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Control-message exchange of lightpath setup over colored optical packet switching in an optical packet and circuit integrated network

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Abstract: We have proposed the concept of an optical packet and circuit integrated network to provide service diversity, energy efficiency and a simplified control mechanism toward new generation networks. In this integrated network, optical data packets and data on lightpaths are transmitted on common physical resources for efficient resource use. In addition, path signaling for lightpath setup and release thorough optical packet switch block is implemented. We set up a primitive optical packet and circuit integrated network including one switching node and a set of packet/path transceiver. We demonstrate 80 ($8\lambda \times 10$) Gbit/s colored optical packet switching and 8-lightpaths establishment by transferring optical control packets over the optical packet switching.

Keywords: optical packet and circuit integrated network, colored optical packet switching, optical path, lightpath, optical circuit switching

Classification: Fiber-optic communication

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1 Introduction

To cope with current rapid growth of data traffic on the Internet, high-throughput core nodes are required on backbone networks. Currently, the node throughput is limited due to processing capability of electronic routers. Although the total throughput is improved by increasing the number of line cards and by employing electrical parallel processing, such processing makes electronic-circuit scale larger, which causes a serious power consumption problem. Therefore, optical switching techniques without optical-to-electrical-to-optical (O/E/O) conversion are quite attractive for high-throughput node systems. On the contrary, it will be also required to provide diversified services such as best-effort and quality of service (QoS) guaranteed service for various types of contents demanding large or small data-size, and high or low quality. However, current IP techniques are suitable only for transferring best-effort data, and cannot always guarantee high QoS.

To satisfy these requirements, we have proposed an optical packet and circuit integrated network, which is based on common physical resources (e.g., wavelength and fiber), as one of key technologies for new-generation networks [1, 2, 3]. In this integrated network, hop-by-hop 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 transmissions. The convergence of packet switch

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and circuit switch architectures on control-plane or data-plane has received much attention and been investigated also in other research projects [4, 5]. Our proposed integrated network has four main advantages described below. 1) The integrated network provides best-effort and QoS guaranteed services by OPS and OCS links, respectively. 2) Optical switching technologies decrease O/E/O conversions and increase throughput without extra power consumption due to transparency for various format and bit-rate compared with electronic switches. 3) By dynamically sharing wavelength resources for OPS or OCS links, new or urgent services are supported. 4) By multiplexing OCS control packets for signaling and resource control on OPS links, extra interfaces are decreased and networks are simplified.

As basic technologies of integrated networks, we have already developed an energy-efficient 1.28 Tbit/s/port OPS system using colored optical packets based on wavelength division multiplexing (WDM) techniques [6]. We have also implemented our own signaling/routing protocols on control plane for OCS networks [7]. Before now, we have demonstrated only OCS part in an integrated optical packet and circuit switching (OPS/OCS) node and evaluated the OCS control system [3]. In this letter, we set up a primitive integrated network with an OPS/OCS node and a set of packet/path transceivers. We demonstrate switching and buffering of 80 ($8\lambda \times 10$) Gbit/s colored optical packets. The signaling for 8-lightpaths by transferring control packets on OPS links is achieved through optical packet switch block.

2 Optical packet and circuit integrated network

Figure 1 (a) shows a conceptual diagram of an optical packet and circuit integrated network. The network multiplexes optical packets and data on lightpaths which are also called as optical paths, and also sends OCS control packets for path signaling on OPS links. Although data and control packets flow on the same link, higher priorities are set for control packets to avoid the nondelivery situation of control packets. This integrated network can effectively utilize wavelength resources depending on traffic conditions. As shown in Fig. 1 (b), the wavelength resources are divided by waveband. Some

