PoC Project name:

Mobile Front Haul over APN PoC Step1

Classification: IOWN Global Forum Recognized PoC

Stage: SSF PoC Report

Confidentiality: Public

Version: 2.0

JANUARY 24, 2024

1. PoC Project Completion Status

Overall PoC Project Completion Status:

Phase one of the multi-phase POC is successfully completed.

PoC Stage: Significant Step Forward (SSF)

PoC Stage Completion Status:

- Phase one focused on demonstrating connectivity in a simple linear point to point topology and with a non-automated switch over between the DU or the test equipment – in this document: point to point refers to a single RU interface connected to a single DU interface over an All Photonic Network (APN). This phase focuses on latency, synchronization, proper functioning of the features pertinent to a mobile Fronthaul network through an APN.

⇨ Phase one of the POC is successfully completed.

- In phase two, a continuation of phase one, Elastic networking will be demonstrated via a multi-point connection APN architecture. In this sense, point-to-multipoint connectivity refers to a single Radio Unit (RU) communicating with several Distributed Units (DUs) over an (APN). The connectivity between the RU and a particular DU is determined by the time of day or, more specifically, the quantity of User Equipment (UEs) connected to the corresponding DUs. This phase will largely focus on latency and synchronisation inside such a multipoint network within an APN, both of which are key features of a mobile Fronthaul network and end-to-end User Equipment (UE) call performance. The process of moving mobile services from one DU to another is carried out directly at the Photonic layer, specifically inside APN-I, by utilising wavelengths.

⇨ To be planned and targeted to be completed by the end of March 2024 when relevant KPIs are defined.

2. PoC Project Participants

PoC Project Name: IOWN-GF-RD-MFH_over_APN

Company	Name
NOKIA	Ben Zhao
	Norikazu Funaki
	Ayumu Shimura
	Tommy Choo
	Hideichi Oshima
NTT	Manabu Sugihara
	Takashi Sakaue
	Masayuki Furusawa

Table 1 – List of PoC participants

3. Confirmation of PoC Demonstration

PoC Demonstration Event Details:

- The PoC was demonstrated at DOCOMO R&D Center in Yokosuka Research Park, Japan.
- The date of PoC was Conducted during the period from 20th September to 5th October 2023
- PoC report submission date – 24 October 2023

4. PoC Goals Status Report

The PoC Project Goal #1: Goal Status: Achieved the original PoC objectives.
Comply with IOWN-GF-RD-MFH_over_APN_PoC_Reference [1]

- ⇨ Evaluation of feasibility of Mobile Fronthaul over APN, reference to
  - O-RAN specification (O-RAN Fronthaul Interoperability Test Specification (IOT)) [2]
  - Technical requirements from IMN document

5. PoC Feedback Received from non-member (Optional)

Not applicable

6. PoC Technical Report (IMN)

This PoC was conducted in accordance with the Step 1 definition described in IOWN-GF-RD-MFH_over_APN_PoC_Reference_1.0.pdf [1], and involved NTT and Nokia.

Reference 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)

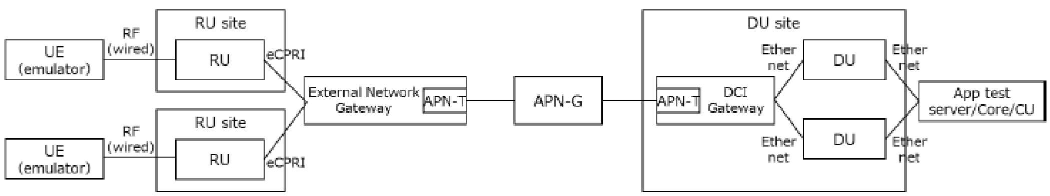


Figure 1 - Deployment scenario for Step 1

6.1. Implemented System

6-1-1. The Network Configuration – including fiber length

The network configuration consists of two different architectures: one where a single RU and DU are connected by APN-G (Call it “APN with a single APN node scenario), and another where APN-I is inserted between APN-G and APN-G. (Call it APN with distributed APN nodes scenario). The fiber spools with different lengths were installed between Flexible Bridge and APN-G, between APN-G and APN-G, and between APN-G and APN-I. The fiber spools that were tested had lengths of 10 km and 25 km.

