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Analysis of Inconsistent Routing Components in Reactive Routing
Protocols

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# Analysis of Inconsistent Routing Components in Reactive Routing Protocols

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**Abstract:** In reactive routing protocols, additional routing information is often collected to reduce the response time and the overhead of the future routing demands. However, these protocols do not have any mechanism to refresh this routing information and soon it become obsolete. Therefore, routing components based on this prior-to-demand collected information are not consistent with the reactive nature of the protocol. In this work, we have identified such inconsistent components in AODV routing protocol and have analyzed their effect. Our simulation based analysis has revealed that the presence and use of stale routing information degrades the protocol performance. However, if the dependency of protocol operations on this obsolete information is reduced, the protocol performs better in terms of overhead and packet delivery ratio.

**Keywords:** Routing, Wireless Ad hoc Networks, Stale Routing Information

## 1 Introduction

Routing protocols for wireless ad hoc networks are mainly divided into two categories: Proactive and Reactive. In proactive routing protocols, nodes in the network periodically exchange routing information and maintain a route to every other node in the network at all times. On the other hand, reactive routing protocols do not periodically exchange routing information; instead, perform routing operations on-demand. Whenever a route is needed, a route discovery is performed. Similarly, only active or in-use routes are repaired in case of link breakage or failure.

It is observed that the routing operations or actions of reactive routing protocols sometimes try to exploit existing or previously acquired routing information. Obviously, the objective is to optimize the performance by either reducing the response time or overhead. For example, the Dynamic Source Routing (DSR) protocol [JHM07] maintains alternate routes in its route cache by overhearing the routing packets. Ad hoc On-Demand Distance Vector (AODV) routing protocol [PBD03] uses the previously known hop count value of a destination while performing route discovery. In Ad hoc On-Demand Multipath Distance Vector (AOMDV) routing protocol [MD01], a modified version of the AODV, multiple path-disjoint routes for a destination are discovered by overhearing the route request messages during the route discovery. AODV with Backup Routes (AODV-BR) [LG00], another modified form of AODV, establish backup routes by promiscuously overhearing the route reply messages. In all these examples, the additional routing information is acquired prior to its demand.

Since reactive routing protocols do not have any mechanism to periodically refresh routing data, the feature of using the prior-to-demand collected information leads to a design anomaly. The routing components which are based on this old routing information are inconsistent with the reactive nature of the protocol. The future and fortune of the stale information is totally dependent on the network and topology conditions. Therefore, the behavior and the effect of these inconsistent operations on the overall performance are volatile and unpredictable. An important question in this context is that how significant is the influence of these inconsistent operations, and to which extent is this inconsistent behavior tolerable.

To understand this important issue and to have a better insight into the dependency of reactive routing protocols on the stale routing information, we have particularly studied the AODV routing protocol. We have observed and analyzed some inconsistent components of the AODV routing protocol and their effect on the performance of the AODV. The approach of our analysis is to target the problem from two directions. First, observe the effect of eliminating an existing routing component which is dependent on stale routing information. Second, analyze the effect of introducing a new component which collects more routing data than desired for future use i.e. increases the amount of routing information that will be obsolete soon. The rest of this paper is organized as following. In the next section, we briefly introduce the working of AODV routing protocol. In section 3, the two inconsistent components of AODV routing protocol selected for the analysis are described. Finally, section 4 provides the details of our simulation based analysis, its outcomes, and our findings.

## 2 Ad hoc On-Demand Distance Vector (AODV) Routing Protocol

AODV employs the traditional distance vector approach, but in an on-demand fashion. AODV nodes maintain routing tables that contain an entry for each known destination. Like any other reactive routing protocol, AODV has two main functional components: route discovery and route maintenance.
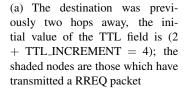
When a source is in need of a route to a destination, either because it is previously unknown or the route to this destination is no more valid, it disseminates a route request message (RREQ) in the network. Every recipient of the RREQ first creates or updates the route entry for the originator of the RREQ, called reverse route. Then, it further broadcasts this RREQ if it is neither the destination of this RREQ nor has a valid route to the destination of this RREQ. If this node is the destination of this RREQ or has a valid route to the destination, it generates a route reply message (RREP). RREP is sent unicastly on the recently created reverse route for the source.

