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Tabu Search Algorithm for Survivable Network Design Problem with Simultaneous Unicast and Anycast Flows

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***Abstract*—In this work we focus on the problem of survivable network design for simultaneous unicast and anycast flows. This problem follows from the growing popularity of network services applying the anycast paradigm. The anycasting is defined as one-to-one-of-many transmission and is applied in Domain Name Service (DNS), peer-to-peer (P2P) systems, Content Delivery Networks (CDN). In this work we formulate two models that enables joint optimization of network capacity, working and backup connections for both unicast and anycast flows. The goal is to minimize the network cost required to protect the network against failures using the single backup path approach. In the first model we consider modular link cost, in the second we are given a set of link proposal and we must select only one of them. Because these problems are NP-hard, therefore optimal solutions of branch-and-bounds or branch-and-cut methods can be generated for relatively small networks. Consequently, we propose a new heuristic algorithm based on Tabu Search method. We present results showing the effectiveness the proposed heuristic compared against optimal results. Moreover, we report results showing that the use of anycast paradigm can reduce the network cost.**

***Keywords*—anycast, network design, tabu search, survivability**

I. INTRODUCTION

IN this paper we focus on survivable computer networks using simultaneously unicast and anycast flows. The unicast – defined as a one-to-one transmission – is the most popular traffic in the Internet. The anycast – defined as a one-to-one-of-many transmission technique – has the goal to deliver a packet to one of many hosts. Examples of network services that applies the anycasting are: Domain Name Service (DNS), Web Service, overlay network, peer-to-peer (P2P) systems, Content Delivery Networks (CDN), video streaming, software distribution, sensor networks [10], [17], [20]. Since the same information is replicated in many replica servers located in the network, the user can select one of these servers according to some criteria including also QoS parameters. As a result, the anycast transmission can decrease the network traffic and avoid the congestion causing big delays in the data delivery. An additional benefit is that replica servers provide a fault-tolerant service, since users can select another server offering the same data, and even a failure of one server does not cause the data to be unreachable. For these two reasons, in this paper we apply the anycast transmission to improve the network survivability.

Moreover, it should be underlined that most of the interest in the context of the network survivability networks has been focused on the unicast traffic [9], [15]. On the other hand, various techniques applying the anycast flow paradigm have been becoming popular recent years, e.g. CDNs, P2P systems, video streaming. We concentrate on connection-oriented (c-o) networks. We can observe that c-o network techniques like MultiProtocol Label Switching (MPLS) and Dense Wavelength Multiplexing (DWDM) gains much attention especially in transport backbone networks [14]. This can be explain ed by the fact that connection oriented transmission enables delivering of traffic engineering capability and QoS performance including reliability issues [9].

In order to provide network survivability two methods can be used: protection and restoration. The distinction between the protection and the restoration consists in the different time scale in which they operate. The protection needs preallocated network resources while the restoration applies dynamic resource establishment. In this work we use the protection method to provide the network survivability. For more details on the survivability of connection-oriented networks refer to [9], [18]. The main contribution of this paper is proposal and verification of a new Tabu Search (TS) heuristic algorithm applied for the survivable network design problem with simultaneous unicast and anycast flows. We verify the algorithm through numerical experiments concentrating on comparison against optimal results.

The remainder of this paper is organized as follows. In the next section we present briefly the related work on survivable networks and anycasting. In section 3 we formulate and discuss the survivable network design problems for simultaneous unicast and anycast flows. Section 4 includes description of the Tabu Search heuristic algorithm. Section 5 includes results of numerical experiments. The last section concludes this work.

II. RELATED WORK

Research related to network survivability problems has been gaining much attention for last 20 years. Current computer

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networks are crucial in almost all aspects of our lives including business and private issues. Thus, a network failure – even a short one – can lead to severe consequences regarding people, institutions, corporations, etc. Therefore, many new solutions have been developed to improve network survivability. The most popular in connection-oriented networks (e.g. optical networks, MPLS) is the backup path method. The main idea of this approach is as follows. Each connection, i.e. label switched path (LSP) in MPLS networks, has a working path (route) and a recovery (backup) path (route). The working route is used for transmitting of data in normal, failure-free state of the network. After a failure of the working path, the failed connection is switched to the backup route [9], [16], [18].

In modern computer networks a single-link failure is the most common and frequently reported failure event [9]. Therefore, in most of optimization models a single-link failure is considered as the basic occurrence. The spare capacity is computed to provide full restoration in case of a failure of any single-link [9], [15].