Based on the LLS-C1 specified in the O-RAN WG4 CUS-Plane specification, the PTP synchronization architecture for MFH used by NTT DOCOMO’s RAN equipment places the grandmaster on the DU/CU side. Both RU and DU are connected to external network gateways, flexible bridges in other words, with DOCOMO’s exclusive SFP transceivers. In addition, DOCOMO’s exclusive SFP is used to connect the RU and DU using bi-directional transmission.

Network Configuration	Detail	Applicable use cases.

APN-G Pattern1	Basic pattern using APN-G, without fiber spools	—
Pattern1-1	Installing fiber spools between APN-G and APN-G using the APN-G pattern	Realization cases of C-RAN wide-area coverage
Pattern1-2	Installing fiber spools between RU and Flexible Bridge using the APN-G pattern	Case where Flexible Bridge cannot be installed directly under RU
Pattern1-3	Installing fiber spools between Flexible Bridge and APN-G using the APN-G pattern	Case of placing Flexible Bridge directly under RU but placing it in the APN-G aggregation center
APN-I Pattern2	Pattern using APN-I, without fiber spools	—
Pattern2-1	Installing fiber spools between APN-G and APN-I using the APN-I pattern	Realization cases of C-RAN wide-area coverage using APN-I installation

Table 2 – The PoC considered network configurations based on the location of the different fiber spools

The locations of the inserted fiber spools are illustrated in the following test diagrams and tables. This configuration is LLS-C2 specified in the O-RAN WG4 CUS-Plane specification.

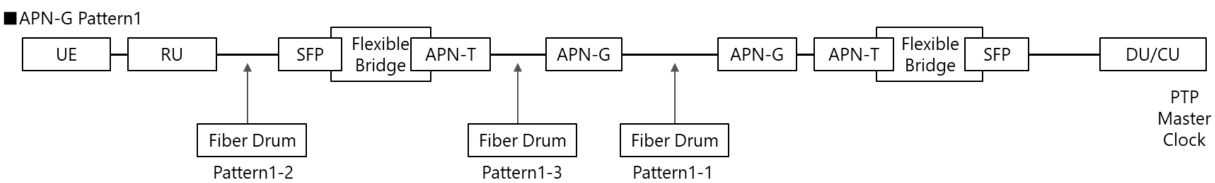


Figure 2 - The APN-G Pattern1 details network topology with the different fiber spool locations

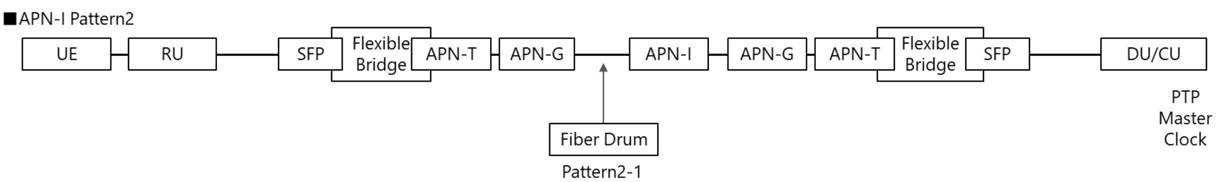


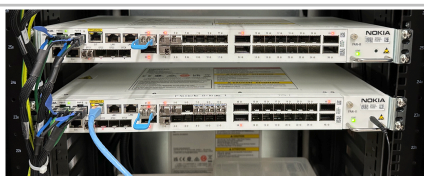
Figure 3 - The APN-G Pattern2 details network topology with the different fiber spool locations

