# Design of Wavelength-Routed Optical Network Topologies to Minimise Lightpath Blocking Probabilities

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**Abstract:** We investigated the influence of network topology on light-path blocking probability in wavelength-routed optical networks (WRONs) carrying non-uniform traffic loads. Through extensive simulations of a number of similar networks, it is shown that even small differences in the topology can result in large variations in the blocking probability. The results of the simulations are used to assess the features of WRON topologies which exhibit low blocking probabilities with widely varying traffic demands.

## 1. Introduction

Photonic networks can be easily planned to satisfy fixed, known demand patterns with minimal agility and cost. In real networks, however, the process of network planning is generally an ongoing process, with the network having a low level of fill at day 1 and the operator selling capacity and expanding the network incrementally. While this minimises short term costs, it generally leads to inefficient use of resources, stranded capacity and higher overall costs.

The alternative, building a network with additional wavelengths and connection agility, through the use of wavelength tunable transmitters and receivers and switched optical cross-connects (OXC) and optical add-drop multiplexers (OADM) may allow more efficient use of resources and lower long term costs. However, the initial cost may be difficult to justify against future unknown traffic revenues.

In this paper, we describe simulations carried out to identify features of physical topologies that ensure high tolerance to widely varying traffic demands.

## 2. Methodology

There are many aspects that might influence the performance of any WRON in terms of blocking probability: for example, the traffic load and non-uniformity [1], the network physical topology, the network reconfigurability, the routing algorithm used, the wavelength allocation method, etc. The aim of the work described here is to investigate the relationship between the network physical topology and the network tolerance to uncertain future traffic demands.

The analysis considers an existing network, NSF-Net [2], which is tested with many different traffic histories. The non-uniform traffic pattern is randomly generated and the results are compared with those obtained assuming uniform traffic demand. Simple K-shortest path routing [3] is applied with first-fit wavelength allocation. Wavelength conversion is not used in the network, and hence the wavelength continuity rule is applied. The total traffic load of the non-uniform traffic matrix is kept the same as in the uniform case. The total traffic load is equal to $N(N\text{-}1)\ r_u$, where $N$ is the number of nodes in the network, and $r_u$ is the offered load per node-pair in the uniform traffic case, expressed as a fraction of one lightpath capacity. In the non-uniform case, $r_{ij} = r_{ji}$, where $r_{ij}$ is the traffic load from node $i$ to node $j$. Between each node pair, the lightpath request inter-arrival period is a Poisson distributed random variable with a mean value $a_{ij}$ = 1.5 in the uniform case, and the lightpath holding time is an exponentially distributed variable with mean value $t_{ij}$ = 1.0 in all cases considered. The load between each node pair is given by $r_{ij} = \dfrac{t_{ij}}{a_{ij} + (2X - 1)V}$, where $X$ is a uniformly distributed random value between 0.0 and 1.0, and $V$ is the non-uniformity factor. When $V = 0$, $r_{ij}$ becomes the uniform load $r_u$.

It is important to ensure the total traffic load in the non-uniform matrix is identical to that of the uniform matrix. To keep the matrix total traffic load strictly same as uniform case, following the random load generation, a scaling factor $b$ is required, where $b = \frac{\sum_{i=0,j=0}^{i,j=N-1} r_{ij}}{N(N-1)\,r_u}$, and the adjusted traffic load between $i$ and $j$ becomes $r'_{ij} = b\,r_{ij}$. For each non-uniform traffic factor, every different random seed generates a different traffic matrix. With different traffic matrices, the network exhibits different blocking probabilities over a certain range. The width of this range quantifies the robustness of the network.

## 3. Simulation Result and Analysis

A series of NSF-Net and similar networks were tested through simulations. The similar networks have only a single link difference with the original NSF-Net, resulting in a number of networks having the same number of nodes, links and hence connectivity. The NSF-Net topology and a typical similar network are shown in Fig. 1

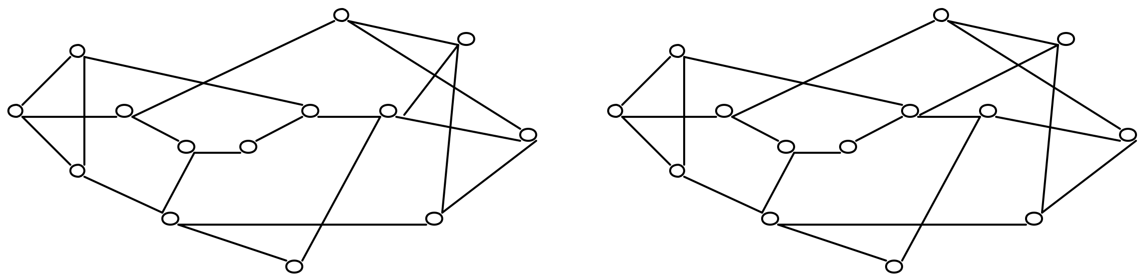

Figure 1 NSF-Net (left) and a similar network topology (right) with one link difference.

The distribution of calculated light-path blocking probabilities for the 21 uniformly loaded networks ($V$ = 0) are plotted in Fig. 2, for load $r_u$ = 0.67. The mean blocking probability is 1.03%. An interesting result is that the range of blocking probabilities is very large, almost an order of magnitude, despite the similarity of the different network topologies.

