Routing and Wavelength Assignment in WDM and Advanced Communication Networks

P. Krishnaiah[1],
Research Scholar,
Department of Computer Science & Technology,
Sri Krishnadevaraya University, Anantapuramu, A.P. India.

Dr. K.Bhavana Raj[2],
Assistant Professor, Institute of Public Enterprise,
Hyderabad.

Dr. M.Suresh Babu[3],
Professor, Department of CSE,
Goutham Buddha Development Society, Anantapur, A.P. India.

***Abstract*-The rapid growth of Internet traffic has been the driving force for faster and more reliable data communication networks. Networking is a very promising technology to meet these ever increasing demands. Broadly speaking a computer network is an interconnected collection of interdependent computers that aid communication in numerous ways. Apart from providing a good communication medium, cost effectiveness and sharing of available resources (programs and data) are some of the advantages of networking. Nowadays, the need for error-free, high bandwidth communication channels has been on the rise. The services provided by computer networks are mainly remote information access. This rapid growth of internet traffic has been the driving force for faster and more reliable computer and data communication networks. Wavelength division multiplexing (WDM) is a very promising technology to meet the ever increasing demands of high capacity and bandwidth. WDM networks are a viable solution for emerging applications, such as supercomputer visualization and medical imaging, which need to provide high data transmission rate, low error rate and minimal propagation delay to a large number of users. The commercialization of WDM technology is progressing rapidly. Most important for the development of the WDM technology was the invention of Erbium Doped Fiber Amplifier, (EDFA) an optical fiber amplifier in 1987. The optical fiber amplifier is a component capable of amplifying several optical signals at the same time without converting them first to electrical domain (opto-electronic amplification).**
Keywords : Wavelength division Multiplexing, Erbium Doped fibre amplifier.

INTRODUCTION

1.0 Wavelength Division Multiplexing

Theoretically, fiber has extremely high bandwidth (about 25 THz [terahertz]) in the 1.55 low-attenuation band and this is thousands times of the

total bandwidth of radio on the planet Earth [3]. However, only speed of a few gigabits per second is achieved because the rate at which an end user (a workstation) can access a network is limited by electronic speed, which is a few gigabits per second. Hence, it is extremely difficult to exploit all the bandwidth of a single fiber using a single high-capacity wavelength channel due to optical-electronic bandwidth mismatch or “electronic bottleneck.” The recent breakthroughs (Tb/s) are the result of two major developments: WDM, which is a method of sending many light beams of different wavelengths simultaneously down the core of an optical fiber and the EDFA, which amplifies signal at different wavelengths simultaneously regardless of their modulation scheme or speed.

WDM is essentially same as frequency division multiplexing (FDM), which has been used in radio systems for more than a century. For some reasons, the term FDM is used in radio communication but WDM is used in the context of optical communication, perhaps because FDM was studied by communication engineers and WDM by physicists . The idea is to modulate optical signals at different wavelengths and to transmit the data simultaneously by combining resulting signals over the same optical fiber. A wavelength can also be shared among many nodes in a network by electronic *time division multiplexing*. Note that WDM eliminates the electronic bottleneck by dividing the optical transmission spectrum (1.55-micron band) into a number of non-overlapping wavelength channels. These channels coexist on a single fiber with each wavelength supporting a single communication channel operating at a peak electronic speed. The attraction of WDM is that a huge increase in available bandwidth can be obtained without the huge investment necessary to deploy additional optical fiber. The DWDM technique effectively increases the total number of channels in a fiber by using very narrow spaced channels.

