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Thesis for the Degree of Master of Engineering

A Study on Routing Algorithms for Ubiquitous Sensor Network Services Based on Broadband Convergence Networks

by

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Department of Telecommunication Engineering

The Graduate School

Pukyong National University

February 2007

A Study on Routing Algorithms for Ubiquitous Sensor Network Services Based on Broadband Convergence Networks

광대역통합망 기반 유비쿼터스 센서네트워크 서비스를 위한 라우팅 알고리즘 연구

Advisor: Prof. Sung-Un Kim

by

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A thesis submitted in partial fulfillment of the requirements
for the degree of

Master of Engineering

in Department of Telecommunication Engineering, The Graduate School,
Pukyong National University

February 2007

이춘재의 공학석사 학위논문을 인준함

2007년 2월 23일

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A Study on Routing Algorithms for Ubiquitous Sensor Network Services Based on Broadband convergence Networks

A dissertation

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A Study on Routing Algorithms for Ubiquitous Sensor Network Services Based on Broadband Convergence Networks

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Abstract

Over the past decade, the advances of communications technologies and the rapid spread of WWW (World Wide Web) have brought on the exponential growth of users using Internet and real-time multimedia services like IPTV (Internet Protocol Television) and TPS (Triple Play Service). As the growth of users using multimedia services, a lot of research activities to transport converged various services have continuously been performed. Specially, in our country, Broadband convergence Network (BcN) has been studied by many service providers under the support of government's u-IT839 policy. An IP/GMPLS-based control plane combined with a wavelength-routed dense-wavelength division (DWDM) optical transport network is seen as a very promising approach for the realization of a future backbone of BcN.

To provide the Ubiquitous Sensor Network (USN) services (one of the most important services in the u-IT839 policy) based on BcN backbone network and access networks for USN service manager, combining the data that comes from many sensor nodes into a set of meaningful information and sending them to the sink node through an optimal route are considered the crucial issues to solve.

For surmounting these problems, this thesis proposes a new routing algorithm

for reducing the power consumption of each sensor node in WSNs, combining energy aware cluster head election technique with DAG (Directed Acyclic Graph) concept in TORA (Temporally-Ordered Routing Algorithm).

And also this thesis suggests a multicast routing algorithm that utilizes DWDM optical resource efficiently when the useful data gathered at the sink node is transmitted to a USN service manager.

Ⅰ. Introduction

Over the past decade, the advances of communications technologies and the rapid spread of WWW (World Wide Web) have brought on the exponential growth of users using Internet and real-time multimedia services like IPTV (Internet Protocol Television) and TPS (Triple Play Service).

Moreover our country has 13.8 million broadband subscribers in a population of 48 million people. Now it plans to build a nationwide Internet access infrastructure capable of speeds between 50M bps (bits per second) and 100M bps by 2010. This project is called the Broadband Convergence Network (BcN). BcN will offer telecommunications, broadcasting and Internet access from a wide variety of devices.

BcN is the next generation convergence network in order to use the quality guaranteed broadband multimedia service condensed with telecommunications, broadcasting, and Internet access at anytime and anyplace. In order to provide this network, the next generation convergence network must be equipped with Dense Wavelength-Division Multiplexing (DWDM) based transmission network, which multiplex one fiber into various wavelengths to send much information. Whereas on purpose to control for both optical and electronic networks, Generalized Multi-Protocol Label Switching (GMPLS) has shown up and is currently under standardization at the Internet Engineering Task Force (IETF). Therefore IP/GMPLS over DWDM is emerging as a dominant technology for use in the next generation convergence backbone network.

To provide the Ubiquitous Sensor Network (USN) services (one of the most important services in the u-IT839 policy) based on BcN backbone network and access networks for USN service manager, combining the data that comes from many sensor nodes into a set of meaningful information and sending them to the sink node through an optimal route are considered the crucial issues to solve.

For surmounting these problems, we need to develop energy efficient routing algorithms to lengthen network lifetime in Wireless Sensor Networks (WSNs). And also we have to implement optimal Routing and Wavelength Assignment (RWA) schemes that utilize DWDM optical resource efficiently when the useful data gathered at the sink node is transmitted to a USN service manager. Moreover, the multicast routing method supplies more efficient solution than the previously used unicast routing method in the respect of bandwidth utilization in the next generation convergence network because USN services are commonly established a point-to-multipoint connection.

To support multicast services at the WDM layer, the concept of the light-tree was introduced in [1], which is a point-to-multipoint extension of a lightpath (i.e., an all-optical WDM channel). The key advantage of light-tree is that only one transmitter is needed for transmission and intermediate tree links can be shared by multiple destinations. To support all-optical multicasting sessions efficiently, some nodes in DWDM networks need to have the light splitting capability [2]. A node with splitting capability can forward an incoming message to multiple output channels, and therefore is multicast-capable (MC). An MC node, however, is expensive to implement throughout the whole networks, so the concept of sparse-splitting was first introduced in [3]. With the sparse splitting capability, only small percentages of nodes in the networks are MC, and the rest are Multicast Incapable (MI). MI nodes can forward an input signal only to one of the output ports; thus it cannot serve as a branching node of a light-tree.

In order to provide the multicast services, some multicast routing algorithms were proposed based on Source-based tree and Steiner-based tree. In Source-based tree, a multicast tree was constructed to minimize the cost of individual paths from a source to each destination [3]. In [4], Steiner-based multicast methods were proposed to minimize the total cost of the tree. However, the previous researches had following restrictions. In wide area networks, the destinations of a session are distributed over the globe, so the delay incurred in constructing the light tree will be very high. Moreover, the tree may need to be reconstructed, if a link or a node fails. Therefore it needs to have a simple procedure to add and delete a node from the existing multicast session.

To overcome these limitations, [5] proposed Virtual Source (VS)-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 that 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 overheads due to the resource reservation for paths between VS nodes also increase, especially in the frequently used links, i.e., the critical links. In order to reduce the overheads in the critical links that affect the network performances, it needs a link-managing scheme between VS nodes throughout the networks [6].

To surmount this problem, we propose a new Multi-Cast RWA (MCRWA) method choosing a link that does not interfere too much with potential future multicast session requests, called Virtual Source-based Minimum Interference Path

Multicast Routing (VS-MIPMR) [6-10]. Our work is inspired by the previously proposed Minimum Interference Routing (MIR) algorithm with traffic engineering in a multi-protocol label switching (MPLS) network [6-9]. Moreover, in [7] Multi-Wavelength Minimum Interference Path Routing (MW-MIPR) was proposed for an extension of MIR from the viewpoint of providing an appropriate traffic-engineering scheme through efficiently utilizing wavelengths by taking into consideration the potential future network's congestion states. Using MW-MIPR, this paper provides a new MCRWA method for multicast services, which efficiently uses the wavelength resources in comparison with VS-based tree generation method.

In addition to the efficient control of DWDM-based backbone network, external networks must be equipped with approximate control algorithms according to their applications. Especially, the USN service shows proper solutions of what we want to gain at anytime and anyplace, in which it is mandatory to reduce the battery consumption of each sensor node in order to extend the whole network lifetime of WSNs.

WSNs have been envisioned to have a wide range of applications in military, environment, health, home and other commercial areas [11]. Recently, a lot of research activities have recently been dedicated to WSNs including design issues related to routing, MAC and collaborative data gathering mechanisms. Among these design issues, energy efficiency is a key design objective because it is directly influencing the network lifetime in WSNs. Therefore, many power saving algorithms have been studied. Specially, several routing techniques have been designed for WSNs.

The routing techniques are classified into three categories based on the underlying network structure [12]: flat, location-based, and hierarchical routing. In flat routing, each node typically plays the same role and sensor nodes collaborate to perform the sensing task. In location-based routing, sensor nodes are addressed by means of their location and these sensor nodes' positions are exploited to route data in the network. On the other hand, in hierarchical routing, nodes play different roles in the network. Thus, hierarchical routing is mainly two-layer routing where one layer is used to select CHs and the other for routing. However, most hierarchical routing protocols have not taken into consideration the routing but rather data aggregation, channel allocation, and so on.

In [13], Heinzelman, et al. proposed Low Energy Adaptive Clustering Hierarchy (LEACH) as a hierarchical clustering algorithm for WSNs. In LEACH, cluster member nodes send information to their CH node. And CH nodes compress data arriving from cluster member nodes and then send an aggregated packet to the remote base station (BS). LEACH randomly selects a few sensor nodes as CHs with some predefined probability and rotates this role to evenly distribute the energy load among the sensor nodes in the network. Therefore, LEACH accomplishes significant energy savings and prolongs the network lifetime over fixed clustering and other conventional schemes. But LEACH has some problems, such that a CH node uses up own energy while it plays a role of CH and cluster member nodes away from the CH node consume much more transmission energy comparing to the nodes close to the CH node.

In order to reduce the transmission energy consumed by cluster member nodes to send information to the CH node in LEACH, we proposed Data Aggregation algorithm Using DAG rooted at the Cluster Head (DAUCH) algorithm [14].

DAUCH is one of the hierarchical routing protocols in WSNs, combining the random CH selection technique in LEACH with Directed Acyclic Graph (DAG) in Temporally-Ordered Routing Algorithm (TORA) [15]. Due to the short propagation distance between a sender and a receiver, DAUCH makes improvements in the energy savings and the network lifetime compared with LEACH. But, DAUCH has the same problem with LEACH in the sense of the energy exhaustion of CH because CH selection algorithm of DAUCH is identical to that of LEACH.

This paper also proposes Energy aware DAUCH (EDAUCH) that ameliorates the CH selection algorithm of DAUCH. EDAUCH performs CH selection by considering residual energy level of a node that is the ratio of a node's current energy to initial energy. In DAUCH, if a CH node does not fill the role of CH during the DATA transfer phase, cluster member nodes waste own energy on useless transmission to their incapable CH node and BS cannot receive any information from the incapable CH node. In order to resolve the problem mentioned above, in EDAUCH, if the residual energy level of a node is less than a defined value at that time, it cannot be selected as CH. Hence, EDAUCH has better energy efficiency than DAUCH.

The rest of the paper is organized as follow: in section II, we review the state of previous routing researches in WSNs and BcNs. We define a new routing algorithm for WSNs in section III, and define a new MCRWA algorithm for BcNs in section IV. Experiment results showing effects of new algorithms and our conclusion are presented in section V and VI, respectively.

Ⅱ. Background

1. Ubiquitous Sensor Network Services Based on Broadband Convergence Networks

USN is drawing a lot of attention as a method for realizing a ubiquitous society. It collects environmental information to realize a variety of functions, through a countless number of compact wireless nodes that are located everywhere to form an ad hoc arrangement, which does not require a communication infrastructure. An example for its application under consideration is forecasting the outbreak of forest fires by monitoring the temperature of the hills and fields.

USN is constructed by allowing an electronic tag, which is attached to objects to sense the surrounding environment. It manages real-time information through a network. The USN expands the information-oriented society from a strictly human centered paradigm to one including objects.

The end result is a unified BcN and ultimately a Ubiquitous Network. In the early phase, USN will be developed from individual identification of an RF tag. In the next phase, the ability to sense its environmental surrounding will be added into the tag. In the final phase, ad hoc network among objects is built and will control the other tags, which are operating at a lower functionality[16].

USN technology is the combination of wired and wireless networks consisting of an electronic tag, reader, middleware, and application platform. Especially, the technologies related with WSN and BcN are the basis of USN services based on BcN. Figure 1 presents point-to-point (P2P) and point-to-multipoint (P2MP) RWA problems of IP/GMPLS over DWDM based BcN backbone network and access networks. The same figure shows the routing problem of WSN for USN services.

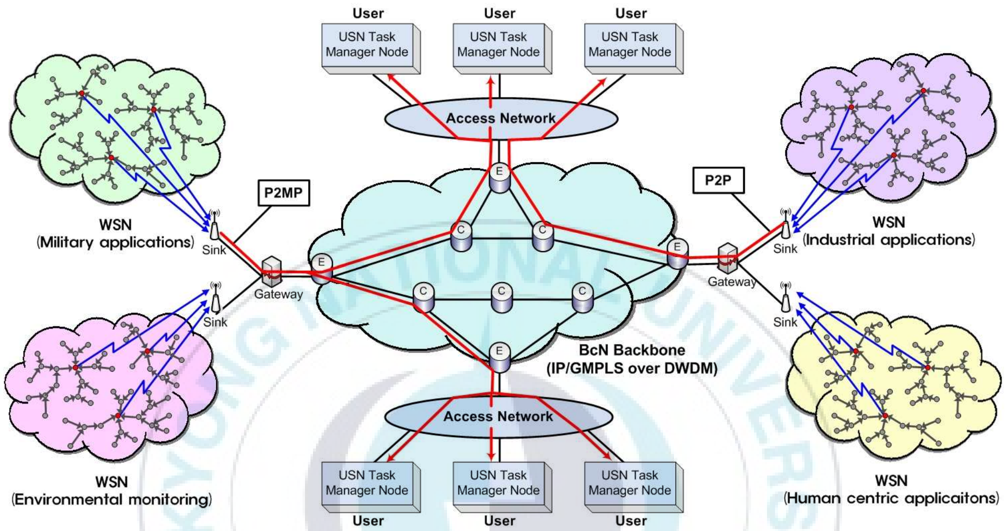


Figure 1. Ubiquitous Sensor Network services based on Broadband convergence Network

There are the numerous USN services that utilize WSNs. Table 1 summarizes applications and research institutions for USN services[11, 17].