In AODV, a route error happens when a node while forwarding a data packet detects that the link to the next hop node is broken, or when a node receives a data packet for a destination for which it does not have a valid route, or if a node receives an intimation from a neighbor about a route error. In all these situations, the node prepares a list of unreachable destinations that consists of those routes in its routing table which are disturbed as a result of this route error. These neighbors are informed by transmitting a route error message (RERR).

(a) The destination was previously two hops away, the initial value of the TTL field is (2 + TTL_INCREMENT = 4); the shaded nodes are those which have transmitted a RREQ packet



(b) The initial value of the TTL field is TTL_START i.e. 1; the shaded nodes are those which have transmitted a RREQ packet

Figure 1: The effect of the initial value of the TTL field when destination is closer than the previously known hop count

## 3    Inconsistent Routing Components in AODV

The two AODV components selected for our analysis are, the initialization of the TTL field in RREQ packets, and route sharing scheme. In the rest of this section, these two components are described in detail.
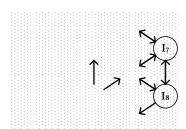
### 3.1    Initialization of the TTL Field in RREQ Packets

AODV uses an expanding ring search technique to control the overhead of the route discovery. According to this scheme, the value of the TTL field in the IP header is set to a lower value in the first RREQ i.e. TTL_START. After every failed attempt i.e. having no response within the RING_TRAVERSAL_TIME, the value of the TTL field is increased by TTL_INCREMENT for the next attempt. Thus, the value of the TTL field in the RREQ packet indicates that how far this RREQ packet will travel during the route discovery i.e. how deep its dissemination would be in the network.

When a node is in need of a route to another node, if an invalid route entry for this destination is already present in the routing table, the initial value of the TTL field in the RREQ packet is set to TTL_INCREMENT + the hop count value in this invalid entry. The underlying assumption for this variation in the route discovery process is that the destination node was previously that many hops away. Therefore, by initiating route discovery with a TTL value higher than this previously known hop count, it is ensured that the RREQ will disseminate beyond that previously known point in the first attempt. Performing route discovery in the standard manner i.e. starting from TTL_START and increasing the search ring step by step would simply increase the route discovery time in such a case. However, when the destination has been moved closer to the source, this varied approach only causes extra overhead as it transmits extra RREQ packets.

The effect of the value of the TTL field on the route discovery is explained in Figure 1 and Figure 2. The previously known hop count of the destination node D in these figures is two. In

(a) Even when the destination is two hops away, the RREQ dissemination in case of previously known hop count is quite similar to Figure 1(a) because the initial value of the TTL field i.e. 4 is enough to cover the whole network

(b) If the destination is two hops, the first step of the route discovery will be as for TTL = 1 in Figure 1(b). Later, TTL will be incremented by TTL_INCREMENT i.e. 2, and RREQ is transmitted again with this new value i.e. 3

Figure 2: The effect of the initial value of the TTL field when the destination is at the same distance as earlier

Figure 1, the destination currently is closer i.e. one hop away. In this case, the route discovery time and the number of RREQ packets transmitted both will be higher if a higher initial value of the TTL field would be used. In Figure 2, the current distance to the destination is same as the previously known hop count i.e. two. Here, the number of RREQ packets transmitted is slightly less when the initial value of the TTL field was less. However, the route discovery time might be less when a higher initial value of the TTL field was used as it can disseminate deep in the network in less steps.

The unusual initialization of the TTL field in case of an existing entry is an obvious example of the use of stale routing information. Therefore, this component is selected for the analysis. Since this component is already present in AODV, the idea is to eliminate this component from the protocol i.e. in all the cases, use TTL_START as the initial value of the TTL field. Afterwards, the effect of this change on the performance of AODV is analyzed.