Item	PoC reference	Conditions for this PoC
Functional layer split	option 7.2	Compliant option 7.2
Category for use case	Enhanced Mobile Broadband (eMBB)	Compliant Enhanced Mobile Broadband (eMBB)
Interface Bandwidth per RU	10G/25G/50Gbps	Compliant 25Gbps
Distance between RU and DU	L1+L2 equal 7km, 30km Considering impact of delay due to distance)	Not compliant L1+L2 equal 10km and 25km
Number of RU site	2	Not compliant 1

Number of RU per RU site	1	Compliant 1
Number of RU site per DU site	2	Not compliant 1
Traffic volume from UE	fixed	Compliant Fixed
Time synchronization scenario	not limited to a specific method	Compliant LLS-C2 specified in the O-RAN WG4 CUS-Plane specification

Table 3 – PoC characteristics and configuration specifics

Below are the detailed configuration diagrams of NOKIA's APN device:

Front rack: Flexible Bridge x2units	Rear rack: APN-G1 (Bottom), APN-I (Center), and APN-G2 (Top)
	
Rear rack: APN-G1 (Bottom), APN-I (Center), and APN-G2 (Top) plus the fiber spools.	

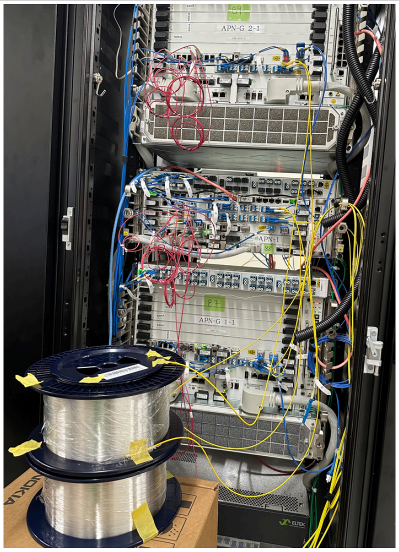


Table 4 – Photographs of the PoC rack installed equipment in the lab.

The overall view of the verification environment is as follows. The RU and DU are installed in separate shield rooms. The Core NW simulator is connected to the DU to establish C-plane and U-plane connections, and transfer user data flow between the UE and APL server. An Anritsu Network Tester is installed for latency/jitter measurements, and a TAP is installed for packet capture to confirm the successful establishment of C/U/S-plane signals.

Evaluation Configuration: MFH_over_APN (APN-G)

