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A Survey of Minimum Wavelength Conversion Routing and Wavelength Assignment in WDM Networks

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ABSTRACT

Generally, research on routing and wavelength task over wavelength directed WDM networks is worried about immediate reservation (IR) requests. An IR demand typically does not specify a holding time for data transmission and the start time of the data transmission are assumed to be immediate (i.e. when the connection request arrives). The idea of advance reservation (AR) has as of recently been picking up consideration for optical networks. An AR request commonly determines data about the beginning of the information transmission or a cutoff time, just as the holding time of the transmission. AR has a few significant applications for both wide-region networks and Grid networks. For instance, AR can be utilized for modifying virtual geographies to adjust to predictable peak hour traffic use. It very well may be utilized to give high- bandwidth transmission administrations, for example, video conferencing and in Grid applications requiring the booked circulation of enormous records and for co-allotment of organization and grid assets. AR can likewise be advantageous to the organization by permitting the organization administrator to more readily design asset use and accordingly increment use. Information on the holding time can prompt more ideal choices for asset distribution. This translates to better quality of service for users. In this paper we give a complete study of the past and current work on booking ahead of time for optical organizations. There have been numerous varieties of the advance reservation of time idea proposed, so we will likewise give an expansive grouping. Notwithstanding the review, we will examine what we accept are significant regions of future work and open difficulties for early booking on optical organizations.

Keywords: *Advance reservation, scheduled demands, WDM, survey, wavelength-routed, and RWA*

INTRODUCTION

OPTICAL wavelength-routed WDM [1] networks, or optical circuit switched (OCS) networks, are a potential candidate for future wide-area backbone networks as well as scientific Grid networks. In WDM networks, each fiber is partitioned into a number of wavelengths, each of which is capable of transmitting data. This allows each fiber to provide data transmission rates of terabits per second. An optical WDM network consists of fibers connected by switches, or optical cross connects (OXCs). In order to transmit data over the network, a dedicated circuit is first established when a user submits a connection request. When a connection request arrives at the network, the request must be routed over the physical topology and also assigned a wavelength. This is known as the *routing and wavelength assignment* (RWA) problem [2]. The combination of a route and wavelength is known as a *lightpath* [3]. The RWA problem is NP-complete so heuristics are typically used [4]. The bandwidth granularity of the circuit does not necessarily have to be one wavelength.

There is work on traffic grooming, which performs aggregation of multiple sub-wavelength traffic streams onto a single wave- length [5], [6]. An example of a wavelength-routed network is shown in Figure 1 (with no traffic grooming). There are three lightpaths in the network using two different wavelengths.

One lightpath is sourced at Node 1 with a destination on Node 7 using wavelength λ_2. Another is sourced at Node 2 with destination of Node 6 on λ_1. The final lightpath is sourced at Node 7 and destined for Node 5 with wavelength λ_2. No two requests can use the same wavelength on the same link. If more requests arrive over time new lightpaths must be allocated as long as there are enough wavelengths to establish them.

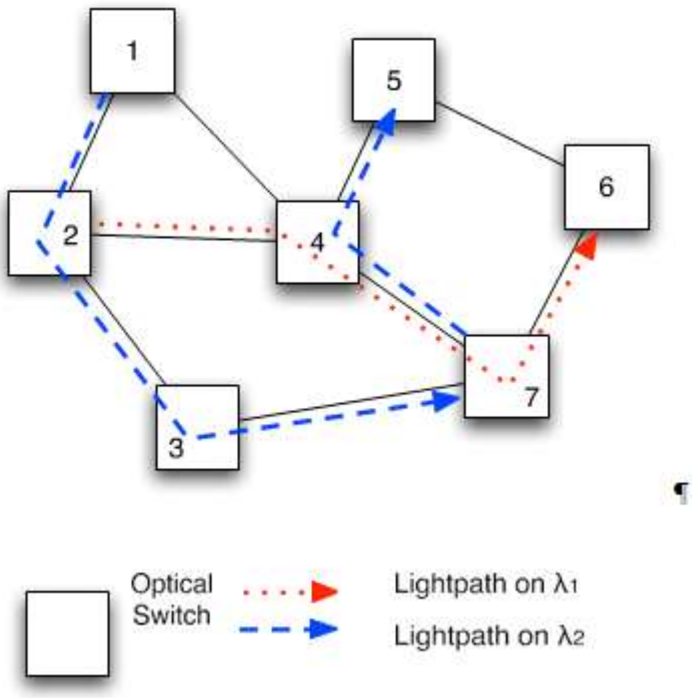

Fig. 1: *Wavelength-Routed Network.*

In a single-hop, or all-optical, WDM system, the signal is transmitted all-optically through the network. There is no con- version of the signal back to electronics in the network. These are also known as transparent optical networks. In multi-hop systems the signal may undergo optical/electronic/optical (O/E/O) conversion at some intermediate nodes. If O/E/O conversion occurs at every node, then the networks is called an opaque network, whereas if only some nodes employ O/E/O the network is called a translucent network. In the absence of wavelength converters (which are expensive), a connection in a single-hop WDM system must use the same wavelength across all links. This is known as the *wavelength continuity constraint*. Multi-hop systems can use different wavelengths on different links because the signal may undergo O/E/O conversion at some intermediate nodes, allowing it to be retransmitted on a wavelength different from the received wavelength. This conversion process can be expensive, how- ever, both in terms of cost of equipment and due to the dependence of the conversion process on the connection line rate and modulation format. The disadvantage of single-hop systems is that, in the absence of regenerators, the signal noise accumulates from physical layer impairments such as cross- talk, ASE noise, and nonlinear impairments like four-wave- mixing, cross phase modulation, and stimulated Brillouin and Raman scattering. To counter this, impairment-aware routing can be used to ensure the signal to noise ratio is at acceptable levels when the signal reaches the destination. There has recently been significant work in impairment-aware routing [7], [8].

