Technical Outlook for Mobile Networks Using IOWN Technology - Advanced Transport Network Technologies for Mobile Network

Classification: APPROVED REFERENCE DOCUMENT

Confidentiality: PUBLIC

Version 1

April 2023

[IMN-PHSE2]

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Executive Summary

This document covers the following technical topics related to mobile and transport networks to support the IOWN Global Forum's efforts to develop fundamental technologies on communication, computing, data handling, and energy efficiency that would bring a quantum leap in performance improvements over existing networks and enable a much smarter world with advanced applications.

- Review of the current transport network landscape supporting wireless networks
- Projection of the key requirements for networks beyond existing 5G and future 6G transport networks
- Offering members' insights regarding the technology gaps to enable the IOWN Global Forum's target use cases
- Discussion of various transport network deployment options and configurations from technical and total cost of ownership (TCO) perspectives
- Evaluation of proposals to improve the performance of transport networks to accommodate emerging wireless technologies and evolving network architectures
- Exploration of future transport network architectures leveraging APN and DCI frameworks currently being developed by the IOWN Global Forum
- Recommendations

1. Introduction

1.1. Scope of Document

The reference document on Technical Outlook for Mobile Networks using IOWN Technology produced by the IOWN Global Forum (IOWN GF) in January 2022 [IMN] identified challenges and recommendations to support Open APN-based transport networks for applications in 5G and beyond / 6G networks. They include:

- Projection of the key requirements to support use cases envisioned by IOWN GF
- The technology gaps to be overcome to enable the IOWN GF's target use cases
- Proposals of various enhanced transport network options and configurations from technical and economic perspectives to accommodate emerging wireless technologies and evolving network architectures
- Exploration of future transport network architectures leveraging All Photonic Network (APN) and Data-Centric Infrastructure (DCI) frameworks currently being developed by the IOWN GF

This document presents advancements that members have made since the publication [IMN], as the members have vigorously engaged in research to achieve the audacious goals set by the IOWN GF [IOWN GF AIC], [IOWN GF CPS]. In addition, this document also validates the 5G traffic projections and transport network technology adoption as described in the earlier publication, based on newly available data.

1.2. 5G Adoption and Mobile Network Traffic Trending

Over 40 network providers have deployed standalone 5G networks. By the end of 2022, 5G mobile subscriptions are expected to surpass 1 billion. Data usage of a typical smartphone user has reached ~15 GB/month, representing a 67% increase since 2020 [Ericsson Mobility Report]. Increased use of video content-sharing applications such as Tik Tok Instagram, and others, combined with less reliance on wireless LANs and Wi-Fi in public areas such as restaurants and airports may have contributed the continuing data usage increase. It has been observed that people using mobile networks over public wireless LANs because (1) they offer better indoor cellular network coverage compared with previous generations; (2) security concerns over public wireless LANs are significant, and; (3) more and more users have higher data caps or unlimited data plans. In the USA, 5G-capable users spend ~70% times on 5G in selected carrier networks, indicating widely-deployed 5G mobile networks. In Korea, 33% of all mobile subscribers are using 5G which generates 70% of total mobile traffic for the country. By the middle of 2022, which is about 3 years after the issue of 5G licenses, China 5G user penetration has reached more than 50% [Gizchina]. Applications such as Virtual Reality (VR), Mixed Reality (MR), Augmented Reality (AR), and the so-called metaverse are expected to reach hundreds of millions of users worldwide around 2030. Mobile traffic volume in Japan is estimated that downlinks in 2030 will be 17,734 petabits, or 13 times the volume of 2020. It is also suggested that mobile network traffic will grow even more explosively with the emergence of special trendy services and contents [B5GPC]. To meet these high-speed and high-capacity requirements of the 6G era, candidates of 6G technologies include potential new radio access technologies, integrated satellite, terrestrial communication, and Tera-Hz communication. These new technologies will demand a huge number of cells for capacity and coverage and also require more X-Haul (Front Haul (FH), Mid Haul (MH) and Back Haul (BH)) connection and capacity.

Mobile operators have reinforced their investments in fiber networks to handle ever increasing 5G data traffic [FIERCE Wireless].

Applications have moved well beyond enhanced Mobile Broadband (eMBB) as more industrial and IoT use cases are supported. This is evident from use cases identified in IOWN GF's AI-Integrated Communication (AIC), Cyber-Physical

System (CPS), and Metaverse use case documents [IOWN GF AIC][IOWN GF CPS][DTF Metaverse] (Editing ver), and DTF analysis [IOWN GF DTF Analysis, note: replace this reference with the published one after it is published].

The projected trends for 5G network deployments and user data usage are validating the traffic forecast and capacity and performance requirements outlined in [IMN]. In 5G and beyond / 6G networks, extremely dense networks are required to deliver high capacity. The low latency requirements from time-sensitive applications pose significant challenges to mobile transport networks. To densify 5G networks, small cells are generally deployed. Small cells, which typically sit atop streetlights and rooftops rather than large cell towers, are primarily deployed to improve capacity rather than service coverage. Verizon has so far deployed 30,000 small cell sites for its millimeter wave (mmWave) 5G network. T-Mobile expects eventually to operate around 40,000 to 50,000 small cells when it builds out its 5G network [Light Reading]. Analysts predict that by 2027, there will be 13 million outdoor 5G small cell deployments globally, with 5G small cell deployments overtaking 4G in 2028 [ABI Research].

There are two methods to link transport networks to a small cell. The small cell can link to a macro cell and be piggybacked on the macro cell, which increases capacity requirements onto the backhaul links currently feeding the macro cell. Alternatively, the small cell can directly connect to a transport node. In both cases, it generates more transport network traffic which goes through metro networks toward the data centers to connect to various application services.

The 5G network utilizes the mmWave frequency band to achieve a high data rate for high bandwidth availability. With 6G, this trend is more pronounced. It is expected that in 6G, carrier frequencies can expand to above 100 GHz and up to 300 GHz, with a single channel bandwidth up to 10 GHz.

However, higher frequency signals such as mmWave decreases quickly with distance, needing more cell sites for the coverage. Cell densification increases and complicates X-haul networks. This document presents various deployment scenarios to fit different sizes and configured X-haul systems to provide cost-effective and optimized transport networks.

To improve service introductions, provisioning agility, operational cost reduction, and increased diversity of applications, mobile network infrastructures are evolving toward cloud native-based network function virtualization. Transport networks serving mobile networks need to align with this trend toward network function virtualization. Features such as Cooperative Transport Interface (CTI) and Time-Sensitive Networking (TSN), when deployed, can help to improve network latency, synchronization, and reliability /

The following topics are covered in this document:

- examination of the current landscape of transport network supporting mobile network
- technical gap for future wireless and transport network needs
- projections of key requirements of 5G and 6G transport networks resulted from use cases developed by IOWN GF members
- proposed future transport network architecture leveraging Open All Photonic Network (APN) and Data-Centric Infrastructure (DCI) frameworks being developed by the IOWN Global Forum

Several study items are suggested to improve the performance of the transport network. In addition, various transport network options and configurations from technical and economic perspectives are discussed. Finally, recommendations are made on the transport network to meet future capacity and performance goals demanded by evolving applications.

2. Transport Network for Mobile Network Challenges

As shown in the Technical Outlook for Mobile Networks document [IMN], the new services and applications envisioned by the IOWN GF's use cases will generate an enormous amount of wireless data with very stringent low latency requirements. This significant increase in data traffic will, in turn, impact capacity requirements throughout the transport network, from fronthaul to data centers. As an example, the Area Management Security Use Case estimates that for a monitoring area with 1,000 cameras, the data rate generated would be 7.5 Gbps [IOWN GF CPS]. Streaming data from many of these cameras will be aggregated via wireless/mobile networks, enabling flexibility in the positioning of surveillance cameras.

IOWN GF analyzed 6G key performance indicators (KPIs), which are summarized in Table 1, and targeted Fronthaul Bandwidth and Latency Requirements, are shown in Table 2, in [IMN].

Table 1 Projected 6G KPI Improvement over 5G

E2E KPI	**5G**	**6G**	**Improvement Factor**
Peak Data Rate (Gbps)	10	100-1000	10-100
Connection Density	1/m^2	10-100/m^3	10-100
User Plane Latency (m sec)	1	0.1	10
Jitter (m sec)	N/A	0.0001-1	N/A
Reliability	Five 9s	7 9s – 9 9s	100 – 10000
Synchronization	3μs (cell phase) Three ns for 1-meter position accuracy	<1 ns for <0.2-meter position accuracy	10[1]
Position Accuracy	1m-level	1cm-level[2]	100

[1] 10x improvement factor is targeted based on the general expected improvement factor between two wireless generations of technologies

[2] [NTT Docomo 6G]

Table 2 Targeted Fronthaul Bandwidth and Latency Requirements for Various RAN Split Options

KPI	**5G (2020)**	**6G (2030) (Projected)**
E2E		
Peak Data Rate	< 10Gbps	< 100Gbps~1Tbps
User Plane Latency (ms)	1	0.1
Transport: Lower layer split (Option 7)		
Bandwidth	< 25~50Gbps	< 250Gbps~5Tbps

Frame delay **(one-way)**	0~160us Fiber delay: 0~150us (0~30km) Packet Delay Variation (PDV): 0~10us (0~2 switches)	0~larger than 160us Fiber delay: 0~larger than 150us (0~larger than 30km) PDV: 0~less than 10us
Transport: Higher layer split (Option 2)		
Bandwidth	< 10Gbps	< 100Gbps~1Tbps
Frame delay **(one-way)**	Up to ms order (up to 100km order)	Up to ms order (up to 100km order)

3. State of Art and Gap Analysis

This chapter review briefly updated work since the publication of the reference document on Technical Outlook for Mobile Networks using IOWN Technology [IMN] by other SDOs in a similar market for transport networks supporting mobile networks.

3.1. BBF (Broadband-Forum)

BBF published a Technical Report on ‘5G Transport Networks’ [BBF TR521] in June 2022 (Reference Document link: 5G Transport Networks (broadband-forum.org))

- This BBF report defines functional and architectural requirements for a suite of transport nodes for 5G transport networks to address backhaul (N2, N3) and optional functional splits of the 5G RAN [3GPP TR38.801], as well as User Plane – Control Plane split options. Specifically, Cell-site Gateway and Aggregator devices would be deployed for higher layer splits (F1-interface). while dedicated fronthaul nodes are engineered for low-layer splits that are out of scope for this BBF document. The considered reference architecture for BBF and scope of the document is depicted as in Figure 1.

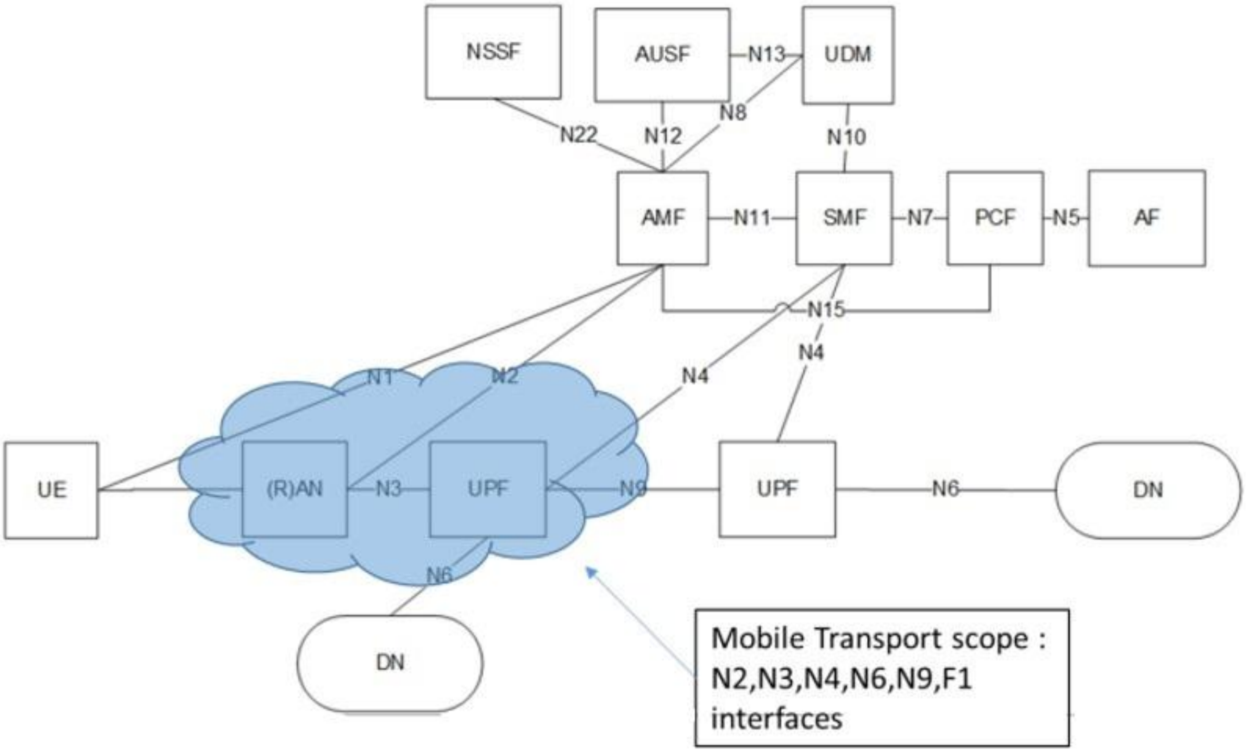


Figure 1 5G system architecture as depicted in standard document with Mobile transport portion

The transport network in [BBF TR521] is for the 3GPP-defined backhaul interfaces (N2, N3), core network interfaces N4, N6. and N9, plus the high layer RAN split (option 2) defined as an F1 interface.

As the lower layer RAN split (Option 6 or Option 7) fronthaul is out of scope, the [BBF TR521] should be seen as complementary to the work done in this IOWN Mobile Network Task force [IMN].

- BBF also published a Technical Reports on ‘Slice management’ TR522 [BBF TR522]. This BBF report is based on the similar work by IETF: [draft-ietf-teas-ietf-network-slices-16]. This document uses IETF terms “5G Network Slice Orchestrator” for “NSMF” and “IETF Network Slice Controller” for “NSSMF”. For RAN Slice Controller and Core Network (CN) Slice Controller, they are referred as “Other External Controllers”. This term is similar to the informally used industry term {NSMF, NSSMF}. For an informative example of industry usage of those terms [3GPP TR 28.801].

3.2. MOPA

Mobile Optical Pluggable Alliance (MOPA) stipulates the blueprint for optical pluggable solutions to enable 5G deployments as defined by Ericsson, Lumentum, Sumitomo Electric, Nokia and II-VI [MOPA Technical Paper, Version 2.0]. It aims to gain a common view in the industry to ensure that the right optical pluggable is achieved at the right time and at the right cost for building out 5G in a variety of deployment scenarios, including various network sections such as fronthaul and backhaul, and deployment scenarios such as C-RAN and D-RAN.

In the fronthaul, Dense Wavelength Division Multiplexing (DWDM) has been shown to be suitable from the viewpoint of scalability as a long-distance solution in the C-RAN architecture. IOWN GF is reviewing MOPA’s work and may explore opportunity to leverage MOPA’s results in the IOWN GF’s APN related activities.

3.3. Open Programmable Infrastructure (OPI) Project

The Open Programmable Infrastructure (OPI) Project was established this summer in 2022 as a part of the Linux Foundation (LF) to work on next-generation architectures and vendor-agnostic frameworks for network function, storage function, and security function deployment in Data Processing Unit (DPU) and Infrastructure Processor Unit (IPU) technologies. Since each DPU/IPU vendor has a 5G RAN, UPF, MEC deployment use case by its specific Application Programming Interfaces (API) / Software Development Kit (SDK), it is not easy to deploy a single container software to multiple vendors DPU/IPU. OPI project intends to delineate what a DPU/IPU is, to loosely define a framework(s) and architecture for a DPU/IPU-based software stack(s) applicable to any vendors hardware solution, to allow the creation of a rich open source application ecosystem, to integrate with existing open source projects aligned to the same vision such as the Linux kernel, various vendors’ SDK and Data Plane Development Kit (DPDK) to create new APIs for interaction with and between the elements of the DPU/IPU ecosystem:

- DPU/IPU hardware
- DPU/IPU hosted applications
- Host node
- Remote provisioning software
- Remote orchestration software

OPI will nurture an ecosystem to enable easy adoption of these innovative technologies. OPI is designed to facilitate the simplification of network, storage and security APIs within applications to enable more portable and performance applications in the cloud, datacenter and edge across DevOps, SecOps and NetOps.

OPI’s approaches are aligned with deployment model of Function Dedicated Network (FDN) in IOWN GF’s DCI framework which leverage various vendors' hardware/software to deploy mobile network nodes flexibility and cost effectively.

4. DCI and APN Applicability over Mobile Network

4.1. IOWN Mobile Network for CPS/AIC use case

This section describes the possibility for wireless access network deployment over Open APN based on the following reference implementation model (RIM) to realize three CPS/AIC use cases.

- CPS-RIM Area management for security
- CPS-RIM for remote robot control
- AIC-Entertainment for Interactive Live Music

4.1.1. IOWN Mobile Network for Area Management Security Use Case in CPS

The first edition of the RIM for area management security use case [CPS-RIM-AM] was published in early 2022. The RIM document primarily describes the fixed networks leveraging APN and DCI technology. For example, in the RIM, the local aggregation node in the monitored area receives the 60Mbps Motion JPEG captured data with Real-time Transport Protocol (RTP) from each of the 1000 surveillance cameras. The local aggregation node decouples the RTP protocol and transits the 60Gbps total traffic of captured data with Remote Direct Memory Access (RDMA) over User Datagram Protocol (UDP) to the regional edge DCI subsystem. In the case of the current wireless access network, RDMA over UDP is not reliable compared to APN. UE of local aggregation nodes (i.e., a local aggregation node with wireless connection capability) must consider supporting reliable network protocols such as “Internet Wide-Area RDMA Protocol (IWARP) - RDMA over TCP”, “RDMA with Packet Data Convergence Protocol (PDCP) duplication enhancement in 5G wireless access” or etc. Figure 2 illustrates data pipeline diagram for area management security use case [CPS-RIM-AM] in case of the wireless access network.

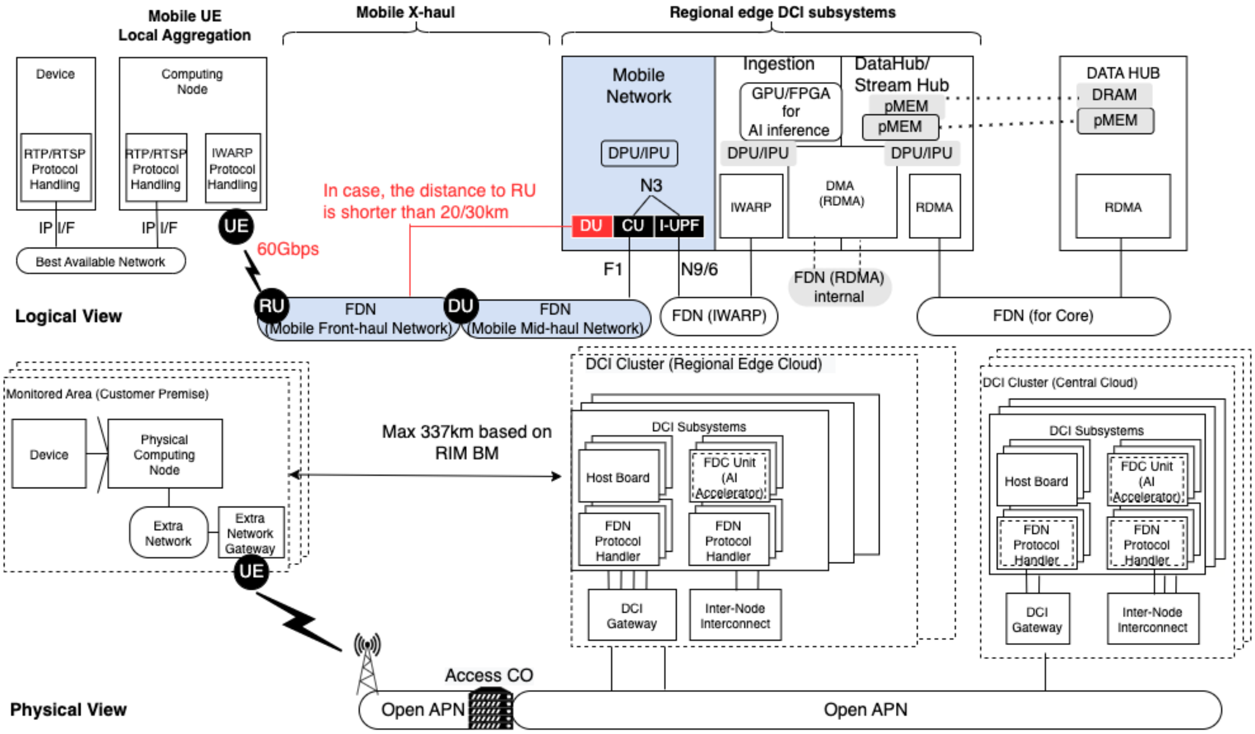


Figure 2 CPS Area management - security use case

To build the following mobile FDN (Function Dedicated Network) segment and interconnect for the CPS use case workload, such as an Ingestion node and Streaming hub on the other Logical Service Node (LSN) in a DCI subsystem, mobile network workloads CAN or WILL run on the container platform in a DPU/IPU-like Logical Service Node.

- Mobile Fronthaul Network segment over Open APN
    - between Radio Unit (RU) and Distributed Unit (DU)
        - In case the distance between RU and DU is shorter than 20/30km, the DU can be integrated into an LSN in the DCI subsystem as the same as Centralized Unit (CU) and User Plane Function (UPF).
- Mobile Midhaul Network segment over Open APN
    - between each DU and CU-UP

As current 5G wireless access does not support 60Gbps bandwidth produced by the UE of local aggregation node aggregating traffic from each surveillance camera, an alternative solution, or further steps toward 6G is required. The following figure (Figure 3) shows an alternative solution, in which case each surveillance camera can have 5G UE capability and send the captured data over RTP (750Mbps of RAW data) via 5G wireless access to the regional edge DCI subsystem. In the following figure. the Local aggregation node is deployed in the regional edge DCI subsystem and decouples each RTP packet (same as RDMA behavior) to directly transfer the user’s payload to the memory in an accelerator card to reduce CPU consumption.

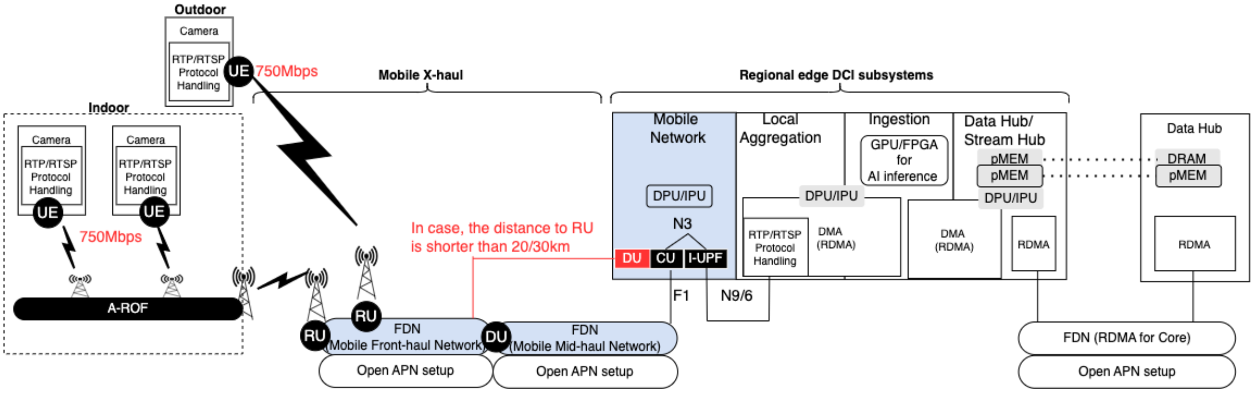


Figure 3 CPS Area management - security use case with wireless access

4.1.2. IOWN Mobile Network for Remote Controlled Robot Inspection Use Case in CPS

The first edition of the RIM for Industry management (IM) remote-controlled robot inspection use case - [CPS-RIM-IM] was published in early 2023, which describes an IM use case primarily based on Open-APN service and the managed DCI service.

