QoS RWA Algorithm Considering Multi-Constraint in the Next Generation Optical Internet Backbone Networks

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by

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A Dissertation

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Contents

A study on QoS RWA Algorithm considering multi-constraint in the Next Generation Optical Internet Backbone Networks

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Abstract

In the Next Generation Internet(NGI) backbone network, a Dense Wavelength Division Multiplexing (DWDM) technology has been more and more highlighted to cover the increasing subscribers and various requirements. For such a DWDM network, multi-constraint QoS RWA is regard as one of the key issues in providing multiple constraints, such as optical signal quality attributes, survivability and limited wavelength conversion. However, finding a qualified path meeting the multiple constraints is a multi-constraint optimization problem, which cannot be solved by a simple, efficient algorithm. As a strategy to tackle this problem, in this paper, we propose a multi-constraint QoS Routing, based on flooding method, which is called qualified path routing (QPR) with minimum computation and implementation complexity which relies on local link-state information only. Also, we introduce the differentiated QoS class with recovery scheme. On basis of this QoS class, we propose new multi-constraint QoS RWA with the limited wavelength conversion. To prove the efficiency of the proposed algorithm, simulations are carried out in terms of blocking probability, survivability ratio, routing overhead, and effect of the limited wavelength conversion.

1. Introduction

The next generation multimedia applications such as video conferencing, teleimmersive virtual reality, online shopping and Internet games have raised tremendous challenges on the network design, both in bandwidth and service. But current Internet based on time division multiplexing (TDM) cannot supply sufficient transmission capacity for these multimedia services. To solve these problems, dense wavelength division multiplexing (DWDM) is currently believed to be the most promising technology for Tb/s fiber-optic communications [1]. It partitions the available optical bandwidth in optical fiber into a few independent wavelengths that enable multiple users to simultaneously access the optical fiber.

In such a DWDM network, end users communicate with each other by all-optical WDM channel referred to a lightpath [2]. Given connection requests, the problem of setting up the lightpath is generally called the routing and wavelength assignment (RWA) problem [3]. The RWA plays an important role in improving the global efficiency for resource utilization in WDM network providing multi-wavelength per fiber.

As previously stated, the new generation of the multimedia applications involves real time-intensive traffics with various quality of service (QoS) requirements. One of the key issues in supporting multi-constraint is QoS RWA, which is not only selecting a path and assigning the wavelength on it for transmitting data from source to destination but also enabling some form of resource reservation and admission control so as to ensure that the data flow in the path is consistent with the service requirements of the traffic and the service restrictions of the network.

Unfortunately, though this multi-constraint QoS RWA has been regarded by researchers as a vital mechanism to support multimedia communication, finding a qualified path meeting the multiple constraints is a multi-constraint optimization problem, which has been proven to be NP-complete [4] and cannot be solved by a simple, efficient algorithm.

However, there are at least two common approaches to search the qualified path, not optimal path. One is the constrained QoS routing based on graph theory. It tries to optimize one constraint without violating other constraints [5-7]. The second is the multi-constraint optimization based on operations research. One intuitive way is to extend the single objective "cost" as a trade-off among multiple metrics such as available or residual bandwidth, delay, hop, throughput and so on [8,9]. However, it is too hard to find the combination function on so many parameters. Therefore, because of the computational complexity, such the existing QoS RWA algorithms are impractical and unattractive.

In this paper, to solve the problem such as multi-constraint and computational complexity, we propose a multi-constraint QoS Routing, based on flooding method, which is called qualified path routing (QPR) with minimum computation and implementation complexity which relies on local link-state information only. The rest of the paper is organized as follows. Chapter 2 describes the proposed QPR algorithm. In chapter 3, we introduce the differentiated QoS class with recovery scheme. Chapter 4 presents differentiated QoS RWA that is considering the various constraints such as signal quality attributes, survivability and limited wavelength conversion. In Chapter 5, we study performance of the proposed algorithm, in terms of blocking probability, survivability ratio, and routing overhead through simulation. Finally, Chapter 6 concludes this paper.

2. Qualified Path Routing (QPR) algorithm

The majority of previous work [5-7] has viewed QoS routing as an extension of the current Internet routing paradigm where routers exchange their QoS states using an OSPF-link protocol. But because these approaches have huge global link state information, it is not efficient.

Accordingly, comparing to the exiting QoS routing heuristics, the proposed QPR algorithm has the following three advantages.

First, there is no need for link-state information distribution and complex route computation, thus reducing operational overhead and implementation complexity.

Second, routers are not required to keep the database of the link-state information, thus saving storage space.

Third, parallel route search shortens the connection set-up time and can select the available best route based on multiple QoS constraints.

The proposed QPR algorithm is based on flooding method and search all possible routes concurrently, i.e., passing the connection request message to all possible routes on nodes, reserving resources and performing QoS checks on all of them, and finally selecting the route among the many possibilities through the first connection request arriving the destination node. The concept of flooding is not new. It is simple, robust and distributed but is seemingly the inefficient approach. This is because a request message that passes through a node results in reservation of resources for all ports through which it is flooded, leading to a phenomenon called 'over reservation' problem. Another potential drawback of the pure flood routing is its considerable routing overhead due to the large number of copies of the request packets. However, the proposed QPR algorithm can remove these problems as follow.

First, the request packets are allowed to flood only those links passing the QoS admission checks.

Second, to prevent and check the looping of requests and the multiple requests for the same connection, keeping up the History Table, at the all node on the network, which records the requests to visit the node

Through this two methods, we can prevent a potential congestion condition emerged on network in advance.

2.1 The Key Requirements

To perform the procedure of multi-constraint QoS routing, our QPR algorithm uses three messages and three tables. Functions and types are as follows.

1) Messages

The key functions performed by each message are as follows.

• Con_Req (Connection Request) message

: Flooding the connection request message (Con_Req) to all links connected with the node passing the QoS admission check of the request. but a link where the message has arrived is excluded.

