

Caching of Routes in Ad hoc On-Demand Distance Vector Routing for Mobile Ad hoc Networks

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Abstract

Ad hoc networks are characterized by multihop wireless connectivity, frequently changing network topology and the need for efficient dynamic routing protocols. Recent comparative studies between Ad hoc on demand routing protocols like Ad hoc On demand Distance Vector routing (AODV) and Dynamic Source Routing (DSR) (the two on demand routing protocols for Ad hoc networks) have shown that AODV performs better than DSR for high mobility cases but faces the problem of high routing and MAC load as compared to DSR. This is because DSR resort to aggressive use of caching of routes while AODV does not. In this paper, we have incorporated caching of routes in AODV with the aim to reduce the routing and MAC load of AODV without changing the basic structure of the protocol. A detailed simulation model with MAC and physical layer models is used to study the effect of caching of routes in AODV and to compare its performance with AODV without cache and DSR. We show that caching of routes in AODV can lead to significant reduction in routing and MAC load as well as in delay in delivering the packet as compared to AODV without much compromise in terms of packet delivery fraction.

1 Introduction

In an ad hoc network, mobile nodes communicate with each other using multi hop wireless links. There is no stationary infrastructure such as base stations. Each node in the network also acts as a router, forwarding data packets for other nodes. A central challenge in the design of Ad hoc Networks is the development of a dynamic routing protocol that can efficiently find routes between two communicating nodes. Many routing protocols have been proposed till date but none of them are efficient enough to perform well in all scenarios. The routing protocol must be able to keep up with the high degree of node mobility that changes the network topology often drastically and unpredictably. The availability of low cost laptops and palmtops with radio interfaces have renewed the interest in the field of ad hoc networks.

AODV and DSR are the two most popular routing protocols for Ad hoc networks. Both AODV and DSR are on-demand routing protocols which means they discover routes on an as-needed basis. This reduces the routing load of the on demand protocols as compared to the traditional proactive protocols. High routing load usually has a significant performance impact in low bandwidth wireless links. Route discovery in either protocol is based on query and reply cycles, and route information is stored in all the intermediate nodes along the routes in the form of route table entries (AODV) or in route caches (DSR). However there are several important differences in the dynamics of these two protocols, which may give rise to significant performance differences.

In the next section we will see that AODV does not cache the routes it learns during RREQ broadcast and faces the problem of high routing load. In this paper, we have incorporated into AODV, caching of routes which it learns in the process of route request broadcast. The caching of routes reduces the routing and MAC load of AODV and also the delay in packet delivery without changing the basic structure of the protocol. In some scenarios, caching of routes in AODV also leads to better packet delivery fraction than

that of AODV without cache and DSR. A detailed simulation is carried out to study the effect of caching of routes in AODV and to compare the performance of AODV with and without caching with each other and with that of DSR.

2 Description of AODV

AODV [3] shares DSR's[7] on-demand characteristics in that it also discovers routes on an as-needed basis by flooding the network with route request broadcast (RREQ) packets. Each node receiving an RREQ rebroadcasts it, unless it is the destination or it has a route to the destination in its route cache. Such a node replies to the RREQ with a route reply (RREP) packet that is routed back to the original source. However, AODV adopts a very different mechanism from DSR to maintain routing information. It uses traditional routing tables, one entry per destination. This is in contrast to DSR, which can maintain multiple route cache entries for each destination. Without source routing, AODV relies on routing table entries to propagate an RREP back to the source and, subsequently, to route data packets to the destination. AODV uses sequence numbers maintained at each destination to determine freshness of routing information and to prevent routing loops [4]. These sequence numbers are carried by all routing packets. An important feature of AODV is the maintenance of timer-based states in each node, regarding utilization of individual routing table entries. A routing table entry is expired if not used recently. A set of predecessor nodes is maintained for each routing table entry, indicating the set of neighbouring nodes which use that entry to route data packets. These nodes are notified with RERR packets when the next-hop link breaks. Each predecessor node, in turn, forwards the RERR to its own set of predecessors, thus effectively erasing all routes using the broken link. In contrast to DSR, RERR packets in AODV are intended to inform all sources using a link when a failure occurs. Route error propagation in AODV can be visualized conceptually as a tree whose root is the node at the point of failure and all sources using the failed link as the leaves. The recent specification of AODV [4] includes an optimization technique to control the RREQ flood in the route discovery process. It uses an expanding ring search initially to discover routes to an unknown destination. In the expanding ring search, increasingly larger neighbourhoods are searched to find the destination. The search is controlled by the Time-To-Live (TTL) field in the IP header of the RREQ packets. If the route to a previously known destination is needed, the prior hop-wise distance is used to optimize the search. This enables computing the TTL value used in the RREQ packets dynamically, by taking into consideration the temporal locality of routes.

3 Caching in AODV

We saw that AODV finds new routes by making a route request broadcast which travels through various intermediate nodes before reaching the destination node. These requests carry a lot of information about the network topology as they pass through different nodes but due to lack of caches at intermediate nodes, this information can not be tapped by the nodes to be used later. So by providing all the nodes with an extra cache and by making changes in the RREQ packet such as to enable them to carry the information about the nodes through which they pass, intermediate nodes can save the information about the network topology contained in the RREQ packets. This reduces the time and overhead to find new routes in cases of route failure. From now on, we will call the AODV with cache enabled as AODV-WC and AODV without caching as AODV-WOC.

3.1 Implementation Details for Caching of Routes in AODV

To implement caching in AODV, we made the following modifications to the present AODV :

1. Each node now has a separate queue (apart from the queue which AODV has for maintaining routing information) which acts as a cache for the routes. For this purpose, we have used the same queue structure which AODV uses for maintaining its routes.

