Link-Quality Aware Ad Hoc On-Demand Distance Vector Routing Protocol

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***Abstract*— Current ad hoc wireless routing protocols typically select the route with the shortest-path or minimum hop count to the destination. However, routes chosen according to such criteria tend to include longer hop-length links with possibly bad signal quality. It is expected that the routing protocol can be improved by eliminating the usage of routes with bad links. In this work, we modify the Ad hoc On-demand Distance Vector (AODV) routing protocol to avoid routing through bad quality links. We also integrate the "hand-off" concept into our protocol to prevent link breakages during route maintenance. The herein reported OPNET simulation results seem very promising and they show that our protocol introduces a much lower routing overhead while still providing equal or better performance than the original AODV protocol in terms of throughput and delay.**

I. INTRODUCTION

Most of the existing ad hoc routing protocols optimize hop count when making a route selection. Significant examples are Ad hoc On Demand Distance Vector (AODV) [1], Dynamic Source Routing (DSR) [2], and Destination Sequenced Distance Vector (DSDV) [3]. However, the routes selected based on hop count alone may be of bad quality since the routing protocols do not disregard weak quality links which are typically used to connect to distant nodes. These links usually have poor signal-to-noise ratio (SNR), hence higher frame error rates and lower throughput.

In this work, we modify the *route discovery process* of the AODV routing protocol to select a route based on both hop counts and the SNR feedback from the physical layer. Each node monitors and maintains the link quality statistics from measuring the SNR of all the control and data packets received from its immediate neighbors. During the route selection mechanism, wireless links with SNR below a certain pre-determined threshold are excluded so that the protocol only chooses a stable route. However, if there is no stable route available, then the weak-links are re-included back so that the network connectivity is preserved.

After the route is discovered, AODV uses a distributed route maintenance mechanism where each node notifies the upstream nodes if it loses connectivity to the next-hop node. To repair a broken route, either the source or the node who detects the broken link can issue a new route discovery. In either case, the data transmission is paused until a new route is discovered. In order to cope with the communication disruption, we propose a route "hand-off" concept, where each node uses the link quality feedback from the physical layer to determine whether or not to issue an early link failure notification so that a new route can be discovered prior to link breakage. Our modified AODV protocol is implemented using OPNET [4] and tested against various scenarios. Preliminary results show that our protocol can perform better than the original AODV protocol, especially in the network with mobile nodes or with a large number of bad links.

The rest of this paper is organized as follows. The details of the modified AODV protocol are described in Section II. The simulation results from various scenarios are presented in Section III. In Section IV, we briefly discuss related work and give a summary of our contributions. Finally, concluding remarks are given in Section V.

II. LINK QUALITY AWARE AODV ROUTING PROTOCOL

A. Route Selection Metric

A good link quality metric should (i) accurately represent quality of the physical channel; (ii) be sensitive to gradual changes in the link quality (such as mobility); (iii) not be sensitive to the temporary changes in the link quality (such as fading); and (iv) not be sensitive to the link load. In order to meet the above requirements, each node keeps track of the neighbor's link SNR from the received packet in order to adaptively calculate Smoothed-SNR (SSNR) metric similar to the cumulative SNR computed in [5]. Denoting the SNR value of the

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n^{th} packet sent by node A by $S_{n,A}$, the Smoothed SNR (SSNR) value to node A can be formulated as

$$\mathrm{SSNR}_{n,A} = \sum_{i=0}^{n} \alpha(1-\alpha)^{n-i} S_{i,A} \tag{1}$$

where α is a parameter between 0 and 1. The larger the α value, the more sensitive the SSNR to the current SNR. By using this exponential averaging, each SNR sample gradually loses its influence on current SSNR value as newer packets from the same source arrive. Using SSNR one can keep track of the large scale fading while eliminating the effects of small scale fading which may be the cause of the weak correlation between packet delivery probability and instantaneous SNR reading of the corresponding transmission observed in [3]. A simplified version of (1) is given by the following recursive expression

$$\mathrm{SSNR}_{n,A} = \alpha S_{n,A} + (1-\alpha)\mathrm{SSNR}_{n-1,A}. \tag{2}$$

