Priority를 제공하는 파장 할당 시그널링 프로토콜의 성능 분석

준회원 김 민 식*, 정회원 정 재 일**

Performance Analysis of Wavelength Assignment Signaling Protocol with Priority

Min-Sik Kim* *Associate Member*, Jae-Il Jung** *Regular Member*

요 약

WDM(Wavelength Division Multiplexing)과 광 Cross-Connect의 개발은 예상되어지는 사용자의 요구를 지원할 수 있다. 광 네트워크는 무한한 잠재성을 갖고 있으며 낮은 bit error rate와 IP에 투명성을 보장한다. 그러나 파장의 수는 많은 node들을 지원하기에 충분하지 못한 경우가 발생한다. 파장 경쟁에 의한 blocking은 파장 변환 기술에 의해 어느 정도 해결 가능하지만 모든 상황을 해결하기 위한 완벽한 solution이 될 수 없다. 이와 같은 이유로 많은 그룹들은 고유한 파장 할당 알고리즘과 프로토콜을 제안해왔다. 대부분의 기술들은 priority 개념을 지원하지 못한다. 이 논문에서는 throughput을 기반으로 한 priority 개념을 묘사한다. 우리는 제안한 priority 개념을 SWAP(Simple Wavelength Assignment Protocol)에 적용하여 성능을 보인다. 제안한 Priority 개념은 WDM 네트워크에서의 파장 경쟁에 의한 blocking 문제를 해결할 수 있는 좋은 방법이 된다.

키워드: 광 네트워크, 시그널링, 파장 할당

ABSTRACT

All-optical networks provide unlimited potential for bandwidth, the very low bit error rate, and the transparency to IP. Optical networks promise to be the next generation networks that can meet the higher bandwidth demands. However, the number of wavelengths is often not large enough to help a large amount of nodes. The blocking by wavelength contention can be reduced by wavelength conversion, which can't perfectly resolve all situations. Because of that, a lot of groups have proposed unique wavelength assignment algorithms and protocols. Most schemes don't support the priority concepts. This paper describes the unique priority scheme based on the throughput. In this paper, we apply our priority scheme to SWAP (Simple Wavelength Assignment Protocol) and show the performance of the proposed priority scheme. Our proposed priority scheme can be a better solution to solve an important problem about the blocking by wavelength contention into WDM optical networks.

I. Introduction

Recently, telecommunications has been recently going through a large-scale transformation. Trials presented by the increasing need for inter-communication have resulted in great demands for broadband services for the Internet. Optical networks promise to be the next generation networks that can meet the higher bandwidth demands[1].

To provide integrated service with the high bandwidth in optical networks, one of the most

* 한양대학교 전자통신전파공학과 (kms76@mulab.hanyang.ac.kr)
논문번호 : 030020-0113, 접수일자 : 2003년 1월 13일

important research areas is the study of techniques that can efficiently distribute the high bandwidth among lots of network applications. Although different types of optical switching networks have been reported and demonstrated, basing optical networks on WDM techniques and OXC(Optical Cross-connect) systems is clearly the best way to support the intense demand anticipated. With the recent developments in WDM technology, WDM networks make very effective utilization of fiber bandwidth and offer flexible interconnections based on wavelength routing[2].

However, recent WDM technology is limited to a few wavelengths per link. In dynamic WDM networks, the number of wavelengths is often not large enough to support a large number of nodes. The blocking by wavelength contention can be reduced by wavelength conversion, which can't perfectly resolve all situations[3].

This blocking due to a scarce wavelength resource stimulates to develop the new optimal methods. Lots of groups have proposed unique wavelength assignment algorithms and protocols. They have considered centralized control versus distributed control and with or without the capability of wavelength conversion. But most existing wavelength assignment algorithms and protocols don't support the priority concepts. Lack of priorities in the recent wavelength assignment algorithms and protocols can seriously limit the viability of WDM as the next generation networks.

