PoC Project name: Investigation in Power Consumption of Mobile Fronthaul Solutions

Classification: IOWN Global Forum Recognized PoC

Stage: SSF PoC Report

Confidentiality: Public

Version: 1.4

January 24, 2024

1. Introduction

The multiple number of mobile fronthaul solutions were implemented to meet the requirement of the emerging disaggregated radio access network for 5G and beyond. The intention of this Proof of Concept (PoC) is to demonstrate fixed WDM fronthaul solutions that currently work in SK Telecom's 5G network and to verify their performance in terms of maximum cell throughput, transport latency, and power consumption. One aspect of this PoC is the benchmark that the power consumption of All-photonics fronthaul system is less than that of semi-active fronthaul system. We want to figure out how much the difference of power consumptions is.

This PoC report describes the architecture of fixed WDM network, as an example of the future mobile fronthaul solutions for beyond 5G or 6G. The measurement methods and results interworking with Nokia 5G system are also explained.

2. PoC Project Completion Status

This PoC project is the first of 2-step projects. The background of PoC demonstration is described in Section 4, including description of the relationships to the PoC Reference [1]. In section 6, the performance measurements and evaluations were conducted using the demonstration system described. Section 6 also include the analysis of the PoC measurement results. The plan of Step 2 PoC was described in Section 8.

- Overall PoC Project Completion Status: On-going
- PoC Stage Completion Status: Step 1 PoC Complete

3. PoC Project Participants

Specify PoC Team:

- PoC Project Name: Investigation in power consumption of mobile fronthaul solutions
- Member A: SK Telecom Contact: Hongseok Shin
- Member B: Nokia Contact: Cloud Jung
- Additional Members: HFR Networks (non-member) Contact: Sunik Lee

4. Background Information of PoC Demonstration

As one of possible fronthaul network deployment scenarios, the mobile operator may choose an option that has less flexibility but needs small expense. Fixed WDM network is not reconfigurable, but is attractive in CapEx point of view, compared to use ROADM. In 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. Fixed WDM based network can be divided into 3 types: Active, Semi-Active and All-photonics. In this PoC, the Semi-Active and All-photonics are considered.

For Semi-Active type, the central office terminal (COT) of fronthaul system, which includes Optical-Electrical-Optical (OEO) conversion channel cards, operates active, and the remote terminal (RT) of fronthaul system consist of passive devices. Grey optical transceivers are applied between Digital Unit (DU) of radio system and OEO card of COT of fronthaul system. Colored optical transceivers are applied between COT and Radio Unit (RU) to increase the efficiency of optical cable. But the number of optical transceivers required to build one fronthaul channel is 4 in Semi-Active type. And OEO card consumes more electrical power.

On the other hand, for All-photonics type, both COT and RT of fronthaul system are passive, and there is no wavelength conversion. The control or management function is not implemented enough, which may require more effort in the installation or in the operation. However, it has the advantage in cost. Colored optical transceivers are applied in DU and RU directly. It consumes only 2 optical transceivers per channel and no power consumption is required in a line.

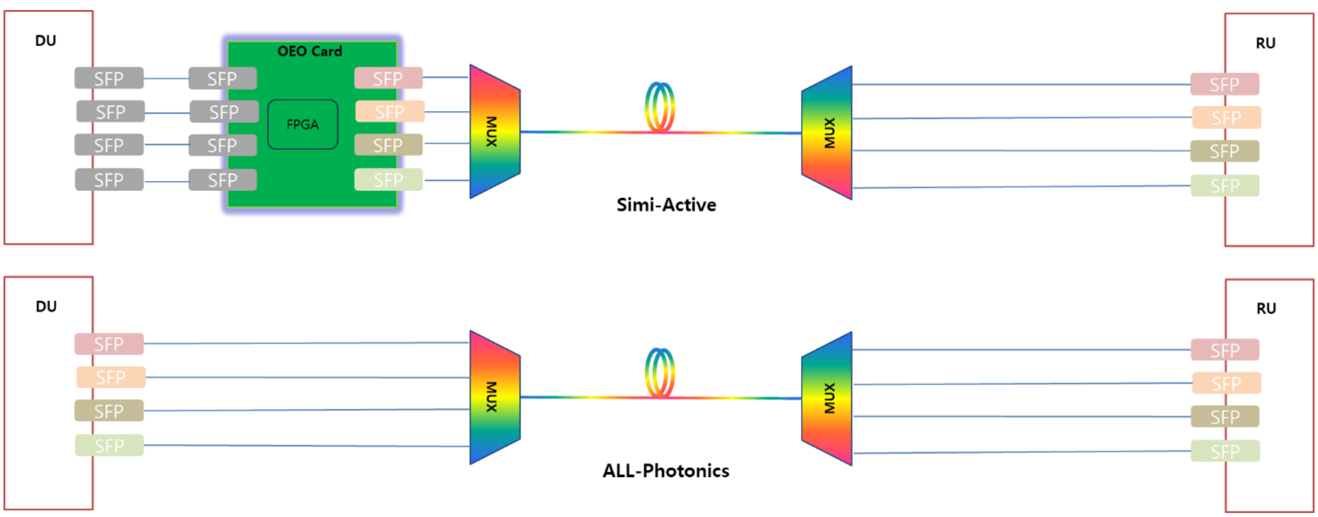

Figure 1 Fixed WDM based fronthaul network structure

SK Telecom developed fixed WDM fronthaul solutions with semi-active type and with All-photonics type consecutively and applied to 5G network. These systems use the same wavelength allocation, which multiplex up to 96 channels on one optical cable. One channel requires 2 wavelength, thus the total number of wavelength is 192 DWDM into 12 CWDM bands. Tunable SFPs are introduced to reduce the number of optical transceiver inventory. One tunable SFP covers 4 DWDM wavelengths, so 48 types of tunable SFPs were prepared.

