Prospects and Issues of Future Optical Transport Node

(Invited Paper)

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Abstract— **Recent developments optical networking technology have been brought up various implications on the optical networking node architecture. The future optical networking will be coined by combination of MAC functions and all-optical PHY functions. This paper will review such layer-convergence models and technical optimization considerations of electrical and optical functions for future internet prospects, including recent research trend in PBB and MPLS-TP.**

I. Introduction

OPTICAL networking, by the definition, transports information over the optical transmission resources such as fiber and the free space. During the past decades, the major technology developments have enabled such networking goals, utilizing SONET/SDH or DWDM transmission systems. Such technologies have reduced the capital expenditure and operational expenditure by an order of magnitude because of nearly unlimited available bandwidth and small form factor of fiber. Further developments of the all-optical DWDM switch technology have introduced additional cost reduction by a factor of a few. The main driver of the past technology development has been associated limitedly with path switching. The future network evolution and revolution will undoubtedly make the best use of a packet switching network technology, because of the utilization efficiency by load balancing, openness by reachabililty, and easy and secure virtualization of networks. The standards developments at IEEE, IETF, and ITU-T introduce various packet transport network technology – a few important examples include provider backbone bridge (PBB) Ethernet and T-MPLS (MPLS-TP) which provide network functions that can directly replace a SONET/SDH layer. In this end, the optical links carry optical packets switched by electrical functions at optical nodes.

The optical packet switching (OPS) has been believed to be the ultimate goal of optical network for its potential to achieve very high throughput beyond the electronics limit. All optical data processing and switching are the key enablers to achieve the goal. Power consumption is one of the major concerns for Tbps data process and switch. However, recent developments expose application limits of all optical data processing and switching – logic gates are not scalable enough to handle even a minimum set of packet header information and switch power savings are not promising. An optical burst switching technology can replace the header processing power requirement with electronic process. However, the data plane optical cross-connect is still the bottleneck for cost and capacity efficiency.

Considering the fundamental technical boundaries and newly available technology concepts, the optimal node design concept can be inferred as an extrapolation for future evolutions. This paper will review the state of the arts of optical packet switched networks, i.e. so-called 1.5 layer, such as PBB, PBB-TE, Ethernet OAM (operations, administration, and management), Ethernet protection, T-MPLS, T-MPLS OAM, and T-MPLS protections.

II. Evolution or revolution

An all-optical switching technology is first approached by component research community, as there are so large potential to provide nearly Tbps switching capacities. This bottom-up technology revolution is fairly successful to introduce DWDM switches pursuing the technical solutions for 'optical transparency,' 'minimum node delay,' and 'bit-rate independent optical channels' as the optical system gain. In fact, bypassing unnecessary optical-to-electrcal-to-optical (OEO) data conversion by the use of low-cost fiber and wavelength switches helps reduction of cost by far. A revolution is led by the pursuit of all-optical packet switching in networks. However, the benefits with al optical path (circuit) switch may not be applicable again due to the following reasons:

Need for large buffers again – One of the main goals for OPS/OBS technology is to minimize the use of optical packet and burst buffers as all-optical memory technologies are not practically available. For this reason, buffer considerations are limited only to fiber delay lines (FDLs). Optical packet or burst contention is mainly resolved by wavelength conversion, assisted by small FDL buffers. However, this assumption has been one of the critical roadblocks to achieve a practically low packet loss rate requirement in the optical layers. Moreover, all-optical solution by either FDL buffers or true optical memories do not cost necessarily lower than OEO devices with electronic memory buffer.

Elimination of large OEO delays – OEO delay in principle is merely the sum of 'one bit delay (for detection)' and 'propagation delay on PCB', which is negligibly small compared with propagation delay time in a 1-m fiber. In synchronous networks, there might be one frame delay (eg. 125 usec for SDH) that are required commonly for both OEO or OOO switch nodes. The delay will be a network design parameter, instead of OEO or all-optical circuit delays.