In this use case, a 5G RAN is deployed in the customer plant site, either as the multiple semi-integrated gNB (RU+DU) or Integrated Access and Backhaul (IAB) node (DU+MT) to cover the area where UEs of the Mobile robots which include Uncrewed Aerial Vehicle/Drone (UAV) in IOWN GF and UEs of Sensor are located (Figure 4). CU is deployed in the managed DCI system together with UPF. This will be a key benefit for the Mobile Robot with noticeably better quality of experience and efficiency of mobility when compared with full integrated gNB (RU+DU+CU), as packet forwarding is reduced within the broader CU coverage footprint at the handover phase. Even if the Mobile Robot moves to the neighboring cell, there will be no Radio Resource Control (RRC)/PDCP anchor change. There will be no traffic forwarding during the handover procedure, as the DU and CU were split. And each UE of the mobile robot will support a reliable protocol such as Access Traffic Steering, Switching, and Splitting (ATSSS) to connect to UPF running MPTCP/MPQUIC proxy function. The UPF running in DPU/IPU will need to support MPTCP/MPQUIC proxy and the mobile robot controller app, such as a UAV controller, which will run Inter Process Communication (IPC) over RDMA by remote navigation application. This implementation helps to increase command & control packet speed between the mobile robot and remote inspection center via a Local aggregation node. The mobile robot also will monitor a specific area and transfer the captured data via a specific network slice to UPF, connecting the DPU/IPU that decouples the protocol header and stores the payload data to GPU memory.

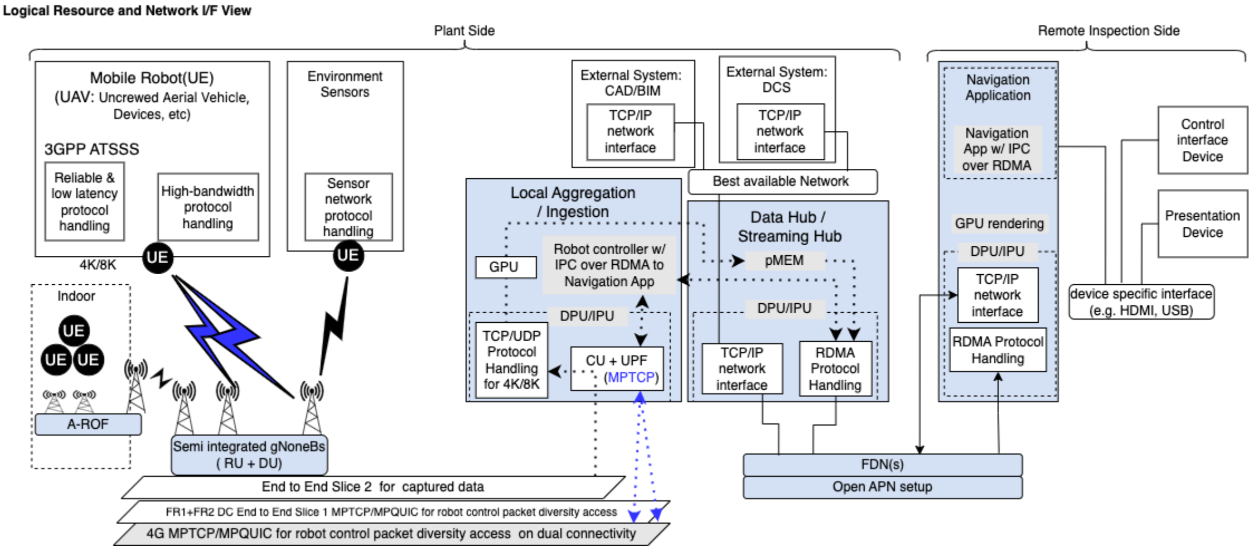


Figure 4 Remote controlled robot inspection use case

3GPP Rel16/Rel17 introduced Industrial IoT features including PDCP duplication enhancements, and ATSSS that will cover some requirements such as high reliability and dual connectivity described in IOWN GF's Industry Management remote robot inspection RIM [CPS-RIM-IM]. In addition to the dual connection of FR1 and FR2, the UE (e.g., Drone) may need multi-access (primary 5G and secondary existing 4G) with MPTCP/MPQUIC/etc., so that the UE can be controlled with a diverse means of reliable access methods from the navigation application locating in the remote inspection site.

5G Network slices are also needed as follows.

- Slice 1: Robot control packet with MPTCP/MPQUIC that has multiple access technologies, including secondary 4G. MPTCP/MPQUIC Packet via 5G/4G at the Local aggregation node.
- Slice 2: Robot inspection captured data and sensor data at the Local aggregation node. The following captured data are transferred via wireless network slice to a Local aggregation node.

Video stream data

A monitoring video camera equipped with a motion sensor and a microphone attached to a robot captures video at an uncompressed 8 K 60 fps, picks up audio, monitors the area, and transmits captured data to the data center. The flow rate of video stream data is about 48 Gbps to 72 Gbps.

3D location data

Accurate 3D location data of a remote points to be inspected will be captured from a plant site and merged with CAD/BIM data in a data center.

Haptic data

An arm connected to the robot sends information to the data center when it palpates the equipment. The stream data flow rate is about 1 Gbps at the maximum.

4.1.3. IOWN Mobile Network for Interactive Live Music Use Case in AI Integrated Communication

The first edition of the reference implementation model for the Interactive Live Music use case [CPS-RIM-ILM] was published in early 2023, and is primarily based on fixed networks leveraging APN and DCI technology.

The XR performance is the key factor in realizing AIC Interactive Live Music. Based on the 3GPP Technical Report [3GPP TR 26.928] that is still a work in progress, the following figure illustrates a possible integration with the DCI subsystem for XR in 5G. The DCI subsystem can potentially compose three types of Logical Service Nodes - LSN1 (a part of Animation data generation node), LSN2 (renderer node, DMA/RDMA), and LSN3 (Mobile Network node). Each function workload as a container application runs on container platforms such as Kubernetes worker in Logical Service Node.

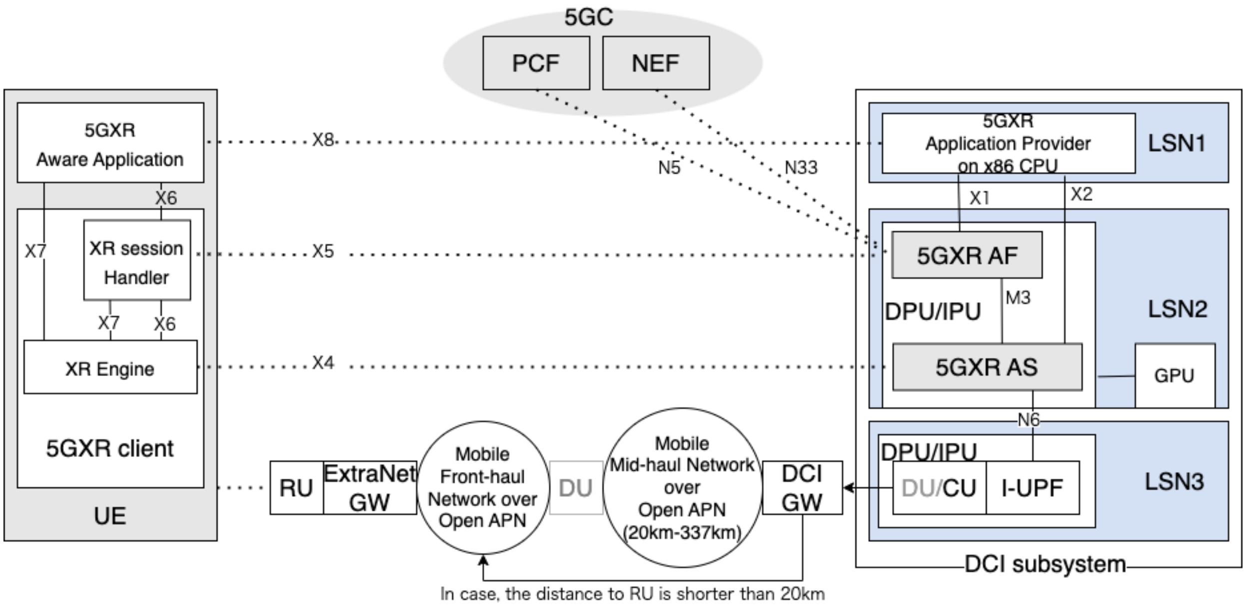


Figure 5 XR in 5G

For instance, in the RIM over a 5G wireless access network, the animation generation function on an LSN in DCI subsystem will need to receive video data, depth sensor data, and eye tracking and facial expression data from the movement of the mobile UE audience and generate animation data. Then it sends the animation data internally via DMA/RDMA to the memory on the accelerator card (e.g., GPU) composed in the same/other LSN. At the same time, the rendering function of the LSN receives artists' 3D model data and 3D scene data from the bounding box data generator (for artists) node and collects avatars' positions from the virtual space creator and overlays the polygon data on it and renders the scene. Then it will send the data to display of mobile UE audience via 5G wireless access.

Functional blocks such as renderer in AIC interactive live music use case are a part of LSN1 and LSN2. The following figure (Figure 6) shows how to adapt the mobile network to the interactive live music RIM.

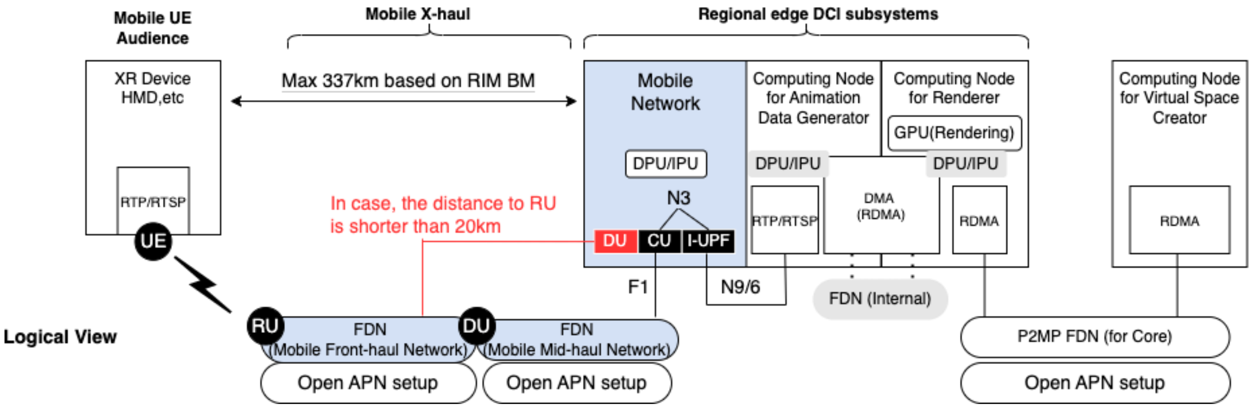


Figure 6 AIC entertainment - Interactive Live Music use case

Mobile Network workloads run on the container platform in DPU/IPU-like LSN to build the following mobile FDN segment and interconnect to the AIC use case workload such as animation data generation and renderer on the other LSN in DCI subsystem.

- Mobile Front-haul Network segment over Open APN
  - between RU and DU
    - In case the distance between RU and DU is shorter than 20km, the DU can be integrated into a LSN in the DCI subsystem as the same as CU and UPF.
- Mobile Mid-haul Network segment over Open APN
  - between each DU and CU-UP

The current technology gap to implement Interactive Live Music over wireless access networks is motion-to-photon latency. According to [3GPP TR 26.918], the latency of action of the angular or rotational vestibulo-ocular reflex is known to be on the order of 10 milliseconds or in a range from 7-15 milliseconds. It seems reasonable that this should represent a performance goal for XR systems. This results in a motion-to-photon latency of less than 20 milliseconds. The IOWN Interactive Live Music RIM is going to demonstrate 10 milliseconds motion-to-photon latency for the 2030 “quantum leap” paradigm leveraging the IOWN Open APN. The Fixed network-based IOWN GF ILM RIM and 3GPP model illustrated in “Figure 5 XR in 5G” may need to be compared. Based on IOWN ILM RIM, the IOWN GF will need a wireless access speed over at least 72 Gbps supported by the Open APN. Further exploration in potential 6G technologies will be needed to implement Interactive Live Music over wireless access instead of the Open APN Fixed network.

4.2. RAN Deployment Scenario Over IOWN Global Forum APN/DCI

This section describes the way to apply an APN (which is defined in [IOWN GF Open APN FA]) to FH/MH/BH.

- An APN provides a wavelength path as transport for FH/MH/BH and doesn’t terminate any protocol of FH/MH/BH (Figure 7).
- The APN allows both L1 multiplexing (L1 mux) and L2 multiplexing (L2 mux), and the multiplexing scheme can be both.
- Each RAN functionality is connected to the APN by terminating the wavelength path with an optical transceiver directly or by using a bridge function such as Flexible Bridging Service, as shown in Annex A of [IOWN GF Open APN FA].
- In the case of the RU side, a Passive Optical Network (PON) can be used as a method of direct connection to the APN, and Time Division Multiplexing (TDM) -PON is one of the methods to realize this. However,

when TDM-PON is applied, the RU-DU distance must be limited to 10 km in order to absorb the effects exceeding the Packet Delay Variation (PDV) requirements (10 microseconds).

- Flexible Bridging can define multiple types of services to support multiple QoS levels (such as delay and jitter) depending on use cases (Figure 8). Type D1 [IOWN GF PoC-MFH], which supports QoS with bandwidth reservation and very strict latency, should be applied for FH transport (both CUS-plane (Control, user, and synchronization) and M-plane), and Type D2 [IOWN GF PoC-MFH], which also supports QoS but less strict than Type D1, supports bandwidth reservation and strict latency should be applied for MH/BH transport in order to meet the requirement described in section 2.1. Flexible Bridging Service and supported service types are defined in Annex A of [IOWN GF Open APN FA].

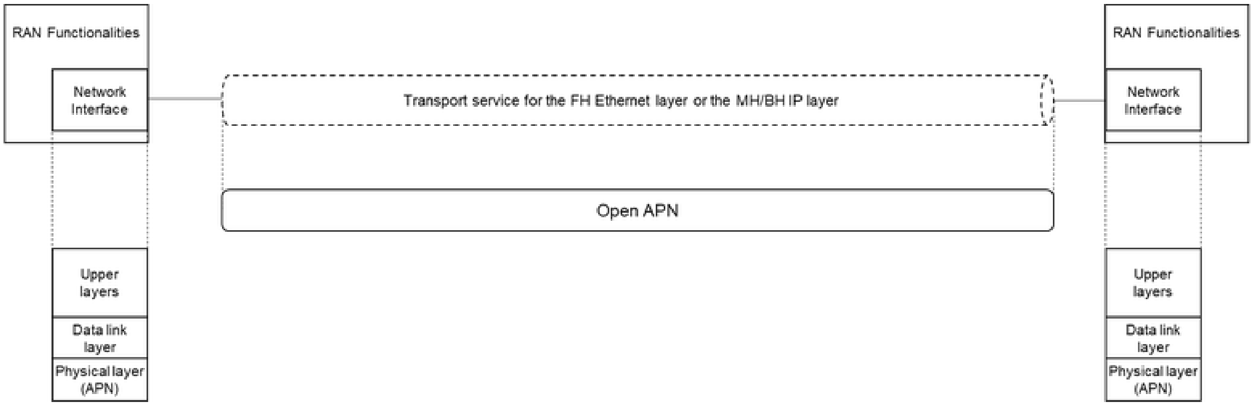


Figure 7 RAN deployment scenario with direct path over APN

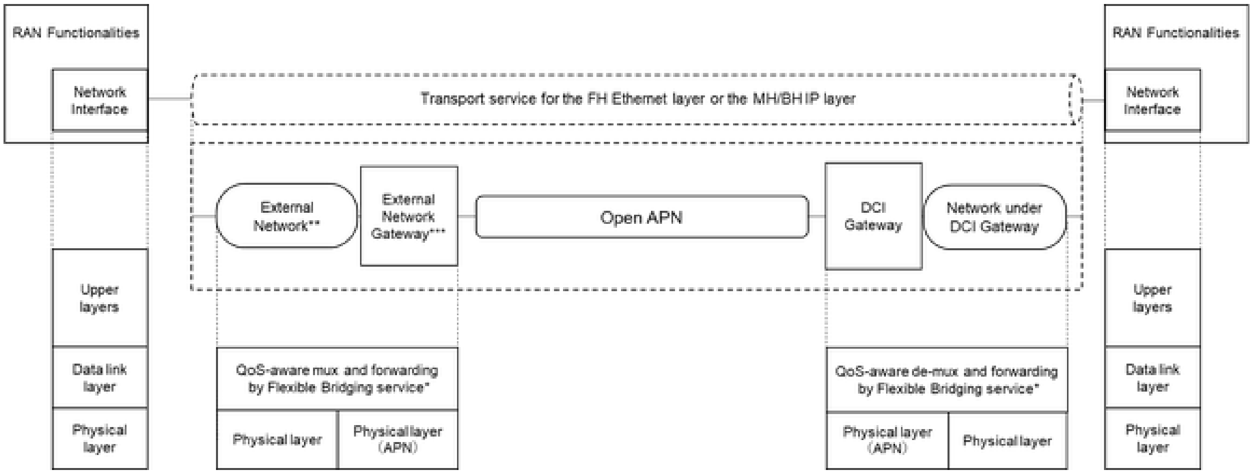


Figure 8 RAN deployment scenario with bridge function over APN

*The implementation technologies should be studied during activities that follow this document. Several multiplexing methods, including packet-based at L3/L2 and non-packet-based at L1, are being considered.

**For MH and BH, this segment is a network under DCI gateway.

***For MH and BH, this segment is a DCI gateway.

4.3. High Availability and Elastic Load Balancing with DCI and APN

By combining the APN, DCI subsystem, and RAN Intelligent Controller (RIC), it is possible for a FH network to flexibly switch DU within the DCI resource pool. The assumption here is that the DU is a virtual node running on the Network Functions Virtualization Infrastructure (NFVI) and can be freely reconfigured on multiple NFVIs located in different geographical locations, with the objective to save energy. The association between the physical server DU and RU in the FH network will change based on external triggers, such as a failure condition of any of the involved components, a load balancing requirement, or an energy saving requirement (Figure 9). Once the trigger is initiated, the physical association between the RU and DU will change and can take different forms. High availability is achieved when an autonomous action is executed via reconfiguration of RU-DU association to correct an issue detected by the network, be it a failure, or service degradation, ---).

In one scenario, all user devices (UE) connected to an RU will need to be reconnected to a new DU which is reconfigured on physically different server. In another scenario, some of the connected UE will connect through an RU that is dual homed to two physically different DUs. These changes will allow for greater flexibility and efficient resource utilization in the FH network. This is expected to improve availability and power efficiency of the RAN system compared to conventional FH. In terms of power efficiency, it is expected that this will improve the power efficiency of the RAN system, as unused DCI resources (vDUs) are shutdown and thus have no power associated consumption.

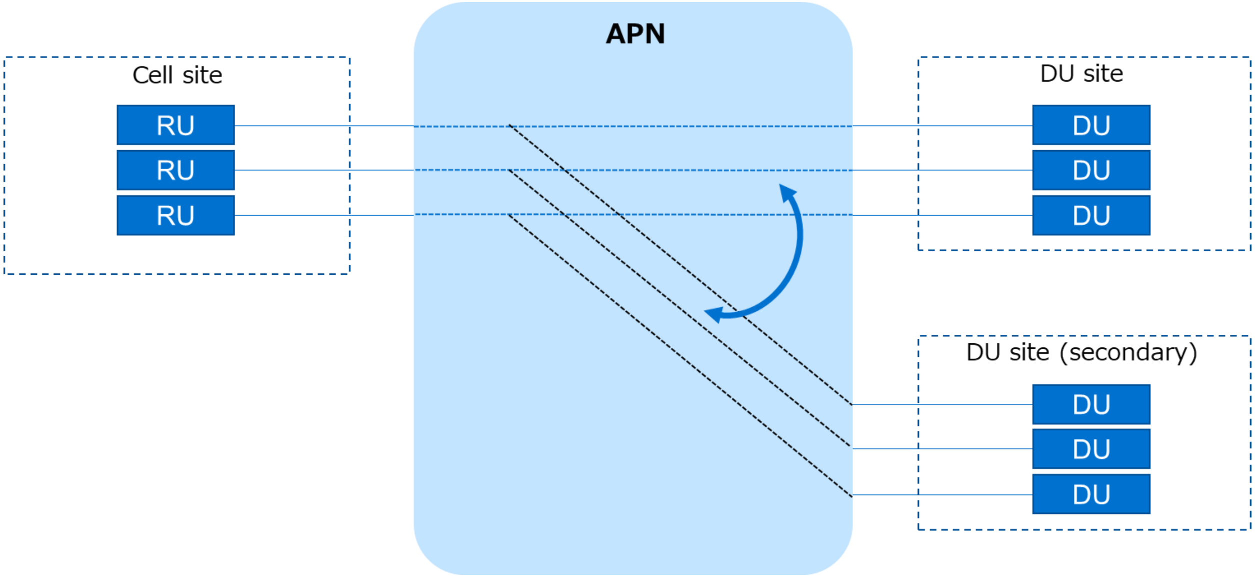


Figure 9 Dynamically switching path for High Availability and Elastic Load Balancing

Specifically, the following three methods for switching methods are used depending on the configuration:

(1) Optical path switching by APN-G/I (Figure 10)

APN-G and APN-I, refer to [IOWN GF Open APN FA], switch optical path that associates the current vDU with the new vDU trigged by configuration update. Note that these vDUs could be deployed in geographically different locations - i.e., not necessarily in the same Data Center. This solution needs many transceivers, and the cost is more expensive than other methods, though it consumes low power due to no L2/L3 processing

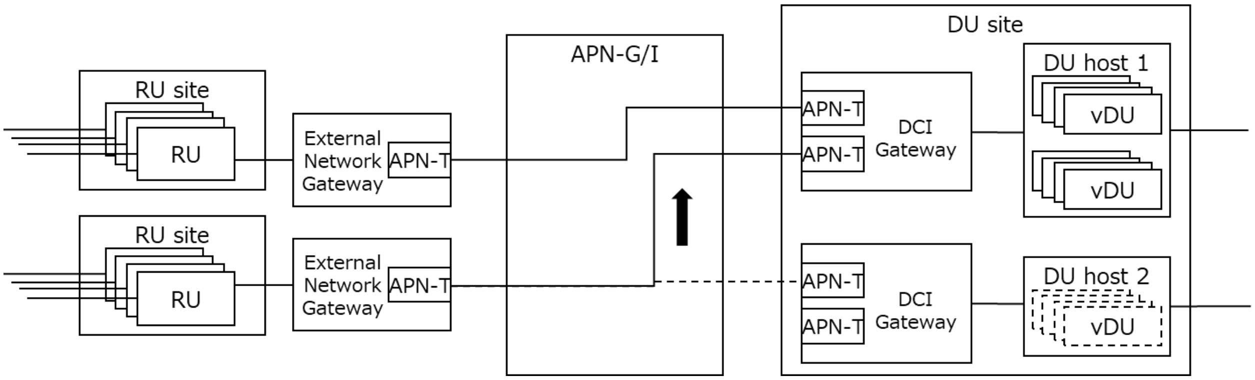


Figure 10 Optical path switching by APN-G/I

(2) Packet switching by DCI Gateway (Figure 11)

DCI gateway switches packet destination according to the configuration change on the DU side. High power consumption with L2/L3 processing, but a small number of transceivers are required, and this option’s cost is less expensive than method (1).

