Impact of Node Density on Cross Layer Design for Reliable Route Discovery in Mobile Ad-hoc Networks

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Abstract :
　　　The mobile nature of nodes and dynamic topology of Mobile Ad-hoc Networks (MANETs) lead to route failures and requiring the transmission of control packets. It is important to reduce the number of control packets to save resources and to improve the overall performance of the network. Ad-hoc On-demand Distance Vector (AODV) is appealing as an efficient on demand routing protocol because of low routing overhead and high performance. However, AODV is not robust against topology variations as it uses weak links due to long hops introduced by shortest path metric. In this paper we propose a mobility adaptive cross layer design to enhance the performance of AODV routing protocol by establishing stable routes. The adaptive decision making according to the speed of mobile nodes on Route Request (RREQ) packet forwarding results in stable routes. We also test the impact of node density in the network on our algorithm, to tell, when to invoke the our cross layer design in mobile ad-hoc networks. To demonstrate the efficiency of our protocol and its impact on network connectivity, we present simulations using network simulator, GloMoSim.
Keywords: Mobile Ad-hoc Networks, AODV, Routing Overhead, Stable Route, and Cross Layer Design.

I. Introduction

　　　Recent growing interest on potential commercial usage of MANETs has led to the serious research in this energy and bandwidth constrained network. It is essential to reduce control packet overhead as they consume resources. Routing in MANETs is non trivial. Since mobile nodes have limited transmission capacity, they mostly intercommunicate by multi-hop relay. Multi-hop routing is challenged by limited wireless bandwidth, low device power, dynamically changing network topology, and high vulnerability to failure and many more. To meet those challengeous, many routing protocols have been proposed for MANET [1]. They are categorized as proactive and reactive protocols. Proactive protocols such as DSDV periodically send routing control packets to neighbors for updating routing tables. Reactive routing protocols such as

AODV and DSR send control packets only when route discovery or route maintenance is done. When a route is created or repaired, the control packets, particularly RREQ packets flooded by source is network wide broadcast. Moreover, the number of control packets increased rapidly with network size and topology changes.

　　　The primary goal of an ad-hoc network routing protocol is correct and efficient route establishment between a pair of nodes so that messages may be delivered in a timely manner. Route construction should be done with a minimum of overhead and bandwidth consumption. The on-demand routing protocols create route only when desired by the source node. When a node requires a route to a destination, it initiates a route discovery process within the network. This process is completed once a route is found or all possible route permutations have been examined. Once a route has been established, it is maintained by a route maintenance procedure or until the route is no longer desired. The Ad-hoc On-Demand Distance Vector routing protocol builds on the Destination Sequenced Distance Vector (DSDV) algorithm. It is an improvement on DSDV because it typically minimizes the routing load by creating routes on a demand basis.

　　　AODV [2] is a pure on-demand route acquisition system, since node that are not on a selected path do not maintain routing information or participate in routing table exchanges. When a source node desires to send a message to some destination and does not already have a valid route to that destination, it initiates a "route discovery" process to locate the destination. It broadcasts a route request packet to its neighbours, which then forward to their neighbours and so on, until either the destination or an intermediate node with a "fresh enough" route to the destination is located. During the process of forwarding the RREQ, the intermediate nodes record in their route tables the address of the neighbor from which the first copy of the broadcast packet is received thereby establishing a reverse path. If additional copies of the same RREQ are later received, these packets are discarded. Once the RREQ reaches the destination or an intermediate node with a fresh enough route, the destination /

intermediate node responds by a unicast route reply (RREP) packet back to the neighbor from which it first received the RREQ. (The route maintenance process and other details of AODV are not considered here as they are out of scope of this paper).

AODV prefers longer hops to form shortest path, which in turn makes route with weaker links. The presence of node mobility may induce route failures (link failures) frequently. Many studies have shown that the on demand approach is relatively quite efficient under a wide range of scenarios. But when seen in isolation, route discovery component is the major bottleneck in on demand protocols. Since route discovery is done via network wide flooding, it incurs significant routing overhead and eats greater network resources. Actually, the longer distance between intermediate nodes on the route rises route maintenance cost, reduces the packet transmission rate (due to increased packet loss), and induces frequent route failures [3].