In this paper, we propose a new concept for wavelength assignment priority based on the throughput. Among a large amount wavelength assignment algorithms and protocols, in this study, we apply our priority scheme to SWAP(Simple Wavelength Assignment Protocol) with the capability of wavelength conversion under distributed control. SWAP is a signaling protocol created to dynamically configure the lightpath for flows in a WDM optical network coupling IP routers with wavelength-selective optical cross-connects. After that, we try to show the effect of our priority scheme based on throughput by using the result of simulation that is performed on the NS simulator[4].

The rest of the paper is organized as follows. Section 2 presents Background Information to study wavelength assignment protocols. Section 3 explains WASPP(Wavelength Assignment Signaling Protocol with Priority) that is the enhanced SWAP. The modeling and the result of the simulation are showed in Section 4. The last section concludes the paper.

II. Background Information

2.1 Optical Network

The rapid demand of user applications has outstripped the gains possible via the traditional approach. This has increased interest in building all-optical networks because of the tremendous bandwidth and the very low received bit error rate.

IP processing relies on longest-prefix match in a large routing, followed by updates of portions of the IP header, such as hop-count and checksum. However, as optical wavelength routing is transparent to IP, packets can bypass traditional forwarding and are routed directly through the optical cross-connects. Because of that, a very high throughput and low delay time can be achieved. Most importantly, WDM appears to be the best mechanism for information transport in metropolitan and wide-area core networks[4][5].

Clearly, in a network with N nodes, the ideal situation would be to have the capability of setting up lightpaths between all N*(N-1) node pairs at the same time. But this is usually not possible because of the wavelength constraint. An immediate solution of that problem is to use wavelength converters at some intermediate nodes. Even if the converters add to the cost of the network, this seems to be a mandatory alternative to control the problem[6].

2.2 POW(Packet over Wavelengths) Switch Architecture

The instance of IP-WDM switching approaches is called POW(Packet over Wavelengths). The POW switch architecture consists of four major components like Figure 1.

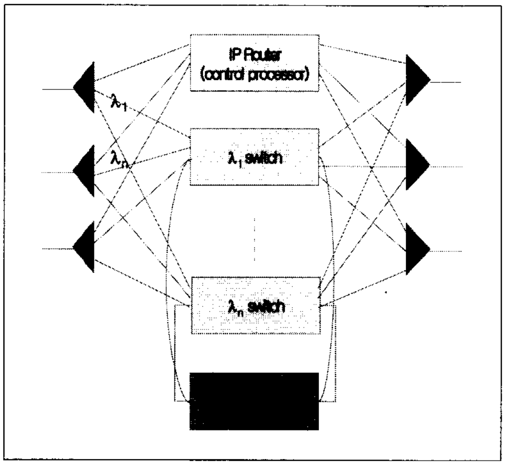

Figure 1. POW Switch Architecture

- Control Processor

An IP router is equipped with gigabit data interface(s) and a control interface. Depending on the scalability and complexity trade-off, multiple data interfaces of the control processor could be implemented as a single electronic interface, where the optical path is terminated early but the optical interface ID must be stored in the form of internal headers.

- Optical Fabric

An interconnection network of optical switching elements. The elements are capable of switching optical signals from one input port to one of a set of output ports, where the output port is selected based on the wavelength of the signal at the input port.

- Wavelength Converters

These devices convert signals with input -wavelength to signals with output-wavelength.

- Wavelength MUX/DMUX

Redirect a specific wavelength to a particular fabric, and merge the output of the fabrics to the external fibers.

These are special cases of statically configured optical switching elements. Although the details of the components are beyond the scope of this paper, the arrangement of the components follows the share-with-local wavelength-convertible switch architecture to reduce the number of wavelength converters per node[4].

2.3 Centralized Control versus Distributed Control

- Centralized Control

Each request is processed by a central controller, which chooses a path and assigns an appropriate wavelength on each link along the path to establish the connection. In large networks, centralized control is not feasible[7].

