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Utilization Balancing Algorithms for Dynamic Multicast Scheduling Problem in EON

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Abstract—**Dynamic data transfer demands are often being a challenge for present communication networks, as they appear in unpredictable time and must be satisfied prior to deadline. Important kind are the multi-target demands occurring in task of replication, backup, database synchronization or file transferring in pear-to-pear networks. Optimal scheduling usually depends of the nature of transport network. In the paper dynamic deadline-driven multicast scheduling problem over elastic optical network is considered. Particularly, the method for improving link utilization by traffic balance for multicast demands is proposed. Few heuristic algorithms and results of experiments, proving the benefits of balancing concept are presented**

Keywords—**elastic optical network, multicast, load balancing, flow assignment, dynamic scheduling, heuristic algorithms**

I. INTRODUCTION

DATA traffic in present networks in notable part is unpredictable and impossible to plan in advance. User demands are generated at random time, they characterize with random targets and data rates. Although the data transfer in data centres and between data centres is usually more predictable, some services also generate incalculable transfer demands, which in many cases are multicast demands. An excellent example is the synchronization process along replicas. Synchronization logs are being pushed from one replica to others, when the log buffer on replica becomes full [1], e.g. in result of users operation. Synchronization interval and amount of data to send depends on unruly operation of many users on all replicas. During synchronization servers usually are put into the ‘off’ state and services are suspended. That is why the whole process should be completed before the fixed time in order to start the services again as soon as possible. Another examples of deadline-driven dynamic multicast demands are multi-target backup, data or virtual machine migration to multiple destinations, software updates distribution (or anti-malware updates distribution) and others.

Data transfer requires some network resources (like bandwidth, spectrum, time window), that must be reserved in the transport network. Due to unpredictable character, dynamic data transfers may cause planning problems for network administrators.

In this work elastic optical network (EON) as a transport layer is considered. EON architecture is being found as a future solution for optical networks [2]. It assumes division of optical spectrum into slots (called also slices) of 6.25 GHz width [3]. Optical channels are built of continuous blocks of even number of slices. The main physical components, allowing to divide spectrum into slices are bandwidth-variable transponders and wavelength cross connects (WXCs) [4]. The advantage of EONs is the elasticity of choosing spectrum width for optical channel – unlike in traditional WDM networks, any multiple of 12.5 GHz may be used. Then, optical channel capacity may be better suited to required bandwidth, what minimize the wasting of spectrum and allows to optimize usage of optical resources [5].

The paper relates to the problem of dynamic multicast traffic optimization in EON based communication network. The optimization task is to assign the route, spectrum and time window for dynamic multicast requests. Requests appear dynamically, and are not known before the time of arrival. Each of them has the given volume and strict point in time, before which must be finished (the deadline). Unlike in case of multimedia streaming, the holding time of considered demands is not determined, the necessity of complete the data transfer before deadline is the only condition. It means, that each demand may be realized with higher number of slots or/and higher modulation level in shorter time or with low bandwidth in longer time period. It is also assumed that the data transfer may be scheduled in further time, subject to the deadline, it is not obligatory to start the transfer immediately.

As it was said before, such problem formulation relates to many practical appliances other than multimedia streaming, in example to inter-datacentre multi-target backups or data archiving, replica or database synchronization, virtual machine replication, data processing in clouds, and other cases, where problem consist in sending the given amount of data, not holding connection for specified time.

In online problems, decision about allocation of demands (assigning multicast tree, spectrum range and starting time) should be taken in real time (even though demand may be finally allocated for further time period). Algorithms appropriate for this kind of problems must be able to find the time window, path and spectrum in very short time (on average before arrival of next demand). The computation time of algorithm is important criterion and time consuming optimal solutions are not useful.

Different signal modulation formats may be used over EON networks. Higher modulation format denotes the higher spectral efficiency and higher traffic rate with the same spectrum width. Possibility of use of each modulation format is limited by the distance of lightpath and the chosen bitrate – higher modulation format can be used for shorter distance and lower bitrates.

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In the previous work [6] the optimization problem of deadline-driven dynamic multicast traffic optimization has been formulated and few heuristic algorithms have been proposed. Two common methods for building the multicast tree for each demand (shortest distance and cheapest insertion) and two strategies for capacity (bit-rate) assignment (maximal capacity, resulting with shortest completion time of demand; and minimal optical channel width) were used. During experiments, it was observed, that proposed methods effect quite well, but in many cases the links in the network are utilized in unequal manner. Links belonging to 'best paths' were over-utilized, while utilization of some other links was at the minimal level. Since the multicast tree for each demand was built with the best of pre-calculated paths, it caused the situations, when demands were blocked, while free spectrum resources were available on some network links, and worse paths might be used to satisfy multicast demands.

The main contribution of the paper is the method of calculating multicast trees, assuring uniform utilization of network links for dynamic multicast traffic optimization problem in EON (ensuring traffic balancing among all network links). In the paper new algorithms based on invented method are proposed. Reported results of experiment show that those algorithms in all cases overcome previous un-balanced algorithms. Moreover, new strategy for capacity assignment in the network (best modulation strategy) is proposed and results obtained with algorithms are reported.

