논문 2006-43TC-8-1

DWDM 기반의 차세대 광인터넷에서 QoS 기반의 제한적 플러딩 RWA 알고리즘에 관한 연구

(QoS-Aware Bounded Flooding RWA Algorithm in the Next Generation Optical Internet based on DWDM Networks)

김 용 성*, 이 재 동*, 황 진 호**, 우 종 호**

(Yong-Seong Kim, Jae-Dong Lee, Jin-Ho Hwang, and Chong-Ho Woo)

요 약

실시간 멀티미디어 서비스들을 전송하는 DWDM(Dense-Wavelength Division Multiplexing) 기반의 차세대 인터넷에서는 DWDM 망의 다양한 QoS(Quality of Service) 파라미터들을 복합적으로 고려하는 QoS RWA(Routing and Wavelength Assignment) 방식으로의 접근이 요구되어진다. 본 논문은 flooding 방법을 기반으로 하고, 다중제약조건을 만족하는 새로운 QoS 라우팅 알고리즘인 Bounded Flooding Routing (BFR)을 제안한다. BFR 알고리즘의 주요목적은 network overhead, blocking probability그리고 wavelength utilization의 성능 분석 파라메터의 향상에 있다. 더욱이, 이러한 목적을 달성하기 위해 본 논문에서는 새로운 개념인 ripple count 개념을 제안하여, 링크 상태정보 및 계산량을 줄임으로써 라우팅의 성능을 높인다. 또한, 제안된 알고리즘의 광범위한 분석을 위해서, DWDM을 기반으로 하는 망에서 중요한 요소인 제한된 파장 변환기를 적용한다. 제안된 BFR 알고리즘의 성능분석 결과는 본 논문에서 제시하는 방법이 network overhead, blocking probability 그리고 wavelength utilization 측면의 성능 평가를 통해 제안된 알고리즘들의 효율성을 검증하였다.

Abstract

Multi-constraint QoS routing has been seen as crucial network property in the next generation optical Internet based on DWDM Networks. This paper proposes a new QoS routing algorithm based on flooding method, called bounded flooding routing (BFR) algorithm which can meet multi-constraint QoS requirements. Primarily, the BFR algorithm tries to reduce network overhead by accomplishing bounded-flooding to meet QoS requirements, and improve blocking probability and wavelength utilization. Also, as one effort to improve routing performance, we introduce a new concept, ripple count, which does not need any link-state information and computational process. For extensive analysis and simulation study, as a critical concern, in DWDM-based networks we deploy limited wavelength conversion capability within DWDM nodes. And the simulation results demonstrate that the BFR algorithm is superior to other predominant routing algorithms (both original flooding method and source-directed methods) in terms of blocking probability, wavelength channels required and overhead.

Keywords : Flooding, Ripple-count, QoS, RWA, DWDM

Ⅰ. Introduction

While coping with the rapid growth of IP and multimedia services, current Internet based on time division multiplexing (TDM) cannot supply sufficient transmission capacity for high bandwidth-needed services. However, the huge potential capacity of one single fiber, which is in Tb/s range, can be exploited by applying DWDM technology which transfers multiple data streams on multiple wavelengths

---

* 정회원, 경남정보대학
(Kyungnam College of Information & Technology)
** 정회원, 부경대학교
(Pukyong National University)

접수일자: 2005년11월28일, 수정완료일: 2006년8월18일

simultaneously. So, DWDM-based optical networks have been a favorable approach for the next generation optical backbone networks [1].

In DWDM backbone networks, the problem of setting up a lightpath is generally called routing and wavelength assignment (RWA) [2-3] and the RWA plays an important role in improving the global efficiency for resource utilization. Moreover, the current multimedia applications involve real time-intensive traffics with various QoS requirements (multi-constraint). So, one of the key issues is QoS RWA that is not only selecting a path and assigning a wavelength but also enabling resource reservation and admission control by considering multi-constraint QoS requirements. That is, data flows are consistent with service requirements of the traffic and service restrictions of the network.

Though the multi-constraint QoS RWA has been regarded as a vital mechanism to support real-time multimedia communications, 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 algorithm. The majority of previous works [3-5] in DWDM networks has viewed QoS routing as an extension of the current Internet routing paradigm where nodes exchange QoS states through in-band or out-of-band control channel. Basically, there are two common approaches to QoS routing: source-directed and flooding-based.

In the source-directed approach (also called link-state routing)[3-6], the source node selects a path based on each connection's traffic requirements and available resources in the network. In this scheme, periodic or triggered distribution of link-state information is deployed. However, because of its high operational overhead in distributing and maintaining link-state information, source-directed routing may not scale well. And possibly, this approach can yield inaccurate route computation when inaccurate link-state information is used for QoS routing. So, the source-directed approach is impractical and unattractive.

On the other hand, in flooding-based QoS routing approach, local nodes are not required to keep link-state information for the entire network[4,7-8]. The source node simply broadcasts each connection request message to its neighbors, which then relay the message to their neighbors, and so on, until the message reaches the destination. In order to limit the number of request messages, the algorithm does not flood through a link which is found unable to guarantee the connection's QoS. Although this approach incurs considerable operational overhead due to the large number of request messages, it still has its own merits as follows. First, there is no need for disseminating link-state information and calculating shortest paths, thus reducing operational overhead and implementation complexity. Second, nodes are not required to maintain the database of link-state information, thus saving space and time to store and process the information. Third, information kept for each local link is used to determine whether it can accommodate a new connection or not, the algorithm can always find a qualified route, if any, thereby outperforming link-state routing in terms of connection blocking probability ratio. This aspect will be more pronounced when the network is unstable or the network undergoes changes in its topology.

In this paper, we propose a flooding-based QoS routing algorithm called bounded flooding routing (BFR) algorithm which incurs much lower message overhead yet yields a good connection establishment success rate (blocking probability), as compared to the existing flooding-based algorithms and also source-directed methods. In order to reduce the flooding overhead, we introduce the new ripple-count concept which can classify incoming messages into three types and determine whether the message is necessary or not through simple comparison without state information and operational process. And also, with the BFR algorithm, we adopt first-fit [2] as a wavelength assignment algorithm, which requires no global information and has low computational cost.

