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On QoS multicast routing algorithms using *k*-minimum Steiner trees

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ABSTRACT

In this paper, we study how to obtain Steiner trees appropriately for efficient multicast routing. We first introduce a scheme for generating a new weighted multicast parameter by efficiently combining two independent measures: cost and delay. We call our proposal the Weighted Parameter for Multicast Trees (WPMT) algorithm. The WPMT can be adjusted by the weight $\omega \in [0, 1]$. For instance, if ω approaches 0, then the delay of the multicast tree may be relatively lower than the delay of other trees that are obtained as ω approaches 1. Otherwise, as the weight approaches 1 then the cost of the obtained tree may be relatively lower compared with other trees. A case study shows how to find an appropriate Steiner tree for each ω. The simulation results show that the use of the proposed WPMT produces results similar to the *k*-minimum Steiner tree algorithm. The WPMT can be applied to several existing multicast problems as we describe. We also propose several multicast algorithms using the WPMT in order to solve well-known multicast problems, and compare the proposed algorithms-based the WPMT with representative algorithms for the well-known problems.

1. Introduction

Next-generation mobile communications based on All-IP networks provide multimedia services via high-speed data transmission. The integration of wired networks, local area wireless networks, and wireless networks through the merging of existing wired and wireless communication systems have been extensively studied. Recently, Mobile Ad-hoc NETworks (MANETs) with IP connectivity for mobile nodes have emerged as environments that can satisfy user requirements [1]. In heterogeneous networks comprised of multiple MANETs attached to a backbone Internet, the backbone network performs the function of forwarding data packets. Multicast services have been increasingly used by various media streaming applications. For example, the Multicast backbone (Mbone) of the Internet has been used to transport real time audio/video for news, entertainment, and remote learning. Multicasting refers to the transmission of data from one node (source node) to a selected group of nodes (destination nodes) in communication networks. These group applications demand a certain amount of reserved resources to satisfy their Quality of Service (QoS) requirements such as end-to-end delay, delay variation,

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cost, loss, throughput, etc. Since the resources are reserved along a selected path for each destination in the constructed multicast tree, it may fail to guarantee the required QoS if a single link cannot support the required resources. Thus an efficient solution for multicast communication should include the construction of a multicast tree that has an optimal chance of satisfying the resource requirements.

The previous techniques for multicast routing solve two representative optimization problems-the delay and cost problems; however, their goals address distinct problems. For instance, let us consider a constructed multicast tree for source and destination nodes. First, the optimal delay solution is that the tree delay is at a minimum, such that the tree delay is the maximum value of the path delays for every destination. Here the path delay is the sum of the link delays along the considered path from the source to each destination node. Dijkstra's shortest path algorithm can be used to generate the shortest paths for a delay measure from the source to each destination node. On the contrary, the cost optimized multicast route is a tree spanning all destinations such that the sum of the link costs of the tree is at a minimum. This problem is also known as the Steiner tree problem that is known to be NP-complete.

Some heuristics [2] for the Steiner tree problem have been studied with polynomial time and produce near optimal results; however, they still consider only one measure (e.g., link cost) when solving this problem. In Ref. [3], the authors mention the Bounded Shortest Multicast Algorithm (BSMA). It solves a Delay-Bounded Minimum Steiner Tree (DBMST) problem that is considered by two measures at the same time. The DBMST problem deals with the minimum tree cost satisfying a tree delay bound, wherein the obtained tree delay is not bigger than the given tree delay bound. Although the performance is good for the BSMA, one of the major drawbacks may be high time complexity. In order to overcome this drawback, we should consider a lower time complexity algorithm than the k-shortest path algorithm used in [3]. In addition, problems of satisfying multiple QoS constraints for the multicast routing are discussed in Refs. [4,5]. The authors try to find the minimum cost tree with constraints including delay, bandwidth, delay-jitter, or degree. That is, the solution is the minimum cost tree satisfying another constraint. However, previous research on multicast routing algorithms that are capable of adjusting two and more measures is limited.

