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Quality of Service Multicast Routing Protocol for Large Scale MANETs

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***Abstract*—Mobile Ad hoc NETworks (MANETs) are collection of mobile nodes communicate in a multi-hop manner without relaying on any infrastructure or central administration. Multimedia and group-oriented applications over MANETs gain high popularity, which makes providing Quality of Services (QoS) a key requirement. This work proposed a new efficient approach which aims to find paths between the source and all the multicast group members using paths that meet the bandwidth and delay requirements. Unlike some of multicast routing protocols, the proposed approach has limited maintaining the network topology to certain nodes to reduce communication overhead and provide scalability. The proposed protocol partitioned the network into equal size hexagonal cells and a leader and backup leader are elected inside each cell. The location information provided by GPS receivers are used at route discovery and route maintenance. This protocol allows multicast group members to join/leave the held session dynamically. The proposed protocol is scalable for large area networks with large multicast members. Also, it achieves a significant reduction in processing overhead than non hierarchical algorithms.**

Keywords —Multicast Routing, Ad hoc Networks, QoS, GPS

I. INTRODUCTION

Recently, the use of wireless communication between mobile users has become increasingly popular due to the performance advancements in computer and wireless technologies. Also, the widespread use of mobile and handheld computing devices increases the popularity of mobile wireless networks. This has led to lower prices and higher data rates, which are the two main reasons why mobile computing is expected to see increasingly widespread use and applications.

There are to variations of wireless mobile communication. The first one is known as infrastructure wireless networks, where the mobile nodes communicate with a base station that is located within its transmission range (one hop away from the base station). The second one is infrastructureless wireless network which is known as mobile Ad hoc networks.

In MANETs, mobile nodes communicate with each other over wireless links in the absence of any infrastructure or centralized administration. In this type of networks, the mobile nodes function as both hosts and routers at the same time. Two nodes communicate directly if they are within the transmission range of each other. Otherwise, they reach each other via a multi-hop route.

Since the bandwidth of MANETs is limited and shared between the participating nodes in the network, it is important to efficiently utilize the network bandwidth. Multicasting can minimize the link bandwidth consumption and reduce the communication cost by sending the same data to multiple participants.

Group communication becomes increasingly important in MANETs because it support applications that facilitate effective and collaborative communication among groups of users with the same interest. Video conferencing, interactive television, temporary offices and network gaming are common examples of these applications [1]. As a consequence, multicast routing has received significant attention recently. 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 [2].

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 networks. QoS support is tightly related to resource allocation and reservation to satisfy the application requirements; the requirements include bandwidth, delay, delay-jitter and probability of packet loss. It is a challenge to support QoS in MANETs because the network topology changes as the nodes move and network state information is generally imprecise. This requires extensive collaboration between the nodes, both to establish the route and to secure the necessary resources to provide QoS. Also, the centralized design of the medium access layer and limited resources make it more difficult to guarantee QoS in Ad-Hoc networks. So, combining QoS with multicasting faces several challenges due to the difficulty in finding paths between the source and all the destinations that satisfy certain QoS requirements.

In this paper, we investigate the problem of QoS routing in MANETs using multicast communication. Due to the dynamic network topology and the need for robustness and scalability, the geographical positions of the nodes are used to forward the data packets [3]. The remainder of this paper is structured as follows: In section II we provide some overview on related works in the area of QoS multicast protocols in MANETs. In section III, we introduce our approach for providing QoS multicast routing protocol. Finally, section IV concludes the paper.

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II. RELATED WORKS AND PROBLEMS

Multicasting in MANETs is relatively unexplored research area, when it is compared with unicast routing [4]. Multiple QoS multicast routing protocols have been proposed for Ad-Hoc networks such as [2] [5] [6] [7] [8]. Also, many position-based multicasting protocols have been proposed including [9] [10] [11] [12] [3]. However, few works have been done in QoS position-based multicasting. In the following section, some QoS multicast routing protocols are reviewed.

Lantern-Tree-Based (LTB) in [5] 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, which needs distributed time synchronization. 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 [8]. 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. Also, using flooding to discover the paths add extra processing overhead for non-member nodes and waste the network resources.

