New Photonic Gateway to Handle Digital-Coherent and IM-DD User Terminals and Enable Turn-back Connections in Metro/Access-Integrated All-Photonics Network

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Abstract: We propose and demonstrate a novel Photonic Gateway architecture that can flexibly and scalably handle both 100-Gbit/s digital-coherent and IM-DD user terminals with direct optical connections including turn-back channels.

1. Introduction

Emerging use cases based on advanced technologies (e.g., digital twin computing, VR) are demanding guaranteed large-bandwidth and extremely low end-to-end latency and jitter. Unfortunately, today's networks typically convert all optical signals into electrical signals when transferring traffic from access to metro sections. Then, electrical aggregation or multiplexing is applied, which limits the effective bandwidth per user and service and induces delay and jitter. Based on these background, we proposed the Photonic Gateway (GW) as the access node of the All-Photonics Network (APN) [1, 2]. APN provides optical transport for Innovative Optical Wireless Network (IOWN) in which computing and networking are deeply converged for advanced distributed computing [3]. APN flexibly provides direct optical connections between any endpoints, e.g., end-user premises, edge cloud, and center cloud.

The Photonic GW can handle various types of optical paths including non-DWDM for short reach (e.g., MFH) as well as DWDM by using fiber cross-connects (FXCs). The Photonic GW realizes convergence between access and metro by multiplexing/demultiplexing and routing DWDM optical paths that cross the boundary between the access and metro without optical/electrical conversion. The Photonic GW has two unique functions. The first is the provisioning of control channels to user terminals (UTs) [3]. Since the optical-path endpoints could be in end-user premises or in cloud operator's facility, unlike conventional ROADM-based metro networks, remote and in-channel control to the UT via the Photonic GW is indispensable. End-to-end optical-path setup and reconfiguration were demonstrated in [4], by provisioning 10G Ethernet and raw 4K HDMI as the main signals to 10-Gbit/s Intensity Modulation and Direct Detection (IM-DD) UTs. To achieve operation independent of the main-signal protocol, the AMCC, which is an out-of-band channel in the lower frequency region [5], was used when the Photonic GW mediates control-signal exchange between the APN controller (APN-C) and the UTs. However, end-to-end optical path provisioning for digital coherent UTs has not been demonstrated yet. The second unique function of the Photonic GW is turn back [3]. This function provides the shortest path between the UTs under the same Photonic GW to realize local communication that satisfies strict latency requirements. The number of UTs accommodated in the Photonic GW can be increased in a scalable manner by arranging the FXCs in parallel. Therefore, it is necessary to investigate a scalable turn-back configuration where a UT under one FXC can be connected to another UT under any FXC.

In this paper, we propose a novel architecture of the Photonic GW that enables digital coherent UTs as well as IM-DD UTs to be provided with direct optical connections including turn-back channels flexibly and scalably. By exchanging control signals on a wavelength different from the wavelength of the main-signal light, insertion and extraction of control signals are easily implemented at the Photonic GW regardless of the modulation/detection method of the main signal. A newly incorporated turn-back module realizes flexible and scalable connectivity between FXCs. Demonstrations using Photonic GW prototypes and 100-Gbit/s digital coherent and 10-Gbit/s IM-DD UTs verify the feasibility of the proposed Photonic GW architecture.

2. Proposed Photonic GW architecture and remote UT control

Figure 1 shows a proposed architecture for the Photonic GW. The Photonic GW operates in accordance with the directions of the APN-C. The Photonic GW mainly consists of FXCs, wavelength multiplexers/demultiplexers (λ MUX/DEMUX), turn-back module, direction modules and a control-signal mediator. By using FXC, the Photonic GW can not only forward the C/L-band DWDM optical paths to the neighboring node without optical/electrical conversion but also allow short-reach non-DWDM optical paths to be dropped to outside the Photonic GW and terminated between the access/metro boundary for some processing in the network or service function layers.

For remote and in-channel control of UTs, the control-signal mediator sends/receives control signals on a wavelength of λ_C, which is a wavelength different from the wavelength of main-signal light, λ_M. The control-signal light is multiplexed with the main-signal light and transmitted between the Photonic GW and the UT. This control approach has three features. First, it does not require each optical path to have a relatively expensive external modulator unlike the scheme that superimposes the control signal on the main-signal light as AMCC at the Photonic GW [6]. Instead, the Photonic GWs are equipped with the low-cost optical components (e.g., directly modulated narrow bandwidth lasers, wavelength-band multiplexers) widely used for cost-sensitive access applications. Second, the Photonic GW can keep on transmitting the control signal even when the main-signal light does not input from the metro unlike the scheme in [6]. Third, the Photonic GW can easily exchange control signals with UTs regardless of the modulation/detection method or protocol of the main signal. This is because the main-signal and control-signal lights are easily demultiplexed at the input of the UTs, and detected separately.