Two traffic models are usually considered for wavelength- routed networks: static and dynamic [4]. A static traffic model gives all the traffic demands between source and destinations ahead of time. A traffic matrix is given and the goal is typically to find an RWA that can meet all the demands and minimize overall cost (e.g. using the least number of transmitters/receivers). Dynamic traffic requests arrive one-by- one according to some stochastic process and they are also released after some finite amount of time. When dynamic traffic is considered, the number of transmitters and receivers is fixed and the goal is to minimize request blocking. A request is said to be blocked if there are not enough resources available to route it. There is extensive work for these problems, see [2], [4], [9], [10], among others.

We can further classify the above traffic models as immediate reservation (IR) or advance reservation (AR) [11] requests. The information transmission of an IR request begins immediately supply of the solicitation and the holding time is regularly obscure for dynamic traffic or thought to be limitless for static traffic. AR requests, conversely, ordinarily determine an information transmission start time that is soon and furthermore indicate a finite holding time. We can see that the resource allocation occurs when the request arrives at the network. The duration of the request is unknown. The resources are reserved when the request arrives, but they can be used by other requests before the reservation time. The difference between the arrival of the request and beginning of the transmission is the book-ahead time, which is specified by the request. The extent of the request is also definite in advance and known by the network. The fact that holding time and book-ahead time is known by the network allows the network to more efficiently optimize resource usage. This is just one example of an AR request; we discuss the variations.

Advance reservation was initially proposed for non-optical networks, focusing on circuit-switches, packet-switched, and ATM. We briefly mention some of this work here. Initial work focused on traffic modeling and call admission for telecommunication systems (e.g. [12], [13]). Wolf *et al.* [14], [15] proposed advance reservation for quality-of-service of multimedia applications like video conferencing. Greenberg *et al.* [16], [17] focused on similar applications with some theoretical results concerning mixed immediate reservation (IR) and AR traffic. They assume that AR traffic has higher priority than IR and focus on admission control algorithms for the two types of traffic. Extensions to RSVP were proposed in [18]. A detailed discussion on path computation of advance reservation requests was presented in [19]. In this work, the authors focus on routing algorithms to handle both spatial and temporal aspects of AR.

Advance reservation for optical networks was first proposed by Zheng and Mouftah in [20], [11]. While some solution techniques may be adapted from the electronic domain to the optical domain, the advance reservation problem for optical networks presents new challenges, such as the wavelength continuity constraint, grooming, survivability, and others.

MOTIVATION

In this section we discuss the motivation for advance reservation over optical networks. Advance reservation has applications for both wide-area networks and Grid networks. We will discuss the applications specific to these types of net-works in the following subsections. Some of these applications can be applied to both types of networks, but many advance reservation papers focus specifically on Grid networks. In general, advance reservation benefits the network because knowledge of future state information (due to declared arrival and holding times of data transmission) can be used to improve the admission control and planning/provisioning to increase network utilization and maximize profits. It also benefits the User because the network can provide better quality-of-service to requests that book-ahead.

ADVANCE RESERVATION CLASSIFICATION

In this section we define advance reservation and consider the variations that have been presented in the literature. There are two defining characteristics of advance reservation requests. First, the holding time must be explicitly declared or must be able to be calculated based on other information. For example, a request may specify a file size, which can then be used to determine the holding time. Second, the deadline, or the end of the data transfer, must be greater than then request arrival time plus the holding time. In other words, the transmission of data does not need to start immediately at the request arrival. This broad, informal, definition is able to classify a wide range of similar work as advance reservation, though different terminology has been used in the literature.

The two most common terms used for these types of demands are *advance reservation* and *scheduled demands*. Schedule demands, or scheduled traffic, are typically used when describing static traffic demands whereas advance reservation is typically used when describing dynamic traffic, particularly in Grid related papers. We will use the term advance reservation throughout the survey. Advance reservation can be classified into several types as denoted by [20].

Before doing so, we define some terms. The *horizon* is the time range from the current time to the latest available time that the network allows resources to be reserved. The book- ahead time is the time difference between the requested start time and the current time (the request arrival time). In the following subsections we assume we are given the network, $G = (V, E, W, H)$, where V is the set of switches, E is the set of links, W is the set of wavelengths available on each link, and H is the horizon. We will consider request tuples that describe each type of advance reservation. For traditional unicast immediate reservation, we can describe a request by a two-tuple, (s, d), where s, d, V are the source and destination nodes, respectively.

