EFFICIENT ROUTING SCHEME FOR UNIDIRECTIONAL LINKS IN MULTI-HOP NETWORKS

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ABSTRACT

This paper presents an efficient routing scheme for Multi-hop Network in the presence of unidirectional links. The distinct feature of this routing scheme is the capability to actively provide routing paths even though a large number of unidirectional links are present in the network. The results depict that the routing scheme is able to reduce the delay and routing overhead compared with the already available routing scheme like AODV and AODV-Blacklist. The performance of proposed routing scheme called Active Reverse Route (ARR) scheme is compared with AODV and AODV-Blacklist routing protocols in Multi-hop networks. The performance analysis when compared with the three routing protocols to manage unidirectional links shows that our proposed ARR scheme is superior to the AODV and AODV-Blacklist.

KEYWORDS: *Multi-hop Networks, Routing, AODV*

INTRODUCTION

This paper presents a novel and practical routing scheme called Active Reverse Route (ARR), implemented over the prominent AODV (AlShalabi et al., 2017) routing protocol. To setup a routing path, the scheme follows the fundamental operation of AODV. However, the main feature of the algorithm is the ability to build a routing path as efficiently as possible on a network with high number of unidirectional links. The scheme reduces additional routing overhead incurred by the routing construction while rapidly re-computing alternative paths around the nodes that are blocked by unidirectional links. The routing performances are quantified using several performance metrics, which are; packet delivery ratio, normalized routing load, packet loss, and average delay.

RELATED WORK

Mobile Adhoc Network is a wireless multi-hop network which is decentralized, deployed based on request, where devices communicate using radio links, and forward information through multiple hops from source to destination nodes. When the transmitting and receiving power among nodes are unequal, we get bidirectional and unidirectional links. Most of the routing protocols ignore unidirectional links and are based on bidirectional links. Nevertheless, some protocols have taken care of unidirectional link and they are summarized here.

Reactive routing protocols, like Dynamic Source Routing (DSR) (Singh & Singh, 2017) and Reverse Ad-hoc On-Demand Distance Vector (R-AODV) (Ahn et al., 2006) successfully discover reverse and forward routes by using independent two-way flooding. This method avoids the unidirectional links effectively. However, it increases the routing overhead.

Bidirectional Routing Abstraction (BRA) (Mosse and Ramasubramanian, 2008) scheme for reverse paths discovery for unidirectional links. BRA was based on Distributed Bellman-Ford Algorithm. This scheme improved the connectivity issue between nodes.

Clustering technique is proposed by utilizing the acknowledgements to tackle the unidirectional in multi-hop ad hoc networks (Dow et al., 2008). Utilizing clustering reduced the overhead while for unidirectional links, tunneling and multi-hop acknowledgements techniques had been proposed which detected unidirectional links and relationship had been maintained with unidirectional neighbors.

An efficient adaptive gateway discovery algorithm is proposed which successfully connected mobile ad hoc network having unidirectional links (Liu et al., 2010). AODV protocol had been modified for gateway advertised message and gateway discovery messages. In this research, the unidirectional links were avoided to have communication over mobile ad hoc network.

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An effective and useful approach for on-demand mobile ad hoc network having unidirectional links utilizing neighbor monitoring mechanism (NMM) routing mechanism had been proposed (Tang, and Wang, 2007). Instead of avoiding unidirectional links for path establishment it utilized the unidirectional links and this scheme was more effective than blacklisting scheme and had low overhead when compared with Hello mechanism.

ARR ROUTING SCHEME AND ITS WORKING

The ARR routing scheme can efficiently handle unidirectional links. ARR can be easily incorporated into other routing protocols that share similar characteristics with the AODV (Das et al., 2003) routing protocol. The scheme is capable of minimizing routing overhead and efficiently avoids multiple route request discovery, caused by the loss of Route Reply (RREP) packet during reverse path construction.

Majority of the on-demand routing protocols relies on the bidirectional link availability between nodes. In bidirectional link, the same path is used for communication. However, there are network scenarios where the routing packets are forwarded via unidirectional or asymmetrical links and the reply packet won't be able to follow the reverse created forward path. When the reverse path fails another route discovery broadcast is initiated by the AODV. This increases the delay to establish the routing path.

