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Adaptive QoS Multicast Routing with Mobility Prediction in MANETs

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ABSTRACT

A Mobile Ad hoc NETwork (MANET) is a collection of wireless mobile hosts that form a temporary network without a centralized administration or wired infrastructure. Due to the high mobility of nodes, the network topology of MANETs changes very fast, making it more difficult to find the routes that message packets use. Network control with Quality of Service (QoS) support is a key issue for multimedia applications in MANET. Most of the real time applications have stringent requirements on bandwidth, delay, delay-jitter, packet loss ratio, cost and other QoS metrics. This paper proposes a Multi-constrained QoS routing with mobility prediction protocol. If the node has enough resources to transmit data packets, it uses the Global Positioning System (GPS) to get the location information of the mobile nodes and selects the routing path with the maximum Route Expiration Time (RET). A set of static and mobile agents are used to find the multicast routes and transmit the packets. Extensive simulations have been conducted to evaluate the performance of MC_MAODV using Network Simulator (NS-2). The simulation results show that the proposed protocol achieves good performance in terms of improving packet delivery ratio and minimizing end-to-end delay.

KEYWORDS**:** *MANETs, Multi-constrained routing multicasting, clusters, end-to-end delay, packet loss ratio.*

1. INTRODUCTION

A MANET is a dynamically re-configurable wireless network with no fixed infrastructure. In such a network, each mobile node operates not only as a host but also as a router and it can move in any direction. Such networks have recently drawn significant research attention since they offer unique benefits and versatility with respect to bandwidth spatial reuse, intrinsic fault tolerance and low-cost rapid deployment. In order to facilitate communication within the network, a routing protocol is used to discover routes between nodes [1]. The primary goal of such an ad hoc network routing protocol is to provide an efficient route establishment between a pair of nodes so that messages may be delivered in a timely manner. Route construction should be done with a minimum of overhead and bandwidth consumption.

The increasing popularity of collaborative multimedia applications is enabling the support for multicast communication. Multicasting plays an important role in ad hoc networks when applications must send the same data to more than one destination. Multicasting facilitates bandwidth saving, reduced delays and high scalability. Most of conventional multicast protocols were designed for best-effort data traffic [15]. They construct multicast trees primarily based on connectivity. Such trees may be unsatisfactory when Quality of Service is considered due to the lack of resources. QoS is more difficult to guarantee in ad hoc networks than in other type of networks, because the wireless bandwidth is shared among adjacent nodes and the network

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topology changes as the nodes move. With the extensive applications of MANETs in many domains, the appropriate QoS metrics should be used, such as bandwidth, delay, packet loss rate and cost for multicast routing [16]. Mobility prediction has also been applied to determine the duration of life time between two connected mobile nodes using GPS [11]. Using mobile prediction mechanism the proposed scheme chooses the most stable links which satisfy the multiple QoS constraints in MANETs .

This paper presents a QoS multicast routing protocol with mobility prediction to meet the requirement of a single call under multiple QoS constraints. The rest of the paper is organized as follows. Related work is presented in the next section. Section 3 explains the network model, mobility prediction mechanism and agent model. In Section 4, the proposed QoS aware multicast routing is explained in detail. Some simulation results are presented in section 5. The paper concludes with section 6.

2. RELATED WORKS

Multicast routing protocols in ad hoc networks must deal with typical limitations of these networks, which include high power consumption, low bandwidth, and high error rates. Most of the conventional multicast protocols are designed for maximizing the throughput or for minimizing the end-to-end delay. When QoS is considered some protocols may be unsatisfactory or impractical due to the lack of the resource and the excessive computation overhead [1]. Some algorithms [2] provide heuristic solutions to the NP-complete constrained Steiner tree problem, which is to find the delay-constrained least-cost multicast trees. These algorithms however are not practical in the Internet environment because they have excessive computation overhead, require knowledge about the global network state, and do not handle dynamic group membership.

Jia's distributed algorithm [3] does not compute any path or assume the unicast routing table can provide it. However, this algorithm requires excessive message processing overhead. The spanning join protocol [4] handles dynamic membership and does not require any global network state. However, it has excessive communication and message processing overhead because it relies on full flooding to find a feasible tree branch to connect a new member. QoS MIC, proposed by Faloutsos et al. [5] alleviates but does not eliminate the flooding behavior. In addition, an extra control element, Manager router, is introduced to handle the join requests of new members.

