# ETSI GR F5G 020 V1.1.1 (2024-06)


**Fifth Generation Fixed Network (F5G);
F5G Advanced Use Cases;
Release 3**

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# Foreword

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

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# 1 Scope

The present document describes the use cases to be enabled by the F5G Advanced network. The use cases in the present document include services and applications for residential users, enterprises, vertical industries, network operation optimizations, and evolved fixed end-to-end infrastructure, which were not supported by the F5G network. Use cases will aim to introduce new technical requirements for the F5G Advance network along various characteristic dimensions. The use cases will be used as input to F5G Advanced Technology Requirements and Gap Analyses activities to extract technical requirements.

# 2 References

## 2.1 Normative references

Normative references are not applicable in the present document.

## 2.2 Informative references

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

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

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

[i.1] ETSI GR F5G 021: "Fifth Generation Fixed Network (F5G); F5G Advanced Generation Definition".

[i.2] ETSI GR F5G 008: "Fifth Generation Fixed Network (F5G); F5G Use Cases Release #2".

[i.3] ETSI GS F5G 015: "Fifth Generation Fixed Network (F5G); F5G Residential Services Quality Evaluation and Classification".

[i.4] IEEE 802.11be™: "Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment: Enhancements for Extremely High Throughput (EHT)".

[i.5] Nokia Lab report: "Focusing on latency, not throughput, to provide a better internet experience and network quality".

[i.6] ITU-T GSTP-FTTR: "Use cases and requirements of fibre-to-the-room (FTTR)".

[i.7] IEEE 802.11k™: "Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 1: Radio Resource Measurement of Wireless LANs".

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

[i.9] IEEE 802.11r™: "Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 2: Fast Basic Service Set (BSS) Transition".

[i.10] China Unicom: "China Unicom Computing Power Network White Paper, 2019".

[i.11] China Mobile: "Computing Force Network White Paper, 2021".

[i.12] Recommendation ITU-T G.9940: "High speed fibre-based in-premises transceivers - system architecture".

[i.13] Recommendation ITU-T G.652: "Characteristics of a single-mode optical fibre cable".

[i.14] Nanomaterials 2022, 12(3), 429: "Investigation of Autostereoscopic Displays Based on Various Display Technologies".

[i.15] ETSI GS F5G 014 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Network Architecture Release 2".

[i.16] Recommendation ITU-T G.984.3 (2014): "Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification".

[i.17] Recommendation ITU-T G.988 (2022): "ONU management and control interface (OMCI) specification". .

[i.18] WFA, 2019: "Wi-Fi Data Elements Specification 2.0".

[i.19] ETSI TR 103 775 (V1.1.1): "Access, Terminals, Transmission and Multiplexing (ATTM); Optical Distribution Network (ODN) Quick Construction and Digitalization" .

[i.20] IEEE 802.11ad™-2012: "IEEE Standard for Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band".

[i.21] IEEE 802.11ay™-2021: "IEEE Standard for Information Technology -- Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks -- Specific Requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 2: Enhanced Throughput for Operation in License-exempt Bands above 45 GHz".

[i.22] IEEE 802.11aj™-2018: "IEEE Standard for Information Technology -- Telecommunications and information exchange between systems Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput to Support Chinese Millimeter Wave Frequency Bands (60 GHz and 45 GHz)".

[i.23] Recommendation ITU-T G.672 (10/2020): "Characteristics of multi-degree reconfigurable optical add/drop multiplexers".

[i.24] Robot Operating System.

[i.25] Linux® Foundation Project CAMARA website.

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

# 3 Definition of terms, symbols and abbreviations

## 3.1 Terms

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

**binocular parallax:** disparity between the two retinal images of a three-dimensional object or scene arising from the slightly different vantage points of the two eyes, such binocular disparity functioning as one of the binocular cues of visual depth perception and providing the basis for stereopsis

NOTE: As defined in https://www.oxfordreference.com/.

**motion parallax/moving parallax:** monocular depth cue arising from the relative velocities of objects moving across the retinae of a moving person

NOTE: The term parallax refers to a change in position. Thus, motion parallax is a change in position caused by the movement of the viewer. Motion parallax arises from the motion of the observer in the environment.

## 3.2 Symbols

Void.

## 3.3 Abbreviations

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

| | |
|---|---|
| 3D | three-dimensional |
| 6DoF | six Degrees of Freedom |
| AGGN | AGGregation Network |
| AI | Artificial Intelligence |
| AOA | Angle Of Arrival |
| AP | Access Point |
| API | Application Programming Interface |
| APP | APPlication |
| AR | Augmented Reality |
| B2B | Business to Business |
| BC | Business Continuity |
| BNG | Broadband Network Gateway |
| BoD | Bandwidth on Demand |
| BSS | Basic Service Set |
| BYOD | Bring Your Own Device |
| CAPEX | CAPital EXpenditure |
| CO | Central Office |
| CPE | Customer Premise Equipment |
| CPN | Customer Premise Network |
| CPU | Central Processing Unit |
| CSMA | Carrier Sense Multiple Access |
| DBA | Dynamic Bandwidth Allocation |
| DC | Data Centre |
| DCN | Data Communication Network |
| DCSW | Dada Centre Switch |
| DDS | Data Distribution Service |
| DR | Disaster Recovery |
| DTU | Distribution Terminal Unit |
| E2E | End to End |
| EMS | Element Management System |
| E-ONU | Edge ONU |
| F5G | Fifth Generation Fixed Network |
| F5G-A | Fifth Generation Fixed Network Advanced |
| FDT | Fibre Distribution Terminal |
| FIN | Fibre-based In-premises network |
| FOADM | Fixed Optical Add/Drop Multiplexer |
| FTTR | Fibre-To-The-Room |
| FTU | Feeder Terminal Unit |
| GIS | Geographic Information System |
| GPU | Graphics Processing Unit |
| GUI | Graphical User Interface |
| ICT | Information Communication Technology |
| IoT | Internet of Things |
| IoV | Internet of Vehicles |
| IP | Internet Protocol |
| IPTV | Internet Protocol TeleVision |

| | |
|---|---|
| IT | Information Technology |
| JSON | JavaScript Object Notation |
| KPI | Key Performance Indicators |
| KQI | Key Quality Indicators |
| LAN | Local Area Network |
| LCD | Liquid Crystal Display |
| LOS | Loss of Signal |
| MAN | Metropolitan Area Network |
| MCM | Multi-Carrier Modulation |
| MFU | Main FTTR Unit |
| MQTT | Message Queuing Telemetry Transport |
| MSE | Multi-service Edge |
| NAS | Network Attached Storage |
| NE | Network Element |
| NMS | Network Management System |
| NOC | Network Operations Centre |
| NP | Network Processor |
| OAI | Optical Artificial Intelligent |
| OAM | Operation And Maintenance |
| OCh | Optical Channel |
| ODN | Optical Distribution Network |
| ODSP | Optical Digital Signal Processing |
| ODU | Optical Data Unit |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OLT | Optical Line Termination |
| OMCI | ONU Management and Control Interface |
| ONU | Optical Network Unit |
| OPEX | OPerational EXpenditure |
| OPGW | OPtical Ground Wire |
| OSU | Optical Switch Unit |
| OTDR | Optical Time Domain Reflectometer |
| OTN | Optical Transport Network |
| OTT | Over The Top |
| OXC | Optical Cross-Connect |
| P2P | Point to Point |
| PC | Personal Computer |
| PCB | Printed Circuit Board |
| PCM | Pulse Code Modulation |
| PDH | Plesiochronous Digital Hierarchy |
| PON | Passive Optical Network |
| P-ONU | Primary ONU |
| PPPoE | Point-to-Point Protocol over Ethernet |
| QoD | Quality on Demand |
| QoE | Quality of Experience |
| QoS | Quality of Service |
| QR | Quick Response |
| RaaS | Robotics as a Service |
| RGB | Red Green Blue |
| ROADM | Reconfigurable Optical Add-Drop Multiplexer |
| ROS | Robotic Operating System |
| RTT | Round Trip Time |
| SDH | Synchronous Digital Hierarchy |
| SFU | Sub FTTR Unit |
| SLA | Service-Level Agreement |
| SLAM | Simultaneous Localization And Mapping |
| SME | Small and Medium-size Enterprises |
| SNCP | Sub-Network Connection Protections |
| SOP | State Of Polarization |
| STA | Station |
| TCP | Transmission Control Protocol |
| TDMA | Time Division Multiple Address |
| TPU | Tensor Processing Units |

| | |
|---|---|
| TTM | Time-To-Market |
| TTU | Transformer supervisory Terminal Unit |
| UDP | User Datagram Protocol |
| UHV | Ultra High Voltage |
| VLAN | Virtual Local Area Network |
| VoD | Video on Demand |
| VoIP | Voice over Internet Protocol |
| VR | Virtual Reality |
| WDM | Wavelength Division Multiplexing |
| WLAN | Wireless Local Area Network |
| WMM | Wi-Fi® Multimedia |
| WSS | Wavelength Selective Switch |
| XR | eXtended Reality |

# 4 Categorization of use cases

## 4.1 F5G Advanced Key Focus

As described in ETSI GR F5G 021 [i.1], the main business needs identified by F5G Advanced are outlined in Figure 1. They improve various dimensions over previous generations of fixed networks.

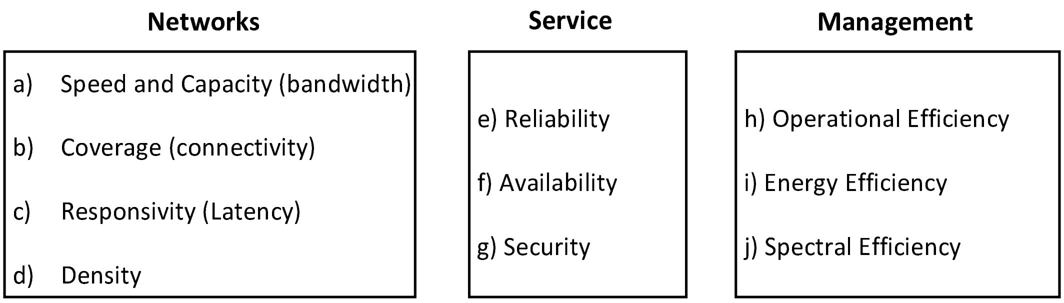



**Figure 1: Key Focus for F5G Advanced in the categories of Network, Service, and Management**

In the present document, there are seventeen use cases described, which take advantage of the key technical characteristics defined for the F5G-A network. Each use case may demand a different subset of the 10 high level categories depicted in Figure 1. With further research, subsequent use cases may be specified.

## 4.2 Driving the characteristics of F5G Advanced

The use cases as described in the present document are driving the six characteristic dimensions that are specified in the document on generation definitions ETSI GR F5G 021 [i.1], namely enhanced Fixed Broadband (eFBB), Real time Resilience Link (RRL), Guaranteed Reliable Experience (GRE), Optical Sensing and Visualization (OSV), Full-Fibre Connection (FFC), and Green Agile Optical network (GAO).

Figure 2 shows that:

- Depending on the use case, one or more dimensions are particularly important.
- All dimensions of the F5G-A system architecture are implemented by the following use cases.

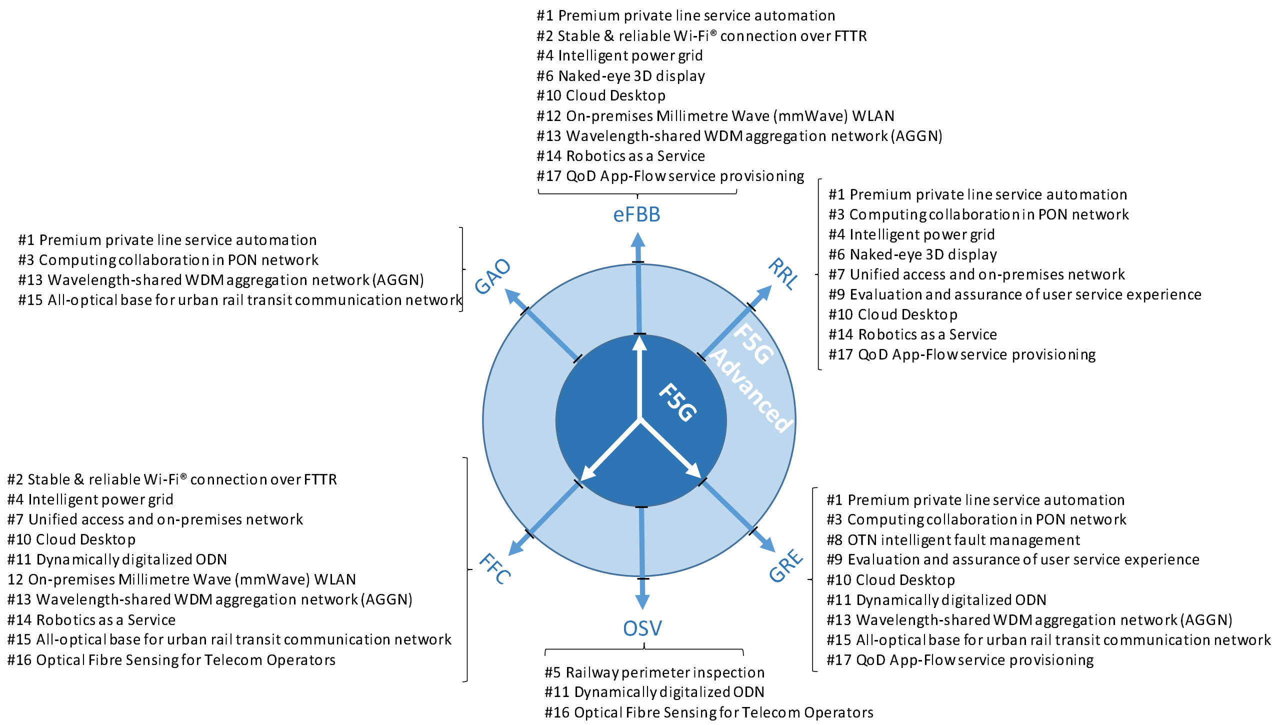



**Figure 2: F5G-A use cases (illustrative)**

## 4.3 Paving the Way for Fibre to Everywhere and Everything

F5G-A is leveraging technologies of fibre optical networks to benefit multiple segments including residential applications, enterprise applications, network internal topics such as network optimizations plus the use of F5G-A for the mobile infrastructure and service convergence, and finally vertical industries-oriented use cases.

Figure 3 shows the different high-level segments where fibre to everywhere is applicable. The larger circle named network features focus on optimization of the networking technologies.

In the present document, the aspects of mobile have a limited number of use cases assigned to it. Future use cases might add more mobile oriented aspects.

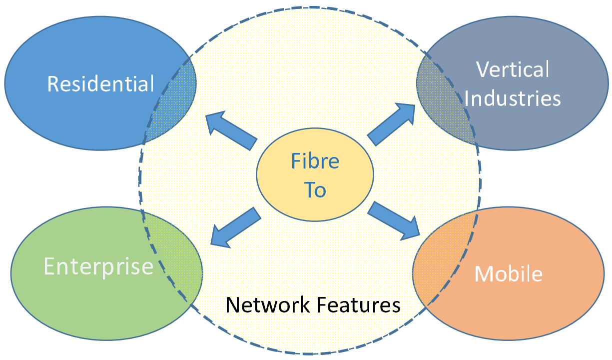



**Figure 3: High-level Segment Perspective**

As a quick reference, Table 1 summarizes the different use cases from three different perspectives:

a) Key F5G-A dimensions. This column is filled in alphabetical order per use case.

b) Key segment and business area addressed.

c) Key focus of the use case - new or enhanced services, network infrastructure and service features or in network management and optimization.

**Table 1: Use cases with key dimensions, segments and focus**

| F5G-A Use Cases | Key F5G-A Dimensions | Key Segments | | | | | Key Focus | | | Clauses |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Residetial | Enterprise | Mobile | Vertical Industry | Network Features | Services | Network | Management | |
| F5G-A Use case #1: Premium private line service automation | eFBB, GAO, GRE, RRL | x | x | | | | | x | | 5.1 |
| F5G-A Use case #2: Stable & reliable Wi-Fi® connection over FTTR | eFBB, FFC | x | | | | | | x | | 5.2 |
| F5G-A Use case #3: Computing collaboration in PON network | GAO, GRE, RRL | | | | | x | | | x | 5.3 |
| F5G-A Use case #4: Intelligent power grid | eFBB, FFC, RRL | | | | x | | | x | | 5.4 |
| F5G-A Use case #5: Railway perimeter inspection | OSV | | | | x | x | | x | | 5.5 |
| F5G-A Use case #6: Naked-eye 3D display | eFBB, RRL | x | x | | x | | x | | | 5.6 |
| F5G-A Use case #7: Unified access and on-premises network | FFC, RRL | x | | | | | | x | x | 5.7 |
| F5G-A Use case #8: OTN intelligent fault management | GRE | | | | | x | | | x | 5.8 |
| F5G-A Use case #9: Evaluation and assurance of user service experience | GRE, RRL | x | | | | | x | | x | 5.9 |
| F5G-A Use case #10: Cloud Desktop | eFBB, FFC, GRE, RRL | | x | | | | x | | | 5.10 |
| F5G-A Use case #11: Dynamically digitalized ODN | FFC, GRE, OSV | | | | | x | | | x | 5.11 |
| F5G-A Use case #12: On-premises MillimetreWave (mmWave) WLAN | eFBB, FFC | x | | | | | | x | | 5.12 |
| F5G-A Use case #13: Wavelength-shared WDM aggregation network (AGGN) | eFBB, FFC, GAO, GRE | | | | | x | | x | | 5.13 |
| F5G-A Use case #14: Robotics as a Service | eFBB,FFC, RRL | | x | | x | | x | | | 5.14 |
| F5G-A Use case #15: All-optical base for urban rail transit communication network | FFC, GAO, GRE | | | | x | x | | x | | 5.15 |
| F5G-A Use case #16: Optical Fibre Sensing for Telecom Operators | FFC, OSV | | | | | x | | x | x | 5.16 |
| F5G-A Use case #17: QoD App-Flow service provisioning | eFBB, GRE, RRL | | | | | x | x | | x | 5.17 |

# 5 Use cases

## 5.1 F5G-A Use case #1: Premium private line service automation

### 5.1.1 Use case context

Traditional OTN-based premium private line services have the characteristics of high bandwidth, ultra-low and deterministic latency, availability and security, and are widely used in many scenarios such as government institutions, financial organizations, medical organizations and large enterprises (see Use Case #2 and #16 in ETSI GR F5G 008 [i.2]).

As F5G evolves to F5G-A, new applications such as Business to Business (B2B) high-speed transport, 5G, Virtual Reality (VR) and Cloud Data Centre are rapidly developing, which leads to the emergence of a variety of new application scenarios. These new applications will need different and higher network performance from the operators' premium private line services.

To keep up with the changing application needs and take advantage of the business opportunities, the network operators need to enable fast rollout and provisioning of premium private line services. To achieve these improvements, the premium private line service has to provide a higher degree of automation, with the improvement of self-service, on-demand provisioning, high agility and flexibility.

## 5.1.2 Description of the use case

### 5.1.2.1 Overview

In the current premium private line services, many manual processes are involved. For example, during the CPE installation, the private line bandwidth provisioning and bandwidth modification, needs manual service handling at the Service Centre and manual configuration of the network.

As a result, the entire processes of premium private line service provisioning and modification becomes very complex, and takes a long time to achieve. This significantly reduce the users' service experience and the network operators' operation experience.

Additionally, once the premium private line services are provisioned, the users do not know what is the actual qualities of the premium private line services they purchased, such as the latency, availability, and bit error rate of the service.

For F5G-A, the automation capabilities of the premium private line services need to be improved, to enable the evolution towards a higher-level of autonomous optical networking. This includes but not limit to:

- CPE plug-and-play, to enable fast deployment and installation of a large number of CPEs.
- Automatic provisioning of premium private line services and flexible online adjustment of the service bandwidth, operating in an e-commerce environment.
- Visualization of private line SLA information after provisioning.

Figure 4 shows an overview of the premium private line service automation.

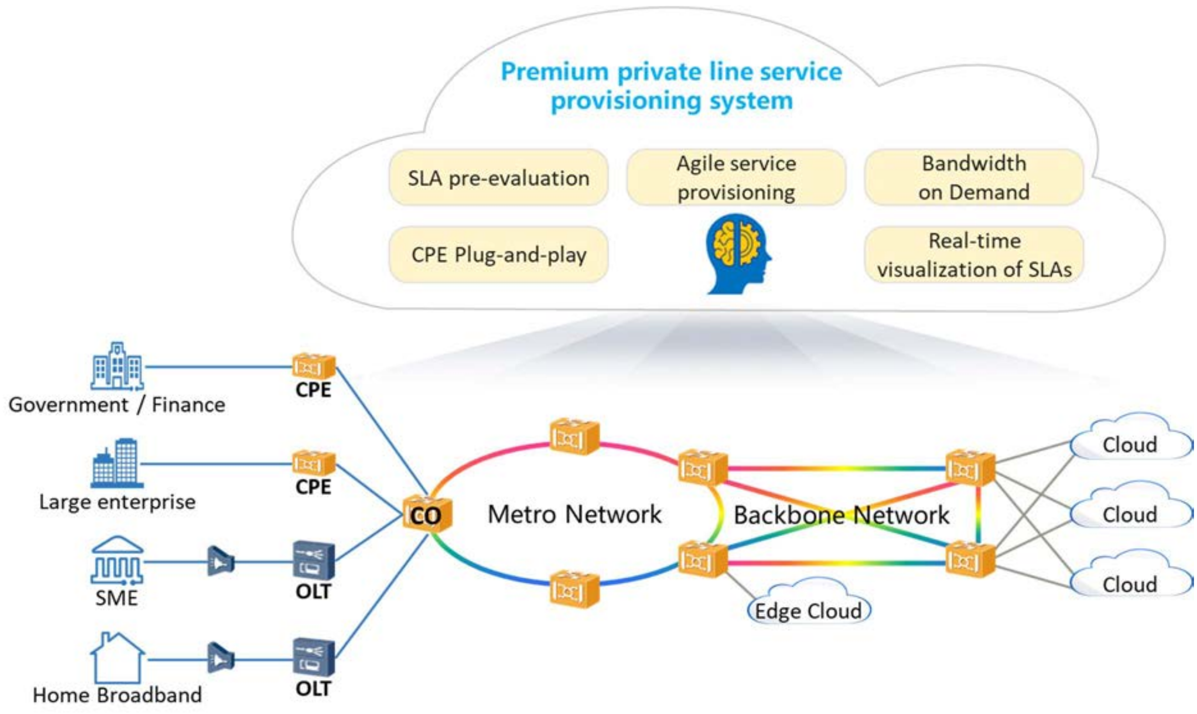



**Figure 4: Overview of premium private line service automation**

### 5.1.2.2 Motivation

The main motivation for premium private line service automation include:

- Accelerating the deployment of premium private line services: The customers that desire to accelerate the deployment of their private network infrastructure (including the deployment of premium private line services purchased from the network operators), to help them deploy new applications and seize new business opportunities. This becomes even more important for cloud application evolution.

- Enterprises need more flexible adaptation of the communication services due to the on-demand addition of new cloud applications. The enterprise infrastructure is continuously changing in a reorganization situation, the reassigning workplaces, and the flexible work environments such as work from home.
- Improving network operation efficiency and reducing operator's OPEX: The network operators need to improve the automation capabilities of the network operation and service provisioning. This will improve the network operator's operational experience and reduce their OPEX.
- Visibility of SLA: The customer's demands to know the exact quality of the premium private line services, which they purchased, so that they can manage their private networks to better support their applications.

#### 5.1.2.3 Service Functions and capabilities

Private line service automation capabilities are developed based on key features such as installation and deployment of a large number of CPEs for premium private line services, flexible adjustment of private line bandwidth, and E2E operation of premium private line services. CPE plug-and-play, online bandwidth adjustment, e-commerce provisioning and operation of private lines, and SLA visualization after provisioning:

1) Automatic evaluation of private line SLA before provisioning

   Prior to the premium private line service provisioning, the network operator needs to evaluate whether the customers' SLA can be satisfied by the current network, and to evaluate how the network will be changed after the service provisioning. Traditionally this is done manually, which is complex and inaccurate.