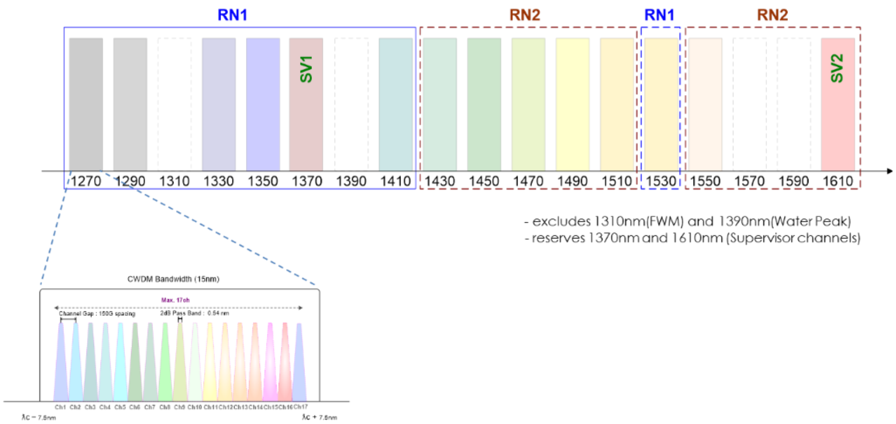

Figure 2 Wavelength map of SK Telecom's Fixed WDM fronthaul solution

There are two different type of Main Remote Node (MRN), which are MRN1 and MRN2, with different group of wavelength bands. Cell site Remote Node (CRN) is DWDM filter and one CRN delivers 16 wavelengths. To be prepared for the line failure, it is designed to be operated in a ring network structure. Optical Switch unit (OSW) monitors the status of links and switches the path in case of sensing the link failure.

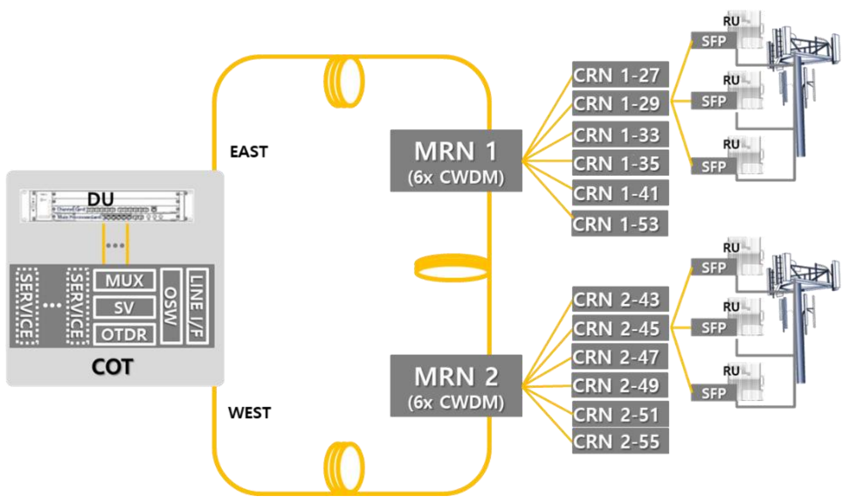

Figure 3 Network Architecture of SK Telecom's Fixed WDM Fronthaul Solution

The differences of semi-active system and All-photonics system are the presence of OEO card and the type of optical transceiver in DU. These systems have common units of MUX, supervisory, and optical switch. OEO card in semi-active system can be connected with up to 4 channels, and the number of OEO cards for full capacity is 24. The additional functions provided by OEO cards were introduced such as delay compensation, channel performance monitoring, and automatic channel information collection.

In semi-active system, the wavelength of each fronthaul channel is decided in OEO card, and grey SFP, which costs relatively low, is used in DU. Grey SFP does not have thermo-electric cooler, resulting low power consumption compared to colored SFP. In All-photonics system, tunable SFP is applied in DU. In both cases, tunable SFP is used in RU side.

This fronthaul solution can be categorized as 'Passive DWDM over a single fiber Blueprint' for low layer split in centralized radio access network based on the technical paper from Mobile Optical Pluggable Alliance. [2] But the optical pluggables for 20km RU-DU are not defined yet.

5. Confirmation of PoC Demonstration

- PoC Title: Investigation in power consumption of mobile fronthaul solutions
- PoC Place: SK Telecom 5G Test Lab
- PoC Date: June 24 ~ 28, 2023
- PoC Purpose: Comparison of Power Consumption between Semi-Active Fronthaul and All-photonics Fronthaul
- PoC Picture:

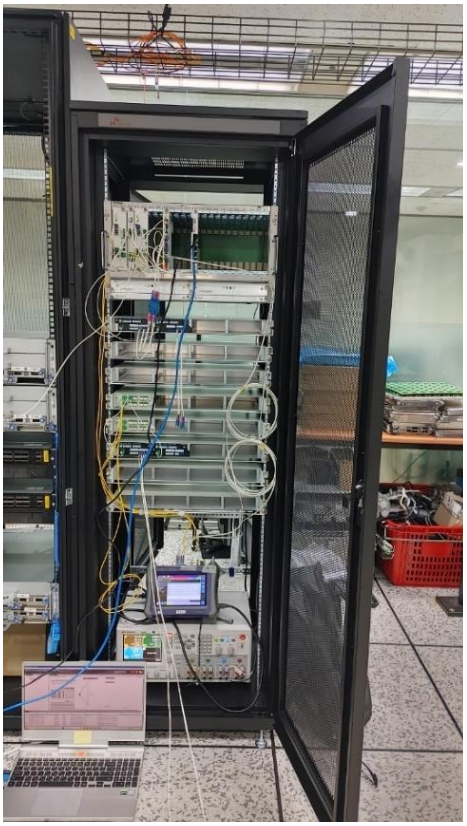

Figure 4 Photograph of the PoC rack in SK Telecom's 5G Lab

The semi-active system and All-photonics system were configured in the same COT shelf consecutively, using the common parts such as MUX unit, supervisory unit and optical switching unit. The fronthaul systems were interoperated with Nokia 5G NR system, which transport 25G eCPRI signals between DU and RU. Due to the limited number of system available in the lab, 4 fronthaul channels were configured in this PoC. The outline of the system configuration for Semi-Active fronthaul and All-photonics fronthaul is shown in the figure below.