1.2 Wavelength Channels in Optical Spectrum

WDM systems can be classified further on the basis of the Wavelength channels used. The first WDM systems were so-called broadband WDM systems, using two widely-separated signals (typically at 1310 nm and 1550 nm). On the other hand, the term DWDM refers to a technology used in backbone networks, where up to 40 or 80 signals are combined on the same fiber. Furthermore, there is coarse wavelength division multiplexing (CWDM), where the channel spacing is 20nm in the range of 1270nm to 1610nm giving up to 18 channels in total. Unlike the other two, CWDM is targeted at metropolitan area networks. The International Telecommunication Union (ITU) has standardized the use of wavelength channels. Standard G.692 defines channel spacing for DWDM systems as 50 GHz or 100 GHz around the reference frequency of 193.10 THz, as depicted in figure (1.). The reference frequency 193.10 THz corresponds to about 1550 nm, and hence the proposal is meant for the 1540 nm - 1560 nm pass band of the optical fiber.

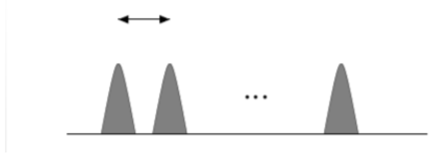

Figure 1.1: The optical spectrum and 8 wavelength channels.

2.0.Components of All-Optical WDM Network

During recent years lots of efforts have been made for the development of better optical components to enable all-optical WDM-networks. The most important components are light sources, tunable optical filters, optical switches and of course the fiber. Different components are briefly presented in the following sections.

2.1. Light Sources

One of the important elements of an optical system is the light source. For communication purpose, a good light source should be quickly tunable with a wide range of wavelengths. To make a component commercially attractive low price and low power consumption are vital parameters . The time scale of tuning depends upon the technique used i.e. with optical packet switching the requirements are somewhere between microseconds and nanoseconds while with circuit switched WDM-networks the time scale is slower.

2.2. Tunable Filters

A tunable optical filter is also one of the important parts of the optical network. Many promising approaches have been studied including Fabry-Perot, acousto-optic, electro-optic and liquid crystal Fabry-Perot filters. The filters have two important parameters dealing with the performance: tuning range and tuning time. The tuning ranges are from around 10 nm up to 500 nm, while the tuning time is from few nanoseconds up to 10 milliseconds.

2.3. Optical Cross-Connects/Switches

The optical switch or Optical Cross-Connect (OXC) is a device which can dynamically be configured to connect the given input ports to any of the output ports. The optical switches can be classified according to their flexibility:

1. A *non-blocking switch* means any connection pattern can be realized by reconnection of some or all of the current connections.
2. *Wide-sense non-blocking switch* is a switch which can be configured to add any new connections without interrupting previously configured connections through the switch.
3. *Strict-sense non-blocking switch* on the other hand can be defined as that switch which can add new connections any time without interrupting any of the current connections.

3.0. Components of Wavelength Routed Networks

In WDM-networks each fiber contains *W* wavelength channels and thus the optical switches should be capable to treat channels individually. The optical cross-connects used in WDM-networks can be divided into two categories [10]: wavelength selective cross-connect (WSXC) and wavelength interchange cross-connect (WIXC). A wavelength selective cross-connect is a device capable of configuring any given input λ-channel from arbitrary input port to a given output port (using the same wavelength). *Wavelength translation* (conversion) is an operation where an incoming signal using λ_1-channel is converted to another channel λ_2 at the output port. Wavelength interchange cross-connect as depicted in figure (1.4), is a more advanced device than WSXC which can manipulate wavelengths of the signals as well, i.e. an incoming signal can emerge from the switch using another wavelength. Hence, such a device can configure λ_1-channel from any input port to any output port using λ_2-channel, i.e. it is capable of doing wavelength translations as well. Clearly, a WIXC device is not only more complex than WSXC, but it also gives more flexibility in the configuration of the network and hence leads to more efficient use of the network resources. Both the WSXC and WIXC are devices where every input channel is connected to not more than one output-channel (permutation switch).

