Reliable Multicasting in Ad-hoc Networks – An Analysis of Various Protocols and the Open Issues

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Abstract — This paper identifies some of the open problems with the ad hoc networks. It is observed that to support group communication in mobile ad hoc networks (MANET), various multicast protocols have been proposed. The goal of these protocols is to deliver multicast packets to all group members efficiently and reliably. However, still some problems remain with each of the protocols. Ad-hoc networks are characterized by fast topological changes, which are disorderly and unpredictable. Also, packet routing and forwarding task is managed by nodes itself, which makes it essential to explore and determine the usage and suitability of the various ad-hoc multicasting protocols in different requirements.

This paper tries to fill the current gap by bringing out an analysis of various ad hoc multicasting protocols along with their strength, weaknesses and usage suitability in different environments. A comparative analysis of various protocols (like AMRoute, ODMRP, AMRIS, CAMP, MAODV and flooding) in different network scenarios is brought out, including the open issues and the impact of node mobility, number of senders, multicast group size. It is expected that the study and comparative analysis of various multicasting routing protocols shall help in choosing an appropriate and most suitable multicasting protocol in a given scenario and thus add value to the current state of research in this area.

Index Terms – Ad-hoc Network, QoS, MANET, AMRoute, AMRIS, ODMRP, CAMP, MAODV, Flooding.

I. INTRODUCTION
In group oriented applications data is broadcasted from one node to group of nodes. For these, multicasting communication is most suitable instead of multiple unicast in view of reduced transmission cost, lesser power and bandwidth consumption, minimum forwarding and routing handling cost, less delivery delay. Further, with increased usage of mobile and Bluetooth technology, the sharing and broadcasting of information among the hand held devices increases, and hence the importance of the issue, e.g. even in a meeting room or researchers in a workshop or conference there is an ad-hoc network to share the information. Mobile ad-hoc network (MANET) applications include battlefield area as well as disaster aid situations.

It is observed that multicasting and routing in mobile ad hoc network is full of challenges, which have been discussed in various research papers [1] [9]. Further, multicast protocols in the existing fixed networks (e.g. DVMRP, MOSPF, CBT and PIM) are not directly applicable for ad hoc networks because multicast trees are fragile and need to be reconfigured as network topology changes. Keeping in view these issues, various
multicast protocols have been proposed [11] [17]. All these protocols aim towards a common goal of efficient and reliable multicasting. However, the problem in these protocols is that multicast packet delivery paths become fragile with respect to mobility when they try to be optimal in reducing the transmission cost, on the other hand these are not optimal if made to be resilient to mobility. Efforts continue towards an optimized multicast for ad hoc network [2].

The rest of the paper follows the following sequence: Section II presents the open issues of ad hoc networks, typically characterized by MANET, while Section III brings out different aspects relating to reliable multicasting. An analysis of available ad hoc multicasting protocols is presented in section IV. Section V brings out various network scenarios and further comparison of the widely used protocols (AMRoute[13], ODMRP[6], AMRIS[3], CAMP[7], MAODV[4] and flooding in such network scenarios. The analytical study is based on the impact of mobility speed, number of senders, multicast group size, varying network traffic load on network reliability. Retrospect observations and concluding remarks find a place in Section VI.

II. OPEN ISSUES / PROBLEMS IN MANET

Ad-hoc networks are characterized as infrastructure-less due to absence of fixed infrastructure, where all nodes, including mobile hosts, are required to compute, maintain, and store routing information. Various issues with such ad-hoc networks like MANET are as follows:

A. Issue of Power Constraints

Issue of utilizing limited battery efficiently – as the devices in MANET have limited battery. Power can be conserved by reducing the routing overhead and finding a power efficient route which includes the shortest path and less traffic. Such a power efficient route can then be stored in cache to reduce the route finding overhead. In ad-hoc networks, sending periodic messages by the core node or source node for maintaining the route information increase the traffic as well as consumes more battery.

B. Scalability Issue

The issue is related to the maximum limit of the nodes in an ad-hoc network? Due to lack of infrastructure in MANET, all nodes compute, maintain and store routing information. The increase in nodes in MANET increases the issues of the efficiency and performance. Mobility in MANET adds to the issue of scalability. Transmission overhead and delivery delay concerns also add to the issue of scalability. The impact of groups’ size is studied later in this paper.

