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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

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document specifies the end to end F5G Advanced network architecture, features and related network elements' requirements including On-premise, Access, Aggregation, and Core Networks. The present document defines new features and enhances features from previous releases.

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.

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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 necessary for the application of the present document.

[1] ETSI GS F5G 014 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Network Architecture Release 2".

[2] IETF RFC 4760: "Multiprotocol Extensions for BGP-4".

[3] ETSI GS F5G 023 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Technology Requirements and Gap Analyses; Release 3".

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

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

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

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

[8] Recommendation ITU-T G.709: "Interfaces for the optical transport network".

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

[10] Recommendation ITU-T G.9804.2:"Higher speed passive optical networks - Common transmission convergence layer specification".

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

[12] IETF RFC 8402: "Segment Routing Architecture".

[13] IETF RFC 8986: "Segment Routing over IPv6 (SRv6) Network Programming".

[14] IETF RFC 7209: "Requirements for Ethernet VPN (EVPN)".

[15] ETSI GS F5G 018 (V1.1.1): "Fifth Generation Fixed Network (F5G); Architecture of Optical Cloud Networks".

[16] Recommendation ITU-T G.959.1 (01/2024): "Optical transport network physical layer interfaces".

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

[18] IEEE 802.11-2020™: "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".

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 021 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Generation Definition".

[i.2] ETSI GR F5G 020 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Use Cases; Release 3".

[i.3] ITU-T SG15/Q3 Work Item G.wmci: 'WLAN management control interface (WMCI) for in-premises network'.

[i.4] Recommendation ITU-T Y.110 (1998): "Global Information Infrastructure principles and framework architecture".

[i.5] Recommendation ITU-T G.9943: "High speed fibre-based in-premises transceivers - management".

[i.6] Recommendation ITU-T G.709.1: "Flexible OTN common elements".

[i.7] Recommendation ITU-T G.709.3: "Flexible OTN B100G long-reach interfaces".

[i.8] Recommendation ITU-T G.709.5: "Flexible OTN short-reach interfaces".

[i.9] Recommendation ITU-T G.709.6: "Flexible OTN B400G long-reach interfaces".

[i.10] Recommendation ITU-T G.872: "Fine grain flexible ODU (fgODUflex) path layer network".

[i.11] Recommendation ITU-T G.672: "Characteristics of multi-degree reconfigurable optical add/drop multiplexers".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

compute functionality: generic term for the basic computing functions, which include input, processing, storage, and output. Usually, processing is flexibly programmable

NOTE: The compute functionality needs compute resources for the computational success of a program.

compute resource: compute resources are measurable quantities of compute power that might be requested, allocated, and consumed for computing activities

EXAMPLE: Possible compute resources include Central Processing Units (CPU) and Memory among others.

control process: control process is a sub-class of a compute process, which is a generic compute functionality (see above)

NOTE: The control process is the way compute might be used for controlling components, devices, systems, or equipment. The compute function is scoped to the input from, and output to the controlled components, devices, systems, or equipment. A control process might control other control processes building overall hierarchy of control processes.

customer: depending on the market segment, the customer is either a subscriber, a user, or both

equipment: implementation of one or more functions in a single physical container

NOTE: The term is derived and adapted from Recommendation ITU-T Y.110 [i.4]. The equipment will have at least one function implemented in hardware and will have interfaces through which it might be connected to other equipment. It may be designed in a modular way in that the equipment might be made up from a number of smaller pieces of equipment. In addition, some functions may be implemented in software, which might be changed during the lifetime of the equipment.

fgOTN: stands for fine grain Optical Transport Network (OTN) that supports from 10 Mbit/s up to 1 Gbit/s

NOTE: See [8] for the specification of OTN including fgOTN in Annexes M and N of Recommendation ITU-T G.709 [8] and see Recommendation ITU-T G.709.20 [9] for an overview of fgOTN.

(fg)OTN: is defined as an OTN network supporting both standards OTN and fgOTN with service rates from 10 Mbit/s up to 800 Gbit/s and beyond

NOTE 1: See the following for more detailed information and the specification of (fg)OTN for a variety of deployment options and situations [8], [i.6], [i.7], [i.8], [i.9], [9] and [i.10]

NOTE 2: (fg)OTN network elements supports OTN with or without support for fgOTN.

(fg)O-CPE: Customer Premises Equipment (CPE) supporting OTN with or without support for fgOTN

fibre sensing network element: network element that has fibre sensing capabilities

interface: point where independent and distinct systems or equipment interact and communicate with each other

NOTE 1: In the industry there are various definitions and more specialized terms for the term interface, such as a Reference Point, logical or physical interface. Depending on the interface described in the present document, any of those terms apply.

NOTE 2: ITU (see Recommendation ITU-T Y.110 [i.4]) has defined the terms "implementational interface" and "physical interface", which has a similar meaning to interfaces used in the present document.

Lambda (λ) fabric: network consisting of optical connections only with different wavelength being switched

NOTE: In the context of the present document, the λ fabric is used for the Aggregation Network, other applications for the λ fabric are for further study.

non-real-time control: non-real-time control process, is a compute process, where the time from receiving the input data to the output action is non-urgent and might take some time for the process to finish

NOTE 1: Due to that characteristic the control process might be located remote from the component being controlled and the component and the control process need to be connected with a communication channel with more relaxed requirements than in the real-time control case. The bandwidth and latency of the communication channel depends on the control process and the amount of data being transmitted between the component and the control process.

NOTE 2: The present document describes concepts that are predominantly classed as real-time control of the F5G-A network. Non-real-time control features are for further study and are usually part of a network management related work items.

real-time control: real-time control process, is a compute process, where the time from receiving the input data to the output action is very short

NOTE: Due to that characteristic the control process needs to be located close to the component being controlled and the component and the control process need to be connected with a high-speed, low latency communication channel.

subscriber: legal entity who pays regularly to receive or access a service

user: somebody using a service

3.2 Symbols

Void.

3.3 Abbreviations

For the present document, the following abbreviations apply:

(fg)O-CPE	(fg)OTN Customer Premises Equipment
AEL	Aggregation Edge Leaf
AgF	Aggregation Fabric
AggN	Aggregation Network
AI	Artificial Intelligence
AL	Access Leaf
AN	Access Network
AP	Access Point
API	Application Programming Interface
BGP	Border Gateway Protocol
BNG	Broadband Network Gateway
BSS	Business Support System
CDC	Central Data Centre
CE	Customer Equipment
CO	Central Office
CPE	Customer Premises Equipment
CPN	Customer Premises Network
DC	Data Centre
DC-GW	Data Center Gateway
DCI	Data Centre Interconnect
DDS	Data Distribution Service
DECT™	Digital Enhanced Cordless Telecommunications
E2E	End-to-End
EC	Edge Compute
E-LAN	Ethernet virtual private LAN
E-Line	Ethernet virtual private Line
E-ONU	Edge Optical Network Unit
EoS	Ethernet over Synchronous
E-Tree	Ethernet virtual private Tree
EVPN	Ethernet VPN
F4G	4^{th} Generation Fixed Network

NOTE: See the F5G Advanced generation definition in ETSI GR F5G 021 [i.1].

F5G-A	F5G Advanced
FAN	Fibre Access Node
FDM	Frequency Division Multiplexing
fgOTN	fine-grain Optical Transport Network
FIE	FAN Intelligent Engine
FlexO	Flexible Optical transport network
FMCI	Fibre Management and Control Interface
FTTM	Fibre to the Machine

FTTO	Fibre to the Office
FTTR	Fibre-To-The-Room
GMPLS	Generalized Multi-Protocol Label Switching
GUI	Graphical User Interface
GW	Gateway
HGW	Home Gateway
HS-PON	High-Speed PON
ICT	Information and Communication Technology
IE	Industrial Equipment
IoT	Internet of Things
IP	Internet Protocol
IPTV	Internet Protocol Television
KPI	Key Performance Indicators
KQI	Key Quality Indicator
L2VPN	Layer 2 VPN
L3VPN	Layer 3 VPN
LAN	Local Area Network
LCAS	Link Capacity Adjustment Scheme
LDC	Local Data Centre
MAC	Media Access Control
MCA	Management, Control and Analytics
MD-ROADM	Multi-Dimensional ROADM
MP-BGP	Multiprotocol extensions for BGP
MPLS	Multiprotocol Label Switching
NaaS	Network as a Service
NAS	Network Attached Storage
NE	Network Element
O&M	Operation and Maintenance
OAM	Operation, Administration and Maintenance
OCh	Optical Channel
OCN	Optical Cloud Network
ODN	Optical Distribution Network
ODU	Optical Data Unit
ODU0	Optical Data Unit 0
ODUk	Optical Data Unit k
OE	OTN Edge
OLT	Optical Line Terminal
OMCI	ONU Management and Control Interface
OMS	Optical Multiplex Section
ONU	Optical Network Unit
OPEX	Operational Expenditure
OSP	Optical Service Protocols
OSS	Operations Support System
OTN	Optical Transport Network
OTS	Optical Transmission Section
OTSiA	Optical Tributary Signal Assembly
OTUCn	Optical Transport Unit-Cn
OTUk	Optical Transport Unit (k = 0 to 4)
P2MP	Point to Multi-Point
P2P	Point to Point
PBX	Private Branch Exchange
PC	Personal Computer
PDH	Plesiochronous Digital Hierarchy
PE	Provider Edge
PHY	Physical layer
POL	Passive Optical LAN
PON	Passive Optical Network
P-ONU	Primary Optical Network Unit
PPPoE	Point-to-Point Protocol over Ethernet
QoD	Quality on Demand
QoE	Quality of Experience
QoS	Quality of Service

RaaS	Robotics as a Service
RG	Residential Gateway
ROADM	Reconfigurable Optical Add/Drop Multiplexer
SAP	Service Access Point
SC	Sub-Carrier
SCM	Sub-Carrier Multiplexing
SDH	Synchronous Digital Hierarchy
SDN	Software Defined Networking
SDO	Standards Development Organization
SLA	Service Level Agreement
SME	Small and Medium Enterprises
SMP	Service Mapping Point
SPP	Service Processing Point
SR	Segment Routing
SRv6	Segment Routing over IPv6
STM	Synchronous Transport Module
STM-N	Synchronous Transport Module N (N = 1, 4, 16, 64, 256)
TDM	Time Division Multiplexing
VC	Virtual Container
VCAT	Virtual Concatenation
VC-n	Virtual Container n (n = 1, 2, 3, 4, …)
vCPE	Virtual CPE
VLAN	Virtual LAN
VNF	Virtual Network Function
VoIP	Voice over IP
VPN	Virtual Private Network
VR	Virtual Reality
VxLAN	Virtual extensible Local Area Network
WDM	Wavelength-Division Multiplexing
WG	Wireless Gateway
WMCI	Wireless Management and Control Interface
WSS	Wavelength Selected Switch
XC	Cross-Connect
xDSL	x(Version) Digital Subscriber Line
XGS-PON	10-Gigabit-capable Symmetric PON

NOTE: Also known as symmetric 10G-PON.

XR	eXtended Reality

4 Business requirements for the F5G Advanced Network Architecture

4.1 Context

The F5G-A Use Cases [i.2] show the various services and application that the F5G-Advanced architecture needs to support. The F5G-Advanced Generation Definition [i.1] has defined a set of network characteristics that the F5G-A network architecture shall support.

The present clause lists the various requirements from a business perspective. Note that they are not technically exact but show the direction and business benefits of the F5G-Advanced network architecture.

4.2 Flexible on-demand new residential user service packages

The transition from a relatively limited residential service portfolio, such as triple play service (High-speed Internet, Voice, IPTV) to a much wider service portfolio including but not limited to IoT, new entertainment (4K and 8K video, VR gaming), metaverse applications, digital twin, e-medicine, etc., implies that application specific network requirements are needed. Due to on-demand service deployment, more flexibility allocation and adaptation of the network is needed. The on-demand aspect means full configuration automation of specific service packages with the necessary networking capabilities and automated delivery of high-quality services.

4.3 Flexible on-demand new business service packages

The transformation of enterprise networking to an "as a Service" model, requires additional functionality in the network to access multiple clouds from different cloud providers. Having Software "as a Service" requires network adaptation to service specific needs. Enterprise services might be bundled into packages such that these packages are ordered on-demand and based on the actual business needs.

4.4 Evolution to application-oriented 10 Gigabit guaranteed residential services

The introduction of many service packages, means that a network subscription requires network quality differentiation within the residential premises as well as in the access and core networks. For some of the services, guaranteed QoS also needs to be supported. A subscription needs differentiated network performance for the network operator to provide its own applications and as well as for 3rd party applications.

Due to the higher number of end-systems and higher bandwidth services more network capacity per customer is needed. The network speed will increase from 1 G to 5 G today to 5 Gbit to 25 Gbit in the future [i.1].

4.5 Optimization of large Wi-Fi® networks for residential and enterprises

For both residential and business scenarios, the customer premises network needs extensive coverage providing connectivity to every corner of the customer premises without interruptions. In addition, it is not just about providing connectivity, but having high quality and high capacity capability in all areas of the customer premises. This means the on-premises Wi-Fi® network is expanding to include a Wi-Fi® Access Point in every room or office (FTTR2H or FTTR2B).

In many cases it is about a Wi-Fi® network providing high quality of experience to the residential or enterprise users including easy installation or self-install and low network wide energy usage. From a service provider perspective self-install might help lower operational cost and significantly reduce the number of residential or business call-outs.

4.6 Automation of application scenario detection and network adaptation networking to provide the best services

Since various applications are running in various network scenarios, the network should be capable of automatically detecting and reacting to them providing the best possible service. This also means that network adaptation to changes in the environment, application usage profile, or any other changes affecting the service quality shall be performed automatically.

4.7 Advanced services through networking in conjunction with computing capabilities

More advanced services are not restricted to communication and networking anymore. Combinations of networking and computing/storage resources in a single platform enables combined service creation and deployment. The network providing compute and storage capabilities benefits the overall service twofold. Firstly, compute and storage are used to improve the quality of the service and experience through AI. Secondly the service itself is deployed as a combination of networking and compute/storage. Examples include cloud storage easily accessible from residential or business, application as a service installed in the cloud and the GUI provided to the customers.

4.8 Improved energy usage through all optical networking to the edge

The need to lower energy usage is addressed by reducing the number optical to electrical to optical conversions in the E2E network. Transitioning the longest portion of an end-to-end network path to all optical is beneficial in lowering the energy usage as well as OPEX. The service providers improve market positioning thought providing climate neutral and sustainable network services.

4.9 Flexibly sharing optical resources

Transforming to all-optical networks, requires additional steps as optical communication gets closer to the network edge. Since wavelengths are a precious resource and underutilising them is wasteful, therefore the sharing of wavelengths lowers the cost of deployment of optical communication in the all-optical space. To realize the automatic allocation and management of wavelength resources, the F5G-A network should be capable of fast tracing and monitoring of optical channels, and evaluating optical parameters. This effectively avoids the manual process during network maintenance and shortens the network adjustment time. Moreover, for wavelength-level one-hop direct services, this automatic wavelength allocation and management need to be performed across different network layers. Still electrical aspects need to be envisioned, when all-optical solution is either cost prohibitive. Either there are insufficient users to justify the wavelength approach or the services are too fine granular that a wavelength-based communication is an excessive concept.

4.10 Service-oriented Optical Networks

The business requirement for optical communication is to enable the full the spectrum of networking capabilities, such that small to large capacity connections are possible. The various levels of infrastructure sharing provide isolation of different service from each other. Since typically services are provided using cloud computing, which is a dynamic approach to deliver compute functionality in the "as a Service" model, the optical network needs to support the "as a Service" model as well. So dynamic provisioning and adaptation of the optical network to cloud services requires the Network as a Service (NaaS) model.

4.11 Use optical communication for special dedicated networks

There are several special dedicated networks (non-typical telecommunication networks) being deployed today including networks in power distribution, utilities, railways, and subways (see the F5G-A Use Case Document Release 3 [i.2]). In the context of special dedicated networks, which are typically purpose built and isolated for a particular application. This is not a cost effective and efficient use of resources. The reuse and sharing of a common telecommunication network infrastructure is cost effective and efficient, while still maintaining the requirements of the special dedicated networks.

4.12 Deterministic Optical Networks

Due to the move to the cloud and growing trend towards digitalization in the various industries, enterprises and residential. Many of the applications require deterministic network performance to operate securely and reliably. The requirements may change over time due to the evolution of the applications and the business criticality of the application. Therefore, the required determinism needs to be supported in all segments of the F5G-A optical network. Since the optical networks many times include on-premises network segments, a more service-oriented operation and flexible adaptation is needed.

4.13 Operation as a Service

One aspect of the "as a service" model is outsourcing the operation of ICT tasks and network infrastructure. That is relatively straightforward for virtual components in the compute and storage space. However, it is more difficult for physical equipment on-premise. Therefore, there is a business interest of outsourcing the operation to knowledgably business partners, being more efficient due to the consolidated knowledge operating similar networks for several customers. The F5G Advanced network architecture shall support the operation "as a service" model for customer premises networks specifically including the physical equipment, besides the already supported network and compute as a service area.

4.14 Use of Optical Infrastructure for Sensing

The optical infrastructure either the existing communication infrastructure or specifically deployed fibre infrastructure is used to sense environmental conditions or to sense the fibre quality or failure itself for operational purposes. The sensed information is used for various applications for monitoring pipelines, fences, railway tracks (see the F5G-A Use Case Document Release 3 [i.2]). in addition to being reused for communication.

5 F5G Advanced Network Architecture

5.1 Architecture design principles

5.1.1 Quality on Demand (QoD)

Since the F5G Advanced architecture is service driven and enables a plethora of different services and applications, the F5G Advanced (F5G-A) network shall make the Application Programming Interfaces (APIs) available to service management functions to configure a specific quality of service in the F5G-A network for an excellent user experience for given applications.

5.1.2 Autonomous End-to-End Slice Creation and Adaptation

Various services and applications require isolated network slices to enable the delivery of high quality and secure services and applications to the customers. The services and applications shall be automatically detected by the F5G-A network and the network slices are automatically created as required. The adaptation of the network slice to changes of the service or the addition of more users or devices to the service shall be automatically facilitated. The F5G-A MCA plane shall support the autonomous E2E slice features based on the collected knowledge of the F5G-A network and appropriately optimized end-to-end.

