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An Efficient Dynamic Routing Scheme for Delay-Bounded Multicasting

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ABSTRACT

The purpose of multicasting is to reduce the network costs for transmitting the same traffic to multiple destinations. In this paper, an efficient delay-bounded multicasting routing algorithm is proposed, which satisfies the network conditions of cost minimization and can adjust the dynamic events, such as 'leave and/or join ones' from the multicast group. Also, our algorithm is designed for various network requirements such as the efficient dynamic group support, high-quality data distribution, and adaptability to variable situation. After the delay tolerance and the maximum group size are determined according to network state and requirements for delay and cost, the dynamic delay-bounded multicast tree is constructed using partial multicast routing. We evaluate the performance of the proposed algorithm by running simulations on randomly generated test networks using a Sun Sparc 20 workstation. We were able to obtain good simulation results, which means optimal solutions that lies between the minimum cost solution and the minimum delay one.

I. Introduction

Multicasting is the ability of sending a message to multiple recipients at possibly different locations in communication networks. A good example is a multi-site audio/video conference as well as the distributed simulations and games.[1][2] Furthemore, various future applications such as teleconferencing, medical imaging, environmental remote sensing, distance education, defense and intelligent systems will demand network capability to store and manage a very large amount of data. The data often needs to be processed in real time and distributed to end users who are widely separated in the geographical locations, which may be often needed in these systems to transmit the same data simultaneously from one source to two or more destinations. Therefore, multicasting, simultaneous transmission of data to multiple recipients, is becoming a key requirement for data networks supporting multimedia applications, which will be likely an essential part of future networks, especially Broadband(ATM) networks.

The current approach to supporting a muticast session efficiently in the network consists of establishing a multicast tree for the session, along which session information is transferred. Routing algorithms called "Multicast routing algorithm" are needed in the network for constructing multicast tree.[3] The most popular solution to multicast routing uses the tree construction since the data can be transmitted in parallel to many different destinations along the paths of the tree, and a minimum number of copies of the data

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need to be transmitted, with duplication of data being necessary only at branches in the tree.[2][4] Up to now, many optimization techniques for multicast routing and many algorithms for constructing multicast trees have been proposed. A heuristic argument was proposed for multicast tree construction that depends on bounded end-to-end delay along the paths from source to each destination, and minimum cost of the multicast tree, where edge cost and edge delay can be independent metrics.[4] Fred bauer and Anujan Varma[7] studied algorithms for finding efficient multicast trees in the presence of constraints on the copying ability of the individual switch nodes in the network, modeled it as the degree constrained Steiner problem in network. They formed that efficient multicast trees can be found in large, sparse networks with small multicast groups even with limited multicast capability in the individual switches. The problem of optimal distribution of destinations was investigated by Nacham Schacham[8], which subject to their requirement and limitations on variable link capacities, using the 'bids' to express user's requests. In addition, a generalization of multicast was studied, which sends a message to any q-subset out of a selected group of m nodes in a system of n nodes.[5] Also, an interesting heuristic algorithm was investigated for constructing minimum cost multicast tree with delay constraint, based on a feasible search optimization method which starts with the minimum delay along tree and monotonically decreases the cost by iterative improvement of the delay-bound tree.[6] Meanwhile, Fred bauer[7] introduced and evaluated two distributed algorithms for finding multicast trees in point-to-point data networks based on the centralized Steiner heuristics, considering the shortest path and the Kruskal-based shortest path heuristics.

Recently Stephen Deering[10] suggested a protocol independent multicast(PIM) architecture, which maintains the traditional IP mullticast service model of receiver initiated membership and supports both shared and source specific destination trees. Also, there have been a number of proposals for multicast transport protocols, such as XTP as a combined network and transport protocol, ST-II(Experimental Internet Stream Protocol Version 2), MTP(Mulicast Transport Protocol) as a transport level protocol designed to support efficient, reliable multicast transmission, RTP as a transport protocol of real time data, and extensions to the simple and heavily used UDP(User Datagram Protocol). Multicast-based services using Deering's multicast extension to IP are already in use over the Multicast Backbone(MBONE) overlay on the Internet, where applications such as Jacobson's vat audio have met with considerable success. IP multicast is an extension to the standard IP network level protocol that support multicast traffic, which is to transmit an IP datagram to a "host group", a set of zero or more hosts identified by a single IP destination address.