## 3.2 Route Sharing in AODV

It is observed that during the route discovery process, AODV can collect additional routing data by having minor adjustments in its route discovery scheme. In Figure 3, the topology learning that happens as a result of RREQ dissemination is shown. Since, the RREQ packet carries information about the originator node only, at each hop a recipient of this RREQ packet becomes aware of only two nodes in the network, the originator of the RREQ packet and the previous hop. For example, in Figure 3 when node $I_n$ (not necessarily the destination) receives a RREQ initiated by the source S through the path $I_1$, $I_2$, , $I_{n-1}$ (n>2), this RREQ provides knowledge about only two nodes on this whole path to it i.e., S and $I_{n-1}$. Same was the case with previous hop nodes. However, we know that if the path S, $I_1$, $I_2$, , $I_n$, D is selected as a route, all the nodes from $I_1$, $I_2$, , $I_n$ will be part of this active route and will remain active during the use of this route. The same situation also happens when the RREP packet is returned by the destination to the source with the only exception that RREP packets are transmitted unicastly.

Figure 3: AODV: Topology learning during RREQ dissemination

The routing sharing scheme proposes that information about all the intermediate nodes along a path should be included in the RREQ and RREP packet. Hence, there would not be a need for a new route discovery when a node along this path would be in need of a route to another node some hops away on the same path. Every node which is going to forward a RREQ packet and is not a direct neighbor of the originator of this RREQ, appends the information about its previous hop in the RREQ packet. A node receiving a RREQ packet with this additional routing data, updates its routing table accordingly. The expiry time for all the destinations along a single path is kept same. The additional routing data is added to RREQ or RREP packets in the form of an AODV extension [PBD03]. For each additional destination, the IP address and sequence number of that destination is added. Since these additional destinations are appended to the RREQ or RREP packet in the sequence in which they lie on the path, there is no need to mention the hop count for each destination independently.

The route sharing scheme distributes more information about the topology among the nodes with the expectation that this information might be required in near future and can be used instantly without performing an independent route discovery. This scheme collects an ample amount of prior-to-use routing information which soon becomes obsolete. This obsolete information can affect the behavior of AODV in multiple ways:

- The first obvious effect is the size of RREQ and RREP packets. These packets will be carrying more data; hence, routing overhead and the transmission time of frames containing RREQs and RREPs will be higher.

- As this scheme provides more routing data to each node, nodes probably will have larger routing tables than usual.

- Although, under route sharing scheme routing table might have more routing entries than usual, the number of active or in-use routing entries will remain the same as it depends on the active number of data streams, which is fixed. These additional entries will soon be expired and deleted afterwards. Since the presence of an expired entry for the intended route destination requires a higher initial value of the TTL field in the RREQ packet, it is expected that the initial value of TTL field would usually be higher in the route sharing scheme. The effects of the higher initial value of the TTL field are discussed in the previous section.

- Intermediate nodes can also generate a RREP in response to a RREQ if they have a valid route available. If nodes have more knowledge about the network i.e. have more valid routes, more route replies will be initiated by the intermediate nodes. On one hand, it will

Table 1: Simulation Scenarios

| Network Size | Geographical Area | Data Streams | Active Nodes (average) |
|---|---|---|---|
| 25 nodes | 800m *x* 800m | 5 | 8 |
| | | 20 | 20 |
| 100 nodes | 2000m *x* 500m | 20 | 30 |
| | | 80 | 85 |

control the flooding of RREQ as a node replying to a RREQ never transmits this RREQ further. On the other hand, there will be many nodes responding to the same RREQ.

The second candidate of our analysis of the inconsistent components is this route sharing scheme. The route sharing component is added to the AODV routing protocol, and the performance of this modified version of the AODV routing protocol is compared with the standard implementation.

# 4 Simulation Based Analysis of the Inconsistent Components

The effect of inconsistent routing operations is analyzed through simulations. The three protocol variations compared in this analysis are:

- The standard AODV.

- AODV-TTL in which the TTL field always has the same initial value i.e. TTL_START. This variation of AODV is selected as "less dependent on stale routing information" version of AODV.

- AODV-RS which is a combination of AODV and the route sharing scheme described earlier. This version of AODV collects additional routing data which eventually increases the use of obsolete routing information.