The turn-back module is connected to each FXC. The turn-back module has wavelength routing capability. An optical signal input from a FXC is returned to one of the FXCs depending on its wavelength. This architecture has two features. First, the Photonic GW can flexibly provide any two UTs under the same Photonic GW with the shortest optical path between them, regardless of whether the UTs are connected to a single FXC or to different FXCs. Second, the Photonic GW can be scaled out easily. This is because adding new FXCs to increase the number of UTs accommodated in the Photonic GW does not require new fibers between the existing FXCs and the turn-back module. The number of FXC ports reserved on the side of the turn-back module remains unchanged regardless of the number of FXCs unlike architectures without the turn-back module where FXCs are directly connected to all other FXCs to achieve turn-back.

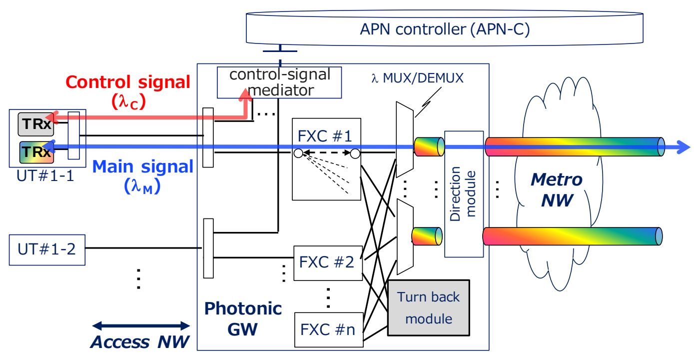

Fig. 1 Proposed Photonic GW architecture.

3. Experimental Results

Figure 2 illustrates the experimental setup. Two Photonic GW prototypes (Ph-GWs) were connected in a ring topology. Each Ph-GW had one or two piezo-based optical SWs for FXC, 50 GHz-spacing arrayed waveguide gratings (AWGs) for λ MUX/DEMUX, wavelength selective switches (WSSs) for turn-back and direction modules, and a whitebox switch (WB-SW) serving as a control-signal mediator. Ph-GW #1 included 96×96 and 32×32 optical SWs while Ph-GW #2 and #3 included a 32×32 optical SW. The turn back module was constructed with two twin 1×20 WSSs connected back-to-back. For direction modules, twin 1×20 WSSs were used. The WB-SWs with 1000BASE-EX TRxs sent/received control signals in the 1.3-µm band to/from the UTs. The control-signal light is multiplexed/demultiplexed with the 1.5-µm main-signal light through an O/C-band filter.

The Ph-GWs were controlled by a single APN-C, which was implemented on an Ubuntu server. The port connection inside the optical SWs and WSSs was controlled over the NETCONF interface. The wavelength-allocation algorithm implemented in the APN-C assigned the longest wavelength among unused ones on the route to a new optical path.

Three types of UTs were used. First, for UT #1-N (N =1, 2, 3), a coherent transport switch, Galileo 1, functioned as a 100-Gbps digital coherent UT for Ethernet signals. A full C-band tunable CFP2-ACO TRx was inserted to transmit/receive the 100-Gbps DP-QPSK main-signal. The wavelength of the CFP2-ACO TRx was set according to the control signal received by a media converter equipped with a 1000BASE-EX TRx. Second, for UT #2-N, a WB-SW equipped with a full C-band tunable IM-DD TRx and a 1000BASE-EX TRx functioned as a 10-Gbps IM-DD UT for Ethernet signals. Third, for UT #3-N, two TRx evaluation boards were connected back-to-back as a 10-Gbps IM-DD UT for non-Ethernet signals. The wavelength of the full C-band tunable IM-DD TRx on the line-side evaluation board was controlled by a Raspberry Pi according to the control signal received by a media converter equipped with a 1000BASE-EX TRx. As a non-Ethernet signal, a 8.91-Gbps HDMI signal that carried an uncompressed 4K video stream (RGB 4:4:4 8 bit) at 30 fps was used.

We established new optical paths under the following scenarios. It was assumed that six optical paths with the wavelength of 1560.60 nm (λ1), 1559.79 nm (λ3), 1558.98 nm (λ5), 1558.17 nm (λ7), 1557.36 nm (λ9), 1556.55 nm (λ11) had been setup between Ph-GWs #1 and #2 in advance. At step #1, three optical paths in turn-back configuration via the 96×96 and 32×32 optical SWs in Ph-GW #1 were setup so that UTs #1-1, #2-1, and #3-1 were connected to UTs #1-2, #2-2, and #3-2, respectively. Then, at step #2, the endpoints of optical paths from UTs #1-1, #2-1, #3-1 were changed to UTs #1-3, #2-3, #3-3 under Ph-GW #2 so that an optical path for direct optical connection that crossed two Ph-GWs was realized.

