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On Reducing Packet Latencies in Ad Hoc Networks

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Abstract. The Ad hoc On-demand Distance Vector (AODV) is an on-demand routing protocol designed specifically for mobile, ad hoc networks. But the packet latencies with AODV can be very high, > 100 ms on average, especially when the network load is low and node mobility is high. To mitigate this effect, we have enhanced AODV with a proactive technique, which lets receiver nodes broadcast periodic 'beacons' throughout the network to keep routing entries in other nodes current. Using simulations we show that beacons reduce the packet latencies by a factor of 2-3. The routing packets transmitted are also reduced as the beacons obviate the need for some route discovery processes.

1 Introduction

A mobile, ad hoc network (MANET) is a collection of wireless mobile hosts, each acting as a router, to form a temporary network without the aid of any centralized administration or standard support services. In a MANET, all the nodes are assumed to be moving continually and thus do not have a default router or fixed set of neighbors. So each mobile host should have an Internet Protocol (IP) routing algorithm for building and maintaining routing tables, just like an internet router node. Currently, there are no major commercial applications which require such impromptu networking capabilities, but there is a real need for MANETs in military and disaster relief situations.

Characteristics that distinguish these networks [1] from other computer networks are dynamic topologies, limited bandwidth, variable (time and distance dependent) bit error rate, energy-constrained operation, limited physical security and variable capacity links.

Compared to the commonly used Internet routing algorithms, the routing algorithms for MANETs must cope up with various challenges like lack of default router, frequent changes in network topology due to node mobility, low bandwidth channels and unreliable broadcasts. Hence efficient routing algorithms to create, maintain and repair routing paths are necessary in such environments.

Conventional routing protocols developed for traditional wired LANs/WANs may be used for routing in ad hoc networks, treating each mobile host as a router. Such algorithms broadly come under the category of *pro-active* algorithms since routing information is disseminated among all the nodes in the network through out the network operating time irrespective of the need for any such route. Since the channel bandwidth is at a premium, many researchers proposed *on-demand* routing algorithms [8, 5, 9, 11, 12]. The on-demand routing algorithms build or maintain only the routing paths that have changed and are needed to send the data packets currently in the network. Many performance comparisons done till now have shown that on-demand algorithms perform better than proactive algorithms and have been claimed as better suited for mobile and ad hoc environments [2, 7, 6]. Two of the widely studied on-demand algorithms are Ad hoc On-demand Distance Vector (AODV) [5] routing protocol and the Dynamic Source Routing [8] protocol.

A recent study [4] indicates that under a wide variety of situations, AODV performs much better than DSR in terms of latency, throughput, and even routing overhead (in bits/s). In absolute terms, however, AODV has very high latencies, over 100 ms on the average, especially when the relative speeds of nodes is high and the network load is low.

In this paper, we show that packet latencies can be reduced drastically in such conditions in AODV, using a simple proactive technique. The technique involves broadcasting receiver-initiated "beacon" packets periodically which help maintain fresh routes to the corresponding receivers at all the nodes. With this technique the packet latencies are reduced by a factor of 2-3 at low to moderate loads in the high speed networks. Using an optimization that reduces the number of separate beacon packets propagated, the total number of IP layer routing packets transmitted are also reduced.

The rest of the paper is organized as follows. Section 2 describes original AODV protocol and the proactive technique we have incorporated into AODV to reduce latencies. Section 3 provides an analysis of the enhanced AODV with the original AODV. Section 4 concludes the paper.

2 AODV

AODV [5] builds and maintains routing entries containing the destination sequence number, next hop node in the shortest path to the destination, and the distance to the destination. AODV is based on the distance vector algorithm. However, AODV, unlike other proactive distance vector algorithms, does not use periodic or triggered updates to disseminate routing information. AODV requests for a route only when needed and does not require nodes to maintain routes to the destinations that are not actively used in communications.

Route discovery Routing entries are built using route discovery technique. When a node needs to send a packet to a destination to which it does not have a routing entry, it broadcasts a route request (RREQ) packet. To prevent unnecessary broadcasts of RREQs the source node uses an expanding ring search technique as an optimization. In an expanding ring search, the a source node initially uses a time-to-live (TTL) = TTL_START in the RREQ packet IP header and sets a timeout for receiving a reply (RREP). Upon timeout the source retransmits with TTL incremented by TTL_INCREMENT. This continues until TTL reaches TTL_THRESHOLD beyond which a TTL = NET_DIAMETER is used for each rebroadcast. Nodes receiving RREQs set up reverse paths to sources of RREQs in their routing tables, and either reply to the RREQ if they already have an entry for the destination in question or forward the RREQ. In the worst-case, the destination will reply, and the source may receive more than one reply to its RREQ.

