Limiting Control Overheads based on Link Stability for Improved Performance in Mobile Ad Hoc Networks

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Abstract. The widespread use of Mobile Ad Hoc Networks (MANETs) in many fields of applications has led to the continuous development of routing protocols which can perform well when deployed under different scenarios, as well as offer better Quality of Service (QoS) support. In this paper, we focus on how link stability is utilized as a metric to provide accurate feedback on the network. We then introduce two mechanisms – L-REQ (Limited forwarding of Route Requests) and L-REP (Limited initiation of Route Replies by intermediate nodes) – which make use of link stability to dynamically adapt the characteristic behaviour of existing protocols to achieve better network performance. The two adaptive schemes are then applied to the Ad Hoc On Demand Distance Vector (AODV) routing protocol as proof of concept.

1 Introduction

MANETs are increasingly gaining pervasiveness in many fields, particularly in the military and rescue operations. This is attributed to the nature of MANETs – they do not require the setup of any existing infrastructure and can be easily deployed under physically hostile terrains.

Several routing protocols have been developed for use in MANETs, including the following: i) reactive protocols such as DSR (Dynamic Source Routing) and AODV (Ad Hoc On Demand Distance Vector) which compute routes on demand; ii) proactive protocols such as OLSR (Optimized Link State Routing) and TBRPF (Topology Dissemination Based On Reverse-Path Forwarding) which store pre-computed paths to reachable destinations; and iii) hybrid protocols such as ZRP (Zone Routing Protocol) and CBRP (Cluster Based Routing Protocol), which make use of the benefits of both reactive and proactive routing schemes. Each of these routing protocols work well under the scenarios which they were designed for: proactive protocols perform well in relatively static networks while their reactive counterparts outperform the proactive ones under highly dynamic network conditions.

In recent times, there has also been a growing trend towards the development of adaptive protocols, which include the ARM (Adapting to Route Demand and Mobility) protocol, ASAP (Adaptive Reservation and Pre-Allocation Protocol), SHARP (Sharp Hybrid Adaptive Routing Protocol) and ADV (Adaptive Distance Vector) protocol. These adaptive protocols recognize that, owing to the indeterministic nature of network conditions in MANETs, conventional routing protocols may not work well under different network scenarios. Hence, they adjust network parameters dynamically to achieve better network performance, often by making use of one or more mobility metrics that can provide information on the network [1].

As such, it is of utmost importance to identify metrics that can accurately reflect the communication potential in a MANET [2]. In this paper, we have identified link stability as a metric that can be used to provide feedback on the network characteristic. Link stability itself is essential for the formation of stable networks, which enjoy high reliability and better QoS support. With network stability, data packets can be delivered more successfully, resulting in improved network performance.

In networks with unstable links, link breakages tend to occur frequently. Due to the breakage of existing routes, more control packets have to be propagated in the network for route maintenance. In the case of reactive protocols, these include Route Request (RREQ), Route Reply (RREP) and Route Error (RERR) packets, since new routes have to be established more frequently, and nodes that make use of broken linkages will also have to be notified. Consequently, there is greater contention for bandwidth, leading to overall deterioration in network performance.

Therefore, adaptive routing protocols should ensure that stable links are established in preference over unstable links during route formation. Here, our work mainly focuses on how link stability can be determined, as well as demonstrate how it can be used as a metric to dynamically adapt any arbitrary reactive routing protocol that makes use of periodic beacons, to achieve better network performance. We then implement our proposed schemes on AODV, a well-known reactive protocol, and use simulations to compare some performance measures.

The remainder of this paper is organized as follows: Section 2 discusses related work and motivation. Section 3 describes how link stability is determined. Section 4 provides a detailed overview of how link stability is being incorporated as a metric in our adaptive scheme. Simulation results and analysis are presented in Section 5. In Section 6, we conclude with directions for future work.

2 Related Work and Motivation

Much of the reported work in the literature have used estimated distance or estimated route lifetime to measure link stability. This requires the use of GPS (Global Positioning System) to gain knowledge about the speed and/or location of the nodes, which can then be used to determine the stability of the link. Other previously studied methods of estimating link stability include using signal strength and Signal to Noise Ratio (SNR). Some of these schemes are briefly discussed below.

