A Survey on Wavelength Assignment in WDM Systems

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***Abstract*—**This electronic document is a "live" template and already defines the components of your paper [title, text, heads, etc.] in its style sheet. *CRITICAL: Do Not Use Symbols, Special Characters, or Math in Paper Title or Abstract. (Abstract)

Communication networks have emerged as a source of empowerment in today's society. At the global level, the Internet is becoming the backbone of the modern economy. The new generations in developed countries cannot even conceive of a world without broadband access to the Internet. The inability of the current Internet infrastructure to cope with the wide variety and ever growing number of users, emerging networked applications, usage patterns and business models is increasingly being recognized worldwide.In optical network, it is necessary to determine the route and assign a wavelength that will be used on all links along the route.In this paper we provide a comprehensive survey of the past and current work on advance reservation for optical networks. There have been many variations of the advance reservation concept proposed, so we will also provide a broad classification. In addition to the survey, we will discuss what we believe are important areas of future work and open challenges for advance reservation on optical networks.

Keywords*—*WDM, Optical packet switching, Optical networks.

I. INTRODUCTION

All optical networks that adopt wavelength-division-multiplexing (WDM) technology have a huge bandwidth capacity, and they show promise as the backbone of the next generation Internet. In all optical networks, data are routed in optical channels called lightpaths. The Routing and Wavelength Assignment (RWA) problem is how to determine both a route and wavelengths for a connection request. Without wavelength conversion capability, a lightpath must use the same wavelength on all the links along its route, which is referred to as the wavelength continuity constraint. The RWA problem is usually classified as the static RWA problem and the dynamic RWA problem. In the static RWA problem, the connection requests are given in advance, and the problem becomes how to establish lightpaths for all these requests so that the total number of wavelengths is minimized. Static RWA has been proved to be an NP-complete problem [1]. In the dynamic RWA problem, the traffic is dynamic with connection requests arriving randomly, making it more difficult. Heuristic algorithms are usually employed to resolve this problem. Generally, a dynamic RWA algorithm aims to minimize the total blocking probability in the entire network. In our work, we focus on the dynamic RWA problem with wavelength continuity constraint. In the literature, the dynamic RWA problem is usually divided into two sub-problems that can be solved separately: routing and wavelength assignment. Routing schemes can be classified into fixed routing, fixed-alternate routing and adaptive routing. In the fixed routing scheme, one route is dedicated for a sourcedestination pair. Whenever a request occurs between this source-destination pair, this route is attempted for wavelength assignment. The fixed routing method is simple but usually causes a high blocking probability. The fixed-alternate routing method has better performance with multiple paths dedicated for a node pair. In the adaptive routing scheme, the route is computed at the time the connection request arrives, based on the current network state, thus it yields the best performance. However, adaptive routing requires high computational complexity. A more detailed survey of routing and wavelength assignment can be found in [2]. The adaptive RWA solutions in the literature always need special support from control protocol to obtain the global state of the network. Moreover, heuristic algorithms that perform route and wavelength searching tasks after a request arrives must take into account the tradeoff between complexity and performance. This also contributes to high setup delay and control overhead. A possible approach to overcome these problems is the use of ant-based mobile agents [3]. The ant-based agent routing approach inherits advantages from both mobile agents behaviors and an ant colony system. Recent results show that this approach could yield efficient performance in the control of both circuit switching [4] and packet switching networks [5].

In WDM many data signals modulate optical signals at different wavelengths and out coming signals are integrated and are transmitted at the same time over the single optical fiber. In WDM every communication channel is allocated to a different wavelength and multiplexed onto a single fiber. At the destination wavelengths are spatially separated to different receiver locations. These Optical networks capable of providing required bandwidth. In a WDM network, all users communicate with one another through WDM channels, which are called as light-paths. A light-path should take the same wavelength over all the fiber links through which it spans. Advantages of Optical Networks

1. Optical Networks have the following Advantages
2. Capacity of the fiber is high Restoration can be done

3. Can achieve long distance transmission Large Bandwidth
4. Less Weight, Small Diameter Attenuation is less
5. Signal distortion is less Power requirement is less Wavelength reuse
6. Requires less space Cost effective 7. Reliable and Secure Flexible in nature

