Port-Agnostic Path Establishment with Point-to-Multipoint Control of Remote User Terminals for Metro/Access-Integrated All-Photonics Network

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Abstract: We propose a port-agnostic initial-connection sequence allowing simultaneous connection of multiple user terminals (UTs), and demonstrate end-to-end wavelength-path and fiber-path establishment for DWDM and non-DWDM UTs through point-to-multipoint-type remote UT control in Metro/Access-Integrated All-Photonics Network.

1. Introduction

Emerging cloud-native real-time use cases and advanced cyber-physical fusion using distributed computing require guaranteed wide-bandwidth and deterministic latency properties, which are difficult for conventional hierarchical networks based on statistical multiplexing to achieve. One direction of network evolution is to integrate access and metro networks [1, 2]. We proposed metro/access-integrated all-photonics network (APN) where the dense wavelength-division-multiplexing (DWDM)-based metro network is extended into access areas. APN provides end-to-end wavelength connectivity between any endpoints with wavelength cross-connect (WXC) functions, and guarantees wide bandwidth, low latency and low jitter. By extending the APN architecture, fiber-paths can be dynamically provided as a new fiber-path layer is defined based on fiber cross-connect (FXC) under the conventional DWDM layer based on WXC [3]. Fiber paths are end-to-end tunnels that can be used regardless of the wavelength without sharing.

In APN, the endpoints of the wavelength and fiber paths are located at the user premises or at the data-center operator's facility in addition to within the network operator's building. This requires remote and in-channel user-terminal (UT) control to flexibly extend the APN area beyond the carrier control-plane network. For the access node defined as a Photonic Gateway (GW), an architecture has been proposed that uses a wavelength different from the main signal light to remotely control the UT [4]. This scheme enables the APN to control and manage UTs regardless of the signal type and modulation/detection method of the main signal. [4] demonstrated autonomous setting of only wavelength paths by providing 10G Ethernet, 100G Ethernet, and raw 4K HDMI video as the main signals to two types of DWDM UT based on 10-Gbit/s Intensity Modulation and Direct Detection (IM-DD) and 100-Gbit/s digital coherent. However, the number of UTs that can be accommodated by the Photonic GW is limited since control signals are transmitted over point-to-point links and the control-signal mediator in the Photonic GW needs to have as many control transceivers as there are UTs.

This paper proposes a novel port-agnostic method to remotely control UTs using a point-to-multipoint (P2MP) control-plane configuration while the end-to-end wavelength/fiber path of the main signal remains in a point-to-point configuration. We present a sequence that actualizes path settings based on the autonomous recognition of physical connectivity between a new UT and the Photonic GW even when multiple new UTs are connected to the APN at the same time. The proposed method improves scalability in terms of the maximum number of UTs supported. The feasibility of the proposed method is verified through wavelength-path provisioning for 100-Gbps DWDM digital coherent UTs as well as fiber-path provisioning for 25-Gbps O-band IM-DD UTs using a disaggregated Photonic GW prototype employing XGS-PON [5] for remote UT control.

2. Proposed autonomous initial-connection sequence with point-to-multipoint-type remote UT control

Figure 1(a) shows a Photonic GW architecture employing P2MP-type remote UT control. The Photonic GW is controlled by APN controller (APN-C), which manages the resources of the entire APN. The Photonic GW has the FXC function in the fiber-path layer and reconfigurable optical add/drop multiplexing (ROADM)-like add/drop and WXC functions in the wavelength-path layer [3]. In addition, the Photonic GW has a function for remote UT control.

For remote and in-channel control of UTs, the control-signal mediator sends/receives control signals on a wavelength that is different from the main-signal light wavelength. The downstream control-signal light is split through a power splitter, and then multiplexed with the main-signal light towards the UT. The upstream control-signal light from each UT is separated from the main-signal light through a wavelength filter and multiplexed with each other. This scheme has following features. First, one transceiver inserted into the control-signal mediator communicates with multiple UTs, increasing the maximum number of UTs that the Photonic GW can accommodate. Second, technically mature and affordable optical access systems such as 1G/10G-class TDM-PON can be employed since the control-plane has no significant bandwidth or latency requirements. PON is based on bidirectional transmission, so even when dual-fiber transmission is employed for the main-signal light, the upstream and downstream control signals can be transmitted on only one of the two fibers for the main signal. This halves the number of wavelength filters in the Photonic GW.

