Improving the Path Optimality of Reactive Ad Hoc Routing Protocols Through De-Coherent RREQ waves

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Abstract

In this paper we show that adding jitter to the forwarding of RREQ waves substantially improves the optimality of routes in a IEEE 802.11 based ad hoc network. We explain the problem of forwarding coherent discovery waves with IEEE 802.11 broadcast messages and why classical metrics fail to capture this problem. Through simulations we show that adding RREQ forwarding jitter to DSR, AODV and LUNAR reduces the amount of packets sent over non-optimal links by a factor of 3 to 4.

Keywords:
Ad Hoc networks, IEEE 802.11, DSR, AODV, LUNAR.

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1 Introduction

This paper examines the routing optimality of AODV, DSR and LUNAR. Amongst the reactive routing protocols suggested in the scope of the IETF working group MANET (Mobile Ad-hoc NETworks) [7], AODV [8] and DSR [6] are the most mature solutions. Their relative performance was extensively studied and reported in the literature (see e.g. [2] and [3]). The more recent Lightweight Underlay Ad-hoc Routing protocol (LUNAR)[9] was designed as a simpler alternative to these IP level routing protocols. DSR uses a source routing mechanism and relies on the caching of overheard routing information. AODV constructs IP level routing tables and uses per-hop IP level forwarding. LUNAR deploys a mechanism similar to the label switching on layer 2.5. Despite these differences, the three protocols have a common initial path discovery phase based on flooding: When a route is needed, a route request message (RREQ) is issued, which is then re-broadcasted by the nodes that receive the RREQ.

In this paper we show that this initial phase has a major impact on the path optimality and overall performance achieved by these three reactive routing protocols. To this end we study the performance of RREQ waves via simulations in ns-2 using a simple synthetically created scenario with predicted movement pattern. We observe that coherent path discovery waves with IEEE 802.11 broadcast messages lead to the establishment of extremely non-optimal paths. We show that using only classical metrics for performance analysis this behavior cannot be captured. For DSR we find that its RREQ jittering is not big enough to prevent unreasonably long routing paths.

The work presented in this paper was done in the scope of a performance comparison of LUNAR to DSR and AODV. A main characteristic of LUNAR is the absence of protocol logic for the maintenance and reparation of established routing paths. All routes for the existing connections are rebuilt from scratch after some fixed time interval. Moreover, LUNAR limits itself to three-hop paths in anticipation of TCP performance problems over longer wireless routes.

The remainder of the paper is organized as follows. In Section 2 we state the problem of coherent RREQ waves and present results of longest path measurements for AODV, DSR and LUNAR. We show in Section 3 how “de-cohering” the RREQ waves significantly reduces the length of established routing paths and its effect for all three protocols. These results and related work are discussed in Section 4 before we conclude in Section 5.

2 The Problem of Coherent RREQ Waves

While evaluating the performance of the three protocols AODV, DSR and LUNAR in a synthetically created scenario with predicted movement, we discovered that during the propagation of route request waves large numbers of RREQ messages were lost due to collisions with their copies. While this problem is well known, we were surprised to see that this leads to the formation of very inefficient routing paths for all studied protocols. In this section we describe our simulation setting and present the corresponding results.

2.1 Simulations description

All simulation results analyzed in this paper are based on the scenario depicted in Figure 1, further referred to as the satellite scenario. This topology contains two rings of static nodes, which will be used purely for routing, one static central node which can be viewed as an access point to the fixed network, and one mobile node circling on the third ring which communicates with the

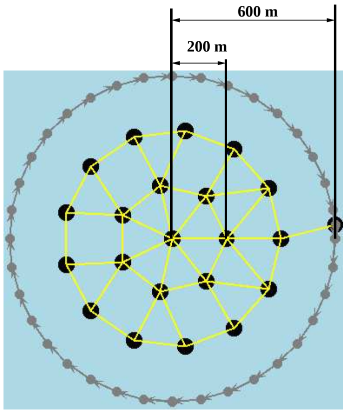

Figure 1: Satellite scenario.

central node. The radius of the three rings are 200, 400, and 600 meters, respectively; The circular internode distance is 179.5 m for the first ring and 193.3 m for the second ring, respectively. This guarantees potential connectivity for the mobile node to the center node over a three hops path at any time. In this scenario we excluded network congestion by having only one pair of communicating nodes. This allows us to examine the reaction of the routing protocols on node mobility in isolation. We varied the linear speed of the mobile node from 5 km/h to 140 km/h. Overall we performed experiments with ten different protocol configurations of DSR, AODV-UU 0.8 (the improved version of AODV from Uppsala University [1]) and LUNAR, as shown in Table 1. A simulation run for each protocol lasted for the time needed for three full rounds of a circling node at a given speed. In all experiments we used CBR traffic with the rate of 10 packets per second.