Table 1. Description of the connection request message

Fields	Description
Request_ID	Unique connection request identifier
Dest_ID	Unique destination identifier
Requirement	Bandwidth, latency, jitter requirements of the connection
Back_ID	Path identifier (Primary path, Secondary path)

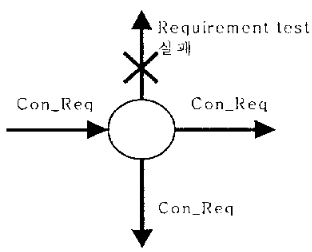

Figure 1. Operation of the connection request message

• Rej_Rsv (Reject Reservation)

: The node will not accept a loop-back or another copy of the same connection request message. When that happens, it sends back a reject reservation message (Rej_Rsv) immediately to release the reserved resources at the node upstream. And if the node finds all the flooded requests unsuccessful, it will propagate a Rej_Rsv to the node upstream.

Table 2. Description of the reject reservation and the connection confirmation message

Fields	Description
Msg_ID	Message identifier (Reject, Confirmation)
Request_ID	Unique connection request identifier
Dest_ID	Unique destination identifier
Back_ID	Path identifier (Primary path, Secondary path)

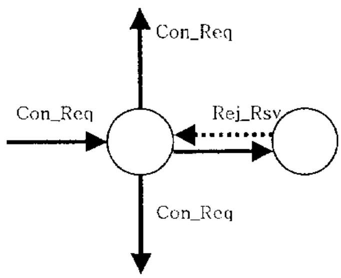

Figure 2. Operation of the reject reservation message

• Con_Conf (Connection Confirmation)

: When the node receives a connection confirmation message (Con_Conf), it reserves the required resources for this confirmed connection. It's message format is similar to the reject reservation message

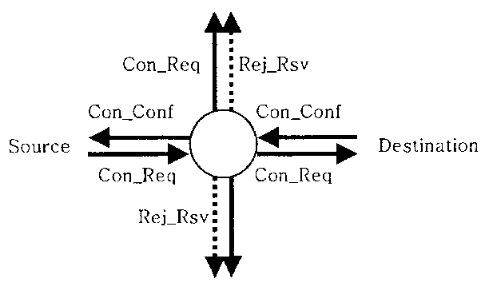

Figure 3. Operation of the connection confirmation message

2) Tables

There are three kinds of tables maintained at each node for related procedure during the connection set-up.

• Pending Routing Table (PRT)

: Each entry of it represents a pending request and contains the fields shown in Table 3.

Table 3. Pending Routing Table (PRT)

Fields	Description
Msg_ID	Message identifier (Reject, Confirmation)
Inport	Input node of the connection request message
Outport_No	Number of the message flooded at this node
Outport_List	Output node list of the message flooded at this node

• History Table (HT)

: Each entry records the requests that have visited this node. So, the algorithm uses this table to check and prevent the looping of requests and flooding of multiple requests for the same connection. Each entry of the HT will be purged after a reasonable period of time.

Table 4. History Table (HT)

Fields	Description
Index1	Request_ID
Index2	Request_ID

• Routing Table (RT)

: Each entry records the information for an established connection. The fields of each RT entry are as in Table 5.

Table 5. Routing Table (RT)

Fields	Description
Connection_ID	Established path identifier
Resources	Reserved bandwidth (wavelength)
Ports	A pair of Input and Output node

2.2 The procedure of QPR algorithm

The entire route establishment procedure is composed of three distinct sub-procedures with the routing messages propagating. Figure 4 illustrates the simple network model used to describe the procedure. The physical topology consists of four users, five nodes and seven links. The nodes, which can be routers or switches, are interconnected by bi-directional point-to-point links. Hosts are end-devices attached to the network. To explain to briefly, we assume that A and C users attend the routing procedure.

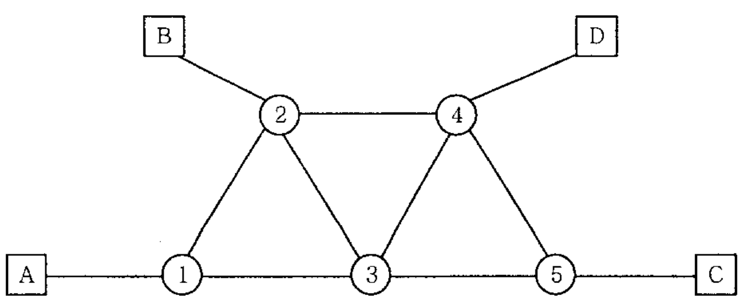

Figure 4. Network model

The three sub-procedures are as follows.

Procedure (1): User A is requesting a connection to user C. It sends a connection request (Con_Req) message to the ingress node 1, which floods this Con_Req message to all nodes meeting requirements except to the node where the message has arrived. At this moment, node 1 adds entry of this message to PRT (Table 3) and HT (Table 4), and then reserves resources for this connection. Meanwhile, each node received the connection request message checks and prevent the looping of requests and flooding of multiple requests for the same connection.

Procedure (2): When node 2 and node 3 receive the connection request message (Con_Req), if the request_ID exists in their HT entry or each node couldn't find the next nodes to meet the requirements, they send back the reject_reservation message (Rej_Rsv) to upstream (input) node. Also, in case that each node received the connection_confirmation message (Con_Conf) from a destination node, they immediately send Rej_Rsv message all nodes that do not belong to a confirmed path. Through this, each node received Con_Conf message releases the reserved resources unnecessarily for other connection requests, and removes the corresponding entry at LT and HT.

Procedure (3): When Con_Req message arrives a destination node through the procedure (1), a destination node sends Con_Conf message to the source node for confirming the path. The information of confirmed path is updated at RT of each node received Con_Conf message. Finally, after this procedure is completed at the source node, the entire procedure is finished. Figure 5 summarize the entire procedure.

```
Procedure the connection establishment

If Request_ID in HT then
  'Rej_Rsv' transmission;
else
  Add Request_ID to HT;
  If this node:=egress node then
    Send 'Con_Req' to destination;
    Send 'Con_Conf' to source;
  else
    Flood Con_Req to all nodes that meet requirements;
    Update 'PRT';
If exist links to meet requirements then
    Update 'PRT';
else
    'Rej_Rsv' transmission;
```

Figure 5. Procedure of the connection establishment

3. Differentiated QoS Class with Recovery Schemes

Generic classification of application types supported by 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 at all. Class 1 (type a above) encompasses all constant bit rate (CBR) application flows characterized by deterministic packet rates and sizes. An inelastic real time traffic is characterized by low tolerances to delays and delay variability; and relatively high tolerance to packet loss. Examples include provisioned connections such as virtual leased lines or switched services for voice and video circuits.

