Mobile Fronthaul over APN PoC Reference

Classification: APPROVED REFERENCE DOCUMENT

Confidentiality: PUBLIC

Version 1.0

August 29, 2022

[MFH/APN PoC Reference]

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1. Purpose, Objectives, and Scope

1.1. Purpose

As quoted below, the emerging disaggregated radio access network for 5G and beyond requires high capacity, high availability, and stringent latency requirements of the fronthaul. The IOWN for Mobile Networks (IMN) TF has identified that those very strict fronthaul requirements are needed for supporting the use cases envisioned by the IOWN GF [1]. Open APN will be a viable solution to meet such requirements. Examining feasibility of mobile fronthaul over APN is urgently needed. This is because various technologies and architectures are being considered as fronthaul solutions, and APN has potential to be widely recognized as a leading fronthaul solution by demonstrating the value of APN ahead of these schemes.

A lower layer split (LLS) option (e.g., Option 7), which is gaining popularity, promotes an architecture that allows more functions to be centralized. However, to make RAN LLS more compelling, cost and availability of high capacity of fiber optical fronthaul links must be taken into consideration as more stringent requirements of massive bandwidth and tight latency come with LLS.

from section 2.1 of the IMN technical report [2]

The intention of this Proof of Concept (PoC) is to demonstrate and illustrate to mobile network operators the benefits and viability of Open APN as a fronthaul solution, or to other operators that want to offer Fronthaul as a service. The recognition of Mobile Fronthaul (MFH) over APN as a viable and promising solution is expected to encourage the participation of mobile network operators around the world and to further promote IOWN GF related technologies.

One aspect of PoC is the benchmark that APN's energy efficiency may be better than other alternative solutions because APN can for example reduce electric to optical conversion and vice versa and consequently less operational cost (fewer moving parts less things that can go break).

Another aspect is the network's capability of supporting high availability services and Elastic Load Balancing. Elastic load balancing is the term used to describe the active and dynamic steering of RU connections to a set of (virtual) DU based on the actual load on DU. Connecting an RU and a DU with fixed leased dark fiber may be more efficient than using APN in the case that the RU directly connects to the DU without multiplexing, etc. However, with a leased dark fiber, mobile network operators will not be able to allocate computing resources dynamically in accordance with the traffic variation. APN can dynamically switch wavelength paths, allowing them to redirect computing resources at the destination according to traffic volume and other factors. With that, APN can be a solution that allows mobile network operators to dynamically allocate/deallocate DU computing resources.

1.2. Objectives

The objective of this PoC is to demonstrate and realize Elastic Load Balancing of mobile fronthaul with APN and demonstrate its value to the mobile network operators.

Figure 1 shows the hourly trend line of population which is inferred from the number of connected mobile User Equipment (UE) in an urban and rural mobile network, and illustrates the steep differences of the number of connected UEs during day and night times. The difference between day and night times is at minimally 10x, but is typically higher for urban areas, while for the rural areas differences of 5x between day and night are measured. As the number of connected UEs in a particular area varies, so does the required number of mobile resources proportionally. When dynamic allocation of computing resources of DU is not possible, it is necessary to provision statically peak-rated resources, which is very inefficient. Elastic Load Balancing solves this problem.

Elastic Load Balancing is a mechanism that flexibly switches the DUs (vDUs) implemented on virtual machines between intensive processing by a small number of units or distributed processing by a large number of units, depending on the load on the host.

There are at least two adjacent areas from a mobile connectivity point of view, the one is RU site and the other is a DU site. There are at least two vDU in a DU site and the aggregated throughput per RU is monitored against a threshold (configurable). When the threshold is reached, a trigger is sent to the Open APN to reconfigure, such that the UEs that are connected to the vDU of which detected the threshold crossing will now need to connect to the other vDU. The traffic flows from the RU will now need to be redirected towards the new vDU. The vDU that is no longer used is shut down. See Section 4 for methods to implement Elastic Load Balancing.

This PoC intends to study, compare the use of APN as a novel solution that enables dynamic allocation of computing resources based on the active number of mobile UEs in a particular area.

