Adaptive transparent photonic network control techniques based on photonic-GMPLS-router network

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Abstract: This paper describes multilayer traffic engineering and very cost-effective adaptive transparent photonic network control techniques based on new signaling technologies in the photonic-GMPLS (generalized multi-protocol label switch)-router network. To realize multilayer traffic engineering, we propose an OSPF extension that advertises both the number of total wavelengths and the number of unreserved wavelengths. According to the OSPF advertisement, the ingress edge node can select best link to establish a transparent optical cut-through path, an optical direct path without any wavelength conversion. In addition, the paper describes the RSVP-TE extension, which uses the least total number of wavelength conversions. Compared to the electrical MPLS network, this approach yields cost reductions of the order of 80%. An OSPF extension and a very sophisticated signaling mechanism using RSVP-TE extension have been proposed and now going to be implemented [4][5]. The OSPF extension is to advertise both the total number of wavelengths and the number of unreserved wavelengths for each link. This information is passed via OSPF packets to all ingress edge nodes so they are aware of the GMPLS link state. Ingress edge nodes try to establish new OLSPs by applying the least-load rule. The least loaded OLSP has the most vacant wavelengths. For OLSP setup, RSVP-TE extension signaling protocol is used. The signaling packet selects the proper wavelength that uses the least number of wavelength converters because wavelength conversion is a very expensive operation. OLSP without wavelength conversion is named the optical transparent cut-through path (OTCP). OTCPs are realized by the passive network components and so are very simple. Establishing OTCP is effective in terms of network cost reduction.

Keywords: Photonic, MPLS, GMPLS

1. Introduction
The explosion of Internet traffic has led to a greater need for a high-speed backbone network. The growth in Internet-protocol (IP) traffic exceeds that of IP packet processing capability. Therefore, the next-generation backbone networks should consist of IP routers with IP-packet switching capability and optical cross-connects (OXC) with wavelength-path switching capability to reduce the burden of heavy IP-packet switching loads. In addition, IP traffic fluctuates often over periods as short as hours.

These needs are satisfied by the photonic GMPLS router developed by NTT [1]; it offers both IP packet switching and wavelength-path switching capabilities [2][3]. Wavelength paths, called optical label switch paths (OLSP) are set and released in a distributed manner based on the functions offered by the generalized multi-protocol label switch (GMPLS). Since the photonic MPLS router offers the functions of both switching and GMPLS, it enables us to create the optimum network configuration dynamically by considering IP and photonic network resources in a distributed manner.

2. Traffic-driven multilayer network
The photonic-GMPLS-router network is shown in Figure 1. Some border IP router pairs use a transit IP router to carry their IP traffic. All electrical MPLS (EMPLS) paths between border routers are monitored by the border IP router function and establish traffic exchanging matrix as shown in Fig. 1. And when the traffic volume becomes heavy, a cut-through path is set by using the GMPLS signaling protocol of the RSVP-TE extension [6][7] as shown in Fig. 2. Note that all ELSP and OLSP are controlled and managed by the same operation paradigm based on GMPLS. This realizes very simple network management as well as dynamic network control for multilayer operation. Details of the signaling and routing mechanism are described below.
OLSP paths are very high performance and cost-effective compared to the ELSP. Because the OLSP paths are switched as wavelength paths, no layer 3 protocol handling is needed. According to our estimation, in the future, the photonic cut-through technique will reduce the volume of OC-192C forwarding by about 1/3. Figure 1 also shows the results of our detailed study on the cost effectiveness achieved by using the proposed photonic multi-layer GMPLS router. The calculation is based on IP traffic demand in the year 2005 and state-of-the-art electrical routers as well as photonic technology. The Cluster ratio is the cross traffic between routers, and so does not offer effective IP forwarding between users. The Cluster ratio is generally 2/3 in today's Internet infrastructure traffic. According to our calculation, we can expect a cost reduction of more than 60% by using the photonic GMPLS multi-layer router. Given today's backbone network traffic pattern, we expect that photonic cut-through will be applicable 60 to 70% of the time. In addition, multi-layer operation can reduce today's duplicative network management to one universal GMPLS operation. This simplification will dramatically reduce network cost.

3. GMPLS-based photonic multilayer router architecture

The basic logical structure of the photonic GMPLS multi-layer router is shown in Figure 3. It consists of an IP router, wavelength router, and photonic-GMPLS-router manager.

The router is based on a photonic universal platform with the addition of 3R (Retiming, Reshaping and Regeneration) functions, wavelength conversion function, and layer-3 functions. These functions are used adaptively. In other words, if the transmission signal is degraded by fiber loss as well as nonlinear effects such as PMD (polarization mode dispersion) or ASE (Amplified spontaneous emission), the 3R function is activated. In addition, wavelength conversion is also used when signaling is blocked by wavelength overbooking. Of course, layer 3 (L3) packet forwarding is adaptively used when L3 packet forwarding is necessarily.