QMRPCAH proposed by Layuan et al.[6] provides multiple guarantees for satisfying multiple constraints but it does not maintain any global network state. The Source Routing-based Multicast Protocol (SRMP) is an on-demand multicast routing protocol proposed in [7]. Route selection takes place through establishing a multicast mesh, started at the multicast receivers, for each multicast session. In SRMP, two important issues in solving the routing problems are addressed: a) path availability concept and higher battery life concept. The former allows the protocol to distinguish between available and unavailable paths.

A new scalable QoS multicast routing protocol (SoMR) that has very small communication overhead and requires no state outside the multicast tree is proposed in [8]. A QoS Multicast Routing protocol (QMR) with a flexible hybrid scheme for QoS multicast routing is proposed in [9]. QMR is a mesh-based protocol which is established on-demand to connect group members and provides QoS paths for multicast groups. The QMR protocol integrates bandwidth reservation function into a multicast routing protocol with the assumption that available bandwidth is constant and equal to the raw channel bandwidth. Admission control mechanism is used to prevent intermediate node from being overloaded and reject requests of new sources if there is no available bandwidth. An agent based multicast routing scheme (ABMRS) in MANETs, which uses a set of static and mobile agents for route discovery and maintenance is proposed in [10]. But it doesn't consider the multiple QoS constraints.

In MANETs, all the nodes are free to move around randomly and network topoly changes dynamically. Due to these characteristic, the routing path is often invalidation. So, it is important that a stable routing is to be found [11]. Thus, predicting the mobility of nodes is an effective and feasible method. At present, the mobility prediction methods are path availability models [12], prediction-based link availability estimation[13], link expiration time model [14] and prediction strategy. Link expiration time model predicts link stability between two nodes according to the node's information such as location, velocity, and direction etc with the aid of Global Position System (GPS).

It is observed from the literature that still multicast routing with QoS needs much more attention so that the routing scheme must be robust, maximize packet delivery ratio and adapt dynamically to changes un MANET topology and environment. This paper proposes a QoS aware multicast routing scheme with mobility prediction that ensures QoS guarantees such as bandwidth reservation, delay constraint, delay-jitter and minimum cost to multicast sessions

3. PROPOSED WORK

This section describes the functioning of the proposed multicast routing scheme. It includes the following steps.

3.1. QoS multicast model

As far as routing is concerned, a network is usually represented as a weighted digraph $G = (V, E)$, where V denotes the set of nodes and E denotes the set of communication links connecting the nodes. Let Φ denotes the set of multicast nodes, $\Phi \subseteq V$. $|V|$ and $|E|$ denote the number of nodes and links in the MANET, respectively. Let $s \in \Phi$ be source node of a multicast tree, and $M \subseteq \{\Phi - \{s\}\}$ be a set of end nodes of the multicast tree. Let R be the positive weight and R^{+} be the nonnegative weight.

- For any Link, $e \in E$, we can define some QoS. metrics: delay function *delay (e)*: $E \rightarrow R$, packet loss ratio *plr(e)*: $E \rightarrow R$, bandwidth function *bandwidth(e)*: $E \rightarrow R$ and delay jitter function *delay jitter(e):* $E \rightarrow R$.

- Similarly, for any node $n \in V$, one can also define some metrics: delay function *delay(n)*: $V \rightarrow R$, packet-loss function *packet-loss(n)*: $V \rightarrow R^{+}$, delay jitter function *delay jitter(n)*: $V \rightarrow R^{+}$

We also use T (s, M) to denote a multicast tree in which the following relationships hold:

$$Delay\ (p(s,t)) = \sum_{e \in P(s,t)} delay(e) + \sum_{n \in P(s,t)} delay(n)$$
$$Bandwidth\ (p(s,t)) = min\{bandwidth(e),\ e \in P(s,t)\}$$
$$Packet\text{-}loss\ (p(s,t)) = 1 - \Pi_{n \in P(s,t)}\ (1\text{-}packet\text{-}loss(n))$$
$$Delay\text{-}jitter\ (p(s,t) = \sum_{e \in P(s,t)} delay - jitter(e) + \sum_{n \in P(s,t)} delay - jitter(n)$$

$$Cost(T(s,M)) = \sum_{e \in T(s,M)} cost(e) + \sum_{n \in T(s,M)} cost(n).$$

where p(s, t) denotes the path from source s to end node t of T(s,M).