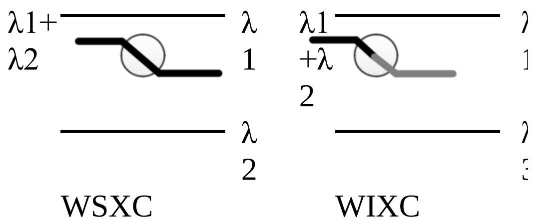

Figure 2.0: The basic components of the wavelength routed network (WSXC & WIXC)

3.1. Wavelength Converters

Wavelength conversion is a process of converting the signal from one wavelength on an incoming link to a different wavelength on an outgoing link and wavelength converters are devices which are used to perform these wavelength conversions. Wavelength conversion allows more efficient use of the network resources and without wavelength conversion the so called wavelength-continuity constraint has to be satisfied, i.e. the lightpath reserves the same wavelength all the way along the route. Hence, even if there are free channels available on every link of the network, some connections may not be configured unless wavelength conversion is possible in some of the nodes. Again, an easy solution is to do the opto-electronic wavelength conversion where the optical signal is first converted to the electrical domain and then reproduced in the optical domain at a different wavelength. This helps to improve the wavelength reuse in which wavelength can be spatially reused to carry different connections on different fiber links in the network. The drawback with this approach is the limited bit rate of electronics. There are four types of wavelength conversion:

full wavelength conversion, limited wavelength conversion, fixed conversion and partial wavelength conversion. In full conversion any incoming wavelength can be shifted to any outgoing wavelength, while in limited conversion not all incoming channels can be connected to all outgoing channels. In fixed conversion each incoming channel may only be connected to one or more predetermined channels. In partial wavelength conversion, different nodes in the network can have different levels of wavelength conversion capability.

3.2.Optical Amplifiers

The attenuation of optical signals is low in comparison to electrical signals. Still there is a possibility that long-distance links may require amplifiers in order to operate properly. The optical signal loses its energy because of transmission impairments in a fiber. Long distance optical transmission is possible only by signal amplifiers that provide a power boost to the signals. The traditional way to solve this problem is to convert the signal back to electrical domain for amplification and retransmit it optically. This approach requires knowledge of used bit rate and modulation. A new solution is to use amplifiers operating totally in optical domain. This solution is called Optical Amplifiers.

3.3 Internet Protocol

The Internet Protocol (IP) has been a massive success story during the last thirty years. Nowadays, the internet standards are defined within the Internet Engineering Task Force (IETF) which coordinates the standardization work in the internet community. The Requests for Comments (RFC) form the backbone of documents and describes how things are to be done on the internet. The IP defines a packet based way to communicate over a heterogeneous environment including slow modem links as well as high capacity backbone routes. Generally, IP network is a best effort network with no guarantee for any Quality of Service (QoS). The related layer 4 protocols are Universal Datagram Protocol (UDP) and Transmission Control Protocol (TCP) which are built upon the internet protocol. The UDP is a connectionless protocol to send an IP packet. Nothing is guaranteed, the packet may be lost without any feedback. It is left to the application to solve the possible problems. The TCP on the other hand is a connection oriented protocol where the stream of bytes is guaranteed to reach the destination in the correct order (or the failure is reported to both the ends).

3.4 SDH and SONET

SDH stands for the Synchronous Digital Hierarchy and is widely used transmission system in Europe. SONET, Synchronous Optical Network is its American counterpart.SDH is defined by the European Telecommunications Standards Institute (ETSI), while the SONET is defined by the American National Standards Institution (ANSI). These standards define the line rates, coding schemes, bit-rate hierarchies, restoration and network management. Equipment from different vendors can be used together and network operators get more freedom in building their networks. Both systems use a small time frame containing header and a payload as a basic building block. Higher transmission rates are obtained by byte-interleaving the basic time frames. Almost all of the processing is done digitally.

