Efficient Route Discovery for Reactive Routing Protocols with Lazy Topology Exchange and Condition Bearing Route Discovery*

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Abstract. We propose LTE and CBRD to reduce route discovery overhead of reactive routing protocols for Mobile Ad hoc Networks (MANETs). LTE proactively distributes topology information of the network by using a lazy update policy. That topology information is used by CBRD to optimize route discoveries. CBRD is a reactive route discovery mechanism which employs topology information provided by LTE to restrict route discovery floods to limited regions containing desired destinations. Our simulation results have shown that LTE and CBRD efficiently reduce route discovery overhead as well as route discovery delay. Also, they improve routing performance of flooding dependent reactive routing protocols like AODV in low- and moderate-traffic networks.

1 Introduction

In Mobile Ad hoc NETwork (MANET), where mobile nodes function as end nodes as well as routers, routing packets to desired destinations is challenging due to topology changes and limited resources such as bandwidth and nodes' battery life. In such an environment, a routing protocol should maintain routing state with a small number of control packets.

Proactive routing protocols such as DSDV [8] exchange routing updates periodically as well as instantly in response to topology changes. Since topology of MANETs can change unpredictably, nodes need to exchange enough routing information within a certain period of time; otherwise data packets will be misrouted. For example, as shown in [9], DSDV can provide acceptable performance in low mobility networks, but it fails to converge when highly increased mobility causes frequent changes in topology. Moreover, proactive routing protocols keep generating many periodic control messages to calculate routes even when there is almost no traffic load. These two disadvantages discourage proactive protocols from being used when mobility is high and the traffic load of networks is low.

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Rather than establishing routes proactively, reactive routing protocols [3, 7, 10] set up routes only when nodes need routes to send data. This reduces routing overheads since routes that are not required for sending data will not be set up. Reactive routing protocols establish routes on-demand by using a route discovery scheme in which route request packets (RREQs) are flooded to search desired destinations. Unfortunately, that flood-based route discovery tends to be costly and can severely degrade the performance of routing protocols.

In this paper, we propose Lazy Topology Exchange (LTE) and Condition Bearing Route Discovery (CBRD) to reduce the overhead of the flood-based route discovery in reactive routing protocols. The former, LTE, aims at setting up an approximate topology of the network at each node by proactively and lazily distributing topology information, and the latter, CBRD, is a route discovery heuristic that employs topology information provided by the former to restrict the route discovery floods to a small region around the shortest path to the destination.

The outline of this paper is as follows: In section 2, related works are discussed; section 3 describes our proposed scheme; simulation results are presented in section 4; and finally, we conclude the paper in section 5.

2 Related Work

Since route discoveries base on flooding, one approach for reducing cost of route discoveries is reducing cost of flooding. Works [1, 5, 6], that has been done on improving the effectiveness of the flooding operation in MANETs, can be directly applied to route discovery of reactive routing protocols.

Restricting route discovery floods is also a promising approach to the reduction of cost of route discoveries. Following this approach, a source node floods route request packets just within a limited region that contains its desired destination. This results in a less number of flooded packets. In Query Localization (QL) technique [4] and Location Aided Routing [11], a source node first estimates a requesting zone containing the current location of its destination based on some historical information and then floods route request packets in that location only. All route request packets rebroadcasted outside the requesting zone are suppressed. Although these techniques can effectively reduce overhead of flooding in re-discovering a route that was recently used, they cannot avoid overhead in the first, and most expensive, route discovery.

Different from LAR and QL, FRESH [12], a recent proposal in restricting route discovery floods, can narrow the route discovery area even for the first route discovery attempt. Restricting global floods in FRESH is based on *mobility diffusion* as follows: Due to mobility, nodes may encounter each other, that means they become one-hop neighbors. When encounters happen, nodes record this kind of events in their *encounter tables*. If a source node s needs to find route to a destination d, s looks for intermediate node k that has encountered d more recently than s by flood-based *expanding ring searches*. Node k then looks for another node that has encountered d more recently than itself. This procedure is repeated until d is found. Although FRESH can reduce flooding overhead even for the first route discovery, routes formed by FRESH tend to run along nodes' trajectories. Hence, routes can be sub-optimal. Also, if mobility is not sufficiently high, reduction in route discovery cost may not be significant.

