-6] The provisioning of OTN fault handling priorities is currently not supported.

4.9.2.5 Report of incident information

The OTN intelligent fault management system shall report the identified incident information to the network administrator. Typical such incident information will be sent to the operator's trouble ticket dispatching system.

[R8-7] The OTN intelligent fault management system shall support reporting the identified incident information.

The reported incident information shall support at least the following elements:

- Root cause.
- Alarm correlation information.
- Fault location.

- Fault occurrence time.
- The impact of the fault.
- The fault severity.
- Handling priority.
- Repair recommendations.

[R8-8] The reported incident information shall support at least the elements listed above.

IETF started discussing the YANG model for OTN configuration and management, covering the Fault, Configuration, Accounting, Performance and Security (FCAPS). The detail fault management models are to be further discussed and defined.

[Gap8-7] The information report of an identified incident is currently not supported.

[Gap8-8] The YANG models for the information report of an identified incident are currently not supported.

4.9.3 Current related standard specifications

4.9.3.1 ITU

Recommendation ITU-T G.874 [20] addresses the management aspects of the OTN NEs, and describes the management network organizational model for communication between an EML OS and the optical Equipment Management Function (EMF) within the NEs in OTN. Fault management is one of the important parts in this recommendation.

4.9.3.2 IETF

IETF defines the Abstraction and Control of Traffic Engineering (TE) Networks (ACTN) architecture and the related YANG models for OTN control. The draft [i.19], which is under development, proposes to integrate the YANG model for OTN configuration and management into the ACTN system, covering the management of Fault, Configuration, Accounting, Performance and Security (FCAPS). The detail fault management models are for further discussion.

4.10 Evaluation and assurance of user service experience

4.10.1 Use Case Briefing

Residential and in general CPN broadband users have become increasingly sensitive to the application service experience. Potentially, the network operators may not be aware of the deterioration in the user's service experience, unless the user makes a complaint. Usually the service experience deterioration is manually resolved on-site, which takes time to fix the problem and increases OPEX.

In F5G-A, proactive evaluation and assurance of the user's experience, and fast identification and rectification of the service experience problems, is critical and needs to be taken into consideration. With the improvements in network automation capabilities, in some cases it is possible that the network operators can remotely fix the problems affecting the user's service quality, or can even optimize the network before the user experience deteriorates. This will greatly shorten the average diagnosis and rectification time of service quality problems, reducing the on-site service rate, saving OPEX, and improving user satisfaction. See Use Case # 9 in ETSI GR F5G 020 [i.1] for more details.

4.10.2 Technology Requirements and Gap Analyses

4.10.2.1 General

To support the evaluation and assurance of user service experience, an F5G-A Access Network QoE analysis system is introduced in the Access Network, see Figure 8. The key capabilities of the F5G-A Access Network QoE analysis system include real-time evaluation of user's service experience, precise demarcation and root cause analysis of poor-QoE problems when applicable, and automatic rectification and regular audits of potential poor-QoE problems.

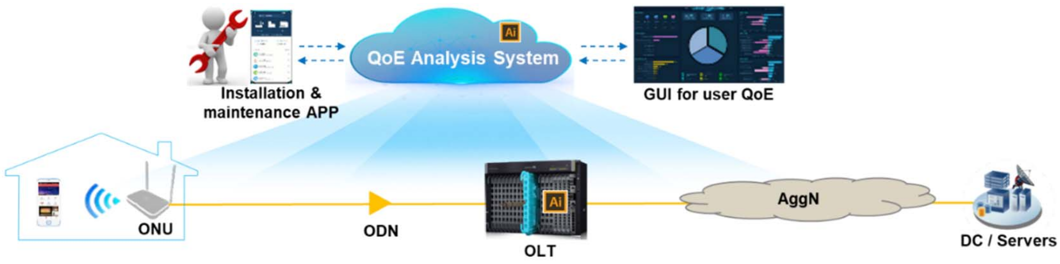

Figure 8: Overview of the F5G-A Residential broadband QoE evaluation and assurance (Source: ETSI GR F5G 020 [i.1])

4.10.2.2 Evaluation of user's service experience

To objectively evaluate a user's service experience, a user experience evaluation model shall be established, which is based on the network KQIs that the users are aware of.

[R9-1] The user experience evaluation model shall be defined.

To evaluate whether a specific user suffers from poor-QoE problems, the F5G-A Access Network QoE analysis system shall obtain the KQIs of the typical F5G-A residential services, and form the normalized and quantified service experience indicator based on the user experience evaluation model.

The typical F5G residential services include telephony, web browsing, data upload and download, IPTV, on-line gaming, on-line education/telework, and cloud VR.

The F5G-A Access Network QoE analysis system shall also obtain the F5G-A Access Network KQIs/KPIs, and analyse the network KQIs/KPIs on both the time dimension and the network segment dimension.

[R9-2] The F5G-A Access Network QoE analysis system shall collect the F5G-A Access Network service and network KQIs.

ETSI GS F5G 015 [21] specifies the service quality evaluation of the typical F5G-A residential services. It uses the concept of Mean Opinion Score (MOS) values, to score the service KQIs on a per-KQI, and per-service level. In this way, the user experience evaluation model is established.

[Gap9-1] None.

ETSI GS F5G 017 [22] specifies the measurement methodologies to evaluate the quality of residential network services and network characteristics/functionalities based on the service and network KQIs defined in ETSI GS F5G 015 [21].

ETSI GS F5G 026 [23] defines the system architecture for residential service quality monitoring (including the service KQIs and the network KQIs) based on ETSI GS F5G 017 [22]. The corresponding technical requirements, interfaces and data models for the service KQI monitoring are also specified.

[Gap9-2] The interface to obtain the F5G-A Access Network service and the network KQIs is currently not supported.

4.10.2.3 User experience demarcation and root cause analysis

The F5G-A Access Network QoE analysis system shall analyse the network KQIs/KPIs on both the time dimension and the network segment dimension, and perform the root cause analysis of the poor-QoE problems, to determine the exact location and the key factors that affect the users' service experience.

For the network segment, the network equipment and the exact location of the poor-QoE problems may be:

- The transport network or a content service network fault.
- The PON equipment or a component fault, including card, optical module, port, ONU, FTTR P-ONU or E-ONU problems.
- The ODN feeder fibre and the distribution fibre problems.

- The CPN network problems, including the Wi-Fi® air interface interference or connection problems, an Ethernet cable problem, or an ONU/AP configuration exception.

Based on the previous analysis, the F5G-A Access Network QoE analysis system shall provide a list of users who are considered to have, or potentially will have service experience problems.

[R9-3] A portal to the F5G-A Access Network QoE analysis system should be provided to report the location and the key factors affecting the user's service experience.

[R9-4] A portal to the F5G-A Access Network QoE analysis system should be provided to report the users who are considered to have, or potentially will have service experience problems.

Currently, there is no standard interface for the F5G-A Access Network QoE analysis system to report the fault location information and the list of users who are considered to have, or potentially will have service experience problems to the management and control system.

[Gap9-3] The F5G-A Access Network QoE analysis system interface that provides the location and the key factors that affect the user's service experience to the management and control system is currently not supported.

[Gap9-4] The F5G-A Access Network QoE analysis system interface that provides the list of users who are considered to have, or will potentially have service experience problems to the management and control system is currently not supported.

4.10.2.4 User experience rectification and audit

If the F5G-A Access Network QoE analysis system determines that there are software problems causing service experience problems, it shall automatically reconfigure the network element(s) to resolve the software problems.

NOTE: A software problem refers to a software issue on a network element that maybe resolved by a software update or network element reconfiguration, without the need for hardware change. An example could be incorrect configuration of the Wi-Fi® antenna, causing transmit power to be too low.

[R9-5] The F5G-A Access Network QoE analysis system shall support automatic reconfiguration of the Access Network element(s) to resolve software problems that cause service experience problems.

If the F5G-A Access Network QoE analysis system determines that service experience problems need to be resolved by manual on-site service, it shall support dispatching the trouble tickets to the network operator.

[R9-6] The F5G-A Access Network QoE analysis system shall support dispatching the user service experience problem trouble tickets.

The F5G-A Access Network QoE analysis system shall re-evaluate the user's experience after user issue rectification, to see if the problems have been resolved. The technical requirements of the re-evaluation are the same as that of the user's service experience evaluation.

Currently, there are no standards describing how an F5G-A Access Network is reconfigured to resolve software problems that cause service experience problems, or how the user's service experience problems trouble tickets are dispatched.

[Gap9-5] The automatic reconfiguration of the F5G-A Access Network to resolve software problems that cause service experience problems is currently not supported.

[Gap9-6] The trouble ticket or maintenance ticket dispatching, when a user's QoE problem or potential problem are detected by the F5G-A Access Network QoE analysis system, is currently not supported.

4.10.3 Current related standard specifications

4.10.3.1 BBF

BBF defines the Access Network YANG models, including BBF oneM2M TR-383 [i.20] and BBF oneM2M TR-385 [i.21], and other standards related to other type of Access Network systems. BBF is also working on the northbound interface of the Access SDN Management and Control (M&C), for Access Network build and service fulfilment. See WT-411i2 [i.22] and WT-454i2 [i.23].

4.10.3.2 ETSI

ETSI ISG F5G specified the service quality evaluation of the typical F5G residential services in ETSI GS F5G 015 [21], and specified the measurement methodologies to evaluate the quality of residential services in ETSI GS F5G 017 [22]. ETSI ISG F5G also specified the system architecture for residential service quality monitoring in ETSI GS F5G 026 [23]. The root cause analysis of the residential service experience problems and the user experience rectification still need further study.

4.11 Cloud Desktop

4.11.1 Use Case Briefing

Cloud desktop is a desktop virtualization platform allowing users to access Windows like desktops or applications that are running in a different physical location. This E2E system includes multiple functional blocks, such as server in the data centre, data processing algorithm for rendering, encoding, framing, etc. and the network for data transmission. The cloud desktop service provides efficient sharing of hardware in the cloud and quick service provisioning. This enables flexible arrangement of hardware/software resources for any innovative applications. See Use Case # 10 in ETSI GR F5G 020 [i.1] for more details.

4.11.2 Technology Requirements and Gap Analyses

4.11.2.1 General

The cloud desktop service forwards real-time video streaming since the local device is simplified, containing no data buffer and processing units. The dynamic interaction with the desktop by end user requires low latency in the network. To fulfil the cloud desktop requirements, an edge cloud infrastructure needs to be introduced to reduce the transmission latency by reducing the physical distance between the cloud server and the end device, helping to off-load computing needs. In addition, network intelligence such as service identification or network slicing is essential to guarantee cloud services. To further reduce the processing delay, the encoding/decoding complexity should be simplified, therefore, shallow compression and low-delay codec solutions (exchange throughput for computing and latency) need to be considered.

4.11.2.2 Edge cloud infrastructure

The F5G-A network enables distributed computing functions. To support lower transmission latency, an edge cloud infrastructure should be adopted to reduce the physical distance between the server and the end user.

[R10-1] The Edge cloud infrastructure shall be deployed close to the end user to support low latency data transmission in a F5G-A network.

[R10-2] The Edge cloud should support coordination with the remote cloud to enable the best service QoS for the end user.

The transmission speed of light in optical fibre is approximately 200 000 km per second. So 2 000 km transmission distance needs 10 ms transmission time. In IP network, the switching time and additional processing in multiple network nodes will add significant time delay to the cloud desktop service. The F5G-A one-hop OTN shall enable transmission delay close to the optical limit. The edge cloud infrastructure solution is based on and should leverage the mature cloud technologies and OTN.

Having several cloud infrastructures providing cloud application services necessitates the need for computing coordination. The computing coordination between F5G-A network elements is necessary.

[Gap10-1] None.

[Gap10-2] The computing coordination mechanism between different F5G-A network elements is not currently available.

4.11.2.3 Enable intelligence in the network

The end user QoE using cloud desktop is affected by the network performance. The end user generally interacts continuously with the cloud desktop, lasting for a period of time for work, entertainment, or other web activities. This requires a network with stable performance. Therefore, the cloud desktop service should be recognized and allocated a high service priority in terms of network communication. This can be achieved by analysing the data streaming characteristics by using AI or can be directly configured by the cloud desktop provider.

[R10-3] The F5G-A network shall support cloud desktop service identification and support the assignment of service priority.

The F5G-A network shall support slicing technology (including intelligent packet offloading/processing/forwarding based on the service priority, the slicing in F5G-A optical network and the Wi-Fi® network) to guarantee network QoS for cloud desktop service delivery.

[R10-4] The F5G-A network shall support slicing technology and guaranteeing network QoS for cloud desktop service delivery.

The AI model of service recognition is not available and is determined by the implementation and the network infrastructure. It is typically based on system vendor internal functionality and difficult for standardization. The training of an AI model is based on machine learning algorithms and available network data profiles. For the network slicing capability, ETSI GS F5G 013 [11] has pointed out the gap for different network segments.