Given a WDM network, the problem of routing and assigning wavelength to lightpaths is of paramount importance in these networks. The clever algorithms are needed in order to ensure that Routing and Wavelength Assignment (RWA) function is performed using a minimum number of wavelengths. The number of available wavelengths in a fiber link plays a major role in these networks which is increasing day by day. Packet switching in wavelength routed networks can be supported by using either a single-hop or a multi-hop approach, in a way similar to broadcast-and-select networks. In the multi-hop approach, a virtual topology (a set of lightpaths or optical layer) is imposed the physical topology by setting WXCs in the nodes.

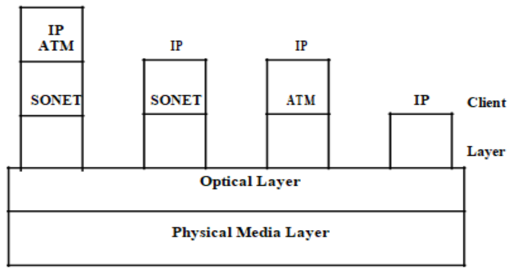

Figure 3.0: Possible layers in a WDM optical transport network

Existing internet backbone network consist of high-capacity IP routers interconnected by point-to-point fiber links. Traffic is transported between routers through high-speed gigabit links. These links are realized by SONET or ATM-over-SONET technology. The backbone routers are IP-over-SONET or IP-over-ATM-over-SONET technology to route IP traffic in backbone network. Most of the SONET-based backbone transport networks provide data interface at the rate of OC-3 and OC-12. The traffic demand is growing at a faster rate and a point has been reached where the data interfaces at the rate of OC-48 and more are required. Upgrading the existing SONET transport infrastructures to handle these high-capacity interface rates is not desirable as it is impractical to go for upgrading every time the interface rate increases. Also, such upgrading is not economical. A viable and cost-effective solution is to use WDM technology in backbone transport networks. In IP-over-WDM networks, network nodes are interconnected by WDM fiber links and those nodes employ WXCs and electronic processing elements. In a typical WDM backbone network, the electronic processing element can be an IP route, ATM switch or a SONET system. Any two IP routers in this network can be connected together by a lightpath. Two nodes that are not connected directly by a lightpath communicate using multi-hop approach, i.e., by using electronic packet switching at the intermediate nodes. The electronic packet switching can be provided by IP routers, ATM switches or SONET equipment leading to an IP-over-

WDM or an ATM-over-WDM or a SONET-over-WDM network respectively.

3.5. Constraints in Wavelength Routed WDM Optical Networks

Some of the important issues in wavelength routed optical WDM networks include routing and wavelength assignment problem as a single complete problem, wavelength routing and rerouting problem, wavelength assignment, connection request, minimizing the effect due to wavelength continuity constraint, design, reconfiguration, survivability, traffic grooming, minimization of blocking probability, improvement of fairness, wavelength conversion and IP-over-WDM.

4.0. Routing and Wavelength Assignment problem

Sitting in the heart of WDM is the *routing and wavelength assignment* problem. The problem of routing and wavelength assignment is crucial in wavelength routing networks. RWA is the unique feature of WDM networks in which lightpath is implemented by selecting the path of a physical link between source and destination edge nodes and reserving a particular wavelength on each of these links for the lightpath. Thus for establishment of an optical connection, one must deal with the selection of the path (Routing problem) as well as allocating the available wavelengths for the connections (Wavelength Assignment problem). This resulting problem is known as *routing and wavelength assignment* problem.

Routing and wavelength assignment is critically important to increase the efficiency of optical networks. Connection requests may be of three types: static, incremental and dynamic. With static traffic, the entire set of connections is known in advance and then the problem is to set up lightpaths for these connections in a global fashion while minimizing network resources utilization such as number of wavelengths or number of fiber links in the network. In incremental traffic case connection requests arrive sequentially, a lightpath is established for each connection and the lightpath remains in the network indefinitely. In case of dynamic traffic a lightpath is set up for each connection request as it arrives and lightpath is released after some finite amount of time. The objective in this incremental and dynamic traffic cases is to set up lightpaths and to assign wavelengths in a manner that minimizes the amount of connections blocking or maximizes the number of connections that are established in the network at any time. In wavelength routed WDM networks a connection is realized by a lightpath. In order to establish a connection between a source-destination pair a wavelength continuous route needs to be found between the node pair. An algorithm used for selecting routes and wavelengths to establish lightpaths is known as routing and wavelength assignment algorithm.

