A Cross-Layer Based Multipath Routing Protocol To Improve QoS In Mobile Adhoc Networks

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Abstract

In Mobile ad hoc networks, due to the high packet loss rates and frequent topological changes, the unbalanced transport layer and reserved amount of traffic is carried out by the network. In a QoS based routing metric for MANETs, it is necessary to combine the minimum available bandwidth and end-to-end delay along with the congestion around a link. In this paper, a cross layer based multipath routing (CBMR) protocol to improve QoS in mobile ad hoc networks to allot weights to individual links, depending on the metrics link quality, channel quality and end-to-end delay is developed. In order to validate load balancing and interference between the links using the same channel, the individual link weights are integrated into a routing metric. Therefore, the weight value helps the routing protocol to avoid the routing traffic through the congested area hence the traffic is balanced and the network capacity is improved. Then the proportion of traffic to be routed to each neighbor is selected to execute routing such that the weight of the node is a minimum. We also propose an enhanced TCP congestion control mechanism for wireless networks, based on a cross-layer scheme. By our simulation results, the robustness of our protocol achieves increased packet delivery ratio with reduced latency was demonstrated.

Index Terms: CBMR, QoS, Congestion, MANET

I. Introduction

A. Quality of Service (QoS) in MANET

Ad hoc wireless network is a special case of wireless network which consists of backbone infrastructure which is determined before. This can be made flexible and organized quickly by using the features of the wireless ad hoc networks. However, using this property important technological challenges are also created. There are many challenges including the issues of efficient routing, medium access, power management, security and quality of service (QoS). When the nodes communicate over wireless links then all the nodes should fight against the unpredictable character of the wireless channels and intrusion from the additional transmitting nodes. Even if the user-required QoS in wireless ad hoc networks is attained, these factors make it as a challenging problem to use on the data throughput.

Due to the mobility of the nodes, repeated route changes cause difficulty in implementing ad hoc networks. Due to the high packet loss rates and regular topological changes, the transport layer is not balanced and the inhibited amount of traffic is carried out by the network. The three famous problems in ad hoc networks are: due to the intrusion and movement of nodes, the reliability of the packet delivery is not sufficient, incomplete bandwidth due to channel limitations and the inhibited node life span caused as an outcome of small battery size.

B. Problems of Adhoc Routing Protocols

(i) An excellent scalable QoS architecture is required for the huge dimension of ad hoc networks. An ad hoc network may not want to (or be able) to limit the number of hosts concerned in the network. The potential for the collisions and contention increases when several nodes join as ad hoc network or the data traffic increases and due to this the protocols face the challenging task to route data packets and results in scalability. The scalability problems have been considered in the QoS in ad hoc networks in the previous works.

(ii) By the Network Interface Queues (IFQ) which are implemented by AODV [1], TORA [2] and DSR [3], the packets which are ready to be transmitted are buffered. These packets are received by the network protocol stack. Generally, the maximum numbers of packets which are present in the IFQ are limited. In addition to this, a maximum timeout policy for packets in the IFQ is implemented by the IFQ. Therefore any packet in expectation of a route in the IFQ for a huge period may be discarded without any notification [4]. Hou and Tipper [5]
have stated that the edge over of the IFQ of congested nodes is one of the key motives for the rejection in throughput for congested networks running DSR.

(iii) The existing routing protocols faced a problem, called the communication Gray Zone problem, which is a major challenge [4]. Based on the control (RREQ) packets, the detection and establishments of end to end routes are carried out in most of the routing protocols like AODV. However, these control packets and data packets have different properties. For example, when RREQ packets are compared with the data packets, it shows that RREQ packets are smaller and are transmitted at lower bit rates. The bidirectional RREQ packets can be transmitted or received by the nodes which are at the distance. On the other hand, as a result of the above mentioned property, the high bit-rate data packets cannot be sent or received. Due to the resultant “fragile” link which triggers link repairs, high control overhead for protocols like AODV is obtained.

(iv) The essential element of any QoS-enabled routing protocol is the end-to-end delay estimation. In order to calculate the end-to-end delay, the existing protocols establish the time taken to route RREQ and RREP packets along the specified path. However, RREQ and RREP packets are impossible to meet the similar levels of traffic delay and loss like data packets which are considerably different from usual packets.