Table 1. Applications and research institutions for USN services

Service	Applications	Research institution
Military applications	• Enemy tracking • Target classification • Reconnaissance of opposing forces and terrain • Monitoring friendly forces, equipment and ammunition • Battle damage assessment • Nuclear, biological and chemical attack detection and reconnaissance	University of Virginia, Ohio State University, Palo Alto Research Center, University of Wisconsin-Madison
Environmental monitoring	• Indoor: home automation, optimal control of the indoor environment, mitigation of fire and earthquake damages • Outdoor: forest fire detection, forecasting weather phenomena, habitat monitoring, irrigation management, crop management	SABER (Sensors and Buildings Engineering Research Center), U. C. Berkeley, Intel Research, University of Hawaii, North Carolina State University
Industrial applications	• Inventory control • Detection of faulty parts • Wearable motes • Monitoring the condition of pumps at gas stations	British Petroleum, Intel Research, Helsinki University of Technology, Shell Oil Co.
Human centric applications	• Telemonitoring of human physiological data • Human vision restoration • Tracking and monitoring doctors and patients • Tracking drug usage inside hospitals	Intel Research, UCLA, Wayne State University
Applications to robotics	• Detection of level sets of scalar fields (like isothermal or isobar curves) • Virtual keyboard • Solution to the “coverage problem” • Support the operation of a sensor network: sustaining the energy resources of the sensor network indefinitely, maintaining and configuring hardware, detecting sensor failures, appropriate deployment for connectivity among nodes	University of Southern California, Intel Research, Deakin University, U. C. Berkeley

2. Analysis of Previous Routing Techniques in Wireless Sensor Networks

Due to recent technological advances, the manufacturing of small and low-cost sensors has become technically and economically feasible. These sensors measure ambient conditions on the environment surrounding them and then transform these measurements into signals that can be processed to reveal some characteristics about phenomena located in the area around these sensors. A large number of these sensors can be networked in many applications that require unattended operations, hence producing a WSN. In fact, the applications of WSN are quite numerous. For example, WSNs have profound effects on military and civil applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance, distributed computing, detecting ambient conditions such as temperature, movement, sound, light, or the presence of certain objects, inventory control, and disaster management. Deployment of a sensor network in these applications can be in random fashion (e.g., dropped from an airplane in a disaster management application) or manual (e.g., fire alarm sensors in a facility or sensors planted underground for precision agriculture). Creating a network of these sensors can assist rescuer operations by locating survivors, identifying risky areas, and making the rescue team more aware of the overall situation in a disaster area.

Typically, WSNs contain hundreds or thousands of these sensor nodes, and these sensors have the ability to communicate either among each other or directly to an external base station. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. Especially, the underlying network structure can play a significant role in the operation of the routing protocol in WSNs. Therefore, the routing techniques are classified into three categories based on the underlying network structure [12]: flat, location-based, and hierarchical routing.

In addition to the routing protocol, data aggregation also plays one of critical factors because the data on the field can be the same information. So data aggregation can reduce the redundant data transfer to save the limited node energies. Figure 2 presents the routing techniques in WSNs.

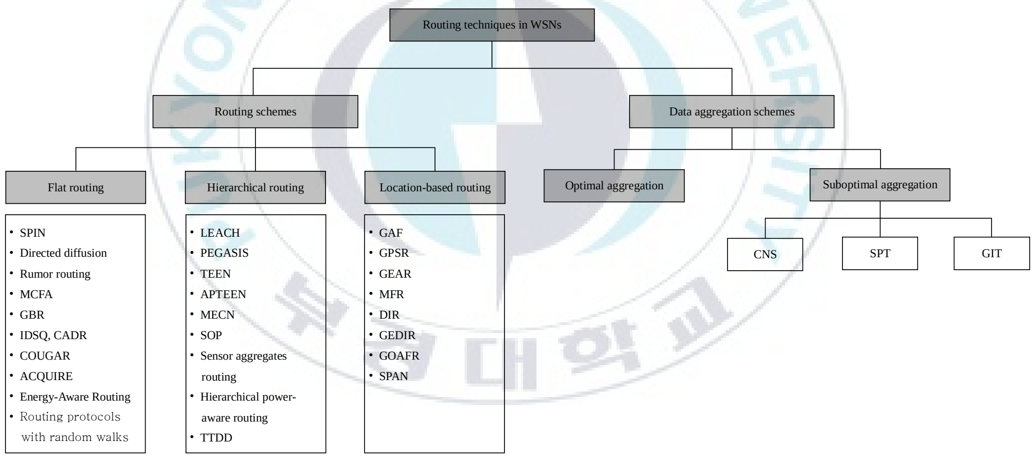


Figure 2. Routing techniques in WSNs

2.1 Routing Schemes

1) Flat Routing

Flat routing is that all nodes in the fields exchange the information with each other in the equal position. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data-centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Early work on data centric routing (e.g., SPIN and directed diffusion [18]) were shown to save energy through data negotiation and elimination of redundant data. These two protocols motivated the design of many other protocols that follow a similar concept. As shown in figure 2, there are several flat routing methods in WSNs.

2) Hierarchical Routing

Flat Routing Method is efficient in the small-scale networks because of its simple routing construction procedure. But the large the scale of network is, the much the quantity of routing information is. And there are long delays in sending the routing information from the remote sensor node and in transferring data from the remote source nodes. Therefore it needs a routing method in which all nodes can waste the equivalent battery in order to guarantee the long lifetime.

Hierarchical routing method was proposed to resolve such a problem, in which all nodes are partitioned into logical groups and each logical group has the head node that control the data traffic in the corresponding group. The creation of clusters and assigning special tasks to CHs can greatly contribute to overall system scalability, lifetime, and energy efficiency.

Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other for routing. However, most techniques in this category are not about routing, but rather “who and when to send or process/ aggregate” the information, channel allocation, and so on, which can be orthogonal to the multihop routing function. As shown in figure 2, there are several hierarchical routing methods in WSNs.

Table 2 summarizes the comparisons of flat and hierarchical routing methods according to the specific parameters.

Table 2. Comparisons of flat and hierarchical routing methods

	Hierarchical Routing method	Flat Routing method
Scheduling	Reservation-based scheduling	Contention-based scheduling
Collision	Collisions avoided	Collision overhead present
Duty cycle	Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Aggregation point	Data aggregation by cluster head	Node on multi-hop path aggregates incoming data from neighbors
Complexity	Simple but non-optimal routing	Routing can be made optimal but with and added complexity
Synchronization	Requires global and local synchronization	Links formed on the fly without synchronization
Overhead	Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Latency	Lower latency as multiple hops network formed by cluster heads always available	Latency in waking up intermediate nodes and setting up the multipath
Energy dissipation	Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Fairness	Guarantee	Not guarantee

3) Location-Based Routing

In this kind of routing, sensor nodes are addressed by means of their locations. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors [19-21]. Alternatively, the location of nodes may be available directly by communicating with a satellite using GPS if nodes are equipped with a small low-power GPS receiver [22]. To save energy, some location-based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping nodes in the network as possible. The problem of designing sleep period schedules for each node in a localized manner was addressed in [22, 23]. As shown in figure 2, there are several location-based routing methods in WSNs.

2.2 Data Aggregation Schemes

1) Data aggregation in sensor networks

Before starting the data aggregation techniques, we should investigate the routing models [24] that are assumed to consist of a single data sink attempting to gather information from a number of data sources. Figure 3 is a simple illustration of the difference between simple models of routing schemes that use data aggregation (which we term Data-Centric (DC)), and schemes that do not (which we term Address-Centric (AC)). They differ in the manner that the data is sent from a source to a sink. In the AC routing, each source independently sends data along the shortest path to the sink based on the route that the queries took (“ end-to-end routing”), whereas in the DC routing the sources send data to the sink, but routing nodes on the way look at the content of the data and perform some form of aggregation and consolidation functions on the data originating at multiple sources.

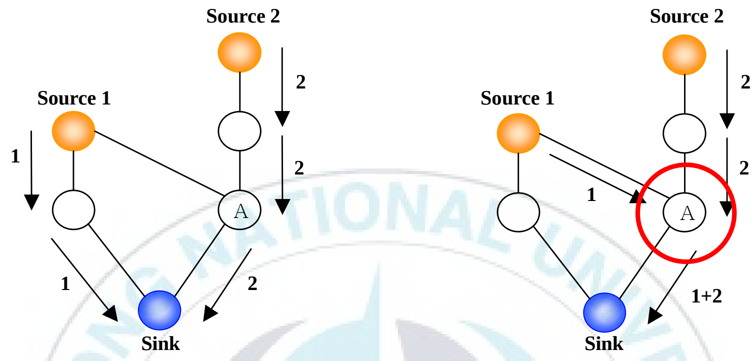


Figure 3. Illustration of AC routing Vs. DC routing

In ad hoc networks, a routing model follows the AC routing, so each source sends its information separately to the sink like the figure 3(a). In sensor networks, a routing model follows the DC routing, so the data from the two sources are aggregated at node A, and the combined data is sent from node A to the sink like the figure 3(b). Therefore in sensor networks, the data aggregation technique is a critical factor different from ad hoc networks to save the power consumptions of the nodes in order to extend the sensor network lifetime.

In sensor networks, the data aggregation tree can be thought of as the reverse of a multicast tree. So optimal data aggregation is a minimum Steiner tree on the network graph. Instead of an optimal data aggregation, sub-optimal data aggregations are proposed to generate data aggregation trees that are aimed to diminish the transmission power. The table 3 summarizes the properties and disadvantages of sub-optimal data aggregation methods.

The prevenient data aggregation methods [24] are efficient to the model where a single point in the unit square is defined as the location of an “event”, and all nodes within a distance S (called the sensing range) of this event that are not sinks are considered to be data sources (which we term Event-Radius Model). In the model where some nodes that are not sinks are randomly selected to be sources, e.g. a temperature measurement and environment pollution detection (which we term Random-Source Model), it needs appropriate strategies for an efficient data aggregation.

Table 3. Comparisons of the data aggregation methods

Data aggregation method		Properties	Disadvantages
Optimal	Minimum Steiner Tree	The optimal number of transmissions required per datum for the DC protocol is equal to the number of edges in the minimum Steiner tree in the network.	The NP-completeness of the minimum Steiner problem on graphs
Sub-optimal	CNS (Center at Nearest Source	The source that is nearest the sink acts as the aggregation point. All other sources send their data directly to this source that then sends the aggregated information on to the sink.	The more great the gaps between the aggregation point and sources, the more the batteries consumptions.
	SPT (Shortest Paths Tree)	Each source sends its information to the sink along the shortest path between the two. Where these paths overlap for different sources, they are combined to form the aggregation tree.	The shorter the overlapped paths when the shortest route is established from each source to the sink, the more the batteries consumptions.
	GIT (Greedy Increment-al Tree)	At the first step the tree consists of only the shortest path between the sink and the nearest source. At each step after that the next source closest to the current tree is connected to the tree.	It takes some time for the identical data to arrive to the aggregation point and to aggregate the identical data from other source nodes.

In LEACH, all of the nodes in the field can be the source nodes in sensor networks, so this model can be considered Random-Source Model. The nodes in LEACH organize themselves into local clusters, with one node acting as the cluster head, which allocates the time slot to its cluster members. All non-cluster head nodes directly transmit their data to the cluster head, while the cluster head node receives data from all the cluster members, performs signal processing functions on the data (e.g., data aggregation), and transmits data to the remote BS (Base Station). If the cluster heads were chosen a priori and fixed throughout the system lifetime, these nodes would quickly use up their limited energy because being a cluster head node is much more energy intensive than being a non-cluster head node. Thus

LEACH incorporates randomized rotation of the high-energy cluster head position among the sensors to avoid draining the battery of any one sensor in the network. In this way, the energy load of being a cluster head is evenly distributed among the nodes. But LEACH needs clustering formation overheads before performing the task, and the nodes which are away from the cluster head consume much more transmission batteries comparing to the nodes close to the cluster head. So it needs a strategy to eliminate the redundancy power consume in LEACH.

