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RESEARCH ARTICLE

A Comprehensive Simulation Study on the Multicast Operation of the AODV Routing Protocol for CBR Traffic in Mobile Ad-Hoc Networks

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Abstract – In certain applications of MANETs like handling emergency operations, the group communications play a crucial role which demands for multicast routing. Moreover, it is known fact that the on-demand reactive routing protocol AODV is very much suited for the mobile ad-hoc environments. Hence, the multicast routing protocol MAODV (multicast extension of AODV) is considered, to get the benefits of using a single protocol for both unicast and multicast routing. In this paper, MAODV is examined for its multicast routing behavior under various mobility patterns in order to check its suitability for dynamic environments of MANETs, for CBR data traffic. The work is done by varying various multicast routing parameters such as number of multicast receivers per group, number of multicast senders per group and number of multicast groups in a network scenario. Further, a special case where the number of receivers is equal to the number of senders in a multicast group (conferencing) is also simulated for exploring the protocol's multicast routing behavior thoroughly. The performance of the protocol is analyzed in terms of the QoS evaluation metrics such as packet delivery ratio, average end-to-end delay, average jitter, throughput and normalized routing load. From the graphs, it is observed that the MAODV works well in MANET environments. Moreover, the benefit of multicast routing is clearly visible in terms of increased throughput and reduced routing loads irrespective of the experiment set.

Index Terms – MANET, MAODV, Mobile Ad-Hoc Network, Multicast Operation of the AODV, Network Simulation.

1. INTRODUCTION

A Mobile ad-hoc network (MANET) [1-5] is a group of two or more mobile nodes that are furnished with necessary wireless communication technologies as well as routing capabilities. The communication is possible anytime and anywhere between/among the nodes without the aid of any centralized administration and/or networking infrastructure. Hence, the nodes connect together instantly in order to serve a purpose on temporary basis.

The peculiar characteristics of MANETs pose multiple design challenges. These include [6-8]:

Infrastructure-less and Decentralized Operation: Since a MANET has neither any fixed infrastructure nor centralized control, each node has to operate in decentralized manner. All network related control and management functions are distributed across them, which has added further difficulty to network's reliability issues.

Mobile Ad-Hoc Nodes with Constrained Resources: In MANET environments, the nodes are small, light-weight and hand-held devices to support portability thereby usually have limited processing capabilities, storage capacities and power resources. This limits the applications and services that can be supported by the network. Moreover, due to cooperative communication environment, a node has to forward the packets whenever is needed to other nodes which also involves power consumption and security of the network. Besides, the mobility of the ad-hoc nodes in wireless medium cause frequent route breaks (because node may move out of the transmission range or may get turned off or link break due to poor wireless channel quality) which again consumes the power as well as bandwidth for determining the new routes and for the exchange of necessary control packets.

Network Resource Constraints: The available and assigned radio band is limited and hence the offered data rates are also limited. This requires the network should rely on multiple access techniques and also on other network protocols that use the spectrum optimally. However, these techniques make the nodes contend for the wireless channels that may lead to conflicts and thereby packet corruptions.

Inherent Problems of Wireless Channels: It is obvious that the wireless links exhibit time-changing characteristics and asymmetric propagation properties. These effects may get multi-fold due to the ever-changing environments of MANETs that results in signal quality degradation, blockage etc. These transmission impediments restrict the network range, data rate and speed of operation.

1.1. Motivation and Objectives

Certain Mobile Ad-hoc Network (MANET) applications like handling emergency (search and rescue actions, earthquakes, floods etc.) situations, military operations require sharing of information among a group(s) of nodes which demands for multicast routing (MCR) [9]. In fact, the multicast (MC) communication in a MANET improves the channel bandwidth utilization by utilizing broadcast nature of the wireless links.

To allow optimal communication to happen in a MANET, the routing protocol must be able to offer both unicast and multicast transmissions [10]. There are various benefits of combining both unicast and multicast communication abilities into a single protocol. In such protocols, the routing information acquired when looking for a MC route will also increase the knowledge about unicast routes, and vice versa. In constrained resources environments like MANETs, any reduction in routing overhead is a notable benefit. Moreover, coding of such protocols can be done in an efficient and simple way. Finally, any improvements that have been done to the basic algorithm can be advantageous for data transmissions of both multicast and unicast. Since in mobile ad-hoc environments, the on-demand reactive routing protocol AODV (Ad-hoc On-demand Distance Vector) is one of the best suited and well accepted protocol [11-12], its multicast extension i.e., MAODV (Multicast Ad-hoc On-demand Distance Vector) has been considered for this simulation work.

The objective of this work is to check MAODV's suitability to the dynamic environments of MANETs considering constant bit rate (CBR) data traffic. In this work, the behaviour of MAODV is observed by varying a number of MCR parameters such as MC receivers per group, MC senders per group, number of multicast groups (MCGs) in a network scenario and a special case where the number of receivers is equal to the number of senders in a MCG (conferencing). The performance evaluation is done in terms of quality of service (QoS) such as packet delivery ratio (PDR), average end-to-end delay (AEED), average jitter (AJ), normalized routing load (NRL) and throughput (TP).

The presentation of the paper is arranged as follows. Section 2 outlines the simulation works conducted on the MAODV protocol for CBR traffic while the Section 3 describes the functioning of MAODV protocol in detail along with the necessary flow charts. The simulation scenario is highlighted in Section 4. In Section 5, the results as well as the discussion on the results are presented. Finally, the conclusions of the work done are expressed in Section 6.

2. RELATED WORKS

A number of research works are available in the literature for various varieties of multicast routing protocols for MANETs. However, only the contributions covering MAODV alone and for the CBR data traffic have been considered in this section.

Moreover, only those works in which the routing protocol's evaluation was done for atleast one of the QoS parameters such as PDR, AEED, AJ, TP and NRL. Further, the research works that had furnished the simulation details either fully or atleast for the parameters such as node speed, number of connections, packet rate and packet size; have been only taken for the consideration. This is required to make sure that the network considered for the protocol's evaluation was absolutely a MANET. Table 1 outlines the research works that had been conducted using the network simulator, NS-2 and wherein the simulation results taken were averaged for atleast three different topology-scenarios.

The authors in [15] compared the performance of MAODV for TCP (Transmission Control Protocol) and CBR traffics over MANET using NS-2.26 in terms of PDF and AEED by varying number of senders (1, 2, 5 and 10) in a MCG, number of receivers (10, 20, 30, 40 and 50) and node speed (0m/s, 1m/s and 20m/s). The created simulation environment consists of 50 nodes in 1500x300m^2 over a period of 910s, IEEE 802.11 at 2Mbps, 250m, random waypoint mobility model with zero pause time, 256byte packet, 2 packets/s and maximum packets sent: 1740. It was concluded that the behavior of MAODV for CBR traffic was better than TCP.

All the three except [14], had evaluated the MAODV's performance by varying two parameters, atleast one from each set, of the following sets: {node speed, node pause time} and {number of multicast receivers, number of multicast senders, number of MCGs}. This is needed to create an environment where the multicast routing protocol's behavior is explored in detail in dynamic environments of MANET. In [14], the number of receivers along with various data rates had been considered. Moreover, the authors in [16-22] had developed various versions of MAODV by concentrating on specific limitations of it.

From the related works, it is observed that still there is scope to research and to explore the multicast routing protocol MAODV's behavior further in all aspects.

Network Parameters*	Varying Parameters	Conclusions
1500mx1000m; 2000s; 50; IEEE 802.11; two-ray ground reflection model; 2MBPS; 250m; random waypoint model; 20m/s; 5s; 4 packets/s; 256bytes; one MCG [13]	1. Mobility speed (1,10,20,30, 40m/s) 2. Group size (5,10,20,30,40) 3. Number of senders (1,3,5,7,10) 4. Long-lived connection - LLC (25 packets/s) and short-lived connection - SLC (0.0125 packets/s)	*Average latency* for LLC is greater than that for SLC; *channel access η* over LLCs is better than that for SLC; *scalability* in SLC situation is better than that in LLC with respect to the number of senders.
1500m×300m; 200s; MAC 802.11; 2MBPS; random waypoint mobility; 20m/s; zero pause time; 2packets/s; 512 bytes [14]	1. Number of receivers (10,20,30, 40, 50m/s) 2. Data sending rate (2,4,8,12,16,20 packets/s)	Shown how the channel bandwidth can be utilized efficiently in multicast routing in terms of **PDR, Average latency, NRO, Packet loss rate, normalized M load, TP, network control overhead.

[*] Simulation area; simulation time; number of nodes; transport layer protocol; MAC layer; physical layer; propagation model; channel bandwidth; node transmission range; mobility model; node speed; pause time; number of connections; packet rate; packet size.

[**] CO-Control Overhead; PDR-Packet Delivery Ratio; NRO-Normalized Routing Overhead; TP-Throughput.

Table 1 Literature Survey Table of MAODV

3. MAODV

MAODV [23], is a distributed reactive-type shared-tree-based multicast routing protocol. Once nodes join the MCG, a multicast tree (MCT) comprising of members and the forwarding nodes that connect group members is formed. The first member of the MCG becomes that group's leader. The MCG leader initializes the sequence number and increments it periodically to ensure the latest routes available. The formats for route request (RReq) and route reply (RRep) messages are same as in AODV [24-25] with some extension fields. Similar to AODV operation, *hello* messages are used for maintaining local connectivity.