5.1.3 Large Wi-Fi® Networks and Policy Control

The F5G architecture [1] provides FTTR with a single Wi-Fi® Access Points (APs) and multiple AP for both residential and SMEs. For large enterprise sites, the F5G-A architecture needs to support a larger number of Access Points. In order to achieve best in class performance, the control of radio interference and easy deployment for excellent data rate coverage on the customer premise is essential to achieve high QoE. In addition, the definition and enforcement of various business policies shall be supported.

EXAMPLE: Business policies include:

1) a single AP for a defined set of users only;

2) the isolation of user groups from each other (e.g. the human resources department from the rest of the enterprise);

3) isolation of applications from each other by Wi-Fi® slicing across the whole customer premise;

4) guaranteeing application performance.

5.1.4 Introduction of additional Residential and Business Service Packages

In today's broadband networks, most service packages are very basic and centred on high-speed Internet access, Voice, and IPTV. In the future, a larger variety of services are expected to be packaged into a customer subscription (residential or enterprise). The services traffic flows have variable network performance requirements.

EXAMPLE: Services include storage as a Service (cloud-based network attached storage), Virtual PC/Cloud Desktop as a Service, XR dedicated lines, live broadcasts, online schooling, e-health services, enterprise cloud applications.

Therefore, the F5G-A architecture shall support variable granular traffic flows to automatically match the service requirements. The F5G-A architecture shall support the matching of the requirements per application and per service. Since some applications and services require small bandwidth, the F5G-A network shall support guaranteed fine granular service flows. The traffic flow from the user device to cloud service/application needs to be established, monitored and adapted in all F5G-A network segments. Since most of the services and applications run in the cloud, the network shall provide on demand "Network as a Service" (NaaS) and needs to dynamically and automatically adapt to application and service requirements.

5.1.5 Addition of Computing and its interaction with the network

The addition of computing to the F5G-Advanced network architecture enables the use of more intelligent algorithms including AI-based functions to steer and control the network. It provides for the creation of on demand customer services based on the on-demand capability of cloud computing technologies. The network needs to coordinate the configuration of computing, storage, and networking. Computing and storage need to be addressed from various perspectives including the physical hardware (general purpose, AI-optimized, special purpose), the cloud computing platform, and the software package. Services need to be installed and configured in the network and the computing needs to be part of the delivery chain in order to provide an integrated user experience of advanced intelligent services.

5.1.6 Optical Layer extension for wavelength sharing

The F5G-A underlay plane shall support all-optical connections to the network access nodes and to the customer premise equipment. The optical layer itself is further extending to the customer and the edge of the network. Having an all optical networking, it is necessary to ensure that optical resources such as wavelength are shared and reused when appropriate still keeping the service guarantees. Other resources are exclusively allocated to certain users, applications, or subscribers.

5.1.7 Fine-Granular Services over Optical Networks

The F5G-A OTN network shall be service aware. Service aware means that the network management and service management systems interact such that a particular service performance and quality is delivered to the customers. When the network is service-aware, meaning that the network itself understands the service requirements and acts upon them accordingly to provide the negotiated network performance. Services require network performance for a wide range of bandwidth and latency. The connection bandwidth granularity shall be from 10 Mbit/s to 800 Gbit/s (see the F5G-A Use Case Document Release 3 [i.2]). The configuration and control of the connections shall be dynamic, flexible and adaptable to the application and users' needs. Since the network bandwidth should be used efficiently, the adaptation of the network connections necessitates bandwidth changes in fine granular steps.

Besides the service awareness, the fine-granular optical network connections are used in the F5G-A Underlay Plane to transport wide-ranging bandwidth and deterministic latency services. This is used for packet-based services mapped to the F5G-A Underlay Plane.

EXAMPLE: The fine-granular connection is used to migrate SDH and PDH to unified fine-granular optical connections (see Annex A).

5.2 Architecture overview

5.2.1 Evolution to the F5G Advanced Architecture

The F5G-Advanced network architecture is an evolution of the F5G architecture as described in [1]. The following features and changes are a summary of the evolution from the Release 2 F5G network architecture to the F5G Advanced network architecture as outlined in the present document:

1) The F5G-A Planes are enhancements of the F5G Planes in Release 2 [1].

2) In the Customer Premises Network (CPN), the technologies in the F5G-A Underlay Plane have evolved from Wi-Fi® 6 to Wi-Fi® 7.

3) In the Access network segment, the technologies in the F5G-A Underlay Plane have evolved from XGS-PON to 50G-PON (HS-PON).

4) In the Aggregation network segment, the OTN technologies in the F5G-A Underlay Plane is enhanced to support finer granularity via adding fgOTN to OTN, called (fg)OTN in the present document and to higher bandwidth beyond 400G (B400G).

5) Across all F5G-A planes and in every segment of the F5G-A network, compute resources and functions are added. Basically, compute resources are distributed throughout the F5G-A network architecture. These compute functions running on that compute resource may coordinate with each other to jointly complete management, control and analytics functions.

6) The compute functionality is addressing tasks in all F5G-A planes. Logically these distributed compute resources and functions form cross-plane computing.

7) The F5G-A architecture enables deep cooperation between the compute functions and the network functions.

8) The all-optical aggregation network segment is sharing wavelength connecting various access network nodes with the aggregation network edge (AggN Edge) nodes through a λ fabric.

9) The F5G-A architecture supports coordinated slice management, such that compute and networking functions are jointly managed.

10) Support a Northbound Interface to configure the Network as a Service (NaaS) and to enable the establishment of connections with a certain Quality on Demand (QoD).

11) The (fg)OTN supports fine granular services to customers, primarily enterprise customers, requiring guaranteed performance guarantees, deterministic latency, clock synchronization, and hard isolation between customer traffic or different services.

12) The F5G-A architecture supports operators to control and manage the customer premise network.

13) The F5G-A architecture supports the capability to manage the services end-to-end. This requires the F5G-A architecture to support Service Access Point (SAP), Service Processing Point (SPP), and Service Mapping Point (SMP) functionality in the CPN.

5.2.2 Architectural Overview

The F5G-Advanced network architecture decouples the F5G-A Service Plane from the F5G-A Underlay Plane. Figure 1 provides an overview of the three planes of the F5G-Advanced network architecture with some example service flows and underlay connections. The F5G-A Management, Control, and Analytics (F5G-A-MCA) plane shows an abstract view of the F5G-A MCA functionalities of the F5G-A network.

The purpose of separating the F5G-A Service from the F5G-A Underlay Plane is making the network more agile for changes, since service and network evolves independently. Through decoupling the services from the network, the service-oriented processing is allocated more freely in the network where the appropriate service functions are running optimally. Also, the capacity on the F5G-A Underlay Plane is enlarged without changing the service and scales elastically.

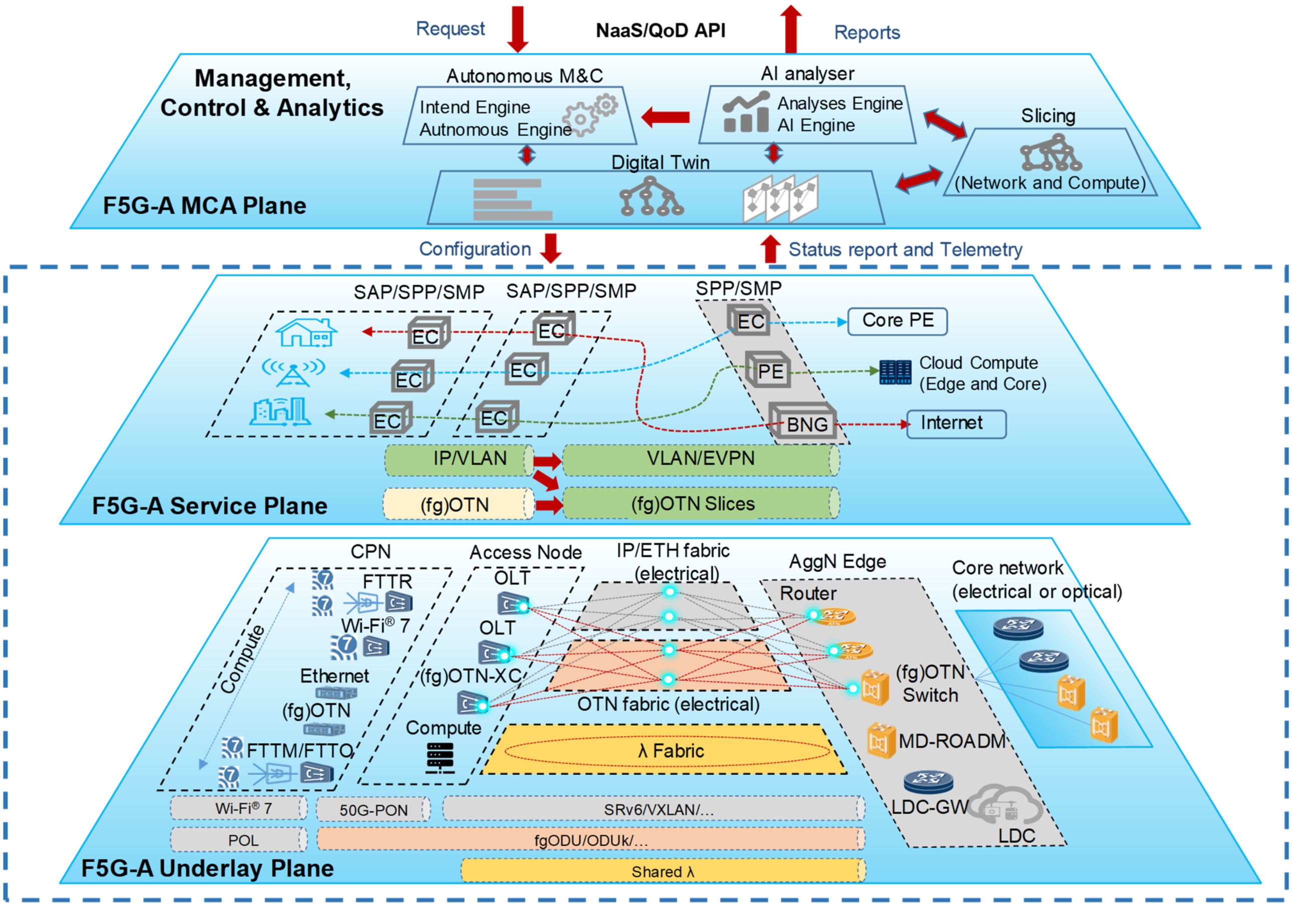


Figure 1: F5G-Advanced network architecture

The F5G-A network architecture consists of three planes, an F5G-A Underlay Plane, a F5G-A Service Plane and an F5G-A Management, Control & Analytics (F5G-A MCA) Plane. In addition, there is a cross-plane compute functionality specified in the network architecture supporting various functions on the different planes. Figure 1 does not show the cross-plane compute functionality but shows compute infrastructure in all segments of the F5G-A Underlay Plane, and the Edge Compute (EC) in the F5G-A Service Plane.

5.2.3 The F5G-A Underlay Plane

This is fundamentally the physical network plane, which includes all physical network and compute nodes and equipment. The F5G-A Underlay Plane provides connections and tunnels. The control and management of connections is under the control of the F5G-A controller in the F5G-A MCA Plane (non-real-time control) or in the equipment in the F5G-A Underlay Plane directly for real-time control functions. The network switching capacity shall scale without interfering with the F5G-A Service Plane.

The F5G-A Underlay Plane has four segments, Customer Premises Network (CPN), Access Network (AN), Aggregation Network (AggN) and Core Network. Various Technologies are used in the CPN, depending on the customer requirements. In residential Access, Wi-Fi® 7 and FTTR are used, while Enterprise Access benefits from Passive Optical LAN (POL)/Fibre to the Office (FTTO) for easy deployment and high bandwidth. The (fg)OTN technology may be deployed in the CPN for customers requiring high-quality on-premise services. This could be deployed for vertical applications (not shown in Figure 1). The primary technology used in the Access Network shall be 50G-PON and (fg)OTN, depending on customer type and service delivery requirements. Specifically, VPN services for Enterprise networking uses (fg)OTN in the case of firm guaranteed connections and hard isolated traffic requirements. The Aggregation Network has three parallel fabrics, an IP/Ethernet fabric, an OTN fabric, and λ fabric. The IP/Ethernet fabric is comprised of spine/leaf switches/routers, while the OTN fabric is comprised of (fg)OTN switching nodes. The λ fabric is purely optical switched wavelength. For the actual deployment of IP/Ethernet or OTN fabrics, they could run over a λ fabric. All fabrics have an Aggregation Network Edge node, which is the handover point to the Core Network. There are multiple connections between the Access Network Nodes and the Aggregation Network Edge, which go over one of the several fabrics.

NOTE: The present document is using the term FTTO, other organizations are also using Passive Optical LAN (POL) for very similar concepts.

Both the IP/Ethernet and OTN protocols run over an all-optical network (either over the λ fabric or point to point fibres). The statistical multiplexing capability of packet switching matches the traffic characteristics of data services to achieve high network utilization. The TDM switching technology features reliable transport, flexible add/drop multiplexing, powerful protection and restoration functions, and carrier-level maintenance and management capabilities. The TDM switching technology guarantees timing transparency, which is unavailable in packet switching. The two technical approaches collaborate during the evolution process and together form a reliable, flexible infrastructure for the F5G-A Underlay Plane network.

The F5G-Advanced λ fabric network provides the all-optical network feature by switching wavelengths from the core network to the access network nodes without optical to electrical to optical conversion. The wavelength from the aggregation network edge node to the access network nodes are dynamically selected for use. When they are free, they can be reused on other connections, maximizing efficient use.

The F5G-A Underlay Plane and the associated network nodes shall support end-to-end network connections and tunnels used for network slices in the F5G-A Service Plane. Therefore, all F5G-A technologies shall support the traffic isolation of different services and customers and guarantee the network performance. The F5G-A Underlay Plane is unaware of the SLA but only focuses on the physical connectivity. The different fabrics and technologies provide large-capacity switching without service processing. The path of the traffic is configured by the F5G-A MCA Plane.

Compute resources should be located in any of the network segments (deployment option). In the CPN, the compute resource is typically collocated with the networking functions (no explicit compute resource is shown in Figure 1). In the Access Node, compute might be integrated or separated from the networking functionality. In the Aggregation Network Edge (AggN Edge), is where the Local Data Centre Gateway (LDC-GW) is located (shown in Figure 1). The LDC-GW may be based on various networking technologies including IP/Ethernet or (fg)OTN. The Local Data Centre (LDC) in Figure 1 runs compute tasks in the Aggregation Network Edge for optimizing the QoE for certain services. Finally, well-known cloud computing may be located anywhere connected through the core network (not shown in Figure 1).

The F5G-A Underlay Plane provides comprehensive fault localization, isolation and troubleshooting functions, which provide the basis for routine network maintenance & management and network optimization in cooperation with the F5G-A MCA Plane. The simplified F5G-A Underlay Plane protocol stacks greatly improve network operation and management efficiency and provide real-time control of the F5G-A Underlay Plane equipment.

The F5G-A network shall provide differentiated connection capabilities. It shall provide both high-quality connections with committed bandwidth and latency and best-effort low-cost connections. For the F5G-A end-to-end network connection, a combination of IP/Ethernet, high-quality fine-grain OTN hard pipes, 50G-PON access, and FTTR is essential.

5.2.4 The F5G-A Service Plane

The F5G-A Service Plane provides service connectivity for customers and the (cloud)-application providers. Compared with the coarser grained connections of the F5G-A Underlay Plane, the service connections on the F5G-A Service Plane are dynamically created when triggered by protocols such as PPPoE, IP, VLANs, or the OCN protocol stack (see the Optical Cloud Network (OCN) Architecture [15]). F5G-A service connections are configured by the F5G-A MCA Plane. The F5G-A Service Plane contains all the functionality needed for networked services and applications to run smoothly.

A Service Access Point (SAP) provides service access to the customer. A Service Processing Point (SPP) performs L2-L7 service processing, which is enhanced by computing provided in the infrastructure. A Service Mapping Point (SMP) is where the service traffic is directed to appropriate underlay fabrics and channels and eventually the MCA Plane triggers changes of the Underlay Plane connections.

The SAP is the access point that identifies the user's application traffic and provides access to the operator's network services. Typically, the SAP is located on the ONU/P-ONU/CPE/(fg)OTN-CPE/HGW and the OLT/(fg)OTN-XC. Functionally, the SAP includes VLAN tagging for ingress and egress traffic, L2/L3 forwarding, QoS processing, and egress packet encapsulation. On the OLT, another SAP might be used to identify the application type and whether an application is online/offline. This provides the necessary information for the SPPs and SMPs.

The SPP is the point where service-specific processing of traffic is performed including application-specific compute. Service processing refers to L2-L7 traffic processing. The location of the SPP depends on the type of function and the compute capability required.

EXAMPLE 1: L2-L7 traffic processing includes VLAN encapsulation and conversion, PPPoE termination, L2 wholesale Gateway, virtual Firewall, egress encapsulation, service optimization.

The SMP is the point where service traffic is mapped into connections on the F5G-A Underlay Plane. Typical functions of SMP includes ingress service tunnel indication, QoS processing, service layer encapsulation, connection selection and mapping. The SMP may be located in any segment. To map the traffic to the correct connections on the F5G-A Underlay Plane, SMP shall have the connection information for these connections even though they are on the F5G-A Underlay Plane. This information is provided and configured by the controller in the F5G-A MCA plane. Also, in some scenarios, the SMP might be located in the CPE, specifically in the cases where OTN technology is used at the (fg)O-CPE, because it is there that the customer traffic needs to be mapped to the appropriate (fg)OTN connections.

Depending on the service, various encapsulations are used for the F5G-A Service Plane traffic. For example, the residential customer's traffic is indicated by S+C, C VLAN tags, are encapsulated by SPP on the OLT and decapsulated by SPP on the BNG. For services like private line and mobile backhaul, a single VLAN tag is used from the CPE, and it is additionally encapsulated by OLT SPP and de-encapsulated by the SPP on the PE of Aggregation Network Edge node. For premium private line services, the packet traffic is mapped to (fg)OTN connections, other traffic uses (fg)OTN service connections right away.

The Customer Premises Network may contain SAP, SPP, and SMP functionality, depending on the deployment option chosen by the operator and the associated network regulatory environment. An Access Network Node contains SAP, SPP and SMP. In addition to providing the access function, it also identifies services and applications, adds or removes encapsulations, and directs the traffic to the appropriate underlay fabric. An Aggregation Network Edge contains SPP and SMP, because it needs to perform service-specific processing and egress/ingress traffic mapping to appropriate underlay fabric connections.