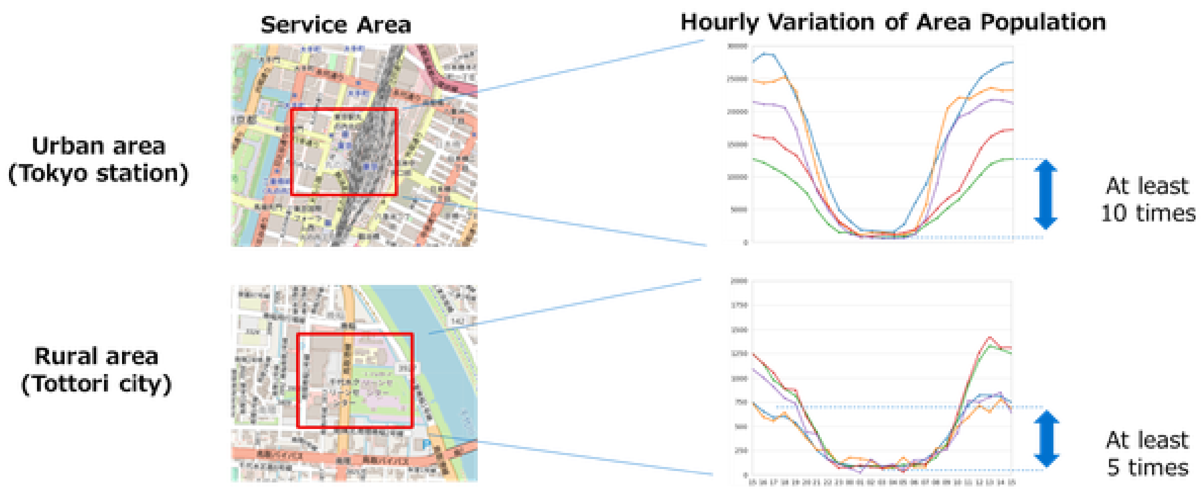

Figure 1. Hourly variation of area population (Urban area: Tokyo, Rural area: Tottori)※

※The data is provided from NTT DoCoMo (see https://mobaku.jp/about/) .

1.3. Scope to be evaluated

This PoC evaluates the power efficiency of Elastic Load Balancing and the impact on E2E traffic due to temporary RU and DU disconnections of the network segment as shown in the following diagram as described in 4.2.3 section of IMN document [2]. The virtual network inside the physical compute node will not be evaluated.

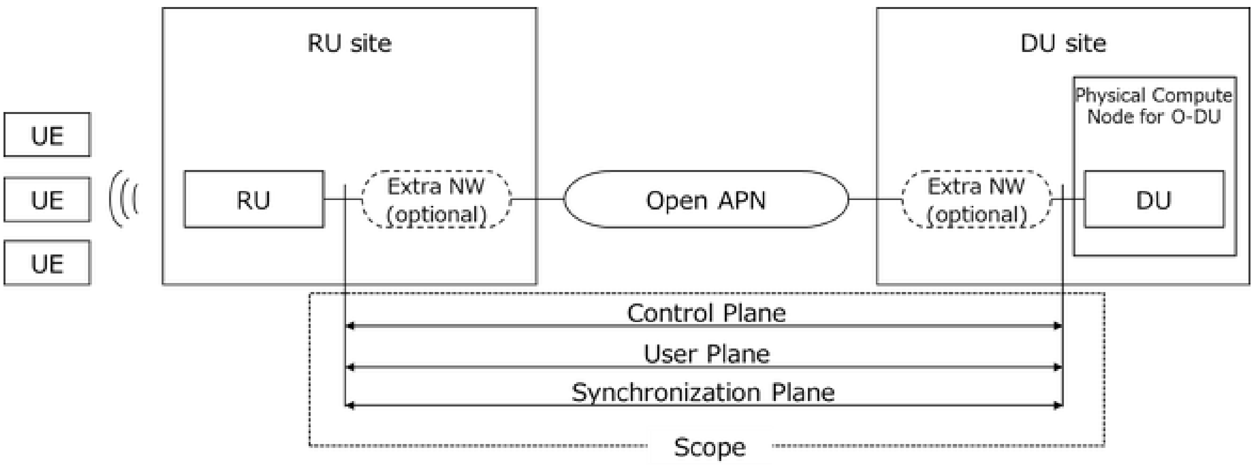

Figure 2. The scope of this PoC

There are two concepts to prove.
(1) One concept is Mobile Fronthaul over APN as described in 4.2.3 section of IMN document.
(2) The other concept is Elastic Load Balancing for energy efficiency.
Latter concept is a new concept and spans three IOWN GF TFs, Open APN

Architecture (OAA), IOWN for Mobile Networks (IMN), and Data-Centric Infrastructure (DCI).

