ON EVALUATING THE TRADE-OFFS BETWEEN BROADCASTING AND MULTICASTING IN AD HOC NETWORKS

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***Abstract*— *Dissemination of information to multiple recipients is of importance in many ad hoc networks applications. Towards this, multicasting in ad hoc networks has received a lot of attention. Most multicast protocols require the creation and maintenance of a structure (such as a tree or a mesh) for distribution of information to the group members. In contrast, broadcast schemes are simple schemes which aim to distribute the information to all or a fraction of the nodes in the network without having such a structural framework. While the creation/maintenance of the structure could potentially be cumbersome and heavyweight, multicast does offer benefits in terms of restricting the number of nodes that perform rebroadcasts. We argue that it is not a given that multicast is a better choice for group communications in all possible scenarios and that there could be circumstances wherein the use of a simple broadcast based technique would be more advantageous. In order to support this claim, we study various scenarios to evaluate and quantify the trade-offs between broadcasting and multicasting. In particular, we perform simulation experiments by choosing the On-Demand Multicast Routing Protocol and the Simple Broadcast Algorithm respectively, as candidate protocols for multicasting and broadcasting. These protocols have been shown to be the elite protocols in their classes in prior work. The results from our studies demonstrate that multicasting is preferable only under conditions of moderate mobility and with multicast group sizes smaller than 40%.*

I. INTRODUCTION

Ad hoc network applications such as tactical deployments, electronic classrooms or disaster recovery missions have a great need for group communications. Thus, disseminating information to multiple recipients has been gaining a lot of attention. The design of multicast protocols for this purpose has been widely explored [1], [2], [3], [4] and continues to gain momentum. Typical multicast protocols require the creation of a tree or a mesh structure via which information is distributed to the group members. The creation and maintenance of such a multicast structure are typically accomplished by flooding control messages to spawn the constituent nodes in the network. These mechanisms could potentially be extremely heavyweight. In many scenarios, the overhead thus incurred may render multicasting an expensive option for group communications. Typically, one might expect this to be the case in high mobility wherein the information tends to stale fairly quickly [5] and there is a need for the periodical invocation of control messages with high frequency. One might, in such scenarios, find broadcasting to be a more attractive option.

Broadcasting typically refers to a network wide dissemination of data. Flooding is probably the most well known means to achieving the above objective (however flooding produces an excessive number of redundant transmissions.) If a broadcast protocol is employed for group communications, it would attempt to deliver the packet to all the nodes in the network regardless of who the intended recipients (we refer to these as multicast group members or simply group members) are. In order to reduce the extent of redundant wasteful transmissions in flooding, many lightweight broadcast protocols with simple heuristic have been proposed. Some examples of these lightweight broadcast protocols are the probabilistic broadcast scheme [6], counter-based scheme [7] and neighbor-aware schemes that make use of local neighborhood information [8], [9], [10]. In spite of reducing the extent of wasteful transmissions, broadcast, if used for dissemination of information to only a fraction of the entire population of nodes in the network can be inefficient due to unnecessary rebroadcasts. One would expect this to be especially true if the group size is small.

Thus, one may assess that there is no clear winner between broadcast and multicast for enabling group communications. Depending on the scenario or context, it may be preferable to use one versus the other.

The objective of this paper is to evaluate the trade-offs between the broadcasting and multicasting in various scenarios. Towards this we choose a candidate protocol from each class; the On-Demand Multicast Routing Protocol (ODMRP) [1] for implementing multicast and the Simple Broadcast Algorithm (SBA) [8] for broadcast. We wish to point out here that in highly dense or large networks, it is seen that the counter-based scheme in [7] outperforms SBA since it does not require the hello messages as required by the latter (to be discussed later). We observe that in such scenarios the counter-based scheme in fact even outperforms ODMRP in terms of packet delivery ratio and overhead. We do not present these results in this paper due to space limitations. These candidate protocols have been shown to outperform most other protocols in their respective classes [11], [12]. The evaluation of protocols should not be solely based on the delivery performance but also take into account the overhead that they incur. Towards this we perform extensive simulations by considering various scenarios and compare ODMRP and SBA in terms of their efficiency (packet delivery ratio or PDR) and relative overhead. Our results suggest that while ODMRP seems to be the preferable choice in scenarios of low to moderate mobility and when the group size is small (less than 40% of the nodes are group members), SBA appears to be the winner in high mobility and if the group size is relatively large.

