In-Line Protocol-Independent Control and Management Method in End-to-End Optical Connections via Photonic Gateway

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Abstract *We propose and experimentally demonstrate novel in-line control and management scheme for in-service end-to-end user connections with any signal protocol in the All-Photonics Network. AMCC signals based on subcarrier allocation yield remote control of user terminals without any optical/electrical conversion with link budget of 47.5-dB.*

Introduction

Advanced network services, such as connected cars, e-sports, virtual reality (VR) and so on, are emerging. They demand guaranteed large-capacity and extremely low-latency networks. To meet these strict demands, the All-Photonics Network (APN) is proposed as the optical transport for the Innovative Optical and Wireless Network (IOWN) concept[1]. APN provides end-to-end and full-mesh optical paths with no electrical signal processes such as aggregation and routing, see Fig. 1. APN allocates a wavelength to each user and service so that optical paths are logically point-to-point connections. Therefore, APN offers not only much higher bandwidth, but also ultra-low latency network services. We recently proposed the Photonic Gateway (GW) as an APN edge node and an autonomous optical-path setup procedure for end-to-end user connections[2]. In this procedure, newly connected user terminals (UTs) and the Photonic GW communicate for path-provisioning requests, wavelength allocation and so on using the auxiliary management and control channel (AMCC)[3]. Since AMCC is an out-band channel in the lower frequency region, AMCC is independent of client signal protocol. Therefore, AMCC enables the Photonic GW to remotely control and accommodate various types of UTs with their application-specific protocols.

The Photonic GW must exchange control signals with UTs for status monitoring and remote control regardless of in-service optical path status. With AMCC, however, the Photonic GW loses the means to exchange control signals with UT once the end-to-end optical path is established because the path passes through the Photonic GW without optical/electrical conversion.

This paper proposes a control and management scheme for in-service end-to-end user connections via Photonic GWs. The proposed scheme passively extracts the

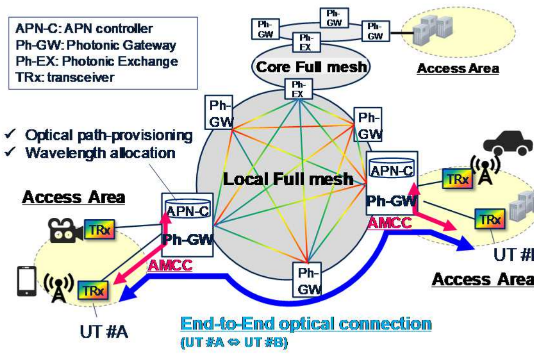

Fig. 1: All-Photonics Network (APN)