[Gap10-3] The F5G-A network adaptation mechanism to the variation of network demand due to the cloud desktop service is currently not available.

The E2E slicing technologies are defined in clause 5.4.1 of ETSI GS F5G 014 [3] for OTN, PON and Wi-Fi® slicing.

[Gap10-4] None.

4.11.2.4 Shallow compression techniques

Cloud desktop is a strongly interactive network service. Deterministic low latency is a key network characteristic for guaranteeing the user QoE in the continuous interactive activities like clicking the mouse, open files, download/upload, and other cloud desktop interactive activities. To further reduce transmission latency, shallow compression techniques should also be considered. Simplified encoding and decoding processes increase the network capacity demand but decrease the processing time of the data. Moreover, parallel processing of the cloud desktop services using network slicing technology provides additional benefits for data processing.

[R10-5] Shallow compression techniques with low compression ratio shall be supported by Cloud desktop technology.

[R10-6] Independent encoding and decoding processes for shallow compression of each frame shall be supported by Cloud desktop technology.

[R10-7] The F5G-A system shall support parallel compression for cloud desktop service slices.

MPEG [24] is a widely used compression technology enabling the I-frame to convey the main content, with B/P-frame conveying the delta to previous frames. This creates a large compression ratio (typically 1:300) with the drawback of triggering correlation between consecutive frames, introducing processing latency. This methodology also produces I-frame throughput bursts, creating throughput demand variation in the time domain. Therefore, to achieve lower processing latency, it is better to enable independent and efficient pipeline encoding and decoding procedures for each frame.

[Gap10-5] Shallow compression techniques with a low compression ratio is currently not available.

[Gap10-6] Independent encoding & decoding for each data frame is currently not available.

[Gap10-7] Parallel compression for cloud desktop service slices is currently not available.

4.12 Dynamically digitalized ODN

4.12.1 Use Case Briefing

The Optical Distribution Network (ODN) is the core infrastructure of FTTx access networks, where x is R, H, M, O [i.24]. With the large-scale deployment, the secure operation and fast fault locating of the ODN infrastructure have become one of the top concerns for service providers and end users. The ODN resource management is the main challenge and the unavoidable issue for service providers. In case of natural disaster like earthquake, or unexpected ODN damage caused by animals in the outdoor environment, a fast or dynamic methodology to show the physical fibre topology is important.

With a dynamically digitalized ODN, it is possible to proactively and periodically inspect the ODN. The dynamic information of the ODN could be collected. This information could include new physical parameters as input for an AI algorithm to perform fault prediction, fault detection and fault recovery. See Use Case # 11 in ETSI GR F5G 020 [i.1] for more details.

4.12.2 Technology Requirements and Gap Analyses

4.12.2.1 General

Dynamically digitalized ODN requires quantitative and dynamic visualization of the ODN, providing new capability to accurately parameterize the ODN, and regularly monitoring the ODN status. The ODN diagnostics and fault recover are very beneficial to network operators. The system shall provide functions including real-time and quantitative visualization of the resource status, facilitating precise capacity expansion, providing the digital twin with the practical ODN information, prudently and remotely locate faults, reducing service interruption duration and proactive inspection of optical path quality to ensure zero potential risks.

4.12.2.2 Dynamically visualization of ODN

Digitalized visualization of the different optical ODN components, includes fibre connectors, passive fibre splitters, path loss, are basic functions. Both the logical connection and physical locations of the ODN shall be displayed.

[R11-1] The digitalized ODN system shall support dynamic visualization of the ODN topology between the OLT and the ONU or P-ONU.

[R11-2] The digitalized ODN system shall support GIS-based location identification and visualization of the ODN.

[R11-3] The digitalized ODN system shall support the dynamic visualization of insertion loss for the different ODN segments.

The current ODN system only provides static ODN visualization. Any changes to the ODN cannot be dynamically monitored. The accurate physical location is not easily identified.

[Gap11-1] The dynamic visualization of the ODN topology is currently not available.

[Gap11-2] The physical location of the ODN is currently not available.

[Gap11-3] The dynamic collection of the ODN insertion loss is currently not available.

4.12.2.3 Proactively diagnostic and remote fault location

Dynamic collection of the ODN status provides the opportunity to determine an ODN failure if any. Therefore proactive diagnostics and remote fault location can be achieved by analysing the potential connection problems. The proactive optical path diagnostics need to support optical attenuation fault location of the connection, optimize weak optical signals, and rectify the risk to the optical connection (including abnormal optical attenuation in advance and identify frequent fault points).

[R11-4] The digitalized ODN system shall support proactive optical path diagnostics.

[R11-5] The digitalized ODN system shall support remote fault locating within 15 minutes.

Manual inspection of ODN faults is time-consuming and inefficient in finding faults. The customer needs a stable and reliable network connection.

[Gap11-4] Proactive diagnostic and recovery of ODN faults are currently not available.

[Gap11-5] Dynamic remote fault location determination is currently not available.

4.12.2.4 ODN resource management

ODN resource visualization helps to better understand the fault types. The ODN resource management includes visualization of level 1 optical splitter status (branching to another optical splitter), direct connection to the ONUs/P-ONUs, suspended optical fibre that are not being used, fibre connection status for various ONUs/ P-ONUs, the connection between splitter ports, or the splitter port and the ONU or P-ONU. The ODN resource management status collection includes fibre connection status, splitter connection status, and ONU or P-ONU connection status.

[R11-6] The digitalized ODN system shall support ODN resource status collection.

Considering the large-scale deployment of FTTx-ODNs around the world where x is R, H, M, O [i.24], the dynamically digitalized ODN aims to improve ODN deployment and management efficiency.

[Gap11-6] ODN resource management is currently not available.

4.12.3 Current related standard specifications

4.12.3.1 Current ODN related standards

For current related standard specification references see ETSI F5G GS 013 [11], clause 4.12.3.

4.13 On-premises Millimetre-Wave (mmWave) WLAN

4.13.1 Use Case Briefing

Millimetre wave Wi-Fi® suffers from significant signal absorption loss by obstacles, including door, wall, and other enclosures that cause signal absorption, which generates on premise Wi-Fi® signal isolated regions. In this case, FTTR enabling full fibre coverage is the best backhauling network for mmWave Wi-Fi®, capable of supporting high throughput, bounded latency and low packet jitter for each AP per room. For an example of practical usage see Figure 9, sub-6 GHz Wi-Fi® enables link connections for corner region while mmWave Wi-Fi® provides collision-free connections for devices requiring high quality connections. See Use Case # 12 in ETSI GR F5G 020 [i.1] for more details.

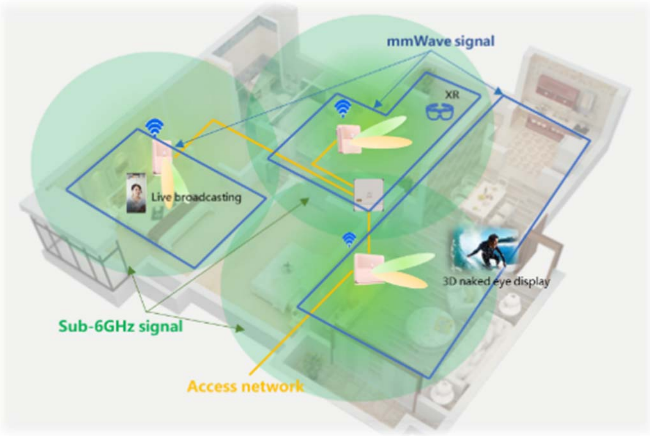

Figure 9: An example of mmWave WLAN network

4.13.2 Technology Requirements and Gap Analyses

4.13.2.1 General

The on-premises mmWave WLAN over FTTR shall support the typical F5G-A network services, enabling 10 Gbps on-premises connections to everywhere. On-premises mmWave WLAN over FTTR provides extremely high quality connections without any packet collisions compared to the traditional Wi-Fi® technology. To coexist with the widely deployed Wi-Fi®, coordination is necessary enabling link switching, which is required for handover, and to improve signal quality issues.

FTTR technologies are specified in ITU-T SG15 Q3 while mmWave Wi-Fi® is mainly developed by IEEE 802.11.

4.13.2.2 Provide necessary throughput to support F5G-A applications

The typical F5G-A network services to be supported includes extended reality, metaverse, digital twins and industrial optical networks, ETSI GR F5G 021 [i.24]. 10 Gbps FTTR and Wi-Fi® 7 are the primary technologies for F5G-A, enabling 10 Gbps on-premises to everywhere through fibre connections. The new mmWave Wi-Fi® specification is currently under study in IEEE 802.11 MMW SG (mmWave Study Group) [i.29]. Therefore, it is also expected that the mmWave Wi-Fi® for each AP is capable of supporting at least 10 Gbps throughput.

[R12-1] The mmWave Wi-Fi® shall support 10 Gbps throughput on the air interface in the unlicensed V-band and Q-band.

The previous mmWave Wi-Fi® technologies, including IEEE 802.11ad [i.25], 802.11aj [i.26] and 802.11ay [i.27], support larger than 10 Gbps data rate. These standards are not aligned with the sub-6 G Wi-Fi®. Therefore, deployment is challenging due to the complexity. On the other hand, based on the multi-link operation feature in Wi-Fi® 7, it is possible to simultaneously have multiple link connections at different frequency. This triggered the IEEE community to re-think leveraging the current sub-6 GHz technology for mmWave Wi-Fi®. Currently, the detailed specifications are under study.

[Gap12-1] The sub-6 GHz alignments with mmWave Wi-Fi® technology is currently not available.

4.13.2.3 Well controlled Wi-Fi® signals to support interference free connection

To enable a quality-assured link, the Wi-Fi® air interface between AP and STA shall be well coordinated. For example, IEEE 802.11ad [i.25] supports time division multiplexing to perform scheduling so as to avoid collision. In addition, the Wi-Fi® transmission power shall be well controlled although signal loss in walls is high for mmWave technology. To achieve wider coverage and high SNR, beamforming technology is widely used in mmWave Wi-Fi® in order to have high antenna gain in both the transmission and reception. The control and feedback of the power in mmWave is important. A balance or compromise needs to be considered between mitigating interference and maintaining a good quality link within a single room.

[R12-2] The mmWave Wi-Fi® shall support a coordinated transmission mechanism to avoid packet collision in the air interface (i.e. within a single BSSID).

[R12-3] The mmWave Wi-Fi® over the FTTR system shall be capable of sensing the signal distribution of each AP and control the transmission power to mitigate interference between rooms.

To achieve an interference free air interface, it is required that the whole on premises network system shall be capable of collecting the signal distribution status and perform adjustments accordingly.

The coordinated transmission mechanism is supported by IEEE 802.11ad [i.25], IEEE 802.11aj [i.26] and IEEE 802.11ay [i.27]. For the new 6 GHz Wi-Fi® aligned system, the new specification is under study.

[Gap12-2] The coordinated transmission mechanism supporting the new 6 GHz aligned system specification, is currently unavailable.

The data model for Wi-Fi® devices are defined in Wi-Fi® Alliance (WFA) Data Element specification while the exchange of such information between different AP is managed by FMCI [i.11] or WMCI [i.12] for FTTR system, which is still under development.

[Gap12-3] The data model for Wi-Fi® devices is currently unavailable.

4.13.2.4 Coordination with sub-6 G Wi-Fi®

Widely deployed sub-6 G Wi-Fi® operates on unlicensed band including 2,4 GHz, 5 GHz, and 6 GHz, providing ubiquitous connectivity. Although using mmWave Wi-Fi® could create isolated region over FTTR. With mmWave Wi-Fi® some issues may occur while users cross the boundaries between regions, including moving from one room to the other, blockage of furniture or other object. These scenarios may cause signal strength variation if the line-of-sight link is blocked or may cause link switching between different APs in the handover procedure. This will require that the mmWave Wi-Fi® shall coordinate with the sub-6 GHz Wi-Fi® in coexistence scenarios.

[R12-4] The mmWave Wi-Fi® over FTTR system shall provide a coordination scheme with sub-6 GHz Wi-Fi® to maintain the quality of connection during link switching within a single AP and link switching between different APs.

The sub-6 GHz Wi-Fi® should be capable of assisting the mmWave Wi-Fi® with beamforming, beam tracking and link adaptation in order the maintain the link quality.

[R12-5] The sub-6 GHz Wi-Fi® should support the mmWave Wi-Fi® by assisting with beamforming, beam tracking and link adaptation.

The sub-6 GHz Wi-Fi® should be capable of transmitting the necessary link control information for mmWave Wi-Fi® to reduce any potential latency of the network services.

[R12-6] The sub-6 GHz Wi-Fi® should support mmWave Wi-Fi® link control information transport.

With the assistance of sub-6 GHz Wi-Fi®, the mmWave Wi-Fi® link will become more robust providing high quality links for dedicated region over the FTTR solution. However, many of the coordinating technologies between sub-6 GHz and mmWave Wi-Fi® are new topics and are under study.

[Gap12-4] The coordination mechanism between sub-6 GHz and mmWave Wi-Fi® for link switching is currently not available.