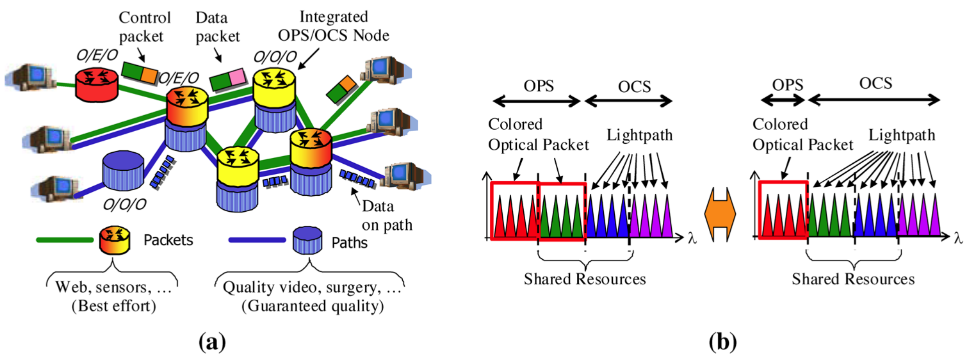

Fig. 1. (a) Conceptual diagram of integrated optical packet and circuit networks. (b) Allocation of wavelength resource for OPS and OCS links.

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wavebands are occupied by OPS and OCS links, and the others are used for shared resources. The shared resources are allocated to OPS or OCS links depending on demands for lightpath establishment or packet transferring (called as resource control). Here, we use colored optical packets using WDM techniques, which consists of a payload with multiple wavelengths and a label [8].

3 Experiment

3.1 Experimental setup

Figure 2 (a) shows the experimental setup of an optical packet and circuit integrated network which consists of two edge nodes and one core node. Optical packet transmission supports a simplex from Node 1 to Node 2 and Node 3. As indicated by chain lines, from Node 3 to Node 2 and Node 1, we send back Ethernet frames for OCS and resource control.