Optical layer transparency – In the past, transparency has been meant for 'low cost solution at a high data rate.' However, recent developments in all-optical technology and electro-optics technology reveal that transparency may not be necessarily the simple solution for high-data-rate low-cost solution. Carrier dynamics of semiconductor optical amplifiers (SOAs) are no longer faster than that in silicon devices. One can try to maximize the optical transparency by the use of transparent passive optical switches. Recent high data rate systems tend to use DPSK, QPSK, and OFDM. For these transmission formats, aforementioned wavelength converters and transparent switches cannot be used. Important requirement is the system transparency to L2/L3 layers.

Higher bit-rate speeds – In reality, a system consists of EO transmitters and OE receivers. When the market adopts a certain high bit rate system, there exists a low cost solution for OEOs. These OEOs typically cost the same as or less than SOA-based all optical solutions. In addition, SOA solutions have speed limit up to 10s of Gbps due to carrier dynamics.

All optical solution may represent a revolutionary progress in technology development while the OEO solution can be considered an evolutionary technology development. The state of the art in this area shows the evolutionary progress may surpass the revolutionary one, with more realistic applications.

III. Optical Packet Transport Technologies

Recently introduced packet transport networks mostly employ optical transport interfaces so that the optical transmission can be switched by optical switches. In this sense, we refer these technology solutions as layer 1.5, i.e. a layer between MAC and PHY in the OSI network model, including PBB, T-MPLS (MPLS-TP). Ethernet networking is historically used for local area network due to the scalability limit. A new standard IEEE 802.1ah PBB have extended the limited forwarding (routing) capability with a hierarchic addressing scheme by the use of MAC in MAC encapsulation. The Ethernet intrinsic forwarding mechanism such as source address learning is not used to allow the use of other sophisticated forwarding and routing methods. With OAM tools and protection methods (Table 1), an Ethernet networking demonstrates a strong potential to replace the circuit switched physical layer in the metro and core networks. A new effort of MPLS-TP has been recently initiated at the IETF to develop a standardized packet transport network technique.

Table 1 Standard Carrier Class Ethernet Packet Switched Network Technologies

Networking Tool	IEEE Standards	ITU-T Recommendations
Traffic engineering	802.1Qay PBB-TE	
OAM	802.1ag CFM	Y.1731
Link protection	802.1Qay Protection	G.8031
Protection ring		G.8032

Now the question becomes how these optical packet switch technologies in a sense of the optical packet transported in fiber links will evolve to meet the requirements for the future networks.

IV. Future Networking Revolution

Future internet principles are being widely studied and drives network function development, defining design requirements and constraints on packet switch networks. For the optical packet transport, there are a few keen requirements for success of the future technology: (a) virtualization of network resources including link capacity access and node switching, (b) federation with horizontal open access point interface for virtualized resources, (c) energy efficient routing, (d) direct OAM functions for optical packets, and (e) integrated and flat architecture. Such consensus has been drawn in widely known future internet study efforts in GENI [1], 4WARD [2], Internet2 HOPI [3], NGN Technologies [4], and FIF [5].

These features are new additions to the previously existing standard network requirements. An important understanding that we have to take into account is that there will be optimization between evolution from system integration and revolution from component technology breakthroughs; a gradual migration of packet switching function in the electronics domain into the optics domain as an extension of optical path switching. The aforementioned future internet requirements, however, need a very high level of functionality that requires revolutionary optical computing and processing technique development.

V. Discussions

The future optical switch node architecture will consist of evolutionary system integration and revolutionary all-optical component technology developments. One of the most fundamental issues will be how the optical networking resource will be virtualized in a shared manner. Limited functionality of all-optical PHY component technology will be the major limiting factor, as well as polarization sensitivity, power consumption and form factor concerns, for which the intermediate MAC functionality of electronic integration of the optical packet switch makes up the gap between the service and the transport layer.

References

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