[Gap12-5] The assistance mechanism of sub-6 GHz Wi-Fi® for mmWave Wi-Fi® for beamforming, beam tracking and link adaptation is currently not available.

[Gap12-6] The separated control and data plane for mmWave Wi-Fi® through sub-6 GHz Wi-Fi® is currently not available.

4.13.3 Current related standard specifications

4.13.3.1 ITU-T SG15

The specifications for the FTTR system are defined in ITU-T SG15 Q3. For the FTTR standardization progress, refer to clause 4.3.3.1 in the present document.

4.13.3.2 IEEE 802.11

The radio frequency spectrum is limited and regulated by ITU-R for global harmonization. In particular, the usage of low frequency bands could be different between countries. To explore higher frequency bands and have more channel bandwidth, V-band (around 60 GHz) and Q-band (around 45 GHz) are released for unlicensed usage globally depending on the regional policy. Based on that, the IEEE 802.11 group developed 802.11ad [i.25], which is an amendment to the IEEE 802.11 standards, providing a Multiple Gigabit Wireless System (MGWS) in the 60 GHz frequency band. Beamforming and larger channel bandwidth are available, enabling the data transmission rate of up to 7 Gbps. This will support various new applications like uncompressed UHD video transmission (as a replacement of HDMI), cloud VR, etc. over the wireless network. The IEEE 802.11ad [i.25] standard defines six different 2 160 MHz channels in the frequency range from 57 GHz to 71 GHz.

To further boost the maximum data rate, the amendment of IEEE 802.11ad [i.25], IEEE 802.11ay [i.27] introduces channel bonding technology to make use of the full bandwidth resources, such as 4 channel integration to 8,64 GHz bandwidth. Multiple Input Multiple Output (MIMO) is also specified with up to maximum of 4 data streams. The link-rate per stream can reach up to 44 Gbps, with four streams reaching up to 176 Gbps. Higher order QAM modulation (256 QAM) is also considered based on the evolution of RF technology in mmWave.

China issued 42 GHz to 48 GHz frequency band (Q-band) for WLAN usage. To adapt this frequency band, IEEE developed a regional amendment of 802.11 standards, IEEE 802.11aj [i.26]. This standard mainly implements MIMO with a maximum channel bandwidth of 1,08 GHz within the band and 4 data streams to support a data rate of up to 15 Gbps.

To leverage the sub-6 GHz technology, IEEE 802.11 recently initiates a study group, "Integrated mmWave" (IMMW) [i.29], to discuss re-using the sub-6 GHz baseband for MMW based on multi-link operation technology. The scope of this study group is to support non-standalone operation in the unlicensed bands between 42 GHz and 71 GHz using Single-User (SU) OFDM based transmissions. The project also supports at least one of the 2,4 GHz to 7,25 GHz (sub-7 GHz) unlicensed bands. The coexistence mechanisms with legacy IEEE 802.11 devices operating in the unlicensed bands between 42 GHz and 71 GHz is expected to be provided. The study group is still on-going in the IEEE 802.11bq [i.29]. Further technical group may be created according to the convergence of the scope.

4.14 Wavelength-shared WDM Aggregation Network (AGGN)

4.14.1 Use Case Briefing

With the acceleration of optical CPN broadband speed and digital economy requirements, Aggregation Networks (AGGNs) are being developed with low cost and complexity, high flexibility and automation. The current connections between aggregation nodes and multi-service access nodes are typically in rings or chains with grey optics, optical fibre direct connections or Fixed Optical Add/Drop Multiplexer (FOADM). All these approaches suffer from low wavelength resource utilization, poor network flexibility, high cost and complex network O&M. It is recommended that the ring connections between the aggregation nodes and multi-service access nodes deploy Reconfigurable Optical Add-Drop Multiplexer (ROADM) supporting wavelength-sharing between the different rings, which satisfies the requirements of future AGGN. See Use Case # 13 in ETSI GR F5G 020 [i.1] for more details.

4.14.2 Technology Requirements and Gap Analyses

4.14.2.1 Network bandwidth

End-to-end wavelength-shared WDM AGGNs introduce huge bandwidth demand due to the increasing flow requirement from different business scenarios (to Customer (to C) / to Home (to H) / to Business (to B)). To meet the increased capacity requirements, there are two potential approaches the first is to increase the bandwidth per channel, the second is to increase wavelength resource utilization, enabling wavelength sharing between different rings.

The combination of these two approaches imposes the following bandwidth requirements:

[R13-1] The wavelength-shared WDM AGGN shall support the smooth evolution to higher data rate beyond 200 G per channel.

[R13-2] The wavelength-shared WDM AGGN shall support efficient utilization of wavelength resources.

Physical layers and management parameters for 100 Gbps and 400 Gbps operation over DWDM systems are defined by IEEE 802.3ct [28] and 802.3cw [i.30]. 800 Gbps interfaces are standardized in Recommendation ITU-T G.709.6 [15] and IEEE 802.3dj [i.31]. However, the wavelength-sharing feature for improving wavelength resource utilization in AGGNs is missing.

[Gap13-1] None.

[Gap13-2] Standard for wavelength sharing between different rings in wavelength-shared WDM AGGN is currently not defined.

4.14.2.2 Multiple-ring network and long-haul transmission distance

Typically AGGN connects aggregation nodes and multiple multi-service access nodes in a multiple-ring structure, where each ring connects multiple multi-service access nodes. For this scenario each aggregation node connects to between four to eight rings, and one ring connects to between four and eight multiple multi-service access nodes, as can be seen in Figure 10. A transmission distance up to 320 km is then required based on this connection scenario without optical-electronic-optical conversions.

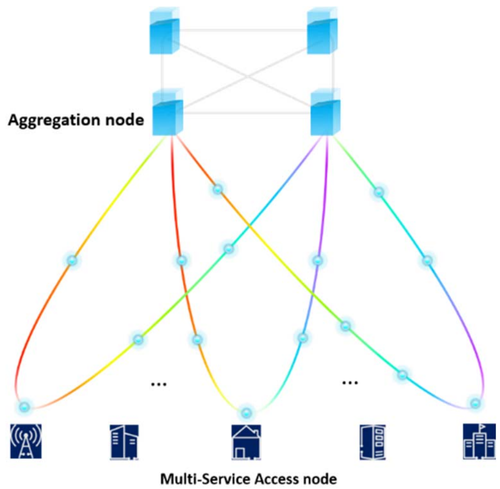

Figure 10: Wavelength-shared AGGN configuration

[R13-3] The wavelength-shared WDM AGGN shall support a multiple-ring multi-service access network structure with the reuse of wavelengths per AGGN node.

[R13-4] The wavelength-shared WDM AGGN shall support an all optical transparent connection up to 320 km.

The DWDM metro applications including optical amplifiers have been standardized in Recommendation ITU-T G.698.2 [25], where "black links" include two or more OADMs connected in a ring. However, the characteristics of this multiple-ring multi-service access network structure are missing.

[Gap13-3] The multiple-ring multi-service access network structure standard is currently not supported.

[Gap13-4] None.

4.14.2.3 Flexible grooming capability

The key features for the various types of business scenarios (to Customer (to C) / to Home (to H) / to Business (to B), and cloud computing) in the AGGN include different bandwidth granularity requirements (2 Mbps to 100 Gbps), and a large number of services (tens of thousands of services on each local network). Therefore, the AGGN requires high flexibility depending on different scenarios.

ROADM technique supports optical-layer flexible spectrum spacing, flexible wavelength allocation, wavelength switching and grooming. ROADMs reduce the number of boards, space, and power consumption of AGGN equipment by replacing multiple FOADM for different rings per aggregation node.

While fine grain OTN (fgOTN) is compatible with the existing OTN architecture, it is oriented to a wide range of service bandwidth granularities, thus achieving aggregation and flexible grooming of 2 M to 100 G bandwidth granularity in the electrical layer.

[R13-5] The wavelength-shared WDM AGGN should support optical-layer wavelength grooming.

[R13-6] The wavelength-shared WDM AGGN should support dynamic allocation of bandwidth granularity.

The classification and the characteristics of Multi-Dimensional Reconfigurable Optical Add/Drop Multiplexers (MD-ROADMs) has been standardized in Recommendation ITU-T G.672 [29]. However, Recommendation ITU-T G.672 [29] cannot meet the wavelength-shared WDM AGGN requirements in terms of functionality, integration, and power consumption. A standard is needed to define a new functional model for integrated ROADM technique in wavelength-shared WDM AGGNs.

Currently OTN standard Recommendation ITU-T G.709/Y.1331 [1] defined the ODUflex container which enables OTN connections with flexible rate, furthermore Recommendation ITU-T G.7044/Y.1347 [30] defined hitless adjustment of ODUflex. Recommendation ITU-T G.709/Y.1331 [1], Annexes M and N also defined fgOTN technology as a flexible fine grain OTN container which enables OTN connections with flexible rate of N by 10 Mbps together with the hitless adjustment of fgOTN. CCSA has also defined OSU technology as a flexible optical service unit container which enables OTN connections with flexible rate from 2,6 M to 10 G, together with the hitless adjustment of OSU. IETF RFC 7139 [i.4] defined the signalling protocol for dynamical creation, deletion and adjustment of ODUflex connections.

[Gap13-5] Standard for function model of integrated ROADM with higher integration, smaller size, lower power, is currently not defined.

[Gap13-6] None.

4.14.2.4 Automatic network O&M

The large number of nodes and diverse service requirements of the AGGN necessitates simplified deployment and network O&M. The optical-layer digital label technique introduced in Use Case #13 [i.1] enables highly intelligent and automatic operations for initial deployment and the subsequent network O&M, which greatly reduces the Operating Expenses (OpEx).

Deployment: hardware installation requires only one site visit and the network management system automatically completes the Network Element (NE) ID and IP address configuration. Wavelength resources are automatically allocated and services are automatically commissioned, eliminating the manual site visit.

O&M: real-time monitoring and detection of single channel power, Optical Signal-to-Noise Ratio (OSNR), dispersion, polarization state, non-linear effect, and link margin are supported. This then enables real-time monitoring of services, fast remote fault demarcation, and automatic optimization after the link attenuation changes.

[R13-7] The wavelength-shared WDM AGGN shall support real-time monitoring of single channels and transmission links.

[R13-8] The wavelength-shared WDM AGGN shall support automatic allocation of wavelength resources and network optimization.

Recommendation ITU-T G.698.4 [31] has standardized remote performance monitoring techniques using a message channel for DWDM systems up to 10 Gbps and 20 km. This does not satisfy the requirements of wavelength-shared WDM AGGNs. Autonomous management and control functionalities have been specified in ETSI GS F5G 006 [32], which serves as a reference to standardize the O&M requirements for this use case.

[Gap13-7] A performance monitoring standard for wavelength-shared WDM AGGN is currently not defined.

[Gap13-8] An automatic network O&M standard for wavelength-shared WDM AGGN is currently not defined.

4.14.3 Current related standard specifications

4.14.3.1 ITU-T

ITU-T has standardized OTN interfaces from 100 G to 800 G, including multi-vendor client-side interfaces (2 km ~ 40 km grey optics), multi-vendor line-side interfaces (80 km for DCI and 450 km for metro), and single vendor line-side interfaces (1 500 km for long haul) [1], [12], [13], [14], [15]. Optical interface specifications up to 100 G in DWDM applications have also been defined intended for metro applications with optical amplifiers in Recommendation ITU-T G.698.2 [25].

4.14.3.2 ETSI

The Aggregation network topology and the interfaces have been defined in ETSI GS F5G 014 [3]. The aggregation network fabric, for both IP/Ethernet fabric and OTN fabric are introduced.

4.14.3.3 IEEE

IEEE has standardized Ethernet interfaces up to 400 GE in different application scenarios, such as SR/DR/FR/LR. ZR applications named "operation over DWDM systems" including 100 GE and 400 GE have also been specified in IEEE 802.3 [26]. An active work item on 800 GE and 1,6 Tbps Ethernet interfaces under 40 km is under discussion.

4.14.3.4 OIF

OIF is mainly focused on 80 km 400 G [27] and 10 km/80 km 800 G interfaces for DCI (LR/ZR), together with the management interface specifications.

4.15 Robotics as a Service

4.15.1 Use Case Briefing

This F5G-A use case aims to overcome the 'cloud barrier' in robotics, where low-level manufacturing tasks are performed at the edge and high-level functions are handled in the cloud. Current systems like the Robotic Operating System (ROS) supports multiprocessing but is hampered by latency issues between different compute units, particularly in motion control, affecting real-time responsiveness. F5G-A networks can significantly reduce this latency, allowing more efficient real-time control directly from the cloud, even across large manufacturing areas. This technology enables the development of Robotics as a Service (RaaS) market, where software solutions for real-time process control can be offered as a service. For instance, in a welding application, AI-driven camera systems could monitor and adjust heat distribution. The key objectives for using F5G-A are to enable high-bandwidth, low-latency transfer of sensor data to the cloud for real-time analysis, decision-making, and to facilitate low-latency control of robots from the cloud, enhancing their coordination and performance in various application scenarios. See Use Case # 14 in ETSI GR F5G 020 [i.1] for more details.

