



GROUP SPECIFICATION

Fifth Generation Fixed Network (F5G); F5G Advanced Network Architecture Release 4

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Reference

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Foreword

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Modal verbs terminology

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1 Scope

The present document specifies the end to end F5G Advanced (F5G-A) network architecture, features and related network elements' requirements for F5G-A Release 4 including On-premise, Access, Aggregation, and Core Networks and its collaboration with computing functionality. The present document defines new features and enhances features from previous releases.

2 References

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- [1] [ETSI GS F5G 024 \(V1.1.1\)](#): "Fifth Generation Fixed Network (F5G); F5G Advanced Network Architecture Release 3".
- [2] [ETSI GS F5G 018 \(V1.1.1\)](#): "Fifth Generation Fixed Network (F5G); Architecture of Optical Cloud Networks".
- [3] [ETSI GS F5G 033 \(V1.1.1\)](#): "Fifth Generation Fixed Network (F5G); F5G Advanced Technology Requirements and Gap Analyses; Release 4".
- [4] [ETSI GS F5G 027 \(V1.1.1\)](#): "Fifth Generation Fixed Network (F5G); F5G Advanced End-to-End Management and Control Release 4".
- [5] [Recommendation ITU-T G.9941 \(07/2024\)](#): "High speed fibre-based in-premises transceivers - physical layer specification".
- [6] [Recommendation ITU-T G.9942 \(07/2024\)](#): "High speed fibre-based in-premises transceivers - Data link layer".
- [7] [Recommendation ITU-T G.988 \(11/2022\)](#): "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] [ETSI GS F5G 022 \(V1.1.2\)](#): "Fifth Generation Fixed Network (F5G); Specification for PON based Industrial Network".
- [13] [Recommendation ITU-T G.9943](#): "High speed fibre-based in-premises transceivers - network management".
- [14] [IETF RFC 7209](#): "Requirements for Ethernet VPN (EVPN)".

- [15] [Recommendation ITU-T G.959.1 \(01/2024\)](#): "Optical transport network physical layer interfaces".
- [16] [IEEE 802.3:2022™](#): "IEEE standards for Ethernet".
- [17] [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".
- [18] [Recommendation ITU-T G.9940 \(12/2023\)](#): "High speed fibre-based in-premises transceivers - system architecture".
- [19] [ETSI GS F5G 031 V1.1.1](#): "Fifth Generation Fixed Network (F5G); Intelligent Management for PON based Industrial network".
- [20] [IETF RFC 4760](#): "Multiprotocol Extensions for BGP-4".
- [21] [ETSI GS F5G 014 \(V1.1.1\)](#): "Fifth Generation Fixed Network (F5G); F5G Network Architecture Release 2".
- [22] [Recommendation ITU-T G.9949](#): "WLAN management control interface (WMCI) for in-premises network".

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- [i.1] ETSI GR F5G 021 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Generation Definition".
- [i.2] ETSI GR F5G 032 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Advanced Use Cases; Release 4".
- [i.3] Recommendation ITU-T Y.110 (1998): "Global Information Infrastructure principles and framework architecture".
- [i.4] Recommendation ITU-T G.709.1: "Flexible OTN common elements".
- [i.5] Recommendation ITU-T G.709.3: "Flexible OTN B100G long-reach interfaces".
- [i.6] Recommendation ITU-T G.709.5: "Flexible OTN short-reach interfaces".
- [i.7] Recommendation ITU-T G.709.6: "Flexible OTN B400G long-reach interfaces".
- [i.8] Recommendation ITU-T G.872: "Fine grain flexible ODU (fgODUflex) path layer network".
- [i.9] Recommendation ITU-T G.672: "Characteristics of multi-degree reconfigurable optical add/drop multiplexers".
- [i.10] [ITU-T G.Xfin-PHY](#): "High speed fibre-based in-premises transceivers - 10G Physical layer".
- [i.11] [ITU-T G.Xfin-DLL](#): "High speed fibre-based in-premises transceivers - 10G data link layer".
- [i.12] [ITU-T G.Sup85 \(03/25\)](#): "FgODUflex over point-to-multipoint networks".
- [i.13] ITU-T G.OMCC4FIP: "Management and control interface of fibre in premises (FIP) networks via OMCC".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

compute functionality: basic computing functions, which include input, processing, storage, and output

NOTE 1: Usually, processing is flexibly programmable

NOTE 2: The compute functionality needs compute resources for the computational success of a program.

compute resource: 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: sub-class of a compute process, which is a generic compute functionality

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

equipment: single physical container with implementation of one or more functions

NOTE: The term is derived and adapted from Recommendation ITU-T Y.110 [i.3]. 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: fine grain Optical Transport Network (OTN) that supports from 10 Mbit/s up to 1 Gbit/s

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

(fg)OTN: 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 references for more detailed information and the specification of (fg)OTN for a variety of deployment options and situations [8], [i.4], [i.5], [i.6], [i.7], [9] and [i.8]

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.3]) 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: 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: 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
3D	Three Dimensional
AggN	Aggregation Network
AI	Artificial Intelligence
AN	Access Network
AP	Access Point
API	Application Programming Interface
APP	Application
BGP	Border Gateway Protocol
BNG	Broadband Network Gateway
BSS	Business Support System
CDC	Central Data Centre
CE	Customer Equipment
CN	Core Network
CO	Central Office
CPE	Customer Premises Equipment
CPN	Customer Premises Network
CPU	Central Processing Unit
DC	Data Centre
DCA	Data Centre Access
DC-GW	Data Center Gateway
DCI	Data Centre Interconnect
DCN	Data Centre Network
DDS	Data Distribution Service
DECT	Digital Enhanced Cordless Telecommunications
DLL	Data Link Layer
E2E	End-to-End
E-LAN	Ethernet virtual private LAN
E-Line	Ethernet virtual private Line
E-Tree	Ethernet virtual private Tree

EVPN	Ethernet VPN
F4G	4 th Generation Fixed Network

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

F5G-A	F5G Advanced
FAN	Fibre Access Node
FDM	Frequency Division Multiplexing
fgODU	fine grain ODU
fgOTN	fine-grain Optical Transport Network
fgP2MP	fine grain Point to Multi-Point
FIE	FAN Intelligent Engine
FIP	Fibre In Premises
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
GPON	Gigabit Passive Optical Networks
GPU	Graphics Processing Unit
GUI	Graphical User Interface
GW	Gateway
HGW	Home Gateway
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
IE	Industrial Equipment
IoT	Internet of Things
IP	Internet Protocol
IPTV	Internet Protocol Television
IT	Information Technology
KPI	Key Performance Indicators
KQI	Key Quality Indicator
L2VPN	Layer 2 VPN
L3VPN	Layer 3 VPN
LAN	Local Area Network
LDC	Local Data Centre
LLM	Large Language Model
M&C	Management and Control
MAC	Media Access Control
MCA	Management, Control and Analytics
MD-ROADM	Multi-Dimensional ROADM
MFU	Main Fibre Unit

NOTE: The MFU was call Primary ONU (P-ONU) in previous releases of the F5G and F5G-A architecture.

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
OCS	Optical Circuit Switching
ODN	Optical Distribution Network
ODU	Optical Data Unit
OE	OTN Edge
OLT	Optical Line Terminal
OMCC	ONU Management and Control Channel
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)
OXC	Optical Cross Connect
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
PPPoE	Point-to-Point Protocol over Ethernet
QoD	Quality on Demand
QoE	Quality of Experience
QoS	Quality of Service
RaaS	Robotics as a Service
RDMA	Remote Direct Memory Access
RFID	Radio Frequency Identification
RG	Residential Gateway
ROADM	Reconfigurable Optical Add/Drop Multiplexer
SAP	Service Access Point
SC	Sub-Carrier
SCM	Sub-Carrier Multiplexing
SDH	Synchronous Digital Hierarchy
SDO	Standards Development Organization
SFU	Sub Fibre Unit

NOTE The SFU used to be called Edge ONU (E-ONU) in previous release of the F5G and F5G-A architecture.

SLA	Service Level Agreement
SME	Small and Medium Enterprises
SMP	Service Mapping Point
SOC	Service-oriented Compute
SPP	Service Processing Point
SRv6	Segment Routing over IPv6
TDM	Time Division Multiplexing
vCPE	Virtual CPE
VLAN	Virtual LAN
VNF	Virtual Network Function
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
XGS-PON	10-Gigabit-capable Symmetric PON

NOTE: Also known as symmetric 10G-PON.

XR	eXtended Reality
YANG	Yet Another Next Generation

4 Business requirements for the F5G-A Network Architecture

4.1 Context

The F5G-A Use Cases, Release 4 [i.2] shows the various services and application that the F5G-A architecture Release 4 needs to support. The F5G-A 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-A network architecture, Release 4.

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), AI-driven applications, etc., implies that application specific network requirements are needed. Due to on-demand service deployment, more flexible 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 Gbits to 5 Gbits today to 5 Gbits to 10 Gbits 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 AI-based 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. AI based automation can learn the behaviour and act accordingly for the best possible experience.

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. The computing capability can be used for traditional computing workloads or for AI-oriented workloads, depending that might require hardware that is more adapted to be efficiently used for AI-oriented workloads.

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 4 [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 knowledgeable business partners, being more efficient due to the consolidated knowledge operating similar networks for several customers. The F5G-A 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 4 [i.2]). in addition to being reused for communication.

4.15 Evolution of Optical Networking Technology for Data Centres

Modern data centres are extreme large scale in terms of the number of processing node for computing and AI workloads. In order to have efficient AI training and inference, the interaction performance between different compute nodes is critical for the efficient operation of the data centre. Finally, data centres are going to be more distributed due to the amount of energy available at one location, the size limit of a single data centre in terms of number of processing nodes and their operation, and resilience against failures. Therefore, the data centre interconnection network needs to be upgraded in terms of speed and latency. The F5G-A network is used by end-users (residential, enterprises, industries) to access to the data centre services.

4.16 Support for Agentic AI

Agentic AI is an approach where AI agents operate services or task on behalf of persons or other agents. The interaction between AI agents is important to achieve a particular request. Since the AI agents can be located on any AI capable nodes, the AI agent need to be provisioned, controlled, and managed.

5 F5G-A Network Architecture

5.1 Architecture design principles

5.1.1 Quality on Demand (QoD)

Since the F5G-A architecture is service driven and enables a plethora of different services and applications, the 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, Release 2 [21] 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 AI capabilities and its interaction with the network

The addition of computing and AI capabilities (a special form of compute eventually requiring specific hardware support) to the F5G-A 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 4 [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. Finally, the fine-granular service shall be also provided over Point to Multi-Point (P2MP) fibre networks.

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.

5.1.8 Optical Networking in all Segments of the Network

The architecture in Release 3 was addressing many segments, but did not include the core network and the data centre networking aspects. From Release 4 onwards data centre networking and core optical network aspects are added. The F5G-A architecture Release 4 is a true end-to-end network architecture covering all segments from an end/ enterprise user devices or industrial devices to applications and services running on cloud processing elements in data centres. The data centres are of different size and location depending on the deployment and service characteristics needed for the applications and services proved from the cloud.

5.2 Architecture overview

5.2.1 Evolution to the F5G-A Architecture, Release 4

The F5G-A network architecture is an evolution of the F5G architecture Release 3 as described in ETSI GS F5G 024 [1]. The following features and changes are a summary of the evolution of the F5G-A network architecture from Release 3 to Release 4, as outlined in the present document:

- From computing planes to the use of computing for intelligent behaviour of the network including using optical communication for supporting AI application in the data centres or on the network equipment.

- Evolution of the scope in Release 4 from end-to-end networking (end user device to the core network) to include the intra-datacentre networking and inter-datacentre networking (for local as well as centralized data centres).
- Using optical sensing for improved operational excellence including co-route detection, detecting and monitoring the passive fibre fabric (access, aggregation, and core network).
- Improved Energy efficiency using intelligent mechanisms for powering on and off equipment and ports.
- Point-to-Multipoint OTN (P2MP OTN) improving the usage of (fg)OTN technology on P2MP Optical Distribution Networks (ODN), typically towards the edge of the network.
- Addition of Generative AI capabilities for various intelligent F5G-A tasks.
- Intelligent FTTR services enhancing the FTTR capabilities from networking to many more intelligent services for homes and businesses.
- The improved large-scale sensing and intelligent operation of industrial networks.
- PON based industrial optical networks as technology for the Fibre To The Machine (FTTM) scenario.

5.2.2 Architectural Overview

The F5G-A 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-A 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 evolve 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.