The rest of the paper is organized as follows: Section Ⅱ presents DWDM backbone network model and RWA research and section Ⅲ describes ripple-count concept and BFR algorithm including analysis of QoS requirements and QoS checking mechanism. Moreover, as an important factor in DWDM networks, we consider limited wavelength conversion capability in nodes for extensive views in simulation. Thereafter, using extensive simulations, the proposed and other existing algorithms are comparatively evaluated in section Ⅳ. Finally, some concluding remarks are made in section Ⅴ.

Ⅱ. RWA Research in DWDM Backbone Network

Architecture of DWDM backbone network is shown in Fig. 1, in which IP traffics are injected into DWDM ingress nodes for various conventional electric domain based-networks, such as LANs, MANs and ATMs. In this architecture, ingress nodes perform traffic aggregation and route optical data to egress nodes. And optical data is transported from source nodes to destination nodes through a lightpath established between ingress and egress nodes. At the egress node, the traffic is disaggregated and delivered to the destination network. Core DWDM nodes are interconnected with each other and perform forwarding of the optical data in the all-optical signal domain.

In such DWDM backbone networks, most previous algorithms for the RWA problem have been decoupled into two separate sub-problems, i.e., the routing sub-problem and the wavelength assignment sub-problem because of hardly finding an optimal solution by solving the RWA problem, known as being NP-complete, at the same time [6]. And generally, the routing scheme has much higher impact on the performance of the connection blocking probability than the wavelength assignment scheme [8-10]. Especially, routing under consideration of the network QoS is more and more important to improve wavelength utilization [11-12].

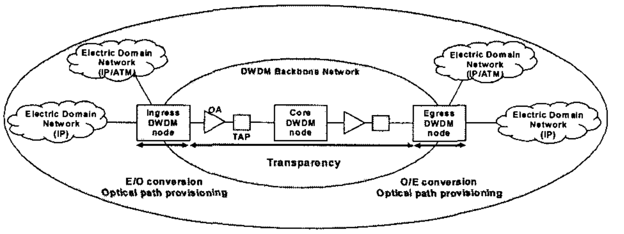


그림 1. DWDM 백본 네트워크 모델
Fig. 1. DWDM Backbone Network Model.

Most of routing schemes are based on dynamic routing (one of source-directed methods) approach because a route is dynamically chosen by considering the network's status (link-state information) at the time of connection request. In this scheme, the information on the available resource on each link must be distributed throughout the network, so that any source can have access to the correct information on the resources available in the network. By applying either Dijkstra's shortest path algorithm or Bellman-Ford shortest path algorithm based on link-state information, one can find a qualified route for each requested connection. However, because of its high operational overhead in distributing and maintaining link-state information, dynamic routing may not scale well. As one of efforts, to improve the scalability in large networks, a hierarchical approach [1] can be adopted to distribute and manage link-state information. But, this approach can yield inaccurate route computation when inaccurate link-state information is used for routing. In addition to use of a hierarchical approach, efforts have been made to reduce link-state messages in order to control the overhead. Periodic or triggered distribution of link-state information is a typical example of this effort. Although less frequent dissemination of link-state information reduces the overhead, inaccurate information may cause undue routing and signaling failures as in the hierarchical approach. A routing failure is said to occur if the source cannot find a route based on link-state information kept in its own database even if a qualified route exists.

On the other hand, for the wavelength assignment sub-problem, it is the goal to efficiently assign a wavelength to each lightpath without sharing the same wavelength with other lightpaths on a given link. It has been respectively studied in terms of static and dynamic traffic. Graph-coloring algorithms [6] were employed to assign wavelengths for static traffic where the set of connections are known in advance. And under dynamic traffic where connection requests arrive randomly, a number of heuristics have been proposed: Random Wavelength Assignment (R), First-Fit (FF), Least-Used/Spread (LU), Most-Used/Pack (MU), Min-Product (MP), Least-Loaded (LL), MAX-SUM (M), Relative Capacity Loss (RCL), Wavelength Reservation (Rsv), and Protection Threshold (Thr) [5-6]. Currently, RCL offers the best performance, however this scheme requires global information and complex computation. On the other side, FF choosing the first available wavelength among all wavelengths numbered in advance is preferred in practice because no global knowledge is required and computation is simple. So, in this paper, we use FF algorithm as a wavelength assignment scheme.

Ⅲ. Bounded Flooding Routing Algorithm

Our scheme is designed for an arbitrary point-to-point network, that is, mesh networks. All links in the network are assumed to be bidirectional (one in each direction).

In a flooding-based method, we primarily try to reduce overhead (i.e. request messages and state information as well) by deploying ripple-count concept which does not need link-state information and computational process in a node. And the proposed algorithm allows multiple QoS admission checks at every intermediate node, so this also reduces overhead by preventing flooding to an unqualified link. Moreover, we also make an effort to improve blocking probability through two different methods (i.e. first come first serve path selection and least-congested path selection) at a destination node.

Besides, in DWDM networks, the wavelength-continuity constraint can be eliminated if a wavelength converter (WC) exists at each node [13]. Especially, in a network consisting of nodes with full WC capability from any wavelength to any other one, a wavelength can be easily assigned if a residual free wavelength is on links along the selected route [14-15]. However, this problem is not quite simple, because the cost of WC is expensive. So, we consider sparse WC placement scheme by applying limited range wavelength conversion capability for extensive simulation results.

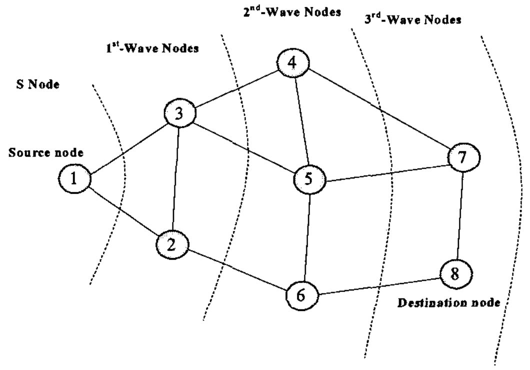


그림 2. Ripple-count 개념
Fig. 2. Ripple-count Concept.

