A New Routing Protocol in Ad Hoc Networks with Unidirectional Links*

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Abstract. Most of the proposed algorithms in ad hoc networks assume homogeneous nodes with similar transmission range and capabilities. However, in heterogeneous ad hoc networks, it is not necessary that all nodes have bidirectional link with each other and hence, those algorithms may not perform well while deployed in real situations. In this paper, we propose a scheme for an ad hoc on-demand routing protocol which utilizes the unidirectional links during the data transmission. Simulation shows that it is not only possible to use unidirectional links but it is also better in terms of performance metrics we defined in different situations.

1 Introduction

Ad hoc networks have emerged as a solution for the type of network where no infrastructure exists and various types of devices communicate with each other in a self-organizing fashion. Military scenarios, disaster relief situations are the examples where diverse communication equipments communicate in multi-hop fashion without any infrastructure. Since devices vary in types and capabilities, heterogeneity prevails in such network scenarios. However, many proposed algorithms assume homogeneous nodes with similar transmission radius and capabilities [1], and hence may not perform well while deployed in real situations.

A unidirectional link arises between a pair of nodes in a network when a node can send a message to another but not vice versa. Let us consider two nodes A and B. If A has the higher transmission range compared to B and the distance between them is greater than the transmission range of B, acknowledgement from B cannot be received by A. In this case both will assume that the link does not exist between them. One of the major causes for the existence of such links is the variation in transmission range of nodes. These links also arise due to collision or noise, which however does not persist for a long time.

The detection of unidirectional links provides two options for routing protocols: (1) either avoid the route or (2) utilize it for current data transmission.

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Avoiding the path with such links incur higher cost of route re-discovery and also lead to network partitions. On the other hand, utilization may cause variability in path affecting upper layer protocols. In this paper, we propose to utilize these links resulting from the disparity of transmission range due to heterogeneity. Using such links has an advantage of retaining the connectivity and using the shortest path route. We show that the routing protocols can effectively use it for data transmission without having to restart route discovery process.

In the performance analysis, proposed scheme is compared with AODV-EUDA [1] using random mobility and static model. We show that the proposed scheme is better based on metrics implying that using unidirectional links for on-demand ad hoc routing protocol is not only possible but also better in terms of efficiency. For the sake of readability, we refer to [1] as the AODV-EUDA.

In the next section we briefly describe research efforts that is close to our work. In Section 3 we present our scheme. In Section 4 we present performance analysis and finally conclude in Section 5.

2 Related Works

Problems encountered due to unidirectional links are uncommon as many routing protocols cannot function normally in such conditions. Unidirectional links affect AODV protocol [2] by causing route discovery failures even in presence of alternate bidirectional paths between source and destination. This is due to the occurrence of such links in the shortest path, where route replies fail to reach the source and re-discovery process recurrently attempts to find the path through same set of nodes. This problem is well illustrated in [1] and [3]. Some of the schemes that handles unidirectional links are studied in [4], [6], [7]. All of these previous approaches avoid the path containing unidirectional links. Our paper extends upon the recently proposed algorithm that detects unidirectional links called AODV-EUDA [1]. In AODV-EUDA detection is immediately done when it receives a RREQ packet during route discovery process. A node embeds its power information either in RREQ or a MAC frame. Each receiving node calculates the distance between itself and the RREQ sender from the parameters in RREQ and compares with its maximum transmit range. The link is unidirectional if its transmit range is shorter than the computed distance and hence discards that RREQ and waits for other RREQs from other bidirectional links. Unlike avoiding unidirectional links detected in AODV-EUDA, in our scheme, we utilize unidirectional links for data packet delivery.

3 Routing with Unidirectional Link

For the purpose of utilizing unidirectional links our scheme requires two steps. In first step, a node detecting a unidirectional link (as in AODV-EUDA) initiates election mechanism for selecting a monitor node. A *monitor node* is a node in a routing path that has a bidirectional link with both sender and receiver. In second step we utilize unidirectional link for successfully transmitting data by

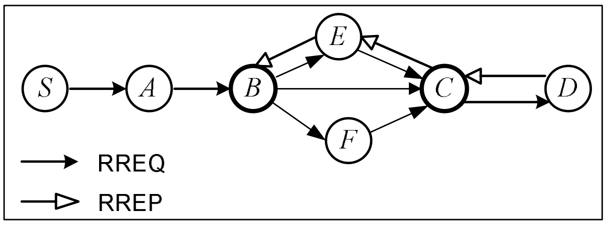

Fig. 1. E and F sends RREQ to C that decides one as a monitoring node. Here, E (monitor) replies with ACK to B.

local broadcast and receive acknowledgement from the monitor node. Detailed operation of our scheme is presented below.

