A Simple Quality-of-Service-Based Connection Setup Management Approach for Optical Networks

Wissam Fawaz, Ken Chen, Zahi Nakad, Chadi Abou-Rjeily

***Abstract*—One of the major challenges for optical network operators is related to realizing profitable networks that preserve the overall satisfaction of their end customers. This necessitates ensuring a controlled network resource usage while decreasing connection blocking probability. However, optical networks are witnessing the introduction of an increasing number of new services, each having different requirements. As such, the evolution towards resource efficient connection setup management strategies that provide differentiated call-blocking probability becomes inevitable. Building on the previous observation, we propose in this paper a novel connection setup management strategy. This latter aims to differentiate the blocking probability among different classes of lightpath requests, while avoiding the starvation of the lower class lightpaths.**

The main idea behind our proposal is to privilige higher class lightpaths via preemption and to protect the lower class lightpaths through rerouting. In this manner, the proposed strategy serves the double objective of minimizing the overall connection blocking probability and of realizing Quality of Service (QoS) differentiation. The previous claim is asserted through our simulation results that gauge the main benefits behind our proposed connection setup strategy. The simulation results drawn from the National Science Foundation Network (NSFNET) and the European Optical Network (EON) show that the proposed strategy achieves both differentiated and low blocking probabilities.

***Index Terms*: - Optical Networks, Performance Evaluationn, Quality of Service, Connection Setup Management.**

I. INTRODUCTION

The perpetual growth in terms of data traffic has been the main motive for the gradual improvement of carrier's optical networks over the last decade. Parallel to this increase in traffic capacity, there is increasingly a strong need for quality of service differentiation due to the introduction of new services, each presenting different network requirements. Hence, a great deal of effort has been made in providing predictable quality of transport (QoT) services [1], [2]. QoT is defined by every parameter affecting data flow once the connection (lightpath) is established (for further information, refer to [3], and [4]).

Nonetheless, parameters applicable to connection setup, namely *the connection setup time* and *the connection blocking probability*, were not considered extensively in the optical literature (see [5] for one of the pioneers in this regard). We believe that it is necessary to account for these parameters to obtain a complete and satisfactory network solution covering all aspects of quality of service. Therefore, we turn our attention in this paper toward the connection blocking probability parameter that reflects the percentage of lightpath requests blocked due to insufficient resources. We investigate quality of service differentiation based on blocking probability through the proposal of a connection setup management strategy that takes into consideration this parameter during lightpath setup.

Our proposal is not solely motivated by the need for service differentiation enforcement during connection setup but also by the major concern of operators related to accepting the maximum number of connections into their networks. Optical operators are indeed striving to tackle the latter issue as this will enable them to build profitable networks. For all of these reasons, we decided to come up with this proposal that will allow optical operators to address service differentiation during connection setup together with the pressing task of increasing their network throughput. Moreover, the idea behind providing controlled connection setup in the network fits the network evolution from single-service networks to multiservices ones, in which each service has different requirements, and thus requires a somewhat different treatement. In this article, we will use the terms high priority and low priority, but the number of classes may be easily increased to reflect the current needs.

The paper is structured as follows: in Section II we revise the related works presented in the literature, pointing out our position relative to these works; in Section III we propose and describe the connection setup strategy; in Section IV, a simulation study is presented where we highlight the service differentiation feature introduced in our proposal along with its mild impact on the overall optical connection blocking probability. Finally, Section V concludes this paper.

II. RELATED WORK AND CONTRIBUTION

In the optical literature, several studies dealt with service differentiation among lightpath requests belonging to different classes [5], [6], [7]. In [6], the authors analyze the proportional differentiation among traffic classes and propose three algorithms, namely intentional blocking, intentional termination, and a hybrid algorithm. All algorithms constantly monitor blocking probabilities in all classes of lightpath requests and either intentionally block some requests or terminate some existing lightpaths to create blocking probability differentiation among the different classes. In [7], the authors analyze the performance of an algorithm that consists in dedicating a specific range of wavelengths to each class of lightpath requests. This concept was further evaluated using a continuous Markov chain and computer simulation.

However, the previous studies concentrated on service differentiation alone and on maximizing the number of high priority clients accepted into the network. As a result, their

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proposed algorithms were not optimal so far as the network throughput is concerned. In fact, we believe that ensuring an efficient network resource usage involves both the maximization of the number of accepted high priority clients augmented with the reduction of the number of blocked low priority clients. As a distinguishing feature from the existing literature, we propose a novel connection setup management strategy that seeks to serve the largest number of high priority lightpath requests and avoids at the same time to penalize lower class clients. In order to increase the number of high priority connections accomodated by the network, we allow a blocked high priority client to preempt the already established lower class clients. Nonetheless, we prevent lower class clients from being devastated by the higher class ones through the adoption of a rerouting policy that reduces the number of preemptions performed in the network.