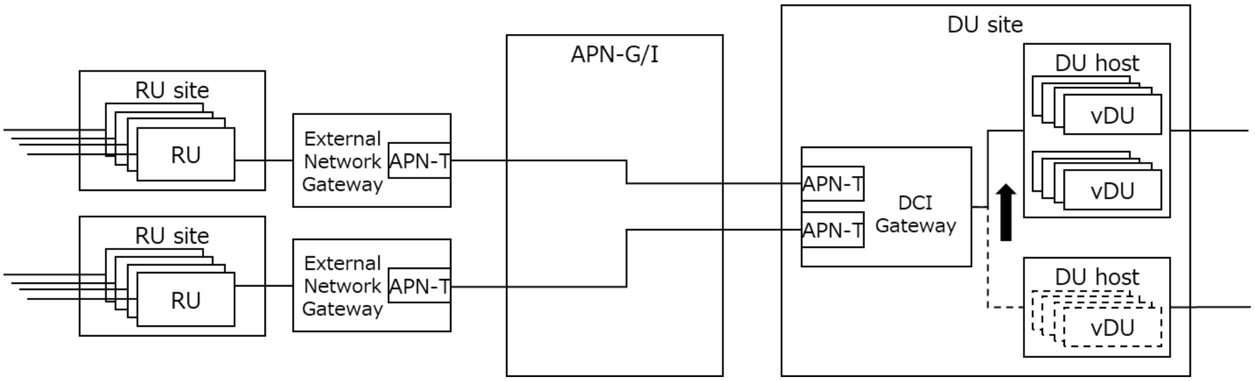


Figure 11 Packet switching by DCI Gateway

(3) Optical path switching by OLT (TDM-PON based method, Figure 12)

OLT switches optical path according to the configuration change on the DU side. Low power consumption without L2/L3 processing, and small number of transceivers are required, and this option’s cost is less expensive than method (1).

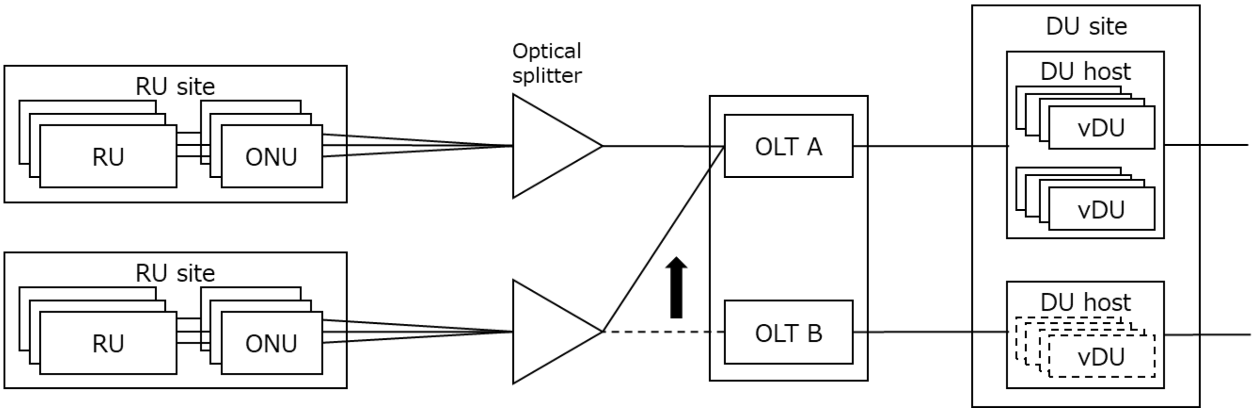


Figure 12 Optical path switching by OLT

5. Study Items

5.1. Study Item 1 Extended Cooperative Transport Interface (CTI) for Mobile NW and APN

This section describes study item of an extended CTI between a mobile network and APN to provide end-to-end low-latency and low-jitter services using IOWN technology. It explains the relationship between extended CTI and APN/DCI reference architecture.

In order to provide uRLLC services that require low latency through a mobile network in addition to an APN, latency need to be controlled in optical paths and/or through the DCI gateway by using the information provided by the network equipment such as DU in mobile network. One option for controlling latency is to collect the mobile information such as aggregated traffic load from a CU/DU (vCU/vDU), and then an orchestrator, which coordinates the mobile network and APN, transfers the data to an APN controller. For example, mobile information is the aggregate traffic load over all UEs per O-RAN Remote Unit (O-RU) interface (and optionally per flow per O-RU interface) at a given time interval. However, end-to-end low latency may not be feasible through communicating with the orchestrator which requires time-consuming procedures, so it would be desirable if the APN controller directly receives the mobile information from the CU/DU (vCU/vDU) through the extended CTI. Because the existing CTI specifications do not apply to short Transmission Time Interval (TTI) and mobile MH/BH in future mobile networks, the CTI specifications should be functionally enhanced as the extended CTI in IOWN GF architecture.

5.1.1. Functional Control Scheme with Extended CTI

This sub-section describes how end-to-end low latency is achieved when the APN controller directly receives mobile information from the CU/DU through the extended CTI. Although the targets of the latency control are mainly optical paths and DCI gateways, the latency control for the DCI gateway is first discussed. Figure 13 shows the functional control scheme with the extended CTI for controlling the latency of a DCI gateway. This scheme is mainly divided into collection, analysis, and control processes, which are as follows.

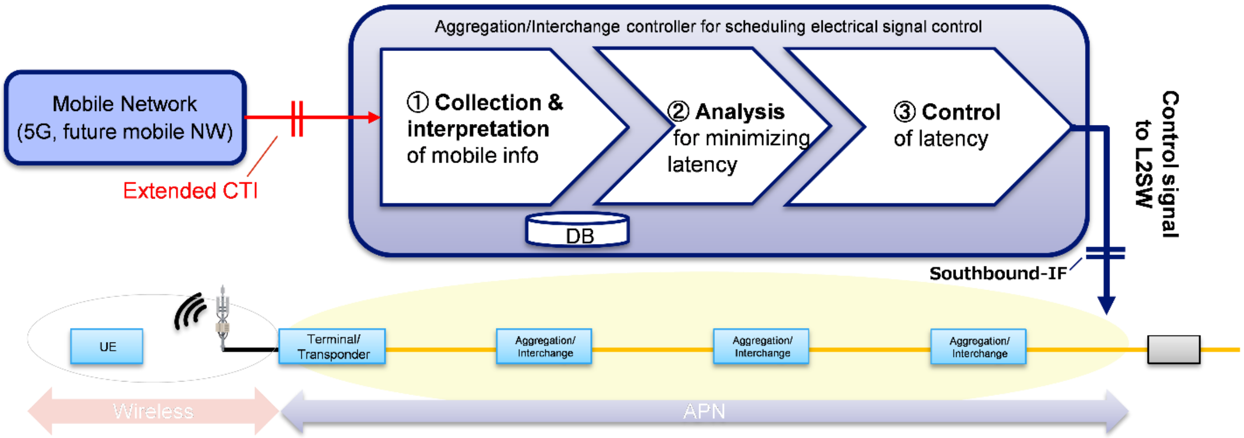


Figure 13 Functional control scheme

A) Collection and interpretation of mobile scheduling information: Receive scheduling information through extended CTI and convert it to an optical scheduling form

B) Analysis for minimizing latency: Analysis based on mobile scheduling and decision-making for DCI gateway scheduling (timing) to minimize end-to-end latency

C) Control of latency: Control timing for the DCI gateway controller in accordance with the resulting decision of the previous process

5.1.2. Scope Control of Extended CTI

The scope of this study item, extended CTI filling the gaps described in [IMN], focuses on the followings:

- Applicability of short TTI considered in uRLLC use case

Specifying the interface between a mobile network and APN should be considered to define the functional and performance requirements of the extended CTI.

- Applicability to mobile MH/BH

Architectures that use the extended CTI need to be specified. Furthermore, it is necessary to identify the kind of information to be exchanged through the extended CTI between mobile networks and APNs.

As described in section 5.1.1, controlling the latency of DCI gateway using extended CTI is focused, but the application of extended CTI is not limited to the DCI gateway. Table 3 shows examples of applicable targets for the extended CTI, along with information on what to control and the expected benefits.

Table 3 Examples of applicable targets for extended CTI

Target	**What to control (Expected benefits)**
DCI gateway	Output timing of signals (low latency, low jitter)
APN-G	Optical path setting (low latency, priority control, bandwidth allocation)
	Optical path switching (congestion control, low latency, priority control)
Optical Transceiver	ON/OFF control (power saving)

5.1.3. Relation between APN/DCI Architecture and Extended CTI

The relationship between extended CTI and APN/DCI architecture to control optical path/DCI gateway is described in Figure 14.

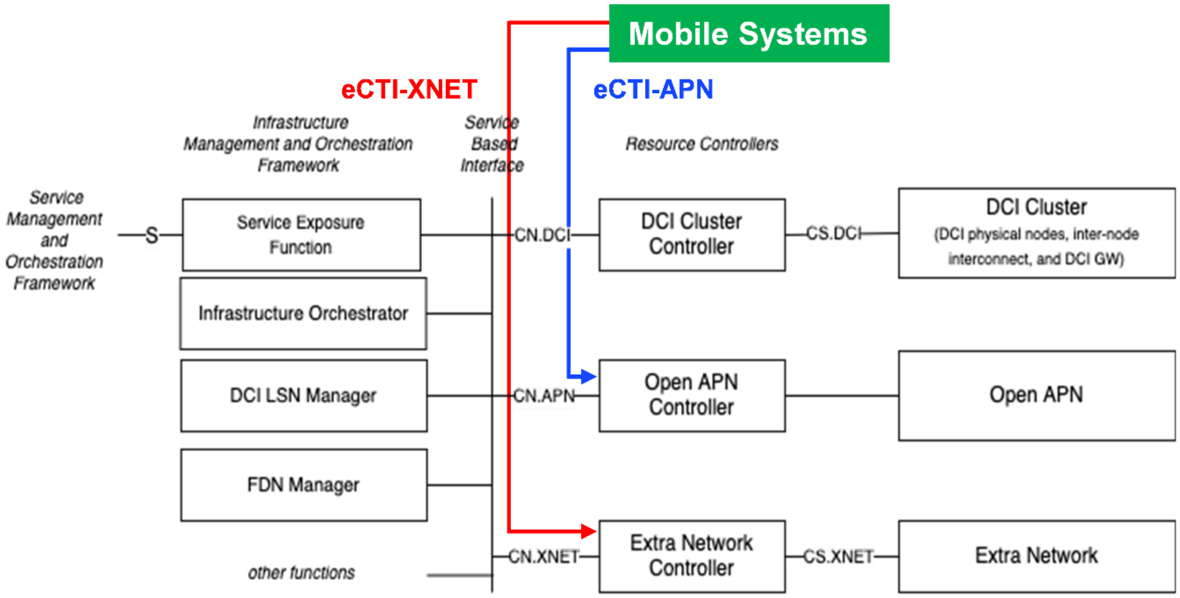


Figure 14 Relation between APN/DCI and extended CTI

Basically, the mobile information (cooperation information) would be obtained from mobile systems via extended CTI (eCTI). As shown in Table 3 in section 5.1.2, eCTI can be divided into two logical interfaces of eCTI-APN and eCTI-XNET depending on a controlling target. The eCTI between Open APN Controller and mobile systems is defined as eCTI-APN, while the other between Extra Network Controller and mobile systems is defined as eCTI-XNET as shown in Figure 14.

RAN is described as mobile systems in the Figure 14. As for the connection of eCTI, both interfaces connecting to vCU/vDU or near-RT RIC should be covered.

The role of each eCTI is follows:

(1) The Open APN controller receives mobile information via eCTI-APN to control the optical switch/optical path and optical transceiver.

(2) Extra network controller receives mobile information via eCTI-XNET for controlling Extra Network gateway to realize low latency/low jitter.

5.1.4. Function Blocks in Applying Extended CTI

In order to specify the time requirement in applying eCTI, time analysis in detail is needed using actual examples with assumptions. Figure 15 illustrates a function block diagram where eCTI is applied between DU and the controller of lower-layer (e.g., layer-2) functions that composes midhaul [O-RAN Xhaul Transport Requirements]. For applying eCTI for backhaul transport, eCTI is used between CU and the controller of the backhaul equipment.

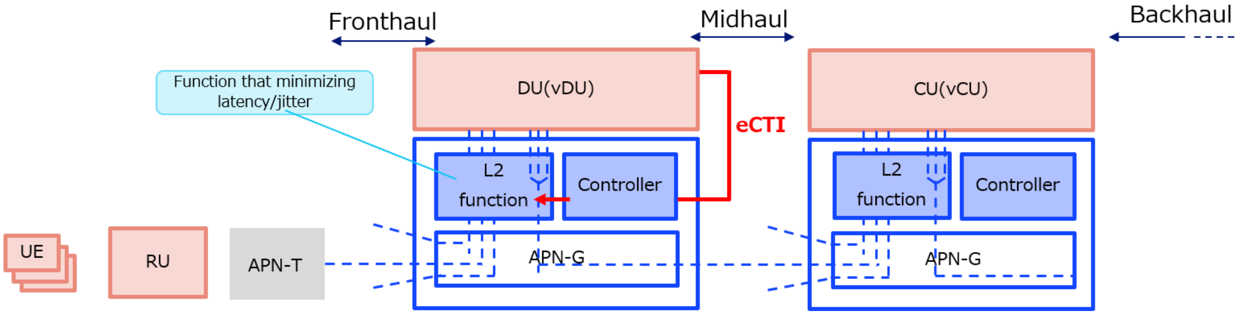


Figure 15 Function block example applying eCTI between DU and L2-function controller of MH

5.1.5. Proactive Network Control with Extended CTI and Time Requirement

One of the key aspects of the mobile information via eCTI is to indicate a future event, including actual traffic arrival at the transport node. This feature enables network elements to be controlled in advance of the actual traffic arrival, which is essentially proactive control. Therefore, the time difference between information receiving time at the controller from the mobile system and user data arriving time at the transport node is important.

In the scheduling of New Radio for 5G (NR) mobile system, the time duration between when gNB sends uplink grant to a UE and when the UE is to transmit user data in physical uplink shared channel (PUSCH) is defined as k2 shown in Figure 16, which is configurable as the number of slots. Considering that the time when the controller receives the control information is the same as the start of k2, the time requirement is bound to k2.

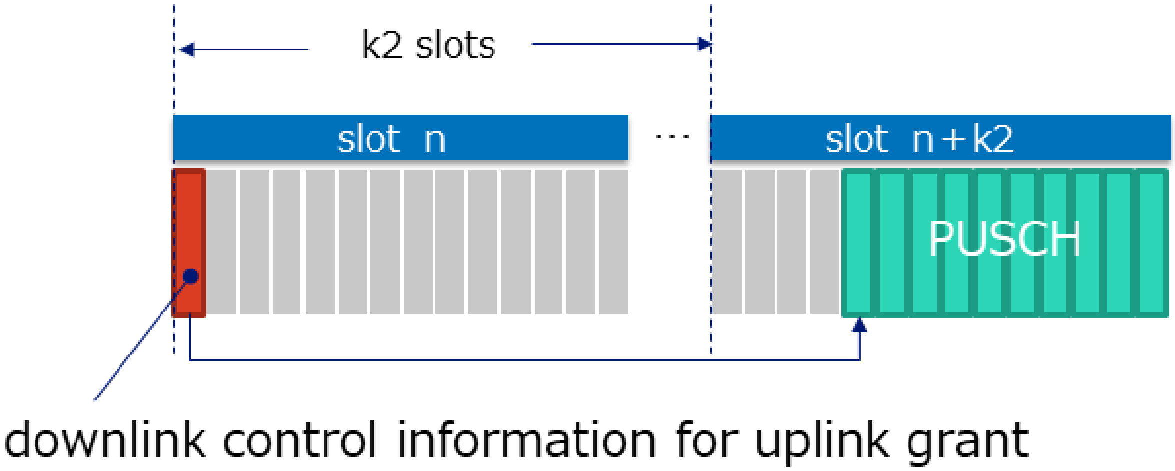


Figure 16 k2 time before actual traffic arrival

In NR system, the time duration of slot depends on the subcarrier spacing. The mobile system which uses 400MHz per component carrier in FR2 (frequency range 2, e.g., 28GHz), the sub carrier spacing could be 120kHz and slot length is 125 us as shown in Figure 17. For example, the system uses k2 as 2 slots, the time requirement to control the transport node in advance of the traffic arrival is 250us.

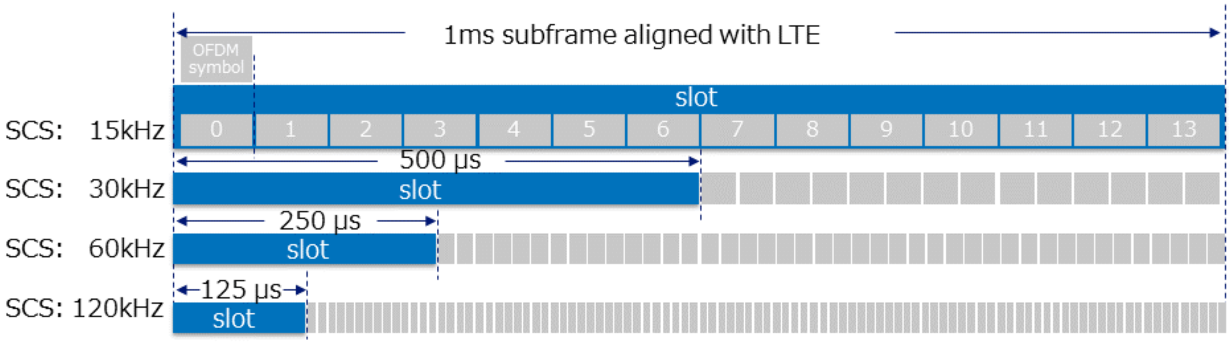


Figure 17 Slot time duration with sub carrier spacing

5.1.6. Jitter Reduction with eCTI

Some use cases require low jitter as well as low latency. This subsection describes techniques to reduce jitter with eCTI, as an example of eCTI applicability for MH/BH. In the uplink transmission of mobile systems, jitter occurs in the output of UE, and it remains in the MH and BH. This is because the current radio transmission uses schemes such as downlink/uplink separation of Time-Division Duplexing (TDD), Medium Access Control (MAC) data unit concatenation to compose transport blocks, and retransmission of lost data units. These mobile transmission schemes often keep uplink data waiting until it can be transmitted. This wait time leads to non-uniform uplink data transmission intervals. Thus, these non-uniform intervals appear as jitter.

The jitter reduction with eCTI performs traffic shaping at an L2 function connected to APN-G. The shaping rate is calculated with mobile scheduling information that is forwarded from vDU via the eCTI. Figure 18 shows the configuration of jitter reduction with eCTI for MH. The vDU forwards scheduling information to the controller via eCTI, and the controller calculates shaping rate by using that information. Then, the L2 function performs shaping before APN-G uplink transmission to MH. The shaping in the L2 function aligns uplink data transmission intervals to reduce uplink jitter. This jitter reduction can be used for BH by performing shaping at the L2 function connected to vCU as shown in Figure 15.

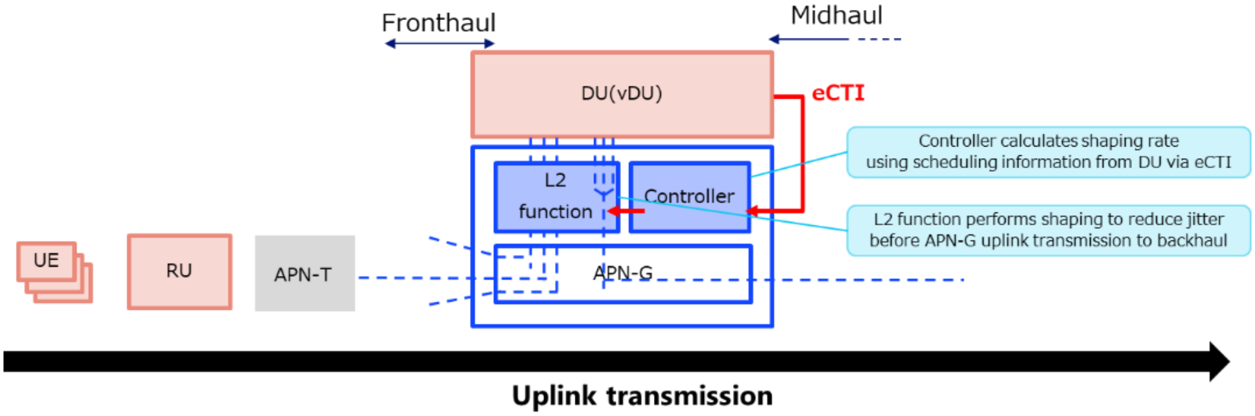


Figure 18 Configuration of jitter reduction with eCTI for MH

5.1.7. Increase Resilience with CTI

This subsection introduces a way that eCTI improves resilience for cell site connectivity. Concerning the optical segment dedicated to X-Haul transport, commercial solutions are available based on:

i) Ethernet layer with link protection of aggregated Ethernet interfaces with two times Ethernet ports (L2 function Bloc), transceivers, and optical fiber paths between the APN nodes and terminal. eCTI could act as a role between RAN blocs and the several APN nodes (Figure 19).

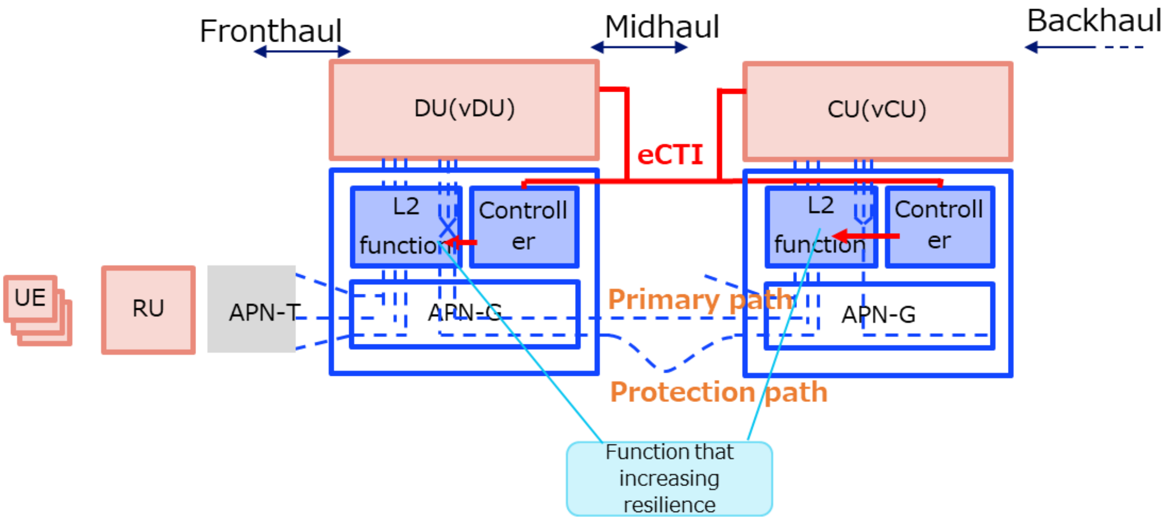


Figure 19 Ethernet layer with link protection

ii) Physical layer with automatic photonic switch using real-time optical power monitoring included in the photonic layer of APN node (Figure 20). This solution includes additional insertion loss for the two optical fiber paths due to photonic switch and/or optical splitter. This solution supports a transport protocol and line-rate agnostic capability with single port and transceiver at the APN node and terminal interface.