3 Proposed Scheme

Lazy Topology Exchange (LTE) and Condition Bearing Route Discovery (CBRD) introduced in this paper follow the approach of restricting floods to solve the problematic route discovery of reactive routing protocols. Different from previous works, this scheme bases on distance information that is proactively distributed among nodes by using LTE. The update policy that LTE uses is periodic and lazy in order to set up an approximate distance-based representation of the network topology at each node. CBRD then uses this topology representation to narrow flood areas resulting cheaper route discoveries. The total overhead for building approximate topology representation and for discovering routes with CBRD, according to our simulation with 100 mobile nodes, is about from 20% to 25% lower than the overhead of pure flood-based route discovery.

Using CBRD, a source node who wishes to find a destination locally floods a route request packet within μ hops to find any intermediate node that has better distance information to the destination than itself. This node called anchor node will find the next anchor node toward the destination. This procedure iterates until the destination is found. Details of LTE and CBRD will be discussed in the following subsections.

3.1 Lazy Topology Exchange (LTE)

Only bidirectional ad hoc networks are considered in our scheme. Two nodes in the networks can communicate with each other if they are within their transmission range R_{Tr}. Otherwise, none of them can receive packets from the other.

LTE, in fact, is a variation of DSDV [8] but with a lazy update policy and a multi-path extension. Similar to DSDV, in LTE, distance information between a source-destination pair is a combination of cost information, represented by the number of hops between nodes, and the freshness of that cost information, represented by a destination-generated sequence number. Each node j stores and maintains distance information of multiple paths from node j to all other nodes via different neighboring nodes of j in a distance table DT_j. The structure of the distance table DT_j is as follows:

1. A set N_j of neighboring nodes of node j.
2. Corresponding to each tuple (d, k), where d is a destination node known by node j, and k is a neighbor of j, the following information is maintained:
   - The most recent update of the shortest distance (in hops) from node j to node d via neighbor k, denoted as $D_j^k(d)$

- The corresponding sequence number $S_j^k(d)$ of $D_j^k(d)$, originated from node d and received by node j

By examining the above $D_j^k(d)$ and $S_j^k(d)$, for each destination node d, j selects a neighbor k corresponding to the best distance to d, called distance entry to d. The distance entry to node d in DT_j, denoted by $DE_j(d) = (d, S_{jd}, D_{jd})$, is that which has the latest sequence number S_{jd} and the fewest number of hops D_{jd}. For convenient explanation, $DE_j(d).D_{jd}$ and $DE_j(d).S_{jd}$ are used to refer to D_{jd} and S_{jd} of $DE_j(d)$, respectively.

Topological information is exchanged among nodes in periodical update messages which contain one or more distance entries in nodes' distance tables. Each node j in the network keeps refreshing the distance entry to itself, $DE_j(j) = (j, S_{jj}, D_{jj} = 0)$, by monotonically increasing the sequence number S_{jj} and sending $DE_j(j)$ in every update message to advertise the current position of j to j's neighbors. Other distance entries can also be sent in an update message together with $DE_j(j)$ if they have been changed but have not been advertised. Update messages are sent periodically after an update interval τ. An update message will be fragmented into several smaller update messages if it does not fit in a single Maximum Transmission Unit (MTU). The distance table is updated according to the following rules:

- When node j receives a distance entry $DE_k(d)$ in an update message from node k, node j updates $D_j^k(d)$ and $S_j^k(d)$ in its distance table if $DE_k(d)$ is a "better distance" to d via k than that being maintained at j, i.e. $DE_k(d)$ contains a higher sequence number than $S_j^k(d)$, or $DE_k(d)$ represents a equally fresh but fewer number of hops than $S_j^k(d)$ and $D_j^k(d)$.
- When node j discovers a new neighboring node k, j sends its distance table to k.
- When node j detects that the link to neighbor k is broken, j removes $D_j^k(d)$ and $S_j^k(d)$ from its distance table.