Network traffic class 2 (type b above) has variable statistical attributes similar to class 3 (type c above) but demands certain minimal statistical guarantees on QoS, and exhibits a greater degree of time-sensitivity. Distributed simulation and real-time streaming are 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.

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. [10] 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 (1:1 protection) 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 MPL(λ)S protection scheme needs less than 100ms for MPL(λ)S 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 N:1 MPL(λ)S protection scheme can be used.

For sustaining QoS of the best-effort service, we propose MPL(λ)S LSP restoration schemes An OCh path restoration (λ-LSP restoration) scheme requires that every affected working λ-LSP be replaced by the MPL(λ)S 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.

Within three classes as described above, the service is classified according to the followings: parameters negotiated upon setting up call (delay, jitter, bandwidth, etc.), bit error rate (BER), electrical signal-to-noise ratio (el.SNR), optical SNR (OSNR) requirements, and survivability required against network failure or attack. And then, this classification will be applied to QPR algorithm. The parameters to consider are described below.

3.1 Service classification parameters

(1) Scope

Scope shows the range of topology in which the policy will be put into force. It is expressed by (Ingress, Egress) interface. Ingress is the identifier of Ingress and likewise, Egress is the identifier of Egress. And 'any' means no specified value.

(Ingress, Egress) interface can be categorized into 5 types as follows [11]:

- (1,1) : One-to-one communication (pipe)
- (1,N) : One-to-multiple communication (N>1) (hose)
- (1,any) : One-to-any communication
- (N,1) : Multiple-to-one communication (N>1) (funnel)
- (any,1) : Any-to-one communication

(2) Flow descriptor (Flow Id)

Flow Id represents IP stream that shares at least one common feature. It consists of the differentiated service code point (DSCP), source address, destination address and applicable information such as protocol number, source or destination port.

(3) Traffic descriptor

Traffic descriptor describes the traffic features of IP packet stream corresponding to Flow Id. By using traffic descriptor, we can identify whether corresponding IP packet stream in Ingress node is 'in-profile' or 'out-of-profile' so as to decide whether to allow the transmission into network. Parameters consisting of traffic descriptor are listed as follows:

- Maximum transfer rate: p (b/s)
- Token bucket transfer rate: r (b/s)
- Bucket size: b (bytes)

- Maximum transport unit (MTU): M (bytes)
- Minimum packet size: m (bytes)

(4) Excess treatment

Excess treatment indicates the parameter that describes how to process excessive traffics beyond profile. It processes those excessive traffics as one of the followings: drop(default), shape and remark.

- If the value is dropping, all packets beyond traffic descriptor are discarded.
- If the value is shaping, all packets beyond traffic descriptor are delayed in buffer until 'in-profile'.
- If the value is remarking, all packets beyond traffic descriptor are re-marked and processed with DSCP value at lower class than corresponding service class.

(5) Performance parameters

Performance parameters are the service assurance parameters that are required to provide IP packet stream corresponding to Flow Id to users on network. It consists of delay, jitter, packet loss and throughput. Delay and jitter indicate maximum packet delay and delay deviation from Ingress node to Egress node respectively. Optionally, the limitation value such as worst-case bound can be specified with regard of these parameters.

Packet loss shows the loss possibility of 'in-profile' packets from Ingress node to Egress node as described in the following formula. Delay, jitter and packet loss are the values in which only 'in-profile' traffic is measured. Throughput means the transfer rate at which the packets corresponding to Flow Id are measured in Egress node. It shows also the value in which all packets are measured, whether in- or out-of-profile. For all four parameters, time interval must be defined.

$$\text{packet loss} = \frac{\text{lost packets between (and including) Ingress and Egress}}{\text{offered (ingected) packets at Ingress}}$$

(6) BER/el.SNR/OSNR requirements

In WDM network, a pair of source-destination has many optical paths. To determine the quality of fiber service on each path, some features such as BER, dalay and protection scheme must be defined, because nothing but they characterize each optical path. To determine the quality of optical service on each path, be sure to define features such as BER, delay, jitter and protection scheme that only characterize each optical path.

While going through components on optical path such as optical cross-connects (OXCs), fiber, segment and erbium doped fiber amplifiers (EDFAs), optical signal may be damaged by several causes such as jitter, wander, crosstalk and amplified spontaneous emission (ASE).

As signals are transferred to Egress node, the transmission signal tends to be more lost or damaged so that the quality of optical signal may be rapidly degraded. Most of these losses or damages can be determined by calculating BER in receiving node.

Therefore, BER is one of the most important parameters for the measurement of optical path performance.

In optical system, the correlation among BER, Q-factor and el.SNR as electronic performance parameter was reported to [12]. According to Rec. G.976 (TSB, 7 Nov.1996), it can be found that there are correlations among BER, Q-factor and el.SNR by the approximation of Gaussian error function in optical TDM and WDM system. The correlation can be expressed as the following two formulas, (1) and (2):

$$BER\,(Q) \cong (1/\sqrt{2\pi}) \cdot (\exp(-Q^2/2)/Q) \qquad (1)$$

$$el.SNR \;=\; 10\log Q^2 \qquad (2)$$

Typical correlation values among BER, Q-factor and el.SNR as system performance parameter are shown in Table 6. If the optical system is located in the internal side of electronic client network such as synchronous digital hierarchy (SDH), asynchronous transfer mode (ATM) and IP, those electronic system performance parameters as described above can be used. Here, the fixed value of BER relates to that of Q factor and el.SNR.