- Distributed Control

Each node maintains global information on the network topology and on the current state of the network, including information pertaining to which wavelengths are being used on each link. As basing its decision on this global information, the node can calculate an optimal lightpath to a destination[7].

This has many obvious advantages over conventional centralized control. Distributed control improves not only scalability but also reliability and reduces the implementation cost of a network, but also presents major challenges in managing and allocating wavelengths effectively[3].

2.4 SWAP(Simple Wavelength Assignment Protocol)

SWAP is a signaling protocol created to dynamically configure the lightpath for flows in a WDM optical network coupling IP routers with wavelength-selective optical cross-connects. SWAP components establish per-neighbor TCP connections, over which the signals are sent. Neighbor connections enable the switch to determine whether it is the first, the last, or the intermediate hop for a particular flow, which is used to simplify the signaling, failure detection, and recovery. Neighbor relationships are maintained per link of the switches.

SWAP picks a common free wavelength along the flow path, therefore SWAP must collect the list of free wavelengths for each flow. If there is one free wavelength common to all the hops, it will be picked. If not, SWAP may choose to construct a non-continuous lightpath. The operation of SWAP is illustrated in Figure 2.

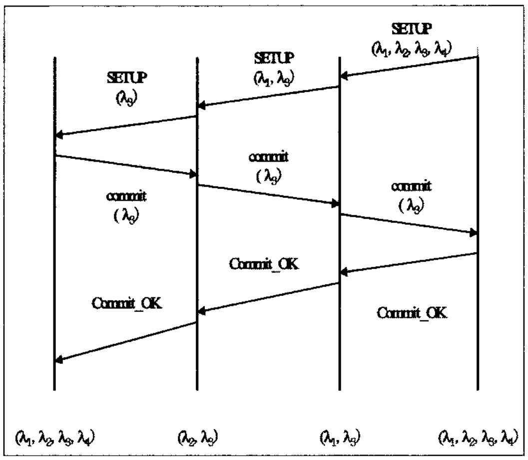

Figure 2. The Operation of SWAP

The operation of SWAP is described as follows.

ⓐ The last hop propagates its free wavelength set through a SETUP message when it detects an active flow. When the previous hop receives that set, it intersects that set with its own free wavelength set and forwards the result to the previous hop.

ⓑ Assuming the final set is not empty, the first hop picks one free wavelength from the resulting set and sends a COMMIT message back to the last node. The COMMIT message tells the next node the decision of a wavelength.

ⓒ Once the initiating node gets the COMMIT message, it will send a COMMIT_OK message to the first node. The COMMIT_OK message informs the previous node that the optical switch has been setup. This message will not be forwarded further if there are no branches waiting for it. If the first node acquires the COMMIT_OK message, it will know that the connection has been established and the transmission of data through the optical cross-connects can start.

III. WASPP

In this section, we describe a unique concept for wavelength assignment priority based on the throughput. Our proposed priority scheme allows wavelength assignment protocols to use priority control. In the optical network that employs our priority scheme in its control protocol, each flow is assigned a priority level according to its throughput.

3.1 The Definition of Messages and Parameters related to WASPP

There are 7 messages related to wavelength assignment in a WDM optical network coupling IP routers with wavelength-selective optical cross-connects.

ⓐ SETUP message

Ask the previous hop to pick a wavelength to setup the connection by sending the free wavelength set (also lock it). The receivers intersect this set with their own free wavelength set, and forward the result to the subsequent hop.

ⓑ SETUP_CONFLICT message

Inform the next hop that one of the wavelength sets along the path has been locked by others. Intermediate hops will pass this message to the next hop. The initiating hop will perform a back-off procedure.

ⓒ CHANGE message

Inform the previous hop that the previous hop has to change a forwarding method from the wavelength switching to the IP routing for the flow with the lowest throughput among flows that are using wavelengths.

ⓓ SETUP_FAIL message

Inform the next hop that the connection cannot be made if free wavelength set is empty in case of a request with the lowest throughput. Intermediate hops will pass this message to the next hop if they are not the initiating hop.