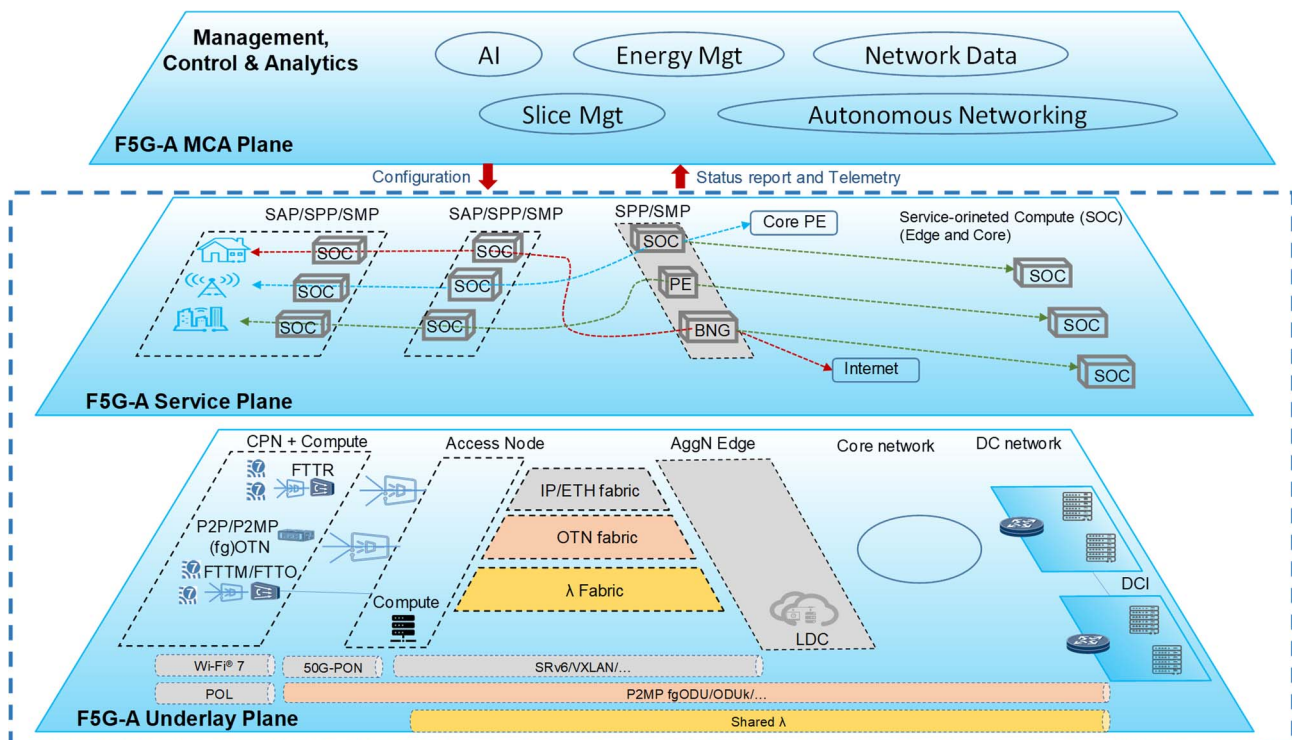


Figure 1: F5G-A network architecture, Release 4, with example service flows

The F5G-A network architecture consists of three planes, an F5G-A Underlay Plane, an F5G-A Service Plane and an 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 Service-oriented Compute including Artificial Intelligence Compute capabilities in the F5G-A Service Plane. The computing elements in the architecture are typically used for providing more intelligent, AI-based services, optimizing the network for best possible Quality of Experience of the service, and can provide intelligent services right from the network equipment. In the following more details for each plane is described.

5.2.3 The F5G-A Underlay Plane

5.2.3.1 Overview

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 five segments, Customer Premises Network (CPN), Access Network (AN), Aggregation Network (AggN), Core Network, and Data Centre Network (DCN).

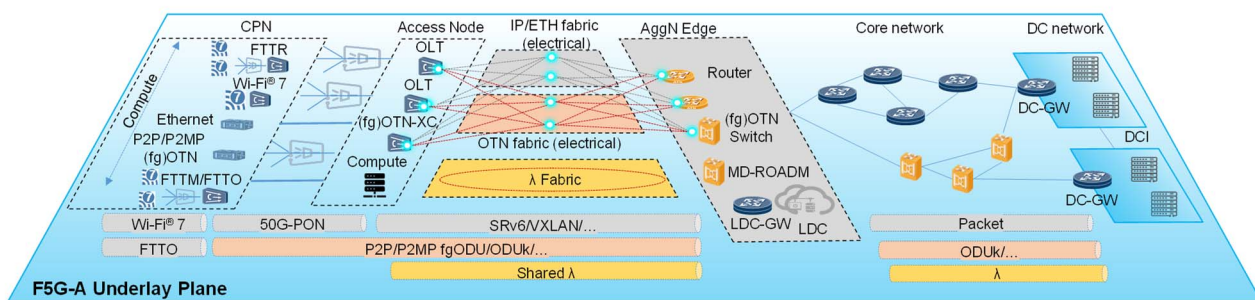


Figure 2: F5G-A Underlay Plane Architecture, Release 4

5.2.3.2 Customer Premises Network (CPN)

Various technologies are used in the CPN, depending on the customer requirements. In residential CPNs, Wi-Fi[®] 7 and 10G FTTR are used, while Enterprise CPNs benefit from 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 or cross premises services. This could be deployed for vertical industry applications (not shown in Figure 2) like in electricity grid control, communication in oil and gas transport, in urban or wide area transportation, etc. Naturally, traditional Ethernet CPN deployments are supported as well.

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

5.2.3.3 Access Network (AN)

The primary technology used in the Access Network shall be 50G-PON and P2P and P2MP (fg)OTN, or P2P Ethernet depending on customer type and service delivery requirements. 50G-PON is used for soft guaranteed, high-speed access for residential and enterprises customers. VPN services for Enterprise networking uses (fg)OTN in the case of firm guaranteed connections and hard isolated traffic requirements. The (fg)OTN based service can be offer over P2P or P2MP fibre fabrics. P2P Ethernet is supported as well.

5.2.3.4 Aggregation Network (AggN)

The Aggregation Network has three parallel fabrics, an IP/Ethernet fabric, an OTN fabric, and a 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.

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-A 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.

5.2.3.5 Core Network (CN)

The F5G-A underlay plane of the core network is all optical network using λ and OTN for wide area core networking functionality. The core network elements may contain compute functionality for AI-based optimizations and improved operations in the area of resiliency, monitoring, and quality of experience.

5.2.3.6 Compute Resources

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 2). In the Access Node, compute may be integrated or separated from the networking functionality. In the Aggregation Network Edge (AggN Edge), the Local Data Centre Gateway (LDC-GW) is located (shown in Figure 2). The LDC-GW may be connected with various networking technologies including IP/Ethernet or (fg)OTN. The Local Data Centre (LDC) in Figure 2 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. This cloud computing infrastructure includes large scale data centres requiring very high bandwidth access to the network and for those mission critical services also requiring highly guaranteed quality.

5.2.3.7 Data Centre Network (DCN) and Data Centre Interconnect (DCI)

Traditionally, a Data Centre Network was copper based technology connecting compute resources due to the short distances in DCN. However, for the new AI-oriented workloads and mission critical services running in the data centre, the Data Centre Network needs to be improved and shall use optical communication technology for guaranteed, ultra-high-speed networking, with low energy usage and simple operation.

For Data Centre Interconnection ultra-high-speed connections over some distance are required, since large AI workload cannot run in a single data centre anymore and for failover cases, the workload shall be distributed over different Data Centres.

5.2.3.8 General end-to-end functionalities

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 a traffic stream is configured by the F5G-A MCA Plane.

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.

5.2.4 The F5G-A Service Plane

The F5G-A Service Plane provides service connectivity for customers and the (cloud/AI)-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 [2]). 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.

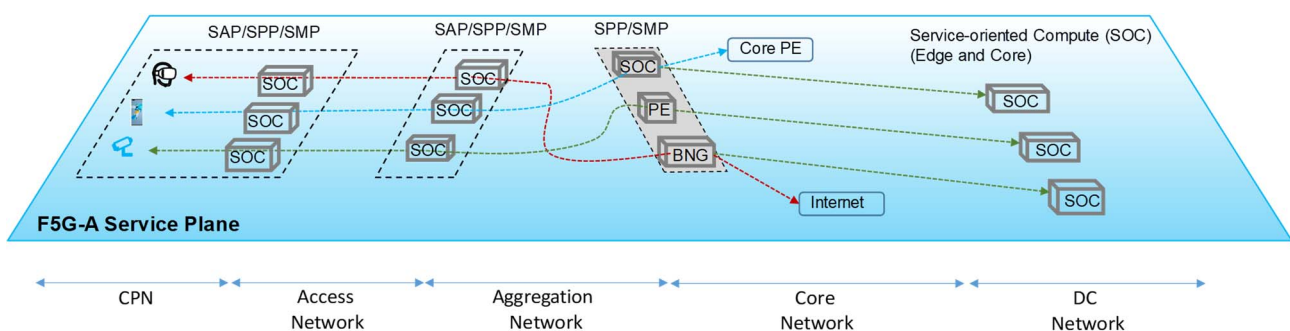


Figure 3: F5G-A Service Plane Architecture, Release 4

A Service Access Point (SAP) provides service access by a customer. A Service Processing Point (SPP) performs Layer 2-7 (L2-L7) service processing, which is enhanced by AI, which may be provided in the infrastructure with AI-optimized hardware. A Service Mapping Point (SMP) is where the service traffic is directed to appropriate F5G-A underlay fabrics and channels and eventually the F5G-A MCA Plane triggers changes of the F5G-A Underlay Plane connections.

The SAP is the access point that identifies the subscriber and user's application traffic and provides access to the operator's network services. Typically, the SAP is located on the ONU/MFU/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 may be used to identify the application type and whether an application is online/offline. This provides the necessary information for the SPPs and SMPs to take the appropriate actions.

The SPP is the point where service-specific processing of traffic is performed including service-specific compute including traditional compute, network-centric compute, or AI compute. Service processing refers to L2-L7 traffic processing achieving higher quality of the service or adapting application traffic to the particular traffic processing demand. The location of the SPP depends on the type of function and the SOC 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 include 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 may be located in the Customer Premises Equipment (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.

EXAMPLE 2: The residential customer's traffic is indicated by S+C, C VLAN tags, which 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 3: 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/MFU and a BNG are typical service connections.

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

EXAMPLE 4: 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 [2] 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 using the SOC functionality for deciding what control action needs to be performed.

The F5G-A Service Plane contains Service-oriented Compute (SOC shown in Figure 3) capability, which is used for network control and management functions as well as for providing intelligent services. The Service-oriented compute functionality supports a combined network and compute service to the users, where the compute services are traditional compute or AI-enhanced services. In the case that the service-oriented compute functionality 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 2 and Figure 3).

Figure 3 also shows data centres connected at the core network. Though the same holds true for LDC, but due to the expected smaller size they may not experience the same scaling issue as large data centres connected via a high-performance core network. Figure 3 also shows the SOC functionality for AI-based services offered to users. The SOC location depends on the particular functionality, privacy, and latency demands of the service oriented and AI-enhanced applications.

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 several logical components. However, the logical components may be implemented in a distributed, centralized or hybrid mode. The distributed functional allocation in the network topology is for further study.

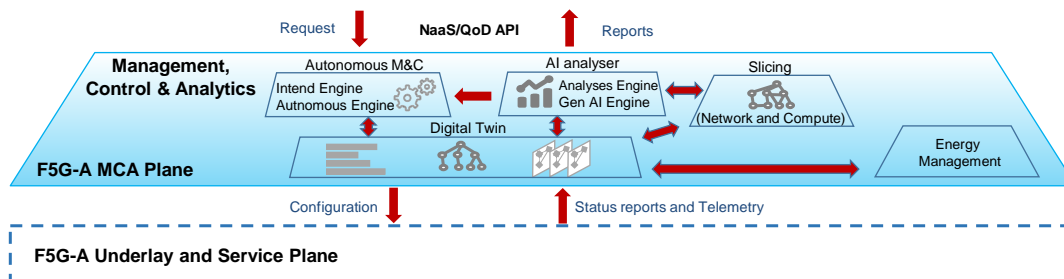


Figure 4: F5G-A Management, Control and Analytics Plane Architecture, Release 4

The logical components of the F5G-A MCA Plane are the following:

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 configuration 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.
- **Generative AI Engine (Gen 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. The operation of the network uses generative AI to learn and allow administrator to talk to the network in more natural language to get information and formulate commands for changes.

Slicing: Slice management and control is an important feature of an F5G-A 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) (Requests received through the NaaS/QoD API in Figure 4). It may choose to setup network and compute combined slices allowing for the installation of service specific compute at the appropriate locations as required.

NaaS: The NaaS/QoD API of the F5G-A MCA Plane 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 to perform the appropriate actions and reports back on status of the tasks.

