Optical Packet and Circuit Simultaneous Transmission Technologies for Dynamic Lightpath Setup/Release and Packet Traffic Change

Hideaki Furukawa[1], Naoya Wada[1], Yoshinari Awaji[1], Takaya Miyazawa[1],
Hatsushi Iiduka[2], Noriyasu Shiga[3], Norihiko Sato[3] and Hiroaki Harai1[1]
[1]National Institute of Information and Communications Technology, 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan.
Phone:+81-42-327-5694, Fax:+81-42-327-7035, E-mail:furukawa@nict.go.jp
[2]NTT Electronics Co., 1-1-32 Shin-Urashimacho, Kanagawa-ku, Yokohama, 221-0031, Japan.
[3]Trimatiz Limited, 4-7-12 Minamiyawata,Ichikawa, Chiba, 272-0023, Japan.

Abstract: For dynamic traffic change on packet/lightpath integration, all-bandwidth amplifiers and high dynamic-range packet receivers are developed. 80-Gbit/s colored optical packets and 8-lightpaths simultaneous 170-km field transmission are demonstrated.

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1. Introduction

In new-generation networks [1], energy efficiency and high-throughput are required. It is also required to provide diversified services such as best-effort and quality of service (QoS) guaranteed services. To satisfy these demands, we have proposed an optical packet and circuit integrated network based on common wavelength and fibers [1]. Optical packet switching (OPS) provides bandwidth-sharing and best-effort data transferring, and optical circuit switching (OCS) provides an occupied bandwidth and end-to-end QoS guaranteed data transmission [2-3]. By dynamically sharing wavelength resources for OPS or OCS links [4], new or urgent services are supported. By multiplexing control packets for signalling and resource control on OPS links, extra interfaces are decreased and networks are simplified. The convergence of packet and circuit switch architectures has also received much attention in other research projects [5-6]. We have already shown an OPS/OCS node system [2-3] based on 1.28 Tbit/s/port OPS system [7] and signalling and routing system on control plane for OCS networks [4]. In integrated networks, the power fluctuation occurs because the dynamic change of the number of lightpaths and the packet traffic causes some transient gain excursion of erbium-doped fiber amplifiers (EDFAs) set on transmission lines and systems. In this paper, we develop an all-bandwidth burst-mode amplifier system and a high dynamic-range packet receiver for the tolerance of the packet power fluctuation. Based on these equipments, we demonstrate 170 km filed transmission and switching of both 80 (8λ x 10) Gbit/s colored optical packets and 8-lightpaths with a low packet-error-rate (PER<1E-4) on a single fiber, and dynamic lightpath setup and wavelength-resources control via OPS links.

2. Optical packet and circuit integrated network and key technologies for tolerance of power fluctuation

In a proposed integrated network, optical packets and data on lightpaths are multiplexed and also transmitted on the same infrastructures as shown in Fig. 1. In edge nodes of an integrated network, low-band signals such as Ethernet frames are en/decapsulated with wide-band optical packets. We use a colored optical packet, which consists of 10 Gbit/s optical signals of N wavelengths. Also, control optical packets for path signalling and resource control are exchanged via OPS links. End-to-end lightpaths are provided for high-quality services on user demands. Wavelength resources are used as occupied resources of OPS and OCS links, and shared resources. The shared resources are allocated to OPS or OCS links depending on demands for lightpath or packet transferring.

Due to the dynamic lightpath setup/release, the change of packet traffic, and the dynamic allocation of shared resources, the total input power to an EDFA is changed and the transient gain excursion occurs. Then, the power of amplified packets or lightpaths is fluctuated. Figures 2 and 3 show examples of the packet power fluctuation. We input 80 (8λ x 10) Gbit/s colored optical packets and 8-wavelength lightpaths into an EDFA, and extracted only optical packets by a band-pass filter after amplification. Figures 2(a) and 2(b) show the spectrum of input 80 Gbit/s optical packets and 8-lightpaths, and the temporal waveform of extracted packets, respectively. Then, we released 6-lightpaths. Figures 2(c) and 2(d) also show the spectrum of input packets and 2-lightpaths, and the temporal waveform of extracted packets, respectively. The packet power increased by about 1