$$\begin{aligned}&\text{Delay Constraint}: delay(p(s,t)) \leq Dt\\&\text{Bandwidth Constraint}: bandwidth(p(s,t)) \geq B\\&\text{Packet loss Constraint}: packet\text{-}loss(p(s,t)) \leq L\\&\text{Delay jitter Constraint}: delay\text{-}jitter(p(s,t)) \leq J\end{aligned}$$

Meanwhile, the Cost(T(s,M)) should be minimum. Where, D is delay constraint, B is bandwidth constraint , L is packet loss constraint and J is the delay Jitter constraint.

3.2. Mobile Prediction mechanism

In mobile ad hoc network, the reliability of a path depends on the stability or availability of each link of this path because of the dynamic topology changes frequently. It supposes a free space propagation model [9], where the received signal strength solely depends on its distance to the transmitter. Therefore, using the motion parameters (such as speed, direction, and the communication distance) of two neighbors, the duration of time can be determined in order to estimate that two nodes remain connected or not. Suppose two nodes i and j are within the transmission distance ra between them. Let (xi, yi) and (xj, yj) be the coordinate of mobile host i and mobile host j. Also let (vi, θi) be the speed and the moving direction of node i, let (vj, θj) be the speed and the moving direction of node j. The LET (Link Expiration Time) is predicted by [9]:

$$LET(i,j) = \frac{-(ab+cd) + \sqrt{(a^2+c^2)\,r^2 - (ad-bc)^2}}{a^2+c^2} \qquad \text{------------------- (1)}$$

Note that $a = v1\cos\theta 1 - v2\cos\theta 2$, $b = x1 - x2$, $c = v1\sin\theta 1 - v2\mathrm{Sin}\theta 2$, and $d = y1 - y2$. Note also that the equation cannot be applied when $v1 = v2$ and $\theta 1 = \theta 2$, and when LET is ∞. In order to get and utilize the information from GPS, the packets must include extra fields. When a source node sends a request packet, the packet appends its location, direction, and speed. The next hop neighbor of the source node receives the request packet to predict the duration of time between itself and the source node. If node *B* is the next hop of the packet for node *A*, node *A* will insert its location information in the packet so node *B* will be able to compute the duration of time between node *A* and node *B*.

Assume that *l* is a routing path and (l_1, l_2, … l_k) is the set of all the links along each hop *l*. The route expiration time of RET(*l*) is the minimum of the LETs along path *l* and can be written as the following equation:

$$RET(l) = \min_{i \in (1,2,\ldots k)} (LET(l_i)) \qquad \text{-------------------- (2)}$$

3.3. Agent model

The proposed scheme employs a set of static and mobile agents. Agents use their own knowledgebase to achieve the specified goals without disturbing the activities of the host. The primary goal of an agent is to deliver information of one node to others in the network. Here, the agents are used to find the multicast routes and to create the backbone for reliable multicasting. It comprises a set of following agents and maintains a knowledgebase for inter agent communication.

