Fair Spectrum Degradation with QoS Assurance for Lightpath Establishment in Elastic Optical Networks

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Abstract

In Elastic Optical Networks (EONs), lightpaths are established in order to transmit optical signals through channels called spectrum grids. EON, with its variable spectrum grids, can use the spectrum efficiently and flexibly because the spectrum can be allocated at a subwavelength level in order to match the required bandwidth. As the network gets congested, an increasing number of lightpath requests get blocked because of the spectrum contiguity constraint. In order to address this issue, degraded spectrum provisioning has been proposed in the literature. In this paper, we propose a QoS assurefd fair spectrum degradation algorithm for lightpath establishment in EON in order to improve fairness. In our proposed method, degraded spectrum provisioning is performed only for lightpaths with large number of hops and large number of required FSs in order resolve the double unfairness that occurs in EON. We evaluate the effectiveness of the proposed method by simulation for the NSFNET topology and discuss its results.

1. Introduction

Optical switching networks allow ultra-high speed communication and are currently used in nowadays networks. In these networks, lightpaths are established in order to transmit data as an optical signal through channels called spectrum grids. Recently, the Internet traffic has grown exponentially and has become burstier than ever due to bandwidth hungry network applications as well as to the increasing number of users getting access to the Internet. This high traffic load has raised concerns in the research community over the capacity of the current optical switching networks and whether its limit would be reached in the near future.

This limit may be reached soon because current optical networks allocate bandwidth in an inefficient manner and because the size of the spectrum is fixed to 50 GHz by ITU. In addition the spectrum unit is at the wavelength level. Therefore, if the required bandwidth is not a multiple of 50 GHz, then part of the unused spectrum is wasted because it is not available to other users.

This introduced the need of flexible new generation optical networks that can support high data bit rates. As a cost effective solution, Elastic Optical Network (EON) has been proposed [1].

In EON, the spectrum grid size can be changed in order to match the required bandwidth by using bandwidth variable transponders that can transmit, receive and switch optical signals at the sub-wavelength unit called Frequency Slots (FS). Hence, EON allocates the spectrum much more efficiently and flexibly without adding more bandwidth. However, in EON all the FSs belonging to the same lightpath have to be allocated adjacently, hence satisfying the spectrum contiguity constraint. Consequently, as the network gets congested, many lightpath requests get blocked because the spectrum contiguity constraint cannot be satisfied [2-3].

In order to address this issue, degraded spectrum provisioning has been proposed in the literature as an effective solution [4-5]. Most of the research work in the literature proposed degraded spectrum provisioning for already established lightpaths and these methods reduce the number of allocated FSs during the lifetime of the established lightpath [6-10]. These methods succeeded in decreasing the blocking probability, however extra costs are incurred due to constant monitoring and delay caused by FSs deallocation. On the other hand, there is few research work in the literature that considered degraded spectrum provisioning method during the lightpath establishment process such as in [11-12]. Performing degraded spectrum provisioning at the lightpath establishment process reduces costs such as constant monitoring and deallocation delays. Therefore, in this paper spectrum degradation at the lightpath establishment phase is considered.

In [12], the authors proposed an algorithm that allocates a smaller number of FSs than required by the lightpath request and increases the holding time in order to keep the total amount of the traffic unchanged. In the numerical results, it was shown that the blocking probability has been significantly decreased. However, this method did not improve fairness between requests which is another major issue in EON. Lightpath requests with a large number of hops and a large number of required FSs tend to be blocked more often than other requests. Consequently, requests with the same priority class may have different QoS, which is not a desirable situation.

In this paper, a QoS assured fair spectrum degradation algorithm for lightpath establishment in EON is proposed in order to improve fairness. In the proposed method, degraded spectrum provisioning is performed only for lightpaths with large number of hops and large number of required FSs in order resolve the double unfairness that occurs in EON. In addition, the proposed algorithm is QoS assured which means that all the requested traffic is transmitted without data loss because the holding time of the lightpath is increased. Numerical results show that not only fairness was improved but also that the blocking probability was decreased compared to conventional EON lightpath establishment method that do not perform degraded spectrum provisioning.