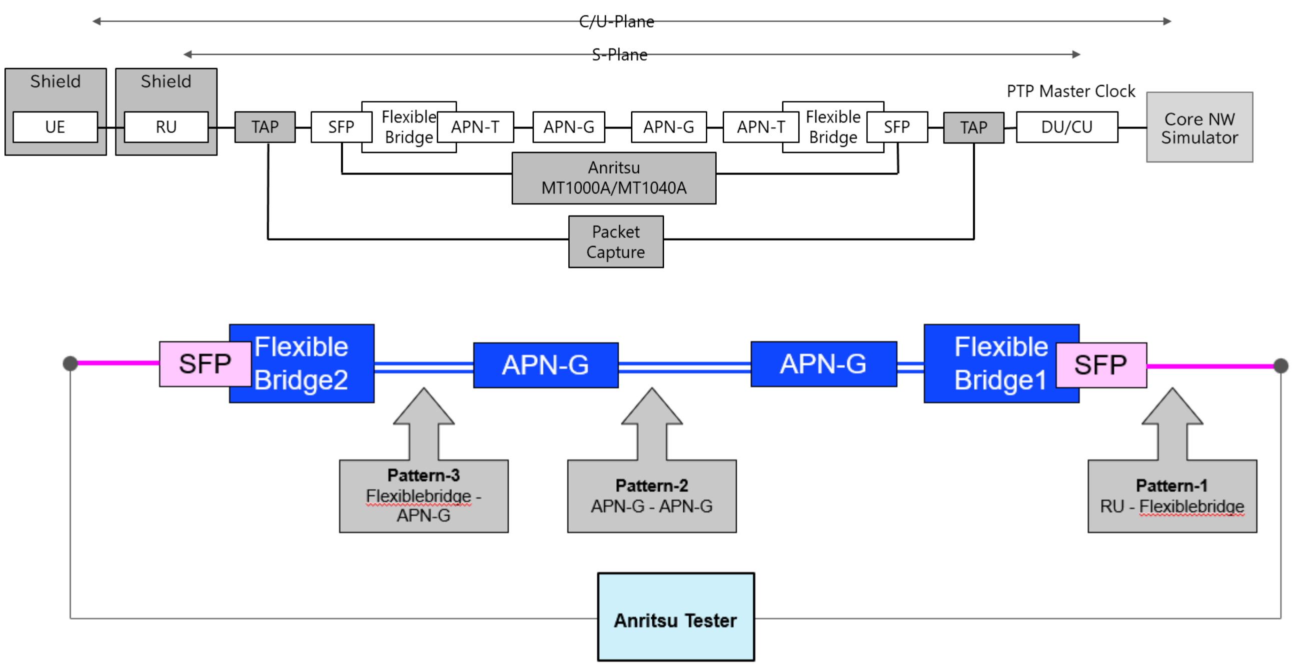


Figure 4 – Evaluation Configuration: MFH_over_APN (APN-G)

Location of the Fiber spool	Fiber spool direction	Evaluation results		
		None of		
Back to Back (Without fiber spool)	N/A	OK		
Location of the Fiber spool	**Fiber spool direction**	**Evaluation results**		
		10.2 km	20.4 Km (10.2 Km + 10.2 Km)	25 Km
Pattern-1 RU – Flexible bridge	Simplex (Bidirectional)	OK	OK	OK
Pattern-2 APN-G – APN-G	Duplex (Upstream/ Downstream)	OK	N/A: Material limitation	OK
Pattern-3 Flexible bridge – APN-G	Duplex (Upstream/ Downstream)	OK	N/A: Material limitation	N/A

Table 5 – Evaluation Configuration: MFH_over_APN (APN-G).

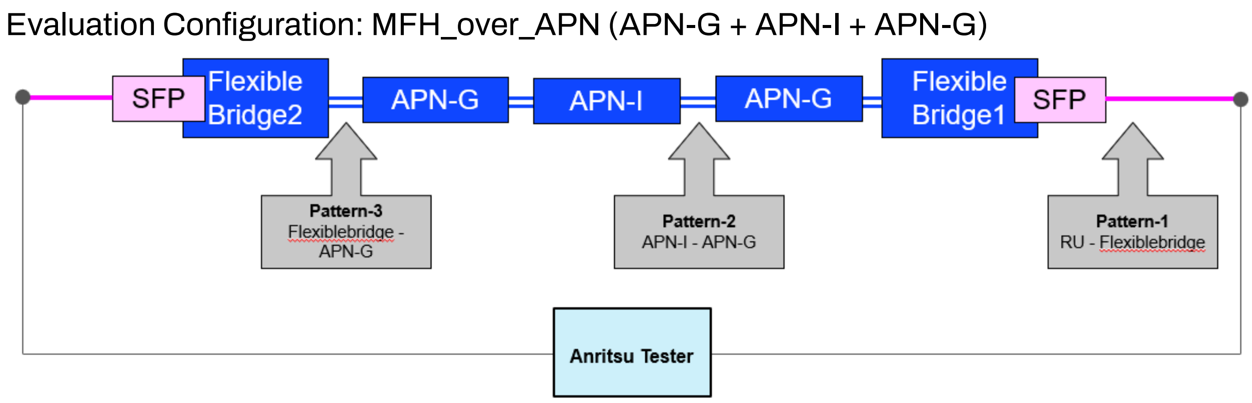


Figure 5 - Evaluation Configuration: MFH_over_APN (APN-G + APN-I + APN-G)