This PoC will prove these two concepts in two steps：

1.3.1. Step1) Evaluation of feasibility of Mobile Fronthaul over APN

Evaluation points：Feasibility

・O-RAN specification (O-RAN Fronthaul Interoperability Test Specification (IOT)) [3]

・Technical requirement from IMN document [2]

1.3.2. Step2) Evaluation of Energy efficiency with elastic load balancing

Evaluation points：

・Positive impact: energy efficiency

-Reduction of power consumption with elastic load balancing in comparison with the baseline model

-The baseline model is the packet multiplexing model Using L2/L3 switch over dark fiber

・Negative impact: decrease of E2E throughput

-Total time required to switch DU hosts

-The change in E2E throughput during switching DU hosts

・Consideration of scenarios for application of elastic load balancing

-Consideration of switching cycle, etc. considering maximization of power consumption reduction and minimization of impact on E2E communication

2. Reference Cases

2.1. Basic scenario

As shown in Figure 3, this PoC considers the case that RUs and DUs are decentralized and DUs are centralized at the same site. The word "L1" means the distance between RU site and APN-G site and the word "L2" means the distance between APN-G site and DU site. To increase the effectiveness in fiber usage of decentralization, DWDM is used as the multiplexing solution in order to make the distance between RU and DU (L1+L2) as long as possible.

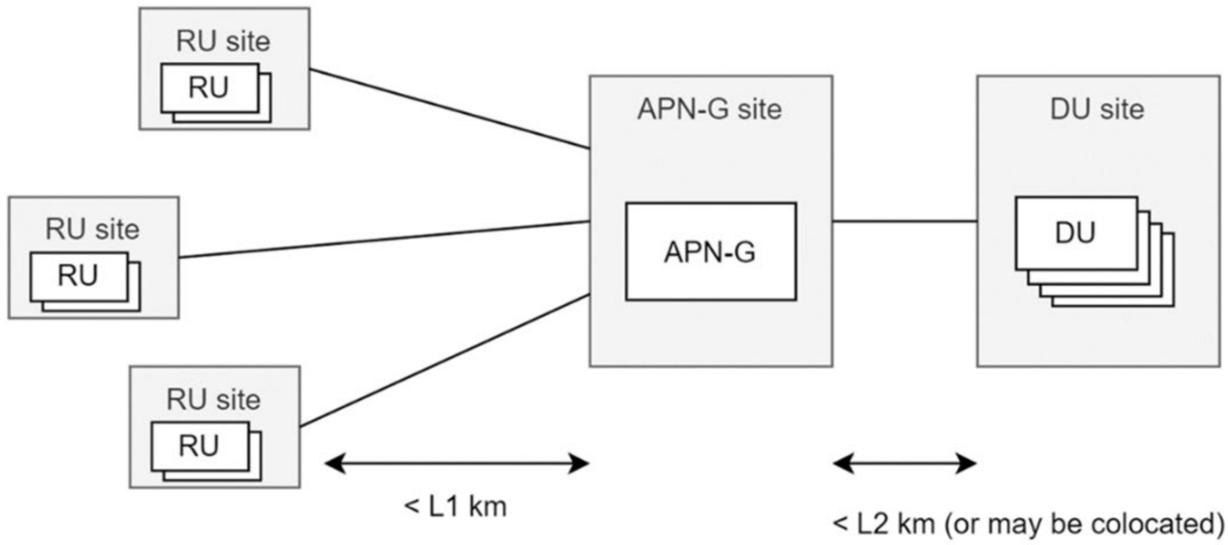

Figure 3. Basic image of reference case

APN-G site and DU site may be provided by the same operator and be located in the same location. This PoC assumes that APN-G and DU site are located at the same location (L2=0) to simplify the requirements in this PoC.

Figure 4 shows the deployment scenario described in section 4.2.3 of IMN document. This is the basic deployment scenario through this PoC.