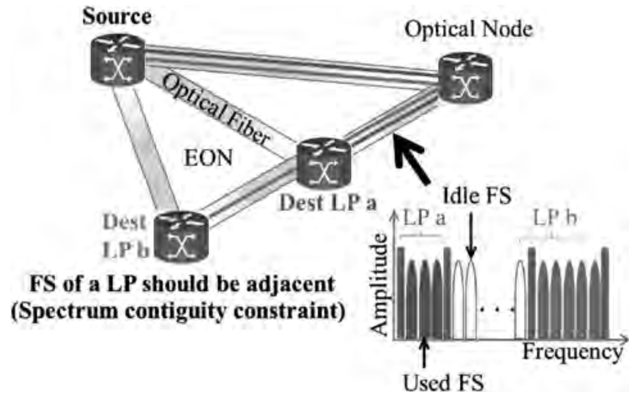


Figure 1. Elastic optical networks.

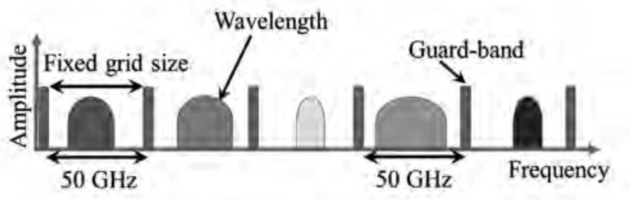
In the following, EON is introduced in section 2 and some related work on degraded spectrum provisioning is summarized in section 3. Section 4 presents and explains the proposed method.

Numerical results are shown in Section 5, and conclusions are presented in Section 6.

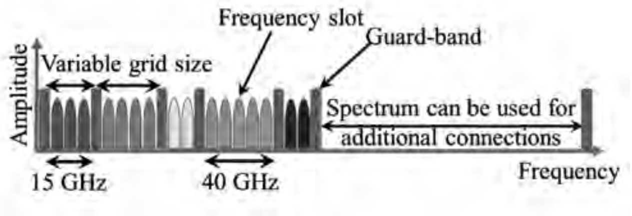
2. Elastic Optical Networks (EONs)

In this section, we explain how data is transmitted in EONs and how spectrum grids are utilized. As shown in Fig. 1, EONs are circuit switched optical networks, therefore, a lightpath, which is an all optical connection, is established between a source and a destination before data transmission. First a lightpath establishment request arrives at an EON source node with information such as required destination node, bandwidth (number of FSs) and the holding time (connection duration). Then, the source node computes the best path until the destination, checks if there are enough available contiguous FSs at each link along the best path until destination, and reserves the FSs at each link of that path. Next, data is transmitted all optically without Optical/Electrical/Optical conversion, allowing ultra-fast transmission. Finally, all the reserved FSs are deallocated and the lightpath is released.

The main advantage of EON over conventional WDM optical networks is its flexible spectrum grids. Figure 2 shows the difference between the spectrum grids of EON and conventional optical networks. The size of every spectrum grid is fixed



(a) Fixed grid optical networks.



(b) Elastic optical networks.

Figure 2. Comparison of spectrum grids.

and is set to 50 Ghz for conventional optical networks (See Fig. 2 (a)). Here, the spectrum is not fully utilized if the required bandwidth of the lightpath request is not a multiple of 50 GHz.

As illustrated in Fig. 2 (a), the whole spectrum grid is not fully utilized and part of the spectrum grid is unused, which leads to inefficient spectrum use. On the other hand, Fig. 2(b) shows that EON spectrum grids have variable sizes such as 15 GHz and 40 GHz in order to match the required bandwidth by the lightpath request. This is possible because in EON a FS is at the subwavelength level and the spectrum is efficiently used, hence EON can accommodate more lightpaths compared to conventional WDM optical networks. Therefore EON can support high data bit rates flexibly.

3. Related Work

Next, we introduce some related work on degraded spectrum provisioning in EON. In this paper, we consider that our lightpath establishment requests are delay tolerant and can accept a lower Quality of Service (QoS) which can be classified into two categories. The first category is called QoS affected degradation that consists in allocating a smaller number of FSs than required and keeping the same holding time, hence resulting in data loss. The second category is called QoS assured degradation and while a smaller number of FSs is allocated, the holding time is increased in order to keep the total amount of traffic unchanged [4-5].