Energy Management: The primary functionalities of the end-to-end energy management component in the F5G-A MCA plane is the monitoring of energy usage and running management mechanisms for reducing the energy usage adapting to the current network load. The energy monitoring can be based on measuring the energy usage directly in case the network equipment supports that measurement or the energy consumption is indirectly guessed based on heuristics using traffic measurement, counting powered-up network element. Energy saving mechanism manage powering off devices or components not used, reducing the power for low load connections, etc. It might interact with the AI analyser for generating energy usage maps and the Autonomous M&C for creating intents to save energy and appropriately configure the energy saving measures in the network.

Domain Controllers: The F5G-A MCA Plane 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 further details in the F5G-A End-to-End Management and Control Architecture [4].

5.2.6 Cross-Plane Computing

A feature added in the F5G-A 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 5 shows the migration from F5G to F5G-A adding the cross-plane computing feature.

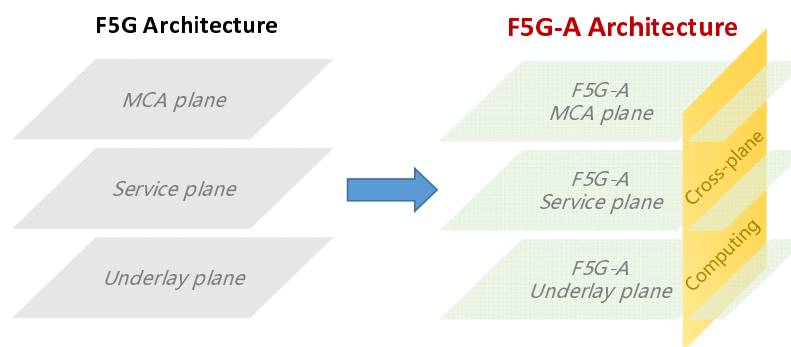


Figure 5: Addition of Cross-plane Computing

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.

For any type of AI-related operation or workloads compute functionality with appropriate AI optimized hardware is a pre-requisite for any sort of AI-services and AI-based operation.

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 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 2: 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 MCA Plane, most F5G-A MCA Plane function require compute and storage functionality.

EXAMPLE 3: 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.

EXAMPE 4: Functionality for the use of compute in the F5G-A MCA plane includes 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 5: 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

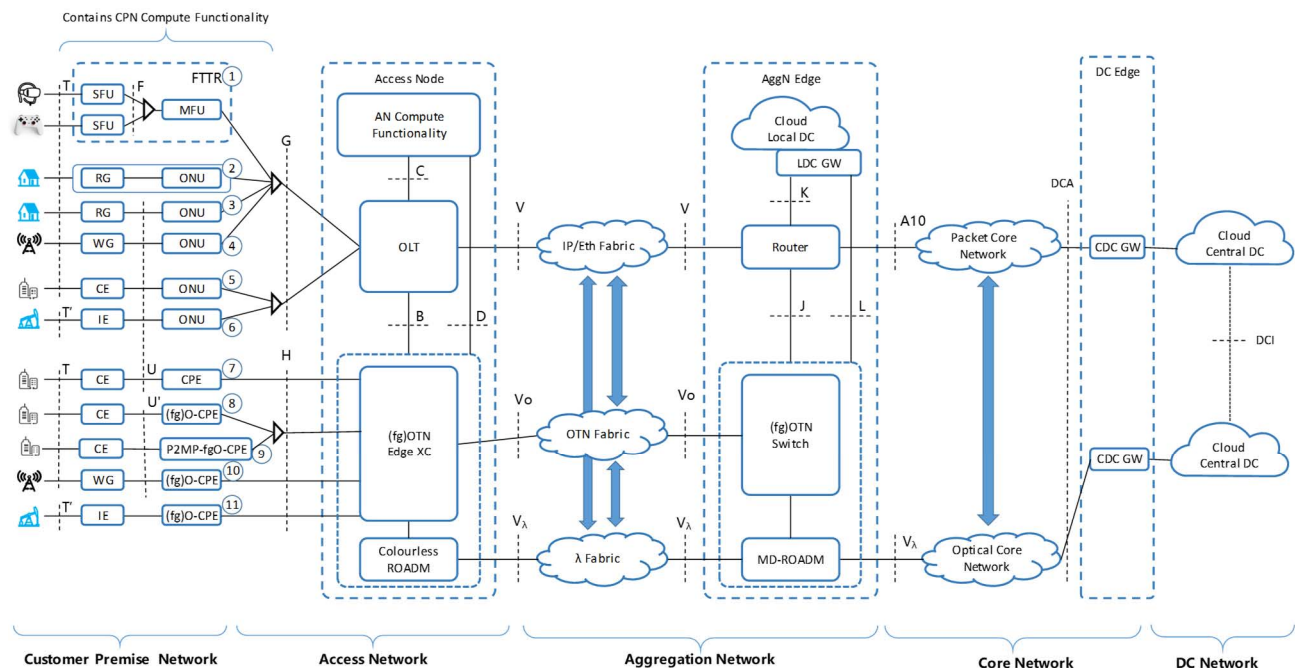
5.3.1 Network Overview

5.3.1.1 General Topology Overview

The F5G-A network architecture Release 4 is an evolution of the F5G network architecture Release 3 as described in ETSI GS F5G 024 [1]. The enhancements of the F5G architecture Release 4, compared to Release 3 are listed in clause 5.2.1 of the present document. The F5G-A network architecture Release 4 adds several network components to the F5G-A network architecture Release 3 both in the network topology as well as in terms of additional or changed interfaces.

Figure 6 shows the F5G-A network topology Release 4 segmented into the Customer Premises Network, the Access Network, the Aggregation Network, the Core Network, and the Data Centre 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 6.

In general, Figure 6 shows the data plane perspective of the F5G-A network architecture for the F5G-A underlay as well as the F5G-A 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.9]. In general, a colourless ROADM is part of the Access Node, however, a coloured ROADM might be used, which is for further study.

Figure 6: F5G-A Network Topology Release 4

- 1) In the Customer Premises Network different scenarios and deployment options are possible and are shown in Figure 6. The following describes the network deployment options as numbered in Figure 6: FTTR is comprised of a MFU, passive splitter(s) and several SFUs (depending on the size of the Customer Premises Network). The link between MFU and the SFUs 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) 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 P2MP-fgOTN-Customer Premise Equipment (P2MP-fgO-CPE) such that fgOTN technology is used on a Point-to-Multipoint optical distribution network (ODN) and traffic is separated and isolated on the P2MP-fgO-CPE. (fg)O-CPEs can run on the same ODN. See clause 5.3.1.2 for more details on extensions for the Enterprise CPN.
- 10) 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.
- 11) 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/ P2MP-fgO-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 6 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 6. 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 V_o 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 6 shows three networking technologies, including an IP/Ethernet fabric, an OTN fabric, and a λ fabric:

- The IP/Ethernet fabric is the traditional deployment option for best effort residential Internet services.
- The OTN fabric is a deployment option for premium services for residential, enterprises or vertical industries.
- The λ fabric facilitates a green all-optical network from the Access Network to the Core Network without any optical-electrical-optical conversion, i.e. 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 6). 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 6 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 V_o 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 run 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.

For the Core Network, 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 (not shown in Figure 6). 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 6).

Figure 6 shows two Central Data Centres (CDC) for the central compute resources and functionality. CDC-GWs are connected to the packet core network and/or the Optical Core Network via the DCA interface. In the case of several central data centres, they may be interconnected by data centre interconnection technology via the DCI interface.

For the Data Centre Network (DCN) used within the Cloud Central DCs, see clause 5.3.1.4 for more details.

The details of the interfaces in Figure 6 are described in clause 5.3.2. The interface naming is the same as for the F5G architecture Release 3 [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-A network architecture. The meaning of interfaces, as specified in Figure 6, 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 7. The FTTO scenario may also use option 7) from Figure 6, 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 7) may be used. Figure 7 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 6, where the FTTO equipment is simplified as Customer Equipment (CE).

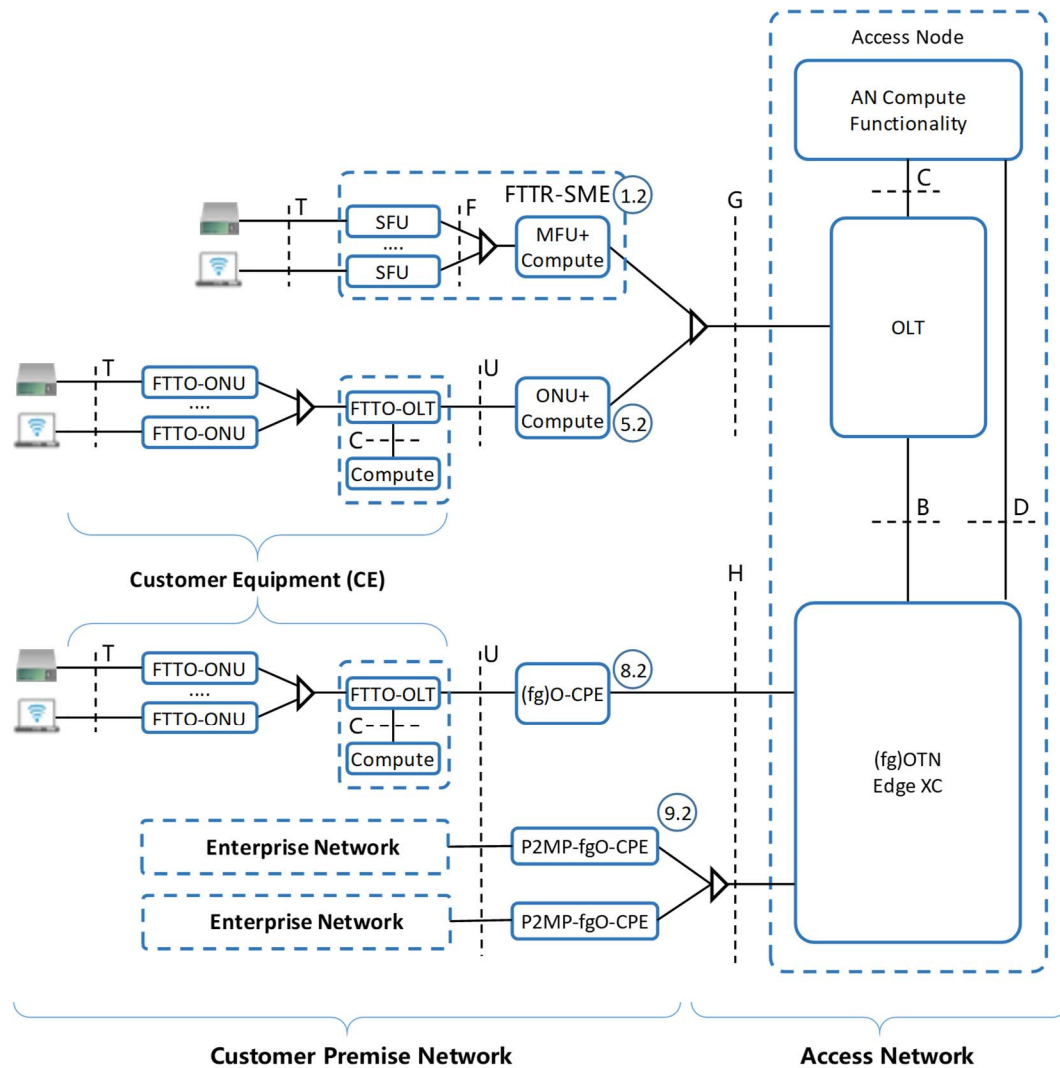


Figure 7: Enterprise CPN Scenario

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 6. The MFUs may 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 6. 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 6. The FTTO-OLT might contain CPN compute functionality.
- Option 9.2 P2MP fgOTN access for enterprise networks: The option is the same as option 9) in Figure 6 and does not show any enterprise network details and can work with Option 8.2 or any other enterprise network technology.

Compared to Figure 6 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 8 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 6 and Figure 7. 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 7 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.