4.15.2 Technology Requirements and Gap Analyses

4.15.2.1 General

The goal of this clause is to provide a clear understanding of what is needed in terms of technological advancements to meet the high demands of modern robotic systems, including the need for low latency in control and communication, as well as the durability and flexibility of physical components like cables.

4.15.2.2 Latency

Latency is a critical factor in the performance of robotic systems, which directly impacts robotic systems efficiency and safety. Safety is largely meant in terms of human safety, and robots need to stop quick enough to not injure somebody. The need to minimize latency in robotic control and safety mechanisms is paramount to ensuring precise and reliable operation. For milling applications, there is the need to follow an accurate predefined toolpath and compensation for process-induced disturbances, which is driving the need for a latency no greater than 1 ms.

Service: Acceptable Milling latency < 1 ms.

Ideal Milling latency = 0,25 ms.

[R14-1] The F5G-A network used in robotic system shall support latency of less than 1 ms for the acceptable milling application.

[R14-2] The F5G-A network used in robotic system shall support latency of 0,25 ms for the ideal milling application.

To allow for the immediate detection of humans and the execution of emergency stop commands a maximum latency of 5 ms needs to be supported.

[R14-3] The F5G-A network used in robotic system shall guarantee a maximum latency of 5 ms for an acceptable safety application.

[R14-4] The F5G-A network used in robotic system shall have a latency of 0,5 ms for the ideal safety application.

The discrepancy between ideal and achievable latencies presents a gap in current technology's ability to meet optimal performance standards. The ideal latency for milling applications is 0,25 ms however 1 ms is what is achievable.

[Gap14-1] None.

[Gap14-2] The latency for the ideal milling application is currently not achievable.

For safety application the ideal latency is 0,5 ms for the execution of emergency commands, however 5 ms is what is achievable.

[Gap14-3] None.

[Gap14-4] The ideal latency for safety application is 0,5 ms is currently not achievable.

4.15.2.3 Cable Requirements

The functionality of Robotics as a Service (RaaS) is not only dependent on the robotic system but also on the quality and performance of the cables, which are cables containing fibres that are used. These cables need to withstand the physical demands of movement alongside the robot, which includes extensive bending and twisting during the movement of the robot. To maintain integrity and functionality during operations the cable bend shall be 10 times the outer diameter of the cable.

[R14-5] Cables utilized in RaaS shall be capable of withstanding a minimum of ±90° twist per meter for acceptable cable twisting.

[R14-6] The cable bend shall be 10 times the outer diameter of the cable for acceptable cable bending.

[R14-7] Cables utilized in RaaS shall be capable of withstanding a minimum of ±180° twist per meter for ideal twisting.

[R14-8] The cable bend shall be 12,5 times the outer diameter of the cable for ideal bending.

The ideal performance of cables goes beyond the minimum requirements, which would ensure longer life and greater reliability.

[Gap14-5] None.

[Gap14-6] None.

[Gap14-7] The ideal cable requirements of ±180° twist per meter which is currently not supported.

[Gap14-8] The ideal bend is 12,5 times the outer diameters not currently supported.

4.15.2.4 Ease of Installation

The success of Robotics as a Service (RaaS) also hinges on the seamless integration of network communication technologies, including the adoption of F5G Advanced networks. For RaaS systems to be truly accessible and efficient, the installation process for these advanced network technologies is straightforward, for robotics experts, who may not have prior knowledge of networking nor for F5G-A specifics. This requirement aims to minimize the barrier to entry for adopting advanced networking capabilities in robotic systems, ensuring that expertise in robotics is sufficient to leverage the benefits of F5G-A.

[R14-9] The F5G-A network communication system shall be designed to allow a robotics expert to complete the installation and configuration without prior knowledge of F5G-A technology.

Despite the need for simplicity in installation, there exists a discrepancy between the current installation complexity and the ideal scenario where F5G-A can be deployed by robotics professionals effortlessly.

[Gap14-9] Simplified installation and configuration of enterprise network communication for RaaS applications effectively is currently not supported and still need for specialized knowledge or training in F5G-A technology.

Overcoming this gap requires simplifying the installation process, enhanced documentation, or providing intuitive installation tools that guide users through the process without the necessity for deep technical knowledge of F5G-A.

5.15.2.5 Integration of F5G-A networks with ROS and DDS

The Robotics Operating System [i.32] is used for a variety of robot control and management tasks. It uses a particular communication sub-system called Data Distribution Service (DDS) [i.33]. The use of DDS is not mandatory, but a large number of implementations are using it. The DDS specification [i.33] describes a data-centric publish-subscribe model for distributed application communication and integration. ROS can use other communication middleware than DDS.

[R14-10] The F5G-A network communication system should support the Data Distribution Service (DDS), when the Robotics Operating System (ROS) is using the DDS communication service.

The DDS is supporting a variety of QoS Policies (see Section 2.2.3 in [i.33] for a set of supported policies). Some of them need the underlying F5G-A network's QoS support.

[Gap14-10] The mapping of the DDS over the F5G-A network architecture is currently not standardized.

4.15.3 Current related standard specifications

4.15.3.1 Cable Specifications

The current cable standards for robotics, particularly those pertaining to Robotics as a Service (RaaS), are driven by industry benchmarks set by leading manufacturers such as Igus®. These standards ensure that cables are robust enough to handle the dynamic requirements of robotic movement, accounting for both flexibility and durability.

Igus® is a cable manufacturing company and is recognized for setting a high standard in the field of robotic cables. Their specifications are designed to ensure that cables can endure the stresses of continuous movement, including bending and twisting, which are common in robotic applications. These specifications are often used as a benchmark for durability and flexibility in robotic cable design.

4.15.3.2 Data Distribution Service (DDS)

As described by [i.33], "The DDS specification describes a Data-Centric Publish-Subscribe (DCPS) model for distributed application communication and integration". This specification defines both the Application Interfaces (APIs) and the Communication Semantics (behaviour and quality of service) that enable the efficient delivery of information from information producers to matching consumers. The purpose of the DDS specification can be summarized as enabling "the Efficient and Robust Delivery of the Right Information to the Right Place at the Right Time".

The mapping of DDS constructs to underlying network technologies of any sort is not specified, but certain QoS Policy objects require the support of the underlying network technology:

- Section 2.2.3.8 in [i.33] LATENCY_BUDGET: indicates to the middleware the "urgency" of the data-communication.
- Section 2.2.3.11 in [i.33] LIVELINESS: the service to ensure that particular entities on the network are still "alive".
- Section 2.2.3.14 in [i.33] RELIABILITY: allows for reliable communication.
- Section 2.2.3.15 in [i.33] TRANSPORT_PRIORITY: to allow the application to take advantage of transports that are capable of sending messages with different priorities.

4.16 All-optical base for urban rail transit communication network

4.16.1 Use Case Briefing

As the important infrastructure and popular city transport, the urban rail transit system plays an important role in the urban economic and social development. The urban rail transit system includes an urban rail transit communication system, a signalling system, an Automatic Fare Collection (AFC) system, and a monitoring system. The urban rail transit communication system supports the railway operation and management system, and is an essential integrated system to ensure safe, fast and efficient train operation. The urban rail transit communication system includes three subsystems, a dedicated communication subsystem, a police communication subsystem, and a civil communication subsystem. This use case focuses on the dedicated communication subsystem. The dedicated communication subsystem primarily includes: the wireline transmission system, the wireless transmission system, the orderwire telephone system, a dedicated telephone system, a video surveillance system, a Passenger Information System (PIS), a broadcast system, a clock synchronization system with support for Network Time Protocol (NTP) providing the unified standard time information, and other subsystems.

The rapid digitalization of the urban rail transit system, requires a dedicated communications subsystem to support the emerging all-digital services, interactive intelligent services, and ultimate user experience. The operation of the urban rail transit system needs to optimize and utilize more digital technology, which results in the requirement to have better and higher performant networks. This means the dedicated communications subsystem requires much more bandwidth, higher reliability, and improved Quality of Service.

With the development of optical communication technologies, the urban rail transit communication system for urban rail transit has evolved over several generations, including PCM/PDH (up to 155 Mbps), SDH (2,5 Gbps and 10 Gbps), and Multi-Service Transport Platform (MSTP with up to 40 Gbps). Currently the dedicated communication subsystem is based on Multi-Service OTN (MSOTN) with 100 Gbps, which supports the intelligent and cloud-based urban rail transit systems. See Use Case # 15 in ETSI GR F5G 020 [i.1] for more details.

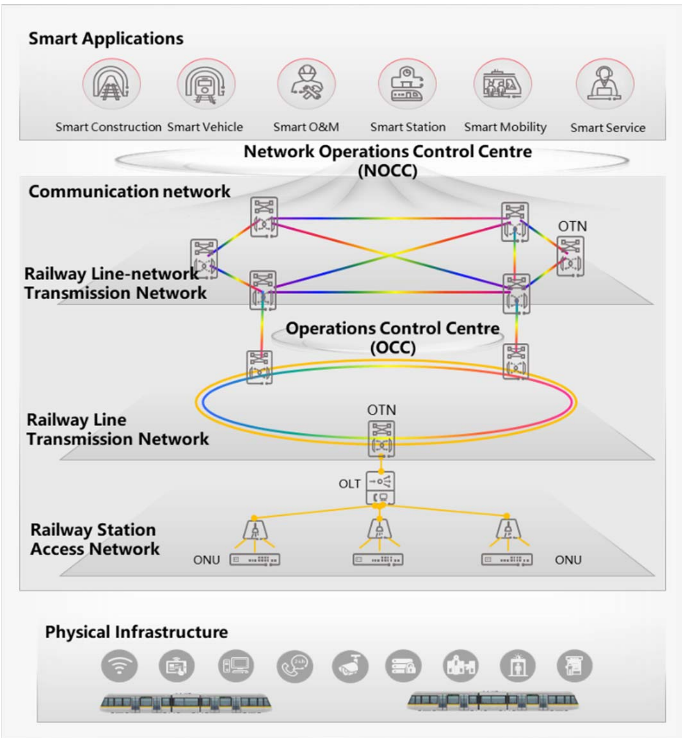

Figure 11: Overview of urban rail transit communication system (Source: ETSI GR F5G 020 [i.1])

4.16.2 Technology Requirements and Gap Analyses

4.16.2.1 General

The urban rail transit network is evolving and is being driven by service cloudification, service intelligence and OAM agility:

1) Service cloudification

The urban rail transit cloud includes cloud computing applications and artificial intelligence in the urban rail transit industry is moving the data storage and the data processing to the cloud. As a result, the dedicated communication subsystem between the urban rail transit system and the cloud needs higher bandwidth, higher reliability, and lower latency connectivity than the legacy communication network.

2) Service intelligence

The current smart services are multi-dimensional and multi-level intelligent systems including smart applications, such as passenger services, railway power system, railway infrastructure, railway operation security, railway network management, and train schedules. The different intelligent systems and applications require a diversified access approach, differentiated transport network, with secure traffic flow isolation, and high reliability.

3) OAM agility

With the rapid development of the urban rail transit network, the operation and management mode are changing from single-railway line independent operation to multi-railway line comprehensive operation. The layout of the urban rail transit network in the metropolitan area needs a unified network for operation and management. This will create an effective inter-connection between the urban rail transit in central cities and neighbouring cities (towns). To further ensure efficient, secure, fast, and smooth operation and management, it is necessary to build a single network to bridge the information silos of each railway line system.

The urban rail transit network is evolving to an all-optical network base communication network requiring high security, low latency, flexible scalability, and simplified OAM. With an intelligent network management and control platform that integrates management, control, analysis, and AI, the all-optical network base communication network for the urban rail transit network will be more agile, intelligent, and secure.

Key capabilities for an all-optical network base communication network for the urban rail transit network are as following:

- Security and reliability: The different intelligent systems and applications require a diversified access approach, differentiated transport network, which is used to carry different types of services with high secure traffic flow isolation, and high reliability.
- Flexible scalability: Cloudification of the urban rail transit network mean cloud computing applications and artificial intelligence is moving the data storage and the data processing to the cloud. This requires greater bandwidth than currently deployed. So network equipment with up to 800 Gbps bandwidth per wavelength will be required to support this cloudification evolution.
- Simplified deployment: The railway station's all-optical access network with additional services and increased number of connected stations results in larger volume of traffic. The capacity in the station needs to be expanded from the current XGS-PON to 50 G PON reusing the current fibre infrastructure.
- Deterministic and low latency: the move to the cloud will necessitate low and deterministic latency for the new smart applications. Services connect to the cloud utilizing a wavelength-level one hop mechanism, eliminating the need for electrical-layer forwarding on intermediate nodes and reduces latency.