It is mentioned that the purpose of multicasting is to reduce the communication cost for applications that send the same data to multiple recipients. Furthermore the situation may be more complicated when the network conditions (which means, here, variation of multicast group membership) will be changed fast. In the case of link-state protocols, changes of group membership on a subnetwork are detected by one of the routers directly attached to that subnetwork and that router broadcasts the information to all other routers in the same routing domain. For extending multicast to the wide area, the existing link-state and distance-vector multicast schemes have good scaling properties only when multicast groups densely populate the network of interest.

In this paper, we propose an efficient multicasting routing algorithm that satisfies the network conditions of delay constraints, cost minimization and can adapt to dynamic conditions of adding and leaving a node from the group. We consider the following network requirements such as the efficient dynamic group support, high-quality data distribution, and adaptability to dynamically changing events. First of all, the delay tolerance and the maximum group size are determined according to the characteristics of the network such as link delays and link costs. And then we construct the dynamic delay-constrained minimum cost multicast tree, using the partial multicast, which is to operate for each dynamic node according to network state and link state.

The remainder of this paper is organized as follows :in Section 2, the network model for multicasting will be described. Then we explain our proposed algorithm, in Section 3. In section 4, numerical results and their implications will be discussed. Finally, Section 5 concludes this work and discusses possible projects.

Ⅱ. Network Model

A network can be modeled as a weighted graph G =(V, E) with node set V and edge set E, and two functions C(e) and D(e) on edge e, where C(e) is a positive real cost function and D(e) is a positive integer delay function on e. On this graph, we define that a source node s and a set of multicast destinations $D \subseteq V$, called the multicast group, and we assume that this graph is undirected for simplicity. We then define a connection request r_i to be a pair (D, Δ) where Δ is delay tolerance. Also, we define a route $R_{r_i}=(\hat{D}, \hat{E})$ for a connection request(r_i) to be a connected subgraph of G such that $D \subseteq \hat{D}$ and the delay constraint satisfies the condition given by the equation (1).

$$(^{\forall}e \in \hat{E})(d(e) \leq \Delta) \qquad (1)$$

We note that the negotiation may be necessary if there may not be any route satisfying the above condition for a given connection request. First we can consider the static multicast problem stating that For a given network N and a connection request r_i, it is to find a route R(r_i) such that has a minimum value among the all possible routes for r_i.

The Steiner tree problem is a specific version of this problem. Consider the sample network shown in Figure 1, which will be used again in next section to explain our algorithm. In this network there are four constrained paths from A to C satisfying delay bound Δ = 8, which are AB-BE-ED, AE-ED, AE-EC-CD, and AF-FE-EC-CD with costs of 9, 6, 5, and 10 respectively. Thus, the path AE-EC-CD can be selected as optimal one based on the path cost, since its cost is smaller than the others. For the dynamic multicast problem, we consider a network N with a sequence of requests $S=\{r_1, r_2, r_3, \ldots r_n\}$ where each r_i is a pair (r_i, v, d_v), $r_i \in C$, $v \in V$, d_v={join, leave}, where C is a set of connection identifiers. Each request include a node of the network which is to be either added to or removed from a connection. Now we are interested in constructing of *DDMST*(Dynamic Delay-bounded Minimum *Steiner* Tree), and the optimization problem can be described that for given a graph G=(V, E) with two weighted functions C(e) and D(e) on edge e, a source S, a set of destinations D, and considering the dynamic condition with a sequence of connection requests, it is to construct Dynamic Delay-bounded Minimum *Steiner* Tree such that the cost function C (e) is minimized while delay condition (1) is satisfied.