QoS Multicast Routing Protocol (QMR) [6] is an on-demand mesh protocol that uses forwarding mesh same as On-demand Multicast Routing Protocol (ODMRP) [13]. The bandwidth is estimated at each node and reserved only when the QoS request is accepted and it is divided into “shared” and “fix reserved”. The intermediate nodes forward the data packets if shared bandwidth is available to prevent multiple reservations to happen simultaneously.

The forwarding nodes are updated when multiple sources sending to the multicast group simultaneously. This prevents congestion and performs load balancing in the network. However, the redundant flooding increases the congestion and the overhead, which affects the QoS flow.

A cluster-based QoS multicast routing protocol is proposed in [14]. This protocol partitions the network into square clusters and the nearest node to cluster center is elected as a cluster-head. A gateway node is selected between the adjacent clusters to rely the packets when the adjacent clusters out of the effective transmission range. The multicast session is started by sending PROPE packet to the cluster-head. The gateway forward this packet to the proper neighbor cluster until the destination or intermediate node with valid route to the destination is reached. The destination or the intermediate node selects the optimal route using best predecessor replacement strategy [15]**.** When the source receives the reply packet, it starts data transmission. This protocol only uses cluster-head, source, gateway and destination nodes in routing. However, only the gateway is responsible for packet forwarding. Thus, the gateway selection becomes the key point of this protocol. Another drawback appears when the network is sparse, in this case the gateway nodes may fail to reach the neighbor cluster-head and then the route cannot be established.

In [16], a Hypercube-based Virtual Dynamic back-bone (*HVDB*) model for QoS-aware multicast communication is proposed. The clusters are formed using mobility prediction and location-based technique used in [17]. The structure is abstracted into three tiers: mobile node (*MN*), hypercube tier (*HT*) and mesh tier (*MT*). The network area is partitioned into overlapped circular shape and a cluster-head (*CH*) is elected for each circle. The *CH* is mapped to a hypercube node at the *HT* tier. Each hypercube is mapped to as one mesh node at the mesh tier. When a node wants to send data to group members, it sends it to its *CH*. Then, the *CH* check the summarize membership to determine the hypercubes that maintain the members of this group. The logical locations of these hypercubes used to compute a multicast tree. And the information about the multicast tree is encapsulated into the messages. When the packet enters a hypercube, it’s forwarded to those hypercube nodes that contain the group members. *HVDB* protocol provides fault tolerance property and scalable. However, it produces a lot of communication overhead due to the periodic messages in the three tiers. Also, the overlapping circles bring extra overhead for the cluster-heads. Another drawback is the mapping between the tiers and selection of border and inner cluster-heads which increases the overhead.

III. THE QoS MULTICAST PROTOCOL

A. *Protocol Design Strategy*

The physical area is partitioned into a number of equal-sized cells. This partitioning must be known to all participating nodes. The cell shape is chosen to be hexagonal; this is because this shape can completely cover a two-dimensional region without overlapping. Also, it enables communication with more neighbors compared to other shapes because it is closely resemble the nearly circular coverage area of a transmitter. Based on our assumption that all the nodes inside a given cell use 1-hop communication; the maximum distance between any two nodes inside the cell should not exceed the transmission range (*R*). Considering the hexagonal, square and triangle cell shapes, and substituting *R* as the maximum distance among the cell nodes; it is obvious that the area covered by the hexagonal ($0.6495 \times R^2$) is larger than that covered by the triangle ($0.433 \times R^2$) and the square ($0.5 \times R^2$). This enables 1-hop communication among higher number of neighbors than provided by the other shapes and reduces the number of cells leaders. This, in turn, results in reduction of the control overhead. Moreover, the advantage of the hexagonal cell is that it offers six directions of transmission, thus possibly fastening the processes requiring cell leaders' communications such as group members' discovery process. In the literature, many researchers have used the hexagonal gridding such as [18] [19] [20]. For all the aforementioned reasons it was decided to use the hexagonal cell.

We have denoted 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. Each cell has a Cell Identity (*Cell-ID*) and inside each cell an election algorithm is executed to elect Cell Leader (*CL*) and Cell Leader Backup (*CLB*) nodes. The cell leader should be powerful enough to take charge of its connecting nodes and it is responsible for maintaining information about all the nodes in that cell and about the *CL*s of the 6-neighboring cells. 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.