2) Data aggregation in ad hoc networks

Most of the ad hoc networks are based on point-to-point communications, so the data aggregation in ad hoc networks is not considered a critical issue except the multipath routing. In some routing protocols such as DSR [25], AODV [26], LMR [27], TORA [15], and so on, multi-paths can be established from the sources to the destination. In that case the data aggregation can be performed through the overlapped paths en route. But it depends on each routing technique, which is implemented in ad hoc networks. Amongst the multipath routing techniques, TORA builds a directed acyclic graph rooted at the destination in ad hoc networks. So using DAG all data in the field can be assembled at the destination node.

3. Analysis of Previous Routing Techniques in Broadband convergence Networks

In Korea, u-IT839 strategy has been developed and being executed under leadership of the Ministry of Information and Communication (MIC). U-IT839 strategy defines key technologies - 8 services, 3 infrastructure, and 9 new growth engines - to achieve economical and technical breakthrough in Korea. BcN is one of the three infrastructures of u-IT839 strategy. BcN provides the foundation of IT industry where various types of future premium services can be easily developed and deployed.

Strategy of BcN is implementing the future network by converging different types of services, i.e., converging wired and wireless service, data and voice service, and telecommunication and broadcasting. As the Internet and optical network technology advances, the IP over DWDM has been envisioned as the most promising solution for BcN. Especially, given the increasing demand for high bandwidth services, DWDM-based BcN has been regarded as a favorable approach for the future BcN.

One of the critical issues in DWDM-based BcN is RWA problem that is embossed as very important and plays a key role in improving the global efficiency for capacity utilization. In addition, many services such as USN, IPTV, and TPS are becoming increasingly popular. These services require point-to-multipoint connections among the nodes in the networks.

As a solution of such services, multicast 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 [28-31].

In a wavelength-routed DWDM network, the network edge systems communicate with one another via all-optical WDM channels, which are referred to as lightpaths [32]. Given a set of connection requests, the problem of setting up lightpaths by routing and assigning a wavelength for each connection so that no two lightpaths on a given link share the same wavelength is called RWA problem. However, it is a combinational problem known to be NP-complete because routing and wavelength assignment problems are tightly linked together [33]. 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 studies, the routing scheme has been recognized as a more significant factor on the performance of the solution of the RWA problem than the wavelength-assignment scheme [34,35]. Therefore, several routing techniques have been proposed as shown in Figure 4. In this section, we review the state of previous research work for routing techniques in DWDM network.

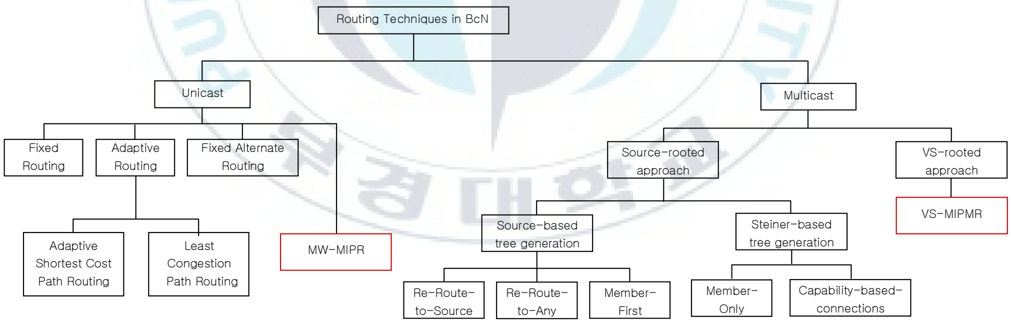


Figure 4. Routing techniques in BcN

3.1 Unicast Routing

In [34], there are basic approaches for the unicast routing problem such as Fixed Routing (FR), Fixed Alternate Routing (FAR), and Dynamic Routing (DR). FR as the most straightforward approach for routing a connection always chooses the same fixed route for a given source-destination pair (S, D). FAR is an approach that sequentially considers an available path among a fixed multiple of routes and selects one. But it is too hard to find an optimal route using static routing approaches such as FR and FAR that determine the route without considering the network's status [36]. Compared to static routing methods, DR approach is the most efficient because a route is dynamically chosen by considering the network's status at the time of connection request. This improves network performance in terms of blocking probability [36-38]. Among the three routing approaches represented above, the FAR and DR approaches can provide protection for a connection by setting up a backup path for link or node failures in the network.

3.2 Multicast Routing

1) 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) [3-4].

In Source-based tree generation methods [3], 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 4 summarizes the properties, merits and demerits of each multicast tree generation method in the source-based tree approach.

Table 4. 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.	The tree is constructed according to the link priorities, which was 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	It requires the largest amount of channel resources and wavelength numbers.	The constructed tree may have some paths, which are not the shortest paths.	Computational complexity.

In Steiner-based tree [4], 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 5 summarizes the properties, merits and demerits of each multicast tree generation method in the Steiner-based tree approach.

Table 5. Comparisons of steiner-based tree generation methods

	Member-Only	Capability-Based-Connection	
		Spawn-from-VS heuristic	Capability-based-priority heuristic
Properties	It is similar to the Member-First method. However, if some intermediate nodes are located in equal distance from the present node, the node is connected to one of them selected arbitrary.	To spawn a new tree, each VS node acts like a source.	The nodes in the networks are assigned with priorities depending on the wavelength conversion and splitting capabilities.
Advantages	It requires the least number of wavelengths and wavelength channel resources among all four algorithms (including this) already explained.	This approach needs less wavelength and channel resources compared to the Member-Only method.	
Disadvantages	Long delay, and 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.

2) Virtual Source-rooted approach

The algorithm based on this approach overcomes the limitations of the source-rooted approach. In the VS-based method, some nodes in the networks are chosen as VS nodes. Here VS nodes have splitting and wavelength conversion capabilities and can transmit an incoming message to any number of outgoing links on any wavelengths. These VS nodes are interconnected in such a way that a lightpath is established between every pair of VS nodes in order to reserve the resources, which can be used to transmit the message and to exchange the routing information for each multicast session request. These interconnectivities among the VS nodes are used when the multicast tree is constructed. Thus the multicast routing works in two phases, namely, a network-partitioning phase and a tree generation phase [5][39].

In the network-partitioning phase, nodes that have high degree of connectivity are chosen as VS nodes in about 20% of the given network's nodes, and the given physical networks are partitioned into several regions based on the vicinity of the VS nodes. A VS node can transmit an incoming message to any number of outgoing links. Therefore VS nodes act as a multicast session distribution point to the set of partitioned nodes that are connected to them. Once the VS nodes are identified, the paths between all VS nodes are computed. Every VS node establishes connections to all other VS nodes, and the remaining partitioned nodes in the networks grouped into sub-trees each with the root as a VS node.

In the tree generation phase, given a source and the set of destinations of a multicast session, the aim is to generate a multicast tree. This phase makes use of the connectivity provided in the previous phase. In order to provide multicast services, the source of a multicast session establishes a connection for the resource reservation to a VS node with the least distance from itself. Therefore, the source can establish the connections to all destinations using the connectivity provided in the previous phase. As a result, the setup time for establishing the multicast session becomes low.

Compared to the Source-rooted approach, this approach has some advantages. First of all, a source does not need to know about the location of the destinations, and there is a maximum of three light hop distance from a source to any destinations. Hence, the fairness among destinations is achieved. And the procedure of dynamic addition or deletion of members in the group is simple in comparison with the Source-rooted approach. Whereas the VS-based tree method has a critical default such like that as the number of VS nodes increases, the overheads due to the resource reservation for paths between VS nodes also increase. Such overheads affect the network performances in the networks that the resources are limited.

Ⅲ. EDAUCH Algorithm for Wireless Sensor Netwroks

1. DAUCH

DAUCH is a hierarchical routing protocol that improves the cluster formation algorithm of LEACH by applying DAG concept in TORA. The operation of DAUCH is divided into several rounds and each round consists of five phases logically: CH selection phase, DAG construction phase, DATA transfer phase, Downlink failure phase, DAG deconstruction phase [14]. Moreover, DATA transfer phase consists of frames when all the nodes send their data to the downlink node or BS once during their allocated transmission slot. Figure 5 shows the operation of DAUCH.

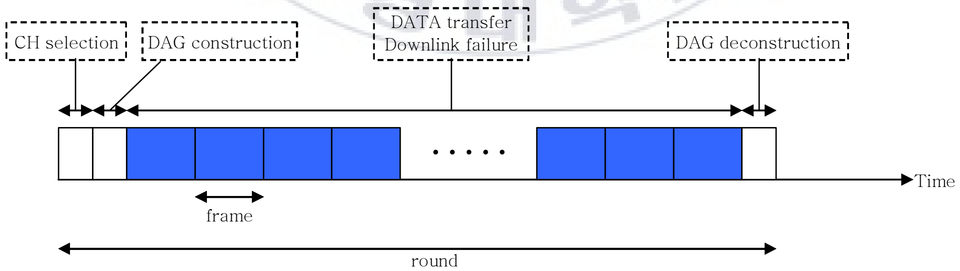


Figure 5. Time line showing the operation of DAUCH

During a round, DAUCH operates as follows. At first, during CH selection phase, CHs are randomly selected as LEACH. And then each CH creates the DAG rooted at itself during DAG construction phase. During DATA transfer phase, the nodes that have more than one uplink node aggregate the data arrived from the uplink nodes and then transmit them to the downlink node. This manner is continued until all data arrive at the CH. The CHs receive and aggregate the data from the adjacent neighboring node, and then transmit them to BS. During Downlink failure phase, reconnecting another node restores the node's downlink lost. Finally, The CHs deconstruct the DAG rooted at themselves and inform their cluster member of the end of a current round during DAG deconstruction phase. Figure 6 illustrates the data transfer of DAUCH.

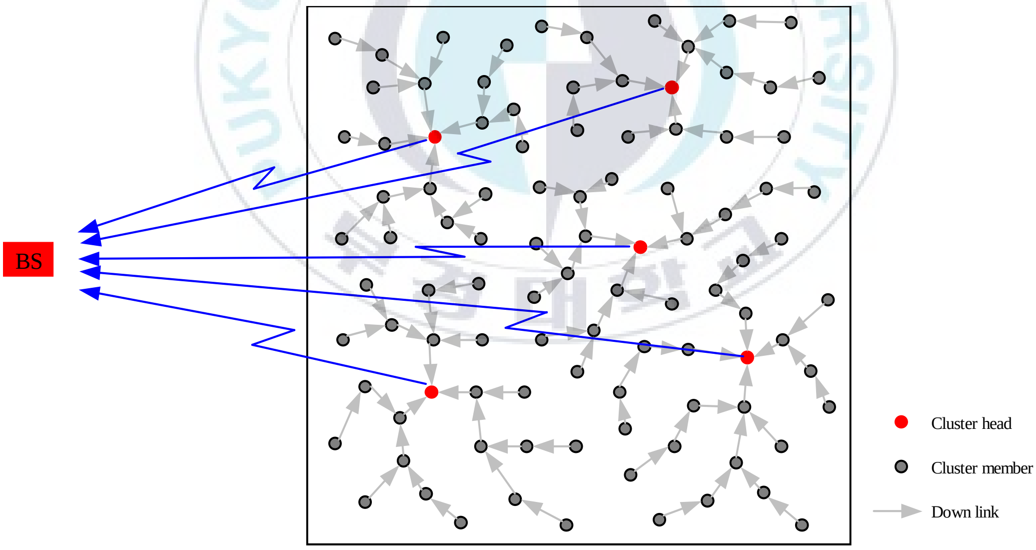


Figure 6. Illustration of the new data aggregation algorithm

When the cluster is formed, LEACH establishes point-to-point connections between a CH node and each cluster member node, while DAUCH constructs

DAG centered at CH node. Thus, cluster member nodes in LEACH directly send data to their CH, while cluster member nodes in DAUCH send data to their downlink node close to them. Therefore, DAUCH saves energy compared to LEACH because the cluster member nodes far away from their CH node transmit the data to a node in less distance than LEACH in the way of multi-hop transmission. Moreover, the task effort of data aggregation in the CH is distributed to non-CH nodes because nodes in the overlapped routes perform data aggregation before the whole data within a cluster get to the CH. Consequently, DAUCH provides energy savings and prolongs the network lifetime compared to LEACH.

2. CH Selection Phase of EDAUCH

We propose EDAUCH that ameliorates the CH selection algorithm of DAUCH. EDAUCH performs CH selection based on residual energy level of a node that is the ratio of a node's current energy to initial energy. The node's residual energy level $E_{residual}(r)$ at the beginning of round r is set as follows:

$$E_{residual}(r) = \frac{E_{current}(r)}{E_{init}} \tag{1}$$

where r is the current round, E_{init} is the node's initial energy (corresponding to a fully charged battery), and $E_{current}(r)$ is the node's current energy at the beginning of round r.