Each node maintains three tables: routing table (RT), multicast routing table (MCRT) and request table (ReqT). The RT is similar to the one discussed in AODV, containing same information fields. The entries in MCRT are only for the MCGs for which the node acts as the forwarding node, i.e., a member of the MCT. In MCRT, connected with each next hop entry, there is a flag called *Enabled* which is used to show whether the node is part of the MCT or not. The ReqT is also known as group leader table. It is basically a small table maintained by each node that supports multicast routing.

The MCG leader broadcasts a group hello (GH) message periodically. On receiving a GH message, the MCT members update their ReqT and MCRT while the others update only ReqT. This information is required for repairing MCTs.

When a node wishes to join or to send the data to a MCG, first it checks its MCRT for a valid route. It broadcasts a RReq packet when it does not find a route to that MCG. For join-requests (RReq with *J*-flag set to 1), only the member of the MCT for the indicated MCG responds if it has a valid route and unicasts a RRep packet with an added extension field Mgroup-hop-count, back to the source of RReq. Initially, Mgroup-hop-count is set to zero and incremented by one each time the RRep is forwarded. Moreover, even the MCG leader can respond to the join-requests. For non-join requests, any node with a valid route responds by unicasting an RRep packet back to the source of RReq. In fact, the non-join requests are handled in the way same as discussed in AODV. If a node has not met the aforementioned conditions, then it simply rebroadcasts the RReq packet.

On receiving the RReq packet, a node first creates/updates its forward as well as reverse route entries in RT, in addition to creating/updating an entry in MCRT. For a node, the reverse route information is required to relay an RRep packet to the source, if it gets one. However, the node updates its RT entry only when it receives a route with higher destination sequence number or receives a route with better metric when sequence numbers are equal. The ReqT is also updated for a join-request message.

When a node receives an RRep, it either updates/creates an entry in both of its RT and MCRT, and then unicasts RRep packet back to the source node with incremented hop-count and Mgroup-hop-count fields. The flow chart in Figure 1 outlines the RReq and RRep processes.

If the source of RReq receives multiple RReps, it selects a route with minimum number of hops to the closest member of MCT. Now, the source node sets the *Enabled* flag for this selected next hop in its MCRT and sends a multicast activation (MACT) message to it. On receiving this, the next hop node also sets the *Enabled* flag for the source node in its MCRT. If this is a member of MCT, it does not disseminate MACT any further. However, if it is not a MCT member, it would have got one or more RRep packets. The node holds the best next hop for its route to the MCG; sends a MACT message to that next hop and sets the *Enabled* flag in respective entry of its MCRT. This process goes on till the node (already a MCT member) that has originated the selected RRep is reached. The MACT process ensures that there are no multiple paths exist for any node in MCT.

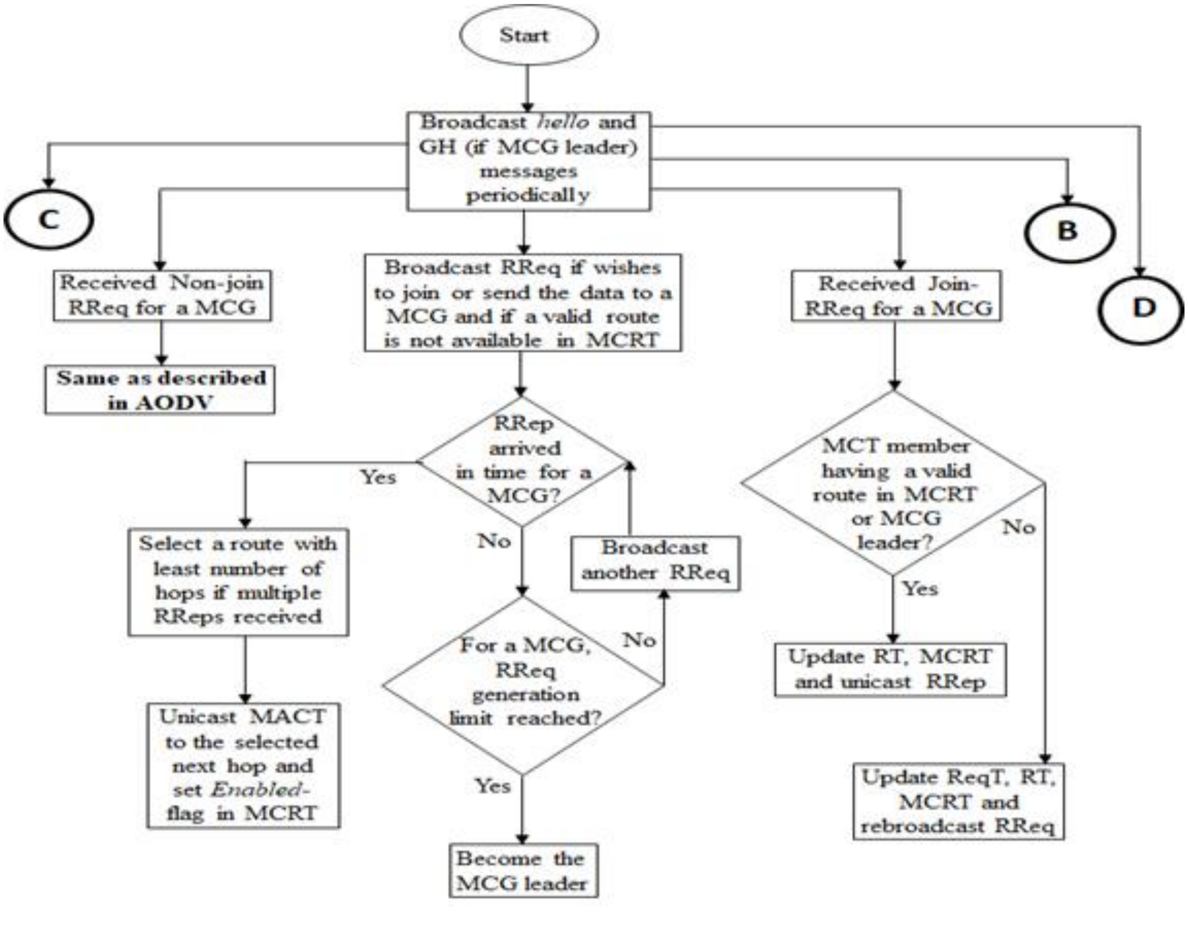


Figure 1 RReq and RRep Processes in MAODV

To forward the data packets, the nodes use only the activated routes in their MCRT. When a node receives a MC data packet, it responds to the data packet only if it is a MCT member, otherwise simply ignores it. The MCT member records the source IP address and packet-id of the data packet and then multicasts it to next hops. The data packet will be processed if the node is a MCG member. Recording of source IP address and packet-id of the data packet is required to discard the duplicate packets.

When a MCG member wishes to terminate its membership, it can revoke its member status but still it has to continue as a forwarding node of the tree if it is not a leaf node. Otherwise, if it is a leaf node, it can prune itself from the tree by sending a MACT message with *P*-flag (prune) set to its next hop. Then the node updates its MCRT. On receiving this MACT message, the next hop node removes the corresponding entry for the sender node in its MCRT. If this node has now become a leaf node and is not a MCG member, it can also cut back itself from the tree in a similar manner as discussed. This tree branch trimming ends when either a non-leaf node or a MCG member is reached. The flow chart shown in Figure 2 describes the route activation, MC data transmission and membership termination processes.

If neither a *hello* packet nor any other packets are received/heard from a neighbor in specified interval of time, then it indicates that the link breakage has occurred. Only the downstream node is allowed to begin the repairing of link once it detects the link breakage. The node broadcasts an RReq packet with its Mgroup-hop-count and *J*-flag set using expanding ring search. Either a MCT member having a valid route with Mgroup-hop-count smaller than indicated in RReq packet or a MCG leader is subjected to respond by unicasting a RRep packet. If no RRep is received within the number of RReq generation limit, the downstream node becomes the MCG leader if it is a group member assuming that the network has got partitioned. Conversely, if it is not a MCG member and has only one next hop, it sends a MACT with *P*-flag set to its next hop. The process continues till a MCG member is reached.

