DYNAMIC MULTICAST ROUTING BASED ON THE MINIMUM CONGESTION PROBABILITY ROUTING[1]

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RELEVANT SYMPOSIUM TOPICS : Routing. (Multicast), Resource allocation and Quality of Service.

NOVELTY AND RELEVANCE

We study the establishment of point-to-multipoint virtual channel connection (VCC) in ATM networks which uses Virtual Paths (VP's). The purpose of this paper is to extend the "Minimum Congestion Probability Routing"(MCPR) algorithm in VP-based ATM networks proposed in [MAR95] to an adaptive multicast routing algorithm with constrained end-to-end cell loss probability. The problem of multicast routing is to construct a graph (tree or ring[2] topology). Based on MCPR, four multicast tree algorithms are designed for the dynamic multicast routing problem. The first algorithm extends the MCPR to the multicast routing problem, which is applied from a source to each destination. The second algorithm considers the partially formed tree, but the MCPR only permits direct routes. The third and the fourth algorithms enable alternative routes to construct the partially formed tree; alternative routes, where transit nodes are also a destination node, are priorised. Moreover, the fourth algorithm priorises some alternative routes over direct routes. Finally, multicast ring algorithms, when all (or several) nodes are simultaneously source and destination, are considered.

FULL PAPER CONTENTS

This paper starts with an explanation of the different ways to establish point to multipoint and multipoint to multipoint connections in ATM networks, different routing algorithms based on the routing cost function that we would minimise, different multicast routing problems depending of the membership changes and previous works.

Then, it will continue with the description of the proposed multicast routing algorithm based on "Minimum Congestion Probability Routing". Tree-based and ring-based algorithms will be presented. Performance evaluation of multicast routing algorithms based on simulations will be given. Finally, the discussion of future works will conclude the paper.

SUMMARY

New applications - as audio and video conferencing, replicated database updating, distributed resource discovery and shared workspaces - involve data delivery from multiple sources to multiple destinations. Multicasting is the ability of an application to simultaneously and efficiently transmit a single data packet to a set of receivers that are members of a multicast group. The problem of multicast routing is to construct a graph, so that the network resources utilisation can be maximised under the constraint that an end-to-end Quality of Service (QoS) must be satisfied from the source to the destination nodes.

Point to multipoint connections

Because ATM is connection oriented, a path has to be established between the source and the destinations before information can be exchanged. There are two basic ways of establishing point to multipoint connections in ATM networks :

- **Naïve approach.** A point to point virtual channel connection (VCC) from the source to each destination is established in this case. This approach leads to a simple implementation but clearly produces a non-optimal solution. The VVC set to each destination is known as a source-specific tree. The drawback is that it can require a large amount of network resources due to the duplication of data and the cost quickly becomes unacceptable.
- **Multicast tree**. A multicast tree, is a ring-free connected subnetwork spanning the source node and the group of destinations nodes. Using such trees, common copies of data are transmitted over the multicast tree; duplications of data

[1] This work has been supported by CICYT (Spanish Education Ministry) under contract TIC95-0982-C02-02
[2] Ring or circuit: A path in which the initial node coincides with the final node.

are avoided and therefore use network resources efficiently. However, finding an optimal multicast tree, called the multicast tree problem, is not easy, and more efficient algorithms are needed.

In [HWA96], Hwang and Huang focus on designing multicast routing algorithms for ATM networks. They limit the study to the multicast routing problem in homogeneous VP networks. They are interested in developing **adaptive multicast routing algorithms** in which routing decision is made based on network state information. Four multicast routing algorithms are proposed in this paper : i) the deterministic reservation multicast algorithm, ii) the deterministic reservation multicast algorithm with dynamic VP capacity sharing, iii) the deterministic reservation multicast algorithm with intermediate exits and iv) the deterministic reservation multicast algorithm with dynamic VP capacity sharing and intermediate exits.

