Multicast Routing in Satellite-Terrestrial Networks

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Abstract *Satellite-terrestrial networks, in which many nodes are interconnected by both satellite and terrestrial networks, can efficiently support multicast service. We have developed a dynamic routing algorithm for satellite-terrestrial networks that selects the route to use according to the multicast group size when a node is added to the group.*

1 Introduction

Multimedia services, such as news delivery, TV broadcasting and automatic software upgrading, are expected to become widely used. Multicasting is well suited for these services because it makes efficient use of the network resources. The smallest amount possible of network resources should be used to set up the multicast connection. The amount required is determined by the route selected.

Multicast routing problems are either *static* or *dynamic*. In *static* routing problems, the members of the multicast group remain unchanged during the lifetime of the multicast connection. In *dynamic* routing problems, members can join or leave the group during the lifetime of the connection. Dynamic multicast routing is important for actual multicast applications and it is supported by protocols in ATM networks [1] and the Internet [2, 3, 4].

Satellite networks are best when the information to be delivered is targeted at a large population of receivers or earth stations, or when they are spread over a wide area. Satellite networks are thus especially suitable for multicasting. Several satellite-terrestrial (ST) network configurations have been investigated [5, 6, 7]. An ST network, in which many nodes are interconnected by both satellite and terrestrial networks, can efficiently support multicast service. This is because satellite broadcasting is suitable for a large multicast group and a terrestrial network is suitable for a small multicast group. By appropriately selecting the satellite and terrestrial routes to use, the cost of the multicast routing tree can be lowered.

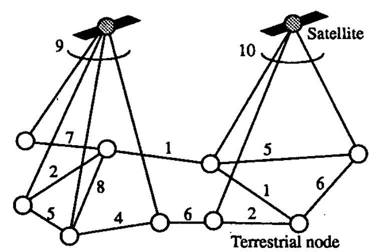


Figure 1: Example satellite-terrestrial network.

A number of dynamic multicast routing algorithms for terrestrial networks have been proposed [2, 3, 4, 8, 10, 9]. The greedy algorithm [8] selects the shortest path to an existing multicast tree when a node is added. The shortest-path tree algorithm finds the shortest path from the source node (or "core" in CBT [2] or "rendezvous point" in PIM-SM [3]) to the nodes in the multicast group when a node is added to the multicast tree. In these conventional dynamic multicast routing algorithms, an approximate optimal path when a new node is added, is selected to become a part of the cost/delay minimum multicast tree. However, the result may not be the minimum cost multicast tree for an ST network. This is because selecting satellites as intermediate nodes is difficult when adding a terrestrial node to a multicast group. The reason is that satellites cost more than terrestrial links unless the satellites work as "copy points" for multicasting. A multicast routing algorithm is thus needed that can select the appropriate satellite and terrestrial routes.

We have developed a dynamic routing algorithm for ST networks, in which the satellites are modeled as vertices with costs. A route is selected according to the size of the multicast group when a node is added to the group. Simulation showed that the proposed algorithm is advantageous when nodes are added to or removed from the multicast group in steady state.

2 Model of ST Network

An example of an ST network is shown in Fig. 1. In this network, both satellites and terrestrial networks interconnect many nodes, which are switching systems or switching systems that work also earth stations. One or more satellites can be used.

To define the dynamic multicast routing problem formally, we use terminology of graph theory for models. In the model used for the conventional dynamic multicast routing problem, the terrestrial network is modeled as a graph whose edges have costs. In our model, the ST network is modeled as a graph in which both the edges and vertices have costs. We call this graph as an edge-vertex-weighted graph in this paper. Some vertices represent the satellites, and their costs are the sum of the costs of up-links and down-links. By including these vertices in the multicast tree, their costs are included in the tree's cost, regardless of the number of terrestrial nodes that use the satellite links.

If nodes can be added or removed during the lifetime of the multicast connection, this problem becomes the dynamic multicast routing problem, i.e., the dynamic Steiner tree problem in an edge-vertex-weighted graph. Let $R = \{r_1, r_2, ..., r_K\}$ be a sequence of requests, where r_i is either adding or removing a destination node to or from the multicast group. Let S_i be the set of nodes in the multicast group after request r_i is made. In response to request r_i, multicast tree T_i is constructed using a dynamic multicast routing algorithm. The dynamic multicast routing problem for the ST network can thus be formally defined as follow.

> Given graph $G = (V, E)$, a nonnegative weight for each $e \in E$, a nonnegative weight for each $v \in V$, and $Z \subseteq V$, and sequence R of requests, find a sequence of multicast trees $\{T_1, T_2, ..., T_K\}$ in which T_i spans Z_i and has minimum cost.