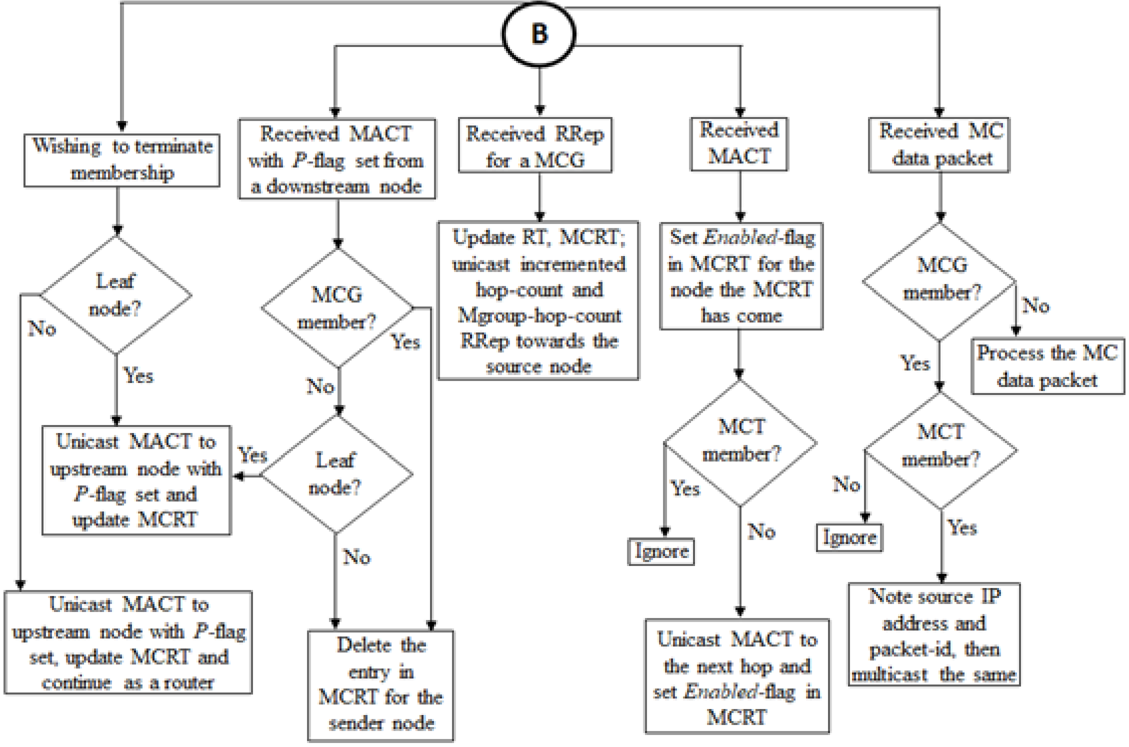


Figure 2 Route Activation, MC Data Transmission and Membership Termination Processes in MAODV

However, if the downstream node is neither a MCG member nor it has one next hop, it unicasts a MACT with *GL*-flag (group leader) set to first of its next hops. On receiving MACT with *GL*-flag, the next hop becomes the MCG leader if it is a group member. This continues till a group member is reached.

After becoming the new MCG leader, a node has to broadcast a GH message with *U*-flag (update) set across its partition. The nodes update their MCRT and ReqT accordingly once they receive this message.

After this, the network scenario contains two disconnected partitions of same MCT with two group leaders for each partition. Eventually, if the partitions reconnect, a node receives a GH for the MCG that contains group leader information that differs from the information it already has. Then it unicasts an RReq with *R*-flag (Repair) set to the group leader, say GL1, possessing higher IP address. On receiving this, the GL1 grants the permission to the node for rebuilding the tree by unicasting an RRep with *R*-flag set. After receiving this, the node unicasts RReq with *R*-flag set to other group leader, say GL2. The GL2 notes this, becomes the leader of the reconnected tree and unicasts an RRep with *R*-flag set back to the node which got the grant to repair. Now, the GL2 broadcasts the GH with U-flag set which completes the merging of the two trees. The Figures 3 and 4 presents the flow charts of handling link breakages and reconnecting partitioned trees in MAODV respectively.

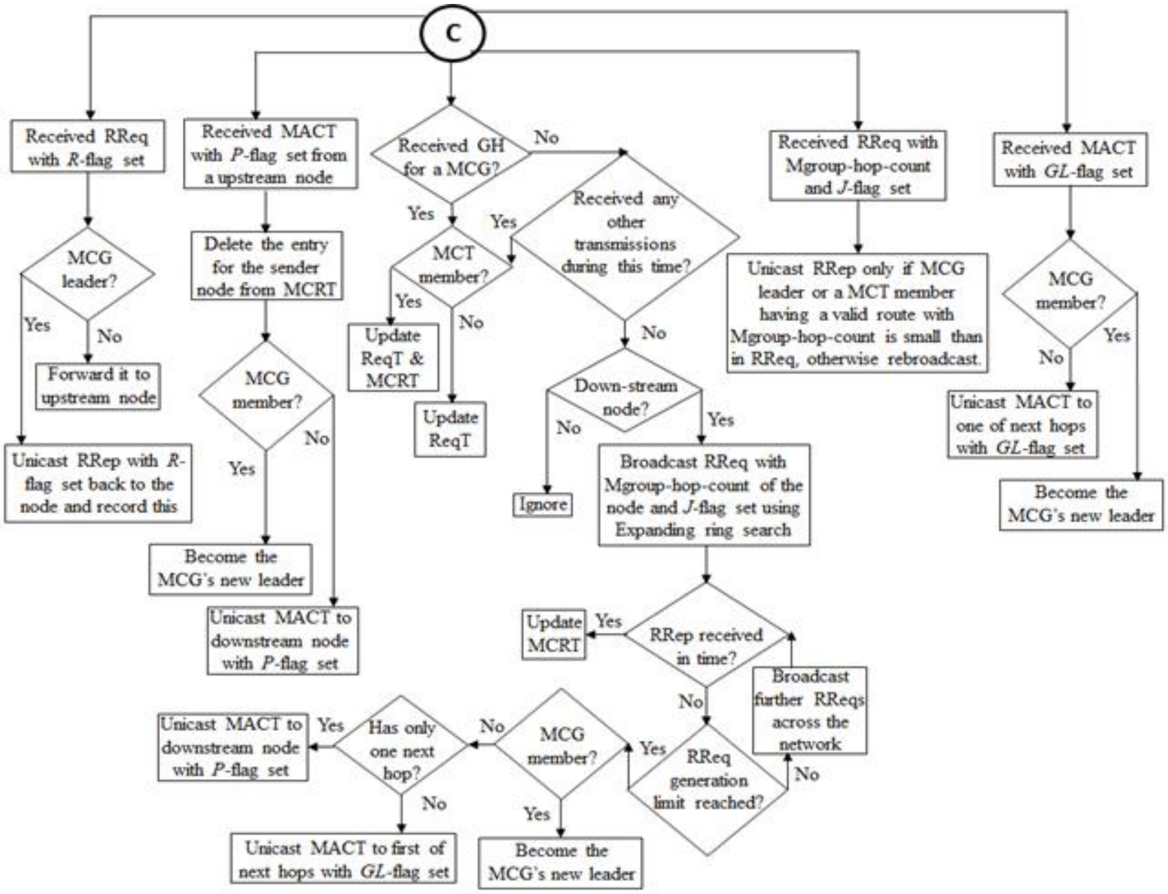
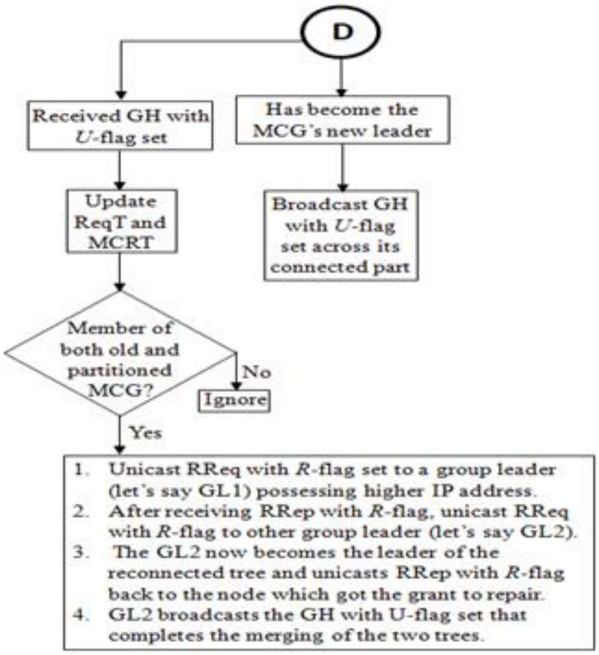


Figure 3 Handling Link Breakages in MAODV



1. Unicast RReq with R-flag set to a group leader (let's say GL1) possessing higher IP address.
2. After receiving RRep with R-flag, unicast RReq with R-flag to other group leader (let's say GL2).
3. The GL2 now becomes the leader of the reconnected tree and unicasts RRep with R-flag back to the node which got the grant to repair.
4. GL2 broadcasts the GH with U-flag set that completes the merging of the two trees.

Figure 4 Reconnecting Partitioned Trees in MAODV

4. SIMULATION SCENARIO

An open-source simulation tool, NS-2 [26-27] has been selected for this work because of its popularity and, availability of proper documentation and user support. Specifically, the version NS-2.34 is used [28-29]. However, the MCR protocol MAODV is not available with basic version of the simulation tool. Hence, it is brought into the NS-2.34's environment through the guidelines provided in [30].

The network parameters used for the simulation setup are tabulated in Table 2. A pause time of 0s corresponds to continuous motion of the nodes in the network, represented by No-Pause (NP). The node speeds: 1.2-2.5 m/s denote Walking-Speeds (WS), 5-10 m/s denote Running-Speeds (RS) while 15-20 m/s denote Tank-Speeds (TS). The node movement patterns are generated using speed- and pause-types equal to '1' respectively.