- Knowledge Base: The knowledgebase maintains a set of network state variables such as status of the node (cluster head, child, others) available power, bandwidth, number of movements made in recent interval, group id, neighbor ids and their status.
- Route Discovery Agent (RDA): It is a static agent that runs on nodes, creates agents and knowledge base, controls and coordinates the activities of the multicast routing agency.
- Node Manager Agent (NMA): It maintains the multicast tree and provides group ID to all the members of the packet-forwarding nodes in the multicast tree.
- Link Management Agent (LMA): When a node moves out of the communication range or dies, LMA initiate route error (RERR) message to the upstream node and again initiates the route request.
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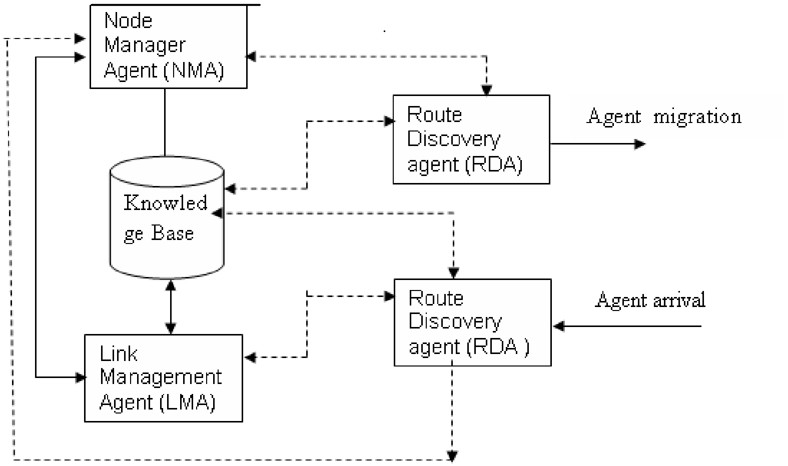

Figure 1. Routing agent model

To initiate multicasting, the mobile agent which resides in the source node provides group ID and distributes multicast key to all the group members. The source node examines all the QoS metric values of next intermediate node using the knowledgebase of agents. If it satisfies all constraints data transmission takes place among all multicast members. When an intermediate node either moves out of the range or fails, the static agent resides at the node that monitored such a situation will find out the new alternate path with minimum cost between the nodes. The alternate path and its connectivity to the network are broadcast, so that the new forwarding table is generated at every node. The agents update their knowledgebase with more recent values.

3. QoS aware Multicast Routing Protocol with Mobility Prediction (MPQMRP)

In this section we propose a QoS aware multicast routing protocol with mobility prediction. In MPQMRP we create a multicast tree for transmitting data packets. The proposed protocol includes the route discovery process and route maintenance process.

4.1. Route Discovery Process

In MPQRMP, **t**he route discovery process is initiated whenever a source node needs to communicate with another node for which it has no routing information in its table. Here the RDA takes care of the routing process. It provides the one hop information to the source node. By using this information, the source node initiates the route discovery by broadcasting a route request (RREQ) packet to its neighbors. The route request packet includes (sequence_id, X_i,Y_i, θ_i, V_i, Source ID, Destination ID, D,J,B,C) fields. When a node receives a new RREQ, it looks in its route table for the destination. If it doesn't match, then it checks the available bandwidth between them. If the available bandwidth is above the constrained bandwidth then it will utilize the location information to get the LET between the nodes. Now, the intermediate node forwards the RREQ to its own neighbors after updating its own information. In the above Fig. 3, node 's' is the multicast source. D_1 and D_2 are the destinations. The network's edge are described by four tuples (B,D,J,C) where B is the Bandwidth constraint, D is the delay constraint, J is the delay-jitter constraint and C is Cost. In this example, B, D, J, C constraints are specified as 45, 15, 30 and 60 respectively. The source node 's' broadcast the RREQ packet to all of its one hop neighbors and it is received by n1, n5 and n6 respectively. All the receiving nodes check the destination id , but it doesn't match with them. In this example the bandwidth constraint 45 is satisfied by the links between the nodes n5 → n7 and n1→n2 are satisfied and hence they forward the RREQ packets to its neighbors. At the same time the link n5→n6 does not satisfy the bandwidth constraint and it discards the route request. This process is continued until the RREQ packet reaches the destination. After receiving RREQ packet, each receiving node calculates the LET between the nodes.