In our previous work, we proposed a cross layer design extension to AODV in order to form stable routes. It reduces route failures and hence, keeps routing overheads as low as possible, at the cost of lengthy routes with more hops. In this paper, we go further in enhancing AODV performance, by using mobility based adaptive cross layer design to optimize the trade off between route stability and number of hops. Our objective is to form reliable routes in order to reduce number of routing control packets, and thus conserving network resources.

The proposed mobility adaptive cross layer design couples the route discovery process with physical layer related received signal strength information and speed of mobile nodes to built stable and optimum routes. As these constraints on received signal strength and node speed will certainly have an impact on network connectivity, we also study the suitability of our algorithm under various node density levels. The remainder of this paper is organized as follows. In section II, we present the related work and emphasize the need for cross layer design. Section III describes the proposed mobility adaptive cross layer algorithm. The simulation model, results and analysis are presented in section IV. Finally we conclude our discussion in section V.

II. Related Work

As an optimization for the current basic AODV, in [4], a novel stable adaptive enhancement for AODV routing protocol is proposed, which considers joint route hop count, node stability and route traffic load as a route selection metric. A QoS routing protocol based on AODV to provide higher packet delivery ratio and lower routing overheads using a local repair mechanism is proposed in [5]. The received signal strength changing rate is used to predict the link available time between two nodes to find out a satisfying routing path in [6], which reports improvement in route connection time. In [7], route fragility coefficient (RFC) is used as routing metric, to cause AODV to find a stable route. Mobility aware agents are introduced in ad-hoc networks and Hello packets of AODV protocol is modified in [8] to enhance mobility awareness of node to force it to avoid highly mobile neighbor nodes to be part of routes and ultimately to reduce the re-route discovery. On receiving the Hello Packet with GPS co-ordinates of the originator, mobility agent compares them with previous ones and hence has awareness about the mobility of the originator with references to itself.

In [9], an AODV based protocol which uses a backbone network to reduce control overhead is proposed. The destination location is given by GPS and transmitted to source by the backbone network to limit the route search zone. But formation of an additional backbone network and GPS enabled service are extra burden for infrastructure-less ad-hoc network implementation. In order to cope with problems such as the poor performance of wireless links and mobile terminals including high error rate, power saving requirements and quality of service, a protocol stack that considers cross layer interaction is required [10].

Multi-hop routing, random movement of the nodes and other features unique to ad-hoc networks results in lots of control signal overhead for route discovery and maintenance. This is highly unacceptable in bandwidth-constrained ad-hoc networks. Usually the mobile devices have limited computing resources and severe energy constraints. Currently ad hoc routing protocols are researched to work mainly on the network layer. It guarantees the independency of the network layer. However each layer needs to do redundant processing and unnecessary packet exchange to get information that is easily available to other layers. This increases control signals resulting in wastage of resources such as bandwidth and energy. Due to these characteristics, there is lot of research work happening in the performance optimization of ad-hoc networks. However, most of the research works are based on optimization at individual layer. But optimizing a particular layer might improve the performance of that layer locally but might produce non-intuitive side effects that will degrade the overall system performance. Hence optimization across the layers is required through interaction among layers by sharing interlayer interaction metrics [11]. By using cross layer interaction, different layers can share locally available information. This is useful to design and standardize an adaptive architecture that can exploit the inter-dependencies among link, medium access, networking

and application protocols. The architecture where each layer of the protocol stack responds to the local variations as well as to the information from other layers is a major challenge [12].

Cross layer interaction schemes that can support adaptability and optimization of the routing protocols can discover and maintain the routes based on current link status, traffic congestion, signal strength etc. Usually routing layer is not concerned with signal strength related information handling. Lower layer takes care of signal strength related issues. Signal strength can be useful to know the quality of link to select for best effort packet forwarding and to achieve power conservation [13]. Only the link with signal strength above the threshold value can forward the packet. Routing algorithm can exploit signal characteristics related information for such benefits.