The Signal Strength based Adaptive Routing (SSA) [3] protocol performs route discovery on demand by selecting longer-lived routes based on signal strength and location stability. The average signal strength at which packets are exchanged between hosts is used to determine the strength of the channel and the location stability is used to choose the channel which has a longer time existence.

Krco and Dupcinov in [4] discuss the problems caused by the underlying MAC (Medium Access Control) protocol, which causes different transmission ranges to be set up for unicast and broadcast packets. The SNR value is hence used to determine if the quality of the interconnecting channel is good enough to carry broadcast and unicast messages without dependency on the underlying MAC protocol.

The Minimum Displacement Update Routing (MDUR) [5] is an updating strategy that controls the rate at which route updates are being sent into the network, based on the frequency of location change of a node by a pre-specified distance (using GPS). This reduces periodic route updates by restricting the update transmission to nodes which have not been updated for a minimum threshold time, or nodes which experience/create significant topology change.

Adaptive Location Aided Routing from Mines (ALARM) [6] describes a hybrid routing protocol that combines the LAR (Location Aided Routing) protocol with a directed flooding method. When the link duration for the node in the route is longer than a specified threshold, the data packets are then forwarded along the route; otherwise, the node will initiate a directed flood of the data packet towards the destination.

[7] introduces a new metric for determining the link stability of routes, so as to select longer-lived routes during route discovery. The Route Fragility Coefficient (RFC) estimates the rate at which a given route expands or contracts. With the selection of less dynamic routes, the route lifetime is often longer, resulting in improved throughput and reduced routing protocol overhead.

MOBIC [8] is a lowest relative mobility clustering algorithm that uses a mobility metric as a basis for cluster formation. The relative mobility metric is computed by measuring the received signal strength detected at the receiving node. The aggregate local mobility value is then calculated and used to choose the preferred cluster heads.

While we acknowledge that a considerable amount of research has been done on link stability, there are some issues of concern which we hope to address in this paper. These issues include the following:

- Direct measure of distance may not be a good basis for gauging the stability of the link because it is subject to approximations. Two nodes in close proximity may not be able to transmit data packets efficiently due to low power levels or interferences from the noise in the environment – these two factors lead to low transmission ranges, which could result in higher packet loss rate.
- Different MAC protocols have varying methods of handling unicast and broadcast packets. Some MAC protocols transmit broadcast packets (such as Hello messages) at lower bit rates than unicast data packets, by making use of a more robust modulation scheme which results in higher transmission ranges.
- Nodes in an ad hoc network usually have limited power and processing capabilities. As such, algorithms to compute the link stability should not be too complex, and any additional information that needs to be maintained should be minimized so as not to incur higher network overhead.

Most of the related work presented above used link stability to control flooding of data packets in highly mobile networks, or as a metric for the clustering of nodes in hierarchical routing strategies. However, the main problem faced by routing protocols in very dynamic conditions is that links may be broken soon after route establishment. This leads to excessive control messages and data packets inside the network, which results in higher bandwidth contention and consequently, reduced performance. We hence propose schemes to reduce network overhead using link stability as a metric.

3 Determining Link Stability

Link stability is a measure of the reliability of the link between any two nodes in a network. It depends on a number of factors, such as: distance between the nodes, signal strength emitted by the transmitting node, sensitivity of the receiving node, antenna gains of both the transmitter and the receiver, environmental conditions, etc.

We use the successive transmission power of packets received by nodes to determine link stability. This is done by measuring the signal strength of packets received by nodes in consecutive time periods, and then calculating the relative signal strength. Here, we have chosen to use the relative signal strength and not the direct measure of signal strength because fading in wireless environments can lead to fluctuations in the received signal strengths. The Ground Reflection (Two-Ray) model is used in our simulations, which considers both the direct path and ground reflected propagation path between the transmitter and the receiver.

$$P_r = P_t \times \frac{h_t^2 \times h_r^2}{d^4} \times G_t \times G_r \quad (1)$$

where P_r = received power; P_t = transmitted power; G_t = antenna gain at the transmitter; G_r = antenna gain at the receiver; h_t = height of the transmitter antenna; and h_r = height of the receiver antenna.