Route Discovery

The route discovery is initiated when the route entry for the destination node is not found in the node's routing table. The Route Request (RREQ) packet is created by the node which has source and destination address, sequence number, broadcast ID, packet type, time stamp, hop count and request packet address. The hop and request packet address changes with every node visited during the course of the route.

To find the address of destination node, the source node broadcast the RREQ packet to neighboring nodes to form a routing path. A broadcast packet is unique by the destination IP address fixed to IP_BROADCAST. When a broadcast packet is received, every node compares the cache information i.e., broadcast ID and sequence number with the contents of RREQ packet. A received packet is considered as a fresh packet if the value of cache is lower than the value of RREQ's sequence number. The unique broadcast session is identified with the broadcast ID along with the source request packet address.

In addition to the highest sequence number, each forwarding node also seeks the lowest hop count and Received Signal Strength (RSS). In some cases, if a RREQ's packet RSS is identical to the content of routing table, the lowest hop count takes precedence. However, if the hop count advertised by the RREQ packet is lower than the entry on the routing table, the packet is considered fresh. Subsequently, the route entry is replaced by the information as advertised by the RREQ packet. The mechanism ensures that a node always maintains the shortest routing path while effectively eliminates the duplicate packets and the route discovery convergence is faster than the base protocol.

Route Establishment

In the route establishment phase, a node responds to the first RREQ packet received by sending a RREP packet back to the source node. Similar to intermediate nodes, the destination node records only the freshest RREQ packet using the sequence of process and the initial content of routing table at each node after the first route request discovery. In Fig. 1, the red line shows the propagated RREQ packets and the blue line shows the dropped RREQ packets, which have been determined to be redundant. At the destination node D, the RREQ propagation is terminated.

After receiving the first RREQ packet, the destination node D, responds by preparing the RREP packet. The destination and source IP addresses is swapped and the next hop node is included within the RREP packet's field. The next hop node follows the ID of the node from which the RREQ is received. For instance, as shown by Fig. 1, assuming the first RREQ packet received is from link E-D, node Detects E as the next hop node. The RREP packet is then sent in a unicast manner via each node, which forwards to the next destination based on its routing table. The reverse path D-E-A-S is created.

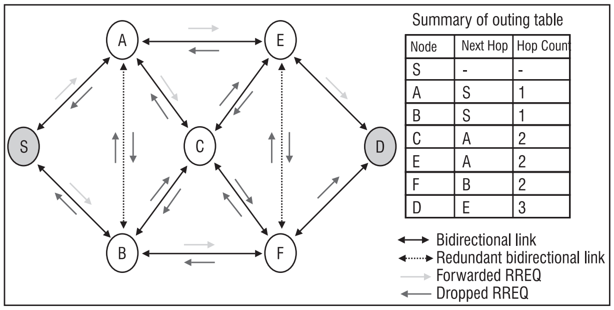

Fig. 1: Forward route creation and routing table

Unidirectional Link Detection

The ARR scheme instead of avoiding the unidirectional link, it utilizes to take advantage during forward route construction. In the event of Acknowledgement (ACK) reception failure, the identified unidirectional link is not blacklisted. Instead, a new reverse route is computed immediately, which can be used to potentially propagate the RREP packet back to the source node. In order to find such a route, the downstream node affected by the unidirectional link invokes a one-hop local reply broadcast packet. Basically, the packet is an exact copy of the dropped RREP packet, and differs only in terms of packet type, i.e., broadcast instead of unicast. The local reply broadcast mechanism takes advantage of the unused route entries recorded by intermediate nodes after the route discovery phase, illustrated by the summary of routing entries in Fig. 1. The details of reverse route construction for the ARR scheme are presented in the following section.

Reverse Route Selection

As shown in Fig. 1, the initial broadcast of RREQ packets has established a forward route through link S-A-E-D. In addition to the active nodes (S, A, E, D) along the forward route, other nodes such as C, B and F also record the RREQ entries pointing to the source node. As previously discussed, these nodes may be able to provide alternative routes to the RREP packet blocked by the unidirectional link A-E. After receiving the RREQ packet, node D responds by unicasting a RREP packet with RREP_NO_FLAG bit set. Additionally, prior to every RREP unicast transmission, each node, including the destination, stores a copy of the packet along with its contents. Such information can later be used by the local reply broadcast transmission, if the preceding RREP forwarding fails. At node E, the RREP packet is forwarded and, in return, node E expects to receive an ACK packet. To avoid high delay, node E waits for a short duration of time indicated by ACK_WAIT_TIME. If node E fails to receive the ACK packet, it results in node A being cached as unreachable. As such, node E promptly invokes the one-hop local reply broadcast mechanism. A copy of the previously stored RREP packet is broadcast to the adjacent nodes with TTL set to 1 and the flag is set to OHR (one-hop-reply broadcast).