   In the case of automatic provisioning of premium private line services, the operator's premium private line service provisioning system can provide real-time visualization of the network resource information (such as link bandwidth, latency, availability, and energy consumption), and can pre-calculate the possible service routes and evaluate whether network resources satisfy the customers' SLA. Such an evaluation is helpful for the network operators to determine how to provision the premium private line services.

2) Agile service provisioning

   A premium private line service may go through multiple OTN NEs in both the optical layer and the electrical layer in the operator's network. This increases the complexity and the difficulty in manually performing resource allocation and verification. To improve the operator's experience, the premium private line service connection provisioning needs to be automated.

   In the case of automatic provisioning of premium private line services, the network operators can simply select the source and destination nodes, and the service templates, and leave the remaining configuration and verification to be done automatically. In this way, the premium private line services are provisioned quickly, significantly reducing the Time-To-Market (TTM).

3) CPE plug-and-play

   To provision the premium private line services, the OTN CPEs need to be deployed on the customer side. Traditionally, CPE deployment is mainly a manual operation. The site engineers need to visit the CPE site multiple times for CPE installation, software commissioning, inspection and acceptance. During the CPE deployment, remote coordination between the Network Operations Centre (NOC) and the site engineers is also needed. Therefore, the entire CPE deployment may take several days, which is inefficient, complex and error-prone. Therefore, CPE plug-and-play becomes an important feature for CPE deployment.

   In the case of automatic provisioning of premium private line services and once the CPE is connected through fibres, it will be online automatically without software commissioning. The pre-set premium private line service is automatically provisioned, which greatly reduces the time for provisioning of the private lines.

4) Bandwidth on Demand (BoD)

   During the premium private line service lifetime, the customer may request to temporarily increase the service bandwidth for a certain major event (e.g. football event or important conferences). After the event, the service bandwidth needs to revert to the original bandwidth.

   The private line operation system needs to automatically provide an online flexible bandwidth adjustment function for the services, to enable the BoD.

5) Real-time visualization of private line SLAs

Key customers such as government institutions and financial organizations may request a set of premium private line services to connect multiple sites to different Cloud Data Centres. Such a set of premium private line services forms a private cloud network service. The key customers may further have the need for visibility and manageability of the private cloud network services for the network operational purpose.

Therefore, the network operators need to provide private network views and related open network APIs for the customers, so that the customers can monitor the private line SLAs (e.g. latency and availability) from their own perspectives.

#### 5.1.2.4 Operation of the use case

1) The network operator installs several toolkits on the premium private line service provisioning system, such as resource map and service evaluation toolkit, premium private line service provisioning toolkit, CPE plug-and-play toolkit, and private line SLA visibility toolkit.

2) Assuming the contract for the premium private line service has been signed, the customer purchases the OTN CPE, and installs it in the customer's equipment room. The CPE will be automatically configured by the operator's CPE plug-and-play toolkit, and then the CPE will be online.

3) The network operator evaluates whether the customers' SLA can be satisfied by the resource map and service evaluation toolkit.

4) The network operator automatically provisions the premium private line services in the operator's network, through the premium private line service provisioning toolkit.

5) Once steps 2) to 4) are complete, the premium private line service is automatically extended from the operator's network to the CPE. As a result, the premium private line service is successfully provisioned.

6) The network operator adjusts the bandwidth through the portal of the premium private line service system.

7) Customers can view the SLA information (latency, bandwidth, and availability) of premium private line services. To what extent the aggregation level information is exposed by the operators is out of scope, but the technologies need to support various information granularity and time scales down to near-real time SLA information shown to customers.

## 5.2 F5G-A Use case #2: Stable & reliable Wi-Fi® connection over FTTR

### 5.2.1 Use case context

Full fibre connection is a key characteristic of the 5th generation of fixed networks, in which Fibre-to-The-Room (FTTR) is the core technology for home and SME application. Based on the advantages of the fibre medium (such as low transmission loss, light weight/cost, long lifetime, extremely high bandwidth, etc.), the fibre-based on-premises network is becoming a promising solution. The ultimate goal is to guarantee user experience.

ETSI GS F5G 015 [i.3] defines the Key Quality Indicators (KQI) for the user experience. A cascaded network consisting of a fibre-based network and a wireless network is difficult to fully guarantee user experience. The on-premises network consists of a backhaul component (e.g. fibre-based network) and a fronthaul component (e.g. Wi-Fi® network). The bottleneck for maintaining good user experience is generally due to last-10-meters' connection (i.e. Wi-Fi®), the bridging connection between the fibre termination to the remote end device. A low-quality Wi-Fi® connection may cause poor user experience for a number of different network services, such as:

1) Long page response time, first screen display time and full load time in web browsing.

2) Non-reliable download/upload rate.

3) Slow response time for IPTV channel switching, initial loading and forward/rewind of the IPTV content; blurred screen or freezing may occur.

4) Feeling of discontinuity of game control, and long waiting time for game set-up.

5) Image freezing, and unsynchronized interaction in online education/telework.

6) Feeling of vertigo, black edge and smearing in Cloud VR video/game.

To achieve, good or excellent user experience needs a stable & reliable Wi-Fi® connection. The aspects causing poor user experience from a Wi-Fi® connection perspective include:

1) Limited spectrum resources lead to an overcrowded channel in the air interface. The newer Wi-Fi® technology IEEE 802.11be [i.4] has extended the channel bandwidth to 320 MHz, however the regional regulations may restrict the application of the new technology (e.g. there is only a few 160 MHz channel available in China). More dense connections in the individual channel can be observed due to limited spectrum resources.

2) No priority mechanism for exchanging networking message or latency sensitive packet. The Ethernet protocol establishes the data transmission channel, but no priority matching of the service needs which may lead to at best effort transmission. The low latency packet may not be transmitted in time. This will significantly impact the user experience for latency sensitive services, such as XR, online games, etc..

3) Difficult to limit network packet jitter due to the Wi-Fi® CSMA mechanism. The air interface in the Wi-Fi® protocol is contention based. If multiple users are sharing the same channel resource, then packet collision will cause retransmission of data packets. This will lead to service data jitter. In the worst case, if multiple collision take place in a sequence, the retransmission in the upper layer will cause service interruption. This induces freezing in the video streaming service.

## 5.2.2 Description of the use case

### 5.2.2.1 Overview

A good quality Wi-Fi® connection is essential to guarantee the E2E user experience. Compared to the traditional multiple AP networking, acting as independent cascaded backhaul links of the Wi-Fi® fronthaul link, a stable and reliable connection needs coordination between different AP (including P-ONU and E-ONU) to avoid potential collisions, fast coordination message exchanging, etc. This leads to achieving continuously satisfactory network performance ensuring consistent user experience for the dedicated service. A stable and reliable Wi-Fi® connection could provide the following benefits for the on-premises scenarios:

1) To support Gigabit/multi-Gigabit coverage for comprehensive network service everywhere

   Take FTTR as an example, a broadband connection based on the same channel with a wide channel bandwidth (like 320 MHz in Wi-Fi® 7 or even wider in Wi-Fi® 8) is shown in Figure 5. The overlapping area with different signals from different APs (E-ONUs or P-ONU) is determined by the operation frequency band (2,4 GHz, 5 GHz, 6 GHz or millimetre wave band).

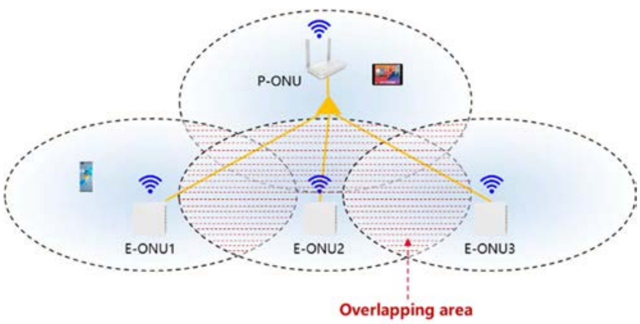



**Figure 5: Distribution of Wi-Fi® signal in FTTR scenario**

   The practical location of users connecting to the on-premise network is determined by the environmental conditions and the user's habits. It is important to guarantee a unique connection quality everywhere in the home and the SME. The current Wi-Fi® connection works independently for individual access points (i.e. P-ONU and E-ONU). The summation of the practical data rate in the overlapping area drops significantly compared to the non-overlapped area due to packet loss caused by collisions.

2) To provide continuous good experience for latency sensitive services (e.g. online games)

Latency sensitive services, such as online games (< 100 ms E2E RTT), XR (< 20 ms E2E RTT), need deterministic latency and low packet jitter to achieve a smooth experience. Figure named "cloud Gaming Latency budget" in page 2 of [i.5] shows an example of the latency budget for online games. The processing computational time on the cloud, encoding, decoding and rendering are relatively fixed since heterogeneous hardware is used here. Therefore, the latency for controlling message exchanging by the game console with a Wi-Fi® connection needs to be limited to few tens of milliseconds.

3) To support seamless handover for service continuity

Mobility causes physical link switching of Wi-Fi® connections, shown in Figure 6. Service continuity during the handover process is essential for the user experience. Large switching time between different access points will lead to an uncomfortable feeling, including interruption of real-time audio or video streaming, freezing of online game, etc. Seamless handover needs fast switchover of the Wi-Fi® connection from the original AP to the newly connected AP. In addition, redirection of the data flow is needed over the backhauling network.

A stable & reliable Wi-Fi® connection therefore needs good coordination between the Wi-Fi® link and the backhauling infrastructure.

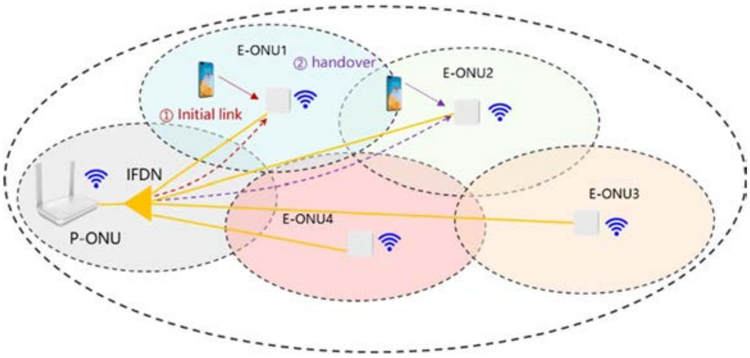



**Figure 6: Schematic of seamless handover**

4) To provide robust control for IoT services

Smart services are important additive services for the service operator. Hundreds and thousands of smart devices are deployed in various application scenarios, like security, automation, health monitoring, energy control, etc. These smart devices are working together to enable comprehensive application logistics. For example, the temperature sensor continuously monitors the room temperature. The detection of the house owner location provides information to switch on/off the air conditioner, the lighting infrastructure or even media devices.

Most of the smart devices are connected through Wi-Fi® to an IoT hub, Wi-Fi® AP, Wi-Fi® extender, etc., shown in Figure 7. These devices may also be collocated with other video device (e.g. TV, VR, etc.), storage device (e.g. NAS), mobile devices (e.g. mobile phone, etc.). The sharing of the Wi-Fi® channel of different access points may lead to unsuccessful control of the device status that causes failure or delay in service logistics.

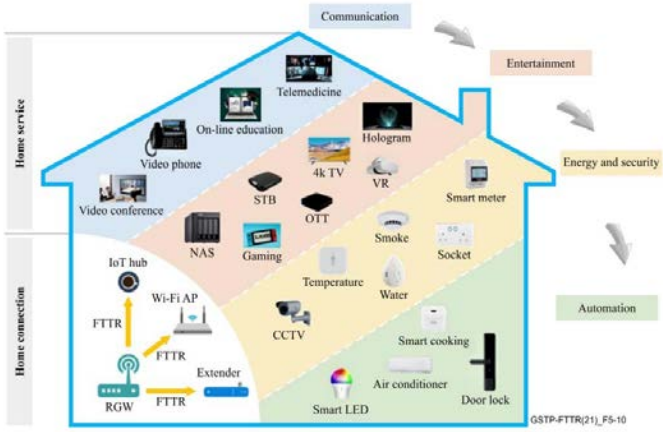



**Figure 7: Device control in typical examples of network devices within home (Source: ITU-T GSTP-FTTR [i.6])**

Stable and reliable Wi-Fi® connections are capable of enabling accurate and robust control of smart devices in IoT applications (like smart home, smart community, small office, etc.). The Wi-Fi® packets carrying the control commands need to be successfully transmitted at an appropriate rate. This means avoiding packet collisions. Otherwise, the collision will result in a longer waiting time for the IoT hub or IoT controller to receive the reply from the IoT devices. This will impact the user experience over the IoT system. In this case, the sequence of smart services can then flow correctly.

### 5.2.2.2 Motivation

Creating a stable and reliable Wi-Fi® connection provides several advantages:

- Enabling consistent Gigabit/multiple Gigabit connections everywhere for the home and the SME. Avoids packet collision in wireless transmission and will create significant network performance improvements, like throughput, latency, etc.
- Achieving deterministic latency guaranteeing QoE for dedicated network services, like online games, XR, etc. The user could obtain a satisfactory experience.
- Maintaining service continuity during user mobility so that user will not sense any uncomfortable interruption at any time.
- Providing robust and accurate control for IoT service in smart home, smart community, etc.

### 5.2.2.3 Service function and capabilities

The stable and reliable Wi-Fi® connection over FTTR in the F5G-A network enables consistent network performance during user's usage of the on-premises network:

- Service type identification and adaptation

  To better allocate network resources for dedicated services, the on-premises network needs to learn the service type and identify the network Wi-Fi® connection needs. The priority of the service flow, assignment of transmission opportunities, etc. are then determined. A stable and reliable Wi-Fi® connection could provide different levels of network transmission capability for different services.

- Wi-Fi® interference recognition and avoidance

  The Wi-Fi® connection between multiple AP may receive co-channel interference. The detection of interference is the precondition to coordinate transmission opportunities over optical link and wireless link. Fibre backhaul link and wireless link could collaborate together to avoid packet collisions in the air interface. Therefore, a stable and reliable performance in the overall on-premise network can be achieved.

- Provide latency sensitive transmission mechanism

  Latency sensitive packets (including control message or data packets) needs to be exchanged in time to ensure the latency needs are satisfied. The stable and reliable Wi-Fi® connection need to provide an extremely low latency channel serving the high priority flow in terms of latency.

- Enable seamless connection switching

  On-premise mobility causes the Wi-Fi® signal level to increase or decrease. The identification of AP switching will trigger the connection switching protocol like IEEE 802.11k [i.7], IEEE 802.11v [i.8], IEEE 802.11r [i.9]. Such a handover protocol is complex and needs multiple message exchanges. Any packet loss due to signal variation by user movement will lead to switching delays or even failure.

  A stable and reliable Wi-Fi® connection needs to provide a mechanism to achieve seamless switching for the Station (STA). The complex switching protocol may be simplified or discarded.

- Large volume of concurrency connection

  To best support IoT services, the Wi-Fi® connection generally needs to support a large number of connections and enable simultaneous control. Wake-up in time over the Wi-Fi® radio and successfully conveying the control message is the foundation to support a comprehensive service.

## 5.3 F5G-A Use case #3: Computing collaboration in PON network

### 5.3.1 Use case context

Recent technical computing innovations, including big data, cloud computing and artificial intelligence have accelerated the development of the digital economy and created massive data. Data processing, analysis and utilization are application oriented, justifying the needs for improved processing time, power consumption, performance, etc. To best leverage computing power, computing distribution is generally implemented in the cloud, central office, and network terminal or even end devices. In addition, to efficiently complete a task, the management and collaboration of such computing power in the different network locations needs to be considered. In this context, coordinating the computing power is advantageous. In the past few years, the concept of computing power networking has been studied by the industry [i.10] and [i.11]. The concept of computing power networks, has been researched, leading to standards and products being developed.

The PON access network has unique characteristics of providing connection capability to a large number of network terminals, transporting comprehensive service profiles, and close to the end users. Therefore, to make better use of the computing power in the PON access network, it is important to improve the network performance, the user experience, the operational efficiency, the energy efficiency, etc. Traditionally, the computing power in the PON access network is typically distributed in the ONU, the OLT and the cloud, working independently from each other, and not collaborating with each other.

This use case explores the collaboration of computing power in the PON access network, showing the benefits of enabling high-quality services, enhancing network performance, etc. Moreover, the similar concept of computing collaboration can also apply to the transport network, and the core network.

### 5.3.2 Description of the use case

#### 5.3.2.1 Overview

The collaboration of computing power in the PON access network facilitates better quality network services. For example, by correctly identifying the service characteristics (e.g. service type, priority, latency, packet jitter) and the transmission status (e.g. packet waiting time, channel quality) in the end device (e.g. residential gateway or access point) which can be shared with the central office (e.g. OLT or cloud platform). This also helps to improve the dynamic configuration of the OLT (e.g. enabling slicing configuration, reserving buffer or bandwidth capacity).

The collaboration in the computing power networks needs to adapt to the different service scenarios. The collaboration of the overall access network computing power, has several advantages:

- The service QoE can be dynamically improved.
- The network status can be reported in real time if necessary. The reporting can flexibly adapt to the service or management demands.
- Hitless power consumption optimization, based on real-time collected status of PON access network and FTTR CPN, and fully control and coordination among access network and CPN, to achieve a greener network.
- Additional applications can be supported in the future.

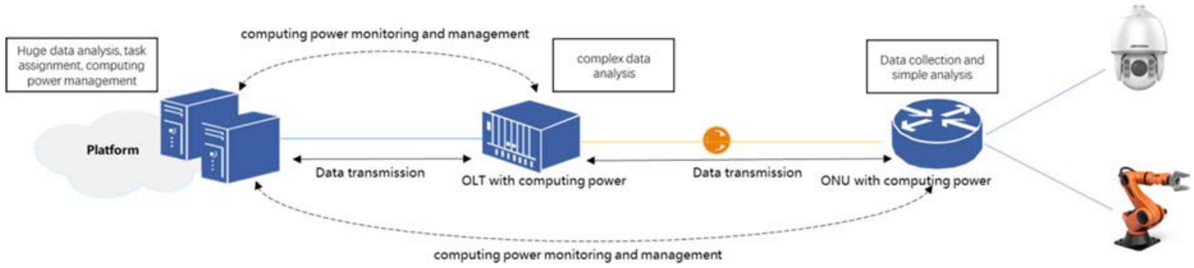



**Figure 8: The basic network element in the computing power access network**

With the evolution of network services, the end users are paying more and more attention to QoE. Service provider's needs to improve the service quality to maintain the registered users and attract new users. To dynamically monitor and improve the service quality, the collaboration of computing power is a useful approach. The following bullets describe the basic functionality of the different computing power network elements in the PON access network, as shown in Figure 8:

- The ONU is the network terminal for broadband access, and is installed at the closest location to sense the in-premises network status. Therefore, the ONU is the appropriate network node to initially evaluate and analyse the status of the in-premises network based on its computing capabilities. Additionally, some basic operations such as Wi-Fi® automatic tuning can be done. The ONU could also provide feedback of the analysed results to the OLT, especially when the ONU cannot solve the problem itself and needs help from the more powerful upper network due to its limited computing capability.
- The OLT compute, specifically in the line card, may have the opportunity to analyse service data through mirroring, and collaborating with the ONU through ONU feedback to derive a deeper and more accurate view of the in-premise network status. Moreover, the OLT is capable of performing certain operations such as service identification, DBA, QoS, etc. Obviously, the OLT may not solve all the problems. For example, it is difficult for the OLT to perform detailed analysis of the user service quality, to solve upper-layer network problems such as PPPoE, to collect and analyse multiple user's service data simultaneously for a long period of time. In many of these cases, the interim analysis results and the processed data will be uploaded to the cloud platform for further processing.
- The cloud platform is considered to have the most computing power, but it is far away from the end user. The platform can perform the deepest analysis of the service quality, analyse the service over a long period of time to come to more accurate conclusions, and request other systems/platforms to collaboratively perform the necessary operations. Moreover, the platform can monitor the computing power status of the OLT and the ONU, and can dynamically adjust the computing tasks if the ONU's computing capability is not sufficient to complete the processing task.

To further demonstrate the functionality of computing power collaboration, two scenarios are described as following:

1) Online interactive service quality assurance

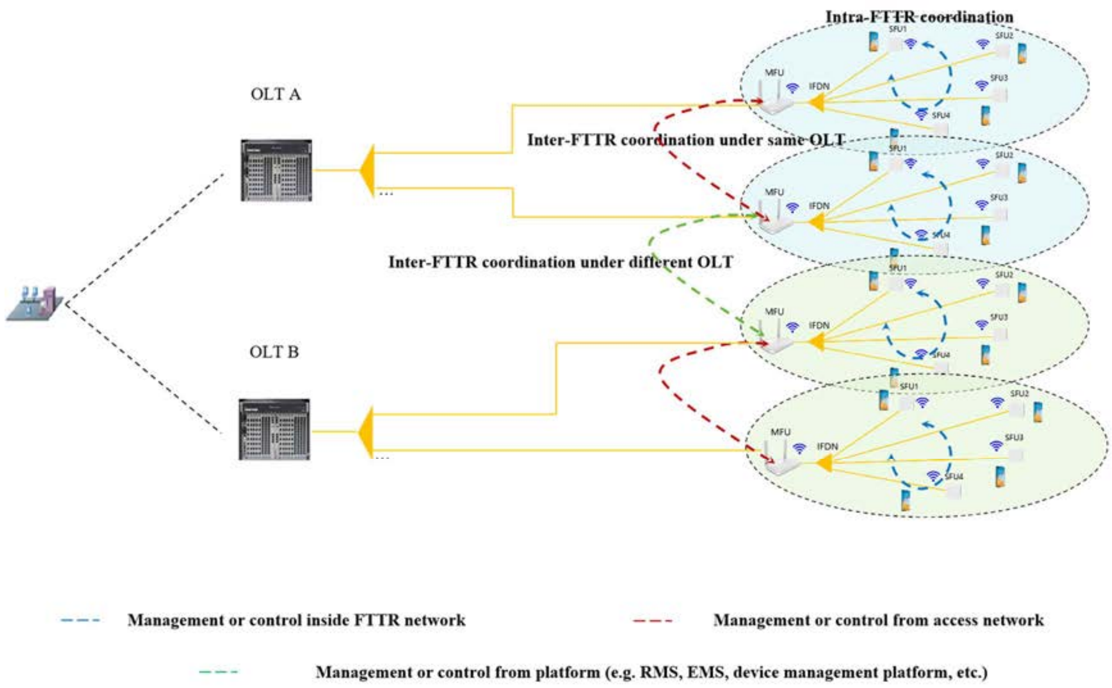
   Online interactive services such as online education, online conference, live streaming, have strict demands on dynamic network quality in terms of throughput, latency, packet jitter, etc. In order to improve the user QoE, the cloud platform, the OLT and the ONU need to collaborate to sense, analyse, and process network information so as to satisfy the QoE needed.

In this case, the ONU needs to sense the in-premise network status including bandwidth usage, number of connected user end devices, Wi-Fi® quality (e.g. signal strength, interference), etc., in order to avoid any defects affecting the service quality of the online services. For example, P2P download application seriously affects the online interactive services. A traffic flow working in the same frequency band compete with data stream of the online interactive services. Weak Wi-Fi® signals in the user location creates a poor-quality communication path. Therefore, the ONU needs to sense, analyse and come to conclusions by leveraging its computing power. Then the ONU can proceed with operations like adjusting the Wi-Fi® configuration or speed limit if it is necessary and feedback a notification to the OLT for further processing.

After receiving the feedback from the ONU, the OLT can identify the service type and analyse the traffic status based on the ongoing traffic data (IP address, throughput, bandwidth usage, configuration, QoS, etc.) and identify the network problems, if any. Then the OLT can process the QoS strategy such as resource priority configuration and slicing to improve the quality of online interactive services. Furthermore, the OLT could also feedback the processed data and analysed result to the cloud platform for further processing.

The cloud platform can analyse the data (flow characteristics, time, latency, packet jitter, etc.) in details based on its computing power to get more accurate results (end user profile, overall network status, whether the end user bandwidth matches the service, AP adopted by the end users, etc.) through the southbound interface (MQTT / Telemetry). At the same time coordinating with other platforms to ensure service quality, such as coordinating with the BNG to improve uplink and downlink bandwidth, or synchronizing the priority applied in the access networks to the aggregation network. Moreover, the cloud platform can analyse the end user behaviour and main applications to promote more suitable services to the end users.