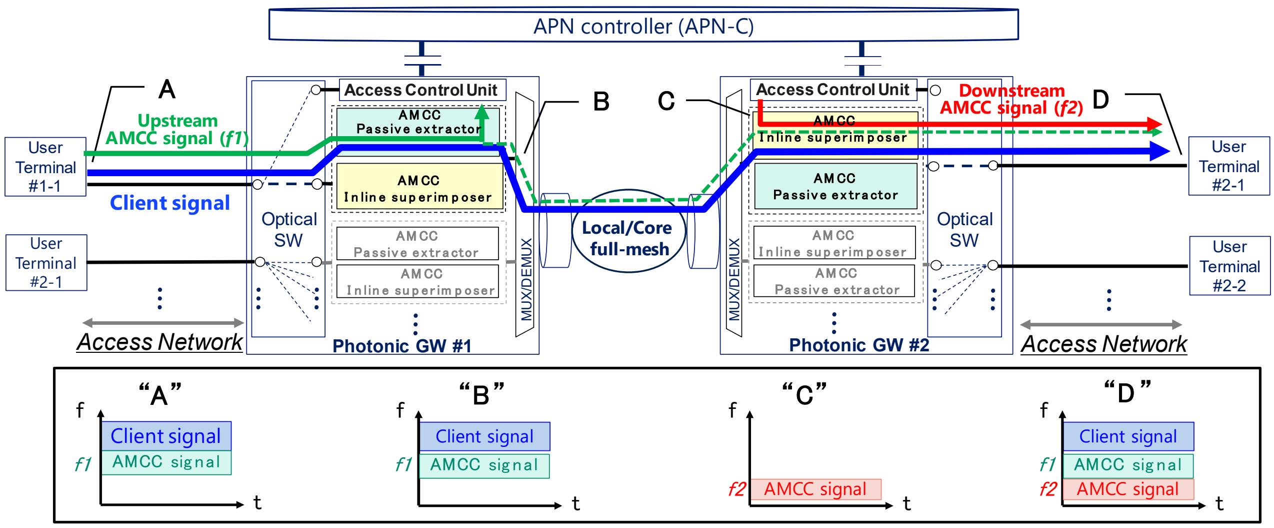

Fig. 2: Schematic of the proposed control and management scheme

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upstream AMCC signal[4] and in-line superimposes downstream AMCC signal at Photonic GW in the middle of the end-to-end optical path. This is very innovative in that the AMCC signals are terminated separate from the client signal, see Fig. 1. Experiments verify the feasibility of the proposed scheme and clarify APN scalability in terms of the link budget.

Proposed Scheme

Figure 2 shows the proposed control and management scheme. The Photonic GW is an edge node at the border of the access and the full-mesh networks; it accommodates various UT types as directed by the APN controller. Its basic function blocks include an optical switch (SW), a wavelength multiplexer/demultiplexer and an access control unit. The optical SW transfers optical signals to the appropriate ports given the destination of each optical path without optical/electrical conversion. The access control unit exchanges AMCC signals with the UTs regardless of client signal protocol.

To control in-service optical paths, we propose that the Photonic GW include passive extractors for upstream AMCC signals and in-line superimposers for downstream AMCC signals. First, the passive extractor in Photonic GW #1 splits optical signals from UT #1-k (k = 1, 2, ···) and drops a part for access control. The access control unit demodulates upstream AMCC signals intended for Photonic GW #1 while discarding the client signal to UT #2-k. Second, the in-line superimposer uses AMCC signals to modulate the optical signals to Photonic GW #2 from the full-mesh networks. These AMCC signals are intended for UT #2-k and generated at the access control unit in Photonic GW #2.

Note that the passive extractor works only as a power splitter. As a result, upstream AMCC signals to Photonic GW #1, which are superimposed at UT #1-k, remain in the input to Photonic GW #2. This leads demands innovation to avoid interference between the upstream and downstream AMCC signals. To address this issue, we allocate the subcarriers of upstream and downstream AMCC signals. Upstream and downstream AMCC signals are set at different frequencies, f_1 and f_2, respectively, see Fig. 2. This allows UT #2-k to successfully receive control signals from Photonic GW #2 without the influence of either undesired AMCC signal at f_1 or client signal simply filtering the AMCC signal at f_2 in the spectral domain after optical/electrical conversion. Needless to say, UT #2-k can also receive client signal from UT #1-k.

The termination points of AMCC signals and those of client signal are different in our proposed configuration unlike conventional use cases of AMCC[5]. To assess APN scalability from the viewpoint of transmission reach comprehensively, the reaches for access and full-mesh networks were determined. Our proposal requires the maximum transmission loss for the access network to be below the upstream and downstream AMCC link budget. Moreover, the maximum end-to-end transmission loss, including insertion loss of Photonic GWs, must be below the end-to-end link budget of client signals.

