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ORIGINAL ARTICLE

# Performance analysis of elastic optical networks (EONs) switches under unicast traffic

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**Abstract**

Bandwidth variable-wavelength cross connect switches (BV-WXCs) play an important role in the routing and spectrum assignment (RSA) problem in elastic optical networks (EONs). These switches, whose structure has been derived from micro electro mechanical systems technology, aim to switch the incoming traffic flexibly such that the existing resources are not wasted and more requests can be served. There exist different quality of service parameters which have to be provided in EON, such as delay, loss, jitter, and so forth. Among these parameters, blocking probability (BP) has been always taken into account in EON and several researches have been done to address it. The main objective of most RSA algorithms is to alleviate BP of requests through efficient usage of resources, such as frequency slots and BV-WXC ports. To show the importance of BV-WXC in routing and resource assignment in EON, its performance is analyzed in this paper. The BP of the BV-WXC is evaluated by means of an analytical model under unicast traffic and the obtained results are compared to the blocking probability results acquired from simulations for different number of input/output ports and available resources. The obtained results show that the analytical model has a good agreement with the simulation results.

**Keywords** Elastic optical networks (EONs) · Bandwidth variable-wavelength cross connect switch (BV-WXC) · Unicast traffic · Blocking probability (BP)

## 1 Introduction

The existing optical networks are divided into fixed-grid and flex-grid networks, where each of them has its own infrastructure. Fixed-grid networks, also known as wavelength division multiplexing (WDM) networks, are constructed based on wavelength, while the basis of flex-grid networks, named elastic optical networks (EONs), is spectrum. The nature of spectrum is flexible so that each spectrum can be divided into a set of frequency slots (FSs). Consequently, EON is a fine granular network whose flexibility is more than WDM in terms of resource assignment. In EON, if the size of a demand is less or more than the capacity of a spectrum, the network can assign resources to the demands, flexibly and hence, avoid resource wasting [1,2].

The granularity of the EON is derived from FSs. Indeed, since the size of each FS can be 6.25 GHz, 12.5 GHz and 25 GHz, its granularity is better than the DWDM ITU-T grid, where the size of its resources is constant [2].

Continuity and contiguity are two main constraints in assigning the FSs to the incoming requests. The continuity constraint implies that the assigned FSs to a request have to be free on all links of a light-path; and based on the contiguity constraint, these FSs must be contiguous in all links of that light-path. For preventing from collision of the assigned FSs to the requests, guard-band (GB) is used between each two requests to separate them [2].

EON is a connection-based network, where each request has its own source, destination, size and holding time (duration). Size of each request denotes the required number of FSs which are assigned to that request. If the BV-WXC can find appropriate resources, it assigns the resources to the request. Otherwise, the request is blocked [2,3].

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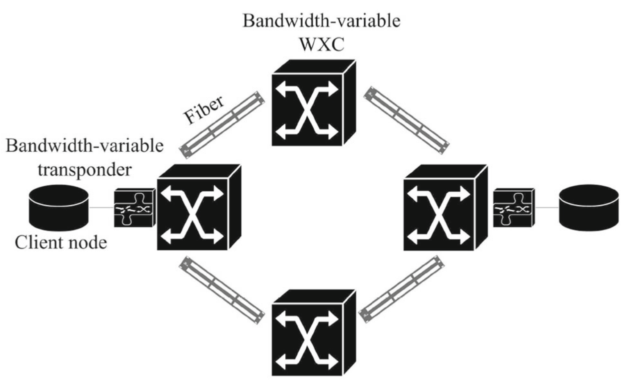



**Fig. 1** Architecture of a EON [4]

In this paper, for the first time, we present a new analytical model for BV-WXC performance under unicast traffic. We evaluate the blocking probability (BP) of BV-WXC by means of this analytical model. The performance analysis is performed for different input/output ports and various amount of available resources. The network model is presented in Sect. 2. Section 3 provides a description for BV-WXC. Traffic model is represented in Sect. 4. Section 5 illustrates the unicast scenario. The analytical model for BV-WXC performance is introduced in Sect. 6. Section 7 includes future work. Finally, Sect. 8 concludes this paper.

