Optical Technologies that Enable Green Networks

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ABSTRACT

Advances in silicon technology are failing to keep up with Internet traffic; this is unfortunate since we can envisage large bandwidth video distribution services carrying super-/ultra- high definition videos. In this context, optical technologies are critical to create bandwidth-abundant and power-efficient networks. Future networks will utilize optical paths not only for network implementation but also for the provisioning of optical circuit switching or optical flow switching services. The large throughput optical cross-connect node and optical path tunneling functions required are effectively attained with the introduction of higher order optical paths, wavebands. This technology can naturally and effectively limit the add/drop ratios of optical paths at nodes, which is very beneficial in reducing the switch hardware scale required to attain colorless, directionless, and contentionless capabilities. Harnessing the full power of light will lead to the creation of future Green networks.

Keywords: optical path, waveband, optical cross-connect, waveband cross-connect, optical circuit switching, hierarchical optical path

1. INTRODUCTION

Energy consumption 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 limitation of electrical routers are becoming more and more obvious [4, 5]. ICT will, however, play a key role in reducing the overall energy consumption of society, which is often referred to as Green by ICT [2, 3]. Discussions have been initiated to evaluate the degree of this reduction and to clarify how to promote the Green by ICT. In this context, optical technologies are critical to create bandwidth-abundant and power-efficient future networks. This paper discusses the direction of optical technology development that leads to future Green networks.

2. ROUTER THROUGHPUT BOTTTLENECK

Figure 1 depicts expected traffic volume increase and ICT power consumption increase in Japan over the near term twenty years period [6]. Compared to 2006 levels, traffic volume and ICT power consumption at 2025 are expected to increase by 190 times and 5.2 times, respectively. The traffic increase rate assumed was 32 %, which is smaller than that of about 40 % as presently measured in Japan. The power consumption estimation incorporates reasonable CMOS technology advances, but will reach 20% of Japan's electric power generation capability in 2025. Router power consumption is among the key factors driving the power consumption increase. Figure 2 depicts recent advances in core router throughput. The chart clearly indicates that the throughput advances appear to be saturating, which stems from the power consumption limitations of LSIs. The fall in CMOS driving voltage has recently saturated and leakage current increases substantially as gate length decreases [7]. In order to create transport networks, routing/switching on a lower layer than layer 3 IP routing offers better power efficiencies and so the throughput can be enhanced at the cost of coarse switching granularity [8, 9]. Among the lower layer transport mechanisms, the optical path/waveband cross-connect provides the highest efficiency. Routing granularity is arbitrary with IP/MPLS routers and Ethernet switches etc., while other lower layer systems offer fixed granularity. It is therefore reasonable to use the best combination of different layer technologies.

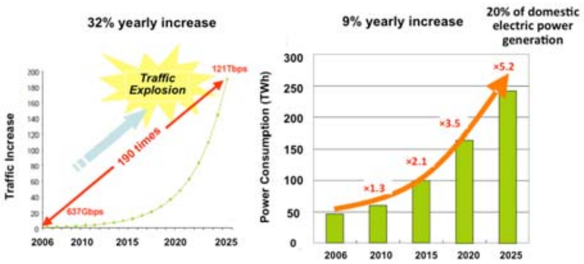


Fig. 1 Estimated traffic increase and power consumption of ICT [6]

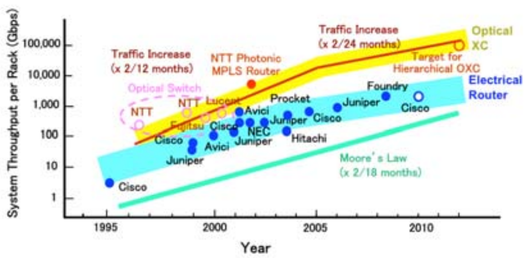
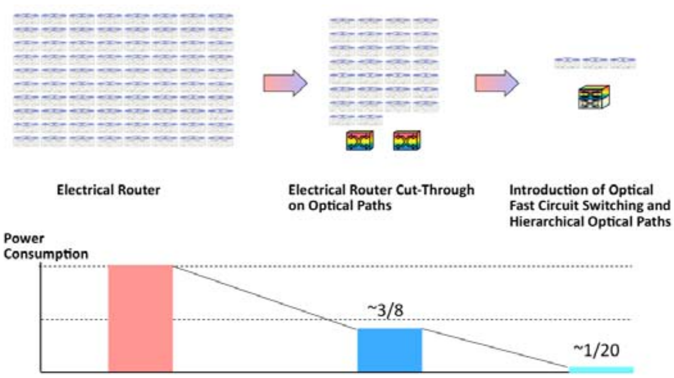