In the previous work on Reliable AODV [14], we used signal strength information as interlayer interaction parameter. The strength (received power) of RREQ broadcast packet is passed to the routing layer by the physical layer. In the routing layer the signal strength is compared with a pre-defined threshold value. If the signal strength is greater than the threshold, the routing layer continues the route discovery process. Otherwise the Reliable AODV drops the RREQ packet. This leads to formation of routes with strong links where adjacent nodes are well within the transmission range of each other. So, even when the nodes are moving, the probability of route failure due to link breakages would be less with Reliable AODV, compared to the existing Basic AODV. The threshold value is set suitably with reference to the nodes' transmission power which dictates the transmission range. The essence of Reliable AODV is illustrated in Fig.1 where the node A sends a RREQ which is received by its neighbors B and C. As the received signal strength at node B exceeds the threshold, it forwards the RREQ but the node C drops the RREQ because it is close to the transmission range boundary of node A and hence has a weak link to node A.
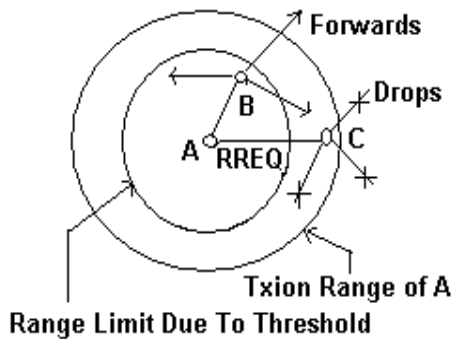

Fig. 1 Reliable AODV

The fixed threshold value used is independent of speed of mobile nodes and it may not be justified to low speed nodes. Hence, in this new adaptive cross layer design, we propose adaptive decision making of RREQ forwarding in accordance with speed of mobile nodes which is discussed in the following section.

III. Mobility Adaptive Cross Layer Design

Routing protocol may let route / link failure happen which is detected at MAC layer by retransmission limits, but dealing with route failure in this reactive manner results in longer delay, unnecessary packets loss and significant overhead when an alternate new route is discovered. This problem becomes more visible especially when mobile nodes move at high speed where route failure is more probable due to dynamic topology changes and negative impact of control packet overhead on network resources utilization is of more significance. We emphasize that routing should not only be aware of, but also be adaptive to node mobility. Hence we propose mobility adaptive cross layer design.

In this cross layer design a node receiving signal, measures its strength and passes it from physical layer to routing layer. We also assumed that information about speed of the node is available to it. Hence the signal strength, when receiving RREQ packet which is a MAC broadcast, is passed to routing layer along with the speed information of the node. The AODV routing protocol's route discovery mechanism is modified to use the above two parameters in making a decision on forwarding / discarding the RREQ packet.

The received signal strength is measured and used to calculate the distance between the transmitting and receiving nodes. The two ray propagation model is considered, where the loss coefficient value used is 2 as the maximum transmission range (d_{max}) of nodes is 350 meters which corresponds to 10dBm transmission power. Hence the received signal strength can be expressed as

$$P_r = P_t \ (\lambda / 4\pi d)^2 \qquad (1)$$

Where, Pt - Transmission Power

λ - Wavelength in meters

and   d - Distance between transmitting and
receiving nodes

Also the unity gain omni directional transmitting and receiving antennas are considered.

When the RREQ packet is presented with received signal strength information to the AODV implementation of the node, it calculates its distance from transmitting node using,

$$d = Sqrt \ (P_t / P_r) * (\lambda / 4\pi) \qquad (2)$$

Next, the receiving node calculates its distance to the transmission range boundary of the

transmitting node using the known maximum transmission range (d_{max}) as,

$$d_b = d_{max} - d \qquad (3)$$

The minimum time needed for a node to go out of the transmission range boundary of the transmitting node depends its distance from the boundary and the speed as given below.

$$t_b = d_b / \text{Speed} \qquad (4)$$

If the source specifies a minimum route life-time (t_l), in its RREQ packet, any intermediate node receiving that packet can calculate its safe distance from transmission range boundary using its speed information as

$$d_s = t_l * \text{Speed} \qquad (5)$$

It is now possible to the node to make a decision on forwarding the RREQ. That is, the decision rule inserted in AODV route discovery mechanism is,

$$\{\text{If } (d_b \geq d_s),$$
$$\text{then forward RREQ}$$
$$\text{else drop RREQ }\}. \qquad (6)$$

Hence the route discovery mechanism of AODV routing protocol is made adaptive to the node speed, which leads to the formation of more stable (reliable) routes. The parameter t_l, the minimum route life-time, is application specific.

This adaptive algorithm will certainly reduce the hop count and hence the average end-to-end delay of data packets than those incurred with fixed signal strength threshold based RREQ processing. To show the efficiency of our new adaptive algorithm, simulation results are presented in the next section.