Any change in $D_j^k(d)$ causes an immediate recalculation of $DE_j(d)$. If a $DE_j(d)$ is changed, it will be marked for sending in the next update message. Thus, the update policy of LTE is periodic without triggered updates.

The update operations of LTE described above may not help node route data packets to destinations since global knowledge of network topology at each node is not up-to-date when mobility causes link states between nodes to change. However, that global knowledge is useful for reducing route discovery overhead if CBRD is used to set up routes.

3.2 Condition Bearing Route Discovery

CBRD is proposed to utilize the information that is provided by LTE to optimize the flood-based route discovery. Any route setup mechanism, such as the dynamically modifying routing table in AODV [3] or source routing in DSR [7], can be integrated with CBRD to establish routes. Like flood-based route discovery

procedure, CBRD is a query-response mechanism, i.e., source node broadcasts Route Request packets (RREQ) to search for its destination; intermediate nodes that receive a route request packet will forward this packet further; and when the destination is found, a route reply packet is sent back to the source node. However, a RREQ in CBRD implicitly carries some conditions, and only intermediate nodes that meet the conditions inside a received RREQ will forward the packet further. Thus, the number of nodes that need to forward RREQs is restricted.
CBRD works as follows:

- The route discovery process starts when a source node j broadcasts a route request packet, RREQ, to find a destination d. The RREQ packet contains the distance entry $DE_j(d)$. This RREQ is a broadcast message which is limited within μ hops by some counter value such as the TTL field in the IP packet header [2].
- When an intermediate node k receives an RREQ for a destination d, if the distance entry at k for destination d, $DE_k(d)$, is "better" than that contained in the RREQ, node k drops the RREQ and initiates a new broadcast RREQ within μ hops for destination d with its distance entry $DE_k(d)$ attached into the RREQ. Otherwise, k rebroadcasts or drops the received RREQ by examining the counter value or the TTL field of the RREQ packets. The criterion for determining a "better" distance entry $DE_j(d)$ is based on $DE_j(d).S_{jd}$ and $DE_j(d).D_{jd}$. More specifically, $DE_k(d)$ is better than $DE_j(d)$ if: $(DE_k(d).S_{kd} > DE_j(d).S_{jd})$ **OR** $((DE_k(d).S_{kd} = DE_j(d).S_{jd})$ **and** $(DE_k(d).D_{kd} < DE_j(d).D_{jd}))$

The idea of CBRD is that when node j needs a route to a destination, j "locally floods" within μ-hop to find nodes, called *anchor nodes*, that "know" the destination better than j. A found anchor node k then searches for the next anchor node toward the destination. This search procedure, called *anchor search*, then iterates until the desired destination is reached resulting in a successful route discovery. If nodes choose sufficiently large values for μ, anchor searches will succeed with high probability, and finally, the route discovery process will end with a route set up to the destination. Since an anchor node is a node that has better distance information to the destination than its previous anchor node[1], searching an anchor node can be considered as discovering the next node toward the destination.

μ, which is called *topological estimation radius*, is a local parameter that node j uses to estimate the position of the next anchor node. The parameter μ used by node j should take the probability of success π of the anchor search into consideration. In fact, π is a function of the topological estimation radius μ, the update interval τ in LTE, and node density. On the one hand, if μ is not sufficiently large to compensate the "laziness" of LTE, which is parameterized by τ, the success probability of route discovery will be low. On the other hand, a too large value of μ leads to unnecessary route request messages injected into

[1] The source node is considered as the first anchor node.

the network. Thus, a suitable configuration of τ and μ is a significant factor for an optimal performance of LTE and CBRD.