NETWORK ARCHITECTURES AND IMPLEMENTATION

In this section we discuss network architectures and implementation issues to support advance reservation. We consider two broad classes of architectures. One is a centralized architecture where a single entity is responsible for handling incoming requests, scheduling, and configuring switching elements. The other option is a distributed approach where each node maintains some information and makes decisions independently when receiving a request.

In addition to deciding between centralized and distributed architectures, we must also take into consideration the length of the horizon, which determines how far we allow requests to book ahead. This impacts the amount of state information we must maintain. Another option to consider is whether or not the time-domain is slotted or continuous. If it is slotted, the duration of a timeslot is an important characteristic.

Centralized Architectures

Most work summarized in this paper considers centralized architectures. In this type of architecture, a centralized scheduler is responsible for call admission. The users (or applications) may interface with the scheduler through a web service API or extensions to the OIF User Network Interface (UNI) [26], for example. The scheduler authenticates the user to ensure they have proper credentials and permissions for the requested resources. The scheduler maintains global topology information and it uses this information to perform RWA for incoming requests.

Distributed Architectures

The authors of [27,28] provide some discussion about supporting advance reservation under a distributed architecture. In order to support a distributed architecture, each node must maintain some state information and must be able to perform path computation. Each node in the network could have an electronic controller that maintains state information. The controller must maintain state information about each wavelength-link incoming and outgoing from that node. In [28] this information is stored in the form of interval vectors. Each vector represents a gap (unused bandwidth) in the time domain (they assume the network is not time-slotted). In a time-slotted network, each node would have to maintain state information about each slot on each link.

Time Domain

An important topic in advance reservation is the management of the time domain. In [29], the authors classify two broad categories of resource management in the time domain. The first is a *reservation-based* approach which uses set of already accepted reservations for the admission control of an incoming reservation request. All provisioned requests that overlap the requested time interval of the current request are identified. In doing so, one can determine if enough resources are available to fulfill the current request. This method has low memory consumption as it only stores accepted requests which are needed for connection establishment.

ADVANCE RESERVATION SURVEY

In this section we begin the survey on advance reservation. As discussed in the previous section, some authors use different terminology, but throughout this paper, the terminology introduced above will be used. We classify the work into two categories, those dealing with dynamic traffic demands and those dealing with static traffic demands. All of the work is summarized in Tables I-IX. We also discuss test beds and frameworks as well as some work related to advance reservation scheduling, particularly in Grids. We defer discussion of network and implementation issues until Section IV.

Advance reservation for optical networks was first proposed by Zheng and Mouftah in [20], [11]. As mentioned earlier, they provide the initial classification of STSD, STUD, and UTSD requests. While they were the first to propose dynamic AR request for optical networks, Kuri *et al.* were the first to propose the static AR problem where the request set is given a priori[31,21]. They focus on STSD AR requests and present heuristics and meta-heuristics to solve the static problem.

Dynamic Advance Reservation

We now begin our survey by discussing

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the work dealing with STSD fixed window requests. The studies in [20], [11] present simple heuristics for the STSD fixed window problem. They assume the network is under centralized control and the time-domain is broken into fixed timeslots. Each request requires one wavelength. They also assume no wavelength conversion. In [11], they use a fixed routing scheme where *k*-routes are precomputed. Each route is checked for a wave- length common to each link for each time interval in the duration of the request. In [20] an adaptive routing approach is used. This removes any links not available during the required fixed window from the network. After this step, the algorithm tries to find a path with the remaining links and assign a wavelength if there is a common wavelength available along the path.

Naiksatam *et al.* propose heuristics for STSD fixed window requests requiring multiple wavelengths [32]. They also assume a network under centralized control, fixed sized times- lots, and wavelength continuity constraint. In order to handle multiple wavelength requests, the heuristics proposed either concentrate all required wavelengths on a single path or spread them over multiple paths. *k* edge-disjoint paths are precomputed. For wavelength balancing, as requests arrive, the lightpaths are assigned on the first wavelength of the first path, first wavelength on the second path, and so on. Once all paths are examined, the algorithm checks the second wavelength on all paths. On the other hand, the wavelength concentrating algorithm tries all wavelengths on the first path, then all wavelengths on the second path, and so on. Both algorithms terminate once enough lightpaths have been allocated for the request. Results show that in networks where all links are requested uniformly, wavelength concentrating performs best, otherwise wavelength balancing should be used. In this work the authors also introduce an advance reservation traffic generator, the Flexible Optical Network Traffic Simulator (FONTS). Later in [33] the authors derive a simple analytical model for STSD fixed window requests. They model a single network link and assume each request requires a single timeslot (though they can use multiple wavelengths).

Wallace *et al*. put on lightpath migration to STSD fixed window requests [34,35]. They assume a network under centralized control with the wavelength continuity constraint. The time-domain is not broken into discrete timeslots. The basic idea behind lightpath migration is to reassign resources to reserved lightpaths that have not yet begun transmission, in order to accommodate a newly arriving request. Two cost functions are evaluated. One that minimizes the number of existing paths that must be migrated and another one that minimizes the path length of the new request (with no restriction on how many existing requests will be migrated). To do this, they construct auxiliary graphs for each wavelength in the network and assign edge weights according to the required cost function. Given these auxiliary graphs, Dijkstra's algorithm is used to find a lightpath. The results show that there is no significant difference between the two cost functions for reducing blocking probability. The overall improvement compared to no migration is up to 23%.

