Multicast Extensions to the Flow-Oriented Routing Protocol and Node Velocity-based Stable Path Routing Protocol for Mobile Ad hoc Networks

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Abstract

We propose multicast extensions to the Flow Oriented Routing Protocol (M-FORP) and Node Velocity based Stable Path (M-NVSP) Routing Protocol for Mobile Ad hoc Networks. M-FORP predicts the link expiration time and connects the source to each of the multicast receivers through paths with the largest predicted expiration time. M-NVSP connects the source to each of the multicast receivers through paths with the smallest bottleneck velocity. The bottleneck velocity of a path is the maximum velocity of the intermediate nodes of the path. We compare the performance of M-FORP and M-NVSP with that of the Bandwidth Efficient Multicast Routing Protocol (BEMRP). Simulation results illustrate a tradeoff between lifetime per multicast tree, average hop count per source receiver-path and the number of edges per tree. M-FORP yields the maximum lifetime per tree, M-NVSP yields lowest hop count per source-receiver path and BEMRP yields the minimum number of links per tree.

Keywords: Multicast, Mobile Ad hoc Networks, Simulation, Stability

1. Introduction

A Mobile Ad hoc Network (MANET) is a bandwidth-constrained, dynamic distributed system of arbitrarily moving battery-powered wireless nodes. The transmission range per node is often limited. As a result, routes between any two nodes are generally multi-hop in nature. Due to node mobility, the routes break frequently and have to be rediscovered. In a dynamically changing topology, typical of MANETs, on-demand route discovery (discovering a route only when required) is preferred over periodic route discovery and maintenance that involves frequent exchange of control information amongst the nodes [1].

Multicasting is the process of sending a single stream of data from one node to several nodes within a network. Multicasting is commonly used in collaborative and distributed computing applications that require one-to-many and many-to-many communications among the participants. A multicast tree connects the source to the set of receivers (called the multicast group) such that there is exactly one path from the source to each receiver. While propagating down the tree, data is duplicated only when required. In a mesh, data flows along multiple routes between a source-receiver pair in order to provide robustness.

Several tree-based and mesh-based multicast routing protocols have been proposed in the literature [2]. The shared tree-based protocols scale with respect to the number of sources, but suffer under a single point of failure. The source tree-based protocols are more efficient with respect to traffic distribution. The mesh-based protocols are not efficient in terms of the number of link transmissions. As a result, we restrict ourselves to the source tree-based on-demand multicast MANET routing protocols for the rest of this paper.

Route stability is an important criterion to be considered while developing either a unicast or multicast MANET routing protocol. Link failures in ad hoc networks mainly occur when the constituent nodes of the link move away from each other. Frequent attempts to rediscover the path or a tree could congest the network and also drain out the battery power at the critical nodes. For multi-media applications that require packets to be delivered in-order with minimum jitter, frequent changes in the routes traversed by the packets will result in out-of-order delivery with high jitter.

The lifetime of the routes discovered by several unicast stable path MANET routing protocols such as the Associativity-Based Routing (ABR) protocol [3], Flow-Oriented Routing Protocol (FORP) [4], Route-lifetime Assessment-Based Routing (RABR) protocol [5] and the minimum hop based Dynamic Source Routing (DSR) protocol [6] was studied in [7][8]. Among these protocols, FORP yielded the sequence of longest-living routes during the course of a source-destination session. FORP predicts the link lifetime using information about the current velocity, location and direction of movement of the nodes. The predicted lifetime of a path (called Route Expiration Time, RET) is the minimum of the lifetime of the constituent links of the path. For a given source s and destination d, FORP selects the s-d path that has the maximum RET.
Recently, Meghanathan proposed a beaconless Node Velocity-based Stable Path (NVSP) [9] unicast MANET routing protocol. All of the other well-known stable path routing protocols such as ABR, FORP, RABR and etc. require the periodic exchange of beacons among the nodes in the network. While beacons help to advertise the presence of a node in its neighborhood and also to assess the stability of the links associated with the node, periodic beacon exchange adds to the control overhead of the network and incurs additional energy consumption and bandwidth usage. The lifetime of NVSP routes is about 60-75% of the lifetime of FORP routes, and NVSP incurs the smallest number of hops per route as well as relatively lower delay and energy consumption than FORP.

