GMPLS-Based Photonic Multilayer Router (Hikari Router) Architecture: An Overview of Traffic Engineering and Signaling Technology

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ABSTRACT

A new extended signaling and traffic engineering method for the GMPLS-based photonic and electrical multilayer router (Hikari router) is proposed. The method allows dynamic optical network management and photonic signal recovery, such as regeneration, reshaping, etc., to be realized adaptively. Wavelength conversion is also adaptive, which reduces network cost. Multilayer traffic engineering, which yields the dynamic cooperation of IP and photonic layers, is described to provide IP services cost effectively. To realize multilayer traffic engineering, we propose the OSPF extension, which advertises both the number of total wavelengths and the number of unused wavelengths, and the RSVP-TE extension, which minimizes the number of wavelength conversions needed. In addition, this paper proposes a heuristics-based multilayer topology design scheme that uses IP traffic measurements in a generalized multi-protocol label switch (GMPLS). The proposed scheme yields the optical label switch path (OLSP) network topology, that is, OLSP placement, that minimizes network cost, in response to fluctuations in IP traffic demand. In other words, the OLSP network topology is dynamically reconfigured to match IP traffic demand. Networks are reconfigured by the proposed scheme so as to utilize network resources in the most cost effective manner.

INTRODUCTION

The explosion of Internet traffic is strengthening the demand for high-speed backbone networks. 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 (OXCs) with wavelength-path switching capability to reduce the burden of heavy IP-packet switching loads. In addition, IP traffic can fluctuate widely, even often over periods as short as hours.

These needs are satisfied by the photonic GMPLS multilayer router developed by NTT [1] that offers both IP packet switching and wavelength-path switching capabilities [2, 3]. We provide a brief description of NTT's photonic GMPLS multilayer router (Hikari router). Wavelength paths, called optical label switched paths (OLSPs), are set and released in a distributed manner based on the functions offered by the generalized multiprotocol label switch (GMPLS), which is being discussed in the Internet Engineering Task Force (IETF) [4, 5]. Since the Hikari router offers the functions of both switching and GMPLS, it enables us to create the optimum network configuration by considering IP and photonic network resources in a distributed manner.

An OSPF extension [6] and a very sophisticated signaling mechanism using the RSVP-TE extension [7] have been presented in IETF. To achieve multilayer traffic engineering effectively, we propose additional OSPF and RSVP-TE extensions based on these IETF approaches, and they are going to be implemented. The OSPF extension advertises both the total number of wavelengths and the number of unused wavelengths for each link. This information is passed via OSPF packets to all egress edge nodes so that they are aware of the GMPLS link state. Based on the least-load rule, egress edge nodes try to establish new OLSPs by using the RSVP-TE extension signaling protocol. The signaling packet selects the proper wavelength that uses

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the least number of wavelength converters because wavelength conversion is a very expensive operation in all-optical photonic networks.

In addition, multilayer traffic engineering, which ensures that IP and photonic layers dynamically cooperate, is required to provide IP services cost effectively. This paper proposes a heuristics-based multilayer topology design scheme that uses IP traffic measurements. The proposed scheme yields the optimum OLSP network topology, that is, OLSP placement, so as to minimize network cost, in response to fluctuations in IP traffic demand. In other words, OLSP network topology is dynamically reconfigured to match IP traffic demand.

TRAFFIC DRIVEN MULTILAYER NETWORK AND PHOTONIC OLSP CUT-THROUGH

The photonic MPLS multilayer router offers the following two transport capabilities. Some source-destination IP router pairs use a transit IP router to carry their IP traffic, while others pass their IP traffic across a direct OLSP. All electrical MPLS (EMPLS) paths are monitored by the IP router function, and when the traffic volume becomes heavy, a cut-through path is set by using the GMPLS signaling protocol such as the constraint-based routing label distribution protocol (CR-LDP) and RSVP-TE extension, as shown in Fig. 1. 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. Because the OLSP paths are switched as wavelength paths, no layer 3 protocol handling is needed. NTT has already realized the IP V6 OC-192c layer 3 wire speed forwarding electrical router named MSN Type-X [8]. This electrical router is very high performance and cost effective; however, in the future the photonic cut-through technique will reduce the volume of OC-192c forwarding by about 1/3. Figure 2 shows the results of our detailed study on the cost effectiveness achieved by using the proposed photonic GMPLS multilayer 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 percent by using the photonic GMPLS multilayer router. Given today's backbone network traffic pattern, we expect the photonic cut-through will be applicable more than 60 to 70 percent of the time. In addition, multilayer operation can reduce today's duplicative network management to one universal GMPLS operation. This simplification will dramatically reduce network cost.