Degraded spectrum degradation methods have been proposed in the literature [6-12]. In [6], the authors proposed a method that performs spectrum degradation in order to reduce the costs incurred from network failure caused by natural disasters. In this method, the main goal is to maintain network survivability. In [7], the authors proposed a method that performs spectrum degradation as a means to provide service differentiation. Here, the algorithm determines the number of reduced FSs depending on the lightpath priority level. In [8], the authors proposed a double optical and electrical degradation method in order to reduce the blocking probability. In electrical degradation, the number of allocated FSs is decreased and the holding time is increased, whereas in optical degradation the modulation format is changed in order to decrease the number of FSs.

In [9-10], the authors proposed spectrum degradation methods for time varying traffic of already established lightpaths. Here, the spectrum allocated to an end-to-end connection between source and destination nodes varies dynamically with time for the duration of a lighpath. These methods use spectrum expansion/degradation by increasing/decreasing the amount of allocated FSs of an already established lightpath as the traffic decreases/increases. While these methods succeeded in decreasing the blocking probability, extra costs are incurred due to constant monitoring and delay caused by FSs deallocation.

On the other hand, there are few research work in the literature that proposed degraded spectrum provisioning method during the lightpath establishment process such as in [11-12]. Performing degraded spectrum provisioning at the lightpath establishment process reduces costs such as constant monitoring and delays due to deallocation of FSs. In [12], the authors proposed

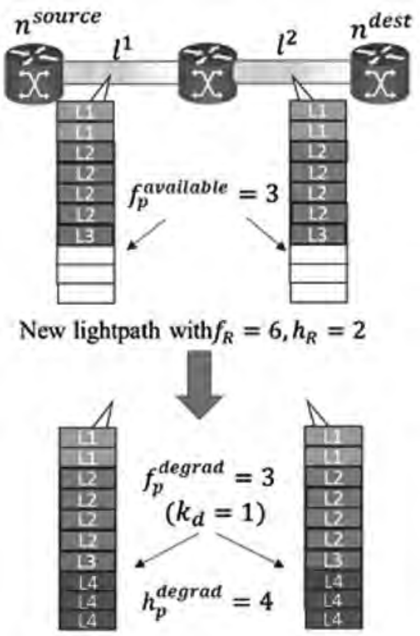


Figure 3. Example of degraded spectrum provisioning.

an algorithm that allocates a smaller number of FSs than required by the lightpath request and increases the holding time in order to keep the total amount of the traffic unchanged. In the numerical results, it was shown that the blocking probability has been significantly decreased.

However, this method in [12] did not improve fairness between requests which is another majorissue in EON. Lightpath requests with a large number of hops and a large number of required FSs tend to be blocked more often than other requests. Hence, requests with the same priority class may have different QoS. After an extensive literature research, it was concluded that this paper is the first to propose a QoS assured degraded provisioning during lightpath establishment, and this is an extension of my previous work in [12].

4. QoS Assured Fair Spectrum Degradation

This section presents the proposed QoS assured fair spectrum degradation algorithm for lightpath establishment in EON in order to improve fairness. In the proposed method, degraded spectrum provisioning is performed only for lightpaths with large number of hops and large number of required FSs in order resolve the double unfairness that occurs in EON. In addition, the proposed algorithm is QoS assured which means that all the requested traffic is transmitted without data loss because the holding time of the lightpath is increased.

4.1 System Model

In this subsection, the system model for the proposed lightpath establishment in EON is presented. EON is modelled as a graph G_{EON} (N_{EON}, L_{EON}) where N_{EON} is the set of EON nodes and L_{EON} is the set of EON links. The maximum number of EON nodes is N and the maximum number of EON links is L. The i^{th}(i=1,⋯, N) EON node is denoted as $n^i_{EON} \in N_{EON}$. The i^{th} (i=1,⋯, L) EON link is denoted as $l^i_{EON} \in L_{EON}$, and the total number of FSs for link l^i_{EON} is denoted as M.

In this network, a lightpath is established based on the information of a lightpath request. This latter contains information about the destination node denoted as n^{dest}, the required number of frequency slots f_R ($f_R \leq$ M), and the holding time h_R for the lightpath.

