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Modelling and Simulation Analysis of Routing Algorithms in Multichannel Optical Communication Networks

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Abstract: In this paper, it is considered the broadband backbone optical networks with wavelength routing and circuit switching used to build long-range wide area networks. In this type of network, if there is an available and acknowledged connection request, it is necessary to determine the optimal path between the optical communication nodes in the network. This also requires the assignment of an optimal set of wavelengths along the selected route between these nodes. This paper takes into account the multichannel optical communication networks with spectral multiplexing. Four different routing algorithms are modeled and analyzed for which their weight functions are determined to take into account various factors, such as the total distance of the individual routes, the total number of available wavelengths for a given route and how many of them are available for use. It is studied and compared the performance of the proposed algorithms in a multichannel optical network in terms of blocking probability.

Keywords: multichannel network, spectral multiplexing, blocking probability, routing algorithms, weight functions.

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1. Introduction

The multichannel optical communication networks with spectral multiplexing combine the advantages of high-speed single-channel optical networks and signal multiplexing in classic communication networks. [1, 2]

This paper examines an optical wavelength routing network. The routers in the network have the ability to convert the wavelength, which allows them to convert data from one input wavelength to another output wavelength in a given operating optical range. The physical device and the state of the network determine the range to which the wavelengths can be converted (in whole or in part). [2, 3, 7]

In this paper, a channel-switching model, where a transmission path is set for the entire duration of a session, will be considered as an example. The set of connections through the intermediate nodes from start to end point determines the transmission path with the wavelength specified for each connection. When the wavelength conversion option is not available on the network, its continuity is mandatory - this means that the same wavelength is used for all consecutive connections. [4,6]

In order to build a transmission path, a route and wavelength decision must be made. Given the existence of a set of connections, the problem of establishing a transmission path by routing and setting the wavelength for each connection has gained popularity in the literature as a routing and wavelength-assignment (RWA) problem [6-8]. One of the main parameters of interest in the analysis of this problem is the blocking probability (due to lack of free wavelength) [9, 10].

The main purpose of this work is to analyze and investigate the blocking probability using four different routing algorithms through modeling and simulation analysis of a multichannel optical communication network.

2. Routing algorithms based on the shortest path

One of the main tasks is to determine the path from the start node to the end node, which is with the shortest length, using a certain algorithm and a given wavelength which is the responsibility of the medium access control protocols [3,7].

Each path in the network could be unambiguously defined with specific weight functions. Specific information for a multi-channel optical network can be incorporated into these weight functions to improve performance. They must take into account the number of wavelengths that are available for use and the total number of wavelengths for a certain path.

The model of formation and establishment of a transmission path (Figure 1) when requesting a session is based on a routing method depending on the status of the transmission lines. Here each router sends periodically to all other routers information about its adjacent lines. This amount of data is used to learn the network topology with the corresponding weight functions of the lines.

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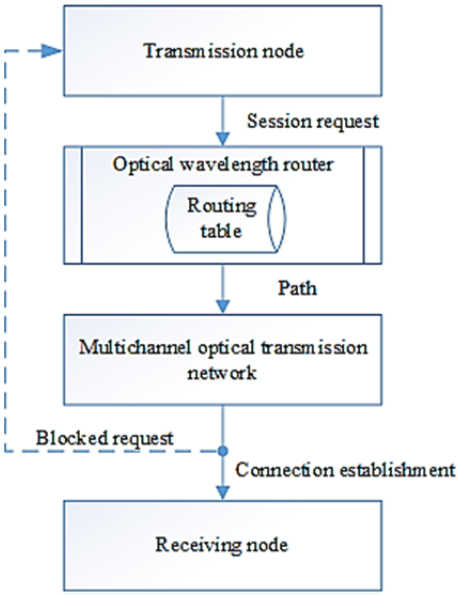


Fig. 1. Model of formation and establishment of transmission path when requesting a session.

Hereupon each router could calculate independently the shortest path connecting it to each available destination, forming a routing table.

When a session request is received, the router determines the shortest path based on the existing records in its routing table, and this is repeated in each network node along the entire path from the source to the destination. The router then assigns a specific wavelength for the given path and declares its assignment to all routers on that path.