EDAUCH uses the average residual energy level of all nodes to reflect node's residual energy level in CH selection algorithm. We define *AREL(r)* that is the function about average residual energy level of all nodes at current round r. In order to choose CHs, each node sets the value of *AREL(r)* and *T(n)* at round r as follows:

$$AREL(r) = \frac{E_{init} - [r \times E_{dissipation}]}{E_{init}} \tag{2}$$

$$T(n) = \frac{P}{1 - P\left[r \bmod (1/P)\right]} \tag{3}$$

where $E_{dissipation}$ is the constant value that is set as the quantity of the average energy dissipation per round of all nodes and *P* is the desired percentage to become a CH. To compute the average residual energy level of all nodes, EDAUCH uses equation (2). Each node has 1 as a value of *AREL(r)* at round 0. As the number of round increases, a value of *AREL(r)* decreases at a uniform ratio. At CH selection phase of round *r*, if $E_{residual}(r)$ of a node is less than *AREL(r)*, then the corresponding node cannot become CH; otherwise, the node decides whether or not to become a CH for the current round using equation (3). The CH selection phase of EDAUCH is shown in Figure 7.

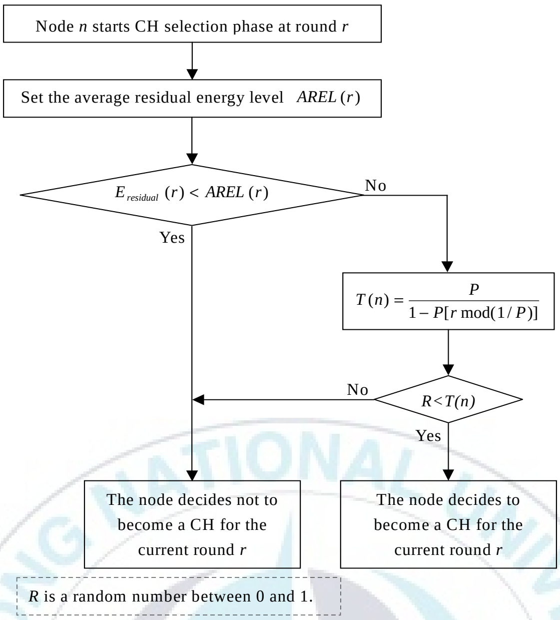


Figure 7. Flowchart of the CH selection phase for EDAUCH

3. Algorithm Calculating AREL(r) in EDAUCH

One of the most important thing in this algorithm is how *AREL(r)* is calculated. EDAUCH calculates *AREL(r)* by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. In EDAUCH, $E_{dissipation}$ is set as the value computed by off-line computation at the network establishment phase and each node computes *AREL(r)* by using equation (2) during each CH selection phase.

To compute *AREL(r)*, EDAUCH does not need to exchange the additional information with other nodes but needs only a little computation load. For various hardware, the ratio of the energy consumption to send one bit compared to computing single instruction is between 1500 to 2700 for Rockwell WINS nodes, between 220 to 2900 for MEDUSA Ⅱ nodes, and about 1400 for WINS NG 2.0 nodes [40]. Disregarding the details, it is clear that communication is a considerably more expensive undertaking than computation. Therefore, EDAUCH has not much overhead over DAUCH because the energy dissipation for computation is a negligible quantity.

We set the reference network to compute $E_{dissipation}$. The reference network consists of 100 nodes randomly distributed across a plain area of 100×100 meters. The BS is located at the position (50, 175). The characteristics of the network, the communication energy parameters, and the energy for data aggregation are set as those described in section 5.

In order to simply compute $E_{dissipation}$ in the reference network, we assume that the reference network consists of five clusters and each cluster is formed as Figure 8. In Figure 8, the inner and outer circles are implemented to easily compute the radio energy dissipation quantities based on the distance between each cluster member and a CH. We set the radius of the inner circle to d, the radius of the outer circle to $2d$, and the distance between the CH node and BS to d_{toBS}. We assume that the energy dissipation transmitting between the nodes in the network follows the free space model and the energy dissipation transmitting from the CH nodes to BS follows the multipath fading model because the distance between the CH nodes and BS is farther than the distance between the nodes in the network.

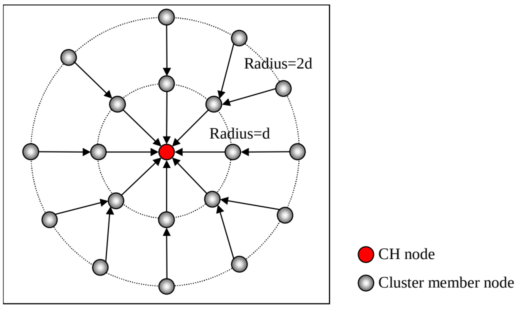


Figure 8. Cluster model of the reference network

The energy dissipation of the nodes in a cluster of the reference network during a frame can be computed. The energy dissipation of the outer nodes is

$$11[kE_{elec} + k\varepsilon_{fs}d^{2}] \ . \tag{4}$$

The energy dissipation of the inner nodes is

$$19[kE_{elec} + kE_{DA}] + 8k\varepsilon_{fs}d^{2} \ . \tag{5}$$

The energy dissipation of a CH node is

$$9[kE_{elec} + kE_{DA}] + k\varepsilon_{mp}d_{toBS}{}^{4} \ . \tag{6}$$

The total energy dissipation of the nodes is

$$39kE_{elec} + 19k\varepsilon_{fs}d^{2} + 28kE_{DA} + k\varepsilon_{mp}d_{toBS}{}^{4} \ . \tag{7}$$

We assume that d = 30m and d_{toBS} = 125m; the total energy dissipation of the nodes in a cluster during a frame is 9.63 mJ. Therefore, the total energy dissipation of all the nodes during a frame E_{frame} is 48 mJ because the reference network consists of five clusters. The duration of a frame T_{frame} is set as follows:

$$T_{frame} = \left[k \times \frac{1}{B} + D \right] \times N_{node} \quad (8)$$

where k is a k-bit message, B is a bandwidth of the channel, D is the processing delay, and N_{node} is the number of nodes. The value of T_{frame} is 0.405 seconds. And the number of frames during a round N_{frame} is set as follows:

$$N_{frame} \approx \frac{T_{round}}{T_{frame}} \quad (9)$$

where T_{round} is the duration of a round. The value of N_{frame} is approximately 49. And the quantity of the average energy dissipation per round of all nodes $E_{dissipation}$ is set as follows:

$$E_{dissipation} = \frac{E_{frame} \times N_{frame}}{N_{node}} \ . \quad (10)$$

The value of $E_{dissipation}$ of the reference network is 23.6 mJ. We show the simulation results using this value in section 5.

In DAUCH, if CH node does not fill the role of CH during the DATA transfer phase, cluster member nodes waste their own energy on useless transmission to their incapable CH node and BS cannot receive data signals from the incapable CH node. However, EDAUCH eliminates the above case by performing CH selection based on residual energy level of a node. Therefore, EDAUCH has better energy efficiency than DAUCH.

Ⅳ. VS-MIPMR Algorithm in Broadband Convergence Networks

1. MW-MIPR

In the VS-based method, it requires shortest paths between VS nodes because each multicast session needs to reserve the resources for paths between VS nodes. Therefore the blocking probability of potential future multicast session requests increases due to the frequently used shortest paths, especially the paths between VS nodes.

In order to overcome such a limitation, it needs a strategy to control the traffics of paths between VS nodes. That is because the paths between VS nodes should be critical paths due to the shortest path selection to make each multicast session request. As a strategy, we can reduce the use of those paths choosing efficient paths, instead of the shortest path; so decrease the utilization of wavelength number throughout the networks.

As a solution of traffic control, we investigated the previously proposed Minimum Interference Routing algorithm with traffic engineering in a Multi-Protocol Label Switching network [6-9]. 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 [7], Multi-Wavelength Minimum Interference Path Routing (MW-MIPR) 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 [6], this algorithm chooses a light path that does minimize interference for potential future setup requests by avoiding congested links. We adopt the concept "critical link" to reduce the utilization of the frequently used paths in each path between every two VS nodes.

2. VS-MIPMR Definition and Notations

The illustrated reference architecture of BcN backbone network in Figure 9 consists of the Provider Edge (PE) nodes (i.e., source nodes and destination nodes) and the Provider Core (PC) nodes (i.e., VS nodes and neighboring nodes). In BcN backbone network, the goal is to establish several connections, which provide a variety of multicast services and need to make resource reservations in order to construct light trees of the corresponding multicast services.

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.

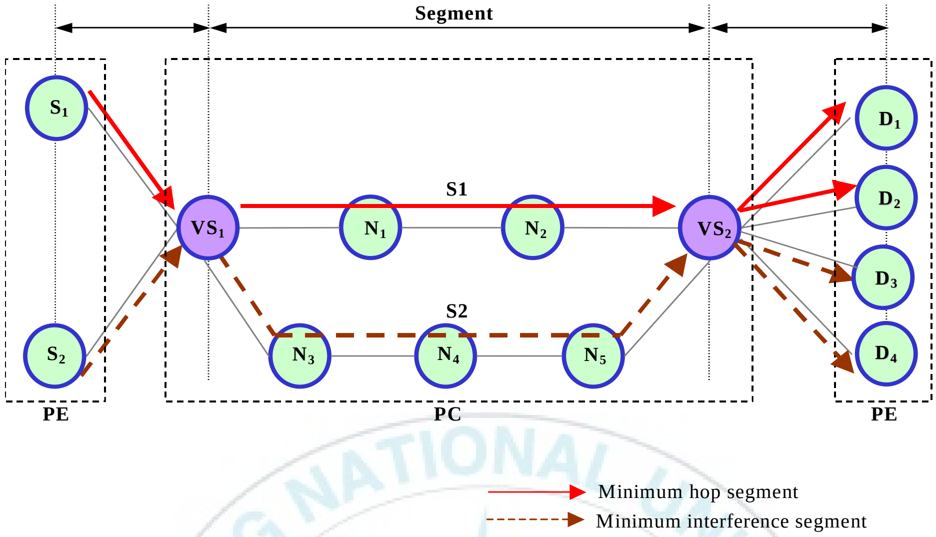


Figure 9. Illustration of a new MCRWA algorithm in DWDM-based BcN backbone network

In this paper, we propose a new MCRWA method choosing a path that does not interfere too much with potential future multicast session reservation requests based on the VS-rooted approach, called Virtual Source-based Minimum Interference Path Multicast Routing (VS-MIPMR) [41]. 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 9 illustrates the new algorithm. We assume that a segment means a path between VS nodes, and each segment must follow the wavelength continuity constraint [34,42], because only VS node can have a wavelength conversion capability.

There are two potential source-destinations pairs such as (S1, D1 and D2) and (S2, D3 and D4). When S1 is chosen for the first multicast session in order to make a resource reservation for the path between VS1 and VS2, 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 S2 that has a minimum interference effect for other future multicast session requests, even though the path is longer than S1. Before formulation of the new 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 PVS-SVS node pairs that can be required a connection establishment by multicast session request in the future. Let (i, j) denote a generic element of this set.
- C: Set of PVS-SVS node pairs required a connection establishment by current multicast session request. Let (a, b) denote a generic element of this set. ($C \subset P$)
- S_{ij}^{m} : Pre-selected m-th minimum hop segment connecting the path between a (i, j)-pair. Here, superscript m denotes segment index. ($1 \leq m \leq 3$)
- π_{ij}^{m} : Set of links over the minimum hop segment S_{ij}^{m}.
- F_{ij}^{m} : Set of wavelengths satisfying the wavelength-continuity constraint over S_{ij}^{m}.
- Ω_{ij}^{m} : Wavelength assigned by the FF scheme among F_{ij}^{m}.
- α_{ij} : Weight between a (i, j)-pair.

- $R(S_{ij}^{m})$: Accumulated total weights for S_{ij}^{m}.

Among the notations, α_{ij} is a key parameter in VS-MIPMR. Here α_{ij} statistically presents the weight for a segment according to the degree of multicast session resource reservation requests between the VS-nodes.

