Network Performance of a Multi-hop Quadrant-based Directional Routing Protocol (Q-DIR) in Wireless Mobile Ad Hoc Network

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Abstract—Routing in mobile ad hoc network (MANET) has been a subject of extensive research over the past several years. Quadrant-based directional routing protocol (Q-DIR) is a routing protocol where only nodes in the same quadrant as the destination will participate in the route discovery process. Q-DIR uses exact location of nodes based on Cartesian-coordinate system to determine the quadrant nodes are located with reference to the source and destination. Unlike other position-based routing protocols, Q-DIR only transmits route request to all nodes that are in the same quadrant as the source and destination instead of broadcasting in all direction and hence, reduces not only routing overhead in route discovery phase, but also wireless bandwidth used and flooding of packets in the network. This paper outlines the performance of a multi-hop Q-DIR in a real MANET test bed that integrate GPS-free self-positioning system with Q-AODVbis which have been developed recently as a Loadable Kernel Module in Linux environment.

Index Terms—Location tracking, self-positioning system, geocast-enhanced AODVbis, Quadrant-based directional routing.

I. INTRODUCTION

Mobile Ad Hoc Network (MANET) is a peer to peer wireless infrastructure-less network which may consists of a large number of mobile nodes such as PDAs and laptops. Since the nodes in a network can serve as routers and hosts, they can forward packets on behalf of other nodes and run user applications [1]. Various routing metrics usually used are shortest path, link stability and minimum number of hops towards the destination. But, recent routing metrics that have been extensively researched are power conservation and optimized bandwidth because mobile nodes in MANET are stand-alone devices and operate on batteries. Performance evaluation criteria usually used in these protocols are packet delivery ratio, end-to-end delay and nodes’ lifetime.

In MANET, communication among nodes can be made and setup almost immediately especially in emergency and disaster operations, military battlefield and even in a building for security and surveillance [1-2].

Routing in MANET is a challenging task as the topology changes as node moves. Over the past several years, more than 50 MANET routing protocols have been proposed and can be categorized into topology-based [3] and position-based protocols [4]. In the former, on-demand or proactive flooding of route request (RREQ) are done at each node to detect routes and are generally considered to be not scalable. However, in position-based protocol (also called geometric or directional routing), routing is optimized by making use of geographical information available at each node. In LGF [5], a geocast-enhanced AODVbis, distance information at the nodes is used to determine nodes’ participation in the routing. The distance information of the all nodes in the network is provided by the work done in [6] or any location service entity [7]. This means that nodes will have to store distance information of itself to other nodes in the network and this will incur delay in route discovery where nodes need to decide to forward or drop the RREQ packet. This paper aims to reduce delay and also eliminate data storage at the nodes by using the coordinates of the node only. Q-DIR assumes that the coordinates of each node are known using self-positioning system [8] and modifies the AODVbis [9] to identify and enable nodes that are in the same quadrant as the source and destination to participate in the routing. Each node knows of its own coordinates and when routing packets to a certain destination, the coordinates of the destination are inserted in the route request packet (RREQ). Therefore, every node that receives this packet will use this information to determine its quadrant compared to source and destination. If it is in the same quadrant, then the node will rebroadcast the packet, otherwise, it will discard and cancel its scheduled rebroadcast of the packet. Nodes that forward the RREQ packet will then insert its coordinates in the source coordinates field so that at the next intermediate node the forwarding process will be more directed. With this method of decision making, only nodes that are in the same forwarding zone will participate in routing until the packet reaches the destination. With the path accumulation (PA) feature in AODVbis, these forward routes will be stored and used in the packet forwarding phase which will forward data packets to the destination via the routes discovered beforehand. Hence, routing overhead and flooding of packets will be reduced significantly.

The remainder of this paper is organized as follows. Section 2 will present related work on self-positioning system and on-demand protocol. The implementation of 3 hops Q-DIR in a...
real MANET test bed will be described in Section 3 followed by Section 4 which will present the field measurements results and Section 5 will conclude the paper.