In the literature there are many papers on network design problems (see [9], [11], [15] and references therein). However, most of them are related to unicast flows. The objective is to select link capacity and assign network flows in order to minimize one or more of the following criteria: cost, network delay, throughput, survivability, Quality of Service, etc. In the case of connection-oriented networks, the network design optimization problems are formulated using the non-bifurcated multicommodity flows in the form of Integer Programming or Mixed Integer Programming. Most of these problems are NP-hard, therefore to find optimal solutions branch-and-bounds or branch-and-cut methods are used. For larger networks various heuristic approaches are proposed, including evolutionary algorithms, tabu search, simulated annealing [9], [15].

The anycast transmission is applied in system that provides the same content in many network locations, using caching and replication techniques. One of the most popular caching technology is the Content Delivery Network (CDN) defined as mechanisms to deliver a range of content to end users on behalf of origin Web servers. The original content is offloaded from source sites to other content servers located in different locations in the network. Each request is redirected to one of CND replica servers offering the requested Web page. The CDN delivers the content from the origin server to the replicas that are much closer to end-users. Thus, the CDNs' servers can approach the hit ratio of 100%. It means that almost all requests to replicated servers are satisfied. Akamai is an example of a CDN system used in the Internet [10], [13].

Most of research on anycasting that touches somehow issues of network flows concentrates on IP networks using connection-less transmission modelled as bifurcated multicommodity flows [1-2], [4], [13]. There are not many works on joint optimization of connection-oriented networks using unicast and anycast flows.

In [3] a WDM anycast routing problem (WARP) is formulated. The problem consists in finding a set of light-paths, one for each source, for anycasting messages to one of the member in the anycast destination group such that not any path using the same wavelength passes through the same link. The objective of the WARP is to minimize the number of used wavelengths. Several heuristic algorithms and a hybrid methods which combine heuristic and simulated annealing techniques are developed. Included results prove that the proposed algorithms are able to achieve good performance.

The author of [19] takes a detailed view on anycast communication from the perspective of network survivability. A new optimization problem is formulated that is equivalent to the problem of joint unicast and anycast flows restoration in connection-oriented networks. Next, an heuristic algorithm solving that problem is proposed. Results of exhaustive numerical experiments shows that anycasting can improve the network survivability in terms of the lost flow.

III. OPTIMIZATION MODELS

In this section we describe the optimization problems of survivable network design for simultaneous unicast and anycast flows. The models were first time introduced in our previous papers [5], [7].

The network is modeled as a graph consisting of nodes and links. Nodes represent network devices like routers, switches. Links $e = 1,2,\ldots,E$ denote physical links, e.g. fibers, cables, etc. The objective is to minimize the cost of a network that protects all flows (unicast and anycast) in 100%. The network cost includes link costs. As in [15], to model the network survivability issues we use the notion of failure states $s = 0,1,\ldots,S$. The state $s = 0$ denotes the normal state of the network, in which all network elements are available. Each failure state s is described by a vector binary link availability coefficient $\boldsymbol{\alpha}_s = (\alpha_{1s}, \alpha_{2s},\ldots,\alpha_{Es})$, i.e. in a given failure state a particular link e is either available in 100% ($\alpha_{es} = 1$) or is totally broken ($\alpha_{es} = 0$) Using this notation we can model different failure scenarios. For instance, if we want to model the single link failure, which is the most common failure in fiber networks [5], we set $S = E$ and for each failure state the link availability coefficient vector is $\alpha_{es} = 0$ for $s = e$ and $\alpha_{es} = 1$ for $s \neq e$. The network node failure can be modeled as failure of all links adjacent to the failed node.

In this work we focus on connection-oriented networks (e.g. MPLS, optical networks) [14]. Therefore, we model the network flow as non-bifurcated multicommodity flow. Consequently, the anycast request (demand) must include two connections: one connecting the client to the server (upstream) and the other one in the opposite direction (downstream).

The upstream connection is used to carry user's requests. The downstream connection is applied to send the requested data. Thus, each anycast demand is defined by a following triple: client node, upstream connection bandwidth requirement and downstream connection bandwidth requirement. In contrast, a unicast demand is defined by a following triple: origin node, destination node and bandwidth requirement. To establish a unicast demand a path satisfying requested bandwidth and connecting origin and destination nodes must be established. Optimization of anycast demands includes: the replica server selection and next computing the upstream and the downstream connections. However, the main constraint is that both anycast connections associated with the same anycast demand must connect the same pair of network nodes and one of these nodes must be a replica server.