So, the proposed connection setup strategy is best described as a combination between a preemption policy and a rerouting policy, and is intended to provide the best results in terms of the blocking probability and carried load. Finally, it is important to note that we consider the rerouting policy as a major part of the connection setup management approach since it contributes enormously to the successful establishment of the lightpath requests.

III. THE PROPOSED CONNECTION SETUP STRATEGY

For economical reasons, optical operators are attempting to ensure an efficient usage of their network resources and are striving for the minimization of network access blocking probability. Consequently, operators need to succeed in fulfilling the following recommendations:

- The largest number of high priority clients is served, that is, most of these clients are provisioned in the network;
- The minimum number of low priority clients is affected by the implementation of the previous recommendation.

We propose to meet the two objectives above through the deployment of our connection setup management approach. The proposed management model presents an efficient approach to the two recommendations by dealing with each one in a separate way. The different strategies that we define, in an attempt to tackle the issues above, are discussed in the following subsections.

A. Preemption Strategies

First, in order to increase the number of high priority clients accomodated by the network, we enable such clients to preempt lower priority ones under blocking conditions (due to network resource shortage for instance). We distinguish in that respect three main classes of preemption policies categorized according to their impact on lower priority clients:

- Soft preemption policy;
- Normal preemption policy;
- Hard preemption policy.

This taxonomy is based on the degree of impact that the preemption strategy has on lower class clients; the more impact we have, the higher the hardness of the preemption strategy.

1) Soft Preemption Strategy: The preemption strategy is considered as *soft* when the set of lower priority connections that may be preempted by a given blocked high priority client is limited to those connections having the same destination as the given high priority client. More precisely, whenever the establishment of a high priority connection t_H originating at a certain node A is not possible, the soft preemption policy is activated. As a result, the set of already established lower priority connections S_L departing from A and going to the same destination as t_H are examined, according to a decreasing order of their hop count. For each visited lower priority connection t_L in S_L, a test is performed to determine whether the preemption of t_L allows the accomodation of t_H. If this latter condition is true, t_L is preempted, and t_H is routed into the network. Otherwise, the tests continue with the remaining connections in S_L until either t_H is established, or the end of S_L is reached. If at the end, all the tests fail, then t_H is blocked.

2) Normal Preemption Strategy: The sole difference between this strategy and the previous one is related to the size of S_L, the set of lower priority connections that are tested for preemption when a high priority connection request t_H can not be accepted. In this case, S_L is not limited to those lower priority connections whose destination is similar to that of t_H. Instead, S_L consists of all the lower priority connections that are originated at the same source node as t_H irrespective of their destination. This strategy is thus defined as follows. Each low priority connection in S_L is tested to see whether its preemption guarantees enough resources for the accomodiation of t_H. These tests pesist until either t_H is established or until the end of S_L is reached. If at the end all the tests fail then t_H is blocked. We consider furthermore a variation of the *normal preemption strategy*. The main idea behind this strategy is to activate normal preemption only when the network resource utilization goes beyond a certain predefined threshold. This variation will be referred to as the *normal preemption with threshold* strategy.

3) Hard Preemption Strategy: The last preemption strategy is the so-called *hard preemption strategy*. This strategy is somewhat similar to the *normal preemption strategy*, where all the lower priority connections are visited during the preemption operation. However, the difference between these two strategies stems from the following observation. In this case, when we start going through the low priority connections in S_L, we keep on preempting the examined connections as long as the establishment of t_H is not possible; as opposed to the previous case where we only preempt the sole low priority connection enabling the accomodation of t_H. Consequently, several low priority connections in S_L are preempted in a row either until all connections in S_L have been considered or until t_H has been established. This property reveals the hardness of the strategy with regard to the preemption of low priority clients.

B. Rerouting Strategy

With the adoption of the preemption strategy as part of the proposed connection setup management approach, one problem remains unsolved. That is, lower class clients are

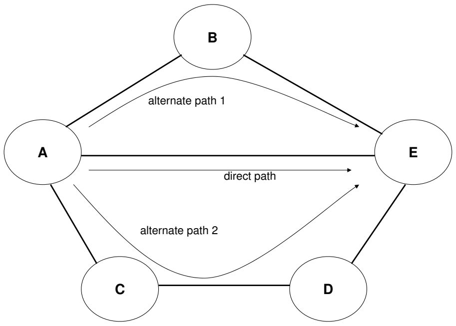

Fig. 1. Sample network topology: Rerouting example

not protected against the greediness of the higher priority clients resulting from preemption. To deal with this issue, we propose to complement the management approach with a rerouting strategy whose main purpose is to smooth the impact of preemption on lower priority clients. A lower class client is actually blocked when at least one of the following conditions holds:

- There aren't enough resources to accomodate its lightpath request;
- The lower priority connection is preempted by a higher class client.

