The Influence of Energy Saving Strategy on Loss Probability in 3-stage Clos Switching Network

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***Abstract*—This article discusses the influence of an effective energy management strategy in nodes of elastic optical networks on the loss probability for calls of individual traffic classes. The structure of the network node is based on the architecture of a 3-stage optical Clos switching network. A key feature of the energy management strategy consists in switching off unused switches of the middle stage of the switching network.**

Keywords–Optical switching network; Energy saving; Loss probability; Clos switching network.

I. Introduction

Backbone networks are comprised of multiple facilities that transmit large amounts of data between the network access points over long distances through interconnected smaller networks, such as local or metropolitan networks. Typically, backbone networks offer large transmission speeds. For example, one fiber optic link is capable of transporting up to 560 channels in a C-band or 360 channels in the L-band. The possibility of effective use of such a large number of available channels to achieve high bitrates (along with different bitrates depending on different demands by users) is provided by a successful implementation of the concept of Elastic Optical Networks [1]–[3]. For competitive provision of services with high bitrates backbone networks demand huge amounts of energy necessary for sustainable transmission of signals in the optical fiber. The bulk of network devices that serve as backbone network nodes are designed with the assumption that traffic offered to inputs of devices has constant value. The reality is, however, that this traffic is changeable in time. This, in turn, leads to a situation where the system does not need as much network resources to service a given traffic intensity. When this is the case, constant power supply to all elements of a device/network node is not necessary. With the application of an appropriate energy management strategy, that can be based on temporary disabling of elements of active network nodes, we are in position to decrease the amount of supplied energy to devices when traffic load offered to them is slight). Then, in a situation where network traffic offered to the nodes increases, additional active elements of a device can be activated.

The issues of energy saving in network devices, as well as in systems/elements used in constructing nodes of the network are highly topical, while the increasing number of relevant publications that have been published over the years clearly testifies the interest in this innovative field [4]–[9].

In this article, the authors show the influence of the applied energy management strategy in a 3-stage Clos switching network on the loss probability for calls in this network. The structure of a large number of present-day network devices that serve as network nodes is based on the Clos structure. The investigated energy-saving management strategy will be based on switching-off individual switches of the middle stage in a 3-stage Clos switching network. Then, the influence of the number of active switches of the middle stage of the optical network on the values of loss probabilities for individual call classes that are offered to the network will be investigated.

The article is structured as follows. Section 2 presents the method for allocating network resources in elastic optical networks and proposes a definition of the frequency slot unit. Section 3 discusses the structure of the optical switching network and the structure of traffic offered to the network and presents a description of the path choice algorithm used to find an optimal sequence of choices to reach a certain connection in optical switching networks. Section 4 includes a description of the simulator (input data, simulation algorithm and the condition of termination). Section 5 shows the results of the simulation experiments for the optical switching networks in which the switches of the middle stage were switched off. Section 6 concludes the article.

II. Elastic Optical Networks

According to the information given in [2], fixed and flexible Dense Wavelength Division Multiplexing (DWDM) frequency grids are available. The advantage of the flexible grid architecture, that forms the basic underlying structure for Elastic Optical Networks (EON), is the possibility of using elastic allocation of network resources. The optical spectrum (e.g., C-band or L-band optical spectrum) available for EONs is divided into frequency slots with fixed spectral width equal to 12.5 GHz [2]. In thus defined slots optical connections are allocated, while the number neighboring frequency slots occupied by them depends on the demanded bitrate and on the applied modulation technique. According to the elastic frequency grid, standardized by the ITU-T [10], channel bands are allocated following a given nominal center frequency f_{nom} and the channel width ω which is the multiple of 12.5 GHz:

$$\omega = 12.5 \times m, \tag{1}$$

where m is a positive integer number, whereas 12.5 GHz is the so-called Frequency Slot Unit (FSU) [11]. The center frequency for particular channels (slots) is determined on the basis of the following formula:

$$f_{\text{nom}} = 193.1 + n \times 0.00625, \tag{2}$$

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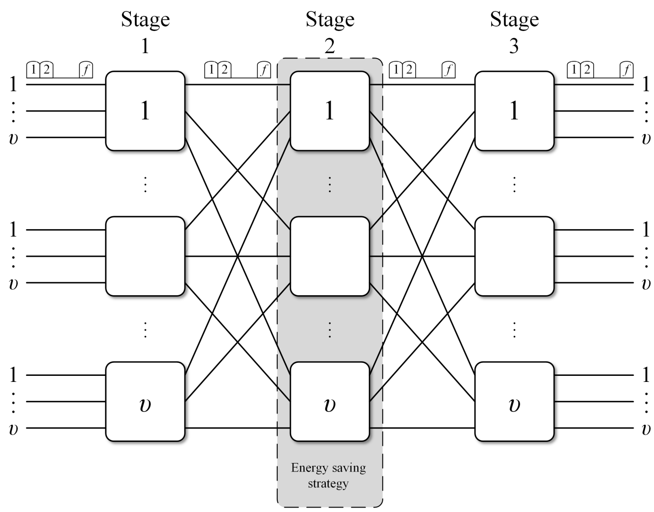

Figure 1. Structure of 3-stage optical Clos network

where n is an integer number, whereas 0.00625 is a fixed frequency shift, expressed in THz. To sum up, in order for an optical channel to be created in an EON network, beside the allocation of the value of the central frequency f_{nom} (similarly as in the allocation of wavelength in Wavelength Division Multiplexing (WDM)), the spectrum ω occupied by it should be also allocated.

III. STRUCTRURE OF SWITCHING NETWORK

A. Structure of 3-stage optical Clos network

Figure 1 shows a 3-stage Clos switching network. The network is composed of square $\upsilon \times \upsilon$ switches. The switches of the first and third stages make it possible for both the frequency slot (wavelength) and the output of a switch (optical fiber) to be changed, whereas the switches of the middle stage allow a change to be introduced in the output only. Each link in the switching network has the capacity equal to f FSUs. In addition, one link from each of the switches of the last stage belongs to one of υ directions. The energy management strategy introduced in the switching network allows us to switch off unused middle stage switches.

B. Structure of offered traffic

The switching network (Figure 1) is offered m independent Erlang call streams with the intensities: $\lambda_1, \lambda_2, ..., \lambda_i, ..., \lambda_m$. The demanded FSUs related to particular traffic classes are: $t_1, t_2, ..., t_i, ..., t_m$, respectively. Service times for calls of all classes have exponential distributions with the parameters: $\mu_1, \mu_2, ..., \mu_i, ..., \mu_m$.

C. Path choice algorithms

Two algorithms for the point-to-group and point-to-point connection path choice can be used in the switching network. One of the two path choice algorithms in the switching network should be selected prior to the activation of the simulation program.

The point-to-group algorithm performs the following steps [12]:

Step 1: The counter of the attempts of setting up a connection is set to $l = 1$.

Step 2: Determination of the switch of the first stage at the input of which a call of class i appeared.

Step 3: Finding the switch of the last stage that has a free output link and has t_i free (consecutive) FSUs in the demanded direction. If none of the switches of the last stage have free t_i FSUs in the demanded direction, the call is lost due to the external blocking. In the instance where there are more than one switch of the last stage that have a free output link in the demanded direction, one of them is chosen randomly.

Step 4: An attempt to set up a connection between the selected switch of the first and last sections.
- ◦ If successful – the connection is set up. The operation of the algorithm is terminated. When there are more than one connection paths between the switches of the first and third stages, then one connecting path is chosen randomly.
- ◦ If unsuccessful, and the counter of attempts is $l < \upsilon$, the algorithm returns to Step 3 and the number of attempts is increased $l = l + 1$.
- ◦ If unsuccessful, and the counter of attempts is $l = \upsilon$, the call is lost due to the internal blocking. The operation of the algorithm is terminated.