The initial choice of wavelength can be random or based on a specific rule or available information (as it is shown in [11-13], for example). If the network allows wavelength conversion, then the transmission path is established by determining and assigning different wavelengths in the different lines along the path. If this request cannot be fulfilled, another wavelength should be selected, which can be determined by feedback from the nearest node on the selected path. It is necessary to find at least one free wavelength by repeatedly performing this process. If not, then this request is blocked, i.e. transmission path cannot be built.

3. Routing algorithms and weight functions for multichannel optical networks

A graph $G(V,E)$ can be used to represent the network topology, where V represents the set of vertices (network nodes) and E – the set of edges (lines) [15-17]. Each connection $(i, j) \in E$ is uniquely defined by a weight function w_{ij} that represents the cost of using the line. The implementation of the shortest path algorithm ends when each router has recorded in its routing table information about the full range of possible paths to each destination.

In multichannel optical networks, the line status information will contain specific parameters that include the total number of wavelengths and the number of available ones [11,13]. Furthermore, lines along which the available wavelengths are already utilized can be tagged as unusable until the next refresh of the table. Weight functions considering these factors are described below.

For a given connection $(i, j) \in E$, λ_{ij}^a denotes the number of available wavelengths in a line when line status information is collected, λ_{ij}^T is the total number of wavelengths in a line, d_{ij} is metrics equivalent to the physical distance or propagation delay.

Four algorithms for calculating weight functions (w_{ij}) will be considered and modeled here:

3.1. Based on the number of hops (NHWF)

The hop refers to the transition from one node to another. The shortest distance between two nodes in the hops will give the number of transitions required to pass the packet from the starting node to the final one. A basic case is presented where $w_{ij} = 1$ and $\forall \in E$. Through this function, the shortest path selection is based on the smallest number of hops.

3.2. Based on the distance (DWF)

Here, $w_{ij} = d_{ij}$ and $\forall \in E$. d_{ij} represents the physical distance by the equivalent propagation delay, expressed in microseconds (ie, the propagation time). This function will select the shortest path with the least propagation delay.

3.3. Based on the available wavelengths (AWWF)

The weight function w_{ij} is defined as:

$$w_{ij} = \begin{cases} -\log\left(1 - \dfrac{1}{\lambda_{ij}^a}\right), & \lambda_{ij} > 1, \ \forall (i,j) \in E \\ 1, & \lambda_{ij} = 1, \ \forall (i,j) \in E \end{cases} \quad (1)$$

where $1/\lambda_{ij}^a$ is the reciprocal of the number of available wavelengths in the line, i.e. it models the possibility of the line to reject session establishment. This parameter will be as small as the number of available wavelengths is greater. Therefore $\left(1 - \dfrac{1}{\lambda_{ij}^a}\right)$ determines the probability of line to accept the session request. The purpose is to maximize this probability. This metric ignores the physical distance as well as the number of hops and it has a dynamic weight function which will change when the network status changes.

3.4. Based on the total number of wavelengths and the available wavelengths (TAWWF)

The weight function w_{ij} is defined as:

$$w_{ij} = -\log\left(1 - \left(1 - \frac{\lambda_{ij}^a}{\lambda_{ij}^T}\right)^{\lambda_{ij}^a}\right), \ \forall (i,j) \in E \quad (2)$$

where λ_{ij}^a and λ_{ij}^T are respectively the number of available wavelengths and the total number of wavelengths. $p^{\lambda_{ij}^a}$ determines at a given time what is the

probability that all wavelengths will be utilized, where p is the probability that the wavelength will be utilized. For a given status, the probability can be calculated as:

$$p = \left(1 - \frac{\lambda_{ij}^{a}}{\lambda_{ij}^{T}}\right) \quad (3)$$

4. Results

The algorithms presented above were modeled in MATLAB environment. An analysis of their behavior in multichannel optical networks was performed by simulation testing. Because these types of networks are with losses, system failure may occur due to a lack of resources. In this type of network, multiple paths share the same lines. The developed model makes it possible to find an answer to how different paths with different traffic utilization interact and what is the blocking probability for each of the given paths. The module offers functions for calculating the blocking probability for different types of networks: a network with, without, and with a partial redistribution of wavelengths. Scripts are also available to define the network structure (user-defined and randomly generated) and traffic matrices. The purpose of the study is to use the weight function modeling approach to determine the total network load, to compare the network performance using the different routing algorithms, and to determine the blocking probability in these cases.