ⓔ COMMIT message

Tell the next hop the decision of a wavelength. Intermediate hops will pass this message to the next hop if they are not the initiating hop.

ⓕ COMMIT_OK message

Inform the previous hop that the optical switch has been setup. Intermediate hops will pass this message to the previous hop. This message will not be forwarded further if there are no branches waiting for it.

ⓖ TEARDOWN message

Inform the next hop to tear down the connection. Intermediate hops will pass this message to the next hop.

In addition to the message types above, WASPP uses an X/Y classifier to detect a flow with the following default parameters:

- FlowDetectionTimer = 20 secs
- FlowActiveTimer = 20 secs
- HighThreshold = 10 packets
- LowThreshold = 5 packets
- BackoffPeriod(Retransmit Time) = 1 ms
- BackoffLimit = 10 retries
- WavelengthConvertEnable = true

A switchable flow is a flow with PacketCount higher than HighThreshold. Non-continuous lightpaths can be constructed if the WASPP parameter of WavelengthConvertEnable is true. If after BackoffLimit tries, it will be given up to construct a lightpath. If the throughput of a switched flow drops below LowThreshold for a specific detection duration(FlowActiveTimer), the flow is monitored for another FlowActiveTimer. If after the second monitoring, the throughput remains below LowThreshold, the TEARDOWN message is sent to the previous node.

3.2 The Operation of WASPP

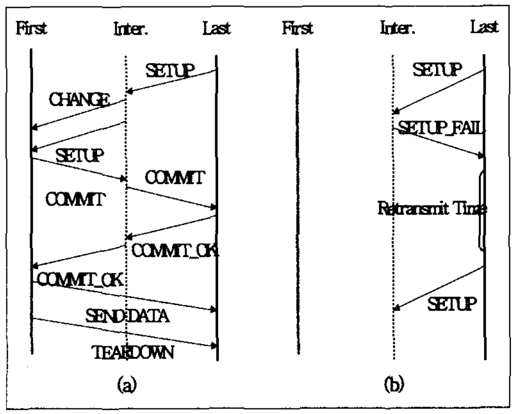

Figure 3. The Operation of WASPP in the case where there aren't any wavelengths available

To verify the practical value of our priority scheme, we put our priority scheme in SWAP with capability of wavelength conversion under distributed control for simulation. WASPP (Wavelength Assignment Signaling Protocol with Priority) is the enhanced SWAP.

SWAP acts the signaling protocol in a POW(Packet over Wavelength) network that couples IP routers with wavelength-selective optical cross-connects. If the throughput of the flow is over a threshold, switches will try to make the flow routed directly through the optical cross-connects. If not, the flow will be routed through the IP router. If there are lots of flows with the throughput that is over the threshold, it's not possible to assign wavelengths to all the flows - besides, in SWAP, if there are no wavelengths available, it's processed as a failure[4].

In WASPP that we propose, if there are no wavelengths available, the wavelength will be used for the flow that has the higher throughput. The flow that has the lower throughput will be transmitted through the IP router. The operation of WASPP is described as follows.

① When the last node(the initiating node) wants to establish a connection of a lightpath, it sends a SETUP message to the first node.

② At the last node, all available wavelengths are considered as candidates, and are reserved.

③ When an intermediate node receives the SETUP message, it will do the wavelength intersection, reserve candidates, and send the SETUP message to the previous node. This set of candidates is carried by the SETUP message.

④ If there aren't any wavelengths available, the node will check the lowest throughput among the throughputs of flows that are using wavelengths. After comparing the throughput of the new flow with the lowest throughput among the throughputs of flows that are using wavelengths, WASPP will decide which flow should use the wavelength. If the throughput of the new flow is bigger than the lowest throughput among the throughputs of flows that are using wavelengths, the CHANGE message is sent to the previous hop. The CHANGE message informs the previous hop that the previous hop has to change a forwarding method from the wavelength switching to the IP routing for the flow with the lowest throughput among flows that are using wavelengths. The flow that has the lower throughput will be transmitted through the IP router. The wavelength will be used for the flow that has the higher throughput. Figure 3-(a) indicates the operation of WASPP in case there aren't any wavelengths available even though the throughput of the new flow is bigger than the lowest throughput among the throughputs of flows that are using wavelengths.