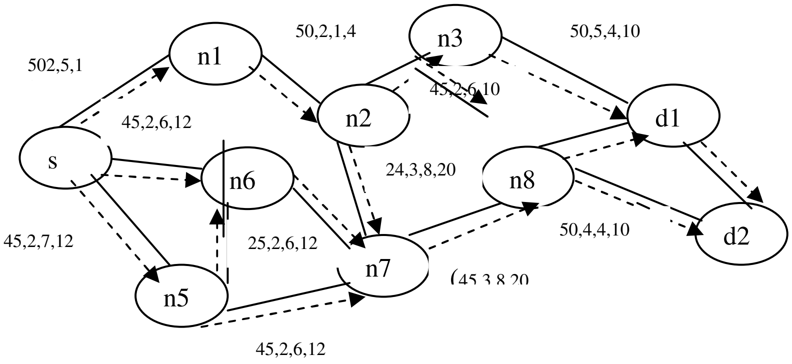

Figure 3. Route discovery process

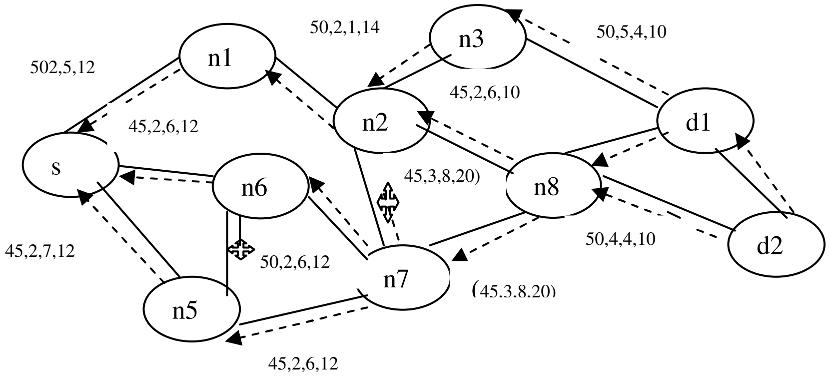

Figure 3. Route relay process

Each destination node sends it Route Reply (RREP) packet back to the source node. Source node receives all the destination nodes reply packets and selects the path with highest RET. The Network Management Agent (NMA) takes care of the multicast data transmission. In the above example, from source 's' to destination node 'd1' there are fours paths exist. S→n1→n2→n3→→d1, S→n1→n2→n8→d1, S→n5→n7→n8→d1, and S→n6→n7→n8→d1. Among these four paths S→n1→n2→n8→d1, S→n6→n7→n8→d1 do not satisfy the delay constraints. The paths S→n2→n3→d1 and S→n5→n7→n8→d1 satisfy delay, delay-jitter, and bandwidth constraints.

Route path	R(S,n1,n2,n3,d1)	R(S,n5,n7,n8,d1)
RET	8	6

Table 1. Paths and their RET values

The RET in these paths are calculated and the route with maximum RET and least cost is selected for data transmission. The RET of the above example is depicted in Table 1.

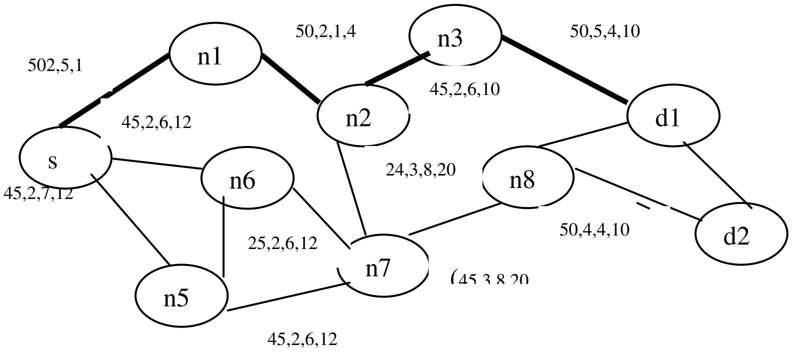

Figure 4. Reliable multicast tree

In the above figure 5, the route R(S,n1,n2,n3,d1) which has the maximum RET and selected for data transmission

4.2. MPQMRP routing Algorithm

The routing algorithm used in MPQMRP protocol is as follows.

Input: a network G = (V,E) and a QoS reuest R = (Source ID, Destiation IDs, B,J,D,C)

Output : a routing path P that satisfies the QoS request R.
For each destination Do

Step 1. Source node broadcasts the RREQ packet to all of its one-hop neighbors.

Step 2: If the packet is new, and node is destination and the link of the node pair can satisfy the QoS requirements such as $B_{ij} \geq B$, $D_{ij} \leq D$ and $J_{ij} \leq J$ then directly send the message.

Step 3: Else, if the packet is new and the node is not destination and $B_{ij} \geq B$ then forward the packet to all one-hop neighbors. Calculate LET between them using the equation (1).