Network Parameter	Value
Simulation area	1000mx1000m
Number of nodes	50 (randomly placed)
Simulation duration	15 minutes
Application data traffic	CBR
Transport layer protocol	User Datagram Protocol
Network layer protocol	MAODV
MAC protocol	IEEE 802.11
Propagation model	Two-ray ground
Wireless network channel interface queue type and length	DropTail/PriQueue and 50
Channel bandwidth	2MBPS
Transmission range of the node	250m
Mobility model	Random waypoint

Table 2 Network Parameters

4.1. Communication Model

A number of communication patterns have been created for analysis of the MAODV and are tabulated in Table 3. The first column of the table represent the varying parameter, the notations for different communication patterns are listed in second column and in the last column the traffic description about the communication pattern is provided. In all topology-scenarios, CBR data traffic has been assumed as the MC traffic. Intentionally, a small packet size of 64 bytes has been chosen in order to reduce the probability of congestion in the network. Moreover, very small packet rates are chosen to investigate continuously the MCR ability of the MAODV.

Varying Parameter	Communication Pattern	Traffic Description
Number of receivers in a MCG (***G***x***S***x_)	1x1x5	1 group, 1 sender; 4 packets/s; 64 byte packet
	1x1x10	
	1x1x15	
	1x1x20	
	1x1x25	
Number of senders in a MCG (***G***x_x***R***)	1x1x25	1 group, 25 receivers; 1 packet/s; 64 byte packet
	1x5x25	
	1x10x25	
	1x15x25	
	1x20x25	
Number of MCGs (_x***S***x***R***)	1x1x5	1 sender; 5,10,15 receivers; 1 packet/s; 64 byte packet
	2x1x5	
	3x1x5	
	1x1x10	
	2x1x10	
	3x1x10	
	1x1x15	
	2x1x15	
	3x1x15	
Conferencing (***G***x***S***x***R*** where ***S*** = ***R***)	1x5x5	1 group, 5 senders, 5 receivers; 1 packet/s, 64 byte packet
	1x10x10	1 group, 10 senders, 10 receivers; 1 packet/s, 64 byte packet
	1x15x15	1 group, 15 senders, 15 receivers; 1 packet/s, 64 byte packet

Table 3 Communication Model

Gx***S***x***R*** is the notation used for representing a communication pattern, where ***G*** denotes the number of MCGs in a network scenario, ***S*** is the number of senders in a MCG, and ***R*** is the number of receivers in a MCG. Different communication patterns are created varying the ***R***, ***S***, ***G*** and a special case where ***S*** = ***R***. The dash in the notation signifies that it is the varying parameter.

4.2. Methodology

Only three mobility patterns such as WSNP (Walking-Speed, No-Pause), RSNP (Running-Speed, No-Pause) and TSNP (Tank-Speed, No-Pause) have been used since the nodes in MANETs are not stationary by their nature and these three mobility patterns are sufficient enough for analyzing the MC behavior of MAODV. Moreover, only one parameter is changed at a time while all other parameters are kept fixed. Since the performance of any routing protocol under mobile ad-hoc environments is very much sensitive to mobility patterns, 10 topology-scenario files are generated for each mobility pattern. A total of 30 topology-scenarios for three mobility patterns and 22 communication patterns are generated. On the whole, 660 different simulation runs, 30 runs for each communication pattern are performed for the analysis work. Hence, each sample point in the graphs plotted in Section 5 is the mean of the results of 10 different topology-scenarios.

5. RESULTS AND DISCUSSION

The simulation work has been divided into four sets as shown in Table 3. In the first set of simulations, fixing both ***G*** and ***S*** to 1, ***R*** has been increased from 5 to 25 with a step of 5. In the second set, ***G*** and ***R*** have been kept constant at 1 while ***S*** is varied from 1 to 20 in steps of 5. The third set used to explore the behaviour of MAODV for change in ***G*** from one-, two- and three- MCGs, having single sender (***S*** = 1) in all cases, however increasing the ***R*** for three values 5, 10 and 15. Finally, the last set is a special case, where a single MCG (***G*** = 1) has been formed and ***R*** and ***S*** values are changed from 5, 10 to 15 at a time.

Under these four sets, the QoS performance of MAODV is analyzed through the evaluation parameters packet delivery ratio (M-PDR) in %, average end-to-end delay (M-AEED) in ms, average jitter (M-AJ) in ms, throughput (M-TP) in BPS and normalized routing load (M-NRL) in %. However, to differentiate the unicast QoS metrics from multicast, a letter ‘M’ (stands for *multicast)* has been used as prefix. *M-PDR* is computed as the ratio of total number of unique data packets received to the total number of data packets transmitted by all sources times the number of receivers. *M-AEED* provides the average time taken by a data packet to reach the destination node from the source node. *M-AJ* is defined as the average of variations in data packets arriving at the destination nodes of all the data connections of the MANET. *M-TP* defines the amount of data transferred per second. *M-NRL* is defined as the number of routing/control (RReq, RRep etc.) packets transmitted per data packet delivered at the destination.

5.1. Varying Number of Receivers in a MCG

Five single-sender communication patterns have been used in which ***R*** is increased progressively: 1x1x5, 1x1x10, 1x1x15, 1x1x20 and 1x1x25. MC members join the group at 1.0s, the data transfer starts at 30.0s and stops just one minute before the simulation ending time. The Figures 5 to 9 show the plots of QoS metrics as a function of increasing ***R*** at WSNP, RSNP and TSNP. The protocol has performed quite well at low mobility pattern compared to RSNP and TSNP for all QoS metrics.

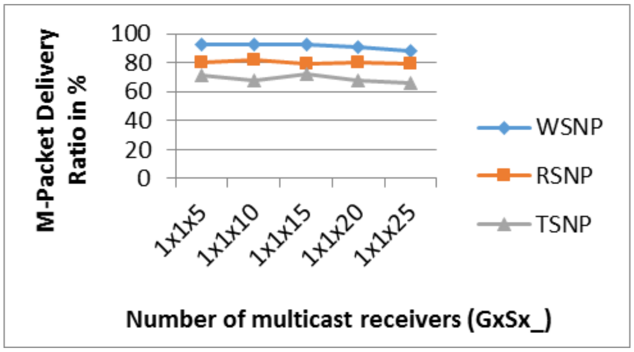


Figure 5 M-PDR in % vs Number of MC Receivers at Various Node Speeds

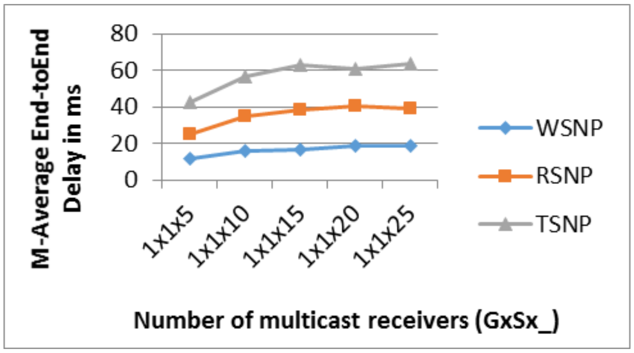


Figure 6 M-AEED in ms vs Number of MC Receivers at Various Node Speeds

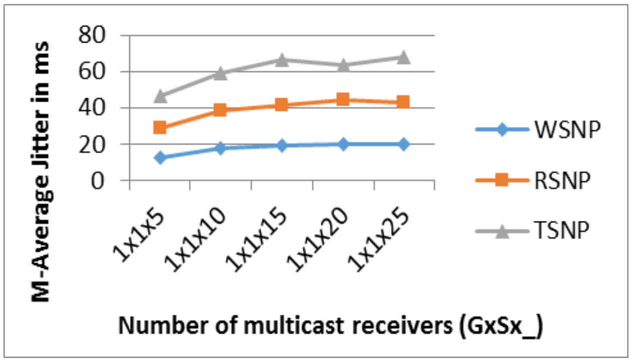


Figure 7 M-AJ in ms vs Number of MC Receivers at Various Node Speeds

In fact, the increasing ***R*** results in large number of MC forwarding states in the network and consequently a large numbers of data packets delivered that should lead to higher M-PDR values. However, decreased values of this parameter have been observed, in Figure 5. This is due to - a packet loss at upstream node affecting a large set of downstream receivers in MAODV. Moreover, for increased values of ***R***, the longer forwarding paths in shared-tree based MAODV are more prone to packet loss due to data collisions. This increases the data and routing packet retransmissions and hence the values of M-AEED and M-AJ have increased, shown in Figures 6 and 7 respectively.

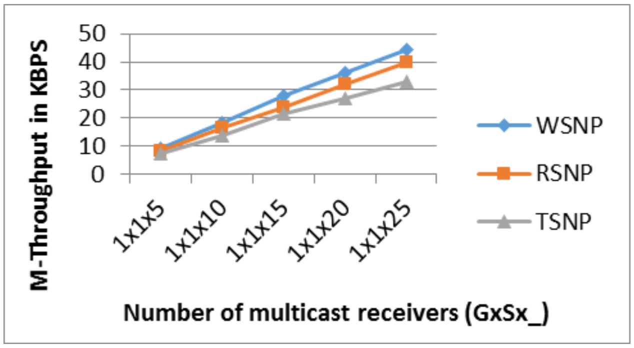


Figure 8 M-TP in % vs Number of MC Receivers at Various Node Speeds

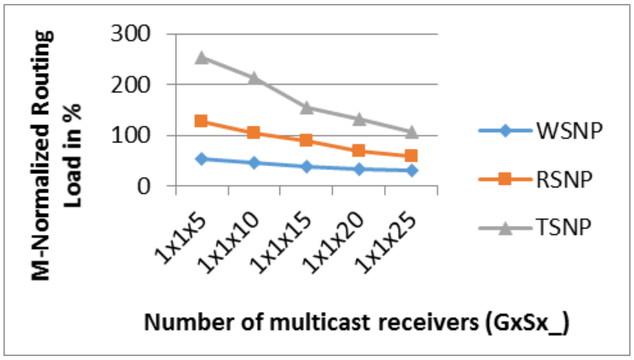


Figure 9 M-NRL in % vs Number of MC Receivers at Various Node Speeds

The increase in M-TP as depicted in Figure 8, is due to the fact that the number of received MC data packets has increased for increased ***R***. Since the added receivers usually join the shared-tree through the immediate MCT member to them, reduced routing overhead is perceived. Moreover, the localized join and repair flooding feature of MAODV has improved the M-NRL values further with increase in ***R*** as in Figure 9.