3.1 Election of Monitoring Node

During route discovery process, while RREQ is being forwarded from the source to destination, node that detects the unidirectional link buffers them instead of forwarding immediately to other nodes for some time period. During this period, if it receives RREQs from the node that has a bidirectional link with itself and the sender, it selects a monitor node from which the first RREQ is received. Note that the collected RREQs must be the ones from the sender node with which the receiver has a unidirectional link. A sender is made aware about the monitor node when RREP is received back from the receiver.

In Fig 1, both E and F send RREQ to C and have bidirectional links with both B and C. C does not immediately forward the RREQ that was received from B, unless other RREQs are received from E and F. So assuming that E's RREQ is received earlier then F, C will select E as the monitor. In the process of sending RREP back to the source, sender B receives RREP from the monitor and hence is informed about the unidirectional link with C.

3.2 Utilizing Unidirectional Links

A sender node aware of unidirectional link needs to locally broadcast data packets so that they can be received by its neighbor nodes. A receiver node with a path further unicast these data packets towards the destination.

A monitor node in between receives passive acknowledgement through overhearing and passes it over to the sender. From this indirect acknowledgement, sender with the outgoing unidirectional link gets confirmation about the proper delivery of the data. This mechanism is illustrated in Fig. 2. Following from the previous example B is aware of the unidirectional link with C. First, when B receives the packets from A, it is locally broadcasted so that both E and C will receive the packet. C delivers this packet to D and at the same time, passive acknowledgement is received by E (a monitor node) through overhearing. Finally, the acknowledgement is sent from E to B. This ensures the proper delivery of the packet through unidirectional link.

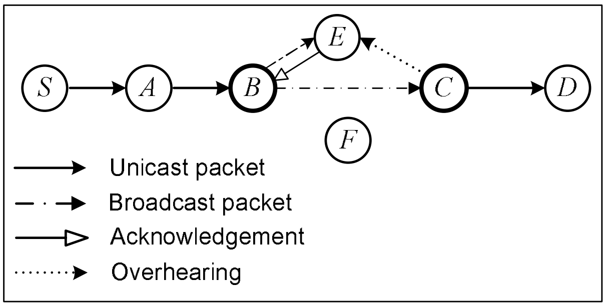

Fig. 2. Local broadcasting of data packets from node, Overhearing by and receiving acknowledgement from E

It is also possible that monitor node can change its location due to mobility and may not be reachable for overhearing. For example, E shifts its position from the current location and becomes unreachable from B. In such cases B will try to re-transmit the data packet three times, and if not successful it will send the route failure error back to source S for route re-discovery. In another situation, if the monitor node is not present in the scene, our protocol subsumes to AODV-EUDA.

4 Performance Evaluation

4.1 Simulation Environment

In this section, our scheme is compared with AODV-EUDA. We performed a simulation using the network simulator ns-2 in static and random mobility model with 100 nodes. In random mobility model all nodes move around a rectangular region of size 1500x300m^2. Speeds ranging from 0m/s to 20m/s are used without pause. Total simulation time is 900 sec and each scenario is repeated ten times. Traffic pattern consists of 10 CBR connections running on UDP generating four 512-byte data packets per second. In static model we linearly increased unidirectional links from 1 to 5, around the rectangular region of size 2000x300m^2 with a simulation time of 300sec.

4.2 Simulation Results

In our experiments, we capture the performance based on packet delivery ratio, delay and energy consumption for both protocols. Fig. 3(a) shows that the packet delivery ratio of the proposed scheme and AODV-EUDA is similar in static model. Both algorithms achieve route on the first attempt by the source, for AODV-EUDA (at least if one bidirectional link is available) and for the proposed scheme even if unidirectional link is present. Fig. 3(b) shows the packet delivery ratio as a function of variation of the maximum speed of nodes. As the mobility of node increases, our proposed scheme shows weaker performance