IV. Simulation Model and Result Analysis

The simulation for evaluating the problem is implemented within the GloMoSim library [15]. GloMoSim provides a scalable simulation environment for wireless network systems. It is designed using the parallel discrete event simulation capability provided by PARSEC, a C based simulation language developed by parallel computing laboratory at University California at Los Angels, for sequential and parallel execution of discrete event simulation models. The simulation area is 1000 x 1000 square meters size, where nodes are placed uniformly. The transmission power and receiver threshold level of nodes are 10dBm and -81dBm respectively. The random way point mobility model is used. In this model, each node chooses a random destination and move towards that destination with a random speed chosen between the minimum and maximum values specified. The node then waits there for the specified pause time and continues it movement as described above. The bandwidth of shared wireless channel is assumed to be 2 MHz. The physical layer employs two ray propagation model. The nodes use the distributed co-ordination function of IEEE 802.11 WLAN [16]

standard with RTS / CTS extension and provide link layer feedback to routing layer. The CBR traffic of 4 packets per sec, with 512 bytes packet size is used. There are two randomly chosen source-destination pairs and each source generates 4200 packets. Simulations are run for 1200 seconds and each data point represents an average of at least four runs with different seed values.

Identical mobility and traffic scenarios are used across the three protocol variants. The fixed signal strength threshold used in AODV-Fixed variant is -78dBm whereas AODV-Adaptive used received signal strength and speed of mobile nodes passed from physical layer through cross layer interaction. The minimum route life-time requirement is set as 4 seconds. We used the following five parameters to evaluate the performance of the protocol variants: 1) Number of routes selected (implies route failures), 2) Number of RREQ packets transmitted (counted hop-by-hop basis), 3) Packet delivery ratio, 4) Number of Hops and 5) Average end-to-end delay.
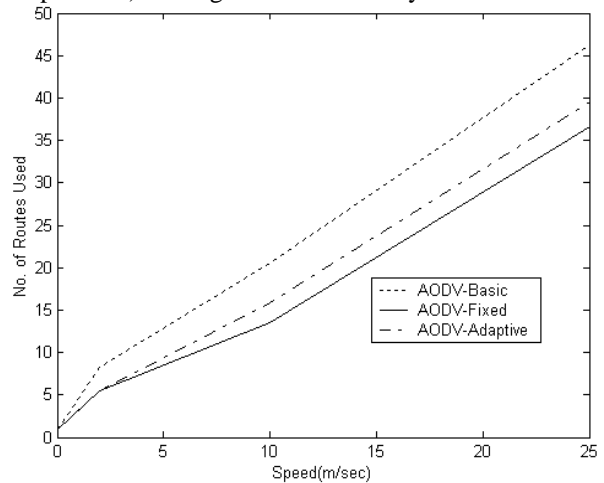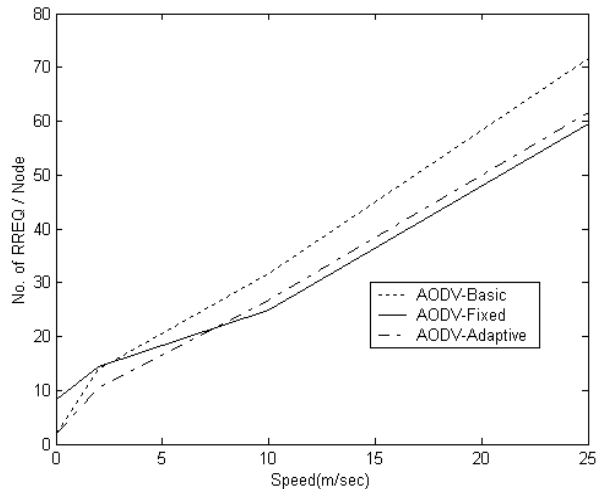