1. Ripple-count Concept

We newly introduce a ripple-count concept, which provides flexible classification by relative positions of nodes. The ripple-count of a node is relative to the particular source-nodes which receive connection request and is of multi-value which means every value is relative to a particular source-node. And related to a source-node, the 1st-wave set is formed of all nodes at which message arrives in one hop from the source, where all elements of the set are called as the 1st-wave nodes; similarly, the 2nd-wave set is formed of nodes in two hops, and so on. This approach accomplishes not to flood unnecessary messages without state information and operational process in each node.

As shown in Fig. 2, if a connection request arrives at node 1, a source node (S node) is node 1, and according to ripple-count concept, the other nodes can be defined as follows;

S node {1}
1st-wave set {2,3}
2nd-wave set {4,5,6}

3rd-wave set {7,8}

If a node K belongs to the jth-wave set of source S, the elements in (j-1)th-wave set are called as the lower-wave nodes, and those in (j+1)th-wave set as the higher-wave nodes. And all messages in the network can be classified into three types-the messages from the nodes with lower-wave to the nodes with higher-wave as type-I, messages between nodes with peer-wave as type-II, while messages from the nodes with higher-wave to the nodes with lower-wave as type-III.

Toward reduction of overhead, only type-I messages can really be contributed to addressing the destination node and therefore called them as 'right messages'. Reversely, type-III messages are not useful at all and therefore called them as 'futile messages', while the type-II messages might have possibility to be changed to type-I messages when some links fail or some messages are lost, so called them as 'possible messages'.

2. The Proposed Bounded Flooding Routing Algorithm

Each node in the network consists of an optical cross-connect (OXC) controlled by an electronic controller (e.g. IP/GMPLS) that is a control domain. The electronic controllers communicate with each other over a control channel, either out-of-band or in band. We assume the existing of a reliable transport protocol in this control channel making sure that messages between controllers are delivered reliably in sequence.

Each node maintains the status of every wavelength on every link emerging from the node. For a wavelength λ_i on link L, the state can be one of the following:

- Free: indicates that the wavelength λ_i is available and can be used to establish a new connection.
- Reserved: indicates that λ_i is being used or reserved in some connection to transmit data.

And for the link L, the number of wavelengths that are in Free state is denoted by $F_{\lambda}(L)$.

Upon receiving a connection request, the source node generates a request message, Req. A Req message contains the following fields.

- Connection identifier Req.ID which uniquely identifies the corresponding connection. For the uniqueness of each connection ID, an identifier is composed of two parts: the node ID (or address) and connection number (unique within a source). This composition of connection IDs ensures their uniqueness throughout the network.
- Source identifier Req.src of the requested connection.
- Destination identifier Req.dest of the connection.
- Ripple-count number Req.wave which represents the relative number of node-wave. This identifier is used to remove the futile messages to reduce the overhead.
- List of intermediate node IDs Req.nodeID that the message has traversed thus far. Every time the request message is relayed to the next node, the new node ID is appended to this field. This information is needed for the destination node to confirm the establishment of the requested connection.
- Connection pertinence parameter Req.cpp which is increased as the Req passes the nodes, the metric value represents the route difficulty that the Req has experienced. This parameter can be used for another criterion (i.e. number of wavelengths, hop count, time to live, and etc.).
- QoS requirements parameter Req.qos which is used to contain the threshold to which a service needs to provide, while executing QoS admission checking procedure.

Since the information of existing connections is necessary for a new connection's admission test as well as for the completion of pending connections belonging to those connections still being processed, each node has to maintain two sets of tables for existing connections (Routing table) and pending connections (Pending table). Routing table (RT) contains established connections, one for each of its outgoing links. Each entry of a RT represents a connection which goes through the corresponding link and consists of the following fields.

- Connection identifier: this is the same as the one in the Req message.
- Wavelength index: the index of corresponding wavelength available. When a wavelength λ_i is occupied, λ_i.Free=0 and λ_i.Reserved=1. Reversely, when a wavelength λ_i is available, λ_i.Free=1 and λ_i.Reserved=0.

For pending table (PT), each node has to maintain fields for temporary pending connection requests, also one for each of its outgoing links. Each entry of a PT represents a connection request and contains the following fields.

- Connection identifier: same as the one in the Req message. When a connection request is conditionally accepted (that is, the outgoing link is able to accommodate the requested connection), it is copied from the connection ID field of the Req message.
- Wavelength index: the index of corresponding wavelength available. When a wavelength λ_i is occupied, λ_i.Free=0 and λ_i.Reserved=1. Reversely, when a wavelength λ_i is available, λ_i.Free=1 and λ_i.Reserved=0.
- Ripple-count number: this field is relative according to the source node and used for dividing incoming messages into right, possible, and futile messages.
- Connection pertinence parameter: this field contains Req.cpp of incoming Req message. This is used to compare the priority while the Req messages which have the same ripple-count number, has arrived.

가. Source Node Action

Upon receiving a connection request, the parameters (Req.ID, Req.src, Req.dest, Req.wave, Req.nodeID, Req.cpp, Req.qos) in Req message are set, and then the source node sends Req messages through each of its outgoing links only if it satisfies QoS admission checking test and the following condition.

$$F_{\lambda}(L) > 0 \qquad (1)$$

where $F_{\lambda}(L)$ is the number of free wavelengths in link L.

나. Intermediate Node Action

For more efficient wavelength utilization, we apply the number of wavelengths to Req.cpp as a constraint. Therefore, the intermediate node sends a request message through each of its outgoing links if it satisfies QoS admission checking test and additionally the following conditions:

$$\text{PT(Req.ID).Ripple-count} = \text{Req.wave} \qquad (2)$$

PT(Req.ID).Ripple-count in the equation (2) represents relative number to which this node belongs. Equation (2) functions to discard futile messages without state information and operational process, and by changing '=' to '>', we can also discard possible messages for a tradeoff between overhead and blocking probability.