We are given a set of connections denoted by index $d = 1,2,\ldots,D$. We assume that connections $a = 1,2,\ldots,A$ are anycast connections including both upstream and downstream connections. If connection a is upstream (downstream) connection, $\tau(a)$ denotes associated downstream (upstream) connection. Connections $u = A + 1,\ldots,D$ are unicast. Notice that to distinguish anycast and unicast connection we use indices a and u, respectively. Let h_d denote the volume of connection $d = 1,2,\ldots,D$. We use the path protection method. For each connection we are given candidate pairs (w_{dp}, b_{dp}) of failure situation disjoint paths for demand d denoted by index $p = 1,2,\ldots,P_d$. Let δ_{edp} denote a binary constant, which equals 1 if link e belongs to working path w_{dp}, 0 otherwise. Furthermore, β_{edp} is a binary constant, which is 1 if link e belongs to backup path b_{dp}, 0 otherwise. The whole working path w_{dp} (used in normal network state) is protected by one backup path which is failure situation disjoint with the working path. This means that in all failure states when a particular working path is not available, its backup path must be available. The binary availability coefficient θ_{dps} indicates if the working path w_{dp} is affected by the failure state s. For each connection it is calculated as $\theta_{dps} = \Pi_{\{e\,:\,\delta edp\,=\,1\}}\alpha_{es}$, i.e. if at least one link e of working path w_{dp} ($\delta_{edp} = 1$) is broken in the state s ($\alpha_{es} = 0$), the path w_{dp} is not available ($\theta_{dps} = 0$) and must be restored using the backup path b_{dp}. Since associated anycast connections a and $\tau(a)$ should be processed jointly, we assume that if anycast connection a is affected by the failure, also the associated connection $\tau(a)$ must be considered. We examine two cases. In the first one we assume that in the failure state s only one connection of the pair $(a, \tau(a))$ is broken. Without loss of generality let a be the broken connection, i.e. the working path w_{ap} selected for connection a includes a link broken in state s. In this case the selected backup path b_{ap} for a must include the same replica server as the selected working path $w_{\tau(a)q}$ of connection $\tau(a)$. In the second case, we make an assumption that both associated anycast connections $(a, \tau(a))$ fail due to a failure s (i.e. both working paths w_{ap} and $w_{\tau(a)q}$ are broken in situation s). Thus, to restore a and $\tau(a)$ we can use backup paths b_{ap} and $b_{\tau(a)q}$ having different replica server that in the case of corresponding working paths w_{ap} and $w_{\tau(a)q}$. This procedure enables us to utilize the advantage of anycasting that provides the same content in various replica servers and intuitively it should lead to a reduction of the network cost.

To illustrate the model we present a simple example on Fig. 1. A client (representing anycast demand) is connected to node 1. In the case of a non-failure state of the network it uses working connections to replica server A: upstream <1,4,2> and downstream <2,4,1>. In the case of failure between nodes 1 and 4 including failure of directed links <1,4> and <4,1>, the client is switched to backup connections using replica server B: upstream <1,6,5,3> and downstream <3,5,6,1>.

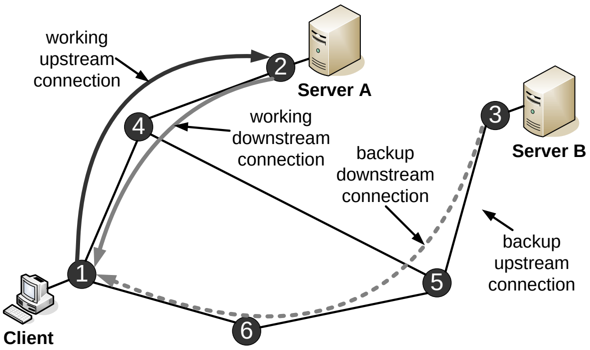

Fig. 1. The example of survivable anycast transmission.