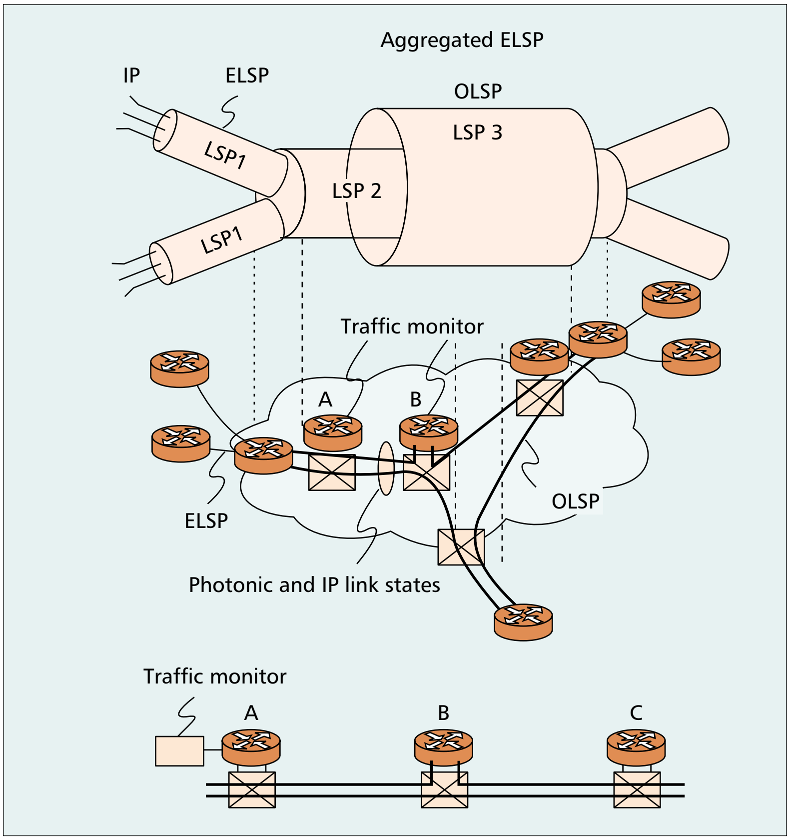


Figure 1. *Cut-through path setup driven by traffic measurements.*

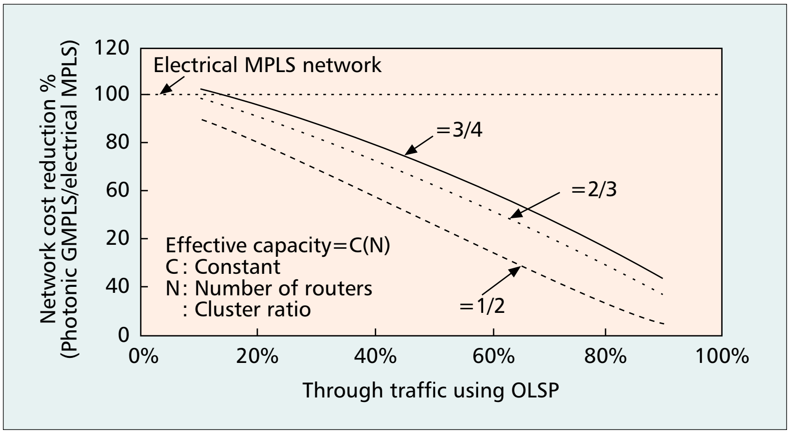


Figure 2. *Cost reduction effect using photonic GMPLS multilayer router and OLSP cut-through technique.*

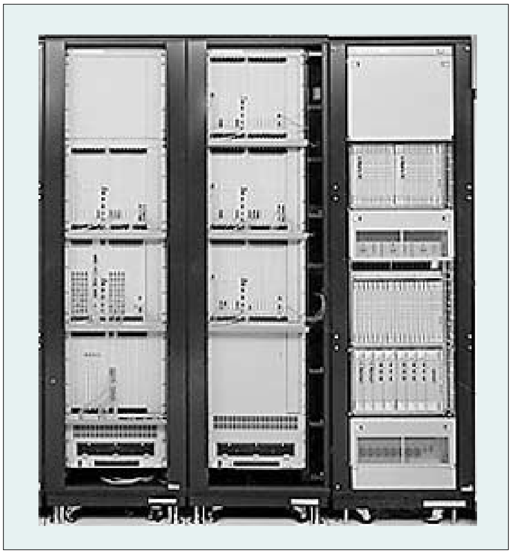
DEMONSTRATED PHOTONIC GMPLS MULTILAYER ROUTER (HIKARI ROUTER)

An overview of the photonic GMPLS multilayer router (Hikari router) was given at SUPERCOM 2001 (see Fig. 3) [1]. It consists of an IP router, wavelength router, and GMPLS-router manager.

