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Blocking Probability Analysis for Enhanced Optical WDM Networks

Sudhakar S [#1], Priyadarshini K C[#2] , Shanmuga Priyaa C[#3], Suvetha V S[#4]

K.L.N. College of Information Technology, Sivagangai,Tamilnadu India.

ABSTRACT — Currently, the Immediate reservation (IR) and advance reservation (AR) are the two main reservation mechanisms implemented on large-scale scientific optical networks. We can also provide hybrid IR/AR scenarios. Nonetheless, such scenarios can increase the blocking of IR if no quality-of-service (QoS) policies are considered. A solution could be to quantify such blocking performance is that to implement the hybrid scenario in an optical network that provide more wavelength and speed efficiency. Hence in this paper we are considering the Enhanced WDM networks. However, current blocking analytical models are not able to deal with both IR and AR. In this paper, we propose an analytical model to compute the network-wide blocking performance of IR/AR classes. Specifically, we calculate the blocking on the network using the fixed-point approximation analysis. The performance results show that our model provides good accuracy compared to simulation results, even in a scenario with multiple reservation classes defined by different book-ahead times.

KEYWORDS — Advance reservation, analytical model, immediate reservation, optical networks, Enhanced wavelength-division multiplexing (EWDM).

I. INTRODUCTION

The growing demand of network bandwidth is not restricted to happen only on the Internet. Recently, we have also seen a number of initiatives fostering the development of high-capacity optical networks to support large-scale scientific experimentation. The purpose of these networks is to enable the transport of data generated by large-scale experiments. So an optical network which will meet the listed problem should be implemented. Enhanced Optical wavelength division multiplexing (EWDM) networks are being used to interconnect computing, storage, and instruments in Grid networks. An optical WDM network consists of fibers connected by optical cross connects (OXCs). In EWDM networks, each fiber is partitioned into a number of Dense WDM and Course WDM wavelengths, each of which is capable of transmitting data at very high-speeds. This allows each fiber to support data transmission rates of terabits per second. 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. The combination of a route and wavelength is known as a lightpaths. Typically, the objective is to minimize the number of wavelengths used in the network in order to handle a given static traffic demand. In the dynamic traffic scenario, the objective is to minimize the cost of each lightpath request based on different cost metrics, such as pathlength and network load. This is known as the routing and wavelength assignment (RWA) problem. The signal may be transmitted all-optically (uses the same wavelength on every hop along the path) or may be converted to electronics and back to optics (O/E/O conversion) at multiple hops.

Lambda Grid networks typically support dynamic traffic. Dynamic traffic requests arrive one-by-one according to some stochastic process and they are also released after some finite amount of time. The goal of the provisioning system of the network 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 dealing with these problems. We can further classify the dynamic traffic model as *immediate reservation* (IR) or *advance reservation* (AR) requests. The connection requests generated by the scientific applications can be classified as either delay-sensitive or delay-tolerant. For instance, immediate reservation can be used by delay sensitive applications that require immediate service provisioning, but at the expense of higher blocking. The data transmission of an IR demand starts immediately upon arrival of the request and the holding time is typically unknown for dynamic traffic or assumed to be open-ended for static traffic [2]. AR demands, in contrast, typically specify a data transmission start time that is sometime in the future and also specify a finite holding time. Fig. 1 shows the difference between an AR and IR requests. We can observe from Fig. 1(a), in IR the resource allocation occurs when the request arrives at the network. In this case, the duration of the request is unknown. In AR (refer Fig. 1(b)), the actual allocation of resources does not occur until a later time. The resources are reserved when the request arrives, but they can be used by other

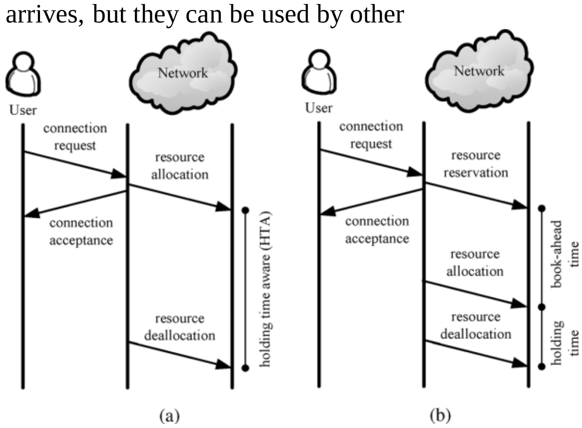

Fig. 1 Reservation types. (a) Immediate reservation. (b) Advance reservation.