If the node and the Req message pass these constraints (equation (1) and (2)), then the Req message is updated and the pending table is set by the corresponding Req message. Thereafter, the node forwards the Req message to a neighbor node via the outgoing qualified link. Somehow, when a message returns back to the previous node, there could be loop-back situation. However, by deploying the ripple-count concept, loop-back is also prevented by comparing ripple-count values.

다. Destination Node Action

As for the destination node action, we append one table called path candidate table (PCT) in the destination node to store candidate paths (Req messages) for further selection. This table contains Req messages in an accepted sequence. Due to performance considerations, we have two different path selection schemes considered here:

First come first serve path selection scheme (FCFS):

In this scheme, the destination node selects the path associated with the Req message that arrives first. This selection criterion is based on the assumption that the first packet to arrive is the most likely the one that has taken the least delay path and, hence, is the one that encounters the minimum delay. If another succeeded Req message arrives for the same connection request, the destination node stores it in PCT until the upstream reservation on the first selected route is confirmed. The stored route can be used in case if the upstream reservation fails. On the other hand, if the Req message has arrived after the upstream reservation has already been confirmed, the destination node discards messages in the corresponding PCT. This path selection scheme minimizes the connection setup time. That is, the destination node doesn't have to wait the arrival of the second Req message to decide on a path to setup the connection request.

Least-congested path selection scheme (LCP):

In this scheme, the path with the minimum value of Req.cpp/Req.wave is selected to setup a connection. In this case the destination node has to wait until Req messages from all attached links are received (or the destination node opens a short time-window to absorb possible further arriving Req messages). If Req messages accepted have the same Req.cpp/Req.wave as a constraint, the first message which might be shorter delay than other paths is chosen. LCP scheme also distributes the traffic evenly in the network. As will be shown later, this scheme can improve the blocking probability compared to alternate path selection schemes.

In order to confirm the qualified path, we define a connection confirmation message called Conf message to confirm a satisfied path. The Conf message contains the following fields.

- Connection identifier Conf.ID: this is the same as the one in the Req message.
- List of intermediate node IDs that the Req message has. This information is needed to confirm the establishment of the confirmed connection.

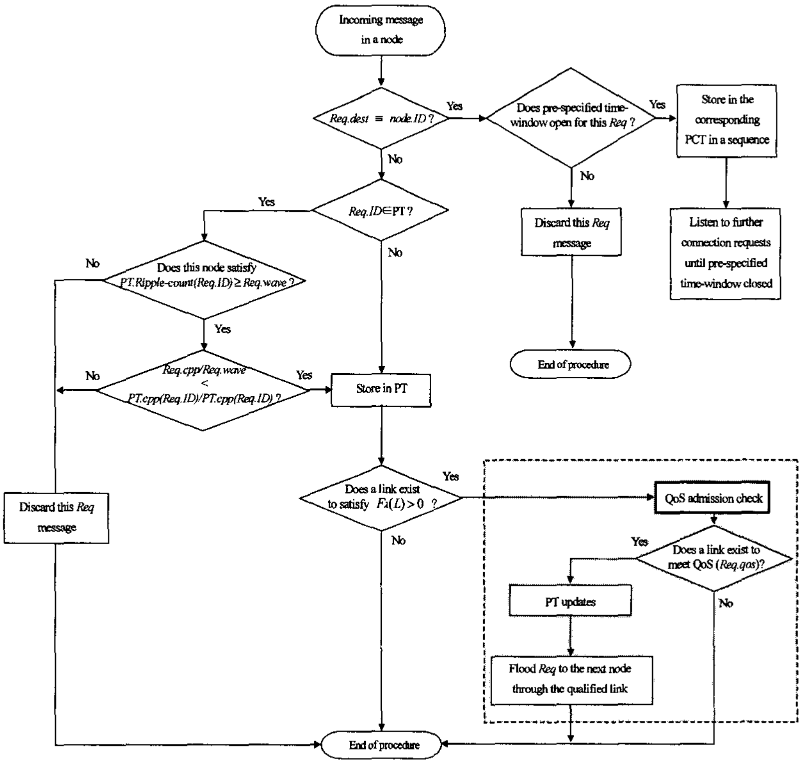


그림 3. Intermediate 와 Destination 노드의 동작 과정
Fig. 3. The flowchart of operation in intermediate and destination nodes.

And we also define a reject reservation message called Rej message to release reserved resources of unconfirmed paths for further connection requests. The Rej message contains the following fields.

· Connection identifier Rej.ID : this is the same as the one in the Req message.

· Destination identifier Rej.dest : this is the same as the one in the Req.src.

· Ripple-count number Rej.wave which represents the relative number of node-wave. This identifier is used to remove the futile messages to reduce the overhead.

The flowchart in Fig. 3 shows the actions in LCP scheme to be taken by both in an intermediate node and a destination node. This flowchart can easily be applied to FCFS scheme by choosing the first incoming Req message at the destination node.

At the destination node, when the pre-specified time-window is expired for the LCP scheme, the path is determined by the following equation.

$$\text{max Req.cpp/Req.wave} = \max\sum_{p} F_{\lambda}(L)\,/\text{Req.wave} \tag{3}$$

The dark dotted box represents QoS checking procedure; this prevents to flood to an unqualified path that does not satisfy Req.qos. The procedure of QoS admission checking mechanism is described in the next subsection.