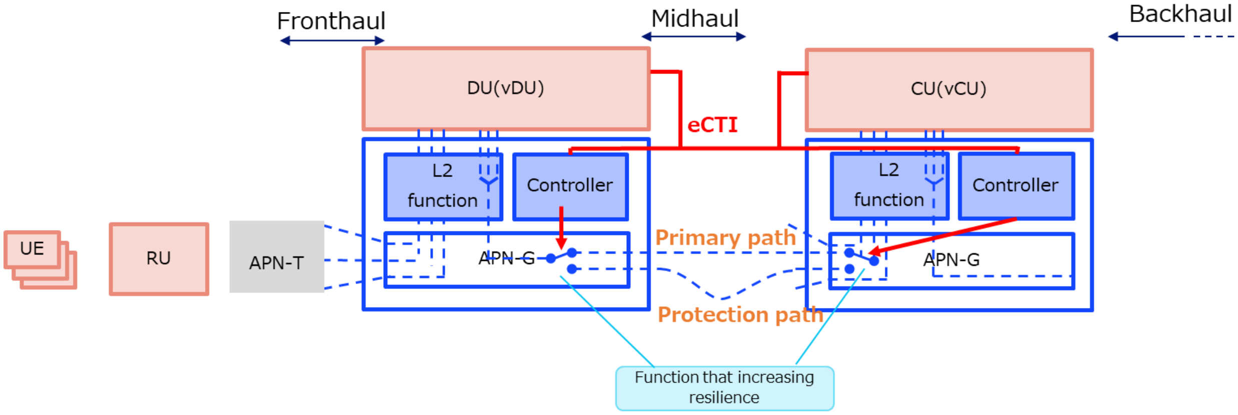


Figure 20 Physical layer with automatic photonic switch

iii) With more and more fiber in the access infrastructure for Fiber To The Home (FTTH), a synergy between the fiber operations dedicated to antenna and residential customer could be applicable (Figure 21). A scenario could be for backhaul and MH a primary link based on PtP, and a secondary protection link based on PON. This solution makes it possible to use the FTTH operation which is much cheaper than the PtP one to provide the protection path. The native PON dynamic traffic allocation allows to guarantee a fairness between residential customers and the protection path for antenna and BH or MH. Coordination between RAN and APN node could increase the performances of such protection scheme.

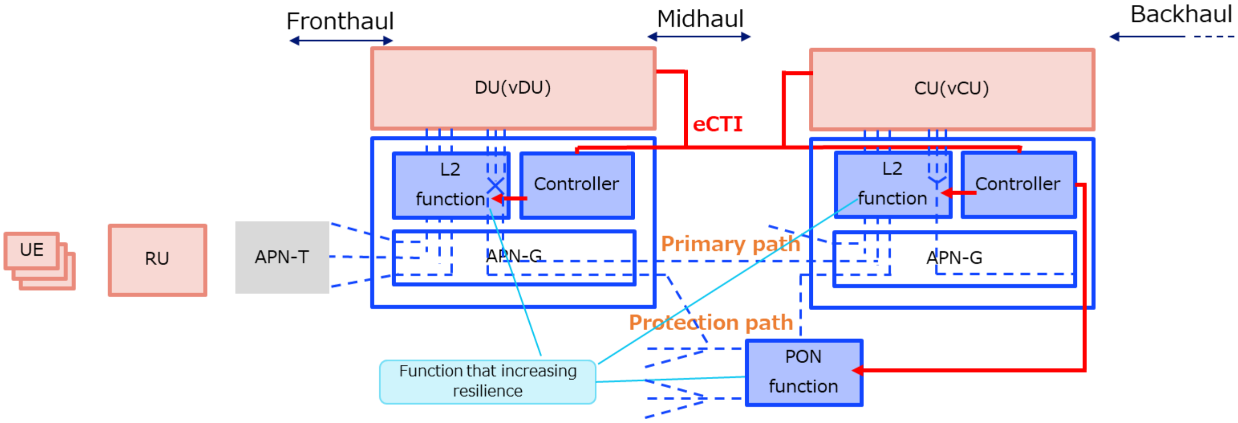


Figure 21 Synergy between the fiber operations dedicated to antenna and residential customer

5.2. Study Item 2 Mobile Network Deployment Scenario over APN

This study item was completed in the IOWN GF Technical Outlook for Mobile Networks using IOWN Technology [IMN]. Further updates may be made if network conditions or configuration of IOWN GF APN architecture are changed.

5.3. Study Item 3 Optimized Transport Network for Cost-Effective RAN Deployment and Operation Efficiency

As capacity demand of mobile transport network increases significantly resulted from adoptions of 5G diversified use cases such as eMBB, URLLC, and mMTC, MNOs face challenges to meet the capacity requirement and need to develop solutions to optimize mobile transport network to lower deployment cost and operation complexity. In this section, several X-haul network options are discussed for cost-effective RAN deployment and improvement of operation efficiency to meet the capacity demand and as well as stringent 5G QoS requirements.

Triggered by vertical drivers, new applications, such as cloud robotics and remote-assisted surgery, will demand new capabilities from 5G and Beyond/6G networks. New applications will be required to support end-to-end (E2E) QoS (e.g., throughput, latency, availability, reliability, resilience) at scale, according to the respective Service Level Agreements (SLA), including services with extreme performances, over three main network deployment areas: local area (like indoor, hospital, campus), confined wide area (like port, airport or railway), and general wide area (geographical, urban…).

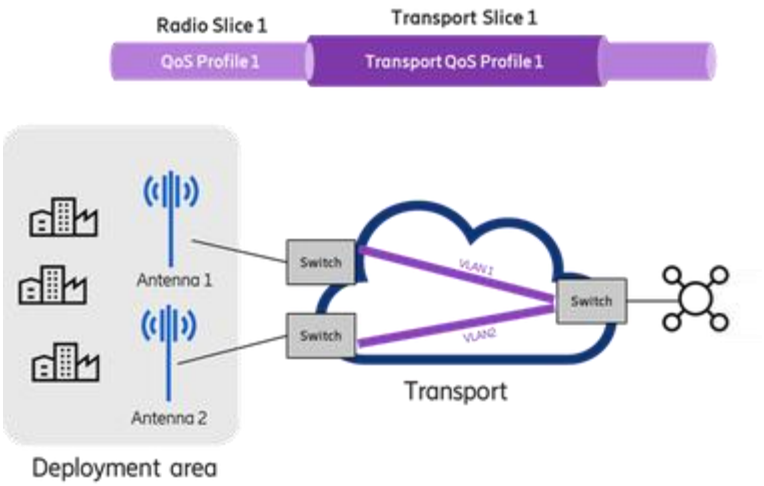


Figure 22 Mobile transport network in the E2E slicing context

Hence, as shown in Figure 22, each service can span more antenna sites, and each antenna site supports differentiated services with proper QoS. Vertical use cases are considering network slicing as a cost-effective solution for their digital transformation. Slicing allows a service provider to define a set of logical networks on top of a shared infrastructure. Each logical network is designed to serve a defined business purpose and comprises all the required network resources, configured and connected E2E, to provide the expected QoS to the vertical.

The E2E QoS is constituted by the “combination” of the QoS guaranteed in the RAN/Core Network (CN) layer and the QoS guaranteed in the transport layer. E2E QoS should be managed automatically and dynamically as provided by a “unique” infrastructure, composed by RAN/CN and transport. Achieving a high level of automation at a reasonable cost needs to be scalable with service area size which may be across various locations.

The corresponding RAN/CN and transport resources are required to be deployed in the specific deployment areas assuring to the service specific “slices” with the required E2E QoS without resorting to the over-provisioning of network resources. From the radio layer, traffic from a single slice or from a group of slices is mapped into transport resources that need to match the required E2E QoS for the slice or group of slices. Each network slice should operate as an isolated E2E network, tailored to fulfill diverse requirements requested by a particular application. The isolation tightly depends on the specific transport technology. For example, in the case of optical networks, it is possible to leverage the separation provided by wavelength channel, while in case of packet networks, a possibility is to provide separation by a dedicated scheduler. Hence, the switch shown in Figure 22, at the edge point of the transport network, could be the interworking or integration of packet and optical switches. The packet switch allows to aggregate the traffic flows at lower granularity than optical channels and enables the adaptation to the traffic variation in time and space, while the optical channels assure to guarantee the tight and deterministic latency, and high bandwidth.

In essence, to support a mix of services for vertical use cases, conventional 5G slice orchestration should be extended in several aspects to increase automation, awareness of transport, and maximize the amount of served traffic by reducing over-provisioning as will be detailed later in this chapter.

The main features to support mobile wireless access are:

- Optical & Packet-based transport for X-Haul network architecture
- Low-latency transport systems
- Monitoring and management of the optical and other network layers for RAN
- Reuse of installed fiber infrastructure
- Technology enablers for the above, such as advanced optical components (e.g., ROADM based on integrated silicon photonics, as description later)
- Transport aware slicing on deployment service areas
- AI-based mechanisms that allow tight QoS support without wasting of network resources

5.3.1. Fixed WDM Fronthaul Network Scenarios with Electric-powered Remote Node or With Non-powered Remote node

As one of several possible fronthaul network deployment scenarios, the mobile operator may choose an option that has less flexibility but needs to be low cost. Fixed WDM network is not reconfigurable but is attractive from a capital expenditures (CAPEX) point of view, particularly when compared to use ROADM (Reconfigurable Optical Add Drop Multiplexer (OADM)) and tunable transceivers. Dynamic steering of RU connections to a vDU based on traffic profile can be supported by placing an optical switch between (virtual) DU and APN-G in the central office. In a fixed WDM network, each remote node is assigned to the wavelengths to be added or to be dropped by fixed optical filters and fixed transceivers. Single ring topology can also be an efficient option to compose a fronthaul network when the incremental cost to complete the ring configuration is limited. There are functional differences between electric-powered remote and non-powered remote to implement line switching protection against fiber cut for a single fiber bidirectional transmission.

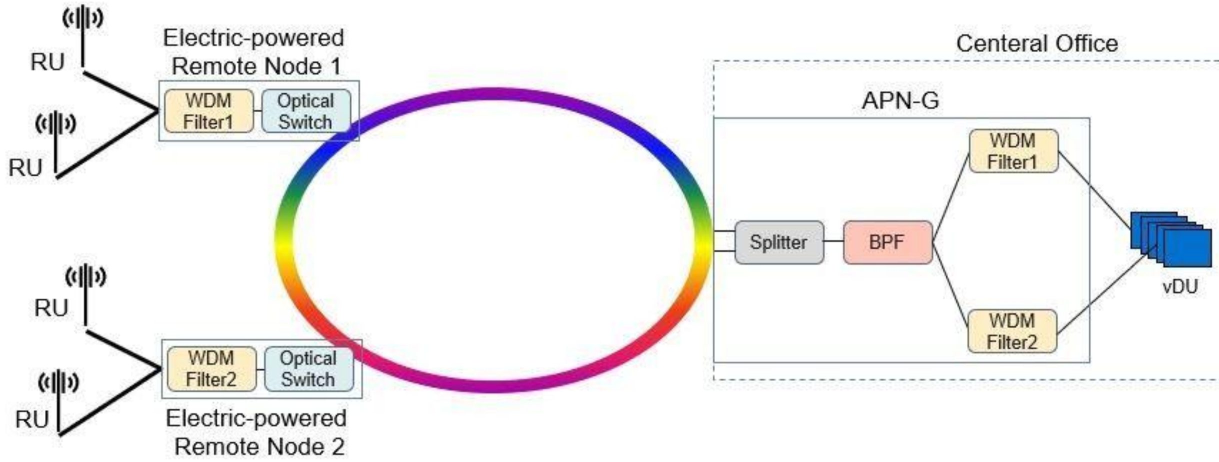
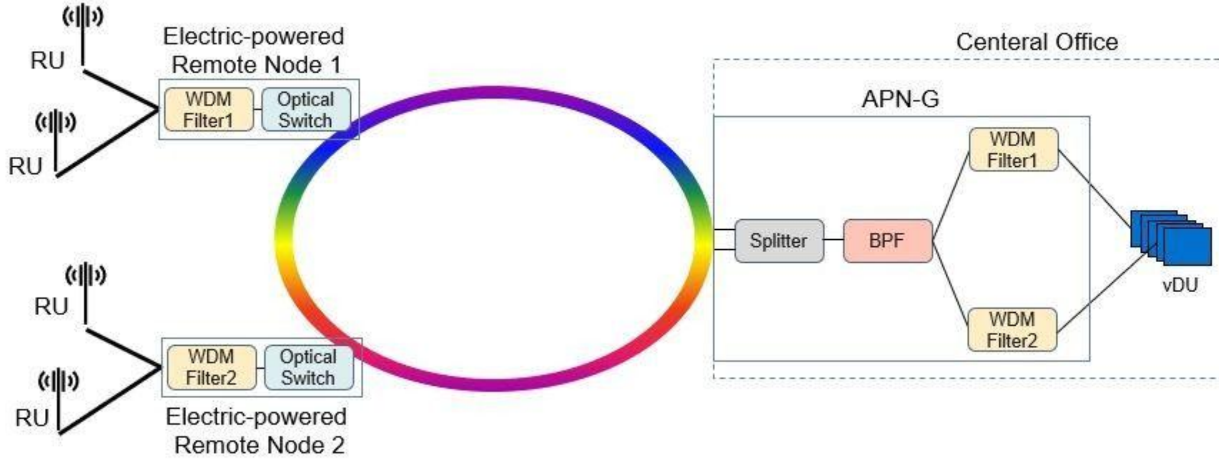


Figure 23 *Fixed WDM fronthaul network with electric-powered remote node*

In the case of electric-powered remote, the optical switch can be in remote site. APN-G in the central office has an optical splitter to transmit the signal in both east and west direction, and a remote node choose the direction of receive with monitoring the optical powers as shown in Figure *23*. Additional channel to control the active remote nodes can be applied. A WDM filter to drop the assigned wavelength range only is required, so the structure of remote node is relatively simple. But an active remote site needs the power supply and if necessary, the cost for installing and maintaining Uninterruptible Power Supply (UPS) and air conditioning should be considered.



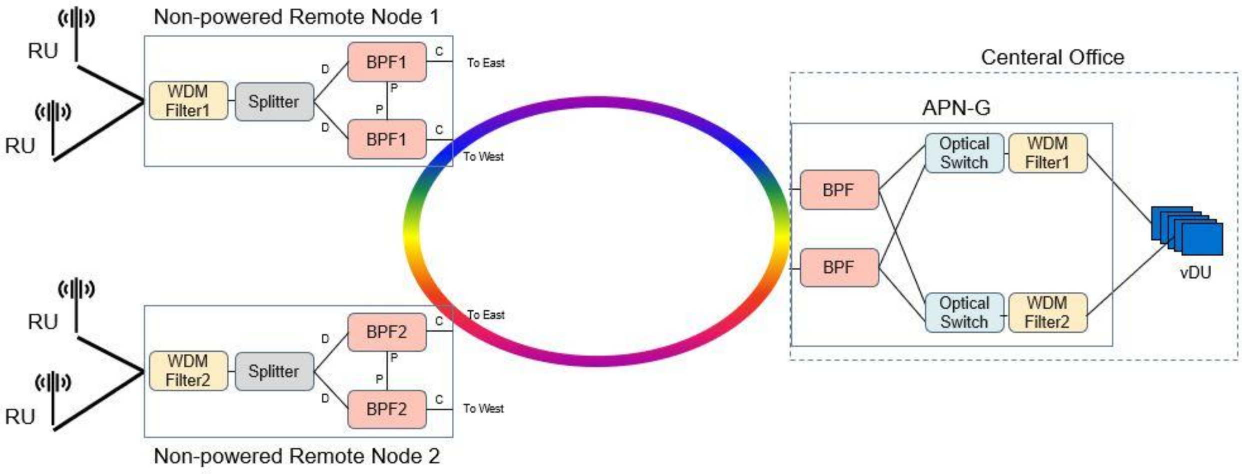
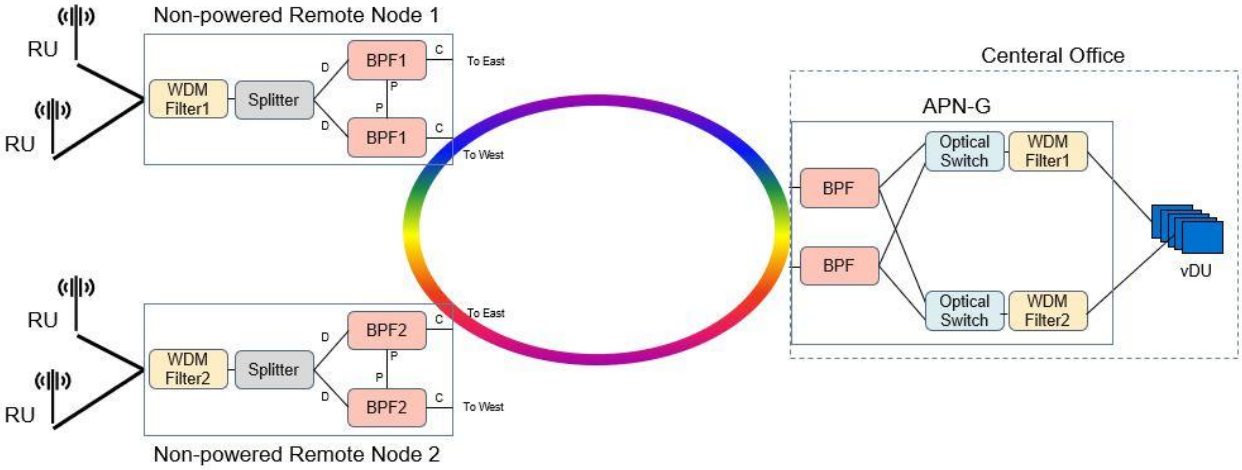


Figure 24 Fixed WDM network with non-powered remote node



In the case of passive remote as shown in Figure 24, APN-G in the central office has optical switches for each assigned wavelength ranges to remote sites and transmit the signal in only one direction. A remote node has an optical splitter, a WDM filter to drop the assigned wavelength, and a pair of by-pass WDM filters for other remote nodes. The signal experiences more insertion loss, but there is no power supply resulting the saving in operational cost.

5.3.2. Low-cost Optical Fronthaul Option: Dark Fiber

Most operations close to the Antenna cell site are facilitated by using a single fiber bidirectional transmission, which refer to the operation with a distance to the antenna site at the order of hundreds of meters to teens of kilometer (typically 15/20KM). Such distance is limited from the latency requirements that could be 75/100 us from CPRI/eCPRI according to standard in case of fronthaul or E2E latency of critical services in case of backhaul. This capability is useful for technical installations with various cables, such as the cable path along the antenna for the FH and for fiber access infrastructure between APN node and antenna location. Now dark fiber could be a scares resource. The first solution is to save space in the ducts or cable paths by using dense cable using reduced coating or cladding of "regular" single mode fiber. In a second step, multi-core fiber is a promising technology to achieve high-density cable.

5.3.3. Proposed Technologies for Low-cost Optical Nodes: Integrated Photonics ROADM

Current mobile fronthaul networks are static, based on point-to-point fiber links or chains of OADMs. This architecture starts suffering from scalability and dynamicity issues when different high-bandwidth time-sensitive services coexist and compete on the same infrastructure, sharing the same resources. Reconfigurability and automation, starting from the physical layer, are essential to exploit the potentiality of network function virtualization and software-defined networks. This is why ROADMs, today common in metro and long optical networks, are expected to be used in earlier aggregation stages, like the X-haul segment. For example, interfaced with a packet switch, a ROADM allows automatically allocating and configuring wavelengths to be bypassed since they carry traffic not to be processed locally. Moreover, ROADMs would relieve operators from installing and storing many fixed OADMs, each variant corresponding to a given set of wavelengths, by replacing them with a single reconfigurable device. Unfortunately, the ROADMs used in optical metro networks are based on expensive Wavelength Selective Switches (WSS). Silicon photonics is a promising integrated photonic technology to realize small size, low-cost ROADM that operates over the short distances of an X-Haul network. In these devices, the number of line ports is lower than the ROADMs used in metro networks: two-line ports are enough to operate over fibers rings, and an additional pair port can be added for interconnecting rings. Although no commercial device is yet available in the market, recently significant research advances indicate the absence of fundamental technology bottlenecks, which may make products available in a short time. Examples of system-on-chip ROADMs utilizing silicon micro-ring resonators (MRR) are reported in literature [P. Iovanna JOCN 2016 Issue 12], [V. Sorianello Opt 2016 Issue 24].

5.3.4. AI-based Transport Network Aware Orchestration

Since the traffic associated with a specific service changes in space and time over the deployment area, the corresponding assignment of the QoS parameters to the transport tunnels supporting a slice should be done dynamically with appropriate mechanisms. In most cases, however, the service traffic is, for its nature, dynamic and (partially) related to predictable situations or historical trends: time of the day, weekdays vs weekend, and similar conditions influencing the traffic load. AI-based, transport-aware slicing on in the service deployment area is relevant for guaranteeing QoS without waste of resources.

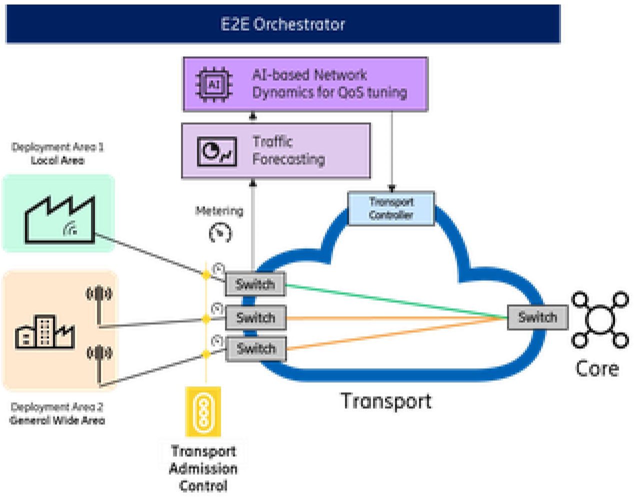


Figure 25 Main functional blocks of Slice Orchestration and QoS Tuning with AI

Moreover, since verticals could not know the required QoS parameters (e.g., PIR, CIR) to be assigned to the services in advance, they tend to overestimate the requested QoS. Thus, it is relevant to dynamically support the current needs and tuning slices' parameters accordingly.

To this end, the following main functional blocks are defined and shown in Figure 25. Please note that the figure shows an example of two services. The colors represent the logical connectivity in the transport domain from source (the antenna site) to the other site (e.g., a baseband site). They could be VLANs. The green color is linked to a service deployed in a confined area (i.e. just one antenna site in the figure), while the orange connections are linked to another service deployed in wide area (i.e. 2 antenna sites in the figure).

- **Transport Admission Control:** The traffic at the ingress of the transport network is regulated by a new Transport Admission Control (AC) mechanism, which is driven by an AI-based Network Dynamics (ND) control structure. The combined effect of these two functional elements is to dynamically redistribute the bandwidth of each slice and sub-slice (the one dedicated to the specific vertical service) among the virtual connections assigned to each sub-slice in the transport network. This avoids bandwidth over-allocation. The Transport AC is invoked in two main phases. The first one is when the slice for the E2E service is created to dynamically verify the availability of the transport resources before their configuration/placement. On the contrary, if resources are not available, the connection is rejected, and a notification is sent back to the originator or requester of the service. The second phase is deputed to limit QoS violation agreed in the SLA while the traffic of the service is transmitted.
- **The AI-based Network Dynamics (ND):** This takes care of allocating and optimizing performance and network resources for the different admitted services, deciding at runtime the best routing based on a transport snapshot and trends derived by the traffic forecasting previously defined. With QoS tuning, based on policy, a certain amount of bandwidth is assigned to each transport tunnel (e.g., Virtual Local Area Network (VLAN) / Virtual Private Network (VPN). Based on traffic prediction and measurements, the QoS parameters (Effective Bandwidth, PIR, CIR, Committed Burst Size (CBS)) are tuned according to actual needs.
- **Traffic forecasting:** This is done by acquiring data at the ingress points of the transport network through a traffic flow analyzer composed by a metering function deemed to measure at any time step (e.g., 10 minutes) each active connection, providing PIR, CIR, CBS and estimating the effective bandwidth. This data is integrated with the current network status and with information related to specific circumstances (time of the day, events…). The traffic forecasting engine, AI-based (Machine Learning) or statistical, determines traffic

trends and behaviors, with time, over the considered deployment area. The mechanism provides insights on the actual radio traffic conditions which could not be observed and understood otherwise.