Table 1 gives the specifications of the Hikari router that includes both an optical cross-connect (OXC) and an L2/L3 router. The OXC establishes both the optical cross connection and long-haul WDM transmission functionalities. Hence, this

Items	Specifications
Switch architecture	DC-SW scheme
Operating wavelength range	1550-nm band (C-band)
Optical channel speed	2.5 Gb/s (upgradable to 10 Gb/s)
Maximum number of wavelengths	32
Number of fiber ports	8 (maximum)
Cross-connection	256 channels
System throughput	640 Gb/s (upgradable to 2.56 Tb/s)
Modular unit	8 channels
Optical channel allocation	Even assignment on 50-GHz grid Anchored at 193.100 THz
Fiber type	Single-mode fiber (G.652 [9])
Optical supervisory channel (OSC)	OTS/OMS-OH [10] transport and high-speed DCC

■ **Table 1.** *Hikari router specifications (wavelength router part).*



■ **Figure 3.** *Overview of Hikari routers.*

prototype includes two optional network element functions. Most optical cross-connect systems require a WDM transmission system. The Hikari router, on the other hand, is equipped with all-in-one type optional network elements [11]. This feature aids in reducing operational costs, maintenance costs, device costs, office space, electrical consumption, and failure rates. The next-generation networks will be enormous, and these aforementioned features will provide great benefits. The OXC has a maximum switching capacity of 256 x 256. The optical path interfaces on the user network interface (UNI) in the photonic transport payload assembler-disassembler (PAD) handle OC-48c signals to carry packets over SDH/SONET [11]. Thus, the maximum total capacity is 640 Gb/s. If the interfaces are upgraded to 10 Gb/s, the capacity would become 2.56 Tb/s. Actually, the optical loss budget design was constructed to support 10 Gb/s OChs [10], making expansion possible without serious difficulties.

In the Hikari router, the OXC is constructed using to the Delivery-and-Coupling Switch (DC-SW) architecture [12], not the basic matrix configuration. The DC-SW architecture allows aggregation of several signals. Output ports, which use wavelength-region multiplexing, employ a basic matrix large-scale multistage switch and a complex switching operation management system to accomplish strictly non-blocking operation. On the other hand, the DC-SW architecture allows for the strictly non-blocking feature with a simple configuration. It also allows for a high degree of link-by-link expandability because it can be divided into link modular units. Such high modularity permits easy switch expansion and initial installation cost reduction for small-scale installation [12].

The demonstrated Hikari router has L2/L3 packet forwarding capability and wavelength conversion functions with 3R (retiming, reshaping and regeneration) function for all ports. Details are presented in [2, 3].

The switching fabric is installed in standard 19-inch shelves. The number of shelves depends on the scale of the node. The minimum configuration occupies two shelves.

