Wavelength Assignment in wavelength division Multiplexing Systems: A Survey

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Abstract—in optical networks, a connection is used to transmit data between source and destination nodes via lightpaths. The optical signal transmitted along a lightpath requires cross-connect switches (OXCs) and telecommunication carriers to switch high-speed optical signals in a fiber optic network. As a signal propagates from the source to the destination, the signal quality is continuously degraded by optical network components and impairments. Wavelength routing networks have two main problems: network design (fiber topology) and traffic requirements (traffic matrix). The network design problem is divided into lightpath topology design (LTD) and routing and wavelength assignment (RWA) problems. The RWA problem is more important for increasing the effectiveness of optical networks. The lightpath routing sub-problem requires determining the physical links for each lightpath that consist of optical channels. The wavelength assignment (WA) sub-problem requires determining the wavelength that each lightpath uses, i.e., assigning a wavelength to each lightpath in the logical topology such that wavelength restrictions are obeyed for each physical link. In this article, we discuss the important concepts of optical networks and the factors that affect in RWAs directly or indirectly

Keywords—*Optical Network; WDM; RWA; Routing; Lightpath;*

I. INTRODUCTION

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. 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. In a WDM network several optical signals are sent on the same fiber using different wavelength channels. Sometimes, the term dense wavelength division multiplexing (DWDM) is used to distinguish the technology from the broadband WDM systems where two widely separated signals (typically 1310nm and 1550nm) share a common fiber. In DWDM up to 40 or 80 signals are combined on the same fiber. 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 [1]. Traditionally, only a small fraction of the fiber capacity was used, but by using WDM it is possible to exploit this huge capacity more efficiently [2]. The possibility to use the existing fibers more efficiently makes WDM a very attractive alternative commercially, as it is very expensive to install new fibers in the ground. This is the case especially in densely populated areas like cities, where fibers must be dug under streets etc. WDM technology has been recognized as one of the key components of the future networks. 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). It is also important to note that EDFAs can be used to amplify signals of different bit rates and modulations. Other important WDM components include lasers, receivers, wavelength division multiplexers, wavelength converters, optical splitters and tunable filters amongst others. There is also wide interest towards the optical networking in academic community as it offers a rich research field for scientists from the component level up to the network protocols.

A. 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. WDM systems use a carrier wave which is higher than that of an FDM channel by a million times in frequency (THz versus MHz). Within each WDM channel, it is possible to have FDM where the channel bandwidth is subdivided into many radio frequency channels each at a different frequency. This is called subcarrier multiplexing. 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 [5]. Typically channel spacing ranges from 0.4 nm to 4 nm.

B. WDM Optical Network

WDM Optical Network is a network of computers in which the backbone is optical fiber cable and the mode of transmission is wavelength division multiplexing. The information stream from multiple sources is optically combined by the star and the signal power of each stream is split and forwarded to all nodes through their fibers. Communication between source and destination may either be single-hop or it may be multi-hop.

C. 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 [75]. 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. 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.

D. All-Optical Networks

Initially, the WDM technique was used to increase the capacity of point-to-point optical links. At the end of each link the signal was converted back to the electrical domain and the gain was simply a larger link capacity. However, the trend has been towards transparent all-optical networks, where signal is routed through a network in optical domain. Something that was especially important for development of all-optical WDM networks was the invention of EDFA in 1987. The optical fiber amplifier, EDFA is a component capable of amplifying several optical signals at the same time without converting them first to the electrical domain (opto-electronic amplification). It is also worth noting that EDFAs can be used to amplify signals of different bit rates and modulations. Other important WDM components include light sources, tunable filters, optical switches, wavelength converters, optical amplifiers and wavelength division multiplexers. In future, these components will together enable us to build the transparent all-optical networks to meet the ever increasing capacity demands.

E. 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 [86]. 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.

F. 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 [17]. Another approach is to do the conversion in the optical domain. Suggested solutions include using the four-wave mixing, fiber nonlinearities and cross modulation with active semiconductor devices. An up-to-date survey on wavelength conversion can be found in [98].

II. LITERATURE SURVEY

Z. Zhang et. al. [1], presented a heuristic algorithm for effective assignment of a limited number of wavelengths among the access stations of a multi-hop network where the physical medium consists of optical fiber segments which interconnect wavelength elective optical switches.