In this paper, we assume multicast routing as a source routing problem, with each node having full knowledge of the network and its status. We associate a link cost and a link delay with each link in a given network. The problem is to construct a multicast tree spanning a source and destination nodes, wherein the tree is able to satisfy some QoS requirements such as the minimum tree cost, minimum tree delay, minimum tree delay with constrained tree cost, minimum tree cost with bounded tree delay, etc. In general, the tree cost of an optimal tree delay solution is relatively more expensive than that of a tree cost optimized multicast route. Similarly, the tree delay of a tree cost optimized multicast route is relatively higher than that of the optimal tree delay solution. Hence, negotiation between the tree cost and the tree delay should be needed to use a proper/efficient tree between tree delay and tree cost. In this work, we introduce a scheme for generating a new multicast parameter that can adjust two measures (e.g., tree/path cost and tree/path delay) by weight, ω, at the same time. After generating the parameter, we use the TM (Takahashi-Matsuyame) algorithm [6], which is a very well-known Steiner tree algorithm, with the proposed parameter. We here note that our proposed scheme seems to perform similarly to the k-minimum Steiner tree algorithm with low time complexity.

The rest of the paper is organized as follows. In Section 2, we describe the network model and well-known Steiner tree algorithms. Section 3 presents details of the new parameter and illustrates with examples. Also, several algorithms using the proposed scheme are introduced. Then we analyze and evaluate performance by simulations in Section 4. Finally, Section 5 concludes this paper.

2. Preliminaries

2.1. Network model

We consider that a computer network is represented by a directed graph $G = (V, E)$ with n nodes ($|V| = n$) and l links ($|E| = l$), where V is a set of nodes and E is a set of links, respectively. Each link $e = (i, j) \in E$ is associated with two parameters, namely a link cost $c(e) \geqslant 0$ and a link delay $d(e) \geqslant 0$. The link cost, $c(e)$, can be associated with the utilization of the link. A higher utilization is represented by a higher link cost. The link delay, $d(e)$, is the sum of the perceived queuing delay, transmission delay, and propagation delay. We define a path as a sequence of links such that $(u, i), (i, j), \ldots, (k, v)$, belongs to E.

Let $P(u, v) = \{(u, i), (i, j), \ldots, (k, v)\}$ denote the path from node u to node v. If all nodes $u, i, j, \ldots, k, v$ are distinct, then we say that it is a simple directed path. We define the length of the path $P(u, v)$, denoted by $n(P(u, v))$, as the number of links in $P(u, v)$. For a given source node $s \in V$ and destination node $d \in V$, $(2^{s \to d}, \infty)$ is the set of all possible paths from s to d. $(2^{s \to d}, \infty) = \{P_k(s, d) | \{\text{all possible paths from } s \text{ to } d;\ s, d \in V, \forall k \in \Lambda\}$, where Λ is an index set. The path cost of P_k is given by $\phi_C(P_k) = \sum_{e \in P_k} c(e)$, and similarly, the path delay of P_k is given by $\phi_D(P_k) = \sum_{e \in P_k} d(e),\ \forall P_k \in (2^{s \to d}, \infty)$. $(2^{s \to d}, \Delta)$ is the set of paths from s to d for which the end-to-end delay is bounded by Δ. Therefore $(2^{s \to d}, \Delta) \subseteq (2^{s \to d}, \infty)$.

For the multicast communications, messages need to be delivered to all receivers in the set $M \subseteq V \setminus \{s\}$ which is called the multicast group, where $|M| = m$. The path traversed by messages from the source s to a multicast receiver, m_i, is given by $P(s, m_i)$. Thus the multicast tree can be defined as $T(s, M) = \cup_{m_i \in M} P(s, m_i)$ and the messages are sent from s to M through $T(s, M)$. The tree cost of tree $T(s, M)$ is given by $\phi_C(T(s, M)) = \sum_{e \in T} c(e)$ and the tree delay is $\phi_D(T(s, M)) = max\{\phi_D(P(s, m_i)) | \forall P(s, m_i) \subseteq T, \forall m_i \in M\}$.