3. Procedure of VS-MIPMR

Based on these notations, the link weights are determined as follows:

$$\begin{aligned} &CS_{ij}^{t}(ab) : \{(\pi_{ab}^{m} \cap \pi_{ij}^{t}) \neq \phi\} \cap (\Omega_{ab}^{m} \in F_{ij}^{t}), \\ &\forall (i, j) \in P \setminus (a, b), \qquad 1 \leq m \leq 3 \end{aligned} \tag{11}$$

$$\begin{cases} [\, if \;\; S_{ij}^{t} : S_{ab}^{m} \in CS_{ij}^{t}(ab) \cap \{(F_{ij}^{t} - \Omega_{ab}^{m}) = \phi\} \,] \\ \quad (\partial F_{ij}^{t} / \partial v_{ab}^{m}) = 1 \\ [\, if \;\; S_{ij}^{t} : S_{ab}^{m} \in CS_{ij}^{t}(ab) \cap \{(F_{ij}^{t} - \Omega_{ab}^{m}) \neq \phi\} \,] \\ \quad (\partial F_{ij}^{t} / \partial v_{ab}^{m}) = 1/2 \\ [otherwise] \\ \quad (\partial F_{ij}^{t} / \partial v_{ab}^{m}) = 0 \end{cases} \tag{12}$$

$$R(S_{ab}^{m}) = \sum_{\forall (i, j) \in P \setminus (a, b)} \left\{ \sum_{t=1}^{3} \alpha_{ij} \cdot (\partial F_{ij}^{t} / \partial v_{ab}^{m}) \right\} \tag{13}$$

Equation (11) reflects whether each minimum hop segment, pre-selected between a (*a*, *b*)-pair, i.e., S_{ab}^{m} (*1* $\leq$*m* $\leq$*3*), interferes with potential future demands or not. If the *m*-th minimum hop segment S_{ab}^{m} of a (*a, b*)-pair shares some links with the *t*-th minimum hop segment S_{ij}^{t} of a (i, j)-pair and a assigned wavelength Ω_{ab}^{m} over S_{ab}^{m} belongs to the set of available wavelengths F_{ij}^{t} over S_{ij}^{t}, then the m-th minimum hop segment of a (a, b)-pair is the congestion segment for the t-th minimum hop segment of a (i, j)-pair.

In Equation (12), let v_{ab}^{m} denote the m-th minimum hop segment S_{ab}^{m} with an assigned wavelength Ω_{ab}^{m} by the FF scheme between a (a, b)-pair. And, let $\partial F_{ij}^{t} / \partial v_{ab}^{m}$ denote the interference weight to reflect the change rate of available wavelengths F_{ij}^{t} over the t-th minimum hop segment of a (i, j)-pair, where $\forall(i, j) \in P \setminus (a, b)$, when the current multicast session between a (a, b)-pair is routed along the m-th minimum hop segment S_{ab}^{m}.

As shown in Equation (12), the value of $\partial F_{ij}^{t} / \partial v_{ab}^{m}$ is allocated the differentiated values as follows: when the m-th minimum hop segment S_{ab}^{m} of a (a, b)-pair is the congestion segment for the t-th minimum hop segment S_{ij}^{t} of a (i, j)-pair, and if segment S_{ij}^{t} can not be assigned any wavelength after wavelength Ω_{ab}^{m} is assigned along S_{ab}^{m}, then $\partial F_{ij}^{t} / \partial v_{ab}^{m}$ is equal to 1, else $\partial F_{ij}^{t} / \partial v_{ab}^{m}$ is equal to 1/2. In all other cases, $\partial F_{ij}^{t} / \partial v_{ab}^{m}$ is equal to 0.

In network partitioning phase, VS-MIPMR algorithm pre-selects three minimum hop segments between each (i, j)-pair, where $\forall(i, j) \in P$, to reduce computation complexity. In tree generation phase, VS-MIPMR algorithm computes the weight of each segment S_{ab}^{m} according to Equation (13), and then chooses the optimal route with the smallest weight $R(S_{ab}^{m})$ among the three pre-selected minimum hop segments between a (a, b)-pair so that the current request does not interfere too much with potential future demands. Figure 10 illustrates such a procedure of VS-MIPMR.

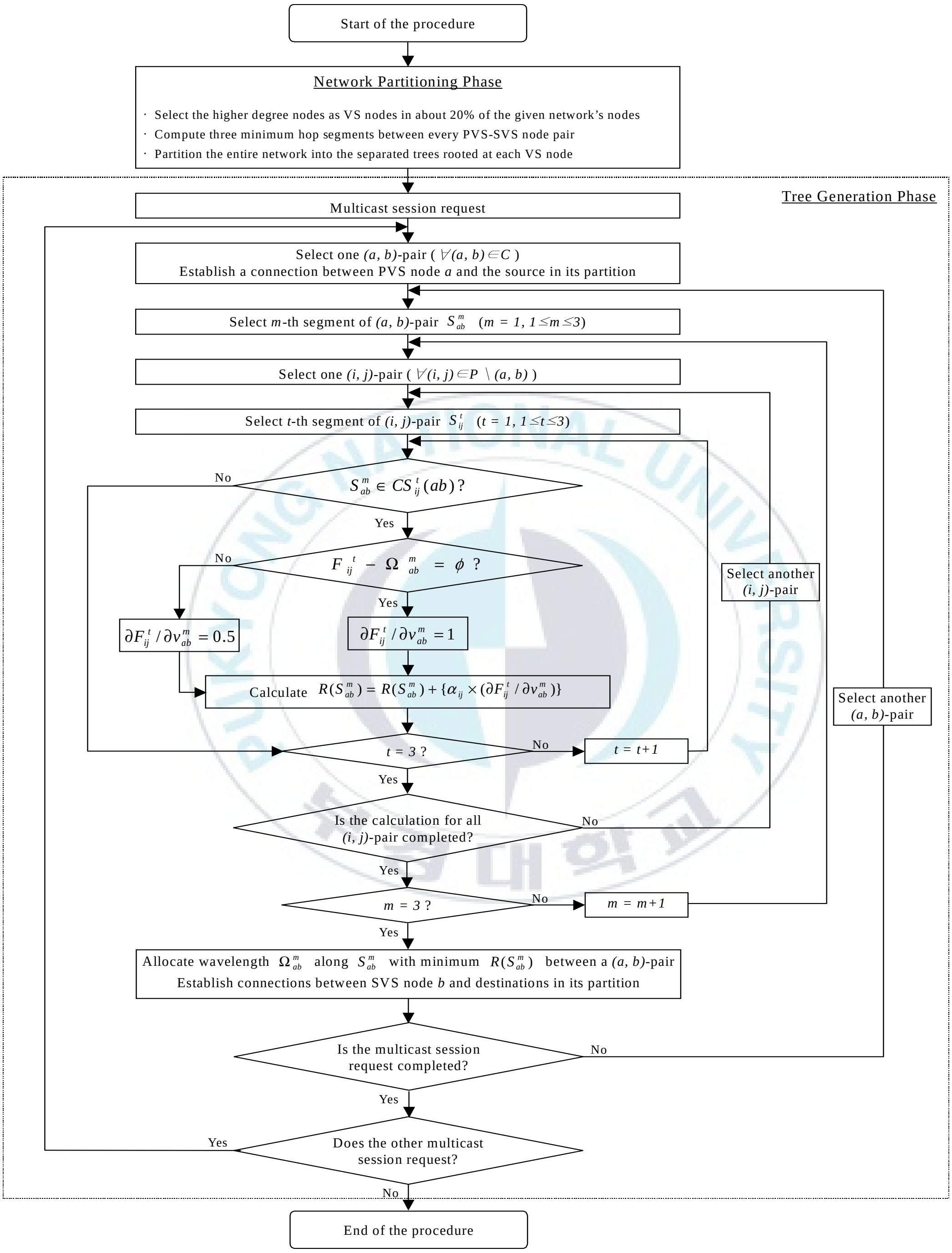


Figure 10. Procedure of VS-MIPMR

Ⅴ. Performance Evaluation

1. Performance Evalution for EDAUCH

1.1 Network and Radio Models

1) The Network Model and Architecture

We assume a sensor network model with the following properties. First, a fixed BS is located far away from the sensor nodes. Second, all sensor nodes in the network are homogeneous, immobile, and energy constrained with a uniform initial energy allocation. Third, the nodes are equipped with power control capabilities to vary their transmitted power. Last, each node senses the environment at a fixed rate and always has data to send to the BS.

The two elements in EDAUCH are the sensor nodes and BS. The BS serves as a gateway to some other networks. It provides powerful data processing, storage center, and an access point to the sensor nodes in its network. The sensor nodes are geographically grouped into clusters and capable of operating in two basic modes: CH mode, cluster member mode. In the cluster member mode, when a node serves as a cluster member node, the node performs sensing tasks, aggregates the sensed data and the data arrived from uplink nodes, and transmits them to the downlink node. In CH mode, when a node serves as a CH node, the node gathers the data from the adjacent neighboring nodes within its cluster, performs data aggregation, and sends the data to the BS.

We assume the characteristics of the network as follows. Each node is equipped with an energy source whose total amount of energy accounts for 2J (Joule). The bandwidth of the channel set to 1 Mbps, and the processing delay is 25 μs on the transmitting side and receiving side. Every node transmits a 500 bytes message. The CH probability *P* is set to 0.05 and each round lasts for 20 seconds.

2) The Radio Model

We assume a simple radio model [13] for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics ($E_{Tx\text{-}elec}$) and the power amplifier ($E_{Tx\text{-}amp}$), and the receiver dissipates energy to run the radio electronics ($E_{Rx\text{-}elec}$), as shown in Figure 11. We use both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models depending on the distance between the transmitter and the receiver [43], i.e., if the distance is less than a threshold d_t, the free space (fs) model is used; otherwise, the multipath (mp) fading model is used. The threshold d_t is cross-over distance for free space and multipath fading model [44]. Therefore, the radio energy dissipation of the transmitter is set as follows:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) = \begin{cases} E_{elec} \times k + \varepsilon_{fs} \times k \times d^2, & d < d_t \\ E_{elec} \times k + \varepsilon_{mp} \times k \times d^4, & d \geq d_t \end{cases} . \quad (1)$$

And the radio energy dissipation of the receiver is set as follows:

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} \times k \quad (2)$$

where E_{elec} is the electronics energy, *d* is a distance from a transmitter to a receiver, and *k* is a k-bit message.

The communication energy parameters and the energy for data aggregation E_{DA} are set as those of [13]: E_{elec} = 50nJ/bit, ε_{fs} = 10pJ/bit/m^2, ε_{mp} = 0.0013pJ/bit/m^4, and E_{DA} = 5nJ/bit/signal. Moreover, the cross-over distance for free space and multipath fading model is set as that of [44]: d_t = 87m.

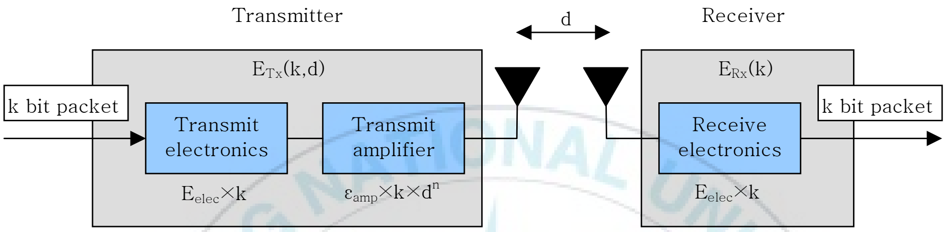


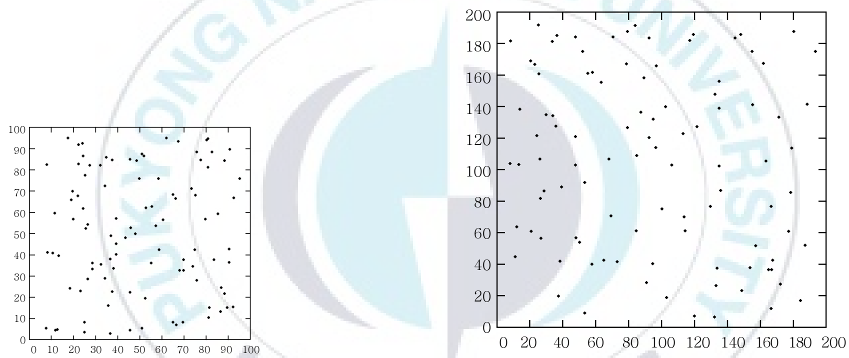
Figure 11. Radio energy dissipation model

1.2 Simulation Setup

We evaluate the performance of the proposed scheme via simulations. The network and radio models described above are used as the simulation model for our simulation. We conduct simulation with two test networks shown in Figure 12. Table 6 summarizes the characteristics of the test networks. In test network 2, the node's initial energy E_{init} is 6J because the value of $E_{dissipation}$ of test network 2 is approximately three times the value of $E_{dissipation}$ of test network 1.