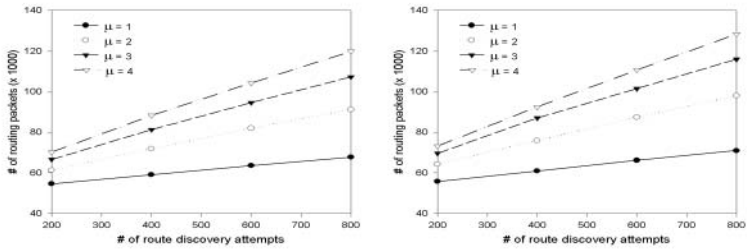
4 Simulation Studies

We have performed several simulations with ns2 (version 2.1b9) to analyze the route discovery operation with LTE and CBRD. We also evaluated the effects of LTE and CBRD on routing performance. Our simulation scenario is arranged as follows: 100 nodes move around in a rectangular region of $1250m \times 1250m$. Random way-point model [13] is used to simulate node mobility. In this mobility model, a node randomly chooses a destination and moves to the destination with a random speed chosen uniformly between 0 and *maxspeed* value. Once a node reaches its destination, it stays there for a pre-defined *pause time* before moving to a new random destination. Following simulations in previous works [9, 14], we set *maxspeed* to 20 meters per second, and vary *pause time* to adjust node mobility. The wireless transmission model is parameterized to be similar to Lucent's WaveLAN interface which has a nominal trans-mission range of 250 meters and a shared radio medium using IEEE 802.11 standard. Since current hardware does not support link layer feedback, we decide to use Hello messages for monitoring link connectivity in both AODV and AODV+&CBRD. The Hello message interval in our simulations is set to one second.

4.1 Route Discovery Analysis

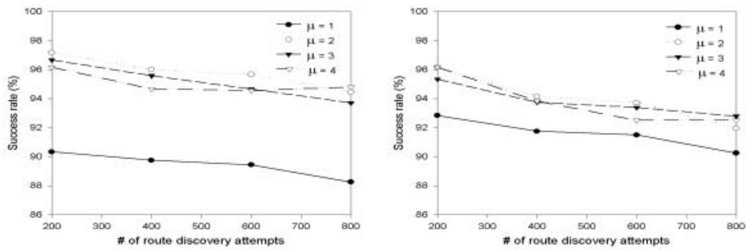
Our first set of simulations is a comparison of route discovery performance between AODV, a flooding dependent reactive routing protocol, and AODV with LTE and CBRD, which is labeled as AODV+LTE&CBRD.

In order to figure out a suitable set of configuration τ and μ parameters for LTE and CBRD, we vary the topological estimation radius μ while the update interval τ of LTE is fixed to 5 seconds. Simulation experiments on route discovery performance of AODV+LTE&CBRD with different values of topological estimation radius μ are conducted with this scenario to figure out a suitable value of topological estimation radius μ. Results shown in Fig. 1 and Fig. 2 help us conclude that $\mu = 2$ is an optimal value in the scenario described above since with $\mu = 2$, LTE&CBRD provides the lowest number of routing packets and a competitive packet delivery fraction. In this comparative simulation with AODV, since we are interested in route discovery of compared protocols, traffic in our simulated network is comprised of hundreds of short conversations occurring in 200 seconds of simulation time. The traffic of conversations is Constant Bit Rate (CBR) between randomly selected source-destination pairs. Each conversation sends a random number of 64-byte packets uniformly distributed between 5 and 10 packets with rate 10 packets per second. The number of conversations is changed to adjust the condition of the traffic load in our simulations. Comparisons in routing overhead and packet delivery fraction under different pause time values in Fig. 3 show that LTE&CBRD enhancement for AODV roughly reduces



(a) Low mobility (pause time = 100s) (b) High mobility (pause time = 0s)

Fig. 1. Total number of route request packets and update packets



(a) Low mobility (pause time = 100s) (b) High mobility (pause time = 0s)

Fig. 2. Success rate of route discoveries

20% to 25% the number of routing packets while it does not hurt the packet delivery fraction. The reduction in routing overhead also indirectly improves route discovery latency as shown in Fig. 4. Since conversations in this experiment are very short, the dominant reason of packet delay is route setup delay. In all observations, AODV+LTE&CBRD results in a smaller mean value of packet delay, usually a half of that of AODV. Also, packet delay in AODV+LTE&CBRD is rather stable. It implies that AODV+LTE&CBRD provides faster and more stable route setups. To explain this simulation result, consider two source nodes simultaneously starting route discovery in the network. In the case of AODV, all nodes in the MANETs will receive RREQs from both the two source nodes. In other words, the two route discovery areas completely overlap and cover the whole network. In the case of AODV+LTE&CBRD, a limited overlapped region exists between the two route discovery areas as the result of route discovery localization. It mitigates mutual interference between concurrent route discoveries. Hence, the network becomes more stable, and route discovery latency is improved.