* This work was supported from grants from Telcordia Technologies and ARL no: 100833196 and from DARPA FTN Grant no: F30602-01-2-0535.

The rest of the paper is organized as follows: In section II, we discuss the related work and provide brief overviews of ODMRP and SBA. In section III, we discuss the trade-offs between the use of broadcast and multicast protocols. In section IV, we provide our simulation results and discuss the implications of the observed results. Finally, we conclude in section V.

II. Related Works

There has been earlier work [11], [12] focused on comparing different multicast protocols or broadcast schemes. However, to the best of our knowledge, the trade-offs between broadcasting and multicasting have not been studied. In [11], the authors compare the performance of various multicast protocols such as ODMRP [1], CAMP [2], AMRIS [3] and AMRoute [4]. They conclude that mesh-based protocols are more reliable than tree-based protocols due to the availability of alternate redundant routes that provide robustness. From their results, they observe that ODMRP outperforms all other protocols in terms of delivery performance.

The comparison of broadcast protocols has been done in [7] and [12]. In [7], the authors discuss the problems with flooding and evaluate five modified broadcast protocols that they proposed. These five broadcast protocols are the counter-based scheme, the probabilistic scheme, the location-based scheme, the distance-based scheme and the cluster-based scheme. They showed that via simple heuristic modifications to the flooding protocol one can significantly reduce the number of wasteful rebroadcasts in the network while maintaining coverage. In [12], broadcast protocols are categorized into 4 different classes: simple flooding, probability based methods, area based methods and neighbor knowledge methods. A representative protocol was chosen for each class and the performance of the candidate protocols was evaluated. From the obtained results, the neighbor knowledge method, which the SBA belongs to, appeared to have the best performance among the chosen broadcast protocols.

The only research that compares multicast and broadcast protocols is in [13]. The authors compared two multicast protocols with flooding over a wide range of mobilities and traffic load conditions. It was shown that multicast protocols do not perform well in extremely dynamic networks. However, they considered only the scenario in which all nodes are receivers. To the best of our knowledge, there is no direct related research on evaluating the trade-offs between multicasting and intelligent broadcasting schemes.

In the following paragraphs, we provide overviews of the protocols that we have chosen for the evaluation:

A. ODMRP

We describe the ODMRP briefly since it is the candidate multicast protocol chosen in our studies. Further details on ODMRP may be found in [1]. It has been shown that ODMRP is one of the best known multicast protocols in terms of its throughput performance [11].

ODMRP is a mesh based multicast protocol that uses a forwarding group concept. When a source node has a packet to send and the multicast group members are yet to be identified, it broadcasts a Join-Query message. The Join-Query message is also periodically broadcasted to refresh group membership information and update routes. When a node receives a Join-Query message, it stores the source ID and sequence number in its message cache; duplicate receptions of the same query message are discarded. If the message received is not a duplicate instance of a previous message and if the Time-to-live indicated in the message is greater than zero, the recipients node rebroadcasts the Join-Query. When the Join-Query reaches a multicast receiver, it creates a Join-Reply message and broadcasts it to its neighbors. When a node receives a Join-Reply, it checks if it is identified to be the next hop entry. If it does, the node is a forwarding node and the forwarding group flag (FG_FLAG) is set. It then rebroadcasts its own Join-Reply. Note that the aforementioned next hop information is obtained from the routing table. Finally, the Join-Reply reaches the multicast source and the routes are established. From then on, until information is further updated, a node will forward the packet only if it is in the forwarding group.

B. SBA

We next describe our candidate broadcast scheme in brief. Further details may be found in [8].