With such distinguishing features and advantages associated with both FORP and NVSP, we are motivated to develop multicast extensions of these two protocols so that we can discover a sequence of long-living stable trees that can be used over the duration of a multicast session. We refer to the proposed multicast extensions of the two protocols as M-FORP and M-NVSP. Through extensive simulations, we compare the performance of M-FORP and M-NVSP with that of the Bandwidth Efficient Multicast Routing Protocol (BEMRP) [10]. BEMRP is designed to minimize the number of links used in a multicast tree for efficient and effective usage of the network bandwidth. In [11], BEMRP has been observed to be the best multicast routing protocol to simultaneously optimize the lifetime per multicast tree and the number of links per tree.

The rest of the paper is organized as follows: Section 2 explains the design of the M-FORP and M-NVSP protocols in detail. Section 3 describes the simulation environment, illustrates the simulation results obtained for M-FORP, M-NVSP and BEMRP with respect to different performance metrics and interprets the results for different operating conditions. Section 4 concludes the paper. Throughout the paper, we use the terms ‘path’ and ‘route’, ‘link’ and ‘edge’, ‘packet’ and ‘message’ interchangeably. They mean the same.

2. Design of M-FORP and M-NVSP

2.1 Assumptions

We also assume the source knows the multicast group size, i.e., the number of receivers that are part of the group. In the case of M-FORP, we assume each node periodically broadcasts a beacon to all the neighbor nodes within its transmission range. The beacon packet of a node contains the current X and Y co-ordinates, the current velocity and the angle of movement (with respect to the X-axis) of the node.

2.2 Prediction of Link Expiration Time (LET)

Given the motion parameters of two neighboring nodes, the duration of time the two nodes will remain neighbors can be predicted as follows: Let two nodes i and j be within the transmission range of each other. Let \((x_i, y_i)\) and \((x_j, y_j)\) be the co-ordinates of the mobile hosts i and j respectively. Let \(v_i, v_j\) be the velocities and \(\Theta_i, \Theta_j\), where \(0 \leq \Theta_i, \Theta_j < 2\pi\) indicate the direction of motion of nodes i and j respectively. The amount of time the two nodes i and j will stay connected, \(D_{i,j}\), can be predicted using the following equation:

\[
D_{i,j} = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)r^2 - (a^2 - bc)^2}}{a^2 + c^2}
\]

where: \(a = v_i \cos \Theta_i - v_j \cos \Theta_j\); \(b = x_i - x_j\); \(c = v_i \sin \Theta_i - v_j \sin \Theta_j\); \(d = y_i - y_j\)

A node upon receiving the beacon packet from its neighbor, estimates the lifetime of the link (LET) with that neighbor using formula (1). As such, each node maintains a table of LET values, with each value associated to a particular neighbor.

2.3 Broadcast of the Multicast Tree Request Messages

When a source node has data packets to send to a multicast group and is not aware of a multicast tree to the group, the source node initiates a broadcast tree discovery procedure by broadcasting a Multicast Tree Request Message (MTRM) to its neighbors. Each node, including the receiver nodes of the multicast group, on receiving the first MTRM of the current broadcast process (i.e., a MTRM with a sequence number greater than those seen before), includes its Information Update Vector, IUV, in the MTRM packet. The IUV for M-FORP is relatively larger in size and comprises of the following: Node ID, X, Y co-ordinate information, Is Receiver flag, Current velocity and Angle of movement with respect to the X-axis. The Is Receiver flag in the IUV, if set, indicates that the node is a receiving node of the multicast group. The IUV for M-NVSP contains the Node ID, the Current velocity and the Is Receiver flag. For both M-FORP and M-NVSP, the Node ID is appended on the “Route Record” field of the MTRM so that the receiver can learn the path traced by the packet.