A. *Related Work*

The elastic optical networks (also called EON or SLICE) are more elastic and beneficial solution in comparison to traditional WDMs. In [4] the architecture, benefits and technologies for EON have been studied.

One of most important optimization problems considered for SLICE networks is routing and spectrum assignment (RSA) problem. It consists in assigning of routes and the spectrum (slots) for data transfer demands. For optical path the same spectrum (set of adjacent slots) must be allocated in all links. Two kinds of demands are being considered in literature: long-term static demands and dynamic demands. For long-term demands the given throughput between source and destination must be assured for days, months or even longer. Details of demand (source, destinations, throughput or number of required slices) are known in advance. Solution of such instances of RSA problems may be found in advance. The offline optimization methods are being used [7], heuristic solutions close to optimal, or even optimal solutions may be applied. Such problems are called EON planning problems. Optimization usually focus on optimizing the spectrum usage, number of required optical regenerators [8], ensuring path protection and network reliability [9].

Dynamic demands are usually short-term demands, lasting few minutes or hours, or just required sending given volume of data. In deadline-driven problems, for each demand the point in time, before which demand must be completed (the deadline) is given. In such instances of RSA problem (called EON provisioning), demands are not known in advance, they have unpredictable volumes and appear on unpredictable time. Allocation decisions must be made up in the real time (on-line). Solutions usually are not optimal, since the lack of knowledge about future demands and computation time restrictions. When the new demand appear and there are no network resources for allocation, demand is being blocked (rejected). The main optimization criteria considered for online RSA problems is blocking probability [7], in some cases the spectrum fragmentation is also minimized. Dynamic RSA problems for unicast and anycast demands have been considered in [10]. Few solving algorithms have been proposed. In [11] Authors present a routing, modulation and spectrum assignment algorithm for unicast traffic. They introduce an allocation method based on grouping demands with similar times of termination, enabling to reduce spectrum fragmentation and blocking probability.

Multicast RSA problem for online and offline traffic optimization in EON is investigated in [12]. For long-term multicast demands the source node, the destination nodes and the number of required frequency slots are given. For online dynamic network provisioning also arrival time and holding period for each demand is known. Authors propose the layered approach, where physical network topology is decomposed into several layered auxiliary graphs and present heuristic algorithms. Comparison of algorithms using different modulation levels for multicast RSA problem in EON is presented in [13]. The blocking probability is considered as the optimization criterion. Authors have made an simplistic assumption, that possible modulation level depends on the path length given in number of hops. Different modulation levels for multicast RSA problem have been taken into account in [14], where distance-adaptive transmission rule is applied for calculating the spectrum requirements. Other formulations of multicast transmission problems over EON may be found in [15, 16].

II. PROBLEM FORMULATION AND NETWORK MODEL

In the paper the deadline-driven dynamic RSA problem for multicast demands in elastic optical network is considered. It is assumed, that the network is built with multicast-capable switches. Different modulation formats may be used, and the length of lightpath (in km) determines admissible formats. Multicast demands requires sending the specified volume of data between source and destinations before specified time of completion. Each multicast demand it is given with the source node, the set of destination nodes, volume (in Gb), time of arrival and the time, up to which it must be completed (the deadline).

The elastic optical network is modeled as the directed graph with V nodes and E links. Each optical link is divided into slices, the number of slices accessible in each link is equal to S. According to EON architecture, continual divisions of slices with even number of slices may be used to build channels, possible sizes of channels are denoted with m=2,4,…,M slices. On each optical link, particular number of channels, depending on the size of the channels, may be built. Multicast demand d is given as a set $\{ N_d, G_d, T_d, \tau_d, h_d \}$, where N_d is the source node, G_d is the set of destination nodes ($N_d \notin G_d$), T_d is an arrival time of demand, τ_d is the deadline and h_d is the volume of demand (in Gb).

The problem consists in assignment of the multicast tree, the spectrum and the time window in order to complete each demand prior to the individual deadline. The optimization criterion is the blocking probability in the network. For the considered problem online heuristic algorithms and original method for multicast tree assignment with traffic balance assurance are proposed. In the network there are many routes (paths) between all node pairs. In the considerations it is assumed that for each pairs of nodes the set of alternative candidate paths is given, and they may be used to build multicast trees for multicast demands. Availability of trees is analysed in the context of free slots in the EON network in particular time window. Following modulation formats can be used for considered optimization problem: BPSK, QPSK, 8QAM, 16QAM, 32QAM and 64QAM. It is assumed that the discrete set of bitrates (from 10 Gb/s to 400 Gb/s, step 10 Gb/s) will be used in the networks. It is also assumed that possible modulation levels depend on the length of the longest route (from the root to the farthest destination) in the multicast tree.