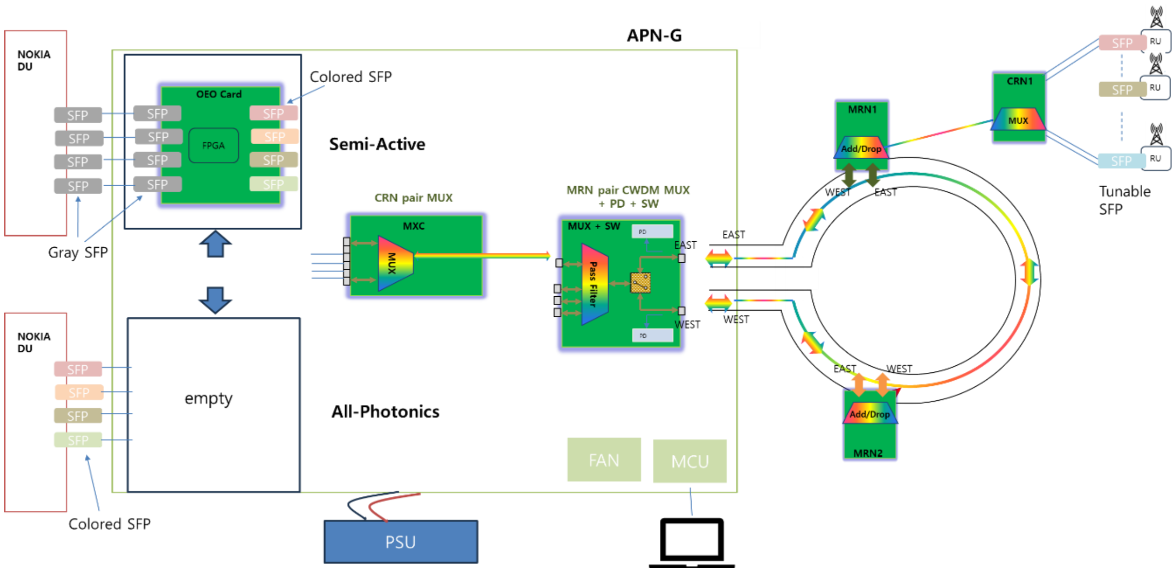

Figure 5 An outline of the PoC configuration

In this PoC, the optical transceivers (APN-T) were applied directly in the mobile systems such as DU and RU. The control and management channel of DWDM signals used Digital diagnostic monitoring interface through I2C. It is also possible to implement the additional control channel between optical transceivers with the auxiliary management and control channel, but it was not done in this PoC. APN-G of passive DWDM solution consists of WDM filters and optical switches, so it does not have the admission control in the user plane or the turn-back test function.

The optical interface between APN-T and ANP-G in this PoC is 25 Gbps eCPRI which corresponds to the exceptional case defined in Section 3.1 in the PoC reference.

The optical transmission/reception specification of O-band DWDM by the standardization body is not available at this moment. SK Telecom defined the detailed parameter of 25 Gbps optical transceivers described as below.

Parameter	Symbol	Min.	Typ.	Max.	Unit	Conditions
Optical Transmit Power	P_f	+4.5	-	+9.0		
Transmitter Disable(Off) Power	P_{off}	-	-	-35	dBm	@Tx_Disable is High
Peak Wavelength Stability	λsta	-100		+100	Pm	@end of life

Spectral Width@-15dB	△λ	-	-	0.21	nm	@-15dB
Spectral Width@-20dB	△λ	-	-	0.45	nm	@-20dB
Side Mode Suppression Ratio	SMSR	30	-	-	dB	
$RIN_{12}OMA$	RIN	-	-	-128	dB/Hz	
Receiver Sensitivity @SMF 20km	S			-20	dBm	For BER of 5E-5
Optical Overload	OL			-6	dBm	
Operational Temperature	Tc	-30		+85	℃	
Power Consumption	Pc			2.5	Watt	

Table 1 Optical specifications of 25 Gbps optical transceiver in this PoC

The wavelength assignment in this PoC was defined as the ITU-T manner. Channels of number 1 ~ 4 are the downstream direction and channels of number 5 ~ 8 are the upstream direction. One tunable transmitter covers the wavelength range of 4 channels.

Channel No.	Wavelength [nm]	ITU-T grid [THz]
1	1263.881	237.20
2	1264.680	237.05
3	1265.481	236.90
4	1266.283	236.75
5	1267.086	236.60
6	1267.889	236.45
7	1268.694	236.30
8	1269.500	236.15

Table 2 Wavelength assignment of 25 Gbps optical transceiver in this PoC

6. PoC Technical Report

6.1. Measurement Method

The goal of this PoC is to verify the power reduction of All-photonics solution compared to semi-active solution to accommodate the same number of fronthaul channels. The additional parameters including the uplink/downlink throughput, the propagation delay of fronthaul system and the recovery time of line protection were also measured.