II. RELATED WORK

A. Self-Positioning System

Knowledge of geographic location of nodes will certainly aid in routing protocol design where packets will be routed or flooded via nodes that gives the best progress towards the destination as in [10]. Nodes need to determine its location either by itself as in self-positioning system or by other nodes as in remote-positioning system. Self-positioning is more preferred in MANET since nodes communicate peer-to-peer and location support is what nodes need rather than location tracking by a centralized processing entity.

One of the most widely used self-positioning systems is the Global Positioning System (GPS). It was used since World War II, focusing on military targeting, fleet management and navigation to the nearest hospital or petrol kiosk [11] and is based on time taken for signals from satellites to reach receivers on earth. Distance from the satellite will be calculated there on. At least three readings from three satellites are needed to perform accurate PL (Position Location) of receivers using triangulation technique.

The Cricket Compass system (CC) [12] uses a combination of RSSI (Received Signal Strength Indication) and AoA (Angle of Arrival) where angle of arrival is determined using multiple transceivers positioned in a “V” shape in the mobile device. The mobile nodes will have knowledge of its location in the building.

A self-positioning method of computing PL [8] with no additional hardware is implemented successfully in a MANET environment. The SS strength readings are readily available in the IEEE 802.11b wireless card at the node itself. The SS can be determined from the periodic transmission of “Hello Messages” by all nodes to signify its existence in the network. The power received will be mapped to a Path Loss Model obtained before the implementation phase.

Once nodes has determined its coordinates, it will be used in the route discovery where node will determine the quadrant the node is located and also the quadrant the destination is located compared to source.

B. On-demand Protocol

Most of the topology-based protocol AODV[13], DSR[14], DSDV[15], ZRP[16] to name a few uses flooding to detect routes on-demand or proactively maintain routing information at each node. This will create a broadcast storm problem and incurs routing overhead in transmission of route request packet (RREQ). Therefore, in order to reduce routing overhead, flooding and bandwidth utilization, geocast-enhanced AODVbis is proposed which is a modification of the AODVbis[17] protocol. Kernel AODV [18] has been promoted to the experimental RFC of IETF MANET charter since July 2003. AODV jr [19] effort investigated an approach to simplify the overall AODV design. This simulation work has proved that, for networks of limited size, reliable communications can be managed by implementing only a very limited number of AODV features. Thus, AODVbis was proposed as MANET Working Group Internet draft [20] in October 2003. Many features are no longer mandated in AODVbis compared to AODV, which has several protocol semantics that provide little added benefit, considered as redundant. Many flags of AODV control messages are removed and replaced by more efficient mechanisms. These modifications are important especially for resource-limited mobile computing devices such as PDAs.

AODVbis incorporates new performance enhancements and simplifies the requirements for implementations based on experiences gained during the development of AODV. As convergence can be eased by creating parameterized modular components, the modularity of AODVbis aids IETF MANET WG’s effort towards the standardization of MANET routing protocols. Three defined packet types are Route Request (RREQ), Route Reply (RREP) and the optional Route Error (RERR).

AODVbis features the Path Accumulation (PA), with which the route from either the routing table or control packet may be used to route an RREP back to the requesting node during route discovery. This is an added advantage especially for nodes with limited resource since they can opt not to record the route during RREQ flooding. In addition, PA enables wider dissemination of route information in route discovery. Whenever a node receives an RREQ, it might update its route table for every path node listed in Accumulation Path List (APL). Consequently, the number of route discovery and broadcast messages is decreased. This is critical when the traffic internal to MANET is high. The PA feature is the preliminary attempt to converge AODV with Dynamic Source Routing (DSR) [14] before standardizing the ad hoc routing protocol.

