Differentiated Lambda Establishment and Wavelength Assignment based on DMS model for QoS guarantees in DWDM Next Generation Internet Backbone Networks

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DWDM 차세대 인터넷 백본망에서 DMS 모델 기반의 차등화된 파장할당 및 LSP 설정

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ABSTRACT

The Internet is evolving from best-effort service toward an integrated or differentiated service framework with quality-of-service (QoS) assurances that are required for new multimedia service applications. Given this increasing demand for high bandwidth Internet with QoS assurances in the coming years, an IP/MPLS-based control plane combined with a wavelength-routed dense-wavelength division multiplexing (DWDM) optical network is seen as a very promising approach for the realization of future re-configurable transport networks. This paper proposes a differentiated lambda establishment process for QoS guarantees based on the differentiated MPLS service (DMS) model. According to the QoS characteristics of wavelength in optical links and the type of used Optical Cross-Connect (OXC) nodes in DWDM next generation optical Internet backbone network, a differentiated wavelength assignment strategy that considers QoS recovery capability is also suggested.

Key Words : Wavelength Assignment, Network survivability, QoS Recovery, DWDM

요 약

최선형 서비스에 기반을 둔 현재의 인터넷은 점차 새로운 멀티미디어 서비스 응용을 제공하기 위해 QoS를 보장하는 통합서비스 또는 차등화된 서비스 제공 형태로 진화되어 가고 있다. 다가오는 시대의 멀티미디어 서비스별 QoS 요구 및 서비스별 높은 bandwidth 보장에 대한 요구는 IP/MPLS 기반의 제어 plane 과 DWDM 광 네트워크 기술이 결합되어 미래의 re-configurable 전송망 실현에 대한 가장 설득력 있는 대안으로 떠오르고 있다. 본 논문에서는 이러한 차세대 DWDM 광 인터넷 백본망에서 멀티미디어 서비스 제공에 대한 QoS 보장을 위해 차등화된 MPLS 서비스(DMS)에 기반을 둔 차등화된 파장할당 과정을 제시한다. 또한 광 링크상의 파장 별 QoS 특성과 DWDM 차세대 인터넷 백본망 상에서 사용되는 OXC 노드의 종류에 따른 QoS recovery를 고려한 차등화된 파장할당 방안을 제시한다.

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I. Introduction

Over the past decade, the exponential growth of Internet traffic volumes has made the IP protocol framework become the most predominant networking technology. Furthermore, the Internet is evolving from best-effort service toward an integrated or differentiated service framework with QoS assurances, that will be necessary for new applications like voice telephony, video conferencing, tele-immersive virtual reality, and Internet games. Given this increasing demand for high bandwidth Internet with QoS assurances in the coming years, an IP/MPλS or IP/Generalized-MPLS(GMPLS) based control plane combined with a wavelength-QoS routed DWDM optical network is seen as a very promising approach for the realization of future re-configurable transport networks[1].

In today's best effort Internet, variable queuing delays on network routers, intermittent latency and dropped packets from congested links make it difficult to provide an acceptable level of performance. The Integrated Services (IntServ) architecture[2] was first introduced along with the Resource ReSerVation Protocol (RSVP)[3]. The Differentiated Services (DiffServ) architecture[4], as a more scalable solution than IntServ, classifies packets into a small number of aggregated flows or service classes specifying a particular forwarding treatment or per hop behavior (PHB)[5]. Even if DiffServ defines a model for implementing scalable differentiation of QoS in the Internet, it cannot give any solution to the problem of unequal traffic distribution for premium services[6]. Moreover, the drawback of the centralized approach is a processing bottleneck at the bandwidth broker because in DifferServ, the resource provisioning for the core routers is performed by the bandwidth broker in a centralized manner. However, within the Multi-Protocol Label Switching (MPLS) architecture, the DiffServ mechanism and traffic engineering associated with constraint-based routing could avoid this congestion. MPLS uses label-switching to aggregate a large number of IP flows onto a label switched path at ingress routers and supports label-based (or aggregated-flow-based) dynamic QoS management. Current efforts are underway to extend MPLS (MPλS) for managing optical network connections and to develop a generalized version applicable to many different network control layers[7].

The upcoming Tbps (or Pbps) high-speed transport networks are expected to support a wide range of communication-intensive, real-time multimedia applications. Tremendous potential for capacity expansion offered by DWDM is revolutionizing the way we look at Optical Transport Network (OTN). Within the OTN framework for providing QoS guaranteed service over DWDM networks, QoS routing is one of the key issues to envisage. QoS routing plays a vital role of selecting network routes with sufficient resources for the requested QoS parameters, for example, routes satisfying the QoS requirements for every admitted connection and achieving the global efficiency in resource utilization. In general, a QoS route is computed by a constrained shortest-path-first (CSPF) heuristic[8]. However, in the process of allocating a wavelength along a QoS routing path, a differentiated (i.e., service flow oriented) wavelength allocation mechanism is needed if we consider QoS recovery capability in response to the QoS failure or degradation caused by devices failures or attack-induced faults in the OTN[9].

This paper proposes a differentiated lambda establishment process for QoS guarantees based on the differentiated MPLS service (DMS) model in next generation optical Internet backbone networks. According to the QoS characteristics of wavelength in optical links and the type of used Optical Cross-Connect nodes in DWDM optical backbone network, we also suggest in this paper a differentiated wavelength allocation strategy for differentiated multimedia services along with QoS routes, that takes into account the QoS recovery capability as related to QoS failure.

