Performance Evaluation of Flooding-Based and Associativity-Based Ad Hoc Mobile Multicast Routing Protocols

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Abstract

Multicasting exhibits a very attractive characteristic by efficiently distributing a single stream of data to a large number of recipients. Recently, several multicast routing protocols have been proposed for mobile ad hoc networks. Issues associated with such a network include dynamics in network topology, limited link bandwidth and limited power life. In this paper, we present the performance evaluation of two categories of multicast routing algorithms for mobile ad hoc networks, namely: (a) flooding-based, and (b) associativity-based multicast routing. Two multicast routing protocols based on these two classes are simulated in a common network environment. Simulation results obtained reveal the superior characteristics of our proposed associativity-based multicast routing scheme under the scenario of low to moderate mobility. The flooding-based scheme, however, results in very high communication overhead eventhough it is able to maintain good throughput in a scenario with very high mobility.

1 Motivation

Multicasting has emerged as an essential technology in many applications including group audio/video conferencing, collaborative and groupware applications, software distribution, etc. With multicast, a single stream of data can be distributed to a large number of recipients without clogging the networks since the data is transmitted once and is duplicated only when necessary. Comparing this to multiple unicast transmissions where the same data must be repetitively sent to each and every receiver independently, the benefit turns out to be tremendous.

Multicast routing protocol is an integral component in realizing multicast communications. It determines the path where multicast packets will transit and the method of forwarding these packets efficiently to all intended recipients. Many multicast routing protocols are currently being used in existing wired networks and the Internet. However, these routing protocols are not well-suited for mobile ad hoc networks due to high control overhead and their inability to cope with mobility. In a mobile ad hoc network, nodes can move around freely and a multihop path is required when the two corresponding nodes are not in wireless range of each other. Because of this highly-dynamic topology of mobile ad hoc networks, several multicast routing algorithms had been recently proposed, such as: AODV [2], LAM [3], ODMRP [4], AMRoute [5], AMRIS [6], CAMP [7], LBM [8], etc. In this paper, we are interested in two categories of multicast routing algorithms for mobile ad hoc networks. Flooding-based schemes employ global flooding to handle changes in network topology while our associativity-based scheme involves maintaining a stable multicast tree so as to achieve efficient transmission of multicast data.

This paper is organized as follows. In Section 2, the flooding-based scheme is explained with details on the operation of ODMRP [4]. ABAM, which is our proposed associativity-based multicast routing protocol, is explained in Section 3. Performance comparison of ABAM and ODMRP is then presented in Section 4. Finally, deductions and observations are given in Section 5.

2 Flooding-Based Multicasting: ODMRP

Flooding refers to the process of disseminating a piece of information to all nodes in the network. In a pure flooding scheme, data packets are flooded throughout the network. As a result, all receivers can receive multicast data regardless of their current locations since data is flooded everywhere in the network except in some special situation (e.g. when the network is partitioned). Pure flooding is viewed as a last-resort mechanism to handle networks with high mobility. The apparent disadvantage of flooding is its inefficient use of bandwidth which is undesirable in mobile ad hoc networks where power and bandwidth are scarce resources.

ODMRP (On-demand Multicast Routing Protocol) [4] is a flooding-based multicast routing protocol for mobile ad hoc networks proposed by UCLA. Unlike

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pure flooding scheme, data is not flooded throughout the network. Instead, control messages are periodically flooded so as to continually maintain its multcast forwarding structure (also known as *forwarding group*), which was first introduced in FGMP (Forwarding Group Multicast Protocol) [1]. The forwarding group is essentially a set of ad hoc nodes specially chosen to forward multicast traffic for a particular multicast group. The formation and maintenance of this forwarding group ensures that all forwarding group nodes provide at least one path from the multicast sender to all receivers. To establish and maintain such forwarding group, ODMRP depends on the following operations: (a) multicast sender advertisement, and (b) JOIN-TABLE broadcast by multicast receivers.

When a multicast sender has data to send, it begins to perform periodic broadcast of JOIN-REQUEST messages. These JOIN-REQUEST messages are flooded throughout the mobile ad hoc network. Each node, upon receiving the JOIN-REQUEST message, will update its unicast routing table with the address of the node from which the JOIN-REQUEST message is received. With this routing table, the unicast path back to the multicast sender is known.

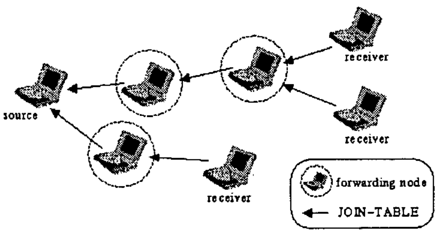

Figure 1: Forwarding Group Formation in ABAM.