5.3.5. Comparative TCO Analysis for Different 5G Fronthaul Networks

Centralization of baseband processing offers multiple benefits for operators, not only technological benefits such as better service deployment at the edge and the potential to utilize advanced technologies that require high processing power, but also equally financially beneficial drivers including reduced site rental fees and maintenance costs while enabling a path towards a vRAN architecture. Compared to D-RAN, C-RAN architectures introduce new stringent technical requirements, such as ultra-low latency, increased bandwidth, and more accurate synchronization. The design of these types of networks with these new stringent requirements involves a considerable amount of thought and reflection to include the multitude of different influencing vectors, such as the site location, the access technology availability, the power and cooling capabilities, amount of radio spectrum, and radio communication types.

To facilitate and develop network design strategies and architectures that will achieve the operator's business goals, this subsection provides guidance to operators regarding the possible choices based on the operators' agreed assumptions and roll-out plans. This subsection focuses on C-RAN deployments since they come with several design parameters, such as the number of antenna locations connected to the hub site, capacity, distance, and technical alternatives.

A. Passive WDM - This configuration is based on an all-passive, end-to-end connectivity and is illustrated in Figure 26, without optical amplification, dispersion compensation or optical-electrical-optical conversion (OEO). The colored optical transceivers insert directly into the RRU at the cell sites, and into the baseband unit at the Central Office hub and connect at a local un-powered outdoor cabinet to a passive Optical Multiplexer/Demultiplexer. WDM-based systems, including Coarse wavelength division multiplexing (CWDM), DWDM, and other more recent schemes such as Metro DWM (MWDM) are considered.

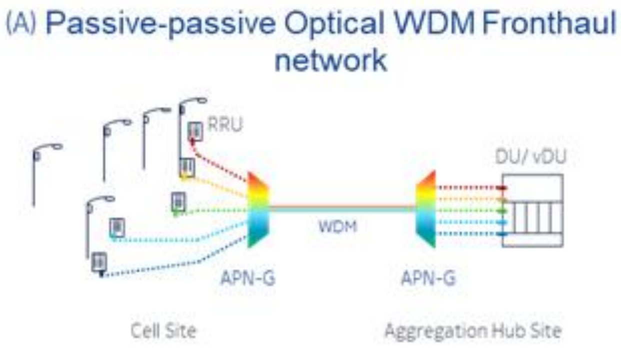


Figure 26 Passive-passive Optical WDM Fronthaul network architecture

B. Active-Active WDM – In this configuration, the RRUs connect using short-reach (SR) optics to the active network elements at the cell and central sites. The different Active-Active packet-based architectures considered, including (i) Packetized Transport with 100Gbps Grey optics in a cabinet Zero Foot Print (ZFP) form factor at Cell sites, equally Packetized Transport with 100Gbps DWDM optics (ii) with cabinet ZFP form factor. Apart from the Ethernet statistical multiplexing gains, further reduction of the transport capacity can be achieved by Ethernet packetizing the Common Public Radio Interface (CPRI) traffic [CPRI Specification] [IEEE 1914.3].

C. Active WDM Chains – In these Active WDM architectures a few ZFP cell sites are daisy-chained before the aggregated traffic is sent to the baseband (BB) Hub site. There are two solutions considered: (i) all connectivity is achieved via 100Gbps Grey optical interconnection Figure 27 (C), and (ii) the aggregated traffic is using 100Gbps DWDM towards to hub while the intra-cell site connections are via grey optics, Figure 27 (D).

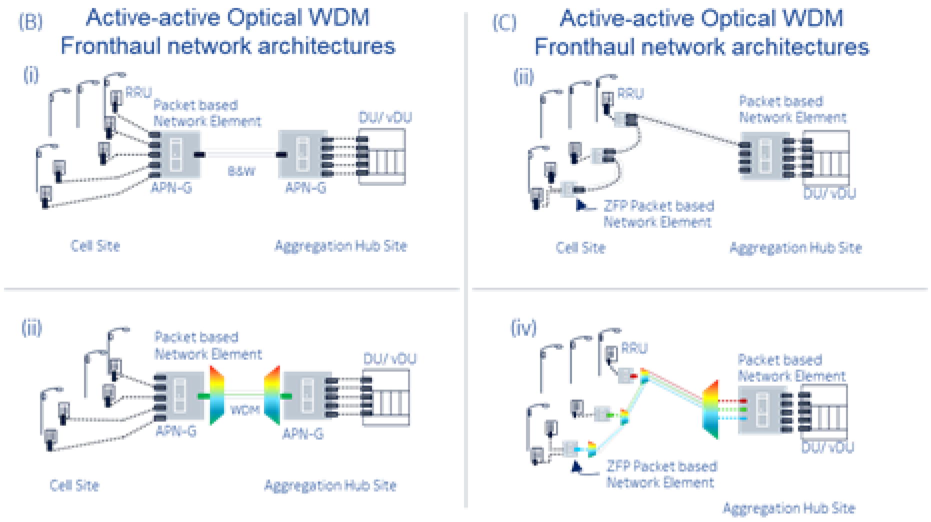


Figure 27 Fronthaul network for hub-and spoke and daisy-chaining active-active Optical WDM architectures

D Semi-Active WDM - The semi-active or hybrid WDM configuration is a simplification of the Active-Active WDM architecture and an enhancement of the Passive configuration; a passive WDM solution is deployed at the remote Cell site, with an active-Transparent WDM solution at the aggregation site.

(i) Semi-Active DWDM – This configuration uses a dedicated point-to-point fiber link from the cell to central sites by means of a band-channel hierarchy of filters to multiplex the DWDM channels from the transceivers plugged into the RUs. Channel filters, located at the cell site, multiplex all radio traffic at a particular cell site onto a single drop fiber, towards a passive Optical Data Network (ODN) cabinet where they are further multiplexed onto the ODN feeder fiber via an appropriate band filter (Figure 28).

(ii) WDM-PON – Based on the Semi-Active WDM configuration for a PON ODN infrastructure using DWDM transceivers in the RUs and connected to an Arrayed-Waveguide Grating (AWG) filter situated in a passive ODN cabinet by individual drop fibers. The configuration overlays new point-to-point wavelengths onto a deployed feeder section of an FTTH-ODN network without compromising the bandwidth of the existing fixed broadband services.

(iii) TDM-PON – This configuration uses ODN optical power splitters, where a single wavelength pair is used for up- and downstream traffic over a single fiber. An Optical Network Termination (ONT) with filters matching that wavelength pair is used at the RU side (ONT Small Form-factor Pluggable (SFP) on a stick). At the corresponding DU at the edge CO facilities an Optical Line Termination (OLT) is used with active-packet support for Lower Layer Split – fronthaul (LLS-FH) defined by [IEEE 802.1CM]. The versions of TDM-PON (>10Gbps) defined in [ITU-T G.9804] series, IEEE for 25G & 50GE PON and MSA [Multi-source Agreement] for 25GS-PON, as only these can meet the LLS-FH profile via new, innovative low-latency features, are considered.

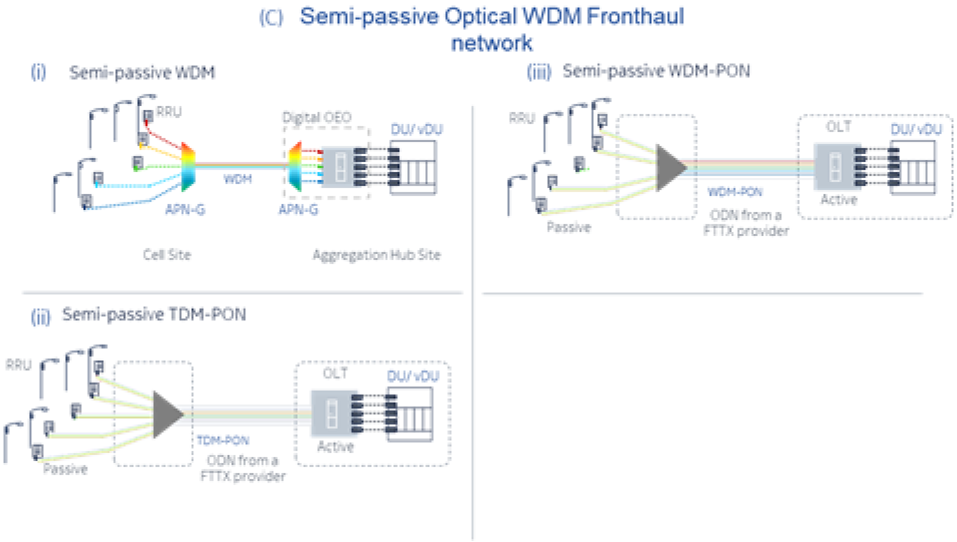


Figure 28 Fronthaul network for semi-active Optical WDM Fronthaul architectures

Sharing of the FTTH-PON infrastructure is considered using two models: Firstly, the Co-Exist (Shared) Model assumes that the 5G LLS FH traffic is wavelength-multiplexed onto the same feeder fiber carrying existing residential or Enterprise services via a WDM filter. The two traffic flows (FTTH and LLS-FH xHaul) are hard-isolated thanks to the standard wavelength plans for these TDM-PON. Here it is assumed that (i) all cost related to initial financing and buildout of the FTTH-ODN infrastructure have been already paid and (ii) additions of 5G FH traffic adds supplementary revenue to the FTTH-PON provider while incurring only the incremental operational costs of connecting and maintaining the new services. Secondly, the Dedicated Model that assumes that an entire feeder fiber is dedicated to 5G FH mobile traffic, and the entire average cost of fiber lease is assigned to the 5G mobile customer.

TDM-PON achieves sharing of a single optical fiber strand amongst many RUs – by using time-multiplexing into 25Gbps or 50Gbps oversubscribed channels using a dynamic scheduling allocation per timeslot (Dynamic Bandwidth Assignment (DBA)).

The O-RAN WG4 [O-RAN-WG4] defines category B type (CAT-B) of radio units RU that not only have compression options to reduce throughput but also have variable bitrates depending on user traffic flows using resource selection physical function in baseband. LLS-FH multiplexing gains based on a radio configuration of a mid-band urban macro-cell according to [Bidkar et al.] 4x4 Single-user MIMO (SU-MIMO), 100 MHz carrier bandwidth per sector and 30 kHz subcarrier spacing have been studied for the Cat-B. This study shows that the maximum possible data rate per sector peak for LLS-FH O-RAN split 7. 2x is around 6. 73 Gbps. However, the peak would be rarely reached, and thus is open to multiplexing gains by sharing the transported bandwidth.

Higher speed PON interfaces 10G for LLS-FH are currently being specified. These include 25GS-PON and 50G-PON that are available from standard organizations like IEEE, ITU-T SG15 and MSA 25GS-PON. These new higher speed PON HSP benefits from ODN co-existing with Gigabit. Ethernet PON (GPON) and XGS-PON [ITU-T G.9807.1]. Apart from the capacity requirements, the HSP Transmission Convergence TC-layer, [ITU-T G.9804.3] used by 50G-PON and the MSA 25GS-PON, also studies add-on low-latency functionalities, such as Quiet Window elimination according to [R. Bonk et al.] as an alternative ranging method, and increase of burst frequency per ONU (shorter gap between bursts).

The Total Cost of Ownership (TCO) study is based on O-RAN WG9 defined [DP(B1], [O-RAN X-haul] architectures. The total cost of ownership of key 5G C-RAN FH network architectures is evaluated and is based on packet and WDM technologies. Higher speed TDM-PON with other WDM architectures are compared for a selected network topology.

5.3.5.1. TCO Study Methodology

The TCO model study considers the hub & spoke network topology consisting of a number of clusters of cell sites, as illustrated in Figure 29, with the spokes connecting to a central aggregation Hub site over a 10km optical link. Each cell site contained a number of 4G and 5G Radios with CPRI and eCPRI interfaces [eCPRI Transport Network V1.1], respectively, with a user-configurable number and relative mix between the two protocols. The clusters were multiplexed at a local central point in a cabinet at each cluster.

Figure 29 Fronthaul network configuration for TDM

For both CAPEX and OPEX, each of the above-described topological and functional architectures, including items such as the component and/or equipment costs at Cell and Hub sites, and fiber leasing costs and remote site power, maintenance and cabinet costs, is calculated to provide a total solution cost per architecture. This is then normalized to a solution cost per Cell site by dividing by the number of Cell sites in the model.

To fully explore the possible C-RAN deployment space, the normalized solution cost per Cell site is calculated as a function of both (1) number of ports per Cell site and (2) number of Cell sites per Cluster. The results are further processed to select the lowest cost architecture at each of the points in this matrix and presented.

For the TDM part the following parameters are used

- Total number of Small Cell sites = 80
- Small Cell Cluster = number of SC sites that can be aggregated for transport to Hub
- Number of SC sites per Cluster.
- Each SC site has a number of Radios (ports)

5.3.5.2. TCO Study Results

Based on the cost and scale parameters from Table A- 1 and Table A- 2 (see Appendix A), the lowest cost architecture for each port count/Cell count per Cluster was derived and presented in Figure 30, with a color-code as shown in the legend on the lower right of Figure 30. This shows the lowest cost architectures for (A) Passive-only, (B) Active-only, and (C) All architectures.

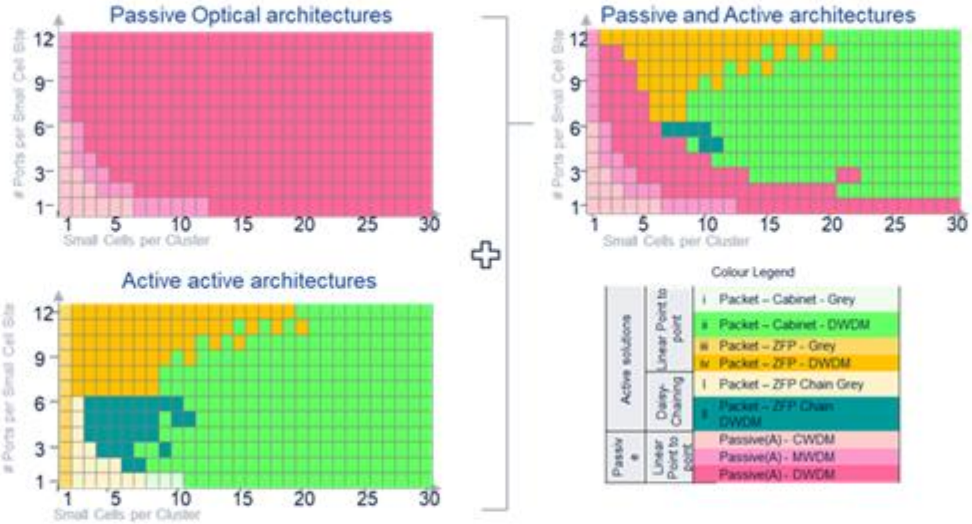


Figure 30 Lowest TCO Heat map for (A) Passive-only, (B) Active-only, (C) Passive and Active architectures

For the TDM-PON related TCO, the TDM-PON is considered as fully dedicated data rate for the LLS-FH services, i.e., no traffic mix with other high latency or low priority traffic, or other non-mobile services and the assigned data-rate is fully allocated to the LLS-FH. The Figure 31 below shows TCO relative to the Semi-Active DWDM scenario (aka WDM-PON).

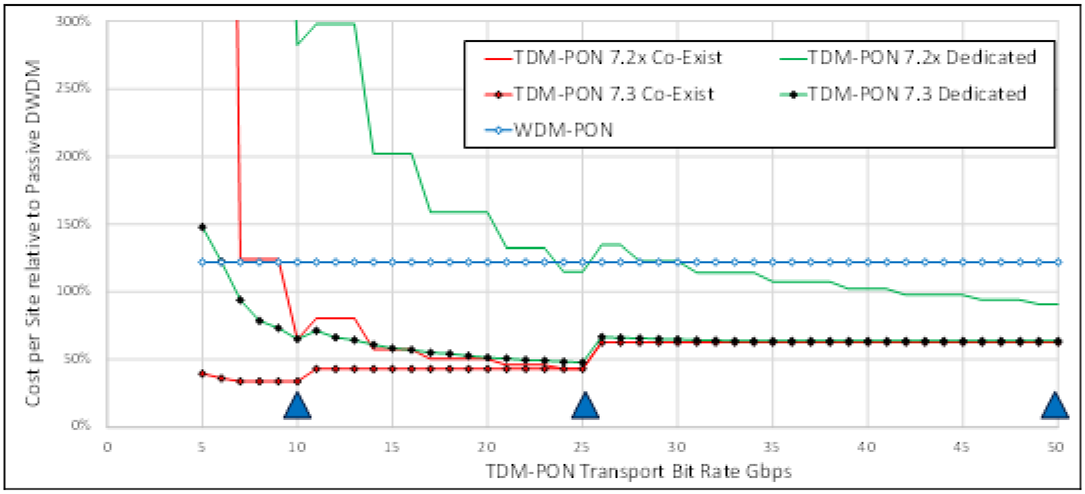


Figure 31 The TCO evolution relative to the Semi-Active DWDM case versus the TDM-PON transmission rate

While the graph shows a continuous variation of transport rate, the relevant practical cases are marked with a blue triangle (i) 10Gbps line rate XGS-PON, (ii) 25Gbps for symmetrical 25GS-PON by MSA 5 and (iii) 50Gbps symmetrical 50G-PON, which is still under definition by ITU-T for 50G upstream. For LLS-FH we included a bandwidth model for both the current O-RAN option 7. 2x as well as an alternative based on option 7. 3. Simulations are performed according to [Bidkar et al.]. The model also distinguishes a 100 dedicated ODN for LLS-FH no sharing of the fibers with other non-mobile, services and a model with a shared feeder fiber co-existing with other services very typical for a combination with FTTH deployed ODNs, including the same splitters.

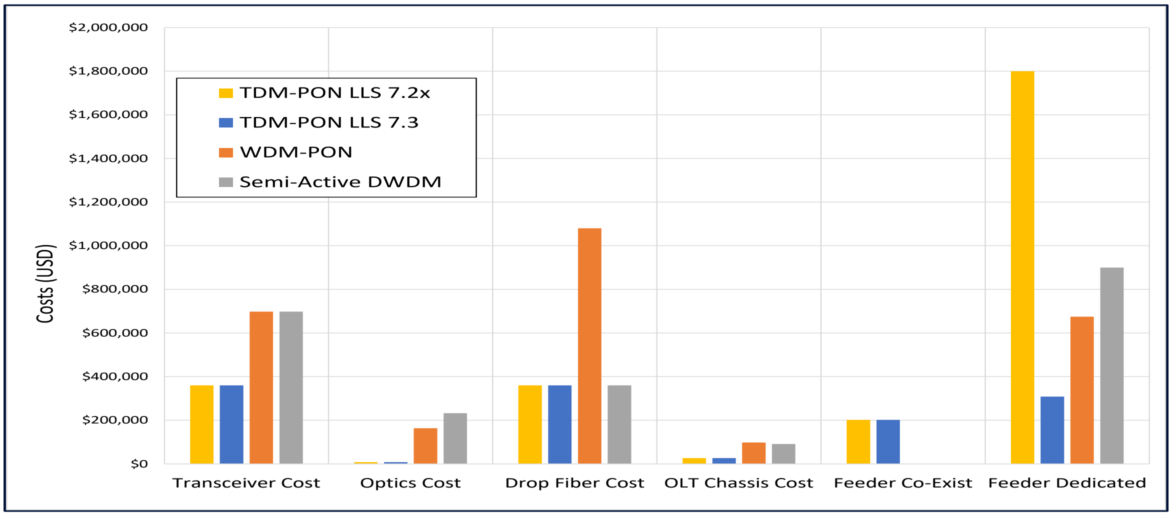


Figure 32 Cost decomposition for the main transport elements for various LLS-FH options with TDM-PON

Figure 32 shows a breakdown of the main transport cost blocks for the various LLS-FH options at a TDM-PON rate of 25Gbps and Carrier Spectral BW of 100MHz, 4-layer MIMO for LLS-FH splits 7.2x and 7.3.

Figure 33 shows the impact of the radio carrier bandwidth and MIMO layer count on the TCO for various options of a 25Gbps TDM-PON system, relative to the Semi-Active DWDM scenario. It shows the zone of applicability, and cost benefit, for the shared or dedicated TDM-PON solution as a function of the radio parameters.

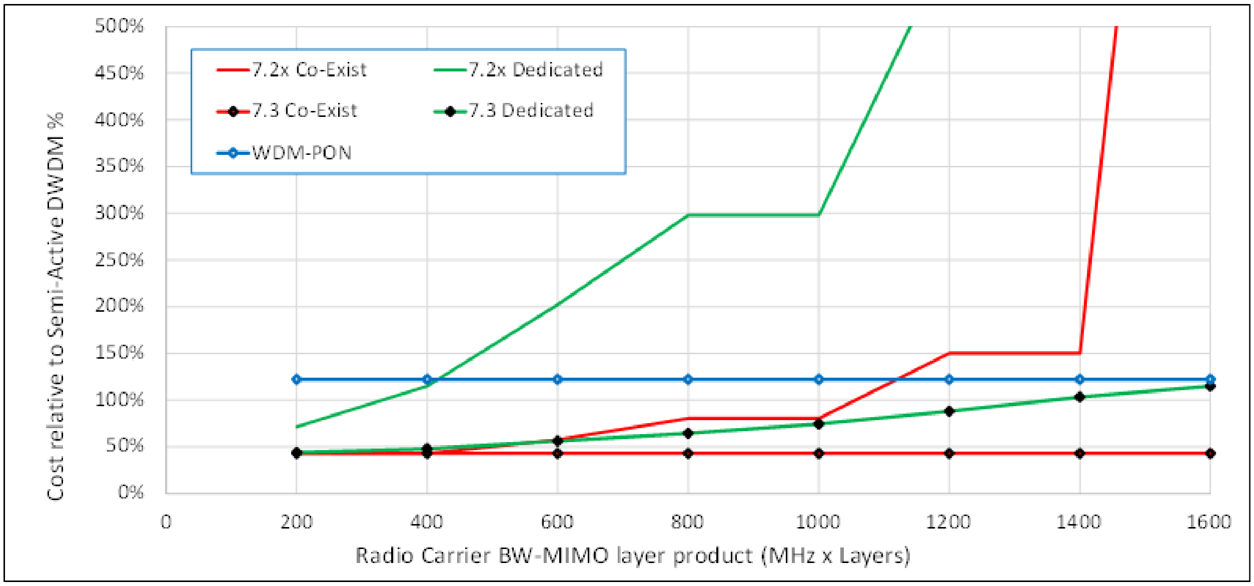


Figure 33 TCO relative to Semi-Active DWDM vs Radio BW x MIMO Layer product

5.3.5.3. TCO Study Conclusions

Various industry studies comparing the multiple FH architectures from a TCO perspective have shown that for the low number of cell clusters, and a low small cell interfaces needing to be aggregated to a centralized hub site, the passive only solutions are the lowest cost for CWDM, MWDM, and DWDM. This is directly related to the wavelength count in the fiber.