III. ALGORITHMS

First, the common basic methods for generating multicast trees are presented. Then the original method for generating multicast trees with assuring balanced utilization of networks links is proposed, it is the main contribution of the paper. Finally new original strategy for choosing the spectrum for multicast demands is formulated and an heuristic algorithm based on new strategy is presented. Two previously invented algorithms are used as the reference.

A. *Multicast Trees*

Two basic methods of building multicast trees (solve the Steiner's problem) have been adapted and used: the shortest distance method [17] and cheapest insertion [17, 18].

In the shortest distance (SD) method (Algorithm 1) the multicast tree is built by the concatenation of the shortest paths between the source node and destination nodes. In experiments the sets of preliminary calculated paths between all nodes in the network were used in order to minimize the calculation time of multicast tree. Multicast tree was built for each demand *d*.

Algorithm 1. Shortest distance multicast tree [6, 17]

```
start with $MT = \{ N_d , \varnothing \}$
for each $v \in G_d$
    find shortest path $p$ between nodes $N_d$ and $v$
    add nodes and edges of $p$ to $MT$
end for
return $MT$
```

Cheapest insertion (CI) method (Algorithm 2) starts with partial multicast tree containing only the source node, then in each iteration the shortest path between any of the destination node not contained in partial tree and any node contained in partial tree is found. Algorithm terminates when all destination nodes are in multicast tree. Shortest distance method gives the shortest (in sense of physical distance in kilometers) multicast tree, what allows to use maximal possible modulation level for demand. In turn, cheapest insertion method gives the multicast tree containing minimal number of links (channels) of the communication network.

Algorithm 2. Cheapest insertion multicast tree [6, 17]

```
start with $MT = \{ N_d , \varnothing \}$
repeat
    find shortest path $p^*_{s^*t^*}$ between nodes $s^*$ and $t^*$
    such that
      $p^*_{s^*t^*} = \min \{ p_{st} \mid s \in MT,\ t \in G_d ,\ t \notin MT \}$
    add nodes and edges of $p^*_{s^*t^*}$ to $MT$
until $MT$ contains all nodes from $G_d$
return $MT$
```

B. *Utilization Balancing Multicast Trees*

Algorithms based on basic multicast tree methods and results of experiments have been presented in [6]. It was observed, that links in the networks have often been not evenly loaded. It often brought us to a situation when demands were being blocked, because overloaded links were incorporated into multicast trees for new demands, while underutilized links were not. In result of increasing of virtual cost of overloaded links, they will not be used (or will be used more rarely) for newly generated multicast trees. Then the method, which allows to generate multicast tree taking into account the utilization of network channels, is proposed. Method modifies costs of links in topology tree – the cost is proportional to link utilization.

Let function *UtilCost* (e, t_1, t_2), modifies the cost of network link *e* based on link utilization in the time period from t_1 to t_2.

Let binary variable occ_{est} be equal to 1 if slice *s* of link *e* is occupied in time slot *t*. Utilization is defined as the percentage of occupied slices in specified time period, according to the formula:

$$util\,(e, t_1, t_2) = \left(\sum_{s=1}^{S} \sum_{t=t_1}^{t_2} occ_{est}\right) / \left(S(t_2 - t_1)\right) \qquad (1)$$

As in basic tree generation methods, the link cost is equal to the physical length of the link (in kilometers). Let $c(e)$ be such defined cost of the link *e*. If utilization of link *e* is higher that denoted threshold α (parameter of an algorithm) function *UtilCost* will modify cost of link *e* in the following way:

$$UtilCost\ (e, t_1, t_2) = \begin{cases} c(e) & if\ util(e, t_1, t_2) \le \alpha \\ c(e) * \left(1 + \frac{1}{1 - util(e, t_1, t_2) * \beta}\right) & if\ util(e, t_1, t_2) > \alpha \end{cases} \qquad (2)$$

The goal of cost modification is to prevent highly utilized links from being chosen for multicast trees. Utilization balancing multicast tree algorithm (Algorithm 3) starts from modifying the cost of network links (lines 1-4), original distance based cost are also stored (line 2). Let us notice, that modification is not being done if the utilization ratio is below α. Link utilization in calculated in time period from present moment (*now*) to the demands deadline. After that, in network with link costs modified according to the link utilization, the SD or CI method is used for building topology tree (line 5). Finally the original costs of links are restored (lines 6-8) in order not to

Algorithm 3. Utilization Balancing Multicast Trees (*d*)

```
1  for each $e \in E$
2      $c'(e) = c(e)$
3      $c(e) = UtilCost(e, now, \tau_d)$
4  end for
5  find multicast tree using SD or CI algorithm
6  for each $e \in E$
7      $c(e) = c'(e)$
8  end for
```

impact the calculation of possible modulation levels. Parameters α and β should be chosen experimentally. Utilization balanced multicast tree method will be noticed as USD (while using SD algorithm) or UCI (algorithm CI).