The point-to-point algorithm works as follows [13]:

Step 1: Determination of a switch of the first stage at the output of which a call of class i appeared.

Step 2: Finding a switch of the last stage that has a free output link and has t_i free (consecutive) FSUs in the demanded direction. If none of the switches of the last stage have free t_i FSUs in the demanded direction, the call is lost due to the external blocking. In the case where more than one switch of the last stage have a free output link in the demanded direction, one of them is chosen randomly.

Step 3: An attempt to set up a connection between the selected switches of the first and last stages.
- ◦ If successful – the connection is set up. The operation of the algorithm is terminated. When there are more than one connection paths between the switches of the first and third stages, then one of them is selected randomly.
- ◦ If unsuccessful, the call is lost due to internal blocking. The operation of the algorithm is terminated.

IV. OPERATION OF THE SIMULATION PROGRAM

A. Input data

The simulator was written by the authors in C++ language using process interaction method. The input data for the simulator are the capacity and structure of the switching network. For each traffic class, the number of demanded FSUs and service time are given. The average value of traffic offered to a single FSU in the system is also given. To perform simulation tests in the switching network composed of the switches with $\upsilon \times \upsilon$ links in which the capacity of a single link is f FSUs, the values of the following parameters are to be introduced:

- the number m of offered traffic classes,

- the number t_i of demanded FSUs necessary to set up a connection of class i and average service time μ_i^{-1} for a call of class i,
- average traffic a offered to a single FSU in the output direction,
- the number of first-stage, middle-stage and last-stage switches.

On the basis of these parameters, the intensity λ_i of calls generated by sources of a given type of traffic stream can be determined in the simulator. Therefore, the parameter λ_i, depending on the average traffic offered to a single FSU, can be determined on the basis of the following formula:

$$\sum_{i=1}^{m} \lambda_i/\mu_i t_i = af\upsilon\upsilon. \qquad (3)$$

The parameter determined on the basis of Formula (3) can be treated as the exponential distribution parameter that describes the process of the occurrence of new calls of individual traffic classes.

B. General simulation algorithm

The general algorithm according to which the simulation program is performed can be illustrated in the following steps that are in line with the process interaction method:

Step 1: Initial configuration of a simulation model – creation of a list of all sources generating calls of different traffic classes.
Step 2: Resetting the count of system time to zero.
Step 3: Activation of traffic sources and placement of events (*occurrence of a new call*) in the list.
Step 4: Checking the condition of termination for the simulation. If the condition of termination is satisfied, the simulation is terminated and the results are stored in a file.
Step 5: Updating system time to the time of the occurrence of the first event from the list (*occurrence of a new call, termination of call service*).
Step 6: Execution of the first event from the list.
Step 7: Removal of the first event from the list and return to Step 4.

Two events are then identified and defined for the switching network simulation model: *occurrence of a new call* and *termination of call service*. According to the process interaction method these events are serviced by one function. Thus described approach allows us to define a large number of traffic classes in the system.

Consider then a system in which m Erlang traffic classes have been defined. In the initial configuration of the system, it is necessary to plan (predict) the occurrence of a call of class i. The function that executes events related to Erlang traffic sources for the point-to-point selection (in the case of the point-to-group selection step 2(b) has to be repeated for each free link of the demanded output direction, if the earlier attempt failed to execute the connection) can be described as follows:

Step 1: Planning (prediction) of the occurrence of a new call of class i according to exponential distribution, where the parameter is the intensity λ_i. Placement of the event in the list.
Step 2: Checking if the system has enough resources for the call to be admitted for service:
 a) Checking if any of the links in the demanded output direction have at least t_i free (neighboring) FSUs. If not - the call is lost due to the external blocking.
 b) Checking if there is a connecting path between the input link at which a call has occurred and an output link in the demanded output direction that has at least t_i free (consecutive) FSUs, where free FSUs are meant to be finding the same frequency slots between switches of the first and the second stages and switches of the second and the third stages. If not – the call is lost due to the internal blocking.