C. Address configuration Issue

What address configuration is used in MANET? MANET maintains various communication groups for ease in maintenance of routing path. Due to absence of infrastructure, proper address configuration technique is required to ensure that no group has identical multicast address. The network partition due to mobility of the nodes adds to the problems in maintenance of multicast address configuration.

D. Quality of service (QoS) Issue

Is Quality of service provided in MANET? Quality of service measures the performance level of the network based on various parameters like bandwidth, delivery delay, loss of packets, jitter delay, creation of loops etc. The lack of infrastructure, bandwidth limitation and mobility/ unpredictable location of nodes add to the QoS issues in MANET. The impact of mobility speed, numbers of senders, multicast group size, varying network traffic load on network etc. impact the QoS, issues which are studied later in this paper.

E. Applications for multicast over MANETs

Whether all applications supported by MANET? MANET applications also include battlefield area, disaster aid situations, online gaming or conversations in a classroom or conference. Transmission overhead, power limitation and routing, delivery delay may add constraints to various applications of MANET.

F. Security related Issue

How MANETs secure itself from malicious behaviors and attacks? The liberty of nodes to connect, disconnect and mobile inside the network raise the security issues. Due to absence of secure boundaries and
centralized coordination/routing, an adversary can easily enter in the network and send the malicious packets. The various attacks like spoofing/impersonation, eavesdropping, denial of services, attacks against routing can be performed.

III. RELIABLE MULTICASTING – DIFFERENT ASPECTS

Reliable multicast is a basic need of various applications in MANET. Reliable multicasting means assurance of the ultimate delivery of all the multicast data packets to its entire destinations. It also ensures delivered data packets to be error free along with minimal use of bandwidth and power. Different aspects and design goals are further brought out hereunder.

A. Sender-initiated versus Receiver-initiated Protocols

A reliable multicast protocol should first be able to detect packet loss and initiate the process of recovery from such loss. However, who is responsible for packet loss detection and loss recovery initiation: the sender or the receivers?

In sender initiated approach, sender preserves the state information of all the receivers. On the arrival of the error free data packet receiving node returns a positive acknowledgement (ACK) to the sender. Sender stores and maintains the state and list of these acknowledgements called ACK list. No receiver acknowledgement to sender indicates the loss of the packets. Packet is retransmitted by the sender after the expiry of timers.

A receiver-initiated approach transfers the accountability for providing reliable multicast to the receivers. It is the accountability of the receiver to identify packet loss (e.g., a wrong checksum, a skip in the sequence number, a timeout while waiting for a data packet or expecting a retransmission, etc.). In case, a packet loss is detected, the receiver begins the procedure of loss recovery (i.e., requesting the retransmission of the lost packet) by returning a negative acknowledgement (NACK) to the sender.

B. Feedback Implosion Control Issue

Both sender-initiated and receiver-initiated reliable multicast protocols can lead to congestion of the network by sending a large number of ACK or NACK messages. This problem is called the feedback implosion problem, which is a crucial challenge for the plan of reliable multicast protocols, since it restricts the scalability for large multicast groups. Feedback implosion control can be accomplished by using either suppression or aggregation.

In feedback suppression, receivers avoid sending (i.e., suppress) their feedback reports if it is useless (e.g., a packet loss has already been declared by another receiver), e.g. as illustrated in Fig 1.

![Illustrative feedback suppression](image1)

On the other hand, feedback aggregation mechanisms organize group members into hierarchies (e.g., trees) where the sender is usually the root of the tree. Feedback reports are collected (i.e., aggregated) from downstream nodes and sent as one message upstream, e.g. as illustrated in Fig2.

![Illustrative feedback aggregation](image2)
C. Centralized versus Distributed Loss Recovery

Centralized (also called source-based) loss recovery allows retransmissions exclusively to be performed by the sender. On the other hand, distributed (also called decentralized) loss recovery allows retransmissions potentially to be performed by all, or a designated subset, of the multicast members. Hence, the loss recovery burden is decentralized over (a part of) the multicast group.

D. Retransmission Scoping

If retransmissions are multicast, they are sent to all receivers. This causes unnecessary bandwidth usage on links leading to those receivers that have already received the packet, and extra usage of resources/processing at these receivers. Hence, a desirable design goal in reliable multicast protocols is how to scope retransmissions so that they are directed only to receivers that need them; this is called retransmission scoping.

