Next Generation Transport Network Architecture

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Abstract: This paper discusses the prospects of and challenges facing the next generation transport network architectures. Enhancements expected in optical path technologies are highlighted and state-of-the-art key enabling technologies are demonstrated.

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1. Development in IP backbone technologies

Figure 1 explains the evolution in IP backbone network technology [1], focusing on the routing mechanisms. Since the early 1990s, IP routers based on software routing have been replaced with hardware routing realized by ASICs, which greatly enhanced router throughput (Fig. 1, upper column). In this early stage of IP networks, routers were connected to each other by leased line services to produce a peer-to-peer configuration, called IP over SDH. To cope with the continual expansion in traffic, node throughput expansion is necessary. One possible approach is to simply develop tera-bit electrical IP routers and to connect them with large capacity WDM links, the IP over (SDH over) WDM technique. To develop more manageable large-scale IP networks, ATM technologies were introduced in the mid 1990's as the underlying transfer mechanism to provide direct mesh-like connections of routers using VPs and VCs (IP over ATM). This enables IP router cut-through on ATM. It also provides the basis for network traffic engineering. The key large-scale IP backbone networks installed around the world are based on this technology. Recently, a more IP-oriented technology, MPLS, and the enhancement, MPLS-TP [2], have been introduced. MPLS/MPLS-TP provides connection-oriented switching capability based on IP routing and an IP signaling protocol. The major difference from IP over ATM is the integrated management capability of layer 3 and layer 2 networks. The next round of enhancement involves IP over Optical Paths and waveband technologies. ROADMs are now widely deployed around the world [3, 4]. These enhance the performance of existing IP networks, and are very effective, especially for creating large bandwidth networks with greatly reduced power consumption. I will focus on photonic network technologies hereafter.

2. Photonic transport network technologies

Energy consumption by ICT (Information and Communication Technologies) is expected to become a pressing issue in the near future [5-7]. Of particular note, the power consumption of electrical routers will become more and more significant [8, 9]. 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 utilized more and more to deliver IP packets when traffic volume explodes. As mentioned above, optical path routing has been widely introduced, and the replacement of IP routing by enhanced layer two/onemo routing has recently been accelerated [10]. In terms of power efficiency and throughput, lower layer switching is more efficient, however, fixed bandwidth path capability is not always efficient compared to the flexible bandwidth path capability provided by 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 provide service access, while the higher order paths provide transmission access [11, 12], mostly. 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 and the limits imposed by the power consumption and throughput restrictions of electrical switching. As traffic demand and fiber transmission capacity increases, much larger bandwidth optical paths, the waveband, will be introduced.

When optical layer services such as OVPN (Optical Virtual Private Network) services, lambda leased line services, optical circuit (circuit and path are used interchangeably in this paper) switching services emerge, hierarchical optical path arrangement will be needed as discussed in the next section. Optical fast circuit switching will be suitable for creating a nation-wide super-high definition source video (72 Gb/s per channel) distribution network to headend nodes. Video-oriented traffic is expected to dominate future networks [12,13].

3. Evolution of optical path layer technology

Figure 4 illustrates the envisaged optical layer evolution; the introduction of higher-order optical paths (wavebands) and optical fast circuit switching. Optical switches support optical signals with a wide range of wavelengths; this means that the same switches can be used for switching multiple optical paths. Switching multiple optical paths or switching wavebands can reduce total switch size (necessary number of cross-connect switch ports) substantially. This mitigates one of the major present challenges in creating large scale optical cross-connects. For example, when waveband add/drop ratio is less than 0.5, switch scale reductions of more than 50% for a matrix-switch-based cross-connect system [14], and more than 20% for a WSS/WBSS (Wavelength/WaveBand Selective Switch) based cross-connect system [15] have been confirmed. The hierarchical path structure, on the other hand, can degrade link utilization, and this effect may be enhanced by the additional complexity created by the waveband/wavelength assignment problem. This problem has been resolved by the development of effective hierarchical optical path network design algorithms [16, 17].

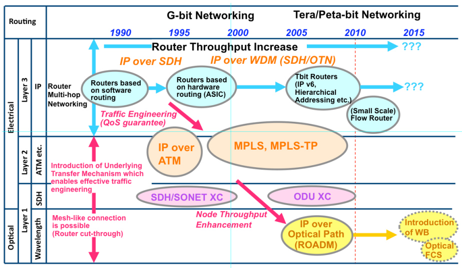

Fig. 1 Evolution of Transport Networks

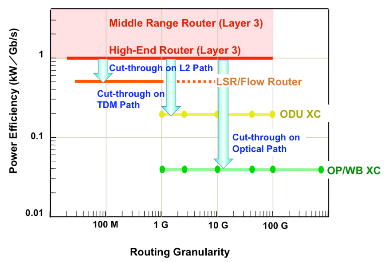

Fig. 2 Evolution of IP transport mechanism

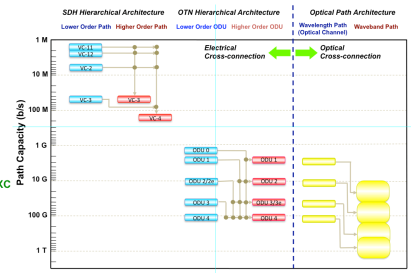

Fig. 3 SDH, OTN, and OP architectures and path capacities

The role of wavebands in realizing efficient optical circuit switching networks is clarified [13, 18]. Figure 5 depicts optical path establishment in a single optical path layer network as well as that in a multilayer optical path network [13]. 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 utilizing one (direct) or multiple wavebands. As a result, in the connection establishment/release phase, the number of nodes involved in the signaling process is greatly reduced and the connection set-up/release delay is minimized. On the other hand, wavebands are usually established semi-permanently. This scheme requires bandwidth reservation even when the optical paths/circuits accommodated within the waveband are not used, which results in reduced resource utilization. The relationship between the optical wavelength path cross-connect and the waveband cross-connect corresponds to that of the electrical switching system and the cross-connect system in POTS networks. In regard to connection establishment and signaling, centralized and distributed control schemes can be applied as demanded by networking requirements.