Table 6. Correlations among BER, Q-factor and el.SNR values

BER	Q-factor	el.SNR
1.3 × 10-12	7	16.9 dB

Recently, there have been some studies on correlation between Q-factor (electronic system performance parameter) and OSNR (optical system performance parameter) [13]. OSNR can be defined as the ratio of optical amplifier output power (Pout ≥ Psens) to optical amplifier spontaneous emission power(Psp). That is, an optical system is limited by ASE noise, and the relationship between OSNR and Q-factor can be expressed as the following formula (3).

$$OSNR_{0.1nm} = \frac{(1+r)\cdot(1+\sqrt{r})^2}{(1-r)^2}\cdot\frac{Be}{Bd}\cdot Q^2 \qquad (3)$$

$r = 0.15,\ 10\log r = 8.2\ dB$ [27] : extinction ratio of the transmitted optical signal
$Be = 0.75 \cdot f_0$: effective electrical noise bandwidth due to bit rate f_0
$Bd = 12.6\ GHz$ or $0.1nm$: optical bandwidth for OSNR measurement
factor $[(1+r)\cdot(1+\sqrt{r})^2/(1-r)^2] = 3.085$

Because valid noise bandwidth 'Be' must depend upon transfer rate f_0 and optical bandwidth (Bd) for measuring OSNR must be pre-defined so as to keep stable values, the differentiated value of OSNR(f0) depends upon either fixed value of BER or Q. Table 6 shows an example of calculating OSNR value according to transfer rate f_0, if BER is 10^{-12}(Q=7).

Table 7. ONSR value according to f_0

f_0 (nominal)	f_0 [Gbit/s]	Be=0.75· f_0[Gbit/s]	OSNR(f_0)
STM-16: 2.5 Gbit/s	2.48832	1.86624	13.5 dB
STM-64: 10 Gbit/s	9.95328	7.46496	19.5 dB
STM-256: 40 Gbit/s	39.81312	29.85984	25.5 dB

3.2 Survivability requirements

In general, optical signal had higher data capacity than anything else, so a little failure would result in considerable losses and damages. Accordingly, protection and restoration mechanism are very critical to ensure that optical paths are transparent against various problems such as dropping optical line and damaged wavelength.

The premium service that transmits real-time data like sound requires very high reliability. This service is protected with local QoS protection mechanism of optical channel level or GMPLS backup procedure within the requirements for specific recovery time.

Within local QoS protection, if there is any occurrence of failure in main path due to fault or attacks, a transmission from failed point to redundant path is executed within recovery time of 50 ms or below. This scheme is based on the concept of link-level hardware protection in terms of distribution method. In addition, it is possible to use GMPLS backup procedure to ensure reliable QoS for premium service. This scheme has a recovery time of 100ms or below for re-routing GMPLS links, which sets up backup path in advance upon setting up λ-label switched path (LSP) and informs other paths of any problem in main path by signaling, followed by switching to backup paths to transmit demanded QoS.

In this paper, 1:1 protection is used for the premium service and, the reliable QoS of assured service is protected with N:1 protection method.

The best-effort service requires using λ-LSP recovery scheme of GMPLS that generates backup path after any occurrence of incidents. λ-LSP recovery scheme has to find the recovery λ-LSP dynamically to replace damaged optical path between Ingress and Egress node, so it requires longer recovery time than that in premium service (tens of ms ~ hundreds of ms). This scheme may have better resource utilization but lower recovery success so that there is a trade-off.

3.3 QoS Classes

If the above considerations are applied to backbone network, the results can be summarized as Table 8.

Table 8. QoS classes

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=l	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 / Silver / Bronze Delay or Loss must be indicated qualitatively	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
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 (1:1)		backup λ-LSP (N:1)			λ-LSP restoration
Recovery time	<50msec (Detection time: <100msec)		<50msec (Detection time: <100msec)			50 – 100msec (Detection time: 0.1msec –100msec)

(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

As shown in Table 8, virtual leased line service thoroughly ensures the requirements such as bandwidth, delay and packet loss between Ingress and Egress node. The example of such service includes real-time service such as voice over IP (VoIP) or video conference, where the traffic beyond specified requirement is discarded in Ingress node. Bandwidth pipe for data service is one of virtual leased line services available for data application. It fully ensures throughput but allows a little flexibility for packet loss. Minimum rate guarantee service ensures minimum transfer rate by allowing excessive traffic. The example of such service includes load control type service of integrated service model, moving picture experts group (MPEG) video service and so on. Funnel service corresponds to the model as shown in Figure 6, which make sure that the traffic entering into B, C, D via network should not exceed transfer rate a_{out}.

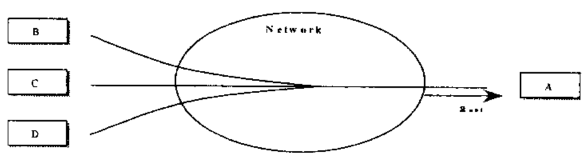

Figure 6. Funnel model

For instance, such service includes the type of service that sets up the maximum amount of web browsing traffic into an enterprise network to prevent network congestion and control traffics. Qualitative Olympic service is the service that gives relative priority without quantifying the requirements of delay and packet loss. To provide better service than best-effort service, it minimizes any delay by discarding traffic beyond requirements or processing 'in-profile' packets in preference to anything else. Best–effort service is the existing Internet service without guaranteeing QoS.

4. Differentiated QoS RWA algorithm

As the strategy to perform multi-constraint QoS RWA, we introduced the differentiated QoS class with recovery scheme in chapter 3. On the basis of this QoS class, we propose multi-constraint QoS RWA considering the limited wavelength conversion. The procedure of QoS RWA is based on the QPR algorithm described in chapter 2.

4.1 QoS admission check

The proposed QoS RWA algorithm considers multiple QoS admission checks at every node. We considered the parameters, such as BER, OSNR, and wavelength continuity constraint described in chapter 3.