3.1 Preliminaries

We define the relative signal strength between any two arbitrary nodes as:

$$Rel_{ss}[x], = 10 \lg(\frac{P_x}{P_x'}) \quad (2)$$

where P_x = signal strength received in current time period; and P_x' = signal strength received in previous time period.

When two nodes are moving away, or when there is increased interference between them, the signal strength that is being sensed will decrease. This leads to a negative value for $Rel_{ss}[x]$, where x refers to a particular neighbour of the node calculating the relative signal strength. The relative signal strength is a good indicator of link stability, because a higher value of $Rel_{ss}[x]$ indicates that the signal strength being received by two adjacent nodes is increasing. Although this can be due to nodes moving closer to each other, or decreased noise/interferences surrounding these nodes, this is nevertheless an indication that the link between the nodes is stable. Hence, links that are established between these nodes tend to last longer, leading to less frequent breakages.

3.2 Implementation

In typical MANET routing protocols, periodic beacons are broadcasted between neighbouring nodes to provide local connectivity information. In AODV, these periodic beacons are known as Hello messages and are used by nodes that are part of active routes. Every HELLO_INTERVAL milliseconds, the node will check if it has sent a broadcast within the last HELLO_INTERVAL; otherwise, it may broadcast a Hello message to its neighbours. This value is set to 1000 milliseconds in RFC 3561.

We make use of the signal strength information which is already available in the periodic Hello messages to calculate the relative signal strength, $Rel_{ss}[x]$ between adjacent nodes (which are assumed to transmit at constant power). Hence, these values of $Rel_{ss}[x]$ are updated every 1000 ms between active nodes. The structure of each neighbour table is also modified accordingly to store the values of $Rel_{ss}[x]$ and P_x.

4 Adaptive Algorithm with Link Stability

Our adaptive algorithm, which uses link stability to reduce the network overhead, comprises of the following two components:

- L-REQ – limited forwarding of RREQ packets to highly mobile nodes
- L-REP – limited initiation of RREP packets by intermediate nodes

4.1 L-REQ

During the transfer of data packets, routes have to be established beforehand. In the event that such routes do not already exist between the source and destination nodes, the former broadcasts a RREQ (Route Request) packet to its neighbouring nodes, which is then propagated into the network via local broadcasts by the receiving nodes.

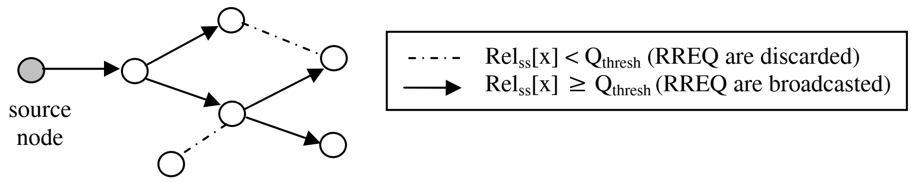

Fig. 1. L-REQ mechanism

The repetitive broadcasting of RREQ packets introduces a high number of control packets into the network. These control packets compete with the data packets for bandwidth, and may thus deteriorate network performance. Our L-REQ scheme (see Fig. 1) works as follows: Since routes via unstable links are not preferred, each RREQ packet that is received by any particular node will only be broadcasted to neighbouring nodes if it is received from a node that has stable links. This will reduce the propagation of RREQ packets to highly dynamic nodes, since they are unlikely to maintain the route should one be established.

4.2 L-REP

When a node receives a new RREQ packet, it may respond with a unicast RREP if it is the destination or an intermediate node with a route that is fresh enough. However, RREP packets may be initiated by intermediate nodes that have already moved away from its previous neighbours. This can lead to the establishment of broken routes, resulting in more RERR packets being released into the network.