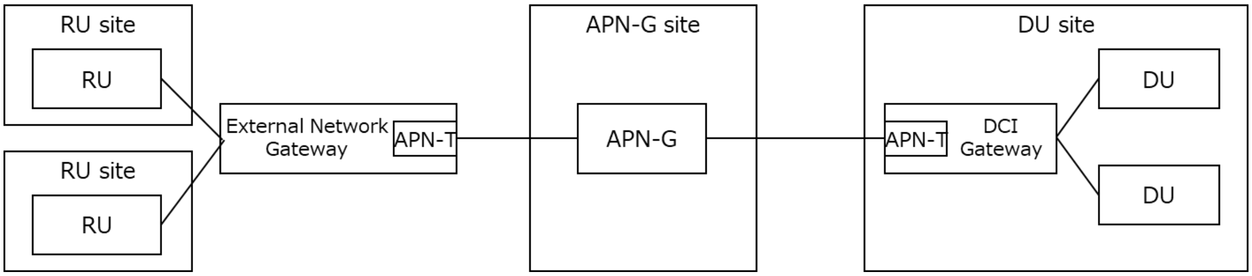

Figure 4. Basic Deployment scenario

Other basic scenarios are as follows:

・Layer split option：option 7.2
・Category for use case：eMBB
・Bandwidth per RU：depends on the RU/DU used in the PoC environment (10G/25G/50G)
・Distance between RU and DU (L1+L2)：2 patterns, L1+L2 equal 7km, 30km (Considering impact of delay due to distance)
※Considering that 60% of all sites are less than 7 km and the maximum requirement is 30 km

2.2. Step1-specific scenario

A minimal environment is described here to perform feasibility study. Assuming multiple RU sites at a single cell site and multiplexing them into a single fiber, at least two RU sites are required.
・Number of RU site：2
・Number of RU per RU site：1
・Number of RU site per DU site：2
・Traffic volume from UE：fixed
・Time synchronization scenario：
not limited to a specific method (depends on the RU/DU used in the PoC environment)

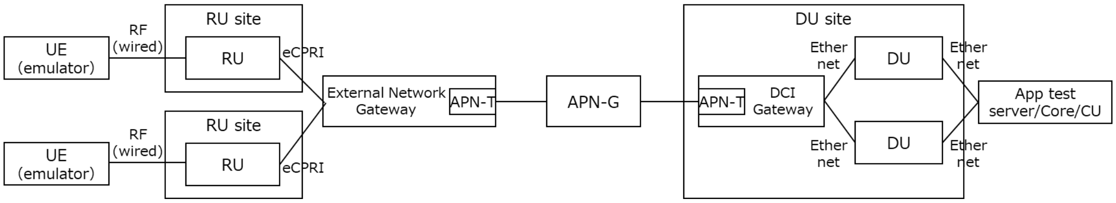

Figure 5. Deployment scenario for Step1

2.3. Step2-specific scenario

To evaluate the effectiveness of Elastic load balancing, it is necessary to build an environment according to the actual situation such as the number of RU per RU site and the number of RU site per DU site. The most significant difference from Step1 is changing the DU from a real server to a virtual server (shown as ‘vDU’ in Figure 6) in order to switch between distributed and centralized processing. From the S-plane point of view, scenario 4 of IMN document 5.2.6.2, which is correspond to LLS-C3 in O-RAN specification, is suitable for elastic load balancing. In other scenarios, the master clock is located at the DU side, and the master clock changes when the RU connects to other DU host by elastic load balancing, whereas in Scenario 4, the time can always be synchronized with the same master.

・Number of RU site：TBD (more than 2)
・Number of RU per RU site：TBD (more than 2)
・Number of RU site per DU site：TBD (more than 2)
・Traffic volume from UE：applying a model that varies over time (TBD for more detail)
・Time synchronization scenario：
Scenario 4 in IMN document 5.2.6.2, which is correspond to LLS-C3 (shown in Figure 7)