Table 6. Characteristics of test networks

Characteristic	Test network 1	Test network 2
Nodes	100	100
Network size	100m×100m	200m×200m
BS location	(50, 175)	(100, 350)
E_{init}	2J	6J
$E_{dissipation}$	23.6mJ	76.95mJ



(a) Test network 1 (b) Test network 2

Figure 12. 100-node random test networks for EDAUCH

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1.3 Analysis of Numerical Results

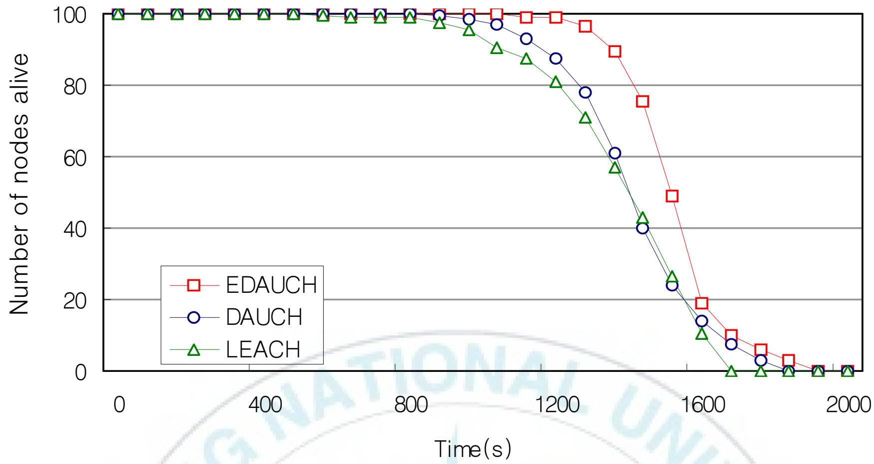
First, we compare the proposed EDAUCH to LEACH and DAUCH in respect of the total number of nodes that remain alive over the simulation time. Fig. 13 shows that EDAUCH is operational and remains alive all the nodes for a longer time than DAUCH and LEACH in both test networks. In test network 2, the nodes gradually exhaust their energy. This is because that test network 2 is sparser than test network 1 and BS in test network 2 is located in more distance than it in test network 1.

The improvement gained through EDAUCH is further exemplified by the graphs in Fig. 14. These plots clearly show that EDAUCH eliminates the case that CH nodes use up their own energy while they play CH's role.

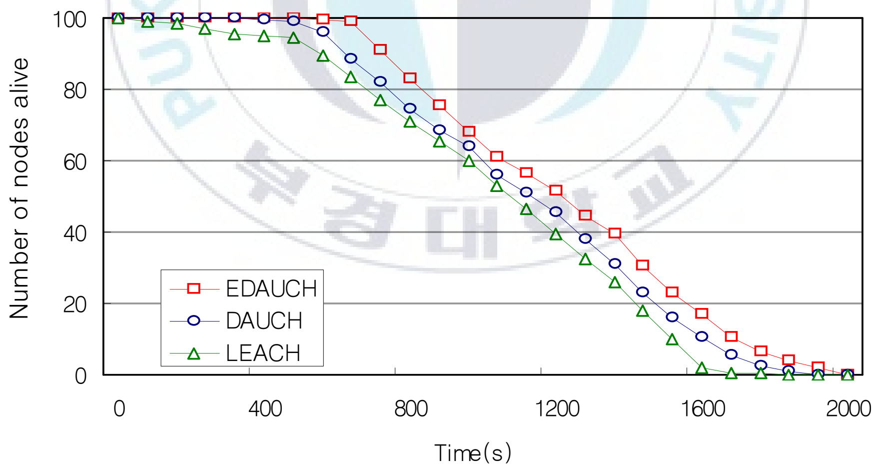
Next we analyze the number of data signals received at the BS for the three routing protocols under consideration. Fig. 15a depicts that EDAUCH improves approximately 48% and 18% comparing to the number of data signals received at the BS in LEACH and DAUCH, respectively, in test network 1. And Fig. 15b shows that EDAUCH offers improvements in data delivery by factors of 45% and 16% over LEACH and DAUCH, respectively, in test network 2.

Finally, we evaluate the performance of EDAUCH, DAUCH, and LEACH in respect of the average energy dissipation per round. Fig. 16a shows that EDAUCH improves approximately 11% and 3% comparing to the average energy dissipation per round in LEACH and DAUCH, respectively, in test network 1. And Fig. 16b depicts that EDAUCH offers improvements in average energy dissipation per round by factors of 6% and 4% over LEACH and DAUCH, respectively, in test network 2.

These simulation results mean that EDAUCH is more energy efficient than LEACH and DAUCH because EDAUCH eliminates the case that CH nodes use up their own energy while they play CH's role by using energy aware CH selection algorithm. Moreover, these simulation results show that EDAUCH works well in both test networks. This means that EDAUCH is suitable for various network environments irrespective of density.

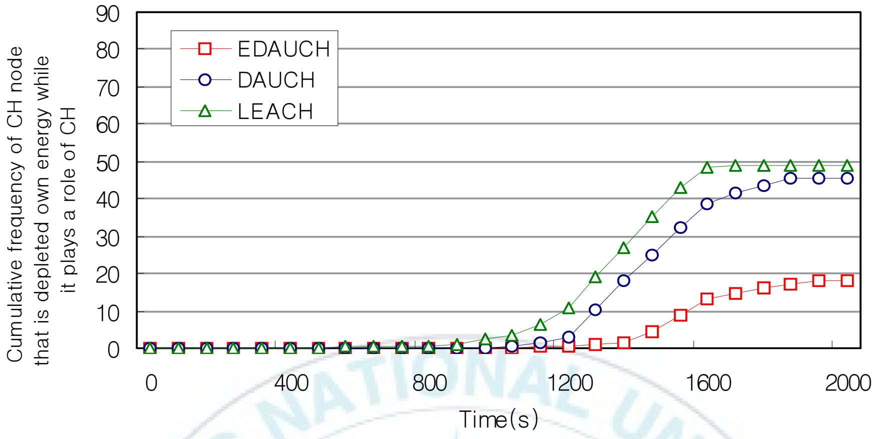


(a) Test network 1

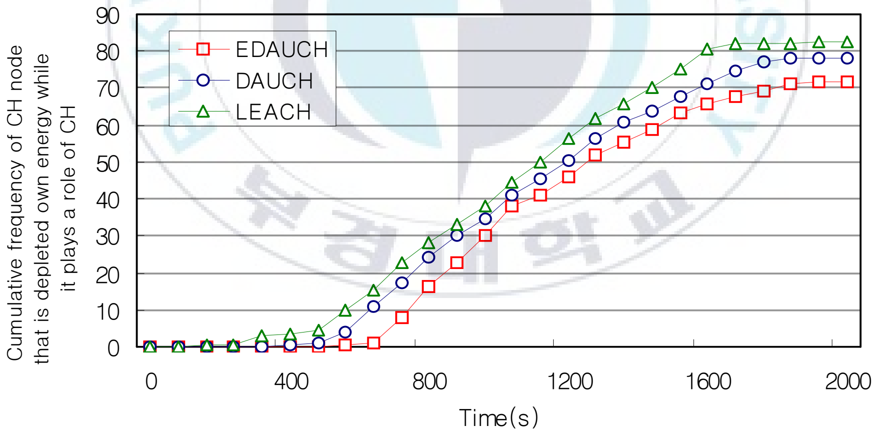


(b) Test network 2

Figure 13. Analysis of the number of nodes alive over time

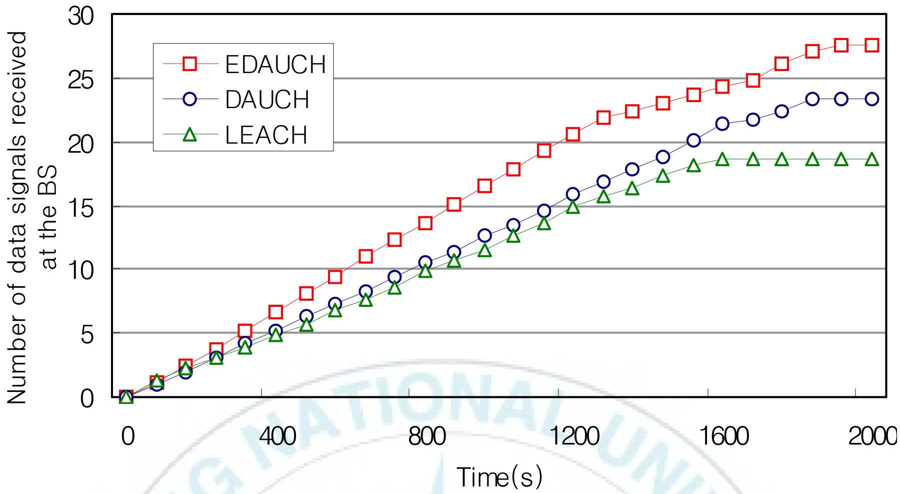


(a) Test network 1

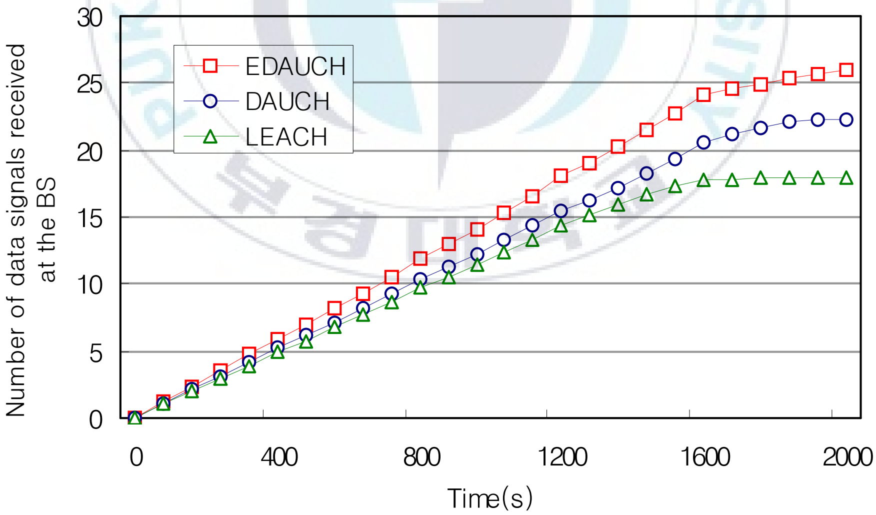


(b) Test network 2

Figure 14. Analysis of Cumulative frequency of CH node that is depleted own energy while it plays a role of CH