To check the performance variation by fronthaul solutions, the downlink/uplink throughput from FTP server to a 5G smartphone was measured. 5G RF antenna and the smartphone under the test were located in the shielded box.

Web Element Manager (webEM) of Nokia 5G system provides the detailed information of optical transceiver in DU and RU with Digital Diagnostics Monitoring function. The types of SFPs were verified in each test case.
Power Supply Unit (PSU), which is N6705B from Keysight, provides DC +48 volts to COT shelf and indicates the current value of ampere at the moment. The power consumption was calculated as the product of the supplied voltage and the displayed current. To minimize the variation of power consumption by the fan, the air temperature was fixed during the testing. As the fronthaul signals are constant, there is no variation of power consumption regardless of the presence of the user traffic.

PoC procedure was performed as follows.

- Reference case
- Semi-Active fronthaul system case
- All-photonics fronthaul system case
- SFP power consumption measurement
- System propagation delay measurement
- Line Protection Test

6.2. Test result

6.2.1. Reference case

The reference case is checking 5G performance without fronthaul solutions. DU and RU were connected directly with grey optical transceivers.

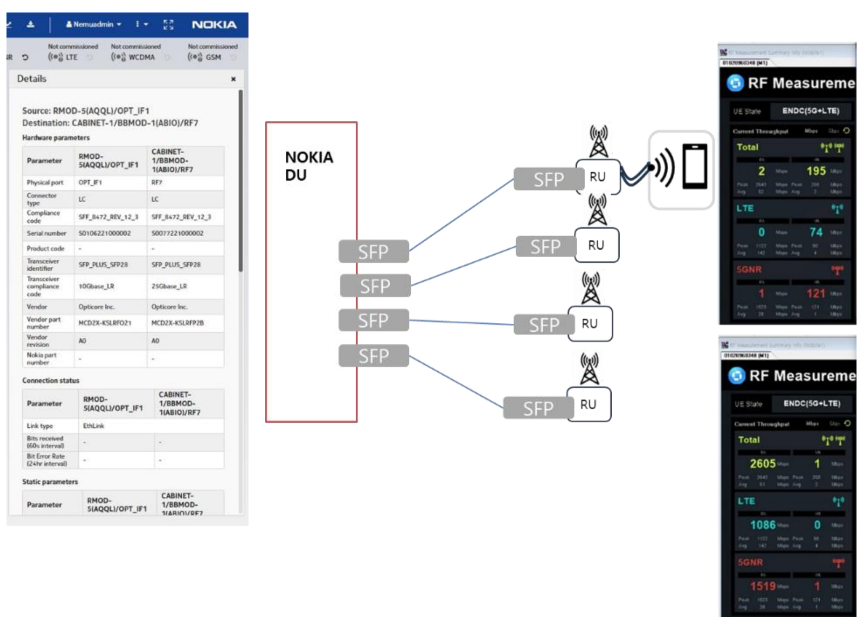

Figure 6 Reference case results - direct connection

- Optical transceivers in DU and RU was verified to be grey SFPs from Opticore Inc.
- DL traffic was generated and DL throughput measured to be 1519 Mbps.
- UL traffic was generated and UL throughput measured to be 121 Mbps.

6.2.2. Semi-Active fronthaul case

In Semi-Active fronthaul system, grey SFPs were applied to connect DU and OEO card, and tunable SFPs in OEO card faced to MUX.

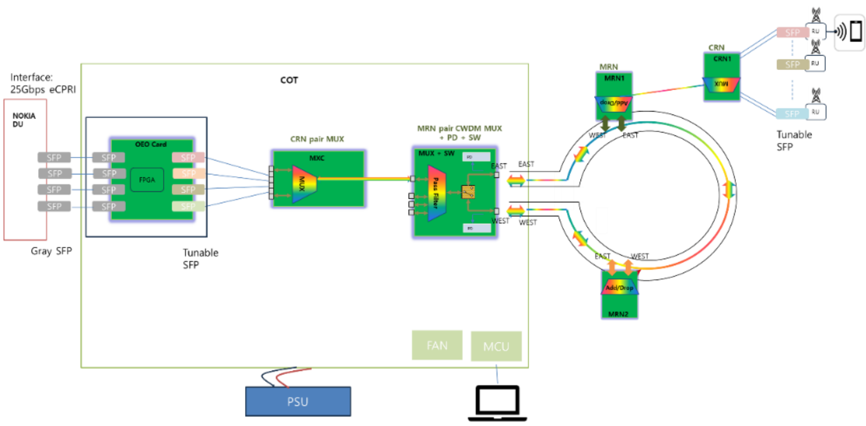

Figure 7 Network diagram of Semi-active fronthaul case

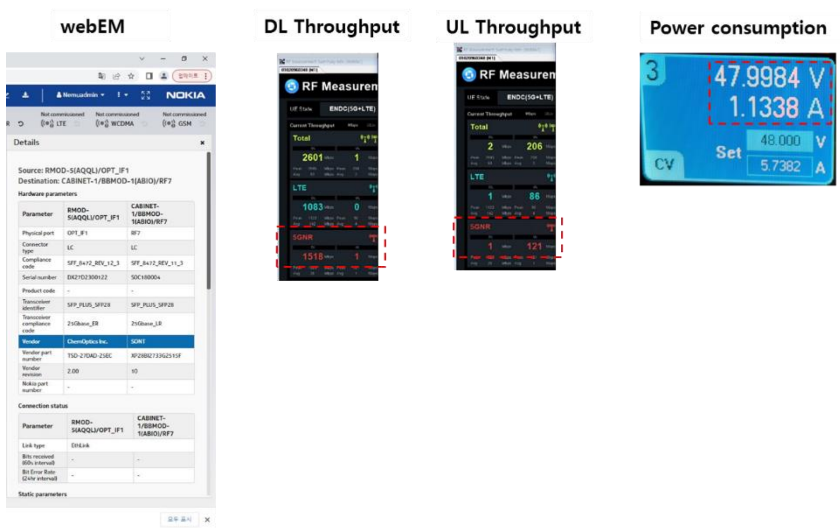

Figure 8 Semi-active fronthaul case results

- Optical transceiver in DU was verified to be grey SFP from SONT and that in RU was tunable SFP from ChemOptics Inc.