B. Route Selection Mechanism

During the route discovery process, the source node broadcasts the Route Request packet (RREQ) which also includes an additional 32-bit Route Quality (RTQ) field in the packet header. Upon receiving the RREQ, a node updates the RTQ in the packet header with its current SSNR if it is the first node receiving the RREQ or if the RTQ in the packet header is larger than its current SSNR. Note that the RTQ in the packet header represents the signal quality of the weakest link in the route. Each routing table entry also contains a 32-bit RTQ field, which will also be updated if either of the following conditions is satisfied:

i. The sequence number is higher than the sequence number stored in the routing table.
ii. The sequence numbers are equal, but the hop count in the RREQ + 1 is smaller than the hop count stored in the routing table.
iii. The sequence numbers are equal, the RTQ in the routing table is smaller than the pre-defined RTQ_THRESHOLD, which is used to distinguish between good and bad routes, and the RTQ in the packet header is larger than RTQ_THRESHOLD.
iv. The routing table contains no entry with the destination sequence specified in the packet header in the routing table.

The fundamental differences between our work and earlier works such as [5] is that our protocol decides whether particular links should be eliminated at the *routing layer* instead of making the decision at the *link layer* and filtering out all routing traffic over the bad links. By doing this, our protocol can maintain the connectivity of the network and keep the overhead low.

C. Route Maintenance

In the original AODV protocol, each node uses *periodic hello packet probe* to detect the link failure and keep track of its immediate neighbors. If a hello packet is not received from the neighbor within a certain time, then a node invalidates all the routes containing this link by sending the *Route Error* packet (RERR) to all the upstream nodes who use this link. Once a source node receives RERR packet, it re-initiates a route discovery process to search for a new route. There are two obvious drawbacks to this approach:

i. There is high routing overhead due to the use of periodic hello messages.
ii. Data communication will be disrupted from the time when the link is broken until the new route is discovered. This disruption duration also depends on the frequency of the hello packets sent and the number of hello packet loss allowed.

To cope with these drawbacks, we propose a hand-off mechanism which uses the link quality feedback from the link layer to monitor the connectivity to its neighbors and issue an early route error notification to the upstream nodes. In particular, the protocol is modified to send out the RERR packet when the monitored link quality (RTQ) to the next hop node drops below RTQ_THRESHOLD. Since the connectivity is monitored at the link layer, e.g., by measuring the SNR of the link-layer ACK and data packets, our scheme does not have to rely on the hello packet probe. In addition, the early RERR notification allows the source to find a new route before the current one is broken. Hence, fewer packets will be lost in the bad link and the disruption duration will be shorter.

III. Performance Evaluation

A. Link-Quality Aware AODV with Hand-off Mechanism Disabled

In this section, we test the proposed cross-layer route discovery mechanism against the conventional AODV. The route maintenance process remains unchanged.

1) Simulation Environment: OPNET Modeler 11.0.A pl1 [4] is used as the simulation platform. Only the route discovery process is modified to support the cross-layer link quality monitoring proposed in Section II-A and II-B. In the following, we consider a static indoor environment with a slow-flat fading Rayleigh channel. Note that for a static network, route maintenance process is not as important as the route discovery process since the link

TABLE I

COMMUNICATION AND NETWORK PARAMETERS

Parameters	**Value**
Data Rate	Fixed at 11 Mbps
Transmit Power	50 mW
Packet Reception-Power Threshold	-95 dBm
RTS Threshold	None
Path Loss Exponent	3.8
Network Size	50 m x 300 m

breakage is a rare event if a stable route is chosen during the route discovery process. However, in an outdoor environment where topology changes constantly due to node mobility, route maintenance process is a necessity for a protocol since it makes sure that the connectivity within the route is preserved during data communication. In the next section, we propose a hand-off mechanism which helps minimizing the communication disruption during the route maintenance process.

We consider FTP files transfer activity over the wireless ad hoc network where each node can be both FTP client and server. During the simulation, a node randomly picks the FTP server to download a series of files from. Each node uses the same connection to download subsequent files by following a pre-specified exponentially distributed "*Inter-Request time*" (or the time between two consecutive downloads). After "*Duration of the connection*" time has elapsed, the node tears down the connection and waits for "*Inter-connection time*" before reinitializing another connection to another randomly picked server. The simulation time is 90 minutes. See Table I-III for other related parameters.