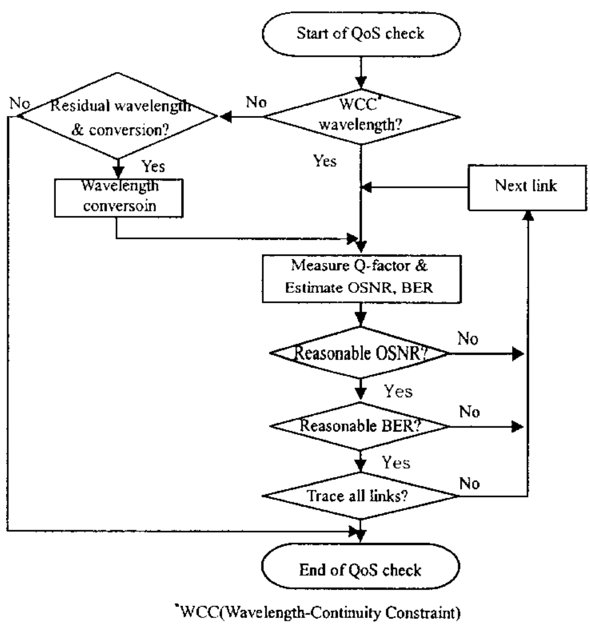

Figure 7. Procedure of QoS admission check

To determine the threshold, we considered equations (1) and (3) in chapter 3.

Figure 7 illustrates the procedure of QoS admission checks. The concrete procedures are as follows.

Procedure QoS admission check.

Step 0: QoS check request arrives. And continue.

Step 1: Check whether wavelength to meet wavelength continuity constraint exists, if yes, continue, and else go to step 6.

Step 2: Measure Q-factor, and estimate OSNR and BER. And continue.

Step 3: Check whether this link meets the OSNR threshold, if yes, continue, and else go to step 8.

Step 4: Check whether this link meets the BER threshold, if yes, continue, and else go to step 8.

Step 5: Finish. QoS admission check success.

Step 6: Check whether node has wavelength conversion and exists residual wavelength, if yes, continue, and else go to step 9.

Step 7: Wavelength conversion and go to step 2.

Step 8: Check whether another link exists, if yes, continue, and else go to step 9.

Step 9: Finish. QoS admission check failure.

4.2 Limited Wavelength Conversion

(1) Wavelength Conversion

In wavelength-routed networks, a lightpath between two nodes along a particular route must use a single wavelength on links, within the route. This requirement is referred to as the wavelength continuity constraint. For instance, consider the two-link route with only two wavelengths shown in figure 8. Imagine that a connection is to be established between nodes 0 and 2 along a route that passes through a optical cross-connect at node 1. This connection can only be established if the same wavelength is available on both links. If only wavelength λ_1 is available on link 1, and only wavelength λ_2 is available on link 2, then the connection is blocked.

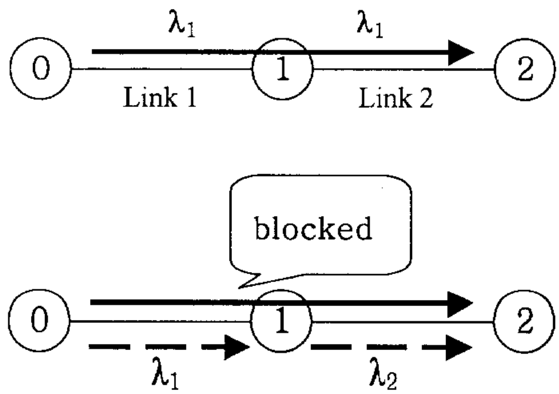

Figure 8. Wavelength continuity constraint

The restriction imposed by the wavelength continuity constraint can be removed by the use of wavelength converter. A wavelength converter is a device that takes the data modulated on an input wavelength and transfers it to a different output wavelength. If wavelength converters are included in the optical cross-connects in WDM networks, connections can be established without finding an unoccupied wavelength that is the same on all the links establishing the route. For instance, if a wavelength converter was available at node 1 in figure 9, the connection could be established using wavelength λ_2 on link 1, and wavelength λ_1 on link 2. This means that networks with wavelength converters are equivalent to traditional circuit-switched networks. Wavelength converters thus result in improvements in network blocking performance.

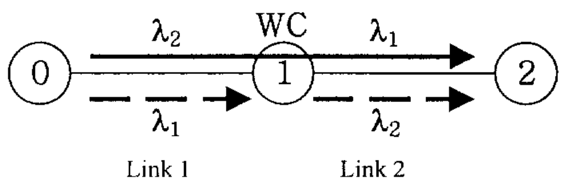

Figure 9. Function of wavelength converter

(2) Limited Wavelength Conversion

In the previous section, we discussed the efficiency improvement offered by the use of wavelength converters in WDM networks. It was assumed that a full set of ideal wavelength converters was available at every cross-connect in the network. That is, it was assumed that in every cross-connect, any input wavelength could be converted to any output wavelength. Although full-wavelength conversion is desirable because it substantially decreases blocking probability, it is difficult to implement in practice due to technological limitations.

Therefore, in this section, we describe networks with limited wavelength conversion, in which we no longer assume that any input wavelength can be converted to any output wavelength in every cross-connect in the network. This may be the result of placing wavelength converters at a limited selection of cross-connects in the network, using limited numbers of wavelength converters in each cross-connect, or using wavelength converters whose performance limits the set of allowable conversions.

Many optical network researchers have built optically-transparent or all-optical networks [14], in which no optical to electronic conversions are performed between each source and destination. Wavelength converters used in these networks must be all-optical wavelength converters. However, many factors, such as optical non-linearity, chromatic dispersion, amplifier spontaneous emission, attenuate the power of signal, so that degrade the S/N ratio to maximum –20 dB [15].

Besides, because separated optical space switches are used for each wavelength, if there are M input and M output fibers, with W wavelengths on each fiber, then W separate M x M space switches are required to implement a cross-connect without wavelength converters. In contrast, a single MW x MW space switch is required to implement the cross-connect with wavelength converters. For reasons of this, if full wavelength converters are placed in every optical cross-connects, the implementation of optical cross-connects becomes complex and also the hardware cost increase highly.

As previously stated, to place full wavelength conversion in every nodes limit not only the use of wavelength converters but also scalability of networks.