5.2. Varying Number of Senders in a MCG

In this set of experiments, the MAODV's performance is analyzed by varying the MCG parameter ***S***. In a single MCG of size equal to 25, five communication scenarios are generated by increasing the number of senders: 1x1x25, 1x5x25, 1x10x25, 1x15x25 and 1x20x25. In all communication scenarios, the members of the MCG join at 1.0s and all communications stop just one minute before the end of the simulation. In 1x1x25, the data communication starts at 20.0s. In 1x5x25 the first data transfer starts at 20.0s while the second starts at 40.0s and so on maintaining a gap of 20.0s. Hence, the fifth data transfer originates at 100.0s. Like this, the tenth data transfer in 1x10x25 begins at 200.0s, the fifteenth data transfer in 1x15x25 at 300.0s and finally the twentieth data transfer in 1x20x25 originates at 400.0s. Figures 10 to 14 represent the graphs for the chosen QoS parameters on the basis of ***S*** at WSNP, RSNP and TSNP. Performance of the protocol is degrading with increased node mobilities for all QoS parameters.

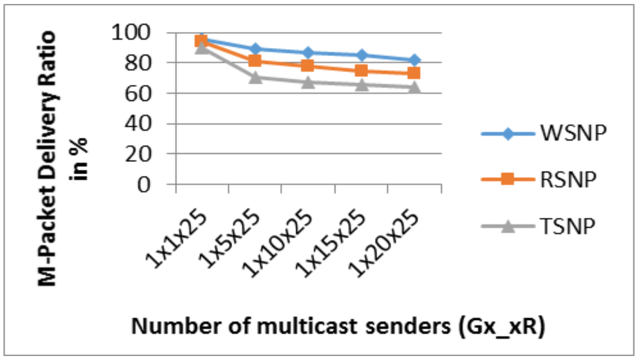


Figure 10 M-PDR in % vs Number of MC Senders at Various Node Speeds

In single-source scenario, the protocol has performed very well and resulted in M-PDRs of nearly 96%. However, in the multi-source scenarios, packet collision losses caused by high network loads have led to lower values of M-PDR, depicted in Figure 10. Moreover, increased network load indicates a busier wireless medium which causes the nodes to wait for longer times before forwarding each data packet that result in packet drops. Since only the number of data traffic sources in the given MCG is increased, the M-AEED and M-AJ have remained fairly constant for increasing ***S*** as depicted in Figures 11 and 12 respectively.

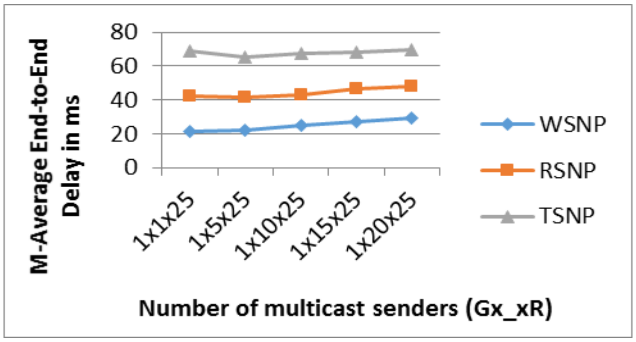


Figure 11 M-AEED in % vs Number of MC Senders at Various Node Speeds

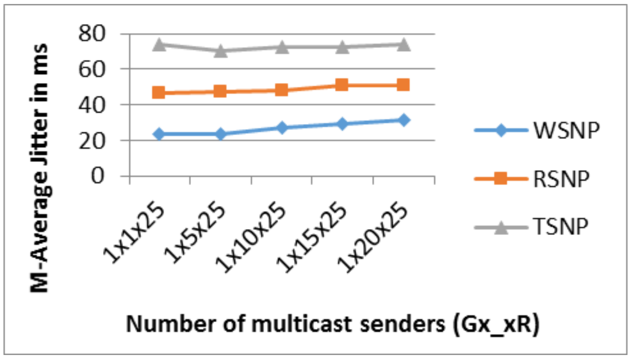


Figure 12 M-AJ in % vs Number of MC Senders at Various Node Speeds

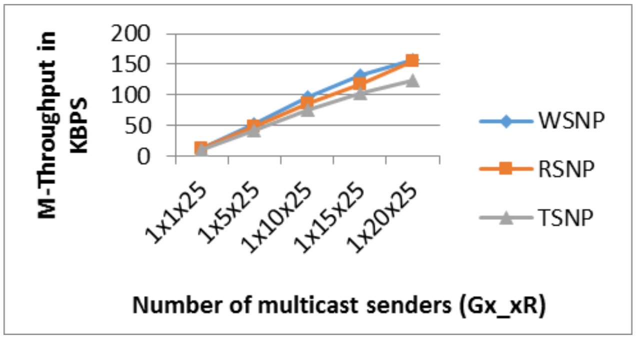


Figure 13 M-TP in % vs Number of MC Senders at Various Node Speeds

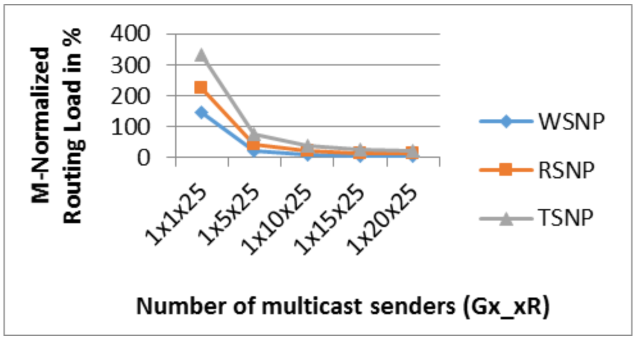


Figure 14 M-NRL in % vs Number of MC Senders at Various Node Speeds

With added each sender, the MAODV has displayed great improvements in M-NRL values, see Figure 14. This is due to the fact that the increasing number of senders will not disturb the MCT. Further, the added senders to the same MCG increase the number of data packets generated that resulted in good values of NRLs. Apart from this, these additional data packets in the network have increased the number of successfully received data packets at MC receivers which has improved the M-TP values significantly, shown in Figure 13.

However, for single-sender scenario, compared to ***R*** case, the improved values for all the QoS metrics are recorded. This is due to the size of the MCG (***R*** = 25) and the decreased data rate of 1 packet/s considered in this case.

5.3. Varying Number of MCGs

The main aim of this set of experiments is to examine the behaviour of MAODV for increasing ***G***, with ***R*** value chosen among 5, 10 and 15 and ***S*** value fixed at 1. Three different ***G*** values i.e., ***G*** = 1 that constitutes a single MCG (denoted by 1-MCG), ***G*** = 2 that constitutes two MCGs (denoted by 2-MCG) and ***G*** = 3 that constitutes three MCGs (denoted by 3-MCG) have been considered. Hence, a total of nine communication patterns: 1x1x5, 2x1x5, 3x1x5, 1x1x10, 2x1x10, 3x1x10, 1x1x15, 2x1x15 and 3x1x15 have been created. In 1-MCG scenario, the data communication starts at 60.0s. Whereas in 2-MCG scenario, for first MCG, the data communication begins at 60.0s while for the other, it commences at 120.0s. Finally, in 3-MCG scenario, the senders in first, second and third MCGs initiate the data communication at 60.0s, 120.0s and 180.0s respectively. The members of MCGs join the group 30s before the beginning of the data communication in each scenario and the data communication stops at one minute before the simulation time. Figure 15 presents the NAM screenshot of 3-MCG scenario where the nodes appeared in red color denote the MCG1, the nodes in green color denote the MCG2 and the nodes in blue color denote the MCG3.

The graphs for QoS performance metrics on the basis of ***G*** at WSNP, RSNP and TSNP are depicted in Figures 16 to 30. Compared to the performance of protocol at RSNP and TSNP, the performance is really good at WSNP for all QoS metrics.

Similar to first 2 sets of experiments, for increasing ***G***, the drop in M-PDR and the increase in M-AEED (see Figures 17, 22 and 27) as well as M-AJ (see Figures 18, 23 and 28) values are seen. The improvement in terms of M-TP and M-NRL has been observed.