TABLE II

SIMULATION PARAMETERS RELATED TO FTP

Parameters	**Value**
Inter-Request Time	exponential(60 seconds)
File Size	exponential(50 KB)
Duration of the connection	exponential(300 seconds)
Inter-connection time	exponential(10 seconds)

TABLE III

SIMULATION PARAMETERS RELATED TO AODV

Parameters	**Value**
Inter-Request Time	5
Active Route Timeout	3 seconds
Hello Interval	uniform(1,1.1) seconds
Allowed Hello Loss	2
TTL Start/Increment	5/2
Local Repair	Enabled
RTQ_THRESHOLD	8.0

2) Simulation Results: Table IV shows that the download response time of the modified AODV protocol is improved by 28.00%, 15.30%, and 2.10%, respectively, as the network density increases. We also discover that the modified AODV protocol performs much better than the original one in terms of TCP delay (see Table V). Notice that the benefit of using the modified AODV protocol diminishes with increasing number of nodes. These results suggest that when a large portion of links are of bad quality as in a sparse network case with 20 or 50 nodes, it is expected that the modified AODV will be able to avoid routing through these weak-quality links. On the other hand, denser network contains mostly good quality links so not much improvement is observed.

TABLE IV

AVERAGE DOWNLOAD RESPONSE TIME (SECONDS)

Number of Nodes	20	50	100
Modified AODV	8.31	10.52	39.34
Original AODV	11.55	12.42	40.18
Time improved (%)	27.99	15.30	2.09

TABLE V

AVERAGE TCP DELAY (SECONDS)

Number of Nodes	20	50	100
Modified AODV	8.58	9.18	38.82
Original AODV	10.59	10.21	37.64
Time improved (%)	19.01	10.05	-3.15

B. Link-Quality Aware AODV with Hand-off Mechanism Enabled

In this section, we test our fully implemented protocol, i.e., with the new route discovery process and the hand-off mechanism enabled, against more realistic outdoor scenarios with mobile nodes.

1) Simulation Environment: In order to test the hand-off mechanism, we consider a small network with four nodes as shown in Figure 1. At the beginning of the simulation, the sender requests a route to the destination. According to the network parameter settings shown in Table VI and regardless of the route selection mechanism used, the sender will discover a two-hop route and start transmitting packets via the "relay_node_1". During the simulation the sender and relay_node_1 will move toward one another, following the projection paths (diagonal solid lines) shown in Figure 1. Clearly, the quality of the link between relay_node_1 and the receiver will gradually decrease as the distance between the two nodes grows larger, and the link will eventually break.

TABLE VI

COMMUNICATION AND NETWORK PARAMETERS FOR THE NETWORK IN FIGURE 1

Parameters	Value
Data Rate	Fixed at 11 Mbps
Transmit Power	1 mW
Packet Reception-Power Threshold	-85 dBm
RTS Threshold	None
RTQ_THRESHOLD	16 dB
Hello Loss Allowed	2
Hello Loss Interval	uniform(1,1.1)
Packet Transmission Rate	2 packets/s
Path Loss Exponent	2
Ricean K Factor	1
Network Size	100 m x 100 m
Speed of Sender	0.03 m/s
Speed of relay_node_1	0.04 m/s

The connectivity between the sender and the receiver is lost after 22 minutes, as shown in Figure 1 (b). After detecting the broken link, relay_node_1 will send out a RERR to the sender. Upon receiving this RERR, the sender will initiate a new route discovery by sending out a RREQ packet to find an alternate route. In this case, the two-hop route with relay_node_2 will be discovered. The connectivity between the sender and the receiver will then be restored.

2) Simulation Results: Figure 2 shows the received traffic at the destination node in the scenario described in Figure 1 with (a) the original AODV with hello messages; (b) the modified AODV with hello messages; (c) the original AODV without hello messages; and (d) the modified AODV without hello messages. With the hello message probe enabled, the packets will be lost in the bad link until the relay_node_1 detects that it lost connectivity with the next hop node, which in this case is also the destination node. However, without exchanging hello messages, relay_node_1 will not be able to detect that the link to the destination is broken at all and, hence, all the packets sent by the source after the link breaks will be lost.

In the modified AODV case, the source will be able to re-route a packet through an alternative route, i.e., through relay_node_2, prior to the link break regardless of whether the hello message is used or not. As illustrated in Figure 3, when the detected link quality drops below the threshold, which in this case is 16 dB, the sender will be notified about the bad link and will reroute its packets through relay_node_2 at about 22 minute into the simulation. Hence, there will be little to no disruption during the data communication when the hand-off is used together with the feedback from the link-layer.

