Position-Based Multicast Routing in Mobile Ad hoc Networks

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***Abstract*—Nowadays, group communications over Mobile Ad hoc Networks (MANETs) have received significant attention. Multicasting plays an important role in simultaneous delivery of information to group of receivers. Meanwhile, multimedia and real-time applications are becoming essential needs for MANET users. Thus, it is necessary to design efficient and effective multicast routing protocol to support this type of applications. Several efforts have been put to improve Quality of Service (QoS) multicast routing. However, they do not consider scalability issue. This paper introduces a position-based QoS multicast routing protocol (PBQMRP). The main objective of this protocol is to design a lightweight scalable QoS multicast routing scheme irrespective of the number of multicast members and network size. To achieve this, virtual clustering strategy has been introduced. This strategy based on partitioning the network into hexagonal cells and each cell is represented by one powerful node. The proposed scheme eliminates the duplicate packets between cells and reduces the number of participating nodes. Simulation results show that PBQMRP offers higher packet delivery ratio with significantly low overhead compared to ODMRP Protocol.**

Keywords-component; Ad hoc networks; multicast; routing; protocol

I. Introduction

Mobile Ad hoc NETworks (MANETs) are composed of a collection of mobile nodes that communicate with each other over wireless links in the absence of any infrastructure or centralized administration. Recently, MANETs have gained worldwide popularity. Absence of infrastructure, mobility, self-organizing, self-configuring, self-administering are the main reasons of this popularity. In spite of their worldwide popularity, MANETs have several challenges and limitations [1-3]. These challenges include dynamic topology changes, lack of infrastructure, bandwidth constraint and shared wireless channel, limited resources (battery, memory) and insecure wireless medium.

Routing in MANETs becomes one of the important aspects that need to be addressed carefully. Routing protocols can be mainly classified based on the cast property as unicast, multicast [4, 5]. Unicast routing protocols are used to provide efficient route establishment and maintenance to transmit packets between one source and one destination so that packets may be delivered reliably and in a timely manner. However, unicast protocols are not efficient when there is a need to send the same packet or stream of data to multiple destinations.

As wireless communications are inherently broadcast by nature, using multicasting is efficient because it reduces the communication costs by minimizing the link bandwidth consumption and delivery delay. Also, multicasting reduces the transmission overhead both on the source as well as on the network nodes and speeds up the data delivery at the receiving nodes [6-8]. For instance, consider the military application; the soldiers have to exchange critical data using their laptops. Since sending the same data for multiple recipients results in wasting the network resources and increase the network congestion. Multicast routing has emerged as an efficient communication paradigm for such applications. Here, instead of sending data via multiple unicasts, multicasting replicates the packets when they need to reach two or more destinations.

Multicast routing protocols become increasingly important aspect in MANETs, as they effectively manage group communications. Meanwhile, the increasing popularity of using multimedia applications and the potential commercial usage of MANETs in group communications make QoS a fundamental requirement. Therefore, supporting QoS multicast routing has received increasingly intensive attention and presented as an active and remarkable field for research [9]. Providing QoS over MANETs using multicast routing protocols will realize some applications to help the society in different fields such as mobile learning systems, conferences, emergency warnings in vehicular networks and public events. However, supporting QoS multicast routing is a challenging task because this type of protocols has to be designed in a different way to that for unicast protocols. In contrast, multicast QoS routing protocols have to find a QoS-satisfied paths to all destinations in the multicast group. This is difficult due to dynamic network topology, centralized design of the medium access layer and difficulties facing multicast packet forwarding.

There are several previous works that studied QoS routing (including unicasting and multicasting) in wired networks and studied QoS unicast routing in wireless ones. Unfortunately, routing protocols for wired networks are not suitable for Ad hoc networks [10]. This is due to their excessive associated overhead, lack of adaptation to the unpredictable network topology. On the other hand, in

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wireless unicast QoS protocols, the resource reservation is done between a source and a destination.

A number of QoS multicast protocols have been proposed recently and they are specially designed for MANETs [9, 11]. Most of these protocols are designed with flat topology and small networks in mind (networks with 50-100 nodes and simulation network area of 1 km^2). Thus, this observation highlights scalability as one of the most important issues to be considered, especially with the existence of large-scale MANETs [12, 13].

With the continuing revolution in wireless communications and decreasing cost of wireless hardware, a mobile device is able to obtain its location information through using GPS receivers or other localization approaches [14]. This awareness of location information has been utilized to improve scalability and efficiency through restricting the broadcast region and reducing the routing packets of MANETs routing protocols. As a consequence, location-based routing has emerged as a promising routing technique.