In order to monitor the movement of the node and that a route is about to break, the communication is based on the received power of the forwarding node. Therefore, the quality of the route is measured. Based on the measured quality of the route, the link breakage can be assumed. A smaller end-to-end delay and a larger throughput to a host can be obtained by using a proactive fault tolerant routing with QoS aware multipath route discovery.

In this paper, a cross layer based multipath routing (CBMR) protocol to improve QOS in mobile ad hoc networks intended for mobile ad hoc networks has been developed. In this paper, the facility to determine multiple routes to a host and switch between them to expand the definition of AOMDV [6] has been employed. Enabling a QoS constrained route from source to destination is one of the objectives of the routing protocol. The route chosen by the protocol must send packets with minimum bandwidth and end-to-end latency, in particular. The protocol should satisfy the above constraints and also select the most robust among all possible candidate routes. Different from wired networks, TCP over wireless networks needs to be cross-layer designed which depends on information of MAC. However, it is difficult to apply existing cross-layer design into hybrid networks. In this paper, we have also proposed an enhanced TCP congestion control mechanism for wireless networks, based on a cross-layer scheme.

The remainder of the paper is organized as follows. In Section II some of the existing work in this area is reviewed. The system design and overview are presented in the Section III. Section IV presents the details of estimating the QoS based routing metrics. Section V describes our proposed QoS based robust multipath routing protocol in detail. The experimental results are presented in Section VI.

II. RELATED WORK

Andre Schumacher, et. al. (2006), have approached the problem of load balancing for wireless multihop networks by distributed optimization using an approximation algorithm for minimizing the maximum network congestion and implement it as a modification of the DSR routing protocol. The algorithm was based on shortest-path computations that are integrated into the DSR route discovery and maintenance process. Therefore, it does not rely on the dissemination of global information within the entire network [7]. Kaixin Xu, et. al., (2003) have proposed a Scalable QoS architecture suitable for large scale mobile ad hoc networks with the help of the scalable LANMAR routing protocol. They have also introduced the mobile backbone network structure to enhance the network performance [8]. Jianbo Xue, et. al., (2003) have proposed a QoS framework for MANETs Adaptive Reservation and Pre-allocation Protocol (ASAP). By using two signaling messages, ASAP provides fast and efficient QoS support while maintaining adaptation flexibility and minimizing wasted reservations [9].

Jangeun Jun and Mihail L. Sichitiu, (2003) have exposed a significant fairness problem existent practically in all wireless multihop networks. They showed that a network layer solution can restore fairness at the expense of bandwidth efficiency[10]. Michael Gerharz, et. al., (2003) have have outlined that it is a very complex task to reserve or even measure available bandwidth in wireless multihop networks. They have introduced and evaluated the DLite algorithm, an approach to service differentiation in ad hoc networks. It applies a fair queuing scheme with separate queues for each service class. Late packets of delay constrained classes were dropped in intermediate routers. [11].

Duc A. Tran and Harish Raghavendra, (2006) have proposed CRP [12], a congestion-adaptive routing protocol for MANETs. CRP tried to prevent congestion from occurring in the first place, rather than dealing with it reactivity. Xiaolin Chen et al.,(2007) [13] have proposed a congestion- aware routing protocol for mobile ad hoc networks which uses a metric incorporating data-rate, MAC overhead, and buffer delay to combat congestion.
Ming Yu et al.,(2007) [14] have proposed a link availability-based QoS-aware (LABQ) routing protocol for mobile ad hoc networks based on mobility prediction and link quality measurement, in addition to energy consumption estimate..Hongxia Sun et al [15], proposed an adaptive QoS routing scheme which is supported by cross-layer cooperation in ad hoc networks. By considering the influence of node mobility and lower-layer link performance, the cross-layer mechanism provides up-to-date local QoS information for the adaptive routing algorithm. Based on the current network status, the multiple QoS requirements are satisfied by adaptively using forward error correction and multipath routing mechanisms. Al-khwildi et al [16], have proposed a novel routing technique called Adaptive Link-Weight (ALW) routing protocol which selects an optimum route on the basis of available bandwidth, low delay and long route lifetime. Those technique adapts a cross-layer framework where the ALW is included with application and physical layer.