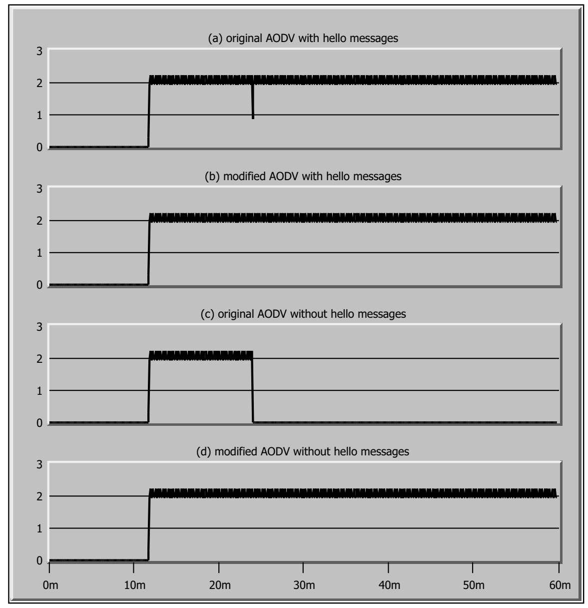
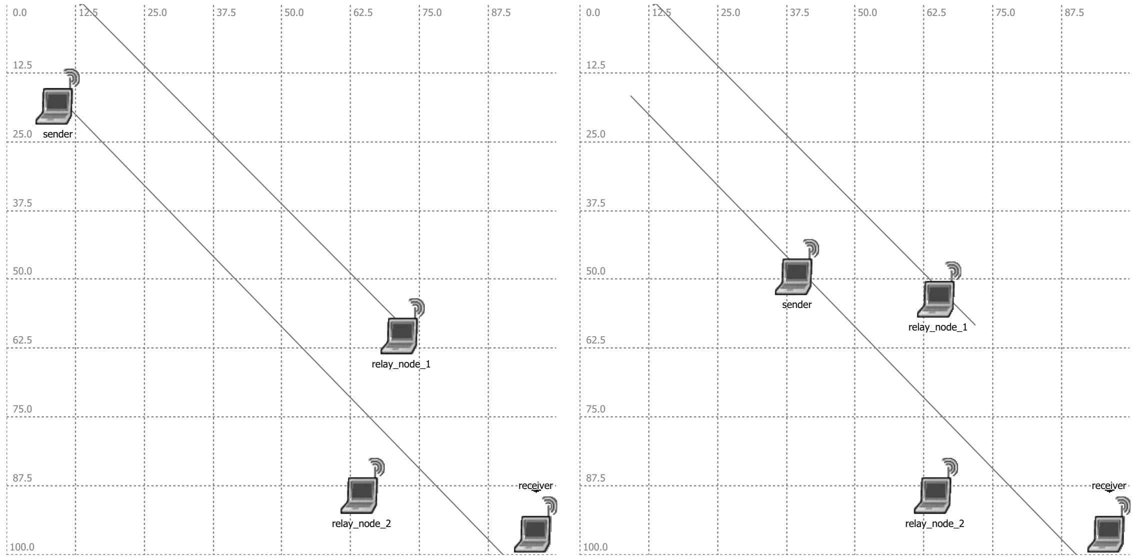


Fig. 2. Received traffic measured at the receiver node with (a) the original AODV with hello messages; (b) the modified AODV with hello messages; (c) the original AODV without hello messages; and (d) the modified AODV without hello messages

IV. RELATED WORK

There are several studies, proposals, and even new routing architectures that address the instability of the wireless channel and consider the link quality in the design of several protocols. The Roofnet team provides an extensive experimental study of the wireless link characteristics of a multi-hop 802.11b network in an urban environment [6, 7]. Based on their link measurements, they conclude that routing through the shortest path *is not sufficient* in multi-hop wireless networks [6]. However, they also report that the correlation between SNR and loss rate on the link with intermediate-quality is rather weak, i.e., the SNR range over which packet loss rates are approximately 50% is fairly wide. To explain this phenomenon, they hypothesize that losses on intermediate-quality links are presumably characterized by multi-path, but do not provide or suggest any solution to reduce the loss rate [7].