2) Coordination function for FTTR across the network in different scenarios:




NOTE: MFU/SFU are the terms defined in SG15 Q3 Recommendation ITU-T G.9940 [i.12]. These terms have the equivalent meanings to the P-ONU/E-ONU, as defined in ETSI ISG F5G documents.

**Figure 9: Coordination function for FTTR across the network**

FTTR provides the foundation for good-quality Wi-Fi®. Moreover, a coordination mechanism over fibre and Wi-Fi® can provide better collaboration between Wi-Fi® applications and APs, which is defined in Recommendation ITU-T G.9940 [i.12]. This mechanism can avoid interference in the air interface over multiple APs without any change in the Wi-Fi® protocol. In addition, as shown in Figure 9, the interference between different neighbours needs to be avoided. The computing power in the different network locations needs to be capable of determining the coordination strategy, i.e. an MFU as the network terminal provides the strategy for a single FTTR network while the OLT provides guidance for the coordination between different neighbouring FTTR networks. Collaboration between the OLT controller and the ONU (MFU) is performed to improve resource utilization in the frequency, the time, and the spatial domains.

The typical network coordination in FTTR networks is described as follows, and shown in Figure 9:

- Wi-Fi® is provided by one FTTR network, so the MFU can process the coordination function over fibre and Wi-Fi® based on the MFU's computing power in real-time.
- Locations, where the Wi-Fi® network is provided by two FTTR networks, and which are supported on the same OLT, will need a cross-network coordination function within a single OLT based on the OLT's computing power. The OLT can process functions such as intra-BSS coordination.
- Locations where the Wi-Fi® network is provided by two FTTR networks, which are supported on different OLTs, will need a cross-network coordination function within a cloud platform based on its computing power. The cloud platform can process the network configuration including channel selection, resource allocation, so as to dynamically manage the network.

Therefore, in this complex Wi-Fi® network, the cloud platform, the OLTs and the MFUs need to cooperate with each other to provide a high-quality wireless network.

#### 5.3.2.2 Motivation

Computing collaboration provides several advantages:

- Breaks the computing power barrier between the ONU, the OLT and the cloud platform in the PON access network.
- Achieves coordination and integration of computing power in the PON access network.
- Controls the computing power operation of the entire PON access network in real time and make dynamic adjustments.

#### 5.3.2.3 Service functions and capabilities

In order to achieve computing power collaboration, there are several functions and capabilities as follows:

Basic:

1) The ONU, the OLT and the cloud platform have sufficient computing hardware performance, including extra CPU/GPU, storage, etc.
2) For the ONU, the OLT and the cloud platform, the computing power information reporting interface needs to be defined, which is used to synchronously understand the status of each element.

For the OLT:

1) A new type of hardware (such as PCB) running computing power needs to be installed in the existing OLT.
2) The hardware is mainly composed of CPU/GPU, storage, forwarding chip and other hardware, similar to that of an edge server.
3) On this board, the relevant applications can be loaded, such as data collection, service analysis, etc., to support intelligent capabilities.
4) The hardware performance of the computing board is sufficiently powerful to perform a relatively large amounts of data acquisitions, processing, analysis, and partial data storage.
5) The computing board mirrors the service data through the OLT backplane to perform the acquisition of data without affecting the normal operations.

For the ONU:

1) The ONU needs to enhance its hardware capabilities, and build an open containerized software system on the gateway, which has the expansion capability of an open system to support applications.
2) The open containerized software system can run on a Linux system on the gateway, mainly including Docker™ container and MQTT/JSON interface module.

3) The ONU interacts with the management platform through the management interface, and the Docker™ container runs the corresponding APP or plug-in.

For cloud platform:

1) The cloud platform is hosted on the local datacentre, and its performance can be enhanced as needed.

2) The cloud platform has more computing power compared to the OLT and the ONU, achieving massive data collection based on Telemetry analysis and storage.

3) The cloud platform is the control centre of computing power, collecting the hardware operation status and computing power capabilities of the OLT and the ONU in real time, analysing the overall computing power status in real time, and dynamically adjusting the computing configuration of each element. For example, the computing power of the ONU is relatively weak. When an ONU is considered to have insufficient computing power to undertake tasks, the cloud platform can assign part of tasks to the OLT or the cloud platform itself.

## 5.4 F5G-A Use case #4: Intelligent power grid

### 5.4.1 Use case briefing

The power grid contains two physically independent networks: power transmission/dispatching network, which transmits electric energy, and the other one is the power grid communication network, which supports production, dispatching, operations and management of the power transmission/dispatching network.

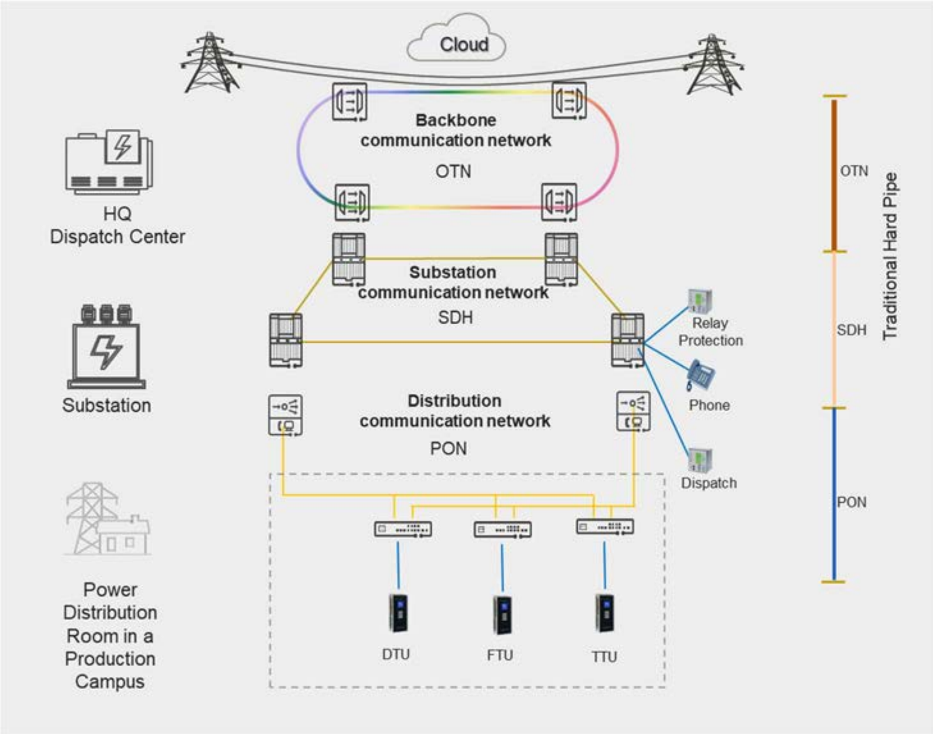
The traditional power grid communication network uses multiple transmission technologies such as OTN, SDH, PDH and PON to provide a secure and reliable communication infrastructure for the power transmission/dispatching network. The power transmission/dispatching network includes the relay protection system, the security stability system, and the automation system (dispatching, transmission and transformation, and distribution). The power grid communication network also provides information services for the overall power grid organizations, their branches and operations. The transition of the current power grid communication network to an intelligent power grid communication network is driven by the following needs:

- a larger number of substations;
- unmanned substations;
- new distributed green energy production from different energy sources;
- expansion of the UHV power grid.

### 5.4.2 Description of the use case

#### 5.4.2.1 Overview

The traditional power grid communication network uses the OTN/SDH/PDH/PON networking technology solutions. The backbone communication network, substation communication network and distribution communication network are physically separated from each other. The current backbone communication network uses 10 Gbps OTN. The substation communication network uses SDH with a maximum bandwidth of 10 Gbps. The distribution communication network uses Ethernet over PON as soft-pipe private lines to carry a single distribution automation service. Figure 10 shows the traditional power grid communication network architecture.




NOTE: DTU stand for Distribution Terminal Unit, FTU stand for Feeder Terminal Unit; TTU stand for Transformer supervisory Terminal Unit.

**Figure 10: Traditional power communication network scenarios and architecture**

1) Trend in the backbone communication network

The interconnection bandwidth between data centres and DR (disaster recovery) centres, the interconnection bandwidth between data centres and the headquarters, and the access bandwidth between data centres and branches is increasing rapidly. A backbone communication network is needed to provide higher bandwidth and more connections.

2) Trend in the substation communication network

Intensive substations and unmanned substations are driving the bandwidth and connection upgrade with the need for dispatching automation and the new services such as video services and IoT services. The traditional substation communication network cannot meet the growing demand for increased bandwidth and connectivity.

3) Trend in the distribution communication network

With the continuous improvement of the distributed new energy grid connections and the distribution reliability, dispatching automation has been moved down to the distribution layer, and the protection system is gradually covering the distribution layer. Services at the distribution layer have expanded from a single distribution automation service to an integrated distribution automation service incorporating multiple services, such as dispatching automation, distribution automation, production/security video services, and IoT services. Real-time control services of dispatching automation and distribution automation need high reliability and security. According to the power grid communication network security specifications, all the services are divided into different security zones, which need hard isolated transport from each other, such as through physical networks/devices, wavelengths or timeslots). To ensure high reliability and security, hard isolated transport technologies are needed for the distribution network when transporting the different zone services.

4) Trend in the overall power grid reliability and security

The UHV transmission and transformation and the uninterrupted operation of the power transmission/dispatching network needs a more reliable and secure power grid communication network to carry the different communication services.

To manage these challenges, the traditional power grid communications network needs to be upgraded by introducing new communication technologies and architectures.

### 5.4.2.2 Motivation

Figure 11 shows the new intelligent power grid communication network, which provides the end-to-end high-quality connectivity to meet the needs of the intelligent and cloud-based overall power grid.

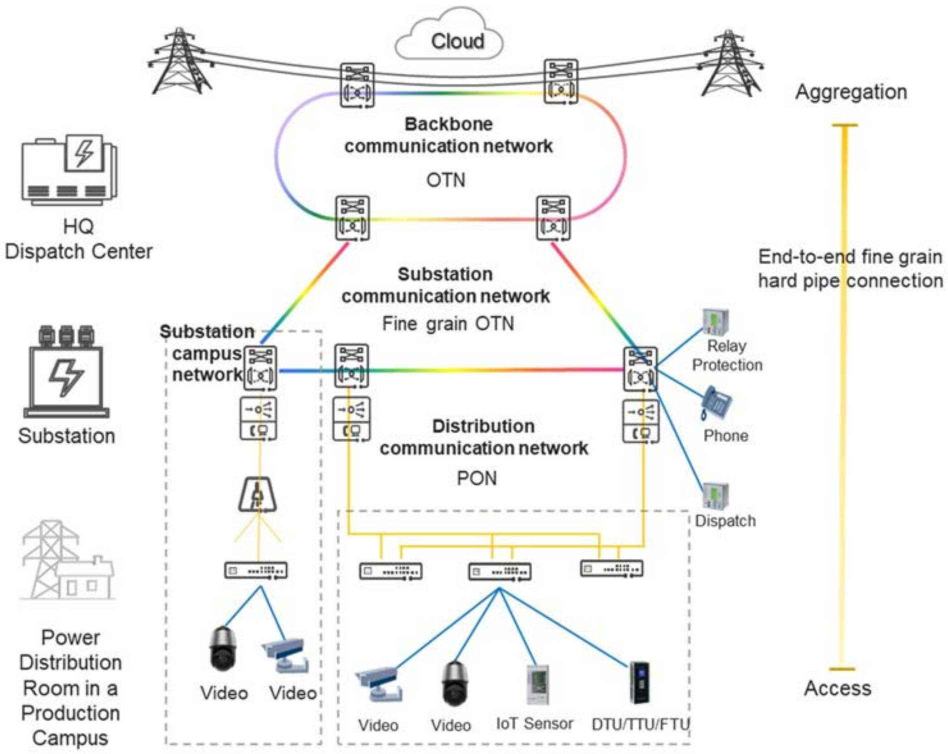



**Figure 11: New intelligent power grid communication network architecture**

The new intelligent power grid communication network can be applied to the following typical sub-networks:

- Data centre communication network (part of the cloud in Figure 11).
- Backbone communication network.
- Substation communication network.
- Distribution communication network.
- Substation campus network.

Optical Cross-Connect (OXC) and Wavelength Division Multiplexing (WDM) coherent modulation technologies have been widely used in carriers' backbone transmission networks. For the power grid data centre communication network, 800 G coherent systems are needed for intra-city DC interconnection scenarios. The OTN backbone communication network needs to support ultra-large State Of Polarization (SOP), 10 G / 100 G hybrid transmission and single-span ultra-long haul, which meets the power grid scenarios such as Optical Ground Wire (OPGW) cables, long distance between site, and smooth bandwidth update. For the substation communication network, the fine grain hard pipe technology is needed to replace the legacy hard pipe SDH/PDH technology and to ensure the reliability and capability of long-distance transmission on the OPGW cable. In addition, the fine grain hard pipe technology is used in the distribution access network and the substation campus access network, to provide the multiple services transport capabilities at the access layer and provide end-to-end private line capabilities across the power grid communication network. For the key power services such as relay protection and security stability, the power grid communication network provides multi-path redundancy protection, ensuring 99,9999 % reliability.

#### 5.4.2.3 Service Functions and capabilities

The new intelligent power grid communication network needs to support the following functions and capabilities:

1) OTN backbone communication network

The OTN backbone communication network is used for interconnection between remote DR data centres, interconnection between remote DR data centres and provincial and municipal data centres, and interconnection between the headquarter and provincial and municipal branches. The OTN backbone communication network features are:

- Optical cables: OPGW cables, which are closely related to the SOP. In thunderstorm scenarios, the 8 M rad/s SOP can cover 97,3 %. The 8 M rad/s performance of the OTN coherent system meets the reliability needs of the data transport network.
- Bandwidth: The bandwidth is continuously increasing, so 100 G OTN or higher is needed.
- Site distance: The typical site distance between the national trunk and provincial trunk sites exceeds 80 km, and the site distance between UHV DC lines can reach a maximum of 2 000 km but typically less than 500 km. Therefore, an OTN system with a minimum of 500 km long-distance single-span is needed.

Based on the functional needs of the OTN backbone communication network, the OTN system has the following key specifications:

- 8 M rad/s SOP performance.
- 10 G / 100 G hybrid transmission.
- 500 km single-span long-distance.

2) Substation communication network:

The substation communication network is used for interconnection between the information centre, dispatching centre, centralized control centre and the substations, and interconnection between the relay protection system and security stability system between substations. The substation communication network has the following features:

- Optical cables: OPGW optical cables, which are closely related to SOP. For the substation communication network, the SOP needs to be 20 M rad/s or higher.
- Bandwidth: The bandwidth is continuously increasing and at least 400 Mbit/s is needed when the new video and IoT access services are introduced in the intensive or unmanned substations. The bandwidth for dispatching automation services have increased from 2 Mbit/s to 20 Mbit/s or even 50 Mbit/s. New transmission technologies are needed to be introduced to increase the single-fibre bandwidth and the number of connections.
- Optical reliability: For the relay protection and security stability system, the reliability of the substation communication network is 99,9999 %. The network needs to be upgraded from a ring network to a mesh network. In addition, more optical routes are needed to provide multi-path redundancy protection or hitless protection.
- Site distance: The typical distance between sites of the national or provincial network exceeds 80 km. For UHV DC lines, the site distance can reach a maximum of 2 000 km but typically less than 500 km. The typical site distance of the municipal networks is less than 80 km.

Based on the features needs of the substation communication network, the fine grain hard pipe technology is used to provide more connections, higher bandwidth and reliability. The substation communication network needs to meet the following key technical specifications:

- Fine grain hard pipe technology.
- 10 G / 100 G hybrid transmission.
- 20 M rad/s SOP coherent technology.
- 500 km long-distance single-span.

- Multi-path hitless protection.

3) Distribution communication network:

The distribution communication network mainly carries the following:

- the services between the power distribution terminal and the power distribution main station;
- the dispatching automation services between the new energy control terminals and the dispatching centre;
- the video and IoT services between the power distribution stations and the centralized control centre;
- the power consumption service between the smart meters and the power supply company.

Compared with the traditional distribution communication network, the new distribution communication network has the following:

- Service types: real-time and non-real-time production control services for dispatching automation, real-time and non-real-time production control services for distribution automation, video surveillance services, IoT terminal connection services, and power consumption data services. Services in different security zones can be transmitted together. Hard isolation and multi-service transport capabilities are needed.
- Bandwidth: The bandwidth of traditional single distribution automation services is 2 Mbit/s, and the egress bandwidth of the distribution station has increased, in the range 50 Mbit/s - 100 Mbit/s per site. High-bandwidth service access capability is needed on the distribution network side.
- Main distribution network interconnection: Dispatching automation, distribution automation, and video/IoT services need to cross the distribution access network and substation communication network. Two-layer network interworking capabilities is needed.
- Reliability: Dispatching automation real-time control services are moved to the distribution access network. The reliability of the distribution communication network needs to be improved to the same reliability of the substation communication network. Relay protection services need to be supported between distribution networks. The distribution communication network needs to support the redundancy protection capability.

Based on the features needed for the distribution communication network, it needs to support the fine grain hard isolation capability. The end-to-end fine grain hard pipe connections need to be supported through the distribution communication network and substation communication network.

4) Substation campus network:

The substation campus network is a new scenario. It is mainly used for video and IoT services connections between substations and centralized station:

- Service type: video and IoT terminal services.
- Bandwidth: The intra-station bandwidth converges to the egress bandwidth of 20 Mbit/s to 400 Mbit/s.
- Industrial-grade terminal: The terminal has industrial-grade capabilities, wide temperature, wide voltage, and electromagnetic shielding.

The substation campus network needs to support fine grain hard isolation capability. The end-to-end fine grain hard pipe connections needs to be supported through the distribution campus network and the substation communication network.

## 5.5 F5G-A Use case #5: Railway perimeter inspection

### 5.5.1 Use case briefing

As the main mean of transportation and an important infrastructure, the railway system plays an important role in the economic and social development of countries. For railway transportation, safety is the first priority, but factors such as illegal intrusion on the railway tracks, illegal destruction or crossing the railway fence, rockfalls and landslides, and other objective factors threaten the train's safety. With the growth and expanse of the railway system, the traditional way of continuing to rely upon personnel patrolling the railway perimeter is becoming less efficient and time consuming. New technologies need to be explored to further strengthen the perimeter inspection capability along the railway tracks.

With the rapid development of sensing technologies, the optical fibre sensing technology provides full coverage, all-weather, and all-intelligence technology for the railway perimeter inspection. Vegetation, animals, pedestrians, vehicles, wind, rain, snow, fog and other complex weather and environment conditions pose serious challenges to the reliability, adaptability and stability of the perimeter inspection system. Vibration sensitive optical fibre is easy to deploy and cost-effective. The optical fibre sensing technology is suitable for detecting human intrusion along irregular and sheltered long-distance railway fences. The optical fibre sensing technology can be one of the important technical defence measures for railway perimeters inspection.

### 5.5.2 Description of the use case

#### 5.5.2.1 Overview

The perimeter inspection along the railway need to be an efficient mechanism to prevent human intrusion and physical damage by the technical capability of the system. Up to now, the security of important facilities along the railway tracks, such as communication stations, substations and other facilities mainly relies on manual patrols by railway protection personnel on site or remote monitoring by the existing video surveillance system. The lack of technical prevention mechanisms, capabilities, and the limitation of patrol in terms of patrol range, not being real-time and efficient allows for frequent human and foreign object intrusions on the perimeter of the railway tracks. This results in a large amount of property loss or damage, especially on high-speed railway lines. High-speed trains need a longer braking distance to respond to emergency situations. The safety of the high-speed railway line operating environment has been the main challenge for the railway safety operation. The occurrence of the railway perimeter security risk is sudden, hidden and complex. These malicious acts or potential dangers are a serious safety risks to railway transportation. These shortcomings can be overcome by deploying an optical fibre sensing railway perimeter inspection system. Figure 12 shows an overview of the railway perimeter inspection system based on optical fibre sensing.

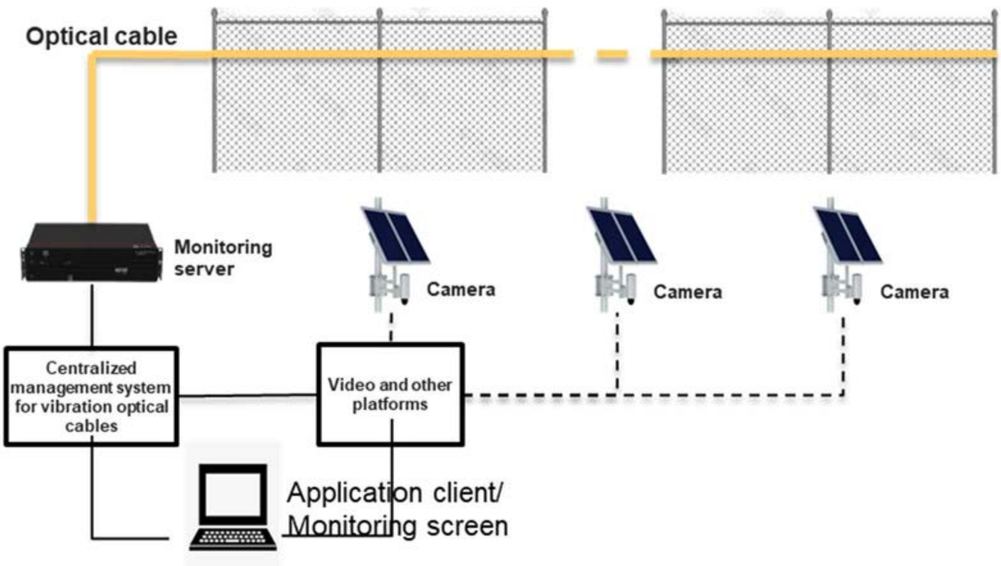



**Figure 12: Overview of railway perimeter inspection system based on optical fibre sensing**

The perimeter intrusion detection optical fibre sensor is deployed on the railway perimeter fence, and the data processing unit and early alarming unit are deployed in the monitoring centre of the stations along the railway. The intrusion events onto the railway track are collected in real time, and the perimeter intrusion characteristics are identified by an AI system. Cameras are mobilized remotely to confirm the intrusion, and then intrusion data is reported to the train control system. The train control system may perform corresponding reactions, such as slows down the speed of the train or performs emergency braking, which will prevent a perimeter intrusion from evolving into a serious accident.

Key features in the railway perimeter inspection scenario are as follows:

- Real-time response: Within the monitoring range of the optical fibre sensor, the response time from the start of the intrusion behaviour to the alarm being raised by the monitoring centre needs to be less than 5 s.
- Position accuracy: The position accuracy of the perimeter intrusion alarm system needs to be less than 10 m.
- Detection accuracy: The perimeter intrusion alarm system needs to ensure it does not generate false alarms, and the detection rate needs to be greater than 99,9 %. The frequency of false positives within one month needs to be less than 0,002 events/km/hour.

### 5.5.2.2 Motivation

Optical fibre, as a sensor, is based on the fact that optical parameters such as intensity, frequency and phase are changed by the environmental conditions surrounding the optical fibre when the light propagates in the optical fibre. Optical Time Domain Reflection (OTDR) is used to measure, analyse, monitor, and locate the physical parameters (vibration, stress, and temperature) surrounding the optical fibre.

Compared with traditional electrical sensors, the distributed fibre sensing technology uses communication fibre as the sensors. It has the following advantages:

Long-range precision:

- Wide range: A single optical fibre covers a range of tens of kilometres, which is better than a large number of electrical sensor points.
- Positioning accuracy: Each point of the optical fibre is a sensor, and the spatial sampling density is set according to the precision needs.

Easy OAM:

- Easy deployment: Reusing communication optical cables. A single optical fibre and a single device can be used to cover the network, facilitating power supply and data backhaul. The existing communication optical cable can be directly reused, or the independent optical cable or fibre can be used for optical fibre sensing.
- Easy maintenance: linear connection, visualized fibre faults, and easy fault location

Inherent safety:

- Anti-interference: Optical signals are not subject to electromagnetic interference and are reliably deployed in strong electromagnetic environments.
- Electrical insulation: Optical fibre electrical insulation, no external electromagnetic interference, or electromagnetic sensitive environmental conditions impose any deployment restrictions.