Routing cost function

The objective of a multicast routing algorithm is to find a path from the source to each destination minimising a routing cost function. From this point of view, a multicast routing can be classified into:

- **shortest path algorithms**, which attempt to minimise the cost of each path from the source node to each destination;
- **minimum Steiner algorithms** [HAK71], which attempt to minimise the total cost of the multicast tree and was shown to be NP-complete [KAR72];
- **constrained Steiner tree algorithms**, which attempt to construct a minimum cost multicast tree without violating the constrained implied by the upper bound. These are presented when it is necessary and sufficient for the network to satisfy a given bound, i.e. it is not necessary to minimise the cost of each path.

Membership changes

The multicast routing problems are classified into two categories depending of the membership changes [WAX88], static and dynamic. In the **static version**, the group of destinations nodes is fixed during the connection and the identities of all destination nodes is available to the multicast routing algorithm at once. Paths from the source to all destinations are computed at the same time and the multicast session is established. In the **dynamic version,** the group of destinations nodes can change during the connection and the identities of the destination nodes is revealed to the routing algorithm one by one. Thus, the routing algorithm needs to build a multicast tree with partial information. Under these conditions, the computation of an "optimal" spanning tree for each new multicast group may not be the best way to proceed.

In [HWA95], Hwang proposed a new approach toward multicast routing in single rate loss in which destination nodes join or leave the multicast tree dynamically. Based on the maximum free circuits routing concept, two algorithms are proposed for the **dynamic multicast routing** problem and one algorithm is designed for the **static multicast routing** problem. Dynamic versions are based on the shortest path model with minimum path cost, and the static version is designed based on the minimum spanning tree concept. A new performance metric, the fractional reward loss, is proposed for evaluating these three routing algorithms.

Multipoint to multipoint connections

In the current standards for ATM, the multicast group address abstraction does not exit. The sender should be aware of all the members of the multicast group. Multipoint-to-multipoint (Many-to-many multicast) is supported through point-to-multipoint VCC's. There are some approaches :

- The simplest way is to establish a **separate tree** from each source to all destinations. The main problem with this method is the complexity. There are as many point-to-multipoint VCC's as sources, as they all have to be controlled and managed.
- The other way is to establish a **single tree shared** by all of the source nodes to send traffic for all destination nodes. We can distinguish this from the Steiner problem by observing that this family of algorithms is aimed at multiple sources / multiple destinations, as opposed to single source / multiple destinations scenario addressed by the Steiner tree. Designing a shared tree is like designing a tree per group. The shared approach does, however, suffer from traffic concentration, as the traffic from all sources of a given group will converge to the root of the tree.
- A model for multicast ATM called SMART has been devised by Gauthier et al. [GAU97]. They consider the provision of a "many-to-many" multicast service directly with an ATM network. It uses a shared tree approach together with an access protocol based on the use of special resource management cells to determine which source may send when.

When all (or several) nodes are simultaneously source and destination nodes the amount of resources required are reduced using a ring-based approach. In contrast with tree-based approaches, ring-based approaches are considered to build a tour for obtaining a ring for all nodes of the multicast group [OFE97]:

- The first approach has two steps: construct a tree to connect the nodes of the multicast group and build an Euler tour on this tree to obtain the virtual ring.
- The second approach is to find a minimum cost tour to visit each multicast node exactly once (i.e. a simple ring). This problem is known as the travelling salesman problem.

The Second approach has an advantage since each link is visited only once, whereas in the first approach the virtual ring results visiting each direction of a link. However, maintenance of a ring is more complicated than that of a tree. Thus, there is a trade off between constructing a ring and a tree to connect the nodes in a multicast group.

Minimum Congestion Probability Routing

In [MAR95], the Minimum Congestion Probability Routing (MCPR) algorithm based on dynamic alternative routing has been presented. The VCC is offered first to the direct route. If the direct route is unavailable, alternative two-VP routes are considered. If any alternative two-VP route is available the VCC is rejected. Note that for an alternatively routed VCC, cell loss can occur at either of the two VPs. End-to-end Quality of Service (QoS) requirements are divided in equal shares among the VPs of the two-VP alternate route (*even QoS division policy*).

