OXC and HIKARI router: Their use in IP over optical networks

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Abstract
An OXC (optical cross-connect) and a HIKARI router (photonic MPLS router) are key components in creating current and future IP-over-optical networks. This paper presents the current OXC and HIKARI router technologies. Application examples of OXCs and HIKARI routers are also presented.

1. Introduction
The amount of IP data traffic has grown remarkably over the past few years. Massive IP routers and flexible route control mechanisms are required to help deal with this growth, and optical technology must catch up with this trend. From the viewpoint of network control, MPLS (multi-protocol label switching) has shown great promise as a solution to this growth. MPLS was initiated on the control plane of cell or frame based systems such as ATM (asynchronous transfer mode) and frame relay. A few years ago, NTT proposed the Photonic MPLS concept [2]. This concept includes MPÃS (multi-protocol lambda switching) [3] and GMPLS (generalized MPLS) [4], and has many extensions for photonic label switching technologies. NTT demonstrated the HIKARI router (photonic MPLS router) [5, 6] which is based on the MPÃS technologies as the first realization of the photonic MPLS concept.

The OXC is strongly associated with the IP network through the photonic MPLS concept and GMPLS. The HIKARI router evolves the OXC into an LSR (label switched router) which is categorized as an IP router. The HIKARI router provides multi-layer traffic engineering toolbox functions to the IP-over-optical networks [7]. This paper presents the IP-over-optical network technologies, the OXC technologies, the photonic MPLS concept, and HIKARI router technologies.

2. IP-over-optical network architecture

2.1. IP over WDM
In the early stage of the IP-over-optical network development, an IP over WDM architecture was the most commonly used architecture. Under the IP over WDM architecture, POPs (Point of Presences) are connected via WDM transmission systems. Figure 1 shows the reference POP model of this network architecture. The POP is constructed with IP routers and point-to-point WDM transmission systems or fixed (i.e. not reconfigurable) OADM (optical add/drop multiplexer) systems.

In this POP model, it is assumed that edge devices of the optical network are WDM transmission systems. The OXC is not required because all the traffic is forwarded and routed in the IP layer. To reduce the POP construction cost, VSR (very short reach) interfaces were developed in the OIF (optical internetworking forum) [8]. The VSR interface was first utilized between IP routers that were installed on the same floor or in the same office. The main target of the coverage length of the VSR interface is 300 m. The utilization area of the VSR interfaces is extended to between the IP router and the WDM system, between the IP router and OXC system, and between the OXC system and the WDM system.

2.2. Introducing OXC into IP networks
In the IP over WDM fashion, all the IP traffic from neighboring POPs is routed to the next hop POPs or local IP network at the IP routers in the POP. If the amount of through traffic is greater than that of the local processed traffic, a cut-through or bypass in the Layer 1 network becomes an attractive solution to reduce the node processing cost. The OXC can be used to realize the Layer 1 cut through. This architecture is called the IP over photonic network. The photonic cut-through technique will reduce the volume of 10 Gbps (STM-256 or OC-192c) forwarding by about 1/3. Figure 2 shows the results of a detailed study on the cost effectiveness achieved by using the IP over photonic network architecture. The calculation is based on the estimated IP...
traffic demand for 2005 and state-of-the-art IP routers as well as photonic technology. The Cluster ratio is the cross traffic between routers, and so it does not offer effective IP forwarding between users. The Cluster ratio is generally 2/3 for the current Internet infrastructure traffic. According to the calculation, we can expect a cost reduction of more than 60% by using the photonic cut-through technique. Given the current backbone network traffic pattern, we expect the photonic cut through will be applicable more than 60 to 70% of the time [7, 9].

Another benefit to introducing the OXC into IP networks is enhancement of the network protection mechanism. If the OXC is inserted between the IP router and WDM system, we can install a shared restoration mechanism or protection switching mechanism in the optical layer.