### 5.5.2.3 Service Functions and capabilities

Figure 13 shows the railway perimeter inspection system based on the sensing the vibration of optical fibre:

1) Sensing optical fibre: It refers to the optical cable deployed along the perimeter fence, through hanging or buried. Sensing optical fibre uses single-mode optical fibre such as Recommendation ITU-T G.652 [i.13].

2) Early alarming unit: transmits optical pulse signals, receives monitoring signals returned by optical fibres near the perimeter fence. The returned monitoring signal is processed by optical digital signal processing, and the processed signal is transmitted to the data processing system. The data processing system analyses and generates the information such as alarm, location and type, and then sends it back to the early alarming unit, which uploads it to the early alarming management system of the regional monitoring centre.

3) Data processing system: receives the information uploaded by the early alarming unit, determines the alarm, location, and type information which is returned to the early alarming unit, and then uploaded to the early alarming management system of the regional monitoring centre. The data processing system needs a server.

4) DCN: connects the network and the fibre sensor system.

5) Early alarming management system: It is used to manage and control the early alarming unit, receives, processes and display pre-alarm information uploaded by the processing unit.

6) GIS map: Is used for location positioning.

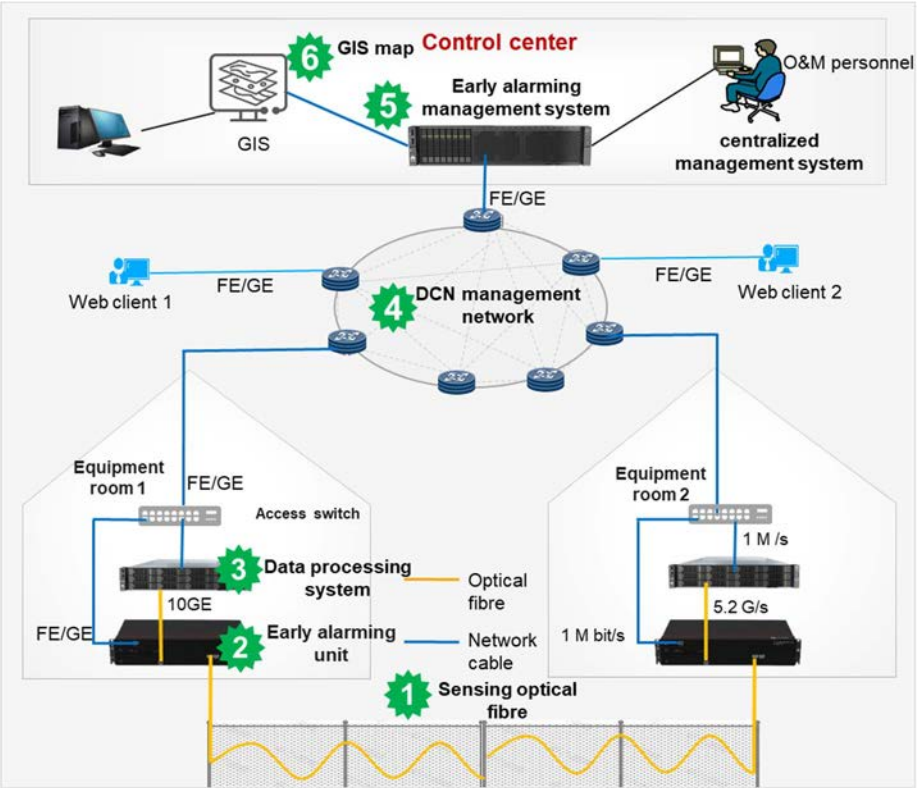



**Figure 13: Functions and capabilities of railway perimeter inspection system based on optical fibre sensing**

Key technical specifications of the railway perimeter inspection system based on the vibration of optical fibre:

1) Unidirectional coverage range: Optical cable coverage range ≤ 50 km. However, greater than 50 km range is still under study.

2) Event identification time for a single port: ≤ 5 s.

3) False positive rate: ≤ 0,002 per km per hour.

4) Detection rate: ≥ 99,9 %.

## 5.6 F5G-A Use case #6: Naked-eye 3D display

### 5.6.1 Use case context

Compared to 2D video streaming, a 3D light field meets the ultimate visual human experience. Technically, to achieve a real 3D feeling, the display system needs to provide binocular parallax (to form a 3D feeling by creating visual difference between a human's two eyes), moving parallax (to quickly adapt to the change of eye actions) and blurred focus (to let the eye adapt to the near and far objects).

Many 3D display technologies have been explored in the past few decades. One of the most popular application of 3D display is 3D movies in the cinema. In this case, the 3D movie is projected with two images that provide a subtle deviation to the left and right eyes through a pair of stereoscopic glasses (with orthogonal light polarization). This simple way is to allow the human eye to sense binocular parallax, enabling the brain to fuse left and right eye images to create the 3D information. There is no eye action involved in this case, meaning that the 3D movies provide only binocular parallax, physiological visual information, but not moving parallax and blurred focus.

Virtual Reality (VR) glasses or helmet provide binocular parallax and moving parallax as following:

- The VR glasses or helmet generate different images for the left and right eyes, providing binocular parallax perception.
- When the human eye moves to different positions or rotates in different directions, the VR glasses or helmet provides images of different viewpoints. As the viewer moves through six Degrees of Freedom (6DoF), different viewpoints of the actor's left face, right face, chin, etc. can be seen, creating moving parallax.
- However, the VR glasses or helmet do not provide blurred focus. For example, the lights from mountain far away and human near are all generated in the same VR display with the equal physical distance to the human real eye. No matter whether the human eye focuses on a "distant" mountain or a "near" human, the ciliary muscles are in the same degree of flexion, which is not consistent with the blurred focus of the human eye when viewing the actual landscape.

Moreover, VR glasses or helmet make people feel uncomfortable when watching the 3D display for long periods of time. To overcome this discomfort, the naked-eye 3D displays are developed to mimic the reality of people's natural perception. This creates new challenges for the communication system.

### 5.6.2 Description of the use case

#### 5.6.2.1 Overview

Naked-eye 3D display, as the name suggest, provides 3D visual sensing from the human eye to the brain without external objects on the human body, such as 3D glasses, helmet, etc. There have been many optical methodologies designed in the past for implementing naked eye 3D display, including light-field display, spatial multiplex, time multiplex, integral imaging [i.14].

Spatial multiplex is widely adopted. Parallax barriers and lenticular lenses are the two typical methods that redirect imagery to several viewing regions. However, this manipulation causes reduced image resolution. When the viewer's head is in a certain position, a different image is seen by each eye, giving a convincing illusion of 3D. Such displays can have multiple viewing zones, thereby allowing multiple users to view the image at the same time, though they may also exhibit dead zones where only a non-stereoscopic or pseudoscopic image can be seen.

- Parallax barrier based optical system (shown in Figure 14):

A parallax barrier is a device which can be placed in front of an image screen (shown in Figure 14 (a)), such as a liquid crystal display, to allow it to show a stereoscopic or multiscopic image without the need for the viewer to wear 3D glasses. Placed in front of the normal LCD, it consists of an opaque layer with a series of precisely spaced slits, allowing each eye to see a different set of pixels, so creating a sense of depth through parallax.

A disadvantage of the method in its simplest form is that the viewer needs to be positioned in a well-defined spot to experience the 3D effect. However, this issue can be addressed by using face-tracking to adjust the relative positions of the pixels and barrier slits according to the location of the user's eyes, allowing the user to experience the 3D from a wide range of positions. Another disadvantage is that the horizontal pixel count viewable by each eye is halved, reducing the overall horizontal resolution of the image, as well as the brightness.

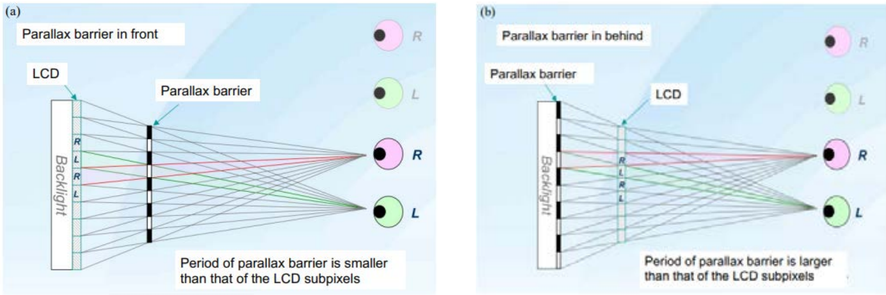



**Figure 14: Typical optical systems with the parallax barrier for naked eye 3D display (Source: [i.14])**

Another way, shown in Figure 14 (b), the parallax barrier is inserted between the display panel and the backlight to make the barrier invisible. In this case, people would not be aware of the existence of black strips.

Figure 15 shows an example of the generation of multiple viewpoints (number of viewpoints is equal to four in this case). The pitch of the parallax barrier (the pitch is the distance between two white gaps in the parallax barrier in Figure 15) is slightly smaller than four times the subpixel pitch to converge the light into a single view, and the width of the transparent region determines the brightness. Wider transparent region increases the brightness, but induces more crosstalk. A common width is one quarter of the pitch of the parallax barrier to avoid significant crosstalk. A multiple view design offers motion parallax on top of a binocular parallax, so it allows multiple people to move around and to watch 3D images. However, the brightness and horizontal resolution is 1/N, where N is the number of viewpoints.

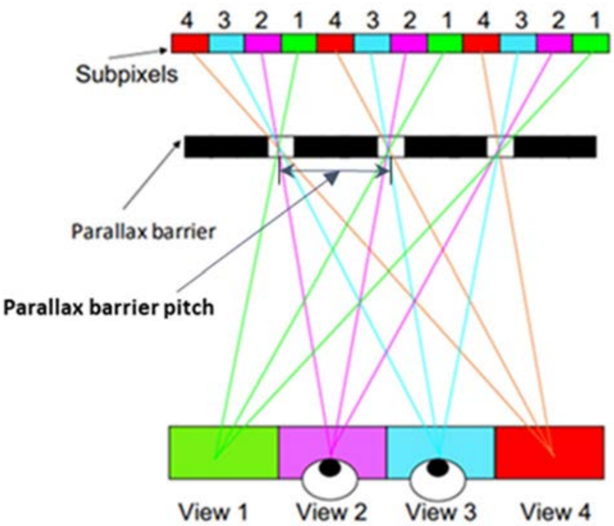



**Figure 15: Generation of multiple viewpoints**

- Lenticular arrays based optical system (shown in Figure 16):

The lenticular sheet is a one-dimensional cylindrical micro-lens array which replaces the role of the parallax barrier and collimates the diffused light from the subpixels into a specific direction, being received by a specific eye. Hence, each eye receive a different image and merge them into a single image with depth. Since the lenticular sheet is a transparent film, none of light is blocked, hence, it maintains the level of brightness. This is an advantage over a parallax barrier based approach. A multi-view setup can be implemented with the pitch of the lenticular array slightly less than M times of the width of a subpixel.

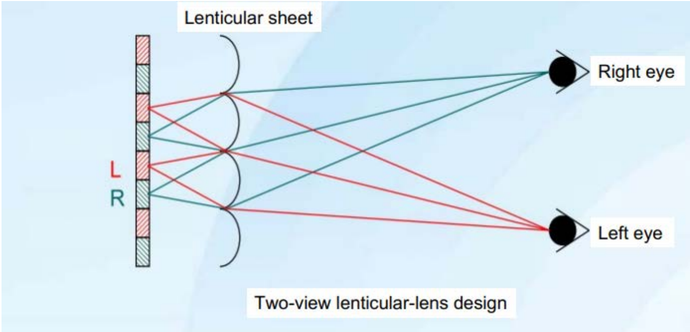



**Figure 16: Typical optical systems with the lenticular arrays for naked eye 3D display (Source: [i.14])**

The naked eye 3D display is believed to have many applications. In the short term, the fixed screen can be applied to scenarios like outdoor advertisements, live broadcasting, and exposition, etc. In the mid-term, with the evolution of social digitalization, digital twin visualization, industrial design, education, etc. could upgrade from 2D to 3D. In the long term, with the various interaction schemes becoming mature, humans can deal with a 3D world, like 3D e-meeting, 3D-assistance in cars, 3D entertainment, etc.

With the help of eye tracking, voice interaction, gesture recognition, tactile feedback or olfactory, a more realistic environment could be created digitally.

Since in naked eye 3D display, multiple viewpoints will be created for different locations. Therefore, the volume of information will increase linearly. Table 2 shows a calculation of the throughput of a naked eye 3D display optical system.

**Table 2: Example throughput for different naked eye 3D display systems**

| Resolution | Viewpoints | Throughput | |
|---|---|---|---|
| | | No compression | H.265 (350X) |
| 3 840 × 2 160 | 20 | 222,5 Gbps | 0,64 Gbps |
| | 36 | 400,5 Gbps | 1,14 Gbps |
| | 45 | 500,6 Gbps | 1,43 Gbps |
| | 60 | 667,4 Gbps | 1,91 Gbps |
| | 84 | 934,4 Gbps | 2,67 Gbps |
| 7 680 × 4 320 | 20 | 889,9 Gbps | 2,54 Gbps |
| | 36 | 1601,8 Gbps | 4,58 Gbps |
| | 45 | 2002,3 Gbps | 5,72 Gbps |
| | 60 | 2 669,7 Gbps | 7,63 Gbps |
| | 84 | 3 737,5 Gbps | 10,68 Gbps |
| Throughput = pixel number × RGB three colour × viewpoint × frame rate (60 fps) × colour depth (8 bit)/compression rate | | | |

For 4K resolution with up to 84 viewpoints, the compressed data stream needs 2,7 Gbps throughput. In contrast, greater than 10 Gbps throughput is necessary for transmitting 8K resolution video compressed data stream with 84 viewpoints. Multiple devices with a 4K resolution profile will need similar throughput.

Moreover, to obtain the 6DoF of the eye's position, the eye tracking methodology like Simultaneous Localization And Mapping (SLAM) is probably needed. The communication system may also need to transport the information in real time, if the tracking calculation is not performed locally (such as in the edge or in the cloud). This will impose limitations on latency.

#### 5.6.2.2 Motivation

Naked eye 3D display is a brand-new network service, revolutionizing the 3D viewing experience from 2D and without any additional device assistance (like glasses). It is the ultimate solution for 3D video display:

- 3D experience instead of 2D is provided without any discomfort.
- Compared to traditional VR devices, it is very easy to apply to outdoor applications and map the 3D information to multiple users simultaneously, which will have more application scenarios in the future.
- This system will be integrated in electronic devices, like smart phone, which will affect the daily life of everyone.

#### 5.6.2.3 Service function and capabilities

The naked eye 3D display optical system basically needs higher F5G Advanced network performance:

- Much higher throughput: as shown in Table 2, greater than 10 Gbps is needed to support the high-end naked eye 3D display system with more viewpoints and higher resolution.
- Latency restricted transmission: the eye movement needs flexible adaptation of the image information. This needs fast recognition of the 6DoF of the eye's position and transmits the correct video stream change request within a bounded latency. This procedure needs local and remote computing power as well as a latency sensitive transmission network.

  To further enhance the naked eye 3D display QoE, other dimensions of interaction methodology are preferred, like voice interaction, gesture recognition, tactile feedback or olfactory. These features can apply to other scenarios in daily life.

## 5.7 F5G-A Use case #7: Unified access and on-premises network

### 5.7.1 Use case context

The E2E F5G network is comprised of multiple segments, including the customer on-premise network, the access network, the aggregation network and the core network [i.15]. Especially for the optical access network and the on-premises network, a TDMA mechanism is adopted by PON [i.16] for access network and by FIN [i.12] for on-premise network. For the Wi-Fi® network, a flexible approach exists through time (CSMA), frequency (OFDMA) and space (spatial reuse). In general, these networks are physically isolated and logically independent of each other since these networks have their own protocol stacks.

This cascaded network may not achieve the best transmission from an E2E point of view since multiple layers of DBA procedures running independently. It is beneficial to have the different segments of the F5G-A network working together to provide a unified view and strategy for network operation. This cooperative network behaviour enables a logically unified network for data transmission.

In device management, the management protocol providing device management is only available for a specific network segments, such as OMCI [i.17] between OLT and ONU in the optical access network, management for the FIN on-premises network between the MFU (equivalent to P-ONU) and the SFU (equivalent to E-ONU), and the Wi-Fi® data elements [i.18] between SFU and the end user device like smart phone or laptop, etc. Unified management cooperation is necessary to better visualize the device status.

### 5.7.2 Description of the use case

#### 5.7.2.1 Overview

The traditional access network and the on-premises network work independently of each other, forming a physical and logical cascaded topology, shown in Figure 17a and Figure 17b. The access network is terminated by the ONU (such as a P-ONU) while the backhauling network for Wi-Fi® is terminated by an E-ONU. The connection between the end user device (like smart phone, laptop), is typically based on Wi-Fi®. The uplink transmission (fragmented data transmission in Figure 17b), when the service data packets are generated and encapsulated as the uplink packet in the end user device (the STA in Figure 17b), a packet-sending request is sent to the E-ONU for scheduling. Alternatively, the STA could directly compete for the channel. Trigger-based scheduling can be used to guarantee a well-ordered transmission in the air interface. After an E-ONU receives the uplink packets from the STA over Wi-Fi®, the E-ONU request a transmission opportunity from the P-ONU, which allocates an available timeslot through a DBA decision. The uplink packet from the E-ONU is then transmitted and received by P-ONU. A similar procedure will take place again in the optical access network with a transmission request, and grant of a timeslot followed by the data transmission in the access network. This procedure creates an additional packet waiting time due to the waiting period necessary in each segment, when the segments are operating independently of each other.

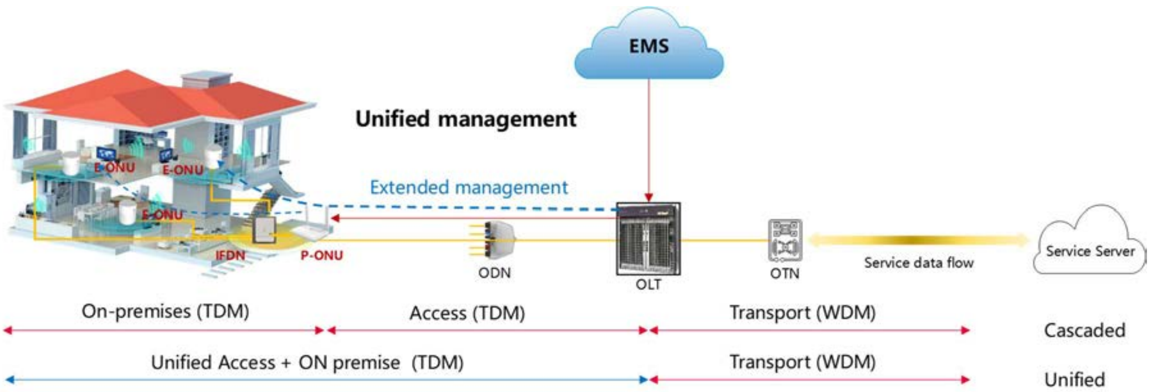



**Figure 17a: Illustration of the access and the on-premises network (cascaded and unified)**

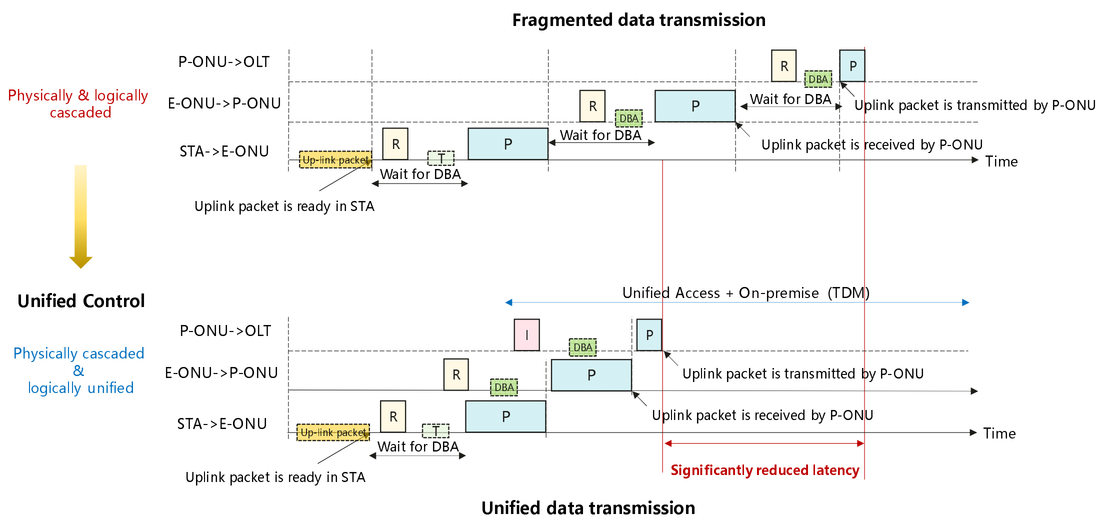



**Figure 17b: Fragmented to unified data transmission**

It is desirable to minimize or eliminate these multiple waiting periods in order to improve the E2E transmission performance. Cooperative operation of a unified management is advantageous. Figure 17b (unified data transmission) shows a cooperative DBA procedure for data transmission between the access network and the on-premises network. The mechanism shown in Figure 17b unified data transmission is that the E-ONU requests an uplink timeslot while the E-ONU is receiving the uplink packet scheduling request from the STA. Simultaneously, the P-ONU sends an indication of the reception of uplink request from the E-ONU to the OLT to request an uplink timeslot in advance. This indication provides the OLT with the expected time for data transmission based on the estimated completion of uplink packet reception from the E-ONU. This enables the DBA algorithm in the OLT to schedule the packets on time. Compared with multiple DBA waiting time procedures, enabling a lower processing data switching period in E-ONU and P-ONU, significantly reduces the E2E transmission latency. This is also beneficial to reduce the data buffer size in the network elements, since the cooperative DBA reduces long waiting queues. Moreover, a stable and reliable Wi-Fi® connection is important to facilitate E2E QoS (see Clause 5.2)). In this case, the P-ONU needs to provide locally controlled capabilities to enable the on-premises resource allocation. For an extreme case without the access network uplink connection, the P-ONU needs to be capable of switching the east-to-west packet if needed.

In addition, cooperative management in the access network is important to provide optimized resources allocation, asset monitoring, energy saving, etc. by leveraging computing cooperation, (see Clause 5.3). Therefore, cooperative management is needed to allow the OLT or EMS manage all the devices in the optical access and the on-premises networks. Such a centralized management scheme can be achieved by extending the current management channel in the optical access network, like OMCI [i.17] or defining a cooperative scheme between the OMCI [i.17] and the management of the FIN.

Unified transmission and management for the access and the on-premises networks enables better optimization of the network performance and operation.

NOTE: The regulation in some countries may impact the management of the on-premises networks, the operators might not perform this by default without a contract.

#### 5.7.2.2 Motivation

Unified access and on-premises networks enhance the network performance in both the data and the management planes. It is not necessary to change the physical topology, but by making logical cooperation for packet scheduling and management methodology:

- A global view of packet scheduling can be performed to reduce the E2E transmission latency, optimize the data buffer size, etc. This is beneficial for the end user's QoE.
- To make use of the computing power of the device in the central office (OLT) to provide a more accurate data transmission strategy.
- Cooperative management provides global mapping of device status to improve network resource utilization (time/spatial/spectrum) and provide network asset monitoring.

#### 5.7.2.3 Service functions and capabilities

The unified access and on-premises networks need to provide the following functions.

For unified control of data transmission:

- The OLT could request and receive the transmission status (data buffer, communication environment, etc.) from any device in the network, including the P-ONU, the E-ONU and the end user device.
- The OLT could configure the transmission behaviour of any device in the network, such as the optical transmission parameters in the optical access and the on-premises networks, or the air interface of the LAN (i.e. WLAN). Therefore, cooperative scheduling is supported through the E2E network.
- The P-ONUs is capable of local control for the E-ONU and corresponding end user devices through a centralized control mechanism.
- To achieve the best network resource utilization, the data scheduling should be based on the QoS for the different service flow.

