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A Tree-based QoS Multicast Routing Protocol for MANETs

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Abstract—**Multicasting communication serves as one critical operation to support many applications of Mobile Ad hoc networks (MANETs) that achieve group communication rather than pairs of individuals. Multicast routing protocols becomes increasingly important in MANETs because they effectively coordinate a set of nodes. Also, it provides efficient routing for multimedia applications such as video conferences, military and rescue operations. Such applications are highly demand for Quality of Service (QoS), which makes an efficient QoS multicast routing protocols is very important. In this paper, we propose a model that searches for QoS paths from a single source to a set of destinations. The physical area is partitioned into equal size hexagonal cells and a leader and backup leader nodes is elected to maintain up-to-date information about the network topology. Efficient routing is performed based on nodes positions to deliver data packets to all the receivers. The simulation results show that, comparing with the well-known multicast protocol ODMRP (Demand Multicast Routing Protocol), PBQMRP achieves less packet drop ratio with significant reduction in control overhead.**

Keywords — Mobile Ad hoc Networks, Multicast Routing, QoS

I. INTRODUCTION

MANETs are collections of mobile nodes that communicate with each other over wireless links in the absence of any infrastructure or centralized administration. Each mobile node acts as a host generating flow, being the receiver of a flows from other mobile nodes, or as a router and responsible for forwarding flows to other mobile nodes [1]. Mobile nodes in Ad hoc networks have a limited transmission range, nodes that relies with the transmission range can communicate directly with each other, while intermediate nodes is needed to forward flow between nodes that are unable to communicate directly. In MANETs, the mobile nodes may be laptops, PDAs (Personal Digital Assistants), mobile phones, or pocket PC with wireless connectivity.

In MANETs, the radio channel is limited and shared among all the nodes in the broadcast region, which makes the available bandwidth depends on the number of mobile nodes and the traffic they handle. Thus, the available bandwidth is small and unreliable. Also, limited transmission range, limited memory, limited storage capabilities, and limited power are serious challenges facing MANETs.

Group communication becomes increasingly important in MANETs because a lot of applications relay on cooperation between a team. Video conferencing, interactive television, temporary offices and network gaming are common examples of these applications [2]. As a consequence, multicast routing has received significant attention over the recent years. In multicasting, a source is sending the same data to a certain set of nodes in the network. This is efficient in saving the bandwidth and improving the scalability, which is essential in MANETs [3].

The increasing popularity of using multimedia and real time applications in different potential commercial in MANETs, make it logical step to support QoS over wireless network. QoS support is tightly related to resource allocation and reservation to satisfy the application requirements; the requirements include bandwidth, delay, delay-jitter and packet to loss ratio. Ad-Hoc wireless networks can support QoS through cooperation between different components. These components include a QoS model to specify which kinds of services to be included in the network, a QoS routing protocol that searches for a feasible path with satisfactory resources defined by the QoS model, QoS MAC protocol solves the problems shared medium and a QoS signaling protocol to perform the resource reservation along the selected path. Thus, combine QoS with Multicasting facing several challenges, due to the difficulty in finding paths between the source and all the destinations that satisfy certain QoS requirements [3] [2].

In this paper, we investigate the problem of QoS routing in MANETs using multicast communication. In particular, a Position-based QoS Multicast Routing Protocol (PBQMRP) was proposed. The remainder of this paper is structured as follows. In section II, we present some related works on multicast routing. Section III presents our model and section IV presents some simulation results. Finally a conclusion will be proposed.

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II. RELATED WORK

Multicasting in MANETs is relatively unexplored research area, when it is compared with unicast routing [4]. Recently, several multicast routing protocols have been proposed. Also, Multiple QoS multicast routing protocols have been proposed for Ad-Hoc networks such as [5] [6]. However, they produce large control overhead, especially when the network size grows up. On the other hand, the scalable multicast routing protocols do not consider the QoS issue as in [7] [8]. In [9], performance comparison of QoS multicast protocols is presented. In this section we discuss the QoS multicast routing protocols that are presented lately.