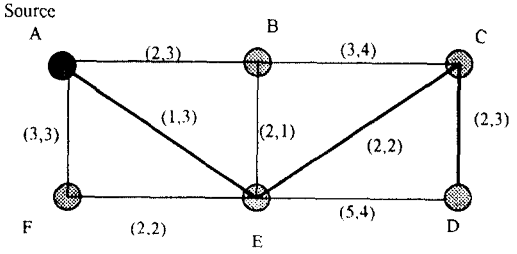


Fig. 1 An example of a delay-bounded optimal path from A to D for Δ = 8 with each link (cost, delay)

Ⅲ. An Algorithm for Dynamic Multicast Routing

In order to find a solution of the problem described in section 2, we have developed a heuristic argument for the dynamic multicast algorithm assuming that only one connection request with the identities of the destination nodes is given to the routing algorithm at one time. Also our algorithm is based on the delay constrained minimum spanning tree algorithm.

3.1 Management of group size and priority queue control

To do multicasting, group management is required. Some way is need to create and destroy groups, and for process to join and leave groups. It is important that each router knows which of their hosts belong to which groups. Multicasting, as we mentioned, is necessary for the simultaneous transmission of data to multiple destinations. The group membership size has influence on the performance of multicasting, which will be shown in Figure 4. Thus we tried to control the size for best performance according to various situations. We define the maximum group size as $\sigma_{\max}$, the minimum group size as $\sigma_{\min}$, and the current group size as σ_c. The value of $\sigma_{\max}$ can be determined at the beginning or at the time of reconstruction of the tree. The current group size may be variable whenever dynamic events occur. The value of σ_c, however, will be restricted to $\sigma_{\max}$ after σ_c is equal to $\sigma_{\max}$. To solve this situation, priority queue can be used to keep the priority order for joining the multicast group. The queue size(Σ) can be set to $n(V)-\sigma_{\max}$, where $n(V)$ is the network size. The minimum spanning tree is maintained even if a node leaves a group. The node turns into an intermediate node unless it is not the end node in the tree. If it is the end node, it will be removed off from the tree. When the group size decreases to $\sigma_{\min}$, the tree will be reconstructed as shown in Figure 2.

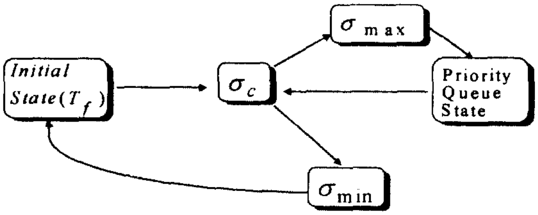


Fig. 2 State diagram for dynamic events

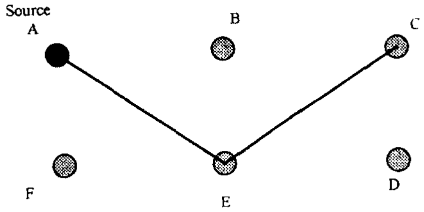
3.2 Description of the proposed algorithm

Here, a dynamic multicast routing(DMR) algorithm will be proposed, which has been studied with focusing how to construct an optimal DDMST based on both a MST approximation algorithm due to P. winter and F.K. Hwang[21][24] and the algorithm for a constrained minimum spanning tree due to V. P. Kompella.[4] Here, it is assumed that the source node has sufficient information about network links to construct a delay bounded multicast tree. This requirement can be supported using one of many topology-broadcast algorithms, which can be based on flooding or other techniques.[3][17] The feasible search optimization and the partial multicast paradigm are also fundamental to our algorithm. Also, the feasible region for the DMR problem consists of the set of all delay-bounded steiner trees. The details of proposed DMR algorithm are as follows.

