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A Multiple Tree Routing for Multipoint-to-Multipoint Communication

Vorawut PRIWAN, Hitoshi AIDA and Tadao SAITOH
The University of Tokyo

1. Abstract

In this article, we study a routing method for the multipoint-to-multipoint communication such as virtual space teleconferencing. The connection approach of this multipoint-to-multipoint service is based on constructing multiple multicast tree routes that each participant (site) has one own multicast tree connecting to the other participants. The optimization goal is to lower cost of all tree of the connections. We propose a heuristic algorithm for this routing method and we show its computer simulation results.

2. The Multiple Tree Routing

The multipoint-to-multipoint communication such as virtual space teleconferencing requires a fully connected network. For a Z-participant (Z-site) video conference, each site transmits one signal and receives Z-1 signals. As a result, the bandwidth required to support the service increases as the number of nodes in the service increases.

The connection setup procedure by multiple direct point-to-point circuits is not an appreciate approach that the connection would be setup for Z(Z-1)/2 circuits such that a large number of bandwidth allocation are required. The connection approach is would better be based on constructing a Z-participant connection which has Z multicast tree paths in the connection. All of Z multicast tree paths are determined and implemented simultaneously that we can optimize the whole cost of the connection. Each participant (site) has one own multicast tree for sending information to the other participants. This approach can lower costs for the subscribers and conserves bandwidth resources for the network providers.

3. Network Constraints and Optimization Objective

Before proceeding, let consider some notations:

- $G = (V,E)$ is a connected graph, where V is a set of nodes, E is a set of links, $\{l(i,j) \mid i \in V, j \in V\}$.
- c_{ij} (≥ 0) is the cost of link $l(i,j) \in E$.
- Z is the set of the participant nodes, $Z \subseteq V$.
- f^k is the amount of traffic flow (bandwidth requirement) of participant node k, $k \in Z$.
- Define $Z^k = Z - \{k\}$, $k \in Z$. Let $x^k{}_{ij} = 1$ if link $l(i,j) \in E$ is in the solution tree of participant node k, 0 otherwise.
- $p(u,v)$ is the minimum cost path between node u and v. $C(p(u,v)) = \sum_{l \in p(u,v)} cost(l)$, is the total cost of path $p(u,v)$.
- $p(u,v;T)$ is the minimum cost path between node u and v in tree T. $C(p(u,v;T)) = \sum_{l \in p(u,v,T)} cost(l)$, is the total cost of path $p(u,v;T)$.
- T^Z is the set of solution trees. The solution tree of participant k, $T^k \in T^Z$, that the source of traffic is node k, span the set of nodes Z^k.

We study the constraints of the multipoint-to-multipoint routing problems in two functions, the individual path delay and available capacity of link. We define two constraints directional functions, d_{ij} and b_{ij} on link $l(i,j)$. d_{ij} is a positive real delay function and b_{ij} is a positive real capacity function, on link $l(i,j)$ in the direction of traffic flow from node i to node j. Given a delay tolerance D, the tree of participant k, T^k, that spans the node in Z^k such that for each node $z \in Z^k$, the delay on the path that the traffic flow from k to z is bounded above by D. Formally, for each $z \in Z^k$, if $p(k,z;T^k)$ is the path in T^k from k to z,

$$\sum_{l(i,j) \in p(k,z;T^k)} d_{ij} \leq D \quad \forall k \in Z \qquad (1)$$

In the connection setup procedure, the connection will be able to setup, if the total required bandwidth of each link is less than the available bandwidth for the service on the link. For each link $l(i,j)$, the available capacity constraint of each link can be defined as,

$$\sum_{k \in Z} f^k x^k_{ij} \leq b_{ij} \quad \forall l(i,j) \in E \qquad (2)$$

Formally, the optimization objective can be written as,

$$\text{minimize} \sum_{k \in Z} f^k \sum_{l(i,j) \in E} c_{ij} x^k_{ij} \qquad (3)$$

subject to

Multiple tree shaped routes (4)

and the constraint functions are the bounded delay of each individual path, Eq. (1), and the available capacity constrained on each ink, Eq. (2).