A service connection refers to a service pipe or virtual network between the CPN or Access Network Node and the AggN Edge Node. The assumption is that the core network connectivity is not service aware, but is about the heavy lifting of high capacity F5G-A Underlay Plane connections.

EXAMPLE 2: The SPP in the AggN Edge Node is typically a router with BNG functionality, a wholesale Gateway, a VPN PE or a VNF for value-added services. Internet service pipes between an ONU/P-ONU and a BNG are typical service connections.

The F5G-A Service Plane also provides service connections between SPPs.

EXAMPLE 3: There may be a service chain between a vCPE instance and a Firewall instance or a VPN from the OLT to the AggN Edge node. For IP-based services, the SPP in the Access Network may perform subscriber or user authentication, while BNG mainly terminates PPPoE and EVPN services.

When the service connection requires guaranteed network performance, very low deterministic latency and clock synchronization, an (fg)OTN connection shall be used. The SPP determines the (fg)OTN connection to be used depending on the identified application and performance needs, and the OCN connection protocol [15] sets up the appropriate service connections. In addition, the (fg)OTN connection supports isolation of the traffic of different services and customers and allows for fine granular service connections that dynamically adapt without interruption of the established service. Those service connections can be routed to different cloud services providing mission critical applications with the required networking support.

The F5G-A Service Plane is decoupled from the F5G-A Underlay Plane. The F5G-A Underlay Plane is unaware of changes in the F5G-A Service Plane, e.g. adding, deleting and directing service traffic to SAPs and SPPs. The SAP and SPP shall be able to scale independently. The F5G-A Service Plane supports multiple services with different SLAs. The deployment requirements for services on the F5G-A Service Plane include connecting endpoints with guaranteed SLAs. The F5G-A Service Plane shall negotiate resource requirements with the F5G-A Underlay Plane, which is coordinated by the F5G-A MCA Plane. It is unnecessary for the F5G-A Service Plane to be aware of the creation of paths through network nodes.

The F5G-A Service Plane control is performed non-real-time with controllers in the F5G-A MCA Plane or through real-time control processes located near the service components.

The F5G-A Service Plane contains Edge Compute (EC shown in Figure 1) capability, which is used for network control and management functions. The compute functionality supports a combined network and compute service to the users. In the case that compute functionally is needed in the AggN Edge Node, the compute is either part of the network equipment or connected to the AggN Edge node as local data centre (LDC in Figure 1).

5.2.5 The F5G-A Management, Control & Analytics (F5G-A MCA) Plane

The F5G-A MCA Plane is the intelligent core of the F5G-A network, which performs the management, control and analytics of the complete F5G-A network. It is comprised of four logical components. However, the logical components may be implemented as distributed, centralized or hybrid mode. The distributed functional allocation in the network topology is for further study. The four logical components are:

Digital Twin: The digital twin models the network, including available resources and configurations. The digital twin also contains an equivalent network model that is continuously updated in real-time. A network digital twin is updated through the real-time collection of network status and in combination with the network resources and configurations produces the network model. Network statistics are continuously computed. Naturally there is a trade-off between the accuracy of the digital twin information and the number of network updates required. A digital twin is the real-time status and configuration of the network, which is the input for autonomous operation and artificial intelligence-based analysis. In order to receive timely information, two types of interfaces are defined per network domain, a telemetry interface and a configuration interface. The telemetry interface is used to send telemetry data from the F5G-A Underlay or F5G-A Service Plane to a collector function in the F5G-A MCA Plane. The configuration interface is used to configure telemetry tasks in F5G-A Underlay or F5G-A Service Plane or both.

Autonomous Management and Control: This is the main function for network configuration, service deployment, and network operation. In addition to the controllers for F5G-A Service Plane and F5G-A Underlay Plane, it also contains the Intent Engine and the Autonomous Engine:

- **Intent Engine:** provides an Intent API for the Operations Support System (OSS). The Intent API is an interface similar to natural language, describing "what is wanted". It is abstracted and decoupled from specific network configurations. The Intent Engine translates and understands the intent from the interface and drives the corresponding operation, validation and feedback.

- **Autonomous Engine:** implements operations such as resource management, device management, service deployment and connection selections on the F5G-A Underlay Plane. In addition, it implements resource management, equipment management and service deployment on the F5G-A Service Plane. One important function of the Autonomous Engine is the coordinated configuration of the planes, which enables plug and play of network nodes, and programmability of both underlay connections and services.

AI analyser: analyses network data, identifies, locates and predicts network failures, provides management tools for QoE and analysis tools for network operations. It includes the Analysis Engine and the AI Engine:

- **Analysis Engine:** a data management platform and algorithms for analytics. Analysing the network digital twin enables the optimal connection selection on the F5G-A Underlay Plane, identifies and analyses network failures, and drives close loop control of the Autonomous Engine.

- **AI Engine:** it performs reasoning and training using Artificial Intelligence. The Analysing Engine leverages the AI Engine for analytics and reasoning, in order to perform prediction of network failure and usage, and failure identification and analysis.

Slicing: Slice management and control is an important feature of an F5G-Advanced Network providing the capability to isolating traffic, having different virtual service networks or having customer specific virtual networks. The management of the slices needs to setup the slices based on the requirements received from business support system(s). It may choose to setup network and compute combined slices allowing for the installation of service specific compute at the appropriate locations as required.

The NaaS/QoD API of the F5G-A MCA provides the capability to request a Network as a Service and configure Quality on Demand (QoD) from the Business Support Systems (BSS). That interface calls the various functions in the F5G-A MCA plane.

The F5G-A network has domain controllers for each of the network segments. The domain controllers perform the network abstraction function to provide a concise view of the network segment resources, without too many detailed technology-specific information. This aids the E2E Orchestrator to orchestrate different network domains with different technologies and different types of network elements. To enable the network and service programming, a set of common standard APIs are required on the northbound interfaces of the domain controllers, which are designed as model-driven interfaces. The key parameters and protocols for the management and control of the F5G-A network segments are for further study.

5.2.6 Cross-Plane Computing

A feature added in the F5G Advanced architecture is the improved, prominent and integrated usage of compute at various locations in the F5G-A network architecture. The location of the compute function is an operational and deployment choice dependent on the optimization of the F5G-A network architecture. Figure 2 shows the migration from F5G to F5G Advanced adding the cross-plane computing feature.

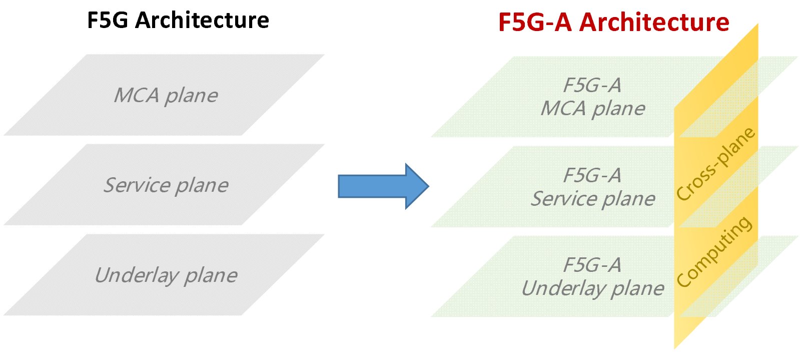


Figure 2: Addition of Cross-plane Computing

The motivation for the addition of compute to the F5G-A network architecture is manifold. Firstly, the addition of compute resources at various locations enables more free choices where the compute tasks are allocated in the distributed computing platform. The allocation takes various dimensions for optimization into account like how real-time or non-real-time the compute task needs to perform. Secondly, compute in general enables the easy addition of new application-oriented services, such as voice and image recognition and Network Attached Storage (NAS). Thirdly, network-oriented connection services are optimized and improved including dynamic provisioning for Network as a Service (NaaS) or Quality on Demand (QoD) scenarios. Finally, improved operational excellence optimizing the network for higher quality of experience through telemetry and predictive operation and management.

In general, there is the need for coordination between different compute functions horizontally and vertically. Horizontal coordination shall coordinate different compute functions and resources in the different segments of the F5G-A network achieving end-to-end quality of experience. Vertical coordination aspect is the cross-plane coordination. Network data about network or service status and performance is gathered in the F5G-A Underlay Plane and the F5G-A Service Plane. The network and service data are then processed by the computing function in the F5G-A Underlay and Service Plane for real-time control or pre-processed to be communicated to the F5G-A MCA plane for detailed analytics.

EXAMPLE 1: Raw network data is gathered and then aggregated in the F5G-A Underlay plane, the aggregated monitoring data is sent to the MCA-A plane for detailed analytics and statistics. The same gathered network data is used to make adaptation decisions in real-time in the F5G-A Underlay Plane. Similarly, service quality data are collected and pre-processed in F5G-A Service Plane and are collected by F5G-A MCA Plane, the data is then analysed and actions are derived to either fix the service problems or optimize service performances.

On the F5G-A Underlay Plane, compute resources are located in any of the network nodes or are co-located with the network nodes. The cloud Local Data Center (LDC) in Figure 1 is connected to the AggN Edge nodes with short reach network links. The LDC is the medium data centre level compute resource, and is used by a multitude of services. On the access network nodes, compute is used as an optimization function of the services. It is co-located with or integrated in the OLT. Compute is used in cloud Central Data Centres (CDC) (not shown in Figure 1 for simplicity), for large scale computing needs of a service, but is typically located rather far away from the customer. The compute could also be located in the Customer Premises Network (CPN) (Figure 1 only sketches it as compute being part of the CPN). Example functionalities, which need compute, include Wi-Fi® coordination and optimization, or the measurement and collection of optical characteristics. In addition, on the CPN, user- or application-oriented tasks are more prominent improving the quality of experience or providing new services to customers.

On the F5G-A Service Plane, the SPPs in Figure 1 are the service level processing entities used depending on the service needs. The SPPs are located anywhere in the F5G-A network architecture. In addition, Cloud Computing functions in the Edge or the Core, shown in Figure 1, run on the LDCs or CDCs to provide service specific compute functions.

On the F5G-A Management, Control & Analytics (F5G-A MCA) Plane, most F5G-A MCA Plane function require compute and storage functionality. For example, the AI analyser is a compute intense function providing analyses of the network status data stored in the digital twin function. Autonomous Management and Control runs the various management and control functions of the compute infrastructure and software. The slicing function combines networking and compute resources, and therefore shall allocate and manage compute resources and services for a particular combinational slice. Example functionality for the use of compute in the F5G-A-MCA plane include supporting Wavelength Division Multiplexing (WDM) digital twin, and perform network equipment modelling.

In general, the compute tasks need access to some network related information like telemetry data, traffic data for deep analysis, and the capability to steer certain traffic to the computing units for detailed processing. The compute units shall be capable of running AI algorithms, and therefore require enough memory and typically an AI-optimized processing unit. The AI algorithms might have different uses depending on the location.

EXAMPLE 2: In the CPN, AI is more used for user-oriented tasks like voice and image recognition. In the Access Network, AI-oriented operational tasks are foreseen such as fault diagnosis and service optimizations in the access network infrastructure.

5.3 F5G-A topology and interfaces

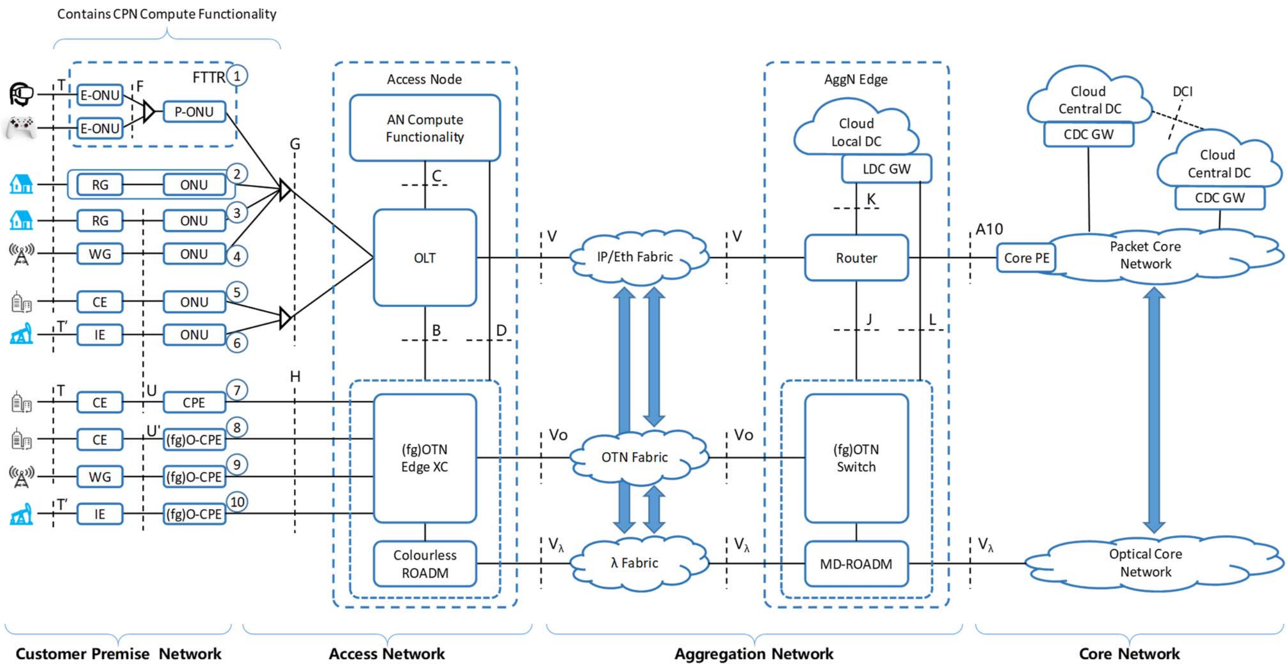
5.3.1 Network Overview

5.3.1.1 General Topology Overview

The F5G Advanced network architecture is an evolution of the F5G architecture Release 2 as described in ETSI GS F5G 014 [1]. The enhancements to the F5G architecture are listed in clause 5.2.1. The F5G Advanced network architecture adds several network components to the F5G-A network architecture both in the network topology as well as in terms of additional interfaces.

Figure 3 shows the F5G-A network topology segmented into the Customer Premises Network, the Access Network, the Aggregation Network and the Core Network. In the following the various network segments are described in sequence. See clause 5.3.2 for the description of the interfaces shown in Figure 3.

In general, Figure 3 shows the data plane perspective of the F5G-A network architecture for the underlay as well as the service plane. In the Aggregation Networks there are different deployment option based on which fabric is used to carry traffic, a combination of these fabrics is also possible. For a control and management-oriented perspectives see clause 5.3.3.



NOTE: The terms colourless ROADM and MD-ROADM are used here as defined in Recommendation ITU-T G.672 [i.11]. In general, a colourless ROADM is part of the Access Node, however, a coloured ROADM might be used, which is for further study.

Figure 3: F5G Advanced Network Topology

In the Customer Premises Network different scenarios and deployment options are possible and are shown in Figure 3. The following describes the network deployment options as numbered in Figure 3:

1) FTTR is comprised of a P-ONU, passive splitter(s) and several E-ONUs (depending on the size of the Customer Premises Network). The link between P-ONU and the E-ONUs is through a P2MP passive optical network.

2) Integrated home network deployment comprising an adaptation function labelled RG (Residential Gateway) and an Access Network node labelled ONU.

3) Disaggregated home network deployment comprising an adaptation function labelled RG (Residential Gateway) and an Access Network node labelled ONU. The difference between item 2 and item 3 is that the adaptation function is external to the ONU.

4) Cellular Backhaul network deployment comprising an adaptation function labelled Wireless Gateway (WG) and Access Network node labelled ONU. This illustrates the scenario of using the access network for mobile backhauling of mobile network traffic.

5) Enterprise business (small, medium, and large) network deployment comprising an adaptation function labelled Customer Equipment (CE), and Access Network node labelled ONU. See clause 5.3.1.2 for more details on the Enterprise CPN.

6) Industrial network deployment comprising an adaptation function labelled Industrial Equipment (IE), and an Access Network node labelled ONU. See clause 5.3.1.3 for more details on the industrial CPN.

7) Ethernet Premium Private Line network deployment differs from item 2 to item 6, and it comprises an adaptation function labelled Customer Equipment (CE) and an Access Network node labelled Customer Premise Equipment (CPE) such that Ethernet technology is used.

8) Fine-granular Premium Private Line network deployment differs from item 2 to item 6, and it comprises an adaptation function labelled Customer Equipment (CE) and an Access Network node labelled (fg)OTN-Customer Premise Equipment (fg)O-CPE) such that (fg)OTN technology is used and traffic is separated and isolated on the (fg)O-CPE. Whether fgOTN or OTN is used is a deployment choice depending on the required capacity and capability. See clause 5.3.1.2 for more details on extensions for the Enterprise CPN.

9) Mobile Infrastructure Access network deployment differs from item 4 and it comprises of adaptation functions labelled Wireless Gateway (WG) and an Access Network node labelled (fg)O-CPE. Whether fgOTN or OTN is used is a deployment choice depending on the required capacity and capability.

10) Vertical industries network deployment differs from item 6, and it comprises of adaptation functions labelled Industrial Equipment (IE) and an Access Network node labelled (fg)O-CPE. Whether fgOTN or OTN is used is a deployment choice. See clause 5.3.1.3 for more details on the Industrial CPN.

For the Customer Premises Network (CPN), the U or U' interfaces are between the Access Network termination and the customer premises equipment. The T and T' interfaces show different network interfaces where different types of devices (end-user devices, enterprise devices, industrial devices) are connecting to the CPN. In the case of premium private line (coarse or fine grained) and vertical and mobile access, an (fg)O-CPE represents the device that communicates with the (fg)OTN (implies with or without fine grain functionality) edge cross-connect ((fg)OTN Edge XC) on the network side.

