Sub-ms Data Recovery at 1,000-port Scale Optical Switch Developed with Customized Practical Devices

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Abstract: We have successfully demonstrated a large optical switching system with short switching times. Our transient time optimized digital coherent DSP, wavelength tunable laser, and silica-based PLC switch are the key components of the system.

1. Introduction

Network traffic is growing continuously as the speed of computing processors increases. This is causing a significant increase in network power consumption because current switching technology based on electronics will consume a great deal of electric power [1]. Optical switches are expected to play an important role in solving this problem because their power consumption is very small. However, optical switches are not widely used in local area networks (LANs) for intra-datacenter communications or in high performance computing (HPC), because their port counts are not large enough (up to several hundred with MEMS-based technology, which provides a larger number of ports) [2]. Furthermore, switching times are not short enough (on the order of milliseconds or more with practically available technology such as silica-based planar lightwave circuit (PLC) technology, which provides low-loss and faster optical switches) [3]. To address these issues and take advantage of the low-power-consumption characteristics of optical switches even in LANs, optical switching systems with a large port count and short switching time are necessary. We consider it reasonable to assume that optical switching systems will be used in combination with electrical packet switches and handle only flows greater than 100 Mbytes [4]. Under this assumption, switching time of several hundred microseconds would be sufficiently shorter than the switch holding time for 100- to 400-Gbps-class transceivers, so switching time reduction to several hundred microseconds is an appropriate target. With this context, we have already shown that the transient response time of devices for switching can be reduced to less than 100 µs by customizing carrier-grade devices, namely a silica-based PLC spatial switch, wavelength tunable laser, and digital signal processor (DSP) for digital coherent communications [4-6]. In this study, we utilized the transition- time-reduced devices and experimentally demonstrated optical switching capabilities with a short transceiver downtime of several hundred microseconds and with 1,000-port class scalability.

2. System configuration

The most promising approach to realizing large-scale optical switching systems is to utilize two different switching capabilities in the wavelength and spatial domains [4, 6, 7]. Although there are several variations in specific configurations, in this study we adopted a configuration that utilizes a wavelength switch comprising wavelength division multiplexed (WDM) light sources and wavelength tunable filters. For the spatial switch, optical selector switches with multiple input ports are employed.

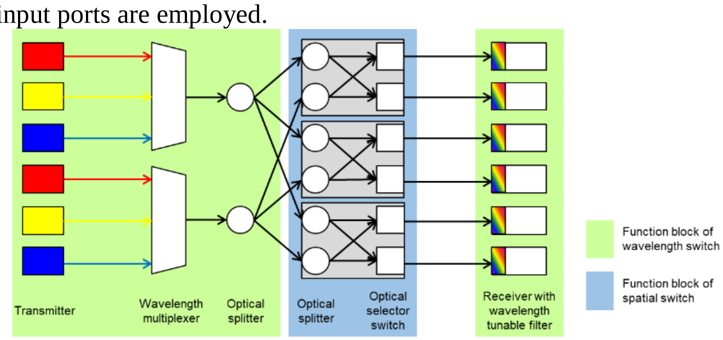

Fig. 1. Schematic diagram of the switching system configuration.

Figure 1 shows a schematic diagram of the switching system configuration. The switch consists of wavelength-defined transmitters, wavelength multiplexers, optical splitters, optical selector switches, and receivers with a wavelength tunable filter. The input signal is converted by the transmitter into a signal of suitable wavelength to be multiplexed. Then, the signals are wavelength-multiplexed and split into the same number of I/O ports. At the optical selector switch implemented for each output port, each input port is connected to a different wavelength multiplexer to select a WDM signal from one of them. Finally, the wavelength tunable filter selects one signal from the WDM signal, and the signal is received at the receiver. The number of I/O ports corresponds to the product of the number of wavelength division multiplexer channels and the number of input ports on the selector switch. In this study, we developed a system using 64 wavelengths and 16-port selector switches, and the number of ports in the switching system reaches 1,024.