4. A Heuristic Algorithm

We apply Lagrangian relaxation to simplify the problem. We associate nonnegative Lagrange multipliers w_{ij} with the available capacity constraint, Eq. (2), creating the following Lagrangian subproblem:

$$L(w) = \min \sum_{k \in Z} f^k \sum_{l(i,j) \in E} (c_{ij} + w_{ij}) x^k_{ij} - \sum_{l(i,j) \in E} w_{ij} b_{ij} \qquad (5)$$

Note that since the term $-\sum_{l(i,j)\in E} w_{ij} b_{ij}$ in the objective function of the Lagrangian subproblem is a constant for any given choice of the Lagrange multipliers, for any fixed value of there multipliers, this term is a constant. The resulting objective function for the Lagrangian subproblem has a cost of $c_{ij}+w_{ij}$ associated with $x^k{}_{ij}$. Consequently, to apply the subgradient optimization procedure to this problem, we would alternately:

(1) Solve a set of minimum cost delay constrained trees with the cost coefficients $c_{ij}+w_{ij}$.

(2) Update the multipliers by the subgradient update formula[2].

In **(1)**, the problem of finding a set of minimum cost delay constrained trees with the cost coefficients $c_{ij}+w_{ij}$ is NP complete. We propose a heuristic algorithm for finding the bounded delay constrained minimum cost trees as illustrated in the follow.

Define $\sigma(p(i,j))$ to be the delay of path p(i,j) in the direction from i to j, $C_d(i,j)$ to be the minimum cost path from node i to node j with the delay d, $P_D(i,j)$ to be the delay D constrained minimum cost path between node i and node j, where

$$P_D(i,j) = \min_{d \le D} C_d(i,j) . \qquad (6)$$

The procedure of the algorithm is described as follow.

(1) For all pairs of nodes v, w in the set Z, in both directions of v to w and w to v, find the delay constrained minimum cost paths $P_D(v,w)$ if they exist.

(2) For each participant node k, $k \in Z$, build the delay constrained minimum cost tree $T^k{}_D$ as the following step.

(2.1) Initialize subtree $T^k{}_D$ by defining as the source node k.

(2.2) Repeat the following steps until all destination node z in Z^k are in $T^k{}_D$.

(2.2.2) Choose the pair of node u in $T^k{}_D$ and node z' in Z^k ,that yields the minimum path cost C(p(u,z')) and $\sigma(p(k,u;T^k{}_D))+\sigma(p(u,z'))\le D$.

(2.2.3) Add the path p(u,z') to $T^k{}_D$. If the added tree $T^k{}_D$ has loops, prune the unnecessary branches in loops, which is not satisfied the condition $\sigma(p(k,z';T^k{}_D))\le D$.

The computation time of this heuristic method is $O(|V|^4)$.

5. Simulation Results

The network topology is constructed by random graph[1]. Fig. 1 shows the characteristics of average total cost versus the bounded delay constraint in the multiple directed point-to-point circuit routing and the multiple tree routing, where the number of nodes in graph is 30 and the number of participants is 10. The multiple tree routing yields better cost performance than the multiple directed point-to-point circuit routing.

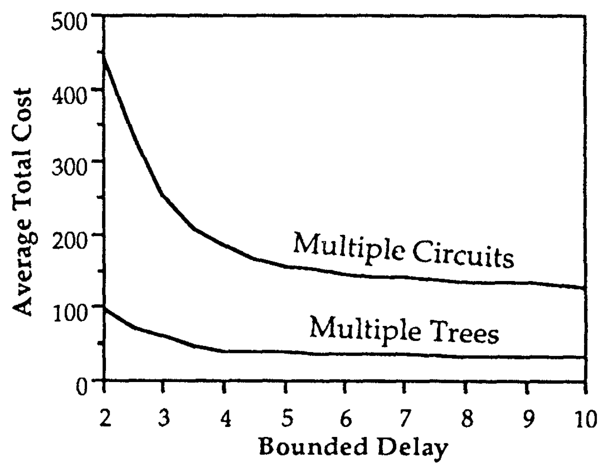

Fig. 1 Comparison between the multiple directed point-to-point circuit routing and the multiple tree routing

References

[1] B. M. Waxman, " Routing of Multipoint Connections," *IEEE J. Select. Areas Comm.*, Vol. 6, pp. 1617-1622, 1988.

[2] M. Held, P. Wolfe and H. P. Crowder, "Validation of Subgradient Optimization," *Math. Program.*, Vol. 6, pp. 62-88, Jan. 1974.