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 duration of the request is also specified in advance and known by the network. The fact that holding time and book-ahead time is known allows the network to efficiently optimize resource usage [3]. Advance reservation was initially proposed for non-optical networks, focusing on circuit-switched networks, packet switched networks, and ATM networks. Initial work focused on traffic modeling and call admission for telecommunication systems. Additional work was proposed to provide quality of- service (QoS) for multimedia applications like video conferencing. There were also extensions for RSVP to support advance reservation.

BACKGROUND: IMMEDIATE AND ADVANCE RESERVATIONS AND THEIR APPLICATIONS

In immediate reservation, the resource provisioning and allocation for the connection request starts as soon as the call arrives into the system [refer to Fig. 1(a)]. If the reservation is successful, then the resources are allocated, and the user/client is positively acknowledged to start transmitting data. We can consider two general IR request types: IR with and without specified duration. The former does not specify the holding time, thus the connection uses the network resources until the tear-down request is explicitly sent by the user or upper-layer application. The latter does provide the duration, and it is also known as holding-time-aware (HTA) IR. Fig. 1(a) shows an example wherein the holding time is announced, so the provisioning system can deallocate the resources without an explicit tear-down request. In this paper, we assume that IR requests always specify their holding time [8]. This assumption holds true for a great number of applications, especially in the field of large-scale experimentation. For instance, from the size of the experimentation data and the bandwidth provided per wavelength, we can compute the connection duration necessary to transmit the data set. In general, advance reservation allows the allocation of bandwidth to start after a book-ahead time [see Fig. 1(b)]. In this case, the reservation blocking is resolved at the connection arrival. It is worth noting that IR can also be treated as a special case of AR, but with a zero book-ahead. Commonly, AR requests announce their expected holding time. Requests that specify a start time and duration are denoted as specified-start specified deadline (STSD). Another type is flexible AR, wherein the start time of the resource allocation is flexible as long as it fits within a specified time window and before a maximum deadline. In spite of the benefits of flexible AR, the model under evaluation only handles IR and fixed AR as many of the applications, especially in scientific Grid environments, require strict start and end reservation times. Among the number of nodes along the route, the book-ahead time of AR is usually specified by the user or the service-to-network interface. One last significant difference is the duration of the reservation, in the order of milliseconds for a burst, and of minutes, hours, or even days in the case of wavelength-routed optical networks. Grid and large-scale experimentation applications can benefit from advance reservation. Also, many Grid applications involve delay-tolerant background or recurring tasks. The process requires sending out the data over the Grid to be stored and processed. Such connections can be submitted as AR requests. Network provisioning frameworks, such as On-demand Secure Circuits and Advance Reservation System (OSCARS), Dynamic Resource Allocation Controller (DRAC) or G-Lambda, have immediate and advance reservation capabilities.

II. Network Model

We assume a multilayer application-aware framework with a centralized network resource provisioning system. The centralized model is extensively used, especially in hybrid immediate and advance reservation capable optical Grid networks. Production networks like ESnet and others devised in recent projects make use of this approach [4]. Although multi-domain features can also be defined, within each domain the centralized approach is the norm. In the proposed application-aware service framework, requests are handled by the network service layer [9] (see Fig. 2). This layer is responsible for translating the request into a proper network service setup call. The call is then forwarded to the service-aware adaptation-layer module in order to be mapped onto an existing reservation class according to the delay constraints and the book-ahead time. At the end of this stage, connection requests are forwarded to the network provisioning system with a specific book-ahead corresponding to one of the available reservation classes. The network under consideration in this analysis can be represented by a graph G= (V, E, W, H), where V is the set of network nodes, E represents the links interconnecting the nodes, and W stands for the number of wavelengths per link H stands for the time horizon of the resource's state information (future availability) held by the centralized network provisioning system.