2. To reduce the problem of stale caching, a cache timer is introduced in the caches and an appropriate cache timeout value is found to get the maximum efficiency from the cache even in the case of high mobility (low pause time). So any route that does not get updated within the cache timeout period from the time of its addition to the cache, is discarded as stale.
3. Route request packets (RREQ) should be able to carry the node addresses and latest sequence numbers (It is the same sequence number as used by AODV to check the freshness of a route) of the intermediate nodes they have passed before reaching the destination node. For this purpose, we have implemented a special data structure in the AODV RREQ packet header which forms a link list of node addresses and sequence numbers of the nodes through which the packet has crossed.
4. All the nodes on receiving a route request packet should, apart from doing their already specified tasks, read the node addresses and sequence numbers in the packet and add them to their caches as the nodes reachable from the last node through which the packet is coming. Then before broadcasting the packet to the neighbouring nodes, the nodes should append their own address and a latest unused sequence number into the packet.
5. As AODV is not a source routing protocol like DSR, so caching of routes can cause the problem of looping of data packets because of deletion of routes due to cache timeout. In order to avoid the looping of packets, a packet sequence number is generated by the source node before sending the packet by incrementing by one the last sequence number used by that node. This sequence number is attached with each packet so that the packet sequence number along with the source id uniquely determines a packet and so nodes can detect the packets forwarded by them self. On encountering a packet which has looped, the node drops the packet and deletes the path on which it was last forwarded which resulted in the loop and informs the source of the packet that the path to the destination does not exist any more.
6. Caching of routes enables intermediate nodes to salvage data packets as alternate routes may be available with every node. So if the older route breaks, the intermediate node which detects the route failure first looks for an alternate route in its cache and if it finds any route, it sends the packet on that route. But it informs the source that the old route has expired so that the source can initiate route discovery to find a new route. This prevents over lengthening of routes after many routes have expired.

4 Simulation Model

We use a detailed simulation model based on ns-2. The changes mentioned above are made to the existing code of AODV available in ns-1b8a and the performance of the new routing protocol is compared with AODV and DSR under various scenarios.

We used traffic and mobility models similar to those used in [1] using ns-2. Traffic sources are continuous bit rate (CBR) for a major part of the simulation though we have analyzed the effect of caching on TCP traffic as well. The source-destination pairs are spread randomly over the network. Only 512-byte data packets are used. The number of source-destination pairs and the packet sending rate in each pair is varied to change the offered load in the network. The mobility model uses the random waypoint model in a rectangular field. Two field configurations are used: "1500 m x 300 m field with 50 nodes " and "2200 m x 600 m field with 100 nodes". Here, each packet starts its journey from a moving source to a moving destination. The mobile terminals move with a randomly chosen speed (uniformly distributed between 0 to 20 m/s). Once the destination is reached, another random destination is targeted after a pause. We vary the pause time, which affects the relative speeds of the mobiles. Simulations are run for 500 simulated seconds for 50 and 100 nodes. Each data point represents an average of at least three runs with identical traffic models, but different randomly generated mobility scenarios. Identical mobility and traffic scenarios are used across protocols.

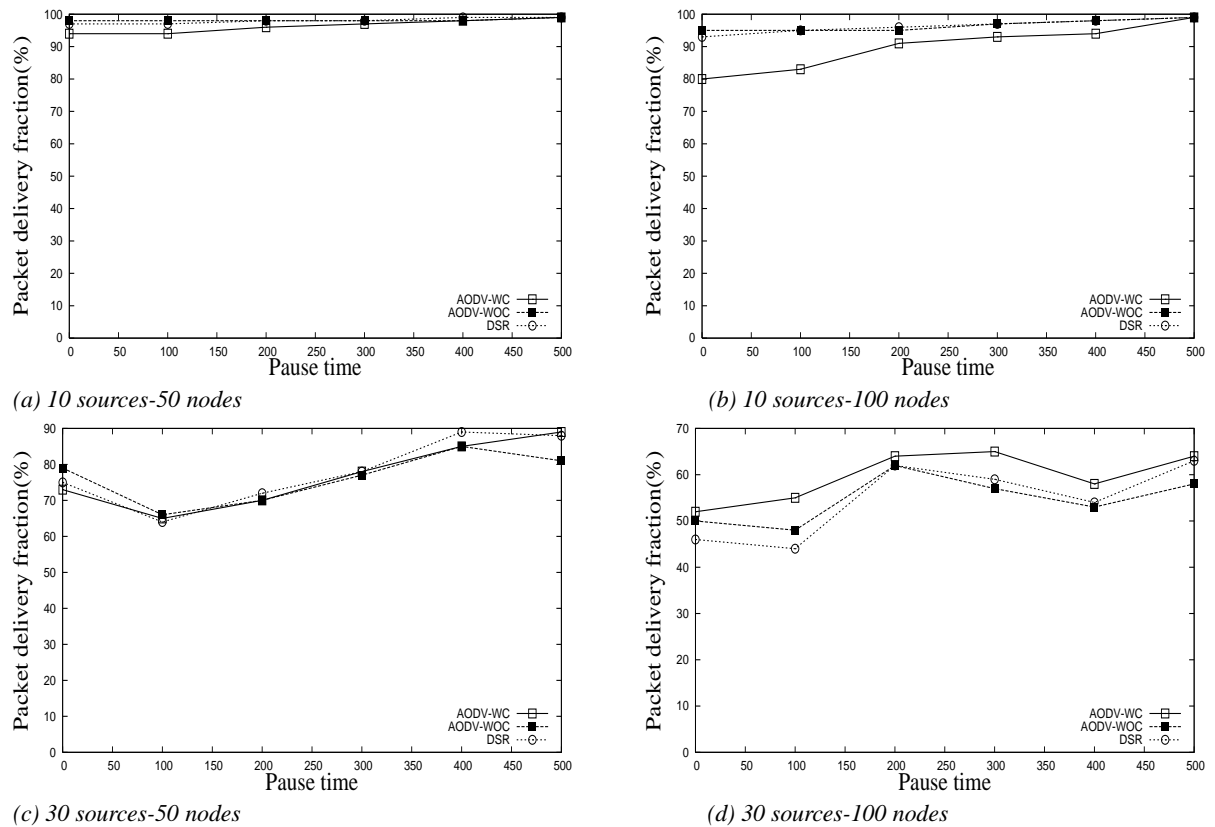


Figure 1: Packet delivery fractions for the 50 and 100-node model with various numbers of sources