II. LITERATURE

Literature depicts that there are two generations of development in the Optical Network. Initially to meet the increasing telephony traffic demands optical networking was the prospect of tapping the vast usable bandwidth of optical fiber of 30 THz [6]. First generation development of optical fiber started in the 1970s and employed optical fibers as replacements for copper cable links. In this generation, informational bottlenecks were preempted at transmission links, but loomed at network nodes whose operations were constrained by the speed of electronics. Second generation emerges from the year 1990 onwards. This employs optical networking devices in addition to the optical fiber. The data traffic served by these networks is characterized by detailed statistics like governing transaction length and burstiness. The first generation optical fiber networks are quite different from the telephony traffic in the quality of service demands. This is similar to traffic arising from the heavy-tailed nature of data transactions [7].

Besides a singular session for a specific service, a number of terminals can be online at the same time, connected to a single access link. By the year 2005, the traffic increase rate fell to 40%-50% every year, while router throughput became almost saturated due to the high IP related processing burden and the energy issues. The traffic growth rate of 40% a year is still huge and results in traffic that is 30 time the present traffic in 10 years [8]. Network protection and restoration functionality is one of the essential requirements for next-generation networks that will have huge capacities, since a small time of outage in these networks will cause a large amount of user traffic loss [9]. Network survivability is the ability of a network to maintain the continuity of critical services to end users in the presence of network failures and can be realized through connection protection and restoration [10]. All the layers above the optical layer will have full protection functions of their own. Because of the speed, cost-effectiveness, and efficiency in dealing with certain types of failure, optical layer protection and restoration have an important role in network survivability.

Ramamurthy et al [11] presented Integer Linear Program (ILP) formulations for the routing and wavelength assignment problem are developed for a static traffic demand for both path and link protections schemes. Ho et al [12] proposed that the networks primary path is divided into several overlapped segments and the backup path for each sub-domain can be calculated individually. Redundant trees are used to provide rapid recovery and are presented by Medard et al [13]. Their algorithm constructs two trees in such a fashion that each destination vertex is connected to the source by at least one of the directed trees when any vertex in the graph is eliminated. Anand et al [14] described the performance of sub-path protection scheme in terms of capacity utilization and recovery time, compared with path and link protection schemes. Zang et al [15] developed an on-line network control mechanism to manage the connections in WDM mesh networks using path protection schemes. They use the two-step approach to route the connections. A new multiplexing technique called primary backup multiplexing is proposed by Mohan et al [16] to improve resource utilization. This technique allows a primary light path to share the same wavelength with some backup lightpath. Sen et al [17] proposed to use the link-disjoint path pair, whose longer path is shortest among all such pairs of paths, for path protection so that the delay on the backup path is minimized. They prove that the problem of finding such a pair of paths is NP-complete, and they use the one-step approach as the approximation solution. Xin et al [18] attempted to optimize the network resource utilization of each call by minimizing the overall cost of the primary and backup path. The paths are selected from K precomputed candidate route pairs. Hybrid multiplexing and demultiplexing schemes with the capability to integrate microwave and millimeter-wave frequency radio-over fiber signals in a WDM passive optical network infrastructure was proposed by Masuduzzaman et al [19]. The proposed schemes exploited the benefits of a spectrally efficient wavelength interleaving technique and enhance the performance of optical millimeter-wave signals without employing an additional device. The schemes are demonstrated experimentally with simultaneous transport of 1 Gbit/s baseband, 2.5 GHz microwave, and 37.5 GHz millimeter wave signals that have the potential to converge last-mile optical and wireless technologies. Clustering is a proven effective approach for self-organizing a network into a connected hierarchy. Chen et al [20] viewed clustering as a hub and spoke model as in the airline industry. Assuming static traffic, a heuristic based on the K-Center problem to create K virtual stars of nodes was proposed. Hideaki et al [10] proposed a 640 Gbit/sport optical packet switch prototype consisting of multiple optical label processors, polarization-independent plomb lanthanum zirconate titanate waveguide optical switches, optical fiber-delay line buffers and a parallel pipeline buffer manager. Urban et al [22] presented a hybrid ring-shaped wavelength division multiplexing time division multiplexing passive optical network that is capable of providing bandwidth on demand at high bit rates in a transparent and dynamic manner. Steven Fortune [23] presented a dynamic programming algorithm that chooses the minimum-cost amplifier placement subject to bounds on introduced nonlinear phase shift and noise. By introducing intelligent control, agile all-optical networks can serve dynamic and flexible bandwidth on demand. A protection scheme for single-duct ring networks is proposed by Wei et al [24] followed by a rearrangeable bandwidth allocation scheme to decrease blocking in critical connection setup. The survivable dual-duct ring infrastructure proposed will have survivability for the type of network in order to improve the efficiency of network resource utilization and signal quality. The main limiting factors for scaling the current architectures are the power consumption. This approach has capacities of hundreds of terabits or even petabits per seconds. Slavisa Aleksic [25] addressed power consumption issues in high capacity switching and routing elements. Also they examined different architectures based on both pure packet-switched and pure circuit switched designs. All these were done by assuming either all electronic or all optical implementation. The implementation results show that optics is more power efficient; especially circuit switched architectures have a low power consumption. Mohammad et al [26] addressed both problems in non-splitting capabilities and in splitting networks, where the nodes do have optical splitting capabilities. The cost of a WDM network is dominated by the cost of higher-layer electronic ports. Based on the observations from optical solutions, Mohammad et al developed a heuristic approach for each network by relaxing and simplifying its corresponding mixed integer linear program.