We now discuss papers that propose RWA for STSD flexible window requests. Tanwir *et al.* consider RWA for STSD flexible window requests in networks with full wavelength conversion [36]. In this work it is assumed that the time is slotted into fixed length slots and that the network is under centralized control. In addition to traditional STSD flexible window requests, the authors also analyze the scenario with a non-blocking scheduler. In this case, instead of blocking a request that cannot be scheduled, the request can be moved outside its window until it can be scheduled. Two different routing strategies are proposed, both using *k* precomputed routes. The routes are computed by first selecting the shortest- path route, then checking wavelength availability on each link. If there is any link with no wavelengths available, it is removed and the shortest-path route is recomputed. This is done until a path is found or *k* links have been deleted. In the first strategy: Slide Window First (SWF), the algorithm tries all possible starting timeslots on one path and then moves to the next path trying all timeslots in order, and so on. The second plan: Switch Path First (SPF), loops over the start time slots first. The algorithm tries the first start timeslot on path 1, then path 2, and so on up until path *k*. If the request cannot be accommodated, the next timeslot is checked. The algorithms are also modified to include load balancing, where the cost of the link is based on the number of wavelengths currently used. Given a path in the network, each link must be assigned a wavelength. They propose different wavelength assignment strategies to minimize fragmentation in wavelength usage on each link. The authors in [37] investigate STSD flexible window requests with and without wavelength conversion using a continuous-time model. The state of each link is maintained by recording the times when the available bandwidth changes. For each incoming request, a start time list is computed for each wavelength/link. Next they compute a vector of start times that can be used to accommodate the request. The authors investigate two RWA algorithms. The extended Bellman-Ford (EBF) algorithm finds the lightpath that uses the shortest-path and the list sliding window (LSW) algorithm finds the lightpath with the earliest possible start time. These algorithms are compared to the algorithms proposed in [36], which were extended for the continuous-time model. The algorithms in [36] were not guaranteed to find a solution if one existed (i.e., the routing does not take wavelength availability into account until after a route is found), while the algorithms present in [37] make this guarantee.

Shen *et al.* investigate both fixed and flexible STSD requests in a time-slotted network with no wavelength conversion. In their work [38-40] they propose RWA heuristics and also use a re-optimization technique. As for their RWA algorithms, *k*-shortest-paths are precomputed and a slotted first-fit wavelength assignment is used. For each possible start time (fixed requests only have one start time), and for each path the first wavelength available for the duration of the request (slotted first-fit) is added to a solution pool. Once all paths and start times are scanned, a lightpath is selected based on an objective function. The first objective function minimizes the path length and the second minimizes the load (load-balancing). If a request would be blocked, re- optimization is performed. Given the blocked request, all scheduled (but not yet transmitting) requests that overlap with this request in time are found. These requests are then ordered and RWA (with the load-balancing objective) is performed for each request one by one. If they can all be re-routed, then the new request is accepted, otherwise it is still blocked. For flexible window requests, this process is repeated for each possible start time. The set of overlapping requests are ordered by increasing start time, increasing minimum hop path, and increasing service durations. In addition to re-optimization on request arrival, the authors also propose periodic background re-optimization, which is performed before the start of each timeslot. The results show that re-optimization at blocking can improve performance by up to 50% (for a 7:3 ratio of fixed and flexible window requests) while periodic re-optimization has little impact (around 6% improvement).

In [41], the authors extend the work in [40]. In [40], re- optimization is done at blocking only. In [41] continuous re-optimization is proposed. To accomplish this, two independent algorithms are used that run in separate threads. One algorithm is used to schedule user requests when they arrive. This algorithm is based on the slotted first-fit algorithm in [40]. The other algorithm is a genetic algorithm that continuously tries to improve the requests that have already been scheduled. Both algorithms work on their own copy of the network state information. If the genetic algorithm finds a better solution at the end of a timeslot than the current solution the greedy algorithm has, the state information is copied over from the genetic algorithm to the greedy algorithm. The results show that this continuous optimization approach improves upon the performance of re-optimization at blocking.

Andrei *et al.* propose RWA for STSD flexible window multicast AR requests [44,45]. They take on all nodes are opaque (which permits wavelength conversion) with traffic grooming abilities. A centralized scheduler is used and the time-domain is time-slotted. Requests specify an arrival time, file size, transmission rate, and end time. The authors propose a number of different heuristics. For all heuristics, the routing of a tree is based on a previously proposed Steiner tree heuristic. Two heuristics are based on pre-computed route trees where one heuristic generates a single pre-computed tree while the other generates a number of random trees. Another heuristic uses dynamic routing and examines all possible start times of the request. In addition, the authors propose heuristics to divide the tree into multiple subtrees where each destination can be reached independently (in space and time). The authors also consider the case where data can be buffered at intermediate nodes on the tree (using some spare storage capacity) in the event that some links are not available during particular time slots. The authors propose a heuristic that breaks the file into equal-size pieces. These heuristics are compared to using separate unicast requests to provision a multicast request. Finally, modifications are proposed to some of the heuristics to work in all-optical networks (i.e. no wavelength conversion).

