# THE BLOCKING PROBABILITY MODEL IN ALL-OPTICAL NETWORKS FOR LIMITED WAVELENGTH CONVERSION

Miroslav Bahleda* – Karol Blunár – Miroslav Bystriansky – Ivana Brídová

***Optical WDM networks are providing the huge bandwidth and they are still very attractive in backbone networks. In this paper we study the blocking probability model by Barry and Humblet for single fiber WDM networks and model by Al-Zahrani et al. for multifiber WDM networks. The model by Barry and Humblet is proposed for no and full wavelength conversion and we extend this model for limited wavelength conversion. In fact, the proposed model is generalized for no, limited and full wavelength conversion.***

## 1. Introduction

Increasing the bandwidth of optical networks can be done by providing more channels in a wavelength division mutliplexing (WDM) system or by enhancing the bit rate of already existing optical channels using optical time division multiplexing (OTDM) in optical domain or by combination of both WDM/OTDM. Today, WDM is the favorite choice against OTDM. OTDM could be viewed as a long-term network solution, because there are still technology limitations. In these days, it is possible to realize WDM systems using components that are already or will be very nearly available commercially.

WDM network enables transmission on different optical wavelengths through the same optical fiber. In a WDM network, it is possible to route data to their respective destinations based on their wavelengths and it is referred to as *wavelength routing* (*wavelength routed network*). In order to data transmission from the source to the end node, a wavelength continuous route must be set up at the optical layer, which is called a *lightpath*. It is assumed that the optical signal still remains in the optical domain between two access nodes and such a network is called *all-optical network* (*photonic network*). The data transmission is transparent in consideration of data speeds, data formats and data modulations and even analog communication is possible [1].

All lightpaths using the same fiber link must allocate different and distinct wavelengths (*distinct wavelength assignment constraint*). We will deal with optical WDM networks only, where each different wavelength correspondents to a data communication channel (*circuit switched optical WDM network*). WDM network consists of two types of nodes: optical cross-connects (OXC), which connect the fibers in the network, and end nodes, which provide the interface between non-optical end systems and the optical systems.

The OXC provides the switching and routing functions in order to establish the connection between edge nodes. The OXC can be equipped with wavelength converters (WCs) for supporting wavelength conversion. It is able to switch any incoming optical signal at its port from a wavelength to different wavelength among the available wavelengths from its output port.

## 2. Wavelength conversion in WDM networks

If the nodes have the optical cross-connects without wavelength converters, the same wavelength must be used on all the fiber links along physical path for establishing a lightpath. This is also known as *wavelength continuity constraint*. Such a network is called *network with no wavelength conversion*. However, if the nodes employ wavelength converters, different wavelengths can be assigned for a lightpath on each fiber link along the physical path. Such a network is called *network with full wavelength conversion*.

---

* Ing. Miroslav Bahleda, Department of Telecommunication, Faculty of Electrical Engineering, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, phone: +421 41 513 2207, fax: +421 41 513 1520, e-mail: bahleda@fel.utc.sk, blunar@fel.utc.sk, bystriansky@fel.utc.sk, bridova@fel.utc.sk

Unfortunate, the all-optical converters with full range of wavelength conversion are still very expensive and there are also technological limitations. Moreover, in recent years the research has shown that it is also not economically feasible to place wavelength converters to all network nodes. Hence, it leads to the focus on networks with limited wavelength conversion. There are allowed conversion but with some restrictions. They can be of following types:

- A limited range of wavelengths to which an input wavelength may be converted (it is referred to as *limited wavelength conversion with conversion degree k*),
- A limited number of wavelength converters are placed at the node,
- A limited number of converters at the nodes of the network.

Unfortunate, the detail explanation is out of the scope of this paper and it can be found in [1, 2]. We concentrate only on the limited wavelength conversion with limited range of wavelength conversion with conversion degree $k$. In this scenario, any incoming wavelength can be converted to one from $k$ outgoing wavelengths on output side.

## 3. Network model

In this paragraph, we first introduce the basic networks assumptions and give a review of the model by Barry and Humblet and model by Al-Zahrani et al. Then, we explain our generalized model for network with limited wavelength conversion.

In these models, there are considered two independence assumptions [3]:

- Link independence assumption: the link states on different links are independent.
- Wavelength independence assumption: the individual wavelengths are utilized independently of the utilizations of other wavelengths on the same link.

