International Journal of Computer Engineering Science (IJCES)
Volume 2 Issue 3 (March 2012) ISSN : 2250:3439
https://sites.google.com/site/ijcesjournal/ http://www.ijces.com/

QoS Routing for Heterogeneous Mobile Ad Hoc Networks

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ABSTRACT. Ad hoc networks which have seen drastic increase in their usage scenarios and convergence of different applications. Efficient routing is very important for mobile ad hoc networks. Existing protocols for ad hoc networks provide little support for QoS and security. In many ad hoc networks, multiple types of nodes do coexist; and some nodes have larger transmission power, higher transmission data rate, better processing capability and are more robust against bit errors and congestion than other nodes. Hence, a heterogeneous network model is more realistic and provides many advantages

We present a new routing protocol called QoS routing, which is specifically designed for heterogeneous Mobile Ad Hoc Networks. QoS routing utilizes the more powerful nodes as backbone nodes (B nodes). The routing area is divided into several small, equal-sized cells. One B-node is maintained in each cell, and the routing among B-node is very efficient and simply based on location information and cell structure. A source discovers a route to destination in an on-demand way, and most of the routing activities are among B-nodes. This reduces the number of routing hops and makes the routing more efficient and reliable, since B-nodes have large bandwidth, transmission range, and are more reliable.

Keywords - cell*,* ad hoc networks, routing, Manet, Heterogeneous networks.

1. INTRODUCTION

An mobile ad hoc network is a collection of mobile nodes with wireless interfaces, which can dynamically form a multihop wireless network with no fixed infrastructure, dynamic topologies, variable capacity links, limited physical security, bandwidth-constrained and energy-constrained operation. Such networks have the ability to provide a quick and cheap communication link, hence they find useful applications in military battlefield networks, aircrafts, satellites etc. Routing in *ad hoc* networks has been extensively studied over the past few years [1]–[8], and many *ad hoc* routing protocols have been proposed. Most existing routing protocols assume homogeneous mobile *ad hoc* networks (MANETs), that is, all nodes in the network have the same characteristics, e.g., having the same transmission power (range), transmission data rate, processing capability, reliability, and security level. However, in many realistic *ad hoc* networks, nodes are actually heterogeneous [9]–[11]. For example, in a battlefield network, portable wireless devices are carried by soldiers, and more powerful and reliable communication devices are carried by vehicles, tanks, aircraft, and satellites; these devices/nodes have different communication characteristics in terms of transmission power, data rate, processing capability, reliability, etc

In this paper, we propose a new routing protocol called QoS routing, for heterogeneous MANETs. QoS routing achieves good performance by exploiting node heterogeneity in many MANETs
The rest of the paper is organized as below. Section II presents our QoS routing protocol. Section III concludes the paper.

2. QoS ROUTING PROTOCOL

The *ad hoc* networks are heterogeneous MANETs, where physically different node present. Thus it would be more realistic to model nodes in such networks as different types of nodes [11]. For simplicity, we consider there are only two types of nodes in the network. One type of node has larger transmission range (power) and data rate, better processing capability, and is more reliable and robust than the other type. We refer to the more powerful nodes as Backbone capable nodes (BC node). In QoS routing, BC-nodes can be elected as the backbone nodes (B-nodes). The less powerful nodes are referred to as general nodes (G-nodes). Usually, the transmission range of a B-node is much larger than that of a general node. The main idea of QoS routing is to let most routing traffic go through B-nodes.

A. TERMS

Cells - It refers to a collection of nodes, grouped for the functioning of QoS routing protocol. Each cell may be referred to by its B node.
Backbone node(B-node) - Every cell is characterized by a unique node called its B-node. It has certain extra responsibilities.
Bridge - *Bridge* is a node which belongs to more than one cell. It thus has more than one B-node.

General node(G-node) - All cell nodes other than bridges and master, are called *G-nodes*. Each *G-node* has only one B-node and hence belongs to only one cell.
State - A node's *state* describes whether the node is a G-node, bridge, B-node or *none* (*none* means the node is uninitialized, i.e. it does not belong to any cell).
Mapping - On detecting a link failure to B from A, A informs B-node of B or B-node of A depending upon its state. Bb (or Ba) may suggest a node C to A as a substitute for B. A will now forward all the traffic of the corresponding connection to C, which is called a *mapping*.