The benefits of the Active solutions are evident where the statistical multiplexing gain from a large number of cells can significantly reduce the transport bandwidth, and thus the cost. This result is not surprising given that the three WDM technologies have been deliberately developed by the industry to target this cost vs capacity trade-off. Once the number of ports per small cell site or the number of cell sites that need to be aggregated becomes more significant, then the active-active packet solutions have the lowest TCO. Furthermore, the burden of a powered location for the Active equipment can be significant and leads to a Passive or Semi-Active solution being more cost effective, especially when the number of Cells per cluster, and/or fiber lease costs are low. The WDM APN Point-to-multi-points (P2MP) architectures are furthermore complemented with a Semi-Active hybrid configuration, shared, over a FTTH PON ODN infrastructure, with a TDM-PON as LLS-FH transport. There are two additional aspects of interest in the TCO analysis, firstly the scenario of the co-existence or sharing on a P2MP ODN of the LLS-FH traffic with existing residential or Enterprise services, and secondly, the level of statistical multiplexing that can be achieved with a TDM-PON technology using the LLS-FH profile.

Figure 34 attempts to provide a general illustration of the discussion above, showing the regions of lowest TCO as a function of Cell site ports and cluster density.

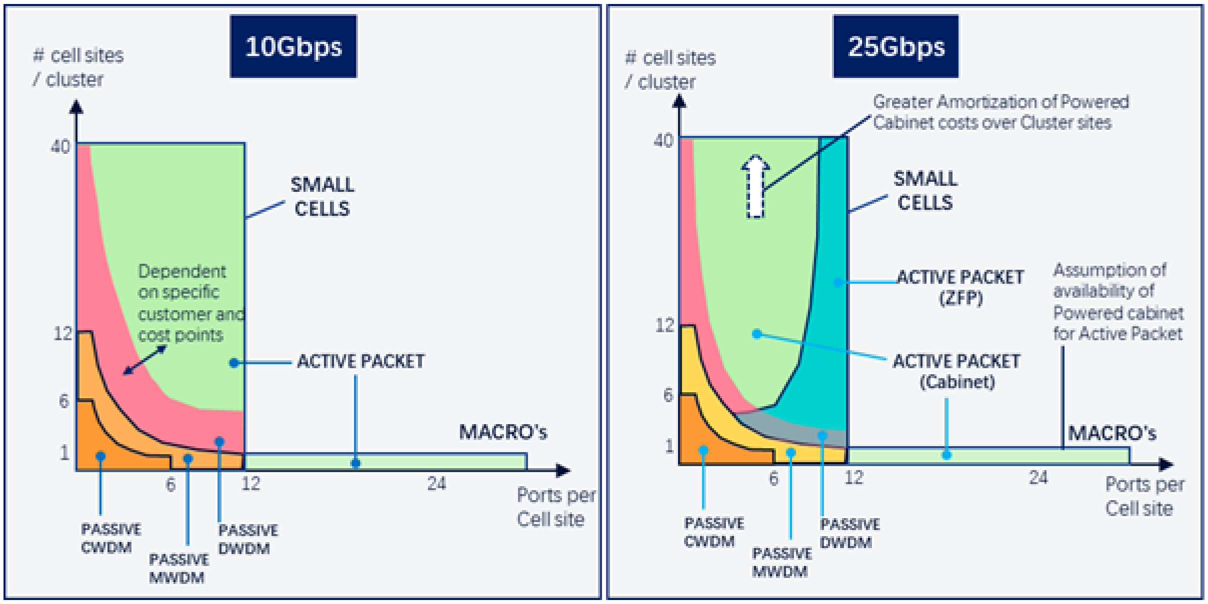


Figure 34 Active-active Packetized Fronthaul network architectures

5.4. Study Item 4 Cloud-native Network Function (CNF) Model with DCI

The Technical Outlook for Mobile Networks using IOWN Technology, IOWN GF [IMN], described virtual network functions (VNF) and CNF deployment. This document focuses on CNF deployment for 5G which advanced edge computing and 6G which will be used to advance the end-to-end computing capabilities. Since DPU/IPU officially releases to the market, DPU/IPU are changing the way enterprises and service providers deploy and manage compute resources across their networks; OPI is working to nurture an ecosystem to enable easy adoption of these innovative technologies. Based on the activity in OPI for DPU/IPU deployment, 5G/6G CNF deployment possibility is described in this document. This section describes the study item for the resource allocation method of cloud native function deployment models especially for 5G/6G RAN/MEC workloads co-existing with AIC/CPS use case workloads in the regional edge DCI subsystem. Section 5.4.1 describes the CNF-based mobile network architecture challenge and CNF deployment challenge for DPU/IPU-based logical service node hardware components. Section 5.4.2 describes mobility management by gNB Shared Memory Communication over RDMA which will be one of the possibilities for DCI.

Mobile Network Operators (MNOs) will often need to deliver mobile network service in the same regional edge DCI system, which is designed as a disaggregated computing architecture, in which CPS/AIC application providers need to analyze the end user’s payload data with accelerator functional cards such as a GPU. The right resources for compute, network, storage, and memory access need to be provided by the DCI system for each administrator managing each workload, such as 5G/6G Mobile FDN and CPS/AIC.

5.4.1. Mobile Network Architecture Challenge

5.4.1.1. Mobile User Plane Innovation

Core to the advancement and growth of the cloud native model is the ability to quickly and easily create and dispose of the compute resources required to power its services. Data Processing and Infrastructure Processing Units – DPU and IPU – bring this same type of flexibility to a DCI system because they can be configured to be instantiated in software rather than having to literally design and build a different server every time a different capability is needed. The software-defined DPU/ IPU can innovate the way service providers and CPS/AIC enterprises deploy and manage compute resources across the DCI system over an APN. An open-source community like OPI will nurture an ecosystem to enable the easy adoption of these innovative technologies. DPUs/IPUs can then be implemented as a LSN configured for a specific purpose on their own, running their own Linux OS for such 5G RAN and MEC to build a FDN in each network segment between RU and DU, DU and CU and CU and I-UPF, while host CPUs can implement separate LSNs for user workloads of various CPS/AIC use cases. The following figure (Figure 35) illustrates an example that can allocate computing resources in a flexible, cloud native manner (isolate/share) between service providers and CPS/AIC enterprises. There are some challenges. When DU, CU, I-UPF and AIC/CPS workloads are integrated into the DCI subsystem with multiple functional cards, many internal transactions will occur based on the current network protocol stack such as GPRS Tunnelling Protocol (GTP) decapsulation, etc. Further exploration of how to terminate User’s payload directly to the user's memory space of AIC/CPS user case such as AI/ML/Rendering is needed. There are several approaches that to reduce mobile network overhead by SRv6(Segment Routing IPv6 for mobile user plane) or to create data pipeline inside the programmable accelerator in DPU/IPU for service chaining between network and shared memory space or etc.

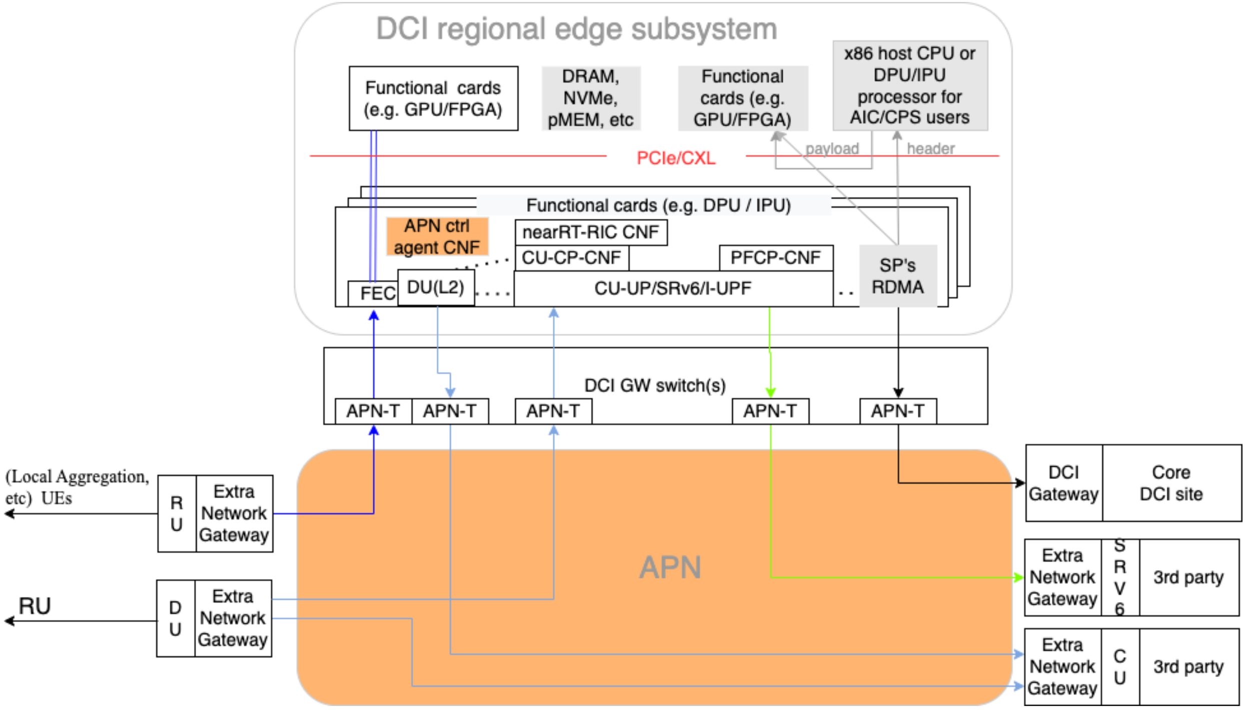


Figure 35 Example of resource isolation between MNO's LSN and other's LSN

In the computing industry, several memory access technologies such as Peer-to-Peer Direct Memory Access and CXL-based memory access are under development in the Linux kernel, in addition to RDMA. Other than DPU/IPU innovation, the memory access innovation may help to increase data velocity in DCI system for CPS/AIC use cases. DPU/IPU-based Logical Service Node for Mobile Function Dedicated Network will be able to become an intelligence front end processor for CPS/AIC use case workloads in DCI system.

5.4.1.2. DPU/IPU discovery and provisioning

DPU/IPU discovery and provisioning is also a challenge to compose vendor-agnostic, purpose-built logical service nodes in DCI for a Mobile Function Dedicated Network. There are several solutions to deploy DPU/IPU separately from the host CPU. The real challenge is how to deploy Network Function on multi-vendor DPU/IPU in a common provisioning method. Multi-vendor DPU/IPU deployment needs a common API, such as the one that OPI is developing called a shim layer API (Figure 36).

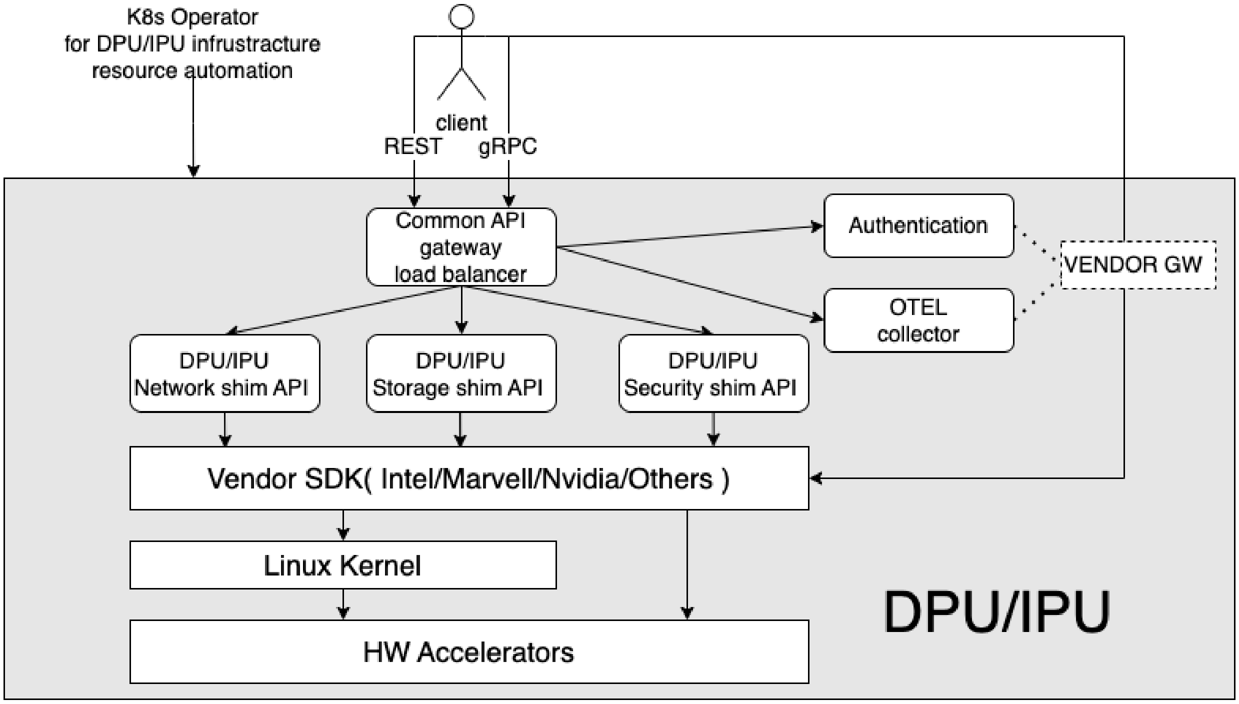


Figure 36 OPI API and Behavioral model

Such a common API for DPU/IPU, tiered deployment, and configuration methods can be designed such as follows. Through the infrastructure workload deployment procedure, an all-photonics path for each function dedicated network can be configured dynamically via APN controller/multi-orchestrator demanded from APN controller container agent. The APN controller container agent, such as a CTI client, runs in each DPU/IPU which knows to implement an FDN connection as needed (Figure 37).

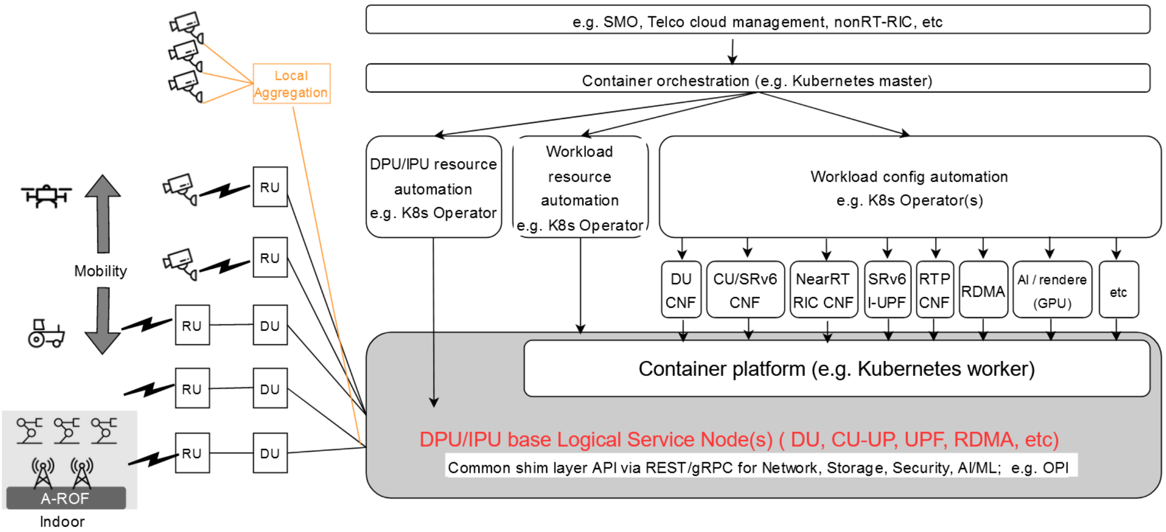


Figure 37 Multi-tiered deployment and configuration method

There are many open source software development activities, such as OPI in the above example, outside IOWN GF. In this study item, PoC such as DCIaaS and MFN-over-APN leveraging the latest open source upstream software code and latest hardware will be needed. The IOWN GF anticipates and will evaluate corresponding PoC reports that demonstrate best practices to support further consideration of DPU/IPU-based 5G/6G deployment methods in the DCI functional architecture document and future editions of Section 4 “Mobile Network and DCI.”

5.4.2. Mobility management by gNB Shared Memory Communication over RDMA

The IOWN Global Forum published a Proof of Concept (PoC) reference document for a Mobile Fronthaul Network over Open APN [IOWN GF PoC-MFH] that targets DU load balancing managed by RIC with the same anchor CU, which can maintain PDCP between CU and UE even though DU has been switched. The real challenge is CU-based load balancing in Mobile MH Networks between different cell groups. This is because when an anchor CU moves to another anchor CU, it cannot keep PDCP packet without data replication. This solution is fast data replication or handover with shared memory communication by RDMA over a long distance Open APN between two different CUs(gNB) located at different sites (Figure 38). This helps mobility management and reliable communication.

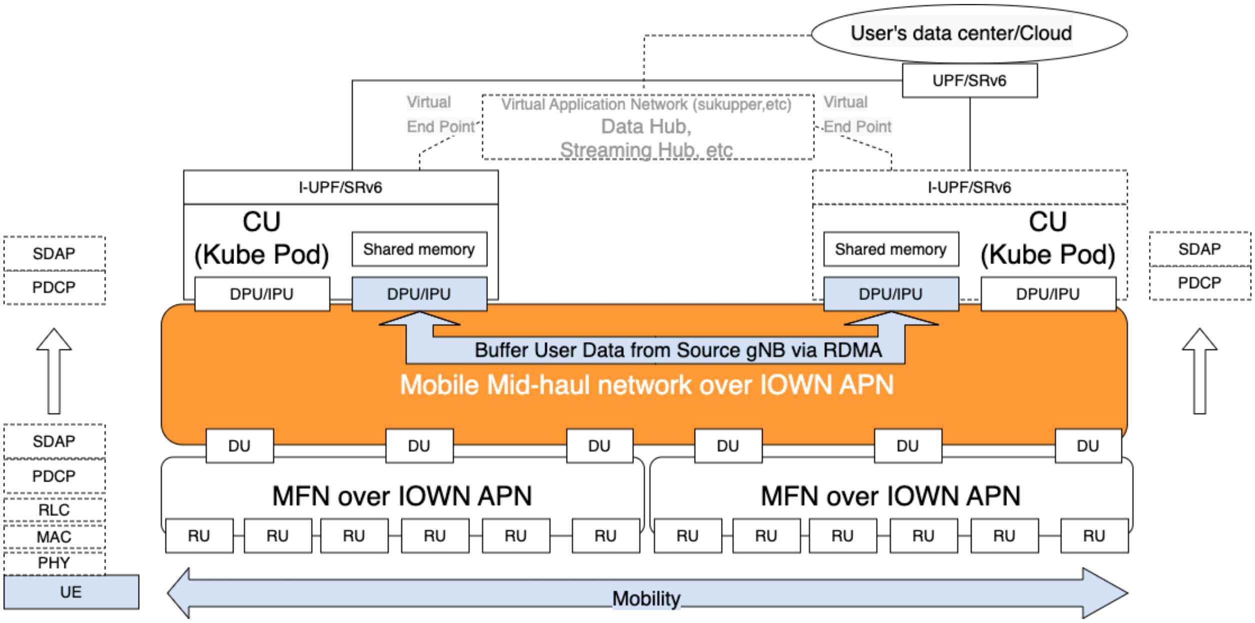


Figure 38 Shared Memory Communications over RDMA between two gNBs

Mobility management use case

In the mobility management use case, RDMA over APN helps facilitate the UPF and DAPS handover procedure that maintains the source gNB connection after reception of a RRC message for handover, and until releasing the source cell after successful random access to the target gNB. In the following RDMA implementation sequence procedure (Figure 39), the source gNB shares Buffer User Data from source gNB to targeted gNB with RDMA (memory access latency) over a long-distance APN (distance latency) without processor delay of packet networking.

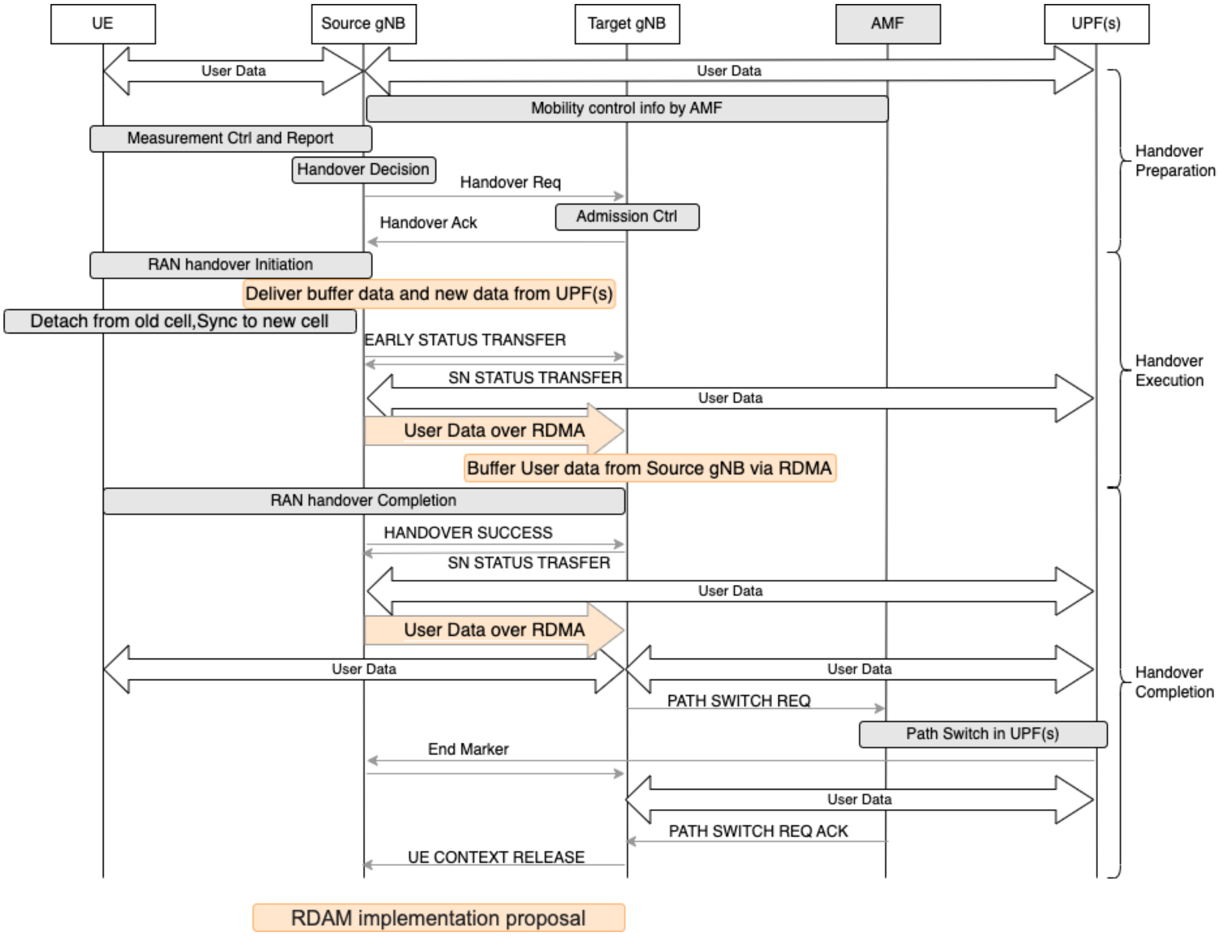


Figure 39 UE handover procedure

5.5. Study Item 5 Time Sensitive Network (TSN) over APN in Mobile Network

5.5.1. Introduction

5.5.1.1. Applicability of TSN Over APN in Mobile Networks

Since the dawn of the 5G era, TSN technology has been increasingly deployed on packet switches in mobile fronthaul networks to meet stringent Hybrid Automatic Repeat reQuest (HARQ) criteria. Towards 2030, it is expected that low-latency services will be increasingly available, and TSN technology will be widely deployed to leverage beyond-human response speed, thus enabling paradigm shifts in smart and connected world applications.