C. Best Modulation Algorithms

Let function *ChkAll* (MT_d, t, s, w_d, n_d) return 1 when demand d may be established over all links belonging to multicast tree MT_d with the spectrum width equal to n_d number of slices and over w_d number of time slots, starting from slice s and time slot t. Otherwise *ChkAll* returns 0.

Algorithm SD+BM (Algorithm 4) uses shortest distance (SD) method for obtaining multicast tree (line 1). The length of multicast tree determines possible modulation formats. For each possible modulation format algorithm calculates the required number of time slots and slices (lines 2-5). The product of both values is used as a metric for choosing the best modulation format (BM) for demand (line 6). Finally the algorithm looks for the continuous range of slices and time slots, where allocation of tree is possible (lines 7-14). Searching starts from the first time slot after arrival time. When the range of slices and time slots are found (establishing of demand is possible) then demand is allocated (line 10) and algorithm successfully finishes (line 11). If it is not possible to find proper slice and time space, demand is blocked and dropped (line 15).

Algorithm 4. SD+BM (*d*)

```
1   build the shortest distance multicast tree $MT_d$
2   for each possible modulation level $m_{di}$
3       Calculate required number of slices $n_i$ and number of time slots $w_{di}$
4       $L_{di}=n_{di}*w_{di}$
5   end for
6   $x=i: L_{dx} = minLU_{di}$
7   for $t=T_d$ to $\tau_d - w_{dx}$ do
8       for $s=1$ to $S-n_{dx}$ do
9           if (ChkAll ($MT_d$, $t$, $s$, $w_{dx}$, $n_{dx}$) == 1) then
10              allocate demand $d$
11              return 1   // demand established
12          end if
13      end for
14  end for
15  return 0  // demand blocked
```

Algorithm CI+BM (Algorithm 5) differs from SD+BM only with the method used for multicast tree building – it implement cheapest insertion (CI) method.

Algorithm 5. CI+BM (*d*)

```
1      build the cheapest insertion multicast tree $MT_d$
2-15   follow steps 2-15 of Algorithm 4 (SD+BM)
```

D. Reference Algorithms

Algorithms SD+MS and CI+MS have been proposed in [6]. The idea of algorithm SD+MS (Algorithm 6) is to utilize minimal spectrum width (number of slices) for each demand. Algorithms using minimal slices method are noted with MS. Chosen number of slices must guarantee, that demand will be completed before the deadline. The maximal number of time slots for the demand is calculated first (line 2). Then, the minimal number of slices and maximal possible modulation level (offering the highest bitrate) are being found (line 3). It may happen, that with the calculated modulation format demand may be completed in time shorter than v_d, then the final number of time slots is calculated (line 4). During next steps the time and spectrum range for allocation is being found and finally demand is allocated or blocked – those steps are similar to SD+BM algorithm (lines 5-13).

Algorithm 6. SD+MS (*d*)

```
1      build the shortest distance multicast tree $MT_d$
2      $v_d = \tau_d - T_d$
3      calculate the minimal number of slices $n_d$ and maximal modulation level $m_d$ for $MT_d$, required for completing demand $d$ in time not longer than $v_d$ time slots
4      calculate time $w_d$ required to complete demand $d$ using $n_d$ slices and $m_d$ modulation level
5-13   follow steps 2-15 of Algorithm 4 (SD+BM)
```

Algorithm CI+MS (Algorithm 7) differs from SD+MS with the method used for multicast tree building – it implement cheapest insertion (CI) method.

Algorithm 7. CI+MS (*d*)

```
1      build the cheapest insertion multicast tree $MT_d$
2-13   follow steps 2-13 of Algorithm 6 (SD+MS)
```

E. Heuristic Algorithms with Utilization Balancing

Algorithms USD+BM, UCI+BM, USD+MS and UCI+MS use the utilization balancing multicast trees method (with SD or CI strategy) in place of simple SD or CI (line 1 of Algorithms 4-7).

IV. EXPERIMENTS

The main goal of experiments was to evaluate the quality of solutions obtained with proposed heuristic algorithms for different multicast demand characteristics (e.g. different number of destination nodes and intensity of demands) and to proof the benefits of proposed utilization balancing multicast tree method. Experiments were conducted for three network topologies: EURO16, EURO28 and UBN24, presented in the Fig. 1, details of all experimental networks are listed in Table I. The sets of demands were generated randomly (source and destination nodes, number of destination nodes, volume, time of arrival, deadline) in the ranges presented in Table II.

TABLE I.

EXPERIMENTAL NETWORKS

Network	No of nodes	No of links	Length of links [km]
EURO16	16	48	147-517
EURO28	28	82	218-1500
UBN24	24	86	250-2600

TABLE II.