⑤ In case of a request with the lowest throughput, if candidates are empty, A SETUP_FAIL will be sent back to the last hop and the request will be dropped. Figure 3-(b) describes this situation.

⑥ The SETUP_FAIL message releases all the wavelengths reserved by a corresponding SETUP message and informs the failure to the last node. The last node will send another request later in an attempt to re-establish the connection.

⑦ If the SETUP message arrives at the first node with a non-empty set of candidate wavelengths, the first node will select one wavelength to use for the connection and send a COMMIT message back to the last node. The COMMIT message tells the next node the decision of a wavelength. Intermediate nodes will release all the wavelengths reserved by the SETUP message except the wavelength chosen by the first node and pass this message to the next node if that is not the initiating node.

⑧ Once the initiating node gets the COMMIT message, it will send a COMMIT_OK message to the first node. The COMMIT_OK message informs the previous node that the optical switch has been setup. Intermediate nodes will pass this message to the previous node. This message will not be forwarded further if there are no branches waiting for it.

⑨ If the first node acquires the COMMIT_OK message, it will know that the connection has been established and the transmission of data through the optical cross-connects can start.

⑩ After transferring all the data, the first node will send a TEARDOWN message to the next node to tear down the connection. Intermediate nodes will pass this message to the next node.

Ⅳ. Simulation

To evaluate the practical value of the proposed priority scheme based on the throughput, we simulated WASPP(the enhanced SWAP) with a simulation tool that is adapted from the well-known simulation package NS(the Network Simulator).

4.1 Modeling for Simulation

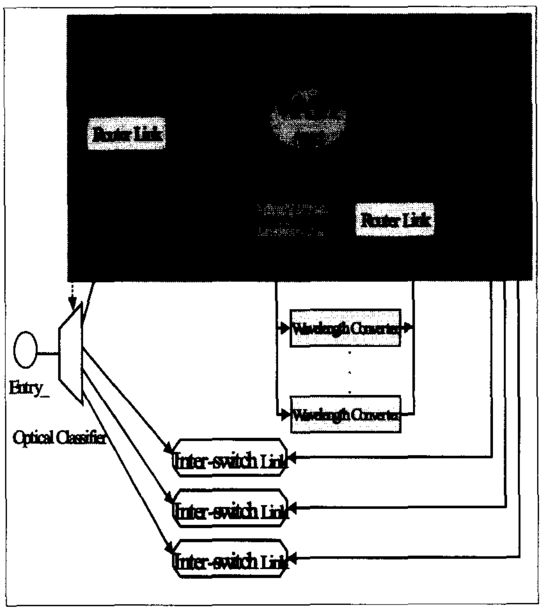

Figure 4. The NS Model of the POW switch for WASPP

WASPP is designed to enable the evaluation of the performance of the proposed priority scheme based on the throughput. The NS modeling of the POW(Packet Over Wavelengths) switch for the simulation of WASPP is the same as that for the simulation of SWAP except the WASPP component. The WASPP component models signaling based on the suggested priority scheme between the POW switches[4].

Essential NS components of the POW switch simulation model for WASPP are shown in Figure 4.

Essential NS components of the POW switch for WASPP:

ⓐ Optical Classifier

Model the optical switching fabric. For the simulation, each wavelength is represented as an integer value in our specific.

ⓑ Router Links

Model the bi-directional electrical data interfaces between the IP router and the fabric. The interface operates at OC-12 rates.

ⓒ Inter-switch Links

Model the high speed optical links between POW switches. This interface operates at OC-48 rates.

ⓓ Wavelength Converters

Simulate wavelength converters in the POW switches. For the simulation, a wavelength converter reassigns the integer value in the header representing the wavelength.