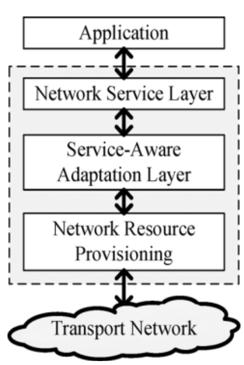

Fig. 2 Multilayer application-aware service framework.

Moreover, we also assume that time is divided into time-slots, and applications request to set up a lightpath between the source and destination node for a certain duration or number of time-slots. This assumption is reasonable in optical circuit-switched networks where connections are active for a specified time period of seconds, minutes, or even hours. The size of the time-slot is not determinant for the present analysis. However, its size needs to be considered in real implementations in order to satisfy physical device specifications (e.g., optical cross-connect switching time, configuration delay, etc.) and increase channel utilization given an average connection duration. In this paper, we assume a first-fit slot and wavelength assignment (FF-SWA) policy. In FF-SWA, the first wavelength in increasing index order with enough free slots to allocate the connection request is assigned and reserved. Fig. 3 illustrates an example using FF-SWA. Let the book-ahead time and duration of the connection be defined by and, respectively. From, we can compute the starting slot for this connection as, where denotes the current arriving slot of the connection request.

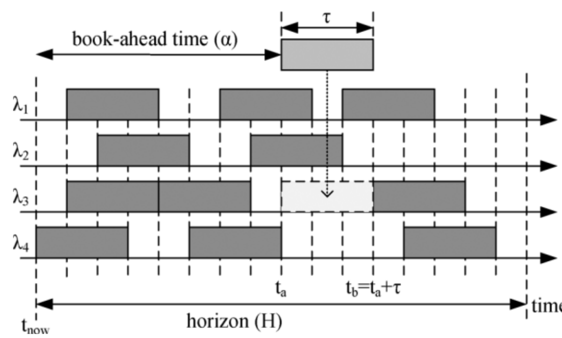

Fig. 3 FF-SWA policy.

With this information, FF-SWA allocates the lowest index wavelength that fits the connection request duration. With current connection scheduling knowledge, first-fit performs better than random because, in the former case, capacity usage is packed across fewer wavelengths, which leaves more wavelength scheduling options under continuity constrained scenarios. Also related to the wavelength assignment, we propose two blocking probability models. First, we assume wavelength conversion between an input and output link at intermediate optical cross-connects. This allows a connection to be reserved a lightpath that can make use of a different wavelength at every link along the path. Second, we propose a model for the wavelength- continuity constrained network, i.e., network nodes do not have wavelength converters, hence the same wavelength must be used on all the links between the source and destination nodes [12].

III. REDUCED LOAD ERLANG FIXED-POINT APPROXIMATION FOR NETWORK-WIDE BLOCKING

Once we have computed the blocking probability of all routes and all classes, we can calculate the average network blocking probability per class, which is simply defined as

$$L_c^{G} = \frac{\sum_{s,d} \lambda_c^{s,d} / \Box . L^{s,d}}{\sum_{s,d} \lambda_c^{s,d} / \Box}$$

Analogously, the total average network blocking probability is given by

$$L^{G} = \frac{\sum_{s,d} \sum_{c} \lambda_c^{s,d} / \Box . L^{s,d}}{\sum_{s,d} \sum_{c} \lambda_c^{s,d} / \Box}$$

Typically, the blocking probabilities and the arrival rate to a link are related since blocking determines the traffic carried by the network, which in turn determines the blocking [5].We use the reduced-load Erlang fixed-point approximation (EFPA) algorithm to obtain the network-wide approximate blocking probability for each IR/AR class and for both scenarios, with and without wavelength conversion. In the reduced-load EFPA, the contributed load into a network link is reduced due to blocking on other links pertaining to the route under consideration. For instance, let us consider two traffic flows between source–destination pair and that have one link in common in their respective lightpaths. The load into the link between nodes and of class is equal to the current load into the link contributed by the route loads minus the load blocked on the remaining links of both routes [7]. After the initialization stage, the traffic load decomposition process in step 5 is iterated until the maximum route blocking probability difference for any class is under a specified error threshold (see step 10). Within the loop, we first calculate the link blocking probability (step 6). Then, using this information, we compute for all routes and class the route blocking probability as shown in step 8.

