Ultra Low Power Optical Routing Network

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I. TRAFFIC INCREASE AND ELECTRICAL POWER CONSUMPTION

Energy consumption by ICT will become a pressing issue in the near future [1]. Of particular note, the power consumption and throughput limitation of electrical routers are becoming more and more obvious [2]. Recent IP router throughput advances have been much smaller than the yearly traffic increase rate of 40-60%. The fall in CMOS driving voltage has recently saturated and leakage current increases substantially as gate length decreases [3]. When we consider the power efficiencies of different transport mechanisms, switching on a lower layer than layer three IP routing offers significant power efficiencies and so the throughput possible can be enhanced, while the available switching granularity becomes coarse. Among the lower layer transport mechanisms, the optical cross-connect provides the highest efficiency. This project aims at development of large scale and cost effective optical networks exploiting multi-granular optical path cross-connect.

II. IMPACT OF HIGHER-ORDER OPTICAL PATH

A. *Multi-granular optical path switching*

TDM paths such as VCs (Virtual Containers) in SDH and ODUs in OTN (Optical Transport Network) are hierarchically structured; basically, the lower order paths provide service access, while the higher order paths provide transmission access [4]. At present, a wavelength path (channel) is defined and utilized as a single order entity. As traffic demand and fiber transmission capacity increases, higher order optical paths, wavebands, will be introduced. They may be used as virtual fibers [5]. They will also play a key role in realizing efficient optical circuit or flow switching networks [6]. In a single layer optical path network, optical path establishment/tear-down requires node (optical cross-connect) by node optical switch setting. On the other hand, in a multilayer optical path network, optical path establishment can be done by utilizing one (direct) or multiple wavebands that provide tunnels. As a result, in the connection establishment/release phase, the number of nodes involved in the signaling process is reduced and connection set-up/release delay is minimized. The relationship between the optical wavelength path cross-connect and waveband cross-connect corresponds to that of the electrical switching system and cross-connect system in PSTN (Public Switched Telephone Network). The major benefits of multi-granular optical paths are: (1) throughput enhancement of optical cross-connect (or optical switch scale/cost reduction), (2) support of virtual fiber networking for OVPN services, (3) simplification of optical circuit or flow establishment (simplification of connection set-up/release process).

B. *Hierarchical optical cross-connect (HOXC) system*

An optical switch can switch multiple optical paths. Switching groups of optical paths or wavebands can reduce the total switch size (necessary number of cross-connect switch ports) substantially. Hence, one of the fundamental benefits of wavebands is that they can reduce the switch scale needed to realize a specific throughput. This is critical in creating bandwidth-abundant future networks, since optical switch scale increases with the node degree or the number of input/output fibers. Figure 1 (a) shows a basic hierarchical optical cross-connect switch architecture using matrix-type switches; (b) shows the switch scale reduction available compared to the corresponding single layer optical cross-connect switch [7]. Here the switch scale is measured by the number of basic 2x2 switches needed to construct the matrix switches. The conventional optical path add/drop ratio for each transit node ranges from 0.25 to 0.5, and the ratios yield switch scale reductions of more than 50% with the addition of waveband technologies. This switch scale reduction is also true to a 3-D MEME based WSS/WBSS (Wavelength/WaveBand Selective Switch) cross-connect system [8], and more than 48% have been confirmed. The switch scale reduction obtained is much larger for matrix-switch-based architectures, since the hardware scale is proportional to the square of the number of input/output ports of matrix switches.

The grooming ratio is an important parameter that determines total switch scale of a hierarchical cross-connect. Recently, a novel node architecture and a network design algorithm that incorporates a grooming ratio restriction were developed [9]. The analyses showed that even when grooming ratio is restricted to a small value, say 0.25, the resultant network cost increase is marginal compared to the case with no restrictions. In other words, coarse granular routing (waveband routing) with supplemental intermediate grooming can create cost-effective networks. Please note that carriers do not need to recognize the grooming ratio. It is sufficient that they declare the necessary number of terminating/originating wavelength paths at a node and necessary node degree, and then the network design tool automatically determines the necessary switch hardware scale to accommodate the demands with consideration of the grooming ratio restriction.

II. HARDWARE TECHNOLOGY DEVELOPMENT

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Hardware development on matrix switch based HOXC is explained below. Waveband routing can be applied to a ring connecting node; wavelength level grooming can be done if necessary. The optical path demand accommodation efficiency offset compared to single-layer optical path rings was proven to be marginal [10]. The key components of the ring connecting HOXC system have been developed as shown in Fig. 2 [11]. The switch architecture is shown to achieve 75% switch scale reduction compared to a single layer architecture. Their optical performances were tested and shown to be satisfactory for practical applications [11].