ⓔ Address Classifiers

Model IP router forwarders. The classifier determines which output link a packet should be directed to. Locally-destined packets are delivered to the local application.

ⓕ Flow analyzer

An X/Y classifier, where X is HighThreshold (10 pkts) and Y is FlowDetectionTimer (20 secs). The analyzer may perform flow classification based on several tuples.

ⓖ WASPP agent

Model signaling between the POW switches.

POW switches for the simulation of WASPP are interconnected using NS Tcl script that encodes the backbone topology like Figure 5. LBL-PKT5 is chosen as the traffic model[4][8].

The Flows are classified by the following criteria:

CASE A:
{Ingress Node, Source IP, Source TCP Port} =>> {Egress Node, Destination IP, Destination TCP Port}

CASE B:
{Ingress Node, Source IP} =>> {Egress Node, Destination IP}

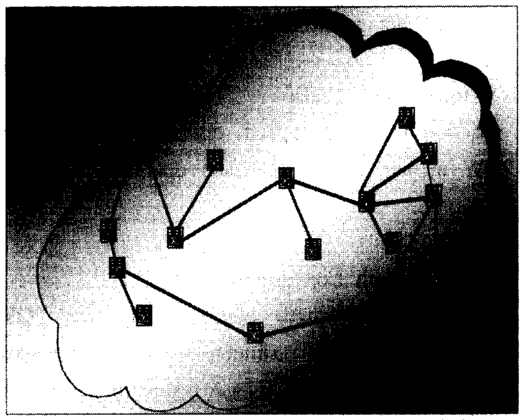

Figure 5. The Backbone Topology for Simulation

4.2 Performance

To verify the performance of WASPP, we show the overhead and percentage packets-switched. The performance of WASPP is evaluated in different numbers of available wavelengths per link: 4, 8, 16, 32, and 64.

In terms of the overhead, the ratio of messages is compared with the offered traffic. Figure 6 indicates a comparison of the overhead between WASPP and SWAP. The overhead is proportional to the number of switchable flows. There is no significant difference from a viewpoint of the overhead between WASPP and SWAP.

Figure 7 and Figure 8 indicate a comparison of percentage packets switched between WASPP and SWAP. From the results, we see WASPP enables more packets to be switched on wavelengths than SWAP although there are not enough wavelengths to construct the lightpaths. Especially, in CASE A, there are bigger differences of the performance than in CASE B.

Although there is small difference of the performance in using 64 wavelengths, if we consider the feature of WASPP, we can be sure that the performance of WASPP cannot be bad anyway.

Future networks are expected to support broadband services. They will be required to provide a guaranteed QoS(Quality of Service). Our proposed extension strengthens the viability of WDM networks as the next generation network.

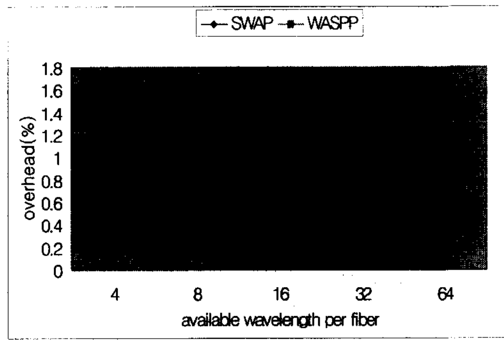

Figure 6. Comparison of the Overhead between WASPP and SWAP in CASE B

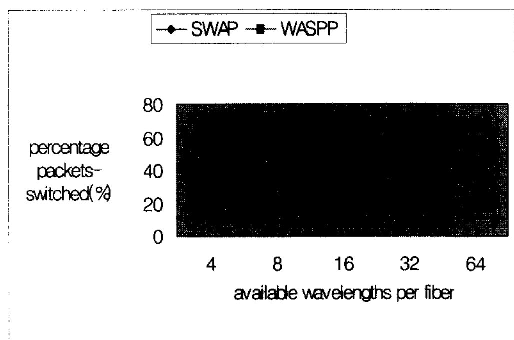

Figure 7. Comparison of Percentage Packets Switched between WASPP and SWAP in CASE A