In this paper, we address the scalability problem of multicast routing protocols that support multimedia and real-time applications. The main objective of this protocol is to design a lightweight scalable multicast routing scheme irrespective of the number of multicast members and network size. To achieve this, virtual clustering strategy has been introduced. This strategy is based on partitioning the network into hexagonal cells and each cell is represented by one powerful node. The proposed protocol exploits nodes' positions in gathering information about subscribers and searching for routes that satisfy the QoS constraints. Furthermore, a hierarchical construction of the multicast members has been proposed to improve forwarding efficiency and scalability. The performance measures of the proposed protocol are evaluated using simulation. The results show that our protocol offers higher packet delivery ratio with significantly low overhead compared to ODMRP Protocol.

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.

II. Position-based QoS Multicast Routing in Mobile Ad hoc Networks

This section describes our Position-Based QoS Multicast Routing Protocol (PBQMRP). The protocol operation is divided into multiple phases. These phases include network construction, network maintenance, location service, multicast group partitioning, routing discovery and maintenance as well as data transmission.

A. *Network Construction*

In this phase the whole network is divided into several hexagonal cells. Each hexagonal cell has a cell identity (*Cell_ID*) and each node is a member in only one cell. When the node moves to different cell, the identity of the cell it belongs to is modified as well. The cell size is chosen to enable 1-hop communication among all the nodes inside a particular cell. Each cell has a Cell Leader node elected to maintain information about all nodes in its cell till they join a new cell. Also, each cell has a Cell Leader Backup (*CLB*) node to replace the *CL* node when it fails or leaves the cell. Details about the election process are found in [15]. Figure 1 shows a general overview of the network architecture.

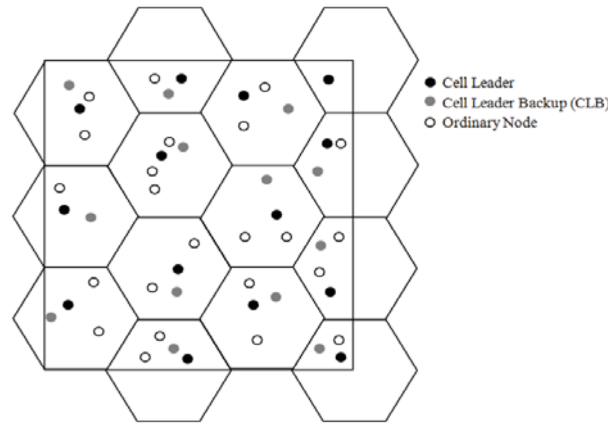

Figure 1. General overview of the network architecture.

B. *Network Maintenance*

In this phase, the necessary communications among nodes are described to ensure the maintenance of the network structure in case of nodes movement in and out the network as well as corrupted and destroyed nodes. The proposed protocol provides efficient solutions to nodes' mobility and failure to maintain a stable structure. The maintenance operations include performing periodic election, performing backup confirmation with backup nodes, handling nodes intra-cell and inter-cell movement of mobile nodes and handling empty cells.

The communication between all nodes inside a particular cell is done within only 1-hop communication (cell broadcast). This is because the side length of the cell is chosen to enable every two nodes inside the cell to communicate directly. Any node in the neighbor cells upon receiving packets destined to nodes inside another cell will drop it without any further processing. This mechanism significantly reduces the traffic of control packets.

The communication between neighboring cells is performed within at most 3-hop communication using the information stored in the CL node about nodes in its cell and the location information about the neighbor CLs. This is performed as follows: If the neighbor CL is within the transmission range of the sending CL, they can communicate directly and the packet will reach its destination in only 1-hop. Otherwise, the sending CL will send the packet to its 1-hop neighbors. If the destination CL is reachable directly, then the communication needs only 2-hops from the original CL. Otherwise, the packet is forwarded another hop to reach the destination using Restricted Directional Flooding (RDF);

i.e., only 3-hops from the original CL, which is the worst case. In RDF [16], the node resends the packet only if it is closer to the destination than its previous hop. Using RDF eliminates flooding the network and restricts packet forwarding to the nodes in the way to the anticipated destination.

C. Location Service Algorithm

This algorithm enables the source to map the geographical positions of the destinations interested to participate in the multicast session in order to build the multicast tree within these destinations. Then, this information is used in the following phase to divide the destinations into manageable subgroups.