A lightpath is established if there are enough idle and contiguous FSs at each link of the computed path p with p_{hops} hops between the source and the requested destination node n^{dest}. The number $f_i^{available}$ of available FSs at link i is collected for each link i in p until the requested destination node n^{dest}. Here, we define the number $f_p^{available}$ of available FSs for path p as follows:

$$f_p^{available} = \min_{i \in p} f_i^{available} \quad (1)$$

If $f_p^{available} \geq f_R$, the lightpath will be established with f_R FSs and with a holding time h_R. Otherwise, the lightpath is either established with a degraded spectrum provisioning or blocked. The next subsection explains the conditions that must be satisfied in order for to perform degraded spectrum provisioning for a lightpath.

4.2 Fairness-awareness: Conditions for spectrum degradation

In EON, lightpath requests with a large number f_R of FSs and a high number p_{hops} of hops at path p tend to be blocked more often than other lightpaths with smaller f_R and p_{hops}. This is because it is more difficult to find available and contiguous FSs when f_R and p_{hops} are large. Consequently, this results in different blocking probabilities for lightpath requests within the same priority class.

In the proposed method, fairness awareness is implemented by providing almost the same blocking probability for all requests regardless of the values of f_R and p_{hops}. In the proposed method, fairness awareness is implemented by allowing spectrum degradation only for lightpaths with large number of f_R and p_{hops} and by blocking other requests. Therefore, if $f_p^{available} < f_R$, then the following two conditions are checked.

<u>*Condition 1:*</u>

The number of hops p_{hops} of path p should be larger than or equal to a certain threshold M_{hop}.

<u>*Condition 2:*</u>

The number f_R of requested FSs should be larger than or equal to M_{FS}.

If conditions 1 and/or 2 are satisfied, then spectrum degradation is performed as explained in the next subsection.

4.3 QoS assured degradation

In this paper, the case of delay tolerant traffic that can accept a lower QoS is considered. In addition the proposed spectrum degradation technique is QoS assured, which means that even though a smaller number of FSs are allocated, the holding time is increased in order to keep the original traffic amount unchanged, hence no data loss occurs. In the proposed method, spectrum degradation is performed at lighpath establishment by allocating a number f_p^{degrad} of FSs which is smaller than the required f_R as follows:

$$f_p^{degrad} = k_d \cdot f_p^{available}, \; k_d \in (0,1] \tag{2}$$

k_d is a coefficient that represents the degradation level.

On the other hand, the original holding time h_R of the lightpath request is increased to h_p^{degrad} as follows:

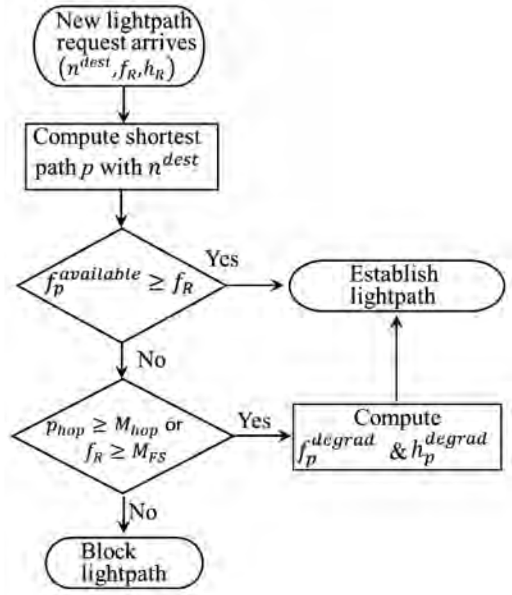


Figure 4. Flow chart of the proposed method.

$$h_p^{degrad} = h_R \cdot \left(f_R \big/ f_p^{degrad} \right) \tag{3}$$

Finally, the lightpath is established with f_p^{degrad} FSs at each link of p with holding time h_p^{degrad}.

4.4 Overview

In this subsection we give an overview of our proposed QoS assured fair spectrum degradation method. Our proposed method establishes a lighpath according to the following steps (Fig. 4).

Step 1: A new lightpath establishment request arrives at a node n_{EON}^i with information containing the destination node n^{dest}, the required number f_R of FSs, and the holding time h_R.