 If any of the conditions a) or b) are not satisfied, the next steps are not executed.
Step 3: Occupancy of the resources demanded by a call of class i.
Step 4: Planning of the termination of service according to the exponential distribution, where the parameter is the intensity λ_i. Placement of the event in the list.
Step 5: Service termination and release of resources.

C. The condition of termination in the simulation

The condition of termination for the simulation experiment is, with a determination of the loss probability, the counted appropriate number of generated calls of the least active class (typically, it is the class with the highest number of demanded FSUs). The mean result is calculated on the basis of 5 series. In practice, to obtain 95%-confidence intervals of not more than 5% of the mean value of the results obtained on the basis of simulation experiments, about 1,000,000 calls of the least active class are necessary to be generated. Confidence intervals are determined in the following way:

$$\left(\bar{X} - t_\alpha \frac{\sigma}{\sqrt{r}}; \bar{X} + t_\alpha \frac{\sigma}{\sqrt{r}}\right) \qquad (4)$$

where $\bar{X}$ is the arithmetic mean calculated from r results (simulation courses), t_α is the value of the *t*-Student distribution for $r-1$ degrees of freedom. The parameter σ that determines standard deviation is calculated from the following formula:

$$\sigma^2 = \frac{1}{1-r}\sum_{s=1}^{r} x_s^2 - \frac{r}{r-1}\bar{X}^2, \qquad (5)$$

where x_s is the result obtained in the s-th course of the simulation.

V. Results

The simulator makes it possible to investigate switching networks with any number υ of inputs/outputs in a single switch and any number υ of outer-stage and arbitrary number of middle-stage switches in the switching network.

The number of demanded FSUs necessary to set up a connection of individual traffic classes not only depends on the required transmission speed, but also on the type of applied modulation format or range. For example, using the data given in [3], Table I shows the number of FSUs demanded by calls of traffic classes in relation to the type of modulation and range.

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TABLE I. NUMBER OF FSUs IN DIFFERENT CONNECTIONS DEPENDING ON REQUIRED BITRATES AND MODULATION FORMAT [3].

Number of FSUs	Bitrate (Gb/s)	Maximum distance (km)	Modulation format
1	40	685	64-QAM
1	40	1024	32-QAM
1	40	1677.9	16-QAM
2	40	2585.2	QPSK
2	100	546	64-QAM
2	100	847.2	32-QAM
3	100	1342.5	16-QAM
5	100	2007.3	QPSK
3	160	475	64-QAM
4	160	756.5	32-QAM
4	160	1170.5	16-QAM
8	160	1710.9	QPSK
7	400	335	64-QAM
8	400	579.6	32-QAM
10	400	835.1	16-QAM
20	400	1133	QPSK
10	600	274	64-QAM
12	600	501.4	32-QAM
15	600	686.7	16-QAM
30	600	877.3	QPSK

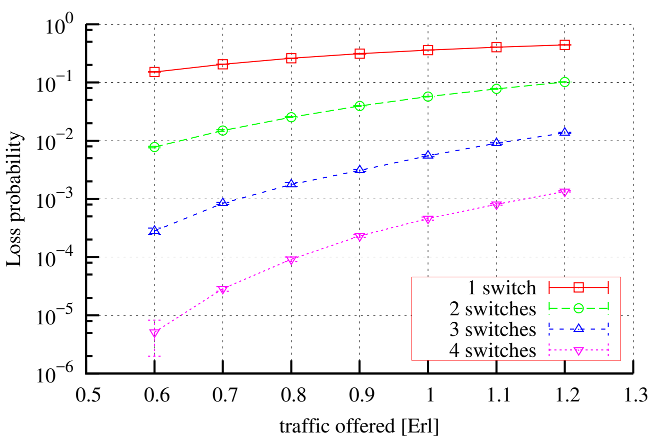

Figure 2. Loss probability for class 1 calls in System 1 with point-to-group selection and given number of middle stage switches