For unified management of the whole system:

- An extended OMCI [i.17] management interface or a new method needs to be supported to enable global management of any device in the access and the on-premises networks centralized in the OLT.
- The P-ONU is capable of managing the E-ONU independently. The unified management needs to support the coordination between the OLT and the P-ONUs.
- The unified management provides a mechanism to collect the device information from different network elements simultaneously. This also helps to diagnose network failures with aligned data.
- The unified management provides visualization of the logical link for the different service flow, enabling an association between the service flow and the scheduling strategy.

# 5.8 F5G-A Use case #8: OTN intelligent fault management

## 5.8.1 Use case briefing

Traditional OTN networks uses an alarm-based fault management approach. A single network fault may result in a large number of alarms, and may trigger a large number of trouble tickets. The root cause of the alarms is identified manually, based on human experience and the appropriate online operations (e.g. using optical power meter to measure the optical power). This produces a large number of complex manual operations and therefore increases the Network Operators OPEX. In addition, due to the large number of trouble tickets, fault resolution will be slow, and may not be satisfactory to the Network Operator.

This use case describes an OTN incident-based intelligent fault management system, aiming to automatically analyse the alarm information and determines the network faults recovery. This in turn will increase OTNs level of Autonomous Networking for fault management.

## 5.8.2 Description of the use case

### 5.8.2.1 Overview

In traditional OTN, the network operators need to invest a large amount of dedicated maintenance resources and generate complex standard workflows for handling network faults.

When the OTN equipment detects faults, it will report the alarms to the Network Management System (NMS), the NMS reports the alarm information (in a human-readable form) to the fault management system. The fault management system generates multiple trouble tickets based on the alarm severity and location, and submits them to the trouble ticket system. The trouble ticket system then dispatches the trouble tickets to the maintenance engineers.

On receiving a trouble ticket, the maintenance engineer logs into the NMS, determines the root cause of the fault based on the service path information, the network topology information, on experience, and appropriate online operations, and then repair the fault on site or remotely.

However, when a serious fault occurs in OTN, a large number of correlated alarms may be generated in the upstream and downstream direction of the affected paths, and may expand into different network layers (e.g. Optical Channel (OCh) layer and Optical Data Unit (ODU) layer). In such a case, a large number of duplicated or erroneous trouble tickets will be triggered, which greatly increases the complexity and the difficulty for the maintenance engineers to repair the faults, consuming significant Operator's resources. This will only become more complex as the network scales up.

There is a need in F5G Advanced, for an intelligent OTN fault management system, to enable the automatic Root Cause Analysis (RCA) in the presence of multiple alarms, significantly reducing the number of trouble tickets, and improving the efficiency of fault management.

### 5.8.2.2 Motivation

The main motivation for the OTN intelligent fault management approach is to reduce the fault management OPEX, and improve the network Operator's experience. Specifically, the network operator's desire is to:

- Improve the accuracy of root cause identification and fault location.
- Improve the accuracy of trouble ticket generation and dispatching.
- Improve the automation of fault management, and reduce the complexity of handling network faults by the maintenance engineers.
- Reduce the reliance on human experience.
- Shorten the recovery time from the fault.

### 5.8.2.3 Service Functions and capabilities

In this use case, the incident-based intelligent fault management approach is introduced in the OTN fault management system, to replace the traditional alarm-based fault management approach, see Figure 18. As such, a network fault incident will be identified, and a trouble ticket will be dispatched for this incident. This greatly reduces erroneous trouble ticket and shortens the fault handling time.

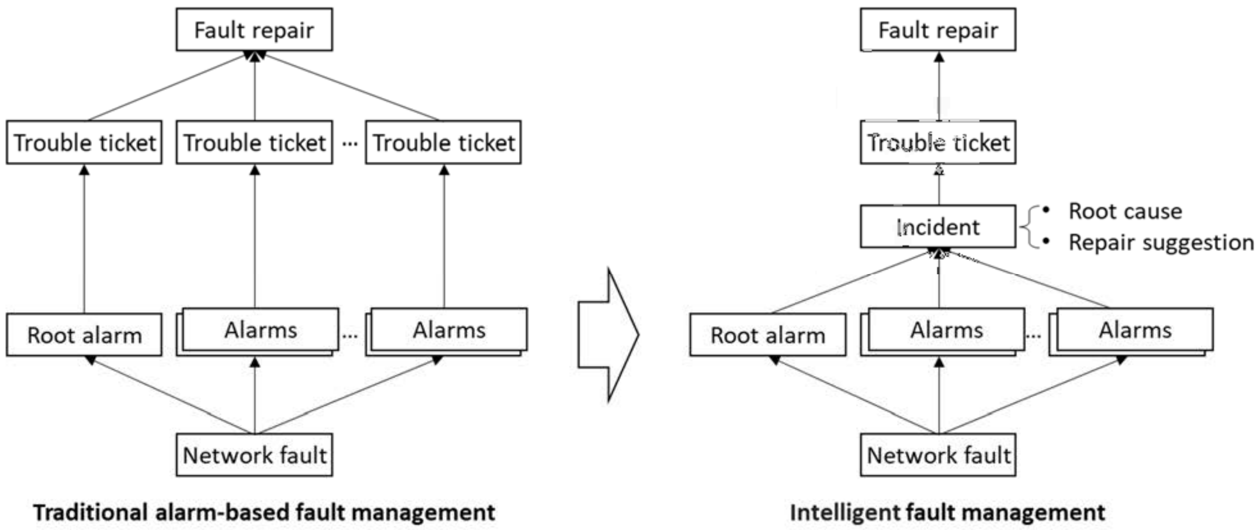



**Figure 18: Alarm-based fault management vs. intelligent fault management**

The key capabilities of OTN intelligent fault management includes:

1) Alarm aggregation:

   OTN faults, such as link failure, optical performance degradation and hardware faults, will usually trigger a large number of upstream and downstream path alarms in multiple network layers. Multiple correlated alarms triggered by the same fault need to be aggregated into a single incident in real time, to accelerate the fault handling process.

   Once the incident is identified, the alarm cause needs to be determined, so that the root alarm can be determined from all the correlated alarms.

2) Troubleshooting:

   Based on the root alarm information, the OTN fault management system could perform fault diagnosis to identify the root cause which led to the correlated alarms.

   For example, for optical path failure or degradation, the OTN fault management system could identify the failed fibre span along the optical path, or even identify the exact fault location along the failed fibre span.

The OTN fault management system could further provide fault recovery information. This can significantly reduce the complexity of handling network faults by the network operators.

3) Fault impact analysis:

The OTN fault management system needs to analyse the impact on the OTN by the identified faults, for example, to analyse the network services which are affected by the faults. This eases the network operator's view of the affected services, such as the service type, the source and destination information.

When multiple faults occur, the OTN fault management system could also provide a priority indication to handle different faults, based on the severity of the impact on the network.

4) Report of incident information:

The OTN fault management system needs to report the information of the identified incident to inform the operator (e.g. through the trouble ticket dispatching system). Such incident information includes but not limit to root cause, alarm correlation information, fault location, fault occurrence time, impact of the fault, fault severity and handling priority, and repair suggestions.

Figure 19 shows a simple OTN fault management example. In this example, it is assumed that a hardware failure (marked as "HW_Err") has occurred on a board in node B. As a result, the corresponding OCh optical power is reduced (marked as "Power_Low") on the downstream node C, and therefore node C will lose the optical signal on the receive side (marked as "LOS"). In such a case, all the ODU connections (e.g. the green line in Figure 19) on this OCh will be interrupted. If Sub-Network Connection Protections (SNCPs) are configured on these ODU connections, then protection switching will be triggered in the source and destination nodes (e.g. nodes A and D) of these connections, and therefore the SNCP_PS (SNCP Protection Switching) alarms will be generated.

It can be seen that the NMS finally receives at least five alarms from four different nodes, due to a single hardware failure on one node.

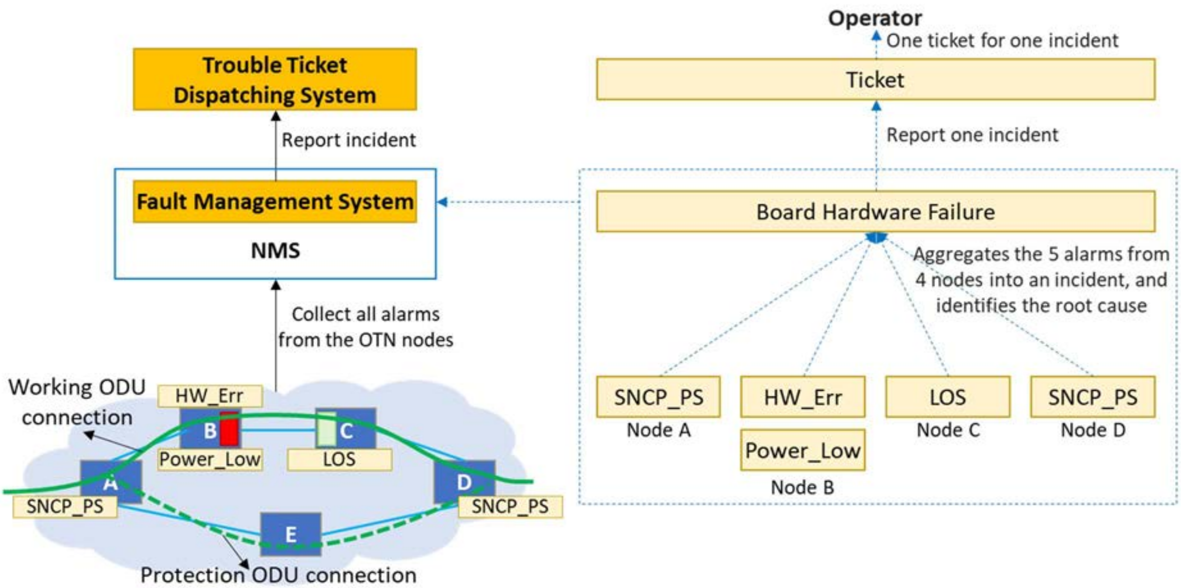



**Figure 19: Example about fault management in OTN**

The OTN fault management system firstly identifies the incident and determined the root alarm (HW_Err) from the received alarms, and determines that the root cause is the board hardware failure on node B. The OTN fault management system then provides the repair instruction for the incident (e.g. to replace the board with a new one), and reports the related information of the incident to the trouble ticket dispatching system, so that the trouble ticket dispatching system can generate a trouble ticket and dispatches it to the maintenance engineer.

# 5.9 F5G-A Use case #9: Evaluation and assurance of user service experience

## 5.9.1 Use case briefing

In the F5G Advanced era, home broadband services have become essential to daily life. The main applications of the home broadband network have changed from web browsing and low-bit-rate videos to online education, telecommuting, and real-time gaming. In addition to the access bandwidth, the home broadband users have become increasingly sensitive to the application service experience.

## 5.9.2 Description of the use case

### 5.9.2.1 Overview

Traditionally, there are several challenges for the operation of home broadband services:

- The network operators usually have no technical mechanism to automatically detect the service quality.
- The network operators may not be aware of the user's service experience deterioration, unless the user's complaints are received.
- Mainly the service experience deterioration problems need to be resolved manually on-site. This approach takes time to fix the problem, and increases OPEX (e.g. increasing the human resource investment).

For F5G Advanced, proactive evaluation and assurance of user's experience, and fast service experience problem identification and rectification, are critical and need to be considered. With the improvements in network automation capabilities, it is possible in some cases that the network operators can remotely fix the problems which are affecting the user's service quality, or even can optimize the network before the user experience deteriorates. This will greatly shorten the average diagnosis and rectification time of service quality problems, reducing the unnecessary on-site service rate, saving OPEX, and improving the user's satisfaction.

NOTE: This use case could be seen as an enhancement to UC#11: Enhanced traffic monitoring and network control in Intelligent Access Network, which is described in ETSI GR F5G 008 [i.2].

### 5.9.2.2 Motivation

The main motivation for the evaluation and assurance of the home broadband user experience include:

1) To improve users' experience, by changing from "passive response to users' complaints" to "proactive experience management and rectification of poor-QoE problems".

2) To improve market perception based on the user experience evaluation results, e.g. to promote home broadband package upgrades to the users who suffer from poor-QoE problems.

3) To improve the network operation efficiency, the network maintenance, the network monitoring and the network optimization, fast closed-loop control mechanisms are used. Hence improving the key factors that affect the user experience.

### 5.9.2.3 Service Functions and capabilities

Figure 20 shows the key capabilities of evaluation and assurance of the home broadband user experience, including:

- Evaluation of user's service experience:

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

  To evaluate whether a specific user suffers from poor-QoE problems, the QoE Analysis System needs to obtain the network KQIs of multiple typical user services (such as voice, web, and streaming), and form the normalized and quantified service experience indicator based on the user experience evaluation model.

- User experience demarcation and root cause analysis:

  The QoE Analysis System needs to support the analyses of the network KPIs on both a time dimension and network segment dimension, to determine which network segment or network equipment is causing the poor-QoE problems (e.g. end user devices, home network, ODN, OLT, bearer network or content service network), and to analyses the key factors that affect the user's service experience KPI/KQI.

  In addition, the QoE Analysis System needs to determine the exact fault location and perform the root cause analysis of the poor-QoE problems. The root cause can be, for example, the bearer network or the content service network fault, the PON equipment or a component fault (e.g. card, optical module, port, ONU, FTTR P-ONU or E-ONU), the ODN feeder fibre and the distribution fibre problems, the Wi-Fi® air interface interference problems, the Wi-Fi® connection problems, the Ethernet cable problems, or the ONU/AP configuration exceptions.

  Based on the previous analysis, the QoE Analysis System also needs to provide a list of users who are considered to have (or will have) service experience problems.

- User experience rectification and audit:

  1) For software problems (e.g. Wi-Fi® antenna transmit power is too low because of incorrect configuration), the QoE Analysis System needs to support automatic optimization of the network, enabling proactive closed-loop control of the network optimization, even before the user complains.

  2) For the problems which need to be resolved by manual on-site service (e.g. replacement of the optical modem, or adding new APs), the QoE Analysis System needs to support dispatching the trouble tickets, so that the installation and maintenance engineers can be arranged to fix the problems on-site. Alternatively, the network operators provide tools or guideline to the users, so that the users can fix the problems themselves.

NOTE: The regulation in different countries and regions may vary, which may impact on who and how to fix the CPN problems on-site.

  3) The QoE Analysis System needs to support re-evaluating the users' experience after the rectification, to see if the problems have been resolved.

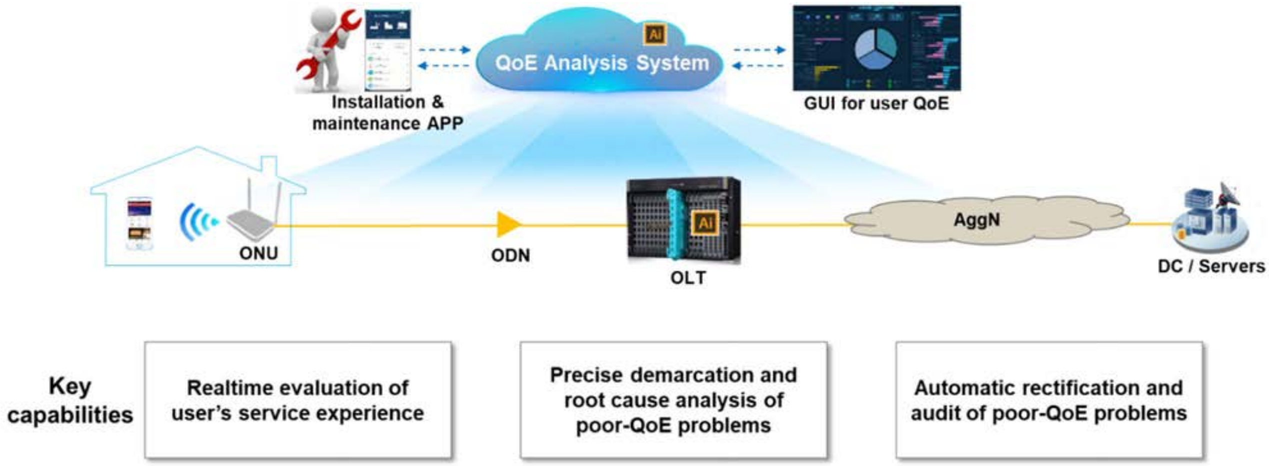



**Figure 20: Overview of home broadband QoE evaluation and assurance, and the key capabilities**

### 5.9.2.4 Operation of the use case

1) The QoE Analysis System monitors the performance of the network, evaluates the user experience, and generates a list of users who are considered to have or will have a poor service experience.

2) For software problems which cause poor user experience, the QoE Analysis System determines the solutions to resolve the problems. Once the problems are confirmed to be resolved, by the network operators OAM department, the QoE Analysis System automatically performs network optimization without on-site visits.

3) For other problems which need on-site resolution, the network operators OAM department exports the user list with poor experience.

4) Resolve the poor-QoE problems in Step 3). There may be different options depending on the network operator's policies and the country and region regulations. For example:

   a) Option 1: The network operator contacts the users on the list to reserve the time for an on-site service, and generate the corresponding trouble tickets. On receiving the trouble ticket, the installation and maintenance engineer visits the user to fix the problem on-site, and feeds back the result to the QoE Analysis System. Software tools (e.g. an APP installed on the engineer's smartphone) may be used to assist in completing the above operations. The QoE Analysis System re-evaluates the users' experience, and provides the audit result according to the feedback from the installation and maintenance engineer.

   b) Option 2: The network operator provides tools or guideline to the users, so that the users can fix the problems themselves.

5) The customer response centre initiates the return visit to the users (e.g. phone follow-up or online survey), and optionally investigates the users' satisfaction.

## 5.10 F5G-A Use case #10: Cloud Desktop

### 5.10.1 Use case context

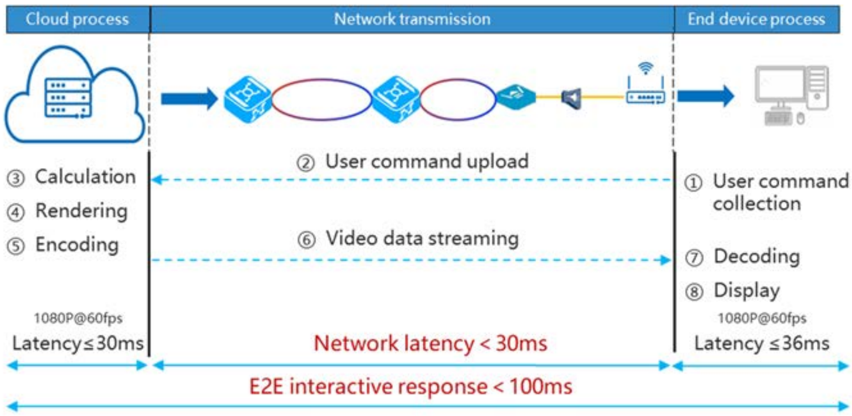
Cloud desktops are an approach for end-user computing where virtual desktops and applications are hosted on cloud-based resources rather than resources in an on-premises corporate data centre. Cloud desktops can be accessed from anywhere, using any device, as long as they are connected to the internet. There are many valuable scenarios of cloud desktop:

- Work from anywhere. Cloud desktop provides the flexibility and ease for the employees to work from wherever they wish.
- Securing casual users. Cloud desktop presents a way for an organization to allocate proper access rights for dedicated application and data for contractors or other users.
- IT consolidation due to mergers and acquisitions. Cloud desktop enable access continuity for the new members to reuse the old resources, which improves productivity and enables new hired teams to be quickly integrated.
- Disaster recovery and business continuity (DR/BC). Cloud desktop gives relief from all such scenarios, mitigating the risk of misplaced work and accidental data exposure that could constitute a data breach.

All these use cases point out the obvious benefits of adopting cloud desktop, including increased productivity (anywhere, anytime access directly translates to more productivity and efficiency), savings (organizations can save in several ways, such as hardware, maintenance, etc.), enhanced security, self-service simplicity (cloud desktops can be provisioned, accessed, and de-provisioned whenever needed - in seconds or minutes), increased agility (cloud desktops receive application updates and utilities automatically).

However, to support cloud desktop, an E2E solution needs to be considered. Based on the traditional centralized cloud-based infrastructure and streaming methodology, there still exist a lot of QoE problems. The multiple network segments led to instability of data flow, concerns of data security and privacy, compliance of accessories (such as keyboard, printer, touchpad, mouse, etc.), long interactive time, desynchronization of audio and video.

Figure 21 shows an example of the E2E interactive process.




NOTE: The term video data streaming in this figure, refers to a stream of display content from the cloud process to the end device process.

**Figure 21: An example of interactive process triggered by a user command (i.e. move or click the mouse)**

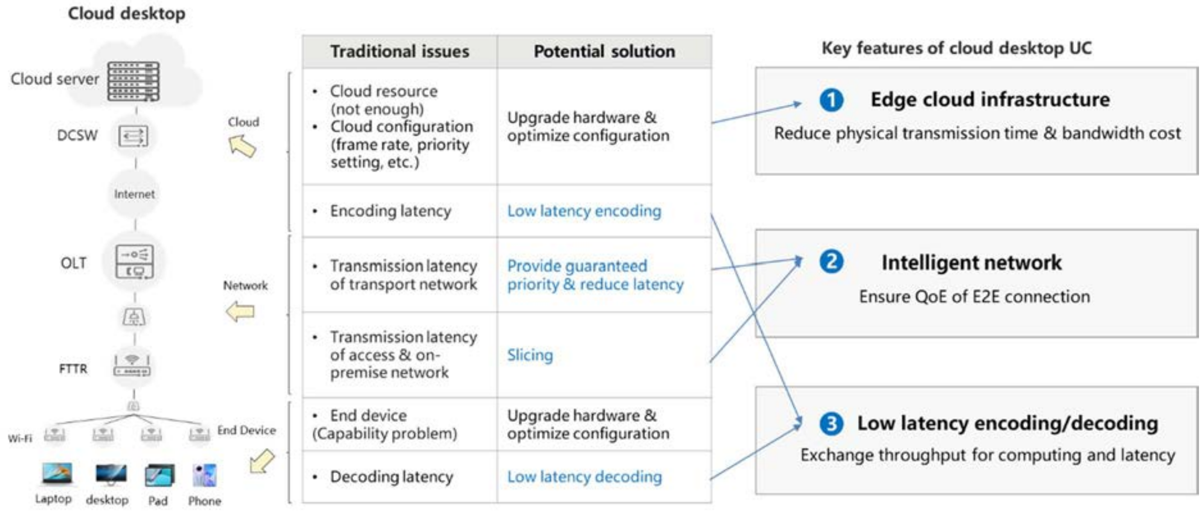
The E2E interactive request-response contains multiple time interval steps for processing. To improve the E2E service experience of cloud desktop, each of the processes need to be optimized.

## 5.10.2 Description of the use case

### 5.10.2.1 Overview

Typically, cloud desktop is a desktop virtualization platform allowing users to access Windows like desktops or applications that are running in a different physical location (shown in Figure 22):

- A server running in a data centre creates a unique visual desktop to each individual user. Desktop virtualization infrastructure manages the configuration of those instances of Windows and assigns users to them. Insufficient resource will lead to processing delay.
- A necessary encoding procedure is adopted to reduce transmitted data volume, which introduces extra encoding latency and consume computing resources.
- Data transmission takes place in the E2E network. The performance of the network (throughput, latency, etc.) impacts the data reception. The typical low-latency lightweight compression coding such as JPEG XS provides typical a 10:0 compression ratio. This needs the system to enable at least 10 Gbps data rate for a typical 4K resolution video (see Table 2) for 10 simultaneous connections.
- Processing in end devices needs additional time for decoding, processing and displaying.




NOTE: The end devices displaying the cloud desktop can be of any type including laptops, desktops, pads, and phones (as shown in this figure).

**Figure 22: Key features to support a good quality cloud desktop service**

To overcome the traditional issues of the cloud desktop, edge cloud infrastructure needs to be introduced to reduce the transmission latency by reducing the physical distance between the cloud server and the end device (shown in Figure 23). In addition, the deployed edge cloud could help to off-load the computing needs. In edge cloud, the enterprise cloud desktop services are deployed at the edge nodes, allowing users to access the nearest node. This optimizes the service data transmission over the transport network and reduces the transmission latency.