In our proposed L-REP scheme (see Fig. 2), if the intermediate node has a valid route to the destination, it may only unicast a RREP back to the source if the adjoining link is relatively stable. If the link between a pair of nodes has a low relative signal strength $Rel_{ss}[x]$, link breakages tend to occur more often and this will increase the amount of control overhead in the network. Hence, we restrict the probability of this happening by preventing RREPs that are otherwise initiated from intermediate nodes which form relatively unstable links with the neighbouring node in consideration.

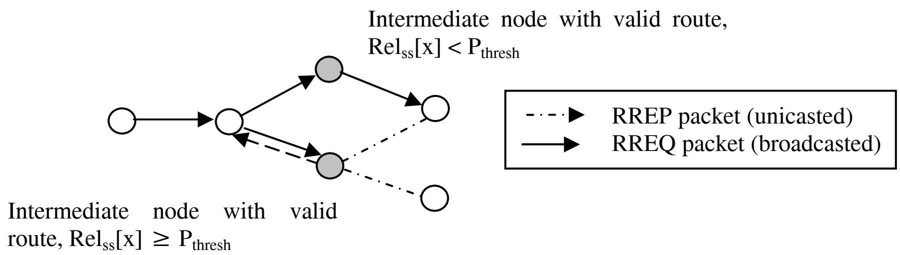

Fig. 2. L-REP mechanism

4.3 Adaptive Algorithm

Combining the two mechanisms together, our adaptive algorithm works as follows:

During the transfer of data packets, a route discovery process will be initiated when there is no existing route to the targeted destination. The source node broadcasts a RREQ packet to its neighbouring nodes, which then calculate the relative signal strength in order to determine the link stability of the adjoining link. If the link is very unstable, the RREQ is discarded immediately because unstable links are unlikely to last and may result in many broken links. If the link is fairly stable, the receiving node will broadcast the RREQ to its other neighbours.

When the RREQ is intercepted by an intermediate node that has a valid path to the targeted destination, it will compute its relative signal strength $Rel_{ss}[x]$ with the adjacent node with which a route may be established. A low value for $Rel_{ss}[x]$ indicates that the link between the two nodes is fairly unstable, and it will not generate a RREP packet. Instead, it will continue to forward the RREQ packets to other nodes. The RREQ packet will eventually initiate a RREP packet from either the destination node or an intermediate node that has a high value of $Rel_{ss}[x]$ with the respective neighbouring node. RREP packets are then unicasted back to the source node.

Our two mechanisms aim to reduce the overall control overhead in the network by reducing the number of control packets that are being released. These control packets include RREQs, RREPs, RERRs as well as Hello messages that are used to provide local connectivity information. With lesser control overhead, there is less contention for bandwidth with the data packets, which leads to improved network performance.

5 Simulation Results and Analysis

We apply our proposed methods of adapting protocols (i.e. L-REQ and L-REP) on AODV-LR, an enhanced version of AODV [9] with local repair, and evaluate them using the following performance measures:

- Control overhead – total number of RREQ, RREP, RERR and Hello packets that are being propagated into the network.
- Packet delivery ratio – total number of data packets received as a fraction of the total number of packets originated from all the nodes in the network.
- End to end delay – time taken to transmit a packet from source to destination.
- Throughput – total number of successfully delivered data (in kilobytes).

Simulations are run on GloMoSim [10], a simulation platform for networks. Each scenario is run for 300 seconds with different seeds, and the measurements are averaged to reduce the randomness of the mobility patterns. We use the Random Waypoint mobility model, where nodes move towards randomly selected destinations with speeds between $10ms^{-1}$ to $20ms^{-1}$ and rest there for a specified pause time. The terrain size is set to 2000×2000 metres. The CBR (Constant Bit Rate) generator is used to emulate data traffic between randomly selected nodes. At time intervals of 100ms, the selected nodes transmit 512 bytes of data for specified time intervals.