5 Performance Metrics

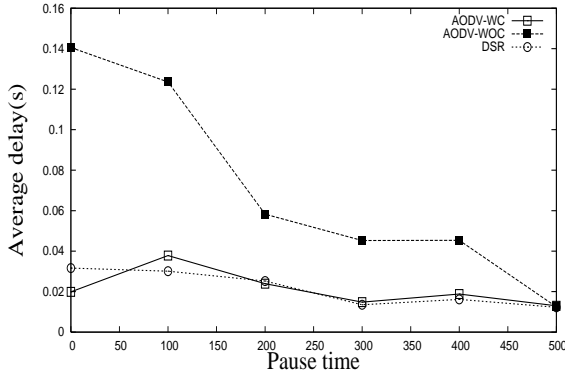
Four important performance metrics are evaluated:

1. Packet delivery fraction : The ratio of the data packets delivered to the destinations to those generated by the CBR sources. Also a related metric, received throughput (in Kilobits per second) at the destination has been evaluated in the case of analysis of TCP traffic.
2. Average end-to-end delay of data packets : This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times.
3. Normalized routing load : The number of routing packets transmitted per data packet delivered at the destination. Each hop wise transmission of a routing packet is counted as one transmission.
4. Normalized MAC load : The number of routing, Address Resolution Protocol (ARP), and control (e.g., RTS, CTS, ACK) packets transmitted by the MAC layer for each delivered data packet. Essentially, it considers both routing overhead and the MAC control overhead. Like normalized routing load, this metric also accounts for transmissions at every hop.

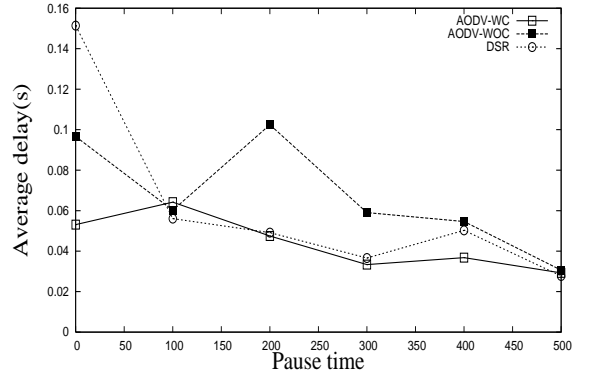
6 Performance Results

6.1 Varying Mobility and number of sources

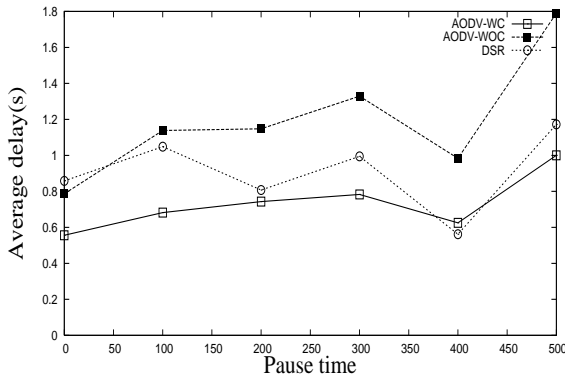
The first set of experiments uses differing numbers of sources with a moderate packet rate and varying pause times. For the 50 node experiments, we used 10 and 30 traffic sources and a packet rate of 4 packets/s.



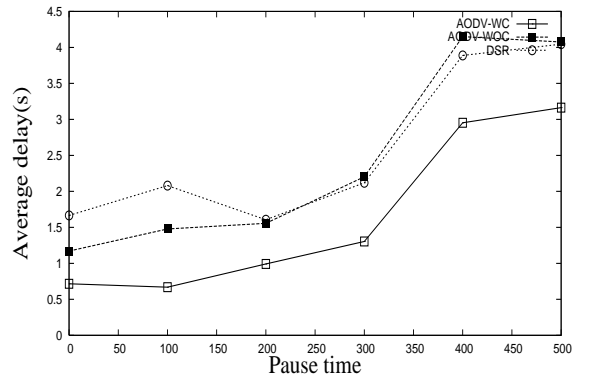
(a) 10 sources-50 nodes



(b) 10 sources-100 nodes



(c) 30 sources-50 nodes



(d) 30 sources-100 nodes

Figure 2: Average delay for the 50 and 100-node model with various numbers of sources

The Packet Delivery Fraction for DSR and AODV-WOC are very similar with 10 sources (Figure 1a) while that of AODV-WC is lesser than that of DSR and AODV-WOC at lower pause times (high mobility) and becomes equal to them at higher pause times. With 30 sources (Figure 1c), AODV-WOC and DSR outperforms AODV-WC at lower pause times while AODV-WC overtakes AODV-WOC at higher pause times (low mobility) and becomes comparable to the packet delivery fraction of DSR.

For the 100-node experiments, we have used 10 and 30 sources. The packet rate is fixed at 4 packets/s. Figure 1b shows that the packet delivery fraction of AODV-WC is lesser than that of AODV-WOC and DSR for 10 sources while for 30 sources (Figure 1d), AODV-WC outperforms both AODV-WOC and DSR for almost all the cases in terms of packet delivery fraction.