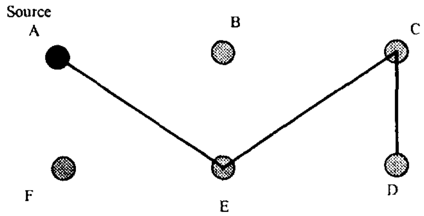
1. First, the maximum and the minimum group sizes are determined due to network link states, which may be negotiable according to network requirement.
2. Second step is to construct a fundamental delay-bounded minimum spanning tree(T_f) from the constrained closure graph.
3. Then, examine whether there is a delay constrained minimum spanning tree which satisfies the initial conditions or not. If not, it may be tried to reconstruct a new constrained minimum spanning tree by the negotiation for solving the violations.
4. Find an optimal delay-bounded spanning tree (T_b) to minimize the cost in case of the consequent dynamic events={join, leave}.
5. Whenever a node joins or leaves a multicast group, σ_c increases or decreases one by one, and return to T_f.
6. In case of the join event, first of all, it is examined that the current group size may exceed the maximum group size.
7. If the current group size exceed the maximum group size, it should wait for joining in the pri-

ority queue until it will be permitted.

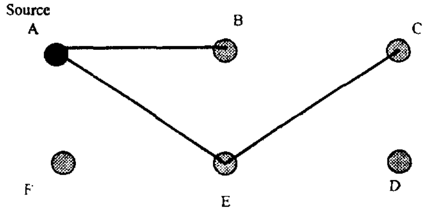
8. Otherwise, try to find the shortest direct node from this node to any nodes in the group without violating the delay bound. If there are no direct nodes, find the shortest path from the source node.
9. And then connect the node which the path intersects with the group node while delay constraint is satisfied. If not, return to step 2.



(a) DDMST for the sample network with multicast group set {A, C, E}



(b) DDMST after node D joins : group set {A, C, D, E}



(c) DDMST after D leaves and B joins:group set {A, C, E, B}

Fig. 3 Dynamic Delay-Bounded Minimum Spanning Tree for each event : the initial network with multlicast group set {A, C, E}

10. When a node failure happens, it will be proceeded to reconstruct a new delay constrained minimum spanning tree with getting rid of the node
11. The last step is to update the routing table and manage the priority queue for the control of group membership size according to the requirements and link status.

Fig. 3 shows the example network with a sequence of three events handled by the dynamic algorithm described above. The dynamic event 1 is assumed as the case node D joins in the group, and the event 2 as a case that node B joins and node D leaves. The initial network with multlicast group set {A, C, E} is shown in Fig. 3(a), assuming that a delay bound is 8 units. Fig. 3(b) shows the DDMST after node D joined in the group, considering the delay bound and minimum cost condition. The result for event 2 is illustrated in the Fig. 3(c).

Ⅳ. Performance Evaluation

We evaluate the performance of the proposed DMR algorithm by running simulation, written in C++, with randomly generated test networks on a Sun Sparc 20 workstation. For the exact performance evaluation of our scheme, we generate the random graphs which have some of the characteristics of real networks in a manner similar to that proposed in [2]-[4].

4.1 Simulation model

The n nodes of a graph are randomly distributed on a Cartesian coordinate plane, and the (x, y) coordinates of each node was chosen between (0, 0) and (Ω, Ω), creating a forest of n nodes spread across the plane. The value of Ω was set to 10 for the simulation, therefore the maximum distance is 100. The nodes are then connected by a random spanning tree, which edges are chosen by examining each possible edge (x, y) and generating a random number $0 \leq p < 1$. If p is less than the probability function P(x, y), then the edge is accepted. We used the probability function given by

$$p(x, y) = \mu * \exp^{-\frac{-d(x, y)}{d_{\max} v}} \tag{2}$$

where $d_{\max}$ is the maximum value among all possible distances between two nodes, and d(x, y) is the distance between them. The parameters μ and v govern the density of the graph. An increase of v raises the number of connections to distant nodes, and as the value of μ increases, the number of edges also increases from the end node. We chose $v = 0.2$, 04, $\mu = 0.1 \sim 0.4$, after some experiments, for generating the graphs used in this simulation.