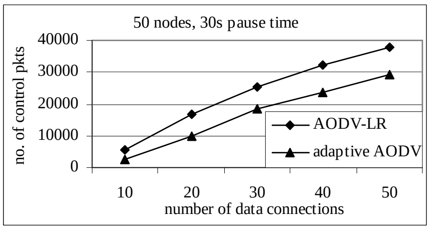

Fig. 3. No. of control pkts vs data load

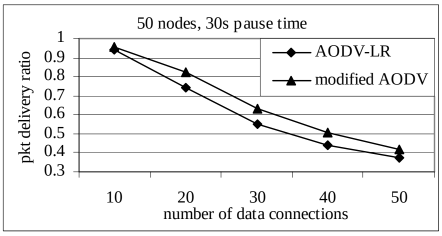

Fig. 4. Packet delivery ratio vs data load

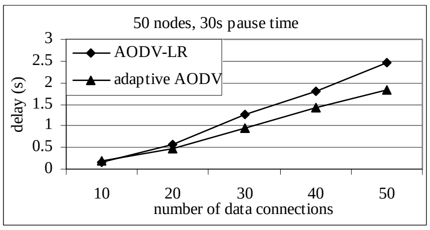

Fig. 5. Delay vs data load

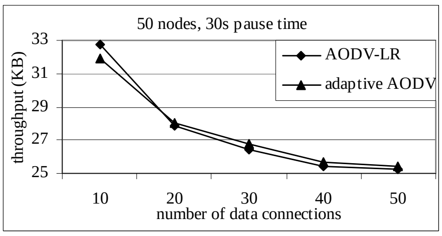

Fig. 6. Throughput vs data load

Figures 3-6 show the comparisons between AODV-LR and the adaptive AODV enhanced with the L-REQ and L-REP schemes. Nodes are uniformly placed and the pause time is set to 30s. Fig. 3 shows a marked decrease in the total number of control packets, which comprises of RREQ, RREP, RERR and Hello messages. This is expected, since the total number of RREQ packets (and hence RREP packets) that are being propagated into the network is greatly reduced, with the use of a threshold, Q_{thresh}. The use of P_{thresh} in the L-REP scheme also reduces the number of link breakages and thus the number of RERR messages. We also discover that our adaptive schemes have indirectly reduced the number of Hello packets being transmitted by nodes. This is because the restriction of propagation of control packets between unstable links reduces the number of nodes which receive RREQs from highly mobile nodes and become part of active routes which are prone to link breakages.

With a significant decrease in network overhead caused by control packets, there is less congestion in the network. This leads to a higher packet delivery ratio since there is now lesser contention for bandwidth between data and control packets, as shown in Fig. 4. We observe shorter end to end delay and increased throughput in Fig. 5 and Fig. 6 respectively. With the formation of more stable links within routes, the probability of link breakages decreases. This reduces the frequency of route repairs and route requests and hence reduces the end to end delay during the transfer of data packets. As such, the overall throughput will also increase because more data packets are delivered within the specified time intervals. There is however, a slighter longer delay and lower throughput for 10 data connections because there is already very little congestion in such networks. Hence, restriction of control packets for the formation of routes may lead to longer times needed for route establishment.

We also compared the performance of AODV-LR and the adaptive AODV using the Random Waypoint mobility model with 0s pause time, which emulates continuous random motion of nodes in the network. Similar to the previous set of results with 30s pause time, there are significant improvements in network performance.

Our next set of simulation explores the effects of our adaptive schemes on large scale networks. Different number of nodes are uniformly placed and simulated under the Random Waypoint mobility model with a pause time of 30s. 10 data connections are established at varying time intervals, each one transmitting 512 bytes of CBR traffic at periodic intervals of 100ms. The comparative results are shown in Fig. 7-10.

In Fig. 7, there is a clear reduction in the number of control packets that are being released into the network. There is also higher packet delivery ratio for the varying number of nodes in the network, as shown in Fig. 8. This improvement is more pronounced in dense networks with more than 100 nodes, because comparatively fewer nodes are involved in the sending of control packets via unstable links.

There are also significant improvements in the total end to end delay and the network throughput as shown in Fig. 9 and Fig. 10 respectively. However, there is slightly higher end to end delay and lower throughput for networks with less than 100 nodes, because relatively more nodes are involved in the data connections, and limiting RREQs and RREPs under these situations can lead to longer times needed for route establishment. More data packets may also be dropped during the longer wait, which can result in lesser throughput.