Step 2: Compute the shortest path p with the smallest number of hops between n_{EON}^i and n^{dest}.

Step 3: Compute $f_p^{available}$. If $f_p^{available} \geq f_R$, go to Step 6. Otherwise go to Step 4.

Step 4: Check Conditions 1 and 2 of Section 4.2. If either one or both conditions are satisfied, go to Step 5. Otherwise go to Step 7.

Step 5: Compute f_p^{degrad} and h_p^{degrad}. Then go to Step 6.

Step 6: Establish the lightpath.

Step 7: Block the lightpath.

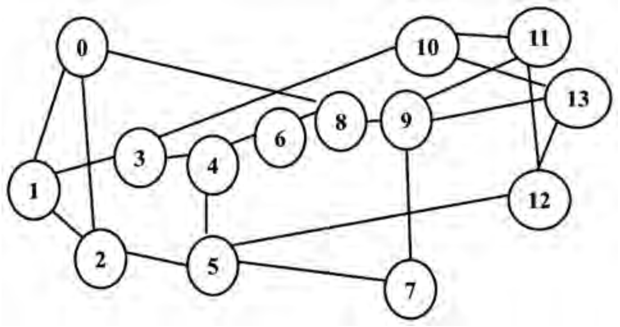


Figure 5. The NSFNET topology.

Table 1. Simulation parameters.

Simulation Parameters	NSFNET
Nodes	14
Links	21
Number of FSs/link	64
k_d	0.3 0.5 0.7
M_{hop}	2
M_{FS}	44 (70% FSs/link)

5. Numerical Results

In this section, the performance of the proposed method is evaluated by Monte Carlo simulation for the NSFNET topology as shown in Fig. 5 and Table 1. In this topology, the number N of nodes is 14 and the number L of links is 21. The number M of FSs at a link is 64. Lightpath establishment requests are assumed to arrive at an EON according to a Poisson process with rate λ [Requests/ms], and the utilization time of a lightpath follows an exponential distribution with rate 1.0.

The performance of the proposed method is compared with two other lightpaths establishment methods under the spectrum contiguity constraint. These methods are "Simple Degradation" proposed in [12] and "Conventional EON" which is a lightpath establishment method that does not perform spectrum degradations, therefore if there are not enough idle and contiguous FSs, the lightpath request is dropped. Simulations were performed for the values of parameters k_d, M_{hop} and M_{FS} as shown in Table 1.

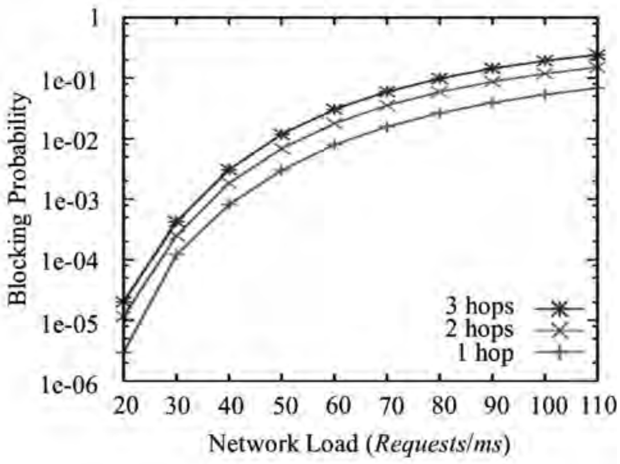


Figure 6. Blocking probability vs. network load for simple degradation of [12].

The performance of all three methods are compared using the blocking probability and the fairness index as performance metrics.

The blocking probability BP is derived as follows:

$$BP = \frac{R_{blocked}}{R_{accepted} + R_{blocked}} \quad (4)$$

Where $R_{blocked}$ corresponds to the number of blocked lightpath requests and $R_{ccepted}$ refers to the number of accepted lightpath requests.

The fairness index FI, as defined in [13], is derived as follows:

$$FI = \frac{\left(\sum_{hp=1}^{H} B_{loss}^{hp}\right)^2}{H \times \sum_{hp=1}^{H} \left(B_{loss}^{hp}\right)^2} \quad (5)$$

Where B_{loss}^{hp} is the blocking probability for lightpath requests whose path p has hp hops, and H is the maximum number of hops any path can have for a specific EON topology.