Experiment and result

To evaluate the feasibility of our proposal, we measured bit-error-rate (BER) of client and two AMCC signals with subcarrier allocation. Figure 3 shows the setup used. UT #1 transmitter consisted of a commercially available 10G λ-tunable SFP and a semiconductor optical amplifier (SOA) as AMCC modulator. As the client signal, 10.3125-Gbit/s NRZ signal with pseudo-random bit sequence (PRBS) 2^{31}-1 pattern was applied to the SFP operating at the wavelength of 193.00 THz (1553.33 nm). The SOA was modulated by 128-kbit/s amplitude-shift keying (ASK) with PRBS2^7-1 and 500-kHz subcarrier[3] (AMCC signal #1). The output signal

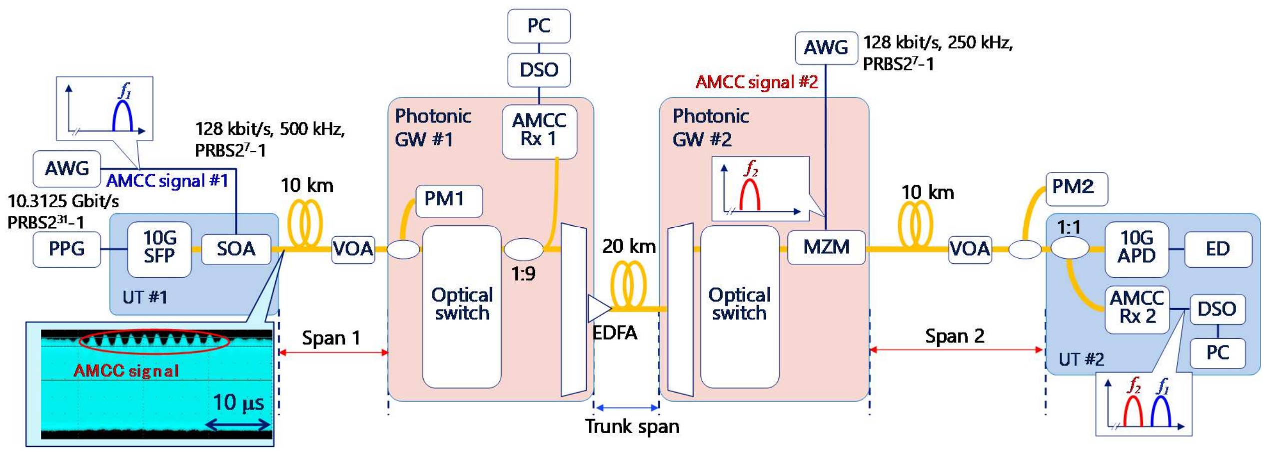

Fig. 3: Experimental setup

is shown in the inset of Fig. 3. The launched optical power from the SOA was +11.0 dBm. The AMCC signals were generated by an arbitrary waveform generator (AWG) with sampling rate of 64 MSa/s; modulation index was 10 %.

First, we evaluated the link budget between UT #1 and Photonic GW #1: Span 1. Photonic GW #1 consisted of a 32 × 32 optical switch, an 1:9 optical splitter as the passive extractor, and 100-GHz spaced arrayed waveguide grating (AWG). AMCC signal #1 tapped through the 1:9 optical splitter was detected by avalanche photodiode (APD) based AMCC receiver (Rx). Received signals were captured by the digital storage oscilloscope (DSO) at 62.5 MSa/s. The BER of AMCC signal #1 was calculated from the Q-factor. Figure 4(a) shows the BER performance of AMCC signal #1 after 10-km SMF transmission with and without the client signal against input power to Photonic GW #1, respectively. The receiver sensitivity defined at the BER of 1.0x10^{-3} was -10.7 dB. Hence, the link budget of 21.7 dB was obtained for the Span 1.