The Lantern-Tree-Based (LTB) in [6] is a bandwidth constrain QoS multicast routing protocol. A lantern is defined as one or more sub-paths with a total bandwidth between a pair of two neighboring nodes. A lantern path is a path with one or more lanterns between a source and a destination. The multicast tree contains at least one lantern path between any of its source-destination pairs. Lantern-tree protocol measures the bandwidth as the available amount of free slots based on CDMA-over-TDMA channel model at MAC layer. One drawback of LTB is the long time needed to find all the paths and to share and schedule the time slots. Another drawback is the use of high number of links, which increase the contention at the MAC layer.

On-demand QoS multicasting protocol is proposed in [10]. This protocol simultaneously use multiple paths or trees in parallel to meet the required bandwidth of a single QoS request within a delay bound between the source and the destination. The bandwidth is considered as the number of free slots using CDMA-over-TDMA channel model. They propose three multiple path construction strategies to enable the source node to aggregate the bandwidth over the links. The source computes the optimal routes to the destinations and manages the group membership, which overload the source with extra processing overhead. Using flooding to discover the paths add the processing overhead for non-member nodes and waste the network resources.

QoS Multicast Routing Protocol (QMR) [11] is a hybrid scheme for supporting QoS routing. It is an on-demand mesh protocol connects group members using QoS paths. QMR define forwarding nodes that provide at least one path from each source to each destination. CDMA-over-TDMA is used to estimate the available bandwidth. A distributed admission control is used to enable intermediate nodes to reject the routes that not satisfy QoS requirement. The forwarding nodes are updated when multiple sources sending to the multicast group simultaneously. This prevents congestion and performs load balancing in the network.

III. DESIGN OF THE PROPOSED ARCHITECTURE

A. NETWORK SETUP

The first step in our model is the network setup phase. This step describes the construction of a virtual structure for the network topology by dividing the physical area is into a number of equal-sized hexagonal cells.

A.1 Area Partitioning

The area containing the Ad hoc network is partitioned into equal size cells, this partitioning must be known to all participating nodes. The cell shape are chosen to be hexagonal, this is because this shape can completely cover a two-dimensional region without overlap. Also, it enables communication with more neighbors than the other shapes because it is closely resemble the nearly circular coverage area of a transmitter.

The availability of small, inexpensive low power GPS receiver makes it possible to apply position-based in MANETs. We denote the transmission range of a node as R and the side length of the hexagon cell as L. The relation between R and L is set as $L=\frac{R}{2}$ to guarantee that each pair of nodes in the same cell are always within the effective transmission range. So, each two nodes inside the cell can communicate with each other directly.

Each cell has a Cell Identity (Cell-ID), Cell Leader (CL) and Cell Leader Backup (CLB). The CL node is responsible for maintaining information about all the nodes in that cell including their positions and IDs. Also, it is responsible to maintain information about the CLs of the neighboring cells as shown in the figure below. The responsibility of CLB node is to keep a copy of the data stored at the CL in order not to be lost when the CL node is off or moving the cell.

By knowing the coordinates of a node position, nodes can perform our self-mapping algorithm of their physical locations onto the current cell and calculate its *Cell_ID* easily. Figure 1.shows the general overview of the network architecture.

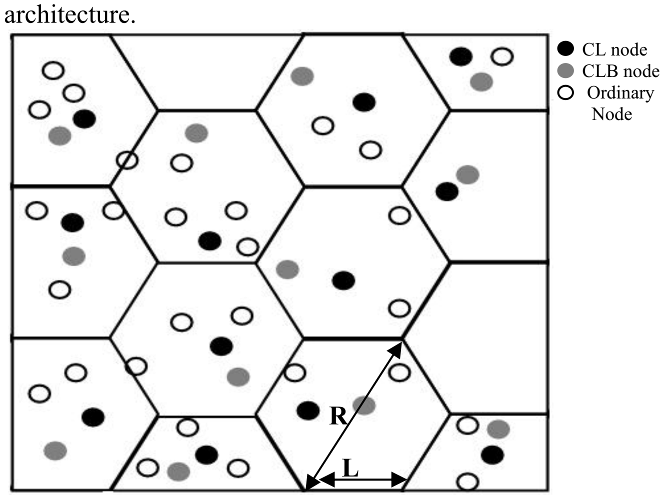

Figure 1: General overview of the network architecture.