Algorithm 1: Reduced-load Erlang fixed-point approximation.
1: Initialize all route blocking probabilities to zero, i.e.
2: Set error threshold and **false**.
3: Decompose traffic load to source–destination pairs and routes (see Section IV-A).
4: **repeat**
5: Decompose and compute the arrival load to links based on the reduced-load due to blocking using (30).
6: Compute per link blocking probability for each class, as specified in Section V-A using (13).
7: **for all** route **and do**
8: Compute the route blocking probability, under WC (17) or WCC (26).
9: **end for**
10: **if then**
11: **true**.
12: **else**
13: Update.
14: **false**.
15: **end if**
16: **until** is **true**

IV. SIMULATION RESULTS

In this section, we assess the analytical blocking model proposed in the paper and compare its results to others obtained from simulation. In order to deeply assess the model, we used different network topologies having different network characteristics. In the simulations, we assume a Poisson arrival process with a total average rate of connections and a geometric mean holding time of slots. For a given simulation set, we changed the arrival rate in order to generate the desired offered load. Moreover, we simulate the arrival of different IR classes according to different input traffic class ratios. In our performance analysis we have considered two different optical network scenarios with different IR classes. Also, we evaluated different holding times to check their influence with respect to the book-ahead times of the AR classes. That is, all classes use the same scheduling policy (FF-SWA) to allocate the time-slots and wavelength. We divide the performance analysis into three sections. First, we analyze the proposed model for the case where the optical WDM network is wavelength-conversion capable. Second, we assess the results for the wavelength-continuity case. Finally, we evaluate the results as a function of the number of wavelengths per link and the lightpath length.

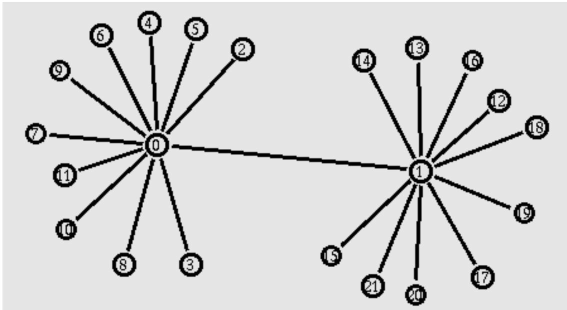
Fig . 4 Simulation Model

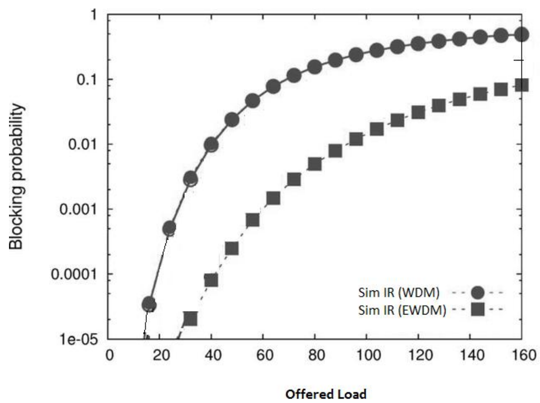

Fig. 5 Load versus Blocking Probability.