## 4.1 Simulation Settings

The simulations discussed in this paper are conducted using OPNET Modeler version 14.0 [OPN]. We have used the manet_station node model provided in the OPNET Modeler. Our analysis is based on discrete event simulations and our installation of the OPNET Modeler also contains OPNET Modeler Wireless Suite, which provides support for wireless networks. These simulations are performed on an SMP machine with two Intel Xeon 3.0 GHz processors, two GB RAM, and Microsoft Windows Server 2003.

In order to incorporate the effect of network size, these simulations are performed for two different networks sizes: 25 nodes and 100 nodes. The geographical area for the two cases is 800 meters *x* 800 meters and 2000 meters *x* 500 meters respectively. Similarly, for each network size two different data traffic patterns are introduced so that the effect of traffic congestion can also be analyzed. Table 1 provides an overall picture of the four simulation scenarios. Every simulation run is 1800 seconds long and is repeated with five different seed values. The nodes

Table 2: Simulation settings for Pause Time, Node Speed and Packet Rate

| Variation of | Pause Time (seconds) | Node Speed (meter/second) | Data Packet Rate (packets/second) |
|---|---|---|---|
| Pause Time | 0, 30, 60, 300, 900, 1800 | 1 | 4 |
| Node Speed | 0 | 1, 2, 5, 10, 20 | 4 |
| Packet Rate | 0 | 1 | 1, 2, 5, 10, 25 |

follow the Random Waypoint mobility model. Different simulation sets are designed by varying the values of Pause Time, Node Speed, and Data Packet Rate; these values are listed in Table 2. The Random Waypoint model is known to suffer from the density wave and the speed decay problems. Therefore, we first have created different Random Waypoint mobility traces for each combination of the values of the Pause Time, Node Speed, and Data Packet Rate. Then, for every combination we have selected five traces which do no contain the density wave and the speed decay problems. This approach further ensures that the three protocols strictly follow the same node movement during the simulation.

## 4.2 Simulation Metrics

Following evaluation metrics are selected after an extensive review of the earlier research work.

**Routing Overhead** is the total number of routing bits/bytes/packets sent during the simulation. The routing overhead of a simulation run is calculated as: the number of routing packets or bytes generated by the routing agent of all the nodes in the simulation run.

Like routing overhead, **MAC Overhead** is the total number of MAC control bits/bytes/frames sent during the simulation.

**Packet Delivery Ratio** is defined as the ratio of number of data packets delivered at the destination to the number of data packets sent by the source. The packet delivery ratio of a simulation run is evaluated as: the ratio of all the data packets received at all the destinations to all the data packets originated by all the sources.

**Route Discovery Time** or Route Acquisition Time is the time required to establish a route. The route discovery time of a route is computed as: the time interval from when the first RREQ message is generated by the routing agent of the source to when the first RREP is received by the routing agent of the source. The average for all route discoveries is taken to compute the route discovery time for the whole simulation run.

## 4.3 Simulation Results

In Figure 4 and Figure 5, the **MAC overhead** and the **routing overhead** of the three protocol variations are presented. It can be observed that the AODV-TTL always has less overhead than the AODV. On the other hand, the overhead of the AODV-RS is always higher. However, the difference between the overhead of the three protocol variations is limited and is mainly significant when network conditions are aggressive i.e. network size is large, or more data streams are in progress, or both. The overhead gain in case of AODV-TTL is less than the overhead loss in case of AODV-RS.
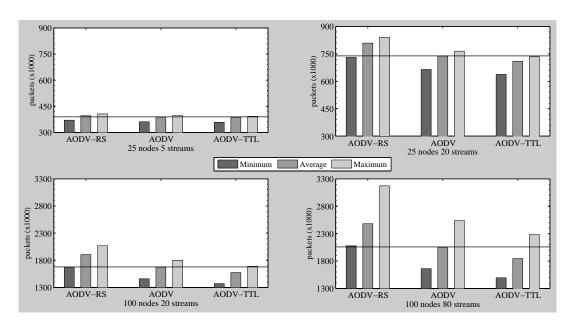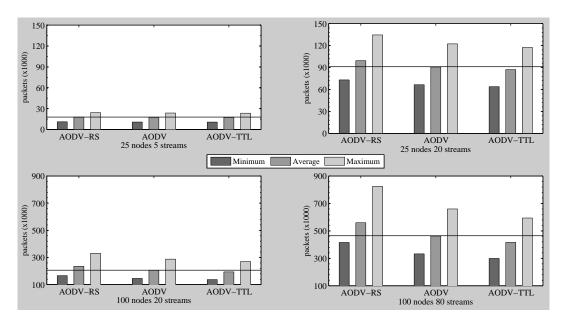
Figure 4: MAC overhead