Location of the Fiber spool	Fiber spool direction	Evaluation results		
		None of Fiber spool		
Back to Back (Without fiber spool)	N/A	OK		
Location of the Fiber spool	Fiber spool direction	Evaluation results		
		10.2 km	20.4 Km (10.2 Km + 10.2 Km)	25 Km
Pattern-1 RU – Flexible bridge	Simplex (Bidirectional)	OK	N/A	N/A
Pattern-2 APN-I – APN-G	Duplex (Upstream/ Downstream)	OK	N/A: Material limitation	OK
Pattern-3 Flexible bridge – APN-G	Duplex (Upstream/ Downstream)	N/A	N/A: Material limitation	N/A

Table 6 – Evaluation Configuration: MFH_over_APN (APN-G + APN-I + APN-G)

6-1-2. Bill of Materials

Below is the list of equipment that was used during the Proof of Concept tests.

Equipment	Detail	Preparation
UE	The commercially used equipment by NTT DOCOMO	NTT
RU		NTT
DU/CU		NTT
CoreNW Simulator	Simulator for AMF/UPF/Application server to establish C/U-plane connections and transfer user data flow.	NTT DOCOMO
Flexible Bridge/APN-T	1830 TPS-24 (code Version Release 2.1)	NOKIA
APN-G	1830 PSS-16II (code Version Release 22.12) S2AD200 – 3KC69659AA	NOKIA

APN-I	1830 PSS-8 (code Version Release 22.12) Modules iROADMv (8DG62445AA/AB)	NOKIA
Network Tester	Anritsu MT1000A/MT1040A	NTT
Fiber spool	two 10-kilometer-long drum-type optical fibers two 25-kilometer-long drum-type optical fibers	NTT
SFP-25G-LR (Flexblebridge)	Exclusive product of NTT DOCOMO with Bi-Directional compatibility	NTT

Table 7 – Network element equipment Bill of material for the POC

6.2. Measurement Method

We conducted measurements from two perspectives.

6-2-1. Interoperability between RU-DU

The first perspective involved inserting an APN device between the RU and DU and extending the distance using fiber spools to ensure that PTP synchronization, Cell settings, and call connections were successfully established, as well as the observation of user plane exchanges.

6-2-2. Latency and Packet Delay Variation

The second perspective involved measuring latency and Packet Delay Variation (PDV) (also known as jitter) in the MFH section during that time.

6.3. Results

6-3-1. Mandatory Requirements

The Mandatory requirements defined in the PoC reference are as follows:

I. Interfaces

PoC Reference		PoC conditions and results
Optical interface between APN-T and APN-G	1. Case Flexible Bridging Service In the case where there is a Flexible Bridging Service is used for aggregating several RUs, – S2AD200 33Gbaud @ 200Gbps 16QAM 50GHz/ 100Gbps QPSK 33Gbaud – C2DCO4 – 400Gbps Pluggable (16 Shaped QAM) 65Gbaud 75GHz /100GHz	Compliant
	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.	This model is not applicable this time.

Medium Access layer Framing technology	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):	Compliant

Table 8 – Interface of mandatory requirements

II. Latency

PoC Reference	PoC conditions and results
Metrics definitions and requirements: Packet delay（one-way）: 0-160μs Packet Delay Variation: 0-10μs	All results are satisfied. Details are described in 6-3-3.
Examination Method and Success Criteria: To be studied. At this moment, we don't intend to normalize the measuring method.	The measurement method environment is as shown in 6-1-2.

Table 9 – Latency of mandatory requirements

III. O-RAN specification

PoC Reference	PoC conditions and results
S-Plane 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	Compliant as described in 6-1-1 Although not measured - We confirmed that the S-Plane signal was processed correctly.
C/U-Plane PoC implementers must use RU/DU as a real server: 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	Compliant as described in 6-1-1 ・C-Plane: We confirmed that the call connection was completed normally. ・U-Plane: We confirmed that the uplink throughput/downlink throughput was the same whether we inserted an APN device between the RU and DU or not. Details are described in 6-3-2

Table 10 –O-RAN specification of mandatory requirements

6-3-2. Interoperability between RU-DU

In all patterns where an APN device was inserted between the RU and DU, PTP synchronization in the M/S-plane was successfully completed, call connection sequences in the C/U-plane were completed without issues, and user data was transmitted successfully in the U-plane with UL/DL throughput being the same as data without the APN device.

