Thesis for the Degree of Master of Engineering

Priority-based Minimum Interference Path Multicast RWA Algorithm with QoS Guarantee in Optical Virtual Private Network

by

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Priority-based Minimum Interference Path Multicast RWA Algorithm with QoS Guarantee in Optical Virtual Private Network

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Abstract

OVPN(Optical Virtual Private Network) based on DWDM(Dense Wavelength Division Multiplexing) backbone framework with QoS(Quality of Service) guarantee is considered as a promising approach for the future VPN. This thesis proposes a new routing algorithm, called MIPMR(Minimum Interference Path Multicst Routing) algorithm which can meet differentiated QoS requirements. The proposed algorithm finds an alternate route considering node priorities when the congestion is occurred in a network. Also, the current multimedia applications involve real time-intensive traffics with various QoS requirements. So we proposes a QoS MIPMR in combination with QoS constraints and a recovery strategy based on the differentiated QoS service model to provide QoS guarantee for a wide variety of multicast applications. And we apply QoS MIPMR to the architectural framework for QoS support in terms of QoS routing and congestion avoidance. The MIPMR algorithm tries to improve blocking probability and wavelength utilization by avoiding congested path for potential future connection requests. We verify the performance of the proposed algorithm in terms of blocking probability and resource utilization. And the simulation results demonstrate that the MIPMR algorithm is superior to the previous multicast routing algorithms based on capability-based-priority and spawn-from-VS heuristics.

Ⅰ. Introduction

VPNs (Virtual Private Networks) are well-recognized as one of the critical applications of the future Internet market and have gained increased acceptance due to the economic benefits, scalability and reliability [1-2]. Given the increasing demand for high bandwidth services (i.e. video-conferencing, VoIP, digital library, tele-immersion, data mining and etc.), OVPNs (Optical VPNs) are expected to be one of the major applications for the future VPNs. Therefore the OVPN over IP (Internet Protocol)/GMPLS (Generalized Multi-Protocol Label Switching) over DWDM (Dense Wavelength Division Multiplexing) technology has been suggested as a favorable approach for realizing the next generation VPN services [3-5].

OVPN should be considered in the aspect of the unicast or the multicast manner according to the types of the OVPN services. In the unicast method, one optimal light path between source and destination should be established for point-to-point (P2P) connection. On the other hand, the light paths should be established for point-to-multipoint (P2MP) connections in the multicast method. In general, major benefits of the multicast method are bandwidth savings and scalability inherent [1].

One of the critical issues in OVPN is the RWA (Routing and Wavelength Assignment) problem which is embossed as very important and plays a key role in improving the global efficiency for capacity utilization. However, it is a combinational problem known to be NP-complete because routing and wavelength assignment problems are tightly linked together [6]. Since it was more difficult to work out RWA as a coupled problem, this problem has been approximately divided into two sub-problems: routing and wavelength assignment.

In previous unicast RWA, the routing scheme has been recognized as a more significant factor on the performance of the RWA problem than the wavelength assignment scheme [7-8]. Among approaches for the routing problem, dynamic routing(DR) yields the best performance because DR approaches determine a route by considering the network status at the time of connection request [9]. On the other hand, static routing approaches such as fixed routing (FR) and fixed alternate routing (FAR) set up a connection request on fixed paths without acquiring the information of the current network status [10] And existing routing schemes that do not consider potential traffic demands can lead to serious network congestions by inefficiently utilizing wavelengths in terms of traffic-engineering.

In previous multicast RWA, some multicast routing algorithms [11] have some defects such as the long delay incurred in constructing the tree. In [11], four multicast tree generation algorithms have been proposed. Among approaches for the routing problem, Member-only algorithm yields the best performance in terms of the number of wavelengths per fiber and number of channels per forest. On the other hand, the performance in terms of the delay from the source to the individual destination is poorer for Member-only than other algorithms. However, the delay in optical networks is normally very low. Hence, it is preferred to minimize the cost of the forest than minimizing the delay on individual paths. And also it is difficult to add or delete a node from a session, because adding or deleting a destination to the existing session may change the structure of the tree.

To overcome these limitations, [12] proposed VS (virtual source)-based tree generation method. Using a VS node that has both splitting and wavelength conversion capabilities, a node can transmit an incoming message to any number of output links on any wavelengths. In addition, the setup time for a VS-based multicast tree is much less compared to the of source-rooted multicast tree construction because each VS node should make reservations for the paths to support the multicast sessions prior to the multicast service requests. But as the number of VS nodes increases, the congestion due to the resources reserved for paths between VS nodes also increases.

In [13], multicast tree is generated based on Member-only algorithm using spawn-from-VS and capability-based-priority. The proposed algorithm has two different phases namely tree construction phase and wavelength assignment phase. During tree construction phase, multicast tree include destinations by priority. The nodes in the network are assigned some priority depending on the capabilities they have. But the path which is routed by higher priority nodes can be congested.

To overcome this problem, this paper proposes a new multicast routing algorithm choosing a route that dose not interfere too much with potential future connection requests and call it PMIPMR(Priority-based Minimum Interference Path Multicast Routing). Existing routing schemes which do not consider potential traffic demands can lead to serious network congestions by not efficiently utilizing wavelengths in terms of traffic-engineering. They cannot either provide services with satisfied quality-of-service (QoS) guarantee. Therefore we also propose a QoS MIPMR in combination with QoS constraints and a recovery strategy based on the differentiated QoS service model to provide QoS guarantee for a wide variety of multicast applications.

The rest of the paper is organized as follows: Section 2 presents the analysis of previous RWA schemes and section 3 describes the multicast tree generation concept and the proposed PMIPMR algorithm. And in section 4, we provide the architectural framework for QoS support and propose QoS MIPMR with differentiated QoS classes. Thereafter, using extensive simulations, the proposed and other existing algorithms are comparatively evaluated in section 5. Finally, some concluding remarks are made in section 6.

Ⅱ. Analysis of Previous RWA Schemes

1. Previous RWA Schemes

The trend of RWA researches approached to various viewpoints with respects to traffic assumptions and the possibility of wavelength conversion. Almost all existing 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 finding an optimal solution by solving the RWA at the same time known as NP-complete problem [7]. Each sub-problem is independently solved as shown in Figure 1 and Figure 2. In Figure 3, MW-MIPR and VS-MIMR are describes in next section for minimum interference path routing algorithm. Next two sub-sections focus on various approaches to routing connection requests and assigning a wavelength to them.

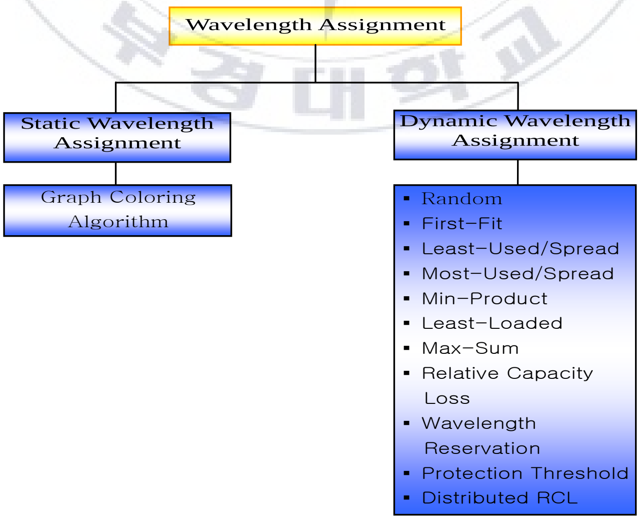


Figure 1. The previous wavelength assignment schemes

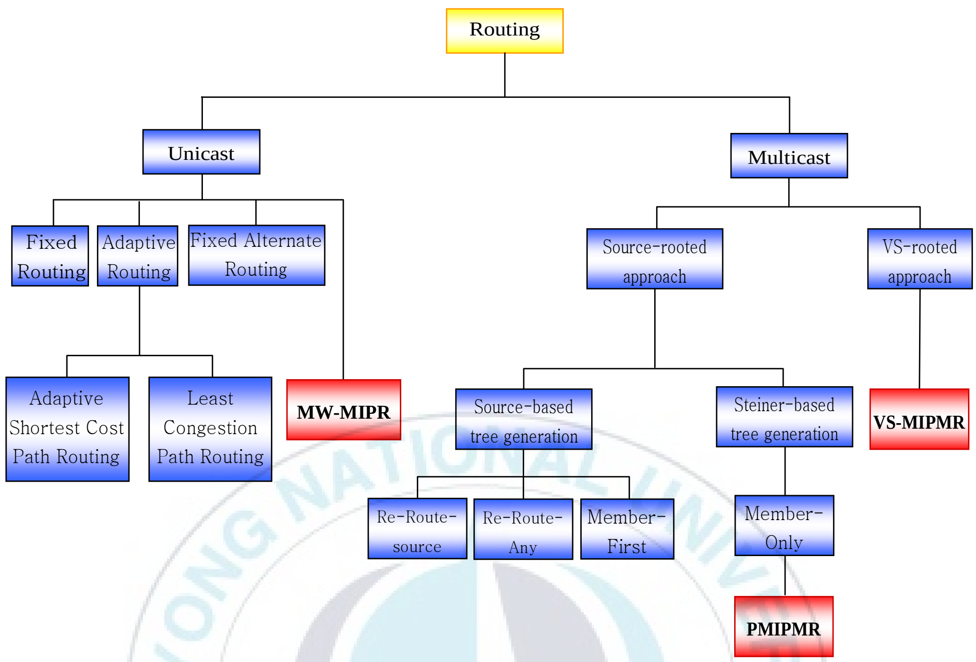


Figure 2. The previous routing schemes and proposed algorithm

1.1 Routing Schemes

1) Architecture of DWDM-Based OVPN for Unicast and Multicast Schemes

As shown in figure 3, a generic OVPN reference architecture is composed of VPNs in the electric control domain and the DWDM-based backbone network in the optical control domain. We assume that external VPNs aggregate IP packets (the same destined packets at the CE nodes (Client Edge)) to make operations simple. The internal OVPN backbone network consists of the PE nodes (Provider Edge) and the P core nodes (provider).