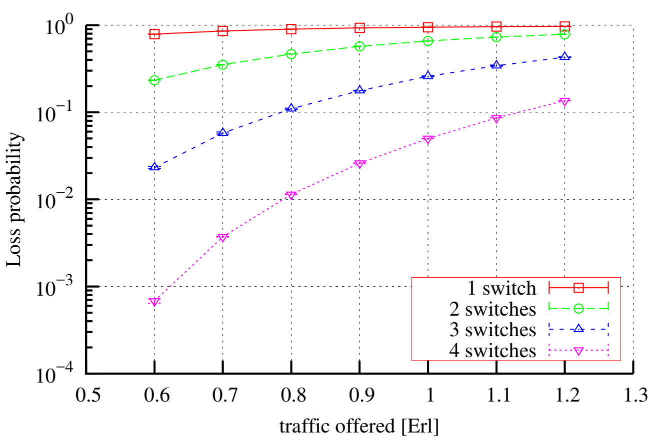

Figure 3. Loss probability for class 2 calls in System 1 with point-to-group selection and given number of middle stage switches

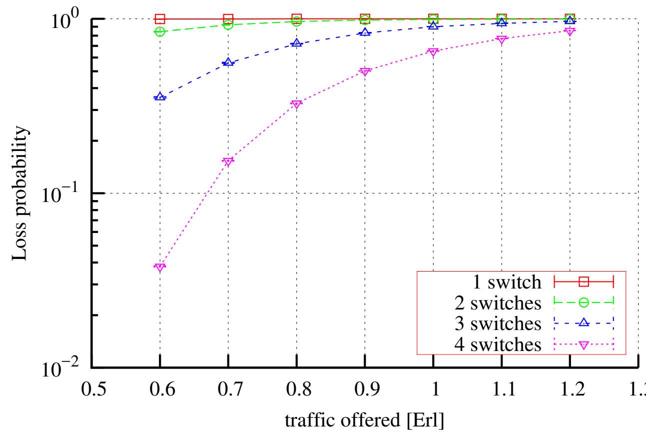

Figure 4. Loss probability for class 3 calls in System 1 with point-to-group selection and given number of middle stage switches

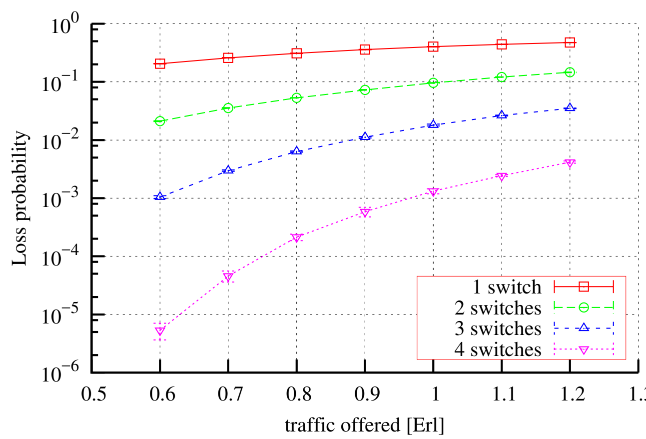

Figure 5. Loss probability for class 1 calls in System 2 with point-to-point selection and given number of middle stage switches

The findings presented in the article represent data referring to the investigations related to the influence of applied energy saving strategy in optical switching networks on the loss probability in individual call classes offered to the network. The following systems were investigated:

System 1:
- Structure of offered traffic: $t_1 = 5$ FSUs, $\mu_1^{-1} = 1$, $t_2 = 10$ FSUs, $\mu_2^{-1} = 1$, $t_3 = 20$ FSUs, $\mu_3^{-1} = 1$,
- Structure of switching network: $\upsilon = 4$, $f = 120$ FSUs,
- Path choice algorithm: *point-to-group*.