For the Access Network, Figure 3 shows the F5G-A network topology with Point-to-Multi-Point (P2MP) and Point-to-Point (P2P), Optical Distribution Network (ODN) between the Access Network termination on the customer premise and Access Node (OLT, (fg)OTN Edge XC, ROADM and AN compute) in the central offices. The OLT, (fg)OTN Edge XC and the AN compute functionality may be separated or integrated, shown as dashed node in Figure 3. The AN compute functionality on the access network node is shown as a single node, but consists of several compute servers or compute OLT cards connected to the backplane of the OLT (if integrated). The F5G-A network architecture does not make any assumption about the software stack on the AN compute functionality. The (fg)OTN Edge XC again is either a separated or integrated function and is providing the access to the OTN fabric using the (fg)OTN technology for connecting the OLT to the Aggregation Networks. The (fg)OTN Edge XC is used similarly for P2P enterprise access networks, providing the benefits of (fg)OTN technology to enterprises or vertical industries. The ROADM technology, again separated or integrated into the Access Node, is use to connect the OLT and or the (fg)OTN XC with the λ fabric. The interfaces to the ROADM are for further study. The interfaces B, C and D are regarded internal or external depending on the deployment choice. The OLT communicates directly with an IP/Ethernet Aggregation Network (V interface) or uses the (fg)OTN Edge XC for premium services. The (fg)OTN Edge XC communicates with the OTN fabric using the Vo interface. The OLT or the (fg)OTN Edge XC uses the ROADM to connect purely optical over the λ fabric through the V_λ interface.

For the Aggregation Network, Figure 3 shows three networking technologies, including an IP/Ethernet fabric, an OTN fabric, and a λ fabric:

1) The IP/Ethernet fabric is the traditional deployment option for best effort residential Internet services.

2) The OTN fabric is a deployment option for premium services for residential, enterprises or vertical industries.

3) The λ fabric facilitates a green all-optical network from the Access Network to the Core Network without any optical-electrical-optical conversion, it is purely λ switching.

The IP/Ethernet and the OTN fabric is partially or fully carried over a λ fabric (blue arrow in Figure 3). Depending on the Aggregation Network technology selected, different deployment options for the AggN Edge are possible including routers, (fg)OTN switches, and Wavelength Selective Switches (WSS). The dashed line enclosure in Figure 3 shows that those functionalities may be separated or integrated. The IP/Ethernet fabric is connected to the AggN Edge through the V interface. The OTN fabric is connected to the AggN Edge through the Vo interface. The λ fabric is connected to the AggN Edge through the V_λ interface. For compute-oriented workloads the AggN Edge has a Local Datacentre Gateway (LDC GW) with local datacentres running cloud-oriented software stacks. The AggN Edge is connected to the LDC GW through the H interface.

NOTE 1: Traditional broadband networks (F4G and earlier generations) use BNG functionality, which is a service function and is part of the F5G-A service plane. The BNG functionality may runs on the OLT or on the router function in the AggN Edge. A subscriber-oriented service is transported over a high-quality fgOTN path with the required bandwidth and network performance.

Even though the Core Network is not the primary scope of the present document, the interfaces between the AggN Edge node and the Core Network are specified in the present document. The A10 interface is the traditional interface to packet core network via the Core PE. Figure 3 shows a central data centre for the central compute resources and functionality. Cloud CDC are connected to the packet core network via the CDC-GW. In the case of several central data centres, they might be interconnected by data centre interconnection technology via the DCI interface.

In addition, the AggN Edge node is connected to the Core Network using an all-optical V_λ interface. It is assumed that the OTN traffic is carried over the all-optical core network. Depending on the deployment choice, the packet Core Networks may run over the optical Core Network (blue arrow in Figure 3).

The details of the interfaces in Figure 3 are described in clause 5.3.2. The interface naming is the same as for the F5G architecture Release 2 [1], where applicable. However, the protocol stacks have changed to more recent versions of the baseline standards. There are several new interfaces being specified, due to the evolution of the functionality of the F5G Advanced network architecture. The meaning of interfaces, as specified in Figure 3, are used in the most generic way and does not prescribe a particular type of an interface. The interfaces are usually connections between different equipment. The interfaces are located on the different plane and across planes, so a particular interface type is specific to a particular interface. Many of the interfaces are reflecting a subset of the functionality, which is specified or is associated with a particular plane. The interfaces are divided into data- and control-oriented interfaces. The management-oriented interfaces are for further study. In addition, Application Programming Interfaces (API) are shown at some locations in the overall architecture. The details for APIs are for further study.

NOTE 2: The term interfaces have a variety of meaning in the industry refer to the definition of interfaces and equipment in clause 3.1.

5.3.1.2 Enterprise CPN: Fibre To The Office (FTTO) Scenario

For the Enterprise CPN, usually on a campus/office network, there are different deployment options. Traditionally, an Ethernet-based CPN using copper cables (CAT5/6) and an IP router/Ethernet Switch as a network facing CE is used. In the following, the Fibre To The Office (FTTO) scenario is described, where fibre-based Ethernet is possible, but not shown in Figure 4. The FTTO scenario may also use option 7) from Figure 3, which is not shown below.

Depending on the size of the enterprise and the capacity and functionality required for the network, either of the F5G-A access technologies PON or (fg)OTN or Ethernet (not shown in Figure 4) may be used. Figure 4 shows more detailed deployment options with regards to the Enterprise CPN for FTTO. The following sub-options are extensions to the ones shown in Figure 3, where the FTTO equipment is simplified as Customer Equipment (CE).

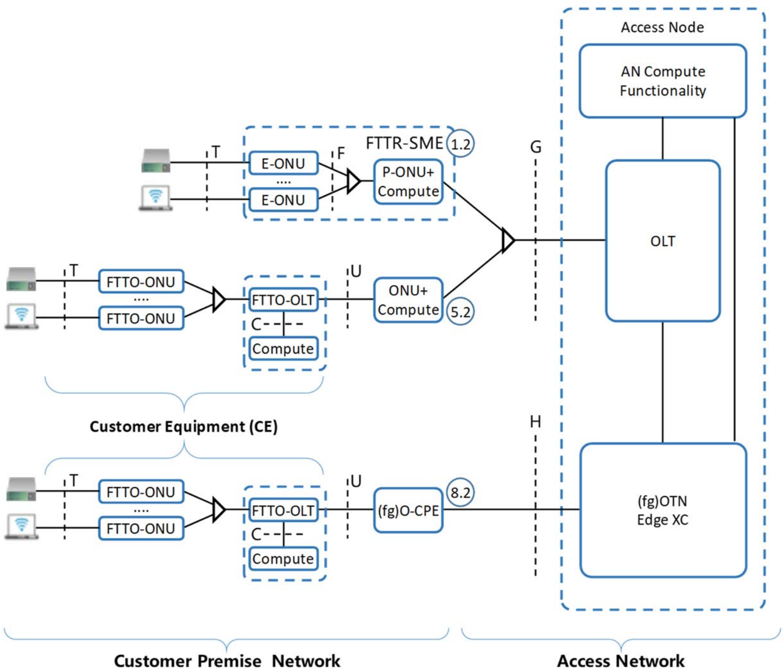


Figure 4: Enterprise CPN Scenario

Enterprise CPN deployment options are as follows:

- Option 1.2 FTTR-SME: The fibre to the room technology is applied to the SME networks, and therefore is similar to option 1) in Figure 3. Note that the P-ONUs might contain CPN compute functionality.
- Option 5.2 FTTO with PON access network: Fibre to the office shows the use of an FTTO-OLT connected to an ONU using PON technology for the access network. The FTTO-OLT has several FTTO-ONUs connected through a P2MP ODN. This option is similar to option 5) in Figure 3. The ONU as well as the FTTO-OLT might contain CPN compute functionality.
- Option 8.2 FTTO with an (fg)OTN access network: The option is the same as option 5.2 in terms of the Enterprise CPN deployment, but the FTTO-OLT is connected to a (fg)O-CPE using (fg)OTN technologies to access. This option is an extension to option 8) in Figure 3. The FTTO-OLT might contain CPN compute functionality.

Compared to Figure 3 the U interface between the FTTO-OLT and the (fg)O-CPE is assumed, since some legacy interfaces as specified in the U' interface (PBX connections, legacy SDH equipment) will not be supported in FTTO.

5.3.1.3 Industrial CPN: Fibre To The Machine (FTTM) Scenario

For the Industrial CPN, usually on a manufacturing site/shop floor, there are different deployment options. Depending on the size of the industrial site and the capacity required either of the F5G-A access technologies (PON or (fg)OTN) may be used. Figure 5 shows more detailed deployment options with regards to the customer premises network. All of the options here are in addition to the ones shown in Figure 3 and Figure 4. In some aspects it is very similar to the Enterprise CPN. Specifically, since the use cases in the FTTM segment assume that an Enterprise CPN is part of the FTTM solution for office-oriented applications, which is similar to FTTO in Figure 4 being part of FTTM. The FTTM-ONUs have in addition to the T interface, an additional set of interfaces to industrial devices supporting for industrial protocols.

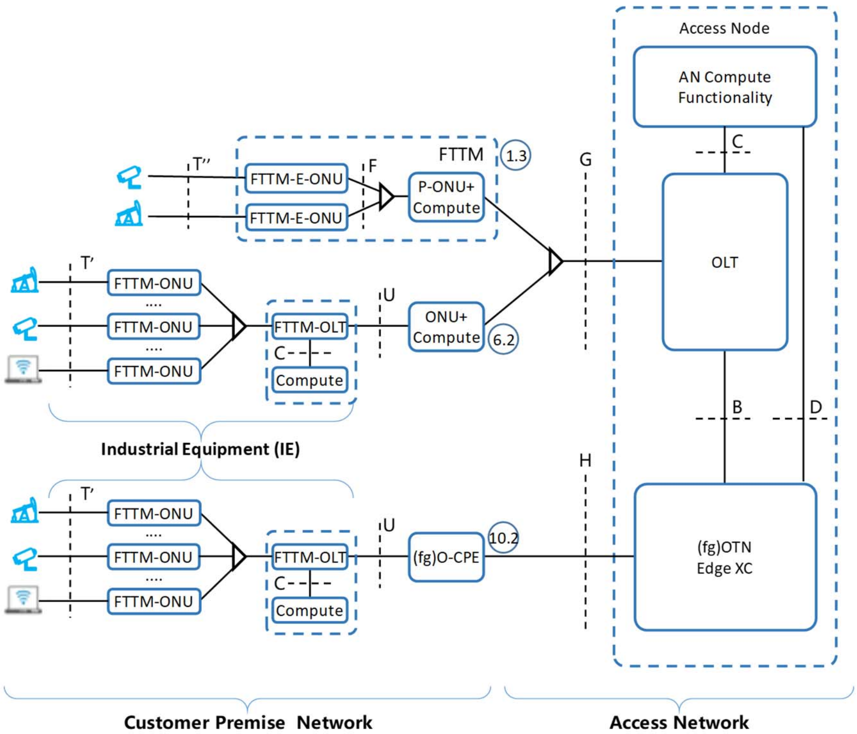


Figure 5: Industrial CPN Scenario

Industrial CPN deployment options are as follows:

- Option 1.3 FTTM: The fibre to the room technology is applied to the industrial networks, and therefore is very similar to option 1) in Figure 3. It is particularly relevant for small industrial sites. Besides industrial application also office and usual Enterprise applications need to work over the FTTM infrastructure. Note that the P-ONUs might contain CPN compute functionality. The FTTM-E-ONU is an industrial variant of an E-ONU (shown in Figure 3) providing industrial specific interfaces (T' interfaces).
- Option 6.2 FTTM with PON access network: Fibre to the machine shows the use of an FTTM-OLT connected to an ONU using PON technology for the access network. The FTTM-OLT has several FTTM-ONUs connected through a P2MP ODN. This option is very similar to option 6) in Figure 3. In some industrial scenario, the CPN compute functionality needs to be located nearer to the application end-point of robots or manufacturing machines due to the strict latency requirements. Note that the ONUs and the FTTM-OLT might contain compute functionality.
- Option 10.2 FTTM with an (fg)OTN access network: The option is similar as in option 6.2, but the FTTM-OLT is connected to a (fg)O-CPE using an (fg)OTN access network. This option is very similar to option 10) in Figure 3. In general, option 7) in Figure 3 is used to deploy a CPE connecting with Ethernet to the Access Node. In some industrial scenarios, compute functionality needs to be located nearer to the application end-point of robots or manufacturing machines due to the strict delay requirements.

Compared to Figure 3 the U interface between the FTTM-OLT and the (fg)O-CPE is assumed, since some legacy interfaces as specified in the U' interface (PBX connections, legacy SDH equipment) will not be supported in FTTM.

The details of FTTM is for further study.

There are F5G-A use cases described in ETSI GR F5G 020 [i.2], which assume a CPN using OTN technology for hard isolation and guaranteed services with time synchronization. This applied specifically for mission critical applications such as power grid or railway communication networks. This case is not shown in Figure 5 and is for further study.

5.3.2 Definition of Interfaces

5.3.2.1 T interface

The T interface is between the E-ONU/RG/WG/CE and the customer devices/network. This includes residential customers, business customers, and wireless backhaul. Because of the diversity of customers, besides Ethernet and Wi-Fi® 7, there might be other types of interfaces like Bluetooth® or DECT™. Such interfaces shall be translated to Ethernet/IP protocols before being transferred to the E-ONU/Gateways/CE devices.

5.3.2.3 T' interface

The T' interface is between the Industrial Equipment (IE) and industrial network devices. There are many types of industrial protocols and interfaces, like EtherCAT, serial interface, etc. They are supported by the IE device depending on the industrial deployment. Industrial interfaces may translate the industrial protocols to Ethernet/IP protocols on the IE devices.

NOTE: The translation may be performed at the connected industrial devices, in this case the connected industrial devices uses the T interface to the IE.

5.3.2.4 U interface

The U interface is between the RG/WG/CE/IE and the ONU/CPE/(fg)O-CPE. For a PON based network, the ONU is considered an extension of the Access Network, even though it physically resides in the CPN. Therefore, the U interface is the user-facing interface of an ONU. It could be an internal interface if the ONU and the RG are integrated on a single physical device as in item 2 in Figure 3. In case it is an external interface, it shall support Ethernet [17] as shown in Figure 6.

For the Enterprise and Industrial CPN scenarios (see clauses 5.3.1.2 and 5.3.1.3) the impact of the FTTO and FTTM networking to the U interface is for further study.

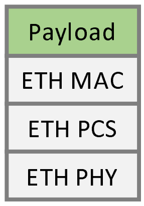


Figure 6: Protocol stack on the U interface

5.3.2.5 U' interface

The U' interface is between the CE/WG/IE and the (fg)O-CPE. For an OTN Access Network, the (fg)O-CPE is considered an extension of that OTN Access Network, even though it physically resides in the Enterprise, Wireless and Industrial CPN. Therefore, the U' interface is the user-facing interface of the (fg)O-CPE. The interface shall support Ethernet [17], but may support legacy PDH/SDH protocols. The protocol stacks on the U' interface is depicted in Figure 7.

For the Enterprise and Industrial CPN scenarios (see clauses 5.3.1.2 and 5.3.1.3) using FTTO and FTTM networking, the U' interface changes to a U interface without any legacy protocol support.

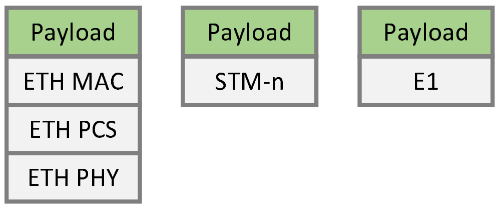


Figure 7: Protocol stacks on the U' interface

5.3.2.6 F Interface

The F interface is between the E-ONUs and a P-ONU. It uses a point-to-multi-point fibre on premises ODN in the CPN. The F interface shall implement Recommendation ITU-T G.9941 [5] and Recommendation ITU-T G.9942 [6]

5.3.2.7 G Interface

The G interface is between the (P-)ONUs and an OLT. It uses a point-to-multi-point fibre ODN in the access network. The G Interface shall support 50G-PON (Recommendation ITU-T G.9804.2 [10] and Recommendation ITU-T G.9804.3 [11].

5.3.2.8 H Interface

The H interface is between the CPE or (fg)O-CPE and the (fg)OTN Edge XC. It is a point-to-point fibre ODN in the access network. The H Interface shall be an OTUk (k=0, 1, 2, 3, 4) which supports the transport of OTN and fgOTN ([8] and [9]). In case of scenario 7) in Figure 3, a CPE using Ethernet [17] as access network technology is used.

5.3.2.9 B interface

The B interface is between the OLT and the OTN Edge cross-connect (OTN Edge XC) in the Access Network node. This is either an Ethernet interface [17] or an OTUk (k=0, 1, 2, 3, 4), which supports the transport of OTN and fgOTN ([8] and [9]).

The B interface is only visible in the case that the OLT and the OTN Edge XC are separate physical network equipment. Otherwise, it is an internal interface and does not necessitate a description.

5.3.2.10 C interface

The C interface is between the OLT and the AN compute functionality in the Access Network node. This is an Ethernet interface [17], which may require an Ethernet switch to allow connectivity to several compute servers (when deployed external to the OLT). The protocol stacks on the C interface are depicted in Figure 8.

Payload
ETH MAC
ETH PCS
ETH PHY

Figure 8: Protocol stacks on C interface

The C interface is only present in the case that the OLT and AN compute functionality are separate physical network equipment. Otherwise, it is an internal interface and does not necessitate a description.

5.3.2.11 D interface

The D interface is between the OTN Edge cross-connect (OTN Edge XC) node and the AN compute functionality in the Access Network node. The details of the protocol stack are for further study.

The D interface is only present in the case that the AN compute functionality and the OTN Edge XC are separate physical network equipment. Otherwise, it is an internal interface and does not necessitate a description.

5.3.2.12 V interface

The V interface is the IP/Ethernet-based handover point between the OLT and the IP/Ethernet fabric and between the IP/Ethernet fabric and the router in the AggN Edge. Compared with a legacy IP/Ethernet Fabric, SRv6 and VxLAN are the primary technologies for the Underlay Plane of IP/Ethernet Fabric. At the same time, EVPN is used for the Service Plane. The protocol stacks on the V interface are depicted in Figure 9.

Payload	Payload
EVPN	EVPN
VxLAN	SRv6
ETH MAC	ETH MAC
ETH PHY	ETH PHY

Figure 9: Protocol stacks on V interface

5.3.2.13 V_o interface

The V_o interface is the (fg)OTN based handover point between (fg)OTN Access Network node and the OTN fabric and the OTN fabric and the OTN XC in the AggN Edge node. The interface rate depends on the OTN bandwidth requirement. The interfaces are either OTUk (k = 0,1,2, 3, 4) for bandwidth requirements between 1,25 G up to 100 G or OTUCn/FlexO for bandwidth greater than 100 G. These are the primary technologies for the OTN Fabric Underlay Plane, while VLAN or (fg)ODU is used for the Service Plane.