Ⅱ. All-Optical Transport Network and Network Survivability

1. AOTN and Control Protocol[7]

Core transport networks are currently in a period of transition, evolving from SONET/SDH-based TDM networks with WDM used strictly for fiber capacity expansion, toward WDM-based all optical networks with transport, multiplexing, routing, supervision, and survivability at the optical layer. Moreover, given that the IP protocol framework will become a dominant form of data transfer in the future, there has been an increasing interest in the implementation of IP over photonic networks by using optical networking. A consensus is emerging in the industry on utilizing an IP-centric control plane within optical networks to support dynamic provisioning and restoration of lightpaths. Specifically, we note that IP routing protocols and MPLS or Multi-Protocol Lambda Switching signaling protocols could be adapted for optical networking needs.

Within AOTN(All Optical Transport Network) framework for implementing Next Generation Internet (NGI), a key issue is how to combine the advantages of the relatively coarse-grained WDM techniques with optical switching capabilities to yield a high-throughput optical platform able to efficiently control the IP traffic. The main issue while designing optical networks for Internet application is specifying the right transport/control modalities for IP packets. Actually, several transport/control options have been proposed by several standards organizations and industry consortia, such as IP over ATM over WDM and IP over SDH/SONET over WDM, and recent trend favors IP over WDM. IP/MPLS (or MPλS) based control plane combined with DWDM technology, makes it possible to provide a framework for optical bandwidth management and the real time provisioning of optical channels in an automatically switched transparent optical network. Actually, in IETF, generalized-MPLS signaling is defining extensions to MPLS routing and signaling protocols for application to optical networks. Figure 1 illustrates a currently agreed upon layered framework for IP/MPLS over WDM via the optical adaptation layer.

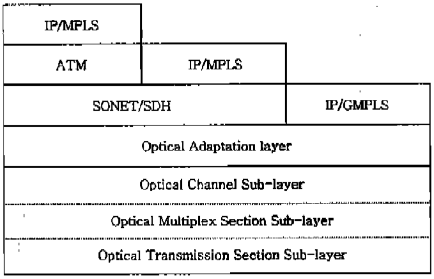

Fig. 1. IP/MPLS over WDM

Global standards for Optical Transport Network (OTN) are under development at the ITU-T. The layered architecture of optical networks is standardized in ITU-T G.872 1). In Optical Internetworking Forum (OIF) and ANSI T1X1.5, as a function of the optical adaptation layer, the proposals for implementing frame-monitoring layer overhead information include the use of a TDM frame-like “SONET-lite” or “digital wrapper” to support OCh (Optical Channel) layer management

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1) In an equivalent layered network modeling as defined in the ITU-T standards for Optical Transport Networks (OTN), a WDM node can be represented by following hierarchical layers (from top to bottom): Optical Channel layer (OCh), Optical Multiplex Layer (OMS) and Optical Transmission Layer (OTS). The OTS layer provides optical signal propagation functionality and represents transmission medium, taps and amplification modules. The OMS layer enables wavelength routing that provides functionality for networking of a multi-wavelength optical signal and the OCh layer handles channel for information content of varying formats.

functions such as performance monitoring, connectivity, and fault indicator monitoring. On the other hand, the Automatic Switched Optical Network (ASON) is a framework that specifies the requirements and architecture of the control and management of an automatic switched optical transport network. Accepted as a study item by SG13 of the ITU-T in March 2000, G.ASON describes several signaling interfaces whose combination can enable a service capability with end-to-end dynamic connectivity in the optical transport network.

2. AOTN Architecture

The architectural model for AOTN, as depicted in Fig. 2., is a network where the user-network interface is optical and data does not undergo optical to electronic (O/E) conversion within the core AOTN. The optical components that constitute a DWDM node, in general, include a cross-connect switch (with or without wavelength conversion functionality) consisting of opto-mechanical switches, a demultiplexer comprising of signal splitters and optical filters, and a multiplexer essentially made up of signal combiners.

As shown in Fig. 2., we consider two functional control domains. The external one is the electronic control domain, where the routing/forwarding functions based on IP packet header processing should be performed. On the other hand, the internal one is the optical control domain so as to access the huge fiber bandwidth that performs transmission and low-layer switching functions based on optical technology. IP traffic is injected into ingress AOTN nodes by a variety of conventional electronic domain legacy networks (i.e., LANs, MANs, ATMs, etc.). In MPλS with DifferServ for QoS-routed (DQOS) packet forwarding process, the ingress node fulfills two basic functions such as traffic aggregation and routing of optical data packets to any given egress node; and control co-ordination between the elements of legacy electrical and optical domain networks.

Once the optical data packet is assembled and aggregated, the AOTN transports optical packets from source to destination nodes through a classified QoS routed lightpath. An optical channel trail is a path for transporting the aggregated traffic that belongs to the same service class (i.e., an aggregated set of premium, assured, or best effort services) and is forwarded through a common path. For example, IP flows that enter the optical transport domain at the same node and leave the domain at the same node may be classified according to the QoS service class. They are aggregated and tunneled within a single optical Label Switched Path (LSP[10]. This concept helps to conserve the number of wavelengths used by the legacy network domain. A LSP hierarchy concept (i.e., nested concept of LSPs) is also applied to deal with the discrete nature of