Route maintenance An existing routing entry may be invalidated if it is unused within a specified time interval (route expiry time) or the next hop node is no longer a viable node to reach the destination. In that case, the invalidation is propagated to neighbors that have used this node as their next hop. Each time a route is used to forward a data packet, its route expiry time is updated to be current time plus ACTIVE_ROUTE_TIMEOUT. AODV requires the neighbors to exchange hello messages periodically or feedback from the link layer when a loss of a neighbor is detected. When a node detects that a route to a neighbor is no longer valid, it will remove the routing entry and send a link failure message, a triggered route reply message to the neighbors that are actively using the route, informing them that this route no longer is valid. For this purpose AODV uses an active neighbor list to keep track of the neighbors that are using a particular route. The nodes that receive this message will repeat this procedure. The message will eventually be received by the affected nodes which can either choose to stop sending data or request a new route by sending out a new RREQ.

Enhancing AODV

The receivers periodically (for example, 1 second intervals) send beacons that are broadcasted through out the network. A beacon entry has the receiver's sequence number, IP address, broadcast ID and the hop count. The hop count is incremented at each of the forwarding nodes. If the received sequence number (or a better hop count with the same sequence number) is higher than the one in the routing table, then the routing table is updated, with the next hop set to the node that sent the beacon packet. If a beacon entry does not result in adding/updating the corresponding entry in the node's routing table, then the node does not propagate it further. Thus beacons refresh the routing entries for receivers in other nodes' routing tables, even before they are expired. Consequently the data packets will have fresher routes to its destinations available readily without the need for a route discovery process. This, in turn, reduces packet latencies.

A possible disadvantage of this technique is the increase in the number of routing packets due to beacon packets. To mitigate this, we let each node accumulate all the beacons received for a preset duration and send a consolidated beacon at the end of the duration. Each consolidated beacon will have multiple beacon entries. Nodes process consolidated beacons the same way as before except that they process multiple entries for each beacon received. Furthermore, beacons are allowed to be piggybacked on route requests (RREQ), since both are of broadcast type. If there is a RREQ going out within 0.75 to 1.0 of the beacon interval and if there is a pending beacon, then it is piggybacked on the RREQ; otherwise a separate beacon packet is sent at the appropriate time.

3 Performance Comparisons

We have used the ns-2 simulator with CMU extensions [3] for our simulation studies. The algorithm that we presented is denoted by 'BCAODV'.

Network and mobility model. The simulated network has 50 nodes randomly placed, initially, on a 1000m x 1000m field. Each node moves in a randomly chosen direction at an average speed of 10 m/s, uniformly chosen from (0-20) m/s. The distributed coordination function (DCF) of IEEE standard 802.11 [13] for wireless LANs is used as the MAC layer. The 802.11 DCF uses Request-to-send (RTS) and Clear-to-send (CTS) control packets for unicast data transmission to a neighboring node. Data packet transmission is followed by an ACK. The RTS/CTS exchange can also be used to detect if a neighbor is lost and report the same to the routing algorithm in the network layer. A wireless channel has 2 Mb/s bandwidth and a circular radio range with 250 m radius. These assumptions have been used in other studies [2] and [4].

Traffic load. The traffic simulated is constant bit rate (CBR) with 20, 40 and 60 connections. In each connection, the source sends 64-byte data packets at an average rate of 0.125-7.0 packets/s. Each simulation point represents the average of four 500-second simulations, after a 300-second warmup. For these simulations, the beacon interval is a constant 1 second.

Performance metrics. We use the average data packet latency (the time it takes for a data packet to reach its destination from the time it is generated at the source), which includes all the queuing and protocol processing delays in addition to the propagation and transmission delays. We also give the network throughput (total number of data bits delivered) in Kb/s and the packet delivery rate which gives the ratio of number of packets delivered at the destinations to the number of packets originated by the sources. To study the overheads of various routing algorithms, we plot routing information packets transmitted per second and overhead bits/second. The overhead bits/s gives the bits transmitted as routing packets and packet headers in the data packets. All the metrics are plotted with respect to offered (data) load in Kb/s.