Payload	Payload	
ODUj	fgODU	Payload
ODUk (k=0,1,2)	ODUk (k=0,1,2, flex)	ODUk/ ODUCn
OTUk/OTUCn FlexO	OTUk/OTUCn FlexO	OTUk/OTUCn FlexO

Figure 10: Protocol stacks on V_o interface

5.3.2.14 V_{λ} interface

The V_{λ} interface as shown in Figure 3 is:

- between the ROADM component in the Access Node and the λ fabric.
- between the λ fabric and the AggN Edge WSS component.
- between the AggN Edge WSS component and the optical core network.

The interface shall support OCh/OTSiA over OMS/OTS as defined in Recommendation ITU-T G.959.1 [16].

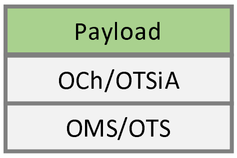


Figure 11: Protocol stacks on V_{λ} interface (based on Recommendation ITU-T G.959.1 [16]

5.3.2.15 A10 interface

The A10 interface is between the AggN Edge node and the packet Core Network. Depending on the capability of the Core Provider Edge (Core PE), the handover protocol may be selected from EVPN, VxLAN, SRv6, or MPLS. The protocol stacks on the A10 interface are depicted in Figure 12. The AggN Edge node may be required to implement protocol interworking between the Aggregation Network and the Core Network. The PHY for A10 interface is an Ethernet PHY [17].

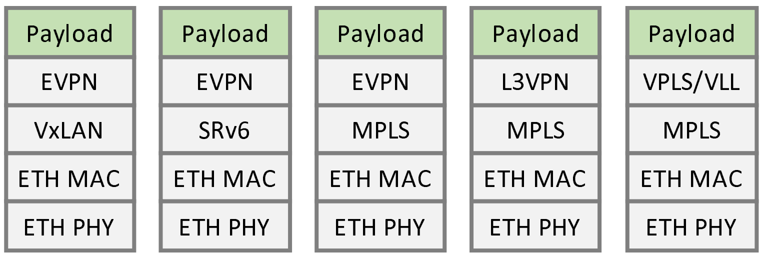


Figure 12: Protocol stacks on A10 interface

5.3.2.16 K interface

The K interface is between the Router and the Cloud Local DC gateway (LDC GW) in the AggN Edge node. The link shall be short reach point-to-point Ethernet [17] link. Protocol stacks on K interface are depicted in Figure 13.

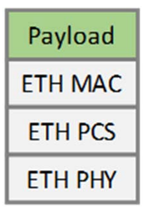


Figure 13: Protocol stacks on K interface

5.3.2.17 L interface

The L interface is between the (fg)OTN switch and the compute functionality of the Cloud Local DC with the LDC-GW in the AggN Edge node. The details of the protocol stack are for further study.

The L interface is only present in the case that the (fg)OTN switch and the Cloud Local DC/ LDC-GW are separate physical network equipment. Otherwise, it is an internal interface and does not necessitate a description.

5.3.2.18 J interface

The J interface is between the (fg)OTN switch and the router in the AggN Edge node. This is either an Ethernet interface [17] or an OTUk (k=0, 1, 2, 3, 4), which supports the transport of OTN and fgOTN ([8] and [9]).

The J interface is only present in the case that the (fg)OTN switch and the router are separate physical network equipment. Otherwise, it is an internal interface and does not necessitate a description.

5.3.2.19 DCI interface

The DCI interface is a logical interface between two Cloud Central Data Centres, and is either connected via point-to-point optical Ethernet [17] technology up to 80 km. Alternatively, the DCI uses the packet or optical core network for connecting the data centres.

5.3.3 Near real-time Control Topology

The near real-time control topology of the F5G-A network architecture is shown in Figure 14.

NOTE: There is not a clear difference separation between the control and management functionality. In general control functionality need fast reaction time, called "near real-time" and is therefore often implemented on the network elements themselves, whereas management functionality, called non-real-time is implemented in management systems, which communicate with network elements.

Figure 14 is a simplified version of Figure 3 in order to focus on the control aspects only. Some of the near real-time control components have an effect on the data transmission, whereas others have a more service-oriented aspects being covered.

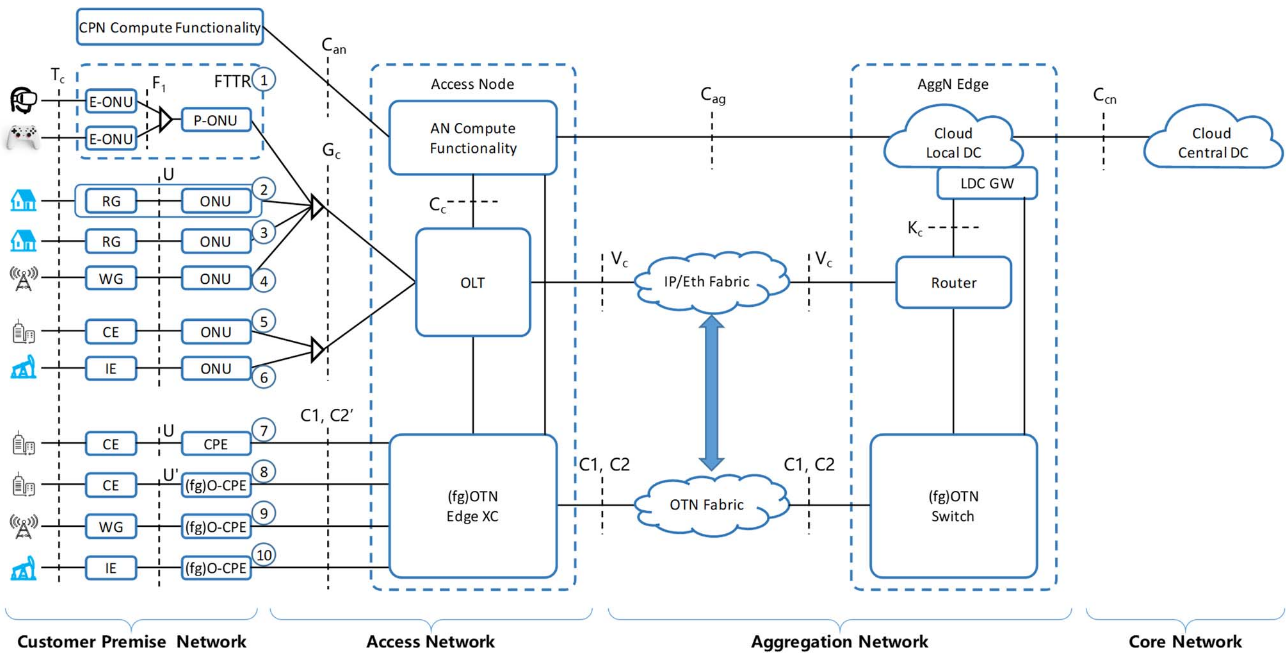


Figure 14: Control Topology

The non-real-time control is traditionally called network management. The management functional framework is not shown in Figure 14 and is out of scope of the present document.

5.3.4 Near real-time Control Interfaces

5.3.4.1 The F1 FTTR control interfaces

To guarantee customer experience, the FTTR network should ensure a close collaboration with the Wi-Fi® network. Thus, dynamic coordination between the different E-ONUs should be achieved over the F1 interface. This requires an architecture that reflects fibre and wireless (Wi-Fi®) integration within FTTR (shown in Figure 15), forming a single cascaded multiple link LAN through centralized control (Recommendation ITU-T G.9940 [4]).

The centralized control procedure is shown in Figure 15. The P-ONU collects the Wi-Fi® status information. from the E-ONU Wi-Fi® entities. Such status information is sent from the E-ONUs to the P-ONU through the F1 interface. In addition, the controller in the P-ONU sent the actions and control strategy to be performed by the Wi-Fi® module of the E-ONUs. The F1 interface shall support the G.fin Fibre Management and Control Interface (FMCI) [i.5] and Wireless Management and Control Interface (WMCI) [i.3]. The two control interfaces may run in separate and isolated channels.

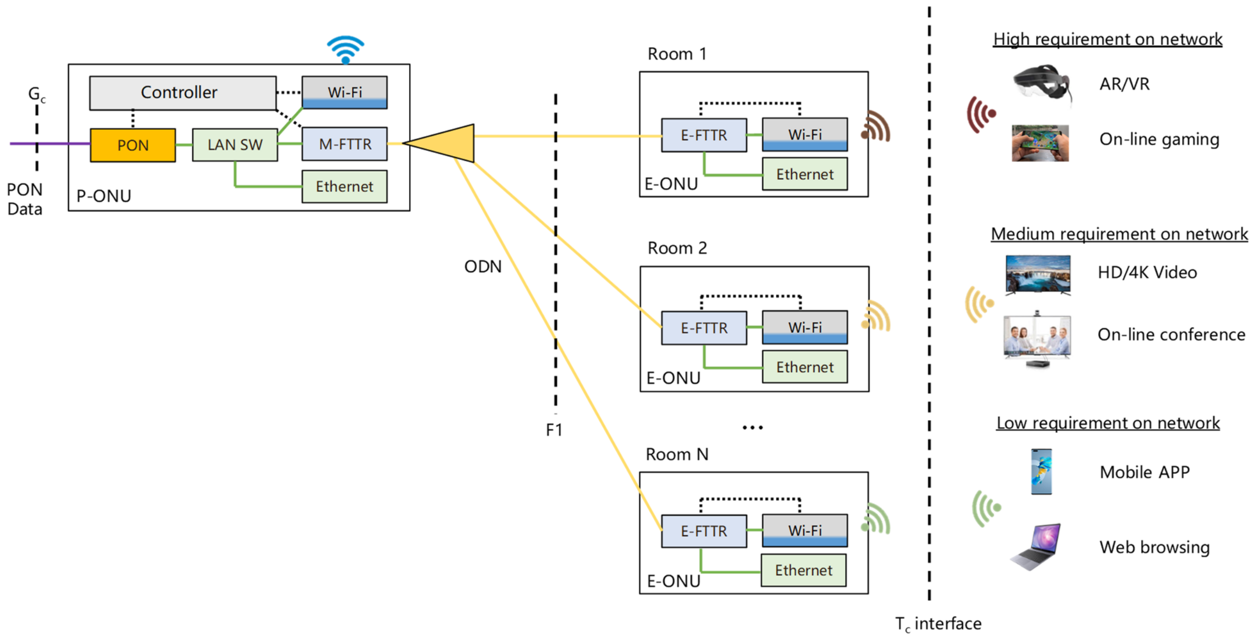


Figure 15: Centralized Wi-Fi® access network architecture through centralized control in FTTR

The FTTR control functions focus on the coordination of the Wi-Fi® and the fibre-based FTTR connection network, which does not change the characteristics of the T interface in Figure 3 (such as physical layer properties, MAC framing, etc.). Specifically, the Wi-Fi® specification in the air interface is defined by the IEEE 802.11 [18] Other technology like Ethernet may also be dynamically managed, but this is for further study.

The control of FTTR from an Access Node's OLT functionality over the G_c interface is for further study.

5.3.4.2 G_c Control Interface

The G_c control interface is the interface between an OLT and the ONUs/P-ONUs. The interface shall implement the OMCI [7] protocol with the appropriate data models depending on the PON technology and ONU/P-ONU functionality deployed. Specifically, in the case of coordinated Wi-Fi®, controlled from the OLT, the G_c control interface might contains FTTR and Wi-Fi® related control information. This extended control functionality is for further study.

5.3.4.3 T_c Control Interface

The T_c control interface is the control from the end-devices (enterprise network equipment, industrial network equipment or residential end-user device) to the network. The interface shall implement a secure and simple plug and play network attachment procedure. In addition, it shall support service-oriented functionality.

5.3.4.4 C_c Control Interface

The C_c is the control interface between an OLT and the compute functionality located in or next to the OLT in the Access node. It shall support network and compute coordination functions. The architecture of computing collaboration in PON is for further study.

5.3.4.5 V_c Control Interface

The V_c is the control interface between an OLT and an IP/Ethernet Fabric. It shall support EVPN [14] and SRv6 control protocols. EVPN [14] uses MP-BGP [2] to carry IP/Ethernet routing control plane messages. It learns the local MAC/IP addresses and routes from the access side, learns the remote MAC addresses and routes from the core network and automatically discovers VPNs. Therefore, Layer 2 and Layer 3 packet forwarding entries are generated to guide packet transmission on the data plane. EVPN provides a wide range of services, such as L2VPN (E-LAN, E-Line and E-Tree) and L3VPN, meeting the requirements for availability, scalability, bandwidth utilization and simplified O&M.

5.3.4.6 K_c Control Interface

The K_c control interface is the control interface between the router function and the cloud local datacentre compute functionality in the AggN Edge node. The interface shall support the coordination between compute and the F5G-A network. The interface is for further study.

NOTE: The similarity or difference between Kc and the Cc interface is for further study.

5.3.4.7 C1 and C2/C2' (fg)OTN Control Interfaces

In F5G Advanced networks, the (fg)OTN network is used to carry high-quality services. To enable the automatic (fg)OTN connection creation for these services, the (fg)OTN control architecture shall be enhanced. The (fg)OTN control plane is separated from the data plane, and the interfaces in the (fg)OTN control plane are shown in the modified F5G Advanced network topology in Figure 16. Unlike the centralized MCA plane, the (fg)OTN control is a signalling procedure between (fg)OTN nodes.

The (fg)OTN control interfaces transmit the provisioning protocols for the (fg)OTN-based services. There are two (fg)OTN control interface types:

1) The C1 control interface is used to control the (fg)OTN network connections.

2) The C2 and C2' control interfaces are used to control the (fg)OTN-based service connections. The C2 and C2' are end-to-end concepts on the service plane, since the service is end-to-end.

NOTE: With end-to-end it is meant that a service is provided from one end-point to another end-point of the (fg)OTN service. The end-points are the Service Mapping Points (SMPs), as defined in the overall F5G-A network architecture.

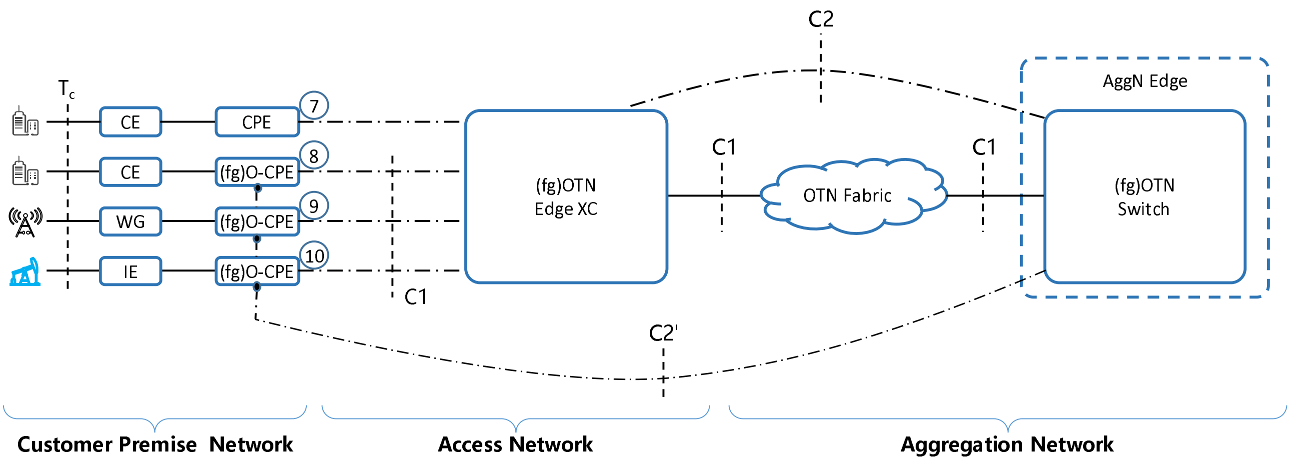


Figure 16: (fg)OTN control interfaces

The C1 interface is the control plane handover point between two network nodes, where the (fg)OTN-based connections are used. The C1 interface exists between the (fg)OTN Edge XC and the OTN Fabric, and between the (fg)O-CPE and the OTN Edge XC. For both locations, the C1 interface has the same control functionality and is used to exchange the (fg)OTN signalling messages to control the (fg)OTN network connections across the network segments. The main functions of the C1 interface include:

1) To transmit the signalling messages used to create, modify or delete (fg)OTN network connections automatically. The F5G Advanced management and control system will trigger this signalling process (not shown in Figure 16 for simplicity).

2) To transmit the signalling messages used for bandwidth adjustment of the (fg)OTN network connections. A typical network scenario is the use case [i.2] for premium home broadband service, supporting connections to multiple clouds. The OTN Fabric is used to transport the services of multiple users. The bandwidth adjustment of the (fg)OTN network connection is based on a change in the number of users, an adaptation of the user's bandwidth needs, or a shift in application bandwidth needs.

3) To perform fast (fg)OTN connection recovery after network failures, specifically in the case of a large number of connections, as expected with fine granular containers in the OTN network. At the same time, compared with legacy GMPLS protocol, the C1 interface shall be enhanced with the ability to recover a large number of connections in a short and committed recovery time period. This is required to meet the SLA requirements of the (fg)OTN-based services and ensure high-quality customer experience.

The protocol design of the C1 interface is out of scope of the present document.

The C2 and C2' interfaces are the control plane handover points between the two end-points of an (fg)OTN-based service connection, where the service traffic is mapped into/de-mapped from an (fg)OTN network connection. The C2 interface exists between the (fg)OTN Edge XC and the AggN Edge node. The C2' interface exists between the (fg)O-CPE and the AggN Edge node. The C2 and C2' interfaces are used to negotiate between and to configure the Service Mapping Point (SMP) in the Service Plane. The C2 and C2' interfaces may be different depending on the provisioned services and might require different security measures due to the physical security applicable to the location of the deployed equipment.

The main functions of the C2 and C2' interfaces include:

1) To learn and exchange the MAC/IP addresses between the network endpoints, such as between the private networks in both the CPN/Access Network side and the Core Network side, signalling endpoints ((fg)OTN edge nodes). This helps the (fg)OTN edge nodes (i.e. the (fg)O-CPE, the (fg)OTN Edge XC and the AggN Edge node) to generate the appropriate service mapping/de-mapping rules. Such rules include the mapping of the service traffic into the (fg)OTN network connections and the de-mapping of the service traffic from the OTN network connections.