## 2 Network model

Bandwidth variability is one of the remarkable features that distinguishes EON from other networks. Figure 1 shows the EON architecture including two important components: bandwidth variable-transponders (BV-Transponders) and bandwidth variable-wavelength cross-connect switches (BV-WXCs), where each BV-WXC is considered as an EON node. EON can flexibly allocate network resources to connection requests by using these components. When a BV-Transponder generates an optical signal according to a traffic demand, BV-WXC allocates a cross-connection according to the required spectrum bandwidth for establishing an efficient end-to-end path [1–3].

Figure 2 shows the structure of a BV-WXC which comprises of splitters and bandwidth variable-wavelength selective switch (BV-WSS) at its input side and output side, respectively. Splitters split incoming wavelengths and send them to the appropriate BV-WSSs. The splitting of spectrums is based on the Micro Electro Mechanical Systems (MEMS) or Liquid Crystal on Silicon (LCoS) technologies [4,5]. Each BV-WSS receives optical signals, which consist of multiple spectrum channels, multiplexes them, switches them to the proper outputs, and demultiplexes them using integrated spatial optics [1–3].

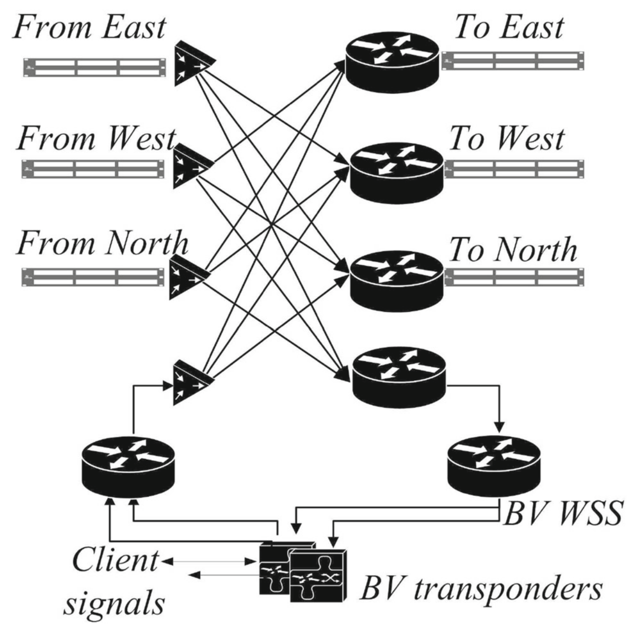



**Fig. 2** An architecture of a 4 * 4 BV-WXC [4]

## 3 Elastic optical network (EON) switches

In this section, we study the structure of the BV-WXC and calculate its complexity [1]. We assume that each fiber in EON comprises multiple FSs and the size of each request is fixed. Totally, each request needs $\frac{\text{Size of request}}{\text{Size of one FS}}$ number of FSs, which is defined as a slot block (SB) [6]. The used notations for the complexity model are mentioned in Table 1.

The structure of a $N * N$ BV-WXC can be seen in Fig. 2, where $N$ represents the number of input and output ports. For example, $N$ is set to 4 in this figure. One of the $N$ ports is local port which is used for fiber adding/dropping from/to local stations. Each port is connected to a link and each link includes one fiber that comprises $S$ spectrums. There exist other elements in BV-WXC, which are splitters, BV-WSSs, and transponders. As can be seen in this figure, there are $M$ transponders, where $M = N - 1$. According to [7,8], BV-WSSs could be either $(M * 1)$ or $(1 * M)$ [1].

Moreover, Fig. 3 shows the architecture of a $(M * 1)$ BV-WSS that supports single-fiber structure, where $M$ is the number of demultiplexers. In addition, there is one multiplexer, $S$ number of $(M * 1)$ switches, and $S$ optical variable attenuators (VOAs). Since it has been assumed that the architecture of the BV-WXC is derived from the MEMS technology, a VOA is also based on the MEMS technology and its cost could be equal to the cost of a $2 * 2$ switching element (SE) [10]. The cost of each element can be expressed as follows [1]:

**Table 1** Notations used for cost modeling

| | |
|---|---|
| $C_{MD}$ | Complexity of multiplexers–demultiplexers |
| $C_{Split}$ | Complexity of splitter |
| $C_{TX-RX}$ | Complexity of BV-transmitters and BV-receivers |
| $C_{WXC}$ | Complexity of wavelength cross-connect |
| $k$ | A coefficient to consider effect of bandwidth variable feature |
| $f$ | Multicasting parameter |
| $G$ | Size of a guard band |
| $L$ | Size of a request or slot block |
| $M$ | Number of slot blocks in each link |
| $N$ | Number of input/output ports in BV-WXC |
| $N_b$ | Number of blocked requests |
| $N_f$ | Number of frequency slots on each link |
| $N_g$ | Number of guard bands on each link |
| $N_o$ | Total number of offered requests |
| $N_{sw}$ | Total number of switches |
| $P$ | Blocking probability |
| $P_{sw}$ | The probability of selecting a switch |
| $p$ | The probability that a request is directed to a given output channel |
| $R$ | All number of incoming requests |
| $S$ | Number of data spectrums on each fiber |
| $u_0$ | The probability that a request arrives at a given input channel |
| $V$ | Average number of output fibers to which a request is directed |

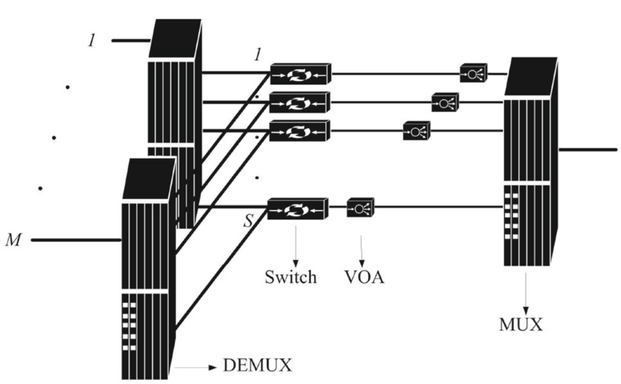



**Fig. 3** An example architecture of a $M * 1$ BV-WSS [9]

- *Multiplexer and demultiplexer complexity* ($C_{MD}$): the complexity of MUX or DEMUX for $S$ spectrums equals to $C_{MD} = (S - 1)$ [1].
- *Splitter complexity* ($C_{Split}$): there is one splitter in the front of each link or input, which broadcasts input fiber to other BV-WSSs. Therefore, in a BV-WXC, there are $N$ splitters [1].
- *BV-transponder and BV-receiver complexity* ($C_{TX-RX}$): there are $S$ BV-transmitters and $S$ BV-receivers in a BV-WXC for local ports. Moreover, the BV feature affects the complexity. Hence, for a BV-WXC, the complexities of BV-transmitters and BV-receivers are calculated as $C_{TX-RX} = k \times S$, where $k$ is a weight coefficient to show the effect of BV [1].
- *BV-WSS complexity* ($C_{BV-WSS}$): there are $N+2$ number of $(M * 1)$ BV-WSSs in a BV-WXC [7]. It is assumed that a BV-WSS switch is based on the Clos (2) switch architecture [11] that uses (input_numbers − 1) switching elements. As mentioned before, there are $S$ switches in a BV-WSS, $M$ demultiplexers, one multiplexer and $S$ VOAs. Hence, the cost of a BV-WSS is calculated as Eq. (1) [1]:

$$C_{BV-WSS} = N \times C_{MD} + S \times C_{SE} + S \times C_{VOA}. \quad (1)$$

In a BV-WXC, there are $N + 2$ BV-WSS components, $N$ splitters, and $M$ BV-transponders for local ports. According to the above mentioned costs and Eq. (1), the whole cost of a BV-WXC is defined as [1]

$$C_{BV-WXC} = N \times C_{Split} + (N+2) \times C_{BV-WSS} + M \times C_{TX-RX}. \quad (2)$$

## 4 Traffic modeling

We assume that each request arrives independently on the $MN$ number of SBs. In our analysis, we consider unicast traffic, where an arriving request can be directed only to one output fiber (OF) and this event occurs with probability $p$. Since all OFs have equal probability, $p$ equals 1.