4. Recent developments in waveband node technologies

Ring networks are utilized extensively in metro networks to create cost-effective large bandwidth networks. At present, ROADM ring interconnection is done in an electrical layer with OE/EO conversion and electrical switches. Removing the costly and power consuming electrical stage can be realized by exploiting the optical path routing provided by OXC. The OXC architectures that utilize multiple WSSs or optical matrix switches have been investigated, however, the expected higher costs needed to create the OXCs have prevented their introduction for cost-sensitive applications. As mentioned above, the Hierarchical OXC (HOXC) architecture can substantially reduce OXC switch scale. Regarding optical path demand accommodation algorithms, we have recently succeeded in developing a new efficient algorithm for multiple-ring connected networks; it imposes practically no constraint on wavelength assignment as regards inner- and inter- ring traffic [19]. Waveband routing is applied to all traffic at the 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 [19]. Based on this achievement, we implemented the key components of the ring connecting HOXC system as shown in Fig. 6 [20]. This switch architecture is shown to achieve 60% switch scale reduction compared to a single layer architecture with the same routing capability. Their optical performances were tested and shown to be satisfactory for practical applications [20].

The other advance in recent hardware development is an ultra-compact Waveband Cross-Connect (WBXC) switch module [21] that will be utilized for creating cost-effective multi-degree optical cross-connect nodes. We have successfully developed a single chip WBSS using PLC technologies [22]. The device has no moving mechanical parts, requires no adjustment, and is very compact, which will lead to high reliability and low cost. Using the WBSS chips, a very compact one box WBXC module, which will be suitable for application to cost-sensitive areas such as metro-edge and metro-access networks has been developed. Fig. 7 depicts a 5x5 WBXC architecture. At the input side of the WBXC, we use 1x5 optical couplers (SC) instead of WBSSs, since the number of input/output ports is small (this means that they have relatively small loss and are cost effective). The architecture allows optical multicasting, which will be extremely useful for video distribution. Each input fiber carries forty 100 GHz spaced wavelengths in five wavebands; each waveband holds eight wavelengths. The implemented WBXC switch module size is 12.5 x 21 x 5 cm^3. The total throughput is 2 Tbit/s (10 Gbps x 40λs x 5 fibers). Combining two of the modules, their channel grid frequencies are offset by 50 GHz, and using 50-100 GHz interleavers upgrades the system throughput to 4 Tbit/s.

The component 1x5 WBSS architecture is also shown in Fig. 7. The interleaved waveband arrangement was adopted; it allows cyclic AWGs to be used as waveband multiplexer/demultiplexers [22]. The WBSS consists of six cyclic AWGs and five 1x5 thermo-optic switches; they are monolithically integrated on a 34x64 mm^2 chip as shown in Fig. 7. In order to compensate the loss variations of the cyclic AWG output ports, a special connection arrangement between input and output AWGs was applied [22]. The performance of the WBSS modules was tested; after traversing 5 modules the power penalty was about 0.2 dB, which confirms the applicability of the WBSS to metro-edge/metro-access networking.

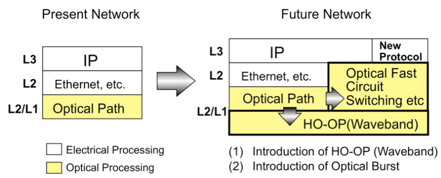

Fig. 4 Envisaged optical layer evolution

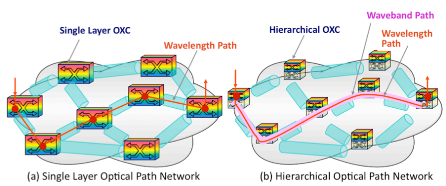

Fig. 5 Comparison of single layer optical path and hardware development

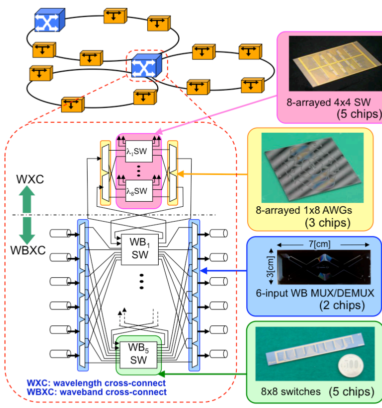

Fig. 6 Application of waveband to ring interconnection hierarchical optical path network

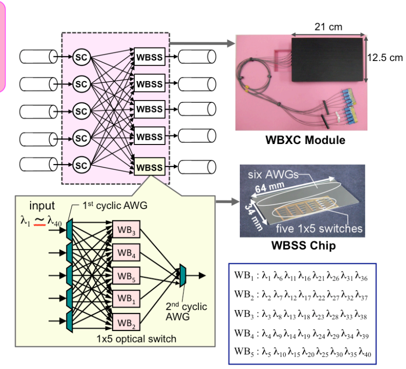

Fig. 7 Ultra-compact waveband cross-connect module

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