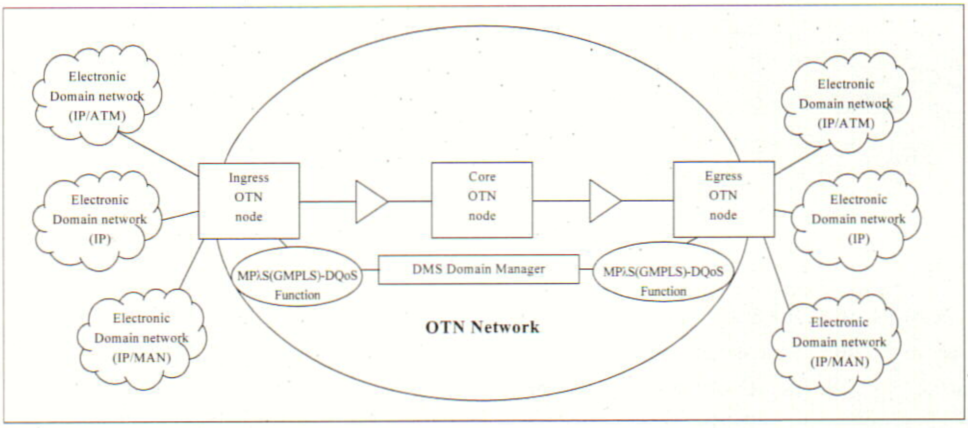


Fig. 2. An architectural model of AOTN

optical bandwidth. Otherwise, a fiber segment carries high-speed classified service flows, consisting of many time-division multiplexed channels associated with optical channel trails. At the destination egress node, the traffic is de-segregated and delivered to the destination network. Core OTN OXC switches along the routes of a OCh(optical channel) trail connect the trail from an input to an output port and perform forwarding of the optical data packets in the all-optical signal domain.

Fig. 3. shows QoS routing mechanism and MPλS functions for OTN edge nodes. Functions such as classification, marking, policing, QoS routing, and λ-LSP setup would be needed only at the edge level OTN nodes of the network. A DMS domain manager takes care of service level agreement (SLA) management and negotiation. It monitors the customer contract and classifier according to the policing criteria. Accordingly, the traffic at the incoming interface is marked. The edge nodes need routing protocols like OSPF or IS-IS in order to exchange the link-state topology and other optical resource availability information for path computation[11]. They also require signaling protocols like RSVP-TE[12] and CR-LDP[13] to automate the optical trail establishment process.

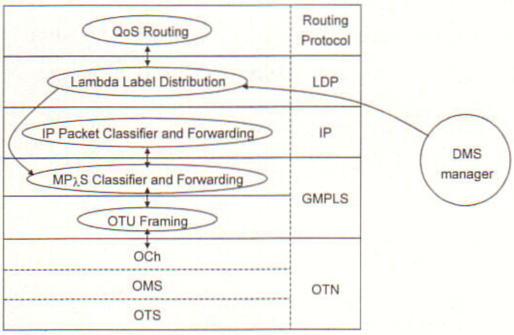


Fig. 3. QoS routing mechanism and MPλS functions for OTN edge nodes

Upon receiving a λ-LSP set up request, the QoS reservation for aggregated IP flows is accomplished by Label Distribution Protocol (LDP)[14] signaling and a DMS manager. The DMS manager passes on the parameters to the LDP module so as to establish the λ-LSP from the ingress router to the egress router and to reserve resources along the established path. Basically, a BGP-like protocol[15] runs on each ingress router to establish external BGP sessions for exchanging interdomain reachability information with the IP-based legacy networks. Internal BGP sessions, in which ingress and egress nodes pass this reachability information through the core IP network, are also established. Thus, each ingress node knows the egress router address associated with destination reachable addresses. Path computation for QoS routing is performed by the extended OSPF or IS-IS[16-17]. The basic function of QoS routing is to find a feasible path satisfying the QoS constraints (like bandwidth, delay, residual error rate, jitter, inter-channel cross-talk error rate, and cost) of a lightpath. In addition, most QoS routing algorithms consider the optimization of resource utilization, given by an abstract metric cost. However, additive quality attributes for optical signal path should also be included.

While setting up a λ-LSP, a QoS route must be selected and wavelengths along this route must also be assigned to the λ-LSP. In this process, it is desirable to consider some degree of protection capability against link/node fault and attackled failures in the network by provisioning some amount of spare capacity. Moreover another important consideration in designing a fault-tolerant routing is that, for a MPλS network, a differentiated recovery strategy could be used as a differentiating mechanism to support the QoS service for higher reliability. Even though, constraint-based routing and fast reroute offer an alternative to SONET as a mechanism for protection/restoration, they are not an optimal solution for differentiated multimedia QoS services. A differentiated wavelength assignment along the entire QoS-routed path is therefore needed.

Instead of specifying minute details of QoS routing and wavelength assignment for MPλS control and signaling protocols, we mainly concentrate here on developing a practical strategy to address the problem of differentiated lambda LSP establishment and wavelength assignment along a QoS routing specific route for multimedia services within IP/MPλS over DWDM framework.

3. Network Survivability and QoS Recovery

In general, network survivability and QoS recovery in AOTNs can be summarized as illustrated in Fig. 4.

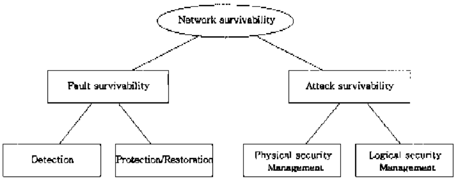


Fig. 4. Network survivability and QoS recovery in AOTNs

The main goals of fault/attack survivability (fault/attack management) are to set up routes in anticipation of faults/attacks (protection), locate the faults/attacks (detection and localization), and to re-route the affected connections (restoration). Protection is the primary mechanism used to deal with faults/attacks. In protection, preplanned protection resources (fibers, nodes, etc.) are set aside for restoring traffic when the working path is established. On the other hand, restoration dynamically discovers an alternate route from spare resources in the network for disrupted traffic, once a fault or attack is detected.