As illustrated in figure 3, different VPNs may provide different services, i.e., point-to-point (unicast), point-to-multipoint (multicast). The congestion in a network is defined as the maximum offered traffic on any link. The congestion can be partially reduced by using an appropriate routing scheme with consideration of the current status of the network in the unicast manner and by constructing multicast tree efficiently in the multicast manner.

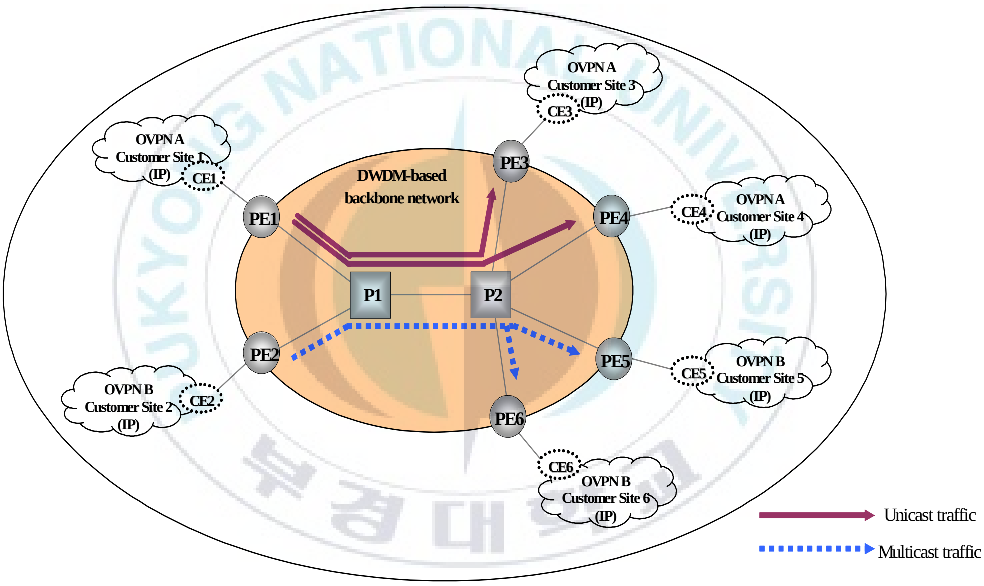


Figure 3. OVPN reference architecture with unicast and multicast connectivities

2) Routing Schemes

a. Unicast Routing Schemes

Current routing schemes are based on source-directed methods because of its easy controllable characteristics. And there are three fundamental approaches to solve routing sub-problem: fixed routing (FR), fixed-alternate routing (FAR) and adaptive routing (AR).

Fixed Routing (FR):

The simplest method for routing a connection always chooses the same fixed route for a given source-destination pair. Generally, the fixed shortest-path routing approach is used. The shortest-path for each source-destination pair is computed off-line in advance using standard shortest-path algorithms, e.g. Dijkstra's algorithm or Bellman-Ford algorithm. When the request comes, the light path is set up using the pre-determined route. Obviously, the disadvantage of this approach is that the routing decision is not made based on the current state of network. It might lead to the situation where some links on the network are over-utilized while other links are underutilized. This might potentially result in high blocking probability.

Also, FR may be unable to handle fault situations in which one or more links in the network failure. To handle link faults, the routing scheme must either consider alternate paths to the destination, or must be able to find the route dynamically.

Fixed Alternate Routing (FAR):

As an improvement over FR, FAR is an approach that sequentially considers an available path among pre-determined fixed routes and selects one. Each node in the network is required to maintain a routing table that contains an ordered list of a number of fixed routes to each destination node. For example, these routes may include the shortest-path, the second shortest-path, the third shortest-path, etc. A primary route between a (S, D) pair is defined as the first route in the list routes to the destination node in the routing table at the source node. An alternate route between a (S, D) pair is any route that does not share any links with the first route in the routing table at the source node. When a connection request arrives, the source node will decide the best route from a list of candidate routes by some metric, e.g. the minimal hop count and then set up the lightpath over that route. This approach can reduce the blocking probability compared to FR, and provide some degree of fault tolerance upon link failures.

Adaptive Routing (AR):

In adaptive routing (AR), the route from a source to destination is determined depending on the network state that is determined by all the connections that are currently in progress. A typical form of adaptive routing (AR) is adaptive shortest-cost-path routing. When a connection request arrives, a source node computes the shortest-cost-path to a destination node based on the network state. If no path is available, the request will be blocked.

Another form of AR is least congested path (LCP) routing. This approach is similar to FAR that pre-selects multiple routes for each (S, D) pair. Upon the arrival of a connection request, least congested path among the pre-determined routes is chosen. The congestion on a path is measured by the number of wavelengths available on the most congested link in the path.

The advantage of AR is that it results in lower connection blocking probability than FR and FAR because it is too hard to find an optimal route using static routing approaches such as FR and FAR that determine the route without considering network's status [10]. Compared to static routing methods, AR approach is the most efficient because a route is dynamically chosen by considering network's status at the time of connection request, which improves network performance in terms of blocking probability [10,14]. Also, AR approach can provide the protection scheme for a connection by setting up a backup path against link or node failures in the network.

b. Multicast Routing Schemes

Source-rooted approach:

In Source-rooted approach, a multicast tree is constructed with the source of a session as the root of the tree. The objective here is either to minimize total cost of the tree or to minimize individual cost of paths between the source and destinations. Depending on the objective there are two methods to construct a multicast tree (i.e. Source-based tree and Steiner-based tree) [15-16].

In Source-based tree generation methods, the destinations are added to the multicast tree in the shortest path to the source of a multicast session. These algorithms provide a computationally simple solution to the multicast tree generation, but have some limitations. Table 1 summarizes the properties, merits and demerits of each multicast tree generation method in the source-based tree approach..

In Steiner-based tree, the destinations are added to the existing multicast tree one at a time in such a way that the total cost of the tree is minimized. To add a node to the tree, it is required to find the minimum cost path tree to all nodes in the tree. This approach is computationally expensive. Hence, heuristics are provided to choose a node to which the present node can be connected. Table 2 summarizes the properties, merits and demerits of the multicast tree generation method in the Steiner-based tree approach.

Table 1. Comparisons of Source-based tree generation methods

	Re-route-to-Source	**Re-route-to-Any**	**Member-First**
Properties	Each destination finds its reverse shortest path heading for the source.	Each destination finds the nearest node in the current tree heading for the source.	Constructing the tree according to the link priorities (determined by whether or not the link is leading to destinations)
Advantages	Shortest delay, and simple implementation.	Moderate wavelength, channel resources, and delay required.	The least number of wavelengths and short delay.
Disadvantages	Requiring the largest amount of channel resources and wavelength numbers	Constructed tree may have some paths, which are not the shortest paths	Computational complexity

Table 2. Steiner-based tree generation method

	Member-Only
Properties	Building up a multicast tree by including members one at a time (the closest member first)
Advantages	Requiring the least number of wavelengths and channel resources
Disadvantages	Long delay, Computational complexity

For a given multicast session, the methods of the source-rooted approach construct a set of trees with an objective of either minimizing the total cost of the tree or minimizing the individual cost of the path between the source and the destinations. But the source-rooted approach has to consider all intermediate nodes that were laid in the paths between the source and the destination nodes in order to establish efficient path constructions. Therefore it has a long light tree setup time. In addition to the long setup time, the light tree needs to be reconstructed if the tree structure is changed or a link fails. For such a case, the Virtual Source-rooted approach was suggested.

VS-rooted approach:

The algorithm based on this approach overcomes the limitations of the source-rooted approach. In the VS-based tree generation approach [11,12,16], firstly some nodes are chosen as VS nodes in the entire network. At this time, the nodes that have the highest degree, or the most number of adjacent nodes, are chosen as VS nodes. And the VS nodes have both splitting and wavelength conversion capabilities. The light path is established between these VS nodes, and the entire network is partitioned into each VS node by exchanging information through the established path. When a multicast session is requested, the multicast tree is constructed for each session based on the partitioned area between the VS nodes and the mutual connectivity. Therefore, the VS-based tree construction approach is generally divided into the network partitioning phase and tree generation phase.

In the network partitioning phase, he given network is partitioned into some parts based on the nodes adjacent to the VS nodes. The nodes that have a high degree are chosen as VS nodes. Once the VS nodes are identified, then the paths between all VS nodes are computed. Every VS establishes connections to all the other VS nodes. As a result, the network can be viewed as a set of the interconnected VS nodes, and the remaining nodes in the network grouped into trees each with the root as a VS node.

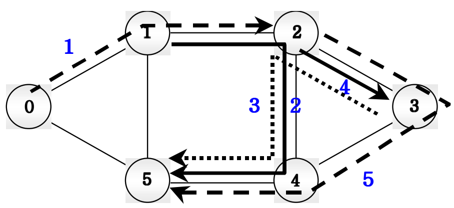
In the tree generation phase, when the set of source and destinations for each request of multicast session are given, the multicast tree is generated by using the connection information provided in the network partitioning phase.

1.2 Wavelength Assignment Schemes

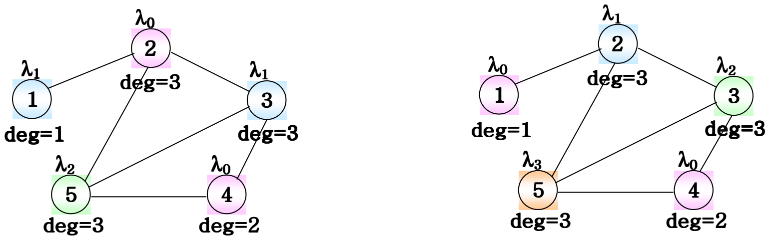
For the wavelength assignment sub-problem, it is the goal to efficiently assign a wavelength to each lightpath without sharing the same wavelength with other lightpaths on a given link, which has been respectively studied in terms of static and dynamic traffic.