Step 4: Repeat step 3 until the RREQ packet reaches the destination.

Step 5: Find the collection of routing path from the source to destination. Let them be R1, R2, …Rn.

Step 6: For each routing path R_i Do
Calculate $\sum D_{ij}$, $\sum J_{ij}$ and $\sum C_{ij}$
{if $\sum D_{ij} \leq D$ and $\sum J_{ij} \leq J$ then calculate RET using formula ( )
Else
Delete the routing path from the collection.

Step 7: Select the routing path with maximum RET. If more than path exists with equal RET select the path with minimum cost $\sum C_{ij}$.

Step 8: End routing.

4.3. Route Maintenance Process

Due to the dynamic nature of the network topology and restricted resources, the established route often gets invalid. When the link is disconnected, the LMA informs it to the upstream node. This node removes the corresponding entry from its multicast routing table and sends route reconstruct packet to the source. The source starts to discovery the route again. Similarly, when a node wants to join a multicast tree, it broadcast a join request across the networks. Only a node that is a member of a multicast tree may respond. It creates a reverse route entry to the new node and broadcasts the join request packet to its neighbors. Each member node of the multicast tree receives join request and make its entry in the routing table and send back the join reply packet to the new node.

5. Simulation

The proposed scheme has been simulated in various network scenarios using NS-2 simulator. A discrete event simulation is done to test operation effectiveness of the scheme. In this section we describe the simulation model and the simulation procedure.

5.1. Simulation model

A mobile ad hoc network consisting of 'n' nodes is generated by using a random placement of the nodes and allowed for the free movement within the area of 'l x b'm^2. Each node starts from a random location and moves in all directions. A maximum number of movements allowed per node every period 'per' is 'move_max'. The communication range for each node is selected as 'C_ran'. All nodes are considered to be non-malicious and are included in the clustering scheme. All nodes must support an agent server, interpreter and transport mechanism. Every node has enough memory to support the agent's knowledge database. Every mobile agent is only allowed three hops from the parent node to avoid network congestion.

Table 2. Simulation parameters

Parameters	Value
MAC Layer	IEEE 802.11
Simulation area(m)	1000*1000
Simulation Time	60 secs
Number of nodes	25
Node mobility speed	0-60m/s
Mobility pattern	Random way point
Traffic flow	CBR
Packet size	512 bytes
Transmission range	250m

5.2. Simulation Procedure

To illustrate some results of the simulation, we have taken n = 50, l = 1000 m and b = 1000 m, per = 100 s, move_max = 2, C_ran = 225 m. D=15, J=30, B=45, C=60 are given as user input for various scenarios. The proposed routing scheme is evaluated in terms of packet delivery ratio, end-to-end delay and control overhead.

- Packet delivery ratio: The ratio of the average number of data packets received by the destination node to the number of data packets transmitted by the multicast source.
- End-to-end delay: The time when a data packet is sent by the source to the time the data packet is received at the destination node.
- Control overhead: The total number of control received by the destination node.

5.3. Analysis of results

5.3.1. Packet Loss ratio: Figure 5. shows the performance of the average packet loss ratio under various mobility speeds. The packet loss ratio is increased with increasing mobility due to more link breaks.

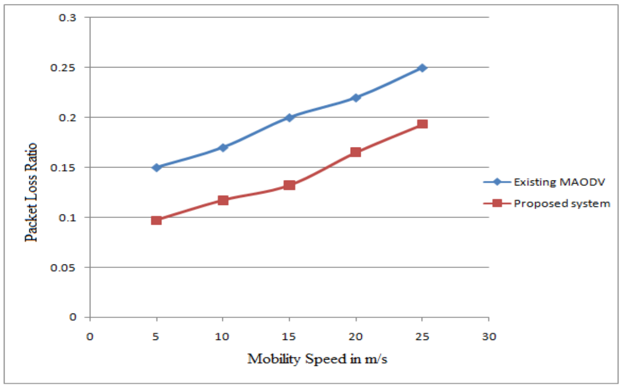

Figure 5. Packet loss ratio vs. mobility speed

When the mobility is low, the multicast tree structure was mostly static and therefore the packet loss ratio is low. In MPQMRP, the required resources are reserved in advance and the most stable path is also identified with maximum RET. Hence the packet loss ratio of MPQMRP is higher than that of MAODV. Packet loss ratio of the proposed system is less than MAODV for all group size values. This is because of finding more reliable path and managing node breakage thereby avoiding the recomputation of route. As the group size increases packet loss ratio also increases since the entire nodes share the common wireless medium for transmission of packets.