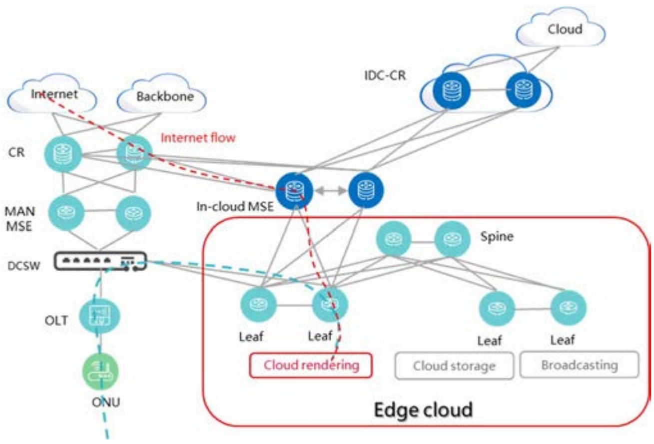



**Figure 23: Edge cloud for cloud desktop application**

To provide a higher priority for cloud desktop services compared to the background network services, like web browsing, VoD, etc., an intelligent networking needs to be adopted (see Figure 24). Such functions include:

- Intelligent identification of cloud desktop service: AI technology may be utilized to perform online inference and intelligently identify various networks and assign higher priority, such as cloud desktop services.

- Network Processor (NP) provides line-rate offloading forwarding. When the network is congested, cloud desktop service flows are preferentially processed.

- Network provides Wi-Fi® air interface acceleration: Wi-Fi® slicing and Wi-Fi® Multi-Media (WMM) technologies ensure that cloud desktop services are preferentially forwarded and network latency is reduced.

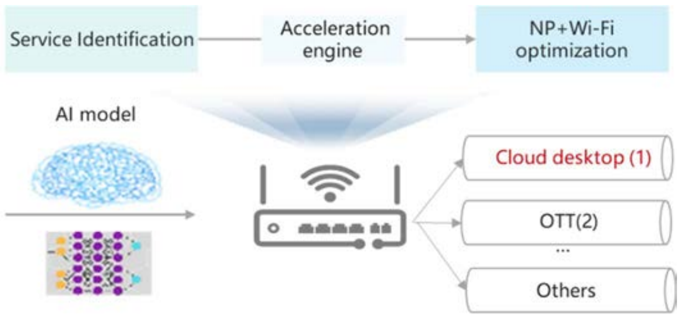



**Figure 24: An example architecture of an intelligent network**

To further reduce the encoding/decoding complexity (i.e. reduced latency), shallow compression and low-delay codec solution (exchanging throughput for computing and latency) needs to be considered.

### 5.10.2.2 Motivation

Cloud desktop is a new network service for enterprise cloudification, bringing new challenges for the network architecture evolution, but on the other hand, provides significant value by reducing cost and increase efficiency for enterprise:

- Improved Productivity:

With a virtual cloud desktop, users have a consistent desktop performance and are not impacted by hardware issues. Productivity is improved because users can easily switch access points when one physical device has a problem. They also have the flexibility of accessing all of their files and applications from any location, improving workflow.

- Easy management:

Cloud-based desktops can easily be updated, patched, and administered from a central control panel, this eliminates the downtime associated with moving a user off their physical workstation while updates are done. All systems being updated regularly may also be easily ensured.

- Easy accessibility & strong security:

Various smart devices are able to access cloud desktop services based on installing local client software. In addition, cloud desktops securely support 'a Bring Your Own Device' (BYOD) policy, allowing employees to access their company desktop from their device of choice. All the data stays in the cloud, not on individual devices, which is much more secure and reduces the chance of data loss.

- Eliminate capital expenditures:

One of the key drivers for businesses moving to cloud desktops is the savings in capital expenditures, including computer upgrades, new purchases, or special projects needing more workstations.

- Standardize & streamline onboarding:

Cloud desktop is easier to administer than several individual physical computers. Client companies can easily streamline and standardize their onboarding of new employees, by using computer images for cloud desktop setup. Taking an image of a computer, allows easily cloning the entire desktop environment to a new cloud desktop. This saves hours of time installing programs, settings, and copying files.

### 5.10.2.3 Service function and capabilities

The cloud desktop needs the E2E network to provide the following functions:

- Deploy Edge cloud infrastructure:
    - To reduce the physical distance between the cloud desktop rendering and the end user device, edge cloud computing resources are deployed. The edge cloud resources (independent of where they are located, e.g. OLT, P-ONU, etc.) supplement the central cloud or the end user device to accelerate processing.

  - The edge cloud needs to work with the centralized cloud to make the best cloud selection for the end user to access.

- Enabling intelligent capabilities in the network:
  - Recognize the network service, identify the cloud desktop service, and assign appropriate priority.
  - Optimize the optical network parameters as a slicing technology to guarantee network service delivery.
  - Enable high-priority scheduling for cloud desktop services.

- Shallow compressing technique:
  - To reduce the latency during encoding and decoding.
  - To save the computing power in the cloud and the user end device.

## 5.11 F5G-A Use case #11: Dynamically digitalized ODN

### 5.11.1 Use case context

To overcome the problems of a traditional Optical Distribution Network (ODN) deployment, including manual handling, time consuming, inaccurate port recognition, inefficient service provisioning, etc., a digitalized ODN is valuable to allow for fast deployment, accurate and efficient resource management. For example, by making use of digitalized and intelligent ODN label identification schemes (e.g. QR code), see use case #14 in ETSI GR F5G 008 [i.2], allows for visualization of the fibre topology, accurate ODN resource recording, and additional digital management helping to enable automatic service provisioning. In addition, provides fast and remote fault localization, easy maintenance and automatic measurement analysis based on AI-enhanced methodology can be achieved by collecting the optical communication device (e.g. OLT, ONU) system information, see use case #32 in ETSI GR F5G 008 [i.2].

AI-enhanced methodology provides accurate identification of faults by training the AI algorithm with the relationship between the fault and the various optical parameters [i.19]. However, this is not a physical methodology therefore it cannot achieve 100 % accuracy. ODN labels provide recovery of optical fibre topology, however it is relatively static. The topology can only be updated when the ODN label information is updated by an engineer or an inspection robot. In the case of natural disaster like earthquake, or unexpected damage caused by animal of the ODN in the outdoor environment, a fast or dynamic methodology showing the physical fibre topology is important.

### 5.11.2 Description of the use case

#### 5.11.2.1 Overview

This use case describes the necessity for a dynamically digitalized ODN methodology. It is the natural evolution of Use case #32 in ETSI GR F5G 008 [i.2].

In dynamically digitalized ODN, shown in Figure 25, besides the functional fibre topology information, the quantization of the ODN could be provided, including the length of the fibre for each segment (between the OLT and the Fibre Distribution Terminal (FDT), the FDT and the1$^{st}$ optical splitter, the 1$^{st}$ optical splitter and the 2$^{nd}$ optical splitter, the length of the drop fibre, etc.). The status of each fibre connection needs to be identified to enable the service operator to understand the utilization of the fibre resources and make appropriate fibre allocation if new users subscribe to the optical fibre network. The status of the ODN typically include splitting status (1-level splitting, 2-level splitting, etc.), which helps to understand the port resource. The identification of the available dropped fibre (fibre-terminal with connector) enables self-installation of the equipment, increasing the efficiency of the installation of new services and reduces cost by eliminating engineering work. Spare ports need to be recognized so that the available infrastructure is well known and could be considered for future usage.

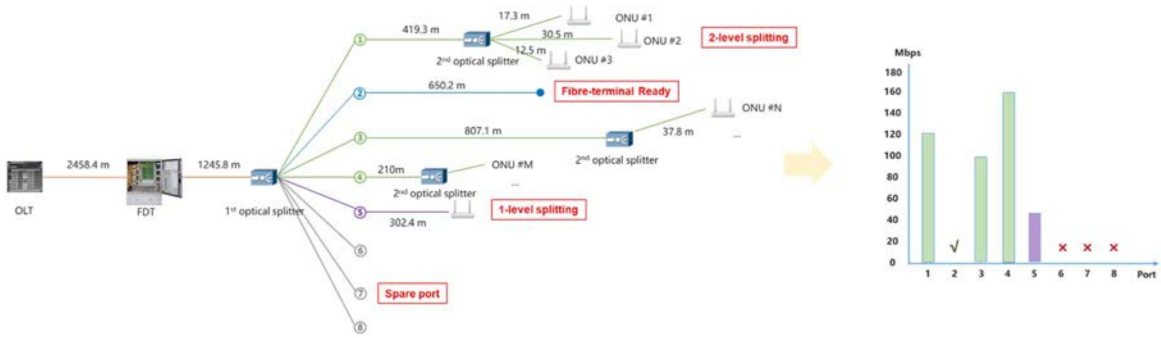



**Figure 25: Dynamically digitalized ODN**

More importantly, the dynamically digitalized ODN could work with the optical access or transmission system to understand the loading on the service data. This will give insight to the service operator to balance between the different ports so as to avoid overloading of the service data, enabling best quality of experience for the end users and global optimization of the network while considering new subscriber connections or even restructuring the connections. For example, too many 1-level connections will waste the network capability. To increase the efficiency or expand the topology, new optical splitter may be deployed to expand the capability of the network.

With the dynamically digitalized ODN, it is possible to proactively and periodically inspect the ODN. The dynamic information of the ODN could be collected. This information could be new physical parameters as input for the AI algorithm to do fault prediction, fault detection and fault recovery.

### 5.11.2.2 Motivation

Dynamically digitalized ODN needs quantitative and dynamic visualization of the ODN, providing new capabilities to accurately parameterize the ODN, regularly monitor the status of the ODN, diagnostics and fault recover is very beneficial to Network operators such as:

- Real-time and quantitative visualization of resource status, facilitating precise capacity expansion.
- The dynamic digital ODN in the data centre supports the digital twin with the practical ODN parameters.
- Quickly and remotely locate faults, reducing the service interruption duration.
- Proactive inspection of the optical path quality to ensure zero potential risks.

### 5.11.2.3 Service function and capabilities

The dynamically digitalized ODN need to provide the following functions:

- To recover the quantitative status of the optical network, including the length of each fibre segment, the functional blocks, the optical attenuation, etc. Figure 26 shows an example of a dynamically digitalized ODN:
  - The passive intelligent optical component (③ in Figure 26) is used instead of the traditional passive optical component (e.g. splitter) to provide feedback to the Optical Artificial Intelligent (OAI) module and to the Cloud Engine to calculate the ODN status (such as length of fibre). For example, the intelligent optical component can reflect certain wavelengths or different coded signals (see combined User1, User 2, and User3 signals in Figure 26).
  - The Optical Artificial Intelligent module (OAI, ② in Figure 26) triggers the measurement. The Optical Switch Unit (OSU) connects to the ODN to be tested. The OAI module then generates the test signals and collects feedback from the ODN under test. The OAI module analyses the feedback and provides the physical parameters of the network based on that feedback from the ODN including those from the intelligent optical component. This can be achieved by combining ONU wavelength (as an example shown in Figure 26 ③ ) or other methodology.
  - An analysis module, located in the cloud engine, (see ① in Figure 26) calculates the ODN parameters based on the obtained measured signals and identifies the ODN faults, when they occur.

- Advanced algorithm or AI-enhanced methodology could be used to further increase the accuracy of the digitalized parameter of the ODN or perform fault diagnostic, detection and recovery.

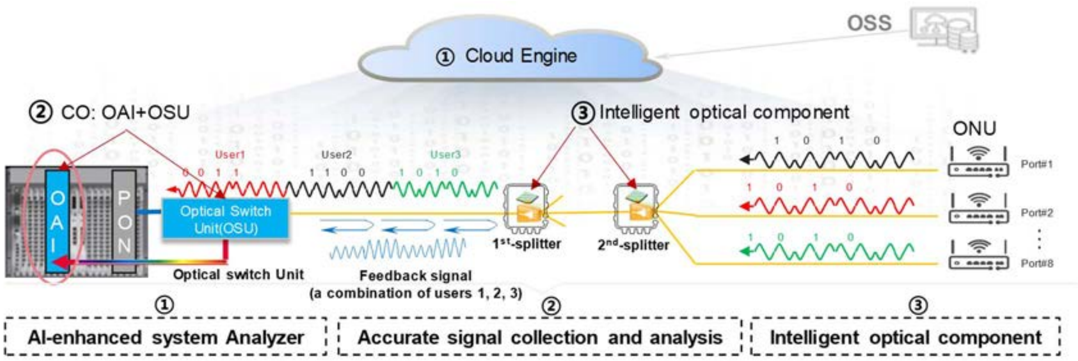



**Figure 26: An example of using wavelength multiplexing for dynamically digitalized ODN**

- The Cloud engine needs to collect the information from the deployed ODN and make decision for the service deployment, dynamic monitoring, alarm generation, deployment strategy etc.

## 5.12 F5G-A Use case #12: On-premises Millimetre Wave (mmWave) WLAN

### 5.12.1 Use case context

User QoE is becoming the key network enabling factor for service deployment. The upcoming network services like AR, VR, 3D displaying, etc. needs multi-dimensional network capabilities (such as large bandwidth, low latency, computing capability, etc.) to support extremely good experience for service subscribers. The well-known bottleneck of E2E quality of experience is mainly the impact of the Wi-Fi® network:

1) Unlicensed spectrum enables sharing transmission opportunities between different Wi-Fi® devices. Limited spectrum in sub-6GHz for the mainstream Wi-Fi® in dedicated national regions do not provide sufficient throughput.

2) Sub-6GHz signals can pass through wall, door, etc., which causes significant interference in scenarios with high density of Wi-Fi® devices. Traditionally, increasing transmission power of a single AP device to obtain larger coverage within the home or the SME further aggravates the interference. The higher transmission power negates the strategy of lower carbon foot-print.

Mainstream Wi-Fi® technology introduces multi-AP coordination schemes to enable stable & reliable Wi-Fi® connection in next generation Wi-Fi®. Such technology intends to control the interference by time/frequency/spatial coordination or make use of the interference through joint transmission across multiple APs. Besides that, an alternative approach is to provide no interference between Wi-Fi® devices. This leads to a free-running Wi-Fi® scheme in which none or weak coordination is necessary for data transmission. In this case, each Basic Service Set (BSS) is independent and only needs to manage its own BSS.

## 5.12.2 Description of the use case

### 5.12.2.1 Overview

To facilitate a free-running Wi-Fi® network, it is necessary to create isolated region for the Wi-Fi® signal. Line-of-sight transmission is needed to constrain the signal leakage. This is the characteristic of mmWave WLAN based on the high frequency band (available unlicensed Q-band around 45 GHz or V-band around 60 GHz). In Figure 27, the right-hand side figure shows the typical signal loss due to blockages (such as windows and walls) in different frequency bands. The penetration loss in the wall varies due to different materials and thickness of the wall. Larger penetration loss of millimetre wave in the wall confines the signal leakage and creates isolated regions (showed in the blue blocks on the left-hand side of Figure 27). To form an on-premises network, FTTR which provides full room fibre coverage is the best matched backhauling network for mmWave WLAN, providing high throughput, bounded low latency, etc. In this case, the sub-6GHz Wi-Fi® enables link connections for regions that are not reachable with high frequencies (shown in the green region, where mmWave signals cannot penetrate (blue enclosures) on the left-hand side of Figure 27). In addition, 10 Gbps throughput is easy to achieve for F5G-A network.

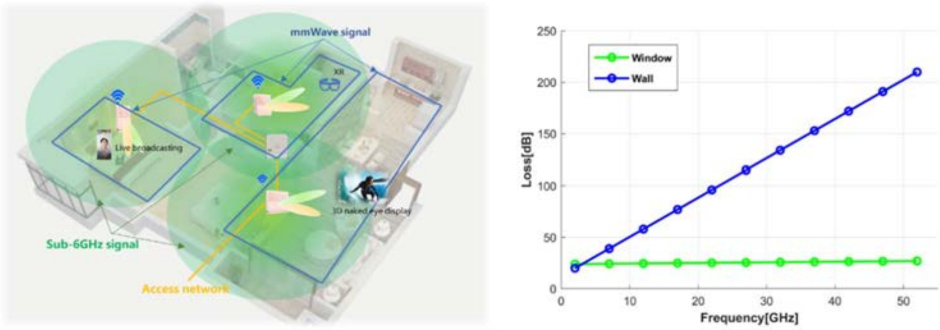



**Figure 27: An example of mmWave WLAN network**

Specifically, human acting as signal blockage needs to be considered for line-of-sight transmission since additional loss takes place. To overcome this issue, beamforming and its alignment are typically used under these circumstances. This needs the system to be designed supporting beamforming circuitry, antenna and algorithm for beam alignment between peering devices. Sub-6GHz assisted beamforming may be possible in this scenario. Moreover, signal handover in mmWave WLAN between different isolated region needs to be considered.

### 5.12.2.2 Motivation

The mmWave WLAN without interference enables the best quality transmission environment for the "last 10 meter" connections for on-premises networks:

- Provides QoS adapted links for various services to support real-time interactive services, like cloud-gaming, remote controlling, etc.
- Supports extremely high throughput (10 Gbps everywhere) for AR/VR/XR, 3D display, etc.
- Simplifies protocol/system design due to signal isolation within a room or region.

### 5.12.2.3 Service function and capabilities

To support an mmWave WLAN network, the following service functions are necessary:

- mmWave WLAN as a fronthaul network to avoid interference

  The mmWave WLAN provides Line-of-sight connections. Based on that, each room can be covered by a single mmWave AP. The wall naturally blocks the signals, so acting as a signal boundary, forming isolated region like a signal cages. The frequency band can be based on unlicensed millimetre wave spectrum (i.e. Q-band or V-band) depending on the national regulation. Time division multiple access, is considered by most of the mmWave WLAN technology (IEEE 802.11ad [i.20], IEEE 802.11ay [i.21], IEEE 802.11aj [i.22]) to support guaranteed latency.

- FTTR as a backhauling network enables the high throughput and bounded latency connections

  FTTR is known as the ultimate solution for data backhauling, matching the technical characteristics of mmWave WLAN, including extremely high throughput and bounded latency. The centralized-control mechanism in FTTR (the MFU shown in Figure 28) is leveraged to increase the transmission efficiency over beam tracking and data transmission, which supports the best handover and link management.

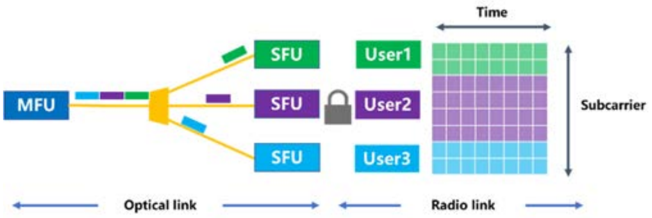



**Figure 28: Centralized resource allocation for FTTR and mmWave**

- Sub-6GHz assisted beamforming and tracking

  The signal bandwidth of mmWave WLAN is larger than that in sub-6GHz. To eliminate the redundancy beam tracking will be valuable to increase the actual data rate and enhance stability. Sub-6GHz assisted positioning based on AOA (Angle Of Arrival) estimation by sub-6GHz could be leveraged to provide accurate position of the end user devices so that an absolute beam direction can be identified (see Figure 29). Furthermore, sub-6GHz signals can easily penetrate the walls and complement the coverage issue due to blockage of the mmWave signals.

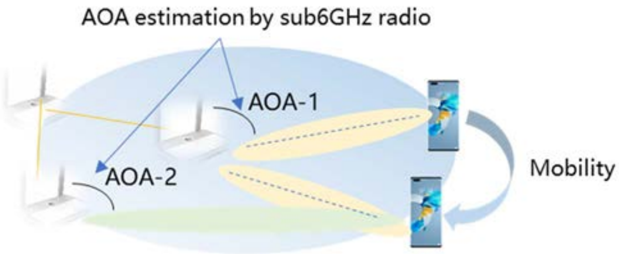



**Figure 29: Sub-6GHz assisted mmWave beam tracking**

- Coordination between sub-6GHz and mmWave

  It is easier to achieve large scale coverage through sub-6GHz bands. Thus, low frequency bands can be utilized to transfer controlling packets to guarantee control continuity (for example, in handover procedure, the handover message could be sent through the sub-6GHz channel), while the data link is mainly transmitted through mmWave bands. Figure 30 illustrate the coordination between sub-6GHz and mmWave bands. The transmission format depends mainly on the control of the sub-6GHz radio.

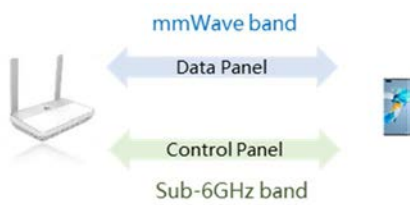



**Figure 30: Coordination between sub-6GHz and mmWave bands**

# 5.13 F5G-A Use case #13: Wavelength-shared WDM aggregation network (AGGN)

## 5.13.1 Use case briefing

In the digital economy, computing power has become one of the most important productivity factors. The data volume from emerging technologies, applications, and other scenarios continues to grow. Various industries urgently need computing force networks, including ultra-high bandwidth, low latency, high-quality transmission, and intelligent management and control, which have become necessary for the aggregation networks.

With the acceleration of the F5G-A residential fibre broadband, users with 1 Gbit/s and beyond speed are becoming the mainstream, 50G-PON and FTTR in F5G Advanced are driving the need for 10 Gbit/s to everywhere. In addition, the deployment of 5G worldwide is also accelerating, and the number of 5G users continues to increase. The speed of 5G is 5 to10 times that of 4G and 5G operators predict that the annual growth of Mobile Broadband (MBB) will be more than 60 %. The above factors are driving the multi-service access node bandwidth to go beyond 100 Gbit/s. By 2030, the bandwidth of the various network nodes in the aggregation network is expected to increase fivefold. This large traffic volume drives the evolution of the aggregation network to support a larger E2E network bandwidth.

Currently, the core network nodes in the optical network are interconnected in a meshed network topology, and Wavelength Division Multiplexing (WDM) is generally deployed from the core network to the aggregation network nodes. The connections between the multi-service access nodes (the Access Edge Nodes) like the OLTs, and the aggregation nodes, are rings or chains with grey light mode or optical fibre direct connect mode. The common deployed aggregation networks to the multi-service access nodes are illustrated in Figure 31. Therefore, a large number of optical fibre resources are occupied on the aggregation edge nodes. For example, in the case of the fibre directly connected to Central Office (CO) nodes as shown on the left hand side of Figure 31, the number of fibre end-point in the aggregation network edge node is very high.

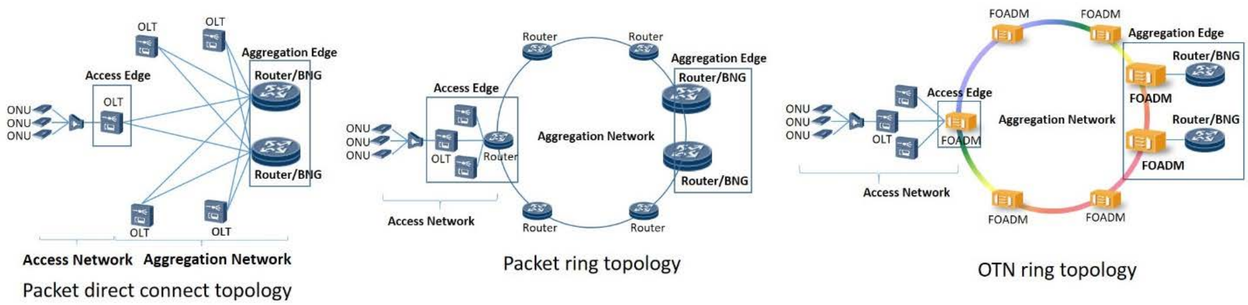



**Figure 31: Example topologies of the aggregation network connecting the OLT Access Edge with the current Aggregation Edge**

To meet the need for large bandwidth, low complexity, high flexibility, and intelligent network configuration, it is becoming more difficult to maintain the current connection topology between multi-service access nodes and the aggregation nodes. The large equipment room space, the high power consumption, the large volume of optical cable resources, and the O&M complexity affect both CAPEX and OPEX. The deployment of WDM technology between the aggregation nodes and the multi-service access nodes solves the problem by deploying a unified access and aggregation network for the various services. The WDM expansion to the multi-service access nodes evolves the F5G networks to the F5G Advanced networks. The example shown in Figure 32 illustrates an OTN aggregation network with WDM to the access edge nodes employing Reconfigurable Optical Add-Drop Multiplexer (ROADM) techniques. An all-ROADM network is realized by a ring topology between the access edge and the aggregation nodes (WSS in Figure 32), and a meshed topology between aggregation nodes and aggregation edge nodes. For simplicity, an OLT connecting to the access edge node is not shown in Figure 32. The ring topology can be regarded colourful, since several lambdas with different frequencies are multiplexed onto the same ring. Colourless ROADMs denote add-drop multiplexers as defined in Recommendation ITU-T G.672 [i.23].

