Enhancement in QoS to AODV protocol for MANETS

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Abstract—A mobile ad hoc network (MANET) is a collection of mobile nodes where each node is free to move about arbitrarily. The Ad Hoc On-Demand Distance Vector (AODV) routing protocol is one of the well-known and efficient on-demand MANET protocols. AODV currently does not support Quality of Service (QoS) and has no load balancing mechanism. We propose some enhancements to the AODV protocol to provide QoS and load balancing features by adding two extensions to the messages used during route discovery. A detailed packet-layer simulation model with media access control (MAC) and physical layer models is used to study the performance of both the AODV and the QoS-AODV protocols. Important performance measures such as average delay, packet delivery fraction and normalized routing load are used in the comparison. Simulation results are presented for networks with 50 mobile nodes with different network loads, delay constraints, topological rate of change and mobility speeds.

Keywords—Ad Hoc Networks, MANET, AODV, QoS, load balancing, routing protocols.

I Introduction

Mobile ad hoc network (MANET) is a collection of mobile nodes where each node is free to move about arbitrarily. Each node logically consists of a router that may have multiple hosts and that may have multiple wireless communication devices. A MANET is self-organizing, adaptive and infrastructureless; this means that a formed network can be deformed on-the-fly without the need for any system administration.

The Ad Hoc On-Demand Distance Vector (AODV) routing protocol is one of the well-known and efficient on-demand MANET protocols. AODV currently does not support Quality of Service (QoS) and has no load balancing mechanism. The QoS routing feature is important in a stand-alone multihop mobile network for real-time applications and also for a mobile network to interconnect wired networks with QoS support. The load balancing mechanism enables the protocol to choose routes in such a way that the data traffic can be more evenly distributed in the network. In this paper, we propose some enhancements to the AODV protocol to provide QoS and load balancing features by adding two extensions to the messages used during route discovery. The first extension (named QoS field) specifies the service requirements (maximum delay is chosen), which must be met by nodes rebroadcasting a Route Request or returning a Route Reply for a destination. The second extension (named Cost field) is used to determine the cumulative network load for a certain route in order to achieve load balancing.

The paper is organized as follows. In the following section, we briefly review the AODV protocol. In Section III, we present a detailed explanation of the enhancements and extensions added to the protocol. Section IV describes the simulation environment. Section V presents the simulation results followed by their interpretations. Finally, we draw our conclusions in Section VI.

II Description of AODV protocol

AODV [6][7][8] is an on-demand MANET protocol. It discovers routes on an “as needed” basis. It uses traditional routing tables, one entry per destination. Route Request (RREQ), Route Replies (RREP), and Route Error (RERR) are the message types defined by AODV. These message types are received via User Datagram Protocol (UDP), and normal IP header processing applies. So the requesting node is expected to use its IP address as the Originator IP address for the messages. AODV uses sequence numbers maintained at each destination to determine freshness of routing information and to prevent routing loops.

III Enhancements to the AODV protocol

A. Overview

To provide QoS and load balancing features we add two extensions and a QoS flag (one bit of the reserved bits is used) to the RREQ and RREP messages. The length of each extension is 16 bits. Also each entry in the routing table is extended to include some additional fields and flags: Maximum Delay field, Available Delay field, Cost field, Required QoS flag, and valid QoS flag. The first extension (named QoS or Delay field) specifies the service requirements (maximum delay) which must be met by nodes rebroadcasting a RREQ or returning a RREP for a destination. The second extension (named Cost field) is used to determine the cumulative network load for a certain route in order to achieve load balancing.

In case of having multiple routes, the originator of a RREQ will choose the route with the minimum cost (but satisfying QoS requirements if any) to enable load balancing. This load balancing mechanism will allow the nodes to transmit data through routes with relatively lower network load.
B. Route Table Entries and Precursor Lists
The QoS requirement (maximum delay) is maintained for each valid route. A Required QoS flag is set for a route, if this route is used (at least once) with QoS requirements. The Maximum Delay field contains the delay required and the Delay Available field contains the actual delay available. The valid QoS flag is set to 1 only if the delay available is less than or equal the maximum delay required, and is set to zero otherwise.