Static Advance Reservation

Kuri *et al.* were the first to propose the static STSD- fixed AR problem [21,31]. They assume a continuous-time network with the wavelength continuity constraint. For all algorithms, k-shortest-paths are precomputed for all source- destination pairs. The first algorithm is a branch and bound algorithm to find the optimal routing (given the precomputed routes). Because of the exponential runtime, they also propose a tabu search meta-heuristic to find a set of routes. Optimality is determined by different cost functions the authors propose. Given the routes, they use a graph coloring heuristic to assign wavelengths. These two approaches branch and bound and tabu search, consider the entire request set at once. They also propose a sequential heuristic which first orders the requests by a weight function and then performs RWA one request at a time using k-shortest-paths with first-fit assignment.

Anycast and multicast

As we discussed previously, the authors of [43] propose solutions to the static STSD-flexible anycast problem as well. In this work the authors present an ILP, with a time-slotted network, that finds the optimal solution for a request set with the objective of accepting the maximum number of requests. The ILP does shared-path protection for each request. The authors also propose a heuristic that

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attempts to spread the demands to reduce the time overlap.

Survivability

Kuri *et al.* were the first to suggest survivability for static AR. They considered the case of STSD- fixed requests in [48]. The goal is to provision a set of requests with primary and arc-disjoint backup paths such that the total number of resources required is minimized. They assume wavelength conversion in the network and continuous-time. Channel reuse is applied for protection. A channel can be reused as long as the requests using it do not overlap in time. The authors also introduce the concept of backup- multiplexing which allows a channel to be used by multiple lightpaths for protection assuming they do not overlap in time *and* share a link on their primary paths. Backup-multiplexing is more efficient than just channel reuse. Two heuristics are proposed in the paper; one that takes advantage of only channel reuse and one that takes advantage of backup-multiplexing. Both problems are formulated as combinatorial optimization problems (with pre-computed paths) and use simulated annealing to find solutions.

Grooming

A heuristic for grooming of static STSD-flexible demands is proposed in [52] for the case of a continuous-time network with wavelength continuity. The authors consider two priorities of demands, high and low. They use the same techniques to minimize overlap and schedule demands within time windows as their work in [46]. They then perform RWA on demands starting with the high priority demands and in order of largest requested capacity. Grooming is incorporated by modifying link costs of a layered wave- length graph for each time window. They also attempt to re- arrange demands if necessary, as in their previous work.

ADVANCE RESERVATION FRAMEWORKS

We now discuss the various advance reservation frame- works[1] and architectures that have been implemented. Some projects propose supporting advance reservation across a single domain, whereas other projects focus on providing inter- domain support as well. There is also work on co-allocation of network and Grid resources (e.g., computing/storage) using advance reservation. Table X provides a comparison of the different frameworks discussed below.

The On-demand Secure Circuits and Advance Reservation System (OSCARS) is a project by the U.S. Department of Energy that supports dynamic end-to-end provisioning of network resources (layer 2/3 VCs) with support for advance reservation [22,53]. OSCARS is used over the DOE's Energy Science Network (ESnet). OSCARS is implemented as a centralized service that provides web-services based API to clients to make advance reservations. OSCARS consists of a web-based interface, an Authorization, Authentication, and Auditing (AAA) module, a bandwidth scheduling module, and a path setup module. Typically, a client will submit a request through the web interface. The client is authenticated and the client's request is then scheduled with the bandwidth scheduler. When the actual data transfer is about to begin, a path is setup using existing signaling protocols such as RSVP- TE. The basic architecture of OSCARS is shown in Fig. 6. OSCARS is designed for a single domain, but interoperability with other domains is also possible.

On-Demand Secure Circuits and Advance Reservation System (OSCARS)

EnLIGHTened

EnLIGHTened (initially funded by the U.S. NSF) is a project that focuses on advance reservation of both Grid and

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network resources (lightpaths) [31]. The objective of the task is to permit Grid applications to demand ahead of time or on-request compute, storage, instrumentation, and network assets. These assets must be co-apportioned and might be spread over numerous areas. The design incorporates a resource broker (ERB), resource checking, and network planning for (a Network Domain Manager). The design uses the Highly-Available Resource Co-allocator (HARC) system, which permits customers to save various conveyed resources in a single step.

G-Lambda

Another project with similar goals was the Japanese project, G-Lambda [32]. The main goal of the project was to define a standard web interface between a grid resource scheduler (similar to the ERB) and network resource management systems (similar to DNM). Network operators could then implement this interface to allow the grid resource coordinators to make advance reservations of network resources. The grid resource coordinators are actualized as middleware and organize organization and calculation/stockpiling resources in line with grid applications.

Phosphorous

The EU's PHOSPHORUS project also incorporates the advance reservation of Grid and networking resources [33]. The goal of PHOSPHORUS is to provide on-demand and in-advance end-to-end provisioning of network and grid re-sources across multiple domains and multiple vendors. The PHOSPHORUS project comprises of two phases. In the first phase each independent domain is controlled by an existing Network Resource Provisioning System (NRPS), while in the second phase interoperability is added with other existing networks and Grid resources through standardized interfaces.