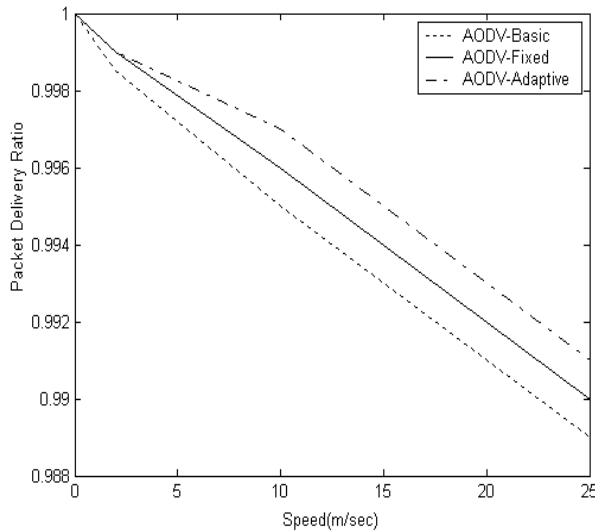Fig 2. Route Failure Frequency

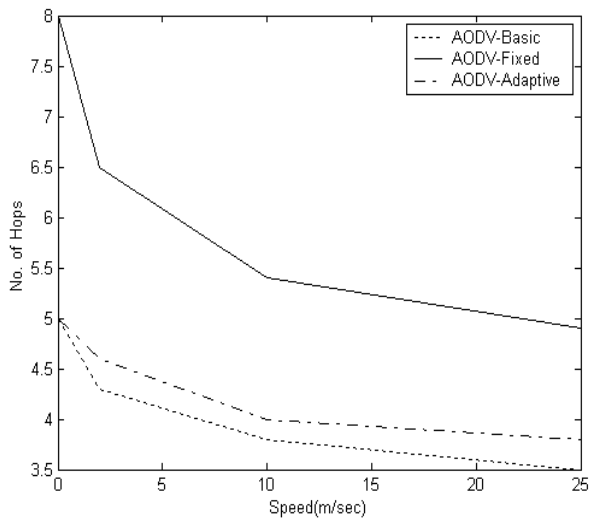Fig 3. Routing Overhead

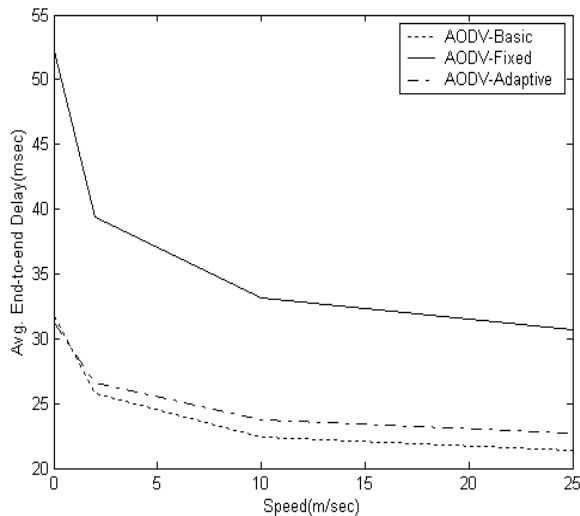Fig 4. Reliable Packet Delivery

Fig 5. Average Path Length

Fig 6. Delay Performance

In the experiment to study the effect of mobility, the maximum speed of nodes is varied between 0-25 m/sec, where 49 nodes are used in the simulation. Fig 2 shows the number of routes used by three protocol variants. The Fixed and Adaptive AODVs result in reduced number of routes selected, i.e. reduced number of route failures that reflect the formation of reliable (more stable) routes. Hence the number RREQ sent by nodes also got reduced as shown Fig 3. We could also infer that usage of fixed threshold value leads to reduced connectivity, particularly at very low speed ranges, which make AODV-fixed to suffer with increased RREQ broadcast during route search process. The improvement in packet delivery ratio is reflected in Fig 4.

Both AODV-Fixed and AODV-Adaptive variants outperform AODV-Basic, because of stable route formation. But this improvement is at the cost of increased number of hops, which is shown in fig 5. This figure also highlights the need of mobility adaptive route discovery which optimizes routes with speed information and helps in reducing the average end-to-end delay of data packets significantly than those incurred with fixed threshold usage. Fig 6 shows the delay performance of three protocol variants.

Further, in order to explore the impact of node density on the proposed new cross layer algorithm, we conducted another experiment, in which the node density is varied between 16 and 64 nodes in 1000 x 1000 sqm area. The maximum speed of mobile nodes is set as 25 m/sec. The imposed signal strength threshold and minimum route life-time constraints reduce network connectivity, which is shown in Fig 7. The number of routes used by AODV-Fixed variant is relatively low at very low node density, which does not imply formation of stable routes but reflects scarcity of network connectivity. The repeated search for connectivity increases the RREQ broadcasts in AODV-Fixed variant which is presented Fig 8. But, the performance of AODV-Adaptive excels in this regard. Hence, the control packet overhead is under control even in lightly densed network with our adaptive algorithm.