4.16.2.2 All-optical network base communication network for urban rail transit network

Based on the discussion above the all-optical network base communication network for the urban rail transit network needs to support the following functions and capabilities:

The railway line-network transmission network using 200 G/400 G OTN and ROADM/OXC technologies with flexible wavelength grooming, needs to support the smooth evolution to 400 G/800 G or above to support cloudification.

[R15-1] The railway line-network transmission network for the urban rail transit network shall support the smooth evolution to 800 Gbps per wavelength.

The railway line-network transmission network for the urban rail transit network interconnection bandwidth is mainly 100 Gbps or 200 Gbps per wavelength, with a limited number of 400 Gbps. 800 Gbps interfaces for DCI/Metro applications supporting the networking and transmission of high-rate clients (e.g. 100 GE, 200 GE, 400 GE, 800 GE) is specified in other SDOs, such as ITU-T SG15, IEEE and OIF. These specifications can meet the demands of the railway line-network transmission network evolution. In this case standardization is ahead of the needs of the railway line-network transmission network.

[Gap15-1] None.

Grey light is widely deployed for the railway line transmission network. For this network to evolve it needs to support a modular configuration of grey light and coloured light to satisfy the reuse of the current grey light resources and the on-demand expansion based on coloured light with one-hop wavelength connection per station.

[R15-2] The railway line transmission network for the urban rail transit network shall support a modular configuration of both grey light and coloured light.

The current technology can support coexistence of grey light and coloured light and there is no need for standardization.

NOTE: Grey light indicates an optical interface with a single wavelength. Coloured light indicates an optical interface with the option of multiple standard wavelengths, which can be optically multiplexed into one fibre.

[Gap15-2] None.

The railway station access network currently supports PON technology (XGS-PON). The all-optical railway station access network with additional services and increased number of connected stations results in greater number of traffic flows. The capacity in the railway station needs to increase from the current XGS-PON to 50 G PON without deploying new fibre.

[R15-3] The railway station access network for the urban rail transit network shall support up to 50 Gbps and co-existence with multiple PON generations.

GPON or 10 G PON is mainly deployed in the railway station access network for the urban rail transit network. 50 G PON has been specified in ITU-T SG15 Q2 [34]. It meets the smooth evolution demands as it supports the coexistence with earlier PON generations.

[Gap15-3] None.

Hard isolation should be used to provide a highly secure, reliable, and scalable transport network for smart services and cloud services, which need to be isolated from each other, which typically come with a TDM based technology. Minimizing bandwidth wastage is important so efficient allocation of service flow bandwidth to transport technology is essential.

[R15-4] The F5G advanced network of the urban rail transit network shall support hard isolation.

[R15-5] The F5G advanced network of the urban rail transit network shall support efficient bandwidth utilization.

[R15-6] The F5G advanced network of the urban rail transit network shall support low latency, low latency variation, efficient Operation, Administration and Maintenance (OAM).

Fine grain OTN (fgOTN) technology has been specified in ITU-T SG15. With the standardization of fgOTN, this technologies can migrate the urban rail transit network from SDH/MSTP to fgOTN. The fgOTN provides fine granular bandwidth, low latency, low latency variation, and efficient transport of a large number of high-quality sub 1 G services.

[Gap15-4] None.

[Gap15-5] None.

[Gap15-6] None.

Because services and processing of the urban rail transit system has moved from a local individual railway stations to a cloud-based processing system, the reliability of the network connection is more important for the efficient management and control to support the urban rail transit system.

[R15-7] The F5G advanced network of the urban rail transit network shall support 99,9999 % reliability.

OTN and fgOTN satisfies the reliability requirement.

[Gap15-7] None.

4.16.3 Current related standard specifications

4.16.3.1 ITU-T

In the past 30 years, ITU-T has driven the standardization of OTN, with the line rate of OTN increasing from 1,25 Gbps to 400 Gbps and beyond. Currently, OTN technology is evolving to the next generation in two directions. The first direction is beyond 400 G OTN technology to support 800 GE clients mapping and up to 800 Gbps flexible OTN interface. The second direction is fine-grain OTN with 10 Mbps bandwidth granularity to efficiently support a large number of high-quality sub1 G services and the migration of legacy SDH/MSTP networks, increasing the value of OTN to meet the future communication demands.

Recommendations ITU-T G.709.x [12] to [15] B400G OTN/FlexO has been approved by ITU-T SG15 on 08 March 2024.

4.16.3.2 IEEE

IEEE P802.3df 400 Gbps and 800 Gbps Ethernet has been completed with the approval of IEEE 802.3df-2024 [33] by the IEEE-SA Standards Boards on 16 February 2024.

4.17 Optical Fibre sensing for telecom operators

4.17.1 Use Case Briefing

Optical fibre communication is essential to modern society, fibre cables are deployed worldwide to carry communication signal, even in some remote places which are uninhabited. Therefore the telecom operators need to perform measurement to monitor their fibre cable plant, ideally in real time, to prevent the fibre cables from being damaged or to quickly locate the damaged fibre cables if damage has occurred. Manual patrols are used which is very inefficient and none real-time, especially in remote uninhabited locations, e.g. in large and unmanned desert areas. Therefore fibre sensing techniques are necessary. See Use Case # 16 in ETSI GR F5G 020 [i.1] for more details.

Fibre sensing has several advantages:

- High positioning precision.
- Easy deployment.
- Easy maintenance.
- High reliability.
- Very secure.

In the F5G-A Use Case # 16 in ETSI GR F5G 020 [i.1] on optical fibre sensing for telecom operators, there are scenarios for real-time fibre plant monitoring by means of fibre sensing and the requirement needs are outlined.

4.17.2 Technology Requirements and Gap Analyses

4.17.2.1 General

Fibre sensing for telecom operators needs to support the following functions and performance:

[R16-1] The vibration waveform detection distance shall be greater than 80 km per fibre sensing node device.

[Gap16-1] Standards enabling vibration waveform detection distance greater than 80 km are currently not available.

It is important to minimize the false negative and false positive rate. The rate should not exceed 1 % in order to achieve an effective signal collection rate of 99 %.

[R16-2] False negative and false positive rate shall not exceed 1 %.

[Gap16-2] Standards which support ≤ 1% false negative and false positive rate are currently not available.

[R16-3] The vibration waveform detection accuracy shall be at least 95 %.

[Gap16-3] Standards supporting vibration waveform detection with an accuracy of at least 95 % are currently not available.

[R16-4] The detected event location accuracy shall be ≤ 10 m.

[Gap16-4] Standards supporting event location accuracy of ≤ 10 m are currently not available.

The sensing system shall be capable of quickly learning from the local measured samples in order to improve the accuracy and efficiency of fibre fault detection in the future.

[R16-5] The fibre sensing system shall support fast learning of fibre fault detection and self-improving.

[Gap16-5] Standards for fibre sensing system which support fast learning and self-improving are currently not available.

The need for the fibre sensing system to support real time monitoring is important.

[R16-6] The fibre sensing system shall support continuous real time monitoring.

[Gap16-6] Standards which support a real-time monitoring capability are currently not available.

The network management system shall manage the fibre sensing system and Geographic Information System (GIS) shall be an integral part of the management system.

[R16-7] The Telecom operator network management system in cooperation with GIS shall be capable to link the detected events to geographic locations.

GIS system is widely used in similar system.

[Gap16-7] None

To manage the fibre sensing system cost and achieve easy deployment, it is important that the fibre sensing system reuses the communication system hardware or at a minimum uses the same components as the communication system. Standards which define the optical interface, the electronic interface and the management & control interface shall be developed.

[R16-8] The fibre sensing system definition of the optical interface, the electronic interface and the management & control interface should be standardized.

[Gap16-8] Standards which define the fibre sensing system architecture, the optical interface, the electronic interface and the management & control, and enabling communication hardware reuse or supply chain reuse, are currently not available.

4.17.3 Current related standard specifications

4.17.3.1 ITU-T

In the ITU-T SG15 plenary meeting in November 2023, a standard project named G.dfos [i.16] was created in Q6 to define the optical layer interface requirements for the Distributed Fibre Optic Sensing system (DFOS). DFOS will define the optical detected distance, crosstalk with the communication system, and sensitivity. The ITU-T Q6 G.dfos [i.16] scope is illustrated in Figure 12.

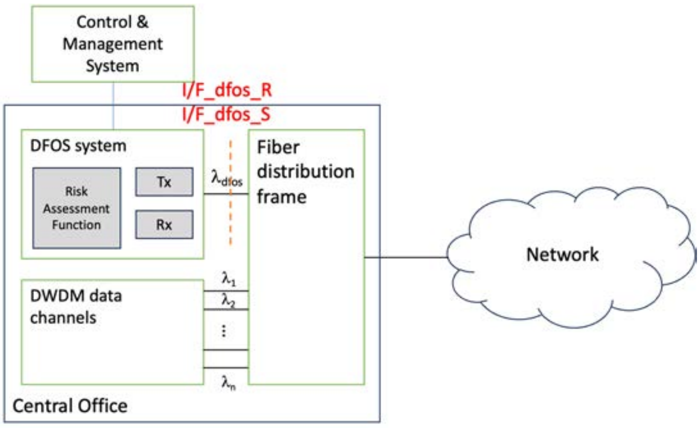

Figure 12: ITU-T G.dfos scope

In ITU-T SG15 Q2, the project G.vhsp (Very High Speed PON) [i.28], which focuses on technologies for beyond 50 G PON), includes the study of fibre sensing based on the PON ODN, which is aiming to perform fibre sensing over short reach (normally within 20 km).

4.18 QoD App-Flow service provisioning

4.18.1 Use Case Briefing

As the residential broadband market develops, there are more and more real-time residential broadband services which improve the home entertainment experience, in addition to IPTV and VoIP, including home health services, work from home, education, security services, and utility services. For the SME scenarios, the advanced broadband services include cloud desktop, VR teleconferencing, security services, surveillance and a larger number of devices among others.

In today's Access Network, the real-time services as mentioned above are transported together with non-real-time Internet services through FTTR, ONU, and OLT. Therefore, those real-time services cannot be guaranteed and the QoE of those real-time services does not satisfy the expectation.

One solution is to abstract the network by service APIs. These service APIs will help the network operators to provide the Network as a Service (NaaS) capabilities with differentiated SLAs, enabling a new business models for network operators.

The Quality on Demand (QoD) API is a key service API, which allows an application to request an improved connection (e.g. guaranteed bandwidth and latency) for a given application flow (App-Flow) from the application client to the F5G-A network server. The QoD API applies in both the Access Network and the Customer Premises Network (CPN), to enable application flow level control for fixed network broadband services. See Use Case # 17 in ETSI GR F5G 020 [i.1] for more details.

4.18.2 Technology Requirements and Gap Analyses

4.18.2.1 General

The F5G-A network shall support a Quality on Demand Application Programming Interface (QoD API) for the application to request a particular QoS for an Application Flow (App-Flow) on-demand. The request can come from the application user, the application provider, or the application itself.

[R17-1] The F5G-A network shall support Quality on Demand APIs.

[Gap17-1] QoD API standards for fixed networks is currently unavailable.

The management and operation support system shall be capable of provisioning service packages, which are a set of communication services bundled together with different QoS requirements and different QoE needs. The individual provisioning of QoS for each App-flow and the total set of communication services is required.

[R17-2] The F5G-A network shall support the provisioning of different App-Flow services with different QoS requirements.

[Gap17-2] A standard for the provisioning of App-Flow services with different QoS requirements is currently unavailable.

Since QoD APIs provide guaranteed SLAs, SLA management needs to be supported including the provisioning of the SLA, the monitoring of the SLA, and the termination of the SLA.

[R17-3] The F5G-A network shall support SLA management.

SLA management does exist for enterprise services but not for residential and SME services. Typically SLA management is focused on larger granularity services, not on per user or per application flow granularity bases.

[Gap17-3] SLA management for fine granular application flows is currently unavailable.

For the fine granular management of application flows, the Customer Premises network and the Access Network need to support QoS management mechanisms on a per application flow granularity in the data plane. Also the data plane needs to continuously react in real-time to maintain the QoS for the application flows.

[R17-4] The F5G-A network shall support application flow granularity QoS management mechanisms in both the CPN and the Access Network.

Coarse granular QoS management is usually supported, but there is no standard for fine granular application flow QoS management mechanisms with very low reaction time.

[Gap17-4] The standard for fine granular application flow QoS management mechanisms with very low reaction time is currently unavailable.

[R17-5] The F5G-A network shall support a real-time QoS control subsystem in both the CPN and in the Access Network.

Non-real time QoS control is usually performed in the network management system.

[Gap17-5] The real-time QoS control and adaptation to application changes is not currently available.

Application flows need to be detected (automatically or through an API interaction between applications and the network) and then mapped to QoS guaranteed connections in the data plane.

[R17-6] The F5G-A network shall support the identification of fine granular application flows through the QoD API.

[R17-7] The F5G-A network shall support the identification of application flows automatically.

[R17-8] The F5G-A network shall support the mapping of fine granular application flows to the underlying QoS guaranteed connections.

For the identification of application flows through an API interaction, similar standards in CAMARA exist, however they are adapted to the needs of mobile applications.