Although many researchers are actively working on fault supervisory management and protection/restoration schemes for AOTNs, many adaptations have been obtained from schemes previously investigated for electronic based networks. For attack detection and protection/restoration endeavors for AOTNs, some researchers have proposed attack detection and management schemes for amplifiers or fiber level partially[18]. However attack detection and protection/restoration schemes for every attack possible at network elements are still in their infancy.

Fault/attack detection is one of the crucial functions and a prerequisite for the above mentioned protection/restoration schemes. The inability of AOTNs to reconstruct data streams at nodes within transparent networks complicates segment-by-segment monitoring of communication links. Nevertheless, many common faults (such as fiber cuts and node malfunctions) may be detected by optical monitoring methods. On the other hand, a resourceful attacker may thwart detection with the relatively simple monitoring methods available now. Although research on attack survivability for AOTN is relatively scant, many interesting issues exist[19].

The management of attacks also involves the protection of data security. This security can be considered at the logical (or semantic) level to protect the information content of the data if an attacker is able to access them. Many of the traditional security problems related to logical security present in traditional electronic networks are still present in AOTNs. However, the approach for logical security (like, encryption, privacy and authentication) taking into consideration AOTN physical characteristics opens up avenues for further research.

QoS restorability in optical networks is introduced in [19] as a performance measure for service-specific restoration methods applied to wavelength connections. However, the protection/restoration methods proposed so far (including those based on MPλS) do not take into account QoS degradation related to the physical device characteristics in AOTN. Moreover QoS degradation led by device failures or attack-induced faults in AOTN, requires service-specific recovery methods with emphasis on appropriate recovery path so as to guarantee the necessary QoS. In this paper, we restrict our discussion to the QoS recovery aspect as applied to the degradation of QoS led by device failures or attack-induced faults.

III. Lambda LSP Establishment

1. Traffic Classes in Next Generation Internet

Generic classification of application types supported on the NGI may be divided into (a) applications that do require absolute guarantees on QoS, (b) those requiring certain minimal statistical guarantees on QoS, and (c) those that do not require explicit QoS guarantees. Class 1 (type a) encompasses all constant bit rate application flows characterized by deterministic packet rates and sizes. As inelastic real time traffic, it is also characterized by low tolerance to delays and delay variability; and relatively high tolerance to packet loss. Examples include provisioned connections such as virtual leased lines or switched services such as voice and video circuits.

Network traffic class 2(b) has variable statistical attributes similar to class 3(c) but demand certain minimal statistical but demands certain minimal statistical guarantees on QoS, and exhibits a greater degree of time sensitivity. Distributed simulation and real-time streaming are as examples under this class. Actually the end-to-end integrity of class 2 variable bit rate (VBR) service may be assured by employing reliable stream protocols similar to TCP. Otherwise applications that subscribe to class 3 (c), such as best effort service or web browsing, are allowed to inject VBR traffic at any arbitrary rate into the network. This service tries to make the best use of the remaining bandwidth. The end-to-end reliability of class 3 data flows may be reinforced by TCP-like reliable stream protocols.

2. Lambda LSP Establishment Process based on DMS model

A major consideration in designing a differentiated MPLS service (DMS) is the issue of scalability. This can be achieved by flow aggregation, thereby ensuring individual end-to-end QoS guarantees without maintaining knowledge base of individual flows on each segment of their paths. This implies that a heavy computational overhead can be avoided in core nodes by manipulating and maintaining the state of QoS for each aggregated traffic flow in the edge node. In the QoS functions of an ingress AOTN node as given in Fig. 5 (see also the DMS domain as illustrated in Fig.2), functions such as classification, marking, and policing would be needed only at the edge level AOTN nodes of the network. The core AOTN nodes only implement forwarding of the data packets in the nodes have the same capabilities as the core AOTN nodes, they use policing to monitor the customer contract and a classifier, and mark the traffic at the incoming interface. Another important consideration in designing a DMS is that for the MPLS network, a recovery priority could be used as a differentiating mechanism to support the service requiring higher reliability.

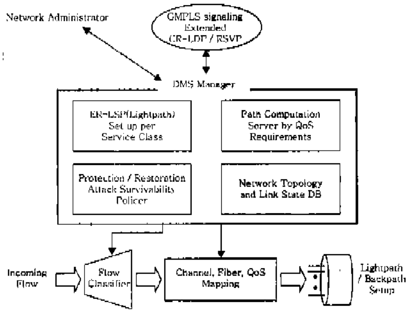
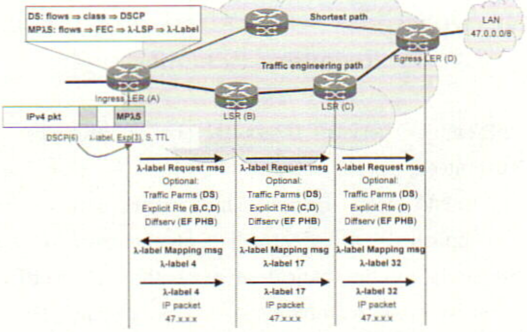