Table 1: Considered protocol configurations.

	Protocol	**Configuration parameters**
1	AODV_LL (default settings)	Link layer feedback, with jittering (0.02*uniform[0..1])
2	AODV_LL(noJ)	Link layer feedback, without jittering
3	AODV_noLL (default settings)	HELLO based, with jittering (0.02*uniform[0..1])
4	AODV_noLL(noJ)	HELLO based, without jittering
5	DSR (default settings)	Native RREQ jittering (uniform[0 .. 0.01])
6	DSR(J)	AODV jittering scheme (see above)
7	DSR(noJ)	without jittering of RREQs
8	LUNAR_3 (default settings)	Re-broadcasting limit = 3 hops, without RREQ jittering
9	LUNAR_15	Re-broadcasting limit = 15 hops, without RREQ jittering
10	LUNAR_15(J)	Re-broadcasting limit = 15 hops, with AODV scheme for RREQ jittering

For an initial performance evaluation we used the two classical performance metrics “packet delivery fraction” and “average end to end delay”. The first metric is the ratio of the totally delivered data packets to those sent by sources. Additionally, we examine the “max route length” and the “route length distribution”.

2.2 Performance comparison using classic metrics

Since the detailed performance evaluation of the protocols using classic metrics is not the main focus of this paper, we present only highlights of the results. Figure 2 shows the packet delivery fraction and the average delay for each protocol obtained from experiments using configurations 1, 3, 6, 8, 9, and 10 (see Table 1).

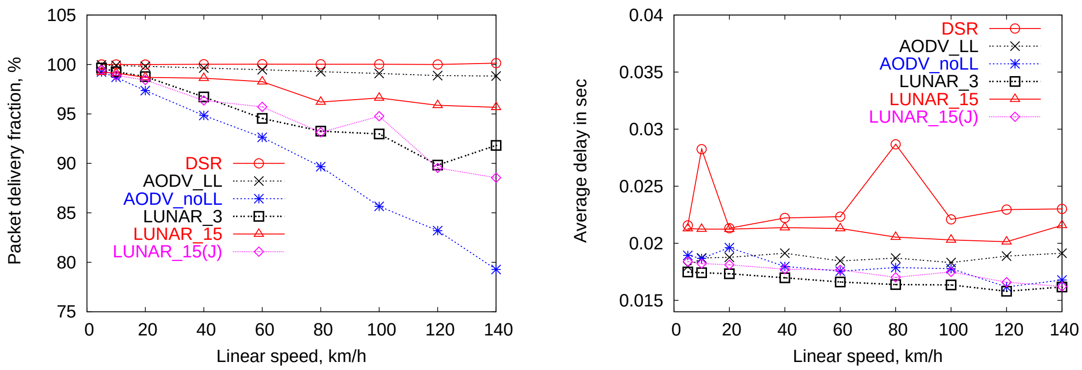

Figure 2: Delivery fraction (on the left) and average delay (on the right) in the satellite scenario.

With respect to the packet delivery fraction our results agree with the previously reported ones for DSR and AODV in small networks (see [3]): DSR performs best over all protocols delivering from 99.9 to 100% of the sent packets, then follows AODV with enabled link layer feedback while AODV based on HELLO messages shows the lowest delivery ratio. We also observed that at some speeds DSR and AODV deliver more packets than that was sent. This is due to the effect of the protocol specific retransmission of failed packets (packet salvation) by the routing layer. Despite its simplicity, LUNAR_3 has a competitive performance: It delivers equal or larger number of packets when compared to HELLO based AODV but less than link layer feedback supported AODV.

When analyzing the average end-to-end delay, we observe that DSR and LUNAR_15 (where the 3-hop limit of LUNAR is changed to 15 hops) have 25% to 50% larger average delays. The fact that DSR produces larger delays than AODV was observed earlier in [2] and was attributed to the high level of congestion which might occur in certain regions of the randomly created topologies. However, congestion can be excluded in this scenario due to having only one data flow. As we show below, this increased delay is due to non-optimal routes.

2.3 Route length measurements

Figure 3 shows the longest paths established by the protocols in the satellite scenario. Recall that in this topology there always exists a potential three hop path for the connection between the circling and the central nodes. LUNAR with the default configuration always establishes an optimal path. Both variants of AODV establish paths from three to six hops. What is more surprising to observe is the longest paths established constantly by DSR and LUNAR_15: for all speeds of the mobile node they are from three to four times larger than the optimal length.