A.2 ELECTION OF CLs AND CLBs

An election algorithm is developed to elect the nodes that satisfy different metrics in order to take the role of cells leaders and survive the longest possible time. Since the elected leader should be the most valued-node among all the nodes in a given cell selection [12], the following metrics are taken into consideration upon the leader selection: the distance of the node from the cell center, residual energy, computing power, available memory and mobility speed.

- **Position of the node in the cell**

Let we assume that the node position in the cell is (x_i,y_i). We can define the distance between node *i* and the hexagonal center (x_c,y_c) as:

$$D_i = \sqrt{(x_c - x_i)^2 + (y_c - y_i)^2} \quad (1)$$

When the node position is closer to the center it is opportunity to be a leader will increase. If we assumed that the maximum distance of a node from the center point of a hexagonal cell is $D_{[max]}$, then the weight of the position metric can be calculated as:

$$P_i = \frac{D_{[max]} - D_{[i]}}{D_{[max]}} * w_1 \quad (2)$$

- **Residual energy at each node**

Let we assume that the residual energy of a node *i* is given as the remaining serving time of the battery and equal to $Eng_{[i]}$. As the node energy increase its opportunity to act as a leader increase. If we assume that the maximum service time of a battery is $Eng_{[max]}$. Then the weight of the residual energy metric can be calculated as:

$$E_i = \frac{Eng_{[i]}}{Eng_{[max]}} * w_2 \quad (3)$$

- **Computation power of the node**

We assume that the computation power of a node *i* is given as a number of instructions per second and equal to $CPU_{[i]}$,. The computation power of the node increases its chance to be a leader. If we assumed that the maximum computation power exists in the market is $CPU_{[max]}$, then the weight of this metric can be calculated as:

$$C_i = \frac{CPU_{[i]}}{CPU_{[max]}} * w_3 \quad (4)$$

- **Memory available at each node**

Let we assume that the memory capacity for a node i is equal to $Mem_{[i]}$ and the maximum memory capacity that can be exists in the market is $Mem_{[max]}$. Then the weight of this metric can be calculated as:

$$M_i = \frac{Mem_{[i]}}{Mem_{[max]}} * w_4 \quad (5)$$

- **Mobility speed of each node**

If we assume that the maximum mobility speed of a node in the network is equal to $Spd_{[max]}$ and the node mobility is $Spd_{[i]}$. Since the chance of a node to be a leader decreases as its speed increases. Then the weight of this metric is calculated as:

$$S_i = \frac{Spd_{[max]} - Spd_{[i]}}{Spd_{[max]}} * w_5 \quad (6)$$

Where w_1, w_2, w_3, w_4 and w_5 are weighting factors for the corresponding system parameters and $w_1 + w_2 + w_3 + w_4 + w_5 = 1$, since we believe that the considered metrics have the same significance upon the election of the cells leaders.

Each node computing P_i, E_i, C_i, M_i and S_i locally and exchange it with other nodes inside their cell found in the cell via a 1-hop transmission. Every node now has information about the capability of all the other nodes in its cell, so it can recognize that the node with the highest probability will be the *CL* and the node with the probability that comes immediately after it will be the *CLB.* After the election algorithm is executed inside each cell, the elected *CL* node has to broadcast the election result to all the nodes inside the cell. After a predefined time, all the cells finish the election process and elect a leader and backup nodes.