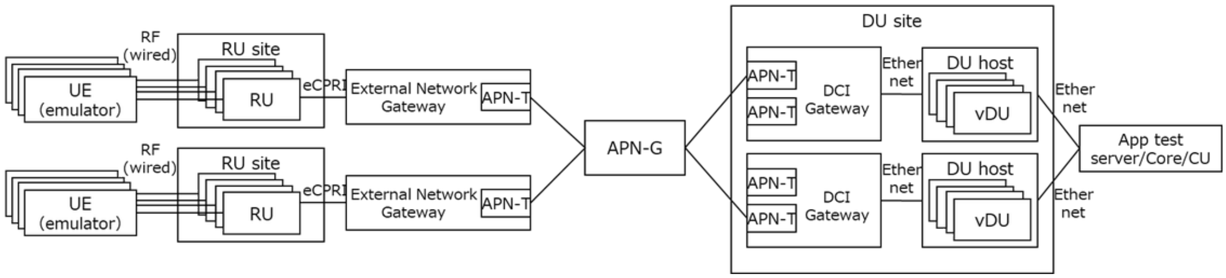

Figure 6. Deployment scenario for Step2

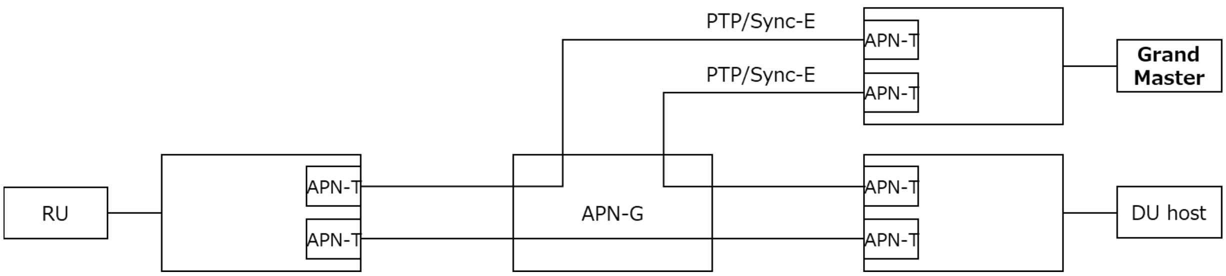

Figure 7. Time synchronization scenario in Step2

3. Mandatory Requirements

3.1. Interfaces [4]

Optical interface between APN-T and APN-G：

1. In the case Flexible Bridging Service is used for aggregating several RUs,
   ・W 100-200G 31.6 Gbaud of Open ROADM MSA Optical Specification Version 5.0
   ・W 200-400G 63.1 Gbaud of Open ROADM MSA Optical Specification Version 5.0
2. In the case RUs connect to APN directly,
   ・NRZ 10G (N, W) of ITU-T G.698.2
   ・NRZ 2.5G (N, W) of ITU-T G.698.2
   ・However, this is not limited depending on the optical interfaces supported by the RU side.

MAC layer interface between RU and DU：
・Ethernet（for transporting eCPRI and PTP/SyncE）
・CPRI
IEEE- 1914.3 (for transporting CPRI over a packet-based infrastructure)

3.2. Latency [2]

Metrics definitions and requirements:
Packet delay（one-way）：0-160μs
Packet Delay Variation：0-10μs

Examination Method and Success Criteria: To be studied. At this moment, we don't intend to normalize the measuring method. We expect PoC implementers to report the measuring method they have adopted. PoC implementers may use RU emulators instead of real RUs.

3.3. Other requirements (from O-RAN specification) [3]

Satisfy the S-plane and C/U-plane requirements of the O-RAN Fronthaul WG's Interoperability Test Specification (Conformance Test is a stand-alone test for each RU/DU, the test for Fronthaul should be IOT-based)

3.3.1. S-plane

Fulfill the requirements for functional test/performance test described in O-RAN Fronthaul WG's Interoperability Test Specification. PoC implementers must use RU/DU as a real server.

Metrics definitions and requirements:
 Maximum frequency error：±50 ppb
 Maximum absolute time error at RU air interface：1500 nsec

3.3.2. C/U-plane

The uplink throughput/downlink throughput must reach the target data rate of the performance level described in O-RAN Fronthaul WG's Interoperability Test Specification (Target data rate varies depending on RU/DU). PoC implementers must use RU/DU as a real server.

4. Key features

Most of items described in this section is required for Step2.
But it is necessary to discuss whether it should be applied to Step1 about section 4.3.

4.1. Dynamic Path Switching for Elastic Load Balancing

4.1.1. Method 1: Optical switching-based method

The APN-G switches the optical path between Extra Network Gateway and DCI Gateway as the vDU is reconfigured due to the aggregated throughput per DU fluctuations. In the case of Figure 8, usually, the upper RU site connects to the upper DU host, and the lower RU site connects to the lower DU host. As the workload on the DU side decreases, it concentrates processing on the upper DU host. At the same time, APN-G switches the optical path connected to the lower DU host to connect to the upper DU host.

