Paper

Comparison of Multicast Algorithm Evaluation Results in Low and High Multicast Saturation Environments

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Abstract—The multicast quality of service-enabled routing is a computationally challenging task. Despite ongoing research efforts, the associated mathematical problems are still considered to be NP-hard. In certain applications, computational complexity of finding the optimal connection between a set of network devices may be a particularly difficult challenge. For example, connecting a small group of participants of a teleconference is not much more complex than setting up a set of mutual point-to-point connections. On the other hand, satisfying the demand for such services as IPTV, with their receivers constituting the majority of the network, requires applying appropriate optimization methods in order to ensure real system execution. In this paper, algorithms solving this class of problems are considered. The notion of multicast saturation is introduced to measure the amount of multicast participants relative to the entire network, and the efficiency of the analyzed algorithms is evaluated for different saturation degrees.

Keywords—quality-of-service, multicast, routing, multicast saturation.

1. Introduction

Modern telecommunications networks are tasked with ensuring an optimal transmission of data between remote peers. The methods for optimal execution of this task have been studied by network researchers and engineers for many years now. Routing-related problems have been viewed from the point of view of protocols [1]–[6], as well as algorithms [7]–[12].

To achieve optimal routing, algorithms such as the Dijkstra algorithm are used, for example in the OSPF protocol [13]. In most cases, the optimal path is the one of the lowest cost, though the development and the increasing complexity of the network traffic changes the meaning of optimality in this context. The minimal cost (defined, for example as the number of interconnecting links), has been accompanied by such metrics as point-to-point transmission delay or path reliability [14]. A single network may be used for sending multimedia data (e.g. VOD or YouTube streams), real time data (e.g. packets conveying Skype or Voice-over-IP traffic), alongside classic data for which the requirements have not changed significantly since the introduction of telecommunications networks many years ago. Therefore, engineers often reach out for a multiple criterion evaluation of selected paths or trees (also referred to as multi-criterion or QoS – Quality of Service [15]), e.g. the DUAL algorithm in the EIGRP protocol [16].

Finding optimal routes for multiple communication participants, rather than for a pair of peers, increases the complexity of the problem even further. The number of connected nodes is especially important when compared to the total number of nodes in the network. For example, interconnection of a small group of participants of a teleconference does not require multicast optimization, as the potential gain, compared to setting up individual point-to-point connections, is negligible. On the other hand, for applications involving IPTV, it is not feasible to utilize point-to-point connections between the transmission source and all individual receivers, as they will likely constitute the majority of the network's nodes.

Therefore, it is important to evaluate the performance of routing algorithms with regard to the amount of multicast participants, compared to the number of nodes in the network – the so-called multicast saturation. Based on that statement, a selection of multi-criterion multicast algorithms (solving the MCMST – multi-constrained minimal Steiner tree problem) were compared for different multicast saturation values, and the results are presented in this article.

The article is divided into the following parts. Section 2 presents the mathematical model of the network and the routing problem considered. Section 3 describes MCMST algorithms that were compared in the article. In Section 4, the experiment methodology and results are discussed, while Section 5 concludes the article.

2. Mathematical Model

The network is modeled by an undirected graph $G(E,V)$, where V is a finite set of nodes and $E \subseteq (u,v) : u,v \in V$ is a set of edges that represent point-to-point links. Each of the edges is assigned whit M metrics, given by the functions: $(m_i : E \rightarrow \mathbb{R}^+, i = 0,1,\ldots,M-1)$, that reflect additive costs of the relevant edges.

Path $p(s,d)$ from node s to the node d, where $s,d \in V$, is defined as a sequence of non-repeated nodes $v_1, v_2, \ldots, v_k \in V$ such that for each $1 \leq i < k$ an edge $(v_i, v_{i+1}) \in E$ and $v_1 \equiv s, v_k \equiv d$. We define the accumulated metrics for the paths, so that the cost of a path p, based on the edges that form it $e \in p \subseteq E$, the i-th is defined as $m_i(p) = \sum_{e \in p} m_i(e)$.