III. SYSTEM DESIGN AND PROTOCOL OVERVIEW

We devise the model by considering a mobile ad hoc network in which each node utilizes IEEE 802.11 DCF for medium access control (MAC). At the application layer, intra-flow interference occurs for the same flow which is transmitted on different wireless links. But it has been presumed as a single data flow. A QOS based multipath routing protocol intended for mobile ad hoc networks is put forwarded. In this paper, we employed the facility to determine multiple routes to a host and switch between them to expand the definition of AOMDV [6].Enabling a QoS constrained route from source to destination is the objective of the routing protocol. The route chosen by the protocol must send packets with minimum bandwidth and end-to-end latency, without facing congestion. The protocol should satisfy the above constraints and also select the most robust among all possible candidate routes.

A QoS-based routing metric for MANETs should incorporate minimum available bandwidth and end-to-end latency along with congestion around a link. Congestion is related to channel quality, which depends on the MAC access contention and channel reliability. So our algorithm should rely on the following metrics to allocate weights to individual links.

- End-to-End Delay
- Channel Quality
- Link Quality

The individual link weights are combined into a routing metric to validate the load balancing and interference between links using the same channel. Consequently, the traffic is balanced and the network capacity is improved as the weight value assists the routing protocol to evade routing traffic through congested area. Subsequently, the selection of the proportion of traffic to be routed to each neighbor is made to perform routing such that the weight of the node is a possible minimum.

IV. ESTIMATING QOS-BASED ROUTING METRICS

A. Estimating Link Quality

Each node in the network estimates its quality of links with its one-hop neighbors. If Nq is the number of HELLO packets received during a time window Twin and Pq is the percentage of HELLO packets received in the last $r$ seconds, then the link quality $L_q$ is measured as

$$L_q = \delta \cdot P_q + (1 - \delta) \cdot N_q \quad (1)$$

The estimated link quality is maintained by each node in its NT. The average link quality of all the links across the path $P$, gives the route quality $R_q$ of the path. RREQ packets of the reverse path and RREP packets of the forward path accumulate the estimated $L_q$ values. The value $\delta$ is application specific.

B. Estimating End to End Delay

There is a significant variation between the end-to-end delay reported by RREQ-RREP measurements and the delay experienced by actual data packets. We address this issue by introducing a DUMMY-RREP phase during route discovery. The source saves the RREP packets it receives in a RREP TABLE and then acquires the RREP for a route from this table to send a stream of DUMMY data packets along the path traversed by this RREP. DUMMY packets efficiently imitate real data packets on a particular path owing to the same size, priority and data rate as real data packets. $H$ is the hop count reported by the RREP. The number of packets comprised in every stream is $2H$. The destination computes the average delay $D_{avg}$ of all DUMMY packets received, which is sent through a RREP to the source. The source selects this route and sends data packets only when the average delay reported by this RREP is inside the bound requested by the application. The source performs a linear back-off and sends the DUMMY stream on a different route selected from its RREP TABLE when the delay exceeds the required limit.

C. Estimating Channel Quality

The channel quality can be represented by both the channel occupancy and channel reliability.

C.1. Channel Occupation

In this network, we consider IEEE 802.11 MAC with the distributed coordination function (DCF). It has the packet sequence as request-to-send (RTS), clear-to-send (CTS), data and acknowledgement (ACK). The amount of time between the receipt of one packet and the transmission of
the next is called a short inter frame space (SIFS). Then the channel occupation due to MAC contention will be

\[ C_{occ} = t_{RTS} + t_{CTS} + 3t_{SIFS} + t_{acc} \]  

(2)

Where \( t_{RTS} \) and \( t_{CTS} \) are the time consumed on RTS and CTS, respectively and \( t_{SIFS} \) is the SIFS period. \( t_{acc} \) is the time taken due to access contention. The channel occupation is mainly dependent upon the medium access contention, and the number of packet collisions. That is, \( C_{occ} \) is strongly related to the congestion around a given node. \( C_{occ} \) can become relatively large if congestion is incurred and not controlled, and it can dramatically decrease the capacity of a congested link.

Therefore, in the design of a congestion-aware metric for networks, the access contention should be considered to more accurately indicate channel capacity.

