Role and Opportunities of Photonics in Future Networks
(Invited)

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Abstract
Relying solely on IP convergence is not the best approach in creating future bandwidth-abundant video-centric networks. Extending optical path layer technologies will be critical in cost-effectively creating networks.

Summary
The amount of energy consumed by ICT (Information and Communication Technologies) is expected to become a pressing issue in the near future [1-3]. Of particular note, the power consumption and throughput limitations of IP in electrical routers will become more and more significant [4, 5]. Video oriented traffic is expected to be dominant in future networks [6,7]. Progress in high-definition and ultra-high-definition TV (more than 33M pixels) is advancing [8], and the expected source video bit rate will reach 72 Gb/s per channel. The inefficiencies of the present TCP/IP protocol will become more tangible given the advances in video oriented services. These inefficiencies will limit the scale of Internet expansion in terms of bandwidth and the number of users [9,10], and the approach of relying on only IP convergence will not be the best approach in creating future bandwidth abundant networks [11].

When we consider the routing granularity and power efficiencies of different node systems, switching using a lower layer than layer three IP routing can be significantly power efficient and the throughput can be enhanced. LSRs (Label Switch Routers) and flow routers that utilize layer two switching, and ODU (Optical-channel Data Unit) cross-connects and optical path cross-connects will be utilized more and more as the underlying transport mechanism to deliver IP packets when the traffic volume sky-rockets. Optical path routing has been widely introduced, and the enhancement of layer two routing replacing IP routing has recently been accelerated [12]. In terms of power efficiency and throughput, lower layer switching is more efficient; however, a fixed bandwidth path capability is not always efficient compared to a flexible bandwidth path capability in an LSP. Therefore, TDM paths such as VCs (Virtual Containers) in SDH and ODUs in OTN (Optical Transport Network) are hierarchically structured; the lower order paths act as a service access and the higher order paths act as a transmission access [13, 6]. At present, a wavelength path (channel) is defined and utilized as a single order entity. The wide deployment of optical path technologies will be driven by the traffic increase. As traffic demand and fiber transmission capacity increase, optical paths with a much larger bandwidth, i.e., wavebands, will be introduced. Furthermore, when optical layer services such as OVPN (Optical Virtual Private Network) services, lambda leased line services, optical circuit (circuit and path are used interchangeably here) switching services emerge, hierarchical optical path arrangement will be necessary [6,7]. Fast optical circuit switching will be suitable for creating nationwide super-high definition source video distribution networks to headend nodes.

Reflecting the situation mentioned above, development of hierarchical optical path networking technologies has recently been accelerated [6,7,11]. In the presentation, some of the recent advances are highlighted. They include the application to metro ring networks, network reliability enhancement with waveband and wavelength path protection, and some key component technologies for creating the hierarchical optical cross-connect system.

The waveband technologies will be applied to various parts of the network, including metro and core. The large-scale deployment of Reconfigurable Optical Add-Drop Multiplexer (ROADM)-based metro ring networks has recently started in North America and Japan. The ring interconnection, at present, is established in the electrical layer with OE/EO conversion and electrical switches. Transparent ring concatenation without using OE/EO conversion is expected to be cost effective and power efficient in the future; however, it has not yet been attained since the OXCs require larger numbers and more complicated devices, i.e., large scale Wavelength Selective Switches (WSS) or matrix switches, than simple ROADM nodes. Use of a HOXC (Hierarchical Optical Cross-Connect) potentially allows us to create a compact and cost-effective ring-connecting node; however, difficulties exist in the optical path

accommodation for a concatenated ring topology. Room for optical path route selection is strictly limited in a ring topology and in the concatenations. In the network, it was not clear whether we could take advantage of coarse granularity routing at the ring connecting node and attain sufficient waveband utilization, however, we recently succeeded in developing a new efficient optical path accommodation method that can be applied to multiple-ROADM-ring connected networks linked via HOXC [14]. The proposed method offers a reduction in the cross-connect switch scale of greater than 60% by introducing the HOXC while suppressing the degradation in the routing capability to only 7.6%. The large impact of introducing waveband routing into the ring connection nodes will resolve one of the key issues preventing the use of optical cross-connect systems in achieving ROADM ring connection.

In the core part of the network, the mesh network architecture is important. Network survivability is a critical issue, however, few studies have addressed this issue using the hierarchical optical path networks so far. To create survivable hierarchical optical path networks, two mechanisms for dedicated protection in the optical layer are identified. One is wavelength path protection, i.e., switching working wavelength paths to their backup paths. The other is waveband protection, which switches wavebands. The latter minimizes the protection processing overhead while the former further reduces the network resource requirements. The former scheme is especially effective when two types of optical paths co-exist. One type requires optical path protection and the other does not. The services that utilize electrical layer protection/restoration, such as Label Switched Path (LSP) fast rerouting, will only need non-protected optical paths (optical layer protection is not required). We already developed a novel network design algorithm that employs waveband protection, and demonstrated its cost effectiveness [15, 16]. The algorithm achieves a cost reduction of almost 50% compared to that for single layer optical path networks with wavelength path protection for large-scale networks. It was proved that survivable hierarchical optical path networks are more cost effective than single layer networks with optical path protection for a wide range of traffic demands, regardless of which protection scheme is adopted, waveband or wavelength path. Which protection scheme should be used will be determined by the requirements imposed by the optical layer protection for the accommodated services. The hierarchical optical path network will be implemented in the not-so-distant future when traffic volumes warrant it.

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