There are a few works which suggest quantifying the wireless link quality by using different information and technologies. In both associativity-based routing (ABR) [8] and signal stability-based adaptive (SSA) routing [5, 8], a temporal link stability is used as the route selection criterion. In particular, ABR relies on the data link layer to periodically transmit beacons and update the link quality metric, *associativity-tick*, which is simply the frequency of the beacon received from neighboring nodes. The higher the frequency, the more stable



(a) t = 0 sec (b) t = 22 mins

Fig. 1. Snapshot of the network topology at two different time instances (a) at the beginning of the simulation (b) at the time the relay_node_1 loses connectivity with the receiver node.

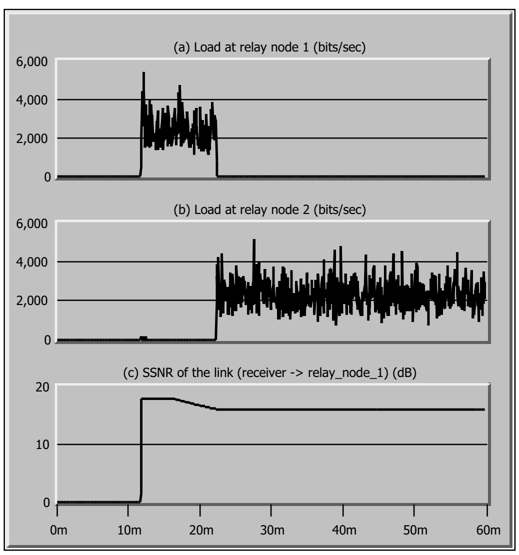


Fig. 3. (Traffic load as submitted by the sender to (a) relay_node_1 (b) relay_node_2 and the SSNR of the link between the receiver and relay_node_1

the link is. Unlike ABR, SSA uses signal strength as an indicator of link quality. However, links are characterized either as strongly connected (*SC*) or weakly connected (*WC*), and only *SC* links are considered for routing. A similar routing protocol, which filters out bad quality links prior to making route selection, is implemented in [9]. While these are interesting routing protocols with certain advantages, omitting some links, even if they have poor quality, can result in network partitioning and may have an adverse effect on network connectivity.

In [10], global positioning system (GPS) information is used along with the proposed propagation model to predict the received signal power that can later be used in calculating the link quality metric. The prediction model was implemented and tested on a real system with Dynamic Source Routing (DSR) routing protocol [2]. Although the authors of [10] present a promising prediction capability, they do not report any network performance results.

In [11], DSR and Dynamic Destination-Sequenced Distance-Vector (DSDV) [3] are modified to use the *expected transmission count* metric (ETX) as route selection criterion to find the high-throughput path on a multi-hop wireless network. However, to obtain the ETX, the modified protocols measure the delivery ratio by counting the number of periodic probe packets received over a certain duration of time. Although the results reported show improvement over original protocols in terms of packet delivery ratio, the trade-offs involved and other network performance indicators, such as delay, routing overhead, etc., are not presented in the paper.

In this paper, we propose a link-quality aware routing protocol which selects the route based on both the link quality and the hop-count. The route quality metric (RTQ), which is computed from the measured SNR of the received data and/or control packets, is used to prune the weak links during the route discovery process. In addition, we also propose a hand-off mechanism, which uses feedback from the link-layer to notify the upstream nodes about the bad links prior to link breakage, in order to minimize the packet loss and communication disruption. Although, we have only applied our proposed scheme to the AODV protocol, we claim that this scheme is general enough to be applied to other ad hoc routing protocols, e.g., DSR, DSDV, etc.

V. Conclusion

In this paper, we modify the AODV protocol to choose routes according to the route stability (RTQ) criterion, which is represented by the SSNR of the weakest link in the route, in order to eliminate the routes with bad links while maintaining the connectivity of the network. We also incorporate the idea of "hand-off" into the route maintenance mechanism, so that early action can be taken prior to link breakage. Low SSNR warning can be considered as an alternative mechanism to indicate link breakage. In addition, our scheme incurs lower overhead and fewer packet loss than the conventional AODV scheme by not relying on using the hello messages to monitor the neighbors' connectivity. The simulation results reported in this paper show a promising throughput and delay improvement in a simple static network with Rayleigh channel model and significant improvement over the conventional approach in a dynamic network with mobile nodes.

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