When a multicast receiver receives a JOIN-REQUEST message, it will update its member table with the address of the multicast sender and periodically broadcast a JOIN-TABLE message. The JOIN-TABLE message contains the list of all multicast senders known to that receiver and also the next-hop nodes towards those multicast senders. These next-hop information are readily available from the unicast routing table. Only the node listed as the next hop in the JOIN-TABLE message will process the JOIN-TABLE message. These nodes will become forwarding group nodes and they will create the new JOIN-TABLE with the next-hop information from their own unicast routing tables. The newly created JOIN-TABLE will be broadcast further. Eventually, the JOIN-TABLE will be propagated back to all multicast senders and all the nodes along the path from each receiver to each sender will be included in the forwarding group, as shown in Figure 1.

By having all these periodic messages, the forwarding group will be continuously refreshed. Timeout mechanism is then used to remove stale forwarding group nodes. In addition, multiple paths are generally available through forwarding group nodes so that when a link is broken, data packets are still being forwarded along these alternate paths.

3 Associativity-Based Multicasting: ABAM

ABAM (Efficient and Stable Tree Multicast) is an on-demand source-based multicast routing protocol for mobile ad hoc networks. It builds source-based multicast trees based primarily on the association stability[1] between nodes and their neighbors. A stable multicast tree, therefore, requires a fewer number of tree reconfigurations.

To initiate a multicast session, the multicast sender broadcasts a MBQ (Multicast Broadcast Query) message. Nodes receiving the MBQ message will append their addresses and other information (e.g. relaying load, associativity ticks[2], etc.) to the MBQ message before it is being rebroadcast. The multicast receiver will collect all these MBQ packets, choose the best path, and send a MBQ-REPLY message back to the multicast sender. The multicast sender will await MBQ-REPLYs from all interested receivers and will subsequently send a MC-SETUP message to establish the multicast tree. The MC-SETUP message will be propagated to all nodes along the tree and these nodes will be programmed to participate in multicast forwarding. As shown in Figure 2, the three receivers send MBQ-REPLY messages back to the sender and the sender later sends the MC-SETUP message to establish the tree. Note that in the MBQ broadcast, we may allow MBQ to be forwarded more than once if the subsequent MBQ promises better quality routes. This can result in more overhead but can provide better choices for route selection. Issues associated with the route diversity problem were pointed out in [14].

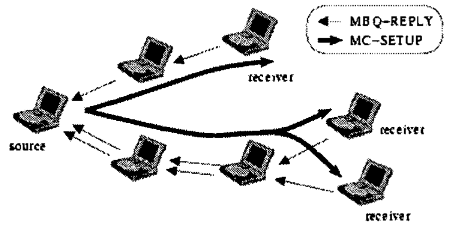

Figure 2: Tree Establishment Process in ABAM.

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[1] Association stability results when the number of beacons received continuously from another node exceeds some predetermined value

[2] Number of beacons continuously received from neighboring nodes

For a multicast receiver to join an existing multicast tree, it need to broadcast a JQ (Join Query) message. Only the on-tree nodes will respond to this query by sending a JQ-REPLY message back to the multicast receiver. The receiver chooses the best path and sends an MC-ATTACH message to create a branch to the existing tree.

Tree reconfiguration is required when the tree association stability property is violated. ABAM employs a localized repair strategy by having the node upstream to the broken link broadcast LQ (Localized Query) message. The maximum number of hops the LQ message can propagate is determined by the number of hops to the farthest receiver on that broken branch. The receiver replies with LQ-REPLY message and the MC-SETUP message is again used to setup the subtree. If the LQ process fails, the immediate upstream node will be notified to initiate another LQ process. This backtracking process continues until LQ tree repair operation is successful or either the branching node or the receiver node is reached. The receivers that are left over by the LQ process will finally timeout and initiate its own JQ process. RN (Route Notification) and RU (Route Update) messages are used to facilitate the reconfiguration process by notifying nodes about route failures.