1) Static Wavelength Assignment

Generally, graph-coloring algorithms [17] were employed to assign wavelengths for static traffic where the set of connections are known in advance. This algorithm operates to minimize the number of wavelength used as follows. First, construct an auxiliary graph G(V,E), such that each lightpath in the system is represented by a vertex(V) in graph G. There is an undirected edge(E) between two vertexes in graph G if the corresponding lightpaths pass through a common physical fiber link as shown in Figure 4. Second, coloring the vertexes of the graph G such that no two adjacent nodes have the same color. If the number of edges at a node denotes degree, then coloring vertexes from the maximum degree (Figure 4(b)) can have the minimum number of wavelengths required for the set of lightpaths in Figure 4(a).



(a) A network with five routed lightpaths



(b) Coloring vertexes sequentially from the maximum degree

(c) Coloring vertexes sequentially from the minimum degree

Figure 4. Graph coloring algorithm

2) Dynamic Wavelength Assignment

Under dynamic traffic where connection requests arrive randomly, a number of heuristics have been proposed as follows; Random Wavelength Assignment (R), First-Fit (FF), Least-Used/Spread (LU), Most-Used/Pack (MU), Min-Product (MP), Least-Loaded (LL), MAX-SUM (MΣ), Relative Capacity Loss (RCL), DRCL (Distributed RCL), Wavelength Reservation (Rsv) and Protection Threshold (Thr) [17-18].

R scheme randomly chooses one among available wavelengths for request route. FF selects the first wavelength among all the available wavelengths numbered. This scheme is preferred in practice because of no requiring global knowledge and simple computation. LU chooses the wavelength that is least used in network. This scheme causes communication overhead that collects global information to compute the least-used wavelength. MU chooses the most-used wavelength in the network contrary to LU method. This scheme is expected to have better performance than LU due to conservation the spare capacity of less-used wavelengths. But MU also has the communication overhead same as LU scheme. MP scheme computes the number of occupied fibers for each wavelength on a link and choose the wavelength with the minimal value in multiple fiber networks. LL chooses the wavelength that has most residual capacity on the most loaded link along the path selected in multiple fiber networks. M∑considers all possible paths in the network and attempts to select the wavelength that minimizes the capacity loss on all lightpaths. RCL tries to minimize the relative capacity loss based on MS. Currently, RCL offers the best performance; however this scheme requires global information and complex computation. DRCL scheme based on RCL is more efficient in a distributed-controlled network. In Rsv, a wavelength on a specified link is reserved for a traffic stream. Thr assigns a wavelength only if the number of idle wavelengths on the link is at or above a given threshold.

In this paper, we use FF scheme because this scheme practically has good performance and does not need link-state information.

2. Minimum Interference Path Routing Scheme

2.1. MW-MIPR Algorithm

As a solution of traffic control, the previously proposed Minimum Interference Routing (MIR) algorithm with traffic engineering in a Multi-Protocol Label Switching network [19-22] was investigated. The key idea of

MIR is to pick a path that does not interfere too much with potential future setup requests between some source-destinations pairs. In [20], MW-MIPR (Multi Wavelength – Minimum Interference Path Routing) was proposed for an extension of MIR. This method suggested an important role in enhancing the resource utilization and in reducing the overall call blocking probability of the networks through efficiently utilizing wavelengths by taking into consideration the potential future network's congestion states. As a result, using the term, i.e., critical link [19], this algorithm chooses a light path that does minimize interference for potential future setup requests by avoiding congested links.

2.2. VS-MIPMR Algorithm

In the VS-based tree method, as the number of VS nodes increases, the overheads due to the resource reservations for paths between VS nodes also increase, where the resources are needed to exchange the information for each sub-tree when the VS-based tree method constructs the multicast trees among the VS nodes. Moreover, many potential future multicast session requests may make the paths between VS nodes busy because they need additive resource reservations and use critical links so that the networks can waste redundant wavelength numbers. So it needs a suitable strategy to follow efficient paths between VS nodes that avoid the critical paths.

In [23], a new Multicast Routing and Wavelength Assignment method choosing a path that does not interfere too much with potential future multicast session reservation requests based on the VS-rooted approach was proposed. Choosing efficient paths considering the potential future network's congestion states instead of the shortest path, the new algorithm overcomes the limitation of the VS-based method and provides the efficient utilization of wavelengths.

Figure 5 illustrates the VS-MIPMR (Virtual Source-based Minimum Interference Path Multicast Routing) algorithm. It assumes that a segment means a path between VS nodes, and each segment must follow the wavelength continuity constraint [7,16], because only VS node can have a wavelength conversion capability.

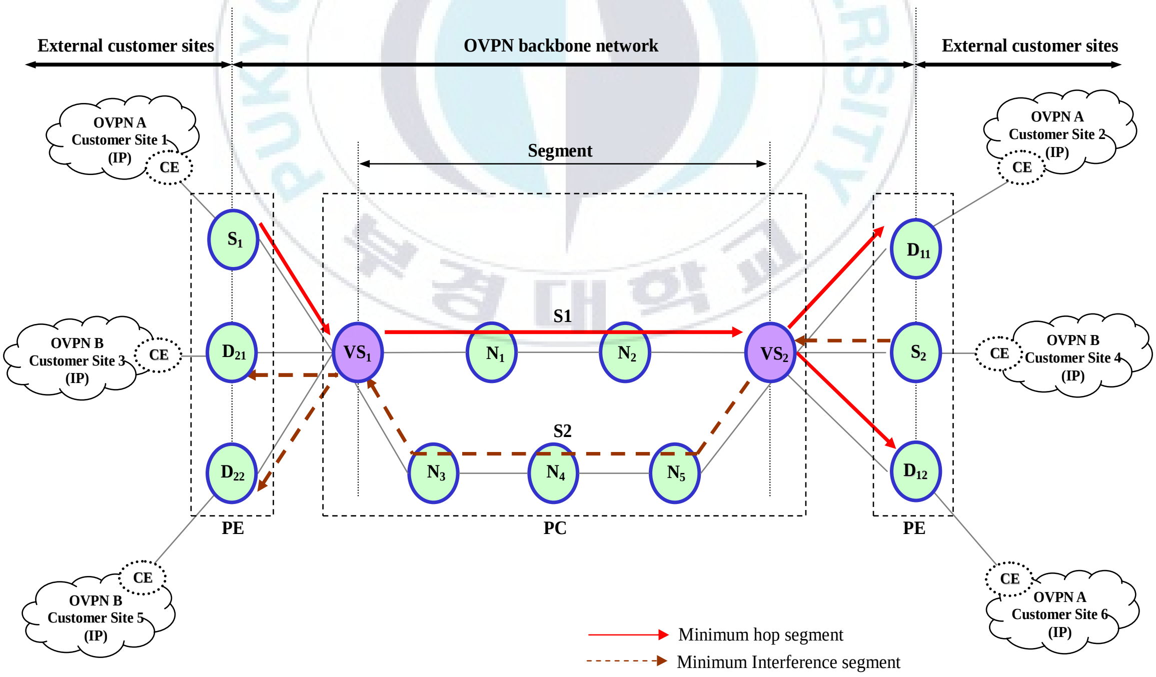


Figure 5. Illustration of the VS-MIPMR algorithm in DWDM-based OVPN

There are two potential source-destinations pairs such as (S_1, D_{11} and D_{12}) and (S_2, D_{21} and D_{22}). When S_1 is chosen for the first multicast session in order to make a resource reservation for the path between VS_1 and VS_2, the other multicast session may share the same path having a minimum-hop path but can lead to high blocking probability by inefficiently using the resource due to the traffic concentration on that path. Thus, it is better to take S_2 that has a minimum interference effect for other future multicast session requests, even though the path is longer than S_1.

Ⅲ. Priority-based Minimum Interference Path Multicast Routing (PMIPMR) Algorithm

Multicast scheme provides an efficient way of disseminating data from a source to a group of destinations, so the multicast problem in the optical networks has been studied for years and many efficient multicast routing protocols have been developed [15,24,25]. Many applications such as television broadcast, movie broadcasts from studios, video-conferencing, live auctions, interactice distance learning, and distributed games are becoming increasingly popular. These applicaions require point-to-multipoint connections in the networks. Among such applications, IPTV including TV broadcasting, Video-on-Demand (VOD), Network-based Personal Video Recorder (nPVR) and network-based Time Shifting facilities, TV on demand or Catch-up TV can be a good example for the multicast service. Figure 6 represents the network providing the IPTV service with USN(Ubiquitous Sensor Network) and user terminal by applying multicast service. In this section, a new routing algorithm for choosing an efficient path that avoids the congestion paths was proposed and also the multicast tree generation method using node priorities is described.