Therefore, in order to protect lower class clients, resource usage must be continuously optimized taking into consideration the dynamic nature of the traffic in the network. This optimization makes more resources available for reuse by low and high priority clients and hence reduces the number of preemptions occuring in the network. We propose to achieve such dynamic resource adaptation and optimization through a novel rerouting strategy. The strategy consists mainly in redistributing network load from time to time to free up more capacity to be used by incoming connection requests. Whenever a connection t_n connecting node A to node B and whose number of hops is n (i.e. routed along n fiber links) leaves the network, the rerouting process is triggered. This involves rerouting all the connections between A and B and whose hop count is greater than n in order to fill up the unblocked capacity. In this respect, the connection t_{n+1} (if any) going from A to B and having a hop count of $n+1$ is rerouted first to occupy the resources that have been freed up by t_n. Then, any of the connections with hop count of $n+2$ between A and B are rerouted to fill up the resources that have been liberated by t_{n+1}. This process is repeated until no further rerouting remains possible.

The proposed rerouting strategy is clarified furthermore through the following example. Let us consider the sample network topology depicted in Figure 1. For instance, suppose that the connection t_1 routed along the fiber link $A-E$ (denoted by direct path in Figure 1) departs. According to our proposed rerouting strategy, all the remaining connections between A and E that occupy more fiber links than t_1 will be rerouted. The connection routed along the path $A-B-E$ will be rerouted first to occupy the path $A-E$, then $A-C-D-E$ will be rerouted along the liberated path $A-B-E$. The activation of the proposed rerouting strategy results in the liberation of 3 fiber links, namely $A-C$, $C-D$, and $D-E$, as opposed to the 1 fiber link ($A-E$) freed up when the rerouting strategy is not deployed. These fiber links may be used by future incoming connections, and the throughput is thus increased.

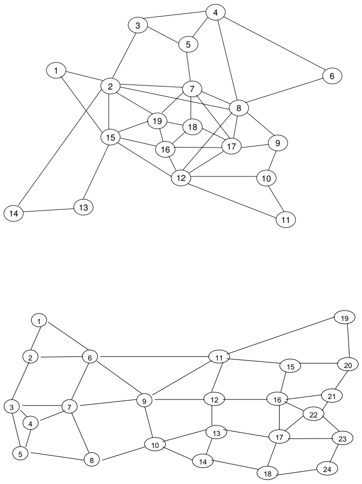

Fig. 2. Reference network topologies used in simulations

The next section investigates the impact of the proposed model on the blocking probability experienced by the different classes of clients. The performed simulation study reinforces our argument stating that the proposed management approach is able to increase the number of accpeted high priority clients while decreasing the number of penalized lower class clients.

IV. SIMULATION STUDY

A. Simulation Scenario

All subsequent results have been obtained based on the two well-known network topologies: the National Science Foundation Network (NSFNET) (lower side of Figure 2) and the European Optical Network (EON) (upper side of Figure 2). Data regarding their physical topologies were taken from Ref. [8] and Ref. [9], respectively. NSFNET has 24 nodes and 43 bidirectional links, while EON has 19 nodes and 39 bidirectional links.

Each connection request is for a point-to-point optical circuit (lightpath) able to carry a randomly generated capacity from the source optical termination to the destination termination. In our simulation model, we consider a dynamic traffic type with the assumption that the connection-arrival process is Poisson and the connection-holding time follows a negative exponential distribution. Following the guidelines presented in [10], 10^6 connection requests are simulated in every experiment. They are uniformly distributed among all node pairs and between two priority levels, namely high priority (denoted hereafter by *Gold*) and low priority (denoted by *Silver*). The average connection-holding time is normalized to unity, and the cost of any link is unity. The routing algorithm used was