The objective of MCPR algorithm is minimising the Congestion Probability from the source to the destination. The performance criteria by the Connection Admission Control (CAC) are the Individual Cell Loss Probability (CLP) requirements and the Probability of Congestion (PC) was applied to the route selection. An alternative route is only considered if the PC on each VP, of the alternative route, is smaller than a threshold: the Routing Control Parameter (RCP). When the RCP is used, some amount of PC is reserved for direct traffic into a VP. In bufferless environments, the PC and the Individual CLP can be calculated by using the New Convolution Approach (NCA) [FAB94] and [MAR97].

Results presented in [MAR95] show different network performances by changing the Routing Control Parameter and the load of the network, especially the load of the alternative route. Using alternative routes does not always decrease the call blocking probability of the network. The Routing Control Parameter overcomes this drawback.

MCPR-based multicast routing algorithm

The purpose of this section is to extend the MCPR algorithm in VP-based ATM networks to an adaptive multicast routing algorithm with constrained end-to-end cell loss probability.

Construction of the multicast trees

The minimum Steiner algorithms [HAK71] were shown to be NP-complete [KAR72], there are clearly some applications for which the set of destinations will be dynamic [WAX88], [DOA93th], [ZHU95], [RAM96]. Adding or removing destinations to an existing Steiner tree may lead to a totally different Steiner tree. This may have repercussions on members who remain in the group, since there may be a disturbance in the communication, because several VCC may be torn down and rerouted. The multicast connection establishment procedure defined in [Q.93B] - the ITU-T draft recommendation protocol for call set up - requires setting up the destination nodes sequentially. A multicast connection is first set up establishing a point-to-point connection between the source node and the first destination node. After this set up is complete, additional destination nodes can be added sequentially.

Based on previous considerations, the practical use of multicast Steiner tree based algorithms in B-ISDN is questionable. Therefore, to establish the **dynamic** point-to-multipoint VCC we propose to add the destination nodes one by one to the tree. To connect a destination node to a partially-formed multicast tree the shortest route with minimum cost from the node to the partially-formed tree is chosen. The cost of a route is the sum of VP costs on the route, which is computed as shown before.

On the other hand, the **static** version of the multicast tree problem will be considered as a particular case of the dynamic version where the available identities of the destination nodes are revealed one by one in a random order. In this case, the solution obtained is not optimal. The optimal solution could be obtained if all possible order are considered.

As Hwang in [HWA95], we assume that the VP network is fully connected and the number of VP to source from destination is limited to two, that the multicast tree is non-rearrangeable, (i.e., the routing algorithms are not allowed to modify the existing multicast tree except to add new nodes and links) and that remove of a destination node from a multicast tree dynamically is not considered.

There are some differences between our approach and related work [HWA95] and [HWA96]. We study the multicast routing problem in heterogeneous VP Networks. In multimedia applications, a call could consist in a number of connections of different traffic types which make it necessary to consider heterogeneous VP Networks. It can yield a better solution than homogeneous VP Networks because it facilitates media synchronisation and simplifies traffic management. On the other hand, the performance criteria by the CAC are Individual CLP requirements. The objective of the algorithm is to minimise the Probability of Congestion (PC) from the source to each destination node. The PC is applied as a route selection parameter. Traffic classes are not limited to on-off sources in our work, multi-state sources are also allowed. Finally, we consider that the Routing Control Parameter is used to restrict alternative traffic and prevent direct traffic when the VP is very busy.

In the following shedule, we propose four tree-based multicast routing algorithms:

NAIVE SOLUTION	(direct routes + alternative routes)[i]
SHORTEST PATH ADDITIVE SOLUTION	(direct routes from partially formed tree with QoS/2 + direct routes with QoS)[i]
SHORTEST PATH ADDITIVE SOLUTION USING ALTERNATIVE ROUTES	(direct routes from partially formed tree with QoS/2 + direct routes with QoS + alternative routes through implicated nodes + alternative routes)[i]
SHORTEST PATH ADDITIVE SOLUTION USING ALTERNATIVE ROUTES	(direct routes from partially formed tree with QoS/2 + alternative routes through implicated nodes + direct routes with QoS + alternative routes)[i]

Construction of rings. The travelling salesman problem.