Model ACMC (All Capacity Modular Cost)

indices

$d = 1,2,\ldots,D$	connections (directed demands) both unicast and anycast
$a = 1,2,\ldots,A$	anycast connections (directed demands)
$u = A+1,\ldots,D$	unicast connections (directed demands)
$p = 1,2,\ldots,P_d$	candidate backup paths (b_{dp}) of failure situation disjoint paths for connection d
$e = 1,2,\ldots,E$	network links
$s = 0,1,\ldots,S$	failure situations ($s = 0$ denotes the normal, non-failure state)

constants

δ_{edp}	= 1 if link e belongs to working path w_{dp}, 0 otherwise
β_{edp}	= 1 if link e belongs to backup path b_{dp}; 0 otherwise
h_d	volume of unicast demand d
k_e	cost of one capacity module on link e
M	size of the link capacity module
$o(d)$	origin node of working path w_{dp}
$t(d)$	destination node of working path w_{dp}
$o_w(d,p)$	origin node of working path w_{dp}
$t_w(d,p)$	destination node of working path w_{dp}
$o_b(d,p)$	origin node of backup path b_{dp}
$t_b(d,p)$	destination node of backup path b_{dp}
$\tau(a)$	index of the anycast upstream (downstream) connection associated with anycast downstream (upstream) connection a
θ_{dps}	binary availability coefficient of working path w_{dp} in state s

variables

x_{dp}	= 1 if a pair of paths p (w_{dp}, b_{dp}) is chosen for connection d, 0 otherwise (binary)
y_e	capacity of link e expressed in number of modules (integer)

objective

minimize $F = \sum_e k_e y_e$ (1)

subject to

$$\sum_d \sum_p x_{dp} h_d(\delta_{edp}\theta_{dps} + \beta_{edp}(1 - \theta_{dps})) \le M y_e \quad e = 1,2,\ldots,E \quad s = 1,2,\ldots,S \tag{2}$$

$$\sum_p x_{ap}\, o_w(a,p) = \sum_p x_{\tau(a)p}\, t_w(a,p) \quad a = 1,2,\ldots,A \tag{3}$$

$$\sum_p x_{ap}\, o_b(a,p) = \sum_p x_{\tau(a)p}\, t_b(a,p) \quad a = 1,2,\ldots,A \tag{4}$$

$$\sum_p x_{dp} = 1 \quad d = 1,2,\ldots,D \tag{5}$$

The objective (1) is to minimize the cost of spare capacity necessary to protect the network against all considered failure scenarios $s = 1,2,\ldots,S$. It is assumed that if the working path w_{dp} is not available (i.e. at least one link belonging to w_{dp} is broken is state s and $\theta_{ds} = 0$), then the backup path must be available (i.e. none link of backup path for d is broken is state s). Therefore, in the capacity constraint (2) we use coincidence coefficient β_{edp}. The left-hand side of (2) denotes the flow of link e related to working paths and backup paths (activated in the case, when the corresponding working paths are broken in state s ($\theta_{dps} = 0$)). Note that we do consider the stub-release, i.e. the flow of broken working path is released in the network and this free capacity can be used for restoration. Constraints (3) and (4) assure that associated anycast paths (both working and backup) connect the same pair of nodes. Finally, condition (5) is in the model to guarantee that a pair of paths (working and backup) is selected for each connection d.

Notice that in the problem (1)-(5) the replica server of anycast connection can be changed due to the restoration process. This is a potential advantage of anycasting. If we want to remove this option, we must introduce to the model the following constraints

$$\textstyle\sum_p x_{ap}\, o_w(a,p) = \sum_p x_{ap}\, o_b(a,p) \quad a = 1,2,\ldots,A \qquad (6)$$

$$\textstyle\sum_p x_{ap}\, t_w(a,p) = \sum_p x_{ap}\, t_b(a,p) \quad a = 1,2,\ldots,A \qquad (7)$$

The next model is very similar to ACMC, but use different modeling of link costs, i.e. we are given a set of link proposal and we must select only one of them. This formulation denotes the situation that many telecom operators offer price list including links with decreasing costs of unit capacity with the increase of overall link capacity. For instance, link 10 Mb/s costs 1000 USD, while link of capacity 30 Mb/s costs 2000 USD. Note that in the SCMC model the cost of link 30Mb/s would be 3000 USD.