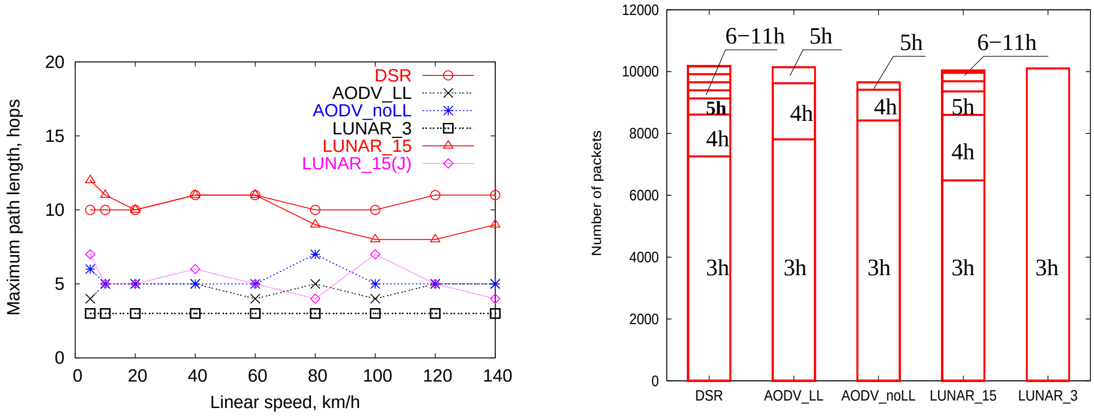

Figure 3: Maximum route length (on the left) and the route length distribution (on the right) in the satellite scenario.

2.3.1 Route length distribution

In order to understand the reason for the establishment of the non-optimal paths we decided to analyze the route length distribution produced by the routing protocols. We concentrate on the case where the speed of the mobile node is set to 40 km/h, because DSR and LUNAR_15 suffer from 11-hop paths already at this speed and because this fairly low speed does not stress-test the protocol's reactiveness to route changes. Figure 3 shows the resulting route length distributions for the considered protocols. Similar behavior was observed for all other speeds.

The figure clearly explains the reason for larger average delays of DSR and LUNAR_15: Almost 29% (2924 out of 10181) of the packets for DSR and 35% (3558 out of 10038) sent packets for LUNAR_15 are forwarded over non-optimal paths. For comparison, AODV with and without link layer feedback forward only 23% and 13% of the packets over paths longer than three hops, respectively.

2.4 Self-colliding coherent RREQ waves

Studying the traces for DSR and LUNAR_15 we observed that large numbers of route request messages were lost due to collisions with their copies that were re-broadcasted by the neighboring nodes. The reason for this behavior is in the processing time of RREQs by the intermediate nodes and the way the IEEE 802.11 protocol transmits the broadcast messages. Since the processing time of the RREQs is equal in all nodes, the transient RREQs (those for which the current node is not the destination) are sent by the routing level to the MAC layer at the same time. The 802.11 standard specifies that the transmission of the broadcast messages is controlled only by the carrier sensing mechanism without retransmission in the case of a message loss. The injection of a single RREQ in the network thus creates a localized broadcast storm where a large number of RREQs are lost due to collisions and radio interferences. In the considered satellite topology we observed the situation where the colliding RREQs blind a whole sector of eight nodes, "forcing" the requests to search for longer paths.

Since all three considered protocol use flooding as a mechanism for disseminating RREQs, we looked at the respective implementation details in order to understand why DSR and LUNAR_15 establish much longer paths than AODV. The study reveals that DSR and AODV use different

Table 2: Route (in-) optimality for different protocol configurations and a node speed of 40 km/h.

Protocol	**Max route length**	**Average e2e delay, ms**	**Fraction of packets on non-optimal path, %**
LUNAR_15(J) (range=15 hops, with jittering)	6	17.7	12
LUNAR_15 (range=15 hops, no jittering)	11	25.3	35
DSR(J) (AODV jittering)	5	19.5	22
DSR(noJ)	7	28.4	66
AODV_LL (Link layer feedback, native jittering scheme)	5	19.1	23
AODV_LL(noJ) (Link layer feedback, no jittering)	7	20.6	39
AODV_noLL (Hello based, native jittering scheme)	5	17.9	13
AODV_noLL(noJ) (Hello based, no jittering)	7	21.8	56

functions to randomize the sending of RREQs from the routing level to the link layer. While in AODV-UU the requests are scheduled with some delay in the range from 0 to 200 milliseconds, DSR picks a delay between 0 and 10 milliseconds. Lunar does not use jittering of RREQs at all, basically sending them immediately down the stack.