Second, BER of AMCC signal #2 superimposed on downstream signal at Photonic GW #2 was measured after 10-km SMF transmission. The output of Photonic GW #1 was transmitted through the trunk span of 20 km after being boosted by the erbium-doped fibre amplifier (EDFA) to compensate the insertion loss in Photonic GW #1. At Photonic GW #2, AMCC signal #2 was modulated by 128-kbit/s ASK with PRBS2^7-1 using $LiNbO_3$ based Mach-Zehnder modulator (MZM). Here, the subcarrier frequency for AMCC signal #2 was set at 250 kHz to avoid interference with AMCC signal #1. Figure 4(b) shows measured BERs of AMCC signal #2 at UT #2 AMCC Rx. Blue plots are for only AMCC signal #2 superimposition while red plots are for superimposition of both AMCC signal #1 and #2. The receiver sensitivity was -22.6 dB for both cases, which proves the effectiveness of subcarrier allocation for interference avoidance. Since the output power from Photonic GW #2 was -0.1 dBm, the link budget of 22.5 dB was achieved for Span 2.

Finally, the BER of the end-to-end client signal was also measured. The receiver sensitivity (BER = 1.0×10^{-3}) was -24.3 dBm as shown in Fig. 5. The power penalty due to superimposition of two subcarrier-multiplexed AMCC signals was only 0.6 dB. Since the output power from UT #1 and the amplified gain of the EDFA were +11.0 dBm and 12.2 dB, respectively, end-to-end link budget including insertion loss of Photonic GWs was 47.5 dB. Consequently, the proposed in-line control and management scheme enables us to flexibly design the APN scale within condition that the link losses of access span and end-to-end are below 21.7 and 47.5 dB, respectively.

Conclusion

We proposed and demonstrated a novel scheme for in-line control and management of in-service end-to-end user connections. With passive extraction for upstream AMCC signal and in-line superimposition of downstream AMCC signals with subcarrier allocation, Photonic GW remotely controls UTs with any client signals' protocol while optical paths pass through without optical/electrical conversion. Link budget of 10 Gbit/s access and end-to-end span were 21.7 and 47.5 dB, respectively.

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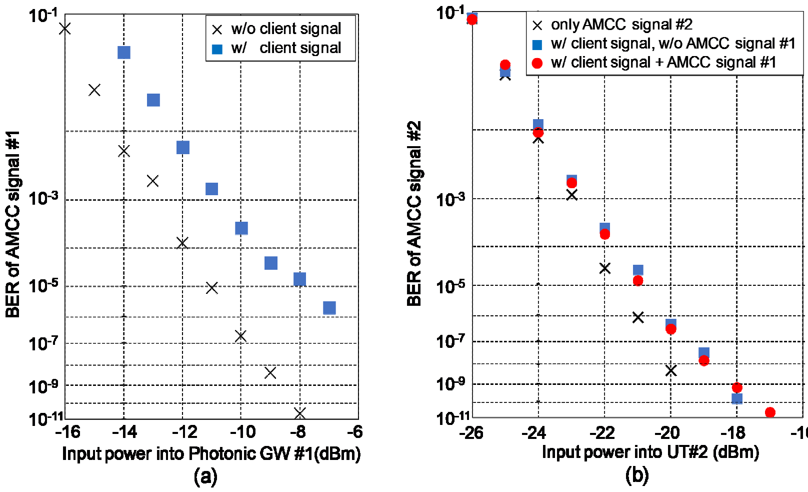

Fig. 4: BER performance of (a) the AMCC signals #1 and (b) AMCC signals #2

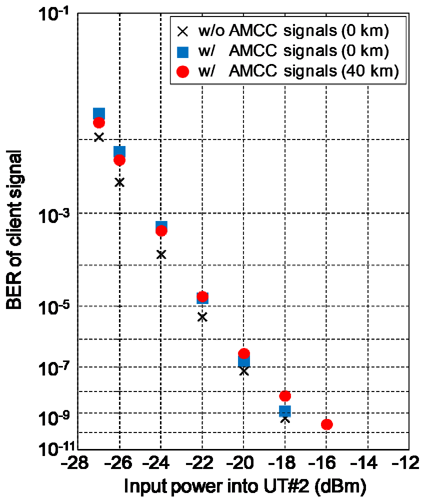

Fig. 5: BER performance of the client signal

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