5.1 Effect of the network load on the blocking probability and the fairness index for each number of hops

In this subsection, the effect of the network load on the blocking probability and the fairness index is analyzed. Figure 6 shows the blocking rate against the network load for "Simple degradation" at hops 1, 2 and 3. Recall that in the NSFNET topology, the shortest path between any two nodes has a maximum of three hops, therefore Fig. 6 shows the blocking probability for hops 1,2 and 3 against the network load. From

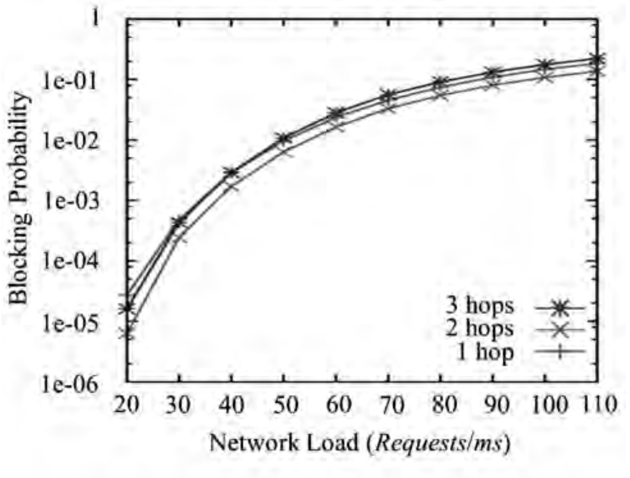


Figure 7. Blocking probability vs. network load for the proposed fair degradation.

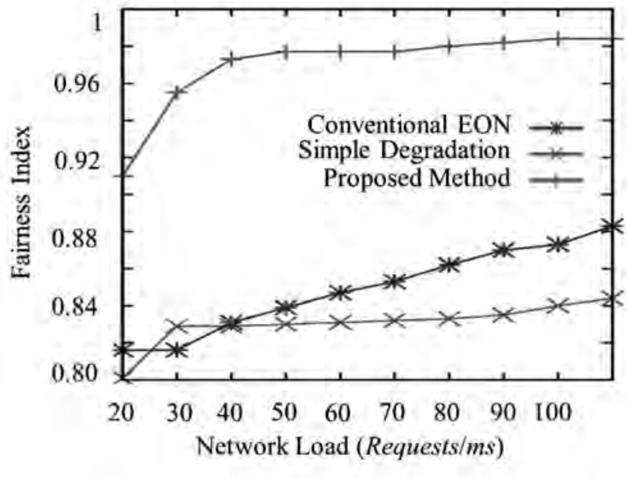


Figure 8. Fairness index vs. network load.

this figure, we find that the blocking rate for all hops becomes large as the network load increases. Moreover, Fig. 6 shows that the blocking rate of 1 hop requests is the smallest and that of 3 hop is the largest. This difference of blocking probability occurs because lightpath requiring 1 hop only have to allocate FSs at one link whereas lightpath with 3 hops will have to allocate FSs at three links. Therefore, lightpaths with 1 hop will have a higher chance of finding available FSs and hence the blocking probability of 1 hop lightpaths is smaller than 3 hop lightpaths. Consequently, this implies that fairness has not been improved with "Simple Degradation".

On the other hand, Fig. 7 illustrates the same situation as in Fig. 6 but for the proposed Fair spectrum degradation method. From this figure, we can observe that all three blocking probabilities also become large as the network load increases. In addition, the blocking probabilities for hops 1, 2 and 3 are almost equal. This implies that lightpath requests have about the same chances of succeeding in establishing a lightpath regardless of the number of hops. Hence, we can conclude that fairness has been improved by the proposed method for all lightpaths by using the blocking probability metric.

Moreover, fairness of the proposed method has been evaluated using the fairness index against the network load as illustrated in Fig. 8 for the proposed method, "Simple Degradation" and "Conventional EON". Please note that the closer the fairness index is to 1, the better the fairness. From this figure, it is shown that the fairness index of the proposed method is larger than the other two methods for all values of the network load. Furthermore, the fairness index of the proposed method is the closest to one. Therefore, we confirm that the proposed method is indeed effective in improving fairness using the fairness index.