In MAODV, multiple MCG scenarios are supported by maintaining one tree for each MCG. It is obvious that for the maintenance of each tree, multiple RReq, RRep and MACT packets are generated in the network. Hence, with increasing ***G***, the probability of these packets interfering each other increases thereby increasing packet loss - the cause for getting low values of M-PDR. Moreover, the increased amount of routing overhead generated for the maintenance of increased number of trees with ***G***, have resulted in increased waiting times of the data packets at interface queues that has caused a raise in M-AEED and M-AJ values.

From the first set of experiments, it has been observed that for increasing number of receivers there is not much decrease in the M-PDRs. Hence, constant values of M-PDRs are observed in this set of experiments for increasing ***R*** as shown in Figures 16, 21 and 26.

With added each MCG, though the amount of routing overhead increases in the network for maintaining the increased number of trees, however the improved values of M-NRL have been observed, shown in Figures 20, 25 and 30. This is due to the fact that the increasing ***G*** has increased the overall number of receivers in the network thereby increased number of data packets delivered to the receivers, and hence resulting in reduced values of M-NRL. Since the successful data packets delivered increases with increasing ***G***, the growing values of M-TP have been noticed.

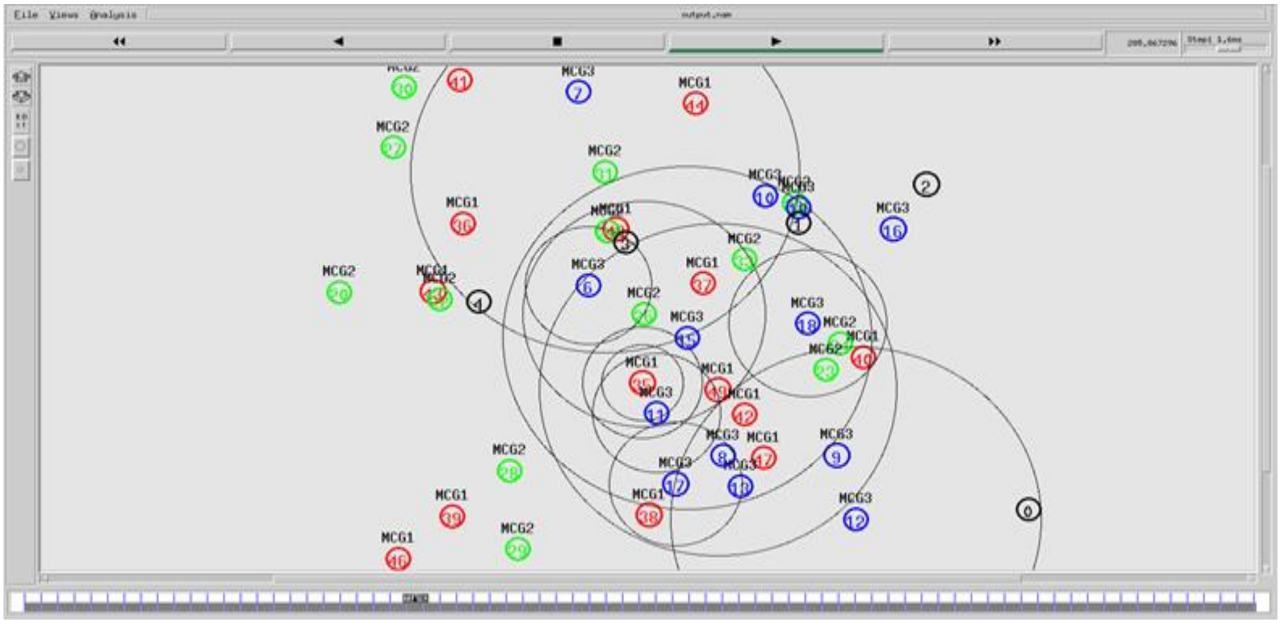


Figure 15 NAM Screenshot of 3-MCG Scenario (Nodes Appeared in Colors Red: MCG1, Green: MCG2, Blue: MCG3)

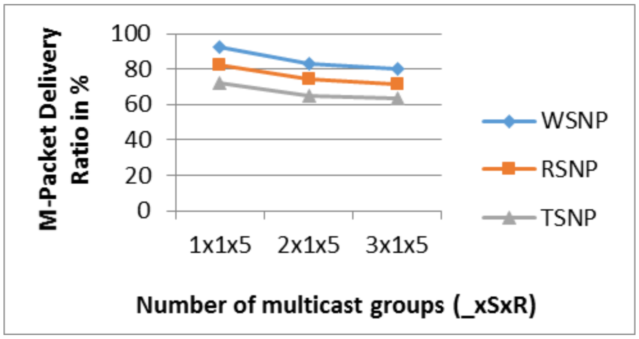


Figure 16 M-PDR in % vs Number of MCGs at Various Node Speeds (5 Receivers)

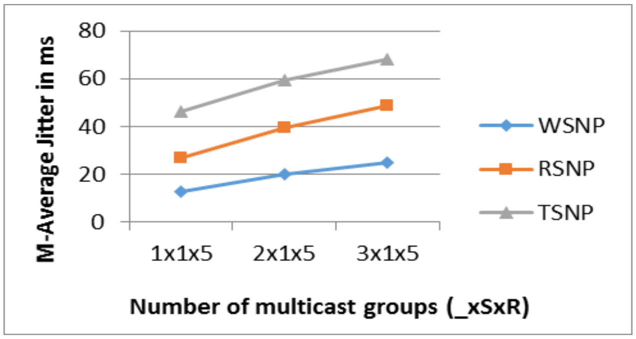


Figure 18 M-AJ in % vs Number of MCGs at Various Node Speeds (5 Receivers)

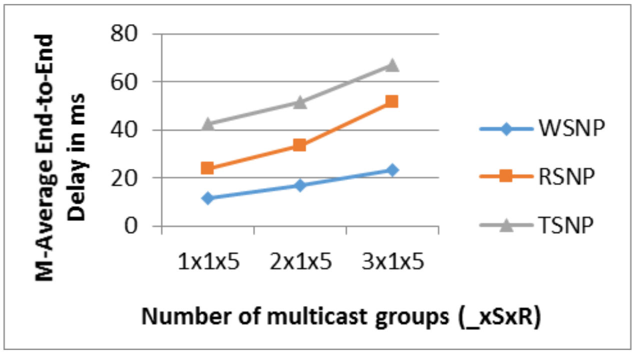


Figure 17 M-AEED in % vs Number of MCGs at Various Node Speeds (5 Receivers)

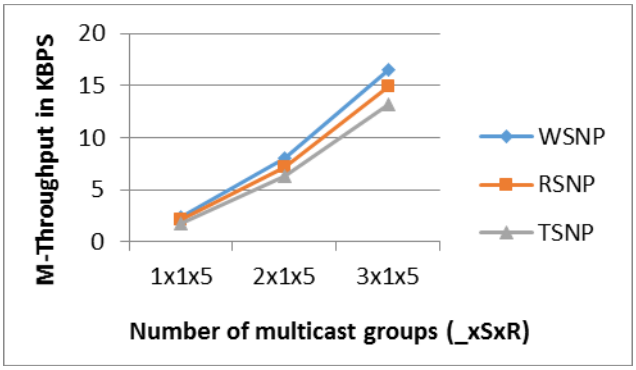


Figure 19 M-TP in % vs Number of MCGs at Various Node Speeds (5 Receivers)

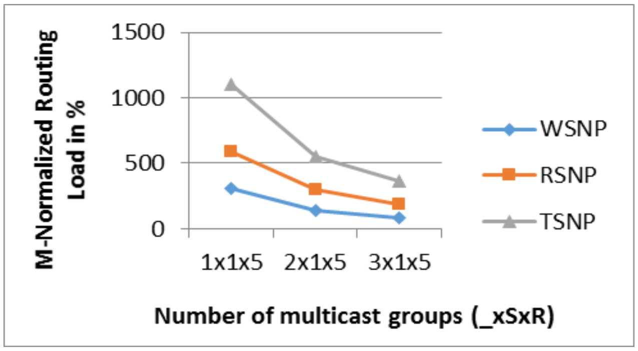


Figure 20 M-NRL in % vs Number of MCGs at Various Node Speeds (5 Receivers)

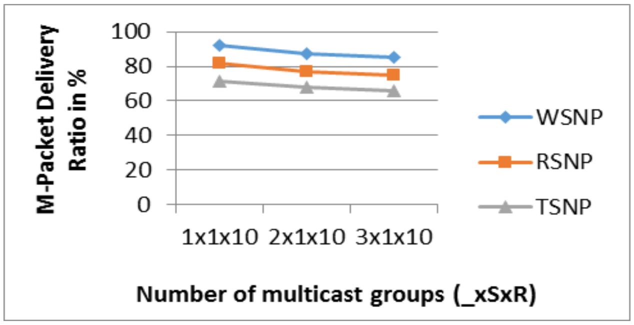


Figure 21 M-PDR in % vs Number of MCGs at Various Node Speeds (10 Receivers)

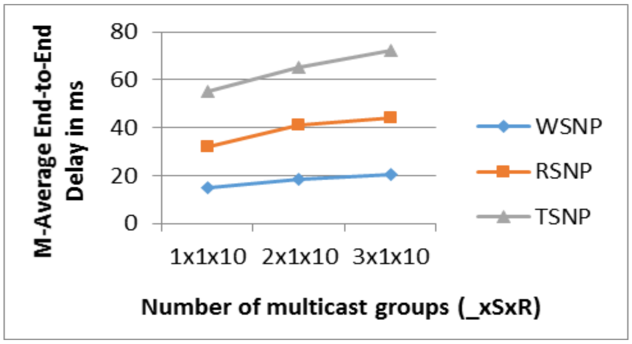


Figure 22 M-AEED in % vs Number of MCGs at Various Node Speeds (10 Receivers)

