TECHNICAL RESEARCH REPORT

Multicast Routing and Resource Allocation in a Mobile Wireless Network Like the Digital Battlefield

by R. Bhattacharya, A. Ephremides

CSHCN T.R. 97-16
(ISR T.R. 97-48)

MULTICAST ROUTING AND RESOURCE ALLOCATION IN A MOBILE WIRELESS NETWORK LIKE THE DIGITAL BATTLEFIELD

Ruplu Bhattacharya
Anthony Ephremides

University of Maryland
College Park, MD 20742

ABSTRACT

"Multicasting" refers to the transmission of the same information to several destinations. In this paper we are addressing the issue of multicast routing in a wireless network that consists of an arbitrarily large number of nodes, each of which is mobile in an unpredictable manner. Most existing multicast algorithms have been developed for non-wireless, stationary networks in which there is an abundance of bandwidth and where intended destinations initiate their connection to the multicast tree. In the Digital Battlefield of the future, bandwidth may be limited if not scarce and, in addition to destination-initiated connections, there will be purely source-initiated multicasts that correspond to typical command or reconnaissance messages. In this paper, we establish the beginnings of a complete multicast algorithm that is capable of adapting to topological changes. More importantly, the algorithm is combined with dynamic channel allocation procedures that are capable of reassigning bandwidth resources on an as-needed basis throughout the network. Power control is applied to tradeoff between routing delays and number of connection requests satisfied. The goal of the algorithm is to establish and maintain the maximum number of connection requests while making efficient use of available bandwidth and avoiding congestion which might lead to network collapse.

I. INTRODUCTION

The Digital Battlefield (DB) of the future provides us with a novel environment in which to consider the problem of multicasting. It is possible that the network may consist of a large number of nodes (as high as in excess of 100,000). These nodes could be mobile in an unpredictable manner. This represents a very chaotic environment. As a result of motion, the topology of the network is subject to frequent, unpredictable change. The topology is also subject to change due to the destruction of nodes as a result of the on-going battle and the subsequent addition of new nodes. Because the network is assumed to be enormous, it may not be possible for any one node to have global topological connectivity information. All the nodes in the network may not have the same capabilities or resources. An example is the WIN [13] architecture which consists of hundreds or thousands of nodes that constitute the "plasmanet" and lesser amounts of nodes at higher echelons that are partially connected with the plasmanet below.

A major characteristic of the Digital Battlefield is the potential for congestion as a result of contention between different multicast and unicast connection requests. A network level algorithm is required which can handle this competition and create and maintain connections without choking the network while making maximum utilization of the scarce available wireless bandwidth.

Most of the research done so far on multicast routing is based on commercial, non-wireless, fixed networks with static topologies. In these settings resource reservation is generally possible as there is an abundance of bandwidth. Often, receivers individually decide if and when they want to be connected to the multicast tree. An example of this is a video-on-demand service.

Since bandwidth is limited in a wireless network, a multicast algorithm is required which combines the process of routing and resource reservation. Each node in the network should be able to execute this algorithm independently to decide which connection requests to

"Prepared through collaborative participation in the Advanced Telecommunications/Information Distribution Research Program (ATIRP) Consortium sponsored by the U.S. Army Research Laboratory under Cooperative Agreement DAAL01-96-2-0002."

accept, where to forward the requests if required to do so, which channels to allocate and at what power levels. For this, the node will need to gather information from surrounding nodes and evaluate a cost function(s) to manage the tradeoff between routing efficiency and network congestion. Our aim is to develop such an algorithm.

The rest of the paper is organized as follows. In section II, we describe some of the current literature on multicast routing. In Section III we describe some of our ideas on how to create multicast routes in the environment of the Digital Battlefield. Section IV summarizes our efforts so far. Section V concludes with a summary of the issue and our approach to the problem.

II. CURRENT MULTICAST ALGORITHMS[1]

Several multicast routing algorithms have been proposed for fixed network topologies like the Internet. One line of research focuses on centralized implementations and formulates the problem as a Steiner tree computation [11]. Since this problem is NP complete, heuristic solutions are applied. Others approximate the Steiner tree by a Minimal Spanning Tree (MST) [12].