C. Generating Route Requests
A node disseminates a RREQ when it determines that it needs a route to a destination and does not have one available. This can happen if the destination is previously unknown to the node, or if a previously valid route to the destination expires or is marked as invalid, or if a valid route to the destination exists, but with lower QoS requirements than those needed. Processing and Forwarding Route Requests
To control dissemination of RREQ with QoS requirements the following enhancements are added to the procedure used for controlling dissemination of RREQ (without QoS requirements):
1. If the NODE_TRAVERSAL_TIME is GREATER than the (remaining) delay in Delay field the intermediate node MUST drop the RREQ.
2. If the NODE_TRAVERSAL_TIME is LESS than the (remaining) delay in Delay field, the node MUST update the value of Delay field in the RREQ message by subtracting from its value the NODE_TRAVERSAL_TIME, and then
   i. If there is a route to the destination in the routing table with delay LESS than the (remaining) delay in Delay field, the intermediate node MUST send a RREP to the originator with the QoS flag set to 1.
   ii. If there is a route to the destination in the routing table with delay GREATER than the (remaining) delay in Delay field but QoS flag in the RREQ is set to 0, the intermediate node SHOULD send a RREP to the originator with the QoS flag set to 0 and MUST continue broadcasting the RREQ.
   iii. If there is a route to the destination in the routing table with delay GREATER than the (remaining) delay in Delay field AND QoS flag in the RREQ is set to 1, OR there is NO route to the destination in the routing table, the intermediate node MUST continue broadcasting the RREQ.

D. Generating Route Replies
When the destination originates a RREP in response to RREQ with QoS requirements, Delay field in the RREP is initially zero. Each intermediate node forwarding the RREP adds its own NODE_TRAVERSAL_TIME to the Delay field and then records this delay value in the route table entry for that destination before propagating the RREP. This enables the intermediate nodes to reply to a later RREQ by just comparing the Delay field in the route table entry and the requested delay in Delay field in the RREQ.

E. Route Error Messages
A node initiates processing for a RERR message in four situations:
i. if it detects a link break for the next hop of an active route in its routing table while transmitting data, or
ii. if it gets a data packet destined to a node for which it does not have an active route, or
iii. if it receives a RERR from a neighbor for one or more active routes, or
iv. if there is a change in its own NODE_TRAVERSAL_TIME affecting a route with QoS requirements.

IV. Simulation Model
A. Network Simulator
We used ns-2 [24], in order to evaluate the performance of the enhanced QoS-AODV routing protocol with respect to the original AODV protocol. Ns-2 has additional features allowing to simulate multi-hop ad-hoc networks, wireless LANs. The wireless model of ns-2 consists of a mobile node at the core. A mobile node has the ability to move within a given topology, ability to transmit and receive signals to and from a wireless channel.

B. Physical and Data Link Layer Model
Propagation models are used to determine if the data transmitted through the air has been successfully received. These models consider propagation delays, carrier sensing, and capture effects. Following this practice, ns-2 signal propagation model combines both a free space propagation model and a two-ray ground reflection model.

C. MAC 802.11 Implementation
IEEE 802.11 MAC is implemented within ns-2. MAC layer handles collision detection, fragmentation and acknowledgements. The protocol may also be used to detect transmission errors. 802.11 is a CSMA/CA protocol, it avoids collisions by checking the channel before using it. If the channel is free, it can start sending, if it is not, it waits a random amount of time before re-sending. For each retry, exponential backoff algorithm is used. In a wireless medium, it cannot be assumed that all stations hear each other. If a station seizes the medium as available, it may not necessarily be so.

D. Address Resolution
Since the routing protocols all operate at the network layer using IP addresses, an implementation of Address Resolution Protocol (ARP) is used to resolve IP addresses to link layer addresses.

E. Packet Buffering
Each node has an interface queue (IFQ) for packets (both data and routing packets) awaiting transmission by the network interface that holds up to 64 packets and is
managed in a drop-tail fashion. The interface queue buffers all data packets waiting for a route, e.g., packets for which route discovery has started, but no reply has arrived yet. Routing packets and data packets with QoS requirements are given higher priority than data packets without QoS requirements in the interface queue.

F. Confidence Interval
We ran different simulations for both protocols (AODV and QoS-AODV) using the same load, but with different simulation times in order to choose the best simulation time. Results are compared for simulation times 400, 600, 800, 1000 and 1200 seconds. There was a large difference for about 20-25% between simulation times 400 seconds and 600 seconds, and also between simulation times 600 and 800 seconds. Most of the results tend to be approximately the same (change in results 3-5%) for simulation times 800, 1000 and 1200 seconds.

Therefore, the efficient simulation time for the work is 800 seconds. Taking a safety margin about 10%, we chose the simulation time to be 900 seconds.

G. Movement Model
Our protocol evaluations are based on the simulation of 50 wireless nodes forming an ad hoc network, moving about over a rectangular (1500m × 300m) flat space for 900 seconds of simulated time. Each run of the simulator accepts as input a scenario file that describes the exact motion of each node and the exact sequence of packets originated by each node, together with the exact time at which each change in motion or packet origination is to occur. Upon reaching the destination, the node pauses again for pause time seconds, selects another destination, and proceeds there as previously described, repeating this behavior for the duration of the simulation. The simulation runs are with movement patterns generated for 7 different pause times: 0, 30, 60, 120, 300, 600, and 900 seconds. A pause time of 0 seconds corresponds to continuous motion, and a pause time of 900 (the length of the simulation) corresponds to no motion.