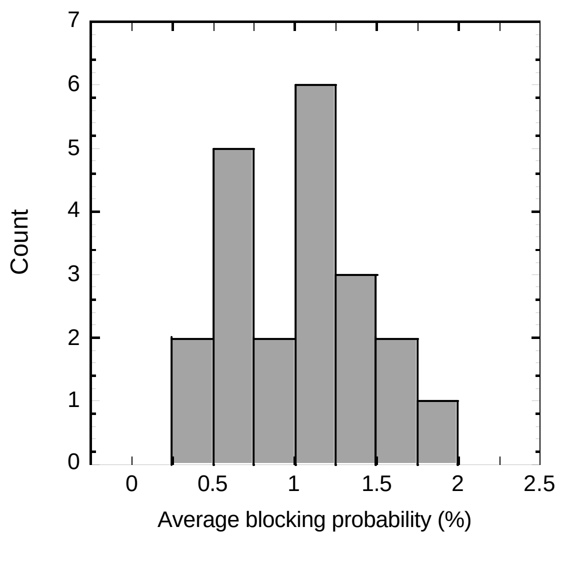


Figure 2 Distribution of blocking probabilities for 21 networks with uniform traffic load

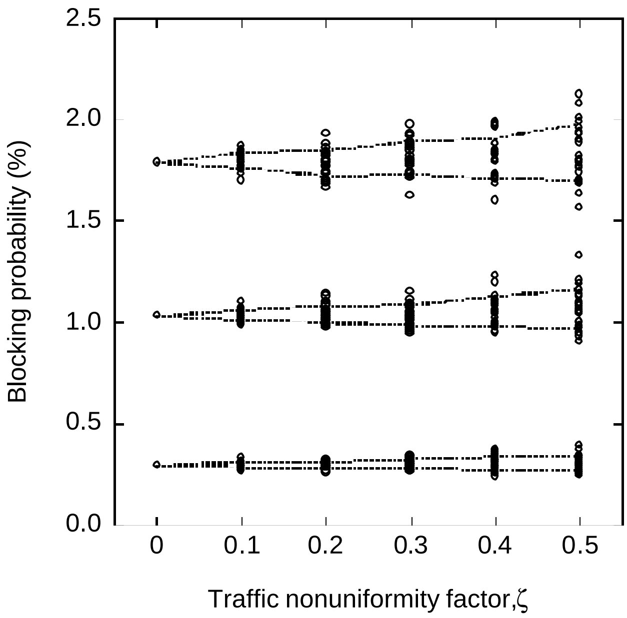


Figure 3 Blocking probabilities for NSF-Net (middle) and best and worst performing networks. Dashed lines: mean values +/– standard deviation

Next, simulations were carried out to assess the networks' performance with non-uniform loading, with $0 = V = 0.5$. Each network was tested with 25 different traffic histories for each value of $V$. The values of blocking probability for three topologies, NSF-Net and the best and worst performing networks, are plotted in Fig. 3. It can be seen that the networks exhibiting the lowest blocking probabilities with uniform load are also more tolerant to unpredictable non-uniform loading, i.e. the spread in values of blocking probability with traffic non-uniformity factors $V > 0$.

An aim of the work is to identify general features of network topologies which ensure low blocking probability. This would allow rapid identification of topologies which would be expected to perform well, significantly reducing the simulation time required in the network planning process. We investigated a number of physical network parameters that may affect the blocking parameter [5].

Two physical parameters were found to have noticeable correlations with the performance in blocking probability, firstly, the average lighpath length (defined as the number of hops between node pairs) and secondly, the number of wavelengths required to fully connect the network in the static case with one wavelength per node-pair [4]. It can be seen from the scatter plot in Fig.4 that networks with low average path length generally exhibit low blocking probability. A strong correlation also exists between static wavelength requirement and blocking probability. Our results show that the lower the static case wavelength requirement, the higher the performance of the network with random traffic demands.

## 4. Conclusions

We investigated a series of physically similar network topologies with the same number of nodes and links with a non-uniform traffic model. The range of blocking probabilities was found to be very large, almost an order of magnitude, despite the similarity of the topologies. Stressing the networks with non-uniform traffic loads, we showed that networks with low blocking probabilities in the uniform traffic case also exhibited high tolerance to unpredictable randomly distributed loading. Two physical parameters were found to have strong correlations with the network performance of handling random traffic – average path length and static case wavelength requirement. This work will allow the rapid identification of network topologies which can be expected to give good performance with unknown future traffic demands.

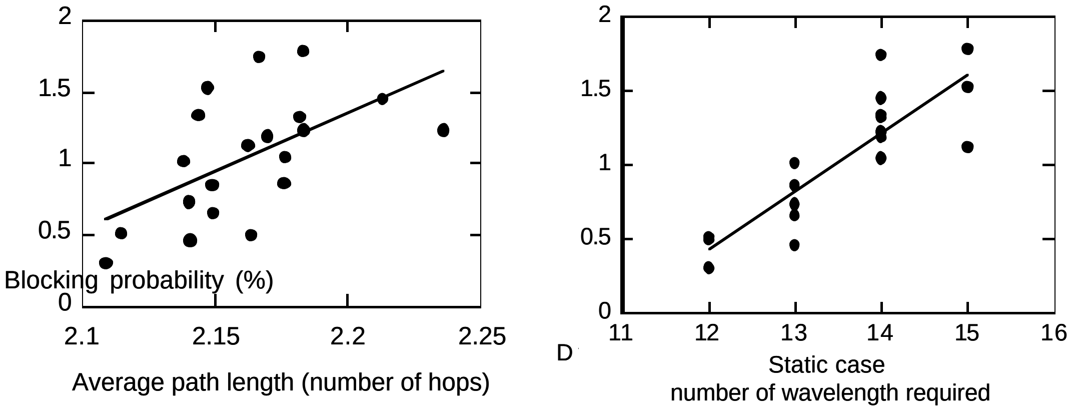


Figure 4 Scatter plots of blocking probability versus average path length (left) and static wavelength requirement (right) for all 21 tested networks. Values calculated for non-uniformity factor $s$ = 0.2. Solid line: Straight line fit to the calculated values.

## Acknowledgments

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## References.

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