C.2. Channel Reliability

The channel reliability also affects the packet transmission in MANETs and factors such as interference and fading in the channel may lead to occurrence of packet losses. In 802.11 DCF, several failed retransmissions lead to packets being dropped. In addition to performance deterioration due to congestion with respect to packet losses, higher packet retransmissions involved owing to augmented packet losses lead to more congestion. A successful transmission of a packet on an unreliable links would consume more time on MAC overhead.

V. CROSS-LAYER DESIGN OF TCP

Currently, the main method of congestion control over wired network is an optimization framework based on utility functions Moreover this method is not applicable to the wireless networks. This is because due to the immanent interference of wireless links the metrics like queue length on routers, sending rate of links cannot characterize the congestion price.

In this paper, according to the RTS retry counts, the ECN scheme will mark packets. IEEE 802.11 is the standard protocol for wireless adhoc networks. It provides two options for accessing namely the basic scheme and RTS/CTS scheme. In this paper only this RTS/CTS scheme is considered because it is used more in ad hoc networks than the basic scheme. But our design can also be applied to the basic scheme.

In RTS/CTS scheme, in order to record the retransmit count of RTS frame in the current node, each node maintains a variable SSRC. When a node fails to transmit RTS frame, then it will retransmit this RTS frame and increases SSRC by 1 at the same time. The sender will report a link failure notification to the network layer if the value of the SSRC reaches 7 and discards the RTS frame and the data frame to be transmitted together and resets SSRC to an initial value of 0. Also the node refreshes the SSRC with an initial value of 0, when it transmits the RTS frame successfully. By this way, when a node starts to transmit a new RTS frame, SSRC will be the initial value of 0, in spite of the initial RTS which was transmitted successfully or discarded. Obviously, the node would not know the RTS retry count of the last frame for its resetting which results that its channel state cannot be known.

To solve this problem, the value of SSRC is recorded when each RTS frame is retransmitted. The packet to be transmitted will be marked as “1” in its congestion experience bit when it exceeds the given the threshold “2”, which shows an imminent congestion in ECN mechanism.

VI. QOS BASED ROBUST MULTIPATH ROUTING PROTOCOL

For establishing multiple disjoint paths, we adapt the idea from the Adhoc On-Demand Multipath Distance Vector Routing (AOMDV) [6]. The multiple paths are computed during the route discovery.

We now introduce the weight metric \( W \) which assigns a cost to each link in the network. The weight \( W \) combines the link quality \( L_q \), channel quality \( C_{occ} \) and the average delay \( D_{avg} \) to select maximum throughput paths, avoiding the most congested links. For an intermediate node \( i \) with established transmission with several of its neighbours, the \( W \) for the link from node \( i \) to a particular neighboring node is given by

\[ W = L_q + C_{occ} + D_{avg} \]  

(3)

A. Route Request

During the route discovery phase of the protocol, each intermediate node uses an admission control scheme to check whether the flow can be accepted or not. If accepted, a Flow Table (FT) entry for that particular flow is created. The FT contains the fields Source (Src), Destination (Dst), Reserved Bandwidth (BWres), Minimum bandwidth (BWmin). Each node collects the bandwidth reserved at its one hop neighbors (piggybacked on periodic HELLO packets) and stores it in its Neighbor Table (NT) . The Neighbor Table contains fields Destination (Dst), Reserved Bandwidth (BWres), No. of Hello Packets (No Hello).

Consider the scenario

Let us consider the route

\[ S -- R1 -- R2 -- R3 -- D \]

To initiate QoS-aware routing discovery, the source host S sends a RREQ. When the intermediate host R1 receives the RREQ packet, it first estimates all the metrics as described in the previous section.
The host R1 then calculates its weight $W_{R1}$ using (3).

$$W_{R1} = \text{RREQ}_{R1} \rightarrow R2$$

R2 then calculates its weight $W_{R2}$ in the same way and adds it to the weight of R1. R2 then forward the RREQ packet with this added weight.

$$W_{R1} + W_{R2} = \text{RREQ}_{R2} \rightarrow R3$$

Finally the RREQ reaches the destination node D with the sum of node weights

$$W_{R1} + W_{R2} + W_{R3} = \text{RREQ}_{R3} \rightarrow D$$

B. Route Reply

The Destination node D sends the route reply packet RREP along with the total node weight to the immediate upstream node R3.

$$W_{R1} + W_{R2} + W_{R3} = \text{RREP} \rightarrow R3$$

Now R3 calculates its cost C based on the information from RREP as

$$C_{R3} = (W_{R1} + W_{R2} + W_{R3}) - (W_{R1} + W_{R2}) \quad (4)$$

By proceeding in the same way, all the intermediate hosts calculate its cost.