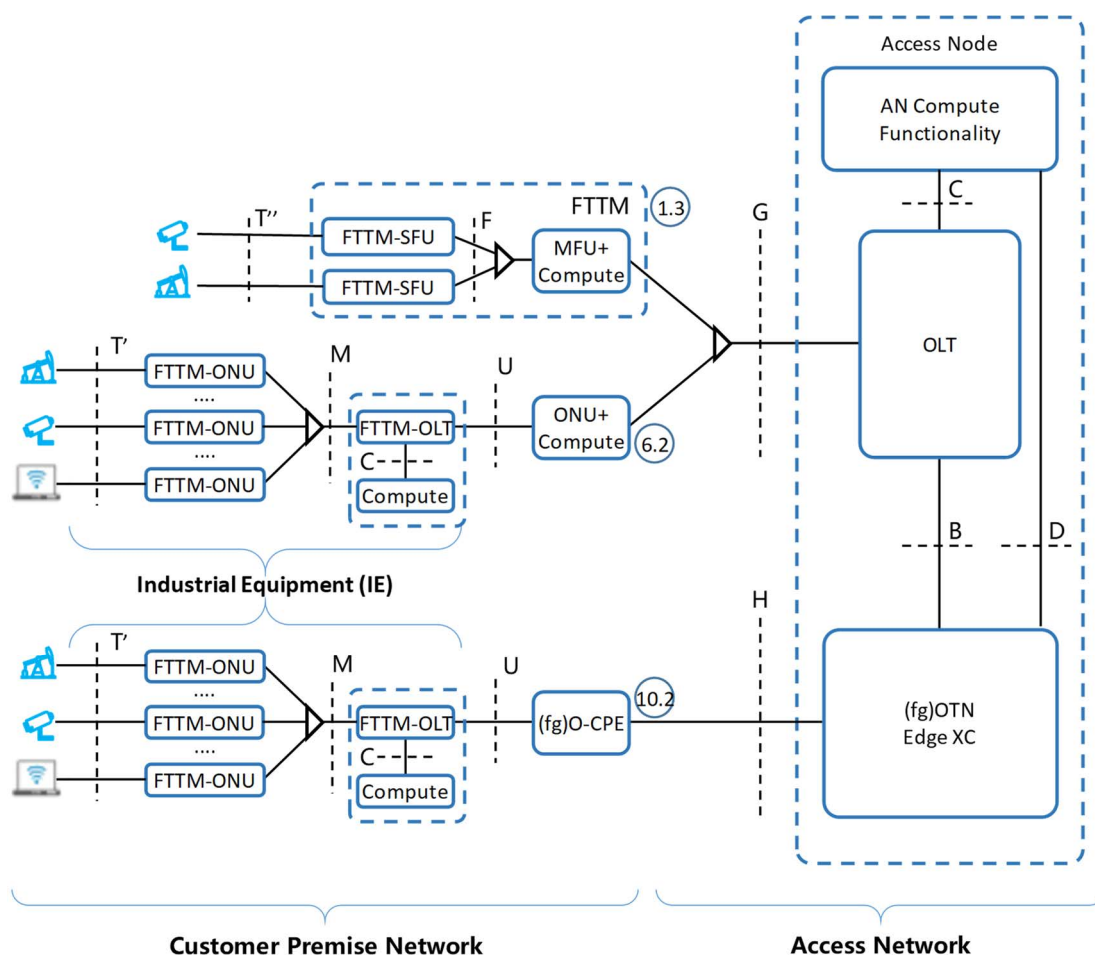


Figure 8: Industrial CPN Scenario

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 6. It is particularly relevant for small industrial sites. Besides industrial application also office and usual Enterprise applications need to work over the FTTM infrastructure. The MFUs might contain CPN compute functionality. The FTTM-SFU is an industrial variant of an SFU (shown in Figure 6) 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 6. 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. The ONUs and the FTTM-OLT may 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 6. In general, option 7) in Figure 6 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 endpoint of robots or manufacturing machines due to the strict delay requirements. The use of P2MP fgOTN for this access is for further study.

Compared to Figure 6 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.

Details of FTTM are described the PON based industrial network specification in [12]. Specific low latency and deterministic networking functions are for further study.

There are F5G-A use cases described in ETSI GR F5G 032 [i.2], which assume a CPN using OTN technology for hard isolation and guaranteed services with time synchronization. This applies specifically for mission critical applications such as power grid or railway communication networks. This case is not shown in Figure 8 and can be regarded a complete dedicated service specific network or as a large CPN. Very large scale CPN are for further study.

5.3.1.4 Networking in Data Center Scenarios

The network within a data centre assumes a traditional data centre layout with compute nodes, single racks, or multiple racks of compute and storage resources. Compute nodes can be traditional compute nodes or AI-optimized hardware nodes. The compute resources are networked within a Data Centre and across Data Centres using a data centre interconnection (DCI). The Data Centre provides network access to the services and applications running in the data centre by a Data Centre Access (DCA) from the end user's (residential, enterprise, or industrial customers). The DCA interface to the applications and services are depicted in Figure 6 running over a Data Centre Gateway (DC-GW). The DCA is connecting to the end-to-end F5G-A network at different locations. In case the data centre is located next to the aggregation node, the DCA interface may also be the K interface (see Figure 6).

5.3.2 Definition of Interfaces

5.3.2.1 T interface

The T interface is between the SFU/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 may be other types of interfaces like Bluetooth[®] or DECT[™]. Such interfaces shall be translated to Ethernet/IP protocols before being transferred to the SFU/Gateways/CE devices.

5.3.2.2 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 over PON or directly over PON network protocols on the IE devices. The T' interface shall at least support the industrial interface to the PON based industrial networks as specified in ETSI GS F5G 022 [12].

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.

5.3.2.3 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 6. In case it is an external interface, it shall support Ethernet [16] as shown in Figure 9.

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.

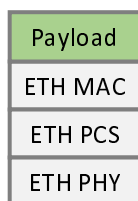


Figure 9: Protocol stack on the U interface

5.3.2.4 U' interface

The U' interface is between the CE/WG/IE and the (fg)O-CPE. For an (fg)OTN Access Network, the (fg)O-CPE is considered an extension of that (fg)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 [16], but may support legacy PDH/SDH protocols. The protocol stacks on the U' interface is depicted in Figure 10.

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.

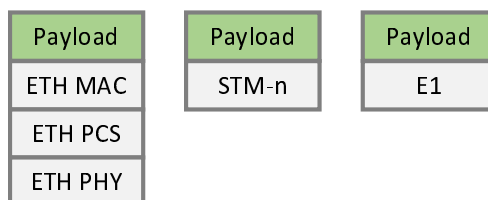


Figure 10: Protocol stacks on the U' interface

5.3.2.5 F Interface

The F interface is between the SFUs and a MFU. It uses a point-to-multi-point fibre on premises ODN in the CPN. The F interface shall implement either Recommendation ITU-T G.9941 [5] and Recommendation ITU-T G.9942 [6] or the G.Xfin specification currently under development in the ITU-T Work Items G.Xfin-PHY [i.10] and G.Xfin-DLL [i.11].

5.3.2.6 G Interface

The G interface is between the ONU/MFUs 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]).

5.3.2.7 H Interface

The H interface is between the CPE, (fg)O-CPE, or the P2MP-fgO-CPE and the (fg)OTN Edge XC. It is a point-to-point or a point-to-multi-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 (Recommendation ITU-T G.709 [8] and Recommendation ITU-T G.709.20 [9]) or P2MP-(fg)OTN [i.12]. In case of scenario 7) in Figure 6, a CPE using Ethernet [16] as access network technology is used.

5.3.2.8 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 [16] or an OTUk (k=0, 1, 2, 3, 4), which supports the transport of OTN and fgOTN (Recommendation ITU-T G.709 [8] and Recommendation ITU-T G.709.20 [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.

5.3.2.9 C interface

The C interface is between the OLT and the AN compute functionality in the Access Network node. This is an Ethernet interface [16], 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 11.

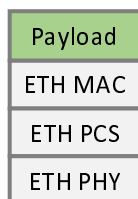


Figure 11: Protocol stacks on C interface

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

5.3.2.10 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.

5.3.2.11 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 12.

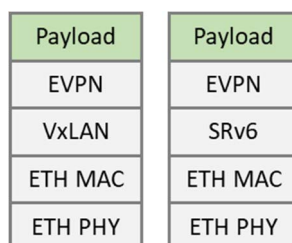


Figure 12: Protocol stacks on V interface

5.3.2.12 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 OTU_k ($k = 0, 1, 2, 3, 4$) for bandwidth requirements between 1,25 G up to 100 G or OTU_{Cn}/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.

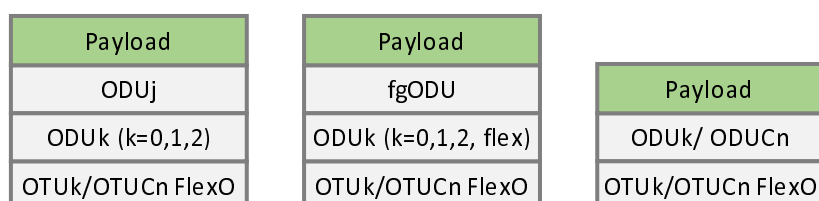


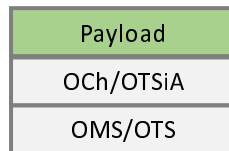
Figure 13: Protocol stacks on V_o interface

5.3.2.13 V_λ interface

The V_λ interface as shown in Figure 6 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 [15].



**Figure 14: Protocol stacks on V_λ interface
(based on Recommendation ITU-T G.959.1 [15])**

5.3.2.14 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 15. 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 [16].

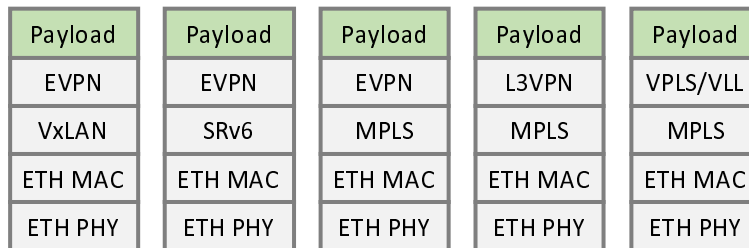


Figure 15: Protocol stacks on A10 interface

5.3.2.15 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 [16] link. Protocol stacks on K interface are depicted in Figure 16.

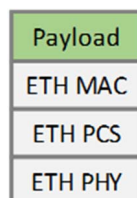


Figure 16: Protocol stacks on K interface

5.3.2.16 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.

5.3.2.17 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 [16] or an OTUk (k=0, 1, 2, 3, 4), which supports the transport of OTN and fgOTN (Recommendation ITU-T G.709 [8] and Recommendation ITU-T G.709.20 [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.

5.3.2.18 DCI interface

The DCI interface (see Figure 6) is an interface between two Data Centres or between a data centre and the network, which connects to other data centres connected to a network. Figure 6 shows the DCI interface between different Cloud Central Data Centres, however, other deployments including the DCI between Local DCs (LDC) and Central DCs (CDC). The DCs interconnect to each other via direct fibre, a packet core network, or an optical core network. Details of the DCI interface are for further study.

5.3.2.19 DCA interface

The DCA interface (see Figure 6) is for allowing end-users, enterprises, or industrial networks connecting to the data centre to access applications and services running in the data centre. Depending on the F5G-A deployment options possible, the DCA interface might be quite diverse. The DCA interface is for further study.

5.3.2.20 M Interface

The M interface is between FTTM-ONU equipment and FTTM-OLT equipment. The M interface shall conform to the PON based industrial network specification as defined in ETSI GS F5G 022 [12].

5.3.3 Near real-time Control Topology

The near real-time control topology of the F5G-A network architecture is shown in Figure 17.

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 17 is a simplified version of Figure 6 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.

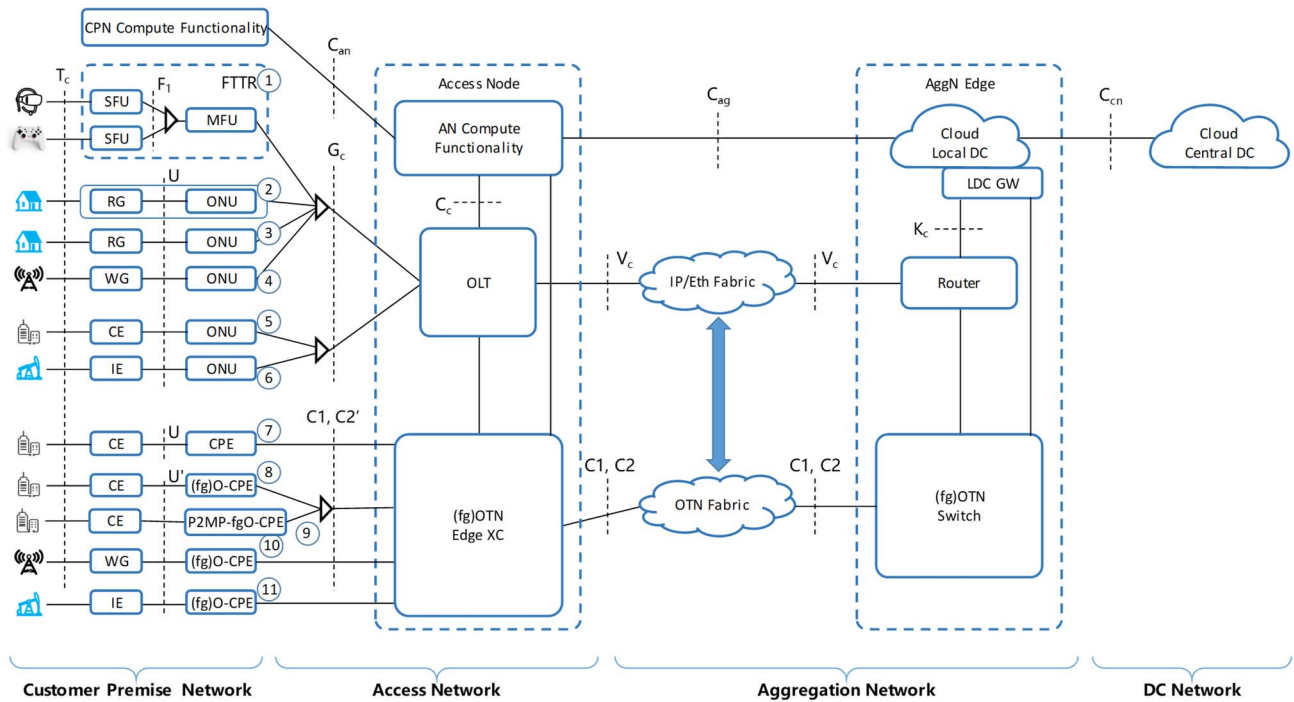


Figure 17: F5G-A Control Topology, Release 4

The non-real-time control is traditionally called network management. The management functional framework is not shown in Figure 17 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 SFUs should be achieved over the F1 interface. This requires an architecture that reflects fibre and wireless (Wi-Fi[®]) integration within FTTR (shown in Figure 18), forming a single cascaded multiple link LAN through centralized control (Recommendation ITU-T G.9940 [18]).