Ring-based approaches are considered when all (or several) nodes are simultaneously source and destination nodes. To establish **dynamic** multipoint-to-multipoint VCCs we propose to add the destination nodes one by one to the ring. To connect the node k to the ring, the route Rij with minimum{Rik+Rkj-Rij} cost is chosen. The route Rij is replaced by Rik and Rkj routes. In this case, the QoS requirements are divided in equal shares among the VPs of the ring. The length of the ring is equal to the number of nodes.

Comparing the algorithms

The performance of these multicast routing algorithms is studied in VPNs, fully connected, where only one VP is established between each origin node and the corresponding destination node. Different heterogeneous traffic patterns and loads are considered. The parameters of interest are: the VP utilisation (in terms of load), the call blocking probability in each VP and the network call blocking probabilities.

Future work

The performance of the proposed algorithms will be studied when the set of destinations is dynamic, i.e. destinations joining and leaving the multicast group during the existence of the connection. Other possible scenario will be examined when the QoS requirements are different for each destination.

References

[DIO97] Ch. Diot, W. Dabbous and J. Crowcroft. “Multipoint Communications : A Survey of Protocols, Functions and Mechanisms”. *IEEE Journal on Selected Areas in Communications*, Vol. 15, nº 3, April 1997. pp. 277-290.

[DOA93th] J. M. S. Doar. “Multicast in the Asynchronous Transfer Mode Environment”. *Ph. D. Thesis*. University of Cambridge. January 1.993.

[FAB94] R. Fabregat-Gesa, J. Sole-Pareta, J.L. Marzo-Lázaro and J. Domingo-Pascual. “Bandwidth Allocation Based on Real Time Calculations Using the Convolution Approach”, *GLOBECOM’94*, pp. 788-793.

[GAU97] E. Gauthier, J-Y. Le Boudec and P. Oechslin. “SMART : A many-to-many multicast protocol for ATM”. *IEEE Journal on Selected Areas in Communications*, Vol. 15, nº 3, April 1997. pp. 458-472.

[HAK71] S. Hakimi, “Steiner’s Problem in Graphs and its Implications”, *Networks*, vol.1, pp. 113-133, 1971.

[HWA95] R.-H. Hwang. “Adaptive Multicast Routing in Single Rate Loss Networks”, *INFOCOM’95*, pp. 571-577.

[HWA96] R.-H. Hwang, "Multicast Routing in VP-based ATM Networks", *ICCCN'96*, Rockville, Maryland, USA.

[KAR72] R. Karp, “Reducibility Among Combinatorial Problems”, in *Complexity of Computer Computations*, (New York : Plenum Press), pp. 85-103, 1972.

[OFE97] Y. Ofek and B. Yener. “Reliable Concurrent Multicast from Bursty Sources”. *IEEE Journal on Selected Areas in Communications*, Vol. 15, nº 3, April 1997. pp. 434-444.

[Q.93B] CCITT, "Draft text for Q.93B", *CCITT Study Group XI*, 23 September- 2 October 1992.

[MAR95] J.L. Marzo, J. Domingo, R. Fabregat, J. Sole. “Dynamic Routing Based on a Single Parameter: Link Congestion Probability”. *High Performance Networking VI*. IFIP sixth international conference on high performance networking, 1995. pp. 307-318.

[MAR97] J.L. Marzo. "Enhanced Convolution Approach for CAC in ATM Networks, an analytical study and implementation." *Ph. D. Thesis*. University of Girona. 1997.

[RAM96] S. Ramanathan. “An algorithm for Multicast Tree Generation in Networks with Asymetric Links”. *INFOCOM’96*. pp. 337-344

[WAX88] B. Waxman. “Routing of Multipoint Connections”. *IEEE Journal on Selected Areas in Communications*, Vol.6. pp. 1617-1622, December 1988.

[ZHU95] Q. Zhu, M. Parsa and J.J. Garcia-Aceves. “A Source-Based Algorithm for Delay-Constrained Minimum-Cost Multicasting”. INFOCOM’95 pp. 377-385.