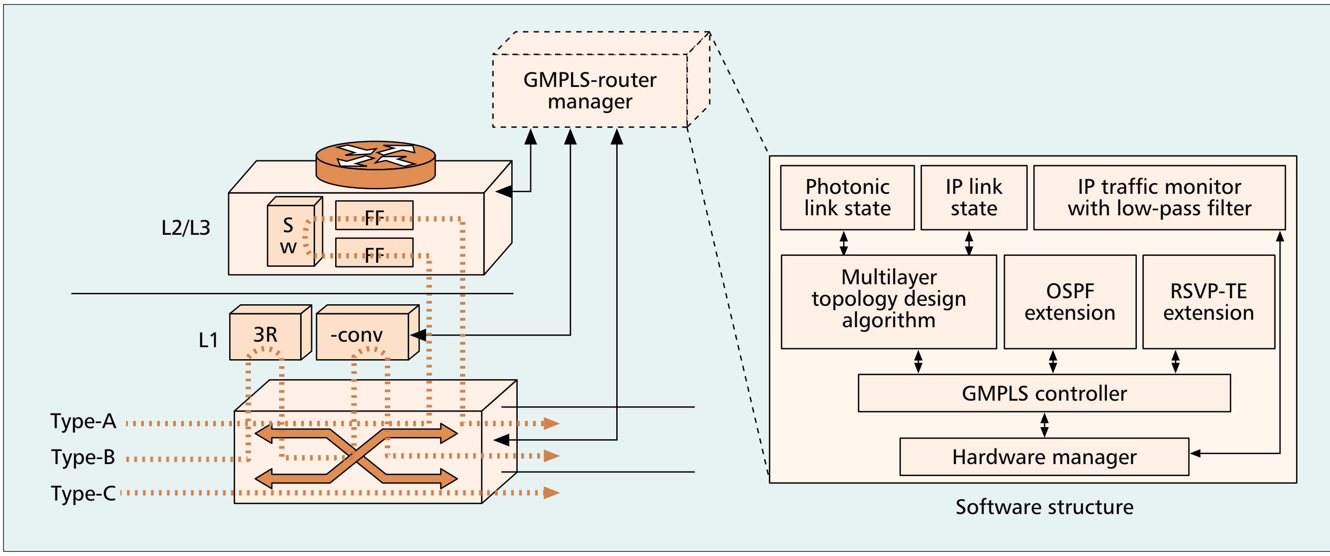
Extension of Routing and Signaling for Photonic GMPLS

The proposed GMPLS router (Hikari router) is based on a photonic universal platform with the addition of 3R functions, wavelength conversion, and layer 3 functions, as shown in Fig. 4. These functions are used adaptively. In other words, if the signal is degraded by fiber loss as well as nonlinear effects such as polarization mode dispersion (PMD) or amplified spontaneous emission (ASE), 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 used adaptively when L3 packet forwarding is performed.

Note that the Hikari router can transfer three types of signal, as is also shown in Fig. 4. Type-A signals involve layer 3 switching functions for operations such as MPLS path aggregation and L3 packet-level forwarding. Type-B signals are λ relay connections that need wavelength conversion. Type-B signals are also supported by the adaptive use of the 3R function. Finally, type-C signals are transparent transfer or bit-rate restriction free. The Hikari router supports all transfer capabilities.

In the photonic-GMPLS-router manager, the GMPLS controller distributes its own IP and photonic link states, and collects the link states of other Hikari routers. IP traffic is always monitored, and the captured data is passed to the GMPLS controller through a low-pass filter [13]. A multilayer topology design algorithm processes the collected IP and photonic link states and the collected traffic data.

To support the above adaptive optical wavelength conversion, we propose the extension of the routing and signaling functions for the photonic MPLS. Optical wavelength conversion is



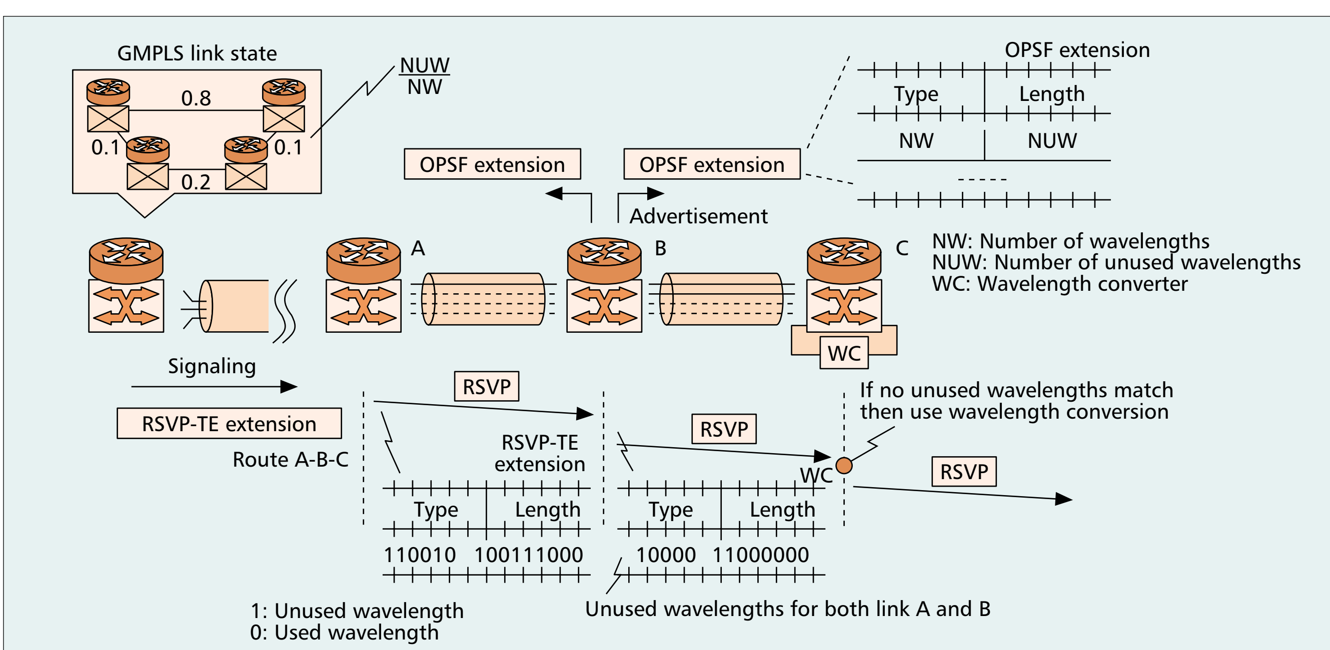
■ **Figure 4.** *Structure of Hikari router with multilayer traffic engineering based on IP traffic monitoring.*