4 Performance Evaluation

4.1 Simulation Environment

ODMRP and ABAM have been simulated using GlomoSim[11] which is a wireless networking simulation library written in PARSEC [12]. The simulated scenario comprises of 40 nodes moving around the 175m x 175m terrain. Each node has the same transmission range of 50m with the path loss computed using free-space propagation model. The link bandwidth is set to 2 Mbps. IEEE 802.11 protocol is used as the MAC layer protocol. ABR (Associativity-Based Routing) [9] protocol, which is an on-demand unicast routing protocol based on association stability, is used at the network layer. The inclusion of ABR in our configuration does not imply that ABAM depends on a particular unicast routing protocol. In contrast, ABAM does not require any underlying unicast routing protocol to operate correctly. However, it requires the associativity information collected by beaconing process which is already implemented in ABR. The beaconing process is, however, disabled in the simulation of ODMRP.

In our simulation result, protocol performance is evaluated for each mobility scenario which is characterized by the fraction of moving nodes. For example, the fraction value of 0.5 means that 20 nodes (50%) are moving and the rest are stationary. The movement of all moving nodes follows the random waypoint mobility model. In the random waypoint model, a node first chooses a random location and moves straight towards that destination location with a fixed speed (which is a uniform random variable chosen from the range 0 to 5 m/s exclusive). After the destination location is reached, the node stops at that position for a period of 60 seconds before moving again.

For brevity, we simulated four multicast sessions with 4, 4, 3, and 2 multicast receivers respectively. Each simulation took 180 seconds. Constant bit rate UDP traffic source is used to send data. The size of the data payload is 500, 500, 200, and 100 bytes with a packet rate of 2 packets/second. Several simulations were performed for each mobility scenario with different random seed numbers. The results are averaged and shown in the following sections.

4.2 Simulation Results

Several important aspects of ad hoc multicast routing protocol performance are evaluated in this section. These aspects include: (a) data throughput, (b) control overhead, (c) average number of hops the data packets travelled, (d) average end-to-end delay of the data packet, and (e) data forwarding efficiency. These results are discussed below.

4.2.1 Data Throughput

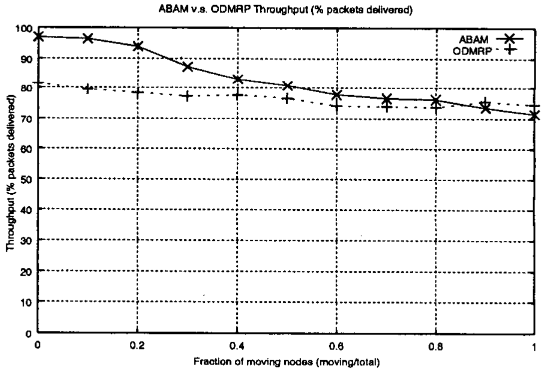

Figure 3: Throughput Comparison of ABAM and ODMRP.

Figure 3 shows the throughput comparison of ODMRP and ABAM, for each mobility scenario. The throughput is derived from the percentage of the number of data packets successfully received at the receivers compared to the total number of data actually sent by the multicast sender. At low mobility, ABAM performs better than ODMRP because of its rigid multicast tree structure together with its exploitation of stable nodes to form the tree. The throughput gradually decreases for ABAM as mobility increases. The decrease in throughput is the result of tree reconfigurations invoked in response to link breakage. As the degree of mobility increases, link breakages occur more frequently and data cannot be forwarded until the route reconstruction process is completed. The worst situation occurs when the tree reconstruction fails, in which case the timeout mechanism is used which can dramatically affect the overall throughput of the protocol.

In contrast, ODMRP shows constant throughput characteristics throughout the range of simulated mobility. Although the throughput of ODMRP is lower than ABAM's at low mobility, its performance drops only slightly as mobility increases. This is because the forwarding group provides multiple paths. In addition, ODMRP periodically reconfigures its multicast forwarding group through its periodic control messages while in ABAM, only one tree is established and parts of the tree are reconfigured when the association stability is violated.

4.2.2 Control Overhead

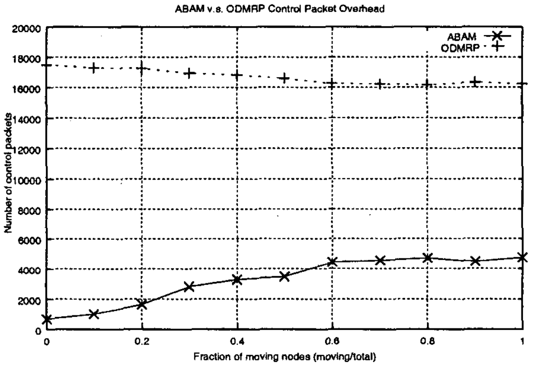

Figure 4: Control Overhead Comparison of ABAM and ODMRP.