Network Layer Acknowledgement

The introduction of ACK packets in the ARR scheme can cause a slight increase in terms of the overall system's routing overhead. Therefore, a necessary countermeasure has been implemented in the scheme to minimize such effects. The operation of ACK packet exchange can be significantly reduced if nodes are set to respond correctly to different type of RREP packet. In the scheme, the ACK packet can only be returned by the receiver node for a RREP packet with the flag bit set to RREP_NO_FLAG. Alternatively, an ACK packet is not returned when the flag bit is set to OHR. As a result, control packet exchange is minimized, leading to more efficient use of bandwidth.

Reverse Path and Local Reply Broadcast

When the propagation of RREP packet is blocked by a unidirectional link, ARR allows a node to rediscover alternative reverse paths. As a result, multiple copies of RREP packets may be received by the source node over several different paths. Such problem can be avoided by comparing the current and previous RREP broadcast packet. In addition, the recorded RREP packet is cached for only a short period of time set by RCAST_WAIT_TIME. The value must not exceed the roundtrip time of RREQ-RREP packet; the time difference between sending the RREQ and receiving the RREP at the source node.

The reverse link created by the local reply broadcast enables the source node to reach the destination node via an alternative reverse path. However, when using such paths, data packet can be transmitted only from the source node to the destination node, but not vice versa. This may not be an issue for some applications, which typically rely on fast data transfer and best effort delivery with using UDP. For instance, sending updates on stock markets, news, and bulletins to customers requires fast data dissemination but may compensate for unreliable communication. Nonetheless, a two-way communication can be enabled with the proposed scheme. Upon unidirectional link detection, an additional flag called RREPAIR is included to the RREP packet advertised by the local broadcast mechanism. The RREPAIR is set to indicate to the source node that the RREP packet has been recovered by one of the nodes along the reverse path. Therefore, when the source node receives a RREP packet with the flag set to RREPAIR, it reconstructs the forward path by propagating downstream a unicast RREQ packet towards the destination node. The packet follows the reverse path created, where details such as hop count and sequence number at each node's routing table are updated. Note that as soon as the RREQ packet is unicasted, the source node can start sending the data packets.

SIMULATION FRAMEWORK

The performance of ARR scheme is quantified using the NS-2 tool, which also provides the routing model for the AODV routing protocol and some basic components of AODV-Blacklist. The two protocols are ideal comparisons for the ARR scheme because both offer extreme mechanism to handle unidirectional links. At one end, the AODV routing performance can highlight the severe effect of ignoring the presence of unidirectional links. At the other end, the AODV-Blacklist shows the impact of improper handling of unidirectional link by blacklisting.

Mobility and Traffic Model

To observe the scheme's robustness to mobility, different nodal speeds are used within the mobility pattern. The Gauss-Markov (GM) mobility model is selected as it provides more realistic nodal movement compared with the classical Random Way Point (RWP) model. It is because the movement of nodes in this model is more human-like, which avoids sharp turns and sudden stops when travelling from one point to another. As such, the number of route breakages is small.

Table 1: Mobility and traffic parameters.

Parameter	Value
Transmitter range	~ 250 meter
.1Transmit power (Pthigh)	15 dBm
Transmit power (Ptlow)	7dBm
Receiver sensitivity	-91 dBm
Nominal channel bandwidth	Mbps

As shown in Table 1, the random traffic model is set as CBR, established between several randomly selected source and destination node pairs. The start of the CBR session between any pair of nodes is also randomized to avoid immediate bursts of data traffic being sent simultaneously by every source node. The size of each packet is 512 bytes set at a rate 4 packets/second; values commonly used in many previous MANET simulation work (Ariyakajorn, 2006, Huda et al., 2010, Khandal et al., 2017, Perkins et al., 2003, Ko et al., 2004). The simulation time is set to be 900 seconds, where each point plotted on the graph corresponds to 25 repetitions of the same simulation setting with different network scenario.