EXPERIMENTAL SETUP

Network	Demands/s	Volume	Number of destination nodes
EURO16	4-7	1Tb - 6Tb	2-10
EURO28	2-5	0,5Tb - 2Tb	4-14
UBN24	1,2-2,5	0,5Tb - 2,5Tb	4-14

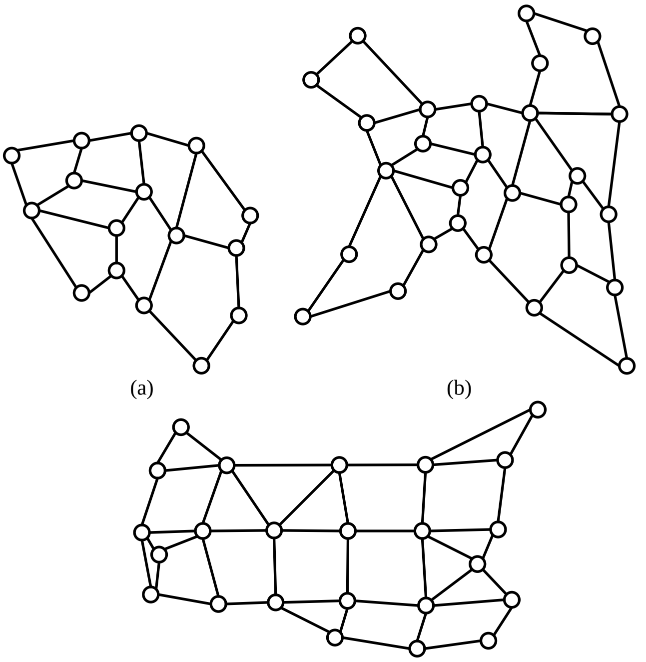


Fig. 1. Topologies of experimental networks: (a) EURO16, (b) EURO28, (c) UBN24.

It was assumed, accordingly to practical implementations, that the maximal throughput (bit rate) and modulation level possible for optical path depend on the length of the lightpath. In order to estimate the maximum transmission reach of an optical signal (for given bit-rate and modulation format), the model and methodology presented in [19] were utilized. Moreover it was assumed, that bitrates from 10 Gb/s to 400 Gb/s (step 10 Gb/s) will be used. Maximal distances for modulation formats, for few exemplifying bitrates, are presented in the Table III and the number of slices (spectrum width) required for exemplifying bit-rates are presented in Table IV.

TABLE III.

MAXIMAL DISTANCE [KM] FOR SPECIFIED BIT-RATE AND MODULATION FORMAT

bit-rate [Gb/s]	Maximal distance for modulation formats [km]					
	BPSK	QPSK	8QAM	16QAM	32QAM	64QAM
10	4083	3429	2774	2120	1466	811
20	3581	3010	2439	1868	1297	726
…						
110	2345	1980	1614	1249	883	518
120	2282	1927	1572	1217	862	507
…						
390	2170	1834	1497	1161	824	488
400	2120	1792	1464	1136	808	480

It was also assumed that optical signal regenerators will not be used in the networks, and the 12.5 GHz guard-band between neighboring channels was assumed. The length of multicast tree is equal to the distance between the source node and the farthest of destination nodes. Since optical regenerators are not used, the multicast demand is directly blocked, if the length of multicast tree is longer that maximal distanced allowed according to transmission reach model. The spectrum width (number of slices) for all experiments was set to 320.

TABLE IV.

REQUIRED NUMBER OF SLICES FOR SPECIFIED BIT-RATE AND MODULATION FORMAT

bit-rate [Gb/s]	Required number of slices					
	BPSK	QPSK	8QAM	16QAM	32QAM	64QAM
10	4	4	4	4	4	4
20	4	4	4	4	4	4
…						
110	12	8	6	6	4	4
120	12	8	6	6	4	4
…						
390	34	18	14	10	10	8
400	34	18	14	10	10	8

A. *Tuning of Utilization Balancing Algorithms*

For the algorithms, that implement link cost modification base on link utilization (USD and UCI), the optimal values of parameters α and β must be determined. For each of the network, the tuning process was performed. Tuning was performed based on solutions for 40 demand sets for each network topology, for different number of demands per second, and number of destination nodes for multicast demands. For each investigated set of parameters $\{\alpha, \beta\}$ 48 experiments for different demands sets were performed, then blocked volume from all 48 experiments was summed up. Exemplifying results of tuning algorithms with UCI method for network UBN24 are presented in the Table V. The optimal sets of parameters $\{\alpha, \beta\}$ for each network, used for next experiments, are presented in the Table VI.

TABLE V.

RESULTS OF TUNING UCI ALGORITHM FOR NETWORK UBN24

		α					
		0,35	**0,4**	0,45	0,5	0,55	0,6
β	0,4	1,33%	1,16%	1,86%	1,66%	1,97%	2,36%
	0,45	1,32%	1,06%	1,74%	1,53%	1,87%	2,26%
	0,5	1,21%	1,02%	1,29%	1,46%	1,87%	2,18%
	0,55	1,22%	0,98%	1,07%	1,45%	1,74%	2,24%
	0,6	1,17%	1,04%	1,17%	1,48%	1,80%	2,23%
	0,65	1,15%	**0,91%**	1,07%	1,44%	1,83%	2,28%
	0,7	1,16%	0,94%	1,14%	1,52%	1,75%	2,28%
	0,75	1,20%	1,06%	1,24%	1,49%	1,88%	2,40%

TABLE VI.