When a source node decides to initiate a multicast session, a query packet (*INCELL_INV_REQ*) is first directed to its local *CL* node to ask for possible participating nodes in the held multicast session. This packet needs only 1-hop communication operation, since all nodes inside a particular cell are within the transmission range of each other. When the local *CL* node receives the *INCELL_INV_REQ* packet, it sends *OUTCELL_INV_REQ* to the six neighbors, then it search its local cell to search for possible participating nodes and reply to the source node with their identities and their geographic positions. Forwarding the *OUTCELL_INV_REQ* packet is continued until all the network cells are covered. The cells that have multicast members reply to the source with information about the multicast members using the reverse path. Here, we utilize the properties of the hexagonal shape to develop a packet forwarding algorithm between the network cells with very low overhead. This algorithm ensures that no duplicate packets are found during performing inter-cell forwarding of location discovery packets.

D. Multicast Group Partitioning

Generally, the multicast group members are distributed over the network area. Hence, partitioning of the multicast group members is proposed to improve the efficiency of multicast packet delivery to the multicast members.

When the source the received the identities and positions of the multicast members, it arrange them into manageable sub-groups. The groups' division process is based on the direct neighbor. In other words, the multicast members that are concentrated in a local area (within the transmission ranges of each other) will be considered as a single sub-group. In each sub-group, the node closer to the source is selected to manage this sub-group (coordinator node). To improve scalability, the number of members in each sub-group is limited to an application-dependent constant (*max_n*). This hierarchical multicasting approach would reduce the size of route discovery packets, decrease the resulting overhead, and efficiently improve the rate of delivered data packets since the nodes resides in the same area can receive the data packets within single data broadcast.

E. Route Discovery Procedure

Here, a QoS path which satisfies a requested bandwidth and delay requirements has to be established from the source to each destination in the destinations list. The requested bandwidth is included within the request packet and the upper limit of the delay value from the source node to any destination is represented as the number of hops. In order to efficiently utilize the network bandwidth and reduce the communication overhead, the route discovery process starts by finding a route between the source and the coordinators; and later between the coordinators and other destinations in the same sub-group using the same mechanism. In other words, the source builds a sparse multicast tree with the coordinators and each coordinator builds a lower multicast tree with the local members in each sub-group.

The source starts by sending a Route Request packet (*QoS_RREQ*) to each coordinator individually using RDF mechanism. Using RDF gives high 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 (while controlling the overhead). The route discovery process continues by searching for QoS paths between the coordinator and each subgroup member. The route selection process is carried out between the source node and the coordinator of each subgroup as well as between the coordinators and the rest of the destinations in their subgroups. To distribute load among nodes, each coordinator bears the responsibility of choosing the route from the source to itself, and each destination will choose the best route from the coordinator to itself.

When the source receives the selected routes to all the multicast members, it adds the routes to the routing table and starts data forwarding using the selected routes. Data forwarding is started from the source to the coordinators. Whenever a data packet reaches the coordinators, they forward a copy of the received data packet to their members in the sub-group. Each intermediate node simply relays data packets to its successor in the route obtained during the route initiation process. Using this approach to forward multicast data packets maximize the benefit of the wireless broadcast. Since the multicast members in the local sub-groups may be receive the data packets in single broadcast operation.

III. PERFORMANCE EVALUATION

The effectiveness of the proposed protocol was evaluated using Glomosim simulator [17]. The simulation model a network of 240 mobile hosts placed randomly within an area of 2km×2km for 600 second of simulation time with a node density of 60 node/km2 is suggested. To evaluate the performance of our protocol we compare the obtained performance with well-known ODMRP [18]. ODMRP is chosen since it has shown to be one of the best protocols in its class.

We assume that one sender chosen randomly to generate multicast traffic to a group size of 48 destinations. Random way point is selected as the mobility model and 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.

In our simulation results, we evaluate the performance PBQMRP and ODMRP under different node mobility speeds, different network area sizes and different multicast group densities. The performance metric of interest is the protocol throughput. Throughput is defined as the data rate in bits per second. It is computed as total number of bits received divided by the deference between the time for last packet received and the time for first packet.

Figure 2 shows the average throughput of PBQMRP and ODMRP, for various mobility speeds. It is observed that average throughput for both protocols decreases as node mobility speed increases because increasing mobility corresponds to decreasing the number of packets reaching their destinations. At low mobility, PBQMRP outperforms ODMRP. This is due to the efficient QoS route discovery for routes satisfying bandwidth and delay constraints. Also, the hierarchal structure of the multicast members provides stable tree construction. As mobility increases, the throughput of PBQMRP is gradually decreased. This decrease is a result of the frequent broken links caused by high mobility, which makes the data packets dropped until the route construction process is completed. ODMRP, however, provides redundant routes via utilizing the mesh topology, which result in having almost stable throughput.