3. The QoS Admission Checking Mechanism

In DWDM networks, an optical signal passing through network components such as an optical cross-connect (OXC), fiber, WC, and EDFA undergoes many transmission impairments. Then, the quality of the optical signal on each link is affected by several impairments ranging from simple attenuation to complex nonlinear effects [16-17], which are determined by calculating the bit error rate (BER) in the receiving node. BER is the most important one among several parameters proposed for monitoring signal quality and is complemented by other parameters to diagnose the system problems like optical signal-to-noise ratio (OSNR) or electrical signal-to-noise ratio (el. SNR) [16]. But it is difficult to measure directly the BER from an optical signal due that an optical signal is forwarded without optical-electrical-optical conversions in DWDM networks. And the OSNR may vary significantly for a specific BER value because of nonlinear effects. We can estimate the BER in an optical network by the Q-factor as a new parameter evaluating signal quality [16]. It measures the signal-to-noise ratio (SNR) based on assuming Gaussian noise statistics in the eye-diagram. Thus, the QoS parameters related to the transmission quality of a lightpath are determined by the following Equations (4) to (6) [18].

$$BER(Q) \cong (1/\sqrt{2\pi})\cdot(\exp(-Q^2/2)/Q) \tag{4}$$

$$el.SNR = 10\log Q^2 \tag{5}$$

$$OSNR_{0.1nm} = \frac{(1+r)(1+\sqrt{r})^2}{(1-r)^2}\cdot\frac{Be}{Bd}\cdot Q^2 \tag{6}$$

$r = 0.15$ (*extinction ratio of the transmitted optical signal*)
$Be = 0.75 \times fo$ (*effective electrical noise bandwidth due to bit rate fo*)
$Bd = 12.6$ *GHz or* 0.1 *nm* (*optical bandwidth for OSNR measurement*

The proposed BFR algorithm considers multiple QoS admission checks at every node. We consider the parameters, such as BER and OSNR. Fig. 4 illustrates the procedure of QoS admission checks. And to compare with the threshold (Req.qos), we involve equations (4)~(6).

4. Limited Wavelength Conversion

In the current research, it is proved of the efficiency improvement offered by the use of WCs in DWDM networks. But it has been assumed that a full set of ideal WCs are available at every node in the network. Although full-wavelength conversion is desirable because it substantially decreases blocking probability, it is difficult to implement in practice due to technological limitations and high cost as well.

Therefore, in this subsection, we describe networks with limited wavelength conversion. This may be the result of placing WCs at a limited range of OXCs in the network, using limited numbers of WCs in each

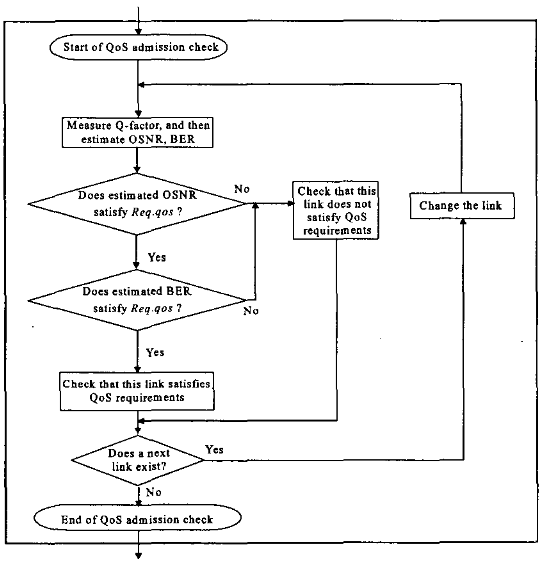


그림 4. QoS 점검 매커니즘의 절차
Fig. 4. Procedure of QoS checking mechanism.

cross-connect, or using WCs whose performance limits the set of allowable conversions.

Many optical network researchers have built optically-transparent or all-optical networks, in which no optical to electrical conversions are performed. WCs used in these networks have to be all-optical WCs. However, many factors, such as optical non-linearity, chromatic dispersion, amplifier spontaneous emission, attenuate the power of signal, so that these factors degrade the SNR to maximum -20 dB [17].

Besides, separated optical space switches are used for each wavelength. So, if there are M input and M output fibers with W wavelengths on each fiber, then W separated M x M space switches are required to implement an OXC without WCs. Otherwise, a single MW x MW space switch is required to implement the cross-connect with WCs.

In this paper, for extensive simulation study, we apply limited wavelength conversion capability. The procedures to deploy wavelength conversion capability in DWDM nodes are as follows: (i) the limited range WCs are used and wavelength conversion is performed after switching, as shown in equation (10) of which output wavelengths are limited within k area based on input wavelength. (ii) the limited range WCs that are sparsely placed in selected nodes are chosen by total outgoing traffic algorithm]. And because the selected nodes have high nodal degree, potentially, the probability to cause the congestion situation is high.

$$\lambda_i \rightarrow \lambda_{\max(i-k,1)} \leq \lambda_o \leq \lambda_{\min(i+k,w)} \qquad (7)$$

Theoretically, if the blocking probability improves significantly with 20%~40% wavelength range conversion, the performance is very close to full range wavelength conversion. And when WCs are placed at a few nodes (about 40%), the performance is similar with full-WCs [14].

Furthermore, to prove the results while applying the limited wavelength conversion for test networks, simulations are carried out in section 4. We adopt 30% range conversion and place 40% nodes of entire nodes.

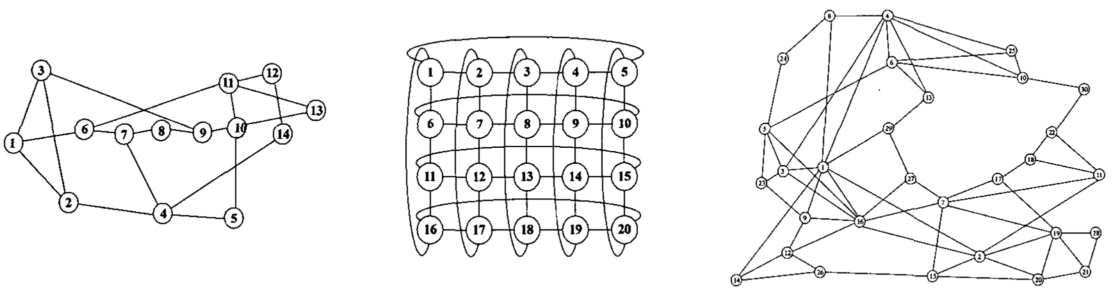
Ⅳ. Performance Evaluation

1. Simulation Model

Simulations are carried out to prove the efficiency of the proposed BFR algorithm and dependable connection guaranteeing algorithm under BFR algorithm. Test networks used in simulations are TN(1), TN(2), TN(3), which have (14 nodes, 20 links), (20 nodes, 40 links), (30 nodes, 61 links), respectively, as illustrated in Fig. 5, and we assume the connection requests arrive randomly according to the Poisson process, with negative exponentially distributed connection times with unit mean. Also, all links in the network are assumed to be bidirectional (one in each direction) and have 8 wavelengths.