Steady-state behavior at high speed

This section presents the performance comparison of various metrics between AODV and BCAODV protocols for the high speed mobile networks at steady-state conditions. Steady-state behavior captures only the stable network conditions, after an initial warm-up time.

Average packet latencies. From Figure 1 we observe that BCAODV improves the latencies by as much as 50% at low and moderate loads. This is because receiver-initiated beacons propagate fresher routes for all the nodes in the network periodically. This obviates the need for additional route discovery processes by the sources, thereby cutting down the packet waiting times. The reason BCAODV not giving the same improvement at high loads, is that the routing overhead due to beacons is becoming relatively high, thus making the wireless channel scarce for the data packets. Because of more number of retries to capture the channel, the data packets incur higher latencies.

Throughputs and delivery rates. Figures 2 and 3 give the throughputs and delivery rates of the two protocols respectively. We observe that, although AODV gives higher packet delivery rates (thereby higher throughputs) for loads greater than 60 Kb/s, the network is already in saturated conditions for those loads.

Routing packets per second. Figure 4 gives the routing packets transmitted per second for the two protocols. We do not see any significant additional routing packets because a node will atmost transmit 1 consolidated beacon packet per second and with the possibility that it can be piggybacked on route

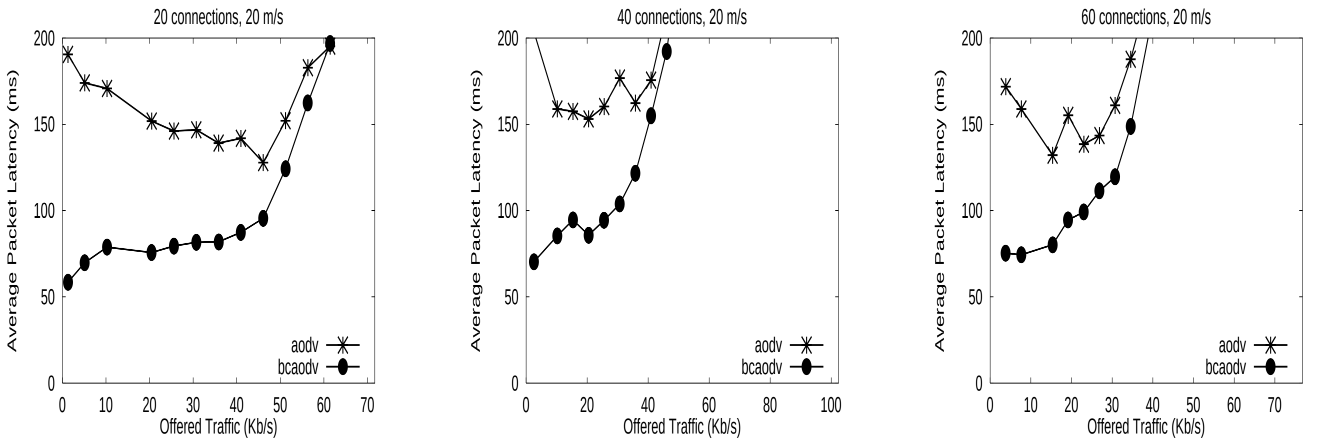

Figure 1: Data packet latencies of AODV and BCAODV for the high node mobility 50 node square field and various CBR connection cases.