The both link and wavelength independence assumptions lead to the overestimation of the blocking probability. Due to these factors, the analysis of blocking probability is simpler. However, it leads to inaccurate of these models, but it has a moderate computational complexity. Moreover, models are used to approximate the blocking probability only along a path (consecutive links).

In this paper, the following parameters and notations are used:

| | | | |
|---|---|---|---|
| $W$ | Number of wavelengths on each link per fiber | $l_{i,j}$ | Direct link between node $i$ and $j$ |
| $H$ | Number of hops along a path | $a$ | End-to-end traffic load on a path |
| $F$ | Number of fibers per hop | $a_{i,j}$ | Amount of traffic a going through link $l_{i,j}$ |
| $Ch$ | Number of channel in a hop; $Ch=W.F$ | $\rho_{i,j}$ | Load per wavelength over link $l_{i,j}$ |

It is assumed that the call request is arrived on each link as Poisson process with rate $\lambda$ and the connection holding time is exponentially distributed with mean $\mu$. Then the load is expressed as $a=\lambda/\mu$. The wavelengths utilization (load per wavelength) $\rho$ is the probability that a wavelength is used on a link and it can be computed by

$$\rho_{ij} = \sum_{R} a_{ij} \Big/ W \quad , \qquad (1)$$

where R is link path. The same link load over all links, i.e. $\rho_{ij}=\rho$ (uniform link load) and the same number of wavelengths on each link are assumed.

### 3.1. Model by Barry and Humblet [3]

The analytical model by Barry and Humblet was proposed to determine the end-to-end blocking probability in all-optical networks with and without wavelength conversion. For networks without conversion, the blocking probability $P_{b,no}$ between any pair of nodes is the probability that each wavelength is used on at least one of the $H$ hops. It is expressed as

$$P_{b,no} = \left[1-(1-\rho)^H\right]^W . \qquad (2)$$

In networks with full conversion, the blocking probability $P_{b,full}$ is the probability that there is a hop with all wavelengths used and it is given by

$$P_{b,full} = 1 - \left(1 - \rho^{W}\right)^{H}. \qquad (3)$$

### 3.2. Model by Al-Zahrani et al. [4]

The model by Al-Zahrani et al. was proposed to determine the blocking probability between the source-destination pair in all-optical multifiber networks with and without wavelength conversion. In multifiber networks, a link hop between two intermediate nodes consists of a bundle of optical fibers. Because the number of wavelengths that each fiber can carry is limited by the physical characteristic of the fiber and the state of optical technology, an alternative approach for increasing the number of channels is to light multiple fibers.

The blocking probability in multifiber networks without wavelength conversion is the probability that each wavelength in every fiber is used on at least one of the $H$ intermediate hops. In other words, the new lightpath request is blocked on a wavelength, if this wavelength is not free on all of the $F$ fibers on a hop along the path. It is thus given by

$$P'_{b,no} = \left[1 - \left(1 - \rho^{F}\right)^{H}\right]^{W}. \qquad (4)$$

The blocking probability in multifiber networks with full wavelength conversion is the probability that there are all wavelengths used in every fiber on at least one of the hops along the path. It is expressed as

$$P'_{b,full} = \left[1 - \left(1 - \rho^{F.W}\right)^{H}\right]^{W}, \qquad (5)$$

where $F.W$ is the total number of channels $Ch$ in a hop.

### 3.3. Model for limited wavelength conversion with a conversion degree k

This model is proposed for the networks with limited wavelength conversion with a conversion degree $k$. It is derived from model by Barry and Humblet taking into consideration that the each incoming wavelength can be converted to one wavelength from $k$ outgoing wavelengths. The probability $P_{b,lim}$ is the probability that there is at least one hop with all occupied wavelengths from a limited set of wavelengths $k$. It is expressed as

$$P_{b,\lim} = \left[1 - \left(1 - \rho^{k}\right)^{H}\right]^{W/k}. \qquad (6)$$

The detail explanation of derivation of these models is can be found in [5]. In fact, this model is generalized model for full, no and limited wavelength conversion. Note that when no wavelength conversion is considered then $k$ equals 1 and the expression (6) can be modified to (2). And for full wavelength conversion the conversion degree $k$ is equal to $W$ and the expression (6) can be changed to (3). Moreover, a multifiber no wavelength conversion network with $F$ fibers per link and $W$ wavelengths per fiber is equivalent to a single fiber limited wavelength conversion network with $F.W$ wavelengths and conversion degree $F$. The equivalence can be derived from (6) by setting $k \rightarrow F$ and $W \rightarrow WF$. Hence, our model (6) is generalized form to determinate the blocking probability for single fiber networks with no ($k$=1), full ($k$=$F$) and limited ($1<k<F$) wavelength conversion and also for multifiber no wavelength conversion network with $k$ fibers and $W/k$ wavelengths per fiber.

