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Beyond Tera Bit Per Second Optical Switching Using WDM Technology

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1. Introduction

The tremendous growth in Internet traffic loads and the continually increasing demand for broadband-data services have generated a need for increased transmission capacity and switching-system throughput in trunk and core networks. Wavelength-division multiplexing (WDM) by means of optical amplifier repeaters is a cost-effective way to expand capacity and throughput in order to achieve around tera-bit per second in transmission systems. It has already been widely used to relieve congestion in public transport networks. The throughput of the switching systems in trunk and core networks, of ATM core switching systems and of IP core routers handling broadband-data services, is still working at the order of a few hundred Gb/s throughput. Electrical switch technology will not be able to keep up with increasing demand for the broadband data services in the near future if it continues to follow the growth rate of Moore's Law.

Optical switch technology is one of the candidates for breaking through the barrier. In this paper, at first, we will describe an application of ultra-large scale optical switch fabric and then introduce our novel wavelength-division/space-division (WD/SD) optical switch architecture that needs far fewer optical switching elements than conventional optical space-division (SD) architecture. By employing our proposed WD/SD optical switch architecture, we have demonstrated beyond tera-bit per second capacity [1,2]. In our demonstration, we have utilized semiconductor optical amplifier gates (SOAGs) which have the advantages of high-speed switching time (around 1 ns), loss compensation function, high on/off ratio, and possibility for PIC (Photonic IC) in the future [3].

2. Optical Packet Switch

A general view of ultra-large throughput ATM switch or IP router (input-buffered packet switch) is shown in Figure 1. Basically, the packet switch consists of data buffers, a switch fabric, and a contention resolution logic circuit (arbiter). Since the optics has not matured for optical data buffering and optical logic technology, we are now focusing on employing optical technologies into ultra-large scale optical cross-bar equivalent switch applications. Our belief is that the data buffering and the contention resolution logic should be performed by using electronics technology, so our optical packet switch uses electrical RAM's for buffers and electronics arbiters. Between electronics buffers and an optical switch itself, there are optical transmitters (OTx's) and optical receivers (ORx's) at the fabric's input and output ports.

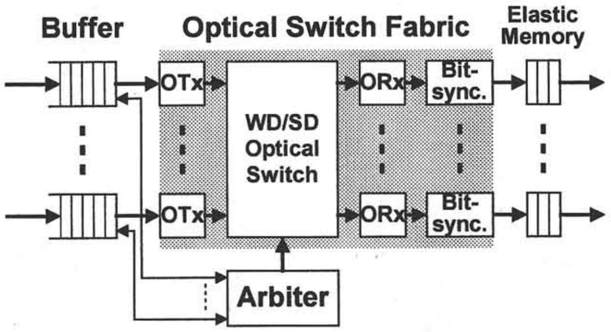

Figure 1. Optical cell/packet switch

In order to minimize the switch fabric hardware cost/size and support sufficient scalability, we have utilized optical switching technology which has the capability of handling ultra-large port capacity such as 10 Gb/s/port and wavelength-division switching technology. A method for utilizing wavelength division switching is explained in the next section.

3. Beyond Tb/s Capacity Optical Switch Technologies

3.1 WD/SD Switch Architecture and its operation

Our proposed WD/SD switch architecture has a crossbar-equivalent function and has fewer SOAGs and higher modularity than conventional SD architecture. Figure 3 shows the configuration of our proposed WD/SD optical switch with 16 wavelengths. Each of the 256 input ports is pre-assigned to one of 16 wavelength channels (λ0 - λ15) of 16 spatial groups (s0 - s15). Sixteen wavelength channels from each of the spatial groups are multiplexed and broadcast to 256 WD/SD selectors, each of which consists of 16 SD SOAGs, a 16x16 arrayed-waveguide-grating (AWG) router, 16 WD SOAGs, and a 16 x 1 combiner.

By turning on one SD SOAG, the WD/SD selector chooses one WDM signal from one of the 16 spatial groups. The selected WDM signal is demultiplexed into 16 wavelength channels by the AWG router. The WD/SD selector then selects one wavelength channel by turning on one WD SOAG. Each WD/SD selector independently selects one input signal out of all the input signals, so the switch is logically equivalent to a strictly non-blocking crossbar switch and it supports multicasting functions. The complexity of the WD/SD switch increases almost proportional to the matrix size, although that of a conventional SD switch increases proportional to the square of the matrix size. Therefore the matrix size can be easily upgraded by adding modularized optical components. The number of SOAGs required to implement a 256 x 256 switch is 8192, which is 1/8 that of a conventional SD type optical switch fabric.