The packet delivery ratio suffers when these constraints are enforced in lightly densed networks. The improvement is visible only when network density increases beyond a particular level as shown in Fig 9. So, it is clear that cross layer design using signal strength threshold is useful and improves network performance in highly densed networks where redundantly available links ensure required network connectivity. Where as the new adaptive algorithm makes a trade off in this regard between the basic and fixed AODV variants. Hence when to invoke cross layer algorithm is also an important design issue.
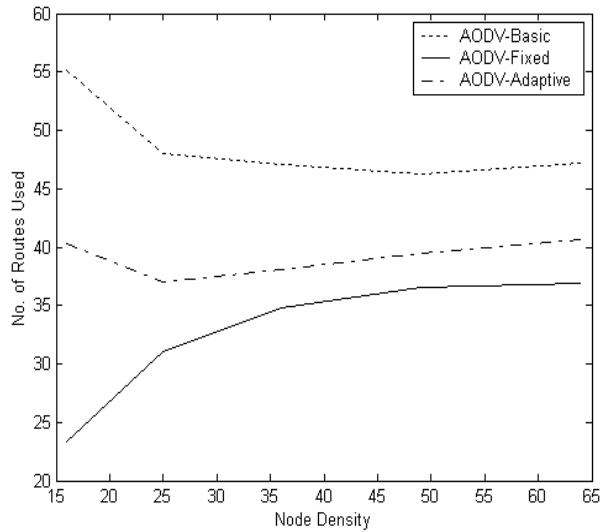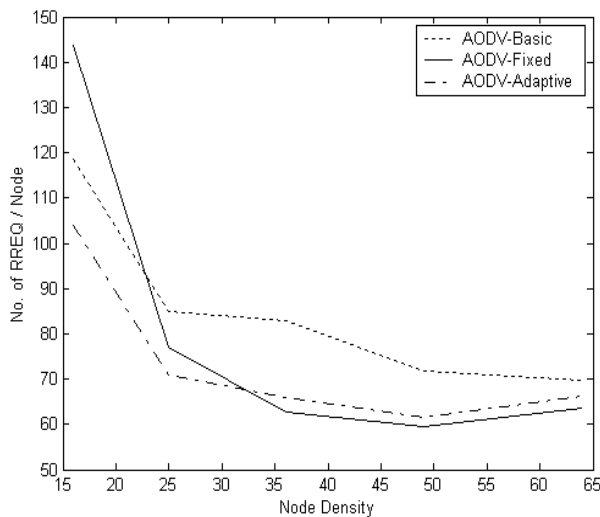
Fig 7. Node density vs Route Failures
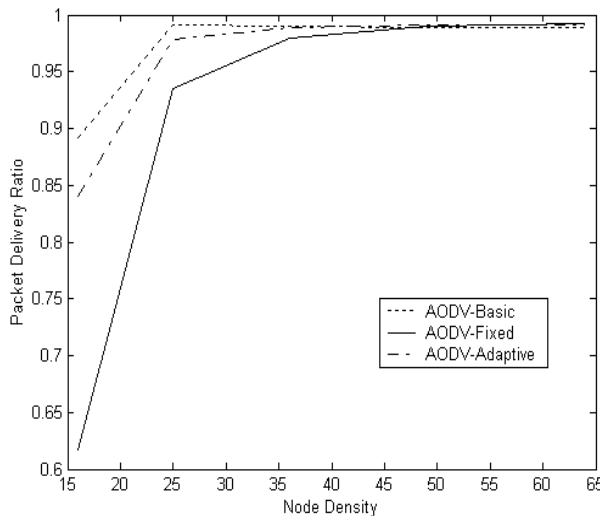

Fig 8. Node Density vs Routing Overhead

Fig 9. Node Density vs PDR

V. Conclusion

We observe that the cross layer AODV with fixed threshold reduces the number of route failures and routing overheads, at the cost of increased hop counts and average end-to-end delay. Certainly the proposed mobility adaptive algorithm for route discovery optimizes the above trade off. The AODV-Adaptive variant reduces number of hops and delay to a greater extent and brings them closer to those of AODV-Basic variant. It is important to note that both cross layer AODV variants improve the packet delivery ratio, but at the cost of slightly increased end-to-end delay. However, the reduced route failures and routing overheads obtained are very attractive for mobile ad-hoc networks which are highly resources constrained. Finally, it is worth to note that impact on network connectivity due to signal strength threshold enforcement is serious in lightly densed networks and hence, the proposed cross layer design is well suited for highly densed networks.

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