A rooted multicast tree $t(s, d_1, d_2, \ldots)$, connecting the source node $s \in V$ with multiple destinations $d_1, d_2, \cdots \in D \subseteq V$, is defined as a tree in G, of which the only leaf nodes are the ones from the set $\{s\} \cup D$, with one of them, node s, arbitrarily selected as the root. We define the accumulated cost of tree t correspondingly to the accumulated path's cost, as $m_i(t) = \sum_{e \in t} m_i(e)$. Let $T(s, d_1, d_2, \ldots)$ define the set of all the trees spanning the nodes from set $\{s\} \cup D$. For tree t, we define path $p_t(s, d_i)$ that is connecting nodes s and d_i within the given tree. We define set of constraints C as $(c_i \in \mathbb{R}^+, i = 1, 2, \ldots, M-1)$. The constraints are associated with the metrics of the same indices.

The MCMST problem is defined as finding the tree t^* spanning source node s and destination node D that fulfills the following conditions:

$$\forall\ t \in T(s, d_1, d_2, \ldots) : m_0(t^*) \leq m_0(t)\ ,$$

$$\forall\ d_i \in D, c_j \in C : m_j(p_t(s, d_i)) \leq c_j\ .$$

The multicast saturation is defined as $S = \frac{|\{s\} \cup D|}{|V|}$.

3. Compared Algorithms

In the experiment presented in this article, three different multi-constrained multicast algorithms have been used. Two of them are developed by the author: aggregated MLARAC and RDP, while the third, HMCMC, has been chosen from the literature as a high quality, well-performing algorithm solving the same class of problems.

3.1. Aggregated MLARAC Algorithm

The aggregated MLARAC algorithm [17] is based on the technique presented in [18], [19], solving the multi-criterion multicast routing problem by aggregating solutions to a multi-criterion unicast routing problem between a given source and each individual multicast receiver.

The unicast routing algorithm used in aggregated MLARAC is the MLARAC algorithm, presented in [20]. It is based on the Lagrangian relaxation-based technique from [21], extended to multiple constraints by the author.

The original algorithm, reduces the routing problem, by means of the Lagrangian relaxation, to finding an optimal coefficient for a modified cost function that is, in turn, used in the Dijkstra algorithm. Iterative approach is applied to obtain increasingly better approximations of the coefficient, until the optimal value is found.

In the variant proposed by the author, multiple optimization criteria may be applied, which results in the necessity of finding multiple optimal coefficients. While intersections of single-argument linear functions are used in the original algorithm to obtain the single optimal coefficient, the author presents a method based on finding multi-dimensional hyper-plane intersections to obtain the set of optimal coefficients for the solution of the multi-criterion problem.

3.2. RDP Algorithm

The RDP algorithm is based on simulating multiple Dijkstra algorithm instances (known as convergence processes) concurrently [22]. The processes are performed concurrently and independently, except for the order in which they progress. Information about which nodes have been visited by particular processes is stored by the algorithm core, along predecessor-related information. The selection of the next process is made based on the assumption that labels assigned by the processes to the nodes may be interpreted as the time that has passed in a given process. Once a given node has been visited by all convergence processes, it may be considered the center of a multicast tree – the RDP. There are two important aspects of this approach.

First of all, the Dijkstra algorithm may be enhanced with a custom cost function. Two different cost functions have been used in RDP: first, minimizing the metric m_0 only, and second, aggregating all metrics considered. The aggregation (found in [23]), takes into account metrics m_i, and constraints c_i in the following formula:

$$m_{aggr}(t) = \max\left\{\frac{m_1(t)}{c_1}, \frac{m_2(t)}{c_2}, \ldots\right\}\ .$$

Secondly, once a RDP candidate has been found, different decisions may be made. In one variant of the algorithm, all subsequent candidates are considered for the final solution. The first to meet the assumed constraints is taken as the result. In a heuristic variant of the algorithm, only the first RDP is considered as the potential solution. If it meets the constraints, it is taken as the ultimate result.