4.1. Static Verses Dynamic RWA

In a wavelength routing network, the connection request (traffic demand) can be considered either *static* or *dynamic*, it can be said that lightpath requests can be either *offline* or *online* respectively. In case of a static RWA connection requests are known as a *priori* The traffic demand may be specified in terms of source-destination pairs. These pairs are chosen based on an estimation of long-term traffic requirement between the node pairs. In a static traffic pattern (offline lightpath requests) a set of lightpaths are set up all in advance and remain in the network for long time; they can be considered *permanent*. The RWA problem is known as *offline RWA* in this case. The objective is to assign route and wavelengths to all demands so as to minimize the number of wavelengths used. The dual problem is to assign route and wavelengths so as to maximize the number of demands satisfied for a fixed number of wavelengths. The above problems are categorized under SLE problem. The SLE problem has been shown to be NP-complete (i.e. it is computationally intractable or, in other words, the only known algorithms that find an optimal solution require exponential time in the worst case). Therefore, polynomial-time algorithms which produce solutions close to the optimal one are preferred. In case of dynamic RWA, connection requests arrive and depart from a network one by one in a random manner. The lightpaths once established remain for a finite time. In a dynamic traffic pattern a lightpath is set up for each connection request as it arrives and lightpath is released after some finite amount of time. The lightpaths are switched in this case and are then provided in a circuit-switched fashion. The RWA problem here is called online RWA.

4.2. Solution to RWA Problem

A good RWA algorithm is critically important to improve the performance of wavelength-routed WDM networks. In, a heuristic RWA algorithm has been proposed to maximize the carried traffic (or equivalently minimizing the blocking probability) when the connection requests arrive dynamically. Solutions based on approximation techniques should be proposed as proposed in, for the RWA problem with an objective of minimizing the number of wavelengths required in both the SLE and DLE cases. We can divide this problem in two problems namely; routing problem and wavelength assignment problem and then we can propose different solutions to this problem.

4.3. Wavelength Assignment and Conversion schemes

There are two constraints that have to be kept in mind by the approaches when trying to solve RWA. In fact the constraints concern the second part of the problem, in which routes of lightpaths are assumed to be known in advance and what remains to be done is *wavelength assignment* (*WA*). The constraints are summarized below:

i. *Distinct wavelength assignment constraint*: All lightpaths sharing a common fiber must be assigned distinct wavelengths to avoid interference. This applies not only within the all-optical network but in access links as well.

ii. *Wavelength continuity constraint*: The wavelength assigned to each lightpath remains the same on all the links it traverses from source end-node to destination end-node.

The first constraint holds for solving wavelength assignment problem in any wavelength routing network. The second constraint applies only to the simple case of wavelength routing networks that have no wavelength conversion capability inside their nodes. Wavelength assignment is a unique feature in wavelength routed networks that distinguishes them from conventional networks.

Based on the order in which the wavelengths are searched, wavelength assignment methods are classified into *most-used, least-used, fixed-order* and *random-order*. In the most-used wavelength assignment method, wavelengths are searched in non-increasing order of their utilization in network. This method tries to pack the lightpaths so that more wavelength continuous routes are available for the request that arrives later. In the least used wavelength assignment method, wavelengths are searched in non-decreasing order of their utilization in the network. This method spreads the lightpaths over different wavelengths. The idea here is that a new request can find a shorter route and a free wavelength on it. The argument is that the most-used wavelength assignment method may tend to choose a longer route as it always prefers the most-used wavelength. In the fixed-order wavelength assignment method, the wavelengths are searched in a fixed order. The wavelengths may be indexed and the wavelength with the lowest index is examined first. In the random wavelength assignment method the wavelength is chosen randomly from the free wavelengths. The most-used and least-used wavelength assignment methods are preferred for networks with centralized control. The other two methods are preferred for the networks with distributed control. The numerical results reported in literature show that the most-used wavelength assignment method performs better than the least-used method and the fixed-order wavelength assignment method performs better than the random method.