5.2 Impact of the number of spectrum degradations

Next, the impact of the network load on the average number of spectrum degradations is investigated in this subsection. Figure 9 shows the average number of spectrum degradations against the network load for the proposed method and for "Simple Degradation". This figure shows that the number of spectrum degradations increases as the network load increases for all methods. This is because as the network loads increases, the network gets more congested due to the fact that there are less idle and contiguous FSs. Hence, lightpath requests tend to get blocked more frequently when the network load increases.

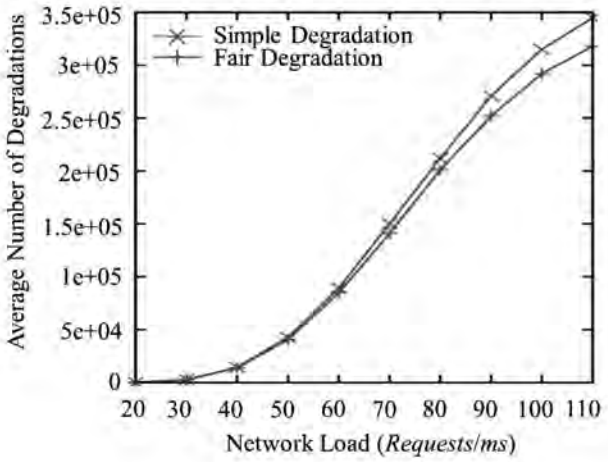


Figure 9. Average number of degradations vs. network load.

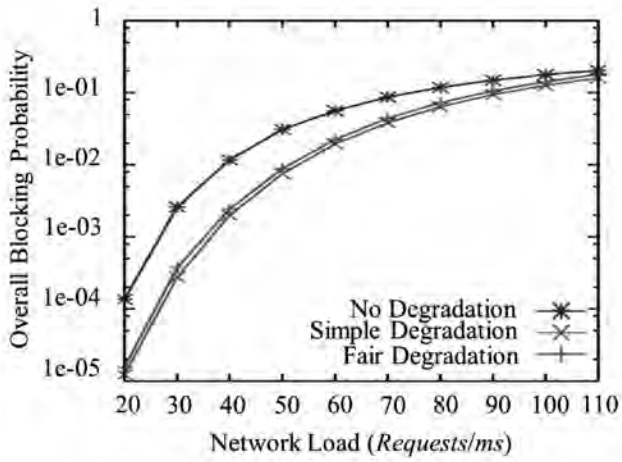


Figure 10. Overall blocking probability vs. network load.

In addition, the average number of spectrum degradations for the proposed method is smaller than that of "Simple Degradation". This is because "Simple Degradation" performs spectrum degradation for all lightpath establishment requests, whereas the proposed method performs spectrum degradations only for lightpaths which require a large number of FSs and hops.

5.3 Evaluation of the overall blocking probability

Finally, we investigate how the overall blocking probability is affected by the proposed method. Figure 10 shows the overall blocking probabilities of the proposed method, "Simple Degradation" and "Conventional EON" against the network load. From this figure, we can see that the overall blocking probabilities for all three methods increase as the network load becomes large, which confirms the same tendency as for local blocking probabilities shown in Fig. 6 and Fig. 7.

Moreover, it is shown that the proposed method has a slightly higher overall blocking probability than "Simple Degradation". This is because the proposed method performs spectrum degradation only for some lightpath requests, and lightpaths that require small number of FSs and hops are blocked in order to improve fairness for all requests. However, the overall blocking probability of the proposed method is still smaller than that of "Conventional EON". Therefore our proposed method can also decrease the blocking probability compared to "Conventional EON" that do not perform spectrum degradations.

6. Conclusion

In this paper, we proposed a QoS assured fair spectrum degradation algorithm for lightpath establishment in EON in order to improve fairness. In the proposed method, degraded spectrum provisioning is performed only for lightpaths with large number of hops and large number of required FSs in order resolve the double unfairness that occurs in EON. We evaluated the performance of the proposed method by simulation for the NSFNET topology. In the numerical results, we show that not only fairness was improved but also that the blocking probability was decreased compared to "Conventional EON".

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