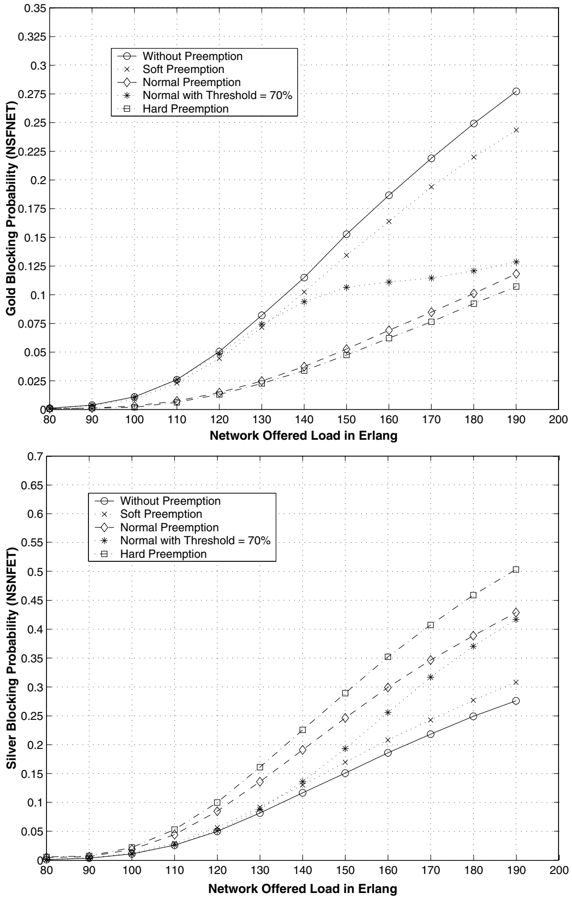

Fig. 3. NSFNET: Gold blocking probability (upper side); Silver blocking probability (lower side)

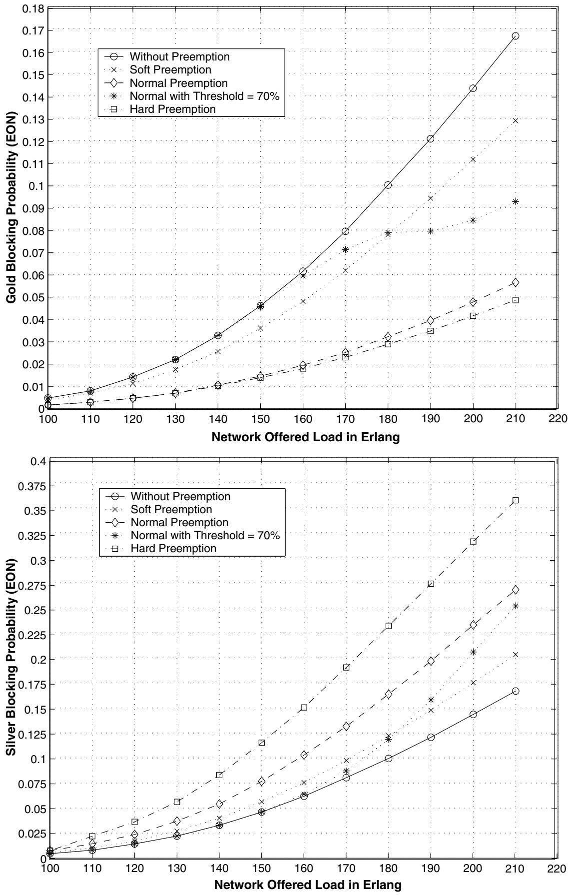

Fig. 4. EON: Gold blocking probability (upper side); Silver blocking probability (lower side)

the shortest path routing with first-fit wavelength assignment. Finally, each link carried 8 wavelengths in each direction and lightpaths are not necessarily wavelength continuous.

The simulation results were obtained using a proprietary C++ based discrete event simulator and each resulting value has been calculated over multiple simulations to achieve very narrow 97.5 % confidence intervals.

B. Illustrative Numerical Results

The main objective of the simulation study is to first assess and compare the performance of the different preemption policy strategies that have been already presented. Then, we determine the benefits of combining these strategies with the rerouting strategy (described in Section III) yielding the proposed connection setup management approach.

1) Performance of preemption strategies (first setting): The first set of results is relevant to the case where only preemption policies are enforced in the optical network. Figure 3 (upper side) plot the blocking probability of the gold connections versus the network load when the different preemption schemes are applied in the NSFNET topology. We observe that when no preemption is performed in the network, the number of blocked gold connections increases drastically as the network offered becomes higher. On the other hand, the improvement in the number of accepted gold connections achieved by the soft preemption strategy prevails for high network loads. This can be easily explained by the higher probability of finding a silver connection, with the same destination as the gold connection, to preempt when the network load increases. Moreover, the number of blocked gold connections can be reduced to more than half with both the normal and hard preemption strategies. This substantial gain is expected since the preempted silver connections in these cases are no more limited to those having the same destination as the gold connection (Figure 3).