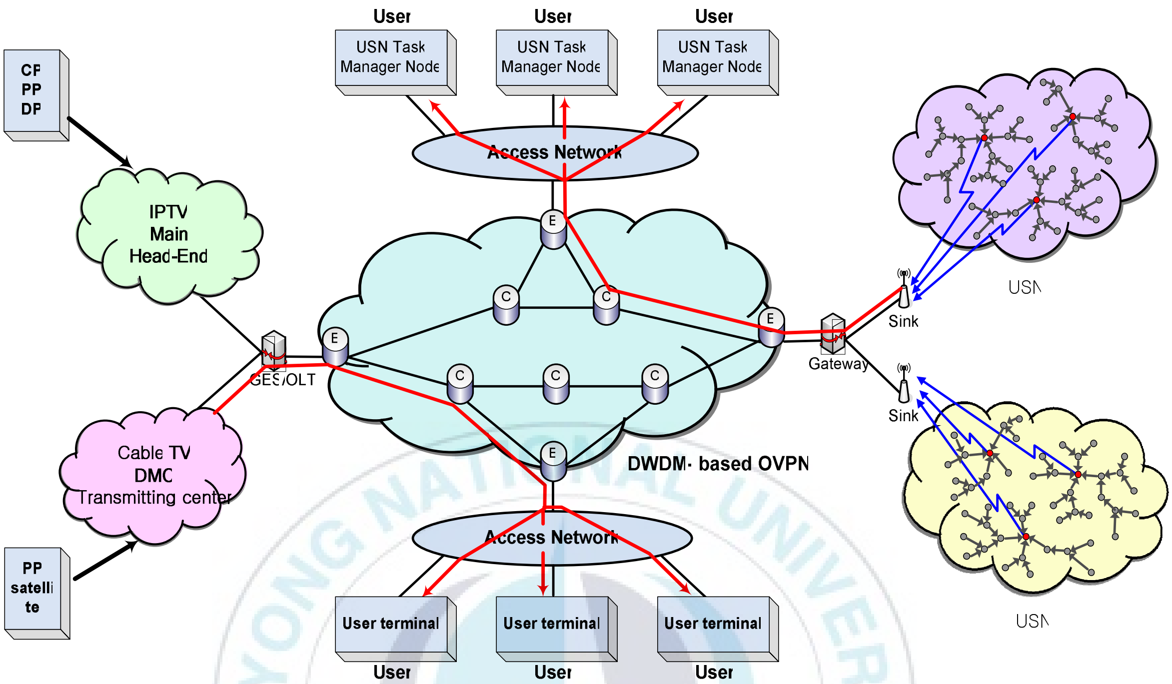


Figure 6. Illustration of multicast service for providing IPTV service in OVPN

1. Multicast Tree Generation Concept

Multicast tree generation is based on the member-only algorithm with Spawn-from-VS Heuristic and Capability-Based-Priority Heuristic proposed in [13]. The member-only algorithm has better performance than other multicast tree algorithms in [11]. It includes as many destinations as possible in a multicast tree. If a destination is at an equal distance (number of hops) to more than one node in a tree, then it connects the destination to one of the nodes which is chosen arbitrarily.

1.1. Capability-based-Priority Heuristic

The network is assumed to have different capable nodes namely split, wavelength conversion, drop-and-continue (DaC) and virtual-source (VS) nodes. The nodes in the network are assigned some priority is used when a destination needs to be included in the tree. VS nodes are assigned the highest priority followed by split-nodes, wc-nodes and DaC-nodes in the decreasing order of priority. A VS node have both splitting and wavelength conversion capabilities. A split-node has the capability of transmitting an incoming message on more than one outgoing link, whereas DaC-nodes and wc-nodes can transmit to only one outgoing link. If a node is at an equal distance to a split-node and to a DaC-node, then the split-node is chosen for connecting the node.

In figure 7, the benefit of using priority is described. Consider a multicast session with a source s and destinations d_1 to d_5. In Figure 7(a), the priorities of the nodes are not considered. Node d1 and node d_2 are directly connected to source node s. Node d_3 is connected to node d1 using wavelength W_0. Since the DaC capability of node d_1 is exhausted, node d_4 requires a separate connection from the source using wavelength W_1. Node d_5 is connected to node d_2. This session requires a total number of six channels and two wavelengths per fibber. In Figure 7(b), the priorities of the nodes are considered. Node d_3 is connected to node d_2 (split-node). Node d_4 can now be connected to node d_1. Finally, only five wavelength channels and one wavelength is required for the session.

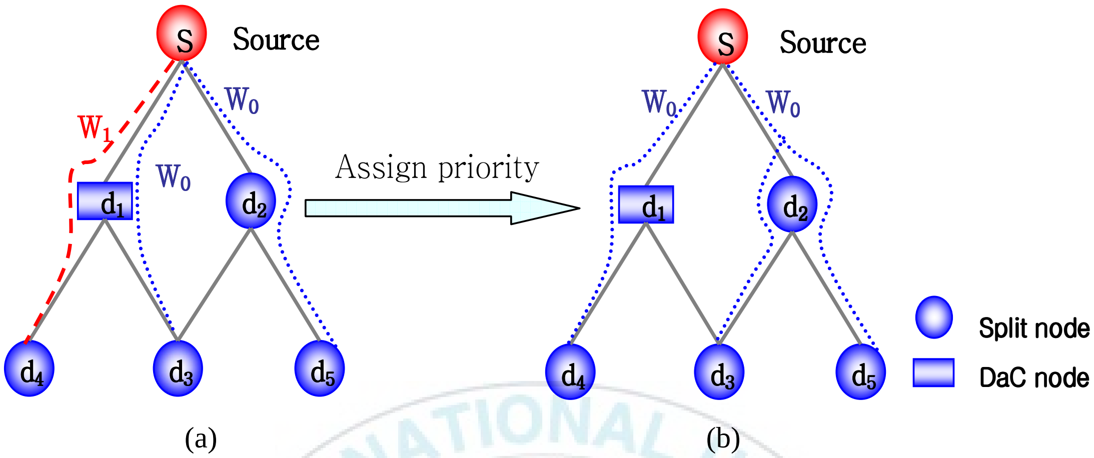
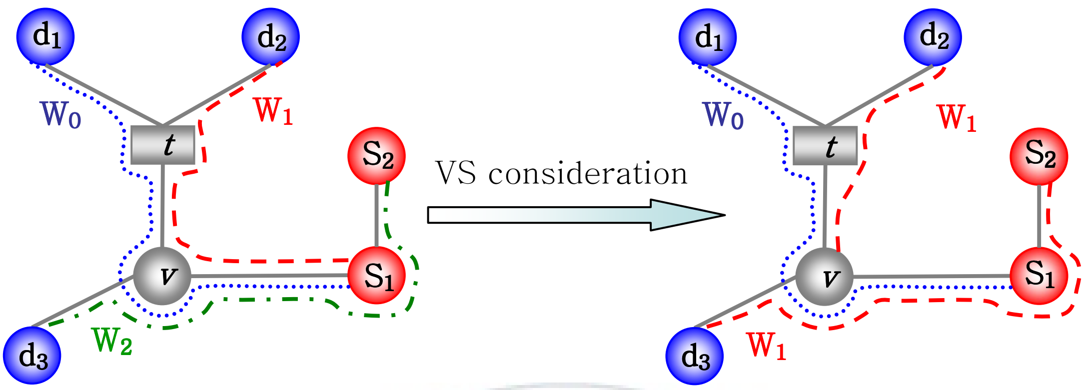


Figure 7. Illustration of the Capability-based-Priority Heuristic

1.2. Spawn-from-VS Heuristic

A VS node can act like source to spawn a new tree. The benefit of using VS node to spawn a tree is illustrated in Figure 8. There are two sessions having source and destinations as s_1, d_1, d_2, and s_2, d_3, respectively. In figure 8(a), the capability of VS (node *v*) is not considered. Node d_1 is connected to the source s_1 using W_0 via node *t* and node *v*. Since the capability of node t is exhausted, node d_2 requires a separate connection using wavelength W_1 from the source s_1. Node d_3 is connected to its source s_2 via node s_1 and node *v* for the second session. This connection requires a new wavelength W_2 as link (s_1, v) carries three connections. In figure 8(b), the capability of VS node is taken into consideration. Node d_2 is connected to node v instead of node s_1. Finally, only two wavelengths and two wavelength channels are required on (s_1, v).

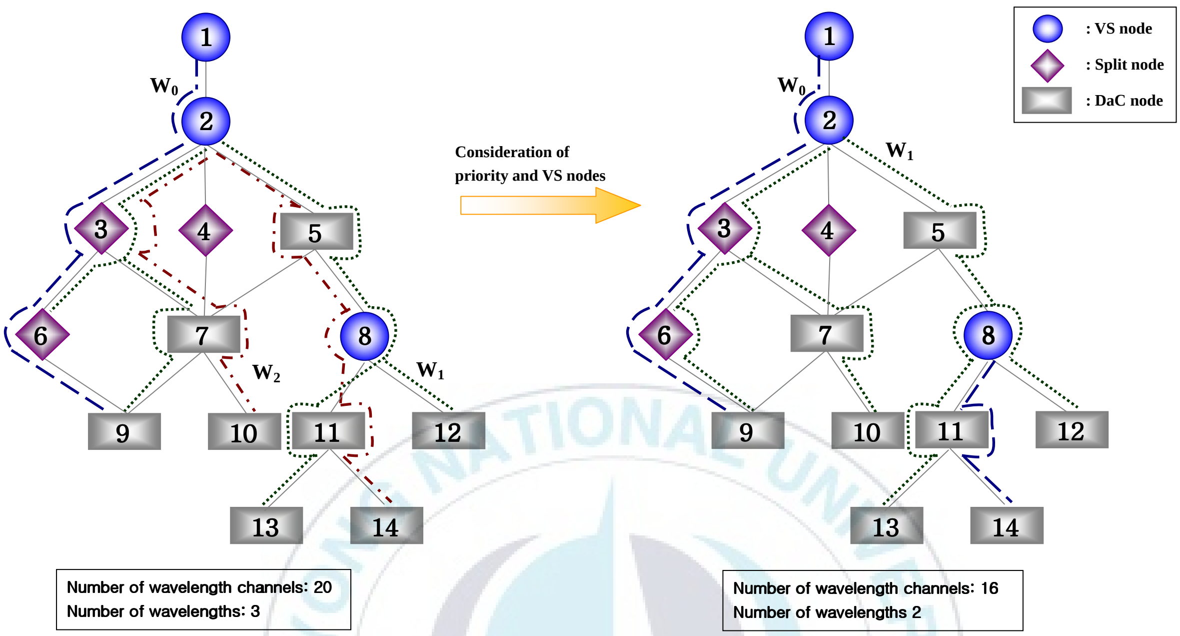


(a) (b)

Figure 8. Illustration of the Spawn-from-VS Heuristic

1.3. Description of the tree generation algorithm

The aim of the multicast tree generation is to construct a multicast forest F(*s*, *D*) for a given multicast sources with a set of destinations *D*, so as to reduce the number of wavelengths per fiber and number of wavelength channels per multicast forest. It is assumed that each node has different capability such as VS node, Split node, and DaC node. The tree generation algorithm uses both capability-based-priority and spawn-from-VS heuristics. It is based on the member-only algorithm which tries to include as many destinations as possible in one multicast tree and destinations are included in the multicast tree one at a time (the closest member node first for the source node).