In contrast to AODV, beaconing in AODVbis is invoked only when the node participates in the routing of data packet or detects neighbors within their transmission radii. This prevents inactive nodes from continuously beaconing HELLO messages to its neighbor(s), resulting in the waste of resource and possibly traffic congestion. Precursor Lists feature is removed with the introduction of PA since route updates can be done on each path node appended in RREQ and RREP. It is important to develop and thus study the performance of AODVbis to determine the essential features of routing protocol required by MANET devices.

In route discovery in the original AODVbis, RREQ will be broadcasted to all neighbors and will create flooding of RREQ packets in the network. Therefore, in order to reduce flooding and bandwidth utilization, geocast-enhanced AODVbis [8] is proposed which is a modification of the AODVbis[19] protocol. [8] uses distance information of nodes in route discovery where only nodes that are nearer to the destination compared to the source will participate. This mechanism will reduce flooding but it needs to allocate storage at the nodes to store distance information of all nodes and different nodes would have different distance information of all nodes. If the number of nodes increases, so will the distance table.
In our work, the x-y coordinates of the nodes in a global coordinate system are utilized in the routing phase. The RREQ packet of the AODVbis was modified so that the coordinates of the source X_s, Y_s and the destination X_d, Y_d can be inserted as shown in Figure 1. Modifications were made only for the coordinates and other fields remain unchanged which is an additional 4 bytes of data.

At the receiving nodes, comparisons were made to determine in which quadrant the node is relative to the source and also in which quadrant the destination is relative to source. It is assumed that the receiving nodes have knowledge of its own coordinates. If the quadrants are the same, the receiving node will forward the RREQ packet otherwise it will discard. This algorithm is shown in Figure 2. When a node forwards the packet, it will insert its own coordinates in the X_s and Y_s field so that the next intermediate node will make the forwarding decision based on the coordinates of the of the preceding node, the destination and its own coordinates. The forwarding of packet will be more directed towards destination. This approach will reduce cost of updating each node’s information in the network and reduce storage capacity if the number of nodes increases. It will also minimize end-to-end delay since nodes need only to compare its coordinates with reference to the source and also the destination’s quadrant compared to source.

### Figure 1. Modified format of the RREQ packet.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>0G</th>
<th>RESERVE</th>
<th>Hop Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_s</td>
<td>Y_s</td>
<td>X_d</td>
<td>Y_d</td>
</tr>
<tr>
<td>Destination IP Address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination Sequence Number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Originator IP Address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Originator Sequence Number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Path Node IP Address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Path Node Sequence Number</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| (additional path node IP address and sequence number pairs) ...

### Quadrant of me compared to source? I
- If same, FORWARD
- If not, DROP.

### Figure 2. Algorithm used to forward or drop a RREQ packet.

### III. QUADRANT-BASED DIRECTION ROUTING PROTOCOL (Q-DIR)

This work combines the nodes’ coordinates’ information obtained from indoor self-positioning system [8] with a modified geocasting capability inherent in [9]. Figure 3 shows the network and how the Q-DIR’s approach to reduce flooding and end-to-end delay.

### Figure 3. The geocasting network model

The network consists of 7 nodes and each node will run the self-positioning PL program and stores its coordinates at the nodes itself. Since the proper integration of PL and Q-DIR has not been done yet, the coordinates of each node will be keyed in when we start the Q-DIR program. This work hopes to show that integration of PL and Q-AODVbis can be achieved.

In this test bed, if node S wants to communicate with the destination D, it will broadcast RREQ to all neighbors. RREQ packet will contain the IP address of node D, x-y coordinates of source S and also of destination D. As in Fig.3, the neighbors of the source node are nodes A, B, C and F. When these nodes receive the RREQ from S, each of them will compare its quadrant compared to destination with the quadrant of source compared to destination. Node A is in quadrant 1 while node F, C and B are in quadrant 2, 3, and 4 respectively. Since the destination is in quadrant 1, node A will forward the RREQ. Nodes F, C and node B will ignore and drop the RREQ packet. The coordinates of A will be inserted in the RREQ packet sent by A and will be received by D which is the destination. D will then send a RREP back to S.