One possible way to overcome the bandwidth loss caused by the wavelength continuity constraint is to use wavelength converters at the routing nodes. A wavelength converter is an optical device which is capable of shifting one wavelength to another wavelength. The capability of a wavelength converter is characterized by the degree of conversion. A converter which is capable of shifting a wavelength to any one of D wavelengths is said to have conversion degree D. The cost of a converter grows with the increasing conversion degree. A converter is said to have full degree of conversion when the conversion degree equals the number of wavelengths per fiber link. Otherwise, it is said to have partial or limited degree of conversion.

The basic function of the wavelength converter is to convert an input wavelength to possibly different output wavelengths within operational bandwidth of WDM systems in order to improve their overall efficiency and hence the reuse factor is increased. Wavelength converters are one of the important building blocks of any WDM system as they enable reuse of wavelengths in that system. This process is needed in order to increase the overall system bandwidth and for wavelength routing. There are four possible forms of waveform conversion: full conversion, limited conversion, fixed conversion and sparse wavelength conversion. In full conversion type, any wavelength shifting is possible and therefore channels can be converted regardless of their wavelengths. In the limited conversion type, wavelength shifting is restricted so that not all combinations of channels may be connected. In the fixed conversion each channel may be connected to exactly one predetermined channel on all other links. Finally, in the sparse wavelength conversion, networks are comprised of a mixture of nodes having full and no wavelength conversion.

A WXC having one or more wavelength converters is called as a wavelength interchange cross connect. A node with wavelength conversion capability is called a Wavelength Converting (WC) node or a Wavelength Interchange (WI) node. A WDM network with WC node is called wavelength-convertible network. A node may have a maximum of F_{in} x W converters, where F_{in} is the number of full-degree converters, its performance reaches the best achievable. Since wavelength conversion is an immature extremely costly technology, it may not be economical to install wavelength converters at every node of a network. Rather, it may be more sensible to put wavelength converters at some but not all nodes in the network called *sparse wavelength conversion network.*

4.4. Wavelength Routing and Rerouting Techniques

There are a number of wavelength routing techniques proposed in literature. The important routing schemes considered in literature are *fixed routing*, *alternate routing* and *exhaust routing*. In the *fixed routing scheme* only one route is provided for a node pair. Usually this route is chosen to be the shortest route. When a connection request arrives for a node pair the route fixed for that node pair is searched for the availability of a free wavelength. In the *alternate routing scheme* two or more routes are provided for a node pair. These routes are searched one by one in a predetermined order. Usually, these routes are ordered in non-decreasing order of their hop length. In the *exhaust routing scheme* all possible routes are searched for a node pair. The network state is represented as a graph and a shortest-path-finding algorithm is used on the graph. While the exhaust method yields the best performance when compared to the other two methods, it is computationally more complex. Similarly, the fixed routing method is simpler than alternate routing method but it yields poorer performance than the other. In, fixed routing, fixed alternate routing and some heuristics for wavelength assignment schemes have been proposed with the objective of minimizing the blocking probability for dynamically establishing lightpaths in response to a random pattern of arriving connection requests and connection holding times.

Rerouting is a concept which was originally introduced in the design of circuit-switched telephone networks. This is simply the action of switching an existing lightpath or connection from one route to another route without changing the source and destination. It has also been applied to optical WDM networks recently. A comprehensive survey of rerouting techniques can be found in. Rerouting algorithms may generally be categorized as follows:

- Passive rerouting: only if the simple routing procedure fails the rerouting procedure tries to accommodate the new connection request by shifting/migrating some existing lightpaths/connections.
- Active rerouting: the rerouting procedure is typically controlled by a timer and it periodically shifts/migrates existing lightpaths/connections to better routes.
- Lightpath level rerouting: traffic of lightpaths at the full wavelength capacity granularity is rerouted.
- Connection level rerouting: traffic of connections at different bandwidth granularities is rerouted.