We believe that these values produced networks of realistic density enough for being regarded as ones of representing the characteristic of the real network. The cost of each edge was set to the distance between its end points, thus the maximum value of the cost is 100. Also, the delay of an edge is set to a uniform random number in [0, 100] time. In order to determine if an event will be added to or deleted from a node from the connection, we consider the probability model obtained by the same method proposed in [2], with the probability function given by

$$P_c(k) = \frac{\sigma(n-k)}{\sigma(n-k) + (1-\sigma)k} \tag{3}$$

where Pc is the probability that an event is the addition of a node, k is the number of nodes in the group of the current connection, n is the network size, and σ is a parameter in (0,1).

4.2 Numerical Results

In this section we present the simulation results of dynamic multicast routing algorithm. Our DMR algorithm was run on 25-, 30-, 50-, 70-, 80- and 100-node networks. For each experiment, DMR ran a sequence of 250 events using the fixed value for $\sigma = k/n$, for which $Pc(k) = 1/2$. We assume that the multicast trees are reconstructed in other algorithms, whenever an event occurs, because they are not able to adapt these situations. For the comparison of the algorithms, we use the average values of the final results.

Figure 4 shows the characteristics of the network cost of dynamic multicast solution as a function of group size. Here, we set the number of nodes is 100, and average degrees as 5 (CASE1), 6.9 (CASE2), and 8 (CASE3) respectively. It may be observed that as the group size increases, as expected, network cost increases. From this results, we may say that the group size should be restricted to obtain efficient network performance. For example, in order to get the performance with the cost below than 50%(CASE2), group size should not exceed 30% of the network size.

The results shown in figure 5 indicate the characteristics of network cost versus the number of nodes, for the group size equal to 25% of the network size. The parameters used in these experiments is represented in detail in table 1. To compare the performance of our solutions with other solutions, the delay bound of dynamic multicast solution was set to those of the corresponding solutions. In these figures, the IMP-MST means the cost of Improved Minimum Spanning Tree, which is the optimum cost solution, even though with the unconstrained delay, while the MDS means Minimum Delay Solution using Dijkstra's algorithm, which is the optimum delay solution, regardless of the network costs. DMR-0 means the cost of dynamic solution with bound equal to maximum delay in the minimum delay solution. DMR-1 is the cost of dynamic solution with bound half the value between that of the minimum delay solution and that of IMP-MST. We note that the cost of MDS may decrease even though number of node increases between some interval, due to the difference of both traffic distribution and the degree of node in test networks. The cost of the DMR solution with the delay bound set to half way between two extremes of IMP-MST and MDS is nearly identical to that of the IMP-MST solution, which is optimal cost solution. This is a desirable property, since it means that our algorithm converges to optimal solution. By choosing the appropriate values for the delay bound, we can obtain the optimal solution, between the optimal cost solution and the minimum delay solution.

Figure 6 shows the characteristics of network cost of dynamic multicast solution as a function of the delay tolerance, Δ. It is assumed that the number of nodes is 100, average degree = 5, group size = 6, 8, and 10, respectively. As the delay tolerance increases, from the value of minimum delay solution to middle value between minimum cost solution and minimum delay solution, network cost decreases to optimal one. In figure 7, we can see the results of one set of simulations on the test network with 50 nodes, which show the network costs of dynamic solution according to the sequence of dynamic events. We assume that the network size is 50, average degree = 5, initial group size = 13, and maximum group size = 15, which is the value equal to the 30% network size. They show the network cost converges between 270 and 300 even though dynamic events happened, which means our algorithm performs well for each event. In this figure

Table 1. Parameters for experiments

# of nodes		25	30	50	70	100
Delay	DMR-0	125	80	110	170	200
Tolerance	DMR-1	156	196	262	215	460
Average degree		5.04	5.06	4.84	5.0	5.04

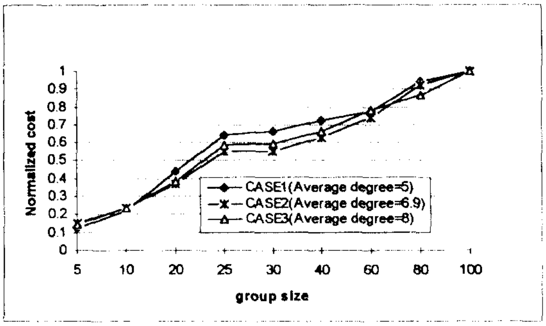


Fig. 4 Normalized network cost of dynamic multicast solution as a function of group size for different average degrees. (Number of nodes = 100)