System 2:
- Structure of offered traffic: $t_1 = 4$ FSUs, $\mu_1^{-1} = 1$, $t_2 = 8$ FSUs, $\mu_2^{-1} = 1$, $t_3 = 12$ FSUs, $\mu_3^{-1} = 1$,
- Structure of switching network: $\upsilon = 4$, $f = 120$ FSUs,
- Path choice algorithm: *point-to-point*.

Figures 2-7 show the results for the loss probabilities in relation to traffic a offered to a single FSU in the switching network for individual traffic classes. In each of the figures the results for a different number of switches of the middle stage (from the minimum number 1 to the maximum number $\upsilon = 4$)

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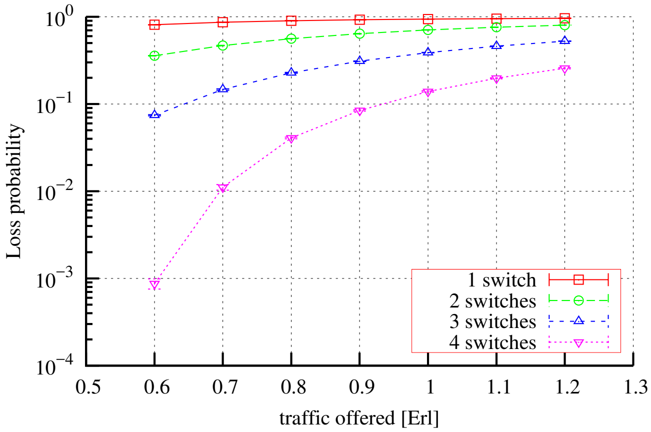

Figure 6. Loss probability for class 2 calls in System 2 with point-to-point selection and given number of middle stage switches

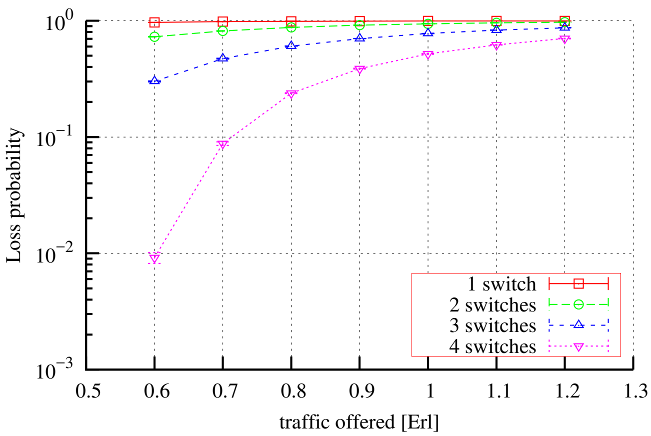

Figure 7. Loss probability for class 3 calls in System 2 with point-to-point selection and given number of middle stage switches

are indicated with a separate line in the graph. Figures 4 and 7 show the loss probability for the classes that demand the highest number of FSUs to set up a connection. It is easily noticeable that with a decrease in the number of switches of the middle stage to 3, the loss probability increases significantly. A different situation occurs with the case of the classes that demand the least number of FSUs (Figures 2 and 5). Here, switching off one or two switches in the middle stage is obviously followed by an increase in the loss probability, even though the obtained values for low loads of the system are still acceptable from an engineering point of view. Decreasing the number of middle stage switches has less impact on the increase in the blocking probability for classes requiring a smaller number of FSUs. For classes requiring a larger number of FSUs, the impact is already significant.

VI. Conclusion

This article presents the results of a study on the influence of energy management strategies on the loss probability in optical Clos switching networks. The simulation program presented in the article makes it possible to determine the loss probability in optical switching networks to which Erlang traffic is offered. The program can be applied to evaluate and assess when and with what load switches of the middle stage can be switched off in order to save energy. In future, the program can be used to verify analytical models of elastic optical switching networks in which an energy saving strategy is used.