[Gap17-6] For the identification of fine granular application flows through the QoD API through API interaction, is currently not available.

[Gap17-7] The standard for the automatic identification of application flows, is currently not available.

[Gap17-8] The mapping of fine granular application flows to the QoS guaranteed connections is currently not available.

Telemetry is needed to be scaled up to monitor the large number of application flows in the data plane, therefore scaled up mechanisms for telemetry are needed.

[R17-9] The F5G-A network shall support telemetry for a very large number of application flows.

[Gap17-9] Standards for telemetry on a large scale are currently not available.

The interaction between the Access Network and the CPN in terms of compute functionality achieves optimized network performance.

[R17-10] The F5G-A network shall support ONUs with computing-enhanced ONU/FTTR functionality.

[Gap17-10] Standards for support of ONUs with compute functionality are currently not available.

The F5G-A compute functionality located in the CPN and the Access Network can be used for various tasks. Specifically, optimizing the overall network performance needs cooperation between the compute tasks running in the CPN (close to the end user devices) and compute task running at the Access Node (additional compute power and information about all connected CPNs). Depending on the task the cooperation between distributed compute tasks is needed for the most optimal outcome.

[R17-11] The F5G-A network shall support cooperation of compute functionality located in the access and the customer premises network equipment.

[Gap17-11] Standards for cooperation of compute located on different Access Network and CPN equipment is currently not available.

4.18.3 Current related standard specifications

4.18.3.1 CAMARA

The CAMARA project [i.34] by the telco global API alliance and an open source project within the Linux® Foundation are defining a set of APIs with a focus on mobile networks and services. Whether the same or similar APIs are suitable for F5G-A networks will need to be determined.

4.18.3.2 ITU-T QoS in PON and G.fin

ITU-T Q2 and Q3 define the Passive Optical Access Network (PON) [35] and Fibre on Premises Networks (G.fin) [7], both technologies have some coarse granular mechanisms for QoS management, usually per class of service granularity.

4.18.3.3 F5G Telemetry

ETSI ISG F5G has defined the access network telemetry data models. The mechanisms and performance as defined in [i.35] are flexible and different telemetry tasks can be performed on-demand. However, due to limitations in the data plane elements, the number of flows which telemetry can be applied to is limited.

5 Technology Landscape Summary

Table 1 is a collection of requirements and gaps addressed in clause 4 of the present document, and organized per use cases.

In case there is no gap for a certain requirement, the gap is "None". In case multiple requirements are mapped to one gap, the following numbered gap is marked as "Same as [GapUC#-yy]", where UC# represents the use case number and yy represents the gap number within that use case. The same is true for requirement numbering [RUC#-xx] where UC# represents the use case number and xx represents the requirement number within that use case.

Table 1: Summary of Requirements and Gaps

Technology requirements	Gaps
UC#1: Premium private line service automation	
[R1-1]: The OTN electrical and optical layer resource information shall be reported to the premium private line service provisioning system in real-time.	[Gap1-1]: Real-time resource discovery of fgOTN resources is currently not supported.
[R1-2]: Computing and creating of both the OTN electrical and the optical layer paths shall be supported for private line service.	[Gap1-2]: Standardized YANG data models for computing and creating both the OTN electrical and optical layer paths for private line service are currently not supported.
[R1-3]: The network management and control system should support automatic discovery and automatic configuration of the OTN CPEs.	[Gap1-3]: CPE plug-and-play is currently not supported.
[R1-4]: The OTN shall support hitless bandwidth adjustment of an OTN connection.	[Gap1-4]: None.
[R1-5]: The OTN shall support instant bandwidth adjustment of an OTN connection.	[Gap1-5]: Standardized YANG data models for bandwidth adjustment of an fgOTN connection is currently not supported.
[R1-6]: The premium private line service provisioning system shall support SLA information query and alarm report APIs.	[Gap1-6]: Standardized APIs and YANG data models for SLA information query and alarm report are currently not supported.
UC#2: Stable & reliable Wi-Fi® connection over on-premises networking	
[R2-1]: The fibre-based on-premises network shall support network application identification and the corresponding QoS mechanisms.	[Gap2-1]: A dynamic and quantitative QoS indication scheme for practical data flows is currently not available.
[R2-2]: The fibre-based on-premises network shall support an on-premises network centralized controller.	[Gap2-2]: None.
[R2-3]: The fibre-based on-premises network shall support real time Wi-Fi® channel information collection.	[Gap2-3]: The messaging mechanism and data model for Wi-Fi® channel monitoring between different APs and end user devices over the fibre link are currently not available.

Technology requirements	Gaps
[R2-4]: The fibre-based on-premises network shall support continuous real time Wi-Fi® transmission behaviour configuration of each Wi-Fi® AP.	[Gap2-4]: The messaging mechanism and data model for Wi-Fi® transmission coordination over the fibre link are currently not available.
[R2-5]: The fibre-based on-premises network shall support a low latency control channel with a 64 µs round trip time between the M-FTR and the S-FTR.	[Gap2-5]: The low latency control channel with less than 64 µs round trip time is currently not available in the fibre DL.
[R2-6]: The fibre-based on-premises network shall support a control messaging procedure with bounded latency as required by the identified QoS.	[Gap2-6]: Dedicated message exchange procedures for different technical features, including seamless handover are currently not available.
[R2-7]: The fibre-based on-premises network shall provide a reliable handover message transmission channel with deterministic latency.	[Gap2-7]: Same as [Gap2-4], [Gap2-5], and [Gap2-6].
UC#3: Computing collaboration in PON network	
[R3-1]: The PON network elements shall support additional computing oriented hardware or modules.	[Gap3-1]: Additional computing oriented hardware or modules in the current PON network elements, including the OLT, the P-ONU and the E-ONU are currently not available.
[R3-2]: The PON network shall support service flow identification and identification of the corresponding QoS requirements.	[Gap3-2]: A dynamic and quantitative QoS indication scheme for practical data flows for the PON network are currently not available.
[R3-3]: The cloud platform shall support the enabling or disabling computing collaboration of the OLT, the P-ONU or the E-ONU.	[Gap3-3]: A Collaboration function is not defined in the current E2E system.
[R3-4]: The cloud platform shall be capable of collecting the computing capability information and utilization of the OLT, the P-ONU or the E-ONU computing resources.	[Gap3-4]: A Data model for computing collaboration is currently not available in BBF oneM2M TR-069 [i.14] and BBF oneM2M TR-369 [i.15].
[R3-5]: The OLT shall support a computing collaboration information and configuration exchange interface with the P-ONU and the E-ONU.	[Gap3-5]: A Data model for computing collaboration is currently not available in OMCI [10].
[R3-6]: The on-premises network P-ONU shall support a computing information and configuration exchange interface with the E-ONU.	[Gap3-6]: A Data model for computing collaboration is currently not available in FMCI [i.11] or WMCI [i.12] for the on-premises network.
UC#4: Intelligent power grid	
[R4-1]: The DCI network of the intelligent power grid shall support up to 800 Gbps per wavelength up to 80 km.	[Gap4-1]: None.
[R4-2]: The backbone transport network of the intelligent power grid shall support ultra-large State Of Polarization (SOP) with at least 8 M rad/s.	[Gap4-2]: None.
[R4-3]: The backbone transport network of the intelligent power grid shall support ultra-long single-span of at least 500 km.	[Gap4-3]: Ultra-long single-span with at least 500 km distance technology is currently unavailable Ultra-long single-span with at least 500 km technology is currently unavailable.
[R4-4]: The backbone transport network of the intelligent power grid shall support ultra-long single-span of at least 500 km.	[Gap4-4]: None.
[R4-5]: The substation transport network of the intelligent power grid shall support fine granularity with 10 Mbps tributary slots.	[Gap4-5]: None.
[R4-6]: The substation transport network of the intelligent power grid shall support hard isolation, low latency, low latency variation, Operation, Administration and Maintenance (OAM).	[Gap4-6]: None.
[R4-7]: F5G advanced network of the intelligent power grid should support migration of legacy SDH network.	[Gap4-7]: None.
[R4-8]: The substation transport network of the intelligent power grid shall support timing transparent transmission for CBR services.	[Gap4-8]: None.
[R4-9]: The substation transport network of the intelligent power grid shall support agile and hitless bandwidth adjustment capabilities.	[Gap4-9]: None.
[R4-10]: The communication network of the intelligent power grid shall support an end-to-end high quality hard isolated connections.	[Gap4-10]: An end-to-end high quality hard isolated connection across the communication network of the intelligent power grid is currently unavailable.

Technology requirements	Gaps
[R4-11]: The communication network of the intelligent power grid shall support a multi-level flexible scheduling mechanism at the wavelength, ODU as channel, and fgOTN as service levels.	[Gap4-11]: None.
UC#5: Railway perimeter inspection	
[R5-1]: Unidirectional coverage range shall be greater than 50 km.	[Gap5-1]: Standards which support unidirectional coverage range greater than 50 km are currently unavailable.
[R5-2]: The detection rate of true intrusion events shall be greater than 99,9 %.	[Gap5-2]: Standards which support the detection rate greater than 99,9 % are currently unavailable.
[R5-3]: The frequency of false intrusion events shall be less than 0,002 events/km/hour on average.	[Gap5-3]: Standards which support the frequency of false intrusion events less than 0,002 events/km/hour on average are currently unavailable.
[R5-4]: The position accuracy of the true intrusion event detection shall be less than 10 m.	[Gap5-4]: Standards which support the position accuracy less than 10 m are currently unavailable.
[R5-5]: Intrusion event identification time shall be less than 5 s.	[Gap5-5]: Standards which support intrusion event identification time less than 5 s are currently unavailable.
UC#6: Naked-eye 3D display	
[R6-1]: The F5G-A access network shall provide symmetric 10 Gbps data rate for each subscriber.	[Gap6-1]: None.
[R6-2]: The FTTR on-premises network shall provide symmetric 10 Gbps data rate.	[Gap6-2]: Symmetric 10 G FTTR technology is currently not available.
[R6-3]: The E2E F5G-A network shall support < 10 ms RTT.	[Gap6-3]: The unified E2E latency control is not specified yet. E2E coordination mechanism is still currently not available.
UC#7: Unified access and on-premises network	
[R7-1]: The OLT shall be capable of requesting and receiving transmission status (including data buffer, communication environment) from any device in the F5G-A access network and on-premises network, including the P-ONU and the E-ONU	[Gap7-1]: The OLT direct collection of the E-ONU's transmission status is currently not available.
[R7-2]: The OLT shall be capable of configuring the transmission behaviour of any device in the F5G-A access network and the on-premises network.	[Gap7-2]: The OLT support for the direct configuration of each E-ONU is currently not available.
[R7-3]: The P-ONUs shall be capable of providing local control for the E-ONUs and the corresponding end user devices through a centralized control mechanism.	[Gap7-3]: None.
[R7-4]: The F5G-A optical access network and the on-premises network shall support an extension of the OMCI management interface.	[Gap7-4]: The extended OMCI management interface to enable global management of any device in the F5G-A access network and the on-premises network is currently not supported by the OLT.
[R7-5]: The unified management system shall support the management coordination between OLT and P-ONUs.	[Gap7-5]: The unified management system between the OLT, the P-ONUs and E-ONUs is currently not supported.
[R7-6]: The unified management system shall support a single management protocol for both the F5G-A access network devices and the on-premises network devices.	[Gap7-6]: The protocol for device information collection based on a single protocol is currently not available.
[R7-7]: The unified management shall support the collection of device information from the different network elements once they are connected by optical fibre.	[Gap7-7]: The direct collection of device information for both the P-ONU and E-ONUs is currently not supported.
[R7-8]: The unified management shall provide visualization of the logical links for the different service flows.	[Gap7-8]: The management system providing visualization of the logical link for the different service flows via the OLT OMCI is currently not supported.
UC#8: OTN intelligent fault management	
[R8-1]: The intelligent OTN fault management system shall support collecting alarm information from the OTN NEs.	[Gap8-1]: None.
[R8-2]: The intelligent OTN fault management system shall support root alarm identification from the received alarms.	[Gap8-2]: Root alarm identification from the aggregated alarm reporting is currently not supported.
[R8-3]: The intelligent OTN fault management system shall support OTN root cause analysis based on a set of correlated alarms.	[Gap8-3]: OTN root cause analysis is currently not supported.
[R8-4]: The intelligent OTN fault management system should support providing fault repair recommendations.	[Gap8-4]: The provisioning of OTN fault repair recommendations is currently not supported.
[R8-5]: The intelligent OTN fault management system shall support fault impact analysis.	[Gap8-5]: OTN fault impact analysis is currently not supported.
[R8-6]: The intelligent OTN fault management system should support providing fault handling priorities.	[Gap8-6]: The provisioning of OTN fault handling priorities is currently not supported.