The *CL* node should announce its leadership role by broadcasting a message to the nodes inside the cell and for the CL nodes of the 6-neighbor cells rather than flooding it to all the *CLs* in the network in order to reduce the number of control packets and reduces the overhead produced from maintaining information about the global network. Each node upon the reception of the message it replies to the *CL* by sending a message that contains its current location and the multicast groups it is interested to join. We assume that all the nodes are aware of the existing multicast groups.

After network construction, each *CL* keeps information about the identity and position of the nodes in the cell it is responsible for, the membership of these nodes in different multicast groups and information about the 6-neighboring cells (cell identity, identity and position of the *CL* of each neighbor cell). This information is used in route discovery and maintenance.

Inside the cell, the communication from the *CL* to the ordinary nodes, from the ordinary nodes to the *CL* and from the *CL* to the *CLB* is done within only one hop unicast communication. While, the Communication between the neighboring cells is done using Restricted Directional Flooding (*RDF*). In *RDF*, the node resends the packet only if it is closer to the destination than it's previous hop [13].

B. Location Service Algorithm

This algorithm enables the source to map the geographical positions of the destinations, this is done as follows:

When a source node has data to send to a group of destinations, an efficient communication procedure is done between cell leaders to provide the source with all the nodes interested in this multicast session and their positions. The source node sends an invitation message to the *CL* node where the source is located to ask for nodes that are interested with this multicast group. This message needs only one hop unicast operation. When the *CL* node in the local cell receives this message, it checks its multicast table to check if there are nodes interested in joining this multicast group, then it reply by sending a reply packet directly to the source node. The search for additional destinations is continued by sending an invitation message to the *CL* of the 6-neighbor cells, and then it propagated cell by cell until it covers the entire network.

When the *CL* node receives reply packets from all the cells, it forwards the position and *IDs* of the destination nodes to the source node. The source node waits for a predefined time to aggregate the reply packets from the *CL* nodes in the network in order to determine the nodes that want to participate in the group.

C. Route Discovery

In our model, we provide an on-demand multicasting protocol to satisfy a certain bandwidth and delay requirements. This is because bandwidth and delay are critical requirements for real time applications. Due to bandwidth constrains and dynamic topology of mobile ad hoc networks, provide QoS routing with multi-constrains is NP-complete problem [14].

After executing the location service algorithm, the source node divides the list of destinations into a number of sub-groups, the number of nodes in a given sub-group is limited to a predefined value (*max_n*). For each sub-group, the node closer to the source is selected to be as a coordinator for that sub-group. The role of the coordinator is to minimize the bandwidth and resource usage and forward the data packets to the members of the sub-group which is under its responsibility.

After division of the multicast members into subgroups, a QoS path which satisfies a given bandwidth and delay requirements has to be found from the source to each coordinator. After that the search for QoS paths is continued in the same mechanism between the coordinator and each destination from the destination list. We have used *RDF* mechanism to perform position-based route discovery process. Using *RDF* increases the probability of having a path satisfying the needed number of hops in addition to giving opportunity of finding multi-segment paths satisfying the required bandwidth.

In this model a QoS path which satisfies a given bandwidth and delay requirements has to be found from the source to each destination from the destination list. The bandwidth requirement is represented in the request as an amount in Mb/s which represents the available bandwidth on a link between two successive nodes. The delay is represented as the number of hops which is the upper limit of the delay value from the source node to any destination. The available bandwidth is estimation from the IEEE802.11 MAC and the Network layer performs routing based on the information come from the MAC layer. The available bandwidth is estimated based on the “Listen” method proposed in [15] [16]. In this method, each node listens to the radio channel and tracks the traffic of the neighboring nodes in order to determine the available bandwidth. In other words, each node listens to the channel and determines the idle duration for a period of time.