4.2 Routing Performance

To evaluate effects of LTE and CBRD on routing performance, we run a set of simulations with multiple long-lived traffic streams: the number of streams is 20;

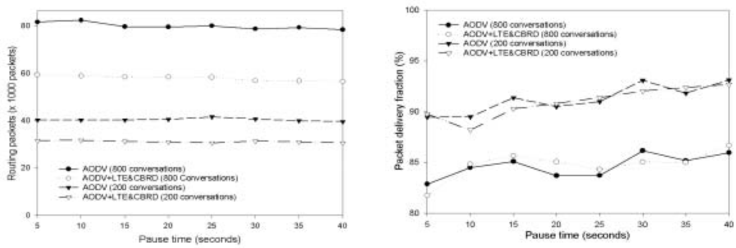


Fig. 3. Route discovery analysis

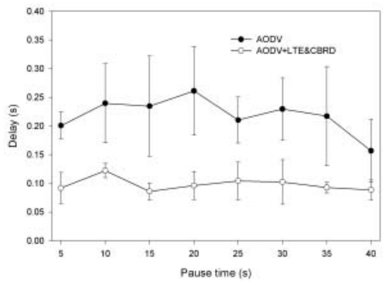
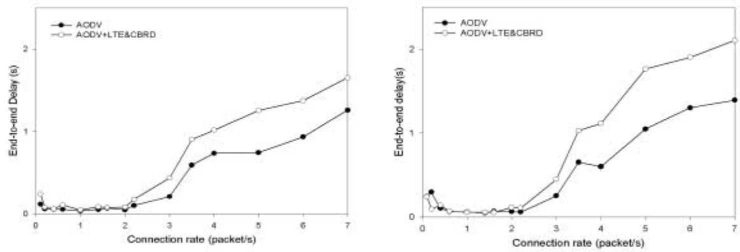


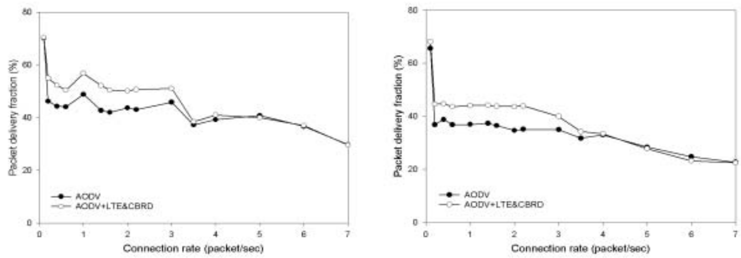
Fig. 4. Route discovery delay

traffic type is Constant Bit Rate (CBR) with 512-byte packet size; each stream is between a randomly chosen pair of source and destination; simulation time is set to 500 seconds; simulation area, node population and moving pattern are the same as those in the route analysis experiment presented above. Connection rates are varied to adjust the traffic load. Fig. 5 shows comparisons in packet delay between AODV+LTE&CBRD and AODV. When the connection rate is greater than 3 packets per second, equivalent to about 150 Kbps total offered load, packet delay in both the two protocols dramatically increases implying that network congestion happens. We also notice that AODV+LTE&CBRD produces larger packet delay than AODV does. Since LTE and CBRD localize route discovery area around the shortest path instead of carrying a global flooding like AODV, if congestion happens to be in a route discovery area, it will prevent route request messages from reaching the desired destination. Thus, the source, in case of AODV+LTE&CBRD, has to re-discover a route while the source, in case of AODV, is able to find a route around the congested area in the first trial. This explains why AODV+LTE&CBRD suffers from higher delay when the network is congested. However, comparison on packet delivery fraction in Fig. 6 shows that, in terms of the packet delivery fraction, AODV+LTE&CBRD is still similar to AODV under network congestion while AODV+LTE&CBRD outperforms AODV when network is not congested. Thus, we can conclude that