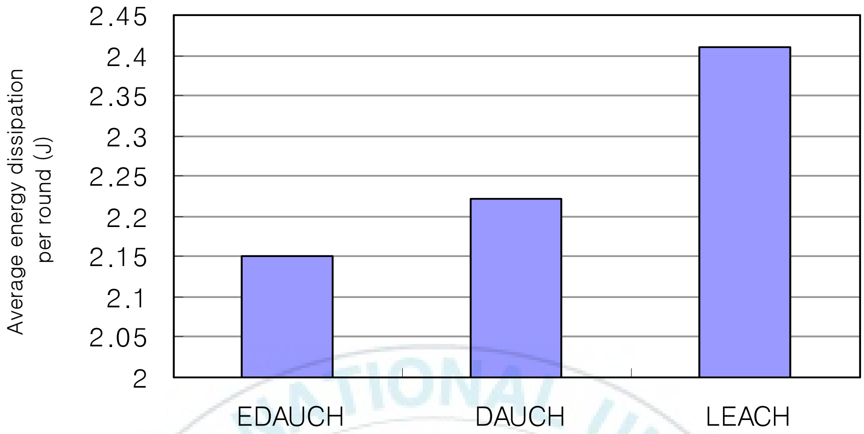


(a) Test network 1

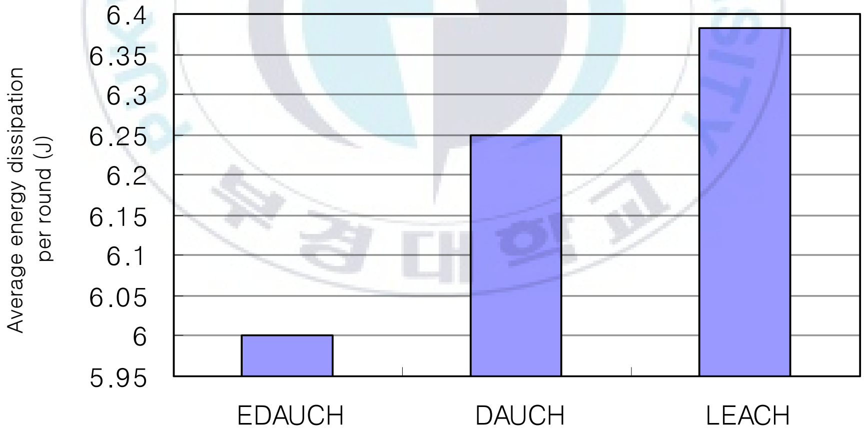


(b) Test network 2

Figure 15. Analysis of the number of data signals received at the BS over time



(a) Test network 1



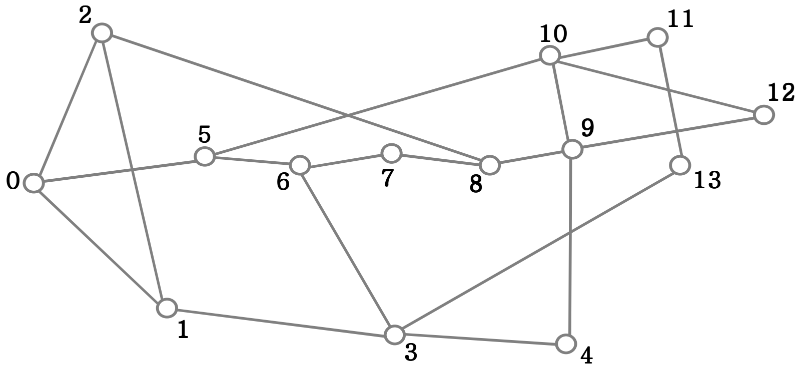
(b) Test network 2

Figure 16. Analysis of the average energy dissipation per round

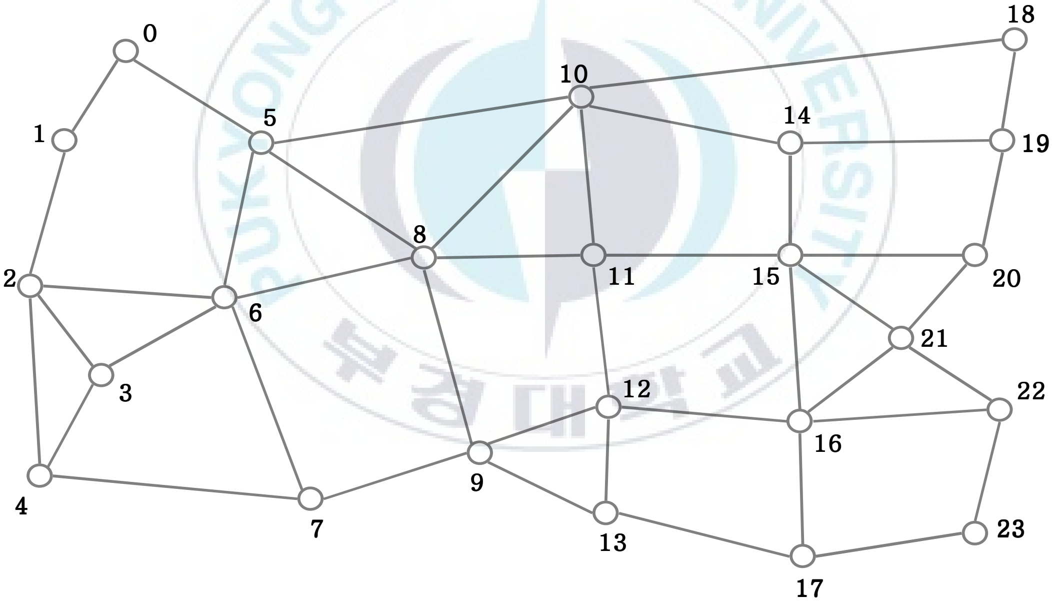
2. Performance Evaluation for VS-MIPMR

2.1 Network Model

Simulations are carried out to evaluate the performance of VS-MIPMR. The network models used in the simulations are 14-node and 24-node topologies, as shown in Figure 17, that are currently often used as DWDM network models and adopted in most of the papers related to DWDM networks. And we assume that the multicast session requests arrive randomly according to the Poisson process.



(a) 14-node topology



(b) 24-node topology

Figure 17. Test networks for VS-MIPMR

2.2 Analysis of Numerical Results

We compare the proposed VS-MIPMR with VS-based method from the viewpoint of the utilization of the wavelength numbers and the wavelength channel numbers, and analyze the gain of the wavelength numbers and the loss of the wavelength channel numbers. Here the gain means the difference of the wavelength numbers between our algorithm and VS-based method, and the loss is defined as the difference of the wavelength channel numbers between our algorithm and VS-based method.

In order to prove the efficiency of VS-MIPMR algorithm proposed in section 4, we showed the wavelength numbers and the wavelength channel numbers of VS-MIPMR and the Virtual Source-based method; here the Group Size (GS) that determines the number of members to construct a multicast session is 0.3 and 0.4 [45]. The plots of wavelength numbers required in both test networks are illustrated in Figure 18. These show that the proposed VS-MIPMR archives wavelength saving in comparison with VS-based method because of selecting the minimum interference path with potential future multicast session requests between VS-node pair. Moreover, Figure 19 depicts more clearly the benefit of the proposed VS-MIPMR over VS-based method. These graphs indicate that the proposed VS-MIPMR has more gain of wavelength numbers than VS-based method (improved by about 16-25%) and also better performance in larger network (24-node topology).

Figure 20 shows that VS-MIPMR needs slightly more number of wavelength channels than that of the Virtual Source-based method due to the detour paths to avoid congestion links. However, we can identify that the loss of the wavelength channel does not exceed 7% and 2% in the 14-node and 24-node topologies, respectively, as shown in Figure 21.

In conclusion, using VS-MIPMR we can construct the multicast trees more efficiently than the VS-based method, even though we experience a bit of loss in the wavelength channel numbers.

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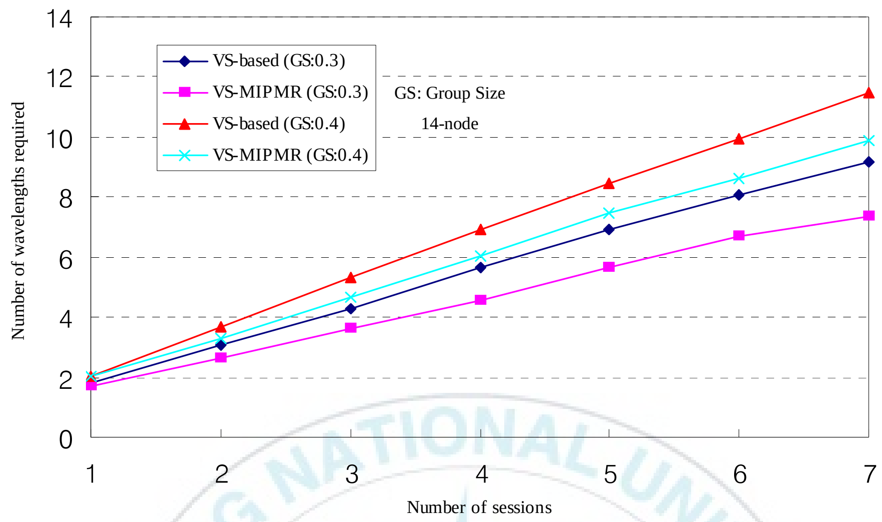
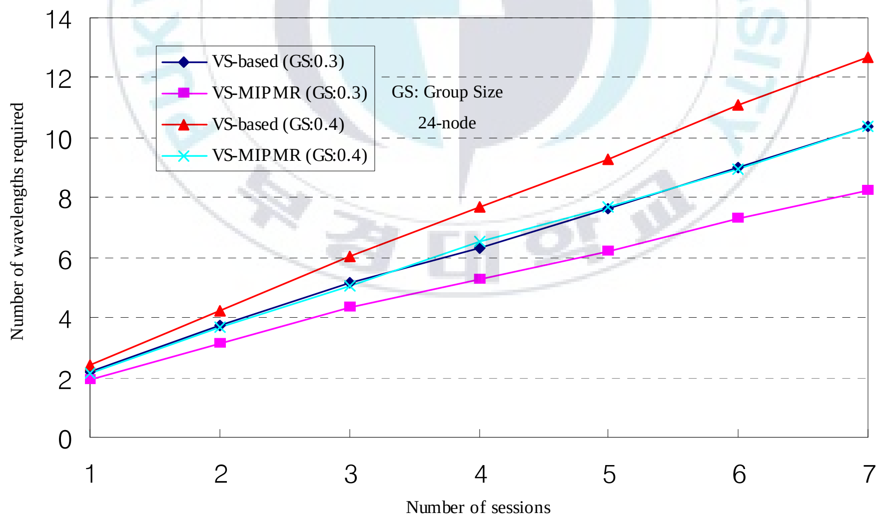
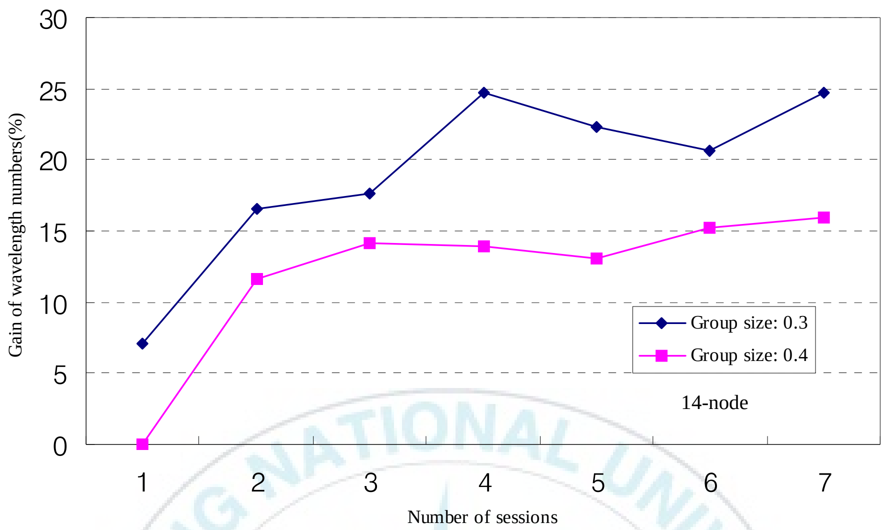