Fig. 2 Advances in core router throughput

3. TRANSPORT ARCHITECTURE OF THE FUTURE

3.1 Impact of Video

Highly granular routing/switching is very effective in collecting relatively small capacity data streams. For example, when sensors become ubiquitously distributed around the globe, say, 10 times the world's population, the IP-based Internet mechanism works well and will be indispensable in collecting such relatively small streams that are spatially distributed. The collected/aggregated data should be transported in the network with the lowest layer transport technologies possible, instead of hop-by-hop IP routing. Optical paths have thus been initially utilized in the network to cut-through routers (Fig. 3 middle). In future networks, video-oriented traffic is expected to be dominant. Progress in high-definition and ultra-high-definition TV (more than 33M pixels) is steadily advancing [10], and the expected source video bit rate will reach 72 Gb/s per channel. The inefficiencies of the present IP protocol will become more evident given the advances in video-oriented services. Bandwidth-demanding applications such as ultra-high definition video will directly use optical paths/circuits, as illustrated in Fig. 3 (right). Regarding traffic volume, in sensor networks, even if each sensor produces 1 kbps and the number of sensors is 7 billion, then the total generated bit rate around the globe is just 7 Tera bits per second. Please note that this is equivalent to just 1,000 ultra-high definition (72 Gbps) video channels (Fig. 4). The impact of broadband video is thus significant, and so will be a major factor in designing future networks.



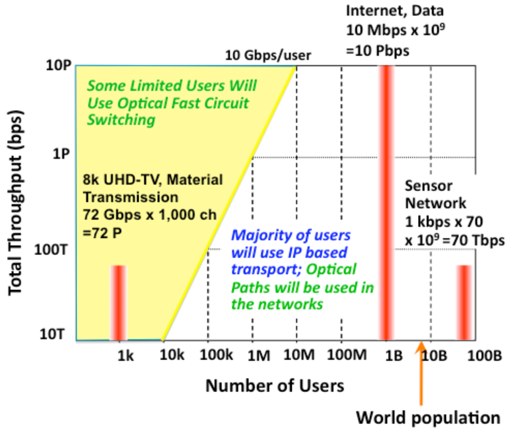
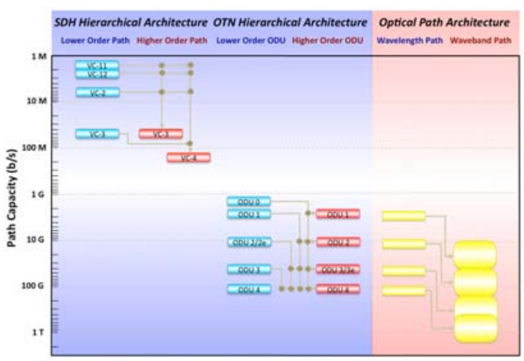


Fig. 3 Electrical router cut-thorough and optical fast circuit switching   *Fig. 4 Different bit-rate services and the bandwidth*

3.2 Hierarchical Optical Path –Introduction of Wavebands–

In terms of power efficiency and throughput, lower layer switching is more efficient, however, the flexible bandwidth path capability provided by LSPs can be more efficient than the more rigid bandwidth path capabilities enforced by lower layer switching. Therefore, TDM paths such as VCs (Virtual Containers) in SDH and ODUs in OTN (Optical Transport Network) are hierarchically structured as shown in Fig. 5; the lower order paths provide service access, while the higher order paths generally provide transmission access [11, 12]. At present, a wavelength path (channel) is defined and utilized as a single order entity. 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) or optical flow switching services emerge, the hierarchical optical path arrangement will be needed. Optical fast circuit switching will be suitable for creating a nation-wide super-high definition source video distribution network that connects video headend nodes.