2) To identify the address of the service traffic and map the service traffic into the appropriate (fg)OTN network connections according to the service mapping/de-mapping rules.

More details on the overall OCN architecture and those interfaces are specified in the Optical Cloud Network (OCN) Architecture [15]. The requirements of Optical Cloud Network (OCN) Architecture [15] shall apply. The protocol design of the C2 and C2' interfaces are out of scope of the present document.

Since the (fg)O-CPE is located on the customer's premises, and its physical security may not be under the control of the network operator, the security aspects of the control interfaces (C1, C2') connecting the (fg)O-CPE and the nodes in the operator's network are for further study.

5.3.4.8 Compute Coordination Interfaces

The F5G-A architecture adds compute functionality at various locations in the network (see Figure 17). Specifically, compute may be located in the CPN, AN, AggN, or CN. The coordination between the various compute functionalities is performed through the following three interfaces:

1) C_{an}: The interface performs the coordination and control between the compute functionality in the access node and the CPN node(s). The protocol used on the interface may be the same as defined in G_c or F1.

2) C_{ag}: The interface performs the coordination and control between the compute functionality in the AggN Edge node and the access node(s).

3) C_{cn}: The interface performs the coordination and control between the compute functionality in the AggN Edge node and Cloud Central DC.

NOTE: The interfaces Can and Cag might use interfaces G_c and V_c jointly for achieving the control required.

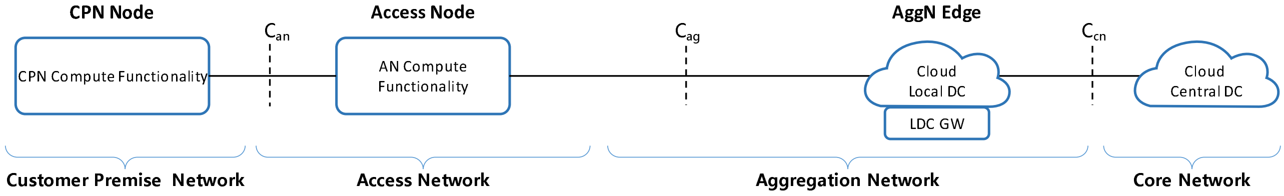


Figure 17: Compute control interfaces

Depending on the particular compute functionality and its location, the interface might need to be adapted to the particular needs. In general, the interfaces are concerned with exchange of information about forwarding functions, measurements on the forwarding functions, and configuration of forwarding function on the network elements (collocated or remote from the compute functionality).

Details on the Architecture of computing collaboration are for further study.

5.4 Key enabling features

5.4.1 Fibre Access Node (FAN) Intelligent Engine (FIE) Architecture

5.4.1.1 Background

Currently, broadband network subscriptions are generally based on a package of several services. The package contract is usually based on either traffic volume or broadband access speed. The majority of the upstream and downstream traffic is asymmetrical with some being symmetrical. In addition, the OLT uplink usually is benefiting from statistical multiplexing gains and therefore is under-provisioned compared to the access traffic speeds. The overall residential premise and access network are service unaware and, in most cases, using best-effort scheduling. The F5G Advanced generation definition [i.1] and the requirements and gap analyses [3] require the F5G-A architecture to support mechanisms for a variety of broadband network services as part of flexible subscription packages. The main features of the Fibre Access Node (FAN) Intelligent Engine (FIE) architecture include network capabilities being accessible through APIs, realizing Network as a Service (NaaS), and provides differentiating service capabilities. Cloud platforms and services use the network services in an on-demand paradigm.

The basic concepts of the FAN Intelligent Engine (FIE) architecture are the programmability through APIs. The real-time and non-real-time control of the architecture, and the use of computing functionality to improve the network and service quality. Additional APIs are for further study.

5.4.1.2 Quality on Demand (QoD) Application Programming Interface (API)

For a broadband access network, the primary service is the on-demand quality of connections, named Quality on Demand (QoD). The QoD-API definition defines the quality on-demand experience and needs to implement prioritized connections based on the application level requirements and implement performance control of the connection.

The main functionality of the QoD API are as follows:

1) QoD prediction: Users' network performance requirements shall be monitored, the quality of experience shall be anticipated, and notifications of experience shall be proactively sent to users.

2) Computing: Network experience simulations, network resource simulations, and resource configuration and adaptation decision-making is computed and then implemented.

3) User/Subscriber Portal (Web-Link): User/Subscriber real-time self-service portal to implement application-level connections. This user/subscriber portal has the SLA-specific capabilities.

4) Storage: The real-time network performance and SLA experience is measured and stored.

5) Control: The SLA experience is detected based on particular network performance threshold characteristics. Once the threshold is reached, the SLA experience shall be controlled in real time and resource adjustment shall be performed.

The dynamic F5G-A network control plane architecture shall perform dynamic full-lifecycle control of services.

The details of the QoD API are for further study.

5.4.1.3 The App-Flow application: A step beyond Slicing

The F5G architecture Release 2 [1] specifies the F5G concept of a network slicing feature. All specification in the F5G architecture Release 2 [1] shall apply except when explicitly mentioned.

Network slicing provides the capability of separating and isolating different traffic classes from each other in order to guarantee a service or virtual network performance. The basic traffic forwarding behaviour is guaranteed with network slicing. More intense control and management for highly automated operations and the interaction with users and subscribers are key aspects added with App-Flow application using the FIE architecture.

The aspects beyond slicing include:

1) Application awareness through AI: the control plane shall support the capability of AI-based application identification, and determining the required network performance. The user privacy shall be maintained.

2) Distributed control plane: a distributed control plane shall be supported by the F5G-A network, because compute, storage, and networking resources reside in different segments.

3) Quality on Demand API: Applications, Cloud services, and third-party providers may request a certain quality on demand for a particular application data flow. The F5G-A network shall provide good quality of experience on a per application flow bases.

4) Fine-granular, application-level flow provisioning: Slicing is designed for a limited number of network services. The FIE architecture allows for a larger number of applications with their individual fine-granular performance level requirements.

An application data flow may be associated with a network slices or independent of a slice. In case the application data flow is associated with a slice, the network slice constrains are applicable to all application flows in that slice.

5.4.1.4 The F5G-A Access Node Architecture for FIE

The F5G-A Access Node architecture for FIE, as shown in Figure 18, consists of an Access Node (see Figure 3), a management system, and CPNs.

The F5G-A Access Node for the FIE architecture consists of an OLT service system and a computing service system. The data plane components of the OLT service systems interact via the Export interface (see Figure 18) with the Compute service system. The control plane components of the OLT service systems interact via the OLT Service interface (see Figure 18). The F5G-A Access Node has an interface to the management system for the App-Flow provisioning and monitoring.

NOTE: Other aspects of the F5G-A Access Node, the ONUs, or the management system not related to FIE are not described here. Figure 18 shows the additional functionality of the management system specifically for the App-Flow service provisioning. The management aspects for other functions of the Access Node are not shown.

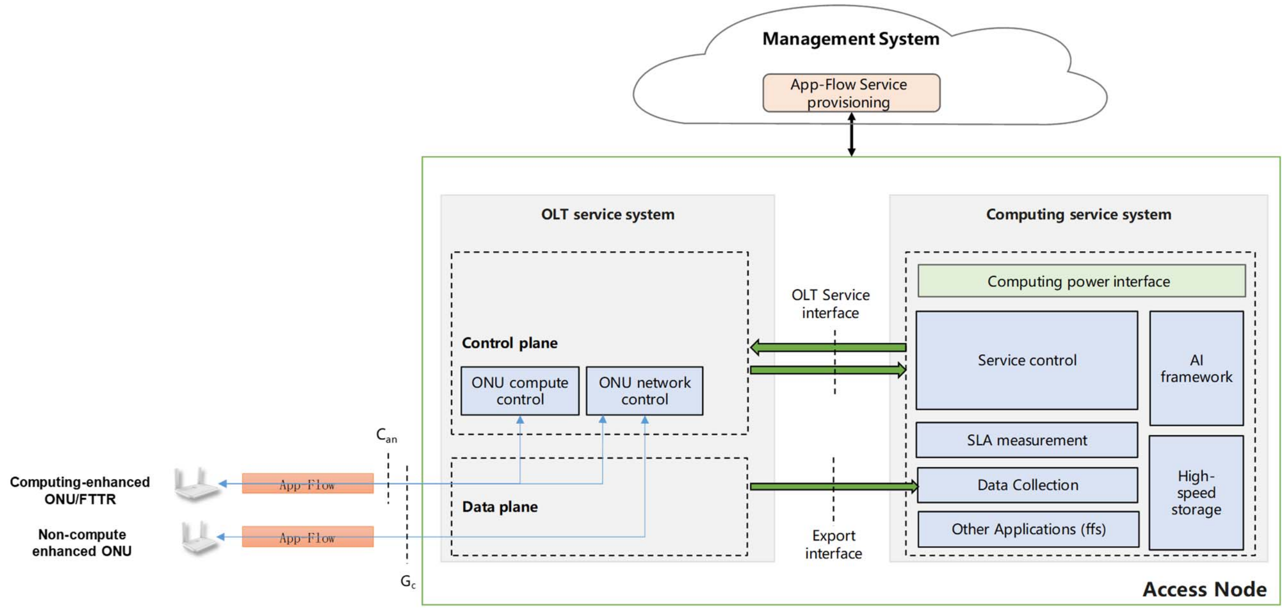


Figure 18: F5G-A Access Node Control Architecture for FIE

The key aspects of the Access Node Computing architecture include:

1) The export interface is used to export data plane information to the data collection component for further processing. Through the compute service system larger compute capacity and more complex analysis are performed.

2) The OLT service interface is used to adapt and optimize the OLT service system based on input from the management system, the AI framework, or the SLA measurement component.

3) High-speed storage is used to store received data and analyse the data using the AI framework.

4) The service control component performs application-level flow control, App-Flow configuration, dynamic application identification, and service control.

5) The SLA measurement component measures the key network KPIs of the App-Flow, specifically delay and packet loss and performs continuous monitoring and reporting of the App-Flows.

6) The ONU network and compute control components interact with the ONUs (depending on their capability). Compute-enhanced ONUs perform data analyses and service configuration based on the OLT system analysis.

7) The management system is performing all non-real-time control functions. The management system shall support an App-Flow Service provisioning function.

An ONU may be either a computing enhanced ONU/FTTR system or a traditional ONU. Both ONUs interact (via the G_c interfaces) with the ONU network control component for the control of the data plane aspects of the ONU. The compute-oriented aspects of a compute enhanced ONU is controlled via the C_{an} interface.

In case of the physical separation of the OLT service system and the Computing Service system, the OLT service interface is the C_c as shown in Figure 14 and the Export interface is part of the C interface as shown in Figure 3.

5.4.2 The Aggregation Network Fabrics

5.4.2.1 The use of different fabrics

The F5G-A network architecture has different options for the Aggregation Network technologies used, depending on the needs and deployments of an F5G-A network. The F5G-A network architecture uses the term fabric for the different types of Aggregation Networks.

5.4.2.2 IP/Ethernet Fabric

The IP/Ethernet Fabric has not evolved from an architectural perspective compared to the F5G architecture Release 2 [1].

The IP/Ethernet fabric provides a simplified Aggregation Network architecture. As shown in Figure 19, the IP/Ethernet Fabric consists of an Access Leaf (AL), Aggregation Edge Leaf (AEL), and a large traffic volume and a high-density interconnection Aggregation Fabric (AgF). Some aspects of these components as described as follows:

1) The AL (part of the Access Node) provides access to the IP/Ethernet fabric. In F5G Advanced networks, the AL has SAP and SMP functionality. The AL is integrated with or separate from the OLT.

2) The AEL (part of the AggN Edge Node) contains the extraction and steering functionality, which directs and interconnects the IP/Ethernet Fabric traffic to the Core Network and L/CDC-GWs, where applicable. In the F5G Advanced architecture, the AEL is part of the AggN Edge Node.

3) The AgF provides a multiple layer large-capacity with high-density interfaces to achieve full connectivity between AL and AEL. The AgF consists of one or more large-scale Layer 3 switches or routers. In addition, a logically centralized Software Defined Network (SDN) controller (not shown in Figure 19 for clarity purposes) provides programmable connection setup and automatic O&M in the Underlay Plane.

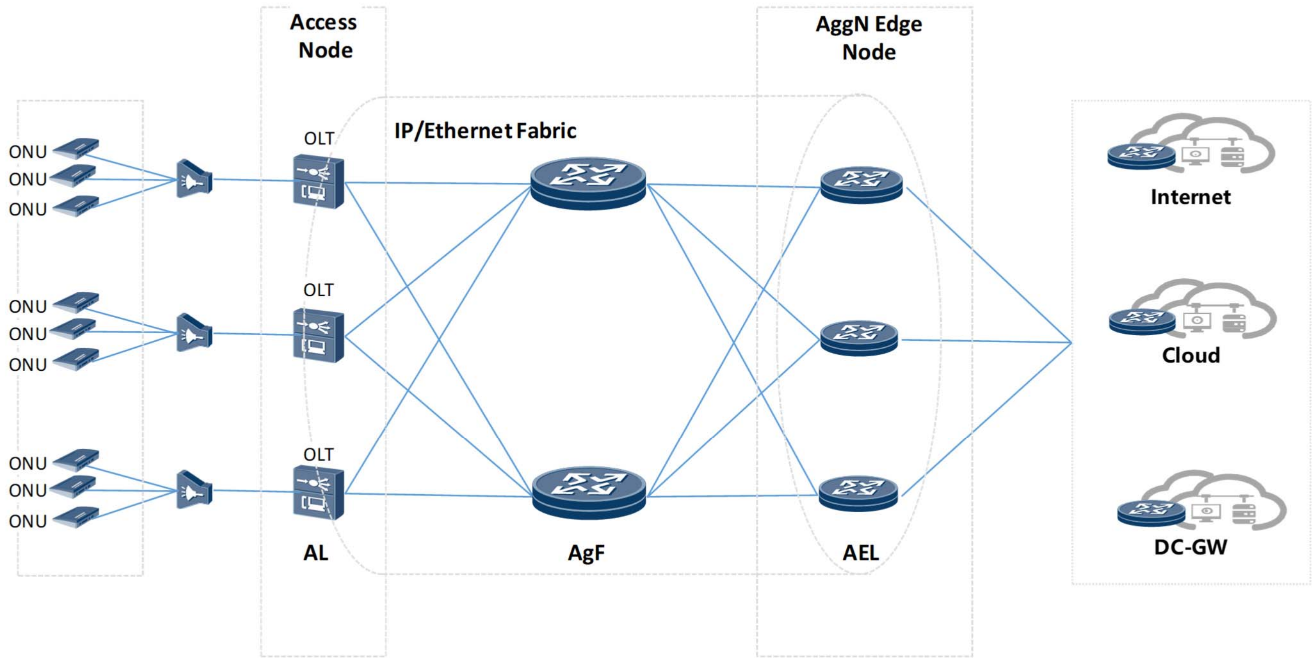


Figure 19: IP/Ethernet Fabric

The IP/Ethernet Fabric architecture uses this infrastructure to implement full connectivity between the Access Nodes and AggN Edge nodes. Based on the principle of decoupling the Underlay Plane from the Service Plane, the IP/Ethernet Fabric uses a simplified protocol stack to simplify the Underlay Plane and uses SDN automation to achieve the following characteristics:

1) Full-mesh:

   - A small number of links implement the full connectivity between the access and AggN Edge nodes, meeting the growing demand for the IP/Ethernet Fabric traffic.

2) Scaling:

   - AgF shall support growing horizontally (through the addition of equipment) or/and vertically (through replacing equipment with higher performance equipment) on demand, and the Access Leaf (AL) and Access Edge Leaf (AEL) are unaware of these changes.

3) Multi-path redundancy:

- Multi-path protection: Multiple paths exist between an access and access edge leaf node and another leaf node. The failure of a single node or link does not interrupt the customer services.

- Programmable path: A path that carries service flows is dynamically selected based on the SLA requirements and path loading.

- Multi-path load balancing: Load balancing is used to distribute traffic to multiple links to improve the overall network bandwidth utilization.

4) Centralized management and control (SDN):

- Centralized management and control implements traffic prediction and supports accurate capacity expansion planning. Inter-domain and multi-vendor networks are centrally managed, and fast end-to-end provisioning is enabled. Network topology, link, and path status are continuously monitored and analysed centrally to implement the programmability of connection paths.

5) Protocol simplification:

- Protocols are simplified and unified. The connection is unified to Segment Routing (SR) (IETF RFC 8402 [12] and Segment Routing over IPv6 (SRv6) IETF RFC 8986 [13]), and the corresponding control protocol is converged to BGP [2], which reduces the complexity.

6) Stateless network:

- The AgF is unaware of the SRv6 tunnel status. Path changes should not affect the traffic characteristics of the tunnel. Tunnel specifications are scalable.

5.4.2.3 OTN Fabric

The F5G OTN topology has evolved to a mesh topology, called an OTN fabric in the context of the F5G architecture Release 2 [1]. See F5G architecture Release 2 [1] for the motivation for the that evolution.

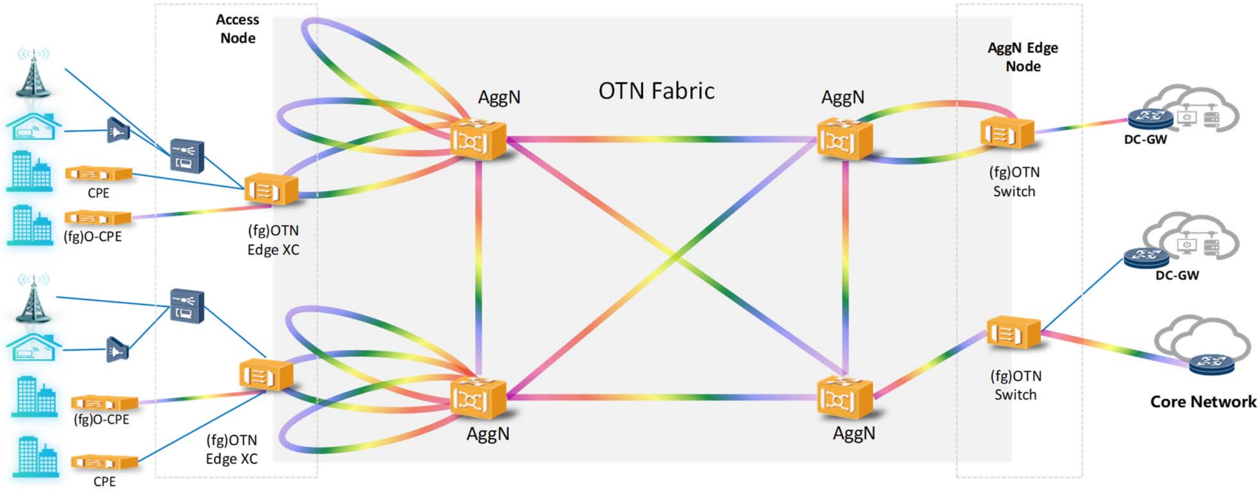
The F5G-A OTN fabric is enhanced with fine grain functionality enabling a more efficient bandwidth utilization of the OTN fabric. In addition, it enables hitless bandwidth adjustment in steps of 10 Mbits.