For simplicity we assume the routing area is a two-dimensional plane. Also, we assume that each node has its unique ID and can obtain its geographic coordinate by using GPS receivers or some other ways. Thus, all nodes are able to do self-mapping of their physical locations onto the cell they reside in. Recently, the availability of small, inexpensive, low-power GPS receivers and techniques for calculating relative coordinates based on signal strengths realize the location-based routing for Ad-Hoc networks [21].

Figure 1 shows the general overview of the network architecture.

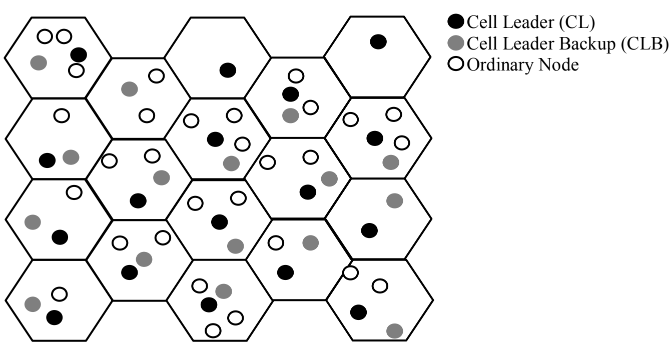

Figure 1: General overview of the network architecture

B. *Cell leader Selection Algorithm*

We have developed an election algorithm that elects the node that satisfies 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 [22], 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. Each of the above mentioned metrics is assigned an equal weight since we believe that these parameters have the same significance upon the election of the cells leaders (the weights of the parameters are calculated below). So, each node computes locally its capability to be a leader, and exchange it with other nodes found in the cell via a 1-hop transmission. When a node in the neighboring cells receives the capability packet it drops it immediately.

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 capability will be the CL node and the node with the second highest capability will be the CLB node. Each CL node should announce its leadership to the nodes inside the cell and the CL nodes of the 6-neighboring cells rather than flooding it to all the CLs in the network. This will reduce the number of control packets and reduces the overhead produced from maintaining information about the global network. Since the capabilities of the mobile nodes can change over time, the CL periodically performs leader election inside the cell.

The waits of the considered parameters are calculated as follows:

- *Node distance from the cell center*

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

$$D_{[i]} = \sqrt{(x_c - x_n)^2 + (y_c - y_n)^2}$$

When the node position is closer to the center, the 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 $D_{[cmax]}$, then the weight of the position metric can be calculated as:

$$Pos\_wt[i] = \frac{D_{[max]} - D_{[i]}}{D_{[max]}}$$

- *Node Residual energy*

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:

$$Eng\_wt_{[i]} = \frac{Eng_{[i]}}{Eng_{[max]}}$$

- *Node computation power*

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:

$$CPU\_wt_{[i]} = \frac{CPU_{[i]}}{CPU_{[max]}}$$

- *Node available Memory*

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:

$$Mem\_wt_{[i]} = \frac{Mem_{[i]}}{Mem_{[max]}}$$

- *Node Mobility*

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 can be calculated as:

$$Mob\_wt_{[i]} = \frac{Spd_{[max]} - Spd_{[i]}}{Spd_{[max]}}$$

Node Capability (NC_i) to be a leader is then calculate as:

$$\left(\frac{D_{[max]} - D_{[i]}}{D_{[max]}} \times \frac{Eng_{[i]}}{Eng_{[max]}} \times \frac{CPU_{[i]}}{CPU_{[max]}} \times \frac{Mem_{[i]}}{Mem_{[max]}} \times \frac{Spd_{[max]} - Spd_{[i]}}{Spd_{[max]}}\right) \times a$$

Where a= 0.2.

After network construction, each node maintains only the identity of both the CL and CLB nodes of the cell where it resides, in addition to the identity of that cell. While, 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 (including cell identity, identity and position of the CL and CLB). In the announcement process, the ordinary nodes in each cell just forward the packet without storing any information about the neighbor *CLs*. Also, the ordinary nodes affiliates with only one *CL* node.

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.