Pros: Energy efficiency, QoS deterministic
Cons: Transceiver cost, dependency on the speed of APN control

The trigger to switch optical path is TBD

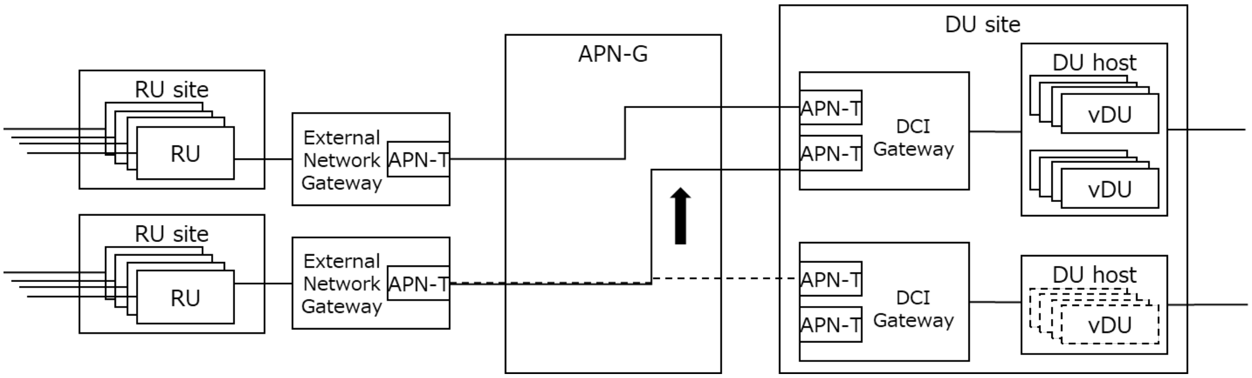

Figure 8. Optical switching-based method

4.1.2. Method 2: Packet switching-based method

The DCI Gateway switches the L2/L3 path between DCI Gateway and DU host as the vDU is reconfigured due to the aggregated throughput per DU fluctuations. In the case of Fig9, usually, the upper RU site connects to the upper DU host, and the lower RU site connects to the lower DU host. As the workload on the DU side decreases, it concentrates processing on the upper DU host. At the same time, DCI Gateway switches the L2/L3 path connected to the lower DU host to connect to the upper DU host.

Pros: Transceiver cost (less stand-by transceivers)
Cons: Energy consumption and QoS indeterministic

The trigger to switch path is TBD.

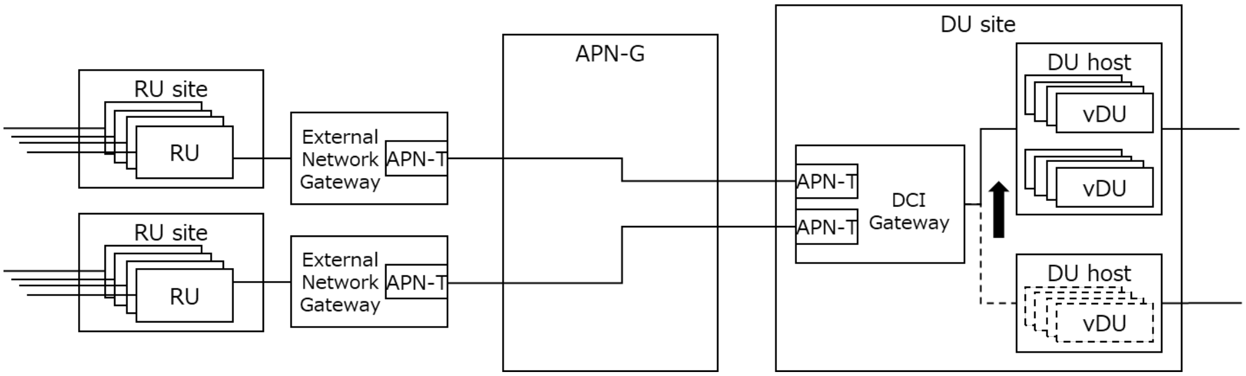

Figure 9. Packet switching-based method

4.2. Dynamic configuration change of NFVI

Out of scope, but trigger and how to synchronize with path switching are important.

5. Key Benchmarks

5.1. Feasibility

5.1.1. Feasibility based on O-RAN specification (S-plane)

Scope: Maximum frequency error and maximum absolute time error at the RU air interface.

Metrics: ppb (maximum frequency error), nsec (maximum absolute time error)

Measuring Method: To be studied.