## 4. Conclusion

The numeric results can be seen from Fig. 1. The blocking probability is plotted for the single fiber network with no, limited and full wavelength conversion as a function of wavelength utilization for $W$=15 and $H$=5, 10 and 20. In generally, the figure shows that blocking probability increases with the number of hops $H$ and always increases along the wavelength utilization $\rho$ for each type of wavelength conversion. Note that the wavelength conversion reduces the blocking probability and thus increases wavelength utilization.

The tree curves from this figure, which are plotted for single limited wavelength conversion with the number of wavelength $W$ and conversion degree $k$, are the same for the multifiber no wavelength conversion network with $F=k$ fibers and $W/k$ wavelengths per each fiber. Therefore, based on the component costs (fibers or wavelength converter) and the blocking probability (Fig. 1) an optimal solution can be determined to improve the network capacity by taking into account the wavelength utilization.

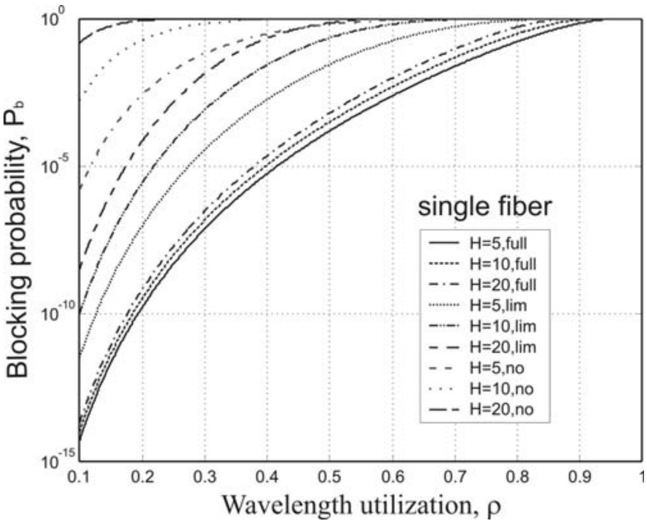


Fig 1. *The blocking probability as a function of wavelength utilization for single fiber network with no, limited and full wavelength conversion and multifiber no wavelength conversion network*

In this paper we presented our model for single fiber network with limited wavelength conversion. The results of this model are compared to the model by Barry and Humblet for single fiber case and by Al-Zahrani for multifiber case. Although these models are not very accurate due to the link and wavelength independence assumptions, they give a very interesting result, which is presented in this paper.


## Acknowledgement

This work was supported by Science and Technology Assistance Agency under the contract No. APVT-20-022404, Technologies for all-optical processing for next generation digital optical networks.


## References


[1] C. S. R. Murthy, M. Gurusamy, WDM optical networks: concepts, design and algorithms, Prentice Hall PTR, New Jersey, 2002.

[2] Bahleda, M., Blunar, K., The wavelength conversion in WDM networks, Komunikácie – the scientific letters of University of Zilina, 6(4), EDIS, Žilina 2004, 98-102.

[3] R. A. Barry, P. A. Humblet, Models of Blocking Probability in All-Optical Networks with and Without Wavelength Changers, IEEE Journal on Selected Areas in Communication, Vol. 14, Num. 5, June 1996, 858-867.

[4] F. A. Al-Zahrani, A. A. Habiballa and A. P. Jayasumana, Path Blocking Performance in Multi-Fiber Wavelength Routing Networks with and without Wavelength Conversion, Proc. 12th International Conference on Computer Communications and Networks, Dallas, TX, 2003, 580-583.

[5] Bahleda, M., Bystriansky, M., Blunar, K.: The Blocking Probability Model in All-Optical Networks for Limited Wavelength Conversion, International Conference on Communication Systems and Networks, September 2005, Benidorm, Spain, accepted paper