2.4 Construction of the Multicast Tree

Paths constituting the multicast tree are independently chosen at each receiver node depending on the route selection principles of the underlying protocol. In M-FORP, the receiver selects the MTRM that traversed through the path with the largest RET. In
M-NVSP, the receiver selects the MTRM that traversed through the path with the smallest bottleneck velocity. Once the path is decided, the Route-Record field in the corresponding MTRM message is used to construct the Multicast Tree Establishment Message (MTEM).

Upon receiving the MTEM, an intermediate node creates (if an entry for the source and the multicast group does not exist) or updates the <Multicast Source, Multicast Group ID> entry in its multicast routing table. The multicast routing table at a node is an ordered entry of <key><value> pairs, where the key and the value are the tuples <Multicast Source, Multicast Group ID> and <Upstream Nodes List, Downstream Nodes List> respectively. Nodes in the Upstream Nodes List and Downstream Nodes List are part of the multicast tree rooted at the source node for the multicast group. The intermediate node adds to the Downstream Nodes List, the ID of the node that sent the MTEM and adds to the Upstream Nodes List, the ID of the node to which the MTEM has to be forwarded further as per the Route Record in the message. We assume a node learns the Identification (ID) of a neighbor node that sent the MTEM through the underlying Medium Access Control (MAC) protocol [12]. After updating the routing table, the intermediate node forwards the MTEM to the next upstream node on the path.

The source node maintains a multicast routing table that has the Downstream Nodes List for each of the multicast groups to which the source is currently communicating as part of a multicast session. For each MTEM received, the source adds the neighbor node that sent the MTEM to the Downstream Nodes List for the multicast group. The source waits to receive the MTEMs from all the receiver nodes within a certain time called the Tree Acquisition Time (TAT). The TAT is dynamically set at a node depending on the time it took to receive the first MTEM for a tree discovery procedure, the hop count of the path traversed by the first MTEM received and the multicast packet sending rate. This approach has also been recently used in [13]. If the MTEMs from all the receivers of the group are not received within the TAT, the source initiates another broadcast tree discovery. If the MTEMs from all the receiver nodes reach within the TAT, then the source starts sending the data packets down the multicast tree.

2.5 Multicast Tree Maintenance

If an intermediate node could not successfully forward the data packet to all of its downstream nodes in the multicast tree rooted at the source, the intermediate node generates and sends a Multicast Path Error Message (MPEM) to the source node of the multicast group. The MPEM is sent to all the upstream nodes of the intermediate node on the tree. The sequence number of the data packet that could not be successfully forwarded is recorded in the MPEM. The intermediate nodes that receive the MPEM remove the entry for the source and the multicast group from their routing table and forward the message towards the source. The source node, upon receiving the MPEM, will clear the entry for the multicast group in its routing table and launch a new broadcast tree discovery process. Note that both M-FORP and M-NVSP have the same structure for the MTEM and MPEM packets.

3. Simulations

Simulations are conducted on a 1000m x 1000m square network. The transmission range per node is 250m. The number of nodes used in the network is 50. We compare the performance of M-FORP and M-NVSP with that of the link-efficient BEMRP protocol. We implemented all of these three multicast routing protocols in a discrete-event simulator developed in Java. This MANET simulator has been also used to obtain the simulation results published recently in [13][14]. The broadcast tree discovery strategy used is flooding. The simulation time is 1000 seconds. Each node is assumed to have an infinite amount of energy and there are no node or link failures due to exhaustion of battery charge. The MAC layer model used is the IEEE 802.11 model [12]. In the case of M-FORP, the beacon exchange period for a node is chosen uniformly randomly from [0…2 seconds] in order to avoid collisions of the beacons from different nodes.