The control overhead comparison is shown in Figure 4. We observe a tremendous difference between ODMRP and ABAM in terms of control packets generated during the course of simulation. Due to the on-demand nature of the tree reconfiguration in ABAM, the result shows very small control overhead because, in ABAM, the total number of control packets for each session has direct dependency on the number of tree reconfigurations invoked. In most cases, the higher the mobility, the higher the link breakage and thus the more tree reconfigurations is needed. Because of this, we observe very low control overhead (50-200 packets) in scenarios with low mobility. This control overhead increases linearly as mobility increases. Note that the control packets recorded in Figure 4 take into account all the control packets sent by the control packet originating node and also the control packets forwarded by the intermediary nodes. These control messages include MBQ, MBQ-REPLY, LQ, LQ-REPLY, MC-SETUP, MC-ATTACH, RU, and RN.

Among all the above-mentioned control messages, MBQ and JQ are flooded to all nodes in the mobile ad hoc networks. LQ is also flooded but within the given local scope so it has less overhead than MBQ and JQ. The rest of the control messages are sent only along the tree path and, thus, incur the least overhead.

ODMRP, however, results in a constantly high control overhead because the nodes participating in multicast sessions need to generate control packets periodically regardless of whether the topology is stable or not. Note that the ODMRP control packets recorded in Figure 4 include JOIN-REQUEST and JOIN-TABLE messages.

4.2.3 Number of Hops

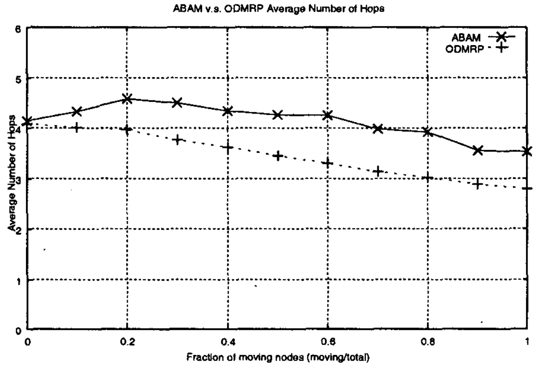

Figure 5: Average Number of Hop Comparison of ABAM and IDMRP.

The average number of hops the data packets are forwarded is shown in Figure 5. The result shows that this number of hops does not vary much in all mobility scenarios with the average value of 3.45 hops for ODMRP and 4.12 hops for ABAM. In all scenarios, ODMRP results in smaller number of hops than ABAM because ODMRP broadcasts the data packets throughout its forwarding group and the first packet that survives to the receiver is taken. Usually, this smallest delay path implies shortest-hop path in long-delay link like wireless physical links in our simulation. On the other hand, ABAM selects the path based primarily on association stability so the resulting path is normally longer than the shortest-path.

4.2.4 End-to-End Delay

In Figure 6, the comparison of the average end-to-end delay is shown for each mobility scenario. This delay is collected only from the data packets that have been successfully received by the receiver. We can see that the resulting end-to-end delay approximately follows

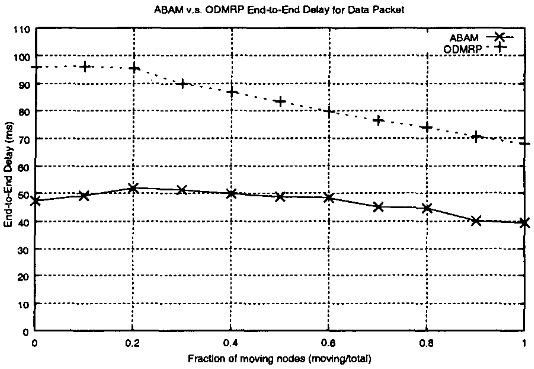

Figure 6: End-to-End Delay Comparison of ABAM and ODMRP.

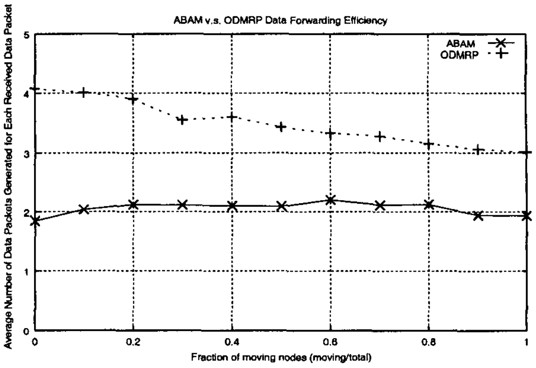

Figure 7: Data Forwarding Efficiency Comparison of ABAM and ODMRP.

the same trend as the number of hops (Figure 5) with the average value of 83.32 ms for ODMRP and 46.82 ms for ABAM. By dividing the average end-to-end delay with the average number of hops, the average delay per hop (or average hop-by-hop delay) can be obtained. From our result, the average delay per hop is approximately 24.12 ms and 11.32 ms for ODMRP and ABAM respectively.