4.1. Input parameters

By using the developed m-functions, a network topology with 20 nodes. This topology is arbitrarily generated and the maximum number of wavelengths/ channels varies between 8, 16 and 40 at the 1550 nm band. Network traffic is modeled by a number of requests for transmission from the source to the final destination. The received transmission requests in each optical node is modeled with a Poisson distribution with an average of λ connection requests per unit time. The transmission duration is modeled with an exponential distribution with an average value of 3 units of time.

The system parameters that are variable are as follows:

- L – the total number of wavelengths for each line;
- λ – the intensity of transmission requests at each node;
- γ – wavelength conversion factor – it is determined based on what part of the total number of wavelengths can be converted for a node.

When there is no wavelength conversion, it is denoted as $\gamma = 0$, while $\gamma = 1$ indicates a complete conversion of the wavelengths. If the value is between 0 and 1, this indicates a partial wavelength conversion.

The parameters to be evaluated are the following:

- P – the blocking probability (that the transmission request will be rejected/ blocked due to the lack of transmission path or available wavelength);
- U – the link utilization (it is determined by the time during which all network lines are utilized);
- D – average delay (the average traffic delay per session; it includes the sum of the mean values of the propagation delay and the wavelength conversion delay in the intermediate optical nodes.

All simulations were performed for two different values of the total number of wavelengths/channels per line, 8 and 16, respectively.

4.2. Blocking probability (P) analysis

Figures 2 to 5 present the results of the dependence of the blocking probability a function of traffic per node for a total number of 8 and 16 wavelengths/channels and respectively at two different values of the wavelength conversion factor $\gamma = \{0.5, 1.0\}$. The results are presented for each of the routing algorithms considered: NHWF, DWF, AWWF, and TAWWF.

The NHWF algorithm minimizes the number of hops in the selected route. It gives the best results in terms of the minimum value of the probability of blocking

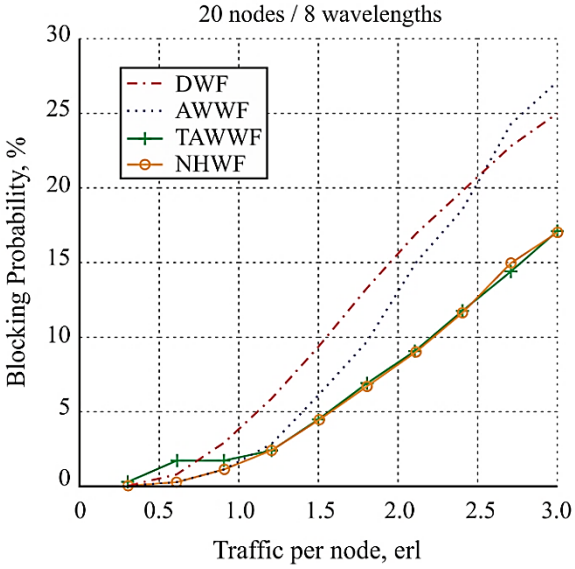


Fig. 2. Dependence of the blocking probability as a function of the traffic per node at $\gamma = 0.5$ and 8 wavelengths/channels.

The DWF algorithm provides relatively poor performance since the shortest path only takes into account the distance as a factor. If there are several different paths between two nodes, the path with fewer hops is assumed to provide a better result. The reason is that the probability of blocking will increase as the number of lines along which an available wavelength is found is increased.

The results of the AWWF algorithm are also relatively poor. This is due to the fact that AWWF chooses longer paths since the number of available wavelengths decreases for shorter paths.

The results of the TAWWF algorithm are nearly identical to those of the NHWF when the traffic load is above average to high.