Colourless ROADM techniques are deployed in the access edge nodes. WSSs are deployed in aggregation nodes and aggregation edge nodes. The Network Management System (NMS) allocates different wavelength channels to different directions.

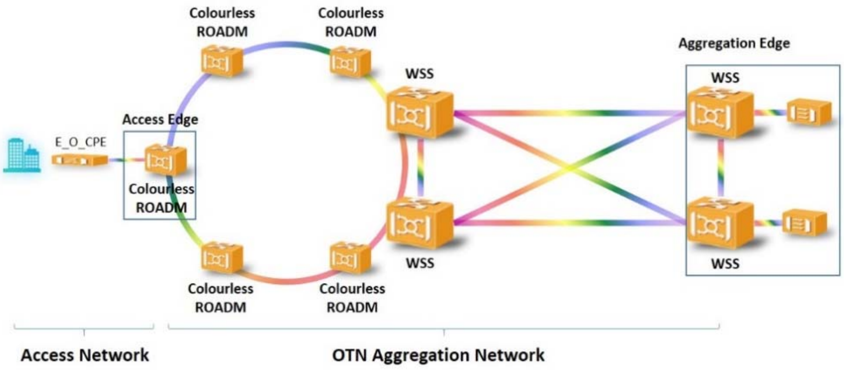



**Figure 32: Example of a ROADM-based OTN Aggregation network**

## 5.13.2 Description of the use case

### 5.13.2.1 Overview

The aggregation network is characterized by a large number of nodes and the multi-ring architecture supports a small number of wavelength channels per ring. The typical scenario is that each aggregation node connects to between four to eight rings, and one ring connects to between four to eight access nodes. Usually, WDM technology is used for this type of aggregation network.

In the traditional deployments, each ring is deployed independently by a dedicated sub-rack (as shown in Figure 33), thus each ring can utilize a full set of wavelength resources. In the scenario of using WDM in the aggregation network, not that many wavelengths are used, because the limited amount of traffic and number of access edges per ring. The wavelength resources cannot be shared between different rings, which leads to a low utilization of wavelength resources in each ring.

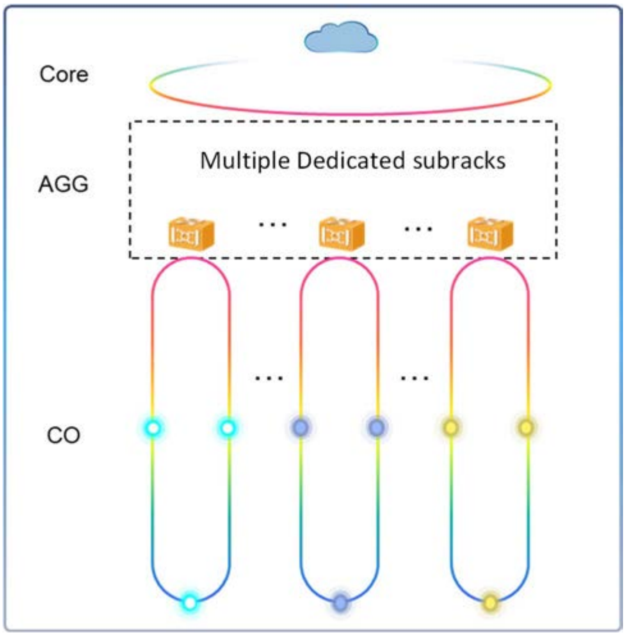



**Figure 33: Current AGGN configuration**

Traditional WDM aggregation networks deploy a Fixed Optical Add/Drop Multiplexer (FOADM) solution, which has a low automation level. The network deployments and upgrades depend on manual site visits, resulting in low deployment efficiency. In addition, FOADMs do not support flexible spacing (Flex Grid) due to its fixed grid feature, therefore smooth evolution to 200G+ could not be achieved in a FOADM based network. While the ROADM solution supports flexible spectrum spacing, flexible wavelength allocation through remote configuration via an NMS wavelength switching and grooming, high automation, and 200G+ evolution capability.

In F5G Advanced, with the increasing bandwidth demands as mentioned earlier, the node capacity, with a single-wavelength rate, and spectrum width of the aggregation network needs to be upgraded to support this increased demand. Meanwhile, reducing the CAPEX by improving the network resource utilization and reducing the OPEX by improving the network automation capabilities with increased O&M and network energy efficiency also needs to be considered.

More specifically, the following points emphases the benefits of the wavelength-shared WDM in the F5G Advanced aggregation network:

1) Continuously reducing network equipment deployment costs (CAPEX) by improving the utilization of the network resources, such as the equipment and wavelength resources, while meeting the needs of the increasing network capacity.

   Improving the current deployment situation that has a large number of boards per aggregation node and low wavelength resources utilization, which is caused by the independent WDM rings and the unshared wavelength resources between rings as mentioned above. By considering Wavelength Selective Switch (WSS) technology, which is highly integrated and which enables the wavelengths to be selected and individually directed to different rings, which means that a given wavelength can be allocated between multiple rings by a single set of devices. This reduces the number of boards, the occupied space, and power consumption per aggregation node. This also improves the wavelength resource utilization, reduces the network deployment costs and supports multiple access rings sharing a single set of wavelength resource at the same time. The configuration is shown in Figure 34.

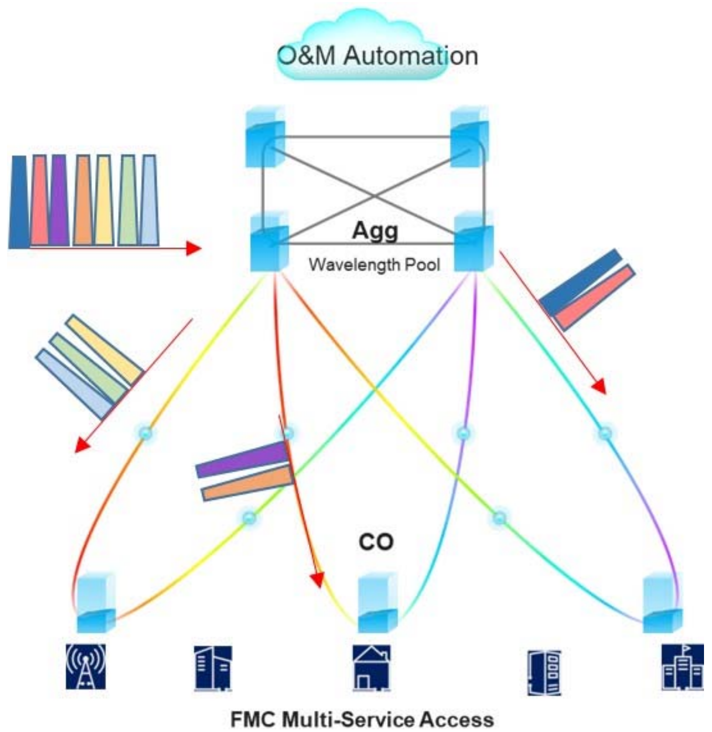



**Figure 34: Wavelength-shared AGGN configuration**

   All the wavelengths supported by an aggregation node can be regarded as a wavelength resource pool. The NMS dynamically selects idle wavelengths from the pool and allocates them to the appropriate CO node according to the service traffic of each CO node. In addition, the NMS can retrieve the wavelengths and allocate them back to the wavelength resource pool when the load capacity of the CO node reduces and the wavelength is no longer in use. In this mode, all wavelength resources of an aggregation node can be dynamically shared and efficiently used between the multiple multi-service access rings connected to the aggregation node. As a result, the number of ports in a given aggregation node is reduced, the CAPEX is reduced, and the network energy efficiency is improved. For the aggregation network evolution, the capacity increase in each ring may not be equivalent. Therefore, the wavelength resources may not be sufficient for some rings, while underutilized in others. Hence, wavelength sharing is beneficial, because the capacity can be increased without equipment upgrade.

2) Reducing the network OPEX by using performance monitoring technology and configurable shared wavelength WDM components managed by the network management software, which enables automatic and fast service provisioning:

Based on the wavelength resource pool mentioned above, visualization of the wavelength resources and monitoring of the individual-wavelength performance could be achieved by a wavelength-level performance monitoring technology, such as an optical-layer digital label technology. It detects the "optical label" in each wavelength channel to identify the channel information such as centre wavelength, service rate, source node and signal power. Thereby offering more service planning transparency, convenience, and improved intelligent network O&M,

The optical-layer digital label uses an MCM-like (Multi-Carrier Modulation) modulation mode. It utilizes the label information of the multi-carrier low-speed modulation superimposed on a carrier of a high-speed digital signals. The label signal is directly modulated on the electrical signals inside the Optical Digital Signal Processing (ODSP) unit and is extracted at the receiver for independent monitoring. The digital signal error correction capability is fully utilized to achieve aggregation network multi-carrier parallel transmission, which has insignificant impact on the high-speed digital signals. The hardware installation can be performed by a single site visit during the deployment phase and the system automatically completes the configuration without additional performance monitoring. This provides automatic wavelength planning, automatic configuration and provisioning, which eliminates the need for software commissioning personnel to visit the aggregation nodes, which in turn reduces network OPEX.

### 5.13.2.2 Motivation

The main motivation for the Wavelength-Shared WDM Aggregation Network (AGGN) includes:

- Lower CAPEX, space, and power consumption: Wavelength resources in the AGGN nodes are pooled and dynamically shared between CO nodes on the aggregation rings which are connected to the AGGN nodes. This reduces the deployed hardware thereby reduces the CAPEX, OPEX and power consumption of AGGN nodes hence achieving an overall AGGN energy saving.

- Simplified network architecture: The Wavelength-Shared WDM technology reduces the number of boards and subracks in the AGGN node and depending on the fibre deployment it reduces the number of interconnecting fibres, thus simplifying the networks.

- Lower OPEX and intelligent network management and control: The optical-layer digital label technology implements automatic network planning, plug-and-play, automatic commissioning, and automatic optimization, reducing OPEX and improving the overall network utilization.

### 5.13.2.3 Service Functions and capabilities

1) Aggregation nodes:

- Wavelength resources: a set of wavelength grooming engines are shared by multiple rings, which supports the inter-ring wavelength resource sharing and grooming, on-demand wavelength allocation / re-allocation, and flexible networking.

- Planning and O&M: automatic deployment commissioning, automatic wavelength planning, real-time performance monitoring, online O&M and optimization.

2) Access nodes：

- Wavelength resources: a number of wavelengths can be added or dropped which satisfies the current traffic demand, but this number can be expanded based on capacity demand.

- Wavelength adding/dropping capability: automatic wavelength verification and conflict monitoring.

# 5.14 F5G-A Use case #14: Robotics as a Service

## 5.14.1 Use case context

### 5.14.1.1 Move to Cognitive Robots

In the past, the operation of robots in factories was characterized by repetitive and static tasks. These robots would tirelessly carry out the same task over and over again without any deviation or adaptability. However, with the emergence of Industry 4.0 and the subsequent demand for increased flexibility in the manufacturing systems, robots had to undergo significant advancements to meet these new demands. This transformative shift in robotics paved the way for the development of cognitive robots, marking a significant milestone in the field. Unlike their predecessors, cognitive robots are equipped with advanced sensors that enable them to perceive and comprehend their surrounding environment. This newfound perception allows them to adapt their behaviour dynamically based on real-time inputs, making them more versatile and capable of handling complex tasks (see Figure 35).

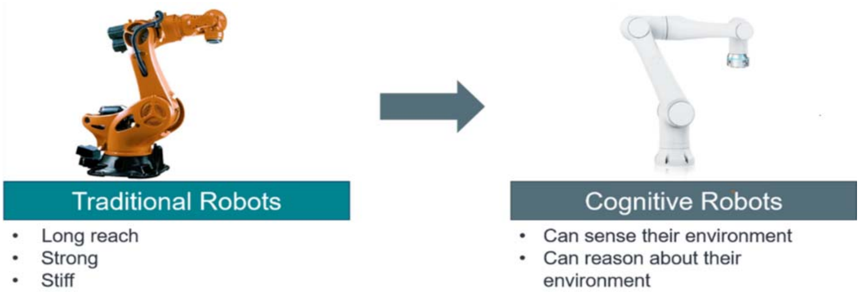



**Figure 35: Move to Cognitive Robots**

### 5.14.1.2 Example Applications

One of the most prevalent example applications of cognitive robots is bin picking (see Figure 36), a process in which a robot is tasked with retrieving specific parts from a bin. Accomplishing this task involves a series of intricate steps. First and foremost, the robot needs to accurately detect the target part amidst a cluttered bin, a task often achieved through the utilization of sophisticated 3D cameras. Once the target part is identified, the robot needs then to devise a path or trajectory to reach the desired object and successfully grasp it. The execution of these tasks demands significantly more computing resources and the utilization of more complex algorithms compared to the conventional robots of the past.

**Figure 36: Bin picking example application**

However, with this increased complexity and reliance on advanced technology, maintaining and managing such cognitive robotic systems becomes a more intricate endeavour. The reconfiguration of these cognitive robotic systems for new tasks, as well as the troubleshooting and optimization of their performance, necessitates a higher level of expertise and technical knowledge. Currently, most of the computational processing needed by these cognitive robotic systems are performed at the edge on an industrial PC in the robot control cabinet, necessitating the presence of a dedicated robotics and IT technician within the factory premises. Note that the location of the edge is deployment and application specific. The key characteristic is that the computational processing is located close to the robot.

#### 5.14.1.3 Move Computing to the Cloud

Nevertheless, the advent of cloud technology presents an opportunity to overcome these challenges and enable remote feedback control of cognitive robots. By leveraging the power of the cloud, the computational burden can be shifted away from the near-robot edge devices and into a centralized on-premise cloud servers or a remote cloud. This shift allows for more efficient resource utilization, as the cloud provides virtually limitless computing capabilities, accommodating the complex algorithms and demanding processing needed for cognitive robots. Specifically, dedicated AI-optimized compute hardware can be leveraged.

The implementation of cloud-based compute for cognitive robots offers numerous advantages, including the ability to perform maintenance tasks remotely. Rather than relying on an on-site technician, the cloud infrastructure enables service technicians to diagnose, troubleshoot, and optimize the performance of cognitive robots from any location. This remote maintenance capability streamlines the operations, minimizes downtime, and facilitates prompt resolution of issues, leading to increased productivity and cost savings.

While many of these potential improvements can be realized with standard Ethernet connections the real time control of these systems and achieving a large multiplexing gain in computing is still a challenge. Ensuring the control signals from the cloud reach the robots promptly and in sync is pivotal to maintaining peak performance. Navigating these challenges demands innovative solutions, such as tapping into the capabilities of optical communication in Fifth Generation Fixed Networks Advanced (F5G-A).

For illustration, consider the precision and ultra-low latency demands in milling machine control systems, wherein control loops need to respond within microsecond to ensure accuracy and quality in operations. Transferring such crucial real-time feedback control to a cloud system, via standard Ethernet technologies, could introduce larger and more importantly non-deterministic latencies, making accurate and immediate control unattainable.

In case of sensors or actuators mounted on the robots, the fibre connected to those sensors like cameras needs to be robust enough for a large number of movements and large temperatures or temperature differences.

By harnessing the additional capabilities of F5G-A networks, the real-time control of cognitive robots from the cloud becomes a viable proposition. The high bandwidth and low- and deterministic- latency characteristics of F5G-A networks allow for the seamless and instantaneous transmission of control signals, ensuring that the cognitive robots respond swiftly and accurately to commands issued from the cloud. This opens up new possibilities for enhanced collaboration, increased efficiency, and improved overall performance of cognitive robotic systems in various industrial settings. In the end this could lead to new business models in which robot cognition is available as a service model straight from the cloud, or as the use case calls it Robotics as a Service (RaaS).

### 5.14.2 Description of the use case

#### 5.14.2.1 Overview

The current robotics stacks, such as the Robotic Operating System (ROS) [i.24], have already facilitated easy multiprocessing, enabling control nodes to be distributed across different machines. However, the introduction of a network into the communication structure inevitably leads to latency. This latency becomes particularly problematic for lower-level functions like motion control, hindering real-time responsiveness in the order of 1ms from sensor message to control command execution.

Emerging from this is a 'cloud barrier' in robotics, whereby lower-level manufacturing operations are executed at the edge, and high-level functionalities are relegated to the cloud. A pivotal goal of other F5G-A use cases is to strategically lower this cloud barrier by leveraging the outstanding capabilities of Fifth Generation Fixed Networks Advanced (F5G-A) - enabling more efficient real-time control in the cloud, even with geographical flexibility around large manufacturing zones.

By utilizing F5G-A network technologies, companies can unlock the potential to offer software solutions for real-time process control as a service, effectively establishing a Robotics as a Service (RaaS) market.

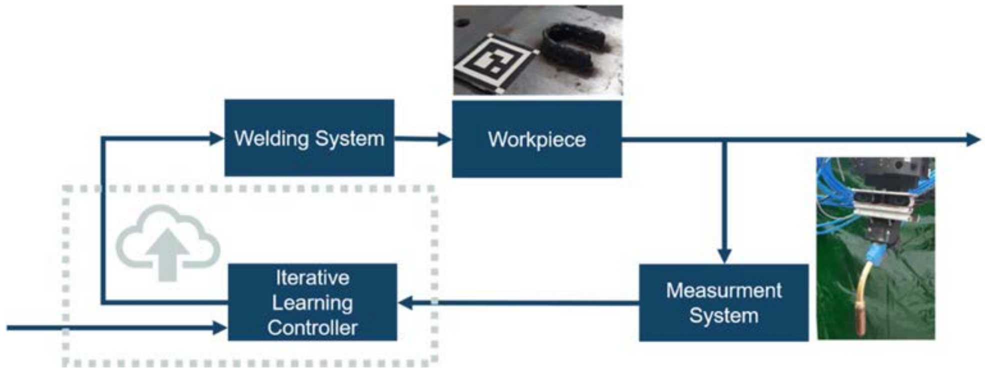



**Figure 37: Sample RaaS Welding Application**

While welding provides an illustrative example (see Figure 37) - where the AI-driven camera systems monitor and adjust heat distribution - the envisioned RaaS model extends far beyond this. It empowers companies to separate the AI control component from the hardware, enabling seamless integration in different hardware and manufacturing scenarios.

The objectives of employing F5G-A for this use case are twofold:

- Enable high-bandwidth, low-latency transfer of sensor data to the cloud: By leveraging the capabilities of F5G-A networks, companies can ensure that sensor data, such as uncompressed camera feeds or other relevant information, can be swiftly transmitted to the cloud with minimal delays. This enables real-time analysis, processing, and decision-making based on the acquired data.
- Enable low-latency control of the robot from the cloud: F5G-A networks offer the potential for rapid and synchronized communication between the cloud and the robotic systems. This low-latency control allows for real-time instructions to be sent from the cloud to the robots, enabling immediate and precise responses. This advancement paves the way for enhanced coordination, adaptability, and overall performance of robotic systems in various applications.

### 5.14.2.2 Motivation

To create a thriving market for Robotics as a Service (RaaS) and facilitate seamless remote control of robots from the cloud, several key factors need to be considered. These factors not only contribute to the success of RaaS but also foster a collaborative ecosystem where different components can easily integrate and work together. The following points outline some essential considerations:

- Enable high bandwidth, low-latency sensor data transfer to the cloud: The foundation of RaaS relies on the ability to transmit sensor data, including visual feeds, environmental information, and other relevant inputs, to the cloud with high bandwidth and minimal latency. This ensures that the data can be processed, analysed, and utilized in real-time, empowering cloud-based systems to make informed decisions and provide accurate control instructions to the robots.
- The space needed for ICT in manufacturing can be removed from the shop floor and the space needed for ICT is minimalized.
- Facilitate low-latency control of the robot from the cloud: To achieve real-time control, it is imperative to minimize the delay between cloud-based instructions and the robot's response. By leveraging a low-latency communication channels offered by F5G-A technologies, companies can significantly reduce the time lag in transmitting control signals. This enhances the synchronization and coordination between the cloud-based control systems and the robots, enabling rapid and precise execution of tasks.
- Establish common interfaces for Robotics as a Service (RaaS): A critical aspect of driving the adoption and integration of RaaS solutions is the development of standardized interfaces. These interfaces serve as a bridge between different components of the robotic ecosystem, enabling seamless interoperability and easy integration of diverse hardware, software, and AI-driven modules. Common interfaces simplify the process of connecting various components, reducing complexity, and fostering collaboration among different stakeholders in the RaaS market.
- All processing needed in such a use case can run in the cloud, either provided by the manufacturing stakeholder or by specialized software for robotics stakeholder.

By addressing these key areas, the foundation for a vibrant RaaS eco-system can be laid. High bandwidth, low-latency sensor data transfer ensures real-time data analysis and decision-making capabilities in the cloud. Low-latency control facilitates instant responsiveness of the robots to instructions issued from the cloud. Lastly, common interfaces promote the compatibility and smooth integration of different components, streamlining the adoption and expansion of RaaS offerings.

#### 5.14.2.3 Service functions and capabilities

To seamlessly integrate the Robot Operating System (ROS) with the Fifth Generation Fixed Network Advanced (F5G-A), it is crucial to consider the communication protocols employed by ROS. ROS uses the Data Distribution Service (DDS), a publish-subscribe protocol that can operate over different transports such as TCP and UDP.

To enable ROS messages to be transmitted over the F5G-A network, a seamless integration between F5G-A and the DDS protocol is essential. This integration prioritizes high bandwidth, and low deterministic latency. Deterministic latency ensures that the latency remains bounded and consistent, minimizing variations in communication delay.

Achieving this integration needs the F5G-A network architecture to be optimized for real-time data exchange. By minimizing processing delays, optimizing data transmission protocols, and efficiently utilizing network resources, low-latency and high-bandwidth communication channels can be established.

However, it is still beneficial to keep computing resources separate from the networking equipment as many advanced robotic applications will use special accelerators such as Tensor Processing Units (TPUs).

The seamless integration of DDS with the F5G-A network enables efficient transmission of ROS messages, ensuring responsive and reliable communication between the cloud and the robots. This integration lays the foundation for Robotics as a Service (RaaS) and facilitates advanced robotics applications in various domains.

## 5.15 F5G-A Use case #15: All-optical base for urban rail transit communication network

### 5.15.1 Use case briefing

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

With the rapid development of informatization for the urban rail transit system, a dedicated communications network will be needed to support the emerging services, rapid bandwidth growth, interactive intelligent services, and ultimate user experience.

With the development of optical communication technologies, the transmission network technologies for urban rail transit have been evolving for serval generations, including PCM/PDH (lower than 155 Mbit/s), SDH (2,5 Gbit/s), Multi-Service Transport Platform (MSTP), 10 Gbit/s, and enhanced Multi-Service Transport Platform (MSTP), 40 Gbit/s. Over the past few years, the dedicated transmission network based on Multi-Service OTN (MSOTN), 100 Gbit/s has been deployed to support intelligent and cloud-based urban rail transit systems.

## 5.15.2 Description of the use case

### 5.15.2.1 Overview

The evolution of the urban rail transit communications network is driven by three factors as follows:

1) Service cloudification

   With the construction of the urban rail transit cloud, the cloud computing applications and artificial intelligence in the urban rail transit industry is pushing data storage and data processing to the cloud. As a result, the dedicated urban rail transit communication network between the railway system and the cloud needs higher bandwidth and lower latency connectivity than the legacy communication network.

2) Service intelligence

   The current smart services involve a multi-dimensional and multi-level intelligent systems and smart applications, such as passenger services, railway power system, railway infrastructure, railway operation security, railway network management, and train schedules. The different intelligent systems and applications need a diversified access approaches, differentiated bearer network, with high security isolation, and high reliability.