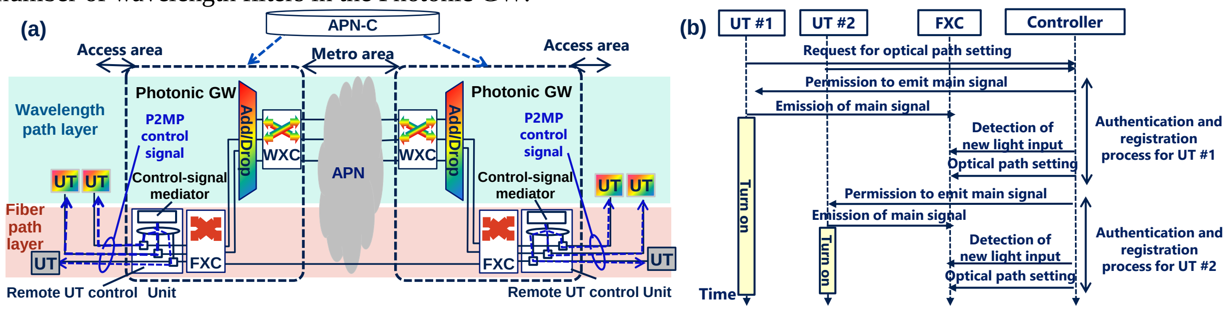

Fig. 1 (a) Photonic GW architecture, (b) Sequence of autonomous initial connection.

Figure 1(b) shows the proposed sequence for the autonomous initial connection, i.e., plug and play, necessary for optical-path setup. APN-C should autonomously discover physical connectivity between a newly connected UT and the Photonic GW via field access fibers. This is because appropriate connection settings inside the Photonic GW are essential to transferring optical signals between the allocated transmission route on the metro side and the access fiber extending the endpoint to the access area. APN-C gives permission to start emitting main-signal light to a UT requesting optical-path setup only after successfully authenticating and registering the UT. The APN-C recognizes that the FXC port that newly detected optical input is physically connected to the UT that requested optical-path setup. Note that the UT continues to turn off main-signal light until permission to emit light is obtained. Even when multiple UTs connect to the APN at the same time, APN-C recognizes physical connectivity between each UT and the Photonic GW in a sequential manner by staggering the start of emission of the main-signal light at sufficient intervals as shown in Fig. 1(b). At the beginning of the sequence, the UT reports its type (DWDM, non-DWDM) and the requested path type (wavelength path, fiber path). Based on these reports, APN-C provides a wavelength path or fiber path after the process of initial connection.

3. Experiments and results

Figure 2 illustrates the experimental configuration. Two Photonic GW prototypes (Ph-GWs) were connected via a 40-km point-to-point link and controlled by a single APN-C. The configuration of each Ph-GW is functionally disaggregated. 96×96 and 32×32 piezo-based optical switches (SWs) were used in Ph-GW #1 and #2, respectively, for FXC on the fiber path layer. Commercial colorless, directionless, contentionless (CDC) ROADM blades were used for add/drop and WXC functions on the wavelength path layer. The function block for remote UT control consists of an SFP+-type XGS-PON OLT inserted into the layer-2 SW and wavelength filters. Since the upstream and downstream operating wavelength ranges of XGS-PON are 1260-1280 nm and 1575-1580 nm, respectively [5], both C-band and O-band main-signal lights can be multiplexed with control signals carried over XGS-PON. O-band is widely used for short-reach non-DWDM applications e.g., MFH. Inset (a) shows the transmission characteristics of the wavelength filter installed in the Photonic GW and each UT. The APN-C controls the optical SWs, the ROADM blade for WXC through the NETCONF interface while UDP is used for remote UT control. The wavelength-allocation algorithm for wavelength path implemented in the APN-C assigned the longest of the unused wavelengths on the route to a new wavelength path.

Two types of UTs were used. First, for UT #M (M =1, 2, 3, 4), a whitebox switch (WBS) equipped with a 25-Gbps wavelength-fixed O-band transceiver (TRx) functioned as a 25-Gbps non-DWDM IM-DD UT. While wavelength-fixed UT #M does not require wavelength control, an XGS-PON ONU in UT #M communicates with the XGS-PON OLT in the Ph-GW for authentication, registration, and request for fiber-path setup. Second, for UT #N (N =5, 6, 7, 8), a coherent transport switch, Galileo 1, functioned as a 100-Gbps DWDM digital coherent UT. 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 the XGS-PON ONU.

We established new optical paths under the following scenarios. It was assumed that five optical paths with wavelength of 1558.98 nm (λ1), 1558.17 nm (λ2), 1556.55 nm (λ4), 1554.94 nm (λ6), 1554.13 nm (λ7) had been setup between Ph-GWs #1 and #2 in advance. At step #1, two fiber paths in turn-back configuration via the 96×96 optical SW in Ph-GW #1 were setup so that UTs #1 and #2 were connected to UTs #3, and #4, respectively. Then, at step #2, two wavelength paths across Ph-GW #1 and #2 were setup so that UTs #5 and #6 were connected to UTs #7, and #8, respectively. Traffic received by UTs #3 and #4 were aggregated at UT #6 and transmitted towards UT #8.