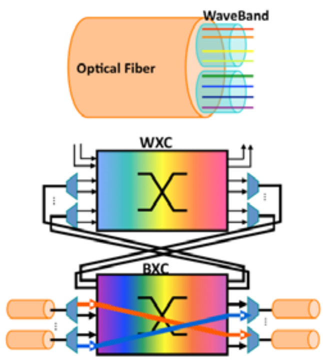
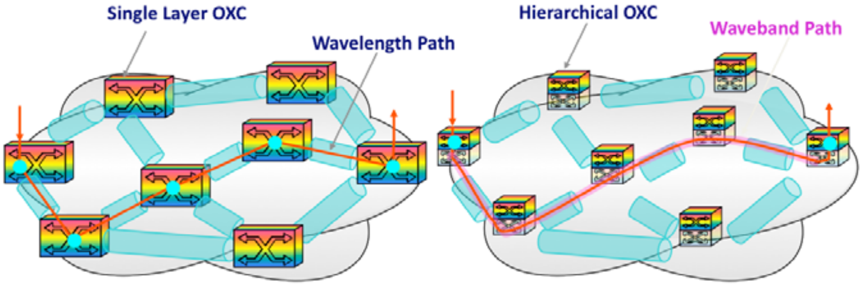


Fig. 5 SDH, OTN, and OP architectures and path capacities   *Fig. 6 Wavebands and hierarchical optical cross-connect*

3.3 Benefits of Wavebands

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. This mitigates one of the major challenges; the need to create extremely large scale optical cross-connects. For example, when the waveband add/drop ratio is less than 0.5, switch scale reductions of more than 50% for a matrix-switch-based cross-connect system [13], and more than 20% for a WSS/WBSS (Wavelength/WaveBand Selective Switch) based cross-connect system [14] have been confirmed. The role of wavebands in realizing efficient optical circuit switching networks has been clarified [8, 12]. Figure 7 depicts optical path establishment in a single optical path layer network as well as that in a multilayer optical path network. 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 signalling process is greatly reduced and the connection set-up/release delay is minimized. 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. With regard to connection establishment and control/signaling, traffic-driven (optical flow switching) or control driven (optical circuit switching), and centralized or distributed control scheme can be applied as demanded by networking requirements.



(a) Single layer optical path network *(b) Hierarchical optical path network*

Fig. 7 Comparison of single layer optical path and hierarchical optical path networks

3.4 Node Architectures

Flexible optical cross-connects demand a colourless, directionless, and contentionless architecture [15], however, this necessitates large scale space switches on the client side. Switch scale can be effectively minimized by limiting the add/drop ratio of optical paths at each node. This limitation can be effectively met by applying the waveband approach. Network design algorithms that effectively incorporate this limitation have been developed [16]. Figure 8 shows hierarchical optical path network cost where add/drop ratio, y_0, is parameterized and varied from 0.1 to 1.0. The network cost is normalized by that of a single layer optical path network. It is shown that when the add/drop ratio is restricted, and the value is less than 0.4, the resultant cost increase is marginal compared to a network with no restriction. Figure 9 shows add/drop ratios obtained with (a) a newly developed network design algorithm, and (b) a conventional algorithm that has no add/drop restriction. It is shown the add/drop ratio is well controlled with the newly developed algorithm. Figure 10 depicts possible cross-connect system architectures that utilize the optical path cross-connect. To reduce the space switches needed to implement the colourless/directionless/contentionless architecture, the most efficient approach is to restrict the add/drop ratios to the minimum value necessary. The space switch can be realized with an electrical space switch or ODU cross-connect that can manage (cross-connect) sub-lambda electrical paths, although this requires additional intra-office OE/EO (Fig. 10). Applying waveband technologies can significantly reduce optical switch scale and hence it allows the use of well-established robust PLC technologies. A recently developed ultra-compact waveband cross-connect sub-system [17] that utilizes waveband selective switches [18] is also shown in Fig. 10.