B. ALGORITHM

The overview of the algorithm is as follows:
1. Initially all the nodes in the network are put in state none. Then the whole ad hoc network is structured in the form of cells.
2. Once the initial cell structuring is done, then the cell management algorithm takes over. The cell management algorithm accomplishes the task of maintaining the clusters using periodic transmission of HELLO packets.
3. Whenever a G-node S wants to establish a connection to a node D, S sends a ROUTE REQUEST packet to its B-node Bs specifying the destination and parameter values for the *QoS specification*. Bs then broadcasts the packet to its bridges.
4. All the bridges of Bs further broadcast the packet and the packet is received by all of their B-nodes, which further broadcast to their bridges. This process continues till a B-node of D hears the request, which adds the destination's address in the *Addr List* of a ROUTE REPLY packet and sends it to the node from which it heard the ROUTE REQUEST.
5. Each of the nodes which receive the ROUTE REPLY packet, sends it to the node from which it heard the ROUTE REQUEST after checking the QoS constraints and adding in the *Addr List*, its own address.
6. When S receives the ROUTE REPLY, it simply uses the path specified in *Addr List* to route its data packets.

C. CELL STRUCTURE

The routing area is divided into cells. Denote a the side length of a cell and denote R the transmission range of a B-node. If $a = R/2\sqrt{2}$, where R is twice as much as the diagonal of a cell, then a B-node can communicate directly with the B-node in any nearby cell. In our cell structure, one (and only one) B-node is elected and maintained in each cell if there are more than one backbone capable (BC-nodes) available in the cell. In Qos routing, we assume the routing area is fixed, i.e., the nodes move around in a fixed territory. This is true for many MANETs (e.g., military battlefield networks, disaster relief networks, networks in convention centers). Since the routing area is fixed, the position of each cell is also fixed. Given the location (coordinates) of a node, there is a predefined mapping between the node location and the cell, in which the node is located. To obtain this mapping, each node only needs to know the side length of a cell and the coordinates of a reference point, which serves as the origin of the entire routing area.

D. B-NODE ELECTION

Given a cell structure as described above, a B-node needs to be selected in a cell before the QoS routing takes place. Initially, one B-node is elected in a cell if there are BC-nodes available in the cell. Since a B-node may move out of its current cell, a re-election algorithm is needed to elect a new B-node to replace the leaving B-node. The re-election algorithm could be triggered by a leaving B-node or a G-node that notices there is no B-node in the cell due to failure of a B-node.

The re-election algorithm works as follows. The leaving B-node or the G-node floods an election message to all the nodes in the cell. When a BC-node receives the election message, it broadcasts a claim message that claims it will become the B-node of the cell. Due to propagation delay, multiple BC-nodes may broadcast within a time period of not more than the propagation delay. To reduce such concurrent broadcasts, we use a random timer; i.e., each BC-node defers broadcasting its claim by a random time set by the timer. If a BC-node hears a claim message during this random time, it gives up its broadcast. Then one of the BC-node T becomes the new B-node in the cell, and T will start using the second address, which is the same as the cell id. Since all nodes in the cell can hear the claim message, they know that T is the new B-node. This idea is similar to the random competition-based clustering (RCC) scheme in [4]. Note that those BC-nodes that do not act as B-node should act as G-nodes, e.g., using transmission range of r rather than R.

The initial election of a B-node is similar to part of the above re-election algorithm (i.e., initially, each BC-node broadcasts a claim message with a random delay, and one of the BC-node becomes the B-node). Once a B-node is elected in each cell, we can run the QoS routing protocol.

E. ROUTE DISCOVERY

Whenever a source S wants to transmit data to destination D and does not have a cached route to D, it initiates the route discovery process by sending a ROUTE REQUEST packet. If S is a G-node, then it unicasts the ROUTE REQUEST packet to its B-node. If S is a bridge or a B-node or a none, then it broadcasts the ROUTE REQUEST packet directly. Every node which receives the ROUTE REQUEST packet acts, based on its state, in the following manner:

1. Every G-node or none node discards the packet.
2. Every bridge *checks* if the packet is from its B-node and it has not recently heard that request and *TTL*(Time to live) field has not expired and it can provide the required QoS:
   (a) Store the *previous hop* of the ROUTE REQUEST and QoS *specification* and broadcast the ROUTE REQUEST packet (after decreasing *TTL* field).
3. Every B-node *checks* if the packet is from its own G-node or bridge and it has not recently heard that request and *TTL* has not expired:
   (a) If D is in its cell, then, it sends a ROUTE REPLY to the *previous hop* of ROUTE REQUEST, after adding D's address in the *Addr List* of the ROUTE REPLY packet.
   (b) Else, it broadcasts the packet after decreasing *TTL* field and storing the *previous hop* of ROUTE REQUEST.

After transmitting the request, S waits for REPLY WAIT TIME seconds. If it does not receive the reply within that period, then it may chose to re-transmit ROUTE REQUEST or to inform the upper QoS layer about the network's inability to provide the required QoS, which may then suggest lesser QoS levels.