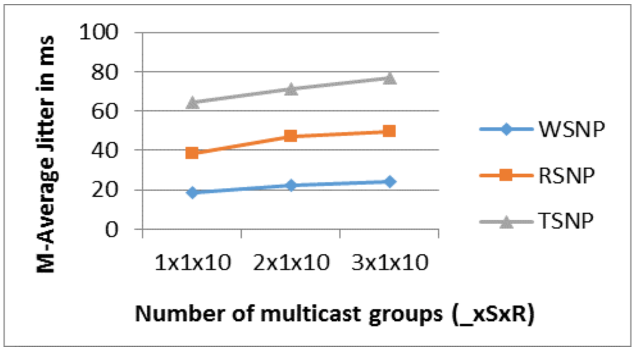


Figure 23 M-AJ in % vs Number of MCGs at Various Node Speeds (10 Receivers)

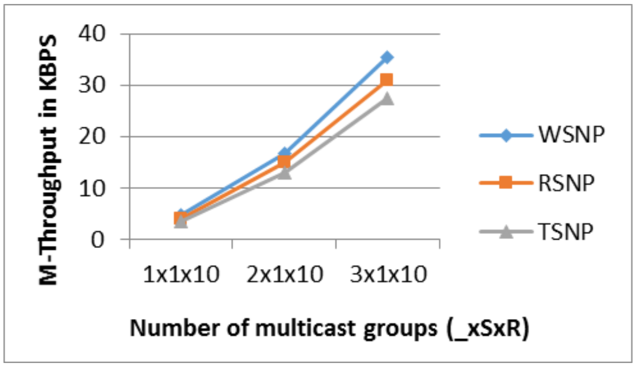


Figure 24 M-TP in % vs Number of MCGs at Various Node Speeds (10 Receivers)

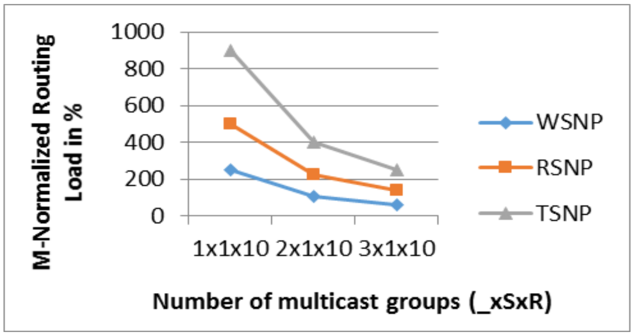


Figure 25 M-NRL in % vs Number of MCGs at Various Node Speeds (10 Receivers)

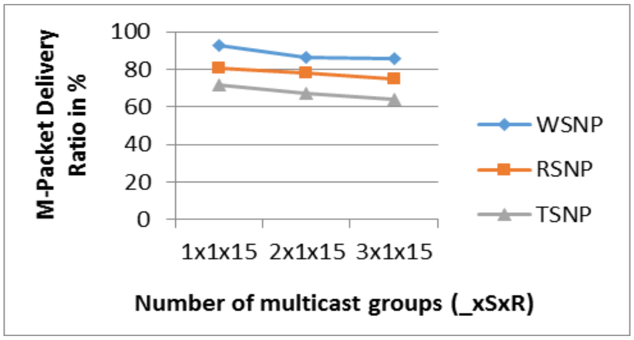


Figure 26 M-PDR in % vs Number of MCGs at Various Node Speeds (15 Receivers)

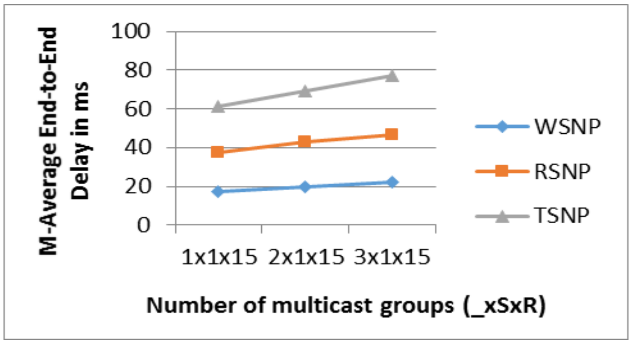


Figure 27 M-AEED in % vs Number of MCGs at Various Node Speeds (15 Receivers)

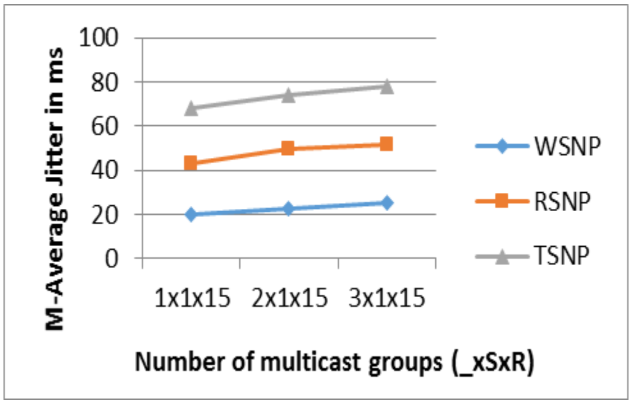


Figure 28 M-AJ in % vs Number of MCGs at Various Node Speeds (15 Receivers)

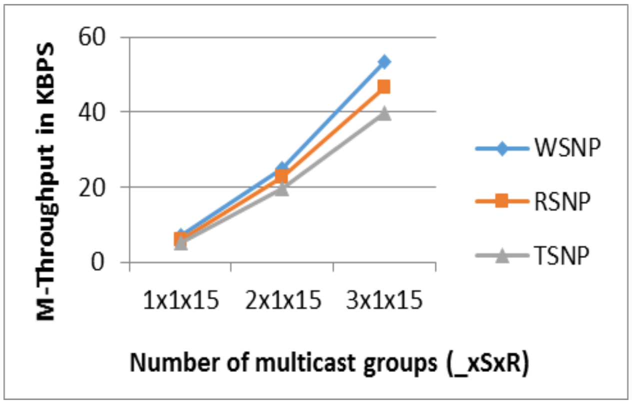


Figure 29 M-TP in % vs Number of MCGs at Various Node Speeds (15 Receivers)

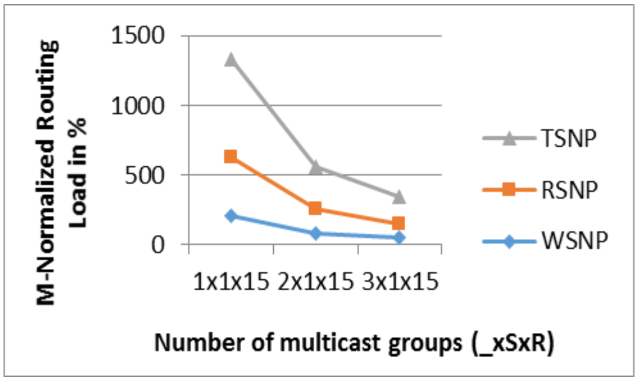


Figure 30 M-NRL in % vs Number of MCGs at Various Node Speeds (15 Receivers)

In fact, the increase in M-TP with ***R*** is due to the fact that the number of received MC data packets has increased with ***R***. Since the added receivers usually join the shared-tree through the immediate MCT member to them, reduced M-NRL is noticed. Moreover, the localized join and repair feature of MAODV has improved the M-NRL values further.

5.4. Conferencing

In this set of simulations, the performance of MAODV is investigated for its suitability to conferencing applications where all members of a MCG act as both senders and receivers simultaneously. In particular, the following set of communication scenarios is created: 1x5x5, 1x10x10 and 1x15x15. The members of the MCG are joining at one minute after the beginning of the simulation. And, all data communications end at 840.0s, irrespective of their beginning times.

The first, second, third, fourth and fifth data connections of communication pattern 1x5x5, are started at 120.0s, 130.0s, 140.0s, 150.0s and 160.0s respectively, separated by a gap of 10.0s. Similarly, in 1x10x10 the ten data communications are distributed from 120.0s to 210.0s with a gap of 10.0s. At the last, the distribution of a total of fifteen data connections of communication pattern 1x15x15 is started at 120.0s and ended to 260.0s with a gap of 10.0s. The NAM screenshot of Conferencing scenario 1x15x15 is shown in the Figure 31 where the nodes appeared in red color constitute the MCG.

The graphs in Figures 32 to 36 represent the QoS performance metrics for this special case of **C** where **C**: ***R*** = ***S*** in ***G***x***S***x***R*** at WSNP, RSNP and TSNP. From the graphs, it is observed that similar to increasing ***R***, ***S*** and ***G*** cases; the protocol is functioning well with walking speeds in comparison to running and tank speeds for the undertaken QoS evaluation metrics. Moreover, at each node speed, for increasing **C**, the protocol is producing decreased values of M-PDR while increased values of M-AEED and M-AJ. The improved values of M-TP and M-NRL have been perceived.