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References

[1] W. Kabaciński, M. Michalski, R. Rajewski, and M. Żal, "Optical datacenter networks with elastic optical switches," in: IEEE International Conference on Communications (ICC), pp. 1-6. Paris 2017. doi:10.1109/ICC.2017.7997410

[2] X. Yu et al., "Migration from fixed grid to flexible grid in optical networks," in: IEEE Communications Magazine, vol. 53, no. 2, pp. 34-43, Feb. 2015. doi:10.1109/MCOM.2015.7045389

[3] C. T. Politi et al., "Dynamic Operation of Flexi-Grid OFDM-based Networks," Optical Fiber Communication Conference and Exposition, Los Angeles, CA, March 2012, pp. 1-3

[4] R. S. Tucker, "Scalability and Energy Consumption of Optical and Electronic Packet Switching," in Journal of Lightwave Technology, vol. 29, no. 16, pp. 2410-2421, Aug.15, 2011. doi: 10.1109/JLT.2011.2161602

[5] S. Zhang, W. Hu, W. Sun, and H. He, "Optimizing electrical power consumption in SOA based optical packet switching nodes," Asia Communications and Photonics Conference and Exhibition (ACP), Shanghai, 2011, pp. 1-6. doi: 10.1117/12.905434

[6] S. Aleksić, "Analysis of Power Consumption in Future High-Capacity Network Nodes," in IEEE/OSA Journal of Optical Communications and Networking, vol. 1, no. 3, pp. 245-258, August 2009. doi: 10.1364/JOCN.1.000245

[7] V. Eramo, A. Germoni, A. Cianfrani, M. Listanti, and C. Raffaelli, "Evaluation of Power Consumption in Low Spatial Complexity Optical Switching Fabrics," in IEEE Journal of Selected Topics in Quantum Electronics, vol. 17, no. 2, pp. 396-405, March-April 2011. doi: 10.1109/JSTQE.2010.2053350

[8] H. Yu, J. Zhang, M. Tornatore, and Y. Ji, "Energy-Efficient Lightpath Reconfiguration in a Decomposed-AWGR-Based Passive WDM Fronthaul," European Conference on Optical Communication (ECOC), Rome, 2018, pp. 1-3. doi: 10.1109/ECOC.2018.8535445

[9] C. Lea, "A Scalable AWGR-Based Optical Switch," in Journal of Lightwave Technology, vol. 33, no. 22, pp. 4612-4621, 15 Nov.15, 2015. doi: 10.1109/JLT.2015.2479296

[10] ITU-T Recommendation G.694.1. Spectral Grids for WDM Applications: DWDM Frequency Grid. Interna-tional Telecommunication Union – Telecommunication Standardization Sector (ITU-T) 2012.

[11] W. Kabaciński, M. Michalski, and R. Rajewski, "Strict-Sense Nonblocking W-S-W Node Architectures for Elastic Optical Networks," in Journal of Lightwave Technology, vol. 34, no. 13, pp. 3155-3162. July 1, 2016. doi:10.1109/JLT.2016.2560624

[12] M. Głąbowski and M. Sobieraj, "A Modified Method for Point-to-Group Blocking Probability Calculation in Switching Networks with Call Admission Control Mechanisms," in 11th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), pp. 1-6. July 18-20, 2018, Budapest, Hungary. doi:10.1109/CSNDSP.2018.8471832

[13] M. Głąbowski and M. Sobieraj, "Modified Direct Method for Point-to-Point Blocking Probability in Multi-service Switching Networks with Resource Allocation Control," in Quality, Reliability, Security and Robustness in Heterogeneous Systems : 14th EAI International Conference, Qshine, pp. 109-118. December 3-4, 2018, Ho Chi Minh City, Vietnam.