Optical Switching and Networking 20 (2016) 35–45

Contents lists available at ScienceDirect

Optical Switching and Networking

journal homepage: www.elsevier.com/locate/osn

Blocking evaluation and analysis of dynamic WDM networks under heterogeneous ON/OFF traffic

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ARTICLE INFO

Article history:
Received 26 May 2015
Received in revised form
4 November 2015
Accepted 11 November 2015
Available online 2 December 2015

Keywords:
Dynamic WDM Optical Networks
Blocking Evaluation
Heterogeneous Traffic
Wavelength Conversion

ABSTRACT

This paper presents an efficient and accurate mathematical method to evaluate the blocking probability of burst loss in dynamic WDM networks with wavelength conversion. The proposed model allows different traffic loads to each network connection (heterogeneous traffic). It is shown that the traffic load heterogeneity on a network significantly affects the blocking probability of the connections, and for this reason, it should be considered in the network design and operation. The mathematical solution is efficient, allowing us to obtain the blocking probability of all users (connections) in less than a second for mesh network topologies. Another desirable characteristic of the proposed method is that it gets results very close to those obtained by simulation, but orders of magnitude faster.

1. Introduction

One of the important metrics related to the performance of dynamic optical WDM networks is the blocking probability. That is, the probability that a burst of information transmitted cannot reach its destiny due to lack of resources on the network. The evaluation of this metric allows us to determine whether or not each network user (connection) is being treated with the required quality of service, in the sense that the blocking probability that its traffic experiences is less than or equal to a specified *B* value.

In the specialized literature several studies have been published that evaluate the blocking probability through simulation, for instance [1–5]. However, this technique is usually very slow compared with the solution obtained via an appropriate mathematical method. The evaluation speed is relevant, because when solving problems of higher order (like designing network routes or a fault tolerant mechanism to failures of links or nodes in the network), it is necessary to calculate the blocking probability of the network, once for each possible scenario of the higher order problem. This number grows exponentially with the size of the network. This is the reason why problems like traffic management of actual networks (with several tens of nodes) have not been investigated in a larger number of possible scenarios in order to find more efficient solutions.

Because high level problems grow exponentially with the network size (requiring numerous evaluations of the network blocking probability) it is not possible to obtain optimal solutions within a reasonable amount of time, the alternative strategy consists in generating a "good" practical solution through some heuristic that quickly produces an acceptable solution to the problem under analysis. The methods proposed so far have usually restricted the different scenarios under which they seek a solution. However, the larger the state space assessed the better will be the obtained results. On the other hand, the higher the speed of solving the problem that must be solved repeatedly (such as the blocking probability of the network), the lower the computational cost associated to solve problems

http://dx.doi.org/10.1016/j.osn.2015.11.001
1573-4277/

of higher order (like fault tolerance), which in turn permits us to enhance the results.

In this latter aspect, mathematical methods can be very useful. Because, based on them, software could be created to assess network performance in times that would be orders of magnitude faster than through simulation. However, in many cases a mathematical model cannot be solved. In these cases, several hypotheses are introduced to simplify the model in order to facilitate its solution. Next, some of the assumptions most commonly used to simplify the mathematical models of the network traffic are described.

Homogeneous load assumption: The vast majority of papers published so far assume that the mean traffic load offered to the network by each connection is the same [6–17], which is known as homogeneous load hypothesis. For example, in [17] the blocking probability for a single node (edge node) in an OBS network was calculated assuming homogeneous arrivals with Poisson distribution; in [16] the blocking probability of a single network link was evaluated assuming an *ON–OFF* traffic; and in [12] the blocking probability of the entire network was assessed, for end-to-end OBS networks, considering nonuniform (but homogeneous at connection level) *ON–OFF* traffic.

The problem of the homogeneous load hypothesis is that it does not adequately represent the operation of optical networks (or computer networks in general), because the traffic in these networks is usually completely heterogeneous, i.e., in general users offer different traffic loads. This is relevant since, as will be shown later, for the same level of mean traffic load on the network, a heterogeneous load distribution can produce a significantly higher (or lower) blocking probability than in the homogeneous load case. This implies the need to include the heterogeneity of the traffic load on the network mathematical models. A first step in this direction was published in [18], where the Engset Multi-Rate model was used to calculate the blocking probability of a network with alternate routing (i.e., when congestion occurs, several alternative routes are used to connect the same pair of nodes), and the load of each alternative route was modelled with a (lower) load, proportional to the blocking of the corresponding primary route. Also, in [19] a mathematical model considering heterogeneous Poisson traffic was presented. In this later case, the authors use the Erlang-B formula to evaluate the blocking probability of the links considering the total traffic load on each link of the network, but it is not sensitive to individual traffic loads of the network connections. As shown below, how the traffic heterogeneity of network connections is distributed clearly affects the blocking probability of the network, a fact not considered by the Erlang-B formula.

Poisson traffic assumption: Many works have assumed that the traffic flow of each source follows a Poisson distribution [1,2,7–10,15,19–22], which obviously simplifies the mathematical solution of the model. Nevertheless, a Poisson process is not representative of the real traffic that occurs in an optical network [12,15,16]. This is because one of the main properties of a Poisson process is that the arrival rates do not change over time. However, an optical network has relatively few users, thus the traffic generation rate at any given time depends on the number of connections that are not transmitting at that moment. This implies that the traffic generation rate changes significantly over time, which implies that a Poisson process is inadequate to model the traffic flow in optical networks.

To characterize the traffic offered by each connection is necessary to consider the burst aggregation method used by the source node. There are various methods of aggregation, which are classified as Aggregation methods of fixed burst length; Aggregation methods of burst during a fixed period of time; and Aggregation methods of mixed burst (seeking a balance between long-time aggregation and burst sizes) [23,24].

The use of either of these methods influences the distribution of the transmission time of a burst (a random variable which we define as t^{ON}) and the distribution of the creation time of a burst (a random variable defined as t^{OFF}). The above description means that the traffic model should consider the type of bursts aggregation used. However, in works such as [25], it has been demonstrated that the blocking probability of OBS networks is mainly affected by the mean times of t^{ON} and t^{OFF}, and is practically insensitive to the specific distribution of such times. In fact, in [26], the sensitivity of the blocking probability in OBS networks on the blocking probability was studied in such networks, concluding that, for practical purposes, we can consider this probability as insensitive to the specific distribution of t^{ON} and t^{OFF}. Consequently, to represent the times of formation and transmission of bursts, this work will use only the mean values of those times.

Assumption of independence between the links of the network: In this case it is assumed that the blocking probability of a link does not depend on the other network links. This is obviously false, because the majority of the connections pass through more than one link, which means that if a connection request is blocked in one of the first links of its route, such request does not reach the following links of the route ("downstream" links). This phenomenon, known as "Streamline Effect" [11], affects the load perceived by downstream links and therefore its blocking probability.

Although the hypothesis of independence does not accurately represent the reality, it, in addition to simplifying the solution of mathematical models, has yielded results relatively close to those evaluated by simulation (with errors in the order of 10%). For this reason most of the published works have made use of this hypothesis, see for example [12–15]. However in some cases, to improve the accuracy of the results, this hypothesis has been complemented by a fixed-point method called Reduced Load Approximation (RLA) [7,10,22,27].

Another way in which the dependence between links has been represented was published in [28,18]. In this case it is assumed that the load provided by a connection to a particular link is equal to the load produced by the source of the connection, less than the blocking probability of the links situated previously on the route associated with that connection ("upstream" links). Here, the blocking probabilities of the "upstream" links are calculated using the independence hypothesis.