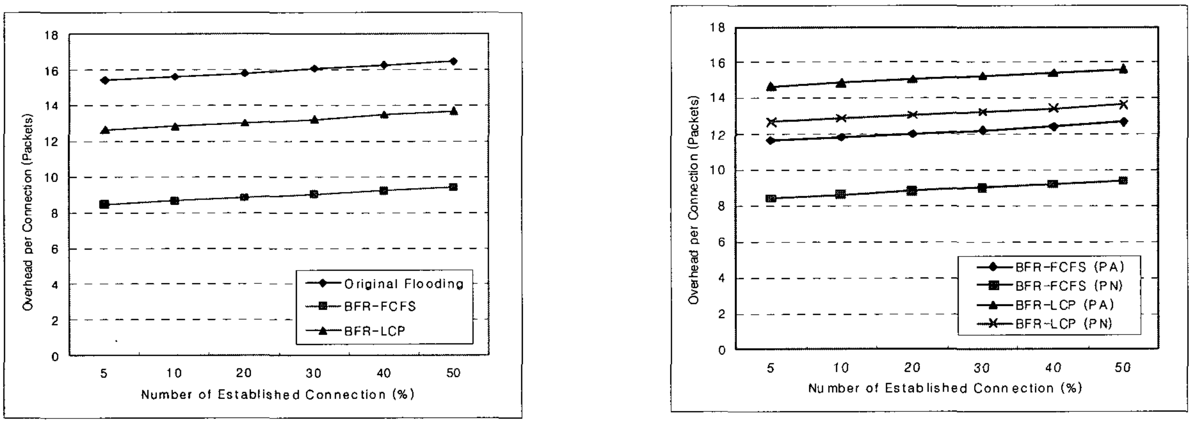
2. Simulation Results

We carry out simulations in terms of routing overhead, blocking probability, and usage of wavelength channels required. For extensive simulation results, we deploy limited wavelength conversion capability (30%-range wavelength convert-sion and 40%-wavelength converters) in DWDM nodes as a critical concern in DWDM-based networks.



(a) TN(1) (14 nodes and 20 links) (b) TN(2) (20 nodes and 40 links) (c) TN(3) (30 nodes and 61 links)

그림 5. Test network models
Fig. 5. Test network models.



(a) Network overhead comparison with original flooding scheme

(b) Network overhead for peer-admitted (PA) and peer non-admitted (PN)

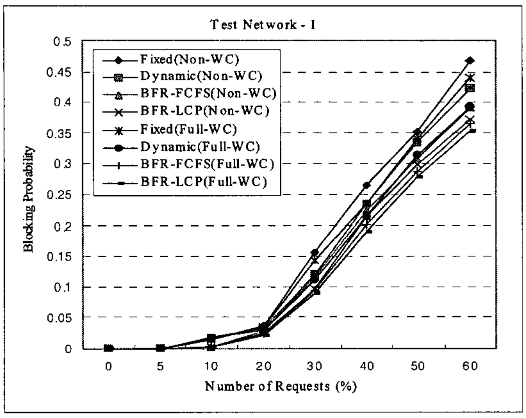
그림 6. Network 오버헤드
Fig. 6. Network overhead (Test Network I).

Firstly, Fig. 6 shows the corresponding results for average routing overhead per successfully established connection. We compare the proposed BFR algorithm with original flooding algorithm in test network I (Fig. 6(a)). By limiting the flooding area through ripple-count method and QoS checking mechanism, we accomplish the routing overhead significantly reduced. And if we admit the peer relations for further bounded area, the average routing overhead for FCFS and LCP increases as shown in Fig. 6(b). In the aspect of routing overhead, BFR algorithm with FCFS methods in peer non-admitted condition performs better than other methods.

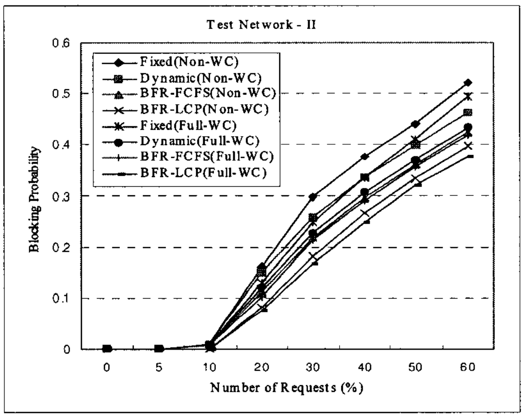
From the results shown in Fig. 7, it can be seen that the proposed BFR algorithm is superior to the existing routing (source directed routing - fixed routing and dynamic routing) algorithms in case of a network with full WC capability and without WC capability as well.

The blocking probability in three test networks shows that until 5% of connection requests, the blocking probability is almost same. But, the results make difference according to each algorithm for connections set above 5%. In the same WC condition, we observe the blocking probability of the proposed BFR algorithm with LCP method is better than dynamic routing algorithm (improved by about 5%). This means that the proposed algorithm is more effective in large scale network topology. And in all of three test networks, as the number of connection requests increases, the BFR-LCP (full-WC) is predominantly outperformed than other schemes.