In mobile networks, as shown in Figure 40, cell sites, edge Central Office (CO) sites located in the edge cloud, regional CO sites located in the regional cloud, and Mobile Switching Centers (MSCs) are physically connected through the APN. In addition, logical connections among RAN components such as O-RAN radio units (O-RUs), O-RAN distributed units (O-DUs), and O-RAN Central Units (O-CUs), and UPFs will be provided using packet switches to encourage network slicing. The TSN technologies are expected to be deployed to enable deterministic low-latency connection among possibly virtualized RAN components and UPFs implemented across multiple servers.

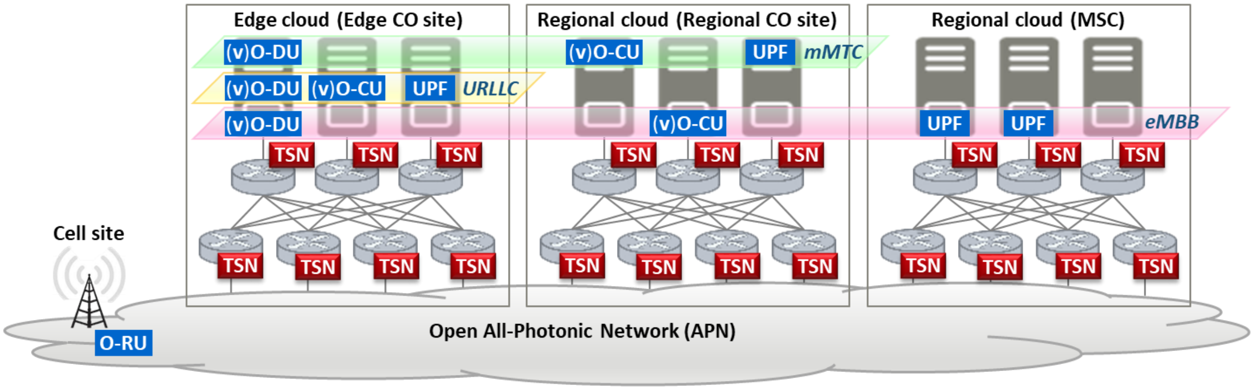


Figure 40 Mobile networks with TSN-enabled packet switches for network slicing

5.5.1.2. Scope of the Study on TSN Technologies

The IEEE 802.1 TSN WG has studied several base technologies for realizing low latency. For an example, Frame Preemption is an approach to reduce the latency of high-priority packets by interrupting any ongoing transmission of a low-priority packet and transmitting one or more high-priority packets before transmission of the low-priority packet is resumed.

In the Time-Aware Shaper (TAS), gates are provided at the exits of up to eight class queues, and Open/Close is controlled by a Gate Control List (GCL). The delay's upper limit can be guaranteed since the bandwidth can be allocated in a time-division manner. Moreover, if the timing of the gate opening can be matched with the timing of the packet arrival, the ultra-low delay similar to the preemption can be realized.

On the other hand, for this accurate control of the GCL, today's TAS requires sensitive GCL setting and precise time synchronization. For the broad availability of TAS technology to succeed, autonomous management of this procedure will be desired. Also, it is desired to further optimize the bandwidth utilization efficiency in TAS.

The scope of this study item focuses on the following [IMN]:

- Investigations on technologies enabling autonomous GCL setting for TAS without precise time synchronization, including:
    - feasibility assessment of each of the candidate technologies
    - applicability of each of them to the IOWN Global Forum Mobile Networks operating over the Open APN infrastructure, and
    - comparison among them with considering their pros and cons from usability, performance, CAPEX, and OPEX perspectives, in addition to the feasibility and applicability perspectives
- Investigations on technologies enabling optimization of the bandwidth utilization efficiency in TAS, including:
    - feasibility assessment of each of the candidate technologies,
    - applicability of each of them to the mobile networks operating over IOWN Global Forum's Open APN infrastructure, and
    - comparison among them with considering their pros and cons from efficiency, performance, CAPEX, and OPEX perspectives, in addition to the feasibility and applicability perspectives

5.5.2. Investigation of Technologies Enabling Autonomous GCL Configuration for TAS

5.5.2.1. Available Technologies and Related Solutions

As described in [L. Zhao IEEE/AIAA DASC 2018] and other publications, TAS generally requires a static off-line time slot setting for each switch. This means that full synchronization among devices, including the source end system, is required. Time synchronization across the entire network is essential, and a design that takes into consideration all relevant information, such as the period (interval), data amount, phase of transmitted data, propagation delay of each optical fiber, and processing delay in each switch on the end-to-end data path, is required. In addition, when a failure occurs, it is almost impossible to recover quickly since each switch setting must be reconfigured from scratch. While this may be acceptable for closed networks with simple topologies and a small number of nodes, like small industrial automation (IA) networks, such requirements may not be acceptable for large or complicated networks such as telecom networks.

On the other hand, as described in [S. Chouksey IEEE CCWC 2021], a unified method for configuring all devices and automating the configuration has not yet been developed. A few suggestions on how to automate configuration have been found. The outline and features of them are described in Appendix B.1., and their feasibility and applicability to the IOWN Global Forum Mobile Networks operating over the Open APN infrastructure, and pros and cons from usability, performance, CAPEX, and OPEX perspectives are assessed into 5 grades by TSN experts.

5.5.2.2. Proposed Technologies

The evaluated scores assessed in Appendix B.1 are summarized in the following table (Table 4).

Table 4 Evaluation results of available technologies enabling autonomous GCL configuration for TAS

Technology / Approach	Ontology-based Plug-and-Play	Window-Based Schedule Synthesis	Intelligent TAS (iTAS)
Feasibility	4 (Very Good)	4 (Very Good)	5 (Excellent)
Applicability to IOWN GF	2 (Average)	4 (Very Good)	4 (Very Good)
Usability	5 (Excellent)	2 (Average)	5 (Excellent)
Automation Performance	5 (Excellent)	2 (Average)	4 (Very Good)
CAPEX	3 (Good)	2 (Average)	5 (Excellent)
OPEX	4 (Very Good)	2 (Average)	4 (Very Good)
Total Score	23	16	27
Sub-section	Appendix B.1.1.	Appendix B.1.2.	Appendix B.1.3.
Reference	[M. H. Farzaneh IEEE IEMCON 2016]	[N. Reusch IEEE WFCS 2020]	[K. Nishimura IEICE CS2017-8] [K. Nishimura IEICE J103–B no.12 2020]

It is recommended that the Mobile Network of IOWN GF adopts intelligent TAS (iTAS) as a technology enabling autonomous GCL configuration for TAS GCL setting over APN, since its total score of the technology evaluation is the highest in the three possible candidates and it is the only technology which can greatly reduce the configuration burden for TAS GCL settings without requiring the precise time synchronization. The minimum performance requirements for autonomous GCL setting for TAS using iTAS and supplemental functions (if any) which are required for the IOWN Global Forum Mobile Networks operating over the Open APN infrastructure will be specified by the further work on this study item.

5.5.3. Investigation of Technologies Enabling Optimization of Bandwidth Utilization Efficiency in TAS

5.5.3.1. Available Technologies

TAS is a technology that can guarantee deterministic communication by ensuring resources can be utilized exclusively to a specific class using GCL within a predetermined time slot. However, even if there is no traffic of a particular class, the monopolization state is maintained, which may cause a decrease in the overall throughput. Focusing on this point, the outline and features of methods for improving bandwidth utilization efficiency are described in Appendix B.2., including their feasibility and applicability to the IOWN Global Forum Mobile Networks operating over the Open APN infrastructure. The pros and cons from usability, bandwidth utilization efficiency, low latency performance, CAPEX, and OPEX perspectives are assessed into 5 grades by TSN experts.

5.5.3.2. Proposed Technologies

The evaluated scores assessed in Appendix B.2 are summarized in the following table (Table 5).

Table 5 Evaluation results of available technologies enabling optimization of bandwidth utilization efficiency in TAS

Technology / Approach	Adaptive Bandwidth Sharing (ABS)	Gate-Shrunk TAS (GS-TAS)
Feasibility	3 (Good)	4 (Very Good)
Applicability to IOWN GF	3 (Good)	4 (Very Good)
Usability	5 (Excellent)	5 (Excellent)
Performance (Bandwidth Utilization Efficiency)	5 (Excellent)	4 (Very Good)
Performance (Low Latency)	2 (Average)	5 (Excellent)
CAPEX	4 (Very Good)	4 (Very Good)
OPEX	4 (Very Good)	4 (Very Good)
Total Score	26	30
Sub-section	Appendix B.2.1.	Appendix B.2.2.
Reference	[A. Nasrallah IEEE Access (vol.7)]	[N. Shibata JOCN 2021]

The Mobile Network of IOWN GF can adopt Gate-Shrunk TAS (GS-TAS) as a technology enabling optimization of bandwidth utilization efficiency in TAS over APN, since its total score of the technology evaluation is the highest of the two possible candidates and it is the only technology which can guarantee the latency of the high priority traffic. The minimum performance requirements for the optimization of TAS bandwidth utilization using GS-TAS and supplemental functions (if any) which are required for the IOWN Global Forum Mobile Networks operating over the Open APN infrastructure will be specified by the further work on this study item.

5.6. Study Item 6 – Extreme Low Latency Network over APN in Mobile Network

For extreme low latency, an approximately 1 ms or less end-to-end latency is considered as the target value with 0.1 ms for the air interface. This decrease in latency started for 4G and 5G operations with typical end-to-end latency from around 40 ms to <10 ms. The existing switch, router and OLT one-way latency is about 10 µs by considering an Ethernet traffic flow through the uplink port, electrical backplane, and PtP line port. In addition, it needs to be considered that the transmission latency is about 5 µs/km. In the first approximation, it is considered that the last mile network segment (20 km) consumes about 110 µs one-way latency for 20km reach.

The first way to decrease end-to-end latency and to exploit the gain of centralization, is to place UPF and MEC that brings the services closer to the mobile customers, at the APN node and DCI. Now, to decrease the latency contribution of optical equipment and fiber infrastructure, new photonic technologies are to be considered for the APN node and for the optical fiber. The APN node could have a photonic layer with optical switching capabilities to bypass the latency and jitter of electrical switching. APN nodes could manage optical circuits for its backplane and optical access links. In other words, an APN node could provide an express path with an all- optical link between the equipment localized at the antenna and the server port hosting MEC and RAN functions. Secondly, for the fiber infrastructure, the one way to reduce latency is to use hollow core fiber which can reduce transmission latency to 3.3 µs/km. In total, these photonic innovations allow to target a latency contribution from the segment of optical access network about 67 µs for 20 km reach.

6. Recommendation

The deployment of 5G networks and the prospecting of 6G applications drives the evolution of transport networks serving the mobile communications network. The IOWN GF's innovative Open APN and DCI architectures aim to enable a "quantum leap" of network performance, realizing diversified use cases envisioned by IOWN GF Use Cases.

For 6G to achieve the projected 10-100 times improvement of KPIs compared with 5G and support more complex and challenging use cases, the following actions are recommended:

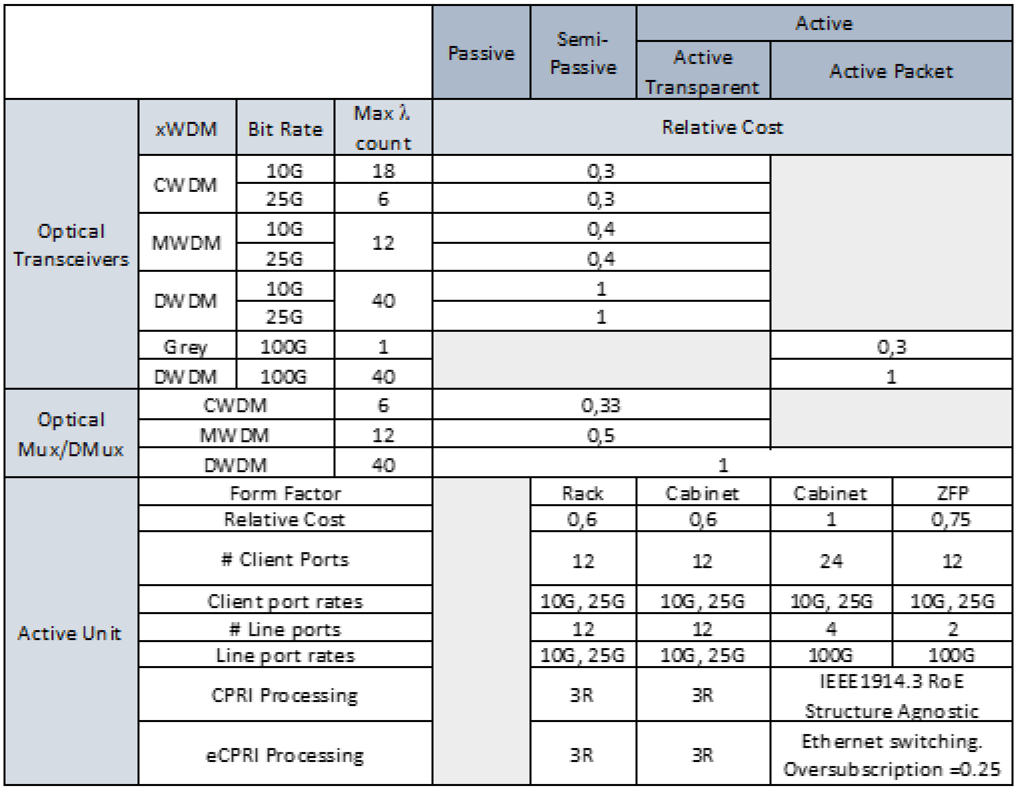
- Promote PoC over mobile transport network utilizing Open APN and DCI to validate IOWN GF technologies' benefits
- Promote PoC to support further considerations of DPU/IPU based 5G/6G deployment method
- The passive only for CWDM, MWDM and DWDM fronthaul solutions for the low number of cell clusters, and small cells and the active fronthaul solutions for sites with a large number of cells
    - revisit the TCO with possible newer architectures and take augmented 6G radios into account
- Adopt Gate-Shrunk TAS (GS-TAS) as a technology enabling optimization of bandwidth utilization efficiency in TAS over APN
- Adopt cloud-native architecture to deliver agile, resilient, flexible, and scalable services
- Harmonization of orchestration, assurance, and ML/AI from E2E perspective to be fully dynamic and automatic for each specific vertical service
- Global standards including open interfaces in FH/MH/BH to embrace open network architecture
    - Specify Interface between APN controller and resource management of other network elements or Kubernetes master (with Kubernetes operator in O-Cloud)
- Enhance and extend performance improvement features, such as eCTI, TSN, between mobile networks and APN
- E2E QoS such as deterministic latency and reliability needs to be applied to all elements of infrastructure, including radio, transport, and cloud
- Technologies developed by IOWN Global Forum need to support:
    - enabling a smooth and economically viable path to evolving current FH/MH/BH architectures with different network sizes to Open APN
    - autonomous setting of parameters to optimize bandwidth utilization efficiency
    - AI based mechanisms that allow tight QoS support without consuming unnecessary network resources
    - commercialize integrated photonic technology to realize small size, low-cost ROADM that operates over the short distances of an X-Haul network
    - elastically deployment of workloads by AI application owner across Mobile Edge/5G RAN, Regional Edge, Mobile Core, and center cloud in a scalable manner
    - accelerating conversion from electrical to optical components to improve energy efficiency
    - integration between electronics and photonics in on-board and co-packaged components

Appendix A: Model Parameters for Comparative TCO Analysis

A.1 Cost Model Parameters

Table A- 1 summarizes the cell site and hub site parameters per architecture with relative costs for Optical Transceivers (normalized to the DWDM Transceiver costs), Optical Mux/DeMux and Active Units.

Table A- 1 Model cost and equipment assumptions



				Passive	Semi-Passive	Active		
						Active Transparent	Active Packet	
Optical Transceivers	xWDM	Bit Rate	Max λ count	Relative Cost				
	CWDM	10G	18	0,3				
		25G	6	0,3				
	MWDM	10G	12	0,4				
		25G		0,4				
	DWDM	10G	40	1				
		25G		1				
	Grey	100G	1				0,3	
	DWDM	100G	40				1	
Optical Mux/DMux	CWDM		6	0,33				
	MWDM		12	0,5				
	DWDM		40	1				
Active Unit	Form Factor				Rack	Cabinet	Cabinet	ZFP
	Relative Cost				0,6	0,6	1	0,75
	# Client Ports				12	12	24	12
	Client port rates				10G, 25G	10G, 25G	10G, 25G	10G, 25G
	# Line ports				12	12	4	2
	Line port rates				10G, 25G	10G, 25G	100G	100G
	CPRI Processing				3R	3R	IEEE1914.3 RoE Structure Agnostic	
	eCPRI Processing				3R	3R	Ethernet switching. Oversubscription =0.25	

Notes and remarks on the cost assumptions:

(1) The aim is to demonstrate a framework for comparing the various Fronthaul transport technologies and how they may be easily visualized. The absolute cost points would be expected to vary from one user to another, so there is no universal result for all customers.

The following cost points are assumed:

- 10km DWDM → X
- 10km CWDM → Y
- 10km MWDM → Z

The relative costs of CWDM and MWDM compared to DWDM are therefore, as indicated in below:

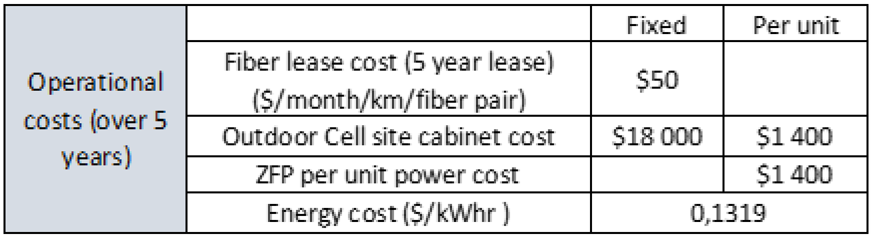
(2) The 10G Transceiver costs is normalized to the 10G DWDM cost, and independently, the 25G Transceiver costs to the 25G DWDM Transceiver cost.

- 10G CWDM relative cost; Absolute 10G CWDM cost / Absolute 10G DWDM cost
- 10G MWDM relative cost; Absolute 10G MWDM cost / Absolute 10G DWDM cost
- 10G DWDM relative cost; Absolute 10G DWDM cost / Absolute 10G DWDM cost = 1
- 25G CWDM relative cost; Absolute 25G CWDM cost / Absolute 25G DWDM cost
- 25G CWDM relative cost; Absolute 25G CWDM cost / Absolute 25G DWDM cost
- 25G CWDM relative cost; Absolute 25G CWDM cost / Absolute 25G DWDM cost = 1

Therefore, the fact that both the 10G and 25G DWDM relative costs are 1, is due to the fact that they are normalized to different values.

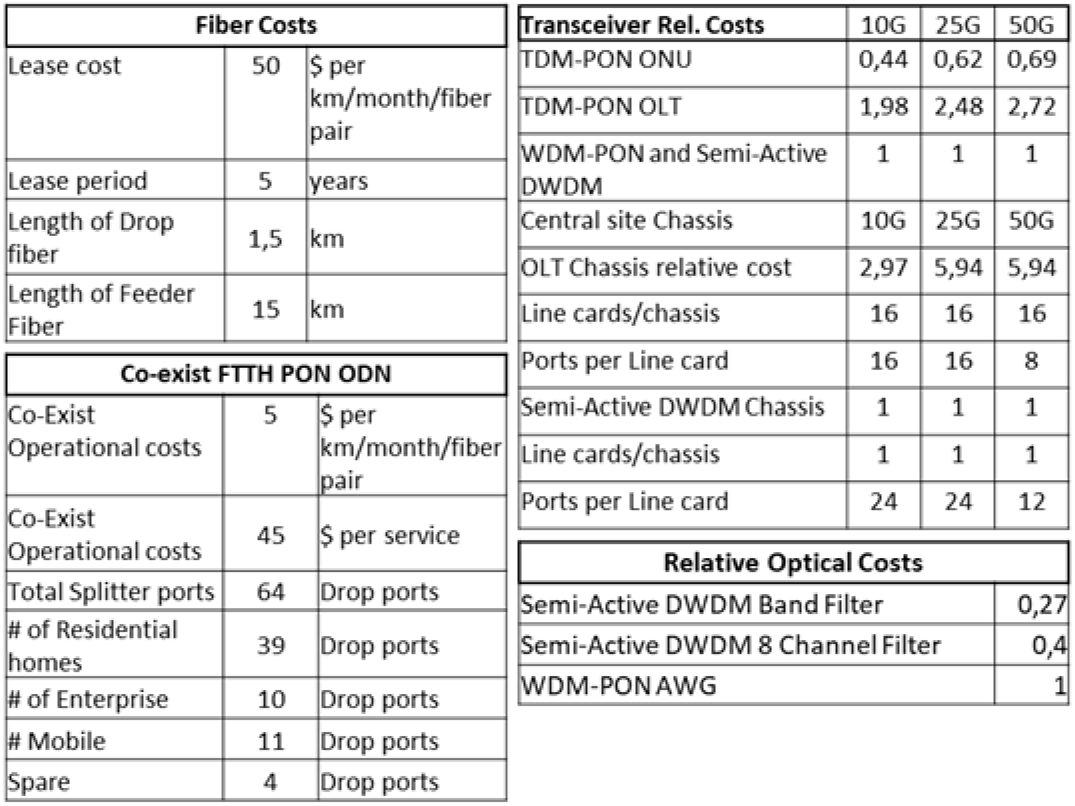
The operational cost assumptions over a 5-year period are provided in Table A- 2. Outdoor cabinet costs include site licenses, equipment (fans, battery backup, etc.), and maintenance with an average energy cost of 0.1319 $/kWhr.

Table A- 2 Operational cost assumptions



		Fixed	Per unit
Operational costs (over 5 years)	Fiber lease cost (5 year lease) ($/month/km/fiber pair)	$50	
	Outdoor Cell site cabinet cost	$18 000	$1 400
	ZFP per unit power cost		$1 400
	Energy cost ($/kWhr)	0,1319	

Table A- 3 Model cost and equipment assumptions



Fiber Costs		
Lease cost	50	$ per km/month/fiber pair
Lease period	5	years
Length of Drop fiber	1,5	km
Length of Feeder Fiber	15	km

Co-exist FTTH PON ODN		
Co-Exist Operational costs	5	$ per km/month/fiber pair
Co-Exist Operational costs	45	$ per service
Total Splitter ports	64	Drop ports
# of Residential homes	39	Drop ports
# of Enterprise	10	Drop ports
# Mobile	11	Drop ports
Spare	4	Drop ports

Transceiver Rel. Costs	10G	25G	50G
TDM-PON ONU	0,44	0,62	0,69
TDM-PON OLT	1,98	2,48	2,72
WDM-PON and Semi-Active DWDM	1	1	1
Central site Chassis	10G	25G	50G
OLT Chassis relative cost	2,97	5,94	5,94
Line cards/chassis	16	16	16
Ports per Line card	16	16	8
Semi-Active DWDM Chassis	1	1	1
Line cards/chassis	1	1	1
Ports per Line card	24	24	12

Relative Optical Costs	
Semi-Active DWDM Band Filter	0,27
Semi-Active DWDM 8 Channel Filter	0,4
WDM-PON AWG	1

A.2 Study Assumptions

Table A- 3 lists the cost assumptions for the three scenarios. The Dedicated TCO Model has the full fiber lease cost assigned to it, while the Shared TCO Model has a fixed operational cost per fiber (10% of the lease cost) + a cost per service connection. These values are operator-dependent and input variables to the model.