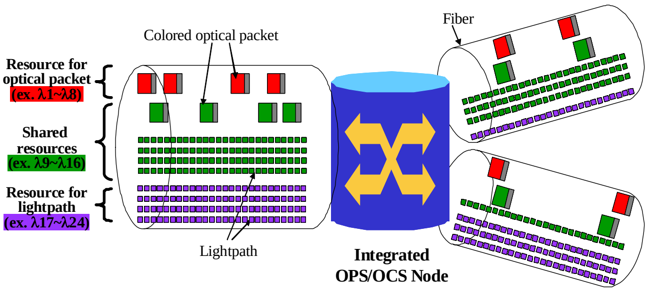

Fig. 1. Concept of an optical packet and circuit integrated network.

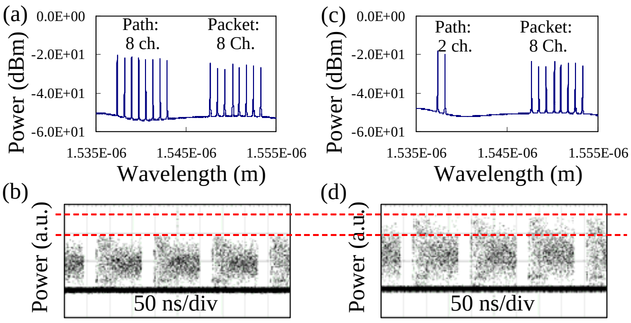

Fig. 2. Amplified optical packets in dynamic lightpath setup/release..

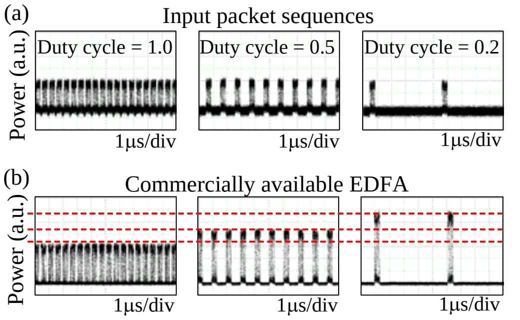

Fig. 3. Amplified optical packets in changing packet duty cycle.

dB. We can confirm that the packet power changes due to the dynamic lightpath setup/release. Next, we changed only the duty cycle of a packet-sequence as shown in Fig.3(a). From results in Fig.3(b), the packet power also changes depending on the duty-cycle. These power fluctuations may cause bit-errors in receivers.

To tolerate the power fluctuation, we developed a high dynamic range packet receiver (HDR-PR), which consists of a PIN-PD, a transimpedance amplifier for sensitive detection, and a burst-mode limiting amplifier with variable thresholding (Fig.4(a)). While a previous Rx. has 5.1 dB dynamic range [7], the new one has 14.1 dB range. Figure 4(b) shows a recovered packet by the HDR-PR from a power-fluctuated packet. We adopted a single phase lock loop configuration to enable instantaneous synchronization of the output clock phase because packets are bursty input. On the contrary, to eliminate optical surge and gain transient for shorter packet, (~100ns) we developed transient-suppressed (TS-) EDFA [8]. However, long term transient still remained. To uniformly amplify streaming packets, we developed all-bandwidth burst-mode amplifier system based on TS-EDFA with external controlling techniques such as optical feed back loop, automatic gain control (AGC) and automatic level control (ALC) (Fig.5(a)). Also, impairment came from multi-wavelength add/drop can be mitigated effectively [9]. Figure 5(b) shows almost uniformly amplified packets by a developed amplifier compared with results in Fig.3(b) at various duty cycles.