3. OXC technologies

3.1. Grooming function (O-E-O OXC)

In the early stage of the OXC system development, it had been taken for granted that the OXC system would use optical switching fabrics. This was changed when the MONET project [10] incorporated electrical switch based cross-connect systems into the test-bed network. They defined that the OXC has a transparent switching function. Transparent switching means that input digital signals are switched to the output ports without changing the signal format and bit/byte data. This function is naturally provided by the optical switch based cross-connect systems. The electrical switch based OXC system does not provide the signal format restriction feature. Basically, only the SDH/SONET signal can be switched. Therefore, commercial OXC products have a SDH/SONET multiplexing function within the OXC box. All incoming SDH/SONET signals, such as 52 Mbps, 156 Mbps, 2.5 Gbps, 10 Gbps, and 40 Gbps in the near future, are demultiplexed into 50 Mbps (VC3/STS-1 level) signals. They are switched and multiplexed into high-speed outgoing SDH/SONET signals such as 2.5 Gbps, 10 Gbps, and 40 Gbps, and vice versa. This function is called a grooming function. As shown in Fig. 3, the electrical switch based OXC is constructed using the conventional SDH/SONET digital cross-connect system and SDH/SONET MUX (multiplexer). This type of OXC system is called an O-E-O type OXC.

3.2. Junction BOX function (O-O-O OXC or PXC)

In 1999, MEMS (micromachine electro mechanical system) technologies became feasible. The optical MEMS switch, especially the 3D-MEMS switch, provided a greater than 1000 port space division optical switch matrix. Optical switch based OXC systems are denoted as O-O-O type OXC or PXC (photonic cross-connect). Basically PXC systems provide a signal format restriction free feature. Therefore, the MEMS based large-scale PXC provides the central fiber management system function at the POP. At each floor, a medium scale PXC system is used as a junction box or a patch panel. An application example of the PX-C system is shown in Fig. 4. The remote fiber configuration management capability will reduce the operation cost of network operators.

3.3. Cut through function outside WDM systems

(AON-XC)

The OXC and PX-C mentioned in Section 3.1 and 3.2 required long-haul transmission systems for inter office traffic transmission. The cross-connect system provides the traffic grooming function and the fiber configuration function between IP routers and WDM systems. The cut through function mentioned in Section 2.2 can reduce the switching cost. As a result, transponders located in WDM systems dominate over the end-to-end transmission cost. This problem can be solved with all-
optical cut through techniques. Figure 5 shows an example of the all-optical cut through. In this example, IP routers as well as WDM systems are cut through by PXCs with WDM input/output ports. There is no O/E and E/O conversion point along the cut through optical path. As the ultimate optical network, an AON (all-optical network) which does not contain any O/E and E/O devices within a core network node was studied. The transparent bit-rate-restriction-free network is very attractive from the viewpoint of low cost and high flexibility. An AON-XC is defined as a PX system with WDM input/output ports. To enhance the network size scalability of AON, insertion of 2R or 3R (reshaping, retiming, and regeneration) devices into an AON-XC system is required. These devices are inserted adaptively. In other words, if the signal is degraded by fiber loss as well as nonlinear effects such as PMD (polarization mode dispersion) or ASE (amplified spontaneous emission), the 2R or 3R function is activated. NTT developed an OXC prototype system that emulates the AON-XC [11, 12].

The integration of WDM and PXCs aids in reducing operational costs, maintenance costs, device costs, office-space requirements, electrical energy, and the rate of failure. In the next generation, AONs will be extremely important and these aforementioned features will provide great benefits.