SBA is an intelligent broadcast protocol in the sense that it considerably reduces the number of rebroadcasts as compared with flooding. Furthermore, it has been shown that SBA outperforms most of other broadcast schemes such as counter-based scheme and location-based scheme in previous work [12]. It minimizes the effects of a broadcast storm [7] by using a simple technique. SBA uses periodic hello messages exchanged between neighbors to enable the acquisition of local neighborhood information in each node. Each hello message contains a list of 1-hop neighbors of the broadcasting node thus, finally, every node in the network will have 2-hop neighborhood information. The collected neighborhood information is used to decide whether or not a received data packet should be rebroadcasted. The decision is made by determining by means of the neighborhood information table if there exists any node that is not covered by previous broadcasts. If all nodes are already covered, the node will not rebroadcast the packet; otherwise the node will schedule a time to rebroadcast the packet based on the number of neighbors that it has. The more the number of neighbors, the sooner will the node rebroadcast the information. This would therefore bias the scheme to have the nodes that have higher degrees broadcast earlier than those that are sparsely connected. Since, this can potentially enable the coverage of a large fraction of nodes with relatively few broadcasts. SBA heavily saves on rebroadcast overhead.

III. Trade-offs between the use of broadcast and multicast

In MANET, transferring messages to multiple receivers is usually done by using multicast instead of multiple unicast connections. Multicast protocols reduce the number of forwarding transmissions from the source to the destination group members, thus reducing the extent of traffic in the network. However, doing this not only requires the knowledge of the network topology but also an effort to construct the multicast tree or mesh that best minimizes the forwarding overhead. Topology information is usually obtained by flooding query messages and the creation of reverse routes when responses from the group members make their way back to the source. Every intermediate node between the source and the destination group members has to maintain state. The aforementioned requirements can potentially incur high levels of overhead and make multicasting complex. We argue that such an effort may not be necessary in many scenarios. For instance, in a highly mobile environment, maintaining state is hard since information becomes stale very quickly. The state information not only causes serious performance degradations but also requires large overheads. In the extreme case where the mobility is extremely high, flooding appears to be the only choice for group communications [5].

We believe that there may be significant benefits to using an intelligent broadcast protocol for group communication. Intelligent broadcast may also require nodes to keep some state information and maintain limited topology information. However, the quantum of storage or the control overhead may not be as large as that with the multicast protocols. In particular, many intelligent broadcast protocols make use of local neighborhood information [8], [14], [9], [10]. As compared with constructing a multicast tree or a mesh which requires network-wide exchange of control messages, the limited neighborhood information exchange in intelligent broadcast protocols is localized. This certainly reduces control overhead. The weakness of broadcasting is due to its broadcast property; a broadcast tries to deliver a message to as many nodes as it can. In other words, it does not care about whether a node is an intended multicast receiver or not. Thus, a broadcast can lead to many wasteful transmissions of the actual information. One might expect this to be especially unacceptable if the multicast group size is small. However, one might expect that this effect may not be significant for larger group sizes. Furthermore, one might expect a broadcasting schemes to be easier to deploy in high mobility.

Towards evaluating these expected trade-offs we choose (as mentioned earlier) a multicast protocol ODMRP and a broadcast protocol SBA respectively. The two protocols have been shown to be among the elite ones in their respective classes in previous studies [11], [12]. We perform extensive simulations with these protocols as the candidate choices to evaluate and understand if our expected trade-offs are indeed seen.

IV. Simulation results & Analysis

In this section we first describe our framework for performing simulations. We then define our metrics of study. Results are reported and interpreted in the following subsection.

C. Simulation environment

We use NS-2 simulator to do our simulations [15]. Implementations of the ODMRP and the SBA protocols are available at [16] and [17], respectively. It is difficult to compare the two protocols directly since their methods of operation are different. In particular the control overhead is due to the hello message in the broadcast scheme whereas it is due to join queries, replies in ODMRP. To make the comparisons fair, we ran the simulations over an exhaustive set of parameter values and choose those parameters that provide the best performance for each protocol for a given scenario. In other words, we compare the *best case performance* of the broadcast scheme with that of the multicast scheme. We list the corresponding parameter values in TABLE I. The settings for the simulation scenarios in which the experiments were conducted are in TABLE II.