Appendix B: Study Item 5 Time Sensitive Network (TSN) over APN in Mobile Network

B.1 Available Technologies Enabling Autonomous GCL Configuration for TAS

B.1.1. An Ontology-based Plug-and-Play Approach for In-vehicle Time-Sensitive Networking (TSN)

[Overview]

An ontology-based approach is proposed to improve the automatic network configuration and plug-and-play support for TSNs [M. H. Farzaneh IEEE IEMCON 2016]. When an application device is connected, the application manager analyzes the location of the device to be connected and the requirements of each application and updates the TSN knowledge database. When a communication request actually comes from the device, the TSN manager loads the knowledge database and issues TSN configuration commands to the switch along the end-to-end path. Requirements and characteristics are made into a database (DB), and the TSN setting is automated in the management plane.

[Evaluation] 5-grade evaluation (5: Excellent, 4: Very Good, 3: Good, 2: Average, 1: Poor)

- Feasibility: 4

This method is applicable to in-vehicle networks. The implementation is relatively easy because the characteristics of the application are clear.

- Applicability to IOWN GF: 2

When it is applied to a general network such as the IOWN GF's APN, concerns remain about scalability, such as whether all application patterns can be made into a DB. Further, since the method spans the entire network construction, including the controller, there is a possibility that the system becomes complicated.

- Usability: 5

Since the application manager and the TSN manager perform autonomous operation according to the flow, the user basically does nothing, and usability is high.

- Automation Performance: 5

The entire network is made into a knowledge DB, and the GCL is set or changed via the management plane every time a communication request comes in, so it can theoretically be fully automated.

- CAPEX: 3

It is necessary to construct a system that spans the entire network. In addition, each end terminal must be a device that can cope with this system.

- OPEX: 4

The amount of operator's work, such as timing setting associated with addition, change, and deletion of the guaranteed low latency service can be greatly reduced by automation. Once the system is built, the configuration for the TSN is basically done automatically, so the operating cost is not expected to be very high.

B.1.2. Window-Based Schedule Synthesis for Industrial IEEE 802.1Qbv-based TSN Networks

[Overview]

When flexibility of the TAS configuration is increased, timing overlap of high-priority flows may occur. A scheduling algorithm based on the GCL iterative optimization that satisfies the delay requirement of the flow in such cases is proposed [N. Reusch IEEE WFCS 2020]. The initial solution is found by a heuristic method, and if the delay requirement of each flow is not satisfied, the optimization of the GCL setting is automatically repeated.

[Evaluation] 5-grade evaluation (5: Excellent, 4: Very Good, 3: Good, 2: Average, 1: Poor)

- Feasibility: 4

Evaluation by simulation is also shown, and the proposed scheduling algorithm is considered to be logically feasible.

- Applicability to IOWN GF: 4

It can be applied as a flexible bridge which multiplexes services. However, there are concerns that not all cases can be optimized.

- Usability: 2

The initial solution should be derived heuristically. Therefore, it is necessary to grasp the requirements of all flows beforehand, and usability is low.

- Automation Performance: 2

While the optimization based on the initial solution is autonomously carried out in the algorithm base, it seems to be the work of the operator to grasp the requirement of all flows and to derive the initial solution. Since the entire network is made into a knowledge DB and the GCL is set or changed via the management plane every time a communication request comes in, it can theoretically be fully automated.

- CAPEX: 2

The equipment cost seems to be not greatly different from conventional switches.

- OPEX: 2

Since the automation is applied limitedly, the effect of reducing operational cost is also limited. Further, when the traffic pattern is changed upon an increase or decrease in the number of communication devices and so on, the initial solution derivation is repeated, and it requires additional significant operational cost.

B.1.3. Low-Latency Switching Technology Using Autonomous Learning for 5G Network (Intelligent TAS: iTAS)

[Overview]

A method for autonomously constructing, correcting, and optimizing a GCL by autonomously learning a period, a bandwidth (burst amount) and a phase of traffic by a packet switch itself is proposed [K. Nishimura IEICE CS2017-8] [K. Nishimura IEICE J103–B no.12 2020]. Phase deviation due to clock deviation between devices such as a data source and a switch or a switch and another switch is also detected to autonomously correct the open/close time slot of the GCL (Figure B-1). Thus, even in a network without time synchronization, the TAS function can be realized.

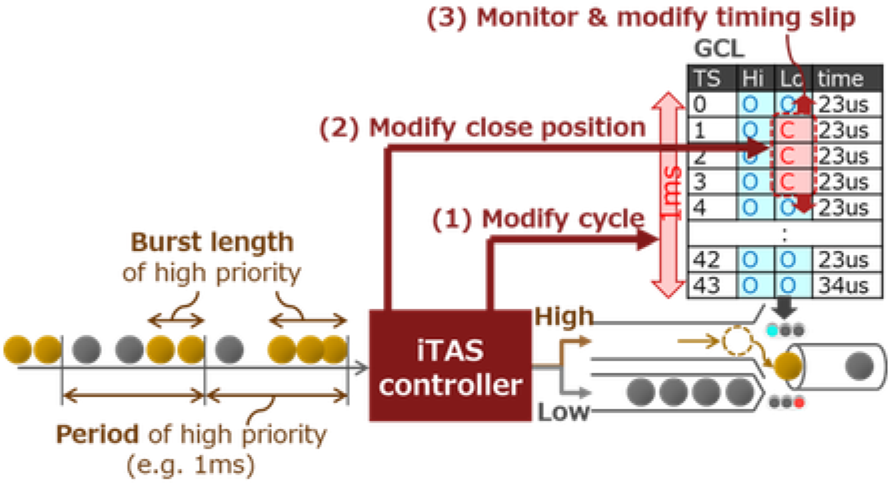


Figure B- 1 Automatic GCL setting Technology based on Autonomous Learning by Intelligent TAS (iTAS)

[Evaluation] 5-grade evaluation (5: Excellent, 4: Very Good, 3: Good, 2: Average, 1: Poor)

- Feasibility: 5

The construction is simple such as grasping the presence/absence of traffic by periodic packet counter reading. Since the prototype using FPGA is also shown, the feasibility is high.

- Applicability to IOWN GF: 4

It can be applied as a flexible bridge which multiplexes services. However, it is concerned that there may be use cases in which delay requirements are not satisfied or learning such as the presence or absence of traffic patterns is not performed correctly.

- Usability: 5

Since the cycle period, bandwidth (burst quantity) and phase are autonomously learned by the switch, no operator work is required. In addition, since each switch operates autonomously even in the case where the traffic passes through multiple switches, adjustment between switches is not required and usability is high.

- Automation Performance: 4

Basically, the GCL configuration is done autonomously by the switch. However, since there are some traffic patterns that cannot be learned, it does not work in all cases.

- CAPEX: 5

Since this function by iTAS software and TSN hardware accompanies the switch, the equipment cost is not significantly different from that of conventional switches.

- OPEX: 4

Autonomous learning can greatly reduce the amount of operators' work to add, change, or delete guaranteed low latency services. Once the system is built, the configuration for the TSN is essentially automatic, so the operating costs are not very high. In addition, even when the traffic source such as an antenna or the like is increased or decreased or a traffic pattern is changed due to a route change caused by a failure, the GCL can be optimized by the autonomous relearning automatically.

B.2 Available Technologies Enabling Optimization of Bandwidth Utilization Efficiency in TAS

B.2.1. Performance Comparison of IEEE 802.1 TSN Time Aware Shaper (TAS) and Asynchronous Traffic Shaper (ATS)

[Overview]

An adaptive bandwidth sharing (ABS) scheme is proposed to improve bandwidth utilization by allowing packets to be transmitted from a low priority queue for which the gate is closed when the high priority queue for which the gate is in the open state is empty [A. Nasrallah IEEE Access (vol.7)]. Furthermore, by measuring the end-to-end delay information, a method called adaptive slotted windows (ASW) that adaptively changes the gate open ratio between the high-priority and low-priority classes and reduces the delay of the high-priority classes is proposed [A. Nasrallah IEEE Access (vol.7)]. It is shown that the combination of both can provide a higher improvement effect.

[Evaluation] 5-grade evaluation (5: Excellent, 4: Very Good, 3: Good, 2: Average, 1: Poor)

- Feasibility: 3

The ABS is a simple mechanism that is closed within each switch device and doesn't require cooperation with other devices. However, there is a high possibility that an actual ultrafast switch cannot perform queue selection change on a packet basis. Therefore, when it is implemented on an actual device, there is a possibility that the operation does not necessarily follow the theory of ABS, and the feasibility of its successful implementation is considered to be moderate (Feasibility: 3). On the other hand, since the ASW method performs control based on the delay between the end points, the end terminal needs a precise delay measurement function. In addition, since it needs to be implemented to every switch in the whole network, it is not considered highly feasible (Feasibility: 1). Since ASW approach has low overall scores, only ABS approach will be discussed below.

- Applicability to IOWN GF: 3

The ABS approach is considered to be applicable as a flexible bridge which multiplexing services. However, since there are concerns about feasibility, the applicability is also considered to be moderate.

- Usability: 5

Usability is high because the ABS is closed within a switch device without requiring any cooperation with other devices and no operator work is required.

- Performance (Bandwidth Utilization Efficiency): 5

The bandwidth utilization efficiency is high, because the other lower priority queues can transmit their traffic when the high priority queue is empty.

- Performance (Low Latency): 2

As mentioned above, the speed of the queue change remains questionable, so the ideal operation of ABS may not be achieved. In other words, a low-priority packet may continue to be read, and a high-priority packet may be kept waiting. The difference from the conventional QoS method (strict priority) becomes considerably small due to the increase in bandwidth utilization efficiency, and it seems that the deterministic nature is lost.

- CAPEX: 4

The mechanism of ABS is very simple, and the equipment cost is not much different from conventional switch.

- OPEX: 4

Since ABS is a function closed in a switch device, operational cost is not increased.

B.2.2. Gate-Shrunk Time Aware Shaper: Low-Latency Converged Network for 5G Fronthaul and M2M Services

[Overview]

TAS realizes low delay by allocating a specific time slot of GCL for high priority traffic. Since this time slot is occupied even if there is no high priority traffic, the bandwidth of the low priority traffic is restricted and the delay of it is increased. Therefore, by utilizing the burstiness of the high priority traffic, when the end of the burst traffic is detected at each switch device, the occupancy of the time slot is released and then the low-priority traffic can utilize it. In the reference [D. Hisano GLOBECOM 2017], a dedicated frame is transferred from the transmission source such as an RRH in order to inform switch devices of the end of the burst traffic. The method requires an additional implementation for transmission sources. In the reference [N. Shibata JOCN 2021], the switch devices autonomously judge that the burst traffic has ended if a certain time passes after the last arrival of frames, and no additional implementation for transmission sources is required. Therefore, the latter method is discussed in the following (Figures B-2, B-3, B4).

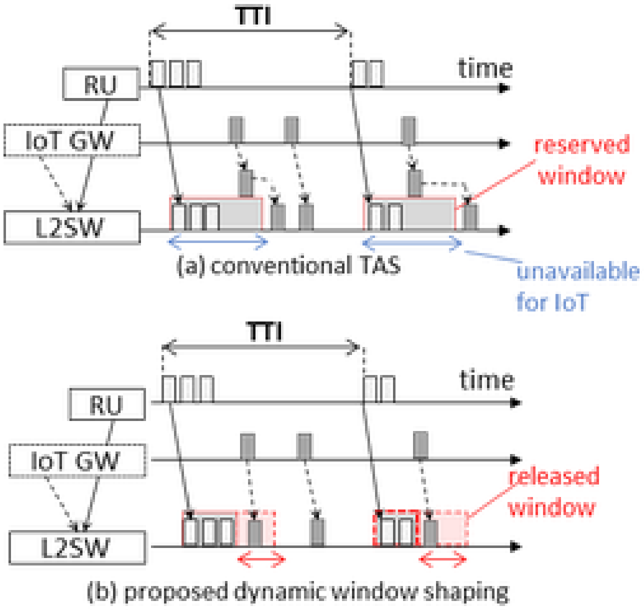


Figure B- 2 Comparison of conventional TAS and dynamic window shaping technique by Gate-Shrunk TAS (GS-TAS))

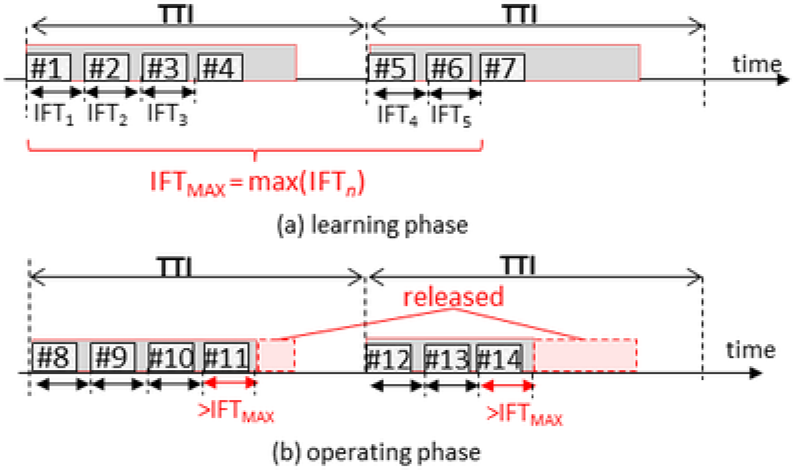


Figure B- 3 Autonomous operations for dynamic window shaping by GS-TAS

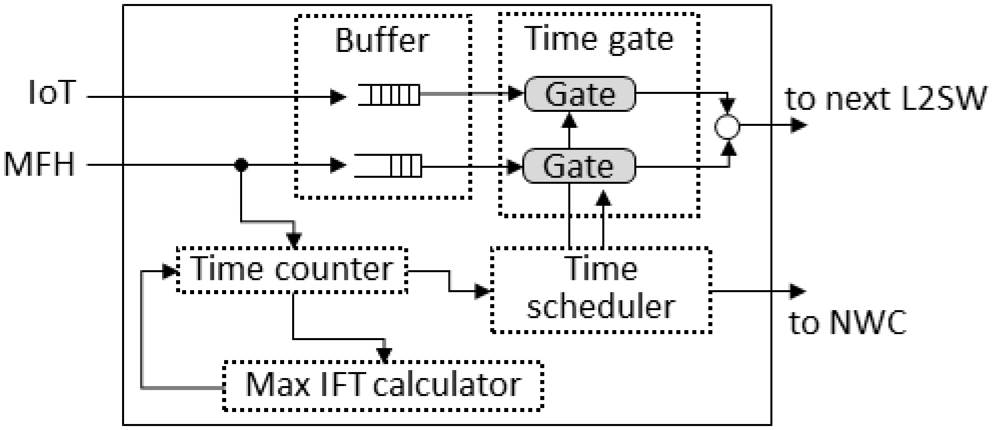


Figure B- 4 Block diagram of switches with dynamic window shaping by GS-TAS

[Evaluation] 5-grade evaluation (5: Excellent, 4: Very Good, 3: Good, 2: Average, 1: Poor)

- Feasibility: 4

The GS-TAS method itself is a very simple mechanism, and it is not considered to be very difficult to implement.

- Applicability to IOWN GF: 4

The GS-TAS method is considered to be applicable as a flexible bridge which multiplexing services.

- Usability: 5

Usability is high because the Gate-Shrunk TAS is closed in a switch device and no operator work is required.

- Performance (Bandwidth Utilization Efficiency): 4

It is considered that the bandwidth utilization efficiency is high because unnecessary bandwidth is surely released for each time slot period. However, the effect may be small depending on the traffic pattern in some cases where the burst amount does not vary so much.

- Performance (Low Latency): 5

Since the transmission of the high priority traffic is guaranteed as the conventional TAS, the low latency of the high-priority traffic can be guaranteed.

- CAPEX: 4

The mechanism of Gate-Shrunk -TAS is very simple, and the equipment cost is not much different from conventional switches.

- OPEX: 4

Since Gate-Shrunk TAS is a function closed in a switch device, operational cost is not increased.

Definitions and Abbreviations

Definitions

For the purposes of this Reference Document, the following definitions apply:

Backhaul [Y.3100]: A network path between base station systems and a core network.

FDN [IOWN GF ST Outlook]: A Function-Dedicated Network (FDN) function is a network built on top of the Open APN to provide dedicated connection among endpoints to support various traffic and QoS requirements.

Fronthaul [Y.3100]: A network path between centralized radio controllers and remote radio units of a base station function.

gNB [3GPP TR 38.801]: A node that supports the NR as well as connectivity to Next-Generation Core (NGC).

Midhaul [MEF 22.3]: The Carrier/Metro Ethernet Network between RAN BS sites. Typically, one of these sites would be a Macro RAN BS site

O-Cloud [O-RAN White Paper]: The O-Cloud is a cloud computing platform that is made up of the physical infrastructure nodes using O-RAN architecture. It also creates and hosts the various virtual network functions (VNFs) used by the RICs and other infrastructure elements.

Orchestration [Y.3100]: In the context of IMT-2020, the processes aiming at the automated arrangement, coordination, instantiation, and use of network functions and resources for both physical and virtual infrastructures by optimization criteria.

GitOps: GitOps is a way of implementing Continuous Deployment for cloud native applications by using tools including Git and Continuous Deployment tools

Istio: An open platform to connect, manage, and secure microservices

Knative: Kubernetes-based platform to build, deploy, and manage modern serverless workloads

SRv6: A technology defining packet processing in the network as a program

Quiet Window[ITU-T G.9804.1]: A time interval during which the optical line terminal (OLT) suppresses all bandwidth allocations to in-service optical network units (ONUs) in order to avoid collisions between their upstream transmissions and the transmissions from ONUs whose burst arrival time is uncertain. The OLT opens a quiet window to allow new ONUs to join the passive optical network (PON) and to perform ranging of specific ONUs.

Abbreviations and Acronyms

For the purposes of this Reference Document, the following abbreviations and acronyms apply:

3GPP: The 3rd Generation Partnership Project

5GS: 5G System

ABS: Adaptive Bandwidth Sharing

AC: Admission Control

AF: Application Function

AIC: AI-Integrated Communications

API: Application programming interface

APN: All Photonic Network

AR: Augmented Reality

A-RoF: Analogue Radio over Fiber

ASW: Adaptive Slotted Window

ATSSS: Access Traffic Steering, Switching, and Splitting

AWG: Arrayed-Waveguide Grating

BB: Baseband

BBF: Broadband-Forum

BH: Backhaul

CAPEX: Capital expenditures

CBS: Committed Burst Size

CIR: Committed Information Rate

CN: Core Network

CNF: Cloud native Network Function

CO: Central Office

CPRI: Common Public Radio Interface

CPS: Cyber-Physical System

CPU: Central Process Unit

C-RAN: Centralized RAN

CTI: Cooperative Transport Interface

CU: Centralized Unit

CWDM: Coarse WDM

CXL: Compute Express Link

DAPS: Dual Active Protocol Stack

DB: Database

DBA: Dynamic Bandwidth Assignment

DC: Data Center

DCI: Data-Centric Infrastructure

DevOps: A compound of development (Dev) and operations (Ops)

DU: Distributed Unit

DPDK: Data Plane Development Kit

DPU: Data Processing Unit

D-RAN: Distributed-RAN

DWDM: Dense wavelength division multiplexing

E2E: End to end

eCPRI: Enhanced Common Public Radio Interface

eCTI: extended CTI

ENNI: External Network to Network Interface

eMBB: enhanced Mobile Broadband

ETSI: European Telecommunications Standards Institute

FDN: Function-Dedicated Network

FH: Fronthaul

FPGA: Field-Programmable Gate Array

FTTH: Fiber To The Home

GCL: Gate Control List

gNB: Logical 5G Radio Node

GPON: Gigabit. Ethernet PON

GPU: Graphic Process Unit

GTP: GPRS Tunnelling Protocol

HARQ: Hybrid Automatic Repeat reQuest

HSP: Higher Speed PON

IA: Industrial Automation

IAB: Integrated access and backhaul

ICT: Information and Communication Technologies

IEEE: Institute of Electrical and Electronics Engineers

IM: Industry management

IOWN: Innovative Optical and Wireless Network

IOWN GF: IOWN Global Forum

IPC: Inter-Process Communication

IPU: Infrastructure Processor Unit

ITU-T: The International Telecommunication Union Telecommunication Standardization Sector

I-UPF: Intermediate User Plane

IWARP: Internet Wide-Area RDMA Protocol

JPEG: Joint Photographic Experts Group

KPI: Key Performance Indicator

L2SW: Layer 2 Switch

LLS-FH: Lower Layer Split – fronthaul

LF: Linux Foundation

LSN: Logical Service Node

MAC: Medium Access Control

MEC: Multi-access Edge Computing

MCG: Master Cell Group

MH: Midhaul

MIMO: Multiple Input, Multiple Output

ML/AI: Machine learning/Artificial Intelligence

MNOs: Mobile Network Operators

MOPA: Mobile Optical Pluggable Alliance

MPTCP: Multipath TCP

MPQUIC: Multipath QUIC

MR: Mixed Reality

MRR: Micro-Ring Resonator

MSA: Multi-source Agreement

MSC: Mobile Switching Center

MWDM: Metro DWM

ND: Network Dynamics

near-RT RIC: near-Real Time RAN Intelligent Controller

NFVI: Network Functions Virtualization Infrastructure

NGMN: Next Generation Mobile Networks Alliance

NR: New Radio for 5G

NSMF: Network Slice Management Function

NSSMF: Network Slice Subnet Management Function

OADM: Optical Add Drop Multiplexer

O-CU: O-RAN Central Unit

ODN: PON Optical Distribution Node

ODN: Optical Data Network

O-DU: O-RAN Distributed Unit

OEO: optical-electrical-optical conversion

OIF: Optical Internetworking Forum

OLT: Optical Line Terminal

ONT: Optical Network Termination

ONU: Optical Network Unit

OPEX: Operating Expenditure

OPI: Open Programmable Infrastructure

O-RU: O-RAN Radio Unit

OTDOA: Observed Time Difference Of Arrival

P2MP: Point-to-multi-points

PDCP: Packet Data Convergence Protocol

PDV: Packet Delay Variation

PIR: Peak Information Rate

PoC: Proof of Concept

PON: Passive Optical Network

PUSCH: Physical Uplink Shared Channel

PtP: Point-to-Point

QoS: Quality of Service

QUIC: Quick UDP Internet Connections

RAN: Radio Access Network

RDMA: Remote Direct Memory Access

RIC: RAN Intelligent Controller

ROADM: Reconfigurable OADM

RoF: Radio over Fiber

RRC: Radio Resource Control

RRU: Remote Radio Unit

RTP: Real-time Transport Protocol

RU: Radio Unit

SCG: Secondary Cell Group

SDK: Software Development Kit

SDO: Standard Development Organization

SFP: Small Form-factor Pluggable

SG: Study Group

SU-MIMO: Single-user MIMO

SLA: Service-Level Agreement

SR: Short Reach

TAS: Time-Aware Shaper

TCO: Total Cost of Ownership

TDD: Time-Division Duplexing

TDM: Time Division multiplexing

TDOA: Time Difference Of Arrival

TSN: Time-Sensitive Networking

TTI: Transmission Time Interval

UAV: Unmanned Aerial Vehicle

UDP: User Datagram Protocol

UE: User Equipment

UPF: User Plane Function

U-Plane: User plane

UPS: Uninterruptible Power Supply

uRLLC: ultra-Reliable Low Latency Communications

UTDOA: Uplink Time-Difference-of-Arrival

vCU: Virtualized CU

vDU: Virtualized DU

VLAN: Virtual Local Area Network

VNF: Virtual Network Functions

VPN: Virtual Private Network

VR: Virtual Reality

vRAN: virtualization of RAN

WDM: Wavelength-Division Multiplexing

WSS: Wavelength Selective Switch

XGS: 10 Gigabit Symmetrical PON

X-Haul: Fronthaul/Midhaul/Backhaul

ZFP: Zero Footprint

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History

Revision	Release Date	Summary of Changes
1	April 2023	Initial Release, Phase 2