(a) (b)

	Source	Destinations
Session 1	1	6, 9
Session 2	2	6, 7, 8, 9, 10, 11, 12, 13, 14

(c)

Figure 9. Illustration of the multicast tree generation algorithm

Figure 9 illustrate the working of the multicast tree generation. Here, node 1 is the source of a multicast session 1 and node 2 is the source of a multicast session 2. Nodes 2 through 12 are destinations. Node 1, 2, and 8 are VS nodes which have both split and conversion capabilities and node 3, 4, and 6 have split capability. All other nodes are DaC nodes. It tries to add as many destinations as possible to the multicast tree. Figure 9(a) shows the multicast tree generation by member-only algorithm and figure 9(b) represents the tree generation using Capability-based-Priority and Spawn-from-VS heuristics and requested multicast sessions are described in figure 9(c).

Firstly, nodes 6 and 9 are destinations of the multicast session 1. Nodes 3, 6 and 9 find their shortest paths to node 1 (1-2-3-6-9). Next, node 6 finds shortest path to node 2 (2-3-6) for multicast session 2. Node 7 is considered to node 3 because node 3 is split node. Also, node 8 finds the shortest path to node 2 through node 5. Next, node 9 is considered. It is at an equal distance to both nodes 6 and 7. In figure 9(a), node 7 is selected arbitrarily by member-only algorithm. Node 10 cannot be connected to the present multicast tree. So node 10 find the shortest path to node 2 (2-3-7-10) by a different wavelength. Node 11 is connected to node 8 and node 12 to node 8. Node 13 is connected to node 11. Node 14 cannot be included in the multicast tree because node 11 does not have spitting capability and its DaC capability has already been exhausted. Node 14 finds the shortest path to node 2. Finally, 20 wavelength channels are needed and 3 wavelengths are needed. However, node 9 is connected to node 6 with Capability-based-Priority heuristic as shown in figure 9(b). Since node 6 is a split node and has higher priority than node 7. Then, node 10 can be connected to node 3 by same wavelength. Also, node 14 is connected to node 8 with Spawn-from-VS heuristic. This is why node 14 is nearer to node 8 than source node. The link (8-11) has already been utilized to connect node 13. Hence, node 8 provides a connection to node 14 on a different wavelength. The path from node 8 to node 14 forms a new subtree rooted at node 8. So, we can save 4 wavelength channels and 1 wavelength totally.

Before the description of the tree generation algorithm, we define some notations commonly used in this algorithm as follows.

F(s,D) : multicast forest from source node(*s*) to the set of destination nodes(*D*)

*D** : the set of members yet to be included

V : the set of nodes which are useful in expanding the tree

Z : the set of *VS* nodes of multicast tree

X : the set of *VS* nodes in the network

Y : the set of split nodes in the network

T : the set of links which consist of the multicast tree

P(v,u) : the set of links which consist of the path from node *v* to node *u* in the tree

$d_{v,u}$: distance from node *v* to node *u*

M(v) : the number of children nodes that node *v* can have

The process of the multicast tree generation in the network is as follows.

Input: Request a generation of multicast tree from source node to the set of destination nodes.

Output: A multicast tree using Capability-based-Priority Heuristic and Spawn-from-VS Heuristic.

Procedure:

Step 1. Initialize $F(s,D)$, D^*, V, and Z, i.e., $F(s,D) = \Phi$, $D^* = D$, $V = s$, and $Z = \Phi$.

Step 2. Update X, Y.

Step 3. Initialize T, i.e., $T = \Phi$.

Step 4. Generate a tree by TG.

Step 5. Move the branches in T to $F(s,D)$.

Step 6. Establish the multicast forest or assign the wavelengths.

a. If $D^* \neq \Phi$ then initialize V, i.e., $V = \Phi$, and add every node $z \in Z$ to V. Go to step 3 to construct another tree.

b. If $D^* = \Phi$ then assign the wavelengths to multicast forests by using wavelength assignment algorithm.

TG (Tree-Generation) Algorithm

procedure tg;
begin
  for each node $u \in D^*$ **do**
  begin
    choose a node v, where node $v \in V$;
    for each node $v1 \in V \setminus v$ **do**
    begin
      if distance $d_{v,u} > d_{v1,u}$ **then**
        $v = v1$;
      else if distance $d_{v,u} = d_{v1,u}$ **then**
        execute TG-CP(v, $v1$);
    end;
    if distance $d_{su} \geq d_{vu}$, **then**
      add every link $e \in P(v,u)$ to the multicast tree T by TG-SVS($P(v,u)$);
  end;
end;

Figure 10. Tree generation algorithm

TG-CP (TG-Capability-based-Priority) Algorithm

procedure tg-cp(node v; node $v1$);
begin
  if (node $v \in Y$) $\cap$ (node $v1 \in X$) **then**
    node $v = v1$;
  else if (node $v \notin X$) $\cap$ (node $v \notin Y$) **then**
    node $v = v1$;
end;

Figure 11. Capability-based-Priority heuristic

TG-SVS (TG-Spawn-from-VS nodes) Algorithm

```
procedure tg-svs(set P(v,u));
begin
    for any node x on P(v,u), where x ≠ u    do
    begin
        M(x) = M(x)-1;
        if M(x) = 0 then
            remove node x from V;
        else move node x to V;
        if node x∈ X then
            add node x to Z;
    end;
    move node u from D* to V;
    if node u∈ X then
        add node u to Z;
end;
```

Figure 12. Spawn-from-VS heuristic

2. PMIPMR Algorithm

In this sub-section, a multicast routing algorithm based on VS-based approach that chooses a minimum interference segment is proposed. The algorithm overcomes the limitation of VS-based approach [13] with capability-based-Priority and Spawn-from-VS heuristics. And the proposed algorithm provides an efficient use of wavelengths.

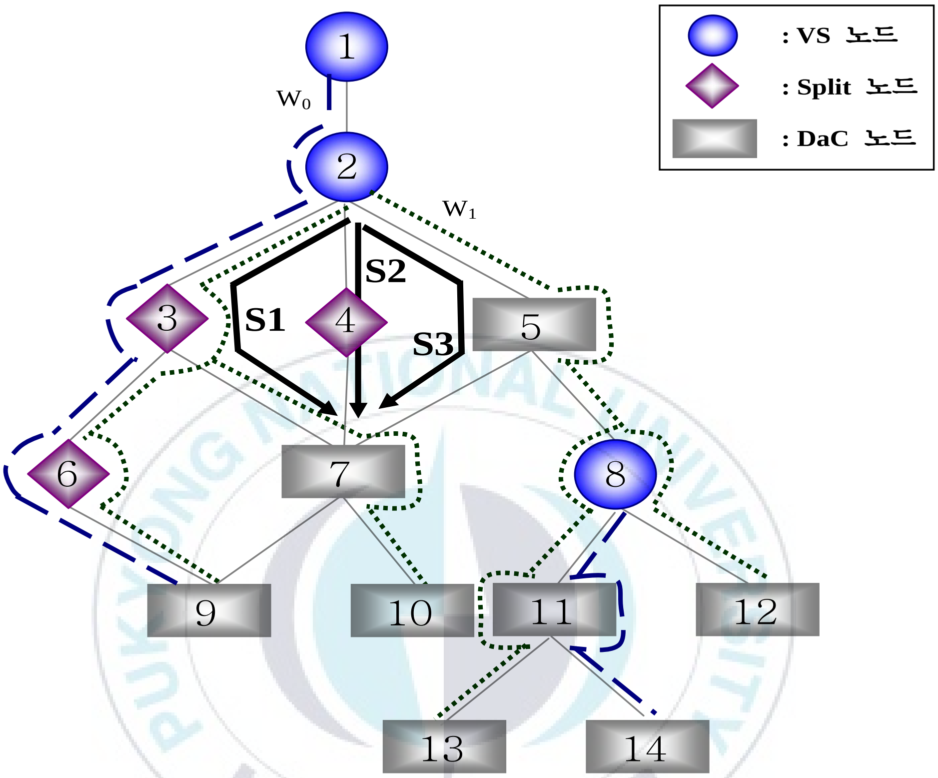


Figure 13. Illustration of the PMIPMR Algorithm

We define that a segment means a path between VS nodes or a source node and a VS node or a VS node and a destination node. And the segment can be a path between a source node and a destination node if a VS node is not existed in the path. Each segment follows the wavelength continuity constraint [8] because we assume VS nodes can only have a wavelength conversion capability.

The proposed algorithm is described in figure 13. The path connected from a node 2 to a node 7 is considered. If the path (2-3-7) becomes a congestion segment due to the traffic concentration on the minimum-hop segment and high priority (node 3 is split node), then we find the alternate segment, i.e., S2, S3. Considering the residual wavelengths and node priority contained in the segment we can calculate the minimum segment weight with other future connection requests. For example, if S2 and S3 have the same residual number of wavelengths, then S2 is selected due to the node priority (node 4). Sometimes an alternate segment is longer than an original segment. But it is better to take the alternate segment that has minimum interference effect for other future multicast session requests. Before formulation of the algorithm, we define some notations commonly used in this algorithm as follows:

G(N, L, W): Given network, where *N* is the set of nodes, *L* is the set of links, and *W* is the set of wavelengths per link. In this graph, the number of wavelengths per link is same for each link belonging to *L*.

P: Set of potential node pairs which consist of a segment that can be required a connection establishment by multicast session request in the future. Let *(i, j)* denote a generic element of this set.

(a, b): A node pair that consist of a segment required a connection establishment by current multicast session request.

S_{ab}^{n}: Pre-selected *n*-th minimum hop segment connecting the path between a *(a,b)*-pair. Here, superscript *n* denotes segment index. ($1 \leq n \leq 3$)

l_{ab}^{n} : A congestion link which has the smallest wavelength in segment S_{ab}^{n}.

S_{ij} : Minimum hop segment connecting the path between a *(i, j)*-pair.

$W(S^n_{ab})$: Accumulated total weights for S^n_{ab}.

α^n_{ab}: The weight between a (a,b)-pair.

Ω^n_{ab} : A wavelength assigned by the FF scheme in S^n_{ab}.

$R(l_{ab})$: The number of currently available wavelengths on a link l between a (a,b)-pair, where l has the smallest wavelengths, $\forall l \in L$.