Figure 2 shows the result for 50-node experiments. For 10 sources, the delay of AODV-WC is similar to that of DSR and is lesser than the delay of AODV-WOC for all pause times. For 30 sources, AODV-WC has better delay than AODV-WOC and DSR for lower pause times. But for higher pause times, the delay for DSR becomes equal to that of AODV-WC but AODV-WC is still better than AODV-WOC.

For 100-node experiments (Figure 2), AODV-WC performs better than AODV-WOC and DSR in terms of delay for all the pause times.

Figure 3 shows that for 50-node experiments, AODV-WC has a lower routing load than AODV-WOC but could not outperform DSR in terms of routing load. But the difference in routing load of AODV-WC and DSR decreases with increase in pause time.

With 100-nodes (Figure 3), the results of the protocols with respect to the routing load are quite similar to the 50-node cases but we see that for 100-nodes, the difference in the routing load between that of AODV-WC and AODV-WOC is more than that of 50-node cases.

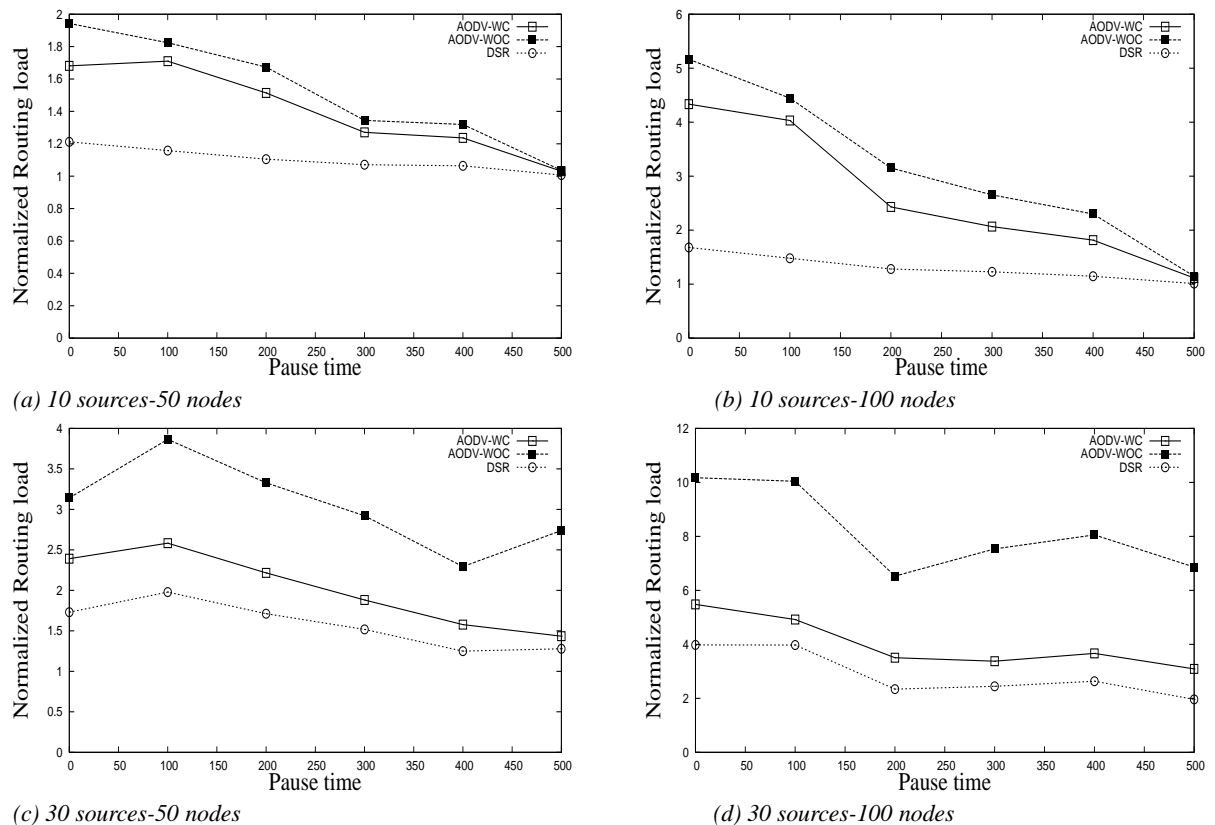


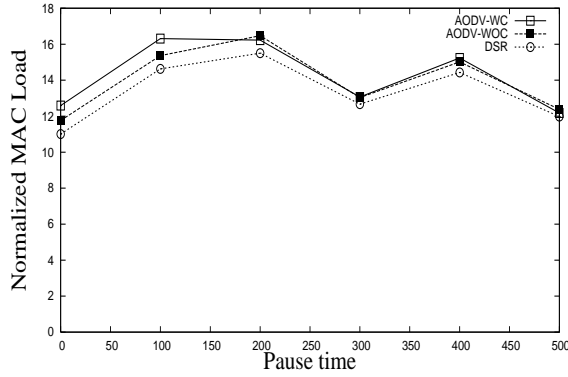
Figure 3: Normalized routing load for the 50 and 100-node model with various numbers of sources

Figure 4 shows that for 50-nodes experiments, the MAC load of AODV-WC is lower than that of AODV-WOC and slightly higher than DSR for most of the cases but for 100-node experiments (Figure 4), AODV-WC outperforms both AODV-WOC and DSR in terms of MAC load for 30 sources. For 10 sources and lower pause times, AODV-WC has more MAC load than AODV-WOC and DSR for both 50 and 100 nodes experiment.