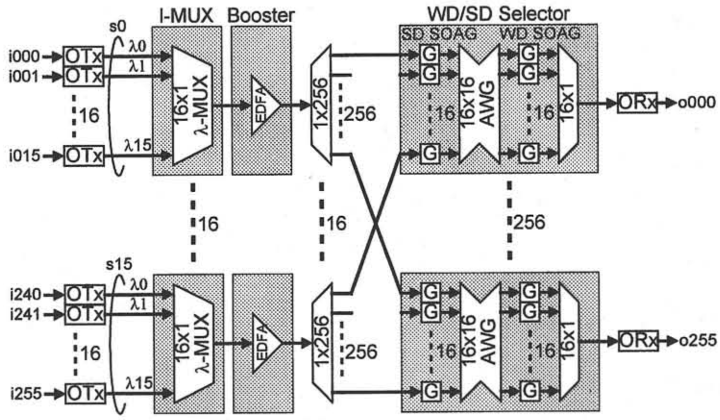

Figure 3. 256x256 WD/SD optical switch

3.2 WD/SD optical switch fabric demonstrator

We have developed a 16-wavelength 16 x 2 10-Gb/s/port optical switch fabric demonstrator upgradable to 256 x 256 (2.56 Tb/s aggregate throughput) [2]. Figure 2 shows photographs of the demonstrator shelf-face and packages. A λ-MUX module [Figure 2(a)], a booster module [Figure 2(b)] for each spatial group (16 wavelength multiplexed) and two WD/SD selector modules [Figure 2(c)] are mounted on a shelf [Figure 2(d)]. A newly developed smaller-sized SOAG module has been used in the WD/SD selector in order to implement the WD/SD selector function on one printed circuit board of 330 x 300 mm.

From the demonstrator size, an entire 2.56 Tb/s switch fabric should be implemented in as few as nine cabinets. By using this demonstrator, we have confirmed that, 1) both the switching time and the switching skew are less than 1 ns, and 2) the sensitivity penalty is less than 3 dB at the bit rate of 10 Gb/s.

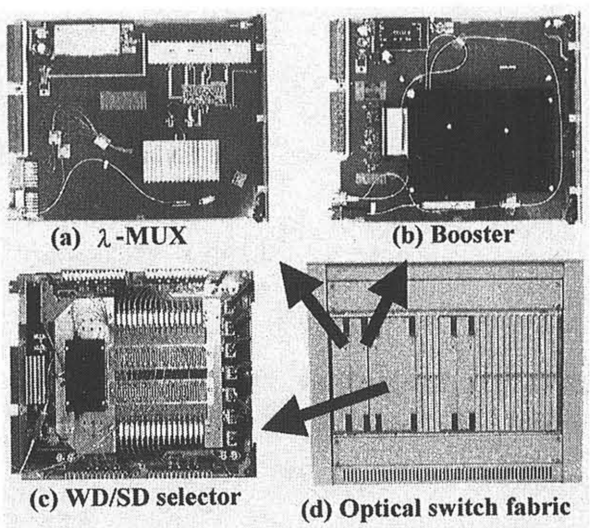

Figure 2. 2.56 Tb/s optical switch fabric demonstrator
The PCB size is 330 (W) x 300 (H) mm

4. Conclusion

A beyond Tb/s throughput optical packet switch is described by focusing on optical switch applications and optical switch fabric architecture. Our proposed WD/SD switch architecture enables construction of a 2.56 Tb/s crossbar-equivalent switch fabric with 1/8 as many SOAGs and higher modularity compared with a conventional SD switch. We believe these technologies will be a key to the implementation of future broadband data networks.

References

[1] Y. Maeno et al., ECOC '97, WE1D, pp. 67-70, 1997.
[2] S. Araki et al., ECOC '98, PDP, pp. 125-129, 1998.
[3] S. Kitamura et al., OAA '97, TuC3-1, 1997.