Model ACDC (All Capacity Decreasing Cost)

indices (additional)

$l = 1,2,\ldots,Z_e$ candidate link types for link e

constants (additional)

c_{el} capacity of link type k for link e

k_{el} cost of link type k for link e

variables (additional)

y_{el} = 1 if link of type l is selected for link e, 0 otherwise (binary)

objective

$$\text{minimize} \quad F = \textstyle\sum_e \sum_l k_{el} y_{el} \qquad (8)$$

subject to (3-5) and

$$\textstyle\sum_d \sum_p x_{dp} h_d(\delta_{edp}\theta_{dps} + \beta_{edp}(1 - \theta_{dps})) \le \sum_l c_{el} y_{el} \qquad (9)$$
$$e = 1,2,\ldots,E \quad s = 1,2,\ldots,S$$

$$\textstyle\sum_l y_{el} = 1 \quad e = 1,2,\ldots,E \qquad (10)$$

As in the context of the ACMC if we introduce the constraints (6-7) we will block the possibility to change the replica server. Both presented models are NP-complete, since they are equivalent to network design problem [15]. For more details on optimization models of survivable networks with simultaneous unicast and anycast flows refer to [5]-[7].

IV. TABU SEARCH ALGORITHM

In this section we present an heuristic algorithm based on the Tabu Search [8] developed for the problems ACMC and ACDC. First, using Top-Down and SRP Algorithm we obtain an initial, feasible solution. The idea of this method was introduced in [6]. According to the results presented in [6] we can notice that selection of the best pair of working and backup paths happens after using the following formula

$$l_{rdp} = l(w_{dp}) + 0.1 l(b_{dp}) \qquad (11)$$

where $l_r(w_{dp})$ and $l_r(b_{dp})$ denote the length of the working path w_{dp} and the backup path b_{dp}, respectively.

Our Tabu Search method uses the provided initial solution as a starting point and tries to improve this solution. We assume that r denotes number of algorithm’s iteration. Let IS denote the initial solution, CS denotes the current solution, BS denotes the best solution and let NS denote the neighborhood which is a set of neighbors N. As a neighbor we assume the solution similar to the current solution – it means that for each current solution the neighborhood is defined as a set of solution which has different selected pair of working and backup paths for unicast or anycast demands. Let $F(CS)$ denote a value of the objective (1) for the current solution CS. Our algorithm has input three parameters: number of iteration R, size of tabu-list L and maximal number of iterations with no improvement to the best solution K. The length of the tabu-list is an important parameter of our algorithm and it states for how many iteration given move (selected in last iteration unicast or anycast demand) is forbidden. To implement the tabu-list we use short-term memory. To evaluate each move we use the cost function (1), i.e. if we switch the path of a selected demand and calculate the new cost function, which is compared against the previous value of the cost. The algorithm terminates according to one of two stopping conditions: (1) R iterations were run, (2) in subsequent K iterations there was no improvement of the solution.

The main idea of Tabu Search algorithm can be described using the following steps.

Step. 1. Find an initial solution IS. Set $CS = IS$ and $BS = IS$, $r = 0$. Calculate $F(BS)$.

Step. 2. Set $r = r + 1$. Calculate NS: for each unicast and anycast demand which are not on the tabu-list change path included in CS (for anycast both upstream and downstream connection). Then for each change of path calculate the objective. Go to Step 3.

Step 3. Select N from NS with minimal value of objective. If $F(N) < F(BS)$, then $BS=N$, $F(BS) = F(N)$, $k = 0$ and put demand in selected N on tabu-list. Otherwise set $k = k + 1$. Go to Step 4.

Step. 4. If $r = R$ or $k = K$ then stop algorithm. Otherwise go to Step 2.

V. COMPUTATIONAL RESULTS

In this section we present only results obtained for the ACMC optimization model using modular links. However, results obtained for the second model ACDC are comparable.

The first goal of numerical experiments is to make tuning of the proposed Tabu Search algorithm, i.e. we want to find the best values of tabu-list length *L* and the number of iterations *R*. The length of tabu-list was changed from 2 to 100 and the number of iterations was changed from 10 to 50 for each network. However, for each network the values of parameters *L* and *R* can be different. The tests are made on the Polska network consisting of 12 nodes, shown in Fig. 2. In Table I we show main parameters of the network and number of demands. Several demand patterns were created. The results presenting tuning of TS are presented in Fig. 3 and 4. Each curve represents results obtained with a particular number of iterations. We can notice that the cost decreases with the increase of iteration number. The highest difference is between 10 and 20 iterations. For number of iteration bigger than 30, the results obtained by Tabu-Search algorithm are comparable. However, increase of the iteration number leads to larger execution time. For each particular number of iterations we can easily find the best value of tabu-list length. We can notice that if the size of tabu-list length is larger than 40, then the results of the algorithm for each number of iterations are comparable and with growing the number of iterations the objective reduces slowly. If we want to find better solution we should increase the number of iterations and/or decrease the size of the tabu-list. On the other hand, if we want to obtain worse solution in better time we should increase the size of the tabu-list and/or decrease the number of iteration. Taking into account the execution time of Tabu-Search algorithm, we suppose than we can obtain the most favorable values of objective for *R* between 20 and 40 and for *L* no less than 30 and no more than 40.