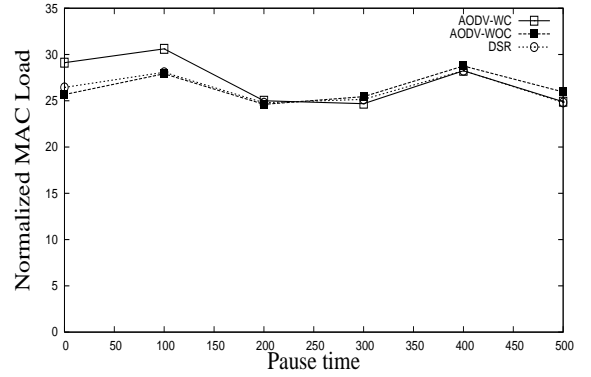
In summary, when the number of sources is less, AODV-WC does not show significant improvement from AODV-WOC and DSR but performs a little poorly in terms of packet delivery fraction. With a large number of sources, for 50-node experiments, AODV-WC outperforms AODV-WOC in terms of delay, routing load and MAC load. For 100-node experiments, AODV-WC shows better delay and lower MAC load than both DSR and AODV-WOC with a large number of sources and also shows improvement in packet delivery fraction as compared to AODV-WOC and DSR. Thus AODV-WC performs better than AODV-WOC and DSR for large networks with higher load.

6.2 Varying Cache Timeout

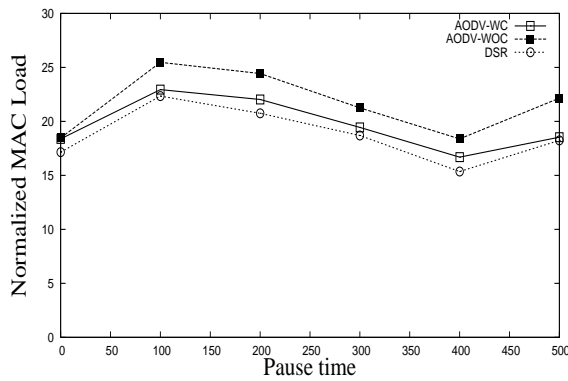
In order to avoid the problem of stale caching as faced by DSR [8], we have introduced cache timers with each cached routes which will discard the route after a certain cache time out value if the route is not updated within that time. Figure 5 plots the performance metrics against varying cache time-out values. This experiment is done for 50 nodes with 30 sources and a send rate of 4 Packets/Sec. This experiment is intended to find out the best time-out (The time after which the cached route is discarded as stale) value for the cached routes. The pause time is taken as zero so that the timeout value gives the maximum efficiency for even high mobility cases. From the figure we find that a time out value of 10 secs performs best for all the cases. So for all the experiments, we have chosen a cache time out value of 10 secs. We can see that as the time out value is increased, packet delivery fraction decreases though normalized load and average



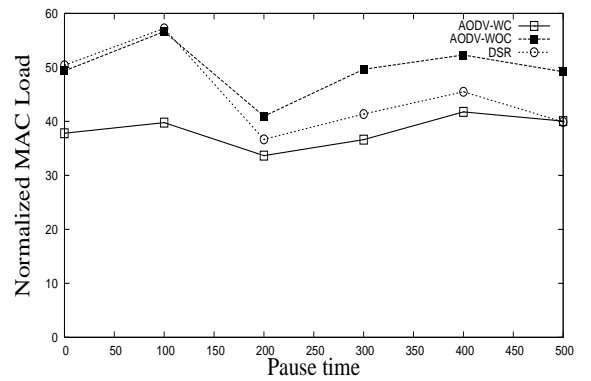
(a) 10 sources-50 nodes



(b) 10 sources-100 nodes



(c) 30 sources-50 nodes



(d) 30 sources-100 nodes

Figure 4: Normalized MAC load for the 50 and 100-node model with various numbers of sources

delay is best at a cache time out of 10 secs. So to improve the packet delivery fraction, the cache time out value can be reduced at the cost of average delay and normalized routing load.

6.3 Varying offered load

The next set of experiments (Figure 6,7) demonstrates the effect of varying the load in the network. The pause time for this set of experiment is zero. We used a 100-node model with the number of sources as 20 and 40. The metrics are kept the same as in the previous experiments. The offered load in the performance plots indicate the packet sending rate of each source.

For 20 and 40 sources (Figure 6), we see that the packet delivery fraction of AODV-WC is lower than that of AODV-WOC and DSR when the offered load is low and as the offered load is increased, AODV-WC starts performing comparable to AODV-WOC and DSR in terms of packet delivery fraction.

Figure 6 shows that routing load for AODV-WC is lower than that of AODV-WOC but is not able to compete with that DSR. But we see that as the offered load is increased, the difference in the routing load of AODV-WC and AODV-WOC increases and that of AODV-WC and DSR decreases. Figure 7 shows that AODV-WC has very low MAC load as compared to AODV-WOC and DSR for higher offered load though at lower offered load, AODV-WOC has better MAC load than AODV-WC but AODV-WC is always better than DSR. Figure 7 shows that AODV-WC outperforms both AODV-WOC and DSR in terms of delay for all the offered load though the difference in the delays of AODV-WC and that of AODV-WOC and DSR is more for higher offered load.