Poompat Saengudomlert et. al. [2], developed an on-line wavelength assignment algorithm for a wavelength-routed WDM tree network. The algorithm dynamically supports all k-port traffic matrices among end nodes. Implementation of proposed wavelength assignment algorithm was also demonstrated using a hybrid wavelength-routed/broadcast tree with only one switching node connecting several passive broadcast sub-trees.

Junjun Wan et. al. [3], proposed a wavelength assignment algorithm, which was based on the method called Dynamic Preferred Wavelength Sets (D-PWS). Also, they described the basic architecture of the optical burst switching network based on Dynamic Wavelength Routing (DWR), under which the guarantee of the quality of service in the DWR-OBS network was discussed. Then they focused on two aspects: the transmission latency of the data packets and the blocking probability, which leads to a quantitative description of the transmission latency and the size of the edge node buffer.

F. Matera et. al. [4], showed how to obtain a wavelength assignment in a wide geographical transport network connecting the main cities of Europe, when all optical wavelength converters are introduced in the network nodes. They also reported an investigation on 40 Gb/s transmission performance in the presence of all optical wavelength converters based on four wave mixing in semiconductor optical amplifiers and on different frequency generation in periodically poled lithium niobate waveguides.

Anwar Alyatama [5], used random and first-fit wavelength assignment approach for presenting an approximate analytical method and evaluated the blocking probabilities in wavelength division multiplexing networks without wavelength converters. The new approach viewed the WDM network as a set of different layers (colours) in which, blocked traffic in one layer is overflowed to another layer. Analysing blocking probabilities in each layer of the network is derived from an exact approach. A moment matching method was then used to characterise the overflow traffic from one layer to another.

Raja Datta et. al. [6], presented a wavelength assignment algorithm which was used for optimal assignment of a single wavelength to single-hop traffic in a tree topology. The work was further extended for the wavelength assignment in a general graph. This polynomial time algorithm gave an optimal solution to the routing and wavelength assignment problem in a tree topology.

P. Rajalakshmi et. al. [7], proposed a new wavelength assignment technique called wavelength reassignment algorithm in which when the new call gets blocked due to wavelength continuity constraint the already established calls were reassigned the wavelength, so as to create a wavelength-continuous route in order to accommodate the new call. During wavelength reassignment the routes for all calls remain the same, i.e. no rerouting was done. The problem of enhancing the blocking performance, in the circuit-switched wide-area optical wavelength-division multiplexed networks with no wavelength conversion at the nodes was also considered.

I. Alfouzan et. al. [8], introduced two new wavelength assignment reconfiguration algorithms, the One-Directional Transfer (1DT) and the Two-Directional Transfer (2DT) algorithms. The simulation results for both these algorithms were shown to outperform the existing algorithms in terms of the trade-off.

Abhisek Mukherjee et. al. [9], proposed a new wavelength conversion algorithm in a DWDM network using online routing. The model for the algorithm has been theoretically developed and the corresponding call connection probability has been calculated. The limitation on the number of wavelength conversions has been addressed by fixing the maximum number of wavelength conversions allowed for the transmissions of a single packet over the network.

Nen-Fu Huang et. al. [10], proposed an efficient distributed Wavelength Reusing/ Migrating /Sharing Protocol (WRMSP) for the Dual Bus Lightwave Networks (DBLN). This protocol constituted of three efficient schemes for carrying out the wavelength reusing, migration and sharing respectively.

Mahesh Sivakumara et. al. [11], studied the effect of wavelength conversion on the blocking performance of connections with multiple rates. The blocking performance of the TDM wavelength routing network was evaluated through simulations.

Nen-Fu Huang et. al. [12], proposed a wavelength reuse algorithm for WDM star networks. They also proposed a wavelength-reusable local lightwave network constituted of two interconnected WDM star networks. Based on this architecture, the lower bounds for the problems of minimizing the switching duration and the number of switching modes were derived.

Raul Munoz et. al. [13], proposed wavelength assignment schemes for dedicated protection rings. A novel Generalized Multiprotocol Label Switching (GMPLS) based lightpath signalling and wavelength reservation schemes were also evaluated for Dedicated Protection Ring (DPRing)-based MANs. Performance evaluation has been carried out in a GMPLS-based test bed named ADRENALINE.