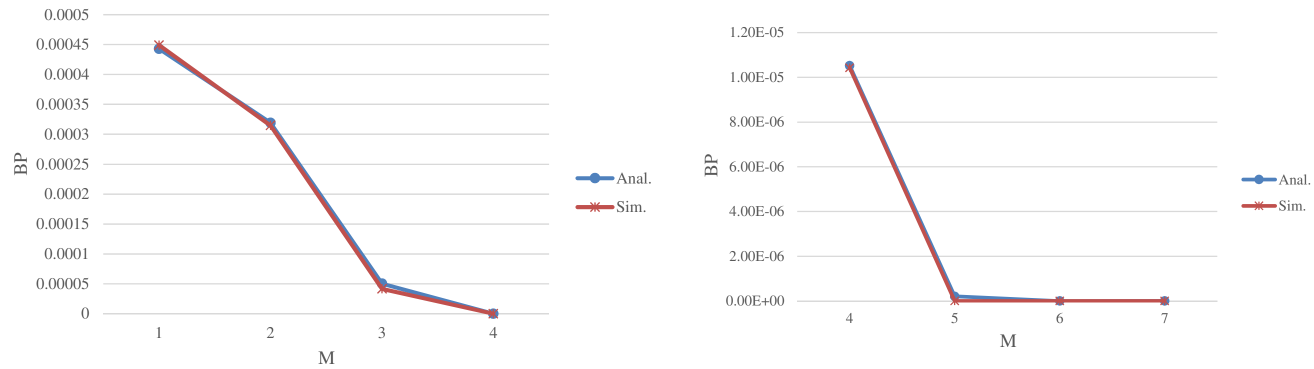
In order to carry out the analysis, some assumptions are introduced. Let $B_k$ show the number of request arrivals addressed to the $k$th OF. The probability of $B_k$ is obtained by [12]

$$\Pr\{B_k = x\} = \binom{N}{x} u_0^x (1-u_0)^{(N-x)}, \quad x \in [0, \ldots, N], \quad (3)$$

where $u_0$ is the probability that a request arrives at a given input channel and it is directed to a given OF. Since all OFs have equal probability, we have $u_0 = \frac{1}{N}$.

## 5 Dimensioning models of the EON switches under unicast traffic ($V = 1$)

When a request arrives at a BV-WXC, the BV-WXC finds the OF that the request has to be directed to it and checks the available SBs on that OF. If there is an available SB on the OF,




**(a)** Blocking probability at $N=4$ **(b)** Blocking probability at $N=8$

**Fig. 4** Comparing BP calculated through analysis model and simulation results

the BV-WXC assigns the SB to the request. Otherwise, the request is blocked. In this section, we calculate the blocking probability of the arriving requests at the BV-WXC.

A fiber in EON comprises $N_f$ FSs, where some of these FSs group together and make SBs and the others make the existing GBs between the SBs. We assume that all SBs have the same size. By considering $M$ and $N_g$, respectively, as the number of SBs and GBs, we have

$$N_g = M - 1. \tag{4}$$

Hence, using Eq. (5), the value of $M$ is obtained by

$$N_f = M \times L + N_g \times G \Rightarrow M = \frac{N_f + G}{L + G}, \tag{5}$$

where $L$ and $G$ are the size of each SB (or request) and the size of each GB, respectively. To compute the blocking probability of BV-WXC, we need some notations. Let $N_o$ and $N_b$ show total number of offered requests and blocked requests, respectively. The blocking probability of BV-WXC is defined as

$$P = \frac{E[N_b]}{E[N_o]}, \tag{6}$$

where $E[x]$ denotes the expectation of random variable $x$. Parameter $E[N_o]$ is the average number of offered requests to the switch. Assume that there are $R$ and $N_{sw}$ requests and switches, respectively. The requests are switched to each of these switches with probability $P_{sw}$ which is defined as

$$P_{sw} = \frac{1}{N_{sw}}. \tag{7}$$

Hence, $E[N_o]$ can be expressed as

$$E[N_o] = R \times P_{sw} \times N \times u_0. \tag{8}$$

Moreover, $E[N_b]$ is the average number of blocked requests defined as

$$E[N_b] = N \times \sum_{j=M+1}^{N} (j-M)\binom{NM}{j} u_0^j (1-u_0)^{(NM-j)}. \tag{9}$$