### IV. FIELD MEASUREMENT RESULTS

A 3-hop MANET test bed that consists of four nodes is set up in Telematic Research Laboratory in Faculty of Electrical Engineering, UTM, as illustrated in Figure 4. The destination node is located three hops away from the source. Therefore, any data packet generated by source to destination has to be routed via the intermediate nodes. The network nodes consists of two laptops that run Red Hat Linux Distribution 9 and Fedora Core 1 Linux Project and two iPAQ H5500 series PDAs with Familiar OS, using kernel 2.4.19-rmk6-pxa1-hh30 obtained from [http://www.handhelds.org](http://www.handhelds.org). The laptop uses the Orinoco WaveLan PC card while the PDAs utilizes the build-in wireless LAN card based on IEEE 802.11b. Mackill 0.2 [21] were installed in all nodes. Mackill is a MAC filter integrated into the test bed that can force different connectivity configurations in the ad-hoc network - without nodes required to be physically separated. This greatly simplifies testing of, for example, routing algorithms.
Network model of 4 nodes were set up to run the original AODVbis, the Geocast-enhanced AODVbis (G-AODVbis) and Q-DIR (Q-AODVbis). Nodes are numbered accordingly and located at the coordinates shown in Figure 4. The AODVbis will broadcast RREQ to all neighbors to discover while G-AODVbis will use distance information and Q-AODVbis will use x-y coordinates to determine the direction of broadcast messages transmission. The distance information of each node to all other nodes in the network are stored in data file sl.c and will be utilized by G-AODVbis.

Using the Mackill facility, node 1 will only see node 2, node 2 will only detect nodes 1 and 3 while node 4 will detect node 3 only and denoted by the transmission range circle in Figure 4.

To measure packet delivery ratio with different packet size, two experiments have been carried out on the same test bed. Data packet size of 56 bytes and 512 bytes were pinged. The Ping utility is used to send continuous data packet from the source node to the destination node. For each data packet size, one hundred continuous Pings were generated and the test was repeated 10 times. Output of the ping command was recorded at the source.

Figure 5 and Figure 6 illustrate the percentage of packet delivered for 64-byte and 512-byte data packets for all three networks. In all networks, for 64-byte packet, 1-hop transmission has 100% packet delivered. However, in 2-hop and 3-hop transmission, there is a degradation of packet delivery ratio. Nevertheless, Q-AODVbis has the highest packet delivery at 93.86% and 79.20% respectively. The results for the 512-byte data packet are about the same with Q-AODVbis having the highest figure at 95.11% and 84.30% packets being delivered.

Figure 7 and 8 shows the end-to-end delay for all three networks in 3-hops transmission. The end-to-end delay for AODVbis is 15 ms for 64-byte data and 24.04 ms for 512-byte data packet, for G-AODVbis is 16.86 ms for 64-byte data and 25.2 ms for 512-byte data packet and lastly for Q-AODVbis is 14.61 ms for 64-byte data and 23.37 ms for 512-byte data packet. Q-AODVbis has the highest packet delivery ratio and lowest end-to-delay for both 64-byte and 512-byte data packet. This shows that with geographical forwarding, transmission will be more directed and takes less time to reach destination.
This paper has presented the implementation of quadrature-based directional routing protocol (Q-DIR) in MANET. The results show that with location information, nodes in MANET have a high packet delivery ratio and low end-to-end delay for a 3-hop communication. Even though there is a degradation of packet delivered between 1-hop and multihop transmission, the problem can be resolved with retransmission as done in TCP/IP mechanism. With Q-DIR, nodes that are not in the direction of transmission will not participate and hence less power and less flooding will occur in the network. Also, the storage capacity at each node (in G-AODVbis) will be eliminated as nodes need not have to keep distance information of all nodes in the network and forwarding is done by comparing x-y coordinates of the node itself, the source and the destination.

REFERENCES