NW Configuration	Detail	Result
APN-G Pattern1	Basic pattern using APN-G, without fiber spools	Call connection OK UL/DL throughput OK.
Pattern1-1	Installing fiber spools between APN-G and APN-G using the APN-G pattern	Length of the fiber spool: 10km,25km Call connection OK UL/DL throughput OK.
Pattern1-2	Installing fiber spools between RU and Flexible Bridge using the APN-G pattern	Length of the fiber spool: 10km, Call connection OK UL/DL throughput OK.
Pattern1-3	Installing fiber spools between Flexible Bridge and APN-G using the APN-G pattern	Length of the fiber spool: 10km, Call connection OK UL/DL throughput OK.
APN-I Pattern2	Pattern using APN-I, without fiber spools	Call connection OK UL/DL throughput OK.
Pattern2-1	Installing fiber spools between APN-G and APN-I using the APN-I pattern	Length of the fiber spool: 10km,25km Call connection OK UL/DL throughput OK.

Table 11 – Interoperability between RU-DU

6-3-3. Latency and Packet Delay Variation

Next, the results for latency and jitter measurements are presented. The latency with the APN device was 10.67µs for the APN-G pattern and around 11.03µs for the APN-I pattern, with an increase of 0.36µs in the APN-I pattern. The jitter result was 0.01 or 0.02µs. For each pattern, the latency of the APN device was added to the fiber optic distance latency.

The respective results are as follows.

NW Configuration	Detail	Result
APN-G Pattern1	Basic pattern using APN-G, without fiber spools	Latency:10.067 µs Jitter: 0.020 µs .
Pattern1-1	Installing fiber spools between APN-G and APN-G using the APN-G pattern	Length of the fiber spool: 10km, Latency:60.457 µs Jitter: 0.010 µs 25km Latency:132.647 µs Jitter: 0.010 µs

Pattern1-2	Installing fiber spools between RU and Flexible Bridge using the APN-G pattern	Length of the fiber spool: 10km, Latency:60.77 µs Jitter: 0.020 µs
APN-I Pattern2	Pattern using APN-I, without fiber spools	Latency:11.03 µs Jitter: 0.020 µs

Table 12 – Latency and Packet Delay Variation results

Evaluation Configuration: MFH_over_APN (APN-G)
Note - Upper: Anritsu MT1000A Lower: Anritsu MT1040A

Location of the Fiber spool	Evaluation results		
	None of Fiber spool		
Back to Back (Without fiber spool)	Only APN Latency: 10.670 µs Jitter: 0.020 µs Latency: 10.071 µs Jitter: 0.010 µs		
Location of the Fiber spool	Evaluation results		
	10.2 km	20.4 Km (10.2 Km + 10.2 Km)	25 Km
Fiber spool itself	Latency: 50.490 µs Latency: 50.295 µs Jitter: 0.010 µs	Latency: 100.760 µs Jitter: 0.010 µs	Latency: 122.650 µs Latency: 122.655 µs Jitter: 0.010 µs
Pattern-1 RU - Flexible bridge	Latency: 60.77 µs Jitter: 0.020 µs	Latency: 111.155 µs Jitter: 0.020 µs	Latency: 133.025 µs Jitter: 0.020 µs
Pattern-2 APN-G - APN-G	Latency: 60.457 µs Jitter: 0.010 µs	N/A	Latency: 132.647 µs Jitter: 0.010 µs

Table 13 – Evaluation Configuration: MFH_over_APN (APN-G) results

Evaluation Configuration: MFH_over_APN (APN-G + APN-I + APN-G)

Location of the Fiber spool	Evaluation results
	None of Fiber spool
Back to Back (Without fiber spool)	Only APN Latency: 11.03 µs Jitter: 0.020 µs

Table 149 – Evaluation Configuration: MFH_over_APN (APN-G + APN-I + APN-G results