Figure 3(a) shows an event log recorded at APN-C at step #1. This clearly shows that the optical-path provisioning was autonomously performed. Fig. 3(b) and (c) are the optical spectra at steps #1 and #2. In step #1, UTs #1-1, UTs #2-1, and UTs #3-1 were assigned wavelengths of 1560.60 nm (λ1), 1560.20 nm (λ2), and 1559.79 nm (λ3), in order. In step #2, UTs #1-1, UTs #2-1, and UTs #3-1 were assigned wavelengths of 1560.20 nm (λ2), 1559.38 nm (λ4), and 1558.57 nm (λ6) to avoid collision with the existing optical paths. These results validate the wavelength-allocation algorithm implemented in APN-C. Fig. 3(d) is the transition of received rates of UT #1-1 and UT #2-1. This shows that UTs connected to UTs #1-1 and #2-1 were changed from UT #1-2 with input rate of 60 Gbps to UT #1-3 with input rate of 80 Gbps and from UT #2-2 with input rate of 6 Gbps to UT #2-3 with input rate of 8 Gbps, respectively.

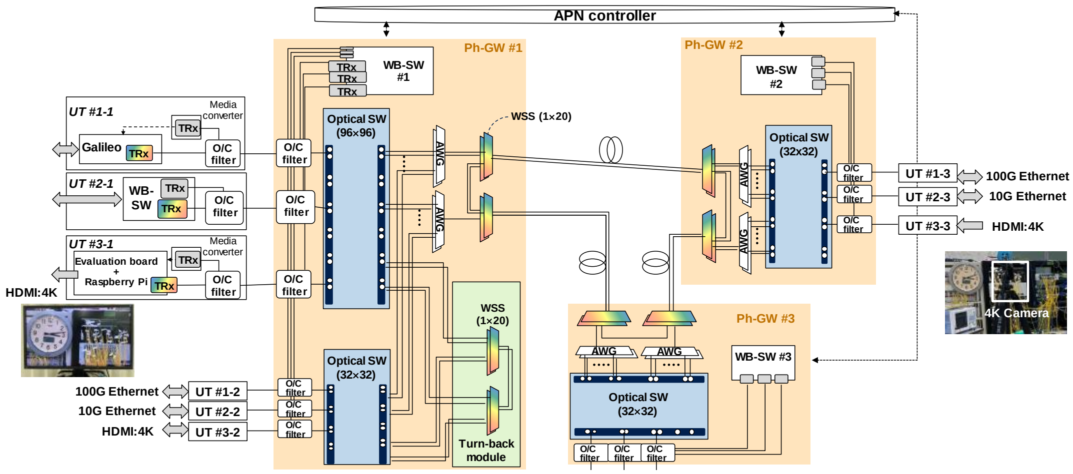

Fig. 2 Experimental setup

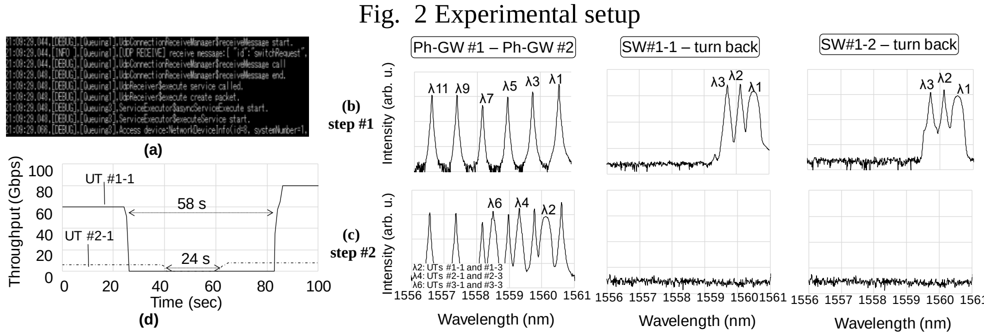

Fig. 3 (a) Event log, (b), (c) Optical spectra, (d) Throughputs of 100G and 10G UTs.

4. Conclusions

A novel Photonic GW architecture was proposed to handle both digital-coherent and IM-DD UTs and turn-back optical connections in a scalable manner in a future metro/access-integrated APN. Experiments confirmed optical-path rearrangements using the remote control of such multiple types of UTs, as well as the scalable turn-back functionality across multiplex FXCs.

References

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