5.3.2. End-to-End delay: Figure 6.a. shows the performance of the end-to-end delay under various mobility speeds. As the mobility speed increases average end to end delay also increases.

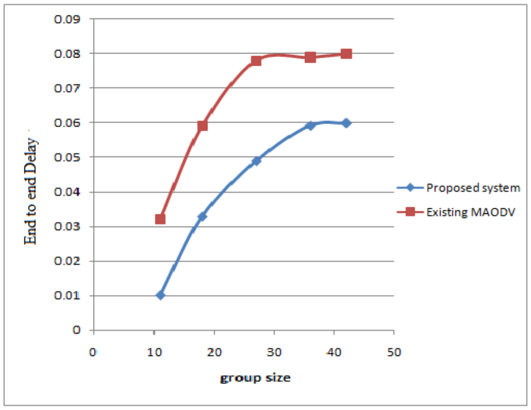

Figure 6 a) End-to-End delay Vs group size

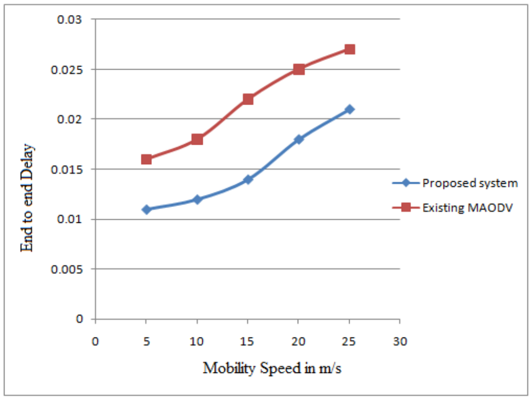

Figure 6 b) End-to-End delay Vs mobility speed

Packet delivery latency is significantly less than that for MPQMRP compared to MAODV (Figure 6.b) even at higher node mobility for constant group size. This is due to the fact, forwarding nodes chosen are reliable nodes and are less prone to scarcity of resource. Also once the transmission path breaks, the intermediate node chooses another backup path immediately for transmitting the data packets.

5.3.3. Control overhead: Figure 7. shows the performance of the control overhead under various mobility speeds. As was expected the control overhead increased as the number of nodes increases. The reason is that the inclusion of extra fields in RREQ packer header. Also, the number of route broadcasts increased when the group size increases.

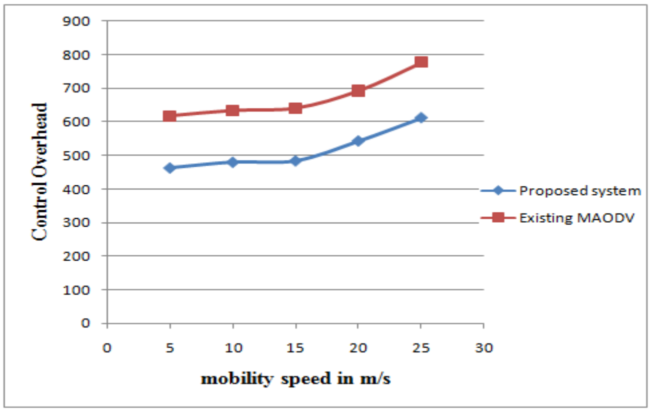

Figure 7. Control overhead vs. Group size

6. Conclusions

This paper proposes a QoS aware multicast routing algorithm with mobility prediction based on mobile agents. It effectively routes data packets to group members even in case of high mobility and frequent link failures. A set of static and mobile agents are used to carry out route discovery and route maintenance process. This routing path satisfies multiple QoS constraints according to the QoS demand. It has higher packet delivery ratio as compared to MAODV and reduces end-to-end delay. This work can further be extended to include the mobile prediction scheme for multiple multicast trees.

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