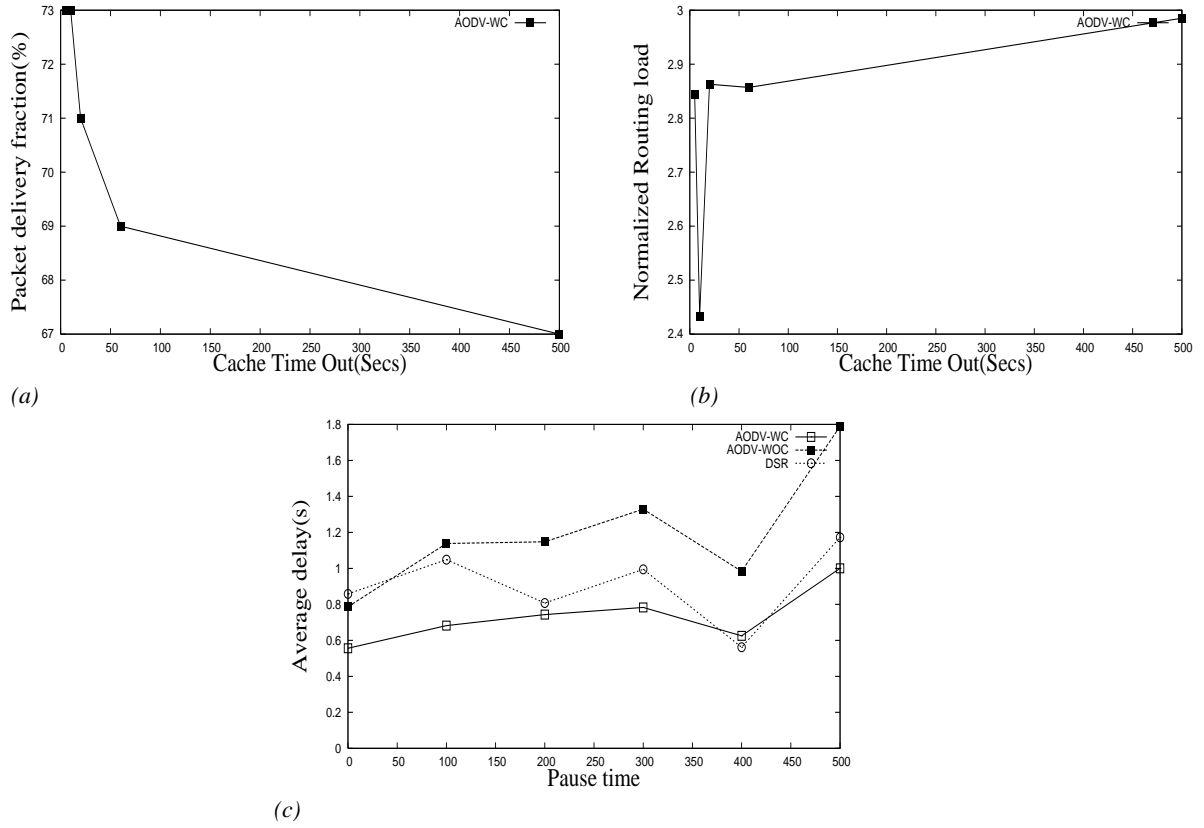


Figure 5: Performance of AODV-WC for 50 node model with pause time 0 and varying cache time out value

6.4 Effect of Caching on TCP

Figure 8 shows the effect of caching of routes in AODV on the performance of TCP. Figure 8 shows that with 10 TCP sources, AODV-WOC performs better than DSR almost over all the pause times and better than AODV-WC for lower pause times (high mobility) cases. With 30 TCP sources, DSR performs better than AODV-WC and AODV-WOC for high mobility cases while AODV-WC and AODV-WOC overtakes DSR for lower mobility in terms of throughput.

Figure 8 shows that AODV-WC has lower MAC load than AODV-WOC for all the cases though the difference in the MAC load of AODV-WC and AODV-WOC is more for higher pause times (low mobility). We also see that for 30 sources, the MAC load of AODV-WC is lesser than that of DSR for almost all the pause times and even for 10 sources, AODV-WC has lower MAC load than that of DSR for higher pause times. So in terms of MAC load, AODV-WC outperforms both DSR and AODV-WOC.

7 Observations

The simulation results bring out several important effects of caching in AODV. These characteristics are discussed in this section.

7.1 Routing Load and MAC Overhead

AODV-WC almost always has a lower routing load than AODV-WOC. Due to caching, AODV-WC is more likely to find a route in the cache and hence will resort to route discovery less frequently than AODV but due to aggressive caching done by DSR, AODV-WC cannot compete with DSR in terms of routing load. Unlike DSR, AODV-WC routing load is not dominated by RREP packets as AODV-WC like AODV-WOC,