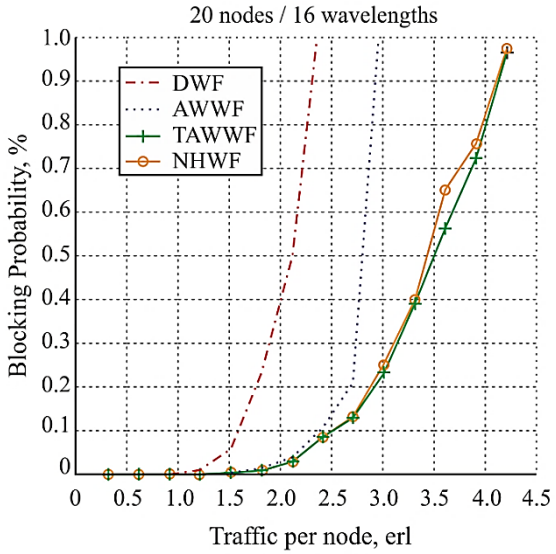


Fig. 3. Dependence of the blocking probability as a function of the traffic per node at γ = 0.5 and 16 wavelengths/channels.

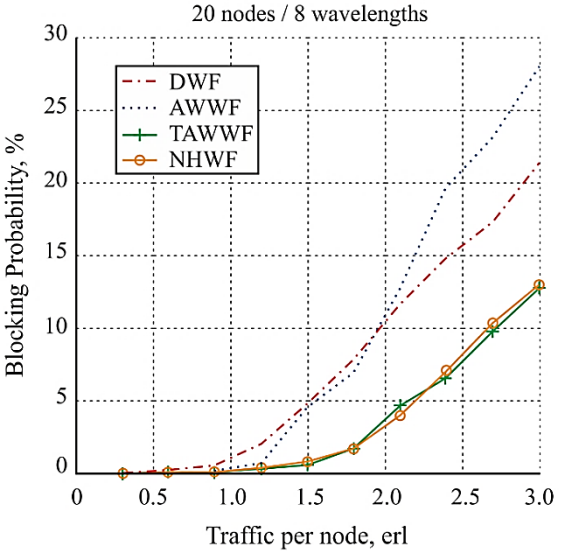


Fig. 4. Dependence of the blocking probability as a function of the traffic per node at γ = 1.0 and 8 wavelengths/channels.

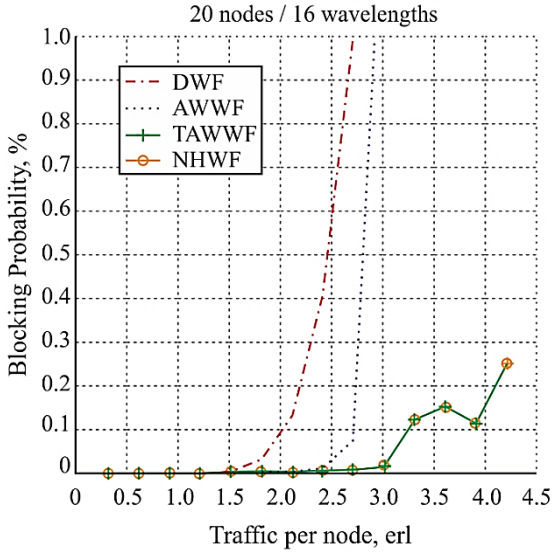


Fig. 5. Dependence of the blocking probability as a function of the traffic per node at γ = 1.0 and 16 wavelengths/channels.

The reason is that this weighting function attempts to select the connections which are least utilized and have the largest number of available wavelengths.

The probability of blocking is slightly lower for full wavelength conversion (Figures 4 and 5) compared to partial conversion at γ = 0.5 (Figures 2 and 3). It is noticed that the probability of blocking increases sharply after a certain threshold value of the traffic load, which is exactly as expected. The total probability of blocking decreases at a large total number of wavelengths.

5. Conclusion

A major problem with multi-channel communication networks with spectral multiplexing lies in the efficiency of the methods, algorithms, and protocols on the basis of which the access of network nodes to the transmission medium is managed as well as the processing of session requests and the routing of transmitted data packets.

A model for determining the blocking probability in multichannel optical networks is defined. Determining the shortest path is performed using algorithms with different weight functions that take advantage of the characteristics of the multi-channel network in different ways, i.e. different routing options are modeled on the network.

The weight functions in the model take into account the total number of wavelengths as well as the given number of wavelengths available at a time for s different links through a given path.

Various weight functions and obtained results are considered in terms of probability of blocking, line utilization, and average delay. The analysis shows that the weight functions based on the smallest number of hops and in combination with the available wavelengths and the total number of wavelengths produces the best results in terms of probability of blocking.

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