5.1.2. Feasibility based on O-RAN specification (C/U-plane)

Scope: Uplink and downlink throughput between RU and DU.

Metrics: bps

Measuring Method: To be studied.

5.1.3. Feasibility based on IMN document

Scope: The latency and jitter of the Open APN and external networks between the RU sites and the DU site should be measured.

Metrics: μs

Measuring Method: To be studied. At this moment, we don’t intend to normalize the measuring method. We expect PoC implementers to report the measuring method they have adopted.

5.2. Energy Efficiency

Scope: The energy consumption of the Open APN and external networks between the RU sites and the DU site should be measured.

Metrics: Watt / total traffic volume between RU and DU

Measuring Method: To be studied. At this moment, we don’t intend to normalize the measuring method. We expect PoC implementers to report the measuring method they have adopted.

5.3. Operational Aspects

TBD

6. Other Considerations

6.1. TDM-PON based scenario

TDM-PON based scenario, which is under discussion in MOPA [5], is one of the possible deployment scenarios for mobile fronthaul. In this scenario, optical splitters have two optical paths to OLTs. If the DU host switched, optical splitter switches the path to another OLT. This scenario doesn't meet some of the requirements described in IMN document in terms of distance, latency, and jitter. It is necessary to discuss the impact on the O-RAN specification. After sorting out this concern, this scenario will be demonstrated in this PoC.

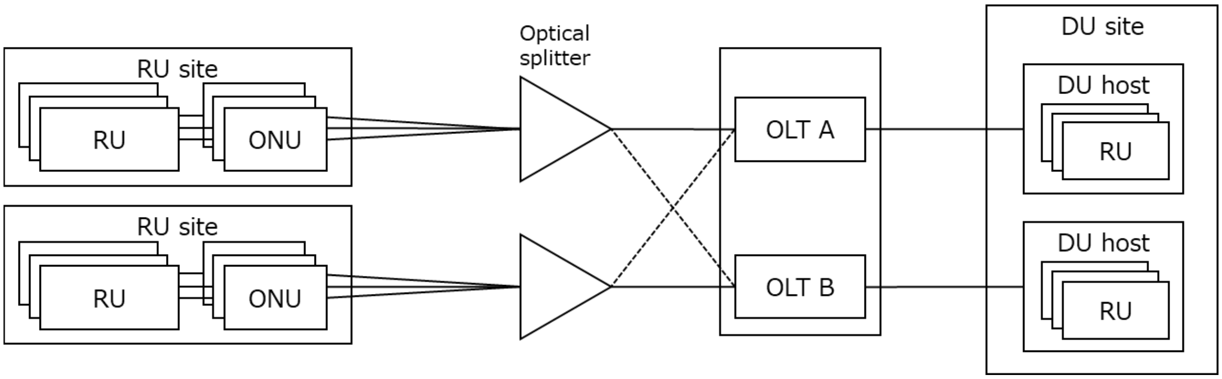

Figure 10. TDM-PON based scenario

6.2. Co-Packaged Optics (CPO)

Elastic Load Balancing uses a lot of optical transceivers. Optical transceiver which uses discrete components (TIAs, drivers, CDRs etc.…) requires a lot of I/Os between internal packages and power dedicated to retiming, SERDES etc. Co-Packaged Optics (CPO) can be a solution for the concern because it is an advanced heterogeneous integration of optics and silicon on a single packaged substrate and can reduce I/Os required for existing optical transceivers. But practical application of CPO may take a long time, so CPO will be not as a target of this PoC and may be discussed as a future issue.

Reference

[1] IOWN Global Forum Use Cases: https://iowngf.org/use-cases/

[2] Technical Outlook for Mobile Networks Using IOWN Technology:
https://iowngf.org/wp-content/uploads/formidable/21/IOWN-GF-RD-Technical-Outlook-for-Mobile-Networks-1.0-1.pdf

[3] O-RAN Fronthaul Interoperability Test Specification (IOT) 6.01

[4] Open All-Photonic Network (APN) Functional Architecture:
https://iowngf.org/wp-content/uploads/formidable/21/IOWN-GF-RD-Open-APN-Functional-Architecture-1.0-1.pdf

[5] Mobile Optical Pluggables (MOPA) Technical Paper Version 1.1

History

Revision	Release Date	Summary of Changes
1.0	August 29, 2022	Initial Release