Transmitting Power

The radio interface equipped for each node on the network follows the settings of Cisco Aironet 350 wireless interface card. Two distinct transmitting powers are set to different numbers of nodes, Table 2 shows the radio settings used in the simulation.

Table 2: Simulation parameter – radio settings.

Parameter	Value
Simulation time	900sec
Number of nodes	50
Terrain size	700x500 m2
Traffic type	Constant Bit Rate (CBR)
Packet rate	4 packets/sec
Packet size	512 bytes
Number of sources	25
Maximum speed	0, 2, 4, 8, 12, 16, 20 m/s
Speed update frequency	2.5 s
Angle of std deviation	45 degree
Speed deviation	m/s

Performance Metrics

The following metrics are used to gauge the schemes performance:

- *Packet delivery ratio:* This value is the average ratio of total packet received at the receiver to the packets transmitted by the sender. Such metric shows the general performance of the scheme in terms of its capability to transmit as much data as possible to the destination. It may also represent the number of packets lost, which can be used to show the scheme's efficiency.

- *Normalized routing load:* Normalized routing load is the number of packets forward and sent by every node in the network to the number of data packet received at the destination node. A high normalized routing load indicates an inefficient network, where the number of data packets received is higher than the number of routing packets generated for a particular connection. Nonetheless, the normalized routing load is also affected by the number of nodes participating in the routing packet exchange. Hence, a low number of nodes participating in route propagation can result in low normalized routing loads.

- *Packet loss:* The failure of one or more transmitted packets to arrive at their destination. The packet loss metric is an absolute number of packets dropped in the network, which quantifies the analysis of packet propagation in the network.

- *Average delay:* Average delay includes all possible end-to-end delays caused by buffering during route discovery, queuing at the interface queue, re-transmission delays at the MAC, propagation time, and transfer time.

SIMULATION RESULTS AND DISCUSSION

The experiments are conducted to evaluate the performance of the routing scheme and compared under different network scenarios. The performance metrics are measured against the attributes that may occur in the network, which are:

- Ratio of nodes with low transmitting power (ratio of Pt_{low} to the total number of nodes).

- Mobility (speed of the nodes)

- In each simulation, there are a several parameters that are configured; these are:

Table 3: Ratio of Ptlow to total number of nodes.

Set No.	Set 0	Set 1	Set 2	Set 3	Set4	Set 5
Ratio of low power nodes(Pt-low)	0	0.1	0.2	0.3	0.4	0.5

Table 4: Simulation parameters – Varying number of low power nodes.

Parameter	Value
Transmitting power (Pthigh)	15 dBm
Transmitting power (Ptlow)	7d Bm
Simulation time	900 sec
Number of nodes	50
Terrain size	700x500 m2
Traffic type	CBR
Packet rate	4 packets/sec
Packet size	512 bytes
Number of sources	25
Maximum speed	20 m/s

- Speed: The speed of node is set between a minimum and a maximum possible setting.

- Number of nodes: A consistent number of nodes are set in every experiment.

- Terrain size: A medium-sized, rectangular network area is selected for experiments.

- Simulation time: The duration of simulation.

Varying Unidirectional Links

A node's transmitting power and its corresponding transmission range are important characteristics that determine whether or not a node can establish a path with its neighbors. By using two power levels the number of unidirectional links can be varied and the impact upon the relevant performance metrics can be investigated. Nonetheless, the effect may be temporary but may still affect the routing path computation. The number of unidirectional links (varied by using two power levels) is employed to investigate the impact it has on the metrics being used. The ratio of nodes, as reported in Table 3 shows 6 sets, where each ends of the table represent two extreme cases of unidirectional link intensity. Set 0 represents a network where all links are virtually bidirectional; although some links may become unidirectional link due to interference, mobility, and etc. On the other hand, set 5 signifies a network, where half of the nodes are low-powered. Such an extreme network scenario is useful to evaluate the robustness of routing protocols, although this may not be a realistic case. Nonetheless, increasing the low power nodes to set 5 is essential to ensure that a significant number of unidirectional links is created on the network. The summary of parameters used in the simulation is shown in Table 4.