Fig. 5. QoS functions at the ingress AOTN node

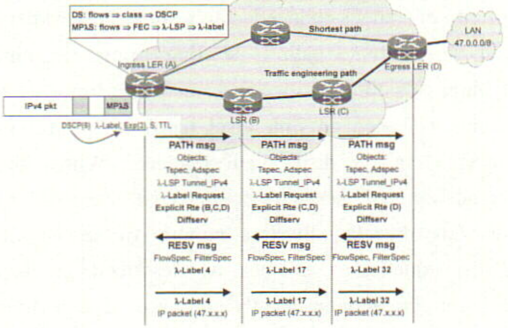
In the case of DiffServ, the DiffServ-field of the packets is set accordingly since the packets are classified at the edge of the network[10]. In the core of a network, packets are buffered and scheduled in accordance with their field. On the other hand, with DMS, while packets still have their DiffServ-field set at the edge of the network, the EXP fields in the MPλS headers are also set according to Diffserv field. When the packets are flowing upon a optical label switched path (λ-LSP), they are buffered and scheduled in accordance with the EXP field. Whether the MPλS is involved or not in providing QoS, the over-all mechanisms are transparent to the end-users. Sometimes it is desirable to use different λ-LSPs for different classes of traffic. This causes the physical network to be divided into multiple virtual networks where every virtual network takes care of the corresponding class of traffic.

These networks may have different topologies and resources according to their priority. However, these virtual networks can be controlled by constraint-based routing (CBR). The CBR computes constrained-based routes explicitly (ER-λ-LSPs) that are subject to the constraints such as bandwidth and administrative policy (see Figure 6). The signaling information such as an explicit route for the constraint-based route can be carried either by CR-Label Distribution Protocol (CR-LDP), or as piggybacked on extensions made to RSVP[14]. Figure 6 shows examples of λ-LSP establishment process based on DMS concepts using CR-LDP and RSVP extensions.

Furthermore, unlike general Diffserv, the DMS could utilize optical layer protection services for the λ-LSP segment that traverses the optical network. That is, the protection services at the MPLS layer for an end-to-end λ-LSP must be mapped onto suitable protection or restoration services offered by the optical layer. Thus, many λ-LSPs can be aggregated into a single lightpath in AOTN. In [20], 111 and 000 are being used for premium service and best effort service, respectively. As an example of assured service implementation, Ref. [20] defines Olympic service, which consists of three service classes: bronze, silver, and gold. So it is possible to assign the different values of EXP field to each class with two more sub classes (low and high drop precedence): Gold: 110, 101; Silver: 100, 011; Bronze: 010, 001.



(a) λ-LSP establishment using CR-LDP



(b) λ-LSP establishment using RSVP extensions

Fig. 6. λ-LSP establishment process based on DMS concepts

Fig. 7 shows service classification and the example of mapping MPLS EXP field onto the classification described above, which is defined by the network administrator[21].

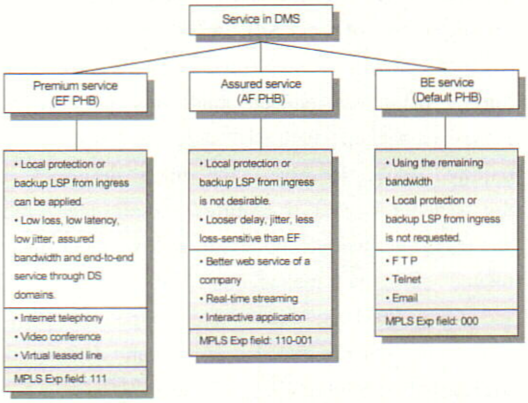


Fig. 7. Service in DMS

Ⅳ. QoS Class with Differentiated QoS Recovery Schemes

Premium service (class 1 above) provides a guaranteed peak bandwidth service with an end-to-end delay bound. This service has to be accomplished in lightpaths guaranteed to be protected by the optical layer, within a specified recovery time requirements. At the channel level, it is possible to use local QoS protection mechanisms or a MPLS backup procedure.

Within the local protection, upon detecting a failure or attack-induced fault on the primary path, an alternate path is starting from the point of failure within a specified recovery time. This scheme is based on link level hardware protection concepts in a distributed manner. When the degradation in service is detected because of intrusion on relatively less number of service λ-LSPs, equalizing schemes as described in Ref. [22] can be applied locally. In case of a serious threat to the quality of service, the cross-connect must be able to identify the problem and switch to the appropriate protection provision. This channel level protection scheme provides less than 50ms protection speed.

On the other hand, we can also use a MPλS backup procedure for sustaining QoS of the premium service. When premium service is assigned to a specific QoS routed lightpath (i.e., establishment of λ-LSP), a backup QoS routed lightpath is also established. Upon detecting a failure or attack-induced fault on the primary path, a backup path is used to sustain the required QoS. However, the main drawback of this scheme is that it requires signal regeneration at every intermediate node for control mechanisms related to the management of primary and secondary backup paths. This type of MPLS protection scheme needs less than 100ms for MPLS link rerouting.

Assured service (class 2 above) offers an expected level of bandwidth with a statistical delay bound. For sustaining QoS of the assured services, a MPLS LSP restoration scheme can be used. An OCh path restoration (λ-LSP restoration) scheme requires that every affected working λ-LSP be replaced by the MPLS restoration mechanism. This further requires longer restoration times since ingress and egress nodes dynamically search for the restoration λ-LSP needed to replace the disrupted λ-LSP. Nevertheless, restoration can be done in even less time intervals ranging from a few dozen milliseconds to a few hundred milliseconds.

Best-effort (class 3 above) service corresponds to current Internet service. For sustaining QoS of the best-effort service, we propose LSP restoration schemes at the IP level. For best-effort traffic, disruptions in service ranging from 100ms to a few seconds can be compensated by TCP retransmits. Otherwise, the services supported in DMS domain can be classified as summarized in Table 1[23].