Figure 3(a) shows the transition of main-signal light power at the 96×96 optical SW input when UTs #1 and #2 are connected at the same time. With the proposed sequence, each UTs emitted main signal with different timing according to the controller's direction. As shown in Fig. 3(b), based on the autonomously recognized ports, internal connections inside the 96×96 optical SW are properly for fiber-path setup. Fig. 3 shows the throughput between UTs #7 and #8 when the input data rate to UTs #1 and #2 are 25 Gbps and 15 Gbps, respectively. This plot reveals that two fiber paths are setup sequentially. For comparation, we investigated the case where the APN-C does not control the emission timing of main-signal light. As shown in Fig. 3(d), the main-signal lights from UTs #1 and #2 reached to the at the same time. In this case, the APN-C cannot identify which port connects to UT #1 or UT #2. When port connected to UT #1 is incorrectly identified as UT# 2, UT #1 is connected to UT #4 which should be connected to UT #2. The success rate of autonomous port identification against duration between connecting UT #1 and connecting UT 2, Δt, is shown in Fig. 3(f). The AOMs are used as a shutter to control the length of Δt. While port is always successfully identified regardless of the length of Δt using the proposed sequence, at least 6 seconds is needed to avoid fail in port identification when the emission timing of main-signal light is not controlled. Inset (b) in Fig. 2 shows the spectrum between Ph-GWs #1 and #2. It was confirmed the new wavelength-path establishment using unused wavelengths according to the wavelength assignment algorithm implemented in the APN-C.

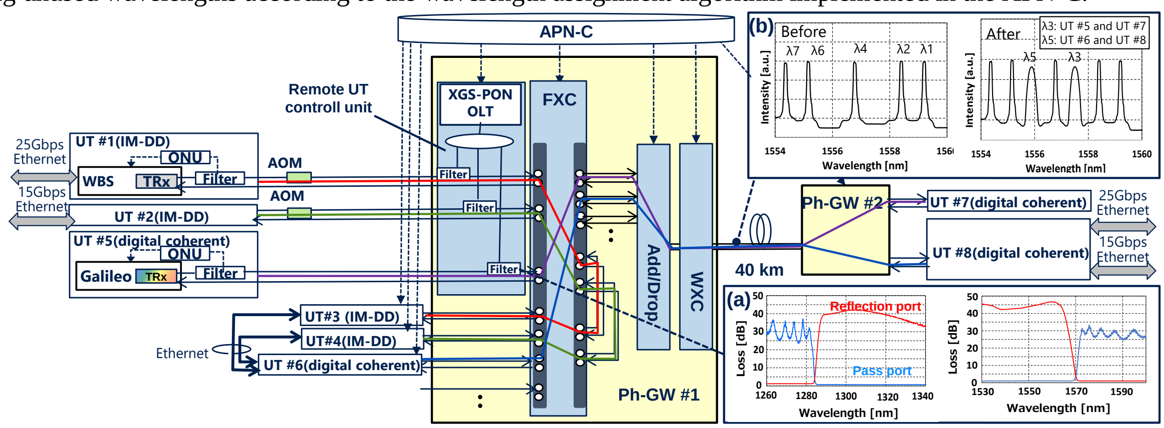

Fig. 2 Experimental configuration.

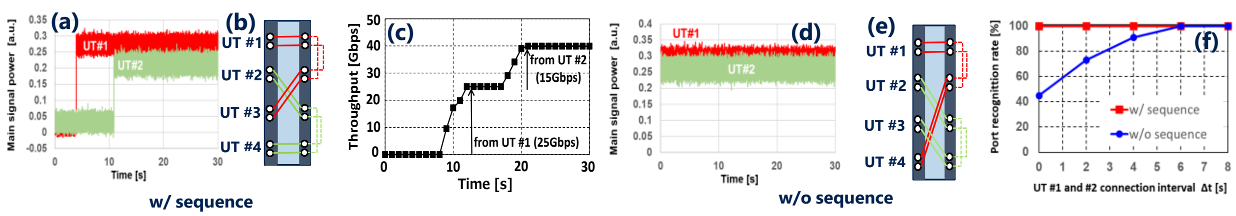

Fig. 3 (a) Optical power at optical SW (w/), (b) Optical SW configuration (w/), (c) Throughput at UT #6, (d) optical power at optical SW (w/o), (d) Optical SW configuration (w/o), (f) Success rate of autonomous port identification.

4. Conclusions

We proposed a port-agnostic initial-connection sequence for remote UTs with P2MP control-plane configuration. Experiments confirmed its feasibility through the autonomous establishment of 100-Gbps C-band and 25-Gbps O-band connections on wavelength and fiber path layers, respectively, using a disaggregated Photonic GW prototype comprising SFP-type XGS-PON OLT, FXC with power monitoring function, and commercial CDC-ROADM products. It was proven that remote transceiver emission control via XGS-PON eliminates the need for a guard time of over 6 seconds between connecting a new UT and connecting another UT, allowing the simultaneous connection of multiple UTs.

References

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