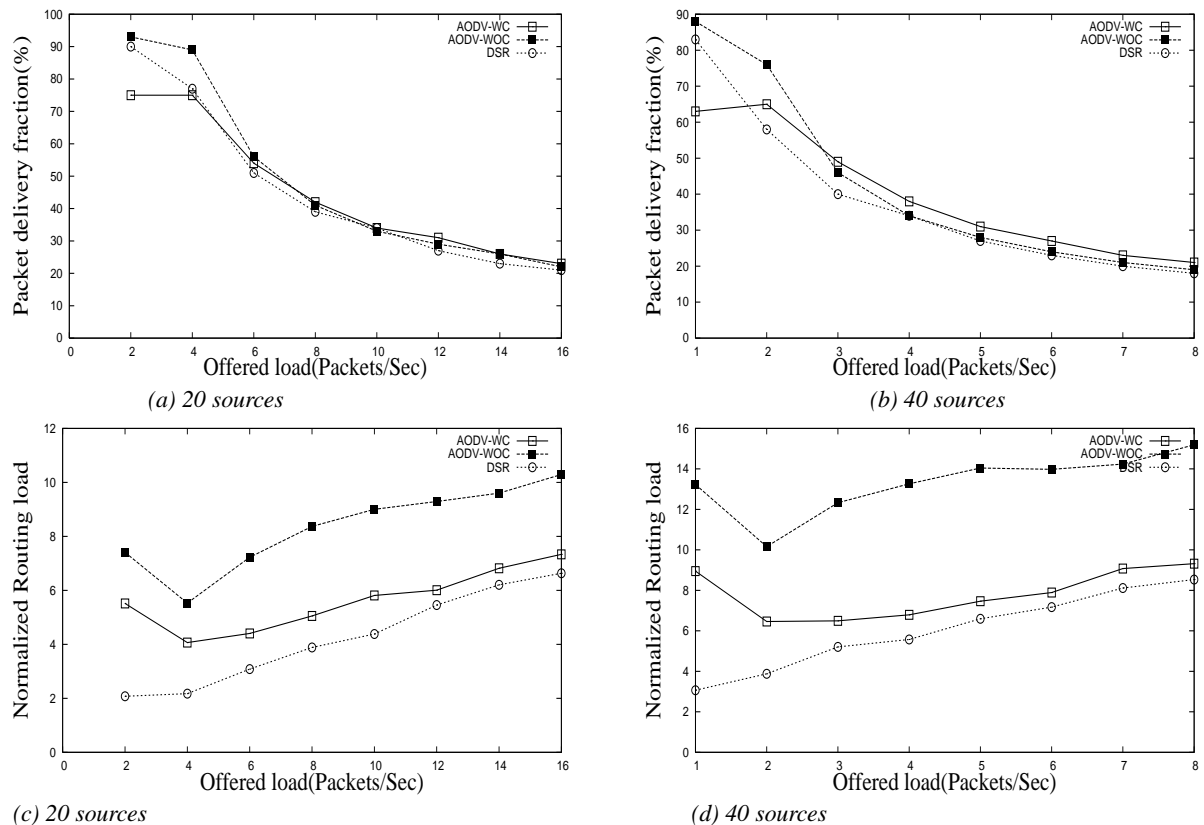


Figure 6: Performance comparison for 100-node model for varying offered load

replies to only the first RREQ and so like AODV-WOC, AODV-WC routing load is dominated by RREQ packets.

However, the lower routing load of DSR does not result in lower MAC load (Figure 8) mainly because RREPs are unicast in AODV and DSR and uses RTS/CTS/Data/ACK exchanges in the 802.11 MAC. RREQs on the other hand, do not use any additional MAC control packets and thus have much less overhead. RERRs are handled differently in each protocol. RERRs are unicast in DSR, and therefore contribute to additional MAC overhead like RREPs. In AODV-WC and AODV-WOC, RERRs are broadcast like RREQs and hence are less expensive. Thus we see that, AODV-WC outperforms both AODV-WOC and DSR in terms of MAC overhead in cases of high mobility or high traffic despite having higher routing load than DSR.

7.2 The Effect of Mobility

Simulation results presented above shows that mobility affects the performance of AODV-WC, AODV-WOC and DSR differently. In the presence of high mobility, link failures are frequent which trigger new route discoveries in AODV-WOC since it has at most one route per destination in its routing table. The reaction of AODV-WC and DSR to link failures in comparison to AODV-WOC is mild and causes route discoveries less often due to caching of routes done by them. This keeps the routing and MAC load of AODV-WC and DSR low even for high mobility scenarios. But staleness of cache in DSR and AODV-WC results in significant degradation in their performance as compared to AODV-WOC in high mobility scenarios. The problem of staleness of cache is more severe in case of DSR as compared to AODV-WOC since DSR does not have a route timer. This results in poorer performance of DSR than AODV-WC for high mobility cases when the traffic load is high.

At low mobility, the possibility of link failures is low. DSR caches are nearly up to date in low mobility