- DL traffic was generated and DL throughput measured to be 1518 Mbps.
- UL traffic was generated and UL throughput measured to be 121 Mbps.
- Power consumption of COT, which consisted of common units and OEO card, was calculated to be 54.42 W (= 47.9984 V x 1.1338 A)

6.2.3. All-photonics fronthaul case

In All-photonics fronthaul system, tunable SFPs in DU were connected to MUX.

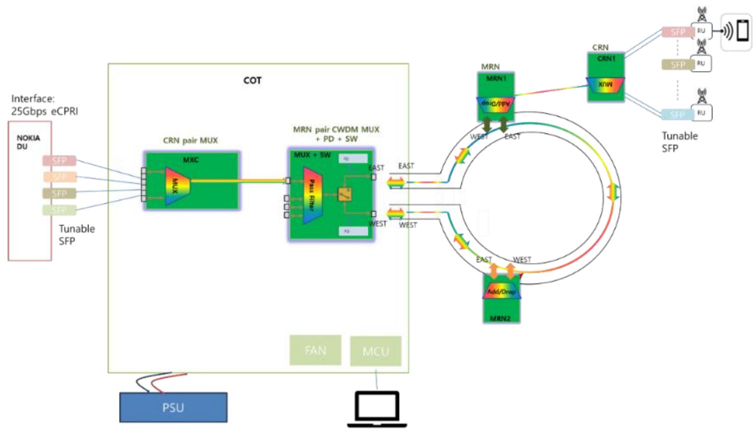

Figure 9 Network diagram of All-photonics fronthaul case

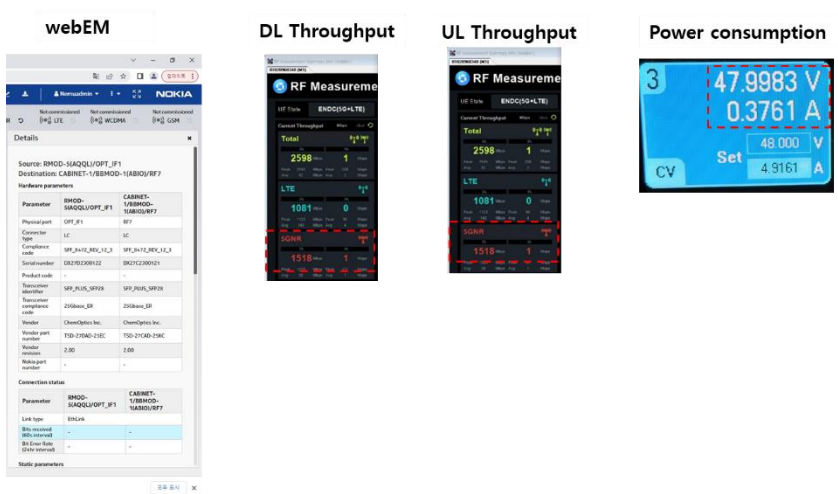

Figure 10 All-photonics fronthaul case result

- Optical transceivers in DU and RU were verified to be tunable SFPs from ChemOptics Inc.
- DL traffic was generated and DL throughput measured to be 1518 Mbps.
- UL traffic was generated and UL throughput measured to be 121 Mbps.

- Power consumption of COT, which consisted of common units, was calculated to be 18.05 W (= 47.9983 V x 0.3761 A)

6.2.4. SFP power consumption Measurement

Tunable SFP usually consumes more electrical power compared to grey SFP due to the temperature-controlled wavelength mechanism. The difference of SFP power consumption in DU between Semi-Active and All-photonics fronthaul should be taken into account for the comparison in COT sides. The power consumptions of SFPs on the jig board with full traffic were measured, thus the power of jig board should be extracted from the measured results.

Figure 11 SFP Power consumption measurement and results

- The power consumption of jig board measured to be 0.0363 W (= 3.3 V x 0.011 A)
- The power consumption of grey SFP was calculated to be 1.0196 W (= 3.3 V x 0.32 A – 0.0363 W)
- The power consumption of tunable SFP was calculated to be 1.1913 W (= 3.3 V x 0.372 A - 0.0363 W)

6.2.5. System propagation delay measurement

The propagation delay of two fronthaul systems were measured. All-photonics fronthaul system experienced a delay from the MUXs only. There are two different type of MRN, which are MRN1 and MRN2, with different group of wavelength bands. A MRN includes 15 m of SMF in both EAST/WEST directions in order to eliminate the geographical error when these two MRNs are installed at the same location. The delay of All-photonics fronthaul system was measured in the configuration of long path, which is a total of 45 m. The system delay of Semi-Active Fronthaul is the sum of propagating OEO card and the MUXs.