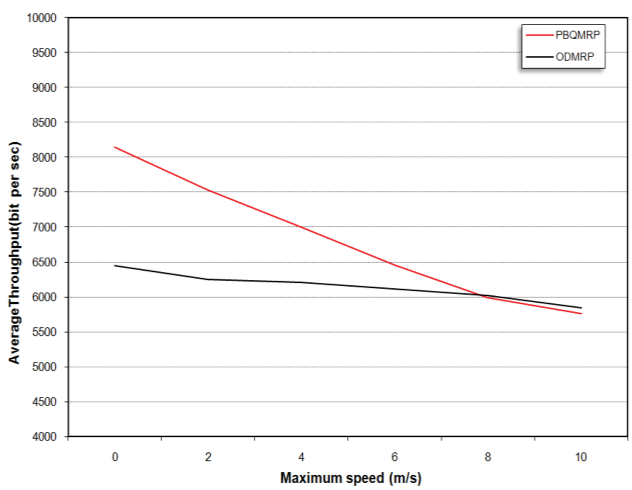

Figure 2. Average throughput vs. node mobility speed.

As shown in Figure 3, the throughput of both protocols drops with increasing the network size, however, ODMRP shows poor throughput compared with PBQMRP. In ODMRP, the data packets are broadcasted in the network. When the packets are received by a forwarding node they are rebroadcasted to the neighbor nodes until all neighbors receive these data packets. This strategy of forwarding may result in duplicate packets and the same packet may be forwarded along different paths. Thus, the probability of collision will increase and reduce the resulting throughput.

Figure 4 shows the average throughput comparison of PBQMRP and ODMRP. It is clear that LBSMRP performs better than ODMRP. PBQMRP's high throughput is due to the hierarchal tree forwarding structure, which delivers data efficiently to different destinations located in the same area. However, with increasing the group size in ODMRP, the forwarding mesh becomes more reliable with more redundant paths. This reliability results in maintaining the network throughput or slightly increases it.

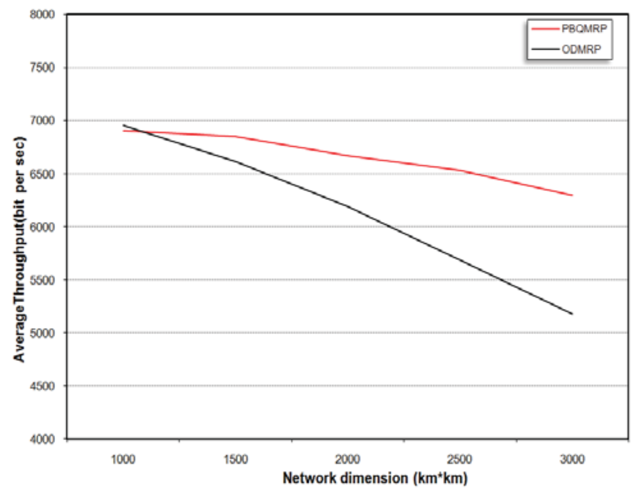

Figure 3. Average throughput vs. network size.

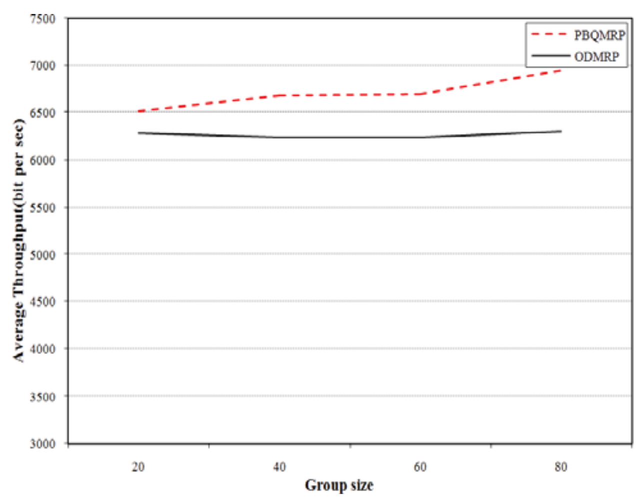

Figure 4. Average throughput vs. multicast group size.

IV. Conclusions

Due to the recent popularity of MANETs' real time applications that involve multiple users, a scalable multicast routing protocol considering multiple QoS constraints has been developed. This protocol, PBQMRP, is based on building a virtual architecture of the network topology. PBQMRP exploits the location information in building the network structure, executing the location service to gather information about multicast members and finding routes that satisfy QoS constraints to construct the multicast tree. The simulation results show that PBQMRP has higher throughput in large scale networks with significantly reduced overhead. Compared to ODMRP, PBQMRP achieves comparable results with different node mobility speeds, network sizes as well as different multicast group members.

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