11ème Atelier en Evaluation de Performances
Toulouse, du 15 au 17 mars 2016

Blocking Evaluation of dynamic WDM networks without wavelength conversion

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1. Introduction

The rapid increase on demand for bandwidth from existing networks has caused a growth in the use of technologies based on WDM optical infrastructures [4]. Currently, this type of network is operated statically [4], i.e., the route assigned to any user is permanently assigned from source to destination. However, this type of operation is inefficient in the usage of network resources, especially for low traffic loads, which is the most common case.

One way to help overcome the inefficiencies of static networks is to migrate them to networks working dynamically. This operation mode consists in allocating the resources required only when the user has data to transmit. A possible lack of resources to successfully transmit can happen because dynamic networks are designed to save costs with the less possible amount of resources and also to be efficient avoiding burst losses (blocking). To achieve a balance between these two aspects, the network must be designed such that the connection blocking probability is less than or equal to a design parameter B. The evaluation of this metric allows to determine whether or not each network user (each connection) is being treated with the required quality of service.

Another technology useful to improve this static network operation is the optical switches wavelength conversion capacity. In the specialized literature the architecture of dynamic WDM optical networks without wavelength conversion is considered the next generation of optical networks, due the dynamic resource assignment (who origins optical networks) already exist and the wavelength conversion capacity is still in an embryonic phase.

Usually the blocking probability is evaluated through simulation [3, 5]. However, this technique is in general very slow compared with the solution obtained via an appropriate mathematical method. The evaluation speed is relevant, because when solving problems of higher order (e.g. routing or fault tolerant mechanism), it is necessary to calculate this metric several times. Thus, a mathematical computational method is required fast and efficient. However, this is difficult due to important aspects to take into account such as traffic load, wavelengths capacity and continuity, network topology, etc. Several models have been proposed to evaluate the blocking probability [2, 1].

In this document we propose a new approach to evaluate the blocking probability (burst losses) in Dynamics WDM optical networks without considering wavelength conversion.

Network and Traffic model

The network is represented by graph $\mathcal{G} = (\mathcal{N}, \mathcal{L})$, where $\mathcal{N}$ is the set of network nodes , and $\mathcal{L}$ is the set of unidirectional links, with respective cardinalities N and L. The set of connections $\mathcal{X} \subseteq \mathcal{N}^2$, with cardinality X, is composed of all the source-destination pairs with communication between them.

To represent the traffic between a given source-destination pair an ON-OFF model is used. During the ON period, with average length t_{ON}, the source transmits at a constant transition rate. During the OFF period, with average length t_{OFF}, the source refrains from transmitting data. Consequently, the traffic load for each individual connection ρ, is given by the following expression:

$$\rho = \frac{t_{ON}}{t_{ON} + t_{OFF}}. \tag{1}$$

Blocking evaluation strategy

Let $\mathcal{R} = \{r_c \mid c \in \mathcal{X}\}$ be the set of routes that enable communication among the different users (connections) in the network, where r_c is the route associated with connection $c \in \mathcal{X}$. For every link $\ell \in \mathcal{L}$, we denote by W_ℓ the number of wavelengths associated with link $\ell \in \mathcal{L}$.

Given the complexity of the exact evaluation of the blocking probability considering the aspects explained before, we developed a strategy to obtain an accurate while light cost computational scheme. Note that the most important aspect to consider is the wavelength continuity problem, because there is not wavelength conversion capability. This means that when a connection transmits, it must use the same wavelength on each link that belongs to its route. We explain below the different steps of this procedure.

- First, the network $\mathcal{G}$ with W_ℓ wavelengths on link ℓ, is divided into a sequence of W_ℓ networks denoted $\mathcal{G}_1$, $\mathcal{G}_2$, $\ldots$, $\mathcal{G}_{W_\ell}$, where each link capacity is equal to 1. This will avoid the problem of wavelength continuity due to the fact that there is only 1 wavelength per network. However, to emulate the operation of the this optical networks, exists a sequential interaction between this networks $\mathcal{G}_w$. This means, all the blocked connection request rate in the $\mathcal{G}_w$ network will be considered as the connection request rate on the $\mathcal{G}_{w+1}$ network. To consider the interaction between the W_ℓ networks, we consider a dependency between $t_{ON_{c,w}}$ and $t_{OFF_{c,w}}$, the mean ON and OFF periods "seen" on any network $\mathcal{G}_w$ by all the connections $c \in \mathcal{X}$. These values will be explained below.

- Next, an analytical model to evaluate the blocking probability of each network of the sequence is developed. The blocking probability of the $\mathcal{G}_w$ network, which we denote by BC_c^w, is evaluated assuming that the states of the links that constitute route r_c are independent, that is,

  $$BC_c^w = 1 - \prod_{\ell \in r_c} (1 - BL_{\ell,w}^c) \qquad (2)$$

  where $BL_{\ell,w}^c$ is the blocking probability of connection c on link ℓ with $\ell \in r_c$ in the network $\mathcal{G}_w$. $BL_{\ell,w}^c$ is evaluated as follows:

  $$BL_{\ell,w}^c = \frac{1 - \pi_0^{\ell,w} - \pi_c^{\ell,w}}{1 - \pi_c^{\ell,w}}, \qquad (3)$$

  where $\pi_c^{\ell,w}$ is the probability that connection c is using link ℓ in network $\mathcal{G}_w$, and $\pi_0^{\ell,w}$ is the probability that no connection is using the link ℓ in network $\mathcal{G}_w$. These probabilities are calculated by means of a Markov Chain analysis considering the $t_{ON_{c,w}}$ and $t_{OFF_{c,w}}$ values, not shown here for lack of space.

- The interaction between the networks in the sequence is considered in the $t_{ON_{c,w}}$ and $t_{OFF_{c,w}}$ values of network $\mathcal{G}_w$. The parameter $t_{ON_{c,w}}$ does not depend of $\mathcal{G}_w$, because it is the time used by the source to transmit, i.e. $t_{ON_{c,w}} = t_{ON_c}$, for each network $\mathcal{G}_w$. To represent the dependencies between the W_ℓ networks, the $t_{ON_{c,w}}$ value must change with w. This changes carries 3 types of dependencies.

  - Bottom-top: All non blocked connections in the network $\mathcal{G}_w$ make $t_{OFF_{c,w+1}}$ grow by 1 cycle.
  - Top-Bottom: All blocked connections in network $\mathcal{G}_1$, but non blocked in network $\mathcal{G}_{m+1}$, with $1 \leq m \leq W_\ell - 1$, make $t_{OFF_{c,1}}$ grow by 1 cycle.
  - General blocking: All blocked connections in the final network $\mathcal{G}_{W_\ell}$ make the first network increase by t_{OFF}.

  Then, to consider these dependencies, a fixed point procedure is proposed.

- Finally, the average network blocking probability of a dynamic optical network, B_{net}, is evaluated as follows:

  $$B_{net} = \frac{\sum_{c \in \mathcal{X}} \lambda \cdot BC_c}{\sum_{c \in \mathcal{X}} \lambda}, \qquad (4)$$

  where BC_c is the general connection blocking probability, calculated by $BC_c = \prod_{\text{all } w} BC_c^w$.

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