The mobility model used is the Random Waypoint model [15], wherein the velocity of a node is uniformly randomly selected from [0…v_max.] every time the node incurs a direction change to travel to a randomly selected location within the network. The v_max values used are 10, 30 and 50 m/s, representing scenarios of low, moderate and high mobility with average node velocities of 5, 15 and 25 m/s respectively. For each v_max value, we generated five mobility profiles of the nodes for the simulation time of 1000 seconds.

The multicast group size is varied with values of 2, 4 (small size), 8, 12 (moderate size) and 16, 20 (larger size) receiver nodes. For each group size, we created five lists of receiver nodes. Simulations were run for each of these five lists using the five mobility profiles generated for each v_max value. The source node of the multicast session for each of the experiments is randomly selected and it is not counted as part of the multicast group size. Each data point obtained for the multicast routing protocols in the performance figures 1 through 4 is the average value obtained from these 25 experiments for a given multicast group size and v_max value.
The performance metrics studied through the simulations are the following:

- **Percentage Network Connectivity**: This is the ratio (expressed as percentage) of the number of time instants the source was able to successfully transmit the data packets to the multicast group to the total number of time instants the source attempted to transmit the data packets to the group.

- **Lifetime per Multicast Tree**: This is the average of the lifetimes of the sequence of multicast trees discovered by a routing protocol over the duration of the entire multicast session.

- **Number of Edges per Tree**: This is the time averaged number of edges in the multicast trees discovered and computed over the entire multicast session. The notion of “time-average” is explained as follows: Let there be multicast trees T1, T2, T3 with 3, 5 and 6 edges used for time 8, 5 and 15 seconds respectively, then the time averaged number of edges per multicast tree is given by \((3\times8+5\times5+6\times15)/(8+5+15) = 4.96\) and not merely 4.66, which is the average of 3, 5 and 6.

- **Hop Count per Source-Receiver Path**: This is the time-averaged hop count of the paths from the source to each receiver of the multicast group and computed over the entire multicast session.

### 3.1 Percentage Network Connectivity

As the multicast group size increases, the percentage of network connectivity decreases as it may not be always possible to connect the source to all of the receivers of the multicast group. For a given multicast group size, as we increase the level of node mobility from low to moderate and to high, nodes are simply redistributed and the percentage of network connectivity is not much affected (the difference is within 5%).

![Figure 1: Percentage of Network Connectivity](image)

### 3.2 Lifetime per Multicast Tree

For all our simulations, M-FORP yielded the sequence of most stable trees. For a given level of node mobility, with smaller multicast groups, the lifetime of M-FORP trees (refer Figure 2) is about 1.6-2.0 and 1.9-2.5 times more than the lifetime of the BEMRP and M-NVSP trees respectively. On the other hand, with moderate and larger multicast groups, the lifetime of M-FORP trees is about 2.2-3.0 times more than the lifetime of both the BEMRP and M-NVSP trees. The lifetime prediction approach adopted by FORP appears to be very effective for multicast situations too. For a given multicast group size, as we increase the node mobility from low to moderate and from low to high, the percentage decrease in the lifetime of the multicast trees for each of the three routing protocols is around 65-75% and 50-65% respectively.

For a given level of node mobility, the lifetime of M-NVSP trees is 25-30% and 10-15% more than the lifetime of the BEMRP trees for smaller and moderate multicast group sizes respectively. For larger multicast group size, the lifetime per tree for both BEMRP and M-NVSP are almost the same. For a given level of node mobility, the effectiveness of the bottleneck velocity based approach of M-NVSP in determining stable trees starts decreasing as the multicast group size increases.

### 3.3 Number of Edges per Multicast Tree

The number of edges per multicast tree (refer Figure 3) is a measure of the effectiveness of the multicast routing protocol in utilizing the available bandwidth and energy resources at the nodes. The smaller the value of the number of edges per tree, the smaller will be the number of link transmissions and energy consumed per data packet as the packet is propagated down the multicast tree. The performance results illustrated in Figures 2 and 3 indicate that there is a significant tradeoff between the lifetime per multicast tree and the number of edges per multicast tree. With M-FORP, we have shown that it is possible to determine multicast trees of relatively very large lifetime compared to that of BEMRP, but such trees also incur a relatively larger number of links compared to that of BEMRP. In both M-FORP and M-NVSP, each receiver is connected to the source through a path with the maximum predicted lifetime and minimum bottleneck velocity respectively, but both the protocols do not intend to minimize the number of links used in the tree. In BEMRP, each receiver is joined to the tree in such a way that the total number of links added to the tree is minimized.