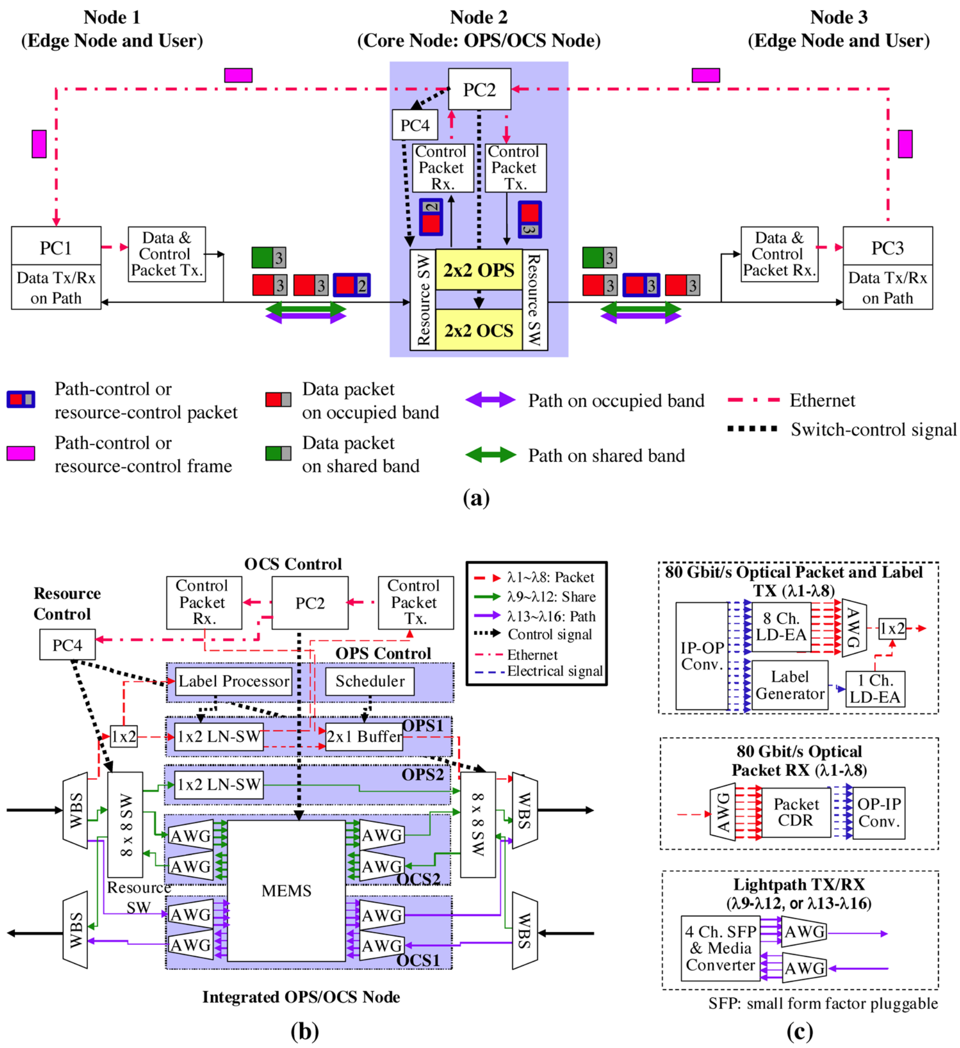

Fig. 2. (a) Schematic diagram of integrated optical packet and circuit network experiment. (b) Integrated optical packet and circuit switching node. (c) Optical packet and path transmitter/receiver.

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Figure 2 (b) shows the configuration of an OPS/OCS node as a core node. The node consists of two OPSs, two OCSs, two resource switches, and their control systems (e.g., label processor and scheduler, OCS control, resource control). Optical amplifiers are set in appropriate positions to compensate optical loss. Here, 16 wavelength-channels are allocated to three wavebands as the shared resource, the occupied resources for OPS and OCS corresponding to 1538.9-1541.3 nm (λ9-λ12, green line), 1547.7-1553.3 nm (λ1-λ8, red line), and 1558.9-1561.4 nm (λ13-λ16, purple line), respectively. The channel-interval is 100 GHz. Input signals are demultiplexed into wavebands by waveband selectors (WBS). The two OPSs and OCSs are used for the occupied and the shared resources, respectively. When a network allocates the shared resource to OPS or OCS links, a resource controller (PC 4) makes 8×8 switch (SW) as a resource switch connect the optical signals with OPS or OCS, respectively. In the OPS links on the occupied resource, optical packets for data, OCS control and resource control are transferred. When the destination address of control packets is matched with this node, the packets are forwarded to this node by OPS. Then, a lightpath setup starts, or the shared resource is re-allocated. Each arrayed waveguide grating (AWG) in the OCS divides the waveband into multiple lightpaths (e.g. 8 lightpaths) by wavelength, and the large-scale switch forwards each signal to an output port. For OCS control, we have implemented a modified RSVP-TE [9] as a signaling protocol, and link-state protocol for advertising information of in-use wavelengths.

Figure 2 (c) shows the configuration of optical transmitter/receivers (TX/RX) for optical packets and data on lightpaths, respectively. In the packet TX, interfaces between 10 Gb Ethernet and optical packets (called as IP-OP and OP-IP converters) divide an IP packet over a 10 Gb Ethernet frames to eight 10 Gbit/s electrical segments and generate an 8-bit label signal corresponding to the IP address [10]. Each segment is converted into a 10 Gbit/s optical signal by each electro-absorption-modulator with laser-diode (LD-EA) with an individual wavelength. In parallel, the 8-bit label signal is converted into a 1.2 Gbit/s optical label by a LD-EA whose wavelength is 1557.5 nm. By coupling the label and eight 10 Gbit/s optical signals, a colored optical packet with the data-rate of 80 ($8\lambda \times 10$) Gbit/s is generated. A lightpath TX/RX generates and receives an optical signal of each wavelength on data-plane. Here, we fix the shared resource for OCS.

3.2 Experimental results

PC 1 at Node 1 sent 10 Gb Ethernet frames with the destination IP address of Node 2 for OCS control and ones with the destination IP address of Node 3 for data to a packet TX. 80 Gbit/s colored optical packets were generated from the frames. In the OPS/OCS node (Node 2), optical signals were divided by waveband and processed by OPS and OCS. In OPS 1 for the occupied resource, only control packets with the label of Node 2 were dropped to PC 2 by a label processor and a 1×2 $LiNbO_3$ switch (LN-SW). PC 2 also sent 10 Gb Ethernet frames with the destination IP address of Node 3 for OCS