6.4. Technical Discoveries from the Proof of Concept (PoC)

Based on the results obtained from this PoC, when inserting Nokia's APN device in the mobile fronthaul section in the network, it added an additional latency of approximately 10μs compared to the latency without the insertion. Assuming a latency of 5μs per 1km for the fiber optic distance, C-RAN implementation over a broad area of up to 28km is still possible, even though the total maximum fiber length is reduced by 2km. During the POC verification, we confirmed that call connections and throughput were possible without issue for distances of up to 25km between APN-G and a combination of APN-G or APN-I extensions. The resulting latency was 132.647μs, leaving a margin of 17.353μs up to 150μs, which indicates that a distance extension of up to 3km based on fiber distance is possible. Furthermore, we were able to demonstrate that the RU-Flexible Bridge and Flexible Bridge-APN-G sections can be extended up to 10km each, and that the RU, Flexible Bridge, and APN-G can be flexibly installed in various locations within this 10km range.

Objective Id:	MFH/Basic Scenario Step1-specific scenario/1/Objective1	
Description:	Description of the PoC Demo Objective: As Step 1 of the PoC, we measured the level at which O-RAN KPIs can be met when an APN device is inserted into the mobile fronthaul between RU and DU. We demonstrated that the application of the APN solution to the mobile fronthaul is viable as a business use case.	
Pre-conditions	Not applicable	
Procedure:	1	Confirm that the S/C/U-plane can be successfully established in a configuration that directly connects the RU and DU via fiber without an APN device.
	2	Measure the basic data of delay for both the APN device and fiber spools using a tester.
	3	Confirm that the S/C/U-plane can be successfully established in a configuration that includes the APN device between the RU and DU.
	4	In a configuration with the APN set between the RU and DU, insert various fiber spools with distances of 10km and 25km at different locations to confirm that the S/C/U-plane can still be successfully established.
	5	Using the basic data, compare the theoretical latency with the latency obtained by inserting the APN device and fiber spools to confirm that they match.

Finding Details:	The synchronization method for PTP is based on the LLS-C2 as specified in the O-RAN WG4 CUS-Plane specification. The demonstration of other types, LLS-C3, and C4, has not been achieved. Due to environmental constraints, we were unable to perform demonstrations using vRAN or multiple instances of RU to DU.
Lessons Learnt & Recommendations	We have gained valuable insights from several aspects that we recommend sharing with the IOWN Global Forum. 1. Low node latency of Flexible bridge - While APN-G and APN-I exhibit minimal latency thanks to photonic-based signal propagation, it's important to note that APN-T's latency contribution may differ. To enhance the flexibility of APN network design within specific fiber length constraints, we can leverage technologies like Nokia TSN 1830 TPS Flexbridge to minimize node latency, thereby enhancing the overall benefits of Fronthaul (FH) over APN. 2. Synchronization distribution in APN node - Synchronization plays a crucial role in establishing communication between O-RAN-based Remote Units (RUs) and Distribution Units (DUs) over a Fronthaul. In contrast to simply passing synchronization transparently over the Access Point Network (APN), the synchronization distribution capabilities of both the 1830 TPS (Flexbridge) and 1830 PSS (APN) ensure reliable and high-performance synchronization distribution. This guarantees stable and precise synchronization distribution from DU to RU, regardless of changes in network topology, resulting in minimal time errors. 3. RAN Fronthaul Service Unawareness in APN Devices - O-RAN employs IEEE 802.1Q VLAN tagging to differentiate various types of traffic to be transported over the fronthaul network, such as RU-DU control communication, user traffic, management traffic, and synchronization traffic. However, it's common for the RAN supplier and Fronthaul (FH) supplier to be different entities. To enhance flexibility and reduce reliance on specific VLAN definitions, we recommend considering MEF's EPL service with statistical multiplexing at the I-NNI (Interconnect Network-to-Network Interface). This approach allows for decoupling between the suppliers and eliminates the need for the APN device to classify fronthaul services unless specific requirements necessitate it for RAN service purposes. 4. In the context of above, TSN-Based Layer 2 Fronthaul Switch for Low-Latency, High-Quality O-RAN Service Over APN Fronthaul Network - The proposed solution advocates the use of a Time-Sensitive Network (TSN) based Layer 2 fronthaul switch to facilitate O-RAN fronthaul service transmission over an APN Fronthaul network connecting Remote Units (RU) and Distribution Units (DU). This approach offers several