H. Communication Model
As the goal of our simulation is to compare the performance of the two routing protocols, with and without the QoS enhancement, we chose our traffic sources to be CBR sources. When defining the parameters of the communication model we chose the sending rate to be 4 packets per second with packet size of 1024 bytes with three different communication patterns corresponding to 10, 20, and 30 sources. We did not use TCP sources because TCP offers a conforming load to the network, meaning that it changes the times at which it sends packets based on its perception of the network’s ability to carry packets. As a result, both the time at which each data packet is originated by its sender and the position of the node when sending the packet would differ between the protocols, preventing a direct comparison between the two protocols.

I. Defaults for Evaluated Protocols
Our simulations had run according to the AODV protocol specific factors given in [7].

J. Performance metrics
The performance measure, which is used for evaluating the performance of the routing protocols, are listed below.

Average end-to-end Delay, in milliseconds: This is the average end-to-end delay of talking parties in the simulation and it includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, propagation and transfer times.

\[
D = \frac{1}{S} \sum \frac{r_i - s_i}{T_f}
\]

\(D\): Average end-to-end delay
\(S\): Number of successfully received packets.
\(r_i\): Time at which a packet with unique identifier \(i\) is received.
\(s_i\): Time at which a packet with unique identifier \(i\) requests a route to be send.

Packet Delivery Fraction, in percentage: The fraction of successfully received packets, which survive while finding their destination. This performance measure also determines the completeness and correctness of the routing protocol. Successful packet delivery is calculated such that, all data packets with unique identifier leaving the source MAC are counted and defined as originating packets. Received packet identifiers are compared to collected transmission data and each unique packet is counted once to ensure prevention of counting excess receptions, which are mainly caused by multiple paths as a result of mobility. The result is the average of the ratio of uniquely received and all uniquely transmitted packets as seen in the following equation.

\[
F = \frac{1}{C} \sum \frac{R_f}{T_f}
\]

\(F\) : Fraction of successfully delivered packets.
\(C\) : Total number of flows, connection.
\(f\) : Unique flow id.
\(R_f\) : Count of unique packets received from flow \(f\)
\(T_f\) : Count of packets transmitted to flow \(f\)

Normalized Routing Load: During the route discovery or any other routing related control information flow, a protocol uses the available bandwidth. Control packets may not be consuming a large amount of bandwidth, but they may interfere with the transmissions. Frequent control packet transmissions increase collisions in the medium and affect the protocol performance. The normalized routing load is the number of routing packets
“transmitted” per data packet “delivered” at the destination. 

\[ N = \frac{1}{S} \sum_{i=1}^{S} H_i \]

- \( N \): Normalized Routing Load
- \( S \): Number of successfully received packets.
- \( i \): Unique packet identifier.
- \( H_i \): Total number of hops of the routing packets corresponding to data packet \( i \).

The first two metrics are the most important metrics for best effort traffic.

![Figure 1: Average data packet delays versus pause time with various numbers of sources](image1)

![Figure 2: Packet delivery fraction versus pause time with various numbers of sources](image2)

V. Simulation Results

We performed two different types of simulations on both AODV and QoS-AODV protocols. In the first group of simulations, we studied the effect of changing the topology (mobility rate). In the second group of simulations, we studied the effect of mobility.

For both group of simulation we increased the number of communication links opened, therefore more number of hosts are involved in the routing process. As mentioned before, three levels of workload are defined, namely 10, 20 and 30 sources. The new protocol is introduced with and without QoS delay constraints. Delay constraints were chosen to be 0.1, 0.2 and 0.3 seconds. The AODV is also simulated to be compared with the new protocol.

A. Mobility Rate Details

The mobility rate is measured using the concept of pause time. We varied the pause time from 0 to 900 seconds and studied its effect on the performance of the routing protocols. The average node speed in this group of simulations is chosen to be 10 m/s (randomly distributed between 0-20 m/s). Simulation results show that QoS-AODV protocol (with no delay constraints) outperforms the AODV protocol when having high network load (30 sources), where the cost extension (load balancing mechanism) has a significant effect. Otherwise, for 10 and 20 sources the QoS-AODV protocol has approximately the same performance as the AODV protocol. Using delay constraints the QoS-AODV protocol has always better delay than AODV because the
The new protocol forces the network to satisfy certain delay constraints, so the delay achieved is always less than or equal the delay required.