In this paper, we apply limited wavelength conversion to QPR algorithm proposed in chapter 2 and the procedures are as follows. First, the limited range wavelength converters in each node are used and wavelength conversion is performed after switching, as presented in equation (4). Equation (4) means that output wavelengths are limited within k area based on input wavelength.

$$\lambda_i \rightarrow \lambda_{\max(i-k,1)} \le \lambda_o \le \lambda_{\min(i+k,w)} \qquad (4)$$

Second, the limited rage wavelength converters are sparsely placed in selected nodes. Nodes placed wavelength converter are selected by total outgoing traffic algorithm [16]. And because the selected nodes has high nodal degree, potentially, the probability to cause the congestion situation is high.

Figure 10 shows the traffic at intermediate nodes and equation (5)-(7) present dropt traffic ($\rho_l(v)$), added traffic ($\rho_n(v)$) and transit traffic ($\rho_c(v)$), respectively. The nodes placed wavelength converter have high traffic cost ($\tau(v)$).

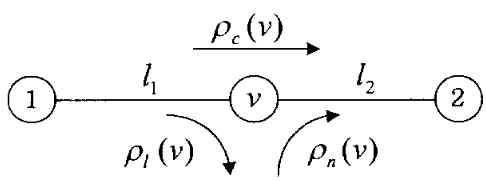

Figure 10, the traffic at intermediate nodes

$$\rho_l(v) = \sum_{\{j:l_1 \in r_j,\, j:l_2 \notin r_j\}} \lambda_j \qquad (5)$$

$$\rho_n(v) = \sum_{\{j:l_1 \notin r_j,\, j:l_2 \in r_j\}} \lambda_j \qquad (6)$$

$$\rho_c(v) = \sum_{\{j:l_1 \in r_j, j:l_2 \in r_j\}} \lambda_j \qquad (7)$$

$$\tau(v) = \rho_n(v) + \rho_c(v) \qquad (8)$$

If wavelength converters are placed at nodes of the 14-node NSFnet by first and second procedure, node 3, node 5, node 6, node 8, node 9 and node 10 with high traffic cost will be selected (figure 11).

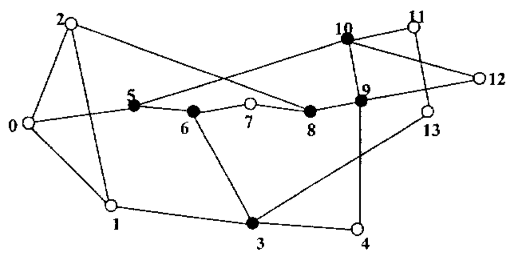

Figure 11. Wavelength convertible 14-node NSFnet

Theoretically, the blocking probabilities improve significantly with just 20% ~ 40% wavelength range conversion and the performance is very close to full range wavelength conversion [15], and when wavelength converters are placed at a few nodes (about 40%), it's performance is similar that of full-converters [15, 17, 18].

To prove the results in case of applying the limited wavelength conversion to QPR algorithm, simulations are carried out in chapter 5. We adopt 30% range converter and place 40% nodes of entire nodes.

4.3 Differentiated QoS RWA algorithm

On the basis of the differentiated QoS class, we propose multi-constraint QoS RWA considering the limited wavelength conversion. The procedure of QoS RWA is similar to that of QPR algorithm described in chapter 2. To provide the differentiated recovery scheme, in the proposed QoS RWA algorithm, according to QoS services class, adopt 1:1 protection, N:1 protection and restoration for premium service, assured service and best effort service, respectively.

The QPR algorithm applied to the proposed QoS RWA is based on flooding method and search all possible routes concurrently, i.e., passing the connection request message to all possible routes on nodes, reserving resources and performing QoS checks on all of them, and finally selecting the route among the many possibilities through the first connection request arriving the destination node.

Together with QPR algorithm of routing algorithm, we adopt first-fit [ ] as the wavelength assignment algorithm, which has low computation cost and also simple implementation. In this scheme, all wavelengths are indexed. When searching for available wavelengths, a lower-numbered wavelength is considered before a higher-numbered wavelength. The first wavelength is then selected. This scheme requires no global information, so that has not only low cost but also good efficiency.

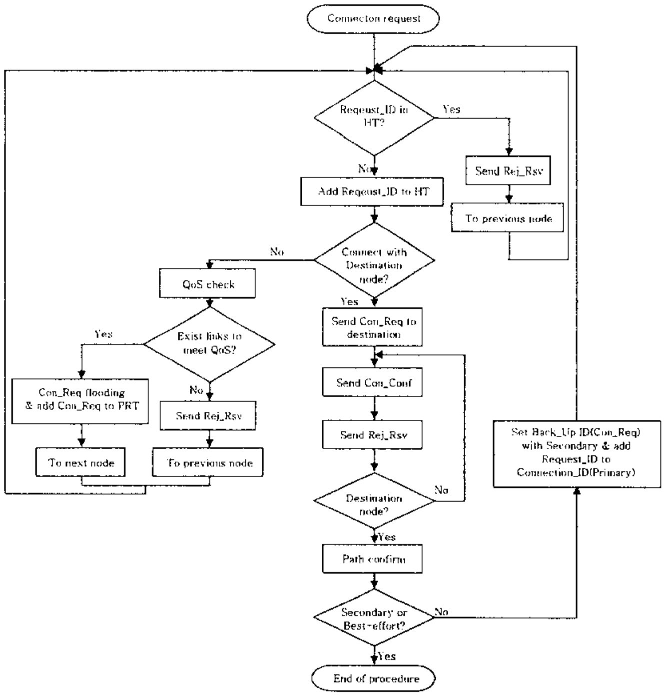

Figure 12. Procedure of QoS RWA

In the procedure, for premium and assured services, primary path and secondary path is established, while for best effort service, after fault occur, secondary path is established.

Figure 12 illustrates the entire procedure of QoS RWA. In the procedure, we assume that the connection requests arrive sequentially. The concrete procedures are as follows.

Input: a connection request from source node to destination node.

Output: a qualified path to meet multi-constraint between source node and destination node.

Procedure the connection establish

Step 0: When Con_Req message arrives a source node, the node floods to the connected next node. And continue.