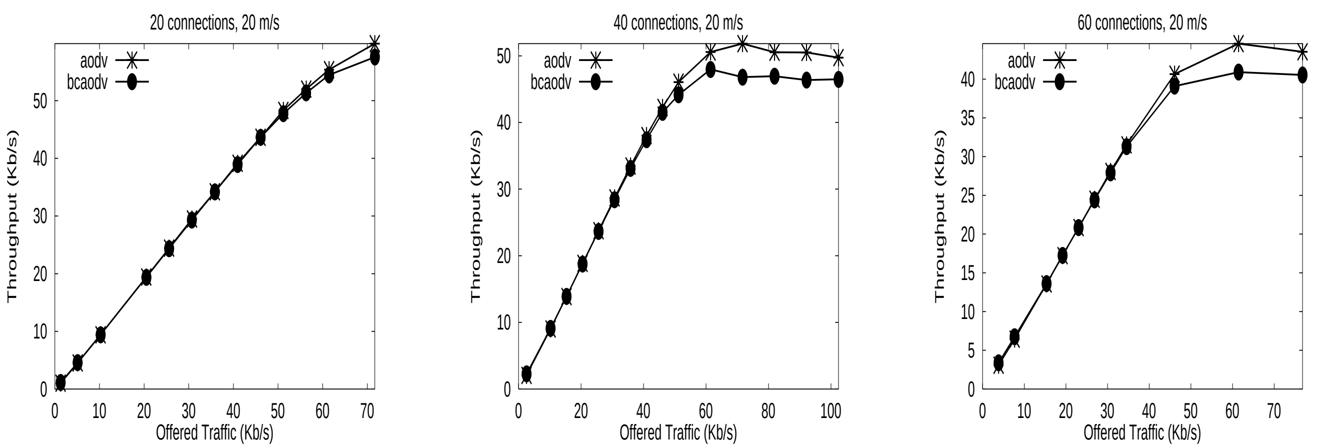

Figure 2: Data packet throughputs of AODV and BCAODV for the high node mobility 50 node square field and various CBR connection cases.

requests there will be little chance of separate consolidated beacon packets accounting for more routing packets. What we see as the number of connections increase is that, AODV sends more routing packets than BCAODV. The more the number of connections the more the number of route discovery processes. In BCAODV, as a single beacon can do the job of a route discovery process, we see less number of route discovery packets (less route requests and route replies).

Routing overhead in Kb/s. BCAODV transmits more routing bytes because of the additional beacon entries propagated whether piggybacked on route requests or sent as separate beacon packets. Also, from Figure 5 we can see that, as the number of connections increase in the network the difference in routing overhead increases as BCAODV is forced to carry beacon entries of more receivers. However, in a wireless medium, obtaining the channel for transmission is much more expensive in terms of power and channel utilization than transmitting a few extra bytes with each bytes.

Additional Observations. An interesting observation that can be made is that the receiver-initiated beacons are not reducing the route discovery packets drastically. The route discovery packets include route requests and route replies. The reason may be that, at high speeds, AODV is updating the routes too fastly that it is not able to use the beacons to its maximum extent. Also the way the beacons are propagated may take significant transmission time before they reach

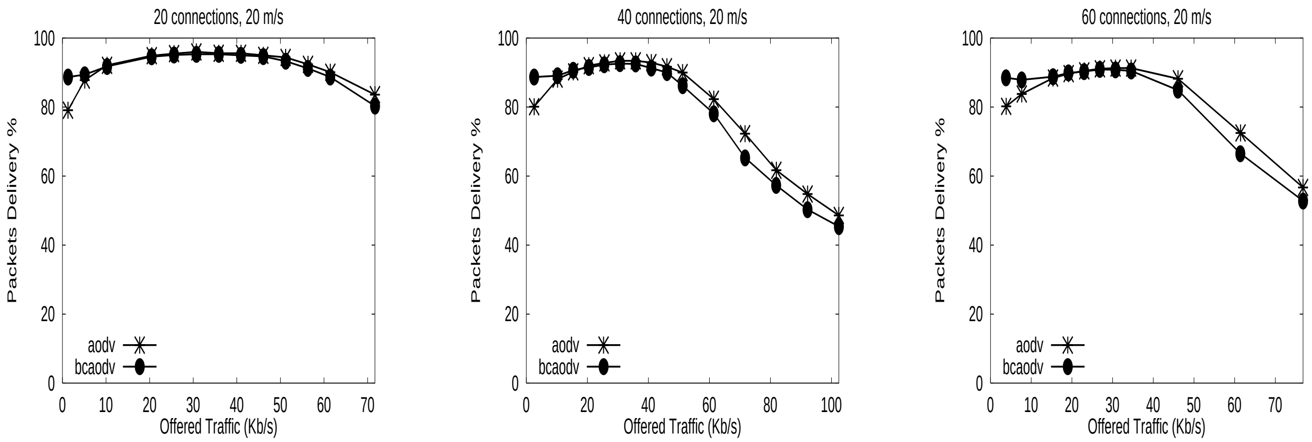

Figure 3: Data packet delivery rates of AODV and BCAODV for the high node mobility 50 node square field and various CBR connection cases.