OTHER RELATED WORK ON ADVANCE RESERVATION

The focus of our survey is on routing and wavelength assignment algorithms for advance reservation over optical networks. In this section we discuss other work related to advance reservation that did not fall in the optical domain or did not perform routing and wavelength assignment. This may include advance reservation for IP/MPLS networks or grid scheduling advance reservation algorithms, for example. The references for these topics do not represent a complete survey. Interested readers should follow references within these papers for more details about the topics.

Zhe *et al.* derived analytical models for blocking of advance reservation requests [30,49]. 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 [50] 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 (similar to the idea proposed in [47]).

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OPEN ISSUES

In this section we discuss several open areas for advance reservation in optical networks. Our intention is briefly point out promising areas of future work in this research area.

Admission Control and Quality of Service

In real-world networks, there will likely be a mix of immediate and advance reservation demands in the network. There are few works that discuss admission control and quality of service for optical networks in detail. While there are some works that start addressing this area, there is no work that makes any type of service guarantees for optical networks. We note that there has also been recent work for non-optical networks as well, e.g. [51].

Instead of assuming that AR is always higher priority compared to IR, it may also be interesting to investigate the case where IR demands are *urgent* and require higher priority. There are many interesting open problems in the area of admission control and QoS for advance reservation over optical networks.

Multi-Domain Advance Reservation

Multi-domain, or inter-domain, setup of dynamic circuits is an important problem for wide area and grid-based net- works. The authors of [42] provide a survey for this area. The work that has been presented needs to be extended for advance reservation demands to incorporate the time-domain information.

Analytical Modeling

We have reviewed a few papers that provide initial analytical results for simplified networks, e.g. a single link. There is no work that proposes a general model which incorporates time- domain information similar to [49].

Survivable Dynamic Advance Reservation

As we have discussed, there is significant work for survivable static advance reservation (see Table VIII). However, there are only a few works that discuss survivable routing with dynamic advance reservation. Both restoration and protection techniques need to be explored in more detail, as well as other communication paradigms such as anycast and multicast.

Grid and Network Layer Integration

The work we discuss in this paper deals with advance reservation of network resources. There is also significant work on advance reservation of Grid resources [118]. The co-allocation of network and grid resources is still an open problem. Some testbeds provide some form of this feature, but there is little theoretical work considering co-allocation of both types of resources. The work in [54], addresses the new evolving paradigms for application-driven networking within the optical layer in the context of Grid computing. The authors discuss open research issues of the optical network control plane and present the issues of interaction between the optical network control plane and applications.

CONCLUSION

In this paper we have presented a comprehensive literature survey on advance reservation in optical networks. We provide a classification of the types of advance reservation that have been proposed in the literature. We discuss motivation for advance reservation in both WAN and Grid-based networks. We discuss architectural issues such as centralized and distributed scheduling and management of the time-domain. We then provide a survey of advance reservation for both static and dynamic traffic, we discuss testbeds and other networks supporting advance reservation, and we discuss other related work. Lastly, we

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provide some areas with open problems dealing with advance reservation.

REFERENCES

1. Keiser, G. E. (1999). A review of WDM technology and applications. *Optical Fiber Technology*, 5(1), 3-39.
2. Ramaswami, R., & Sivarajan, K. N. (1995). Routing and wavelength assignment in all-optical networks. *IEEE/ACM Transactions on networking*, 3(5), 489-500.
3. Chlamtac, I., Ganz, A., & Karmi, G. (1992). Lightpath communications: An approach to high bandwidth optical WAN's. *IEEE transactions on communications*, 40(7), 1171-1182.
4. Zang, H., Jue, J. P., & Mukherjee, B. (2000). A review of routing and wavelength assignment approaches for wavelength-routed optical WDM networks. *Optical networks magazine*, 1(1), 47-60.
5. Zhu, K., & Mukherjee, B. (2002). Traffic grooming in an optical WDM mesh network. *IEEE Journal on selected areas in communications*, 20(1), 122-133.
6. Lee, Y., & Mukherjee, B. (2004). Traffic engineering in next-generation optical networks. *IEEE communications surveys & tutorials*, 6(3), 16-33.
7. Azodolmolky, S., Klinkowski, M., Marin, E., Careglio, D., Pareta, J. S., & Tomkos, I. (2009). A survey on physical layer impairments aware routing and wavelength assignment algorithms in optical networks. *Computer networks*, 53(7), 926-944.
8. Saradhi, C. V., & Subramaniam, S. (2009). Physical layer impairment aware routing (PLIAR) in WDM optical networks: Issues and challenges. *IEEE Communications Surveys & Tutorials*, 11(4), 109-130.
9. Banerjee, D., & Mukherjee, B. (1996). A practical approach for routing and wavelength assignment in large wavelength-routed optical networks. *IEEE Journal on selected areas in communications*, 14(5), 903-908.
10. Ozdaglar, A. E., & Bertsekas, D. P. (2003). Routing and wavelength assignment in optical networks. *IEEE/ACM transactions on networking*, 11(2), 259-272..
11. Zheng, J., & Mouftah, H. T. (2002, April). Routing and wavelength assignment for advance reservation in wavelength-routed WDM optical networks. In *2002 IEEE International Conference on Communications. Conference Proceedings. ICC 2002 (Cat. No. 02CH37333)* (Vol. 5, pp. 2722-2726). IEEE.
12. Roberts, J., & Liao, K. (1985). Traffic models for telecommunication services with advance capacity reservation. *Computer Networks and ISDN Systems*, 10(3-4), 221-229.
13. Virtamo, J. T. (1992). A model of reservation systems. *IEEE Transactions on Communications*, 40(1), 109-118.
14. Wolf, L. C., Delgrossi, L., Steinmetz, R., Schaller, S., & Wittig, H. (1995, April). Issues of reserving resources in advance. In *International Workshop on Network and Operating Systems Support for Digital Audio and Video* (pp. 28-38). Springer, Berlin, Heidelberg.
15. Wolf, L. C., & Steinmetz, R. (1998). Concepts for resource reservation in advance. In *Multimedia Technologies and Applications for the 21st Century* (pp. 217-239). Springer, Boston, MA.
16. Wischik, D., & Greenberg, A. (1998, March). Admission control for booking ahead shared resources. In *Proceedings. IEEE INFOCOM'98, the Conference on Computer Communications. Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies. Gateway to the 21st Century, Cat. No. 98* (Vol. 2, pp. 873-882). IEEE.