TABLE I
Major parameters list

ODMRP parameter values	
Join Query refresh interval	3 seconds
Forwarding group flag timeout	9 seconds
SBA parameter values	
Hello message interval	3 seconds
Neighbor information timeout	4.5 seconds

TABLE II
Simulation environment

Simulation area	500mx500m
Power range	100m
Mobility model	Random Waypoint
Pause time	0 sec
Simulation time	120 sec
Data rate	5 packets/sec, 64bytes/packet
Repeated simulations	60

D. Simulation parameters

In order to create multiple different scenarios that enable an extensive evaluation of the two protocols, we have varied the following four parameters:

1) Multicast group size
2) Node density
3) Node mobility
4) Number of sources

We define the multicast group size to be the ratio of the number of receivers to the total number of nodes. In the simulations, we use six different group sizes (100%, 80%, 60%, 40%, 20%, 10%). The multicast receivers are picked randomly from among the nodes in the network.

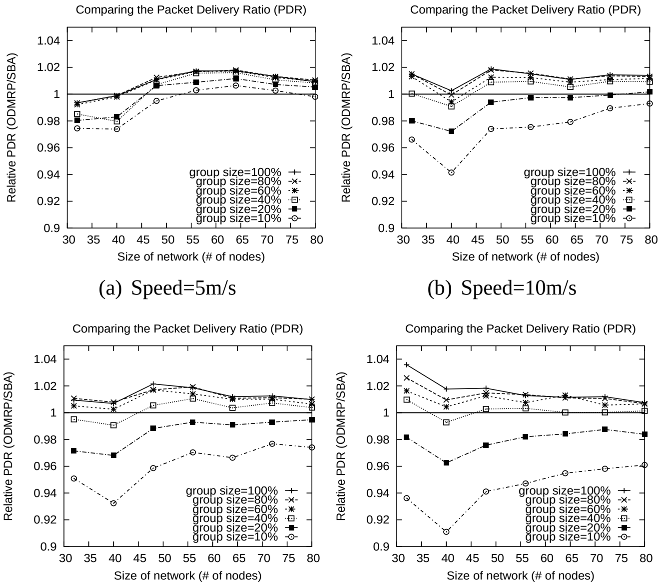
The node density is varied by varying the number of nodes within a fixed simulation area. The number of nodes considered ranges from 32 to a maximum of 110.

We use four different speeds (5m/s, 10m/s, 15m/s and 20m/s) defined by the maximum speed of a node. Nodes move according to the random waypoint model and with a pause time of 0 seconds.

We also vary the number of multicast sources from 1 to 3. The source data rate proportionally increases due to the addition of these sources.

E. Simulation metrics

We evaluate and compare the two protocols in terms of four different metrics. Each metric is defined as follows:



(a) Speed=5m/s (b) Speed=10m/s

(c) Speed=15m/s (d) Speed=20m/s

Fig. 1. The comparison of packet delivery ratio with single source at various node mobilities