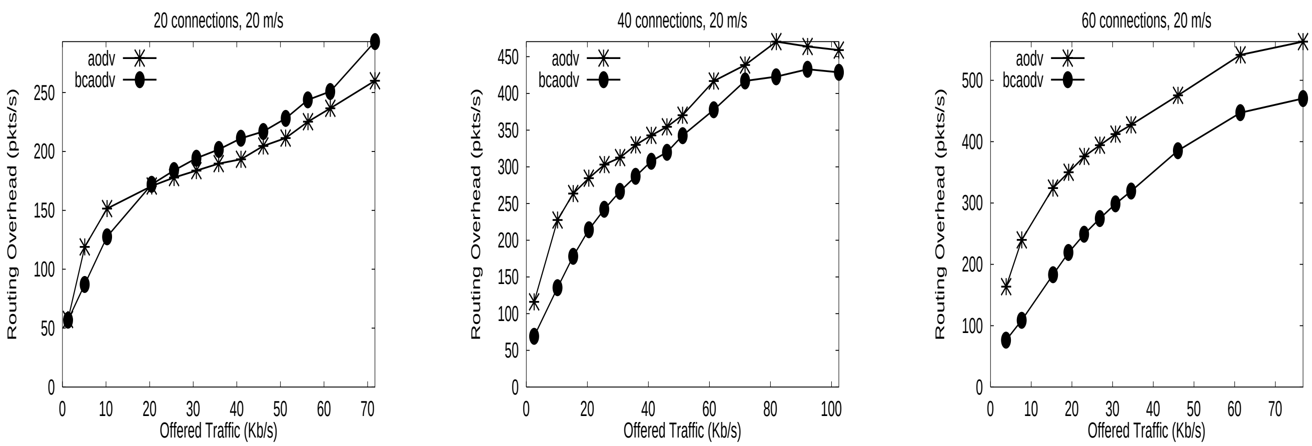

Figure 4: Routing overhead in packets/s of AODV and BCAODV for the high node mobility 50 node square field and various CBR connection cases.

the source nodes, as the intermediate nodes forward the consolidated beacon entries only at the end of the 1 second interval. Thus the immediate effective usage of the beacons may be minimized by the long propagation delay of the beacon entries.

From simulations on low mobility networks, we observed that the beacon technique is not effective. As the number of route invalidations are less in low mobility situations, the need for refreshing routes to the receivers minimize. Also the beacons result in propagation of excessive routing overhead. Reducing the frequency of the beacon interval may result in bringing down the latencies with only a marginal increase in routing overhead.

4 Summary

We have incorporated a proactive technique in AODV to reduce packet delays especially when the packet rate is low and node mobility is high. We have presented simulation results in which packet latencies are reduced by as much as 50% when beacons are used. The effect is more dramatic for fewer (20) connections. Both protocols give almost the same throughputs and delivery rates. Therefore, we find that a mix both proactive and on-demand techniques improve performance of routing protocols in MANETs.

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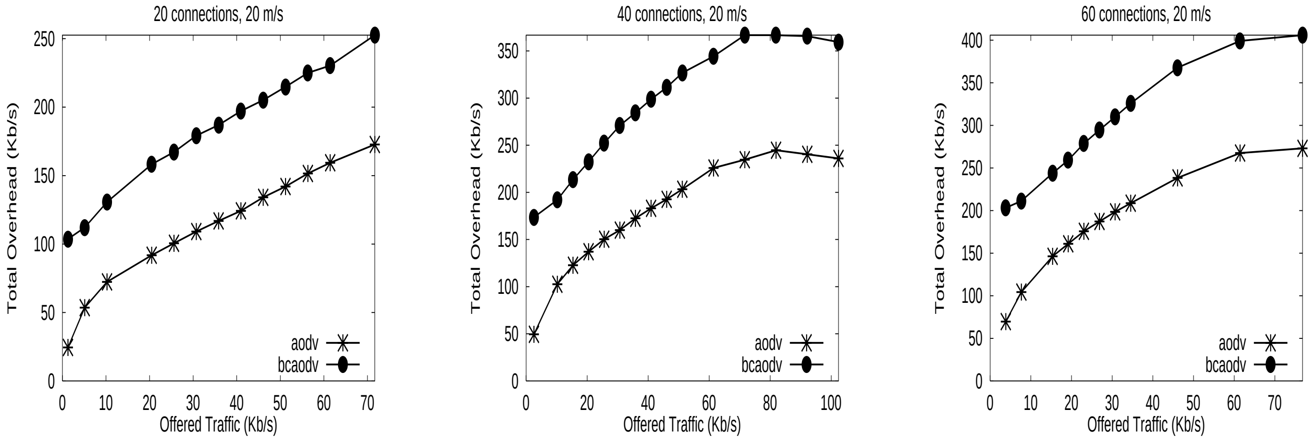

Figure 5: Routing overhead in Kb/s of AODV and BCAODV for the high node mobility 50 node square field and various CBR connection cases.

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