Burchard et al. have done work with advance reservation outside wavelength-routed WDM networks. We discussed earlier a distinction between STSD-fixed and STSD-flexible types of advance reservation. It has been shown that STSDfixed advance reservation leads to resource fragmentation, which can lead to higher blocking. This was first mentioned in [27], where the concept of malleable reservations was also introduced. Other work by the authors related to advance reservation include failure recovery [28], [29], performance evaluation and algorithms rerouting [30], [31]. A number of path selection and computation algorithms have been proposed specifically for advance reservation over single channel networks. The authors in [32] propose a Bellman-Ford based algorithm to find the shortest hop path for STSD-flexible requests. Similarly, in [33] the authors propose another Bellman-Ford based algorithm that finds all time-slots during which a path is available with a specified bandwidth for a specified duration. In [34] several algorithms are presented with different goals from finding specific bandwidth between the start and end slots, to looking for the earliest available time with a specified bandwidth/duration by extending breadth-first search. The algorithm find the highest available bandwidth in a specified timeslot by extending Dijkstra's algorithm. Lastly, they find all available timeslots with a specified bandwidth/duration by extending Bellman-Ford's algorithm. Variable bandwidth path computation algorithms are discussed in [35]. They allow the bandwidth and/or path to change during each timeslot. Several algorithms are presented in [36] with the goal of either finding a path at a specified start time with a specified duration/bandwidth or finding the earliest such time. A number of time-based link metrics are proposed in [37]. The previous algorithms are based on global topology information. The authors in [37] propose a distributed advance reservation routing algorithm, as discussed previously. The algorithm is for STSD-flexible requests that specify a duration as well as required bandwidth. The group also proposed a way to rank timeslot and path combinations when routing an advance reservation request [38] (assuming centralized routing). They also introduce the concept of path switching where a request may use a number of different paths over its duration. The authors of [39] propose a re-routing algorithm based on load balancing. Re-routing, or re-optimization, has been discussed previously for RWA in [50]. Patel et al. have proposed modifications to the basic advance reservation concept. Their work does not consider wavelength assignment, only routing. In [40] they consider time-shift advance reservation. Here, delay elements are placed in the network that can buffer circuits between two links. This can be used to shift the circuit in the time domain. Instead of all links of a path having to use the same timeslots to transfer a circuit, different links can use different slots by shifting the circuit in time. They assume a time-slotted network and maintain state information about links and delay elements. They also use horizon scheduling, which only maintains state information about earliest available times. Requests specify their holding times and the network finds a start time based on the horizon schedule as well as buffer assignment that minimizes end-toend latency. In [41] the same authors also propose variable bandwidth advance reservation. Again the network is timeslotted and no wavelength assignment is performed. The main contribution is to allow the bandwidth of the circuit change as a function of time, i.e. each timeslot can transmit data at different bandwidth. The requests specify a file size and the network finds a start timeslot and bandwidth schedule that minimizes file transfer completion time. The authors of [42] explore the problem of logical topology design given a series of traffic matrices that change over time. The static AR RWA work we have discussed assumes that the set of advance reservation lightpath demands are given. This work will create a set of advance reservation lightpath demands from the time-dependent traffic matrices. The algorithm finds the virtual topology and flow routing over it. Routing and wavelength assignment is not performed (any of the previous work for static STSD-fixed demands could be used). Two MILP formulations are proposed that find a the virtual topology and flow routing on top of it. In one case, it is assumed that the virtual topology cannot change (this creates a static demand set) and in the other case it is assumed that the virtual topology can change over time (this creates a STSDfixed demand set). A tabu search meta-heuristic is derived in [43] and additional variations to flow routing are proposed in [44], but now considering a static virtual topology. The concept of delay tolerance was used in the following two papers [45], [46]. A batch mode scheduling technique was proposed in [45] where a customer specifies a waiting time (delay tolerance). The scheduler queues up requests and then schedules them in batch in order to find a better solution compared to scheduling them one at a time. The authors of [46] propose a notification interval. Batch scheduling is not performed in this work. The interval is used to queue requests that could not be provisioned upon arrival. The authors propose optimizing future reserved requests so that it may be possible to free up resources for queued requests.