An OTN fabric consists of the Access Node (fg)OTN Edge XC, the AggN Edge node (fg)OTN switch, and Aggregation Nodes (AggN), which are basically the OTN fabric switching nodes:

1) The (fg)OTN Edge XC perform the aggregation and appropriate access functionality for residential broadband, leased line ((fg)OTN or Ethernet), industrial networks, and mobile base stations backhaul. The functionality needed in the (fg)OTN Edge XC is basically aggregating traffic from different protocols and sources into the OTN Fabric. See clause 5.4.2.4, for details on the multi-ring optimizations in the Wavelength-shared WDM Fabric. In F5G Advanced networks, the (fg)OTN Edge XC is collocated or an integrated part of the access node.

2) The (fg)OTN switch extracts/inserts aggregation network traffic, switches the traffic to the various destinations, and provides connectivity to/from the Optical Core Network and LDC-GW of Data Centres, where applicable. In the F5G-A architecture, the (fg)OTN switch nodes are typically collocated or an integrated part of the AggN Edge node.

3) The AggN (as shown in Figure 20) are OTN Fabric nodes that provide full interconnection of the access node (fg)OTN Edge XC with the AggN Edge node (fg)OTN switches. There might be a deployment option, where the OTN Fabric enables fgOTN level switches, but a high degree of traffic aggregation has already occurred prior to entering the OTN Fabric, the assumption is that the typical OTN Fabric deployment supports fgOTN at the edges of the OTN Fabric for aggregating fine-granular traffic into ODU connections.



NOTE: There are different deployment options of the links and rings at the edge of the OTN Fabric.

Figure 20: OTN Fabric Architecture

The OTN Fabric architecture (Figure 20) has the following characteristics:

1) **Direct connection supports high-priority services:** If the nodes support electrical cross connects the direct electrical layer connection between (fg)OTN Switches may be achieved. If the nodes support MD-ROADM (not shown) switching, a direct lambda layer connection between (fg)OTN XC may be deployed. High-priority services that were identified in the Service Plane requiring extremely low latency are steered to the OTN fabric in the Underlay Plane. The OTN fabric will then provide high-quality service transport. The OTN fabric nodes are unaware of the fgOTN connection status. The use of alternate paths does not interrupt the services. The OTN fabric are scalable with the number of connections.

2) **Flexible Access Technologies:** The access nodes may have different technologies including OLTs using PON, CPEs using P2P Ethernet, (fg)O-CPE using Ethernet transported over (fg)OTN for leased line highly guaranteed services.

3) **High reliability:** The ring network topology supports a single fibre cut failure condition in the (fg)OTN access ring, as traffic traverses the ring in both directions (depending on where the cut occurs). However, this may introduce higher latency, since the path takes the longer route. The meshed OTN fabric network has alternate paths. If there are N nodes, then there are N-1 interconnecting paths. The OTN controller has at its disposal N-1 path to choose from, allowing it to choose the best path best suited to the service characteristics of the failed link. The OTN fabric, therefore, provides higher reliability.

4) **High overall bandwidth utilization:** Multi-paths networking facilitates network traffic loading and improves the overall network bandwidth utilization.

5.4.2.4 Wavelength-shared WDM Fabric

5.4.2.4.1 Overview

The wavelength shared WDM fabric is a deployment option for the F5G-A Aggregation Network. See clause 5.4.2.3 for other options for the Aggregation Network. Figure 21 shows multiple WDM rings connected with the M*N WSS in the AggN Edge of the F5G-A topology as shown in Figure 3. The nodes called Central Office (CO) in Figure 21 are part of the Access Node in Figure 3.

NOTE: Whether the meshed optical network is part of the Aggregation Network or the Core Network depends on the particular deployment and fibre topologies.

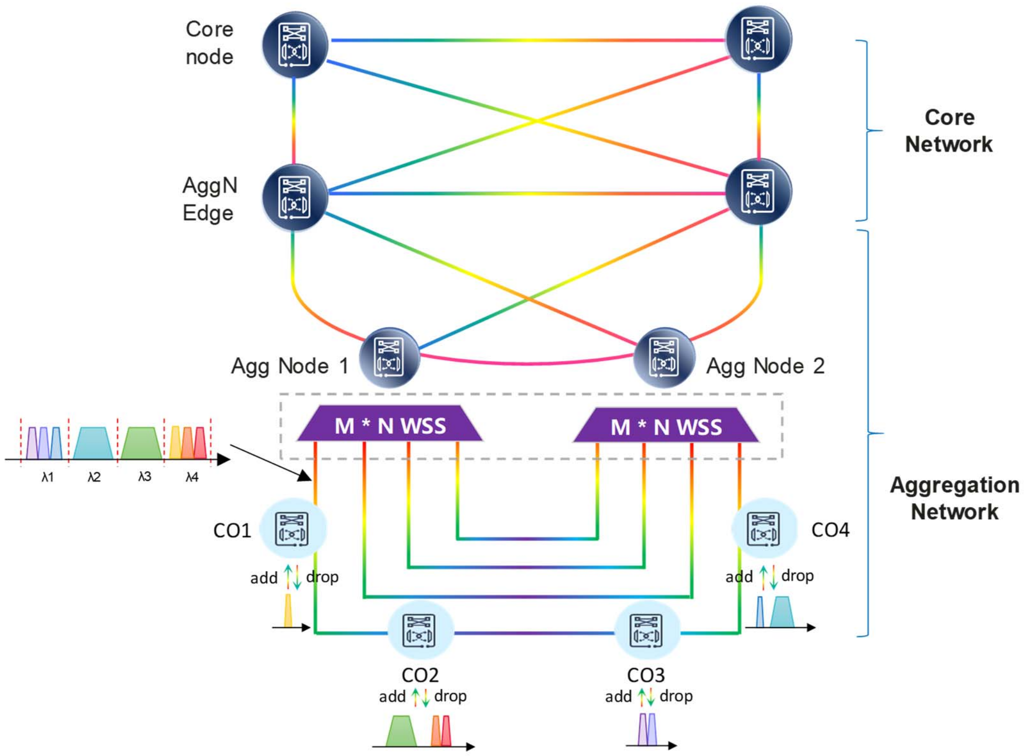


Figure 21: Wavelength-shared WDM Aggregation Network with example λ allocation

The WDM Fabric adopts ROADM technology to meet the requirements of flexible network grooming. The key components in a MD-ROADM is the highly integrated M*N WSSs used in WDM Fabric nodes, where multiple rings are originating or terminating. As shown in Figure 21, a group of WSSs supports multiple access rings, receives optical signals from multiple directions and enables wavelength sharing between different rings, thus reducing the number of boards, space, and power consumption at the WDM Fabric nodes.

Traditional Aggregation Network traffic is a Point-to-Point (P2P) topology, where 2N optical transceivers for N connections are required between AggN Edge and CO nodes (Access Network Nodes). The Shared WDM feature employs the media level Point-to-Multipoint (P2MP) on the ring. based on Sub-Carrier Multiplexing (SCM) a particular way for Frequency Division Multiplexing (FDM). An WDM Fabric node is connected to multiple CO nodes using colourless ROADMs technology. The Shared WDM Fabric enables the co-existence of P2MP and P2P modes as shown in Figure 21.

EXAMPLE: Four wavelength channels in the WDM Fabric nodes are allocated to one ring connecting four CO nodes. Due to the capability of colourless and flex-grid operation of the WSS-based MD-ROADM network, either the single-carrier channels (λ2 and λ3) or the Sub-Carriers (SCs) in one wavelength channel (SCs in λ1 and λ4) could be added and dropped in each CO node (shown in Figure 21).

The single carrier channels are usually used for P2P traffic while the sub-carriers are usually more suitable for P2MP traffic.

5.4.2.4.2 Colourless ROADM technique in access nodes

Figure 22 shows a Colourless ROADM in the access node (see Figure 3). The Colourless ROADM adds and drops wavelength or sub-carriers from the fibre.

EXAMPLE: Figure 22 shows an example of dropping a sub-carrier from λ1 and adding a sub-carrier to a newly added λ2.

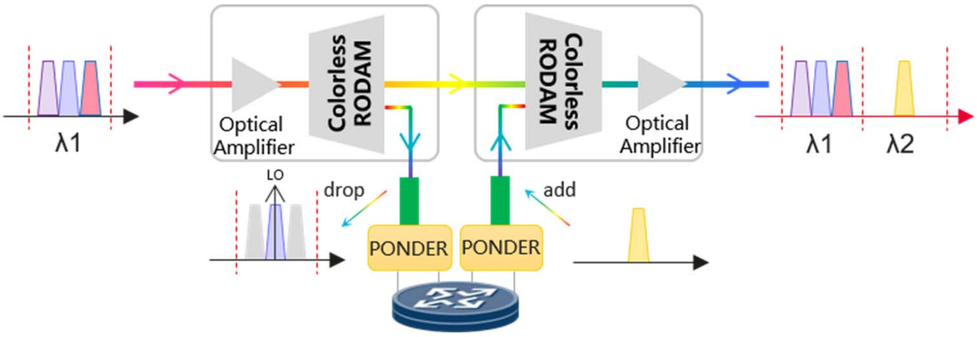


Figure 22: Colourless ROADM in access nodes example

All-optical access nodes are two-dimensional, have low complexity and are cost effective. Thus, colourless ROADM technique with two dimensions is used. A colourless ROADM supports the P2MP and P2P communication modes.

NOTE: In Figure 22, only one transmission direction is shown, the other direction is symmetrical to the structure in Figure 22. In addition, the access nodes use, further increases the integration of optoelectronic chips, reducing complexity, costs, and power consumption.

5.4.2.4.3 Automated OAM enabled by optical-layer digital label

The optical-layer digital label technology is used to implement automatic adjustment and adaptation in the optical-layer. Optical-layer digital labels uses Multi-Carrier Modulation. It utilizes the multi-carrier low-speed modulation superimposed on a carrier of a high-speed digital signal for the label information. The digital label signal is directly modulated on the electrical signal and is extracted at the receiver for independent monitoring.

Wavelength resources are automatically allocated and the Network Elements (NEs) are automatically configured, eliminating manual wavelength planning and software download and upgrade during site deployment. This also supports quick remote fault demarcation and handling, improving network O&M efficiency. In addition, the intelligent management and control plane further supports optical-electrical coordination and intelligent route computation to implement end-to-end automatic service provisioning.

5.4.3 Optical Cloud Network (OCN) Architecture

The Optical Cloud Network (OCN) Architecture is specified in ETSI GS F5G 018 [15]. The OCN architecture provides optical connectivity between OTN Edges (OE), which are the edges of the OTN technology domain. In Figure 3, the OEs are the Access Network Node or (fg)O-CPEs on the left side. The AggN Edge Node and any OTN capable core network node are OEs on the right side of Figure 3. The OTN Edge maps service flows based on cloud service, application, or slice identification to the optical connection. In the overall architecture in Figure 1, this is regarded a Service Mapping Point (SMP).

The key feature of OCN is providing high quality enterprise private line and home broadband connectivity to multiple clouds services. See ETSI GS F5G 018 [15] for the key characteristics. Depending on the service requirements, there is ODUs or (fg)ODUs used in the data plane.

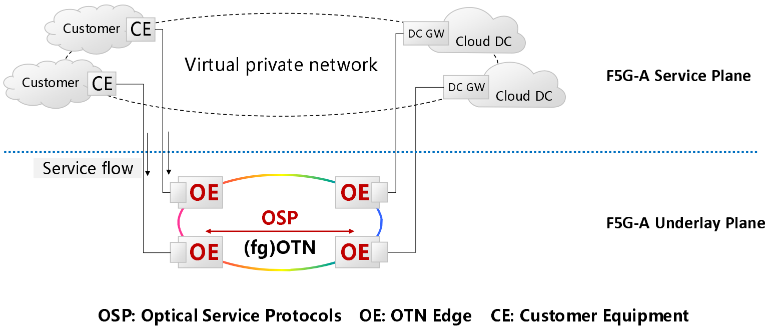


Figure 23: Optical Cloud Network Architecture (see ETSI GS F5G 018 [15])

The OCN architecture requires Optical Service Protocols (OSP) to be specified, which are implemented on the interfaces C1 and C2/C2' as specified in clause 5.3.4.7. The detailed requirements of [15] shall apply.

NOTE: Figure 23 assumes a direct connection between Customer Equipment (CE) in the CPN and the Cloud DC, usually connected via a Datacentre Gateway (DC-GW). The Cloud DC can be local (LDCs) or centralized (CDC). However, different deployments depending on the service flows and cloud service being hosted might apply.

5.4.4 Fibre Sensing Architecture

Fibre sensing has various applications, see F5G-A Use Cases #5 (Railway perimeter inspection) and #16: (Optical Fibre Sensing for telecom operators) (see ETSI GR F5G 020 [i.2]). See Figure 24 for an overview of the F5G-A Fibre Sensing architecture. There is a fibre with or without communication traffic on it. Depending on the application, the fibre is deployed above or below ground. At both ends of the fibre, there is monitoring and active measurement functionality located. The monitoring functionality observes the signals on the fibre. The active measurement functionality sends from one or both ends particular signals on the fibre such that one or both ends detect and measure various parameters of the fibre. The processing functionality analyses the signals and derive application dependent information. The Control and Management functionality provides visualization capability, mapping events from the fibre to geographic location, creating warning (pre-event warnings) or alarms of detected events.

The fibre sensing architecture is rather generic, since it requires to be useful in many different fibre sensing-oriented applications. The details of the fibre sensing are for further study.

The fibre sensing function detects environmental impacts and fibre inherent parameters.

EXAMPLE 1: Environmental impact detected might include vibrations, location of vibrations, temperature among others. In the use case on F5G-A Use case #5: Railway perimeter inspection [i.2], the impact can be caused by intrusion.

EXAMPLE 2: Fibre inherent parameters might include fibre quality, fibre topology, fibre bending, splitter location, connector locations among others.

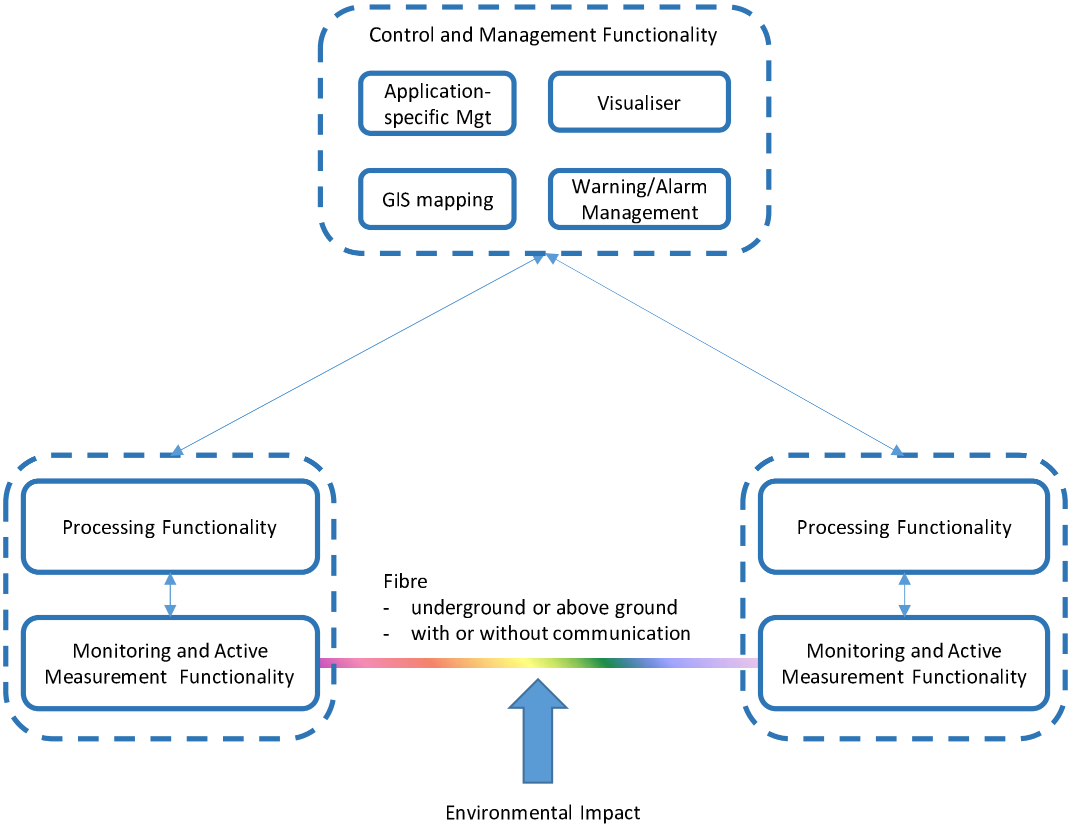


Figure 24: Fibre Sensing Architecture (two fibre sensing network element approach)

In Figure 25, the approach is different in the sense that a signal ended fibre sensing network element is deployed. The approach has a single fibre sensing network element with monitoring and active measurement functionality. The approach relies on the signals on the fibre to be mirrored or reflected or on some passive elements in the fibre being detectable. Everything else is the same as shown in Figure 24 including the need for processing functionality and the control and management functionality.