4. HI KARI router technologies

4.1. Concept of photonic MPLS

MPLS stands for “Multi-protocol” Label Switching. The multi-protocol means that its techniques are applicable to any and multiple network layer protocols. The initial MPLS was likened to a “shim-layer” which is used to provide connection services to IP and which itself makes use of link-layer services from Layer 2. IP packets are accommodated into a label switched path (LSP) which is distinguished and switched by a label value in the shim-header. To set up the LSP within MPLS networks, several signaling protocols such as LDP (label distribution protocol), CR-LDP (constraint based routing LDP), and RSVP-TE (resource reservation protocol traffic engineering) are now being developed. These signaling protocols are used to set up switching devices to define the route of LSPs. Therefore, these protocols can be applied to any label switching device which is not only based on packet, cell, or frame switching but also based on circuit switching. This is the concept of GMPLS [4]. In a wide sense, a photonic MPLS belongs to the category of GMPLS. The photonic MPLS concept covers all photonic label switching technologies. Examples of photonic labels are (a) physical labels, such as wavelength(s), waveband, and mode (or phase) of lightwaves, (b) optical data labels which are multiplexed by OCDM (optical code division multiplexing) technologies or optical SCM (sub-carrier multiplexing) technologies, and (c) time slot labels, in the case of OTDM (optical time division multiplexing) transmission. These labels are added to GbE (gigabit Ethernet) streams, 10GbE streams, SDH/SONET streams, optical channel (OCh) [13] streams, optical bursts which are defined as a short hold stream, and optical packets which are transported in a store and forward manner.

4.2. HIKARI router (photonic MPLS router)

To realize the photonic MPLS concept, as a first step, NTT developed MPLS based photonic MPLS routers [5, 6]. This photonic MPLS router is named “HIKARI router” [7]. The HIKARI router is an integrated system with IP/MPLS routers and optical switch based OXCs (PXCs). The HIKARI router has an IP routing capability, PSC (packet switching capability), and LSC (lambda switching capability). This is the major difference from conventional PTSs (photonic transport systems) such as OXCs and OADMs [12]. The HIKARI router not only works as an intelligent OXC and an LSR but also works as a multi-layer traffic engineering toolbox [14]. Therefore, the HIKARI router operates in the IP layer, LSP layer, and OLSP (optical LSP) layer. LSPs are seamlessly connected by OLSPs, and LSPs are aggregated on OLSPs. Therefore, a controller can manage OLSPs as a layer in the LSP hierarchy.

Figure 6 shows a functional configuration of the HIKARI router. The HIKARI router comprises five functional blocks: a WDM function unit, an optical switch unit, an L1 (Layer 1)-trunk unit, an L2/L3 (Layer 2/Layer 3) trunk unit, and a NE-manager (network element manager). An LRU (lambda routing unit) is defined as an integrated unit from the WDM unit, the optical switch unit, and the L1-Trunk unit. The LRU can switch and add/drop OLSPs, and wavelength conversion is performed at the λ-conv (wavelength converter) in L1-trunks. The NE-manager monitors all the circuit
elements in the node, supervises remote optical repeaters, performs restoration, monitors the quality levels of the signals (L1 level and L2 level), and controls the LSPs and OLSPs.

4.3. IP backbone networks constructed with HIKARI routers

Figure 7 shows an application example of the HIKARI routers. The photonic MPLS network is defined as a core network in the MPLS based IP backbone network. Customer IP routers and MPLS routers are connected to the MPLS based backbone network. An NMS (network management system) of the IP backbone network manages a hierarchical LSP network. Because LSPs and OLSPs can be managed by almost the same management entity, this function can enhance the scalability of the backbone network. Because each hierarchy generates management sections, in a two-hierarchy case, i.e., one LSP and one OLSP, the backbone networks are divided into MPLS router network sections and HIKARI router network sections. This hierarchy can be extended to several LSP hierarchies and several OLSP hierarchies. The photonic MPLS technologies have the potential to enhance the node switching capacity in order to reduce the power consumption and the equipment space.

5. Conclusion

Current OXC technologies and HIKARI router technologies for creating the IP-over-optical networks were presented. We must enhance the intelligence of OXC systems to utilize them effectively as a kind of pseudo IP router system. As an intelligent system, IP router systems, which were first conceptually designed in March 1973, have continuously evolved over 30 years. On the other hand, development of intelligent OXC systems has started only within the past few years. Therefore, we must cultivate and improve the sense of the intelligent OXC systems and HIKARI router systems.

References