The network performance can be measured by blocking probability, which is the statistical probability that a telephone connection cannot be established due to insufficient transmission resources in the network. Usually it is expressed as a percentage or decimal equivalent of calls blocked by network congestion during the busy hour. Erlang-B, also known as the Erlang loss formula, is a formula for calculation of blocking probability. It is derived from the Erlang distribution to describe the probability of call loss on a group of circuits. It is mainly used in planning telephone networks.

CONCLUSION :

The introduction of optical networks and wavelength division multiplexing has been covered in this paper and considering the above mentioned challenges the objectives of paper were formulated. The objective of this paper is to study and analyse the existing wavelength assignment algorithms and to develop new algorithm of wavelength assignment for better performance in wavelength division multiplexed networks. Several Routing and Wavelength Assignment algorithms have been narrated. The functionality of these algorithms is explained and analysed with the existing routing algorithms and to develop new effective routing algorithms for survivable wavelength division multiplexed networks.

REFERENCES :

[1] R. Ramaswami, “Multi wave length lightwave networks for computer communication,” IEEE Communication Magazine, Vol. 31, pp. 78–88, Feb. 1993.

[2] Amit Wason, R. S. Kaler, “Blocking in wavelength-routed all-optical WDM networks,” Optik– International Journal for Light and Electron Optics- Elsevier Science, vol. 121, no. 10, pp. 903-907, June 2010.

[3] Chatterjee S. and Pawlowski S., “All-Optical Networks,” Communications of the ACM, Vol 42, No. 6, pp. 74-83, June 1999.

[4] R. Ramaswami and K. N.Sivarajan, Optical Networks-A Practical Perspective, Second edition, Morgan Kaufmann Publishers-An Imprint of Elsevier, New Delhi, India, 2004.

[5] C. Siva Ram Murthy and Mohan Gurusamy, WDM optical networks -Concepts, Design and Algorithms, Prentice Hall of India Pvt. Limited, 2002.

[6] Biswanath Mukherjee, Optical WDM Networks, Springer, 2006

[7] Esa Hyytia, “Resource allocation and performance analysis problems in optical networks,” Report, Helsinki University of Technology Networking Laboratory, 2004.

[8] M. H. E. Jaafar and T. M. Hussein, “All-optical wavelength conversion: Technologies and applications in DWDM networks”, IEEE Communication Magazine, vol 38, no. 3, pp. 86–92, March 2000.

[9] M. H. E. Jaafar and T. M. Hussein, “Technologies and Architectures for Scalable Dynamic Dense WDM Networks”, IEEE Communication Magazine, vol. 38, no. 2, pp. 58–66, February 2000.

[10] Biswanath Mukherjee, Optical Communication Networks, McGraw-Hill series on computer communications, McGraw-Hill, 1997.

[11] V. Eramo, M. Listanti, and P. Pacifici, “A comparison study on the wavelength converters number needed in synchronous and asynchronous all-optical switching architectures,” IEEE/OSA Journal of Lightwave Technology, vol. 21, no. 2, pp. 340–355, February 2003.

[12] Goran Markovic, Vladanka Acimovic-Raspopovic, “A Procedure of Wavelength Rerouting in Optical WDM Networks”, TELSIKS-2005, Serbia and Montenegro, September 28-30, 2005.

[13] A. Shami, Chadi Assi, and Mohammed Ali, “Dynamic Wavelength Provisioning in DWDM-Based Optical Network,” Fifth Working Conference on Optical Network Design and Modelling (ONDM 2001), pp. 357-370, February 5-7, 2001.