MAODV has really performed well in the conferencing scenarios showing the acceptable performance in terms of all QoS metrics. The increased and equal values of both ***R*** and ***S***, have resulted in hybrid behavior exhibited by the protocol.

The longer data paths in shared-tree based MAODV due to increasing ***R*** have resulted in data collisions. However, this loss to some extent has been compensated by increased number of data packets generated for increased value of ***S*** and vice-versa. Similarly, the longer forwarding paths due to increase in ***R*** along with the increased number of data packets due to increase in ***S*** have kept the values of M-AEED and M-AJ in between the first and second sets of experiments as depicted in Figures 33 and 34.

The increase in ***C*** as depicted in Figure 32, has reduced the M-NRL values considerably compared to ***R*** and ***S*** cases. This is due to the fact that the number of received MC data packets has been increased for increased ***R*** and the number of data packets generated for increased ***S***. Similarly, the TP values produced have occupied the range in between ***R*** and ***S*** cases as depicted in Figure 36.

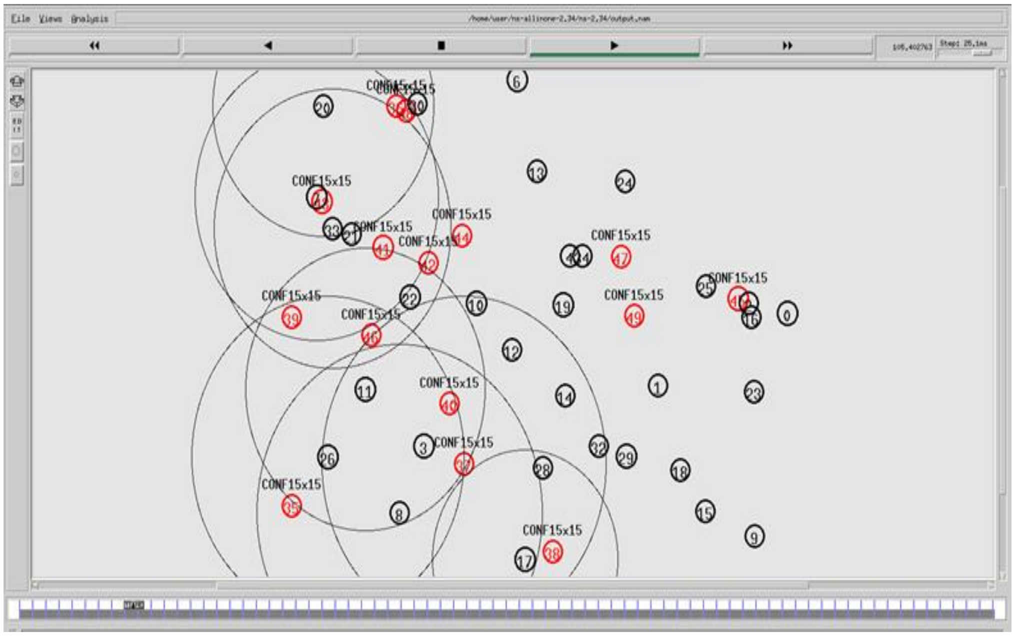


Figure 31 NAM Screenshot of Conferencing Scenario 1x15x15 (the Nodes Appeared in Red Colour Constitute the MCG)

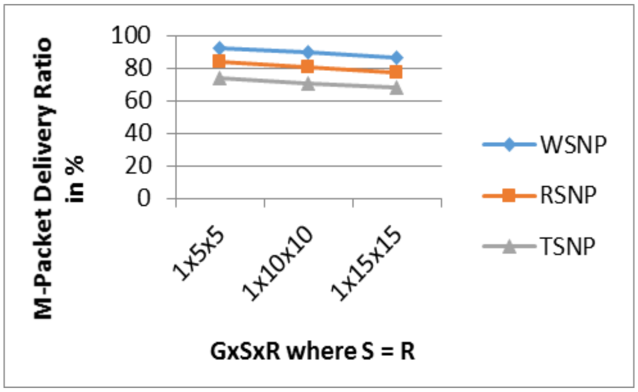


Figure 32 M-PDR in % vs Number of Members in a Conference at Various Node Speeds

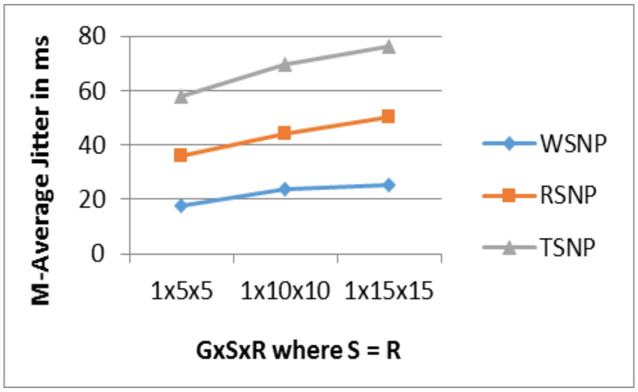


Figure 34 M-AJ in % vs Number of Members in a Conference at Various Node Speeds

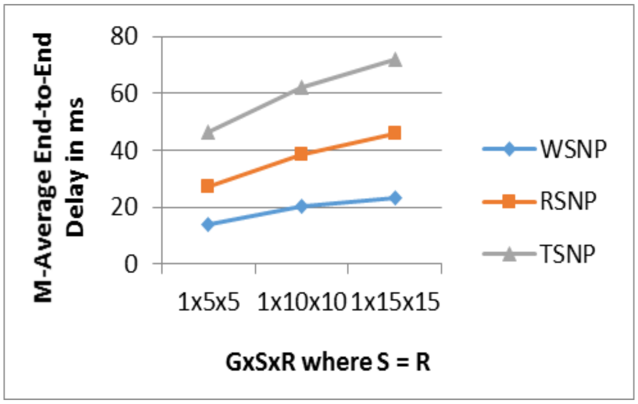


Figure 33 M-AEED in % vs Number of Members in a Conference at Various Node Speeds

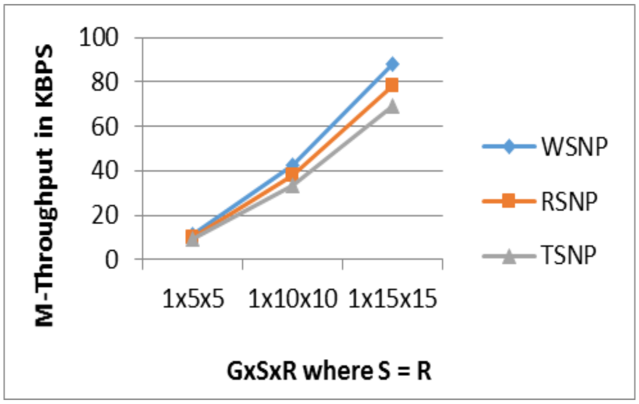


Figure 35 M-TP in % vs Number of Members in a Conference at Various Node Speeds

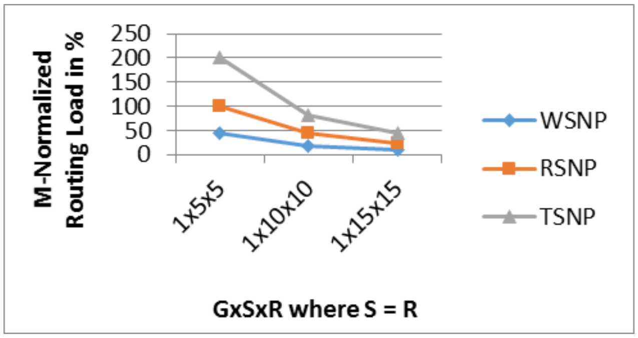


Figure 36 M-NRL in % vs Number of Members in a Conference at Various Node Speeds

6. CONCLUSIONS

The multicast routing behaviour of MAODV has been observed by dividing the simulation works into four parts by varying one of the parameters at a time from the set {number of receivers R, number of senders S and number of MCGs G}. Moreover, the performance is analyzed for CBR data traffic under three mobility-scenarios WSNP, RSNP and TSNP in terms of the QoS metrics: packet delivery ratio, average end-to-end delay, average jitter, throughput and normalized routing load. From the simulation results, the improved wireless channel utilization due to multicast routing has been witnessed by the increased values of M-TP and M-NRL notably, irrespective of the experiment set. For increasing any parameter of the set {R, S, G and R = S}, a fall in M-PDR and an increase in M-AEED and M-AJ values are noticed at all mobility patterns. However, the improvements in terms of M-TP and M-NRL values have been observed. The protocol has performed quite well at WSNP compared to RSNP and TSNP for all QoS metrics regardless of the set of experiments conducted. This is due to the fact that the increased node mobility has resulted in frequent link breaks in the network which has triggered frequent route repairs to take place, either to reconnect or to reconstruct the tree for maintaining up-to-date routing information. This in turn has increased the routing overhead (since a large number of RReq, RRep and MACT messages are generated) as well as the average jitter and delays of the received data packets. Other side, till a new route is established, the data packets have to wait at the buffers during route repair time. However, if a new route is not found, all the packets will be dropped, the main reason for low M-PDRs. Though the low M-PDR values are marked, the increase in M-TP has been noticed. This is due to the increase in successful number of data packets received by the number of receivers. Further, it is observed that the random nature of MANET has kept its mark on simulation results.

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