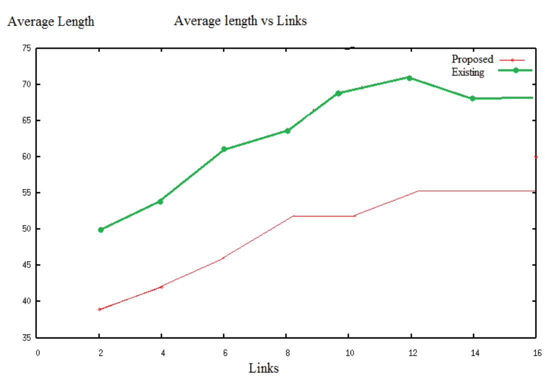

Fig. 6 Links versus Average Length

A. Results under Wavelength Conversion

We can observe that the analytical results accurately match the simulation results. As such, when the average holding time for both IR and AR traffic is five slots, the IR0 class fits almost perfectly; so does the average total blocking probability. The more hops a connection has to traverse, the more resources need to be used and the higher the chances of the connection being blocked [6]. We assume that there is a single path between every source and destination pair. Therefore, upon blocking another path cannot be probed. We can see that in both cases, and for both topologies, the simulation results also match well with the model. The results also corroborate the theory that reservation classes with longer book ahead time experience less blocking. Moreover, when the holding time is five slots (Case 2), the higher blocking classes, IR0 and AR0, analytical results fit almost perfectly to simulation On the contrary, when we set the mean connection duration to 20 slots ,the lowest blocking class in the model (i.e., AR) better resembles the simulation. In the latter case, the model slightly underestimates the higher blocking of IR and AR. This is related to the link-independence assumption and the assumed Poisson overflow traffic of the first-fit wavelength assignment. In summary, we can conclude that in the wavelength conversion scenario, the model captures the simulation results with a very acceptable resemblance, and in particular with higher accuracy when the IR traffic holding time is two orders shorter than the book-ahead of to the AR classes.

B. Results under Wavelength-Continuity Constraint

The second part of the performance analysis compares the model and the simulation results for the wavelength-continuity constrained case. Again, we show the results for different network topologies. The result for the case IR class and one AR class is analyzed. Now, as opposed to the wavelength conversion results, AR shows a better match between the model and the simulation results and reduces a greater overestimation of the approximate analytical blocking probability. In general, we can observe that in the WCC case, the best comparison results are obtained when the mean holding time for the different reservation classes is longer and closer (one order of magnitude of difference) to the book-ahead times assigned to each class (recall that IR has a book ahead of 0). It is worth noting that comparing the results between the WC capable network and the WCC counterpart and for topologies and same traffic case, the blocking probability on the latter is higher. As we analyzed in the blocking probability in the WCC case is the sum of the blocking probability contributed from the wavelength conversion blocking and a term that depends on the wavelength-continuity constraint. Also, in the WC case, the analytical model better approximates the IR blocking than AR, while it is the other way around for WCC. To gain more insight into the correctness of the model, the final set of results in this section shows the blocking probability analysis for three different wavelength scenarios: 8, 16, and 32 wavelengths per link. We picked three representative offered traffic loads, namely 5, 10, and 15 Erlang/Wavelength. As expected, the model shows that increasing the number of wavelengths on the network drops the connection blocking probability. This holds true for both reservation classes under consideration. It is also worth noting that the AR class yields a much better performance when we increase the number of wavelengths available. Final result shows the comparison of the average total blocking probability between two optical networks.

C. Path Length Performance Results

In this section, we analyze the relation between number of links and the path length. To narrow the scope of the results, we consider the Case 1 scenario for such network, the shortest path is at most three hops long. Also, we show the results for two different network CSMA-CD and CSMA-CA for offered traffic loads and 8, 16, and 32 wavelengths per link. When considering the wavelength conversion capable optical network. From graph 3 we see that for CSMA-CD (marked in red) network the path length increases as number of links increases upto maximum link size of 10 an further as preceded link size must increase but here we see length decreases because here network considered is CSMA-CA (marked in black) where path length decreases when number of links increases. This happens regardless of the number of wavelengths on the network and the traffic load.

V. CONCLUSION

Delay-sensitive and delay-tolerant applications require the network to provision the demanded bandwidth at the right time in order to facilitate the best user experience. To satisfy this, IR and AR reservation mechanisms can be utilized. However, IR/AR coexistence requires one to thoroughly analyze the required service level for traffic demands. In this paper, we have introduced an analytical model to compute the approximate network-wide blocking probability in hybrid IR/AR using Enhanced WDM optical networks. The model uses two probability transitions; the first keeps track of the time-slot availability for the connection duration, and the second of the wavelength availability at the reservation book-ahead time. Later, we compute the blocking on the network using a reduced-load fixed point approximation analysis for two common scenarios, with and without wavelength conversion. Results obtained from two different network topologies demonstrate that, with this model, we can approximately compute the blocking probability in the EDWM network even in the case when multiple immediate and advance reservation.

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