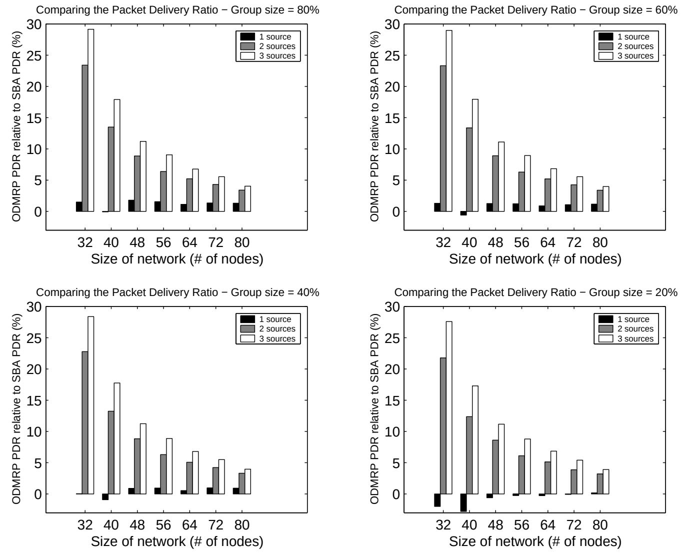


Fig. 2. The comparison of packet delivery ratio with multiple source(s) (speed=10m/s)

1) **Packet Delivery Ratio (PDF)** is the ratio of the number of packets *actually* received by the receivers to the *expected* number of packet receptions. This metric represents the effectiveness of the protocol in terms of delivering packets.
2) **Control Overhead** is the control overhead (in bytes) per useful data byte received. This metric represents the control overhead incurred due to the use of the particular protocol.
3) **Data Rebroadcast Overhead** represents the number of data rebroadcasts performed for each useful data packet received. This metric represents the rebroadcast redundancy caused by the protocol in use.
4) **Total Overhead** is the control and data rebroadcast overhead together (in bytes), per useful data byte received.

F. *Simulation results*

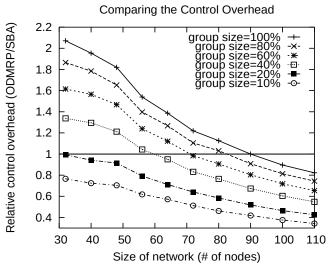
To obtain reliable results, we repeated each simulation 60 times and averaged the obtained results. In each run, a mobility pattern is generated. As mentioned earlier, the sources and the receivers are picked randomly. In the following paragraphs, we present our major observations and discuss/analyze them and provide our interpretations.

In general, **ODMRP performs better when the multicast group size is large.** Fig. 1 depicts the comparison of packet delivery ratio observed with the two protocols with a single source at various mobilities. From the results, we see that both protocols perform similar to each other differing by only about 5%. However, ODMRP has a better delivery performance (by about 3%) when the group size is large. In fact, the packet delivery ratio with ODMRP increases more dramatically as compared with SBA with an increase in group size. The higher delivery ratio of ODMRP in large group sizes is due to the fact that the number of forwarding nodes increases with group size. When the number of receivers increases, a higher number of Join-Reply messages are sent and thus, a higher number of forwarding nodes are set up. This creates additional redundant routes from the source to most of the destinations. This increased redundancy provides fault tolerance during mobility (increased robustness to link failures) and helps achieve a higher packet delivery ratio.

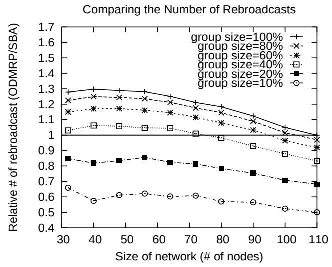
From Fig. 1, we see that **increasing node mobility hurts ODMRP especially when the group size is small**. In other words, with small group sizes ODMRP is very sensitive to increased node mobility. This is because the multicast structure stales faster with higher node mobility. In effect, this reduces the delivery of the right packets at the correct destinations. This is especially the case when the group size is small since there are fewer forwarding nodes meaning that there exist fewer redundant routes. SBA, on the other hand, is relatively unaffected since the number of nodes that rebroadcast the message is relatively unchanged with either mobility or with multicast group size.

When the number of source increases, the packet delivery ratio with ODMRP is significantly higher than that with SBA for all group sizes (by about 5-30%) (See Fig. 2). Note that all sources are assumed to belong to the same group here. The reason for this telling different in packet delivery ratio is that the number of forwarding nodes drastically increases for ODMRP with the addition of sources. The additional forwarding nodes are created due to the increase in the number of Join-Query messages. It is worth mentioning that the delivery performance improves to a greater extent in sparse networks (by about 35%). Due to the poor connectivity in sparse networks, the additional assistance provided by the extra forwarding nodes becomes more pronounced.