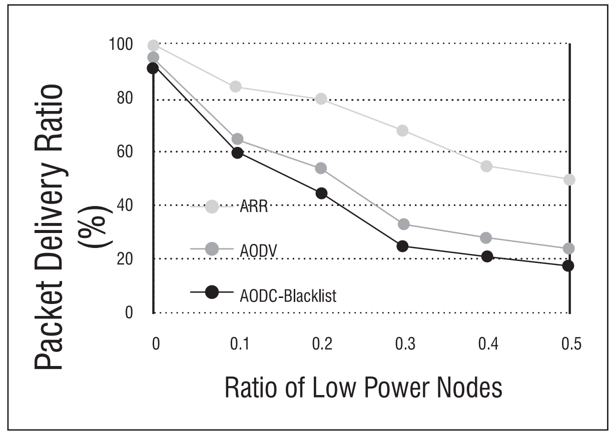

Fig. 2: Packet delivery ratio as a function of node power variables

Packet Delivery Ratio

The variation of packet delivery ratio as a function of low power nodes is shown in Fig. 2. As the number of low power nodes increases, the probability of links created unidirectional also increases. Hence, every routing protocol exhibits rapid deterioration of packet delivery ratio. In the case of set 0, which illustrates a homogenous group of nodes in terms of transmitting power, the performance of each scheme is quite close to each other. In fact, this is an ideal situation where every node performs effectively, because packets have higher probability of being forwarded via bidirectional links. Nonetheless, a slight difference can be observed within set 0. Since nodes are set to move at a maximum speed of 20 m/s, some RREP packets may be dropped. This causes the ARR scheme to invoke the unidirectional link detection mechanism. At set 0, the packet delivery ratio in ARR scheme is improved by 6% compared with the AODV routing protocol. Although the AODV-Blacklist offers nodes a protection from unidirectional links, the scheme relies on the source node re-broadcasting the RREQ packet which may increase delay and routing overhead. As such, the performance of AODV-Blacklist degrades; in particular after set 0.1. The inefficiency of AODV-Blacklist is also heightened by the fact that the network is saturated with the data traffic; a consequence of 25 simultaneous active data sessions. The congestion increases the competition for channel access, causing more packets to collide and subsequently be dropped.

The AODV scheme exhibits the worst performance. Specifically, at set 0.3, the AODV's packet delivery ratio drops as much as 66% compared with the ARR scheme. The absence of any unidirectional link detection mechanism causes the RREP packet propagation to fail and the source has to wait for the timer to expire before it is able to identify any problems. Generally, the ARR scheme exhibits a significant improvement compared with the AODV-Blacklist and AODV scheme.

Normalized Routing Load

The normalized routing load metric characterizes the ability of a routing scheme to perform in low bandwidth and highly dense network conditions. Protocols that operate on-demand typically rely on a high degree of routing packet dissemination to discover routes. Such mechanisms can potentially increase the probability of packet collisions and subsequently cause retransmissions. In essence, an efficient scheme should be able to minimize routing packets as far as possible while maintaining a

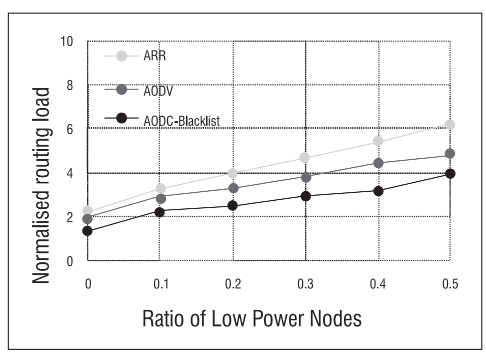

Fig. 3: Normalized routing load as a function of node power variables

high number of successful data packet transmissions. Fig. 3 presents the normalized routing load for a network consisting of 50 nodes.

The normalized routing load in ARR is much lower than AODV and AODV-Blacklist across all sets. Between set 0 and 0.1, the performance of AODV and AODV-Blacklist is nearly identical; however, as the ratio of low power nodes increases beyond set 0.1, the ARR's normalized routing load is significantly lower compared with the competing protocols.