One way to achieve retransmission scoping is to require routers to record the links on which NACKs for a packet have arrived. Hence, NACKs can provide subscription information for retransmissions, enabling routers to determine which outgoing links contain group members interested in receiving a retransmission; thus, routers can forward the subsequent retransmission on these links only.

IV. MANET MULTICASTING ROUTING PROTOCOLS – AN ANALYSIS

The various issues in MANET, e.g. those relating to power constraints, mobility, traffic congestion, routing overhead, maintaining quality of service, and minimizing delay make the traditional multicasting technique ‘Flooding’ not an appropriate approach for multicasting. Flooding degrades the performance and increases the traffic. On the basis of the technique of creating routes in a MANET group we can categorise the various multicasting protocols as described below.

A. Tree-Based Techniques

This approach creates a path with combination of various multicast trees of source and receiver pair from source to receiver. There exists only one path between the source and the destination node. The advantage of this approach is high data forwarding efficiency and low overhead. But high mobility in MANET decreases its efficiency and reliability.

The unavailability of alternate paths provides the low robustness from the change of topology due to mobility in MANET. Routing path can be created using source or shared based approach. In source based technique, individual shortest multicast route is created from each sender to receiver node, e.g. as an illustration shown in Fig-3. The mobility in MANET increases the traffic overhead for this approach.

In shared tree technique, single distributed tree is shared among all sender nodes, e.g. as an illustration in Fig-4. There is a rendezvous point (RP) for group. Senders’ node sends packets to RP and various receivers join at RP. The delay is less in the former approach but traffic load is skewed in the later approach. The various protocols based on this technique are AMRIS [3], MAODV[4], LAM[5], LGT[14].
B. Mesh-Based Techniques

Unlike tree based technique, mesh based technique has multiple paths between source and destination node. The availability of alternate paths provides the robustness from the change of topology due to mobility in MANET. This technique is better than the tree based technique in terms of performance, packet delivery and less delays.

However, mesh based techniques have high cost for maintaining paths, forwarding the packets than the tree based techniques. Also, the availability of different routes will result in the receiver of duplicate data packets at the destination node which result in increase of network load. The various protocols based on this technique are On-Demand Multicast Routing Protocol (ODMRP) [6][10], Core-Assisted Mesh Protocol (CAMP) [7], Forwarding Group Multicast Protocol (FGMP) [8].

C. Stateless Multicast

As observed earlier the mobility in the MANET causes the overhead in maintaining the route and creating new path due to frequent topology changes. Tree based technique as well as mesh based technique have overheads in maintaining delivery tree and mesh respectively. The stateless multicast technique reduces this overhead by openly disclosing the list of destinations in data packet header by sender node. This multicasting technique is most suitable for the small sized groups. No complex routing is required. Basic routing protocol forwards the packet to all receivers. In large sized groups, this multicasting technique increases overhead due to increase in list of destinations addresses. Differential Destination Multicast (DDM) protocol [15] uses this approach.

Hybrid Approaches

Hybrid techniques are the combination of tree based and the mesh based techniques, and also found mention in the research on the topic [12]. The approach of this technique is to join the pros of the mesh based techniques (i.e. robustness) and tree based techniques (i.e. low overhead) to attain the enhanced performance. This proposed scheme is more reliable than tree based scheme and reduces network load. The various protocols based on this technique are AMRoute[13], MCEDAR[16]. AMRoute creates the tree based on source routed approach.

The comparative position of different multicast routing protocols brought out in the paper can be summarized as in Table-1 below:

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Parameters / Protocols</th>
<th>Flooding</th>
<th>AMRoute</th>
<th>AMRIS</th>
<th>MAODV</th>
<th>ODMRP</th>
<th>CAMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multicast technique</td>
<td>Mesh</td>
<td>Hybrid</td>
<td>Tree</td>
<td>Tree</td>
<td>Mesh</td>
<td>Mesh</td>
</tr>
<tr>
<td>2</td>
<td>Dependency on Unicast protocol</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Requirement of periodic Messages</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Requirement of Control Packet Flooding</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Acquisition / maintenance of Routing Information</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Scalability</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
</tr>
</tbody>
</table>

Table I. Comparative position of different multicast protocols
V. MULTICAST PROTOCOLS – COMPARITIVE ANALYSIS

This section brings out the comparative analysis of the various protocols on the basis of different metrics / criteria under different Network scenarios like Mobility speed, number of senders, Multicast group size and Network traffic Load as under:

A. Performance Metrics for the protocols

The performance metrics used in this paper for the multicast routing protocol assessment in MANET are as follows:

- **Packet delivery ratio:** It stands for the reliability and efficiency of the protocol in terms of delivery of packet to the destination node. It can be measured by taking the ratio of number of packets truly reached to the number of packets hypothetically reached at the destination.