The mobility rate has a great effect on the performance. The performance is always getting better (lower average delay, higher packet delivery fraction and lower normalized routing load) as the mobility rate decreases. Comparing low mobility rate (pause time 900 seconds) and high mobility rate (pause time 0 seconds) the performance is almost decreased to the half by high mobility rate. There are slightly some exceptions to this trend in some points in the figures due to the randomization process. Also another large difference, occurs in Figure 1(c). The average delay always increases as the mobility rate increases, for 10 sources (low network load), the delay achieved is much better than that required (see Figure 1(a)) even for high delay constraints (low delay bound 0.1 seconds). On the average the delay achieved is half that required. Also, the AODV protocol has good delay performance for low number of sources, but this satisfies only high delay bound 0.3 seconds, but cannot satisfy lower delay bounds (0.1 and 0.2 seconds).

Increasing the number of sources (network load) to 20 sources (Figure 1(b)) lead to a higher delay for both protocols. The delay achieved is still better than required for the new protocol with different delay bounds, but the ratio between the required and the achieved delay increases to 3/4. For 30 sources the delay highly increases for both protocols, so we need to use a higher scale for the delay in Figure 1(c) compared to Figures 1(a),(b). The AODV protocol has very high delay (Figure 1(c)), on the other side the delay for the QoS-AODV protocol is also increased, but has a much better delay (on the average 40% less) than the AODV protocol. The delay requirements for the QoS-AODV protocol with delay constraints are just achieved. The average delay for 0.1 and 0.2 seconds is exactly 0.1 seconds and 0.2 seconds respectively. That for 0.3 seconds is on the average just 5% below 0.3 seconds. One interesting observation, in Figure 1(c), is that the delay of the AODV protocol increases by low mobility rate. This is due to a high level of network congestion and multiple access interfaces at certain regions of the ad hoc network. The AODV protocol has no mechanism for load balancing.
hence the data traffic are not evenly distributed in the network. This phenomenon is less visible with higher mobility where traffic automatically is more evenly distributed due to source movements.

A similar phenomenon was also observed in [16] and [19]. The new protocol overcomes this problem by the cost extension, this extension allows the protocol to choose routes in such a way that load balancing is achieved.

The packet delivery fraction are very similar for both QoS-AODV protocol and AODV protocol without delay constraints and with high delay bounds (0.3 seconds) for 10 and 20 sources (Figure 2(a),(b)). The packet delivery fraction is less for lower delay bounds, but almost more than 80%. For 30 sources, both protocols lose a high percentage of the packet delivery fraction. AODV packet delivery fraction drops to 80%, which is lower than that for 10 and 20 sources by 10-15%. The QoS-AODV protocol has better packet delivery fraction, where it drops only to 85%. The QoS-AODV protocol with delay constraints has low performance at this point by having a low packet delivery fraction (50-70% for 0.1 seconds delay bound). This is due to the lack of routing paths satisfying the required delay bound especially at high mobility rate and low delay bound, so in this way more packets are being dropped because the routes available for them do not satisfy the QoS requirements.

B. Mobility Speed Details

In the second group of simulation, we varied the speed of the nodes and studied its effect on the performance
seconds, which is chosen to be between high mobility rate (pause time 0 seconds) and no mobility (pause time 900 seconds). Also in this part of simulation the QoS-AODV protocol (with no delay constraints) outperforms the AODV protocol at high network load (30 sources) by having higher packet delivery fraction, and otherwise, for low number of sources has almost the same performance. Using delay constraints, the QoS-AODV protocol always satisfies the constraints and has better delay than AODV.

The average delay for both protocols with no constraints are almost the same (Figure 4) with QoS-AODV slightly better at high network load. The packet delivery fractions for 10 sources (Figure 5) are very similar for both AODV protocol and QoS-AODV protocol without delay constraints. The packet delivery fraction is less for lower delay bounds. For high delay bounds (0.1 and 0.2 seconds), the packet delivery fraction drops to 85% at high mobility. For 20 sources, both protocols lose a low percentage of the packet delivery fraction; it drops on the average to 90% for both protocols. The normalized routing load (Figure 6) increases as the mobility increases. This is because high mobility leads to more link failures and increases the need for new route discovery processes and so increasing the normalized routing load. As the number of sources increases the normalized routing load also increases, for 30 sources the normalized load is increased by 80% more than that for 10 sources.

VI. Conclusions

The new proposed protocol is tested using different delay bounds to achieve QoS requirements. This is a good enhancement to the AODV protocol by adding two features: QoS and load balancing. The protocol can be used to achieve QoS requirements in mobile ad hoc networks with large number of sources.

References


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