The centralized control procedure is shown in Figure 18. The MFU collects the Wi-Fi[®] status information, from the SFU Wi-Fi[®] entities. Such status information is sent from the SFUs to the MFU through the F1 interface. In addition, the controller in the MFU sent the actions and control strategy to be performed by the Wi-Fi[®] module of the SFUs. The F1 interface shall support the Recommendation ITU-T G.9943 [13] Fibre Management and Control Interface (FMCI) and Wireless Management and Control Interface (WMCI) (Recommendation ITU-T G.9949 [22]). The two control interfaces may run in separate and isolated channels.

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 K_c and the C_c interface is for further study.

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

In F5G-A 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-A network topology in Figure 19. 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:

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

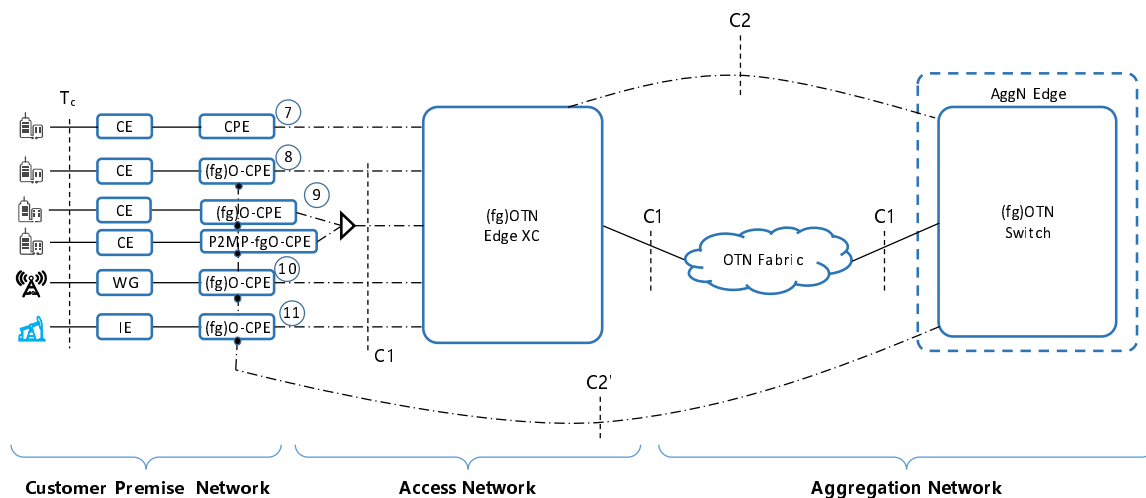


Figure 19: (fg)OTN control interfaces

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/P2MP-fgO-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:

- To transmit the signalling messages used to create, modify or delete (fg)OTN network connections automatically. The F5GA control and management system will trigger this signalling process (not shown in Figure 19 for simplicity).
- To transmit the signalling messages used for bandwidth adjustment of the (fg)OTN network connections. A typical network scenario is the F5G-A use case Release 4 [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.

- 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/P2MP-fgO-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 F5G-A 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:

- To learn and exchange the Ethernet MAC and 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 P2MP-fgO-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.
- 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 OCN Architecture [2]. The requirements of OCN Architecture [2] shall apply. The protocol design of the C2 and C2' interfaces are out of scope of the present document and are for further study.

Since the (fg)O-CPE/P2MP-fgO-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/P2MP-fgO-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 20). 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:

- 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 $F1$.
- C_{ag} : The interface performs the coordination and control between the compute functionality in the AggN Edge node and the access node(s).
- 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 C_{an} and C_{ag} may use interfaces G_c and V_c jointly for achieving the control required.

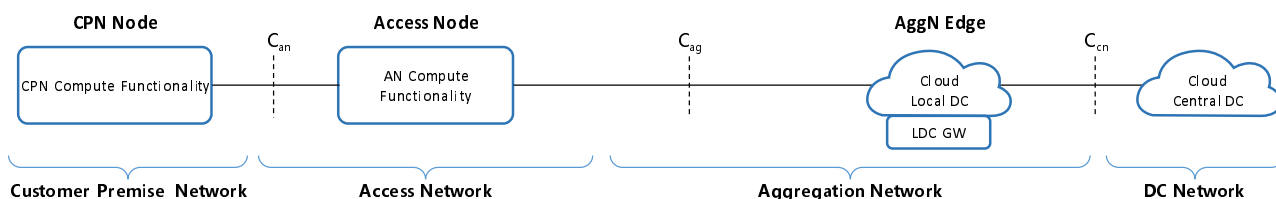


Figure 20: Compute control interfaces

Depending on the particular compute functionality and its location, the interface may 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 AI-enabled Fixed Access Network 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 configuration of the optical broadband network is rather static in behaviour, not able to adapt to the service and applications which are much more dynamic in terms of network needs. The F5G-A generation definition [i.1] and the requirements and gap analyses [3] require the F5G-A architecture Release 4 to support mechanisms for a variety of broadband network services as part of flexible subscription packages and flexibility of network configuration per application. The main features of the AI Fibre Access Network architecture include network capabilities being accessible through APIs, realizing Network as a Service (NaaS), and provides differentiating service capabilities using AI compute functionality in the various network elements. Cloud platforms and services use the network services in an on-demand paradigm.

The AI-enabled fixed access network architecture is an enhancement and extension of the FAN Intelligent Engine (FIE) architecture as described in clause 5.4.1 of ETSI GS F5G 024 [1] with addition of AI-based computing at various network elements. The basic concepts of the AI-enabled fixed access network architecture are the programmability through APIs, the AI-based application aware traffic handling and optimization, and the support of Agentic AI as a Service. The real-time and non-real-time control of the architecture, and the use of AI/computing functionality to improve the network and service quality.

5.4.1.2 Overview

The basic system architecture of the AI-enabled fixed access network consists of customer premises network equipment running various types of applications and accesses to AI services in the network. The Customer Premises Network (CPN) in Figure 21 is expected to run in residential and enterprise scenarios. The CPN is connected to the AI Access Node through data plane and control plane interfaces (see above). The AI Access Node contains data, control, management, and service plane functionality. For providing this functionality, software runs on AI or traditional compute functionality on the AI Access Node. Figure 21 also shows the AI Aggregation Network Node, but is not further detailed and is for further study. The data and control plane interfaces are described above. Finally, as part of the management system, AI/Compute service provisioning functionality is managing the AI and traditional compute function in the CPN as well as in the AI Access Node.

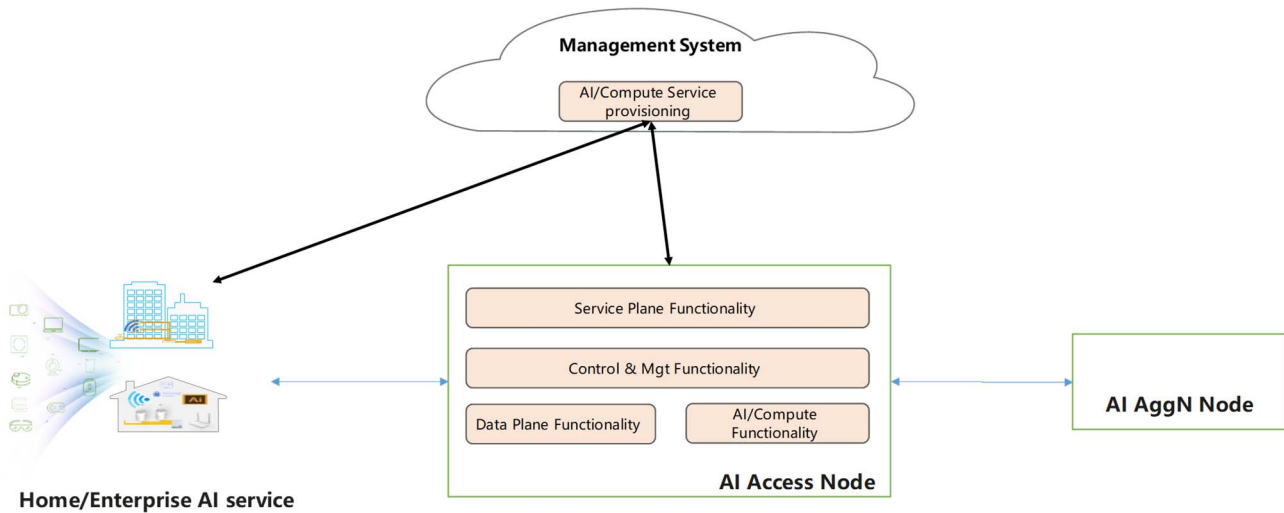


Figure 21: AI-enabled fixed access network overview

In clause 5.4.1.3 to clause 5.4.1.7, various functions in the context of the AI-enabled fixed access network architecture are further detailed.

5.4.1.3 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.

5.4.1.4 The App-Flow application: A step beyond Slicing

The F5G architecture Release 2 [21] specifies the F5G concept of a network slicing feature. All specification in the F5G architecture Release 2 [21] 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 AI-enabled fixed access network 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 AI-enabled fixed access network 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.

5.4.1.5 The F5G-A Access Node Architecture for AI-enabled fixed access network

The F5G-A Access Node architecture for AI-enabled fixed access network, as shown in Figure 22, consists of an Access Node (see Figure 6), a management system, and CPNs.

The F5G-A AI Access Node for the AI-enabled fixed access network architecture consists of an OLT service system and an AI/computing service system. The data plane components of the OLT service systems interact via the Export interface (see Figure 22) with the AI/Compute service system. The control plane components of the OLT service systems interact via the OLT Service interface (see Figure 22). The F5G-A AI Access Node has an interface to the management system for the App-Flow provisioning and monitoring and AI/Compute function management.

NOTE 1: Other aspects of the F5G-A AI Access Node, the ONUs, or the management system not related to AI-enabled fixed access network are not described here. Figure 22 shows the additional functionality of the management system specifically for the App-Flow service provisioning and AI/Compute function management. The management aspects for other functions of the Access Node are not shown.

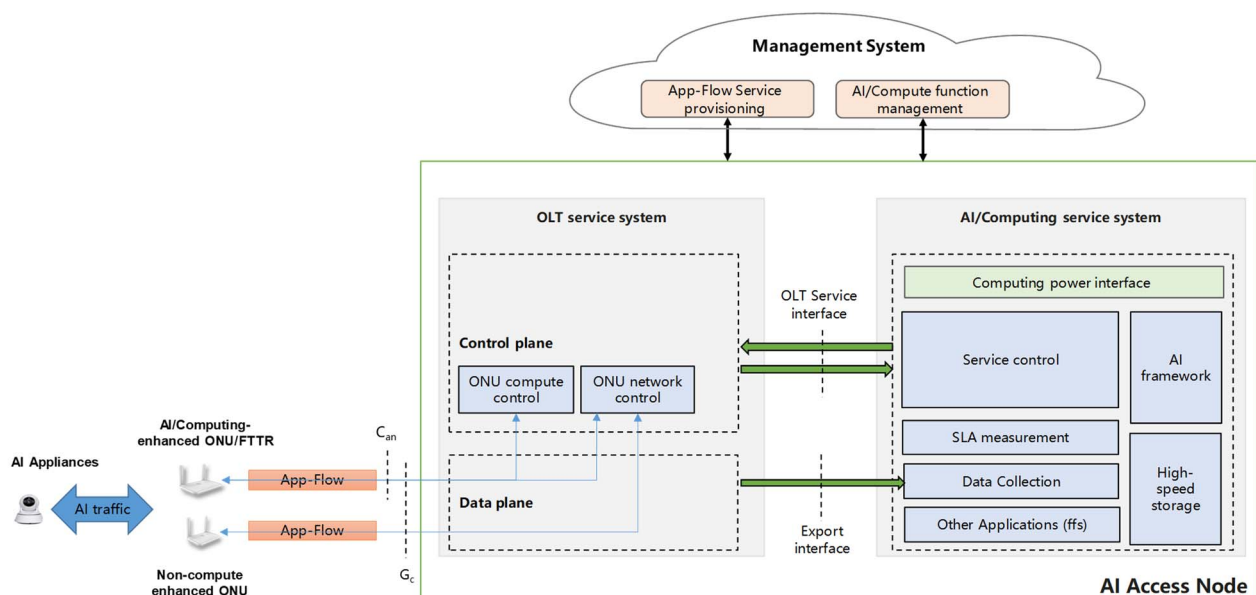


Figure 22: F5G-A AI Access Node Control Architecture for AI-enabled Fixed Access Network and AI Traffic

The key aspects of the AI Access Node architecture include:

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

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

AI appliances running in the home or enterprise customer premises network are sending and receiving AI-related traffic. The AI traffic requires specific handling between the AI appliance and the AI service (located either on the AI/Computing-enhanced ONU/FTTR, the AI Access Node, or in the cloud) with training and interference capabilities.