- **Data packets transmitted vis-a-vis data packet delivered:** In case of unicast protocols the value is equal to or greater than one, while in case of multicast it may be less than one as a single transmission may deliver to multiple locations.

- **Number of control bytes transmitted per data bytes delivered:** It is used as a measure of efficiency with regard to utilization of control packets in data delivery.

- **Control and data packets transmitted vis-a-vis delivery of data packet:** It is used as a measure of the efficiency in terms of channel access.

A. Test Bed Setup And Analysis

A simulator named NS2 was used for performing the analyses. The simulator helps analysis of multi-hop wireless network at Mac layer and physical layer. 50 wireless network nodes, having a roaming range of 1000X1000 were created and the experiment duration was about 1000sec. Nodes mobility was kept diversely from 1m/s to 20m/s. Nodes were the member of only one multicast group at beginning and remained the member of the same group during the experiment duration. Node placement was random. Nodes mobility was also done randomly i.e. nodes could change direction at random. Non mobility time, also known as pause time, was varied to change the relative speed of mobile. Transmission power range of the node was 250 meter.

B. Mobility Speed

**Packet Delivery Ratio:** Due to minimal data loss with availability of redundant routes in a mesh topology the performance of ODMRP is remarkable in dynamic situations, in comparison to CAMP, because of the requirement of network re-convergence by WRP in case of mobility and link breaks, a period during which loop–detection facilities mark these destinations as unreachable.

On account of only one path between member nodes, the delivery ratio is poor in case of AMRIS, as destinations shall fail to receive packets in case of link breaks, and was the least effective with mobility in comparison to other protocols. On account of loop formation and sub-optimal tree causing congestion, packets are not delivered even at low mobility speeds.

Further, ODMRP is significantly more effective, about 104%, in comparison to MAODV with regard data delivery ratio.

**The Number of data transmissions per data delivery to destinations:** Because of loops AMRoute has the best transmissions. It is also observed protocols like ODRMP and CAMP which use meshes transmit higher data packets in comparison to AMRIS, which uses a tree. ODMRP transmission is almost equal to flooding as it takes advantage of multiple redundant routes. With regard packet transmission ratio, ODMRP send significantly less packets, about 40%, for each data packet delivered.

**Control overhead vis-a-vis delivery per data byte:** As Flooding has no control packets, control overhead constitutes of data header and it is not increasing with mobility.

In contrast, overhead increases with the speed in case of other protocols. Relatively, AMRIS has low control overhead vis-à-vis other multicast schemes as there is less transmission of data packets. WRP causes larger control overhead in CAMP, in case of high mobility vis-à-vis ODMRP. Piggybacking of CAMP update messages onto WRP updates further increase the overhead. Overhead is relatively constant in ODMRP as there is no trigger of updates by mobility.

**Total packets transmitted vis-à-vis delivery per data packet:** Smaller number of transmissions in CAMP in comparison to ODMRP is on account of the fact that more data packets are transmitted on redundant paths in case of ODMRP and that control overhead is more in case of CAMP which in turn adds to lower control packet transmissions due to piggybacking of CAMP updates onto WRP updates.
It is observed that AMRIS has the least packet transmissions on account of tree usage whereas on account of loops AMRoute has the largest value. With regard to control and data transmissions, about 48% less packets are sent by ODMRP in comparison to MAODV for every packet delivered.

C. Number of Senders

Packet Delivery Ratio: With loss of more packets due to collision, congestion and channel contention on account of increase in number of sources, there is degradation in the performance of flooding, whereas ODMRP exhibits relative robustness with regard to number of sources on account of better redundancy due to increase in number of forwarding nodes.

Similarly, increased number of senders on account of increased anchors improves the performance of CAMP. Increase in number of sources helps increase redundant paths in a mesh.

