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フォトニックスイッチングネットワークの役割と課題

Development in and Challenges of Photonic Switching Networks

佐藤　健一
Ken-ichi Sato

名古屋大学
Nagoya University

1. Introduction

Transmission technologies are advancing and the highest bit rate achieved by a single optical fiber now exceeds 100 Tbps [1]. Optical fiber is a very thin medium and recent advanced cable technology allows us to accommodate 1,000 fibers within a 23 mm diameter cable. The total bit rate that the 1,000-fiber cable can carry is thus 100 Peta bits per second. While telecommunication nodes can terminate multiple fiber cables, current routing/switching/cross-connect systems have far lower throughput than the capacity of even a single fiber. The future transport bottleneck lies in the transport node and hence node technologies are the focus here.

2. Performance Bottleneck in Electrical Technologies

The difficulty of raising the throughput and/or reducing the power consumption of existing IP transport schemes is becoming more and more of a burden [2]. Figure 1 depicts recent advances in core router throughput [3]. At present, the available largest throughput of a router (single chassis) is less than 4 Tbps (2 Tbps, WAN count), only 2% of the possible transmission capacity of single optical fiber. IP traffic increase had been exceeding Moore's law (doubling in 12-18 months). After 2005, the yearly traffic increase rate fell to 40-50%, but IP router throughput advances have also diminished; only 20 % per year or so recently. This is mainly because CMOS performance improvements have slowed down. LSI power dissipation is proportional to the square of the driving voltage. The voltage reduction became gentle recently [4]. Leakage current is another important factor that determines LSI power dissipation. As gate length decreases, leakage current increases substantially, and the leakage current power dissipation is going to be an equivalent level to the active power dissipation [5]. As discussed so far, the power dissipation of electronic devices is restricting the available throughput of routers and the performance advances have now substantially slowed down. Please note that multiple racks/chassis structure can increase the total throughput, but this approach greatly degrades the throughput per watt performance due to system overhead, namely transporting packets among the multiple racks/chassis.

3. Future Directions and Role of Photonic Switching

Figure 2 depicts the routing granularity and power efficiencies of different node systems. Lower layer switching, under layer three IP routing, can significantly enhance power efficiency and throughput. LSRs (Label Switch Routers) and flow routers that utilize layer 2 switching, and ODU (Optical-channel Data Unit) cross-connects and optical path cross-connects will thus be effective. Power reduction and throughput enhancement can be attained by off-loading IP traffic from transit IP routers; this is particularly effective when traffic volume explodes. Optical path routing has been widely introduced, and the replacement of IP routing by enhanced layer two routing has recently been accelerated [6]. In terms of power efficiency and throughput, lower layer switching is more efficient, however, the fixed bandwidth path capability can be inefficient compared to the flexible bandwidth path capability that is now provided by LSPs. Therefore, TDM paths such as VCs (Virtual Containers) in SDH and ODUs in OTN (Optical Transport Network) provide multiple granularities that are hierarchically structured; the lower order paths mainly provide service access, while the higher order paths mainly provide transmission access [7,8]. The granularities of the TDM and Optical paths will become finer with the introduction of ODUflex and elastic optical paths [9]. To perform grooming in the electrical layer, electrical cross-connect systems (LSP switch, VC-XC, and ODU-XC), which inherently require expensive optical/electrical conversion at the input/output, are necessary at the intermediate nodes of electrical paths. Optical layer grooming dispenses with OE/EO. In this regard, when various optical transmission speeds are available, flexible elastic optical path networking will become attractive assuming that large-scale cost-effective elastic optical path cross-connect systems with full C/D/C (Colorless/Directionless/ Contentionless) functions and cost-effective variable bandwidth transponders are available.