The first practical HOXC system was developed and its feasibility confirmed using field-installed fibers [12] (Fig. 3). Fully-implemented equipment requires a 16-U chassis to manage 4.8-Tbit/s signals from 8 WDM lines and 160 client ports. To prove the feasibility of the developed HOXC node, transmission experiments employing optical fibers installed between Yokosuka telephone office and Yokosuka R&D Center were carried out. Good transmission characteristics were confirmed, where the maximum power penalty at a BER of 1×10^{-9} was less than 0.4 dB after four node transmission with two instances of intermediate grooming. We also examined video transmission with the High Definition Serial Digital Interface (HD-SDI) signal format, and confirmed that the signal was successfully switched without any degradation. We believe that the work constitutes a robust step towards achieving optical networks that can provide abundant, green, and cost-effective bandwidth.

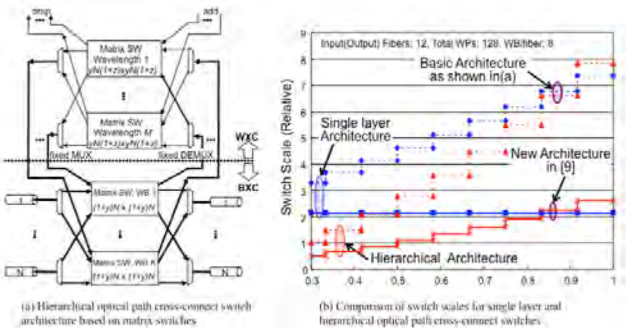

Fig. 1 Comparison of single layer and hierarchical optical path cross-connect switch scale

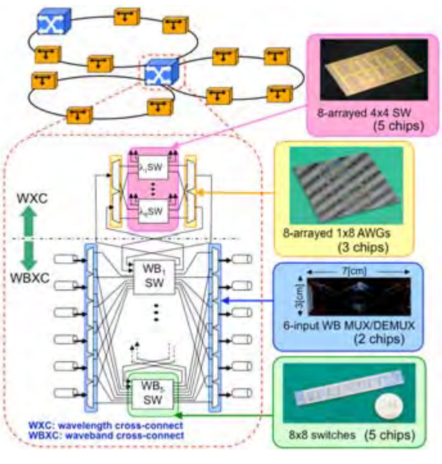

Fig. 2 Ring connecting HOXC system

Fig. 3 HOXC prototype system

II. Conclusions

Optical routing technologies will surely be the key to create future bandwidth abundant and green networks, however, their introduction remains limited. The inefficiencies recognized in present optical node technologies will be greatly mitigated with the introduction of new technologies such as wavebands. Various key technologies [13] including network design algorithms, matrix switch based compact hierarchical cross-connect systems, the application to ring interconnections, and various devices necessary for the realization of the network have been developed in the project.

References

[1] ITU Symposia on ICTs and climate change, Kyoto, Japan, April 15-16, 2008.

[2] J. Baliga, et al., "Energy Consumption in Optical IP Networks," IEEE JLT, vol. 27, No. 13, July, 2009, pp. 2391-2403.

[3] S. Nishimura, “Technology development towards router power reduction,” IEICE Tokai Chapter Special Course, Nagoya, March 13, 2008.

[4] K. Sato et al., "Prospects and challenges of multi-layer optical networks," IEICE Trans. Commun., Vol. E90-B, No. 8, 2007, pp. 1890-1902.

[5] K. Sato, "OOO switching –The role and technological advances," OFC/NFOEC 2011, NThB1, Los Angels, Marchi 6-10, 2011.

[6] K. Sato and H. Hasegawa, “Optical networking technologies that will create future bandwidth abundant networks,” Journal of Optical Communications and Networking, Vol. 1, No. 2, July 2009, pp. A81-A93.

[7] S. Kakehashi, H. Hasegawa, K. Sato, O. Moriwaki, and S. Kamei, "Optical cross-connect switch architectures for hierarchical optical path networks," IEICE Trans. Commun., vol. E91-B, No. 10, October 2008, pp. 3174-3184.

[8] S. Mitsui, et al., “Hierarchical optical path cross-connect node architecture using WSS/WBSS,” Photonics in Switching 2008, S-04-1, Hokkaido, Japan, August 4-7, 2008.

[9] Y. Yamada, H. Hasegawa, and K. Sato, “Coarse granular routing in optical path networks and impact of supplemental intermediate grooming,” ECOC 2010, Th.10.F.1, Torino, September 19-23, 2010.

[10] K. Ishii, H. Hasegawa, K. Sato, "Route and Wavelength/Waveband Assignment for Creation of Compact Hierarchical Optical Cross-Connect for Multi-Ring Connection," ECOC 2009, 4.4.2.

[11] K. Ishii, et al., “Development of hierarchical optical cross-connect system for ROADM-ring connection using PLC technologies,” Photonics Technology Letters, IEEE Volume: 22, No. 7, pp. 489-500, 2010.

[12] O. Moriwaki, et al., “Terabit-scale compact hierarchical optical cross-connect system employing PLC devices and optical backplane,” OFC/NFOEC 2010, Post Deadline Paper, PDPC9, San Diego, March 25, 2010.

[13] K. Sato and H. Hasegawa, "Prospects and challenges of multi-layer optical networks," IEICE Trans. Commun., Vol. E90-B, No. 8, pp. 1890-1902, 2007.