Packet Loss

The packet loss of the three schemes as a function of low power nodes is shown in Fig. 4. In this simulation experiment, a sequence of packets are generated and transmitted according to the rate parameter. The data packet size is fixed to 512 bytes and, therefore, the total size of the accumulated loss packet can be easily computed. However, the packet loss quantification in a real network may be a more complex process. Transmitted packets arrive in different size and forms and as such, the total amount of traffic loss can significantly vary. In this simulation, the packet loss is quantified based on the total count of the packet, instead of the total accumulated packet size. As the number of nodes with Pt_{low} increases, more packets are dropped as a consequence of the increase number of unidirectional links present in the network. The packet loss in ARR is lower, simply because it enables routing packets to be partially propagated around the unidirectional link.

Average Delay

The average delay presents the cumulative holding time for a packet. It includes all possible delays from the moment the packet is generated, transmitted, and received by the destination node. Generally, the length of the routing path is a constituent part of the metric. Thus, a longer routing path generates a higher delay, since data packets take more time to reach the destination node. Fig. 5 depicts a variation of the average delay as a function of low power nodes. Every scheme shows a significant increase of average delay with the increase of the low power nodes. Such a phenomenon is a result of bidirectional link shortage in the network. The probability of successfully constructing a routing path is reduced, causing the number of route re-discoveries to increase. As such, the data packets are delayed in the queue until a new routing path is found. As shown in Fig. 5, the ARR's delay is substantially lower compared with the AODV-Blacklist and AODV routing protocols. Clearly, the ARR mechanism is effective when subject to unidirectional links. A routing path is promptly constructed by the affected node, thus avoiding the route discovery and buffering delay.

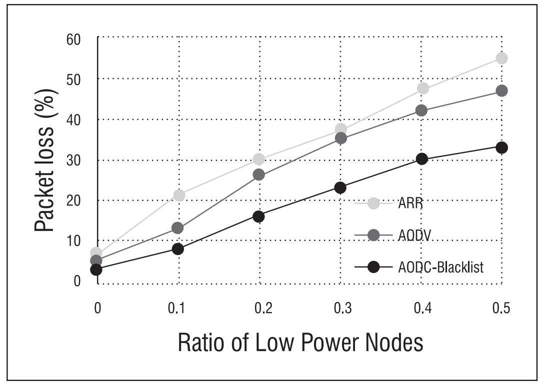

Fig. 4: Packet loss as a function of node power variables

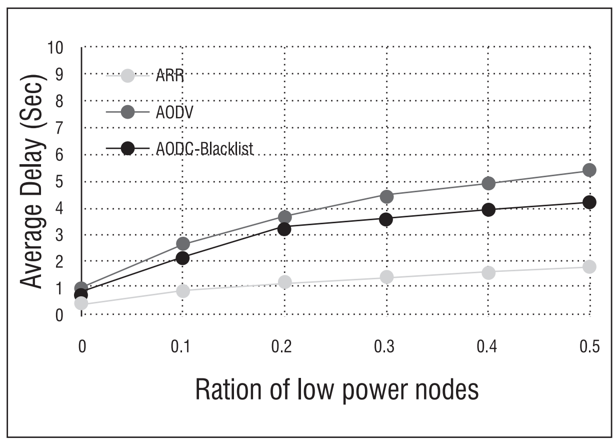

Fig. 5: Average delay as a function of node power variables

Varying Mobility

An important attribute that is commonly associated with MANET is mobility, which causes link state to change in a more dynamic fashion than a stationary system, thus, further impacting network performance. To investigate such an effect, the GM mobility model is selected to generate nodal movement pattern. Every node is mobile and the maximum speed is varied to increase a node's average speed. Typically, a static network corresponds to the speed of 0 m/s while a high mobility corresponds to a speed of 20 m/s. The simulation parameters used for the mobility simulations are similar to the experimental work listed in Table 4 but with minor changes. The changes made are shown in Table 5. Nodes are set with 7 different speeds while the ratio of low power nodes is set to 0.3. Such ratio is chosen because it gives a good compromise between bidirectional and unidirectional links.

Table 5: Simulation parameters – Varying nodes maximum speed.