3. Experimental results and discussion

Figure 2(a) illustrates the experimental setup for BER performance measurement. The signal source is 200 Gbps/λ (64 Gbaud, DP-QPSK) digital coherent transmitter. The optical components through which the signal passes are equivalent to the construction of a 1,024-port switching system utilizing 64 wavelengths with 75-GHz spacing and 16 spatial ports. After these components with appropriate amplification, the signal is received with a digital coherent receiver. As crosstalk signal sources, transmitters of adjacent channels can be input to the wavelength multiplexer, and separated copy signals can be input to the spatial switch. The spatial switch (16×8 multicast switch consisting of sixteen 1×8 splitters and eight 16×1 selector switches) is developed using silica-based PLC technology with thermo-optic phase shifters, and its transient response time is shortened by employing a thin cladding layer structure and a driving method utilizing short- and high-voltage pulses (see [7] for more information on the switch structure and driving method). The local oscillator in the digital coherent receiver is a DBR/Ring monolithic wavelength tunable laser covering the C-band, and its transient response time is reduced by employing an accelerated driving circuit. The detailed structure of the laser is described in [8]. The digital coherent DSP utilized in receiver has a newly developed burst signal processing block that enables high-speed tap coefficient convergence and eliminates or minimizes unnecessary operation sequences such as the chromatic dispersion estimation function (see [4] for more information). These three high-speed devices—the multicast switch, local oscillator, and digital coherent DSP—are controlled by EtherCAT to achieve synchronized operation. The developed equipment for the switching system is shown in Fig 2(b).

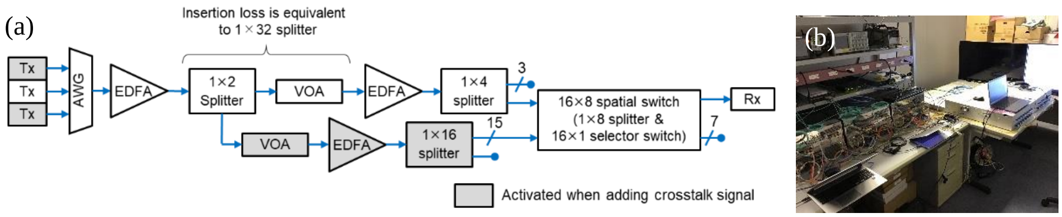

Fig. 2. (a) Experimental setup for BER performance measurement. (b) Developed equipment.