NOTE 2: The AI training and interference capability can be provisioned in the different locations on the AI-enabled fixed access network or in the cloud not shown in Figure 22.

5.4.1.6 Agentic AI as a service

The concept of Agentic AI is the use of several AI compute instances providing different AI services interacting with each other and providing combined output to the end user. In the context of the AI-enabled fixed access network that means that the FTTR equipment in the home and enterprise premise networks have built-in storage capability and AI compute capabilities, which can be used for small memory footprint and low compute power AI agents. However, those AI agents will interact with AI Agents on the AI Access Node and AI Agents running in edge or core data centres, which are typically the large AI models and large data training tasks. Also, since several different appliances and different sized screens are running in the CPN, interaction between all those AI agents within the home and enterprise need to be coordinated and collaboration between the different AI agents need to be enabled with the appropriate network quality, which requires also for the FTTR network on-demand QoS.

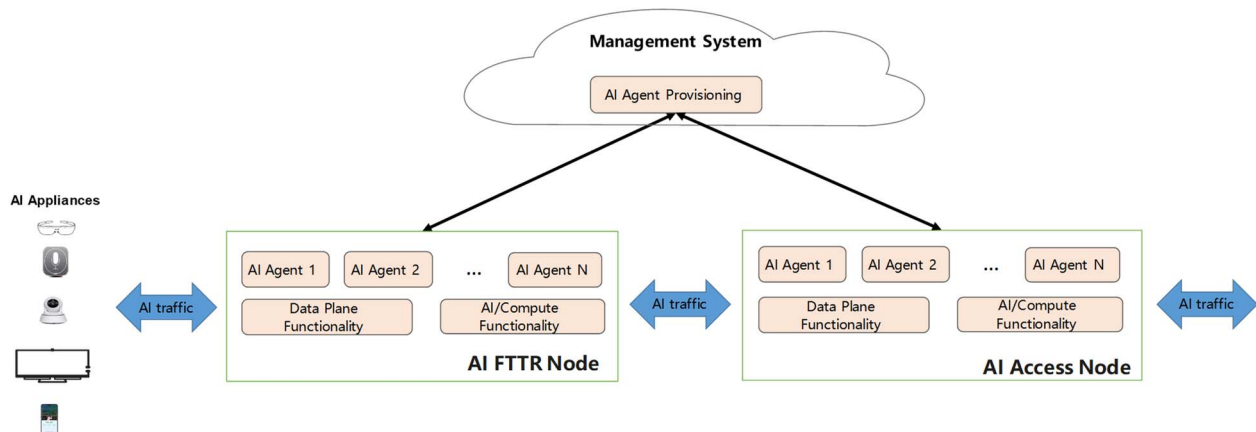


Figure 23: Agentic AI in AI-enhanced fibre access networks example

Figure 23 shows an example setup with AI appliances interacting with AI agents on AI FTTR Nodes and/or AI Access Nodes. The core or edge data centres are not shown in Figure 23. On the AI FTTR Nodes and AI Access Nodes the AI traffic can be directed to AI agents or forwarded to the next hop. The AI/Compute functionality on that nodes are either traditional compute or AI-optimized functionalities.

5.4.1.7 Self-optimization AI-enabled fixed access network

With the AI compute functionality on the FTTR and Access Nodes, the optimization of the Wi-Fi can be done automatically, since the end user devices locations, movement patterns, Wi-Fi® behaviour can be learned and acted appropriately for the best home or enterprise AI service experience. It also allows to optimize the spectral and energy efficiency. The ODN in the access network and the CPN can be monitored through sensing and AI training and therefore faults can be located efficient and quick.

5.4.2 F5G-A Transport and Data Center Network Architecture

5.4.2.1 Overview

The F5G-A transport and Data Centre Network architecture is driven by the move from cloud computing to AI-based computing. This is also the largest difference from Release 3 to Release 4 of the F5G-A network architecture. The move has an impact on the transport network and the Data Centre Network. In Figure 24, the three main aspects are shown:

- The AI Data Center Access (AI DCA) is the connection from end user or enterprise systems and appliances to the AI compute in the cloud data centre. The connection needs low latency and reliable connected, since the access to AI is mission critical for businesses and a very good experience for residential users.
- The AI Data Center Interconnection (AI DCI) is the connection between data centres. Due to the large AI models, which need to run across several data centres, specific attention to this segment of the networks needs to be paid. The AI DCI requires very low latency and high bandwidth due to the data for AI large models are exchanged. Zero packet loss or interruption is acceptable since any packet loss has a high impact on the AI computing efficiency.
- The AI Data Centre Network (AI DCN) is the intra Data Centre Network, which has more advanced requirements when AI workloads are processed. The bandwidth between GPUs and between GPUs and storage systems are large and latency shall be extremely low, otherwise it has an immediate effect on the AI compute efficiency. The AI DCN also needs to scale up and scale out due to the size of the AI models being process and trained. Finally, data centres networking needs also to reduce the energy footprint, where the networking part shall reduce its energy usage as well.

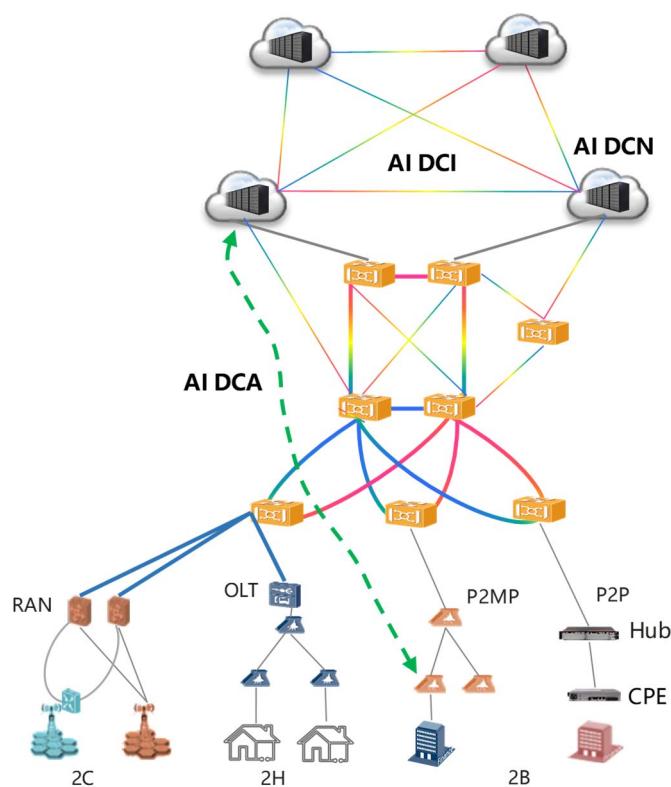


Figure 24: Overview Transport and Data Centre Networking

Figure 24 shows that the transport and data centre networking are independent of the access network technologies. Access network technologies include mobile radio access networks, Passive Optical Networks (PON) to the home, and business network access. The transport and DCNs are the backbone and backhaul of all those access technologies.

5.4.2.2 Technical Solutions and Requirements

5.4.2.2.1 AI Data Centre Access (AI DCA)

The AI DCA covers different segments of the end-to-end network and therefore various technologies are used in the different network segment. On the enterprise access F5G-A Release 4 shall support point-to-multipoint (P2MP) fgOTN for running over P2MP fibre installations and reducing complexity and energy usage through P2MP fgOTN.

From the Access Node to the Aggregation Network Node F5G-A Release 4 shall support Wavelength-shared WDM Fabric as described below. In the core network, the F5G-A Release 4 network architecture shall support 400 G - 1,2 Tbps OTN per wavelength in the C+L bands. See also below on the architecture of the OTN Fabric.

The AI DCA network shall support dynamic setup, teardown, and adaptation of the connections, since the cloud and AI application behaviour is dynamic in nature and build on the on-demand paradigm, which the end-to-end network needs to follow. Specifically, for private line use cases, the connection shall be hard isolated from other traffic and be adaptive to changing traffic behaviour in short timescales.

The use of AI computing capabilities for the operation of the network and connections shall be supported. Specifically, the optimized scheduling and traffic mapping benefits from AI capabilities to achieve the best user experience. AI is used to detect failures and perform fast switch-over for high reliability. The AI processing is based on fine granular measurements and monitoring of the network to quickly react and take appropriate actions to resolve networking problems.

5.4.2.2.2 AI Data Centre Interconnection (AI DCI)

The AI DCI network is between data centres with different reach requirements depending on the data centre deployment strategy. Also, the DCI can be a pure point to point connection or more a network with connections between DCs. The F5G-A Release 4 architecture shall support both cases. Depending on the deployment the DCI may be more of an optical only or an electrical and optical interface. A set of key features of AI DCI are important when migrating to more AI-oriented data centres.

The AI DCI shall have zero packet loss in case of connection failures, because AI processes are very sensitive to packet losses. Therefore, specific technologies shall be supported to have 1+1 protection. AI processing many times use Remote Direct Memory Access (RDMA) protocols for efficient access to memory across AI data centres. To prevent congestion on the AI DCI interface, the network shall be aware of RDMA traffic and schedule and handle it such that no congestion will occur.

The setup and teardown of AI DCI connections shall be dynamic, automatic and available in a short time. So, wavelength and connection planning shall be performed dynamically and the provisioning of the DCI shall be done automatic.

5.4.2.2.3 AI Data Centre Network (AI DCN)

The AI DCN connect the different computing elements in the data centre including processing units (for example, GPUs and CPUs), storage and memory. The AI DCN network shall support the scaling up to several 100'000s of processing units being connected. The AI DCN shall be energy efficient and therefore shall support all optical communication technologies. The AI DCN shall support Optical Cross Connect (OXC) based networking between the different elements. In addition, the OXC-based AI DCN network shall interoperate with legacy DCN networking since as a first step not the full data centre might be equipped with all optical networking. Details of the AI DCN are for further study.

NOTE: The approach of Optical Cross Connect (OXC) based networking in data centres is called Optical Circuit Switching (OCS) for data centres by various industry organizations.

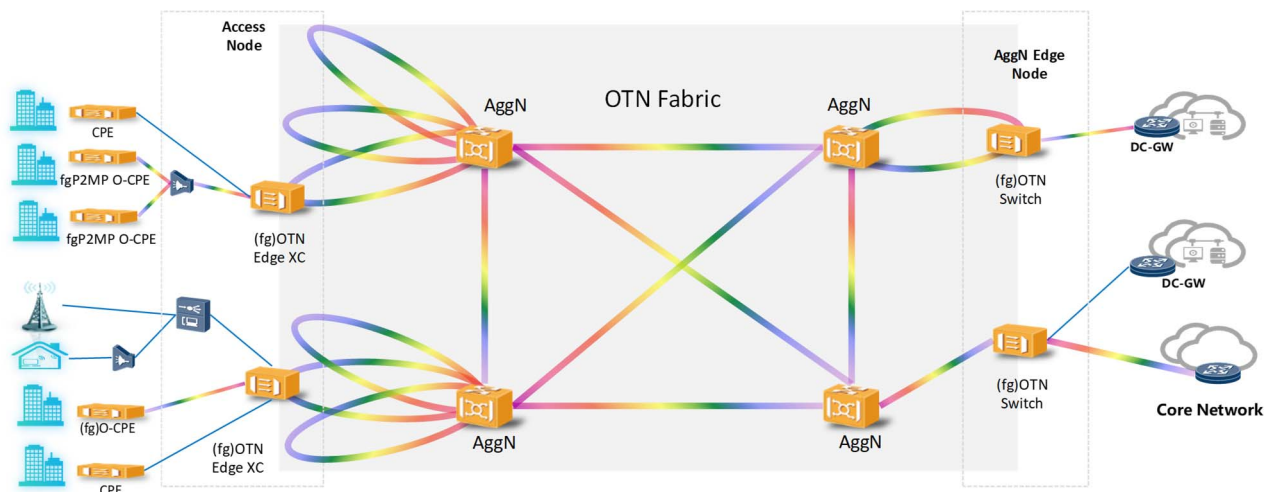
5.4.2.3 OTN Fabric

The F5G OTN topology has evolved to a mesh topology, called an OTN fabric in the context of the F5G architecture Release 2 [21]. See F5G architecture Release 2 [21] for the motivation for the that evolution.