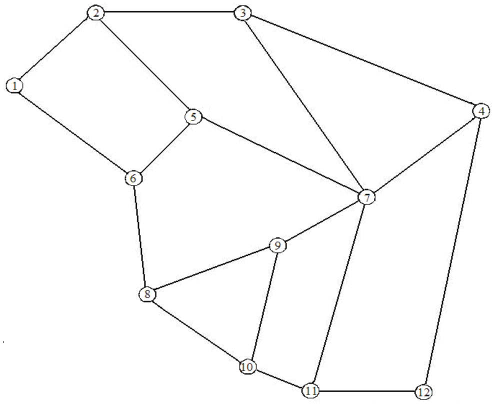

Fig. 2. Topology of Polska network.

TABLE I
PARAMETERS OF TESTED NETWORKS

Network	**Nodes**	**Links**	**Unicast**	**Anycast**
Polska	12	36	65	12
Germany	17	52	119	13
Atlanta	26	82	234	22

The next goal of experiments is to evaluate the Tabu Search approach against optimal solutions. We use the optimal results presented in [5] and [7] obtained for Polska network. Various proportions of the overall volume of unicast demands and anycast demands were used: 70% unicast/30% anycast and 80% unicast/20% anycast. For each demand there is at least 2 proposals of disjoint paths. In Table II we report the comparison between optimal results and Tabu Search for various scenarios in terms of the number of replicas and unicast/anycast proportion. The average gap of TS to optimal results is 2.57% for 70% unicast/30% anycast case and 2.00% for 80% unicast/20% anycast case.

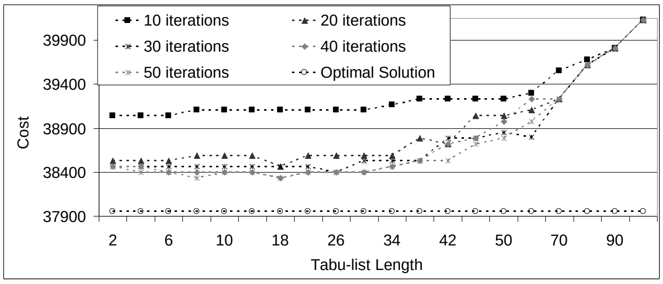

Fig. 3. The cost as a function of the tabu-list size and number of iterations for Polska network.

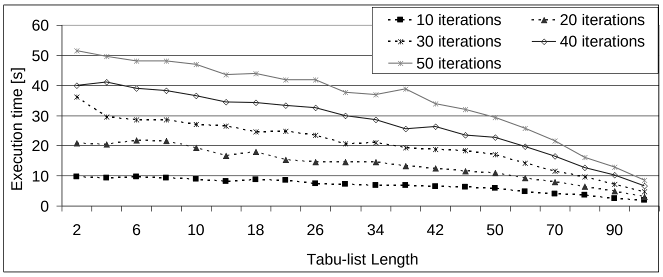

Fig. 4. The execution time as a function of the tabu-list size and number of iterations for Polska network.

TABLE II
AVERGAE GAP OF TABU SEARCH TO OPTIMAL RESULTS FOR POLSKA NETWORK

70% unicast/30% anycast			
Number of replicas	Optimal	TS	Gap
2	24832	25536	2.76%
3	24064	24704	2.59%
4	23936	24448	2.09%
2	25088	25600	2.00%
3	24320	25088	3.06%
4	24192	24832	2.58%
2	28882	29452	1.94%
3	28245	29148	3.10%
4	28023	29173	3.94%
2	28994	29805	2.72%
3	28552	29265	2.44%
4	28187	28637	1.57%
80% unicast/20% anycast			
2	29696	30336	2.11%
3	29440	29532	0.31%
4	29312	30144	2.76%
2	31488	32320	2.57%
3	29696	30272	1.90%
4	29440	30144	2.34%