Figure 5: Routing overhead

Table 3: Initial value of the TTL field (average)

| Simulation Scenario | AODV-RS | AODV |
|---|---|---|
| 25 nodes 5 stream | 1.69 | 1.21 |
| 25 nodes 20 streams | 2.27 | 1.52 |
| 100 nodes 20 streams | 3.03 | 1.81 |
| 100 nodes 80 streams | 4.77 | 2.56 |

Table 4: Composition of the routing overhead-Percentage of RREQ and RREP packets

| | Simulation Scenario | AODV-RS | AODV |
|---|---|---|---|
| **RREQ** | 25 nodes 5 stream | 81.73 | 82.42 |
| | 25 nodes 20 streams | 77.69 | 80.53 |
| | 100 nodes 20 streams | 75.89 | 78.10 |
| | 100 nodes 80 streams | 72.69 | 77.84 |
| **RREP** | 25 nodes 5 stream | 13.66 | 13.53 |
| | 25 nodes 20 streams | 18.32 | 17.10 |
| | 100 nodes 20 streams | 21.73 | 18.59 |
| | 100 nodes 80 streams | 25.34 | 19.29 |

Since the RREQ and RREP packets in AODV-RS are larger in size than the RREQ and RREP packets in standard AODV, it is obvious that the overhead in AODV-RS would be higher when measured in bytes. However, Figure 4 and Figure 5 present overhead results in packets, and a noticeable difference in this case is unexpected. As described earlier, the introduction of the route sharing scheme can affect the AODV route discovery method in two possible ways i.e. either would increase the number of RREP packets generated in response to a RREQ or would affect the initial value of the TTL field. The results presented in Table 3 and Table 4 elaborate these two aspects.

In Table 3, the average initial values of the TTL field used in AODV and AODV-RS are shown; AODV-TTL always initiate TTL field with TTL_START. It can be observed that in AODV-RS the initial value of the TTL field used is significantly higher which eventually leads to higher number of RREQ packets generated. Same is the reason of less overhead in AODV-TTL. Since the initial value of the TTL field in AODV is not much different from that in AODV-TTL, a relatively less difference in overhead is observed.

Table 4 contains the composition of routing overhead i.e. the percentage of RREQ and RREP packets. The contribution of RREP packets is up to 5% higher in AODV-RS while the ratio of RREQ packets is less with the same amount. This difference is due to the fact that in AODV-RS more nodes are in a position to respond to the RREQ packets. In general, the percentage of RREQ packets decreases when the network size grows or more data streams are running in parallel. The contribution of RREP packets behaves inversely i.e. it is higher when the network size is large or more concurrent data streams exist. Since increase in the number of nodes and the data streams both escalate the degree of the routing activities in the network, more routing information is shared among the nodes as a result. Therefore, their effect is similar to the effect
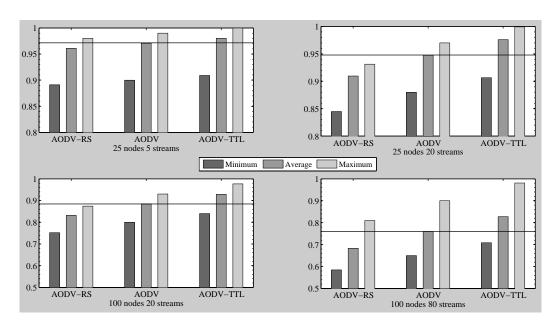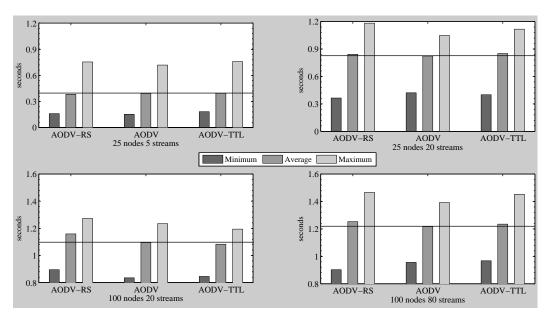
Figure 6: Data packet delivery ratio



Figure 7: Route discovery time

of the higher initial value of the TTL field i.e. more nodes are in a position to generate RREPs.