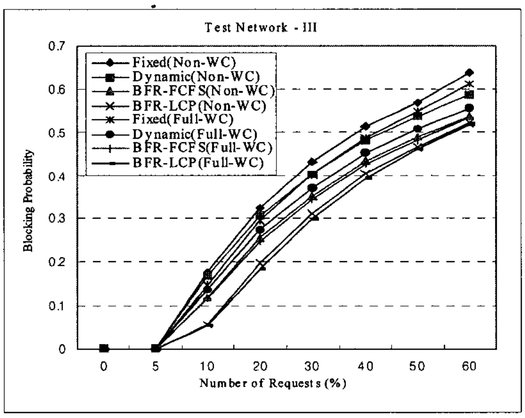
Note that the wavelength conversion capability is very critical problem in DWDM-based networks



(a) Blocking probability in Test network I

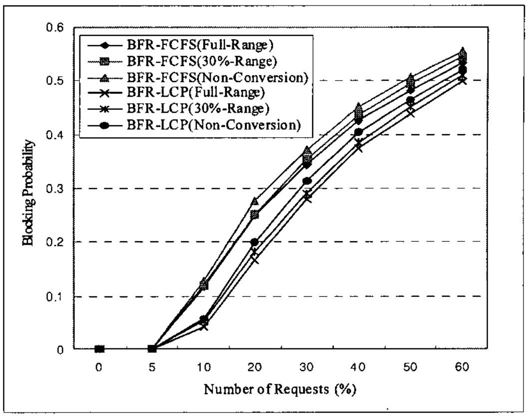


(b) Blocking probability in Test network II

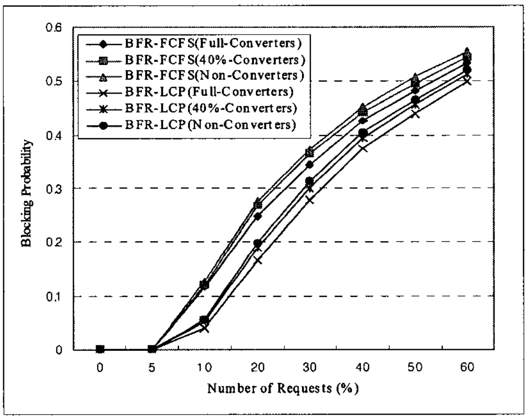


(c) Blocking probability in Test network III

그림 7. source-directed 방법들과 비교시 블록킹 확률
Fig. 7. Blocking probability for comparing with source-directed methods.



(a) Blocking probability for full, 30% and non-range wavelength conversion



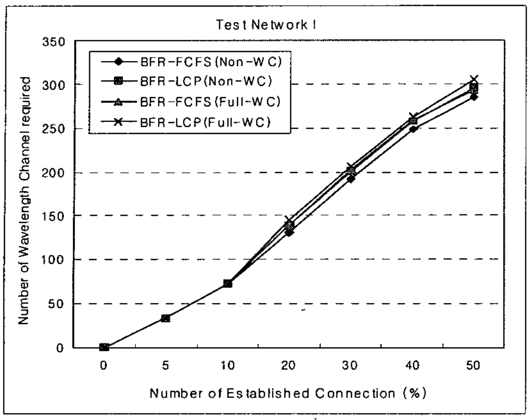
(b) Blocking probability for full, 40% and non-wavelength converters

그림 8. 제한된 파장변환에서의 Blocking probability
Fig. 8. Blocking probability under limited wavelength conversion.

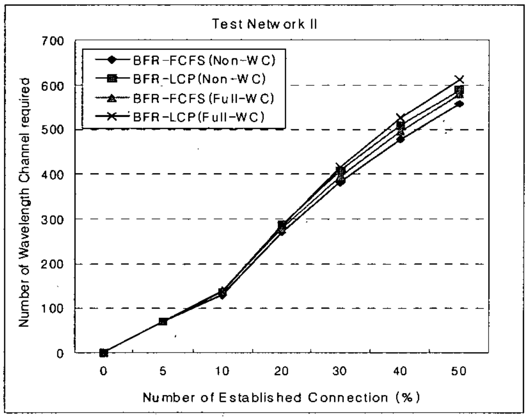
because the WC is high cost and still immature technology. So, as described in section 3.4, within test network I, we deploy the limited wavelength convertsion capability in DWDM nodes as a critical concern.

From the Fig. 8(a), we find that the blocking probability of the proposed BFR algorithm in the network equipped with 30%-range wavelength conversion capability is close to that in the network with full wavelength conversion capability. Moreover, the results presented in Fig. 8(b) illustrate that even when 40% WCs of total network nodes (60% non-WC) are deployed, the blocking probability of the proposed BFR algorithm is slightly deteriorated (about 1%~2%). So, the DWDM with 30%-range or 40% converters as limited wavelength conversion capability can have almost similar performances with full WC.

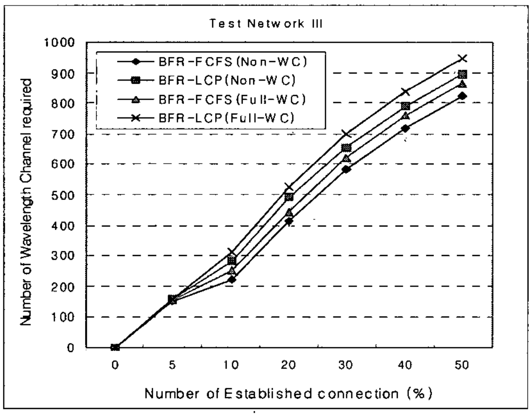
To verify resource utilization performance, we use the number of wavelength channel required as a performance metric. As shown in Fig. 9, the proposed BFR algorithm with two different methods (FCFS



(a) Number of wavelength channel required in Test network I



(b) Number of wavelength channel required in Test Network II



(c) Number of wavelength channel required in Test network III

그림 9. 필요한 파장 채널의 수

Fig. 9. Number of wavelength channels required.

and LCP) has different performance results. The BFR algorithm with FCFS scheme is better resource saving than LCP scheme. And the number of established connection increases, the difference among the proposed schemes is bigger. From the results in Fig. 9, in the aspect of resource utilization, the proposed BFR algorithm with FCFS scheme accomplishes the best performance.

V. Conclusions

In this paper, we proposed a new routing algorithm, bounded flooding routing (BFR) algorithm. We focused on the network performance improvements in terms of network overhead, blocking probability, and resource (wavelength) utilization. And as a bounded criterion, we introduced a new ripple-count concept to classify the messages into three types depending on its necessity. This concept controlled the network overhead without state information and computational process. Also, in intermediate nodes, QoS admission checking mechanism was performed as bounding constraint. From the extensive simulation results, we found out that the proposed BFR algorithm is robust compared to the existing algorithms in respect with performance metrics (network overhead, blocking probability, and resource (wavelength) utilization.

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 these quality attributes.

참 고 문 헌

[1] T. E. Stern and K. Bala, Multiwavelength Optical networks: A layered approach, Addition Wesley Publishers, 1999.