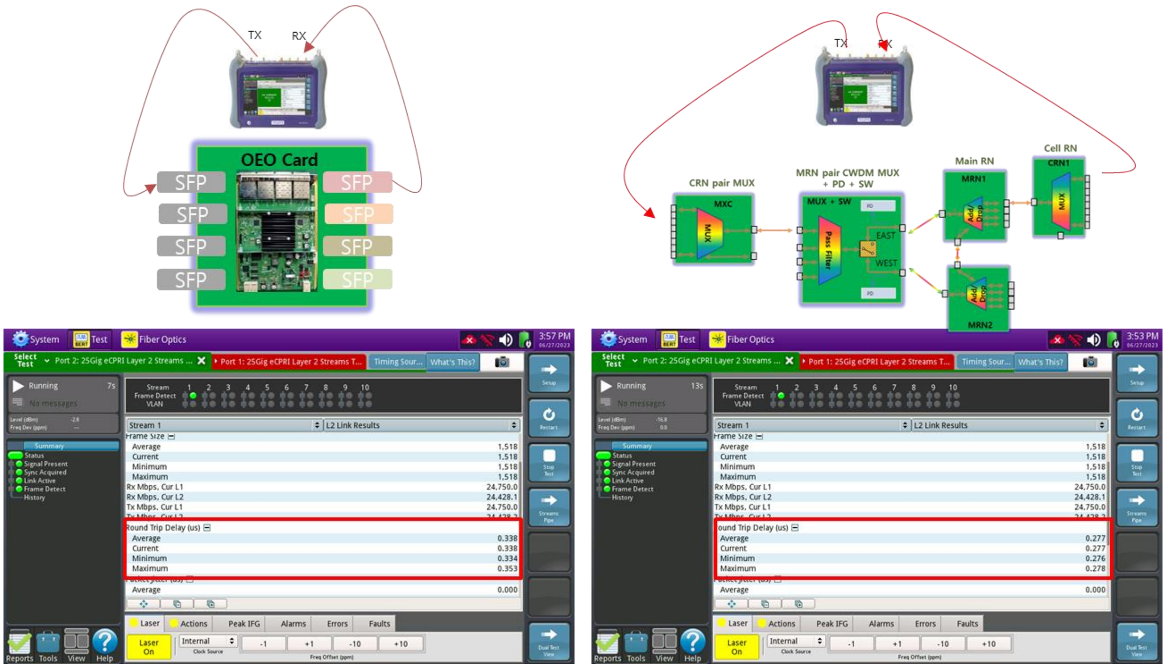

Figure 12 System delay measurement results

- The propagation delay on OEO card measured to be 0.338 us.
- The propagation delay on the MUXs measured to be 0.277 us, which was the delay of All-photonics fronthaul system.
- The delay of Semi-active fronthaul system was calculated to be 0.615 us (= 0.338 us + 0.277 us)

6.2.6. Line Protection Test

Both Semi-Active Fronthaul and All-photonics Fronthaul were designed in a single ring network structure to be prepared for a fiber cut. OSW in COT monitors the incoming optical powers of east/west line and switches to the other line if Loss of Signal (LOS) occurs in working line. The switching time of OSW is required to be less than 50 msec.
In this PoC, the switching time of OSW were measured in two use cases. Manual switching is the case that the user send a command of changing the line to OSW with the operational tool of fronthaul system. Automatic switching is the case that the optical cable of working path was plugged out, OSW senses LOS and changes the line. The test was performed in 5 time of switch operation in both cases and the worst results were noted.
There is no difference in switching time results with Semi-Active Fronthaul system and All-photonics Fronthaul system because OSWs used in both systems are same.