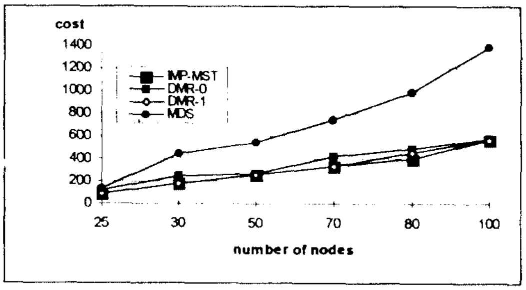


Fig. 5 Network cost versus number of nodes, comparing DMR with IMP_MST, MDS, for the group size equal to 25% of the network size.

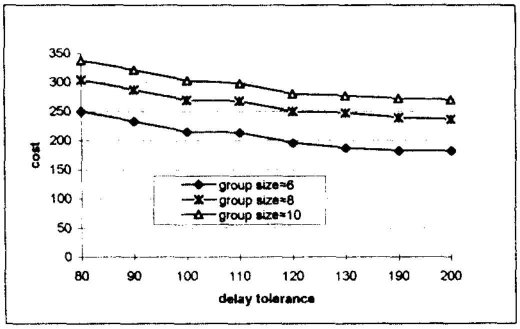


Fig. 6 Network cost of dynamic multicast solution as a function of delay tolerance(Δ), for different group size. (number of nodes = 100, average degree = 5)

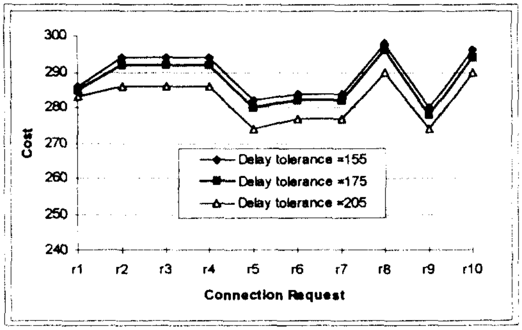


Fig. 7 Network cost of DMR solution versus the sequence of dynamic events (assuming 10 events) for the different delay tolerance(Δ). (number of nodes = 50, average degree = 5)

we can see also a little bit fluctuation according to connection requests, which resulted from the changes of network conditions. We note that they are the optimal solutions respectively, for the dynamic events. Finally we can conclude from these results that our scheme performs reasonably well for each event without violating the delay-bounded conditions.

V. Concluding Remarks

Multicasting can be considered as one of very important technologies, since it provides an efficient way for transmitting the same traffic to multiple destinations. Multicast routing problem is one of the essential problems to support multicast and broadcast communication services.

In this paper, an efficient delay-bounded multicasting routing algorithm has been proposed, which satisfies the network conditions of cost minimization and can adjust the dynamic events, such as 'leave and/or join ones' from the multicast group and adopts priority queue control scheme. Also, we have presented the problems and solutions of dynamic multicasting routing based on modifications of algorithms for the constrained Steiner tree, which is to guarantee the end-to-end delay bound from source to each of destination nodes.

According to network state and requirements for delay and cost, the dynamic delay-bounded multicast tree is constructed using partial multicast routing. The performance of the proposed algorithm was evaluated by the method of numerical analysis on randomly generated test networks. As a result we can say that by choosing the appropriate values for delay bound, the proposed dynamic multicasting routing algorithm satisfies the network conditions of delay constraints Possible future projects include dynamic quality-of service(QoS) routing schemes in all optical networks in order to support a wide range of QoS requirement.

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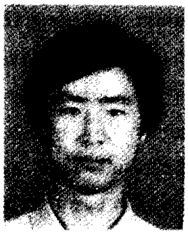

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