Step 1: Node received the message checks whether the request_ID exists in their HT. if yes, go to step 13, and else continue.

Step 2: Add the entry to HT, and then continue.

Step 3: Check whether this node connected with a destination node, if no, go to step 10, and else continue.

Step 4: Send Con_Req message to a destination node, and continue.

Step 5: Send Con_Conf to upstream node and continues.

Step 6: The node received the Con_Conf message from a destination node sends back the Rej_Rsv to all nodes, which don't belong to confirmed path. And continue.

Step 7: Check whether the node received the Con_Conf is a source node, if yes, continue, and else go to step 5.

Step 8: Check whether the confirmed path is secondary path or best effort service, if yes, finish the procedure, and else continue.

Step 9: Set Back_ID of Con_Req with secondary value, and add Request_ID to Connectin_ID of the confirmed primary path. Go to step 1.

Step 10: Perform QoS admission check to know whether exist links to meet QoS, if yes, continue, and else go to step 15.

Step 11: Flood Con_Req to nodes to meet requirement and add entry to PRT for reserving the resources. And continue.

Step 12: Move to the next node. Go to step 1.

Step 13: Send back Rej_Rsv message to the upstream node, continue

Step 14: Move to the previous node, and go to step 1.

Step 15: Send back Rej_Rsv message to input node, and continue.

Step 16: Move to the another node connected with input node, and go to step 1.

To prove the efficiency of the proposed algorithm, in chapter 5, we study performance of it, in terms of blocking probability, survivability ratio, routing overhead, and effect of the limited wavelength conversion. Also, we compare it's results with existing other algorithm.

5. Simulation Results

5.1. Network Model

In this section, we study performance of the proposed QoS RWA algorithm. To prove the efficiency of QPR algorithm proposed in chapter 2, we analyze the routing overhead performance of QPR algorithm, and compare with that of the existing pure flooding algorithm by simulation. Also, to perform an efficiency test for QoS RWA described in chapter 4, the same conditions with the test for QPR are applied. Also, we examine the survivability ratio for each differentiated QoS service classes.

Topology used in simulations is NSFnet currently used for WDM network model in USA and adopted in most of papers relation to WDM networks.

The assumptions are as follows: (i) The physical topology consists of 14 nodes and 19 links as shown in figure 11. (ii) The number of fibers per a link is one, and the number of wavelengths per a fiber is four or eight. (iii) The topology is static and is not reconfigured during the simulation. (iv) A set of node pairs which can originate the lightpath connection setup is arbitrarily selected from the set of total node pairs and we choose 5 pairs for our simulations. (v) Connection requests arrive in sequence. (vi) Blocking probability is the ratio of the number of working or backup lightpath requests rejected to the number of lightpath connections requested. If a connection request for the working path is blocked, the procedure for backup path setup is not done. (vii) The time which the confirmed paths are released increases exponentially.

5.2. Analyses of Results

First, we compare the routing overhead of the proposed QPR to that of the existing pure flooding algorithms. The result is illustrated in Figure 13.

Figure 13 shows the corresponding results for average routing overhead per successful connection. Since the request messages occupy a wavelength, we compare the overhead measured in the number of flows. As the load increase, the overhead decreases, because of the QoS admission check which reduces the unnecessary flooding to regions where resources are inadequate to support the connection requests. The results show that the QPR algorithm improves by 17% ~ 28% comparing to the pure flooding.

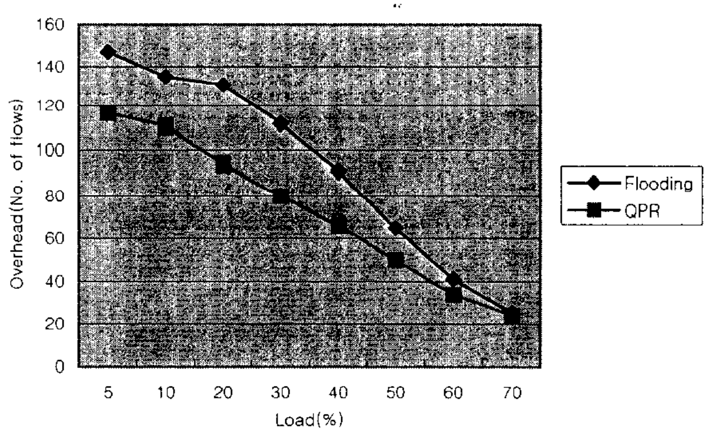

Figure 13. Comparison of the pure flooding and the QPR algorithm

As stated in chapter 4, the restriction imposed by the wavelength continuity constraint can be removed by the use of wavelength converter. Theoretically, with just 20% ~ 40% wavelength range conversion, the blocking performance is very close to full range wavelength conversion. Also, when wavelength converters are placed at a few nodes (about 40%), it's performance is similar that of full-converters.

To prove the results in case of applying the limited wavelength conversion to QPR algorithm, simulations are carried out. In this paper, we adopt 30% range converter and place 40% nodes of entire nodes.

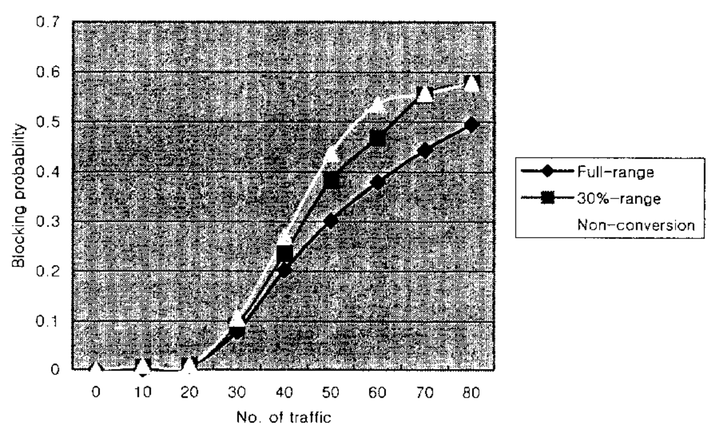

Figure 14. Comparison of non-conversion, 30%-range and full-range

As figure 14 shows, placing the 30% range converters at every node has 80% blocking performance comparing to that of full range conversion. As we explained earlier, this is the reasonable value that is closed to the theoretical value.