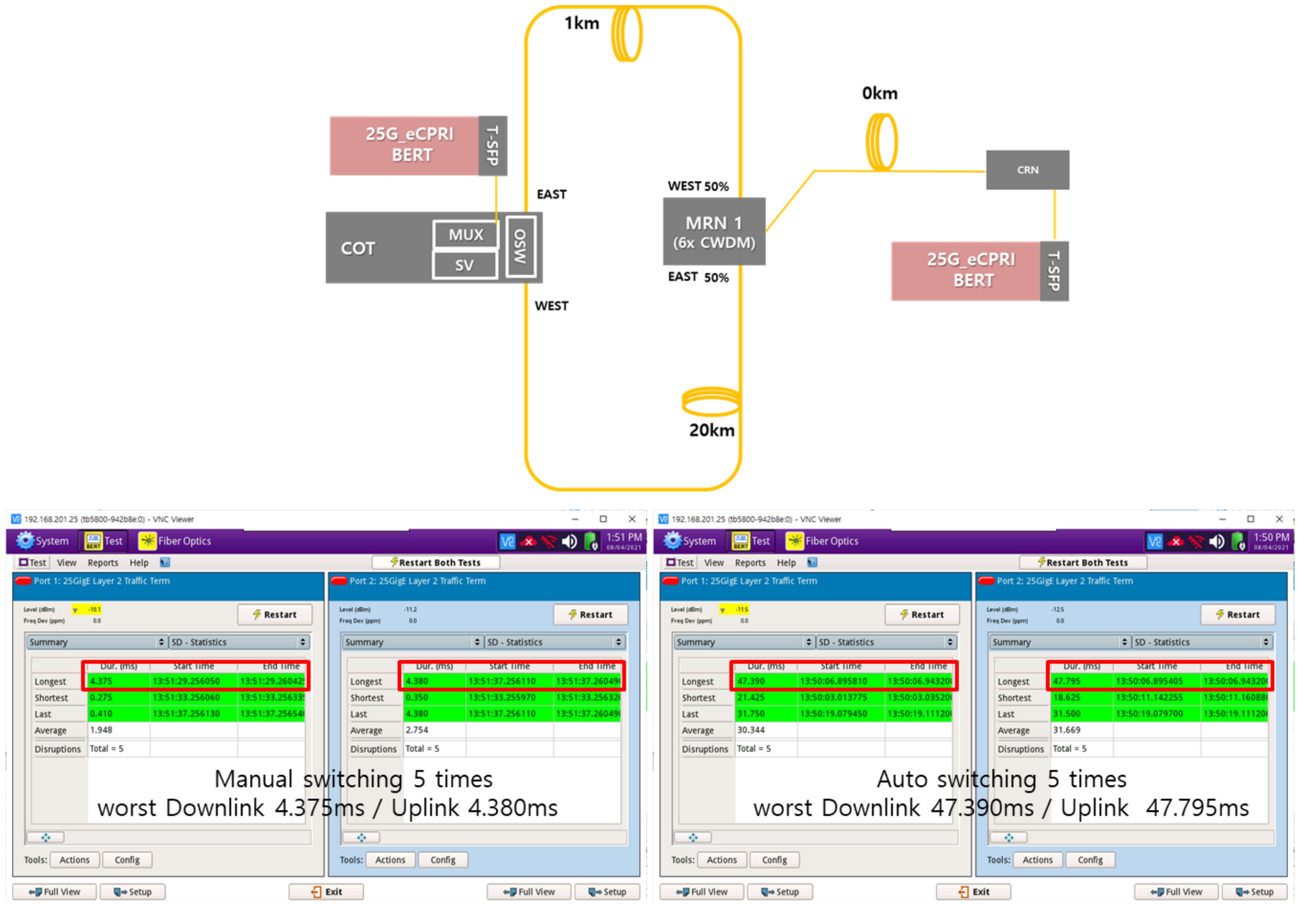

Figure 13 Line Protection Test Results

- The worst results of switching time in manual switching were 4.375 ms for Downlink and 4.380 ms for Uplink.
- The worst results of switching time in automatic switching were 47.390 ms for Downlink and 47.795 ms for Uplink.

6.3. Analysis of results

The information of optical transceivers in 5G system was verified by Nokia webEM regardless of the SFP types. During the PoC, any performance degradation in terms of DL/UL throughput by fronthaul solutions was not observed.

Through this PoC Test, it was confirmed that the All-photonics fronthaul has a power saving effect of about 86.61% compared to the Semi-Active fronthaul. The following conditions were used for examining the power consumption of fronthaul solutions.

1) The full capacity of fronthaul solutions is 96 channels. 2) The fronthaul solutions in RU has the same configuration and is not considered in this power consumption comparison. 3) The power

consumption of optical transceiver in DU is included because the different types of SFP are applied for Semi-Active fronthaul and All-photonics fronthaul solution.

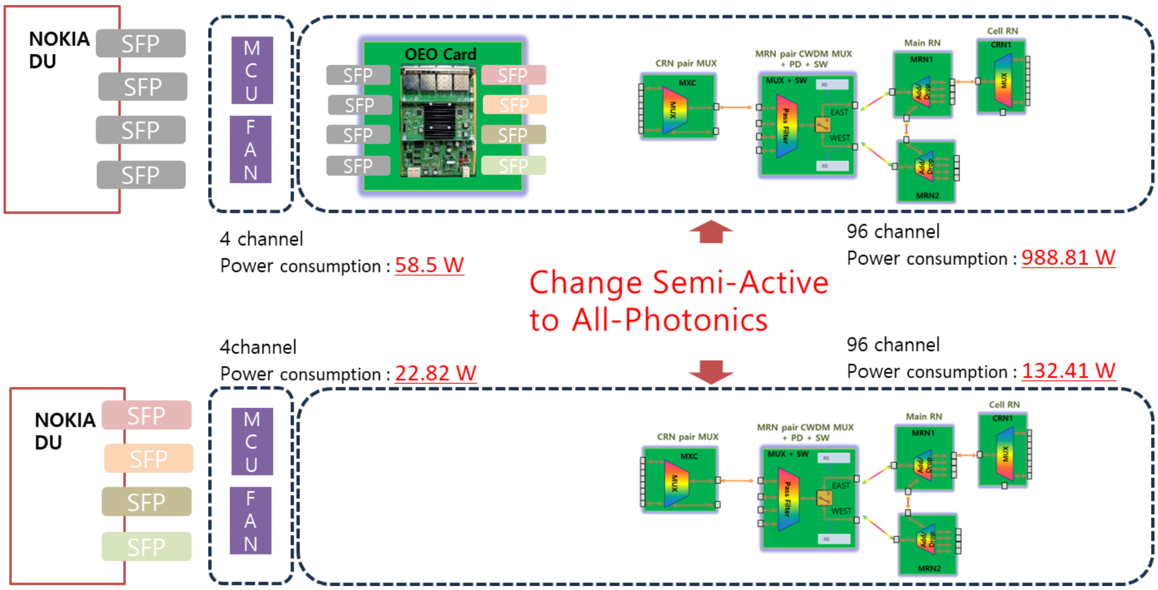

Figure 14 Change Semi-Active to All-photonics (그림에 용어 수정 필요)

	4 channel				96 channel				Save power (%) *
	Common (W)	OEO Card(W)	DU SFP(W)	Total(W)	Common (W)	OEO Card(W)	DU SFP(W)	Total(W)	
Semi-Active	18.05	36.37	4.08	58.50	18.05	872.88	97.88	988.81	-
All-photonics	18.05	-	4.77	22.82	18.05	-	114.36	132.41	**-86.61**

Table 3 Analysis of fronthaul power consumption results

* Power saving is expressed as a percentage of how much less power is consumed.

The power consumption of the Semi-Active fronthaul with 4 channels is 58.5 W. This is the sum of a common units in COT (18.5 W), the OEO card (36.37 W), and four Grey SFPs in DU (4.08 W). The power consumption of the All-photonics fronthaul with 4 channels is 22.82 W, which is the sum of a common units in COT (18.5 W) and four tunable SFPs in DU (4.77 W).