3. Demonstration of optical packet and circuit simultaneous transmission

Figure 6(a) shows the demonstration system, which consists of an integrated OPS/OCS node as a core node, two edge nodes, and some clients which send data by IP-packets or lightpaths, including a camera and a display for uncompressed HDTV transmission. The TS-EDFAs are used to amplify coupled optical packets and lightpaths in fiber lines. To uniformly amplify optical packets, TS-EDFAs with AGC/ALC are used only for OPS links after dividing packets and lightpaths in each node. In addition, HDR-PRs are used to have a tolerance for packet power fluctuation. The shared resource, the occupied resources for OPS and OCS are 1538.9-1541.3 nm (λ9-λ12), 1547.7-1553.3 nm (λ1-λ8), and 1558.9-1561.4 nm (λ13-λ16), respectively. An IP-packet Tx. sends IP-packets with the destination IP address of the core node for OCS control and ones with the destination IP address of an IP-packet Rx. for data. 8-Lightpath Tx./Rx. generate and receive 1.25 Gbit/s signals of 8-wavelengthes on data-plane. Here, OCS control signals from a Lightpath Tx./Rx. are sent via an IP-packet Tx.. In Edge node #1, these IP-packets are encapsulated into 80 Gbit/s colored optical packets with 1.24 Gbit/s optical labels corresponding to the IP address by an IP-OP converter [10]. Then, these packets and 8 lightpaths are coupled and launched into a field fiber line.

The field fiber lines are located between Koganei and Otemachi in Tokyo with loop-back configuration at JGN2plus [11]. One round-trip fiber line consists of 85 km field installed single-mode fiber (SMF) with 27 dB loss and 25 km dispersion compensating fiber (DCF). The dispersion was compensated at -20 ~ +25 ps in C-band as shown in Fig. 6(b). Figure 6(c) shows 2.5 ps or less fluctuation of differential-group-delay (DGD) in one round-trip field fiber measured at 10 times in 1 hour. As a reference, the DGD fluctuation of 100 km our bobbin fiber was about 0.2 ps as shown in Fig. 6(d). This DGD fluctuation causes skew, polarization mode dispersion, and other effects on colored optical packets. These effects are in a margin of OP-IP converters at core node system and Edge node #2. If the DGD is get larger, an OP-IP converter has no problem because of its input electrical buffer, but optical switches may need more guard time or additional compensation.

In the OPS/OCS node, whose the detail of configuration is shown in Ref.[2-3], two 2 x 2 OPSs and two 2 x 2

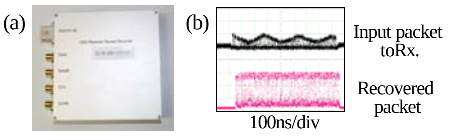

Fig. 4.High dynamic-range burst-mode packet receiver.

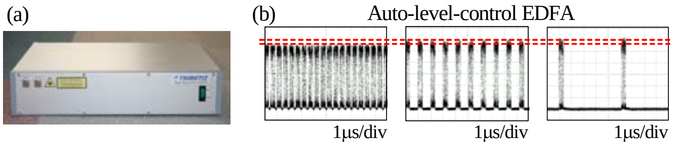

Fig. 5. Transient-suppressed EDFA with automatic level control.