Table 1. Services supported in DMS domain

Classification criteria	**Class 1**		**Class 2**					**Class 3**
	Premium service: Expedited Forwarding (EF) PHB		Assured service: Assured Forwarding (AF) PHB					Best Effort (BE) service: Default PHB
	Virtual leased line service	Bandwidth pipe for data service	Minimum rate guarantee service	Qualitative Olympic service			Funnel service	
Scope	(1|1)	(1|1)	(1|1)	(1|1) or (1|N)			(N|1) or (all|1)	All
Flow descriptor	EF, S-D IP-A	EF, S-D IP-A	AF1x	MBI			AF1x	None
Traffic descriptor	(b,r), r=1	NA	(b,r)	(b,r), r indicates a maximum CIR			(b,r)	NA, the full link capacity is allowed
Excess treatment	Dropping	NA	Remarking	Remarking			Dropping	NA
Performance parameters	D=20 (t=5, q=10E-3), L=0 (R=r)	R=1	R=r	Gold Delay or Loss must be indicated qualitatively	Silver	Bronze	NA	NA
BER (Q)	10^{-12} (7)		10^{-9} (6) ~ 10^{-7} (5.1)					10^{-5} (4.2)
el. SNR	16.9 dB		15.5 dB ~ 14.2 dB					12.5 dB
OSNR (f_0=10Gbit/s)	19.5 dB		18.2 dB ~ 16.8 dB					15.1 dB
GMPLS Exp field	111	110	101	011	010	001	100	000
Resource allocation	Pre-specified percentage (10%) for this service (C band: 1530nm ~ 1565nm)		Pre-specified percentage (30%) for this service (L band: 1565nm ~ 1625nm)					Best use of the remaining bandwidth (L band: 1565nm ~ 1625nm)
Recovery scheme	Local protection/backup λ-LSP		λ-LSP restoration					Restoration at IP level
Recovery time	<50msec (Detection time: <100msec)		50 ~ 100msec (Detection time: 0.1msec ~100msec)					1 ~ 100 sec (Detection time: 100msec ~ 180sec)

(b, r): token bucket depth and rate (Mb/s), p: peak rate, D: delay (ms), L: loss probability, R: throughput (Mb/s), t: time interval (min), q:quantile, S-D: source and destination, IP-A: IP address, MBI: may be indicated, NA: not applicable, CIR: committed information rate

Ⅴ. Differentiated Wavelength Assignment Strategies with QoS Recovery

Within the framework for QoS guarantees based on a DMS, IP traffic (injected into an ingress OTN node by conventional domain legacy networks) is segregated into differentiated service optical packets. Each packet then is associated with a classified optical wavelength that carries many time-division multiplexed channels. Thus, protection or restoration schemes for QoS recovery is sensitive to the class of service flow and accordingly the optical QoS-guarantee is related to comprehensive aggregated traffic flows in contrast to QoS-routed legacy networks. Routing and Wavelength Assignment (RWA) is accomplished according to each service class flow and deals with end-to-end classified-optical QoS routing that considers QoS parameters translated into the optical layer.

A differentiated wavelength assignment is necessary for the appropriate allocation of wavelengths on wavelength routed QoS route with differentiated QoS class and recovery capabilities. This approach can yield the solution to the classified QoS-routing that considers QoS recovery capabilities as related to QoS failure caused by device failures or attack-induced faults.

While setting up such classified QoS-routes, a differentiated wavelength assignment scheme is characterized by a set of particular issues like provision of service-specific guarantees, fair accommodation of all types of services with efficient network utilization, and QoS recovery capability. With these issues in mind, we present a differentiated wavelength assignment strategy under these scenarios: (a) each wavelength passing through the same type of physical components has the same QoS guarantees (b) wavelengths passing through the same type of physical components but with different QoS attributes; and (c) strategies specific to the type of optical nodes on the path.

The differentiated wavelength assignment strategy for the case (a) is just based on the service-differentiation obtained by assigning service-specific wavelength ratio on each link in OTN. Accordingly, the requested service is provided with sufficient QoS within allocated ratio and the amount of total available wavelengths in each node is allocated to each differentiated service like 10% for premium service, 30% for assured service, and 60 % for best effort service, respectively. In general, it is difficult to determine the best operating point for three types of traffic if their distributions are independent. In this paper, we follow the assignment ratio as described in Ref. [24]. Protection for premium services is also accomplished within their assigned wavelength ratios.

For case (a), wavelengths are allocated in a classified QoS route satisfying the assignment quantity-constraint shortest-hop path. The global efficiency in resource utilization (i.e., maximization of the number of flows that are admitted into the network) is achieved by searching an assignment-constraint shortest-hop path which guarantees minimum block rate. The protection path for premium services should be chosen in such a manner so as to support the necessary transmission quality guaranteed along selected edge-disjointed QoS path within the assigned wavelength ratio. QoS restoration for assured and best-effort service classes is done at the level of MPλS and TCP, respectively.