Parameter	Value
Maximum speed (m/s)	0, 2, 4, 8, 12, 16, 20
Ratio of low power nodes (Ptlow)	0.3

Packet Delivery Ratio

The packet delivery ratio is shown in Fig. 6. The three schemes exhibit a gradual decrease as the maximum speed increases. At null mobility, i.e., 0 m/s, the packet delivery ratio of ARR scheme is approximately 29% better compared with the AODV scheme. At higher speed, the ARR's packet delivery ratio is twice as much as AODV's. Such performances indicate the effectiveness of ARR in handling the routing construction despite significant nodal movement. The AODV-Blacklist scheme indicates only a slight increase of packet delivery ratio compared with the AODV routing protocol. On average, the performance increase compared with AODV offered by AODV-Blacklist scheme is only 20%, which is about less than half of the performance gained by the ARR scheme.

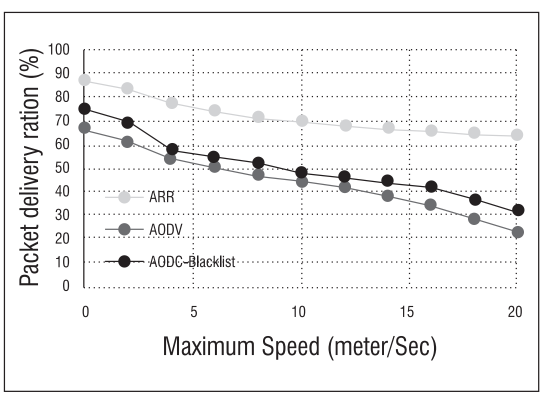

Fig. 6: Packet delivery ratio as a function of mobility

Normalized Routing Load

The normalized routing load performance metric is computed based on the number of control and data packet transmitted and forwarded by the protocol per successfully delivered data packet. Essentially, this metric quantifies the amount of effort consumed by the protocol for the delivery of each data packet. For instance, a normalized routing packet of 10 indicates an average of 10 packet transmissions attempts for each data packet delivered to a destination node. Hence, a normalized routing load of smaller than 1 signifies a highly very effective network. This indicates that the number of routing packets generated for that particular connection is lower than the number of data packets received at the destination node. Nonetheless, the normalized routing load can be affected by many factors such as the frequency of data packets sent, and the number of nodes participating in the routing packet exchange. Since the computation of this metric is based on a large number of nodes, i.e., 50 nodes, this explains the reason for the extremely high value of normalized routing load in every simulation output. In Fig. 7, the normalized routing load incurred by the ARR scheme is the lowest despite the presence of unidirectional links. Although the AODV-Blacklist scheme is able to detect and avoid unidirectional links, route construction may not be as efficient as the ARR scheme. Furthermore, the analysis on AODV scheme indicates an excessive number of routing packets being generated, a consequence of multiple RREQ flooding by the source node.

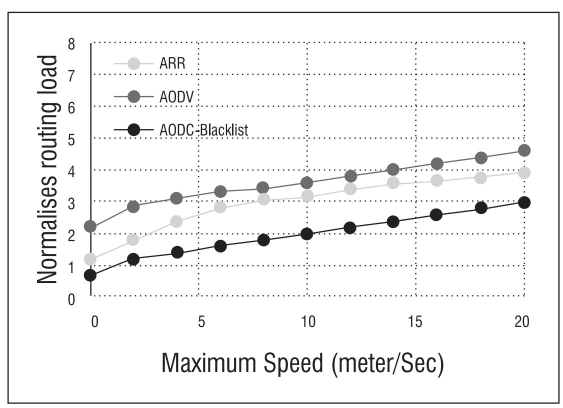

Fig. 7: Normalized routing load as a function of mobility

Packet Loss

The ARR scheme achieves the lowest packet loss, a consequence of prompt avoidance of unidirectional links during the recovery of routing path breakage as shown in Fig.. 8. Generally, every scheme exhibits a gradual increase of packet loss as nodal maximum speed increases. This is expected because, at higher nodal mobility, the links become more unstable, causing more packets to be dropped. At null mobility, a proportion of the links are unidirectional due to the non-identical transmitting power. As such, the packet loss is much higher compared with homogeneous radio power, shown by set 0 previously in Fig. 4.