Some of the well known Internet multicast algorithms include Distance Vector Multicast Routing Protocol (DVMRP)[1], Multicast Open Shortest-Path First (MOSPF)[2], Protocol Independent Multicast (PIM)[3], Core Based Trees (CBT)[4] and ReServation Protocol (RSVP)[5]. DVMRP and MOSPF are "source-based" protocols i.e., the source is informed every time a new receiver is added to the multicast group. This leads to scalability problems as the number of receivers becomes large. PIM is a distributed protocol. Here each multicast group is assigned one or more nodes which act as Rendezvous Points (RP). The location of these nodes is known to all group members. The source sends its information to all the RPs while receivers decide which RP to connect to and which subset of sources to receive. The CBT protocol is similar. Each multicast group is assigned a set of "core" processors. One main tree is constructed which connects all of these cores. The information travels down the tree and receivers extract the information by connecting to a core. The difference between PIM and CBT is that in PIM a receiver may decide to set up a "source-specific" tree i.e., a tree linking it directly to the source. It should be noted that both CBT and PIM are simply routing protocols and do not consider resource reservation. They assume that sufficient bandwidth exists on each link in the chosen route. In RSVP multiple routes are created to the indented destinations. The protocol checks which route has sufficient bandwidth and selects that route and discards the rest. Since routing precedes resource reservation, it is possible that all of the created routes have insufficient bandwidth. A protocol called ST-II has been proposed which combines routing and resource reservation but it allows only one source per multicast group and the source is informed every time a new receiver is added to the group which leads to scalability problems as the number of receivers increases.

All of the protocols listed above are designed for fixed network topologies and cannot be used in mobile networks like the Digital Battlefield. Some of them, like DVMRP and MOSPF are centralized and so are vulnerable to failure of the control nodes and hence are not suitable for the enormous network that we envision for the Digital Battlefield. In wireless networks, where bandwidth is scarce, routing and resource reservation have to occur simultaneously.

Corson and Ephremides [7] developed a unicast routing protocol (CE) for mobile wireless networks. This unicast protocol is highly adaptive and provides "multipath" routing between sources and destinations which is "loop-free" at all times. When a node requires a route to a specific destination, it independently runs a version of the algorithm which creates a Directed Acyclic Graph (DAG) as shown in the figure below.

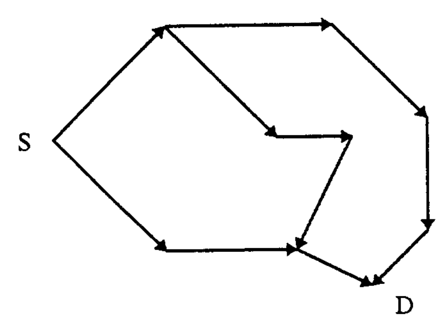

Figure 1. Directed Acyclic Graph from S to D

[1] A good comparison of the different available multicast algorithms can be found in Corson and Batsell [6]

In [6] Corson and Batsell suggest an algorithm for setting up multicast routes in wireless networks. Their scheme called "Reservation-Based Multicast" (RBM) is based on two different levels of routing, both of which occur simultaneously. While the basic protocol specifies different message phases to establish routes to group members, the protocol inherently relies on the unicast routing protocol CE described above. The DAGs provide the low-level connectivity information which RBM needs to create routes from sources to receivers. RBM does not explicitly manage the contention between different connection requests. Each request is considered independently and routes are established only if sufficient bandwidth exists.

In the next section we describe our ideas on creating and maintaining multicast routes in mobile wireless networks.

III. BACKGROUND AND REQUIREMENTS FOR DB MULTICASTING

It should be noted that the multicast algorithm design depends on the rate of mobility. If the rate of change is very high, little can be done in terms of efficient selection of multicast trees since algorithms cannot react fast enough and the only viable alternative is flooding. If the rate of change is low (nearly static) optimal algorithms that are based on the ideas of shortest paths like Bellmann-Ford [11] or Dijksta and Floyd-Warshall [11] can be considered. We are interested in routing when the rate of change is not so fast as to make flooding the only option, but (possibly) not slow enough to allow for one of the minimum length spanning tree algorithms. The aim is to set up as efficient a distribution tree as possible.