The comparison of the **data packet delivery ratio** is presented in Figure 6. AODV-TTL performs better than AODV, while the performance of AODV-RS is worse than AODV. Again, the difference is less when the network conditions are relaxed, but as the conditions become more stringent the difference becomes more substantial. In general, the data packet delivery ratio is higher for larger networks or in scenarios with more concurrent data streams which indicates that network saturation has a substantial effect on the data packet delivery ratio.

Surprisingly, the comparison of **route discovery time** is inconclusive [Figure 7]. The main distinguishing feature among the three protocol variations under observation is the initial value of the TTL field. As per the discussion in section 3, we can determinately say that initializing TTL field with a smaller value will always produce less overhead unless the destination currently locates at a distant point from the source. However, it is not possible to have a definite claim about the effect of the TTL field on the route discovery duration. Although, it appears that higher initial values of the TTL field would result in less route discovery duration, it is not always the case. Since, the 802.11 is a contention based wireless MAC, high overhead increases the probability of the contention which eventually can reduce the amount of successful transmissions. Furthermore, RREQs being broadcast packets are not acknowledged. Therefore, a transmitting node can never be sure of the successful delivery of a RREQ packet. All these issues contribute to the indeterminate behavior of the route discovery time. In three out of the four scenarios, both AODV-RS and AODV-TTL has performed worse than AODV. In case of AODV-RS, it can be claimed that it might be due to the severe network conditions and the resultant overhead; the only exceptional scenario is 25 nodes 5 streams.

The variation of Pause Time, Node Speed, and the Data Packet Rate do not reveal any additional facts about the effect of using the stale routing information. Therefore, due to space limitations individual results for these parameters are not included in the paper.

# 5 Conclusion

In wireless ad hoc networks, due to the highly dynamic nature of the network, routing information need to be periodically refreshed. The use of stale information is inconsistent with the nature of reactive routing as reactive protocols do not have the capability to refresh the stored routing information. We have analyzed the effect of such inconsistent operations on the performance of AODV routing protocol. The initialization of TTL field with a higher value during the route discovery for a previously known destination is a component which is dependent on the stale routing information. We have observed the reaction of eliminating this component from the protocol. The Route Sharing scheme is a component that increases the amount of routing information shared during the route discovery; this eventually leads to a higher amount of stale routing data. We have also compared the performance of introducing this modification to AODV routing protocol. We have concluded from our simulation based analysis that increasing the amount of not-demanded routing information is not beneficial in AODV as it increases the overhead and reduces the packet delivery ratio. It does not even ensure that the connection delay would be lesser in future attempts.

Although, the analysis presented in this paper is limited to AODV routing protocol, it elab-

orates some general aspects of the reactive routing as well when its findings are observed in combination with the earlier work. Firstly, the approach of blindly introducing more routing data, followed in route sharing scheme, is not used in DSR, AOMDV, AODV-BR, or AODV with Accessibility Prediction (AODV-AP) [RW07]. The inconsistency introduced in these schemes does not result in high overhead as they try to acquire additional information through overhearing or other similar approaches. Hence, we believe that explicit sharing of prior-to-demand routing information is not an appropriate optimization approach. Secondly, the use of obsolete routing information has limited but unpredictable benefits. For example, in the AOMDV alternate routes are not helpful anymore if the active route fails after the minimum route life announced during the route discovery. In DSR, the size of route cache grows up to four times the number of nodes in the network [MBJJ99]. The AODV-BR performs better than the AODV in terms of packet delivery ratio, but the end-to-end delay in the AODV-BR is higher than the AODV. Hence, we conclude that the cost or overhead of the modifications introduced by an optimization scheme is the major factor which decides its effectiveness.

In our future work, we are interested in performing a more generalized analysis of this problem based on multiple protocols and characteristics.

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