For case (b), signal parameters like wavelength and its deviations, steady-state and transient power levels, and states of polarization can either change under normal network operations like adding/dropping of channels, or can change inherently slowly over time and temperature like states of polarization, nominal wavelength, and amplifier gain can even change drastically due to an event of any intrusion. Considering these device level vulnerabilities, premium service should be assigned wavelengths that correspond to the C band of the EDFA gain spectrum. This is especially important in case of cascaded non-gain-unclamped EDFAs on the link. In this situation, the allocation of protection wavelength with edge-disjointed QoS path within the assigned wavelength ratio should be done in such a way that the wavelength correspond to the mid-flat band of the overall gain profile of the cascade. Assured services and best-effort services may be

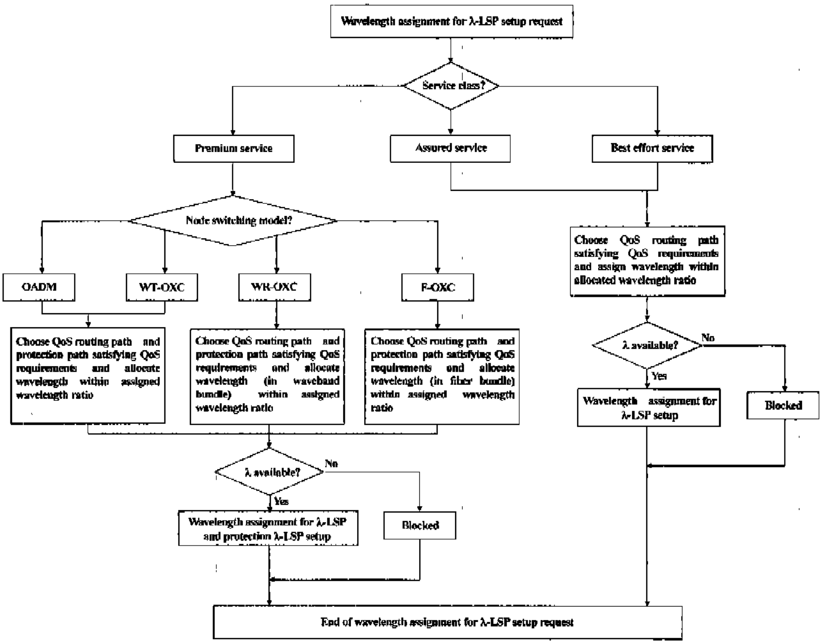


Fig. 8. Differentiated wavelength allocation

assigned wavelengths corresponding to other bands of the EDFA gain spectrum. Classified-QoS path computation and differentiated wavelength assignment; achievement of the global efficiency in resource utilization, and protection/restoration strategy are the same as in case (a) except for the wavelength assignment ratios.

For case (c), according to the type of used optical nodes, Fig. 8. shows a flow chart for a possible differentiated wavelength allocation procedure. It has two assignment categories for QoS routes: premium services and assured/best effort services.

For assured/best effort service, the QoS path computation at each ingress node chooses a QoS routing path that satisfies QoS requirements for assured or best-effort service respectively. And then, LDP assigns a wavelength within the allocated wavelength ratio. Thus wavelength assignment is independent on the type of the used switched nodes. When there is QoS failure or degradation led by physical fiber link breakdown, node fault, wavelength channel fault, wavelength channel attack, or unauthorized access through add/drop ports, the MPLS λ-LSP restoration scheme is evoked for assured service. Similarly, QoS of the best-effort service can be guaranteed by TCP re-transmits enabling λ-LSP restoration at the IP level.

For the category of premium service, wavelength routing optical node models may be divided into (a) OADM (Optical Add-Drop Mux) model, (b) F-OXC (Fiber Cross-Connect) model, (c) WR-OXC/OADM (Wavelength Routing OXC/OADM) model, and (d) WT-OXC/OADM(Wavelength Translating OXC/OADM) model. According to those four models, a differentiated wavelength assignment for λ-LSP setup is accomplished as follows:

(a) OADM (Optical Add-Drop Multiplexer):

λ-LSP and protection λ-LSP might be allocated wavelengths (corresponding to the C band of the EDFA spectrum for the EDFA amplifier) within the assigned wavelength ratio for premium service along the selected classified-QoS routing path. However, considering a physical fiber link breakdown or optical fiber cutting, or OADM node fault at the fiber level, it might be better to allocate a corresponding wavelength in a different fiber (fiber-disjoint protection λ-LSP) for a protection λ-LSP. It should be noted that wavelength conversion is not available at this type of nodes and a wavelength can be either added/dropped or let through the node, and wavelengths within the same fiber can be independently handled.

(b) F-OXC (Fiber Optical Cross-Connect): Similar to that in the case (a) but deals with an additional constraint that all wavelengths in the same fiber must be handled together, i.e., all wavelengths of the same fiber must be either dropped/added or let through. Wavelength assignment for a λ-LSP and protection λ-LSP are the same as in the case of an OADM. However, in fiber-bundling , a set of fiber links are handled together to a set of fiber links as a bundle. Considering that this may reduce the distortion on the individual links and may allow tighter separation of the individual links, it might be better to allocate a corresponding wavelength in the same fiber bundle for a protection λ-LSP.

(c) WR-OXC (Wavelength Routing Optical Cross-Connect): At this node wavelength conversion is not available, thus the wavelength of the incoming connection must remain unchanged in the outgoing connection. Only the output fiber can be selected by the node. Wavelength assignment for a λ-LSP or protection λ-LSP is the same as in the case of an OADM.

(d) WT-OXC (Wavelength Translating Optical Cross-Connect): The wavelength of the incoming optical connection can be converted into another wavelength for the outgoing connection at this type of nodes. The routing problem at this node is greatly simplified as any available output fiber-wavelength pair can be selected for routing the incoming connection. Wavelength assignment for working λ-LSP and protection λ-LSP is similar to that in the case of an OADM. However, in a waveband switching scheme, wavelength assignment for a protection λ-LSP should be accomplished in the same waveband path because a set of contiguous wavelengths is switched together to a new waveband. Moreover, this may reduce the distortion on the individual wavelengths and may allow tighter separation of the individual wavelengths[25].