3) OAM agility

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

   The transmission system is an important subsystem in the urban rail transit communication system. It needs to reliably transport various voice, data, images, and operation management information to ensure safe, fast, and efficient operation of the trains. Going forward, the dedicated communication network needs to support high security, high reliability, high bandwidth, low latency, easy scalability, network convergence, and intelligent and simplified OAM to safeguard a safe, green, and efficient railway transport infrastructure.

### 5.15.2.2 Motivation

Based on the evolution of the urban rail transit network, an all-optical network base communication network needs to be built with high security, low latency, easy scalability, and simplified OAM. With the intelligent network management and control platform that integrates management, control, analysis, and AI, an all-optical network base communication network for urban rail transit network will be more agile, intelligent, and secure.

Figure 38 shows as an example of an overview of urban rail transit physical system.

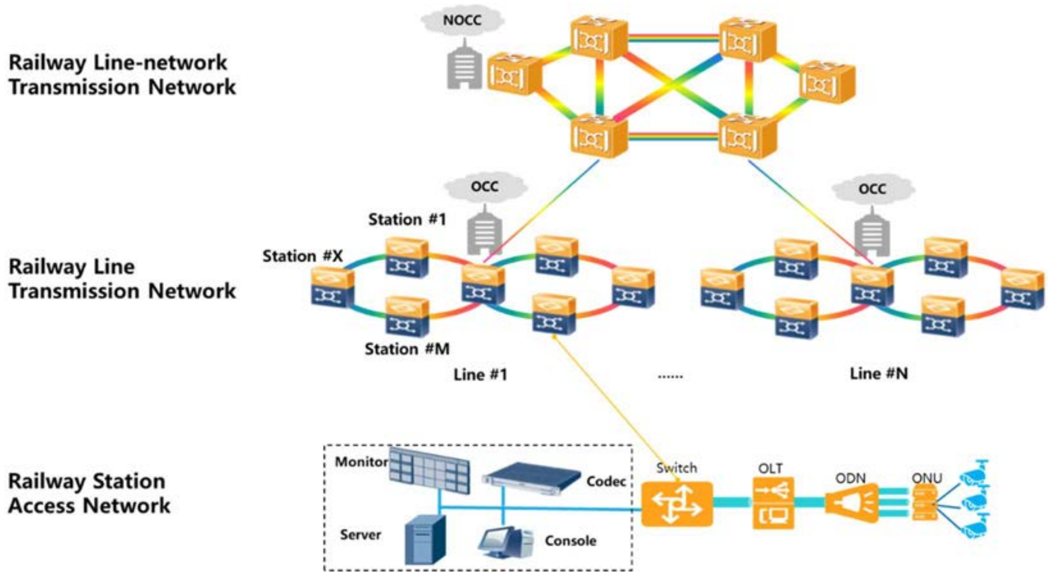



**Figure 38: Overview of urban rail transit physical system**

Figure 39 shows as an overview example of the urban rail transit communication system. It contains the physical infrastructure, the communication network, the Operations Control Centre (OCC), and the smart applications. The urban rail transit communication system with an all-optical network base consists of the railway line-network transmission network, railway line transmission network, and railway station access network. It provides inter-railway line connections, intra-railway line connections, and intra-railway station connections respectively, which will help to meet the continuous evolutional needs of the urban rail transit communication network.

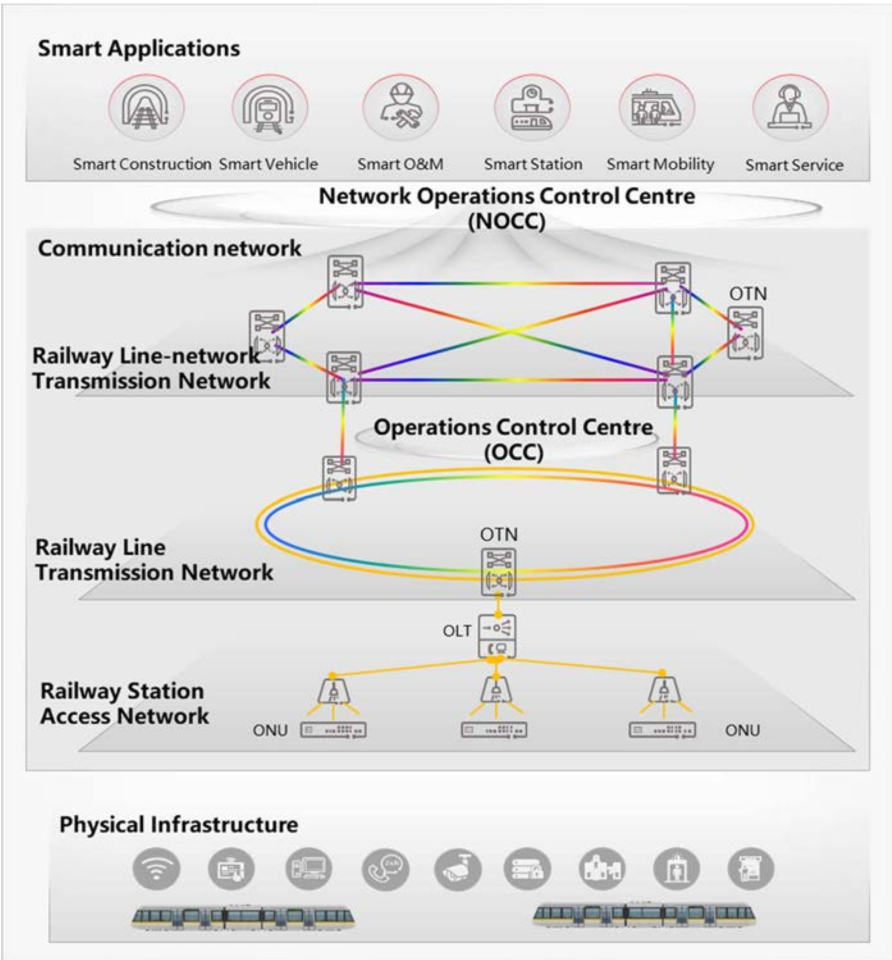



**Figure 39: Overview of urban rail transit communication system**

Some emerging smart applications driving the evolution of urban rail transit communication network are as follows.

1) Smart station

A full-time panoramic smart station management system is built based on holographic perception of equipment, system integration control, and self-operating. It provides full-scene dynamic information services, self-service services, and integrated information sharing with the surrounding commercial and public service facilities in real time. With the intelligent management of the station equipment, the personnel and the passengers, a more efficient management mode of centralized control of regional stations and unmanned stations in outer suburbs can be supported. The smart station applications are deployed in the railway line-network operations control centre. The transmission network uploads the sensing data information of each station to the railway line network operation centre for unified operation management.

2) Smart vehicle (Smart train)

With the deployment of the intelligent vehicle OAM system, the Internet of Vehicles (IoV) system, railway trackside vehicle comprehensive detection system, and vehicle railway track maintenance system are established to innovate the OAM system, improve the OAM efficiency, and reduce the OAM costs.

3) Smart OAM

Implements multi-professional comprehensive applications for urban rail power supply, communication signals, automatic fare collection, and station electromechanical systems. An intelligent OAM system is built based on the urban rail cloud and adapts to different management architectures. Based on big data and massive operation data governance, standard data structure is provided for intelligent operation decision-making, which will help to meet intelligent OAM security demands.

4) Video cloudification

The two-level storage architecture of centralized cloud-based storage and short-term storage in stations can be implemented. Based on the large volume of video data, the urban rail cloud platform can perform comprehensive passenger flow analysis and comprehensive video surveillance.

For example, Beijing rail transit. There are 34 railway lines in the city, and 50 railway lines will be available in the future. Currently, Beijing has built a centralized urban rail cloud platform system. An all-optical network base may meet the continuous development needs of the urban rail smart and cloud-based services.

Key values for an all-optical urban rail transit communication network to be considered are as follows:

- Security and reliability: Physical hard isolation is used to carry different types of services.
- Flexible scalability: In the future equipment with up to 800 Gbit/s per wavelength bandwidth can help to meet the full cycle evolution.
- Simplified deployment: The station's all-optical access network could support two-layer scalability via ONUs and optical splitters. The capacity in the station could be expanded by upgrading to 50 G PON without deploying new fibre.
- Deterministic and low latency: Services connect to the cloud via a wavelength-level one hop mechanism, which could eliminate the need for electrical-layer forwarding on intermediate nodes.

Simplified OAM: The management, control, analysis, and AI platform could support resource visualization, service automation, network intelligence, and OAM agility from the station access network to the railway line-network transmission network, providing simplified and intelligent OAM, such as fast and smooth network expansion, fast service provisioning, potential network failure prediction, and intelligent root cause fault analysis.

#### 5.15.2.3 Service functions and capabilities

Key capabilities of an all-optical base for urban rail transit communication network to be considered are following as:

- Network architecture: The railway line-network transmission network could use 200 G/400 G OTN and ROADM/OXC technologies with flexible wavelength grooming, which could support the smooth evolution to 400 G/800 G or above in the future. The ring topology of the railway line transmission network could support the modular configuration of grey light and coloured light, which could support the network smooth evolution. The station access network could use PON technology, which is greener, more cost-effective and easier to provision and maintain compared to the current network.

- Service bearing: Physical hard isolation could be used to provide a highly secure, reliable, and scalable bearer network for dedicated communication services, smart services, and cloud services.

Network availability: A multi-layer protection mechanism could provide protection switching within 50 ms or less, supporting multi-point failure resistance, and 99,9999 % network availability.

## 5.16 F5G-A Use case #16: Optical Fibre Sensing for telecom operators

### 5.16.1 Use case context

Optical fibre security is an important characteristic for the carrier's communication network. Due to factors such as the remote location of the optical fibre cable, it is difficult to perform real-time monitoring, using manual patrol inspection, which is inefficient and time consuming. There is no effective early warning mechanism for real-time security monitoring of telecom fibre, especially in large, unmanned desert areas.

A solution is needed when a mechanical or manual excavation activity occurs nearby or above the fibre. The monitored optical fibre senses the vibration and transmits different vibration waves to the optical fibre sensing device. The device then quickly analyses the vibration waveform information, identifies the event type, accurately locates the place where the intrusion event is occurring, and reports an alarm. Thereby implementing online real-time monitoring and security warning system for the entire optical fibre. This provides the optimal solution for unmanned fibre inspection.

### 5.16.2 Description of the use case

#### 5.16.2.1 Overview

Optical fibre is a sensor, which collects changes in the reflected signals of the optical waves in the optical fibres due to environmental impacts and measures the vibration, and stress changes along optical fibres.

The solution supports real-time/multi-point alarm reporting, precise positioning, and easy deployment.

It needs to have the following features:

- **Long distance:** More than 80 km detection distance per device.

- **Minimal false negatives and false positives:** Effective signal collection rate of 99 %.

- **Accurate identification:** Vibration waveform identification accuracy of 95 % or above.

- **Event Location accuracy: ≤ 10m.**

- **Fast learning and self-improving:** Capable to learn from local samples and improve accuracy and efficiency in new cases.

- **Real Time Monitoring:** Capable of twenty-four seven real time monitoring.

### 5.16.2.2 Motivation

Compared with traditional point sensors, distributed fibre optical sensing solution needs to have the following advantages:

- **Long distance and low cost:** A single optical fibre covers tens of kilometres, which is better than multi-point sensors.
- **High positioning precision:** The whole optical fibre acts as a distributed sensor. The spatial sampling density can be set based on the precision needs.
- **Easy deployment:** Only one optical fibre and one device are needed, facilitating power supply and data backhaul.
- **Easy maintenance:** Integrating accurate GIS information makes it easy to locate fibre faults.
- **Reliability:** The probe light is not affected by electromagnetic interference, and therefore the sensing physical quantities is reliable in a strong electromagnetic environment.
- **Safety:** The optical fibres are electrically insulated and free of electromagnetic interference. Distributed fibre optical sensors can be used correctly in electromagnetic-sensitive environments.

### 5.16.2.3 Service functions and capabilities

Figure 40 shows the typical network configuration of the optical fibre sensing system. The system includes three parts:

1) The station which contains the fibre sensing devices and is connected to the optical fibre to detect and analysis the vibration signals.

2) The DCN (Data Communication Network) is the management network which connects to the fibre sensing system with the management system called control centre.

3) The control centre is the management system deployed in the OAM centre, and the function of control centre is responsible for configuration, provisioning and optical fibre alarm monitoring.

All devices can be managed through one network management system, The Geographic Information System (GIS) map displays location of intrusions and types of intrusion events, and supports SMS and email notifications.

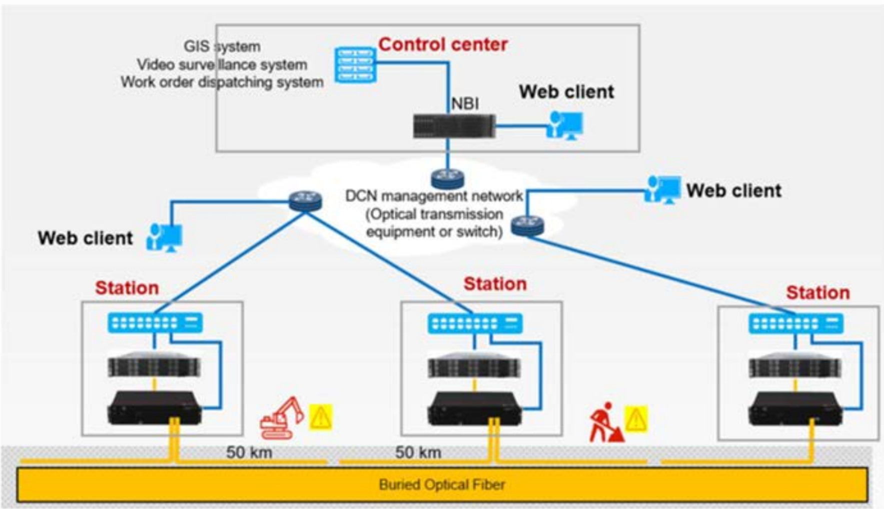



**Figure 40: Typical Networking Diagram for Intrusion Warning System**

### 5.16.2.4 Operation of the use case

1) **Reusing communication optical cable (Optical communication cable as a sensor):** Communication optical fibre cables such as Recommendation ITU-T G.652 [i.13] fibres that collocate with oil and gas pipelines are reused, without the need to lay additional optical cables.

2) **Warning unit:** Transmits optical pulse signals, receives the monitoring signals returned by the fibre along the pipeline, sends the returned monitoring signals to ODSP for processing, and then sends the processed signals to the data processing system. After analysing the alarm, location, and event type information, the data processing system sends the information back to the warning unit. The warning unit then sends the information to the warning management system in the regional monitoring centre.

3) **Sensing algorithm engine** (part of the data processing system)**:** Receives the information uploaded by the warning unit, analyses the information, generates the alarm, the location, and the event type information, and returns the information to the warning unit.

4) **Warning management system:** Manages and controls the warning unit, and receives, processes, and displays warning information uploaded by the data processing system.

# 5.17 F5G-A Use case #17: QoD App-Flow service provisioning

## 5.17.1 Use case context

Traditional home broadband service packages include Internet, IPTV, and VoIP service flows. As the residential market develops, there are more and more real-time broadband services which improve the home entertainment experience, in addition to IPTV and VoIP. For example, live broadcast, home VR and online education services are becoming more and more popular.

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

The industry has recognized these needs and challenges, and has started the related research. For example, CAMARA [i.25], a telco global API alliance and an open source project within the Linux Foundation, aims to abstract the network by service APIs. These service APIs will help the network operators to provide the Network as a Service (NaaS) capabilities with differentiated SLAs, enabling a new business models for network operators.

The Quality on Demand (QoD) APIs are the key service APIs defined by CAMARA [i.25], which allows for an application to request an improved connection (e.g. guaranteed bandwidth and latency) for a given application flow (App-Flow) from the application client to the application server. The QoD APIs could possibly be applied in the Access Network and the Customer Premises Network (CPN), to enable application flow level control for fixed network broadband services.

## 5.17.2 Description of the use case

### 5.17.2.1 Overview

In traditional home broadband services, the network operators are mainly offering static bandwidth services. As shown on the left-hand side of Figure 41, each user subscribes to the service package with a fixed bandwidth in advance, which is used to carry all user's internet application flows, without a specific mechanism to guarantee those important App-Flows, which need real-time network transmission.

In this Use Case, the network operators offer not only static bandwidth, but also dynamic specific App-Flows to improve the users' experience. As shown on the right-hand side of Figure 41, when a user runs an application which needs real-time network transmission (e.g. live broadcast, online course and VR gaming), the App-Flow can be dynamically created in the Access Network and the CPN connection, with deterministic SLA assurance.

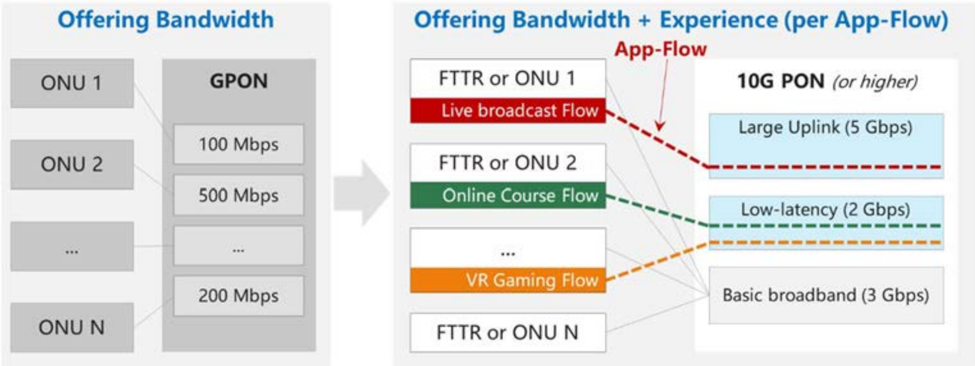



**Figure 41: Evolving from offering bandwidth to offering experience**

To enable the App-Flow services, both the Access Network and the CPN need to be more dynamic to react to the changes of the applications. This means that the Access Network and the CPN will need to have the following key capabilities:

- Dynamically create, delete, modify, and query an App-Flow in seconds.
- Identify different App-Flows, and map the specific application data into their corresponding App-Flows.

Provide deterministic SLA control for each App-Flow.

### 5.17.2.2 Motivation

The main motivation for App-Flow include:

- The Network operators need to provide more value-added broadband services, to increase their revenue from the network. Application-level services will become an important trend going forward. For example, the network operators may offer on-demand private-line-like broadband services to the end users at an application level (e.g. VR application or remote concert viewing application).

The current broadband service users suffer from network problems, such as Wi-Fi® interference and PON upstream sharing, which may affect their deterministic experience for those important applications. Users may expect application-level on-demand broadband packages from the network operator, so that their important applications (e.g. online video conferencing or remote education) can be guaranteed.

### 5.17.2.3 Service functions and capabilities

In the scenario of App-Flow-based services, dynamic control interfaces are needed between the nodes (e.g. OLT, ONU and FTTR equipment) and the management and control system, and between different nodes in the Access Network and the CPN. Figure 42 shows the high-level view of the key capabilities for dynamic network control and App-Flow provisioning in Access Network and CPN:

- Intent awareness: Awareness of the users' service intention (e.g. SLA), and awareness of the network resources and capabilities.
- Resource calculation: Develop and determine the service packages to be offered based on App-Flow prediction and the resources and capabilities of the Access Network and the CPN.
- Provisioning: Dynamically create the App-Flows in real-time, driven by users' application needs.
- SLA monitoring: Continuously monitor the quality of the network in real time, and analyse whether the App-Flow SLAs are being satisfied. The historical data of network quality information needs to be visible and manageable.
- Real-time SLA control: Continuously detect events that may affect the App-Flow SLAs (e.g. user roaming in the FTTR Wi-Fi® network), and control and optimize the quality of service transmission in real time.

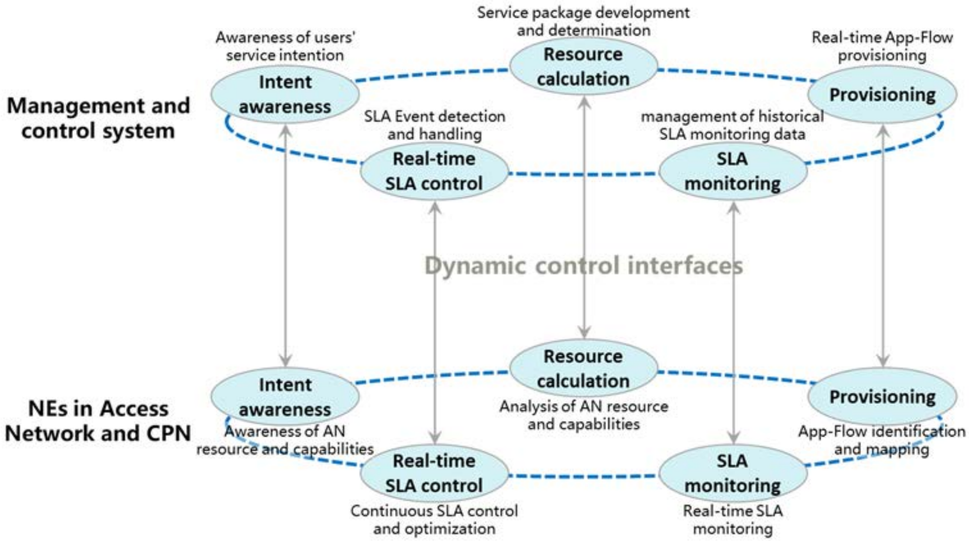



**Figure 42: Key capabilities of App-Flow control of the Access Network and the CPN**

The key functions and capabilities for each Access Network and CPN component to support App-Flow control include:

1) Support of the App-Flow by FTTR/ONU

Traditional Wi-Fi® network in FTTR/ONU is a best-effort network, without recognizing the App-Flows presence and optimizing the App-Flow transmission.

In the scenarios with application-level deterministic experience (e.g. VR application), the Wi-Fi® network needs to be aware of the SLA (e.g. latency) of the App-Flows. It also needs to have the capabilities to create specific connectivity for the App-Flows, and monitoring and controlling the App-Flow SLAs in real time. In this way, the experience of the App-Flows can be assured in the network segment in a home.

2) Support of the App-Flow on the OLT

Traditional OLTs process different service flows at a coarse granularity level, e.g. based on VLANs. To support App-Flow control, the OLTs need to support finer granularity service processing at application level.

Specifically, an OLT needs to have the capabilities of identifying the App-Flows and their SLA (e.g. latency), create connectivity for the App-Flows, and monitoring and controlling the App-Flow SLAs in real time.

3) Support of the App-Flow on the management and control systems of the Access Network and the CPN

The management and control systems of the Access Network and the CPN, with the App-Flow APIs, need to have the abilities to:

- Provide open atomic QoD APIs to be invoked by different applications, to support different App-Flows which have different SLA.
- Send control messages through its control interfaces, to create, query, modify, and delete an App-Flow based on the user's needs.
- Perform App-Flow authentication.
- Collect App-Flow SLA event information from FTTR/ONU and OLT, and analyse the performance of the App-Flow.
- Provide notification to the upper application layer when the App-Flow SLA cannot be met by the network.

Predict future App-Flows and perform network simulation to support new service offerings.

#### 5.17.2.4 Operation of the use case

The App-Flow service may be provisioned in various ways, depending on the business models of the network providers and the Over The Top (OTT) providers. As a simple example, the operational procedure of the App-Flow provisioning could be:

- The network operator opens its atomic network QoD APIs to the Application (APP) developers. Note that the APP developer may also be an OTT provider who provides the remote content to be used by the APPs.
- The APP may need deterministic network transmission (e.g. VR gaming APP).
  - During the development, the QoD APIs are used, and a portal is added in the APP Graphical User Interface (GUI), through which the users of the APP can request a better application experience from the network operator.
- The user downloads, installs and starts the APP, and requests better application experience through the portal in the APP GUI.
  - The user may need to pay for the service when requesting better application experience.
- The management and control system of the network operator automatically creates the App-Flow for the user.

When the user closes the APP, the service ends, and the App-Flow is deleted by the management and control system.

# History

| Document history | | |
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| V1.1.1 | June 2024 | Publication |
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