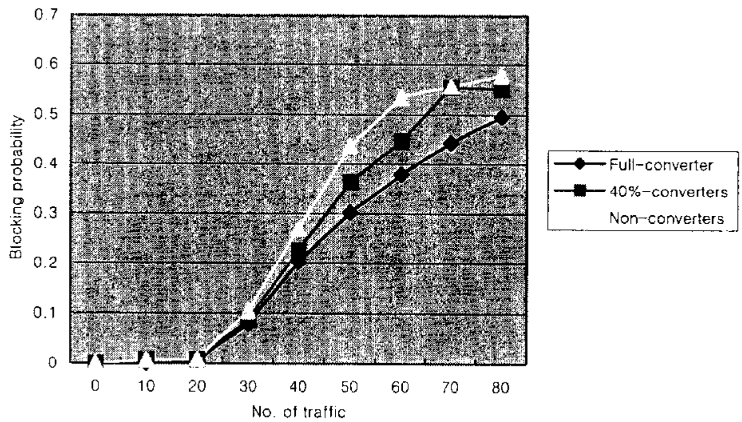

Figure 15. Comparison of non-converter, 40%-converters and full-converters

Figure 15 plots the blocking probability of non-converter, 40%-converters and full-converters with full range conversion. As shown in results, the proposed QPR with 40%-converters has 80% ~ 90% blocking performance of that with full-converters.

Another significant observation in QoS routing is a survivability ratio. For its measurement, we have generated a single fault on arbitrary link in network.

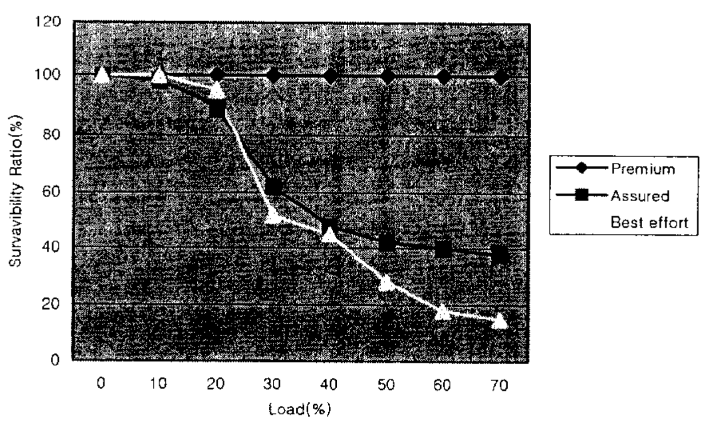

Figure 16. Survivability Ratio

Figure 16 shows the survivability ratios for each service class. As we described in chapter 4, 1:1 protection for premium service is applied. On this account, survivability can be guaranteed 100% from not only single-link failures. Assured service with 1:3 shared protection has lower survivability ratio than premium service, but it is possible to utilize the capacity more efficiently, while still achieving over minimum 30% for single-link failures. Moreover, protection mechanisms for both services can guarantee absolute survivability under any circumstances. However, dynamic path restoration for best-effort can guarantees only relative survivability, according to residual bandwidth. This phenomenon occurs due to discovering backup path after the primary lightpath fails, not to reserve backup bandwidth in advance.

6. Conclusions

In this paper, to solve the problem such as multi-constraint and computational complexity, we propose a multi-constraint QoS Routing, based on flooding method, which is called Qualified Path Routing (QPR) with minimum computation and implementation complexity. Also, we introduced the differentiated QoS class with recovery scheme. On the basis of this QoS class, we propose multi-constraint QoS RWA with the limited range wavelength conversion and the sparse placement of wavelength converters.

Through the performance test, we prove the efficiency of the proposed QoS RWA, in terms of blocking probability, survivability ratio, routing overhead, and effect of the limited wavelength conversion. Also, we compared it's results with existing other algorithm. Therefore, it is possible that the proposed QoS RWA algorithm is applied to Generalized Multi Protocol Label Switching (GMPLS) used for control protocol in DWDM backbone network.

As a future research, we will study about the additive quality attributes that can be considered during the real path establishment and various applications of the QPR algorithm based on this quality attributes.

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차세대 광인터넷 백본망에서 다중 제약 조건을 고려한

QoS RWA 알고리즘 연구

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국 문 요 약

차세대 인터넷 백본망에서 DWDM 기술이 기존의 TDM 기반 인터넷이 가진 회선 부족 문제를 해결하기 위한 대안으로 등장하였고, 이러한 DWDM 망에서는 자원의 효율적인 사용과 각기 다른 사용자 요구 사항을 충족하기 위해 연결 설정 시 다중 제약 조건에 대한 고려가 필수적이다. 즉, 망 자원 및 망 구성장비와 관련된 광신호 품질과 망 장애 발생시 트래픽의 보호와 관련된 생존성 등 다양한 광 QoS 파라미터들이 복합적으로 고려되어야 하며, 이러한 다양한 광 QoS 파라미터를 기반으로 하는 동적 QoS RWA 알고리즘 연구가 DWDM 기반의 차세대 인터넷에서 필수적으로 수행되어야 한다. 본 논문에서는 QoS RWA알고리즘 연구를 수행하기 위한 방안으로 flooding 기법을 기반으로 경로설정에 대한 계산 및 구현을 간소화 시킨 QPR(Qualified Path Routing) 알고리즘을 제안하고 차등화된 QoS 클래스를 제시한다. 이를 토대로 광신호 품질, 생존성 및 제한된 파장 할당 등의 복합적인 요소들을 동시에 고려하여 광 네트워크에서 다중 제약 조건을 만족하는 QoS RWA 알고리즘을 제안한다. 제안된 알고리즘의 성능 평가를 위해 블록률, 생존성 비율, 라우팅 오버헤드, 파장 변환의 효율성 등의 성능 비교 파라미터를 사용하여 효율성 검증을 수행하였다.

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