17. Greenberg, A. G., Srikant, R., & Whitt, W. (1999). Resource sharing for book-ahead and instantaneous-request calls. *IEEE/ACM Transactions on Networking*, 7(1), 10-22.
18. Schill, A., Kühn, S., & Breiter, F. (1998, April). Design and evaluation of an advance reservation protocol on top of RSVP. In *International Conference on Broadband Communications* (pp. 23-40). Springer, Boston, MA.
19. Guérin, R. A., & Orda, A. (2000, March). Networks with advance reservations: The routing perspective. In *Proceedings IEEE INFOCOM 2000. Conference on Computer Communications. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies (Cat. No. 00CH37064)* (Vol. 1, pp. 118-127). IEEE.
20. Zheng, J., & Mouftah, H. T. (2001, October). Supporting advance reservations in wavelength-routed WDM networks. In *Proceedings Tenth International Conference on Computer Communications and Networks (Cat. No. 01EX495)* (pp. 594-597). IEEE.
21. Kuri, J., Puech, N., Gagnaire, M., Dotaro, E., & Douville, R. (2003). Routing and wavelength assignment of scheduled lightpath demands. *IEEE Journal on Selected Areas in Communications*, 21(8), 1231-1240.
22. Guok, C. P., Robertson, D. W., Chaniotakis, E., Thompson, M. R., Johnston, W., & Tierney, B. (2008, December). A user driven dynamic circuit network implementation. In *2008 IEEE Globecom Workshops* (pp. 1-5). IEEE.
23. BIRN - biomedical informatics research network
24. Battestilli, L., Hutanu, A., Karmous-Edwards, G., Katz, D. S., MacLaren, J., Mambretti, J. & Tanwir, S. (2007). EnLIGHTened computing: An architecture for co-scheduling and co-allocating network, compute, and other grid resources for high-end applications. In *Proceedings of 4th International Symposium on High Capacity Optical Networks and Enabling Technologies (HONET)*.
25. Takefusa, A., Hayashi, M., Nagatsu, N., Nakada, H., Kudoh, T., Miyamoto, T., ... & Imajuku, W. (2006). G-lambda: Coordination of a grid scheduler and lambda path service over GMPLS. *Future Generation Computer Systems*, 22(8), 868-875.
26. Figuerola, S., Ciulli, N., De Leenheer, M., Demchenko, Y., Ziegler, W., & Binczewski, A. (2007, November). PHOSPHORUS: Single-step on-demand services across multi-domain networks for e-science. In *Network Architectures, Management, and Applications V* (Vol. 6784, p. 67842X). International Society for Optics and Photonics.
27. Interface, U. N. (2001, April). 1.0 Signaling Specification. In *Optical Internetworking Forum (OIF).*
28. Escalona, E., Spadaro, S., Comellas, J., & Junyent, G. (2008). Advance reservations for service-aware GMPLS-based optical networks. *Computer Networks*, 52(10), 1938-1950.
29. Xie, C., Alazemi, H., & Ghani, N. (2010, December). Routing and scheduling in distributed advance reservation networks. In *2010 IEEE Global Telecommunications Conference GLOBECOM 2010* (pp. 1-6). IEEE.
30. Barz, C., Bornhauser, U., Martini, P., & Pilz, M. (2008, February). Timeslot-based resource management in grid environments. In *IASTED Conference on Parallel and Distributed Computing and Networks, PDCN* (pp. 81-86).
31. Zhu, X., & Veeraraghavan, M. (2008). Analysis and design of book-ahead

bandwidth-sharing mechanisms. *IEEE Transactions on Communications*, 56(12), 2156-2165.