Zhe et al. derived analytical models for blocking of advance reservation requests [47]. They look at a simplified scenario with a single link consisting of a number of discrete channels. They show how flexibility can impact blocking as well as the relationship between the horizon size and blocking. Lastly, we would like to discuss some work with scheduling bandwidth of advance reservation demands. These works consider a scenario where lightpaths have already been established and user demands can be divided into discrete size bandwidth blocks (e.g. size of a timeslot). The problem then becomes a scheduling problem of how to schedule the blocks in the wavelengths and timeslots of the already established lightpaths. For example, the authors in [48] consider sliding window demands mixed with immediate reservation traffic. They also propose categorizing advance reservation demands as preemptable and non-preemptable. To reduce IR blocking and to minimize fragmentation, some AR requests can be split up (preempted) and continued later so they are non-continuous in the time domain .A similar scheduling problem is investigated in [49] where they divide each timeslot into smaller bandwidth slots. During each timeslot, each request must use some number of bandwidth slots. The paper proposes two types of request: streaming and elastic. A streaming request (e.g. real-time traffic) must use the same number of bandwidth slots for the duration of the request whereas an elastic request (e.g. file transfer) can use a variable number of bandwidth slots over time. In order to reduce blocking, the scheduler can take advantage of the elastic request's ability to use more or fewer bandwidth slots in any given timeslot. In [50], the authors consider the scheduling problem with UTSD requests that specify a deadline. Similar to the work just discussed, lightpaths are already established and the scheduler must schedule timeslot sized bandwidth chunks to each request so that it completes by its deadline. The authors propose allowing requests with later deadlines to be pushed back to help accommodate requests with earlier deadlines. Initially, a request is scheduled using as much bandwidth as early as possible. If a request cannot be accommodated, the algorithm determines if another request with a later deadline can be pushed forward in the schedule so the current request does not have to be blocked Advance reservation is also a popular topic for job scheduling in Grid networks. Each job can have start/end times or deadlines similar to circuit requests we have seen for wavelength-routed networks. The job scheduler must determine how to assign these jobs to servers. An example of this work is [51]. The paper provides a number of references and small survey of work related to this area.

III. Conclusion

In this paper, the performance of various wavelength assignment approaches has been analyzed for various performance metrics. Simulation results showed that the First fit wavelength assignment algorithm achieves reduced network block rate with increased channel utilization and throughput than the other wavelength strategies. However it yields better performance, the disadvantage of this approach is that the lower indexed wavelengths are much more used than the higher indexed wavelengths. Hence certain wavelengths are utilized very low. Since all the nodes in the network use the lower numbered wavelengths, contention for these wavelengths increases which results in higher network block rate in the network. Furthermore, it will be concentrated to develop a round robin wavelength assignment approach to overcome the adverse effects. In this strategy, the assignment of wavelength starts with assigning the first indexed wavelength for the first requested light-path. With every subsequent request, the node chooses the next numbered wavelength and so on. In this manner, all the wavelengths can be utilized equally which reduces the blocking probability considerably.

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