[2] H. Zang, Jason P. Jue, B. Mukheriee, A Review of Routing and Wavelength Assignment Approaches for Wavelength-Routed Optical WDM Networks, Optical Networks Mag., vol.1, pp.47-60, Jan. 2000.

[3] Jong-Gyu Hwang, Jae-Il Jung, Yong-Jin Park, Jung-Hyun Bae, Hyun-Su Song, Sung-Un Kim, A RWA Algorithm for Differentiated Services with QoS Guarantees in the Next Generation Internet based on DWDM Networks, Photonic

Network Communications, vol.8, no.3, pp. 319-334, Nov. 2004.

[4] Jun Song, Hung Keng Pung, L. Jacob, A multi-constrained distributed QoS routing algorithm, ICON 2000 Proceedings, IEEE International Conference, pp.165-171, Sep. 2000.

[5] Zheng Wang, J. Crowcroft, Quailty of Service Routing for Supporting Multimedia Applications, IEEE Journal of Selected Area Communications, vol. 14, pp. 1228-1234, Sep. 1996.

[6] Shigang Chen and Klara Nahrstedt. An Overview of Quality of Service Routing for the Next Generation High-Speed Network: Problems and Solutions. IEEE Network Magazine, Special Issue on Transmission and Distribution of DigitalVideo, 1998.

[7] Admela Jukan, Gerald Franzl, Path Selection Methods With Multiple Constraints in Service-Guaranteed WDM Networks, IEEE/ACM Transactions on Networking, Vol.12, No.1, pp.59-72, FEB. 2004.

[8] L. Li and A. K. Somani, Dynamic Wavelength Routing Using Congestion and Neighborhood Information, IEEE/ACM Transactions on Networking, vol. 7, no 5, pp. 779-786, October 1999.

[9] S. Xu et al., Dynamic Routing and Assignment of Wavelength Algorithms in Multifiber Wavelength Division Multiplexing Networks, IEEE Journal on Selected Areas in Communications, vol. 18, no. 10, pp. 2130-2137, October 2000.

[10] Banerjee, D., Mukherjee, B., A practical approach for routing and wavelength assignment in large wavelength-routed optical networks, Selected Areas in Communications, IEEE Journal on, Vol. 14, No. 5, pp. 903-908, June 1996.

[11] J. S. Choi and N. Golmie et al., Classification of Routing and Wavelength Assignment Schemes in DWDM Networks, Proceedings of OPNET 2000 (Paris, France), pp. 1109-1115, January 2000.

[12] J. S. Kim and D. C. Lee, Dynamic Routing and Wavelength Assignment Algorithms for Multifiber WDM Networks with Many Wavelengths, Proceeding of ECUMN 2002 (Colmar, France), pp. 180 -186, April 2002.

[13] S.Subramaniam, M. Azizoglu, A.K. Somani, On the optimal placement of wavelength converters in wavelength-routed networks, INFOCOM '98. Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies, IEEE, pp.902-909, 1998.

[14] Amrinder S Arora, Suresh Subramaniam, Wavelength Conversion Placement in WDM Mesh Optical Networks, Photonic Network Communications, vol.4, no.2, pp.167-177, 2002.

[15] K.R. Venugopal, M. Shivakumar, P.S. Kumar, A Heuristic for Placement of Limited Range Wavelength Converters in All-Optical Networks, INFOCOM '99. Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies, IEEE, vol.2, pp.908-915, Mar. 1999.

[16] Paulo S. André, João L. Pinto, António L. J. Teixeira, José F. da Rocha, Optical-signal-quality monitor for bit-error-ratio assessment in transparent DWDM networks based on asynchronously sampled amplitude histogram, Journal of Optical Networking, vol.1, no.3, pp.118-127, Mar. 2002.

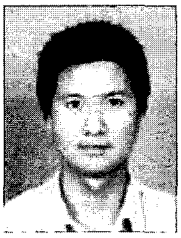
[17] Alcatel's White Contribution COM 15-33-E: Electrical (BER, Q-factor, el. SNR) and Optical (OSNR, OCR) System Performance Parameters for G.DSN, ITU-T SG 15 Contribution, Dec. 2000.

[18] Rec. G.976: Test methods applicable to optical fibre submarine cable systems, COM15R68 (TSB, 7 Nov. 1996), Sect. 7.6.1.1: 'Measurement of Q-Factor', pp.172-174 and Annex A.4: 'Q-factor' p.178.

저자소개

김 용 성(정회원)
1987년 경북대학교 컴퓨터공학과 졸업(공학사)
1991년 경북대학교 컴퓨터공학과 대학원 졸업(공학석사)
1998년 부경대학교 정보시스템 학과 박사과정 수료.
1992~현재 경남정보대학 교수
<주관심분야 : 프로토콜 엔지니어링, WBI 등>

이 재 동(정회원)
1986년 경북대학교 컴퓨터공학과 졸업(공학사).
1991년 경북대학교 컴퓨터공학과 대학원 졸업(공학석사)
2003년 부경대학교 정보통신 공학과 박사과정 졸업 (공학박사)
1998년~현재 경남정보대학 부교수
<주관심분야 : 프로토콜엔지니어링, DWDM 등>



황 진 호(정회원)
2003년 부경대학교 정보통신 공학과 졸업(공학사)
2005년 부경대학교 정보통신 공학과 대학원 졸업 (공학석사)
2005~현재 조지워싱턴대학 (미국) 객원연구과정
<주관심분야 : Network의 분석 및 설계, WDM 등>

우 종 호(정회원)
1978년 경북대학교 전자공학과 졸업(공학사)
1981년 경북대학교 전자공학과 전산공학전공졸업 (공학석사)
1990년 경북대학교 전자공학과 전산공학전공졸업 (공학박사)
1981년~현재 부경대학교 전자컴퓨터정보통신 공학부 교수
1987년~1988년 미국뉴욕, RPI CS, Visiting professor
2001년~2002년 미국루이지애나, LSU at Baton Rouge ECE, Visiting professor
<주관심분야 : Embedded System, Network Evaluation, e-Learning System 등 >