In our model of the ST network, the vertices represent satellites have positive real numbers as costs and the edges represent satellite links have 0 as costs. Furthermore, the vertices represent nodes on the terrestrial network have 0 as costs and the edges represent terrestrial links have positive real numbers as costs. Hence, the model for the ST network is a special case of the edge-vertex-weighted graph. The dynamic multicast routing problem considered in this paper does not allow re-routing of existing connections as the additional requests are received. One node is the source for a multicast communication, and this node is not removed from the multicast group during the multicast connection.

In this paper, the vertices representing satellites are called "satellites" and the vertices representing nodes on a terrestrial network are called "nodes". Vertices that participate in a multicast group are called "existing nodes", the source node is an existing node, and vertices that do not participate in a multicast group but are included in the multicast tree are called "intermediate nodes".

3 Proposed Dynamic Multicast Routing Algorithm

In this algorithm as follows, a domain is defined as a set of vertices consisting of a satellite and several nodes (Fig. 2). Each node belongs to one or more domains. A node may be connected directly to the satellite that is close to it. If there are multiple satellites (number = s), that have the same shortest distance from a node, we consider that $1/s$ of this node to belong to its domains. In counting of the number of existing nodes in the proposed algorithm, the node is counted as $1/s$.

Step 1: Calculate virtual cost of each satellite:

$$\frac{\text{cost of satellite } i}{\max[1, (\text{number of active nodes in domain } i) - 1]},$$

where both existing nodes including the source node and the newly added node are considered in active nodes.

Step 2: Connect to a close existing or intermediate node.

If there are many existing nodes in a domain, the cost of its satellite is lower than that of a domain with few active nodes, so the satellite is more likely to be selected as an intermediate node. If the satellite is selected as an intermediate node and existing nodes in the domain are removed and/or added, the cost of the multicast tree will be lower than if the satellite had not been selected as an intermediate node.

To calculate the virtual cost of a satellite in Step 1, its actual cost is divided by the number of active nodes in its domain minus 1. If all existing nodes in domain i use satellite i and nodes in other domains do not use satellite i, an existing node serves as the sender node for the links of satellite i. Therefore, the number of existing nodes sharing the down-link from satellite i is the number of active nodes minus 1. In Step 2, a new branch of the multicast tree is the shortest route from the newly added node to a close existing or intermediate node. When a satellite is newly chosen as a part of the branch, the satellite link on the side of the newly added node works as a down-link and the satellite link on the side of the close existing or intermediate node works as a up-link.

Next, we describe an example of how the proposed algorithm works. Please refer to Fig. 2. The existing nodes are NO_1 and NO_2 in domain 1 and NO_5

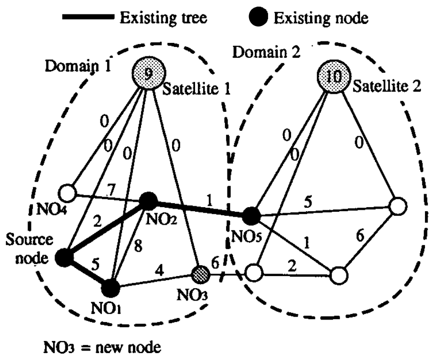


Figure 2: Edge-vertex-weighted graph and domains in proposed algorithm.

in domain 2. When NO_3 is added to the multicast group, the virtual cost of satellite 1 is 3. The existing node having the shortest distance to the new node is found, not by using the terrestrial links, but by using satellite 1 as an intermediate node. The new node can therefore be connected to any of the existing nodes by using the satellite link.

4 Simulation Model

We evaluated the performance of our proposed algorithm by using simulation. The model we used is an extension of previous ones [8, 10, 9].

The terrestrial part of the ST network consists of only terrestrial nodes and links. Satellites and their links are not included. It is modeled as a random graph possessing some of the characteristics of an actual network. The vertices representing nodes are randomly distributed on a rectangular coordinate grid. Each vertex has integer coordinates. For a pair of vertices, say u and v ($0 \leq u, v \leq 1$), an edge is added according to the following probability [8, 10, 9]:

$$P_e(u,v) = \frac{k\bar{e}}{N_t}\beta \exp\frac{-d(u,v)}{L\alpha}, \tag{1}$$

where N_t is the number of vertices in the graph, $\bar{e}$ is the mean degree of a vertex, k is a scale factor related to the mean distance between two vertices, $d(u,v)$ is the Euclidean distance between vertices u and v, L is the maximum distance between any two vertices in the graph, and α and β are parameters (real numbers in between 0 and 1). Once the vertices and edges are generated, we can be sure the graph is composed of only one component.