On the other hand the performance of AMRIS and AMRoute is not affected by increase in the number of senders on account of a shared tree being used in multicast session. Relatively, with regard to data delivery ration, ODMRP is more effective, about 53%, than MAODV in a scenario of increased number of senders.

With regard to packet transmission ratio, MAODV sends significantly fewer packets, about 75%, than ODRMP for each data packet delivered.

Control Overhead vis-à-vis delivery per data byte: Except ODMRP, other protocols show a constant value in this regard, which is on account of the fact that in ODMRP meshes are build on the basis of per-source, while in case of others it is a shared mesh or tree. As such the control overhead also grows accordingly, and ODMRP may not be that much efficient in scenario of large nodes, e.g. 100 or 1000, are multicast sources.

MAODV is observed to send significant lower control overhead packets, about 59%, in comparison to ODMRP for each data packet delivered, where as in respect of control and data transmissions, the figure stands at 90% less packets for MAODV in comparison to ODMRP for every packet delivered.

D. Multicast Group Size

Packet Delivery Ratio: It is observed that number of multicast members do not affect the performance of Flooding and ODMRP. Similarly performance of CAMP is superior with the increase in number of receivers'. With increase in members there are more redundant routes available in a mesh and this improves the performance. In case of AMRIS as well there is marked improvement with increase in members, however it is not as significant as in case of CAMP on account of non formation of redundant routes in AMRIS. In contrast the behaviour of AMRoute is quite opposite, because the delivery ratio drops with increase in size of the group, on account of existence of critical links in the AMRoute multicast tree

With the increase in group size there is increase in number of tree links and the probability of critical links isolating the sources in the tree is also more.

It is observed that effectiveness in data delivery ratio is significant in case of ODMRP than MAODV when there is increase in the number of multicast group members. Further, with regard to packet transmission ratio, MAODV sends significantly less packets, about 48%, for each data packet delivered.

With regard to control and data transmissions as well, MAODV decreases significantly in comparison to ODMRP, about 46%, for each data packet delivered.

E. Network Traffic Load

Packet delivery ratios: AMRIS is very sensitive to amount of traffic and the ratios drops sharply in case of increases in traffic, as a result of significant packet collisions due to beacons size and transmission. In a scenario of relatively low packet rate, AMRoute performs very well, however it degrades sharply with increase in traffic, which in turn is caused by buffer overflow at the members and mesh nodes connecting the members in the tree.

Increase in traffic also affects the performance of CAMP, with increase in collisions and packet losses in a scenario of enhanced traffic load. With the dropping of important control packets there may be delay in anchor construction and failure of data packets in reaching to all the anchors.

Delivery ratios are worse in case of Flooding as compared to ODMRP in case of increase in traffic load. Enhanced traffic load results in increase in collisions and packet losses with the flooding of every data packet and buffer overflows also grow. Since the number of data packet transmissions in ODMRP is less than flooding, the loss of packets is less.

Further, while ODMRP is similar in behavior like CAMP, yet due to less control overhead and buffer overflows it has a better delivery rate as compared to CAMP.
VI. CONCLUSION

Comparative analysis of various ad-hoc network multicast protocols, and the various issues and aspects related thereto, brought out in the paper brings out that normally, mesh based protocols perform better than tree-based protocols in a mobile scenario, where alternate routes add to the robustness to mobility.

In a scenario of medium mobility hybrid protocols are more suitable than a stand alone tree or a mesh structure. Further, in case of multiple small groups, stateless multicast appears to be more promising. This brings out that the usefulness of different protocols varies with the underlying application environments.

In case of high mobility requirements scenario, ODMRP is best suited with regard to multicasting, even though much more is still required for the improvement of performance by the protocols, e.g. in case of ODMRP, controlling the congestion is important if required to be scalable to larger member groups. Similarly while AMRoute is scalable, however it requires appropriate resolution of loops. In the case of AMRIS it is important that transmission numbers and the size of beacons are reduced so that network load decreases. It is also observed that CAMP can perform better with appropriate modifications in case of an on-demand routing protocol and that MAODV needs an appropriate mechanism to enhance data delivery ratio.

In retrospect, some of the issues like QoS, security, and power and location-aware multicasting still need further research and investigation.

REFERENCES