32. Kuri, J., Puech, N., Gagnaire, M., & Dotaro, E. (2002, November). Routing foreseeable lightpath demands using a tabu search meta-heuristic. In *Global Telecommunications Conference, 2002. GLOBECOM'02. IEEE* (Vol. 3, pp. 2803-2807). IEEE.
33. Figueira, S., Kaushik, N., Naiksatam, S., Chiappari, S. A., & Bhatnagar, N. (2004). Advance reservation of lightpaths in optical-network based grids. *Proc. ICST/IEEE Gridnets.*
34. Naiksatam, S., Figueira, S., Chiappari, S. A., & Bhatnagar, N. (2005, May). Analyzing the advance reservation of lightpaths in lambda-grids. In *CCGrid 2005. IEEE International Symposium on Cluster Computing and the Grid, 2005.* (Vol. 2, pp. 985-992). IEEE.
35. Wallace, T. D., & Shami, A. (2007, September). Connection management algorithm for advance lightpath reservation in WDM networks. In *2007 Fourth International Conference on Broadband Communications, Networks and Systems* (BROADNETS'07) (pp. 837-844). IEEE.
36. Wallace, T. D., Shami, A., & Assi, C. (2007). Advance lightpath reservation for WDM networks with dynamic traffic. *Journal of Optical Networking*, 6(7), 913-924.
37. Tanwir, S., Battestilli, L., Perros, H., & Karmous-Edwards, G. (2008). Dynamic scheduling of network resources with advance reservations in optical grids. *International Journal of Network Management*, 18(2), 79-105.
38. Jung, E. S., Li, Y., Ranka, S., & Sahni, S. (2008, July). Performance evaluation of routing and wavelength assignment algorithms for optical networks. In *2008 IEEE Symposium on Computers and Communications* (pp. 62-67). IEEE.
39. Yang, X., Shen, L., Todimala, A., Ramamurthy, B., & Lehman, T. (2006, March). An efficient scheduling scheme for on-demand lightpath reservations in reconfigurable WDM optical networks. In *Optical Fiber Communication Conference (p. OTuN2). Optical Society of America.*
40. Shen, L., Todimala, A., Ramamurthy, B., & Yang, X. (2006, April). Dynamic lightpath scheduling in next-generation WDM optical networks. In *Proceedings IEEE INFOCOM 2006. 25TH IEEE International Conference on Computer Communications* (pp. 1-5). IEEE.
41. Shen, L., Yang, X., Todimala, A., & Ramamurthy, B. (2007, June). A two-phase approach for dynamic lightpath scheduling in WDM optical networks. *In 2007 IEEE International Conference on Communications* (pp. 2412-2417). IEEE.
42. Cavdar, C., Tornatore, M., & Buzluca, F. (2009, March). Availability-guaranteed connection provisioning with delay tolerance in optical WDM mesh networks. In *2009 Conference on Optical Fiber Communication-incudes post deadline papers (pp. 1-3). IEEE.*
43. Stevens, T., De Leenheer, M., Develder, C., Dhoedt, B., Christodoulopoulos, K., Kokkinos, P., & Varvarigos, E. (2009). Multi-cost job routing and scheduling in Grid networks. *Future Generation Computer Systems*, 25(8), 912-925.
44. Munir, A., Tanwir, S., & Zaidi, S. H. (2009, December). Holding time aware multicast requests provisioning algorithm for dynamic optical circuit switched (docs) networks. In *Proceedings of the 7th International Conference on Frontiers of Information Technology* (pp. 1-4).
45. Munir, A., Tanwir, S., & Zaidi, S. H. (2009, December). Holding time

aware dynamic bandwidth allocation algorithm for emerging bandwidth on demand multicast applications. In *2009 6th International Symposium on High Capacity Optical Networks and Enabling Technologies (HONET)* (pp. 16-21). IEEE.

46. Lee, S. S., Chen, A., & Yuang, M. C. (2010). A Lagrangean relaxation based near-optimal algorithm for advance lightpath reservation in WDM networks. *Photonic Network Communications*, 19(1), 103-109.
47. Andrei, D., Yen, H. H., Tornatore, M., Martel, C. U., & Mukherjee, B. (2009). Integrated provisioning of sliding scheduled services over WDM optical networks. *Journal of Optical Communications and Networking*, 1(2), A94-A105.
48. Koubaa, M., Puech, N., & Gagnaire, M. (2005, April). Routing and spare capacity assignment for scheduled and random lightpath demands in all-optical networks. In *Next Generation Internet Networks*, 2005 (pp. 39-46). IEEE.
49. Jaekel, A. (2006, December). Opn09-02: Lightpath scheduling and allocation under a flexible scheduled traffic model. In *IEEE Globecom 2006* (pp. 1-5). IEEE.
50. Jaekel, A., & Chen, Y. (2007, September). Demand allocation without wavelength conversion under a sliding scheduled traffic model. In 2007 Fourth *International Conference on Broadband Communications, Networks and Systems (BROADNETS'07)* (pp. 495-503). IEEE.
51. Zhang, S., & Chan, C. K. (2009, September). Multicast protection in WDM optical networks with scheduled traffic. In *2009 35th European Conference on Optical Communication* (pp. 1-2). IEEE.
52. Jaekel, A., Chen, Y., & Bari, A. (2008, September). Survivable traffic grooming for scheduled demands. In 2008 5th International Conference on Broadband Communications, Networks and Systems (pp. 176-183). IEEE.
53. Charbonneau, N., Vokkarane, V. M., Guok, C., & Monga, I. (2011). Advance reservation frameworks in hybrid IP-WDM networks. *IEEE Communications Magazine*, 49(5), 132-139.
54. Tanwir, S., Battestilli, L., Perros, H. & Edwards, G. K. (2007). Monitoring and Discovery for EnLIGHTened Computing. *High-Capacity Optical Networks and Enabling Technologies*.