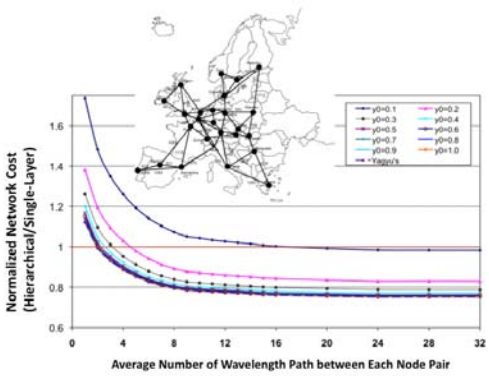


Fig. 8 Network cost evaluations with add/drop restriction

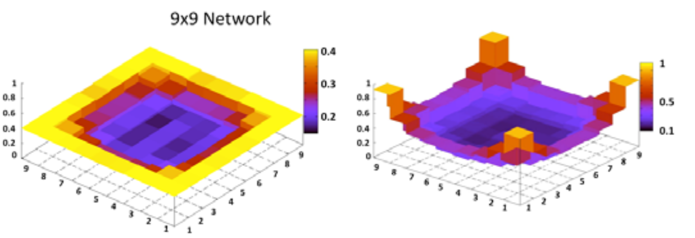


Fig. 9 Add/drop ratios obtained with (a) newly developed and (b) ratio conventional algorithm

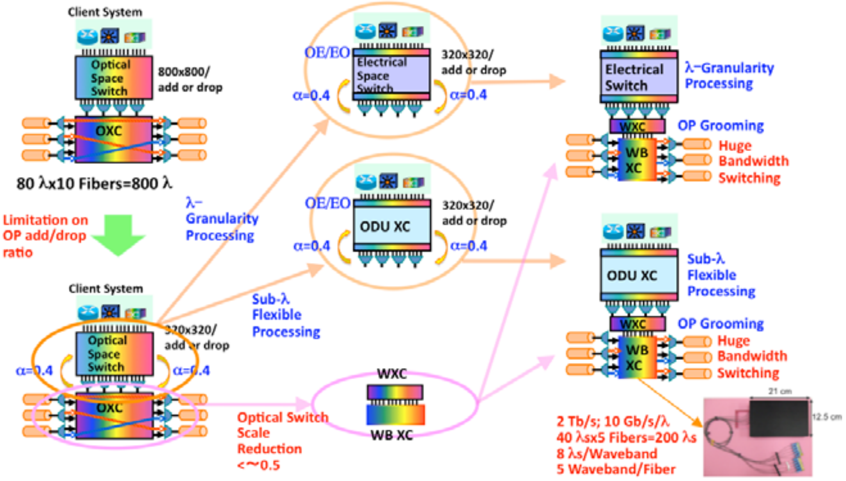


Fig. 10 Optical cross-connect node architectures

4. CONCLUSIONS

Energy consumption by the ICT sector is rapidly growing in lock-step with Internet service take-up. ICT will, however play a key role in reducing the total energy consumed by society, which is referred to as Green by ICT. Given that the pace of silicon technology progress is lagging Internet traffic expansion, and the expected adoption of super-/ultra- high definition video services, optical technologies are critical to creating bandwidth-abundant and power-efficient networks. In future networks optical paths will be utilized not only within networks but also for the provisioning of optical circuit switching or optical flow switching services. The large optical cross-connect node throughput and optical path tunneling functions required are both effectively attained with the introduction of higher order optical paths, wavebands. This technology can naturally and effectively control the add/drop ratios of optical paths at nodes, which yields substantial benefits such as reducing the switch hardware scale needed to attain the colorless/directionless/contentionless architecture.

ACKNOWLEDGEMENTS

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