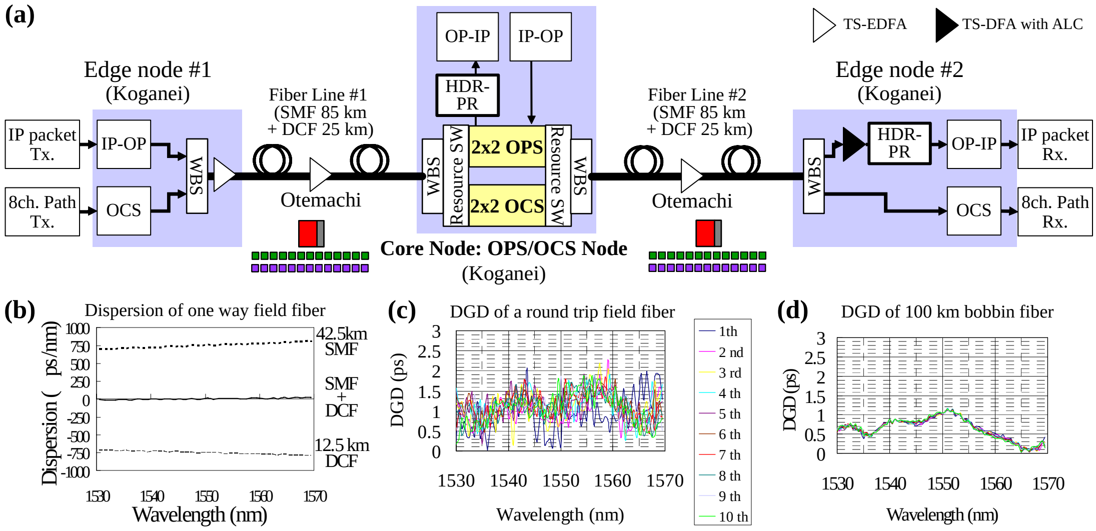

Fig. 6. Demonstration system and characteristics of field installed fiber.

OCSs are used for the occupied and the shared resources, respectively. Optical packets and 8 lightpaths are divided by a waveband selector (WBS). A resource controller makes 8x8 switches (resource switches) connect the optical signals with OPS or OCS, respectively. Control packets with the destination address of core node are forwarded to this node by a label processor and a 1 x 2 $LiNbO_3$ switch (LN-SW) in OPS. Then, a lightpath setup starts, or the shared resource is re-allocated. An arrayed waveguide grating (AWG) in the OCS divides the waveband into 8 lightpaths, and the large-scale switch forwards each signal to an output port. The core node also sends IP-packets to Edge node #2 for OCS control. Control packets from the core node and data packets from Edge node #1 are input into a 2 x 1 optical buffer which consists of plural LN-SWs and fiber-delay-lines. To avoid packet collisions between their packets, the buffer adequately delayed packets. Figure 7(a) shows packet sequences in above-mentioned operations at the input/output port, and the optical buffer of the core node. We confirmed that only control packets with the destination label of the core node were switched to the core node and that the buffer operated normally. Figure 7(b) shows the spectrum at the output of the core node. Figure 7(c) shows the temporal waveform of optical packets and lightpaths after 170 km transmission. In Edge node #2, HDR-PRs receive both data and control optical packets. Then, an OP-IP converter extracts IP-packets from optical packets and sends to the IP-packet Rx.. The IP-PER for data transferred from IP-packet Tx. was 3.33 x 10^{-5} as shown in Fig.7(d), which is high quality transmission. Through ICMP sending/receiving (i.e. ping) and 1.6 Gbit/s HDTV transmission on 8-lightpaths, we confirmed that OCS control packets were safely reached to all nodes and 8 lightpaths were successfully set up.

4. Conclusion

We developed a high dynamic range packet receiver and a TS-EDFA with automatic level control. Field transmission and switching of 80 Gbit/s colored optical packets and 8-lightpaths has been successfully demonstrated.

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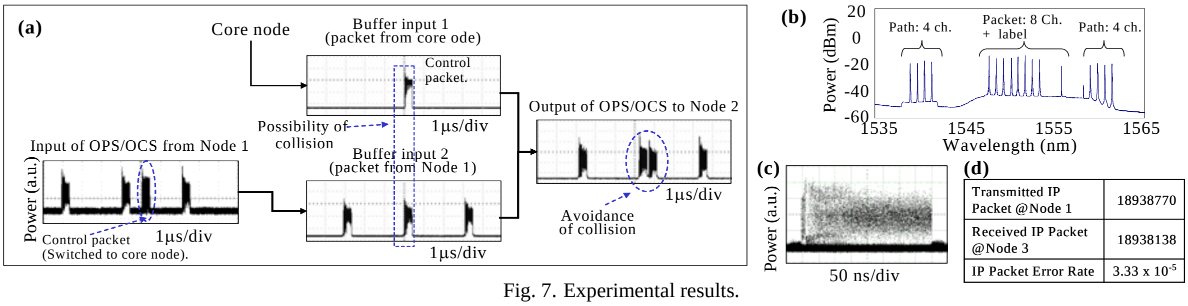

Transmitted IP Packet @Node 1	18938770
Received IP Packet @Node 3	18938138
IP Packet Error Rate	3.33 x 10^{-5}

Fig. 7. Experimental results.