The performance of both the normal and hard preemption strategies is close for low network load. But for high load more silver connections are preempted by the hard preemption strategy until reaching the possibility of establishing the gold connection. This fact is asserted by Figure 3 (lower side) that depicts silver blocking probability as a function of the network load for the NSFNET topology case. Finally, it is interesting to observe the behavior of the *normal preemption with threshold* strategy, meaning that no preemption is allowed unless the network usage ratio goes beyond a certain threshold. The impact of such a strategy with a threshold that we chose to be 70% (refer to Figure 3) shows reasonable performance. this is especially true since for low network load it behaves like a no preemption strategy, and for higher load the policy converges toward a normal preemption strategy.

The same reasoning applies for the results derived based on

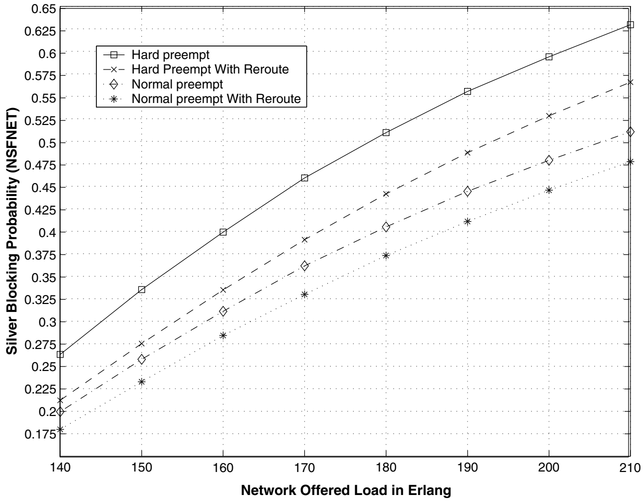

Fig. 5. Silver blocking probability (NSFNET)

the EON topology and which we show in Figure 4.

2) Performance of the proposed approach (second setting): It was proven in the previous subsection that the *normal and hard preemption strategies* outperform the other strategies in terms of the number of gold connections accepted into the network. However, one major drawback of these strategies is the great number of silver connections that are lost due to preemption by the gold clients. It would be of great interest for network operators to find a strategy making it possible to protect silver connections from being exstensively preempted. Our management approach combines preemption policies with a novel rerouting strategy in an attempt to rescue as many preempted silver connections as possible.

Indeed, the proposed strategy will help to increase the number of accepted silver connections, as shown in Figures 5 and 6 where the blocking probability of the silver connections is plotted versus the network load. In fact, redistributing network capacity allows the release of more resources in the network. As a result, the acceptance of more gold connections without the need to preempt silver connections is enabled. This proves the main interest behind the proposed management approach, since gold connections are still provided with the same service level without having to penalize silver connections.

V. CONCLUSION

In this paper we proposed a novel connection setup management strategy. The main purpose of this strategy is on the one hand to enforce blocking-probability-based differentiation among the different classes of lightpath requests, and on the other hand to achieve the best results in terms of blocking probability or carried load. In order to exhibit the main interest of the proposed connection setup approach, we developed a simulation study where different classes of lightpaths requests were provisioned into the network.

Our simulation results showed that the deployment of our proposal will allow optical network operators to offer a wide portfolio of services, while optimizing resource allocation. This is especially true since a reasonable compromise between service differentiation and improved network throughput is made possible through the proposed setup approach.

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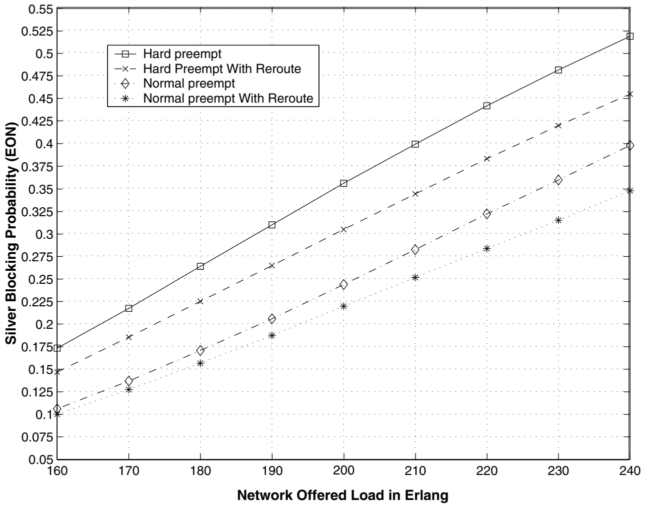

Fig. 6. Silver blocking probability (EON)