As shown above, the average end-to-end delay result is a bit surprising. ODMRP results in extremely long end-to-end delay compared to ABAM. This is due to the way messages are broadcast in our simulation. Generally, the transmission of these broadcast messages need to be jitterred to prevent collision with other broadcast messages that are being transmitted during the same period of time. In our simulation, the maximum jitter value is set to 50 ms for ODMRP and 20 ms for ABAM. This higher value for ODMRP is the main reason for long end-to-end delay in our simulation result. However, this bigger number is rquired for ODMRP to achieve high throughput. The use of smaller jitter value dramatically effects throughput of ODMRP since there will be higher probability of collision with the large amount of packets generated by ODMRP. These large amount of packets comprises of the control packets and the data packets that are redundantly forwarded within the forwarding group.

4.2.5 Data Forwarding Efficiency

Link sharing is an important feature that makes multicasting a useful technology by reducing the total number of data packets generated in the network. In Figure 7, we examine the link sharing characteristics of ODMRP and ABAM through the comparison of their data forwarding efficiency which is measured from the total number of data packets that need to be generated and forwarded for each succesfully received data packets. The results show that, in the same scenario, ODMRP needs to forward data packets 3.48 times on average until it is received by the receiver while the number is 2.05 for ABAM. Note that these number depends on the average number of hops and also how the protocol operates.

We define data forwarding efficiency as the overhead in forwarding multicast data packets. Comparing this to the average number of hops in the previous section, we can compute the saving each multicast routing protocol can achieve over multiple unicast method. In other words, the link sharing efficiency can be calculated. Thus, for ODMRP, the average number of hops is 3.45 while the actual overhead is 3.48. Thus, ODMRP incurs more overhead in data forwarding than the multiple unicast method by 0.86% . For ABAM, the average number of hop is given as 4.12 while the actual data formwarding overhead is 2.05. Thus, the saving obtained in ABAM in terms of data forwarding is 50.24% .

Comparing the two schemes, the low efficiency of ODMRP results from the use of forwarding group which provides multiple paths. Data packets are forwarded on all possible paths in the forwarding group based only on the condition that it is not already forwarded by that forwarding group node. In contrast, the high efficiency in ABAM results from the use of multicast tree which provides only one path to each receiver.

5 Deduction and Observations

In the previous sections, we present the comparison of ODMRP and ABAM in terms of throughput, control overhead, number of hops, end-to-end delay, and link sharing efficiency. In this section, we discuss these results together with some other important criteria we have observed. These includes: (a) multicast delivery structure, (b) storage overhead, and (c) power consumption.

5.1 Multicast Delivery Structure

In ODMRP, the forwarding group forms a mesh for multicast packet forwaring. Since the mesh provides multiple paths between sender and receivers, redundancy exists and is exploited to achieve high packet delivery ratio in a highly-dynamic mobile network. In contrary, multicast tree provides only one path. When this path is broken, data forwarding is disrupted until the new path is established by the tree reconfiguration process. This results in lower throughput than the scheme that utilizes multiple paths when mobility is high.

The disadvantage of multicast mesh is the increase in data forwarding overhead. The redundant forwarding consumes more bandwidth in a bandwidth-constrained wireless network. Moreover, the probability of collision is higher when more packets are generated. This has immediate effect on end-to-end delay as explained in previous sections. In a heavily-loaded scenario, the overall performance can also be effected.

5.2 Power Consumption

When there are no active sessions, ODMRP generates no traffic which results in zero power consumption while the beaconing process used by ABAM is required to be running all the times. However, during the multicast session, ODMRP consumes more power than ABAM due to its high communication overhead.

6 Conclusion

In this paper, we have reviewed two multicast routing protocols for mobile ad hoc networks and compared their performance through simulation. Simulation results show that ODMRP, which is a flooding-based protocol, has good throughput even in a high-mobility scenario and also incurs small storage overhead. Another protocol, ABAM, which is associativity-based tree multicast protocol, exhibits very good throughput at low mobility while lower throughput is observerd at higher mobility. It also incurs smaller communication overhead and results in better end-to-end delay than ODMRP. In summary, the tradeoff between throughput and communication overhead still exists while it is desirable to achieve both especially in a mobile ad hoc network where bandwidth and power are limited.

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