3.3. HMCMC

The Heuristic Multi-Constrained MultiCast algorithm [24] (HMCMC) consists of two phases, with the first of them consisting in finding a partially feasible tree. An attempt is made at building the entire tree, starting from the multicast source, using a modified Dijkstra algorithm that heuristically considers all the criteria – the optimized one, as well as the constraints. It utilizes the same modification as the RDP algorithm. It is possible that the result of the first phase connects all of the multicast participants with a feasible tree, in which case the successful result is returned. However, if any of the multicast receivers has not been feasibly connected with the source, the second phase is performed.

In the second phase, all of multicast participants which have not yet been connected are subject to the correction procedure. The procedure consists in an attempt to solve an MCOP problem from a given receiver to the source with an associated algorithm – H_MCP. The sub-algorithm is a precomputation-based variant of the unicast point-to-point routing algorithm H_MCOP [25]. The result of this step – a path from the source to one of the receivers – is included in the result, whether it is feasible with regard to the constraints or not.

4. Simulation Experiment

In order to evaluate and compare the aforementioned algorithms, the following experiment was performed. A set of topological structures of 500 nodes was generated using the BRITE generator [26] and the Waxman method [7]. This generator has been used extensively in prior work and has proven to be a valid choice for this type of experiments [17], [20], [22], [27]–[29].

Each of the graph edges was assigned with three metrics: m_0, m_1 and m_2. In each experiment iteration, a random group of nodes was selected in a given graph, and the routing problem for fixed constraints was solved using each of the algorithms. The assumed constraints were 17 and 12 for 17 and 12 for m_1 and m_2, respectively.

Two rounds of experiments were conducted, for different multicast saturations. First, for the low saturation, assumed sets of 4, 8, 12, 16, 20, 24, 28 multicast participants. In the second round, for the high saturation, sets of 120, 190, 260, 330, 400 multicast participants were considered.

It is important to note that the optimal value of metric m_0 is the lowest, while it is considered that for the constrained metrics m_1 and m_2, the optimal value is the highest. This stems from the definition of the solved problem. The optimal solution is the one that is of the lowest m_0 metric, while remaining within certain constraints against metrics m_1 and m_2. Therefore, the result which satisfies the constraints with the highest possible values has the advantage of not acquiring more network resources than necessary.

4.1. Low Multicast Saturation

In Fig. 1, the results of tree metric m_0 are presented as a function of group size, for lower multicast saturation. One may notice that the worst results have been obtained for the RDP algorithm, while aggregated MLARAC and HMCMC algorithms have led to obtaining comparable, better values.

Figure 2 demonstrates values of the path metric m_2 under the same simulation conditions. The best results, from the point of view of satisfying the constraints at the lowest cost, were obtained with the use of the RDP algorithm. The second best results were obtained with the aggregated MLARAC algorithm, and the worst m_2 metric results were found using HMCMC.

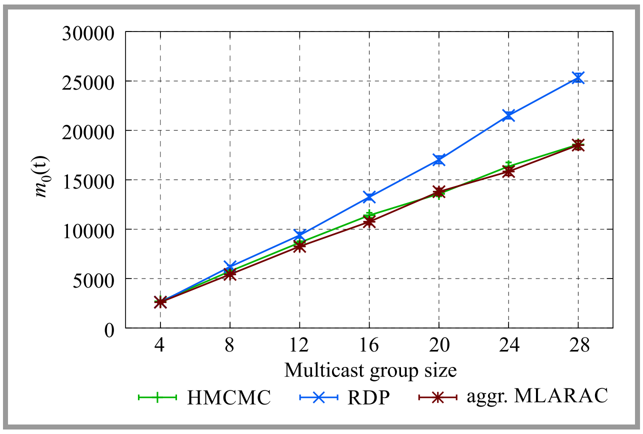

Fig. 1. Average m_0 tree metric values as a function of the multicast group size, for low multicast saturation.