very costly and needs much hardware surrently. In other words, the transparent bit rate restriction free network is very attractive from the perspectives of low cost and high flexibility. Accordingly, we developed an OSPF extension and an RSVP-TE extension to achieve effective route selection as well as to minimize the number of wavelength conversions needed.

First, for route advertisement, the OSPF extension is used, as shown in Fig. 5. Each Hikari router advertises its total number of used and unused wavelengths. Edge nodes use this information to discern GMPLS link state and can select the least expensive path. In addition, we have proposed an extension of the sub-TLV of IETF specification (draft-ietf-ccamp-ospf-gmpls-extensions-01.tex). The changes 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.

To enhance the signaling function, we offer the RSVP-TE extension. Link by link routing is used based on source routing. The first Hikari router sets the unused wavelength information, using a bit map format, in RSVP signaling. Each transit Hikari router overwrites 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. The router, which offers wavelength conversion, creates a new unused wavelength bitmap and sends it to the next router.

This signaling and routing technique minimizes the frequency of wavelength conversion in the network and so can provide very cost effective photonic networks.



■ **Figure 5.** *Photonic GMPLS extensions for both routing and signaling based on OSPF and RSVP-TE.*

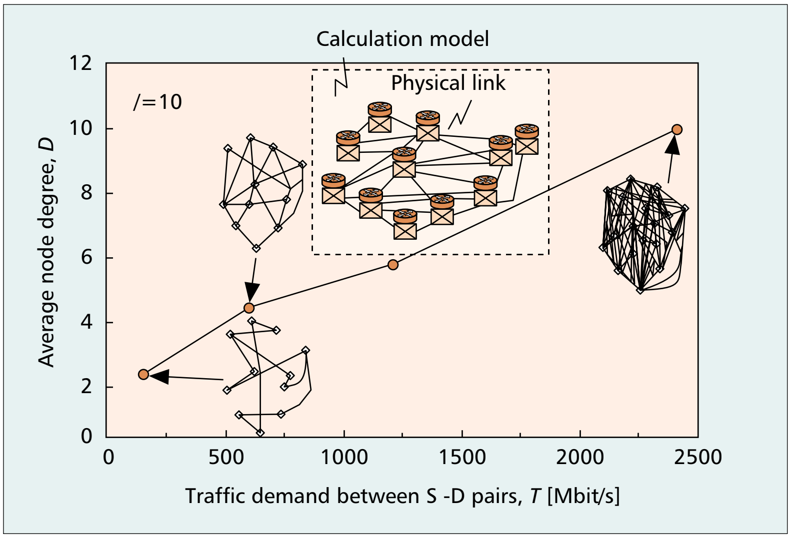


Figure 6. *Numerical model and optimum OLSP topology determined by IP traffic demand.*

GMPLS Multilayer Network Control and a Topology Design Scheme

The bandwidth granularity of the photonic layer is coarse and equal to wavelength bandwidth λ, that is, 2.5 Gbit/s or 10 Gbit/s. On the other hand, the granularity of the IP layer is flexible and well engineered.

When traffic demand between source and destination IP routers is much less than λ, the cut-through wavelength path between the source destination IP routers is not fully utilized and so is not cost effective. In this case, several IP traffic streams should be merged at some IP transit routers to better utilize the wavelength bandwidth at the cost of IP-packet processing at the transit nodes. On the other hand, when traffic demand between source and destination IP routers approaches or exceeds λ, such stream multiplexing is dropped.