OPTIMAL PARAMETERS FOR USD AND UCI ALGORITHMS

Network	UCI		USD	
	α	β	α	β
EURO16	0,6	0,5	0,5	0,4
EURO28	0,4	0,65	0,45	0,7
UBN24	0,4	0,65	0,4	0,6

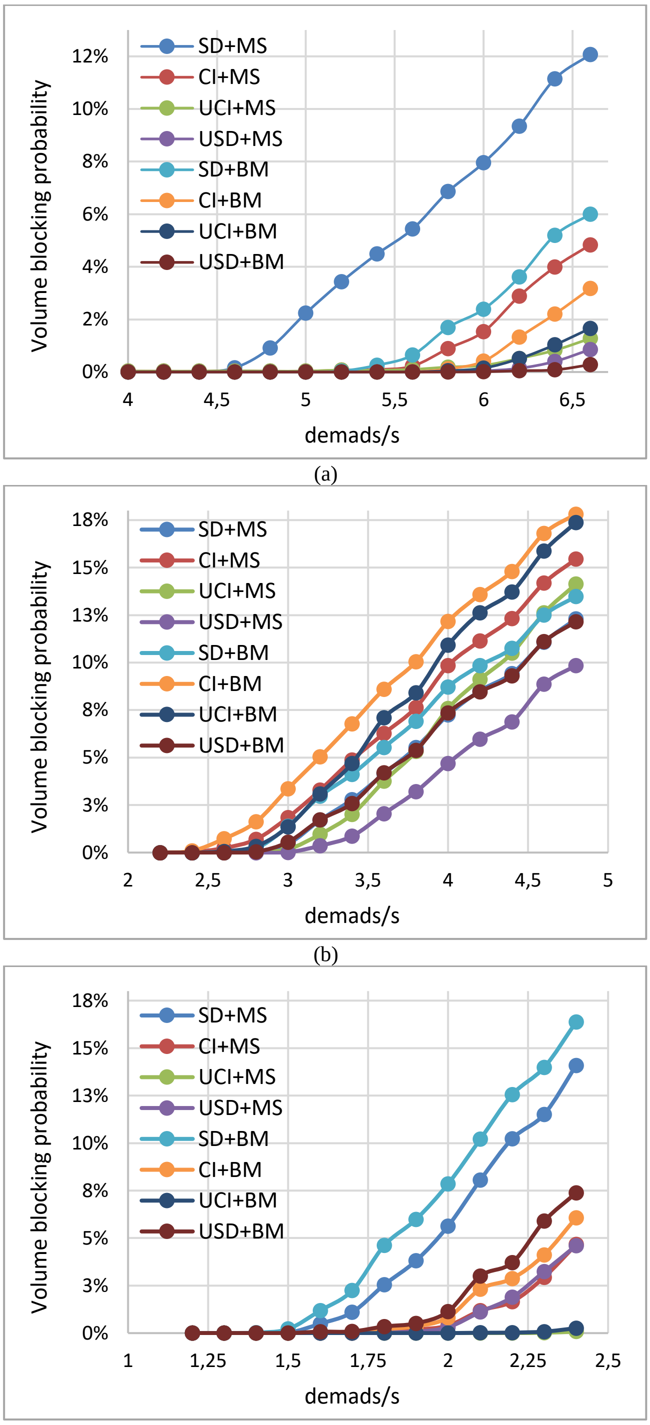
B. *Results of Experiments*

Figure 2 depicts the volume blocking probability (percentage of not delivered volume) as a function of average number of demands per second for all examined network topologies. Average number of destinations nodes during this experiments was equal to 4. As it may be observed in the Fig. 2, for all experiments the algorithms with utilization balancing method (USD and UCI) overcome corresponding algorithms with simple tree generation method. It may be concluded that the proposed method lets to improve the solution in all experimental cases.

For network EURO16 (Fig. 2.a), all utilization balancing algorithms gave better results that simple ones. It was also observe, that proposed best modulation (BM) strategy in majority of experiments gives better results than reference MS strategy. For bigger network topologies (Fig. 2.b and 2.c) the quality of solutions depends mainly on spectrum allocation strategy (MS or BM) and tree generation strategy (SD or CI). Nevertheless, using of utilization balancing algorithm gave the benefits during all experiments. For EURO28 best results were obtained with USD+MS algorithm, and the BM strategy gave relatively worse results than MS. For UBN24 best results were obtained with UCI+BM and UCI+MS algorithms, it was observed that for this topology the cheapest insertion (CI) approach is better than shortest distance method.

The acceptable level of blocking probability (less than 1%) was ensured for demands intensity up to 6,5 demands per second for network EURO16, up to 3 demands per second for network EURO28 and for all experiments (up to 2,4 demands per second) for UBN24. Disproportion in number of successfully allocated demands may be observed while comparing results for small and bigger networks. Since the links lengths in EURO28 and UBN24 networks are noticeably bigger, only the lowest modulation formats and bit-rates might be used. Then, higher width of spectrum is required to guarantee proper bandwidth for demands.