π^n_{ab}: The set of links over the minimum hop segment S^n_{ab}.

π_{ij} : The set of links over the minimum hop segment in S_{ij}.

F_{ij}: The number of available wavelengths in S_{ij} .

Δ: A Threshold value of available wavelengths on S^n_{ab} (30% of the total wavelengths in S^n_{ab}).

U^n_{ab} : The rate of used wavelengths.

Here, α^n_{ab} statistically represents the weight for a segment according to the degree of multicast session resource reservation requests. Before describing the process of choosing the minimum interference segment, we define some equations.

In the proposed routing algorithm, the number of available wavelengths on a bottleneck link that has the smallest wavelengths in the segment is regarded as an important factor to improve network performance in terms of blocking probability. So, we use a notation Δ as a threshold value of the available wavelengths on the segment. Based on notation Δ, we define the critical segment as given in equation (1).

$$C_{ab} : R(l_{ab}) < \Delta \qquad (1)$$

In this equation, the appropriate choice for threshold value Δ is very important for efficient wavelength utilization. If Δ is chosen to be large, then many pre-reserving wavelengths for future connection requests can cause wavelength waste. On the other hand, if Δ is set too small, then the potential blocking probability for upcoming traffic may be high. In this paper, we set the threshold value Δ within 30% of the total wavelength number on a link. This ratio is assumed by our simulation results regardless of the number of wavelengths per link.

For using priority of nodes we use a new notation P_{ab}^{n} as a priority weight in equation (2). Here, $N(D_{ab}^{n})$ means the number of DaC nodes on the segment S_{ab}^{n} except a *(a,b)*-pair. Similarly, $N(T_{ab}^{n})$ represents the number of internal nodes on segment S_{ab}^{n} except a *(a,b)*-pair.

$$P_{ab}^{n} = \frac{N(D_{ab}^{n})}{N(T_{ab}^{n})} \qquad (2)$$

We can check the segment whether the segment can be a congestion segment or not by equation (5).

$$\begin{aligned} &CS_{ij}(ab) : \{(\pi_{ab}^{n} \cap \pi_{ij}) \neq \phi\} \cap (\Omega_{ab}^{n} \in F_{ij}) \\ &\forall (i, j) \in P \setminus (a,b), \qquad n = (1,2,3) \end{aligned} \qquad (3)$$

Equation (3) reflects whether each minimum hop segment pre-selected between a *(a,b)*-pair, i.e., S_{ab}^{n}, interferes with potential future demands or not. If the *n*-th minimum hop segment S_{ab}^{n} of a *(a,b)*-pair shares some links with the minimum hop segment S_{ij} of a *(i,j)*-pair and a assigned wavelength Ω_{ab}^{n} belongs to the set of available wavelengths F_{ij} over S_{ij} , then the *n*-th minimum hop segment of a *(a,b)*-pair is the congestion segment for the minimum hop segment of a *(i,j)*-pair.

We determine the weight of each segment for all *(i,j)*-pairs in the set *P* except the current request setting up between the *(a,b)*-pair as shown in equation (4). Using this formula, we can calculate the weight of each segment.

$$W(S_{ab}^{n}) = \sum_{\forall(i,j)\in P\setminus(a,b)} \alpha_{ab}^{n} \cdot U_{ab}^{n} \qquad (4)$$

Computing the weight for all segments is very difficult in a wide area network environment. So, we define more restricted segment than other segments for routing by using following equation (5). As shown in the equation (5), the value of U_{ab}^{n} is restricted as follows: when the *n*-th minimum hop segment S_{ab}^{n} of a *(a,b)*-pair is the congestion segment for the minimum hop segment S_{ij} of a *(i,j)*-pair, then U_{ab}^{n} is calculated. Otherwise, U_{ab}^{n} is equal to 0. Here, *N(W)* means the total number of wavelengths on a link. Consequently, computing the interference weight of the segment is simplified.

$$\begin{cases} [\ if\ (i,j) : S_{ab}^{n} \in CS_{ij}(ab)\ ] \\ \qquad U_{ab}^{n} = \dfrac{N(W) - R(l_{ab}^{n})}{N(W)} \\ [otherwise\ ] \\ \qquad U_{ab}^{n} = 0 \end{cases} \qquad (5)$$

If the segment becomes a critical segment then we can find the pre-selected minimum hop segment. In PMIPMR algorithm we pre-select three minimum hop segments to reduce computation complexity. Next, we calculate the priority weight of each segment by equation (2). The process of choosing a minimum interference segment can be explained by three cases.

Case 1. The number of the segments having minimum priority weight: 1

If the number of currently available wavelengths on a link l_{ab}^{n} (where l_{ab}^{n} has the smallest wavelengths on the segment) of the segment which has a minimum P_{ab}^{n}, is bigger than the threshold value of available wavelengths, i.e., $R(l_{ab}^{n}) > \varDelta$, then we can choose this segment for an alternative of the congestion segment. Otherwise, we can calculate the segment weights for three pre-selected segments by equation (3). Once the weight of each segment is determined, traffic are routed between the *(a,b)*-pair along the segment with the smallest weight, $W(S_{ab}^{n})$, among the three pre-selected minimum hop segments so that the current request does not interfere too much with potential future demands.

Case 2. The number of the segments having minimum priority weight: 2

In this case, two segments have same minimum priority weight. If only one of them is satisfied with the conditions ($R(l_{ab}^{n}) > \varDelta$), we can select that segment. If both segments are pleased with the conditions, then we can calculate the segment weight of two segments by equation (3) and select the segment with minimum weight. Otherwise, we should compute the segment weights of three pre-selected segments to choose a minimum interference segment.

Case 3. The number of the segments having minimum priority weight: 3

In this case, all pre-selected segments have same priority weight. So we can calculate the segment weights of three segments and choose the segment with the smallest weight.

Ⅳ. PMIPMR Algorithm with QoS Guarantee

The explosive increase of traffic volumes and real-time multimedia applications with the rapid development in Internet technologies calls for OVPN based on DWDM as high-speed transport network [26]. One of the important issues of future generation high-speed networks is the provision of proper QoS guarantees for a wide variety of multimedia multicast services such as voice telephony, video conferencing, tele-immersive virtual reality, Internet games [27]. In this section, we introduce QoS classes to provide a proper QoS services and propose differentiated QoS PMIPMR with recovery schemes for guaranteeing CE-to-CE QoS in OVPN. In section 2, we describe the generic OVPN reference architecture and we assume that external VPNs aggregate IP packets (the same destined packets at the CE nodes (Client Edge)) to make operations simple. And IP packets in an electronic domain are converted optical signal in an optical domain (E-O conversion). So, we apply QoS PMIPMR algorithm to the architectural framework for QoS support and IP packets are managed at CE the CE nodes.

1. QoS Classes

A generic QoS classification by application types is divided into six differentiated service classes based on ITU-T (International Telecommunications Union – Telecommunication Standardization Sector) [28,29].

In this sub-section, we provide three main approaches to QoS evaluation in order to provide with differentiated QoS. QoS requirements and constraints of each class is differentially applied to the OVPN based on DWDM, the result can be summarized as Table 3.

Table 3. Differentiated multicast QoS service model

Classification Criteria	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5
Applications	Real-Time, Jitter Sensitive, High Interaction (VoIP, VTC)	Real-Time, Jitter Sensitive, Interactive (VoIP, VTC)	Transaction Data, Highly Interactive (Signalling)	Transaction Data, Interactive	Low Loss Only (Short Transactions, Bulk Data, Video Streaming)	Traditional Applications of Default IP Networks
IPTD	100 ms	400 ms	100 ms	400 ms	1 s	U
IPDV	50 ms	50 ms	U	U	U	U
IPLR	1*10-3	1*10-3	1*10-3	1*10-3	1*10-3	U
IPER	1*10-4					U
Node Mechanism	Separate Queue with Preferential Servicing, Traffic Grooming		Separate Queue, Drop Priority		Long Queue, Drop Priority	Separate Queue (Lowest Priority)
Network Techniques	Constrained Routing/Distance	Less Constrained Routing/ Distance	Constrained Routing/Distance	Less Constrained Routing/ Distance	Any Route/Path	Any Route/Path
Recovery Scheme	1:1 dedicated protection	1:N shared protection	1:1 dedicated protection	1:N shared protection	Restoration	Restoration

An evaluation interval of 1 minute is suggested for IPTD, IPDV, and IPLR and in all cases. In this table “U” means “unspecified” or “unbounded”. IPTD means IP packet transfer delay defined for all successful and errored packet. IPDV is IP packet delay variation. The variations in IP packet transfer delay are also important. Streaming applications might use information about the total range of IP delay variation to avoid buffer underflow and overflow. IPER means IP packet error ratio. The ratio of total errored IP packet outcomes to the total of successful IP packet transfer outcomes plus errored IP packet outcomes in a population of interest. And IPLR is IP packet loss ratio. The ratio of total lost IP packets outcomes to total transmitted IP packets in a population of interest.

Each dependable real-time connection consists of one primary and one or more backup channels. On detection of a failure on the primary channel, one of its backups is promoted to the new primary. Since a backup is set up before a failure of the primary, it can be activated immediately, without the time-consuming and channel re-establishment process. 1:1 dedicated protection where a backup path and wavelength is reserved at the time of connection setup for each working path, and 1:N shared protection where one protection path shared among several N working paths. In table 3, class 0 and class 2 need constrained routing/distance and IPTD is 100ms. Therefore, 1:1 dedicated protection is applied for the recovery scheme. The path is selected by PMIPMR algorithm. If a failure is occurred in a primary path then a backup path can be used for the new primary path. Whereas class 1 and class 3 call for less constrained routing/distance and 400ms for IPTD. The 1:N shared protection is employed for recovery scheme. 1 backup path is shared with N primary paths which are routed by PMIPMR algorithm. For class 4 and class 5, network technique is any route/distance and 1s for class 4 and “unspecified” for class 5. It is similar to current Internet service. And for recovery scheme, we provide restoration scheme which provide a recovery procedure after link failure is occurred. At first, the path is chosen by PMIPMR algorithm and a new path is routed by the proposed algorithm after the failure occurrence.