The multicast algorithm design also depends on how we structure the environment of the Digital Battlefield. If the network is assumed to have ad-hoc structure (i.e. if there is no hierarchy to differentiate the nodes into types or classes) then it will require peer-to-peer multicasts. On the other hand, Baker and Ephremides [9] have shown how an ad-hoc network can be dynamically configured into clusters where each cluster is assigned a "cluster head" node. This node acts as a temporary "base station" for the other nodes within the cluster. Inter-cluster routing is accomplished via designated "gateway" nodes. The assignment of cluster heads and gateway nodes changes as the relative position the different nodes change. This scheme would go well with the WIN architecture because nodes with greater capabilities can be given higher preference in selection of cluster heads and gateways. If this scheme is adopted then the multicast algorithm would have to be altered accordingly.

Since the size of the network is assumed to be enormous, it may not be possible for any one node to store global connectivity information. Thus the multicast algorithm will have to be distributed in its implementation. Distributed algorithms also have the advantage of graceful degradation to link or node failures and flexible and robust reaction to topological changes caused by mobility. Thus, the inherent military need for survivability tends to favor distributed algorithms. Algorithms like those in [9] can be employed to gather connectivity information up to several hops away e.g. up to 2 or 3 hops away.

There are different ways to identify multicast groups. One scheme requires a list of intended destinations to be propagated via control packets. Another scheme would pre-assign a set of RPs to each group and the source would search for only these RPs. Each RP in turn would be responsible for locating a set of destinations. This enables the "source-initiated" type of multicast. In "receiver-initiated" multicasts the destinations might decide to contact RPs or the source directly. Finally, a more precise scheme would choose RPs dynamically based on the network segments in which destinations are currently concentrated.

In a wireless network, routing and resource reservation have to occur simultaneously. This gives rise to the potential for congestion as a result of contention amongst different connection requests (multicast or unicast). Each node in the network should analyze the different connection requests that it receives and then employ a system of dynamic channel allocation combined with power control to satisfy as many requests as possible. In this process, it needs to determine the state of its neighboring nodes (up to several hops away) to ascertain that allocation of channels in one part of the network should not lead to congestion in some other part. Foschini and Miljanic [10] have suggested a distributed, autonomous wireless channel assignment algorithm with power control for cellular networks. A similar algorithm needs to be designed which can be executed locally by each node in the network, to decide which channels to allocate and at what power levels.

IV. PROPOSED APPROACH

Owing to space limitations we proceed to only summarize our proposed algorithm. There are two basic parts to the algorithm that we propose: (a)routing/re-routing/resource reservation and (b) contention management. Both parts have to proceed simultaneously, i.e. the protocol has to create routes for one multicast group keeping in mind the bandwidth available at each node and also the requirements for other multicast groups. Furthermore, when link failures occur, the algorithm has to re-establish routes. In this paper, we describe Source-Initiated type of multicasting. In this type of multicast, sources decide when routes are to be established to destinations. In subsequent papers, we will address multicasting where destinations initiate the routing process.

It is assumed that the network has a large number of nodes (in excess of 100,000). Each node has a number of transceivers. The number of transceivers may be different for different nodes in the network. There are a total of M frequency channels available (i.e. any node may broadcast at any of the M frequencies, via any of its transceivers, provided such usage does not interfere with other nodes broadcasting at the same frequency). Furthermore, a node may broadcast at any of P power levels. A multicast group is identified by a set of sources and a set of destinations.

Description of Algorithm:

CASE I: We first describe how the algorithm proceeds when there is a single multicast group, i.e. only one source and an associated set of destinations. No other source desires routes and hence there is no contention from other multicast groups. Thus, the algorithm has only to execute part (a) i.e. the part which involves route creation/maintenance and resource reservation. This simpler case permits a clearer description of the issues involved in wireless multicasting and serves as a stepping stone for Case II in which multiple simultaneous multicasts are possible.

The source node broadcasts to its neighbors a query packet which identifies itself as the source of the request and also identifies a set of destinations which the source is seeking. Each neighboring node checks its own routing table to see if it has a path to one or more of the destinations via its neighbors. We distinguish two cases: i)If paths exist to none of the destinations, then that node will forward the query packet to its own neighbors. In this way, the query packet gets forwarded through the network. To avoid loops, the forwarding node will mark itself blocked for the connection requests that may be received subsequently concerning the same multicast session establishment. This blocking marker will remain until the node receives a reply packet confirming the existence of a route to the destinations. ii)If a path is known to a destination, then that neighboring node broadcasts a reply packet to the source (or to the node which had forwarded the query).