(a) 14-node topology

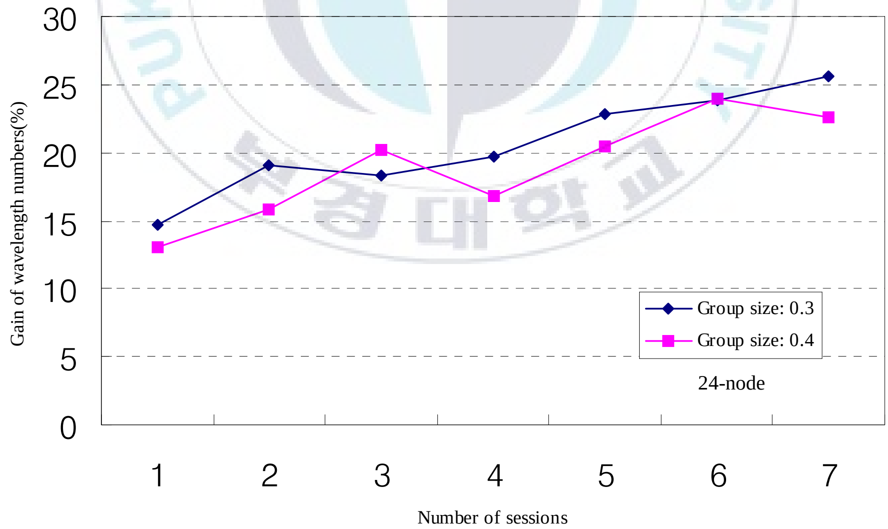


(b) 24-node topology

Figure 18. The number of wavelengths over sessions



(a) 14-node topology



(b) 24-node topology

Figure 19. The gain of wavelength numbers over sessions

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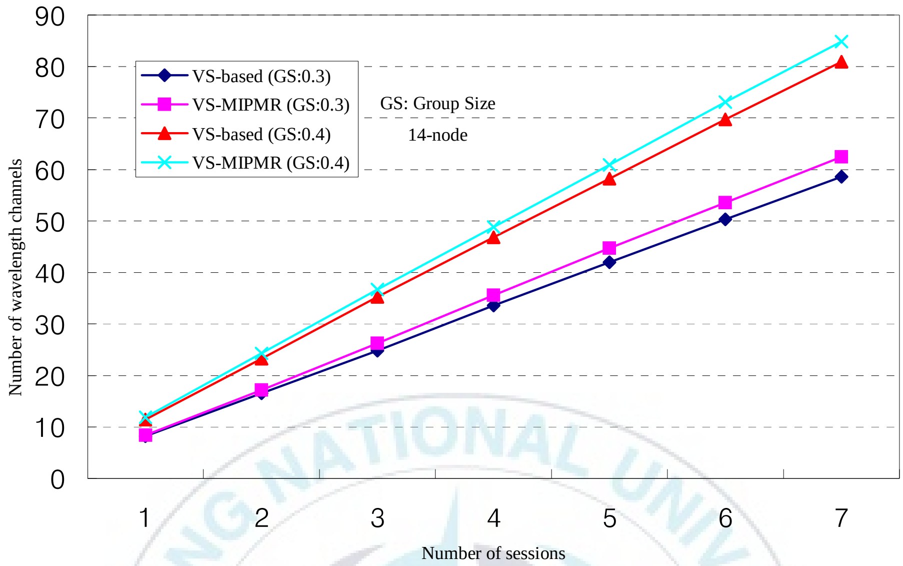
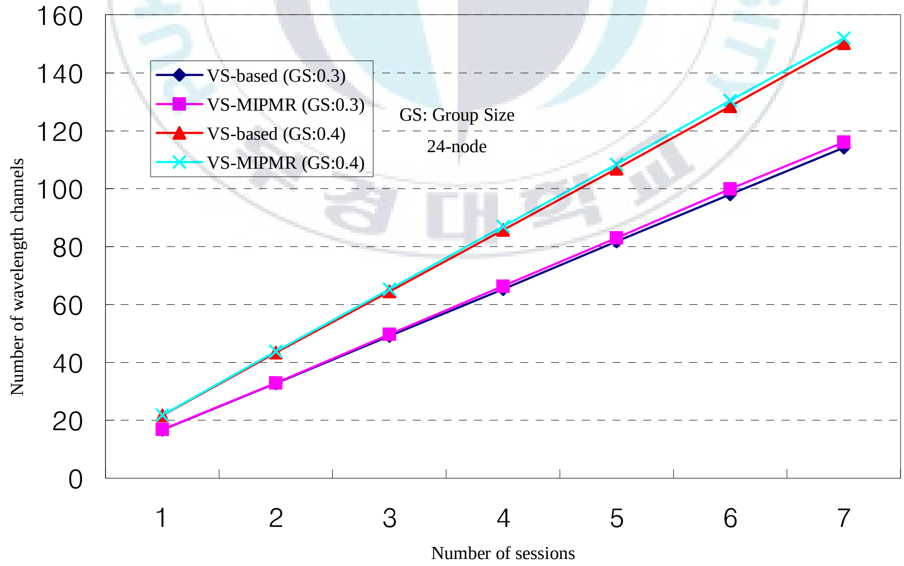
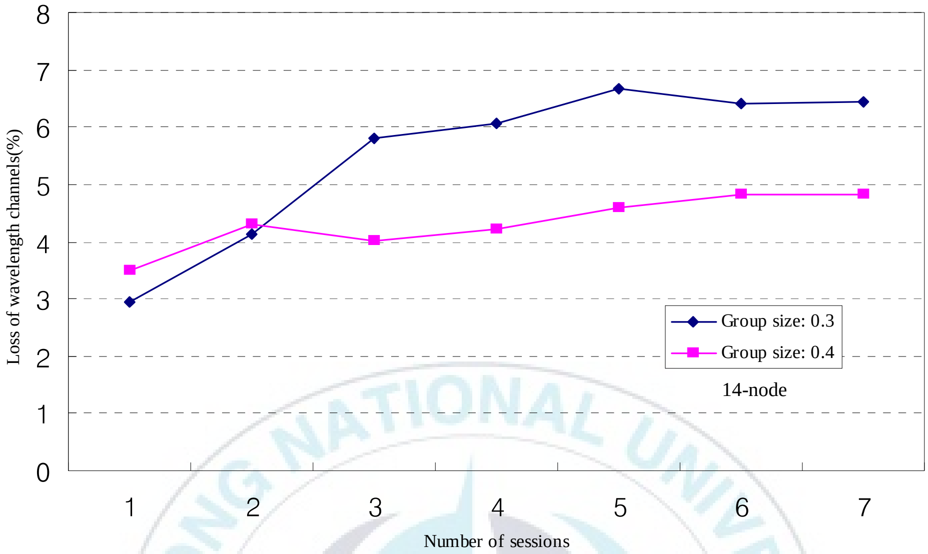


(a) 14-node topology

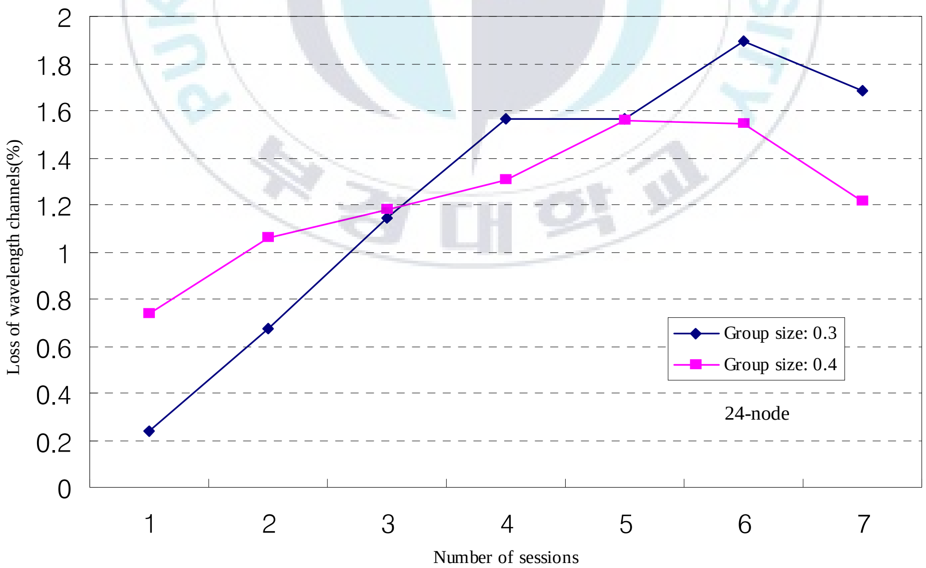


(b) 24-node topology

Figure 20. The number of wavelength channels over sessions



(a) 14-node topology



(b) 24-node topology

Figure 21. The loss of wavelength channel numbers over sessions

Ⅵ. Conclusion

This paper proposed a new routing algorithm in WSNs, combining the energy aware cluster head election technique with DAG which constructs an efficient cluster in DAUCH. The proposed algorithm outperforms DAUCH by eliminating the case that CH node exhausts its own energy while it plays a role of CH. According to simulation results, EDAUCH improves the number of data signals received at the BS, network lifetime, and average energy dissipation per round comparing with LEACH and DAUCH. These results mean that EDAUCH has better energy efficiency than LEACH and DAUCH. Moreover, we find that EDAUCH works well in various network environments irrespective of density. Therefore, EDAUCH provides an energy-efficient routing scheme suitable for the vast range of WSN applications.

In addition to the new routing algorithm in WSNs, we also proposed a new MCRWA algorithm in DWDM-based BcN. According to our simulation results, even though VS-MIPMR needs slightly more numbers of wavelength channels (e.g., 7% and 2% in 14-node and 24-node topologies, respectively) due to the detour paths to avoid congestion links, our algorithm significantly improves the utilization of wavelengths over sessions (approximately 24~25% in our network topologies), comparing with the VS-based method in DWDM-based BcN. The proposed multicast routing algorithm could be applied to the GMPLS call control protocol in DWDM-based OVPN.

To provide the USN services based on BcN backbone network, we proposed the energy efficient routing algorithm to lengthen network lifetime in WSNs and MCRWA algorithm to efficiently utilize DWDM optical resource in DWDM-based

BcN.

As a future research, we have a plan to integrate a routing algorithm for WSNs and a RWA algorithm for USN services in the environment of BcN backbone and access networks. Moreover, we will implement the simulation environment for the integrated framework and evaluation of the integrated algorithms.

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광대역통합망 기반 유비쿼터스 센서네트워크 서비스를 위한

라우팅 알고리즘 연구

이 춘 재

부경대학교 대학원 정보통신공학과

요 약

지난 수 십 년간 통신 기술의 급속한 발전은 인터넷 및 IPTV(Internet Protocol Television), TPS(Triple Play Service) 등과 같은 실시간 멀티미디어 서비스의 급격한 발전을 가져왔다. 이에 따라 다양한 서비스를 통합하여 전송하기 위한 연구가 계속해서 이뤄져 왔으며, 특히 우리나라의 경우 통신, 방송, 인터넷이 융합된 광대역통합망 (BcN: Broadband Convergence Network)을 활성화시키기 위한 움직임이 정부의 u-IT839 정책의 지원 아래 여러 서비스 제공업자들에 의해서 지속적으로 연구되어왔다.

BcN 이란 통신, 방송, 인터넷이 융합된 품질보장형 광대역 멀티미디어 서비스를 언제 어디서나 끊김 없이 안전하게 이용할 수 있는 차세대 통합 네트워크를 말한다. BcN 백본망 기술은 IP 를 제어하는 GMPLS(Generalized Multi-Protocol Label Switching)를 기반으로 DWDM(Dense-Wavelength Diivision Multiplexing) 광네트워크를 사용하는 IP/GMPLS over DWDM 으로 발전되고 있다.

최근 가장 중요시되는 유비쿼터스 서비스 중의 하나인 USN(Ubiquitous Sensor Network) 서비스를 BcN 을 통해 제공하기 위해서는 다양한 실시간 데이터를 수집하여 신속한 경로를 통해 단 한 번의 전송으로 WSN(Wireless Sensor network)의 각종 노드들로부터 Sink 로 전송되어야 한다. 이 과정에서 WSN 에서 망 전체의 생존시간을 증가시키기 위한 에너지 효율적인 라우팅 알고리즘 개발이 필수 불가결한 핵심 기술이다. 또한 Sink 노드에 집적된 데이터들이 BcN 백본 전달망과 액세스망을 통하여 USN 서비스 매니저에게 전달될 때, DWDM 망 내에서 광자원(Lamda)을 효율적으로 이용하는 경로를 선정하는 RWA 알고리즘 개발은 매우 중요한 핵심기술 요소이다.

광대역통합망에서 USN 서비스를 제공하기 위해서 기존의 유니캐스트 방식이 아닌 멀티캐스트 라우팅 방식이 대역폭 활용 측면에서 좀 더 효율적인 해결책을 제공한다. 이에 본 논문은 광대역통합망의 백본 망 계층을 제어하는 IP/GMPLS over DWDM 망에서 멀티캐스트 서비스를 지원하기 위한 멀티캐스트 라우팅 알고리즘을 제안한다.

WSN 에서는 망 전체의 생존시간을 증가시키기 위해서 각 노드의 효율적인 에너지 사용이 필수적이다. 이에 본 논문은 WSN 에서 각 노드의 전력 사용을 줄이기 위한 새로운 라우팅 알고리즘 또한 제안한다.

본 논문은 WSN 에서 효율적인 에너지 사용에 필요한 라우팅 알고리즘을 포함하여 WSN 의 데이터들을 사용자에게 제공하기 위한 BcN 기반의 멀티캐스트 라우팅 알고리즘을 제시하여, 향후 제공될 USN 서비스의 전반적인 해결책을 제시한다.

PUKYONG NATIONAL UNIVERSITY 부경대학교

Acknowledgments

I appreciate a steady attention and precious advice of Prof. Kim, Sung-Un for the completion of this dissertation with all my heart. Moreover, I am very thankful to Prof. Ju, Moon-Gab and Prof. Park, Gyu-Chil for examining this dissertation along with much good advice. Finally, I acknowledge several professors in Dept. of Telecommunication Engineering, Pukyong National University for considerable instructions and encouragement till now.

Meanwhile, I thank my big seniors in the protocol-engineering laboratory, who gave much advice and help to me during my master's degree course. I would like to acknowledge many seniors: Jae-Yun, Young-Suk, Tae-Gyun, Sung-Su, Jae-Ho, Heung-Sik, Eui-Sub, Seong-Kil, Seon-Kyu, Ik-Seob, Mi-Kyoung, Du-Jin, Hyun-Soo, Ju-Dong, Jung-Hyun, Mi-ra, Chang-Hyun, Mi-Seon and Kwang-Hyun, Jin-Ho, Suk-Jin, and Kyong-Dong who were already graduated, and especially, Jeong-Mi, Jong-Keun, Hyun-Hoon, Jin-Ho, Sang-Bo, Seung-Mi, Chan-Hyo who help to me in every respect. I thank, too.

Above all, I would like to acknowledge my parents who have devoted themselves to supporting me even despite many difficulties, as well as my brother Yun-Jai. I am also thankful to other acquaintances, juniors, seniors and my friends as missed on this paper.