2. Architectural framework for QoS support

An aim of the QoS architectural framework is set of generic network mechanisms for controlling the network service response to a service request, which can be specific to a network element, or for signaling between network elements, or for controlling and administering traffic across a network. In this sub-section, we utilize the framework of ITU-T Rec. Y.1291 [30] and apply the proposed QoS MIPMR algorithm for QoS routing and congestion avoidance. As shown in figure 14, the framework consists of three planes. Control plane contains mechanisms dealing with the pathways through which user traffic travels. These mechanisms include admission control, QoS routing, and resource reservation. Data plane contains mechanisms dealing with the user traffic directly. These mechanisms include buffer management, congestion avoidance, packet marking, queuing and scheduling, traffic classification, traffic policing, and traffic shaping. Management plane contains mechanisms dealing with operation, administration, management aspects of the network. These mechanisms include Service Level Agreement (SLA), traffic restoration, metering and recording, and policy.

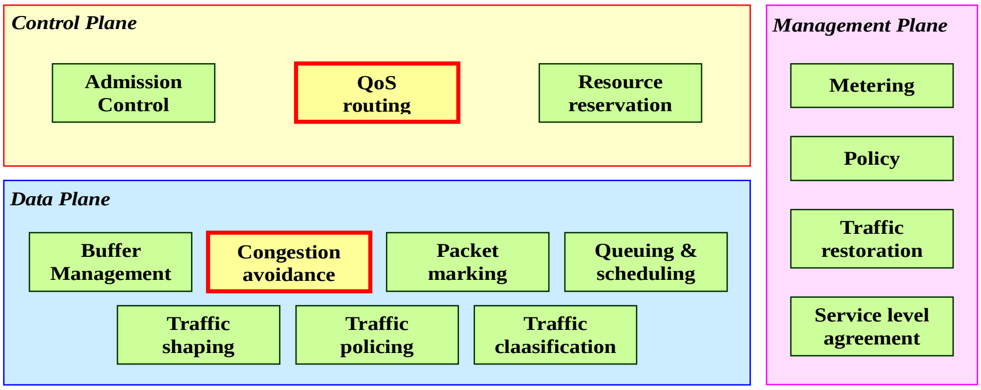


Figure 14. Architectural framework for QoS support

2.1. Control plane mechanisms

Admission control:

This mechanism controls the traffic to be admitted into the network. The decision can depend on if adequate network resources are available so that newly admitted traffic does not overload the network and degrade service to ongoing traffic. For a service provider, maximal traffic should be admitted while the same level of QoS is maintained for the existing traffic. Admission control can also be used to meet requirements for service reliability/availability over a specified period for the desired transaction types as negotiated in the SLA. Admission control policies give preference to traffic streams deemed to be more critical by a service provider under conditions of congestion.

QoS routing:

QoS routing concerns the selection of a path satisfying the QoS requirements of a flow. Practical QoS routing schemes consider mainly cases for a single QoS metric such as bandwidth or delay or for dual QoS metrics such as cost-delay, cost-bandwidth, and bandwidth-delay. To guarantee performance on a selected path, QoS routing needs to be used in conjunction with resource reservation to reserve necessary network resources along the path. The proposed MIPMR algorithm with the requirements of QoS classes (QoS MIPMR) is used for QoS routing in the framework.

Resource reservation:

This mechanism sets aside required network resources on demand for delivering desired network performance. Whether a reservation request is granted is closely tied to admission control. All the considerations for admission control therefore apply. But in general a necessary condition for granting a reservation request is that the network has sufficient resources. Resource reservation is typically done with RSVP-TE+ (Resource ReSerVation Protocol with Traffic Engineering extensions) [31] or CR-LDP+ (Constraint-based Routed Label Distribution Protocol with extensions) [32]

2.2. Data plane mechanisms

Buffer management:

Queue or buffer management deals with which packets, awaiting transmission, to store or drop. A common criterion for dropping packets is the queue reaching the maximum size. Packets are dropped when the queue is full. The order of packets drop depends on the drop disciplines such as tail drop, front drop, and random drop.

Congestion avoidance:

Congestion in a network occurs when the traffic exceeds what the network can handle because of lack of resources such as link bandwidth and buffer space. Congestion avoidance deals with more robust means for keeping the load of the network under its capacity such that it can operate at an acceptable performance level, not experiencing congestion collapse. If congestion occurs, the proposed QoS MIPMR algorithm finds an alternate path that does not interfere too much for potential future traffics. So, utilization of wavelengths and blocking probability can be improved.

Queuing and scheduling:

This mechanism controls which packets to select for transmission on an outgoing link. Incoming traffic is held in a queuing system, which is made of, typically, multiple queues and a scheduler.

Packet marking:

Packets can be marked according to the specific service classes that they will receive in the network on a per-packet basis.

Traffic classification:

This mechanism determines the aggregate to which the packet belongs and the respective service level agreement.

Traffic policing:

Policing deals with the determination of whether the traffic being presented is on a hop-by-hop basis compliant with pre-negotiated policies or contracts. Typically non-conformant packets are dropped. The senders may be notified of the dropped packets and causes determined and future compliance enforced by SLAs.

Traffic shaping:

This mechanism deals with controlling the rate and volume of traffic entering the network. The entity responsible for traffic shaping buffers non-conformant packets until it brings the respective aggregate in compliance with the traffic. Shaping often needs to be performed between the egress and ingress nodes.

2.3. Management plane mechanisms

Service level agreement:

A Service level agreement (SLA) typically represents the agreement between a customer and a provider of a service that specifies the level of availability, serviceability, performance, operation or other attributes of the service. It may include aspects such as pricing that are of business nature.

Traffic metering and recording:

The Metering concerns a monitoring for the temporal properties (e.g., rate) of a traffic stream against the agreed traffic profile. It involves observing traffic characteristics at a given network point and collecting and storing the traffic information for analysis and further action. Depending on the conformance level, a meter can invoke necessary treatment (e.g., dropping or shaping) for the packet stream.

Traffic restoration:

Restoration is broadly defined as the mitigating response from a network under conditions of failure. Network failures are divided in two; node failure and transport link failure. As in the case of admission control, certain traffic streams related to critical services may require higher restoration priority than others. A service provider needs to plan for adequate levels of spared resources such that QoS SLAs are in compliance under conditions of restoration.

Policy:

Policies are a set of rules typically for administering, managing and controlling access to network resources. They can be specific to the needs of the service provider or reflect the agreement between the customer and service provider, which may include reliability and availability requirements over a period of time and other QoS requirements. Service providers can implement mechanisms in the control and data planes based on policies.

Ⅴ. Performance Evaluation

1. Network Model

Simulations are carried out to prove the efficiency of the proposed PMIPMR algorithm. Test networks used in simulations are NSFnet which have 14 nodes and 20 links as illustrated in Figure 15. 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 and the traffic pattern is dynamic.

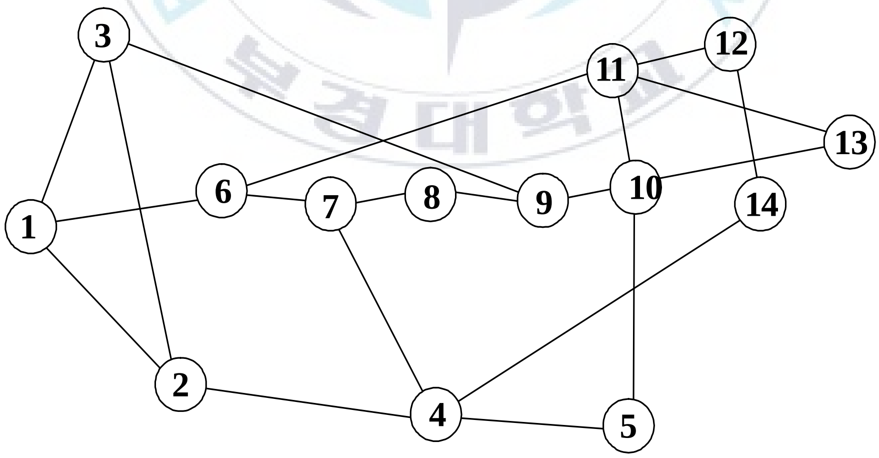


Figure 15. Test network models

2. Analysis of Numerical Results

We carry out simulations in terms of blocking probability, usage of wavelengths required, usage of wavelength channels required.

Firstly, Figure 16 shows the simulation result of the proposed PMIPMR scheme. Here, the group size (GS) that determines the number of members to construct a multicast session is 0.2 and 0.3 [13]. The figure reveals that the blocking probability of the proposed scheme is better performance (improved about 10%~15%) than previous VS-based scheme in both cases of GS 0.2 and 0.3.

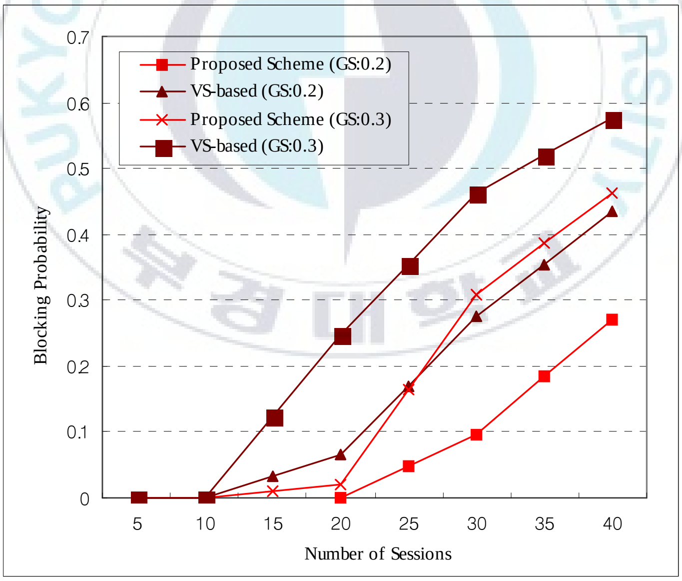


Figure 16. Blocking probability of the proposed multicast RWA

We carried out simulation for network utilization of the proposed scheme. We will compare the result of the proposed scheme with VS-based method in respect of the utilization of wavelengths and wavelength channels, analyze the gain of the number of wavelengths and the loss of the number of wavelength channels. The gain and loss mean the differences of the number of wavelengths and of the number of wavelength channels between the proposed scheme and VS-based method, respectively.