Note that the photonic-GMPLS router can transfer 3 types of signal as shown in Fig. 3. Type-A is transparent transfer or bit-rate restriction free. This type of path is very cost
effective, because it needs only passive elements without any electrical digital function. Type-B is λ relay connections that need wavelength conversion. Today’s wavelength conversion needs O/E and costly electrical and tunable laser devices. This is the weakness of Type-B connections. Type-B connections are also supported by adaptive use of the 3R function. Finally, type-C involves layer 3 switching functions for operations such as MPLS packet aggregation and L3 packet level forwarding. The photonic-GMPLS router can support all transfer capabilities. To improve the network’s cost effectiveness, the proposed GMPLS manager tries to establish Type-A transparent photonic cut-through paths. Details are described in session 4.

In the photonic-MPLS-router manager, the GMPLS controller distributes own IP and photonic link states, and collects the link states of other photonic MPLS routers. IP traffic is always monitored, and the captured data is passed to the GMPLS controller through a low-pass filter [6]. A multi-layer topology design algorithm processes the collected IP and photonic link states and the collected traffic data.

4. Adaptive transparent photonic cut-through path based on extension of GMPLS

Optical wavelength conversion is very costly and needs a lot of hardware today. In other words, the transparent bit-rate restriction free network is very attractive from the viewpoints of low cost and high flexibility. Accordingly, our OSPF extension and RSVP-TE extension can provide effective route selection as well as the least number of wavelength conversions.

The optical transparent cut-through path is shown in Fig. 4. (b) shows the optical λ-relay network, which needs wavelength conversion for each node. Today, wavelength conversion is very costly, especially if based on tunable lasers. The network should use as many transparent paths, shown in (c), as possible. Transparent cut-through leaves the wavelength unchanged. The switch function transfers the same wavelength signal to the output port. This is very simple and cost effective.

Optical transparent cut-through path configuration is shown in Fig. 5. After the cut-through block, only an optical amplifier is needed in the path. In other words, this transparent path can establish a direct optical path between

Figure 3 Logical Structure of photonic MPLS router with multi-layer traffic engineering based on GMPLS management function

Figure 4 Cut-through technique for GMPLS network
Ingress edge router to egress edge router. All components in the path are passive devices. Of course, transmission effects such as loss and cross-talk limit the hop number of the transparent cut-through paths.

First, for route advertisement, the OSPF extension is used as shown in Fig. 6. Each photonic GMPLS router advertises its total number of used and unreserved wavelengths. According to this advertisement, edge nodes can discern GMPLS link state and can select the least expensive path. In addition, we have already proposed to extend the sub-TLV of IETF specification [4]. The extensions include 3R resource information and statistical information such as utilization of each wavelength, and 3R and wavelength conversion resources. This information will be used for source routing based on a combination of shortest path first and load information.

The GMPLS link state is calculated and determined at the Ingress edge node. For the example in Fig. 6, Route-A has small hop number but large load. On the other hand, Route-B has larger hop number but the least load. We employ the least load policy as the optical routing policy. Route-B may be expected to allow more cut-through paths to be set between Ingress and Egress router.

For the signaling function, we offer the RSVP-TE extension shown in Fig. 7. Link-by-link routing is used based on source routing. The first photonic GMPLS router sets the unused wavelength information in RSVP signaling using the bit map format. Each transit photonic GMPLS

![Figure 5 Optical transparent cut-through path configuration](image)

![Figure 6 OSPF routing extension for advertising wavelength resource utilization](image)
router over-writes this information by placing "And" between arriving signaling unused wavelength bitmap and its own unused wavelengths. If there is no unused wavelength, wavelength conversion is used. A router that offers wavelength conversion creates a new unused wavelength bitmap and sends it to the next router.

This signaling and routing technique minimizes the need for wavelength conversion in the network and so can provide very cost-effective photonic networks. Figure 8 shows the cost reduction effect possible by introducing optical transparent cut-through paths. Because optical transparent paths need no costly electrical components, the dramatic cost reduction of approximately 80% can be achieved.

5. Conclusions
This paper presented multi-layer traffic engineering, signaling and routing technologies in photonic-GMPLS-router networks to realize cost effective optical transparent cut-through paths. The photonic-GMPLS-router network architecture is based on OSPF and RSVP-TE extensions. The routing and signaling technique proposed herein yields the least number of wavelength conversions and so achieves very cost-effective photonic networks. By monitoring IP traffic loads, photonic MPLS routers can dynamically change the network configuration; network resources are utilized efficiently in a distributed manner.

References
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