	benefits, including low latency, minimal jitter, precise synchronization, and compatibility with MEF-based services. We would like to express our gratitude for the collaboration on this Proof of Concept (PoC) with the NTT/Docomo team. We have gained valuable insights from this experience, and we believe these insights hold significant value and should be shared with the IOWN Global Forum.

7. PoC's Contribution to IOWN GF

Contribution	WG/ TF	Study Item (SI)/Work Item (WI)	Comments
A	IMN	WI	This PoC evaluates the feasibility of Mobile Fronthaul over APN in aspect of Mobile services throughput, latency/ jitter and synchronization complying with the 5G requirement defined in O-RAN WG4 specifications. This phase is necessary to perform as a base line for the next phase, where APN switching will be necessary to ensure correct RU-DU association over an APN.

8. PoC Suggested Action Items

a) Gaps identified in relevant standardization.

Not applicable.

b) PoC Suggested Action Items

Phase 1 of this PoC evaluated the feasibility of APN in point-to-point configuration between a DU and RU without dynamic switchover. Further work is encouraged in test setups involving wavelength switching and accounting for traffic variations between RU cells, and potentially additional experimentation integrating TDM-PON in the test setup.

c) Any Additional comments the PoC Team wishes to make?

Not applicable.

d) Next Step?

Next step is to continue with Phase two PoC that is intended to demonstrate the switch over a multi-point connectivity architecture referring to a single RU connecting to different DUs based on the time of day (or essentially the UE load of the respective DUs) over an APN. The switching of mobile service from one DU to other DU is done in the Photonic layer itself (i.e. APN-I) wavelength switching by command line or

GUI in manual operations. Also, clock scenario needs further discussion in order to support APN base elastic load balancing which is step 2 of PoC.

9. Acronym list

Acronym	Definition
AMF	Access and Mobility Management Function
APN-G	All Photonic Network- Gateway
APN-I	All Photonic Network - Interchange
APN-T	All Photonic Network – Transceiver
CUS	C/U/S-Plane
EPL	Ethernet Private Line
GUI	Graphical User Interface
IEEE	The Institute of Electrical and Electronics Engineers
IMN	IOWN GF Mobile Networking
IOT	Internet of Things
LLS	Low Layer Split
MEF	Metro Ethernet Forum
MFH	Mobile FrontHaul
NNI	Network to Network Interface
PDV	Packet Delay Variation
POC	Proof of Concept
PON	Passive Optical Network
PSS	Photonic Service Switch
PTP	Packet Timing Protocol
RAN	Radio Access Network
SFP	small form factor pluggable optical transceiver
TAP	Test Access Point
TDM	Time-Division Multiplexing
TPS	Time Sensitive Network Switch
TSN	Time Sensitive Network
UPF	User Plane Function
VLAN	Virtual Local Area Network

10. Reference

[1]Mobile Fronthaul over APN PoC Reference ver1.0 August 29th,2022

[2]https://iowngf.org/wp-content/uploads/formidable/21/IOWN-GF-RD-MFH_over_APN_PoC_Reference_1.0.pdf・O-RAN specification (O-RAN Fronthaul Interoperability Test Specification (IOT))

11. Document History

Version	Date	By	Description of Change
1.0	12th Oct 2023	Ben Zhao Norikazu Funaki, Lieven Levrau - Nokia Manabu Sugihara - NTT	Initial Version: This is the first draft of the document
2.0	26th Mar 2024	Manabu Sugihara - NTT	Revised for publication
	29th Mar 2024	Lieven Levrau	Revised for publication