Figure 17 reveals that the proposed scheme outperforms the VS-based method due to the selection of the minimum interference paths. In figure 18, therefore, the proposed scheme can accomplish approximately 25% and 26% improvements of the number of wavelengths in both cases of GS 0.2 and 0.3, respectively, in comparison with those of the VS-based method.

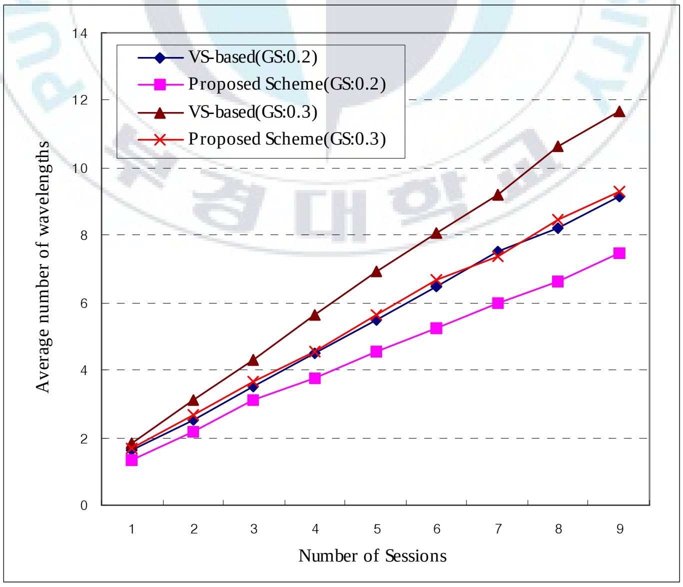


Figure 17. The average number of wavelengths in the proposed multicast RWA

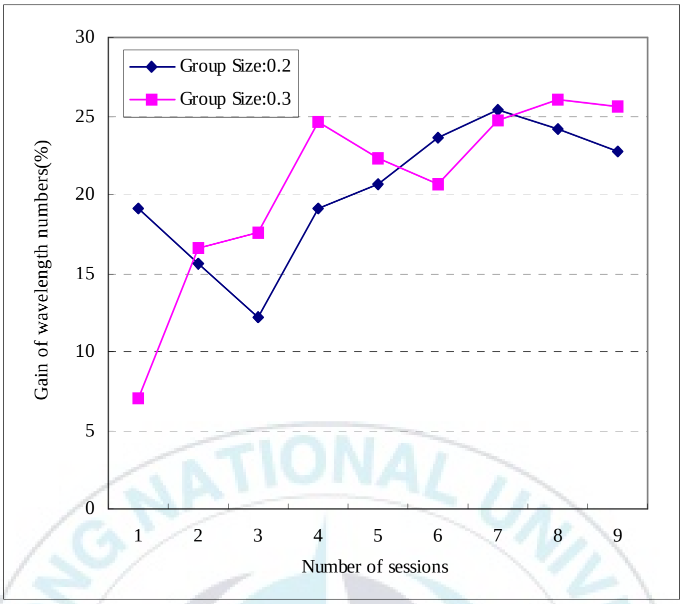


Figure 18. The gain of the number of wavelengths in the proposed multicast RWA

Although the proposed scheme slightly needs more numbers of wavelength channels than those of VS-based method due to the detour paths to avoid congestion links shown in figure 19, we can identify that the loss of the number of wavelength channels does not exceed 8% in both cases of GS 0.2 and 0.3, as shown in figure 20.

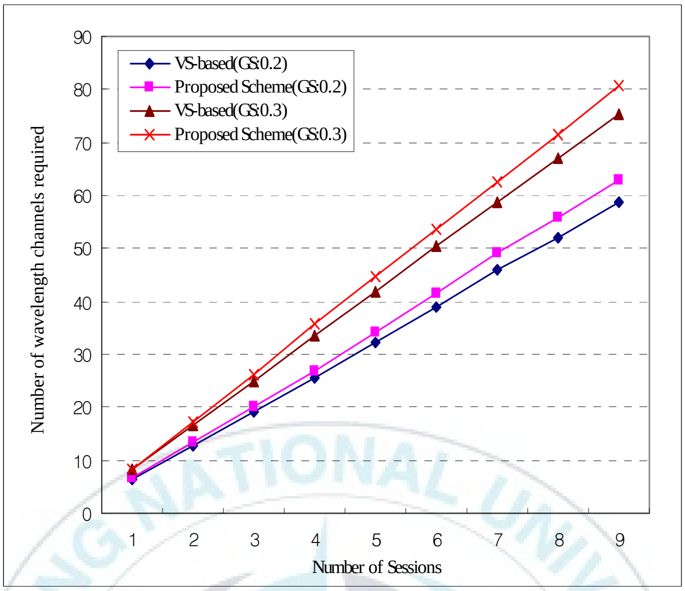


Figure 19. The number of wavelength channels in the proposed multicast RWA

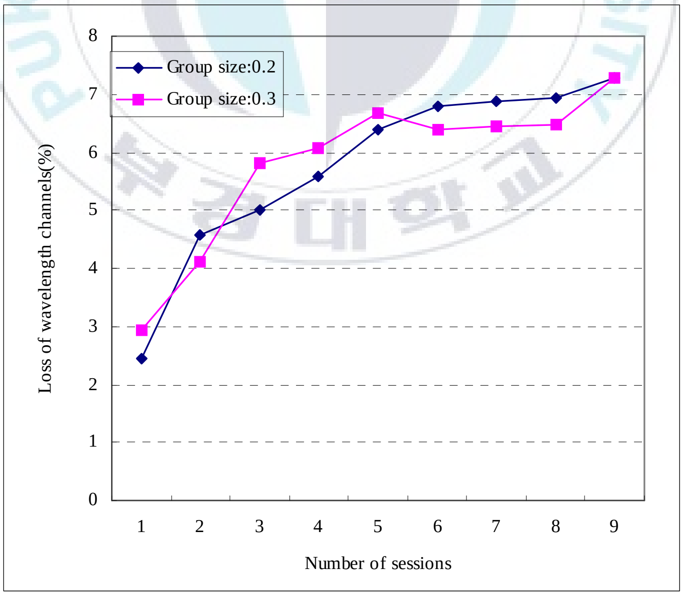


Figure 20. The loss of the number of wavelength channels in the proposed multicast RWA

Ⅵ. Conclusion

In this paper, a new routing algorithm, Priority-based Minimum Interference Path Multicast Routing (PMIPMR) algorithm is proposed in DWDM-based OVPN backbone network. The objective of the proposed scheme is to choose a wavelength route that does minimize interference in accordance with potential future connection requests by avoiding congested segment.

Moreover, we analyzed the architectural framework for QoS support with QoS classes. And a QoS MIPMR is also proposed in combination with QoS constraints and a recovery strategy based on the differentiated QoS classes to provide QoS guarantee for a wide variety of multicast applications.

From the extensive simulation results, the proposed PMIPMR algorithm achieved better performance than the existing routing algorithms for the blocking probability. Whereas we observed that the proposed PMIPMR algorithms slightly need more numbers of wavelength channels due to the detour paths to avoid a congestion segment. However, we experienced that the proposed schemes significantly improve the utilization of the number of wavelengths comparing with the previous methods.

As a future research, we will study about the additive wavelength assignment algorithm that can be considered after the selection of the multicast path. The FF algorithm that used in previous schemes has a simple procedure but we have a plan to study various wavelength assignment methods which need a smaller number of wavelength conversion.

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광가상사설망에서 QoS를 보장하는 우선순위 기반 최소 간섭 경로 멀티캐스트 RWA 알고리즘 연구

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국 문 요 약

차세대 광 인터넷 백본망은 IP 에 의해 제어되는 GMPLS(Generalized Multi-Protocol Label Switching)를 기반으로 DWDM(Dense Wavelength Division Multiplexing) 광 네트워크를 사용하는 IP/GMPLS over DWDM 프레임워크로 발전되고 있다. 이러한 DWDM 기술을 활용한 광가상사설망(OVPN - Optical Virtual Private Network)에서 QoS(Quality of Service)를 보장하는 라우팅 알고리즘의 개발 연구는 중요한 기술 중의 하나이다. 본 논문에서는 차등화된 QoS 요구사항을 만족하는 새로운 멀티캐스트 라우팅(MIPMR-Minimum Interference Path Multicast Routing) 알고리즘을 제안한다. 제안된 알고리즘은 멀티캐스트 트리 생성 후 혼잡 경로(세그먼트)가 발생 시 우선순위가 높은 우회 경로로 라우팅함으로써 블록률 및 자원 사용률을 개선한다. 또한, QoS 보장을 위한 QoS 클래스 분석과 이를 토대로 QoS MIPMR 알고리즘을 제안하고 CE-to-CE QoS 보장을 위한 QoS 구조적 프레임워크를 제시한다. 이와 더불어, 파장할당 알고리즘으로 동작과 알고리즘 수행 과정이 비교적 간단한 First-Fit 방법을 사용하며, 제안된 알고리즘의 광범위한 시뮬레이션을 통해 성능을 평가한다. 시뮬레이션 결과를 통해 제안된 알고리즘이 블록률, 파장 사용률, 파장 채널 사용률 측면에서 기존의 Spawn-from-VS 와 Capability-based-Priority Heuristic 을 사용한 VS 기반의 멀티캐스트 라우팅 알고리즘에 비해 성능이 우수함을 입증한다. 혼잡 경로 발생 시 우회 경로로 라우팅함으로써 파장 채널 수에서는 약간의 손실이 발생하지만, 생존률과 파장 사용률의 비교로 제안된 우선순위를 고려한 멀티캐스트 라우팅 알고리즘 성능의 우수함을 평가한다.

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