F. ROUTE ESTABLISHMENT

A route is said to be established whenever the source S becomes aware of the path that its data packets need to take in order to reach the destination D. This will be accomplished once the B-node of D i.e. Bd hears the ROUTE REQUEST packet in the route discovery process. On hearing the ROUTE REQUEST, Bd unicasts a ROUTE REPLY packet to the *previous hop* of ROUTE REQUEST packet after adding D's address in the *Addr List* of ROUTE REPLY packet. Now every node which receives the ROUTE REPLY packet acts based on its state, in the following manner:

1. Every none node discards the packet.
2. Every G-node *checks* if the ROUTE REPLY is from its master and it is 'S' (i.e. source of connection):
   (a) then, it caches the *Addr List* of the ROUTE REPLY packet.Then it dequeues all the packets destined for D and places the route in their packet header and puts them on air. (All the data packets get routed by source routing at the intermediate nodes).
3. Every bridge *checks* if the ROUTE REPLY is from its master:
   (a) If it is not 'S', then, it forwards the ROUTE REPLY packet to the *previous hop* of the ROUTE REQUEST after adding its own address in the *Addr List*, provided that it satisfies the QoS requirements.
   (b) Else, it caches the *Addr List* and dequeues all the packets destined for D and puts them on air with the route specified in their header.
4. Every B-node *checks* if the ROUTE REPLY is from its bridge:
   (a) If it is not 'S', then, it forwards the ROUTE REPLY packet to the *previous hop* of the ROUTE REQUEST after adding the address of its G-node, which satisfies the *QoS requirements* in the *Addr List* (provided that it finds such a G-node, otherwise it drops the packet).
   (b) Else, it caches the *Addr List* and dequeues all the packets destined for D and puts them on air.

G. ROUTE MAINTENANCE

The route maintenance process helps in correcting a failed route through some local modification in the route. Usually, a route failure in an ad hoc network is caused by the movement of an intermediate node. Hence a route is broken only due to a change in a small fraction of the whole route. Unlike other protocols like AODV[13] and DSR[12] in which the source is informed of the failure and it may have to redo the route discovery, QoS protocol tries to minimize QoS re-establishment delay by a local perturbation. The process is initiated whenever the lower layers like 802.11 report a link failure to QoS protocol. On detecting a link failure on a packet 'p',the node acts based on its state, in the following manner:

1. Every none node *checks* if 'p' is a data packet: (a) Send a ROUTE ERROR packet to the source of 'p'.
2. Every G-node executes the following sequence: (a) If the link to its B-node has failed, then mark self as none. (b) Else, if 'p' is a data packet, then enqueue 'p' and send a FAILURE packet to the B-node.
3. Every bridge executes the following sequence: (a) If the link to its B-node has failed, then, remove the B-node from the stored list.

(b) Else, if 'p' is a data packet, then enqueue 'p' and send a FAILURE packet to the B-node of the next hop in the route. (The B-node of the next hop in the route can be known from the route specified in the data packet. While forwarding the ROUTE REPLY, a B-node in addition to specifying the G-node address also mentions its own address in the *Addr List*).

4. Every B-node executes the following sequence: (a) If the link to its G-node or bridge has failed, then remove the node from the list.

(b) If 'p' is a data packet,and if it is successful in finding a substitute B for the node A whose link has failed, then store B as a *mapping* for A and forward all data packets to B, for this connection.

Else, send a ROUTE ERROR packet back to the source. On receipt of a FAILURE packet, B-node tries to find out a substitute for the node whose link has failed and informs the node N which sent the FAILURE packet, using a FAILURE REPLY packet. N stores this new *mapping*, and forwards all packets directed to the earlier node to this *mapping*. If B-node is unable to find a substitute, it advises N to send a ROUTE ERROR packet back to the source.

3. Conclusion

QoS Protocol, which is a cell based routing protocol provides an excellent platform for implementation of QoS and Security in heterogeneous ad hoc networks. In our QoS routing protocol, a route is established with the involvement of intermediate cells (instead of involvement of just the nodes as in AODV, DSR etc.), so QoS can be ensured. Since in the QoS routing algorithm interactions are at the cell level, things like substitution for node which has moved, providing QoS guarantees on the basis of G-nodes' resources etc. are possible. It is non-trivial to implement QoS in AODV or DSR where all the interactions are at the mobile nodes' level. Cell structuring in the worst case, uses periodic transmission of HELLO packets which is also present in AODV. Even without the availability of QoS information, QoS routing protocol performs comparable to the existing protocols. Existing ad hoc routing protocols have been observed to suffer from problems like large route recovery delays, considerable routing overhead and, overloading on computational and memory resources of the nodes. Certain key advantages of QoS routing protocol over existing protocols, can be summarized as:

- Lesser load on nodes, as they are not expected to maintain any tables or to perform any complex routing logic.
- Support for QoS and security, by making effective use of cells.
- Considerably lesser routing overhead than existing protocols, as it avoids flooding of ROUTE REQUEST packets by using cells.
- Ability to minimize route recovery delay, by localized route correction.

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