Thus, the setting of cut-through paths between source-destination IP routers depends on IP traffic, and the OLSP topology of the photonic layer should change dynamically to match fluctuations in IP traffic demand so as to optimize network resource utilization.

For this purpose, our objective is to minimize network cost Z which is formulated as follows:

$$Z = C_{node} + C_{link} = \alpha \sum_{i} r_{ip} + \beta \sum_{i} \sum_{j} \sum_{p} \sum_{k} l_{ijpk}, \qquad (1)$$

where r_{ip} is the cost of port p in router i, and l_{ijpk} is the cost of wavelength path k at port p in fiber link ij. α/β is the node/link ratio. α/β is set to more than one, because IP routers have IP-packet processing functions such as table look-up and packet-based switching in addition to wavelength routing functions.

To minimize Z, we adopt the extended version of the BXCQ (branch exchange with quality-of-service constraints) scheme presented in [14], named EBXCQ. The BXCQ scheme was originally intended for multilayer ATM network design. In BXCQ, the addition/elimination of links is iterated to solve a topological optimization problem with quality-of-service constraints, such as delay and blocking probability. In EBXCQ, the number of ports in both IP routers and wavelength routers, as well as the number of wavelengths per fiber, are also considered as constraints in addition to the constraints considered in BXCQ.

Numerical Results

We have confirmed the effectiveness of EBXBQ by using a LATA network model (see Fig. 6) [15]. Figure 6 also shows that the optimum OLSP topology changes with the IP traffic demand between source-destination IP routers. We assume that IP traffic demands between source-destination IP routers are evenly distributed and that each wavelength is converted at each photonic MPLS router. Wavelength bandwidth is set to 2.5Gb/s. We used the metric of the average node degree, D, to characterize and evaluate OLSP network topologies. D is the average number of other IP routers to which individual IP routers are connected by OLSPs. As traffic demand increases, the optimum OLSP topology becomes a mesh because each OLSP bandwidth becomes effectively utilized.

Changing the OLSP topology in response to traffic demand fluctuations dramatically reduces network cost. An estimation of the network cost reduction possible is shown in Fig. 7. Network cost is normalized by the fixed optimum topology T = 300 [Mb/s]. If the OLSP network topology is changed based on traffic measurements, the cost reduction effect can exceed 50 percent.

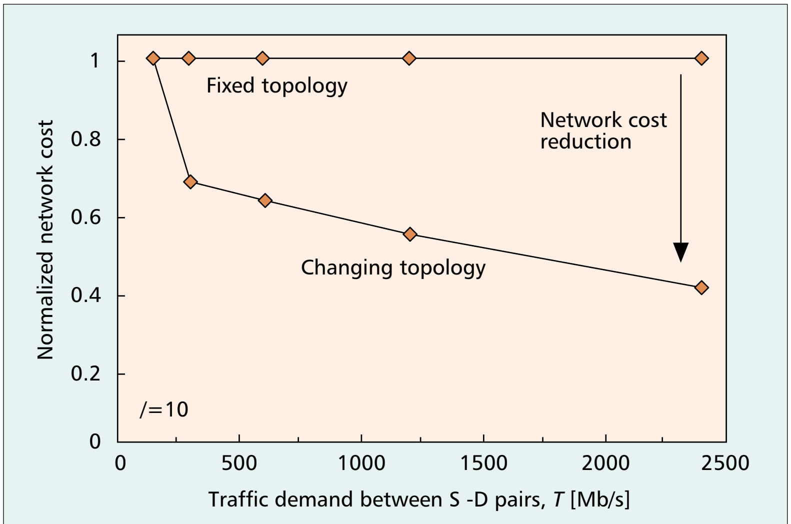


Figure 7. *Cost reduction effect of reconfigurable multilayer network.*

Conclusions

This paper presented, for the photonic GMPLS multilayer router (Hikari router), a cost effective multilayer signaling and routing technique. The proposed architecture is based on OSPF and RSVP-TE extensions. The proposed routing and signaling technique yields the least number of wavelength conversions and thus very cost effective photonic networks. This paper also described a heuristics-based multilayer topology design scheme, called EBXCQ, for IP photonic networks. By monitoring IP traffic loads, Hikari routers are controlled to dynamically change the network configuration; network resources are utilized efficiently in a distributed manner.

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