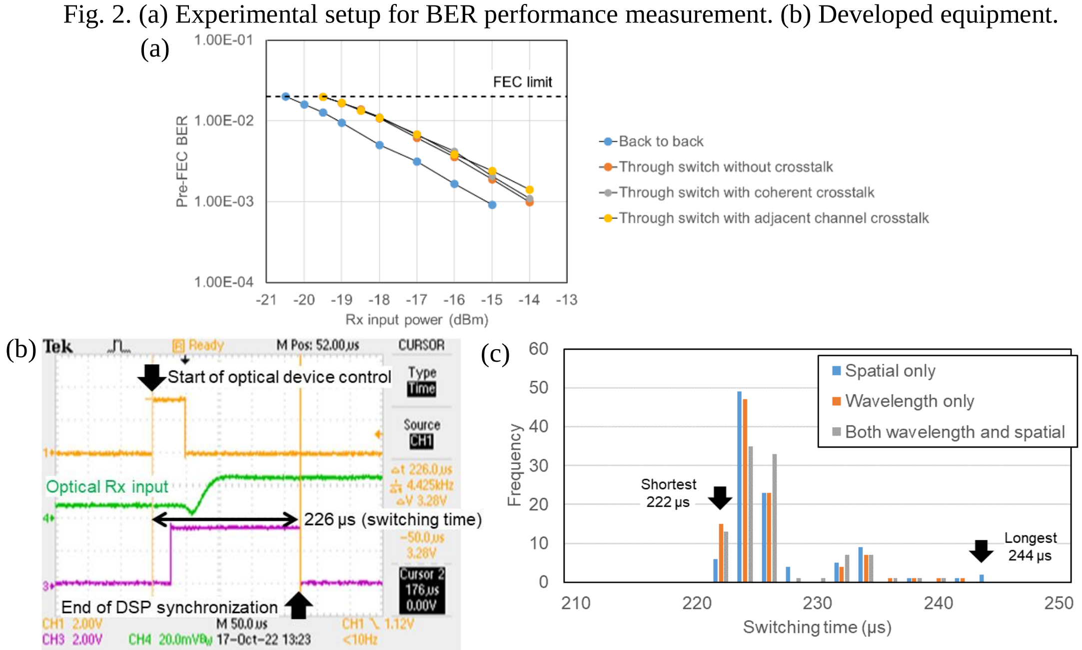

Fig. 3. (a) Obtained BER performance with and without crosstalk signals. (b) Observed timing of the DSP synchronization. (c) Histogram of observed switching time.

Figure 3(a) shows the BER performance to the receiver input power. This includes the back-to-back characteristics and the characteristics when the signal passes through the switching system without any crosstalk signals, with adjacent channel crosstalk signals, and with coherent crosstalk signals at the optical selector switch. As the signal passed through the switching system, we observed power penalty of approximately 1 dB at pre-FEC BER of 10^{-2}. The likely cause of this penalty is the insufficient filter bandwidth at the wavelength multiplexer. On the other hand, the observed impact of adjacent channel crosstalk signals and coherent crosstalk signals was quite small. Therefore, even when all the equipment for constructing a 1,024-port system is installed, the insufficient filter bandwidth at the wavelength multiplexer is the main cause of signal degradation, and the amount of degradation is expected to be small enough to correct errors (there are the conditions where the pre-FEC BER is less than 2.0×10^{-2}). Thus, there are no severe factors disturbing static signal transmission in this system.

Figure 3(b) and (c) illustrate the dynamic characteristics associated with the switching. In this study, the switching time is defined as starting when the high-speed optical devices receive their control signals and ending when the DSP frame synchronization is completed with the received signal. To observe the switching start timing, our control board for the high-speed wavelength tunable laser generates a monitoring signal, whose level changes from low to high when a control signal is received. This corresponds to the rising edge of the top signal in Fig. 3(b). Then, the physical optical signal to the receiver is switched, as shown in the middle signal in Fig. 3(b). As for the switching end timing, our DSP evaluation board generates another monitoring signal, namely “frame synchronization error.” This signal is set to output at a high level when the DSP is not in frame synchronization, in which case error correction is not possible. This appears at the bottom signal in Fig. 3(b), and the switching end timing corresponds to the rightmost dropping edge. Figure 3(b) shows typical monitoring signals, but there are some variations of the switching time in principle. We performed multiple switching time measurements for each switching pattern (wavelength switching only, spatial switching only, and both wavelength and spatial switching). The results are summarized in the histogram in Fig. 3(c). The switching pattern dependence was hardly observed in the switching time, and it ranged from 222to 244 µs, and the targeted several hundred microsecond switching capability is confirmed.

It should be noted that the high-speed devices in this system are based on carrier-grade devices, and their basic structures are not modified. Our intention with this system is not to achieve ultimate short switching time, but a moderate switching time of the sub-millisecond class. None of the other optical components are unique, and all of them are commercially available. Therefore, we will be able to put this system into practical use in a short period of time.

4. Conclusion

The switching capabilities with a 1,000-port scale and sub-millisecond switching time were demonstrated by employing carrier-grade devices customized of their transition times and other commercially available devices. The obtained results indicate that the switch architecture utilizing two different switching capabilities in the wavelength and spatial domains is promising not only to scale up the port count but also to reduce switching time. This work represents an important milestone in achieving a burst switching system for datacenter applications.

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