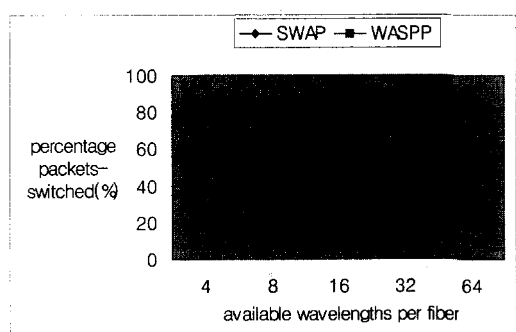

Figure 8. Comparison of Percentage Packets Switched between WASPP and SWAP in CASE B

V. Conclusion

WDM networks make very efficient utilization of the fiber bandwidth and offer flexible interconnections based on wavelength routing. However, when the circumstances of the future networks are considered, to improve the viability of WDM networks, the problem of blocking by wavelength contention is a big obstacle. As a result of that, the development of unique wavelength assignment algorithms and protocols has been required.

In this paper, we described a new concept for wavelength assignment priority based on the throughput. Our proposed priority scheme can be a better solution to solve an important problem about the blocking by wavelength contention into WDM optical networks. Optical networks promise to be the next generation networks that can meet the higher bandwidth demand. Our scheme enabled WDM optical networks to be better suited as the next generation networks.

Future study is required to measure the performance of our priority scheme in more extended experimental circumstances or different cases. The extension of the number of available wavelengths per link is required to make WDM networks be the best solution.

REFERENCES

[1] S. J. B. Yoo.: "Wavelength Conversion Technologies for WDM Network Applications," Journal of lightwave technology, vol. 14, No. 6, June 1996.

[2] Rami Melhem., Shu Li., Taieb Znati.: "Minimizing Wavelength Conversions in WDM Path Establishment," Photonic Network Communications, 3:3, 197-211, 2001.

[3] Wuxu Peng., Chunyan Wei.: "Distributed Wavelength Assignment Protocols with Priority for WDM All-Optical Networks,"IEEE Computer Communications and Networks, 2000, proceedings, Ninth international conference.

[4] Stephen Suryaputra., Joseph D. Touch., Joseph Bannister.: "Simple Wavelength Assignment Protocol," USC/ISI TR-99-473.

[5] Hongsik Choi., Suresh Subramaniam., Hyeong-Ah Choi.: "Optimal Wavelength Assignment Algorithms for Permutation Traffic in Multi-Fiber WDM Ring Networks," Photonic Network Communications, 4:1, 37-46, 2002.

[6] Debashis Saha.: "Lightpath Versus Semi-Lightpath: Some Studies on Optimal Routing in WDM Optical Networks,"Photonic Network Communications, 2:2, 155-161, 2000.

[7] Jason P. Jue., Gaoxi Xiao.: "An Adaptive Routing Algorithm for Wavelength-Routed Optical Networks with a Distributed Control Scheme,"Computer Communications and Networks, 2000, proceedings, Ninth international conference.

[8] http://ita.ee.lbl.gov/html/contrib/LBL-PKT.html

김 민 식(Min-Sik Kim) 준회원

[redacted]

2000년 한양대 전기공학과 공학사
2003년 한양대 전자통신전파공학과 공학석사
2003년~현재 국가보안기술연구소

정 재 일(Jae-Il Jung) 정회원

[redacted]

1981년 한양대 전자공학과 공학사
1984년 한국과학기술원 전기 및 전자공학과 공학석사
1993년 프랑스 ENST 네트워크 공학과 공학박사
1984년~1997년 한국통신 통신망 연구소 선임 연구원
1993년 프랑스 국립 전기통신 연구소 연구원
1997년~현재 한양대 전자전기컴퓨터공학부 교수