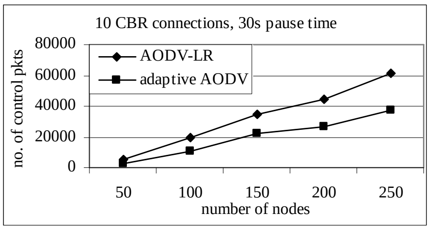

Fig. 7. No. of control pkts vs network size

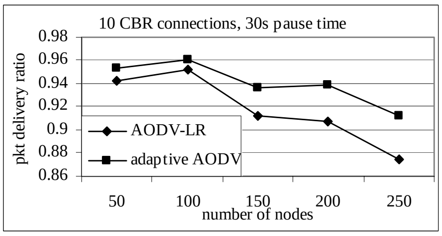

Fig. 8. Packet delivery ratio vs network size

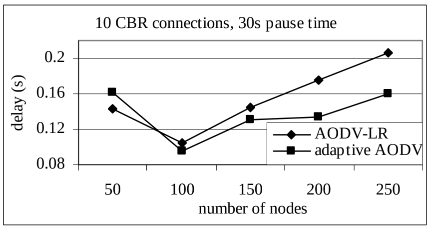

Fig. 9. Delay vs network size

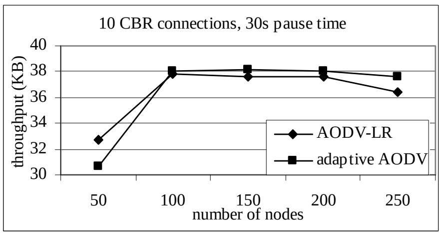

Fig. 10. Throughput vs network size

In all our simulations, we have set Q_{thresh} = -0.25 and P_{thresh} = -0.5, which are optimal values obtained through extensive simulations. These values allow for slight deviations in the signal strength being received by neighbouring nodes, which could be caused by fading, interference, or node mobility. Having negative thresholds allow links to be maintained even when the stability of the link decreases slightly during route establishment. In addition, P_{thresh} allows for a greater tolerance in the deterioration of link stability because more preference is given to existing, valid routes which have already been established, as this reduces the control overhead incurred by propagating more RREQ packets in the network during the route discovery process.

6 Conclusion and Future Work

Link stability is a metric that can provide precise feedback on the behavioral characteristics of a network, such as the mobility pattern of nodes and the estimated route lifetime between nodes. We have proposed a method to measure link stability using the received signal strengths between neighbouring nodes at periodic time intervals. This eliminates the need for additional infrastructure such as GPS and also takes into the account the effects of noise interference and other factors such as the power levels of the transmitting and receiving nodes.

We have suggested two mechanisms to adapt any arbitrary reactive routing protocols using link stability as a determining metric. L-REQ attempts to control the flooding of RREQs in the network, which is a persistent problem faced by many existing ad hoc routing protocols. With the use of Q_{thresh}, RREQs are not broadcasted in cases where routes are likely to break frequently. L-REP addresses the problem caused by route replies originating from intermediate nodes with valid routes to the targeted destinations, but which may cause unstable links to be formed. It limits the formation of such unstable routes with the use of another threshold, P_{thresh}. Pairs of nodes which do not satisfy the criteria have to forward the RREQ packets instead of unicasting a RREP packet back to the source node.

We have implemented L-REQ and L-REP on top of AODV-LR, an enhanced version of the AODV routing protocol with local repair, and simulation results have highlighted that our adaptive schemes can improve network performance in terms of control overhead, packet delivery ratio, end to end delay as well as overall throughput. As very little modification to the protocol architecture has been made, our adaptive scheme is also able to interoperate with the existing unmodified protocol.

We are currently investigating the effects of our adaptive schemes on other types of mobility models, such as the Reference Point Group Mobility (RPGM) model, which simulates group movements are based on the path traveled by a logical centre. Our continued research area includes developing other adaptive schemes based on network characteristics such as traffic characteristics and patterns, etc.

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