Adding OADM or F-OXC nodes to the network starting from a pure WR-OXC-based network requires a careful consideration in differentiated wavelength assignment on classified-QoS routed path while designing mesh OTN networks.

Ⅵ. Conclusion

In this paper, we proposed a framework and a differentiated lambda establishment process for QoS guarantees based on the DMS model. Keeping in mind that QoS routing with differentiated wavelength assignment is a key DMS function for the transmission of differentiated multimedia services across WDM Internet backbone networks, Our paper also deals with practical enhancements required to QoS routing with wavelength allocation in support of differentiated wavelength assignment for multimedia QoS services within IP/MPλS over DWDM transport network.

REFERENCES

[1] M. Listanti et al. "Architectural and Technological Issues for Future Optical MagInternet Networks," *IEEE Communications Mazine*, Vol. 38,

no.9, pp. 82-92, Sept. 2000

[2] R. Braden, et al., "Integrated Services in the Inernet Architecture: an Overview," *RFC 1633, IETF*, Jun. 1994

[3] R. Braden, L. Zhang, S. Berson, S. Herzog, S. Jamin, "Resource ReSer-Vation Protocol (RSVP)-Version 1, Functional Specification," *RFC 2205, IETF*, Sep. 1997

[4] S. Shenker, et al., "Specification of the Guaranteed Quality of Service," *RFC 2212, IETF*, Sep. 1997

[5] Jacobson et al., "An Expedited Forwarding PHB," *RFC 2598, IETF*, Jun.1999

[6] K. Nicholas, S. Blake, F. Baker and D. Black, "Definition of the Differentiated Services Field (DS Field) in IPv4 and IPv6 Headers," *RFC 2474, IETF*, Dec. 1998

[7] S. K. Lee and S. U. Kim, "Standards Activities for Optical Transport Networks in ITU-T," *Optical Network Magazine*, Vol. 2, no. 2, pp.82-83, Mar. 2001

[8] S. Chen and K. Nahrstedt, "An Overview of Quality of Service Routing for the Next Generation High Speed Networks: Problems and Solutions," *IEEE Network*, Vol. 12, no. 6, pp. 64-79, Nov/Dec. 1998

[9] J. K. Patel, S. U. Kim, and D. H. Su, "QoS Recovery Schemes based on Differentiated MPLS Services in All-Optical Transport Next Generation Internet," *Photonic Network Communications*, Vol. 4, no. 1, pp. 5-18, Jan. 2002

[10] Awduche D. et al., "Multi-Protocol Lambda Switching: Combining MPLS traffic engineering control with optical crossconnects," *IETF Internet draft*, Nov. 1999: work in progress.

[11] A. Iwata and N. Fujita, "A Hierarchical Multilayer QoS Routing System with Dynamic SLA Management," *IEEE JSAC*, Vol. 18, no. 12 . pp. 2603- 2616, Dec. 2000

[12] Daniel O. Awduche et al., "RSVP-TE: Extensions to RSVP for LSP Tunnels." *RFC 3209, IETF*, Dec. 2001

[13] B. Jamoussi et al., "Constraint-Based LSP Setup using LDP," *RFC 3212, IETF*, Jan. 2002

[14] L. Andersson et al., "LDP Specification," *RFC 3036, IETF*, Jan. 2001

[15] Y. Rekhter et al., "Carrying Label Information in BGP-4," *RFC 3107, IETF*, May 2001

[16] K. Kompella et al., "OSPF Extensions in Support of Generalized MPLS," Internet Draft, draft-ietf-ccamp-ospf-gmpls-extensions-07.txt, Nov. 2002

[17] K. Kompella et al., "IS-IS Extensions in Support of Generalized MPLS," Internet Draft, draft-ietf-isis-gmpls-extensions-12.txt, Nov. 2002

[18] J. Patel, S. Kim, D. Su, "Attack Management for All Optical Transport Networks," submitted to *IEEE Journal on Survey and Tutorial*.

[19] A. Jukan, A. Monitzer, and H.R. van As, "QoS-restorability in Optical Networks," 24 th European Conference on Optical Communication, pp. 711-712, Vol. 1, Sept. 1998.

[20] Heinanen et al., "Assured Forwarding PHB Group," RFC-2597, June 1999.

[21] N. Golmie, T.D. Ndousse, and D. Su, "Differented Optical Services Model for WDM Networks," IEEE Communications Mag., Feb. 2000.

[22] M. Ali, B. Ramamurthy, and J. S. Deogun, "Routing and Wavelength Assignment (RWA) with Power Considerations in All-Optical Wavelength-routed Networks," GLOBECOM'99(Rio de Janeiro, Brazil), Vol. 2, pp. 1433-1437, Dec. 5-9, 1999

[23] A. Fumagalli and L. Valcarengh, "IP

Restoration vs WDM Protection: IS there an optimal choice?," *IEEE Network*, Vol.14, no. 6, pp. 34-41, Nov./Dec. 2000

〔24〕 C. Villamizer, "Dynamic Behavior of MPLS Traffic Engineered Networks," Technical Session Proceedings of MPLS 2000, (Fairfax, Virginia), Oct. 2000

〔25〕 P. Ashwood-Smith et al., "Generalized MPLS-Signaling Functional Description," Internet Draft, draft-ietf-mpls-generalized-signaling-08.txt, Apr.2002

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