On receiving the RREP from all the routes, the source selects the route with minimum cost value.

The simulation results in the next section showed that these calculations did not increase the overhead significantly.

VII. SIMULATION RESULTS

A. Simulation Model and Parameters

NS2 simulator is used to simulate our proposed protocol. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. It has the functionality to notify the network layer about link breakage.

In our simulation, each node moves independently with the same average speed is assumed. The simulated traffic is Constant Bit Rate (CBR). Our simulation settings and parameters are summarized in table 1

<table>
<thead>
<tr>
<th>Table1: Simulation Parameters</th>
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<tbody>
<tr>
<td>No. of Nodes</td>
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<tr>
<td>Area Size</td>
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<tr>
<td>Mac</td>
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<tr>
<td>Radio Range</td>
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<tr>
<td>Simulation Time</td>
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<tr>
<td>Traffic Source</td>
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<tr>
<td>Packet Size</td>
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<td>Mobility Model</td>
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<td>Speed</td>
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<td>Pause time</td>
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</table>

B. Performance Metrics

We compare our CBMR protocol with the AOMDV [6], CARM [13] and LABQ [14] protocol. We evaluate mainly the performance according to the following metrics, by varying the nodes as 25, 50, 75 and 100.

Control overhead: The control overhead is defined as the total number of routing control packets normalized by the total number of received data packets.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Average Packet Delivery Ratio: It is the ratio of the No. of packets received successfully and the total no. of packets sent

C. Results

C.1. Varying No. Of Nodes

In the first experiment, the performance of the protocols is measured by varying the no. of nodes as 25, 50, 75 and 100. From Figure 1, we can see that the packet delivery ratio for CBMR increases, when compared to AOMDV, CARM and LABQ, since it utilizes robust links.

From Figure 2, it is evident that the average end-to-end delay of the proposed CBMR protocol is less when compared to the AOMDV, CARM and LABQ protocol.

Figure 3 shows that the control overhead of the protocols. Since CBMR make use of HELLO packets for cost estimation, the values are considerably less in CBMR when compared with AOMDV, CARM and LABQ.
B. Varying the Transmission Rate

In the second experiment, we measure the performance of the protocols by varying the transmission rate as 250, 500, 750 and 1000 Kb.

From Figure 4, we can see that the packet delivery ratio for CBMR is more, when compared to AOMDV, CARM and LABQ since it utilizes robust links.

From Figure 5, we can see that the average end-to-end delay of the proposed CBMR protocol is less when compared to AOMDV, CARM and LABQ.

Figure 6 shows the control overhead of the protocols. Since CBMR make use of HELLO packets for cost estimation, the values are considerably less in CBMR when compared with AOMDV, CARM and LABQ.
CONCLUSION

In a QoS based routing metric for MANETs, it is necessary to combine the minimum available bandwidth and end-to-end delay along with the congestion around a link. MAC access contention and channel reliability induces congestion that is related to channel quality. In this paper we have developed a cross layer based multipath routing (CBMR) protocol to improve QoS in mobile ad hoc networks to allot weights to individual links, depending on the metrics link quality, channel quality and end-to-end delay. The weight value helps the routing protocol to avoid the routing traffic through the congested area and hence the traffic is balanced and the network capacity is improved. Then the proportion of traffic to be routed to each neighbor is selected to execute routing such that the weight of the node is a minimum. We have also proposed an enhanced TCP congestion control mechanism for wireless networks, based on a cross-layer scheme. By simulation results, we have demonstrated that the robustness of our protocol achieves increased packet delivery ratio with reduced latency. The security challenges of our proposed protocol will be the subject of our future work.

REFERENCES