Jianping Wang et. al. [14], studied the problem of wavelength assignment for multicasting in order to maximize the network capacity in all-optical wavelength-division multiplexing networks. Two efficient greedy algorithms were also proposed for general multi-hop networks. The objective of this work was to minimize the call blocking probability by maximizing the remaining network capacity after each wavelength assignment.

Arun K. Somani et. al. [15], addressed the wavelength assignment issues in interconnecting optical local area networks in which a wavelength could not be reused for local connections. Static and dynamic approaches for partitioning of wavelengths were analysed and compared by simulations for local and global traffic. Several dynamic wavelength assignment algorithms were also developed and architectural issues interconnecting optical networks were also discussed. The objective was the development of a simple yet accurate model to predict approximate blocking performance with an arbitrary number of LANs.

Xijun Zhang et. al.[16], proposed generic wavelength assignment algorithms for optical WDM networks. These proposed optimal or near-optimal algorithms for traffic grooming. The wavelength assignment algorithm was used to reduce the number of wavelengths and S-ADMs. They were applied to both unidirectional and bidirectional rings having an arbitrary number of nodes under both uniform and non-uniform traffic with an arbitrary grooming factor. Some lower bounds on the number of wavelengths and S-ADMs required for a given traffic pattern were derived and were used to determine the optimality of the proposed algorithms.

Jian Liu et. al. [17], proposed two different wavelength assignment algorithms for the network. These wavelength assignment algorithms were proposed for minimization of blocking probability of the network.

H. Ghafouri-Shiraz et. al. [18], presented a series of wavelength optimization and wavelength assignment algorithms with the objective to optimize the number of required SONET add–drop multiplexers. The other objective of these algorithms was to minimize the number of wavelengths in both unidirectional and bidirectional rings under an arbitrary grooming factor. Both uniform and general non-uniform all-to-all network traffic were considered for these algorithms.

Kuo-Chun Lee et. al. [19], developed wavelength assignment algorithms for hierarchical networks and wavelength-routing algorithms for arbitrary network topologies. Signal to noise ratio was also analysed for in-band/out-band WDM signals.

Milan Kovacevic et. al. [20], proposed the wavelength assignment algorithms for a given path which was used to minimize the number of wavelength changes. They also studied the benefits of electronic wavelength translation in optical networks.

Zhenghao Zhang et. al. [21], studied on-line wavelength assignment in wavelength-routed WDM networks under both unicast and multi-cast traffic where nodes in the networks have wavelength conversion ability. They considered the nodes in the networks having only limited number of converters. They studied the problem of setting up connections in such networks using minimum number of wavelength converters.

D. Guo et. al. [22], presented an optimal wavelength assignment algorithm and three different adaptive wavelength routing algorithms. This wavelength assignment algorithm was used to minimize the number of wavelengths used in the network. The performance of these proposed algorithms was evaluated in terms of call blocking probability. They also presented a method for minimization of call blocking probability with a fixed number of transceivers per node. A scalable multi-hop WDM passive ring architecture for local area or metropolitan area networks was also presented.

Guangzhi Li et. al. [23], studied the off-line wavelength assignment problem in star and ring networks for optical wavelength division multiplexed networks. The results showed that the ability to switch between fibers increases wavelength utilization. Additionally, the complexity of the problem was studied and several constrained versions of the problem were also considered for star and ring networks.

S. J. B. Yoo [24], reviewed various wavelength conversion techniques, discusses the advantages and shortcomings of each technique and addressed their implications for transparent networks.

Jianping Wang et. al. [25], studied wavelength assignment for WDM multicast network to cover the maximum number of destinations for minimizing the network cost. The computational complexity of the problem was also studied. Three heuristic algorithms were proposed and the worst-case approximation ratios for some heuristic algorithms were given. They also derive a lower bound of the minimum total wavelength cost and an upper bound of the maximum number of reached destinations. The efficiency of the proposed heuristic algorithms and the effectiveness of the derived bounds were verified by the simulation results.

III. CONCLUSION

The objective of this survey was to provide an overview of the research and development work in the area of optical networking. In systems that only use WDM, each location that demultiplex signals requires an electrical network element for each channel, even if no traffic is dropping at that site. By implementing an optical network, only those wavelengths that add or drop traffic at a site need corresponding electrical nodes. Other channels can simply pass through optically, which provides tremendous cost savings in equipment and network management. In addition, space and wavelength routing of traffic avoids the high cost of electronic cross-connects, and network management is simplified.

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