Next, satellites and their links are added to construct an ST network. The N_s vertices representing the satellites are randomly distributed as are those representing terrestrial nodes. The edges representing satellite links between the satellites and the nodes are randomly added with probability P_s. They are added regardless of the distance between vertices because satellite links can cover a wide area and are independent of distance.

The satellite cost and satellite link cost is determined as follows. The cost of the vertex representing satellite node i is $\sum_{e \in D_i} distance(e)/h$, where D_i denotes a set of edges which are incident to vertex i, $distance(e)$ denotes distance of edge e and h denotes a positive real number. The cost of the edges representing satellite links is set to 0. The multicast tree costs less when many nodes use satellite links because the satellite cost is set lower than the sum of the edge costs (distances).

In the simulations, we used a probability model to generate the sequence of requests to add and remove nodes. The probability model determined whether the request was to add a node or remove it.

$$P_c(q) = \frac{\gamma(N_t - q)}{\gamma(N_t - q) + (1-\gamma)q}, \tag{2}$$

where q is the current number of nodes in the multicast group, and γ ($0 \leq \gamma \leq 1$) is a parameter (a real number). Parameter γ determines the size of the multicast group in equilibrium. The satellites are not added; they work only as intermediate nodes.

We compared the proposed algorithm with two greedy algorithms. One greedy algorithm, is simply applied; we call it the "greedy algorithm". In the case of the greedy algorithm, the satellite costs are simply the vertex costs. The other is the original greedy is applied to a graph whose edges have costs, which is a modified version of the original edge-vertex-weighted graph; we call it the "modified greedy algorithm". In the case of the modified greedy algorithm, the cost of each satellite link is set to the satellite cost divided by the number of its links, and the satellite cost itself is set to 0.

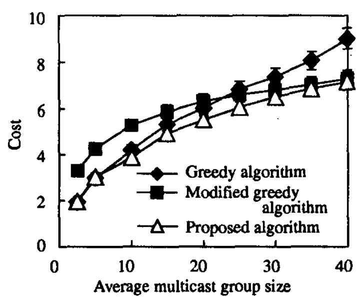
In the simulations, we generated ten different networks and calculated the average tree cost of them. The cost is used as a measure of performance and includes the sum of link costs and satellite costs on the multicast tree. Each multicast connection consists of a sequence of 20,000 requests to add or remove nodes. The costs for the first 2,000 requests were not used in calculating the average costs, to negate the effect of the initial conditions in the simulation. Table 1 shows the default values of the parameters in the simulations.

5 Simulation Results

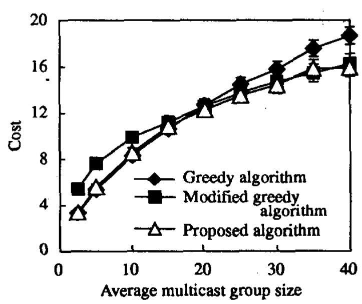
The relationship between tree cost and average group size is shown in Fig. 3 for 50 and 150 terrestrial nodes.

Table 1: Parameters used for simulations.

Item	Value	Item	Value
N_s	3	e	3
α	0.25	k	25
β	0.20	P_s	0.4
h	7		



(a) Tree cost for 50 terrestrial nodes.



(b) Tree cost for 150 terrestrial nodes.

Figure 3: Tree cost for 50 and 150 terrestrial nodes.

In the first case, almost all the nodes could be directly connected to a satellite because the average number of satellite links was 20 ($N_t \cdot P_s$) and the number of satellites was 3. The cost of the proposed algorithm was lower than the costs of both the greedy and modified greedy algorithms on the whole. For the smaller average group sizes, the cost of the proposed algorithm was almost the same as that of the greedy algorithm. This is because the satellite costs are relatively high for a smaller group, so satellites are not usually selected as intermediate nodes. For the larger average group sizes, the cost of the proposed algorithm was almost the same as that of the modified greedy algorithm. This is because, in the modified greedy algorithm, the satellite costs are relatively low for a larger group, so satellites are usually selected as intermediate nodes.

When there were 150 terrestrial nodes (Fig. 3(b)), all nodes could not be connected to a satellite directly because the average number of satellite links was 60 and the number of satellites is 3. In this case, the cost of the route using satellite links was higher than that in the case having 50 nodes. Still, the characteristics were about the same as when the case of the number of nodes was 50.

6 Conclusion

We have studied the dynamic routing problem for satellite-terrestrial networks and have developed a dynamic routing algorithm based on the virtual cost of satellites. Future study includes examining the case where clients are directly connected by satellite links (a "satellite Internet") and implementing an actual network architecture such as those in ATM or IP networks.

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