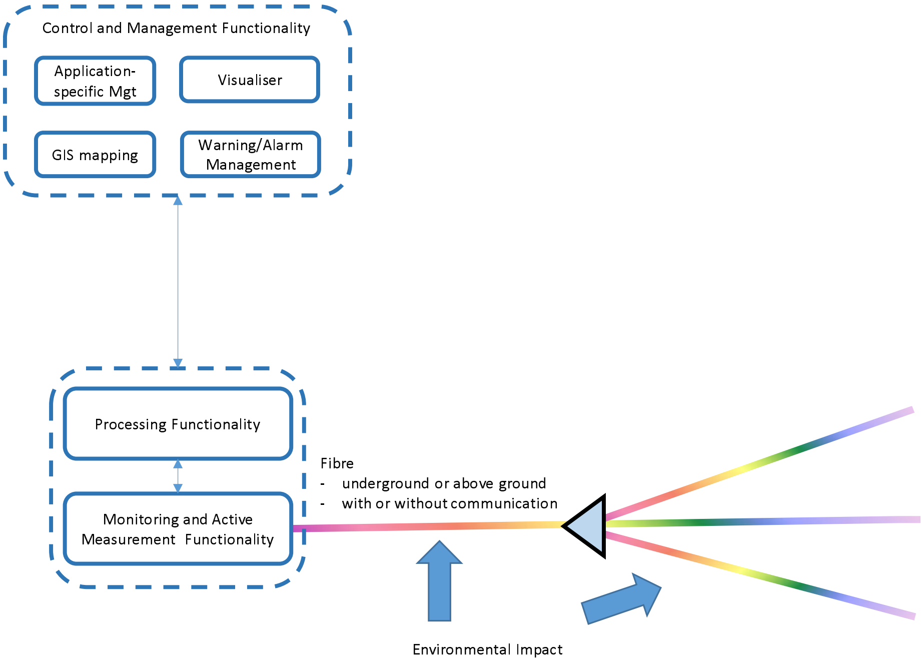


Figure 25: Fibre Sensing Architecture (single fibre sensing network element approach)

NOTE: Though Figure 25 shows a P2MP scenario, a single fibre point to point fibre is applicable as well.

Annex A (informative): SDH migration to (fg)OTN

SDH network equipment is reaching end of life and spare parts are becoming difficult to acquire. The telecom vendor's support for SDH equipment is diminishing. SDH equipment occupies a large area in Network nodes and is power hungry. It cannot support the emerging new high bandwidth services. The highest standardized rate is STM-256 (39,808 Gbps) which is not widely deployed and would require a very large number of VC-n (n by 150 Mbps approximately 686 VC-4s) concatenation to support the popular 100 GE Ethernet services, which introduces significant management complexity using Virtual Concatenation (VCAT)/ Link Capacity Adjustment Scheme (LCAS).

SDH networks are typically deployed in the Access, Aggregation, and Core network segments of a TDM network topology, with standardized STM interfaces carrying traffic from one access domain to another via the core network. The core network is typically a mesh topology while the access network is typically a ring topology. The Core Network would typically be STM-16/STM-64 (2,488 Gbps/9,952 Gbps), while the access is STM-1/-4 (155 Mbps/622 Mbps)

Services carried over SDH can be locally terminated in geographical areas such as SDH Islands and transported island to island via the core network. A typical SDH network service is point to point leased line services. Figure A-1 shows a typical SDH Access/Core Network deployment. It shows the interconnections of the SDH island as well as the private leased line services via CPEs. Originally SDH transported PDH type services such as voice but with the introduction of VoIP telephony this has decrease significantly if not gone completely. The PDH interface predominantly E1 mapped over VC-12 carries packet traffic using VCAT/LCAS or maybe legacy PBX traffic. In fact, EoS traffic over concatenated VC-n's is the predominant traffic over SDH.

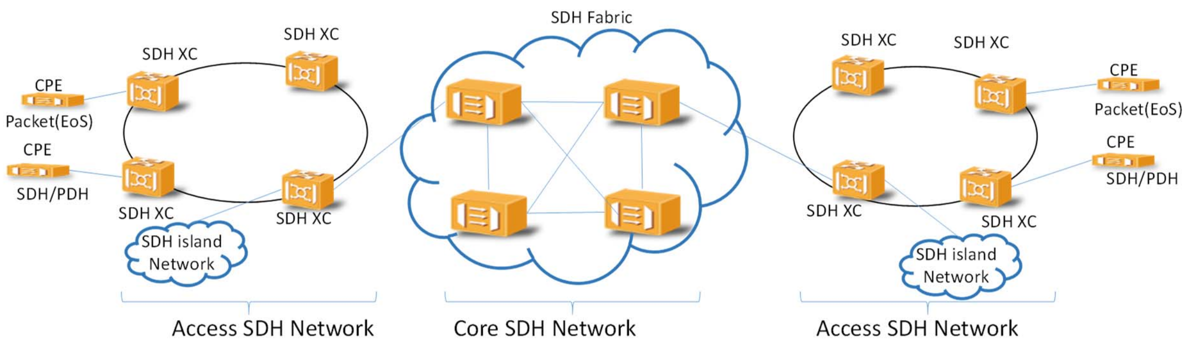


Figure A-1: Typical Access/core SDH networks

The terminology in Figure A-1 differs from that uses in F5G-A. The Access Network and Core network in SDH would be the Aggregation Network of F5G-A with the extremities being the F5G-Access network and the termination being the Customer Premise Network. F5G-A is more aligned with the segmentation terminology of Figure A-2.

When considering the migration from SDH to an alternate transport network it is essential that it is performed step by step minimizing end customer service interruption. One such transport network is OTN. Standard OTN has efficient mapping for STM-16 and STM-64, and even STM-256 if needed. But Standard OTN mapping of STM-1 and STM-4 is less efficient being mapped into and ODU0/ODUflex container. This mapping does not allow for VC-n switching which is an important aspect when migrating SDH to OTN. The mapping takes STM-1/STM-4 (155 Mbps/622 Mbps) and maps them to 1.25G ODU0/ODUflex container which is bandwidth wasteful (12,5 %/49,8 % utilized). Now VC-12, VC-3, VC-4 as well as VC-n concatenation is also not visible, making it impossible to extract E1 (VC-12)/ EoS (n by VC-n) in the OTN network which terminates on SDH equipment for extraction. However, a recent addition to Recommendation ITU-T G.709 [8] and Recommendation ITU-T G.709.20 [9] is the introduction of fgOTN, which supports containers of n by 10 Mbps. So, VC-12 occupies one container, VC-3 occupies 5 containers, VC-4 occupies 15 containers, STM-1 occupies 16 containers, and STM-4 occupies 64 containers, this is far more efficient. The fgOTN containers are mapped over ODUk (k = 0, 1, 2, flex). An ODU0/ODUflex supports 119 fgOTN containers each of which are accessible on OTN nodes supporting fgOTN multiplexing and demultiplexing. OTN support for fgOTN-aware switching tends to be on nodes close the edges of the Aggregation Network and non-fgOTN-aware nodes are more to the central mesh network.

The migration steps are:

- Replace the core SDH equipment with OTN equipment:
    - The SDH core network migration would replace the SDH core network with (fg)OTN Aggregation Network allowing the transport of SDH services over an OTN network. SDH is a synchronous network while OTN is an asynchronous network, so to transport SDH traffic with the same requirement across an OTN requires SDH clock information to be carried along with the SDH data. In doing so OTN can remain asynchronous and timing transparently carry SDH across the network. This replacement is most likely but not restricted to non-Aware fgOTN network nodes.
- Replace the SDH Access network equipment:
    - The SDH Access network migration would replace the SDH Access network with (fg)OTN Edge XC. These replacements are fgOTN aware network nodes.
- Replace the SDH islands:
    - The SDH islands migration replaces the SDH network of the island with (fg)OTN Edge XC, however leaving the customer/ access termination to remain SDH until the final phase. This replacement are fgOTN-aware network nodes.
- Lastly replace the enterprise devices:
    - Finally, the enterprise devices such as CPEs would be upgraded to support (fg)OTN ((fg)O-CPE) allowing the mapping of enterprise services to be mapped directly over (fg)OTN depending on the bandwidth required.
    - This last step will remove the need for SDH equipment in the F5G-A network. Figure A-2 illustrates this migration to a unified (fg)OTN. Now there is a single OTN management system in an operator's domain as opposed to SDH and OTN management systems.

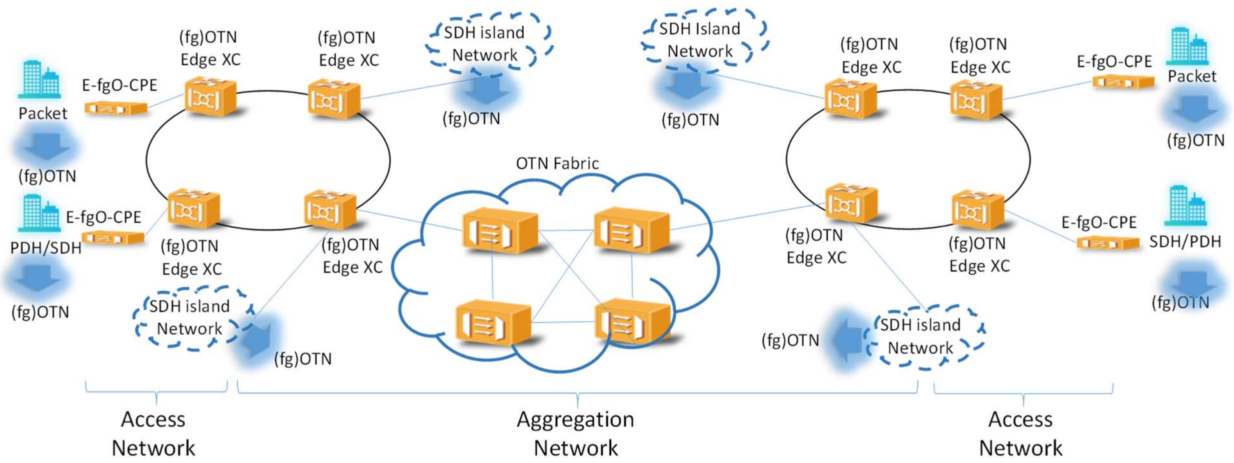
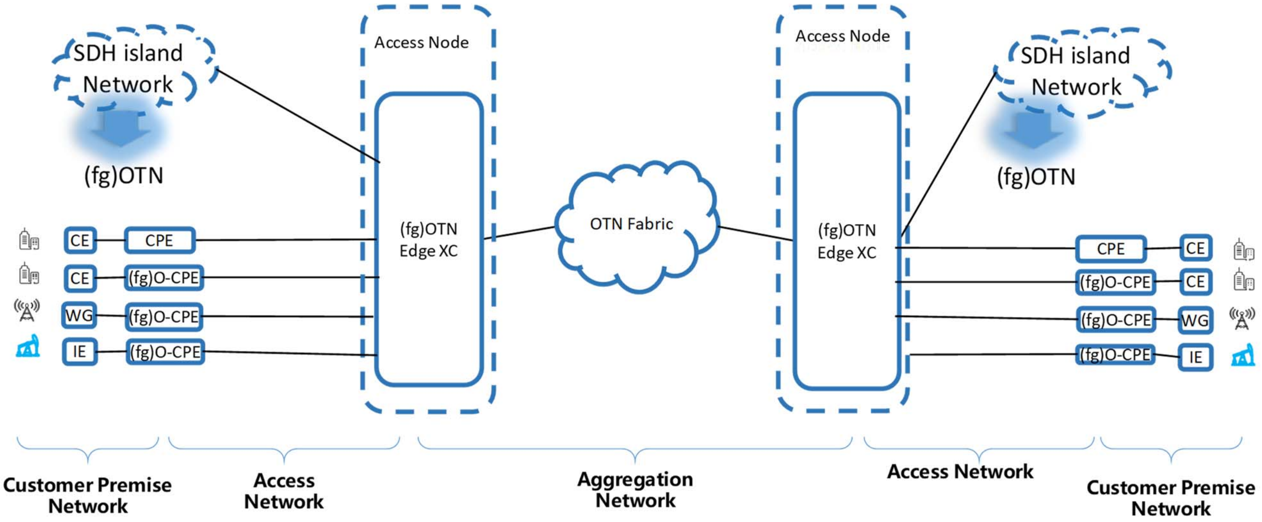


Figure A-2: Illustration of the migration for SDH to OTN in F5G Advanced

As mentioned above the predominant service carried over SDH toady is Ethernet over Synchronous (EoS) packet services using VCAT/LCAS, which allows for dynamic bandwidth expansion or contraction by changing the number of VC-n's that are concatenated, thereby adapting to bandwidth changes. LCAS can dynamic expand or contract the packets bandwidth used. This is an important requirement for the mapping of VC-n, which is needed for VC-n switching within the OTN fabric. In addition, service bandwidth on demand need a flexible mapping scheme to be able to adapt to customer demand. As part of the standardization of fgOTN a mechanism to dynamically and instantly expand and contract the bandwidth capacity of fgOTN in steps of 10 Mbps seamlessly was introduced. This fine grain bandwidth adaptation ensures minimum customer and network bandwidth wastage and maximum bandwidth flexibility.

Finally, Figure A-3 illustrates how this maps to the topology diagram in Figure 3. Figure A-3 differs somewhat from Figure 3 in that the Aggregation Network is used to connect two distant access networks as opposed to cloud/core. SDH is deployed for over 20 years and a lot has changed in that time, the industry has moved from dial-up to xDSL to PON (from 64 kbps to 50 Gbps) in the access allowing access to the internet, a concept not envisioned when SDH was deployed. SDH was primarily a voice network and with a degree of complexity added EoS using n by VC-n (VC-4 which is only a few hundred megabits). PON deployed today allows for XGS-PON to the home and F5G Advanced is moving to 50 G PON. SDH access equipment could not expand to these new bandwidths. The core has also expanded from the 50 Gbps to 400 G and beyond so could not be supported by SDH. So, this is why the topology diagram only covers access to access for SDH and the core is not possible with SDH, but well within the capability of OTN.



NOTE: The Core Network is not shown in Figure A-3, but different Aggregation Networks could be connected through a Core Network.

Figure A-3: Illustration of the topology of F5G-A

Annex B (informative): How the F5G-A Architecture addresses the Gaps

The F5G Advanced technology landscape requirements and gap analysis document [3] has listed several gaps based on the requirements of each use case [i.2]. The F5G-A architecture addresses some of those gaps. Table B-1 is an assessment of the F5G-A architecture with respect to the present document and whether those gaps are addressed. Gaps which are not addressed are for further study. Note that this is at the time of publication of the present document and will change over time.

NOTE: Some of the gaps are addressed from an architectural perspective, but the baseline technologies might still need to be defined in other SDOs, which specify the baseline technology of the F5G-A architecture.

Table B-1: Gaps addressed in the F5G-A architecture

Suggested actions	Relevant gaps	F5G-A architecture addressing the gaps
Define an E2E compute Collaboration function	[Gap3-3]	The high-level concept of cross-computing plane and the addition of compute functionality to the various components including the interfaces for the collaboration between compute functionality of the different network segments are defined.
Standardize an F5G unified E2E latency control mechanism	[Gap6-3]	The interface for specifying this function is available, the detailed interface specification is for further study.
Define an interface for collecting Access Network service and network KQIs	[Gap9-2]	The Access Nodes have interfaces to the MCA plane. The detailed specification of the interfaces for collecting KQIs is for further study.
Define a portal in the Access Network QoE analysis system for user experience issues	[Gap9-3], [Gap9-4]	The interface to the QoE management system is defined, called QoD interface however, the detailed specification of the interface is for further study.
Define an Access Network automatic reconfiguration mechanism	[Gap9-5]	Is not an architectural issue, therefore it is not applicable.
Define a users' service experience problem trouble tickets despatching system in the Access Network QoE analysis system	[Gap9-6]	E2E management functions are for further study.
Define a computing coordination mechanism between different F5G-A network elements	[Gap10-1]	The interfaces for computing coordination are defined between the various locations of compute functionality. The protocols and functionalities are for further study.
Define a mechanism to identify cloud desktop service and apply an appropriate service priority	[Gap10-3]	Service identification is a function in the service mapping point (SMP) in the architecture, the algorithm and mechanisms are for further study.
Define a simplified slicing mechanism to guarantee network QoS for service delivery	[Gap10-4]	The E2E slicing mechanisms are specified including the details for particular slicing technologies in the F5G architecture Release 2 [1]. The finer granular and simpler slicing is defined in Release 3.
Define a standard for sub 1 ms latency for robotic system using the F5G network	[Gap14-2]	This gap is for further study.
Define a standard for sub 0,5 ms latency for safety cases for robotic system using the F5G network	[Gap14-4]	This gap is for further study.
Define a standard for ideal cable requirements of ±180° twist per meter	[Gap14-7]	This gap is for further study.
Define a standard for ideal cable bend for 12,5 times the outer diameters	[Gap14-8]	This gap is for further study.
Define a simplified installation and configuration mechanism for enterprise network communication for RaaS applications effectively	[Gap14-9]	This gap is for further study.
Define a mapping for Data Distribution Service (DDS) over the F5G-A network architecture	[Gap14-10]	The gap is address by the flexible service mapping point allowing identification and mapping the different traffic types over connections with the right QoS.
Define a QoD standard for F5G-A networks	[Gap17-1]	The QoD API is for further study.

Suggested actions	Relevant gaps	F5G-A architecture addressing the gaps
Define a standard for the provisioning of App-Flow services with different QoS requirements	[Gap17-2]	The provisioning of QoS is part of the F5G-A architecture.
Define a standard for SLA management of fine granular application flows	[Gap17-3]	The SLA management is discussed as part of the F5G-A architecture.
Define a standard for fine granular application flow QoS management mechanisms	[Gap17-4]	The QoS management mechanisms is discussed as part of the F5G-A architecture.
Define a standard for real-time QoS control subsystem in the CPN and in the Access Network	[Gap17-5]	Real-time QoS control is specified from an architectural perspective in the F5G-A architecture.
Define a standard for the identification of fine granular application flows through the QoD API in the F5G network	[Gap17-6]	The identification of fine granular applications is defined in the F5G-A architecture. The QoS API is for further study.
Define a standard for automatic identification of application flows in the F5G network	[Gap17-7]	The automatic identification of applications flows is addressed in the F5G-A architecture by using additional compute functionality on the OLT. Details are for further study.
Define a standard for the mapping of fine granular application flows QoD requests to underlying QoS guaranteed connections	[Gap17-8]	The mapping of fine granular application flows QoD requests to underlying QoS guaranteed connections is available in the F5G-A architecture.
Define a telemetry standard collecting for a very large number of application flows	[Gap17-9]	The extension of telemetry to very large number of application flows is discussed in the F5G-A architecture. Details are for further study.
Define a standard for cooperation of compute located on different Access Network and CPN equipment	[Gap17-11]	The cooperation of compute located on different Access Network and CPN equipment is available in the F5G-A architecture.

History

Document history		
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