C. Location Service Algorithm

This algorithm enables the source to map the locations of the destinations. When a source node wants to send data 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 starts by sending an *Invitation* packet to the *CL* node where he is located to ask for nodes that are interested in the held session. The *CL* node searches its multicast table to check if there are nodes interested in joining this session, then it sends a *Reply* packet directly to the source. 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 the *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 *Route Reply* packets from the *CL* nodes in the network. Now the source will be able to divide the group members into manageable sub-groups and choose a coordinator for each sub-group. Then, the route discovery process is started to search for QoS paths between the source and the coordinators of each group and then between each coordinator and the destinations under his responsibility.

D. Multicasting and QoS Routing Admission

In our model we have provided paths that satisfy a certain bandwidth requirements from one source node to a group of destinations. Also, the delay was considered as another QoS parameter. This is because bandwidth and delay are critical requirements for real time applications. Due to bandwidth constrains and dynamic topology of MANETs, providing QoS routing with multi-constrains is NP-complete problem [4].

In our model, the network layer interacts with the IEEE 802.11 MAC layer to estimate the available bandwidth with no control overhead and with considering the activities of the neighboring nodes, which makes our protocol more practical.

In this model, the intermediate nodes perform admission control to manage the bandwidth reservation and prevent multiple reservations. Figure 2 shows a pseudocode of the admission control algorithm.

```
When intermediate node receive QoS_RREQ packet
            It checks for available bandwidth
If (no bandwidth available (Av_BW)at a node) then
                        Drop QoS_RREQ packet
   Else
        Use (previous node Av_BW, current node Av_BW)
        to calculate the link available bandwidth (link_Av_BW)
If (link_Av_BW)<= required BW then
                   Status = allocate (temporarily)
        Else
                   Allocate requested BW and free the rest
If the link is not included in the selected route
                       Release bandwidth allocation
If the link is included in the selected route
            convert status form "allocate" to "reserve"
```

Figure 2: Admission control Algorithm

E. Route Discovery

In order to efficiently utilize the network bandwidth and reduce the communication overhead, the source node divides the list of destinations into a number of sub-groups. In order to have manageable-sized sub-groups and achieve real scalability, 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 energy usage and forward the data packets to the members of the sub-group which is under its responsibility. The data flow start by forwarding a copy of the data packet from the source node to each coordinator then from each coordinator to its sub-group nodes as destinations. By, using this mechanism the packet header is reduced significantly which allows the system to be scalable to more group members. Also, there is no need for the source to maintain the information about the global network topology.

The QoS path which satisfies a given bandwidth and delay requirements has to be found from the source to each coordinator using RDF. Using RDF increases the probability of having a path with reduced delay. In addition it gives opportunity of finding multi-segment paths satisfying the required bandwidth. After that the search for

QoS paths is continued in the same mechanism between the coordinator and each destination from the destination list.

F. Route Setup

To distribute the load among nodes, each coordinator will bear the responsibility of choosing the QoS route from the source to itself, and each destination will choose the best route from the coordinator to itself. The request packets that reach the coordinator and the destinations comes from the paths that satisfy the delay bound. So, they need to select the routes that have the needed end-to-end bandwidth. The proposed scheme exploits the residual bandwidth efficiently by using multi-paths (and multi-segments paths) when the bandwidth of a single path is not sufficient. Each destination selects the QoS path between itself and his coordinator and send the reply using the reverse path. The nodes along the chosen paths reserve the amount of the bandwidth that is considered to be used in the route and reply the packet to the node that send to it in route discovery. During constructing the routes between the coordinator and its destinations, the source node start forwarding the data over the QoS route to coordinator. When the coordinator receives the data packets from the source node, it sends a copy of the data packet to each member of the sub-group.

G. Route Recovery

The proposed model handles join/leave of the multicast members in a way that utilize the network resources. Also, coordinator failure and movement are treated with minimal control overhead. Moreover, the encountered broken links are reconstructed with new paths immediately.

IV. CONCLUSION

This paper has presented a hierarchical multicast routing protocol with multiple QoS constrains for MANETs. This hierarchical scheme is optimized to utilize the limited network resources. Moreover, the distributed admission control mechanism exploits the residual bandwidth efficiently. This approach is efficient in providing QoS capability with significant reduction in control, storage and processing overhead. Also, it is scalable for large area networks with large number of multicast members.

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