The F5G-A OTN fabric is enhanced with fine grain functionality (in steps of 10 Mbit/s) enabling a more efficient bandwidth utilization of the OTN fabric. In addition, it enables hitless bandwidth adjustment in steps of 10 Mbit/s. In addition, the OTN Fabric shall support 400G – 1.2Tbps OTN connections per wavelength in the C+L bands.

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 the OTN fabric switching nodes:

- The OTN access consists of different deployment options including P2P Ethernet, P2P (fg)OTN, and fgP2MP OTN. Compared to the F5G-A Release 3 network architecture [1], the addition of the P2MP feature for OTN has been added. The benefit of that feature is a lower complexity and low energy variant for OTN access running over point-to-multi-point fibre optical distribution networks.
- The (fg)OTN Edge XC perform the aggregation and appropriate access functionality for residential broadband, leased line ((fg)OTN, fgP2MP 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-A networks, the (fg)OTN Edge XC is collocated or an integrated part of the access node.
- 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.
- The AggN (as shown in Figure 25) 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 may 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 25: OTN Fabric Architecture

The OTN Fabric architecture (Figure 25) has the following characteristics:

- **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.
- **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. From F5G-A Release 4 network architecture, a novel feature is the capability to run P2MP fgOTN in the access in order to more flexible handle different fibre deployments, which already exist and which can be reused.
- **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.
- **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 the F5G architecture Release 2 [21] for other options for the Aggregation Network. Figure 26 shows multiple WDM rings connected with the M*N WSS in the AggN Edge of the F5G-A topology as shown in Figure 6. The nodes called Central Office (CO) in Figure 26 are part of the Access Node in Figure 6.

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

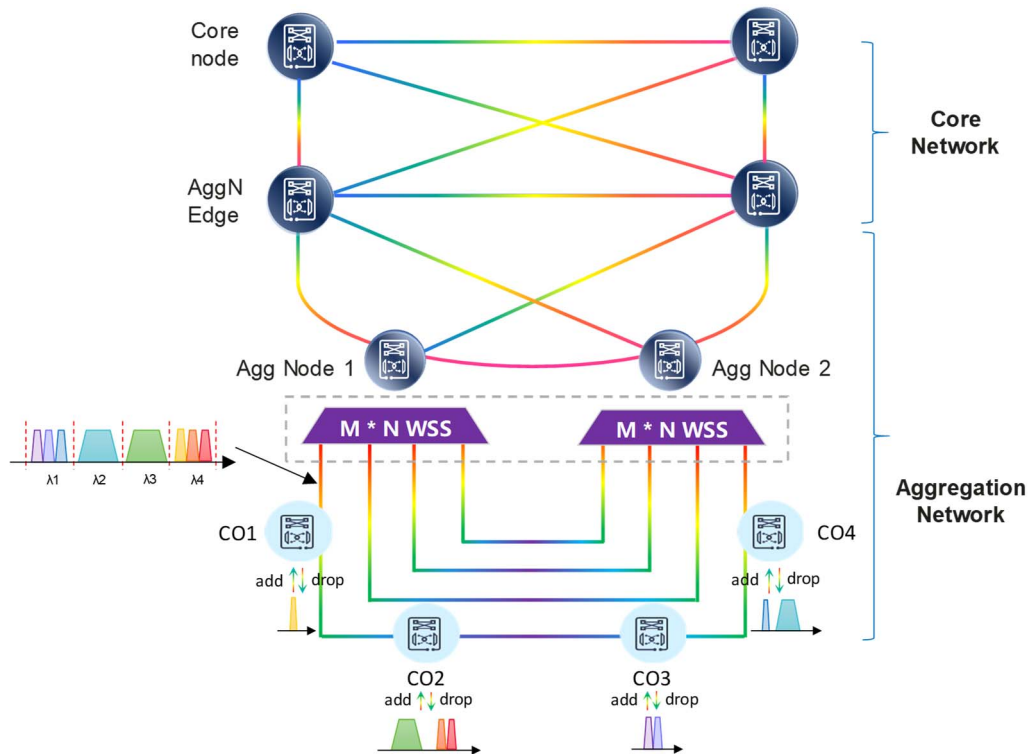


Figure 26: Wavelength-shared WDM Aggregation Network with example λ allocation

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 $M \times N$ WSSs used in WDM Fabric nodes, where multiple rings are originating or terminating. As shown in Figure 26, 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 26.

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 (λ_2 and λ_3) or the Sub-Carriers (SCs) in one wavelength channel (SCs in λ_1 and λ_4) could be added and dropped in each CO node (shown in Figure 26).

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 27 shows a Colourless ROADM in the access node (see Figure 6). The Colourless ROADM adds and drops wavelength or sub-carriers from the fibre.

EXAMPLE: Figure 27 shows an example of dropping a sub-carrier from λ_1 and adding a sub-carrier to a newly added λ_2 .

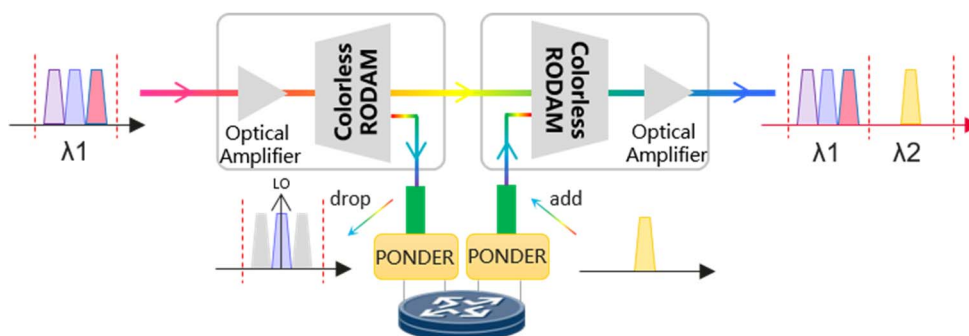


Figure 27: Colourless ROADM in access nodes example

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 27, only one transmission direction is shown, the other direction is symmetrical to the structure in Figure 27. In addition, the access nodes use, further increase the integration of optoelectronic chips, reducing complexity, costs, and power consumption.

5.4.2.4.3 Automated OAM enabled by optical-layer digital label

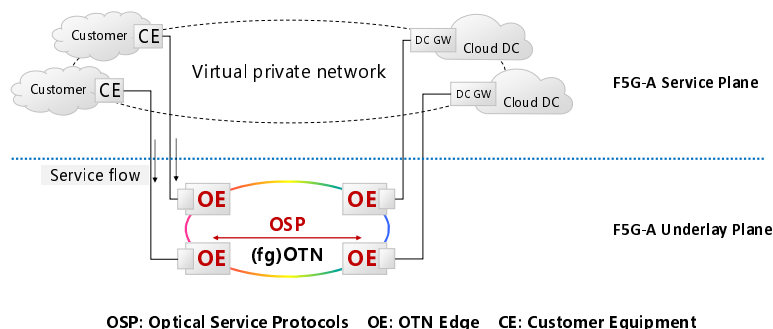
The optical-layer digital label technology is used to implement automatic adjustment and adaptation in the optical-layer. Optical-layer digital labels uses Multi-Carrier Modulation. It utilizes the multi-carrier low-speed modulation superimposed on a carrier of a high-speed digital signal for the label 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 [2]. The OCN architecture provides optical connectivity between OTN Edges (OE), which are the edges of the OTN technology domain. In Figure 6, 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 6. 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 [2] for the key characteristics. Depending on the service requirements, there is ODUs or fgODUs used in the data plane.



**Figure 28: Optical Cloud Network Architecture
(see ETSI GS F5G 018 [2])**

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 [2] shall apply.

NOTE: Figure 28 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), #16: (Optical Fibre Sensing for telecom operators), and #25 (Railway Flatwheel detection using Distributed Acoustic Sensing) (see ETSI GR F5G 032 [i.2]). See Figure 29 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 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 may 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 may include fibre quality, fibre topology, fibre bending, splitter location, connector locations among others.

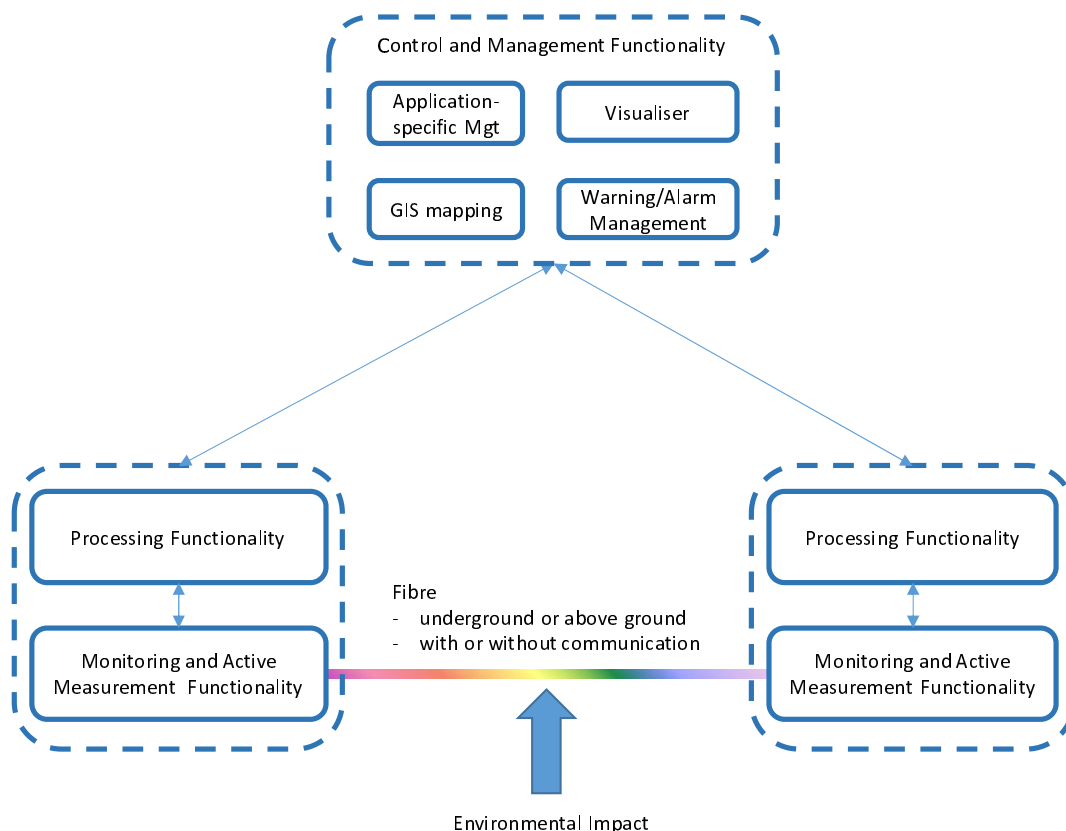


Figure 29: Fibre Sensing Architecture (two fibre sensing network elements approach)

In Figure 30, 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 29 including the need for processing functionality and the control and management functionality.

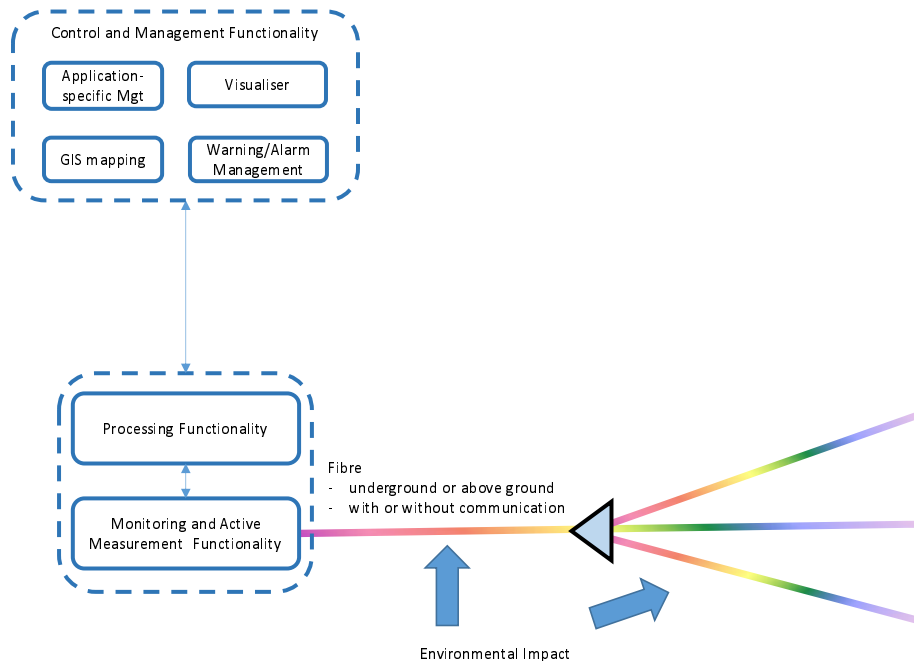


Figure 30: Fibre Sensing Architecture (single fibre sensing network element approach)

NOTE: Though Figure 30 shows a P2MP scenario, a single fibre point to point fibre is applicable as well.