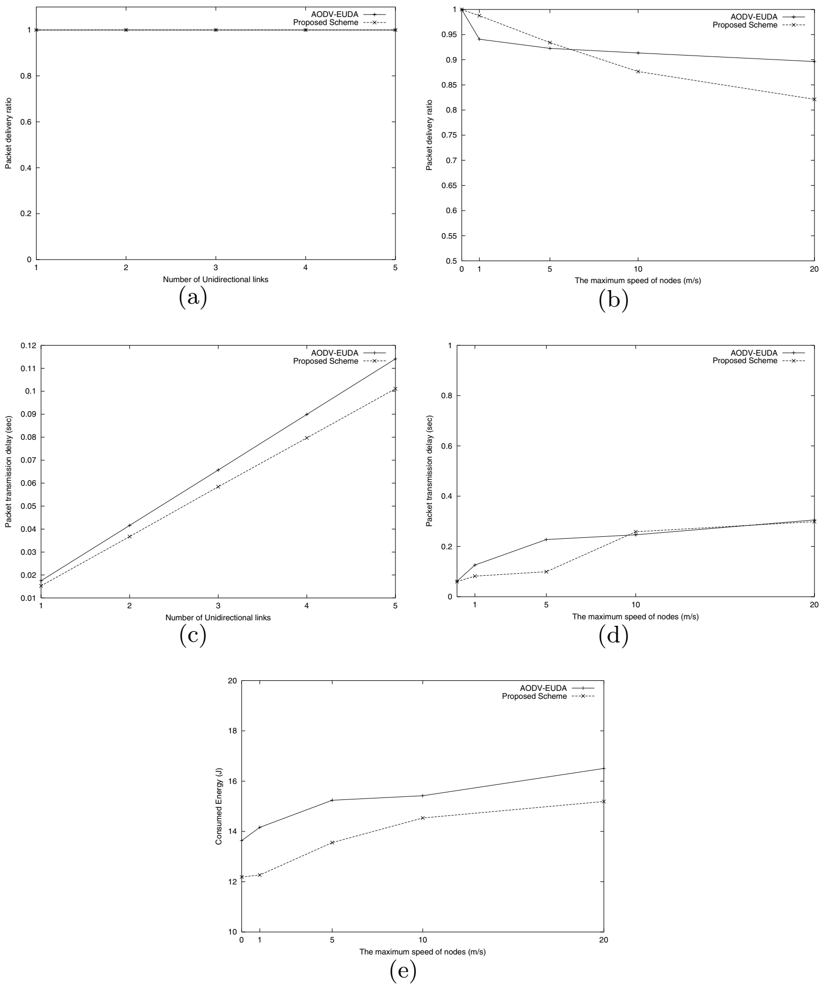

Fig. 3. Results on (a) Packet delivery ratio in static model (b) Packet delivery ratio in mobility model (c) Delay in static model (d) Delay in mobility model (e) Energy consumption

than AODV-EUDA. By analyzing the traces, we found that the stability of unidirectional links becomes poor with the increase in the mobility of nodes. Next, in Fig. 3(c) and (d) we report average end to end delay in static and mobile scenario respectively. Our scheme provides better shortest path in using unidirectional links, and hence shows lesser delay than AODV-EUDA. However, if the mobility of nodes becomes high and the route break occurs more frequently, the route re-discovery time is added to the end-to-end delay. Fig. 3(e) shows the normalized consumed energy per node of the two protocols as a function of the maximum speed of nodes. We can see that, AODV-EUDA consumes more energy then the proposed scheme. It is due to the fact that the number of nodes participating in route discovery decreases when we utilize the unidirectional links. As the mobility of nodes becomes high and the number of control packet increases, both protocols consume more energy. However, the normalized consumed energy is consistently lower for the proposed scheme as it is affected by total bytes (or bits) of data transmitted by nodes. As the amount of successfully delivered packet dominate total bytes, despite of high mobility, proposed scheme consumes less energy than AODV-EUDA.

5 Conclusion

In this paper, we have described a novel scheme that shows how unidirectional links can be effectively used by routing protocols. Results show that our scheme shows better performance in many cases as compared with protocols running over bidirectional links. Our protocol consistently selects the shortest route, consumes lesser energy and shows comparable throughput. So we conclude that utilizing unidirectional link can be beneficial in heterogeneous mobile ad hoc networks. In this research, utilization of unidirectional links has been done over AODV protocol, however any other situation routing protocols can also utilize this technique.

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