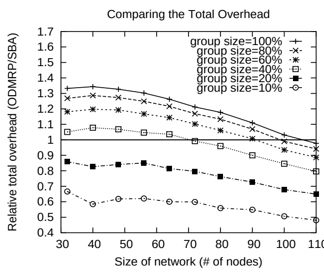
A decision on which protocol is better for group communications in particular scenario cannot be solely based on the delivery performance. The overhead that a protocol incurs should also be considered. It is preferable to use a lightweight protocol instead of an overhead intensive one even if the latter performs slightly better in terms of the achieved packet delivery ratio. As mentioned earlier, we quantify the overhead in terms of the control overhead and the data rebroadcast overhead. In SBA,



(a) Control overhead



(b) Data rebroadcast overhead



(c) Total overhead

Fig. 3. The comparison of various overheads with a single source (speed=10m/s)

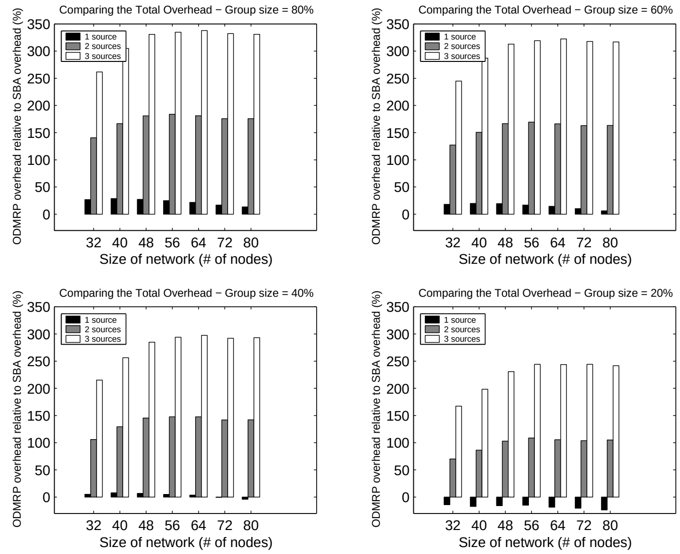


Fig. 4. The comparison of total overhead with 1-3 sources (speed=10m/s)

the control overhead consists of the hello messages; in ODMRP, the overhead includes the Join-Reply, the Join-Query and the Join-Reply-Ack messages. The data rebroadcast overhead in both protocols is due to the rebroadcasts of data packets.

From Fig. 3(a), we see that **the relative control overhead between the two protocols increases dramatically with an increase in group size. Moreover, the relative control overhead starts to decrease as the density of nodes increases.** In fact, the number of control messages in SBA does not change with group size since each node exchanges hello messages at regular intervals. The increase in relative control overhead is mainly due to the fact that ODMRP incurs increased control overhead with increased group size since there are a higher number of receivers that send Join-Reply messages. In addition, the increase in the number of redundant routes and consequently forwarding nodes, results in an increase in the number of Join-Query-Ack messages. SBA incurs high overhead even when the group size is small (up to 60% higher when the group size is 10%). This is due to the fact that nodes exchange hello messages with their neighbors regardless of the group size. With an increase in density, the size of each hello message (to recap the hello message generated by a node contains a list of its one-hop neighbors) increases. This causes the overhead incurred with SBA to increase with node density. Thus the relative control overhead actually decreases and for very high densities, the overhead incurred with SBA is higher than that with ODMRP regardless of the multicast group size.

In fact, the control overhead accounts for only a small portion of the total overhead. This is because the control message size is typically assumed to be much smaller than the data message size (We believe that this assumption is justified since one might expect the control messages to be of fairly small size). Typically, we observed that '*rebroadcast overhead*' that accounts for the rebroadcasts of the original packet generated by the source is the dominant factor in the total overhead (constitutes approximately 90%).