Technology requirements	Gaps
[R8-7]: The intelligent OTN fault management system shall support reporting the identified incident information.	[Gap8-7]: The information report of an identified incident is currently not supported.
[R8-8]: The reported incident information shall support at least the elements listed in clause 4.9.2.5.	[Gap8-8]: The YANG models for the information report of an identified incident are currently not supported.
UC#9: Evaluation and assurance of user service experience	
[R9-1]: The user experience evaluation model shall be defined.	[Gap9-1]: None.
[R9-2]: The F5G-A Access Network QoE analysis system shall collect the F5G-A Access Network service and network KQIs.	[Gap9-2]: The interface to obtain the F5G-A Access Network service and the network KQIs is currently not supported.
[R9-3]: A portal to the F5G-A Access Network QoE analysis system should be provided to report the location and the key factors affecting the users' service experience.	[Gap9-3]: The F5G-A Access Network QoE analysis system interface that provides the location and the key factors that affect the user's service experience to the management and control system is currently not supported.
[R9-4]: A portal to the F5G-A Access Network QoE analysis system should be provided to report the users who are considered to have, or potentially will have service experience problems.	[Gap9-4]: The F5G-A Access Network QoE analysis system interface that provides the list of users who are considered to have, or will potentially have service experience problems to the management and control system is currently not supported.
[R9-5]: The F5G-A Access Network QoE analysis system shall support automatic reconfiguration of the Access Network element(s) to resolve software problems that cause service experience problems.	[Gap9-5]: The automatic reconfiguration of the F5G-A Access Network to resolve software problems that cause service experience problems is currently not supported.
[R9-6]: The F5G-A Access Network QoE analysis system shall support dispatching the user service experience problem trouble tickets.	[Gap9-6]: The trouble ticket or maintenance ticket dispatching, when a user's QoE problem or potential problem are detected by the F5G-A Access Network QoE analysis system, is currently not supported.
UC#10: Cloud Desktop	
[R10-1]: The Edge cloud infrastructure shall be deployed close to the end user to support low latency of data transmission in a F5G-A network.	[Gap10-1]: None.
[R10-2]: The Edge cloud should support coordination with remote cloud to enable the best service QoS for the end user.	[Gap10-2]: The computing coordination mechanism between different F5G-A network elements is not currently available.
[R10-3]: The F5G-A network shall support cloud desktop service identification and support the assignment of service priority.	[Gap10-3]: The F5G-A network adaptation mechanism to the variation of network demand due to the cloud desktop service is currently not available.
[R10-4]: The F5G-A network shall support slicing technology and guaranteeing network QoS for cloud desktop service delivery.	[Gap10-4]: None.
[R10-5]: Shallow compression technique with low compression ratio shall be supported by Cloud desktop technology.	[Gap10-5]: Shallow compression techniques with a low compression ratio is currently not available.
[R10-6]: Independent encoding and decoding process in shallow compressing for each frame shall be supported by Cloud desktop technology.	[Gap10-6]: Independent encoding & decoding for each data frame is currently not available.
[R10-7]: The F5G-A system shall support parallel compression for cloud desktop service slices.	[Gap10-7]: Parallel compression for cloud desktop service slices is currently not available.
UC#11: Dynamically digitalized ODN	
[R11-1]: The digitalized ODN system shall support dynamic visualization of the ODN topology between the OLT and the ONU or P-ONU.	[Gap11-1]: The dynamic visualization of the ODN topology is currently not available.
[R11-2]: The digitalized ODN system shall support GIS-based location identification and visualization of the ODN.	[Gap11-2]: The physical location of the ODN is currently not available.
[R11-3]: The digitalized ODN system shall support the dynamic visualization of insertion loss for the different ODN segments.	[Gap11-3]: The dynamic collection of the ODN insertion loss is currently not available.
[R11-4]: The digitalized ODN system shall support proactive optical path diagnostics.	[Gap11-4]: Proactive diagnostic and recovery of ODN faults are currently not available.
[R11-5]: The digitalized ODN system shall support remote fault locating within 15 minutes.	[Gap11-5]: Dynamic remote fault location determination is currently not available.
[R11-6]: The digitalized ODN system shall support ODN resource status collection.	[Gap11-6]: ODN resource management is currently not available.

Technology requirements	Gaps
UC#12: On-premises Millimetre=Wave (mmWave) WLAN	
[R12-1]: The mmWave Wi-Fi® shall support 10 Gbps throughput on the air interface in the unlicensed V-band and Q-band.	[Gap12-1]: The sub-6 GHz alignments with mmWave Wi-Fi® technology is currently not available.
[R12-2]: The mmWave Wi-Fi® shall support a coordinated transmission mechanism to avoid packet collision in the air interface (i.e. within a single BSSID).	[Gap12-2]: The coordinated transmission mechanism supporting the new 6 GHz aligned system specification, is currently unavailable.
[R12-3]: The mmWave Wi-Fi® over the FTTR system shall be capable of sensing the signal distribution of each AP and control the transmission power to mitigate interference between rooms.	[Gap12-3]: The data model for Wi-Fi® devices is currently unavailable.
[R12-4]: The mmWave Wi-Fi® over FTTR system shall provide a coordination scheme with sub-6 GHz Wi-Fi® to maintain the quality of connection during link switching within a single AP and link switching between different APs.	[Gap12-4]: The coordination mechanism between sub-6 GHz and mmWave Wi-Fi® for link switching is currently not available.
[R12-5]: The sub-6 GHz Wi-Fi® should support the mmWave Wi-Fi® by assisting with beamforming, beam tracking and link adaptation.	[Gap12-5]: The assistance mechanism of sub-6 GHz Wi-Fi® for mmWave Wi-Fi® for beamforming, beam tracking and link adaptation is currently not available.
[R12-6]: The sub-6 GHz Wi-Fi® should support mmWave Wi-Fi® link control information transport.	[Gap12-6]: The separated control and data plane for mmWave Wi-Fi® through sub-6 GHz Wi-Fi® is currently not available.
UC#13: Wavelength-shared WDM aggregation network (AGGN)	
[R13-1]: The wavelength-shared WDM AGGN shall support the smooth evolution to higher data rate beyond 200 G per channel.	[Gap13-1]: None.
[R13-2]: The wavelength-shared WDM AGGN shall support efficient utilization of wavelength resources.	[Gap13-2]: Standard for wavelength sharing between different rings in wavelength-shared WDM AGGN is currently not defined.
[R13-3]: The wavelength-shared WDM AGGN shall support a multiple-ring multi-service access network structure with the reuse of wavelengths per AGGN node.	[Gap13-3]: The multiple-ring multi-service access network structure standard is currently not supported.
[R13-4]: The wavelength-shared WDM AGGN shall support an all optical transparent connection up to 320 km.	[Gap13-4]: None.
[R13-5]: The wavelength-shared WDM AGGN should support optical-layer wavelength grooming.	[Gap13-5]: Standard for function model of integrated ROADM with higher integration, smaller size, lower power, is currently not defined.
[R13-6]: The wavelength-shared WDM AGGN should support dynamic allocation of bandwidth granularity.	[Gap13-6]: None.
[R13-7]: The wavelength-shared WDM AGGN shall support real-time monitoring of single channel and transmission link.	[Gap13-7]: A performance monitoring standard for wavelength-shared WDM AGGN is currently not defined.
[R13-8]: The wavelength-shared WDM AGGN shall support automatic allocation of wavelength resources and network optimization	[Gap13-8]: An automatic network O&M standard for wavelength-shared WDM AGGN is currently not defined.
UC#14: Robotics as a Service	
[R14-1]: The F5G-A network used in robotic system shall support latency of less than 1 ms for the acceptable milling application.	[Gap14-1]: None.
[R14-2]: The F5G-A network used in robotic system shall support latency of 0,25 ms for the ideal milling application.	[Gap14-2]: The latency for the ideal milling application is not currently achievable.
[R14-3]: The F5G-A network used in robotic system shall guarantee a maximum latency of 5 ms for an acceptable safety application.	[Gap14-3]: None.
[R14-4]: The F5G-A network used in robotic system shall have a latency of 0,5 ms for the ideal safety application.	[Gap14-4]: The ideal latency for safety application is 0,5 ms not currently achievable.
[R14-5]: Cables utilized in RaaS shall be capable of withstanding a minimum of ±90° twist per meter for acceptable cable twisting.	[Gap14-5]: None.
[R14-6]: The cable bend shall be 10 times the outer diameter of the cable for acceptable cable bending.	[Gap14-6]: None.
[R14-7]: Cables utilized in RaaS shall be capable of withstanding a minimum of ±180° twist per meter for ideal twisting.	[Gap14-7]: The ideal cable requirements of ±180° twist per meter which is not currently supported.
[R14-8]: The cable bend shall be 12,5 times the outer diameter of the cable for ideal bending.	[Gap14-8]: The ideal bend is 12,5 times the outer diameters not currently supported.

Technology requirements	Gaps
[R14-9]: The F5G-A network communication system shall be designed to allow a robotics expert to complete the installation and configuration without prior knowledge of F5G-A technology.	[Gap14-9]: Simplified installation and configuration of enterprise network communication for RaaS applications effectively is currently not supported and still need for specialized knowledge or training in F5G-A technology.
[R14-10]: The F5G-A network communication system should support the Data Distribution Service (DDS), when the Robotics Operating System (ROS) is using the DDS communication service.	[Gap14-10]: The mapping of the DDS over the F5G-A network architecture is currently not standardized.
UC#15: All-optical base for urban rail transit communication network	
[R15-1]: The railway line-network transmission network for the urban rail transit network shall support the smooth evolution to 800 Gbps per wavelength.	[Gap15-1]: None.
[R15-2]: The railway line transmission network for the urban rail transit network shall support a modular configuration of both grey light and coloured light.	[Gap15-2]: None.
[R15-3]: The railway station access network for the urban rail transit network shall support up to 50 Gbps and co-existence with multiple PON generations.	[Gap15-3]: None.
[R15-4]: The F5G advanced network of the urban rail transit network shall support hard isolation.	[Gap15-4]: None.
[R15-5]: The F5G advanced network of the urban rail transit network shall support efficient bandwidth utilization.	[Gap15-5]: None.
[R15-6]: The F5G advanced network of the urban rail transit network shall support low latency, low latency variation, Operation, Administration and Maintenance (OAM).	[Gap15-6]: None.
[R15-7]: The F5G advanced network of the urban rail transit network shall support 99,9999 % reliability.	[Gap15-7]: None
UC#16: Optical Fibre Sensing for telecom operators	
[R16-1]: The vibration waveform detection distance shall be greater than 80 km per fibre sensing node device.	[Gap16-1]: Standards enabling vibration waveform detection distance greater than 80 km are currently not available.
[R16-2]: False negative and false positive rate shall not exceed 1 %.	[Gap16-2]: Standards which support ≤ 1 % false negative and false positive rate are not currently available.
[R16-3]: The vibration waveform detection accuracy shall be at least 95 %.	[Gap16-3]: Standards supporting vibration waveform identification with an accuracy of at least 95 % are currently not available.
[R16-4]: The detected event location accuracy shall be ≤ 10 m.	[Gap16-4]: Standards supporting event location accuracy of ≤ 10 m are currently not available.
[R16-5]: The fibre sensing system shall support fast learning of fibre fault detection and self-improving.	[Gap16-5]: Standards for fibre sensing system which supporting fast learning and self-improving are currently not available.
[R16-6]: The fibre sensing system shall support continuous real time monitoring.	[Gap16-6]: Standards which support a real-time monitoring capability are currently not available.
[R16-7]: The Telecom operator network management system in cooperation with GIS shall be capable to link the detected events to geographic locations.	[Gap16-7]: None.
[R16-8]: The fibre sensing system definition of the optical interface, the electronic interface and the management & control interface should be standardized.	[Gap16-8]: Standards which define the fibre sensing system architecture, the optical interface, the electronic interface and the management & control, and enabling communication hardware reuse or supply chain reuse, are currently not available.
UC#17: QoD App-Flow service provisioning	
[R17-1]: The F5G-A network shall support Quality on Demand APIs.	[Gap17-1]: QoD API standards for fixed networks is currently unavailable.
[R17-2]: The F5G-A network shall support the provisioning of different App-Flow services with different QoS requirements.	[Gap17-2]: A standard for the provisioning of App-Flow services with different QoS requirements is currently unavailable.
[R17-3]: The F5G-A network shall support SLA management.	[Gap17-3]: SLA management for fine granular application flows is currently unavailable.
[R17-4]: The F5G-A network shall support application flow granularity QoS management mechanisms in both the CPN and the Access Network.	[Gap17-4]: The standard for fine granular application flow QoS management mechanisms with very low reaction time is currently unavailable.
[R17-5]: The F5G-A network shall support a real-time QoS control subsystem in the CPN and in both the Access Network.	[Gap17-5]: The real-time QoS control and adaptation to application changes is not currently available.