D. Route Setup

By the end of route discovery phase, different routes have been discovered between the source node and the coordinator of each sub-group and between the coordinator and the rest of the destinations. The request packets that reach the coordinator and the destinations comes from the paths that satisfy the delay bound. So, the coordinator needs to select a route that has the needed end-to-end bandwidth. If the first route arrived to the coordinator satisfies the required bandwidth at all the path nodes, then the coordinator select this route to be the optimal route, then it sends back this route to the source. Otherwise, the coordinator will search for a segment that is parallel to the link that does not satisfy the bandwidth in the previous route in order to satisfy the requested bandwidth. If a parallel segment is found, then it will take the required amount of the bandwidth and splits the data on that branch node into two parallel paths. This process is continued path by path until a best route is chosen.

When the route reply traverses back to the source and the coordinator, each node along the chosen paths reserves the amount of the bandwidth that is considered to be used in the route and relies the message to the node send to it in route discovery. During constructing the routes between the coordinator and its destinations, the source node start forwarding the data packets over the selected routes to coordinator, and then from the coordinator to each member of the sub-group.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

The effectiveness of the proposed protocol was evaluated using Glomosim simulator [17]. The simulation model a network of 240 mobile hosts placed randomly within a 2000*2000m^2 area for 600 second of simulation time with a node density of 60 node/km^2 is suggested. To evaluate the performance of our protocol we compare the obtained performance with ODMRP. ODMRP is chosen since it has shown to be one of the best protocols in its class [18].

We evaluated both protocols as a function of mobility and group size (number of destinations). For evaluation of the effect of mobility, we assume that one sender chosen randomly to generate multicast traffic to a group size of 48 destinations, the mobility speed was varied between (0 and 10 m/s) and the pause-time was set to 30 seconds. In the simulations, Constant Bit Rate (CBR) data traffic flows are injected into the network from the multicast traffic sources. The data payload had a size of 512 bytes per packet and transmitted by the multicast sources every 500ms time interval (2 packets per second). Also, we study the effect of varying the bandwidth requirements for different mobility speeds. The common parameters are the number of mobile nodes is set to 240, group size is set to 48 members and mobility speed is set to 5m/s with a pause time of 30s. Bandwidth requirements are set to 0.1, 0.2 and 0.4Mb/s.

B. *Simulation Results*

The following performance metrics was used to evaluate the proposed protocol:

Packet Loss Ratio (PLR): The average of the ratio between the number of data packets that did not reach their intended destinations and the number of data packets that the total number of packet sent by the source.

Control overhead (CO): The Number of control packets transmitted to perform multicast routing (Route Request, Route Reply and route maintenance), control packets are counted at each hop.

Figure 2 shows the effect of varying the mobility speed of nodes on the PLR. As expected, PLR is increased with increasing the mobility speed. When the mobility of network nodes increased, the probability of having link failure and topology change increased as well, which leads to higher packets drop out. The results show that PLR for PBQMRP is less than that of ODMRP for low to moderate mobility. This is due to the hierarchical tree structure which provides reliable routes. While when the node mobility increased, ODMRP outperforms PBQMRP due to the redundant paths that the mesh networks provide.

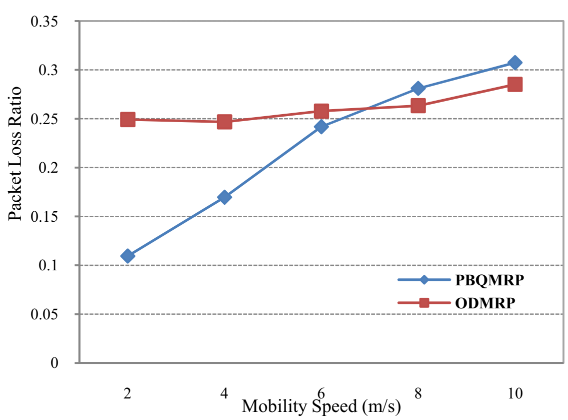

Figure 2: PLR vs. Mobility

Figure 3 shows the effect of varying the requested bandwidth from low bandwidth (0.1 MB/s) to high bandwidth (0.4 MB/s) with different mobility speeds. It is clear from the figure that when the requested bandwidth is high (0.4 MB/s) PLR is the highest value for all scenarios. This is because the probability of finding path links that satisfy this value is decreased.