The last goal of numerical experiments is to run the TS method using larger network for which the optimal solutions cannot be obtained due to complexity of the problem. We use the Atlanta network shown in Fig. 5 and Table I. Various proportions of the overall volume of unicast demands and anycast demands were used: 70% unicast/30% anycast and 80% unicast/20% anycast. For each demand there are at least 2 proposals of disjoint paths. We consider that the number of replicas in the networks is 2, 3, or 4 and there are located in some randomly selected nodes. The objective of the experiments is threefold. First, we want to compare two approaches related to anycasting: fixed replica and switch replica. The former approach refers to the model (1)-(5) with additional constraints (6)-(7), i.e. after the failure anycast demands cannot switch the replica node. The latter case is the model (1)-(5), which enables to switch the replica server after the failure. The second goal is to check how the cost of the survivable network depends on the number of replica servers, i.e. for the same sets of demands we increase the number of replica servers from 2 to 4. Finally, the third objective is to evaluate how the survivable network cost is influenced by the increasing of the anycast traffic, i.e. we run experiments for the following proportions of unicast/anycast traffic 80%/20% and 70%/30%.

In Fig. 6 we show how the objective depends on the number of iteration for the Atlanta network. We present results for the following values of the tabu-list length 30, 35 and 40. In Table III we present the comparison of switch and fixed replica for Atlanta network. The unicast/anycast proportion is 80%/20%. We set a Tabu-Length $L = 40$ and number of iteration $R = 20$. We can notice that the switch replica case can reduce the network cost by about 1% comparing to the fixed replica. Using 4 replicas instead of 2 replicas decrease the network cost by 2%.

VI. CONCLUDING REMARKS

In this paper we have addressed the problem of flows and link capacity joint optimization with simultaneous anycast and unicast flows. The main contribution of this work is a new heuristic algorithm based on the Tabu Search method. The presented algorithm has been tuned and verified against optimal results. The TS algorithm provides results very close to optimal solutions – the average gap to optimality is 2-3%. The next advantage of the TS algorithm is the fact that using heuristic algorithm we can find feasible solution for much larger networks than in the case of exact methods like branch-and-bound or branch-and-cut. In the future work we want to examine the Tabu-Search method taking into account more tuning parameters: i.e. number of neighborhood or long-term memory. Moreover, we want to use the TS approach for other optimization problems related to survivable networks with simultaneous unicast and anycast flows.

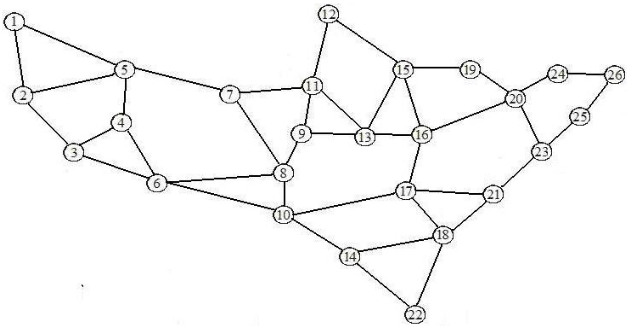

Fig. 5. Topology of Atlanta network.

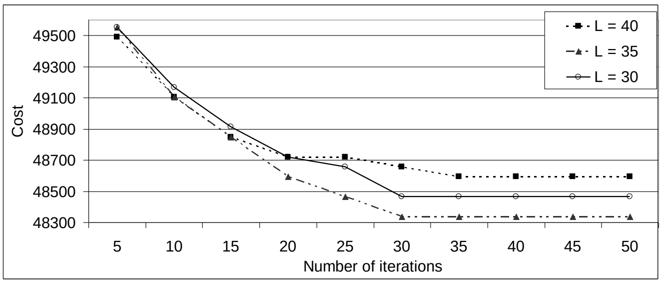

Fig. 6. Cost as the function of the number of iterations and tabu-list length for Atlanta Network.

TABLE III
COMPRISON OF TWO SURVIVABILITY APPROACHES: FIXED REPLICA VERSUS SWITCH REPLICA

Network cost		
Replica location	Fixed replica	Switch replica
(5,10)	50 496	50 112
(2,5,10)	49 856	49 472
(2,5,10,12)	49 472	49 152
Execution time of TS [s]		
(5,10)	11,2	11,7
(2,5,10)	12,8	12,6
(2,5,10,12)	13,1	13,5

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