The total power consumption of the Semi-Active fronthaul with full capacity is calculated to be 988.81 W. This is the sum of a common units in COT, 24 OEO cards (872.88 W) and 96 Grey SFPs in DU (97.88 W). The total power consumption of the All-photonics fronthaul with full capacity is calculated to be 132.41 W, which is 86.61 % less than Semi-Active fronthaul. This is the sum of a common units in COT, and 96 tunable SFPs in DU(114.36 W).

6.4. PoC Technical Finding

<table>
<tr><td>Objective Id:</td><td colspan="2">TBD</td></tr>
<tr><td>Description:</td><td colspan="2">Description of the PoC Demo Objective:
Comparison of Power Consumption between Semi-Active Fronthaul and All-photonics Fronthaul</td></tr>
<tr><td>Pre-conditions</td><td colspan="2">4 fronthaul channels were configured in this PoC to measure the power consumption and to estimate that with full capacity.</td></tr>
<tr><td rowspan="6">Procedure:</td><td>1</td><td>Reference case</td></tr>
<tr><td>2</td><td>Semi-Active fronthaul case</td></tr>
<tr><td>3</td><td>All-photonics fronthaul case</td></tr>
<tr><td>4</td><td>SFP power consumption Measurement</td></tr>
<tr><td>5</td><td>System propagation delay measurement</td></tr>
<tr><td>6</td><td>Line protection test</td></tr>
<tr><td>Finding Details:</td><td colspan="2"></td></tr>
<tr><td>Lessons Learnt & Recommendations</td><td colspan="2">What was learnt with this demo? What are the recommendations for IOWN GF work or the industry as a whole?
As a result, it was found that All-photonics fronthaul system consumed 86.6 % less power than semi-active fronthaul system for a 96-channel configuration.</td></tr>
</table>

7. PoC's Contribution to IOWN GF

Contribution	WG/TF	Study Item (SI)/Work Item (WI)	Comments
Energy efficiency	IMN	NA	This PoC demonstrates energy saving feature of mobile transport network.

8. PoC Suggested Action Items

8.1. Gaps identified in relevant standardization

- NA

8.2. PoC Suggested Action Items

- This Step 1 PoC worked with Physical Network Function-based 5G system. Step 2 PoC which will show the dynamic reconfiguration function of mobile fronthaul is recommended to work with Virtual Network Function-based mobile system.

8.3. Any Additional comments the PoC Team wishes to make?

- NA.

8.4. Next Step

Through this PoC, it can be seen that All-photonics fronthaul is advantageous in reducing power consumption. A switching function that supports dynamic configuration can be included to further power consumption reduction in All-photonics fronthaul. Dynamic configuration of mobile system resources is a way that reduces power consumption because the resource usages of DUs and RUs do not show a constant utilization rate in all regions and times.

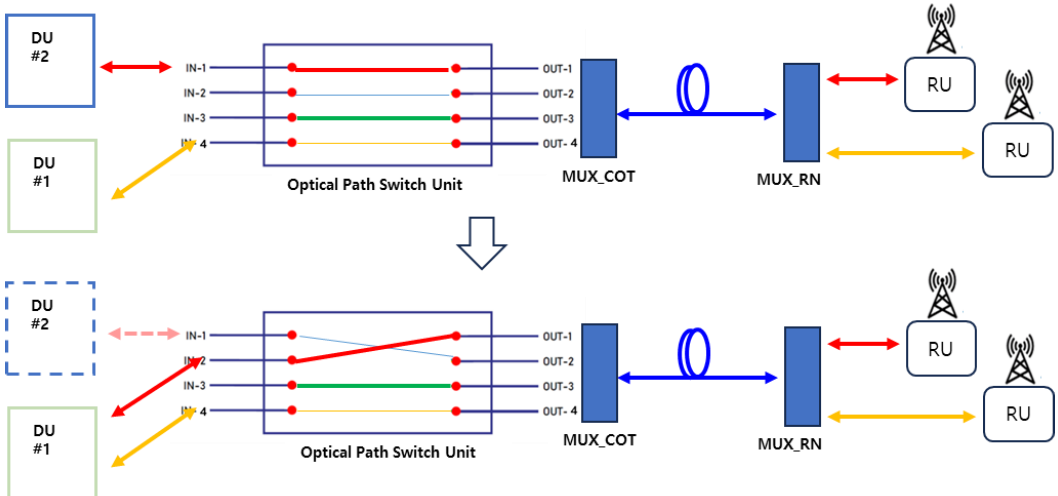

Figure 15 Fronthaul dynamic allocation scenario

The purpose of step 2 PoC is to verify the functionality of dynamic reconfiguration in All-photonics fronthaul system. A optical path switch will be implemented in the COT of All-photonics fronthaul system to support the change of the connection between DU and RU. The step 2 PoC is expected to be completed by December 2023.

9. Document History

Version	Date	By	Description of Change
1.0	July 27, 2023	Hongseok Shin, SK Telecom	Initial draft
1.1	Nov 27, 2023	Hongseok Shin, SK Telecom	Updated version according to WG review
1.2	Jan 10, 2024	Hongseok Shin, SK Telecom	Updated version according to IMN TF review
1.3	Jan 16, 2024	Hongseok Shin, SK Telecom	Updated version according to additional IMN TF review
1.4	Feb. 14, 2024	Hongseok Shin, SK Telecom	With cover page

10. Reference

[1] IOWN Global Forum, "Mobile Fronthaul over APN PoC Reference" (2022.09)
[2] MOPA Technical Paper v2.2 (https://mopa-alliance.org/papers-and-presentations/)