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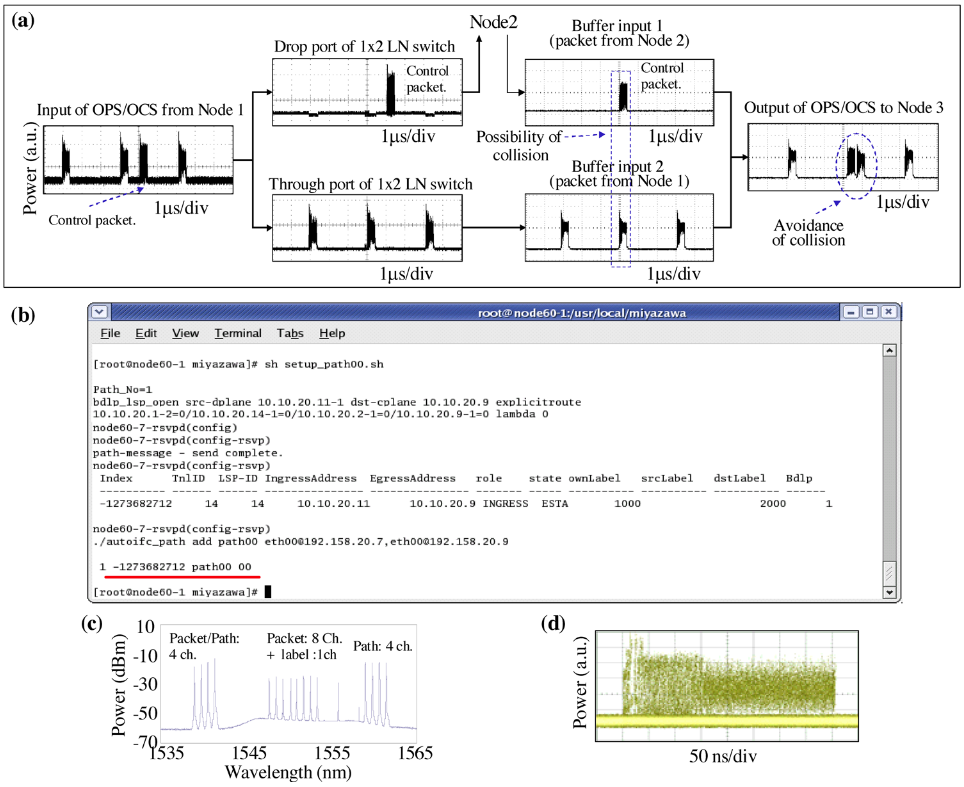

Fig. 3. (a) Packet sequences at switching and buffering in OPS system. (b) Signaling processes for one light-path establishment. (c) Spectrum of 80 Gbit/s colored optical packet and data on 8 lightpaths at output port of OPS/OCS node. (d) Temporal waveform of 80 Gbit/s colored optical packet and data on 8 lightpaths at input port of OPS/OCS node.

control. The operation of the control packet TX is the same as the one of Node 1. Control packets from Node 2 and data packets from Node 1 (through-packets from OPS 1) were input into a 2×1 optical buffer. The optical buffer consists of plural 1×2 LN-SWs and fiber-delay-lines. The buffer size is 2 packets. To avoid packet collisions between their packets, the optical buffer delayed data packets because the priority of control packets was set to be higher. Figure 3 (a) shows packet sequences in above-mentioned operations at the input/output port of OPS/OCS node, the drop-port/through-port of the LN-SW, and two input ports of the optical buffer. We confirmed that only control packets with the destination label of Node 2 were dropped and that the optical buffer operated normally to avoid packet collisions. In Node 3, an optical packet RX received both data and control packets. The signaling processes were implemented as shown in Fig. 3 (b), in which one lightpath named as "Path 00" is established. Figure 3 (c) shows the spectrum at the output of OPS/OCS node. From the results, OCS control packets were safely reached to all nodes on the control-plane because optical signals on 8 lightpaths could be transmitted through OCS. By ICMP sending/receiving

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(i.e. ping), we confirmed that Nodes 1 and 3 communicated each other on 8 lightpaths on the data-plane. Figure 3 (d) shows the temporal waveform of an optical packet and data on lightpaths at the input of OPS/OCS node.

4 Conclusion

We built a primitive optical packet and circuit integrated network with one OPS/OCS node and a set of packet/path transceiver. We demonstrated switching and buffering of 80 Gbit/s colored optical packets, and confirmed 8-lightpaths establishment by transferring optical control packets. We confirmed the basic operation of integrated networks in the control plane.

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