3 Imposing De-Coherence Through RREQ Forwarding Jitter

At this point we decided to broader investigate the effect of RREQ forwarding jittering on the performance characteristics of DSR, AODV and LUNAR. We performed the simulations for the speed of 40 km/h using the configurations 1-4, 6, 7, and 9, 11 (see Table 1) and tested the following two cases: Firstly, in all protocols we enabled the AODV scheme for RREQ jittering; Secondly, we disabled the jittering for all protocols to test the completely opposite case. The results are given in Table 2. LUNAR_3 was excluded because it always establishes the optimal path in the satellite scenario.

3.1 Discussion

It is clearly visible from Table 2 that enabling jittering in the forwarding of RREQs significantly improves the performance of all protocols. Even though for DSR and AODV the decrease in the maximum path length is only two hops, the fraction of the packets delivered over non-optimal routes is significantly lower when jittering is enabled (for DSR this ratio decreases from 66% to 22% and for HELLO based AODV from 56% to 13%). For LUNAR_15 adding jittering reduces the maximum path length from 11 to 6 hops, bringing down the fraction of non-optimally delivered packets from 35% to 12%. Overall, this is a reduction by factor from 3 to 4.

Note that adding jitter to the forwarding of RREQs leads to an increase in the path establishment time, hence lower packet delivery fraction at high speeds (Figure 2 illustrates this effect for LUNAR_15 and LUNAR_15(J)). However, the benefits stated above are clear: With a reduced number of packets sent over non-optimal paths, one achieves lower *average* delays for data packets, as is shown in Table 2. LUNAR, by the way, only suffers from the additional delay due to the added jitter for the first path establishment, as subsequent path discoveries are done in parallel with the ongoing data traffic.

It is noteworthy that DSR in fact implements a form of RREQ jittering but still suffers from long routing paths. When switching to an AODV style RREQ jittering taken from a 20 times larger range, DSR obtains a much more favorable fraction of packets sent over non-optimal routes.

While studying the implementations of the protocols we observed as well that jittering of RREQs is a pure simulation feature. The real code of AODV-UU sends the RREQs down the stack immediately. The same holds for the implementation of LUNAR and the FreeBSD implementation of DSR [4]. Since neither the UDP nor the IP level of the operating system have the duty of shaping outgoing traffic, the situation described above might occur in real networks. A mitigating factor might be the unpredictable computing load of each node and ongoing unicast traffic, which could introduce a small amount of "natural" jitter.

4 Related Work

Broadcast protocols for ad hoc networks are extensively studied and widely reported in the literature. A good overview of the techniques intended to optimize re-broadcasting, thus to improve the performance of the protocols based on it, is given in [10]. Moreover the authors state the problem with rebroadcasting of the messages that take equal processing time and suggest to jitter the scheduling of broadcast packets. However, concentrating on the analysis of other techniques, the paper does not develop the idea of RREQ jittering.

Amongst other approaches towards minimization of the broadcast effect we can highlight the contributions in [11] and [5]. In [11] the authors stress that the probability of collisions for broadcast packets rapidly grows with the number of neighboring nodes. Their proposed solution requires the piggybacking of information about the neighborhood and heuristic formation of clusters of nodes to optimize broadcasting in the whole network. The authors in [5] suggest to make a probabilistic decision on re-broadcasting a routing packet in every node. However, the main goal of this solution is to reduce the control load in the network. It is shown in the paper that this technique may lead to establishment of longer paths than when pure flooding is used.

In comparison, adding RREQ jitter is a simple measure that could improve even these complex forwarding schemes. Further studies should be carried out to investigate the optimal amount of RREQ jittering that takes into account many different scenarios and traffic conditions.

5 Conclusions

The study of reactive ad-hoc routing protocols in a synthetic scenario enabled us to isolate a problematic consequence of coherent RREQ discovery waves: We showed that they are a key factor for the establishment of non-optimal paths. Imposing a jittering scheme on the retransmission of RREQs leads to a significant reduction in the length of established routes and does drastically reduce the number of packets forwarded over non-optimal paths. While the implementations of both AODV and DSR for the network simulator use some form of jittering, none of them implements jittering in the production software. Based on our results we recommend to make the jittering of RREQ forwarding over IEEE 802.11 networks a mandatory element of the protocol specifications of AODV, DSR and LUNAR.

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