## 6 Numerical results

In this section, we compare the obtained results from simulations and the analytical model. In the simulations, we assume that the traffic is symmetric to all output fibers in each switch. Each request is generated according to Erlang distribution for Load = 800, where the holding time of each request ($H$) is set to 5 s. In addition, we calculate the blocking probability for $N_{sw} = 1$. The sizes of GBs and SBs are 2 FSs and 20 FSs, respectively. There are two scenarios, where in the first scenario, we have $N = 4$, $N_f = \{20, 42, 64, 86\}$, and hence, $M = \{1, 2, 3, 4\}$. In the second scenario, we have $N = 8$, $N_f = \{86, 108, 130, 152\}$, and hence, $M = \{4, 5, 6, 7\}$. In the following diagrams, each point in every diagram is the average taken from ten replication scenarios, with 95% confidence intervals within at most 5% of the mean values. Figure 4a, b show the results of both simulation and analytical model in the first and second scenarios, respectively. As seen in these figures, the analytical model is in very good agreement with simulation results, specially at high values of $M$.

## 7 Future works

In this paper, we have presented an analytical model for BV-WXC under unicast traffic. However, multicast traffic and broadcast traffic have not been considered. Each of these traffic has its special conditions which their performance can be analyzed as future works.

## 8 Conclusion

In this paper, we have discussed an EON switch that is BV-WXC, calculated the complexity of BV-WXC, and presented an analytical model for BV-WXC under unicast traffic. Obtained results from both simulations and proposed analytical model show that the presented analytical model has a good agreement with the simulation results.

## References

1. Abkenar, F.S., Rahbar, A.G.: Cost-effectiveness of bandwidth granularities in optical networks. Opt. Switch. Netw. (OSN) **22**, 117–128 (2016)
2. Abkenar, F.S., Rahbar, A.G.: Study and analysis of routing and spectrum allocation (RSA) and routing, modulation and spectrum allocation (RMSA) algorithms in elastic optical networks (EONs). Opt. Switch. Netw. (OSN) **23**, 5–39 (2017)
3. Abkenar, F.S., Rahbar, A.G., Ebrahimzadeh, A.: Providing quality of service (QoS) for data traffic in elastic optical networks (EONs). Arab. J. Sci. Eng. **41**(3), 797–806 (2016)
4. Jinno, M., Takara, H., Kozicki, B., Tsukishima, Y., Sone, Y., Matsuoka, Sh: Spectrum-efficient and scalable elastic optical path network: architecture, benefits, and enabling technologies. IEEE Commun. Mag. **47**(11), 66–72 (2009)
5. Ren, H., Wu, S.-T.: Optical switch using a deformable liquid droplet. Opt. Lett. **35**(22), 3826–3828 (2010)
6. Gong, L., Zhou, X., Liu, X., Zhao, W., Lu, W., Zhu, Z.: Efficient resource allocation for all-optical multicasting over spectrum-sliced elastic optical networks. IEEE Opt. Commun. Netw. **5**(8), 836–847 (2013)
7. Gringeri, S., Basch, B., Shukla, V., Egorov, R., Xia, T.J.: Flexible architectures for optical transport nodes and networks. IEEE Commun. Mag. **48**(7), 40–50 (2010)
8. Tanaka, T., Hirano, A., Jinno, M.: Advantages of IP over elastic optical networks using multi-flow transponders from cost and equipment count aspects. Opt. Express **22**(1), 62–70 (2014)
9. Adams, M.: ROADM and wavelength selective switches (white paper). JDSU (2007)
10. Noell, W., Clerc, P.-A., Dellmann, L., Guldimann, B.: Applications of SOI-based optical MEMS. IEEE J. Sel. Top. Quantum Electron. **8**(1), 148–154 (2002)
11. Shalmany, N.A., Rahbar, A.Gh.: On the choice of all-optical switches for optical networking. In: High Capacity Optical Networks and Enabling Technologies, pp. 1–8 (2007)
12. Eramo, V., Listanti, M.: Performance analysis of opical packet switches equipped with multicast wavelengths converters. IEEE Opt. Commun. Netw. **5**(2), 82–96 (2010)