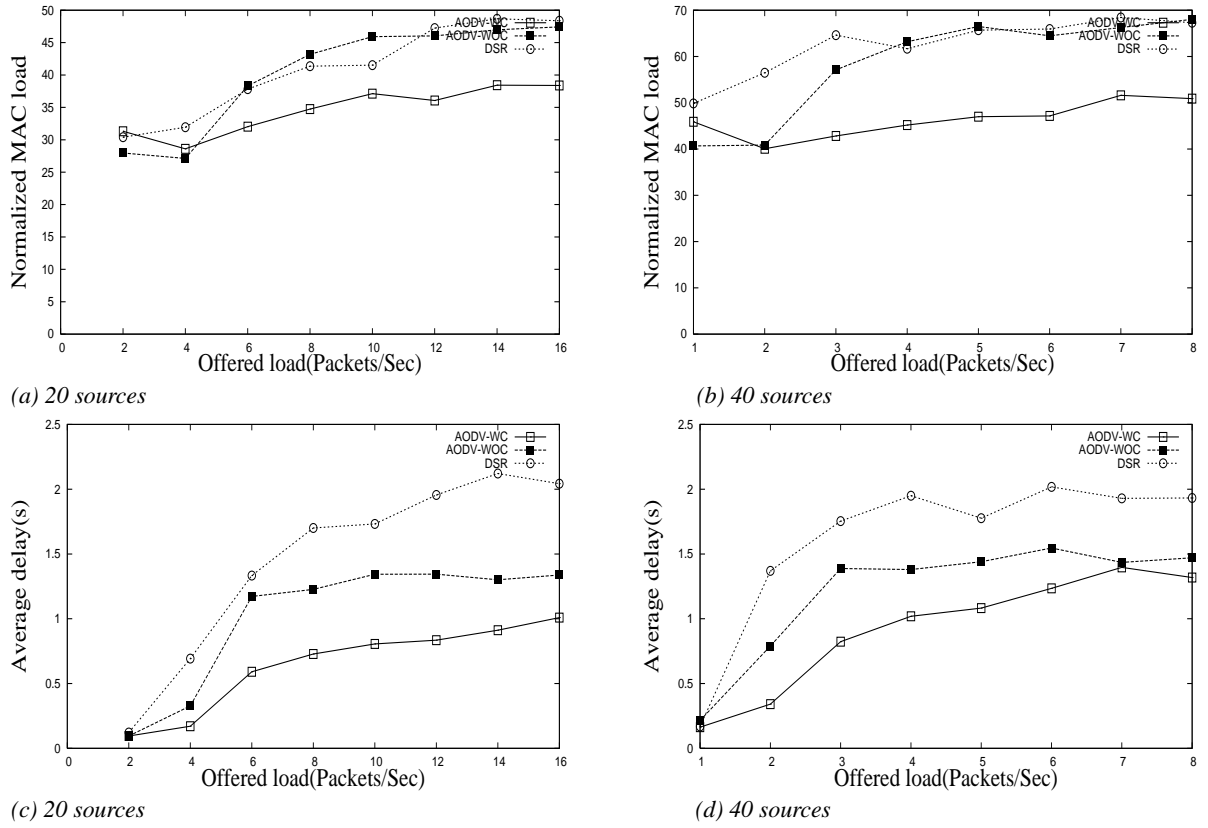


Figure 7: Performance comparison for 100-node model for varying offered load

cases thus giving high performance due to salvaging of packets at the intermediate nodes. AODV-WC also gives better performance due to salvaging of packets at the intermediate nodes. Lower MAC load of AODV-WC also decreases the interference caused by the MAC load to the flowing data traffic and thus improves the performance of AODV-WC against DSR and AODV-WOC when the traffic load is already high.

8 Conclusion

We have implemented caching of routes in AODV. AODV can not compete with DSR in terms of Routing and MAC load mainly because it does no caching of routes, but it perform better than DSR in terms of Packet delivery fraction for high mobility scenario. So we have implemented caching of routes in AODV with the aim to overcome this drawback of AODV but still maintaining the distinguishing characteristics of AODV like its not being a source routing protocol. The comparison results for AODV-WC, AODV and DSR shows that MAC overhead or network overhead produced by AODV-WC is very low as compared to AODV and DSR, so AODV-WC performs better than AODV and DSR when the offered load is high. But like DSR, AODV-WC also faces the problem of stale caching which reduces its performance for high mobility scenario when link failures are frequent. The problem of stale caching has been reduced to some extent by introducing a time out for cached routes. The performance of AODV-WC could be improved further by making the timeout value adaptive with the mobility. The average delay in transferring a packet from source to the destination is also less in AODV-WC as compared to AODV and DSR. Thus we see that adding a cache to AODV reduces the routing and MAC load and delay of AODV without significant degradation in the packet delivery fraction.

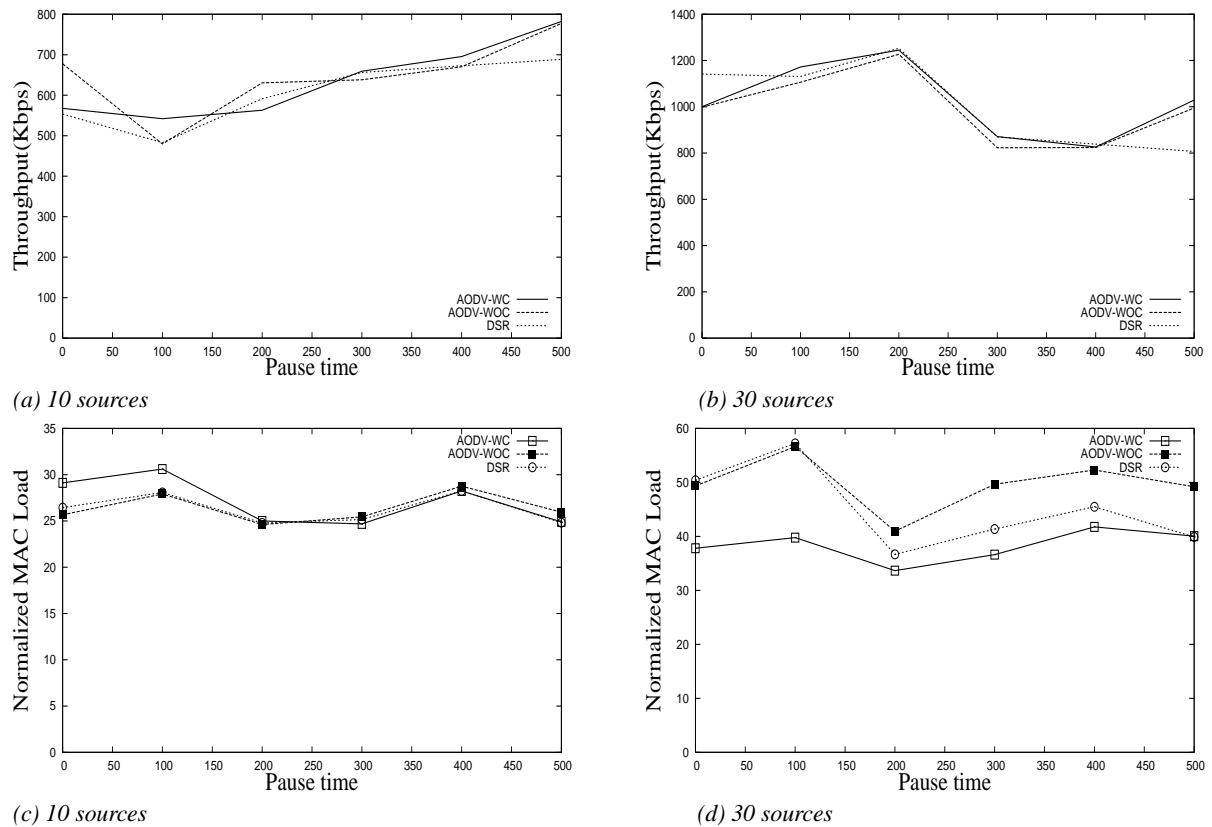


Figure 8: Performance comparison for 100-node model with TCP traffic

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