Technology requirements	Gaps
[R17-6]: The F5G-A network shall support the identification of fine granular application flows through the QoD API.	[Gap17-6]: For the identification of application flows through an API interaction, is currently not available.
[R17-7]: The F5G-A network shall support the identification of application flows automatically.	[Gap17-7]: The standard for the automatic identification of application flows, is currently not available.
[R17-8]: The F5G-A network shall support the mapping of fine granular application flows to the underlying QoS guaranteed connections.	[Gap17-8]: The mapping of fine granular application flows to the QoS guaranteed connections is currently not available.
[R17-9]: The F5G-A network shall support telemetry for a very large number of application flows.	[Gap17-9]: Standards for telemetry on a large scale is currently not available.
[R17-10]: The F5G-A network shall support ONUs with computing-enhanced ONU/FTTR functionality.	[Gap17-10]: Standards for support of ONUs with compute functionality is currently not available.
[R17-11]: The F5G-A network shall support cooperation of compute functionality located in the access and the customer premises network equipment.	[Gap17-11]: Standards for cooperation of compute located on different Access Network and CPN equipment is currently not available.

Table 2 is a list of suggested actions to gaps found in the present document. Suggested actions shall be notified to the other organization or groups to be carried out by members in the corresponding organizations and groups, if appropriate. For actions assigned to ETSI ISG F5G, ETSI ISG F5G may address them in new work items under ETSI directives.

Table 2: Suggested actions for identified gaps

SDO/Group	Suggested actions	Relevant gaps
ETSI ISG F5G	Define an E2E PON compute Collaboration function.	[Gap3-3]
	Standardize an F5G unified E2E latency control mechanism.	[Gap6-3]
	Define an interface for collecting F5G-A Access Network service and network KQIs.	[Gap9-2]
	Define a portal in the Access Network QoE analysis system for user experience issues.	[Gap9-3], [Gap9-4]
	Define an F5G-A Access Network automatic reconfiguration mechanism.	[Gap9-5]
	Define a users' service experience problem trouble tickets despatching system in the F5G-A Access Network QoE analysis system.	[Gap9-6]
	Define a computing coordination mechanism between different F5G-A network elements.	[Gap10-2]
	Define an adaptation mechanism to manage the variation of network demand due to the cloud desktop service.	[Gap10-3]
	Define a standard for sub 1 ms latency for robotic system using the F5G-Anetwork.	[Gap14-2]
	Define a standard for sub 0,5 ms latency for safety cases for robotic system using the F5G-A network.	[Gap14-4]
	Define a standard for ideal cable requirements of ±180° twist per meter.	[Gap14-7]
	Define a standard for ideal cable bend for 12,5 times the outer diameters.	[Gap14-8]
	Define a simplified installation and configuration mechanism for enterprise network communication for RaaS applications effectively.	[Gap14-9]
	Define a mapping for DDS over the F5G-A network architecture.	[Gap14-10]
	Define a QoD standard for F5G-A networks.	[Gap17-1]
	Define a standard for the provisioning of App-Flow services with different QoS requirements.	[Gap17-2]
	Define a standard for SLA management of fine granular application flows.	[Gap17-3]
	Define a standard for fine granular application flow QoS management mechanisms with very low reaction time.	[Gap17-4]
	Define a standard for real-time QoS control subsystem in the CPN and in the Access Network.	[Gap17-5]
	Define a standard for the identification of fine granular application flows through the QoD API in the F5G network.	[Gap17-6]
	Define a standard for automatic identification of application flows in the F5G network.	[Gap17-7]
	Define a standard for the mapping of fine granular application flows QoD requests to underlying QoS guaranteed connections.	[Gap17-8]
	Define a telemetry collection standard for a very large number of application flows.	[Gap17-9]

SDO/Group	Suggested actions	Relevant gaps
	Define a standards for cooperation of compute located on different F5G-A Access Network and CPN equipment.	[Gap17-11]
ETSI TC ATTM	ETSI ISG F5G suggests that ETSI TC ATTM should define a dynamic visualization mechanism of the ODN topology between the OLT and the ONU.	[Gap11-1]
	ETSI ISG F5G suggests that ETSI TC ATTM should define the use of GIS-based location identification for the ODN.	[Gap11-2]
	ETSI ISG F5G suggests that ETSI TC ATTM should define a mechanism for dynamic collection of the ODN insertion loss.	[Gap11-3]
	ETSI ISG F5G suggests that ETSI TC ATTM should define an ODN proactive optical path diagnostics mechanism.	[Gap11-4]
	ETSI ISG F5G suggests that ETSI TC ATTM should define an ODN remote fault locating mechanism.	[Gap11-5]
	ETSI ISG F5G suggests that ETSI TC ATTM should define an ODN resource management system.	[Gap11-6]
ETSI ISG ZSM	ETSI ISG F5G suggests that ETSI ISG ZSM should define a standard for the provisioning of App-Flow services with different QoS requirements.	[Gap17-2]
	ETSI ISG F5G suggests that ETSI ISG ZSM should define a standard for SLA management of fine granular application flows.	[Gap17-3]
	ETSI ISG F5G suggests that ETSI ISG ZSM should define a standard for fine granular application flow QoS management mechanisms with very low reaction time.	[Gap17-4]
ITU-T SG15/Q2	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define additional computing hardware or modules for PON network equipment.	[Gap3-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a dynamic and quantitative QoS indication scheme for data flows for the PON network.	[Gap3-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define an OMCI computing collaboration data model.	[Gap3-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard enabling the OLT the direct collection of E-ONU transmission status.	[Gap7-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 define a standard enabling the OLT to directly configure the E-ONUs.	[Gap7-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard to extent OMCI to manage the on-premises network.	[Gap7-4]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard for a unified management system between the OLT, the P-ONUs and E-ONUs.	[Gap7-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard for a single protocol for device information collection.	[Gap7-6]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard for a unified management system to directly collect device information for both the P-ONU and E-ONUs.	[Gap7-7]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard for a unified management system enabling visualization of the logical link for different service flow.	[Gap7-8]
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define an ONU standard with computing-enhanced functionality.	[Gap17-10]
ITU-T SG15/Q3	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define the on-premises network application identification and corresponding QoS mechanisms.	[Gap2-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define the on-premises real time Wi-Fi® channel information collection.	[Gap2-3]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define the on-premises messaging mechanism and data model for Wi-Fi® transmission coordination over the fibre link.	[Gap2-4], [Gap2-5], [Gap2-6], [Gap2-7]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define additional computing hardware or modules for PON on-premises network equipment.	[Gap3-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define a FMCI computing collaboration data model in.	[Gap3-6]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should standardize an on-premises symmetric 10 G FTTR data rate.	[Gap6-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define a standard enabling the OLT the direct collection of E-ONU transmission status.	[Gap7-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define a standard enabling the OLT to directly configure the E-ONUs.	[Gap7-2]

SDO/Group	Suggested actions	Relevant gaps
	ETSI ISG F5G suggests that ITU-T SG15/Q2 should define a standard for a unified management system between the OLT, the P-ONUs and E-ONUs.	[Gap7-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define a standard for a single protocol for device information collection.	[Gap7-6]
	ETSI ISG F5G suggests that ITU-T SG15/Q3 should define a standard for a unified management system to directly collect device information for both the P-ONU and E-ONUs.	[Gap7-7]
ITU-T SG15/Q6	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define the appropriate technology for Ultra-long single-span of 500 km.	[Gap4-3]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define fibre standards for railway track intrusion sensing.	[Gap5-1], [Gap5-2], [Gap5-3], [Gap5-4], [Gap5-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard for wavelength sharing between different rings in wavelength-shared WDM.	[Gap13-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define multiple-ring multi-service access network structure with the reuse of wavelengths per node.	[Gap13-3]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard for a function model of an integrated ROADM with higher integration, smaller size, and lower power.	[Gap13-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a mechanism for real-time monitoring of individual channels and transmission links.	[Gap13-7]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a mechanism for automatic allocation of wavelength resources and network optimization.	[Gap13-8]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard to enabling vibration waveform detection distance greater than 80 km.	[Gap16-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard for ≤ 1 % false negative and false positive detection rate.	[Gap16-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard for vibration waveform detection accuracy of < 95 %.	[Gap16-3]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard for **e**vent location accuracy ≤ 10 m.	[Gap16-4]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard for a self-adaptive sensing system.	[Gap16-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standard with real-time sensing monitoring capability.	[Gap16-6]
	ETSI ISG F5G suggests that ITU-T SG15/Q6 should define a standards which define the fibre sensing system architecture, the optical interface, the electronic interface and the management & control, and enabling communication hardware reuse or supply chain reuse.	[Gap16-8]
ITU-T SG15/Q7	ETSI ISG F5G suggests that ITU-T SG15/Q7 should define a dynamic visualization mechanism of the ODN topology between the OLT and the ONU.	[Gap11-1]
	ETSI ISG F5G suggests that ITU-T SG15/Q7 should define the use of GIS-based location identification for the ODN.	[Gap11-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q7 should define a mechanism for dynamic collection of the ODN insertion loss.	[Gap11-3]
	ETSI ISG F5G suggests that ITU-T SG15/Q7 should define an ODN proactive optical path diagnostics mechanism.	[Gap11-4]
	ETSI ISG F5G suggests that ITU-T SG15/Q7 should define an ODN remote fault locating mechanism.	[Gap11-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q7 should define an ODN resource management system.	[Gap11-6]
ITU-T SG15/Q11	ETSI ISG F5G suggests that ITU-T SG15/Q11 should define an end-to-end high quality hard isolated connection across the communication network of the intelligent power grid.	[Gap4-10]
ITU-T SG15/Q14	ETSI ISG F5G suggests that ITU-T SG15/Q14 should define a standard for root alarm identification to report aggregated alarms.	[Gap8-2]
	ETSI ISG F5G suggests that ITU-T SG15/Q14 should enhance the OTN fault management system to support OTN root cause analysis of correlated alarms.	[Gap8-3]
	ETSI ISG F5G suggests that ITU-T SG15/Q14 should enhance the OTN fault management system to support OTN fault repair recommendations.	[Gap8-4]

SDO/Group	Suggested actions	Relevant gaps
	ETSI ISG F5G suggests that ITU-T SG15/Q14 should enhance the OTN fault management system to support fault impact analysis.	[Gap8-5]
	ETSI ISG F5G suggests that ITU-T SG15/Q14 should enhance the OTN fault management system to provide fault handling priorities.	[Gap8-6]
	ETSI ISG F5G suggests that ITU-T SG15/Q14 should enhance the OTN fault management system to support incident information reporting.	[Gap8-7]
ITU-T SG16	ETSI ISG F5G suggests that ITU-T SG16 should define shallow compression techniques with low compression ratio for Cloud desktop services.	[Gap10-5]
	ETSI ISG F5G suggests that ITU-T SG16 should define independent encoding and decoding processes for shallow compression of each frame.	[Gap10-6
	ETSI ISG F5G suggests that ITU-T SG16 should define parallel compression for cloud desktop service slices.	[Gap10-7]
IEC TC86	ETSI ISG F5G suggests that IEC TC86 define a standard for ideal cable requirements of ±180° twist per meter.	[Gap14-7]
	ETSI ISG F5G suggests that IEC TC86 should define a standard for ideal cable bend for 12,5 times the outer diameters.	[Gap14-8]
IEEE 802.11	ETSI ISG F5G suggests that IEEE 802.11 should define a sub-6 GHz alignment with mmWave Wi-Fi®.	[Gap12-1]
	ETSI ISG F5G suggests that IEEE 802.11 should define a coordinated transmission mechanism supporting the new 6 GHz aligned system specification.	[Gap12-2]
	ETSI ISG F5G suggests that IEEE 802.11 should define a data model for Wi-Fi® devices.	[Gap12-3]
	ETSI ISG F5G suggests that IEEE 802.11 should define a coordination mechanism between sub-6 GHz and mmWave Wi-Fi® for link switching.	[Gap12-4]
	ETSI ISG F5G suggests that IEEE 802.11 should define a sub-6 GHz Wi-Fi® assistance mechanism for mmWave Wi-Fi® beamforming, beam tracking and link adaptation.	[Gap12-5
	ETSI ISG F5G suggests that IEEE 802.11 should define an independent control and data plane for mmWave Wi-Fi® via sub-6 GHz Wi-Fi®.	[Gap12-6]
IETF	ETSI ISG F5G suggests that IETF should define the real-time resource discovery of fgOTN resources.	[Gap1-1]
	ETSI ISG F5Gsuggests that IETF should define the YANG model for fgOTN for provisioning, alarm handling, and hitless Bandwidth resizing.	[Gap1-2], [Gap1-5], [Gap1-6]
	ETSI ISG F5G suggests that IETF should define an automatic discovery and automatic configuration of the OTN CPEs allowing for CPE plug and play.	[Gap1-3]
	ETSI ISG F5G suggests that IETF should define the YANG models for the information identified reporting of an identified incident.	[Gap8-8]
BBF	ETSI ISG F5G suggests that BBF should add a computing collaboration data model to BBF oneM2M TR-069 [i.14] and BBF oneM2M TR-369 [i.15].	[Gap3-4]
	No action needed.	Gaps with None

History

Document history		
V1.1.1	September 2024	Publication