The number of control packets transmitted for different mobility speeds is illustrated in Figure 4. It's clear from the figure that number of control packets transmitted for ODMRP is higher than PBQMRP and it stay flat. This is due to the periodic generation of JOIN QUERY packets (e.g. 3 seconds) and the mechanism used to construct the forwarding mesh. On the other hand, PBQMRP produce less control packets, since it avoid flooding the network and used limited broadcast. Also, PBQMRP uses only few nodes to participate in the construction of the multicast tree.

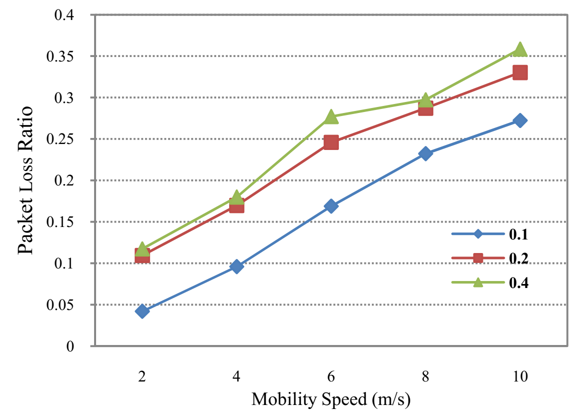

Figure 3: PLR vs. mobility and bandwidth requirement

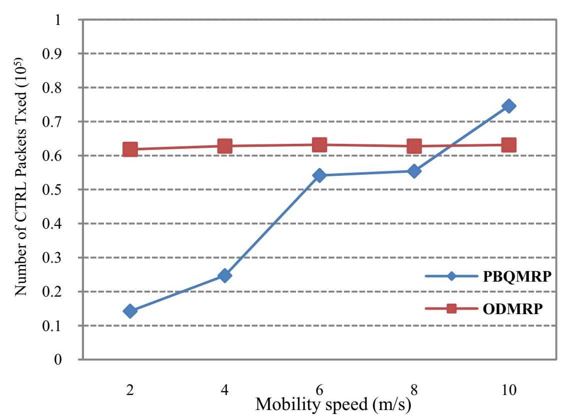

Figure 4: Control overhead Vs. Mobility

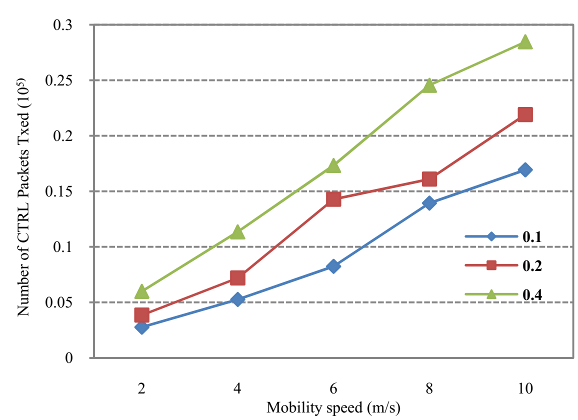

Figure 5: Control overhead vs. mobility and bandwidth requirement

Figure 5 demonstrates the number of control packets transmitted for different mobility speeds with different bandwidth requirement sizes. The figure shows that the total number of control packets is affected with requesting high bandwidth paths. This is due to the increased number of packets generated in the network in order to search for feasible paths. Also, increasing the mobility cause frequent link break, this requires reinitiating of route discovery packets.

V. CONCLUSION

In this paper, we have presented a hierarchical scheme for multicast routing protocol with multiple QoS constrains over MANETs. The hierarchical scheme is optimized to utilize the limited network resources and reduces the resulting overhead significantly. The results show that PBQMRP achieve less packet loss ratio in low to moderate networks with reduced control overhead.

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