Figure 3 details the data sending latency or connection set-up time for present electrical domain services and optical services. In electrical domain services, the IP datagram does not utilize signalling so information is sent immediately. Control driven two-way signalling is utilized for PSTN (Public Switched Telephone Network), and traffic driven two-way signalling is utilized for IP flow switching. Electrical paths are controlled by management systems so path set-up time tends to be longer. At present, in the optical domain, only optical paths are utilized, which are also controlled through management systems. The next systems targeted in the optical domain are optical fast circuit switching and optical flow switching, which are expected to be implemented in the not so distant future. In future networks, video-oriented traffic is expected to dominate. Progress in high-definition and Ultra-High-Definition (UHD) TV (more than 33M pixels) is steadily \advancing [10], and the expected source video bit rate is 72 Gb/s per channel. UHD-TV broadcasting trials using active satellites is expected to commence in 2020 in Japan. Bandwidth-intensive applications such as UHD video will

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directly use optical paths/circuits (path and circuit are used interchangeably in this paper), and as a result optical circuit or flow switching will play an important role.

Optical routing technologies will surely be the key to create future bandwidth abundant and green networks, but their introduction remains limited. The inefficiencies recognized in present optical node technologies need to be resolved. Large-scale cost-effective optical path cross-connect systems with full C/D/C functions are indispensable. The technology developments including the introduction of new technologies such as wavebands [2,8] should be accelerated.

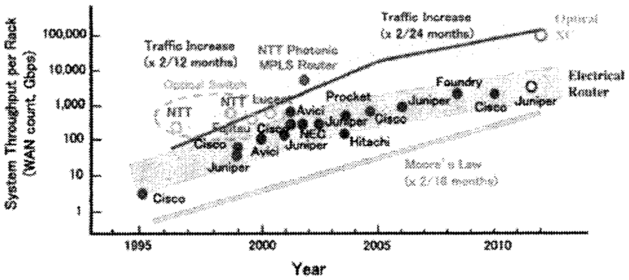

Figure 1 Advances in core router throughput

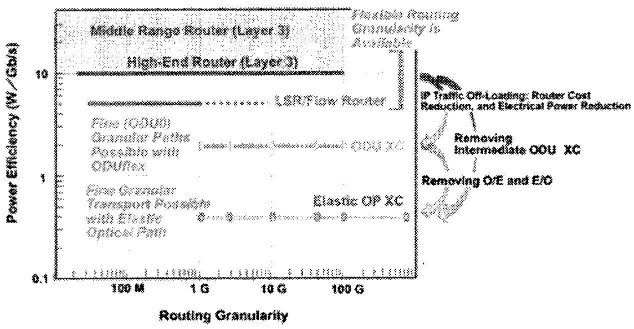

Figure 2 Evolution of IP transport mechanism

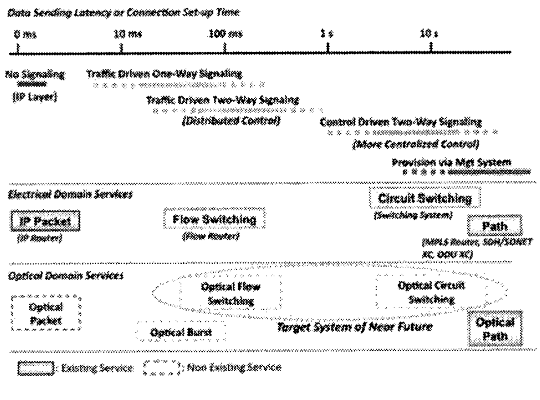

Figure 3 Connection set-up time, and electrical and optical domain services.

4. Conclusions

Performance advances in LSI-intensive systems, routers, were discussed. The performance limitation stems from the power dissipation of LSIs. Optical technologies will pave the way to creating bandwidth abundant and energy efficient future networks. The insufficiencies recognized in present optical node technologies need to be resolved. Large-scale cost-effective optical path cross-connect systems with full C/D/C functions are indispensable. Technology advances including the introduction of new technologies such as wavebands should be accelerated.

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