As stated earlier, in a wireless network like the digital battlefield, routing and resource reservation have to be combined. Thus, each node in the network maintains a database of frequencies being used by surrounding nodes (up to 2 or more hops away) and allocates them in such a way as to avoid interference with the surrounding nodes. Once it decides to use a particular frequency, the node informs its neighbors (2 or more hops away) of its decision, which enables the surrounding nodes to update their frequency usage databases.

The reply packets which are propagated back towards the source need to contain information which identifies the advantages and disadvantages of routing via that particular route (e.g. delay, availability of resources, etc). The information needed by each node in order to correctly assess the quality of the route options may be excessive (e.g. frequency usage status and number of transceivers available along each route). It is thus desirable to compress the components of this information in to a simple, manageable quantity that can be propagated along each route in a manner analogous to that of the delay metric in Bellmann Ford-type routing algorithms. That is we seek a generalized "distance" metric that summarizes route status adequately.

When a node detects a link failure, it operates as in [7] by initiating the propagation of a control packet called a Failure Query (FQ). This FQ is propagated back towards the source node via repeated broadcasts by intermediate nodes along the route. Reception a of failure query causes a node to erase that route's entry from its routing table. Propagation of FQ continues until either a node is found which has an alternate route to the destination or until the FQ reaches the source node having erased the entire route.

At each node in the network, several power levels are available at which transmission can take place. The reason for allowing such a choice is to exploit the inherent trade-off in wireless multicasting between number of relay hops to a destination and level of interference on adjacent nodes. For example, transmission at maximum power reaches more destinations in a single hop but may create interference to multiple neighboring links. On the other hand, transmission at minimum power reduces that interference but requires multiple intermediate transmissions to reach the destination nodes.

CASE II: Next, we describe how the algorithm proceeds when multiple multicast groups exist simultaneously. In this case contention between the different multicast groups needs to be managed. Hence, the algorithm has to execute both part (a) which involves routing/re-routing/resource reservation as well as part (b) which involves the management of contention between different multicast groups. In our approach, we combine the requirements of part (a) and (b) and outline a procedure to be followed by every node in the network.

Each node will service requests as and when they arrive in a batch fashion as follows: an initial request receives immediate processing attention; however, if subsequent requests arrive within a pre-specified period T, then the node will suspend processing unfinished work for T seconds from the time of the initial request so that it can collect a number of possibly contending requests and service them as a batch. This will allow the node to get a clearer picture of the overall bandwidth requirements. A priority scheme to rate the different connection requests needs to be developed. After collecting requests for the period of T seconds, the node will service the requests based on priority. If all requests have the same priority, then the node will analyze the bandwidth requirement of each request and the number of transceivers available. It will consult its database of frequencies which are currently in use by surrounding nodes (2 or more hops away). Also, for every connection request, the node will decide at what power level to broadcast. Again, as in CASE I, there is a tradeoff between number of hops to destination and frequency reuse factor. For each power level, the node will have to initiate a signaling procedure between itself and its surrounding nodes (2 or more hops away) to ascertain the number of hops to destination at that power level and also the network congestion caused by broadcasting at that power level. A cost function that will summarize all these factors and that still needs to be determined will be evaluated to determine the best choice for power level of each broadcast. If a sufficient number of transceivers and/or frequencies do not exist to satisfy all requests, a decision has to be made as to which requests to service and which to drop.

We have considered several data structures which can be used to store channel use and power level information. Some of the data structures considered and tested were i)linked lists embedded within a main linked list, ii)trees embedded within a main linked list and iii)trees embedded within a main tree. These data structures could be used to implement the routing tables at each node in the network. Our results at this time are still preliminary and need to be refined by taking into consideration some of the yet unresolved issues, like the generalized distance metric, cost function choice, etc.

V. SUMMARY

In this paper, we have developed an approach to multicasting in the unique environment of the Digital Battlefield. We propose to combine multicast routing with dynamic frequency allocation and power control. It is our belief that this combination will lead to better performance, in terms of less network congestion and higher number of successful connection requests. We intend to evaluate the performance of our algorithm in terms of delay, throughput and overhead and compare it to alternatives such as flooding or other selected multicast algorithms.

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