As seen in Fig. 3(b), **ODMRP generates a higher number of rebroadcasts (by about 5-30%) than SBA when the group size is large.** This is because of the large number of forwarding nodes that are created in ODMRP when the group size is large. On the other hand, SBA tries to disseminate the packets to spawn the entire network with as few rebroadcasts as possible. By thus, quelling unnecessary rebroadcasts. It incurs relatively small overhead even if the group size is large. However, SBA suffers from a large number of unnecessary rebroadcasts when the group size is small. In fact, SBA attempts to reach all the nodes in the network (as per the very definition of broadcast) even if there is but a single multicast group member.

As the density of nodes increases, the relative total overhead decreases and in highly dense networks ODMRP consumes smaller overhead than SBA for all group sizes. (See Fig. 3(c)) As mentioned previously, the relative control overhead decreases as the node density increases. However, the major factor that causes a decrease in the relative total overhead is the relative data rebroadcast overhead. As node density increases, as one might expect, the network connectivity increases. The ODMRP protocol, under these conditions is able to compute better shared paths from the source to the destinations. The SBA protocol causes a higher number of rebroadcasts as the number of nodes in the network increases (In our studies the density is increased by increasing the number of nodes deployed within a fixed area of interest). Consequently, as one might expect, the relative broadcast overhead increases with density.

When multiple sources are active, although ODMRP greatly outperforms SBA in terms of packet delivery ratio, the overhead that it incurs is drastically higher. As shown in Fig. 4, the relative total overhead incurred with two sources is much higher (more than 100% higher) than that with a single source if ODMRP is used. With three sources, the relative total overhead increases to around 300% of that incurred with a single source if 80% of the nodes in the network are group members. With the addition of the second source, the number of Join-Query messages in ODMRP is doubled. Since a higher number of forwarding nodes are set up, a larger number of data rebroadcasts are produced. However, this increase in control messages and data rebroadcasts does not improve the delivery performance proportionally. In other words, the efficiency of ODMRP decreases with the addition of sources.

In summary, our observations seem to suggest that

a. For large group sizes (≥40% of nodes are group members) with single multicast source SBA (or in general broadcast) is preferable. Although ODMRP performs slightly better in terms of PDR, it incurs much higher overhead in these scenarios.
b. ODMRP (or multicast) is the clear choice if the group size is small and there is a single source with low mobility.
c. In the above case, if low mobility is replaced with high mobility SBA (or broadcast) is preferable.
d. When there is a single source ODMRP (or multicast) may be preferable in dense networks.
e. With an increased number of sources, if the network is sparse ODMRP is preferable; however in dense network, due to ODMRP's excessive overhead SBA may be preferable.

V. Conclusions

In this paper, we argue that in contrary to common belief, broadcast may in fact be preferable to multicast in certain scenarios even if not all the nodes in the network are multicast group members. The basis for this argument is that, while broadcast causes unnecessary or wasteful transmissions, in certain scenarios (such as in high mobility) the cost of creating and maintaining a multicast structure for data dissemination may in fact outweigh the cost of the wasteful transmissions.

In order to validate our intuitions we compare the performance of a candidate multicast protocol ODMRP with that of a candidate broadcast protocol SBA in various scenarios. The choice of the aforementioned protocols as the candidates for this study was based on previous work that demonstrates that these protocols perform strongly in comparison with competing schemes in their respective classes. Our studies indicate that due to the excessive overhead incurred with ODMRP in certain scenarios (high mobility, or when the multicast group size is large. i.e., more than 40% of the nodes are group members), SBA may in fact be preferable.

In conclusion, our results suggest that there is no clear winner between the two schemes considered and that the scenario may in fact dictate the choice of multicast or broadcast. We believe that the design of a hybrid multicast/broadcast scheme that enable nodes adapt to perform the right functions in response to local conditions would be of considerable importance. This will be our objective in future work.

Acknowledgments

We thank Tracy Camp of Colorado School of Mines for providing the source code of SBA.

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