Figure 3 presents the volume blocking probability as a function of average number of destination nodes, for networks EURO16 and UBN24. Utilization balancing method gave benefits in all experiments. For EURO16 network best results were obtained with USD+BM algorithm. Cheapest insertion (CI) algorithms allowed to obtain worse solutions than shortest distance (SD) algorithms. The acceptable level of blocking probability was observed for average number of destination nodes up to 6. For UBN24 (Fig. 6.b) lowest blocking

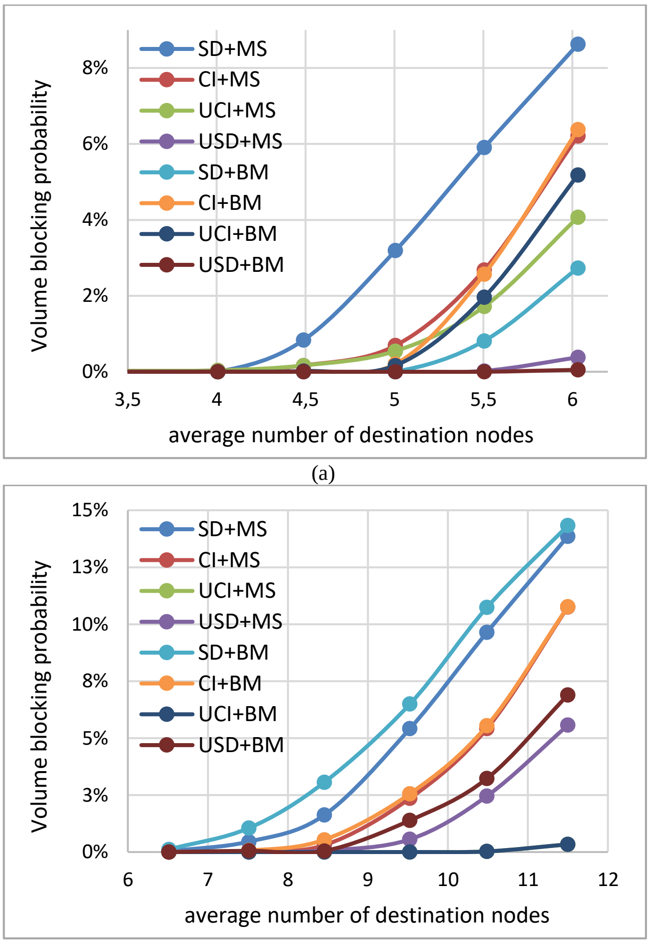


(a)

(b)

(c)

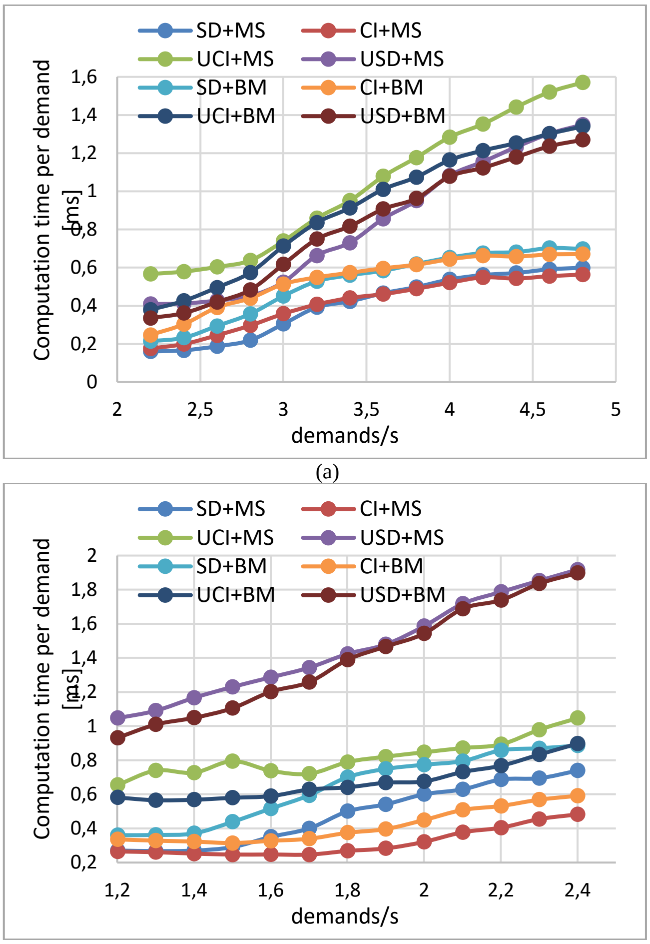
Fig. 2. Volume blocking probability as a function of average number of demands per second for networks: (a) EURO16, (b) EURO28, (c) UBN24.