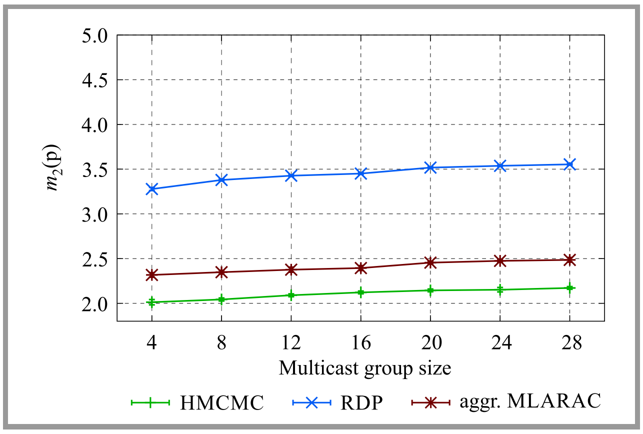

Fig. 2. Average m_2 path metric values as a function of the multicast group size, for low multicast saturation.

4.2. High Multicast Saturation

The following figures show corresponding results for high multicast saturation.

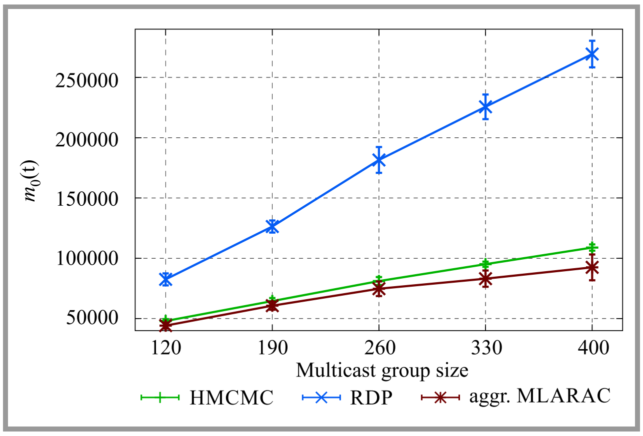

Fig. 3. Average m_0 tree metric values as a function of the multicast group size, for high multicast saturation.

Figure 3 presents the tree metric m_0 for higher multicast saturation values, whereas Fig. 4 demonstrates the tree met-

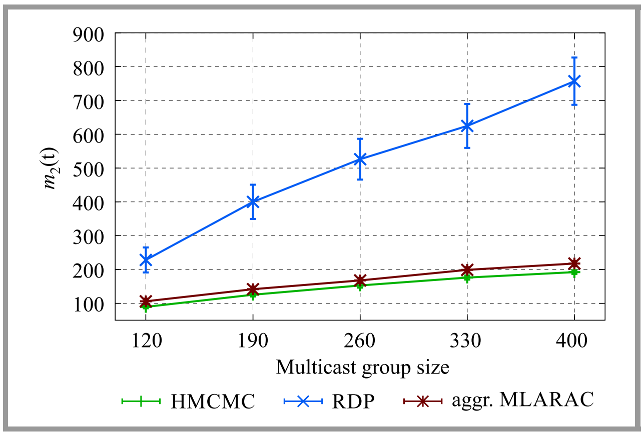

Fig. 4. Average m_2 tree metric values as a function of the multicast group size, for high multicast saturation.

ric m_2. One may notice how the relationship presented in Figs. 1 and 2 has been maintained under higher multicast saturation conditions.

Such a result is not surprising, since the stochastic character of the generated networks should usually lead to obtaining similar results at larger scales. On the other hand, anomalies may occur leading to different results for different saturation levels. Therefore, it is vital to perform experiments under higher multicast saturation conditions, in order to further support the conclusions that may be drawn from the results obtained for lower values of this particular parameter.

5. Conclusions

The relationship between the number of multicast participants and the network nodes may vary depending on the specific application context. It is important to take this factor into account when suggesting an algorithm for real life use, because different results may be obtained in different operational environments.

The results presented in the article show that the conclusions regarding performance of the presented algorithms, as published in previous works for low multicast saturation levels, still hold in the conditions of higher multicast saturation.

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