The number of edges per multicast tree obtained for M-NVSP and M-FORP is respectively about 15-30% and 25-55% more than that of the BEMRP trees. As the multicast group size increases, the impact of the route selection principles of the protocol on the number of links per tree is more evident. For a given multicast group size, as we increase the level of node mobility from low to moderate and to high, we do not notice any significant change in the number of edges per multicast tree.
3.4 Hop Count per Source-Receiver Path

The average hop count per source-receiver path (refer Figure 4) is a measure of the amount of delay that would be suffered by the multicast data packets to reach a specific receiver node. The smaller the number of hops per path from the source to the receiver, the smaller will be the delay suffered by the data packets. From the performance data illustrated in Figures 2, 3 and 4, it is evident that there is a tradeoff between the hop count per source-receiver path, lifetime of the multicast trees and the number of links per tree. None of the protocols can simultaneously yield the best value for all the three metrics. In pursuit of selecting paths with the minimum bottleneck velocity, the M-NVSP protocol attempts to choose routes that have the minimum number of intermediate nodes on the source-receiver paths. Since the receiver nodes are free to choose their own path to connect to the source as part of the multicast tree, the M-NVSP protocol incurs a lower hop count per source-receiver path. The average hop count per source-receiver path in the case of M-FORP and BEMRP is respectively about 15-20% and 5-10% more than that of the hop count per source-receiver path in the M-NVSP trees.

For a given level of node mobility, as we change the multicast group size, the difference in the average hop count per source-receiver path incurred by a particular multicast routing protocol is not much (the difference is usually within 5%). Similarly, for a given multicast group size, as we increase the level of node mobility from low to moderate and to high, there is no significant difference in the average hop count per source-receiver path incurred by a particular multicast routing protocol.

4 Conclusions

The overall contribution of this paper is the development of the multicast extensions to the FORP and NVSP unicast routing protocols for MANETs. The multicast extensions, M-FORP and M-NVSP, determine a sequence of stable long-living multicast trees. The two multicast protocols have been compared with that of the BEMRP protocol that has been observed so far to simultaneously minimize the number of links per multicast tree as well as maximize the lifetime per tree. Through this paper, we discover a tradeoff between the following three metrics: lifetime per multicast tree, the number of links per tree and the hop count per source-receiver path in the tree. We show that with M-FORP,
we can determine multicast trees that have a significantly larger lifetime than that of BEMRP trees, but the tradeoff is that the number of links per M-FORP tree will be as large as 55% more than that incurred with the BEMRP trees. M-NVSP yields trees that are more stable than that of BEMRP trees, at least for small and moderate multicast group sizes, and the relative increase in the number of edges per multicast tree is only at most 30%. M-NVSP trees incur the smallest value for the average hop count per source-receiver path; the M-FORP and BEMRP trees incur a hop count per source-receiver path that is at most 15% more than that incurred by the M-NVSP trees.

To summarize, M-FORP can be preferred when we aim to maximize the lifetime per multicast tree and M-NVSP can be preferred when we aim to simultaneously maximize the tree lifetime and minimize the hop count per source-receiver path in the tree. BEMRP can be preferred when we aim to simultaneously minimize the number of links per multicast tree as well as the hop count per source-receiver path in the tree, but not to maximize the tree lifetime.

5 Acknowledgments

This research is supported through the National Science Foundation grant (CNS-0851646) entitled: “REU Site: Undergraduate Research Program in Wireless Ad hoc Networks and Sensor Networks,” hosted by the Department of Computer Science at Jackson State University, MS, USA.

6 References