(a)

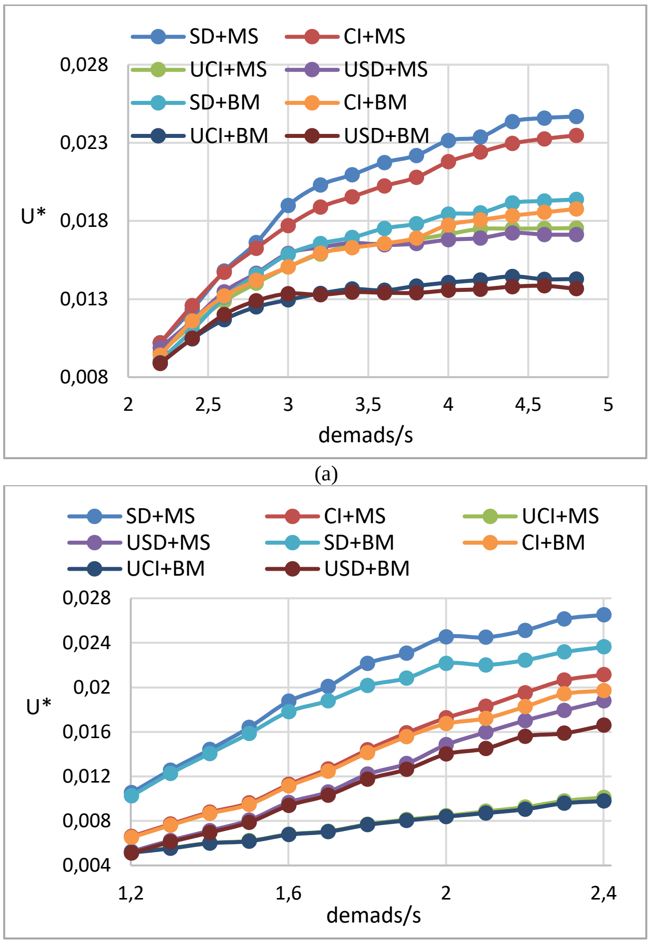
(b)

Fig. 3. Volume blocking probability as a function of number of destination nodes for networks: (a) EURO16, (b) UBN24.



(b)

Fig. 4. Average computation time: (a) network EURO28, (b) network UBN24.



(b)

Fig. 5. Overall utilization MSE: (a) network EURO28, (b) network UBN24.

probability was observed for algorithm UCI+BM (up to 11,5 average number of destination nodes).

The average computation times required for allocation (assigning the multicast tree, time and spectrum) of single demand is presented in the Fig. 4. Allocation decision time fluctuates from 0,2 to 2 ms. For network EURO16 (not presented in the Fig. 4) allocation time fluctuated from near zero up to 1 ms. For EURO28 allocation time for utilization balancing algorithms is higher (usualy around 1 ms) than for simple algorithms. Such results were expected, since calculating utilization of links and cost modification process is little bit time-consuming. For UBN24 topology the USD method needs the noticeably longer computation time that other algorithms.

It is worth to notice, that short computation time is a necessary attribute of algorithms designed for considered dynamic problem. Since decisions must be taken immediately, higher delays are not acceptable. For proposed algorithms the allocation time is at satisfactory level - for worst case (2 ms) algorithm is able to allocate around 500 demands per second.

Finally it was investigated, how the usage of utilization balancing methods influence on utilization. Let U_e be the average utilization of link e over all time slots, and U^{av} be the average utilization of all links. Let U^* be the overall mean squared error (MSE) of link utilization:

$$U^* = \sum_{e=1}^{E} (U^{av} - U_e)^2 \tag{3}$$

U^* shows how the utilization of links in the network differs. The smaller value of U^*, the more balanced is the utilization of network links. Values of overall utilization mean squared error for networks EURO28 and UBN24 are presented in the Fig. 5. For the network EURO28 utilization balancing algorithms assure the smallest differences in channels utilization. The value of overall MSE is smallest for algorithms USD+BM and UCI+BM, while the highest disproportion may be observed for SD+MS and CI+MS. For UBN24 smallest U^* for UCI+MB and UCI+MS algorithms were observed. Like in case of EURO28, overall MSN is smallest for algorithms with cost modification. As it follows from results, proposed utilization balancing method allows for uniform loading of network links and minimizing the blocking probability.

V. CONCLUSION

In the paper the method for utilization balancing of network links and new spectrum allocation strategy BM for deadline-driven dynamic optimization problem in elastic optical networks were proposed. Six algorithms were constructed and examined: four based on balancing methods and two based on basic multicast tree method and new BM strategy. Obtained algorithms were compared with two reference algorithms proposed in previous paper. Results of extensive experiments, performed with all algorithms were presented and analyzed in the paper. As it follows from experiments, usage of proposed method and strategy enables to significantly improve the quality of obtained solutions and reduce load asymmetry of network links. It was also proved, that proposed heuristic solutions offer acceptable optimization time, very important in case of dynamic optimization problem in optical network environment.

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