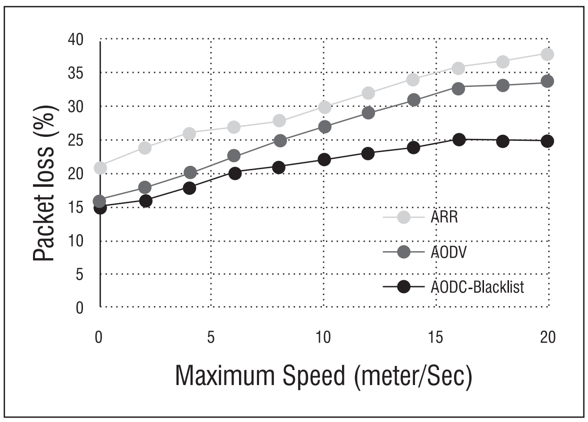

Fig. 8: Packet loss as a function of mobility

Average Delay

The average end-to-end delay as a function of the number of sources is shown in Fig. 9 and illustrates that ARR has a lower average delay across all different maximum speeds. Typically, the delay to construct a routing path may dominate the overall delay incurred in the system. The ARR scheme experiences the lowest average delay simply as a result of lower route discovery latency. The effect of increasing the maximum node speed is clear when comparing the ARR to the competing schemes. The ARR scheme is least affected by the mobility because of the rapid procedure to recover packets and find alternative paths around the unidirectional link. In general, the three schemes show an increasing average delay as the maximum node speed increases. Between 0 and 20 m/s, the ARR scheme exhibit an increase of average delay by as much as 83% when compared with AODV and AODV-Blacklist. Nonetheless, its performance is still better than that of AODV and AODV-Blacklist. Both these schemes incur an average delay (at a speed of 20 m/s) that is approximately 300% higher compared with static nodes.

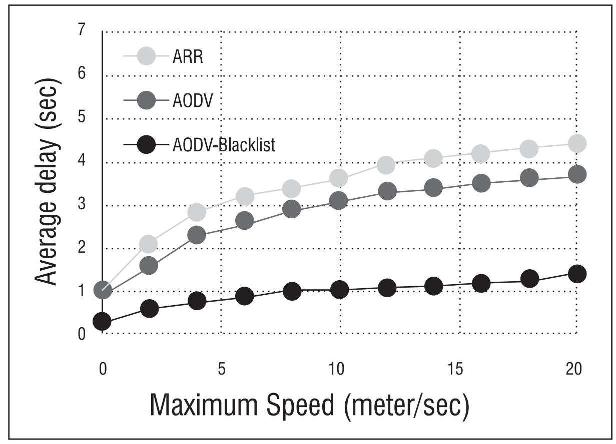

Fig. 9: Average delay as a function of mobility

CONCLUSION AND FUTURE APPLICATION

The scheme is proposed to mitigate the network performance issues caused by unidirectional links. The scheme partially allows the routing protocols to be forwarded via unidirectional link but maintain the data propagation via bidirectional path. The scheme reacts to the unidirectional link by employing a passive detection scheme using ACK packet. The failure to receive such packet triggers the local reply broadcast, which utilizes the temporary route entries stored in the neighbor nodes. Subsequently, alternative paths can be rapidly built, which results in lower delay and lower routing overhead. The advantages of the ARR scheme compared with the existing approaches are a) simplicity b) ability to minimize the routing overhead and delay incurred as a result of multiple route broadcast, and c) rapid recovery from the failure of reverse route breaks by utilizing all possible links pointing to the source node. The proposed scheme is comprehensively evaluated using NS-2 and its advantages are illustrated over the competing protocols. The ARR scheme is analyzed under wide range of scenarios with varying ratio of unidirectional links and mobility. The ARR scheme proposed in this paper is superior to AODV and AODV-Blacklist. The ARR has shown considerable improvement when the network has unidirectional links and when the nodes have mobility.

A possible future application for the proposed scheme is for data tracking of environmental conditions, animal movements, and chemical or biological detection, where nodes are equipped with small wireless tracking devices that are typically limited in terms of battery power. In such a case, it can be difficult to replenish the battery power and thus, the radio transmission range can be severely affected. Consequently, a high number of unidirectional links may be formed, causing the significant degradation of network performance. Other possible applications include information/bulletin aware services in theme parks, outdoor network access using ad hoc wireless network, and ad hoc communication during meetings or lectures in campus. Nonetheless, despite the significant reduction of delay, the proposed scheme may not be suitable for vehicle-to-vehicle network applications, which require a scheme that can provide route stability with high nodal mobility.

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