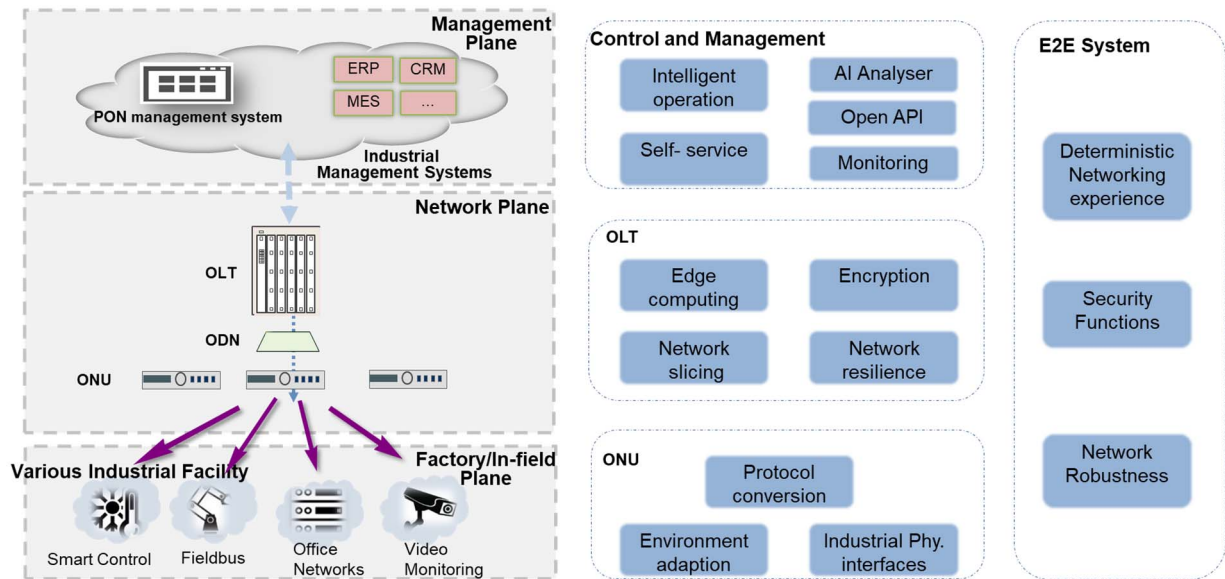
5.4.5 PON based Industrial Networks

The industrial PON system provides service connectivity for the users and devices in the industrial area (see Figure 31). The most often deployed protocols used in the industrial scenarios shall be supported by the industrial PON system. The industrial ONUs (FTTM-ONUs in Figure 8) are ONUs specifically used in PON based industrial networks. These ONUs support industrial interfaces/protocols and industrial scenario specific functions. They perform the Service Access Point (SAP) functions and the OLTs performs the Service Processing Point (SPP) functions of the F5G-A architecture shown in Figure 3.

As the industrial PON system is the industrial factory intranet, the factory intranet may be self-contained depending on the network scale, deployment scenario, and security considerations of the users. The OLT uplink may additionally support F5G-A aggregation edge functions. The PON based industrial network may be connected to higher level network elements or may operate stand-alone.

The Industrial PON system has enhanced capabilities including network slicing, deterministic networking, network resilience, encryption and edge computing to support the industrial services and applications. The compute platform shall support the local data processing in the factory, and shall cooperate with higher layer cloud computing functions to provide dedicated cloud and IT services for industrial customers.

The industrial ONUs shall provide the interconnection capability with machines and shall support the various industrial physical interfaces and protocol conversion capabilities. Various factory facilities, office and surveillance services shall be supported by the PON based industrial network and form a unified factory network. Certain types of industrial ONUs shall support the operation in harsh environments.



**Figure 31: PON based industrial network architecture overview
(Source: ETSI GS F5G 022 [12])**

The PON based Industrial Network shall conform to the specification ETSI GS F5G 022 (V1.1.2) [12]. For the control and management of the PON based industrial network, [19] shall apply. Low latency and deterministic networking extensions are for further study.

Annex A (informative): How the F5G-A Architecture Release 4 addresses the Gaps in the Use Cases

The F5G-A technology landscape requirements and gap analysis document [3] has listed several gaps based on the requirements of each use case in [i.2]. The F5G-A architecture addresses some of those gaps. Table A-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 1: This annex takes a snapshot at the time of publication of the present document and will change in the future.

NOTE 2: 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 technologies of the F5G-A architecture Release 4.

Table A-1: Gaps addressed in the F5G-A architecture, Release 4

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-A unified E2E latency control mechanism	[Gap6-3]	The interface for specifying this function is available, the detailed interface specification is for further study.
Define a protocol for the 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]	It 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 [21]. The finer granular and simpler slicing is defined in Release 4.
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 $\pm 180^\circ$ 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.

Suggested actions	Relevant gaps	F5G-A architecture addressing the gaps
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.
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-A 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-A 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.
Define tests for 50G-PON coexistence with GPON and XGS-PON	[Gap18-1]	The ETSI ISG F5G test WG defines tests along those lines
Specify best current practices when using legacy GPON in an environment with high security demands.	[Gap18-5]	This gap is for further study.
Define a standard for automatic ring network detection	[Gap18-6]	This gap is for further study.
Define a standard north-bound interface (REST API) of the PON management system to be integrated into the enterprise management systems.	[Gap18-8]	The F5G-A network architecture defines PON based Industrial networks including the management thereof.
Define a standard YANG model that provides energy-consumption metrics	[Gap19-1], [Gap24-1]	This gap is for further study.
Define a standard YANG model that provides energy-efficiency metrics.	[Gap19-2], [Gap24-3]	This gap is for further study.
Define a standards interface between the energy analyses and controller component in energy management systems	[Gap19-4]	This gap is for further study.
Define an intent-based standard interface for operators to request energy-saving actions	[Gap19-5]	This gap is for further study.
Define a standard YANG model for port power saving status.	[Gap19-9]	This gap is for further study.
Define a standard metric for energy related parameters in routing protocols	[Gap19-11]	This gap is for further study.
Define standard protocol extensions to be energy-aware	[Gap19-12]	This gap is for further study.
Define a standard for multi-domain path availability interface focused on energy-efficiency	[Gap19-13]	This gap is for further study.
Define a standard management model for low-power port mode	[Gap19-16]	This gap is for further study.

Suggested actions	Relevant gaps	F5G-A architecture addressing the gaps
For large scale deployment, higher bandwidth network technologies are a requirement, specifically in the CPN and AN segment.	[Gap20-3]	The F5G-A network architecture Release 4 provides an upgrade to specifically the home network being higher bandwidth. However, the protocols are defined by other SDOs.
Define a standard for networking and compute converged management and control protocols and data models	[Gap20-5]	The F5G-A Release 4 architecture provides the capability of in-network compute and the MCA plane is having the architectural means to control and manage this.
Define a standard for End-to-end fgOTN service provisioning over P2MP fibre networks	[Gap21-2]	The F5G-A control and management architecture defines such a standard for P2P, the extension towards P2MP is for further study.
Define networking functions for industrial motion control latency of lower than 0.5ms	[Gap22-2]	The F5G-A Release 4 architecture provides the capability to run compute very near to the industrial devices and can with that going very low in terms of latency. Also, PON based Industrial network technology provide that capability in the industrial on-premise network.
Define auditability and traceability on the F5G-A network.	[Gap22-8]	Telemetry functionality allows for detailed monitoring of the network, which can be used for auditability and traceability of the F5G-A network.
Define a standard for F5G-A network anomaly detection and intrusion prevention	[Gap22-9]	This gap is for further study.
Define a standard for NAS data protection	[Gap23-1]	This gap is for further study.
Define a standard for FTTR APP-flow level network slicing	[Gap23-8]	The network slicing concept is part of the overall end-to-end F5G-A architecture, the mechanism on the Wi-Fi® and FTTR low level technologies are defined in other standards.
Define model-driven approach that provides energy data from HVAC and energy supply systems.	[Gap24-2]:	This gap is for further study.
Define a standard energy efficiency metrics useful for energy cost calculations	[Gap24-4]	This gap is for further study.
Define an interface to integrate AI/ML predication/recommendation to the controller.	[Gap24-5]	This gap is for further study.
Define a standard model or schema for creating an energy map that combines network topology and energy metrics.	[Gap24-8]	This gap is for further study.
Define a standard interface to feed energy decision to the controller.	[Gap24-10]	This gap is for further study.
Define a standard for fibre sensing database for improving detection accuracy	[Gap25-1]	The F5G-A architecture provides the sensing capabilities from an architectural perspective, details need to be provided by other SDOs.
Define a standard interface to support the addition of location data to fibre sensor management system	[Gap25-2]	The F5G-A architecture provides the sensing capabilities from an architectural perspective, details need to be provided by other SDOs.
Define standards for the environmental robustness of the sensing system	[Gap25-6]	The F5G-A architecture provides the sensing capabilities from an architectural perspective, details need to be provided by other SDOs.
Define a coordinated control and management of FTTR and RFID.	[Gap26-4]	The interface for that functionality exists in the F5G-A architecture Release4, but the details need to be defined.
Define monitoring and configuring of RFID readers over FTTR.	[Gap26-5]	The interface for that functionality exists in the F5G-A architecture Release 4, but the details need to be defined.
Define a standard for FTTR computing power to be used by AI applications	[Gap28-1], [Gap31-1], [Gap31-2]	The F5G-A architecture provides the computing functionality on all network elements including the FTTR network element.
Define a standard for an OLT computing power to be used by AI applications	[Gap28-2]	The F5G-A architecture provides the computing functionality on all network elements including the FTTR network element.
Define a standard for the synchronization between FTTR devices and 3D glasses including time delay synchronization	[Gap28-3], [Gap28-5]	This gap is for further study.

Suggested actions	Relevant gaps	F5G-A architecture addressing the gaps
Define a standard for managing 3D glasses including management and control interfaces and data models	[Gap28-7], [Gap28-8]	This gap is for further study.
Define a standard framework for integrating generative AI with network model repositories	[Gap30-1]	The F5G-A architecture provides the computing functionality on all network elements including the FTTR network element.
Define a standard for privacy preserving access to vendor data of the network devices	[Gap30-2]	This gap is for further study.
Define a standard for closed-loop pipelines connecting AI algorithm output with schema validation and deployment testing components	[Gap30-3]	This gap is for further study.
Describe LLM deployment guidelines in telco environments	[Gap30-5]	This gap is for further study.
Define a standards interface between digital twin data of the network and the generative AI agents	[Gap30-6]	This gap is for further study.
Define a standard for computing performance benchmarks for compute functionality on network elements.	[Gap31-3]	The F5G-A architecture provides the computing functionality on all network elements including the FTTR network element. However, the benchmarks are for further study.
Define a standard for FTTR per-flow service QoS including per-flow service classification	[Gap31-4], [Gap31-5]	The F5G-A architecture provides end-to-end per flow service classification and QoS handling.
Define a standard for FTTR telemetry streaming including protocol and data model	[Gap31-6]	This gap is for further study.
Define a standard for a data model with fine-granular performance data	[Gap31-7]	This gap is for further study.
Define a standard interface between the FTTR system and OLTs for streaming telemetry data with lightweight encryption for end-user privacy preservation	[Gap31-8]	This gap is for further study.
Define a standard FTTR management framework for the integration of AI/ML components and a standard interface between a network controller and AI pipelines	[Gap31-10]	The F5G-A architecture provides the computing functionality on all network elements including the interfaces between those compute functionalities running on different network elements.
Define a standard for anonymizing sensitive data from customer premises networks	[Gap31-11]	This gap is for further study.
Define a standard for a telemetry with privacy by design principles including the telemetry data, encryption, and local processing of personalized data and conforming to regional privacy requirement	[Gap31-12]	This gap is for further study.
Define a standard for AI-related YANG models for FTTR network element access	[Gap31-13]	This gap is for further study.

History

Version	Date	Status
V1.1.1	April 2026	Publication