(a) pause time = 100s (b) pause time = 0s

Fig. 5. Routing analysis - End-to-end delay



pause time = 100s pause time = 0s

Fig. 6. Routing analysis - Packet delivery fraction

LTE and CBRD can improve routing performance in the low and moderate traffic networks.

5 Conclusion and Future Works

We have presented LTE and CBRD for reactive routing protocols to restrict route request floods. Our scheme is beneficial even to the first route discovery attempt. Based on topology information that is formed by lazily exchanging updates between nodes, our scheme replaces a global flood by successive anchor searches to narrow route request area. Our simulation has shown that with LTE and CBRD, AODV can reduce overall routing overhead and mitigate the effects of the flood-based route discovery. Tradeoffs for these advantages are periodic control packets and degradation in reliability of route discovery. However, the proactive overhead is low and spreads out over time instead of occurring in a short time like flooding. Also unreliability in route discovery can be alleviated by an appropriate configuration of parameters and a retry strategy. Our simulations show that LTE and CBRD have positive effects on route discovery performance, and they can improve reactive routing protocols on low- and moderate-loaded networks. Our future direction will focus on an extended version of LTE and CBRD for multicast routing, and it may result in some considerable results.

References

[1] M. Gerla, T. J. Kwon and G. Pei "On Demand Routing in Large Ad Hoc Wireless Networks with Passive Clustering," In Proceedings of IEEE WCNC 2000, Chicago, IL, 2000. 115

[2] DAPRA Internet program, "Internet Protocol Specification," IETF RFC 791, Sep. 1981. 118

[3] Charles E.Perkins and Elizabeth M. Royer, "Ad hoc On-demand Distance Vector Routing," In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, New Orleans, LA, Feb. 1999. 115, 117

[4] R. Castaneda and S. Das, "Query Localization Techniques for On-demand Routing Protocols in Ad hoc Networks," In Proceedings of the ACM International Symposium on Mobile Ad hoc Networking and Computing (MOBIHOC), 1999. 115

[5] L.Li, J. Halpern, and Z. Haas, "Gossip-based Ad hoc routing," In Proceedings of the IEEE conference on Computer Communications (INFOCOM), New York, NY, June 2002. 115

[6] B. Williams and T. Camp, "Comparison of Broadcasting techniques for Mobile Ad hoc Networks," In Proceedings of the ACM International Symposium on Mobile Ad hoc Networking and Computing (MOBIHOC), 2002. 115

[7] David B Johnson and David A Maltz, "Dynamic source routing in ad hoc wireless networks," In Imielinski and Korth, editors, Mobile Computing, volume 353. Kluwer Academic Publishers, 1996. 115, 117

[8] Charles E. Perkins, Pravin Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," SIGCOMM'94 Computer Communication Review 24(4):234-244, Oct. 1994. 114, 116

[9] D. A. Maltz, J. Broch, and D.Johnson, "A performance comparison of Multi-hop Wireless Ad hoc Network routing protocols," In Proceedings of ACM MOBICOM, October 1998. 114, 119

[10] V. Park and S. Corson, "Temporally-Ordered Routing Algorithm (TORA) Version 1 Functional Specification," IETF, Internet draft, 1997. 115

[11] Young-Bae Ko and Nitin H. Vaidya, "Location Aided Routing (LAR) in mobile ad hoc networks," ACM/Baltzer Wireless Networks (WINET), Vol.6-4, 2000. 115

[12] Henri Dubois-Ferriere, Matthias Grossglauser and Martin Vetterli, "Age Matters: Efficient Route Discovery in Mobile Ad Hoc Networks" In Proceedings of MobiHoc '03, 2003. 115

[13] T. Camp, J. Boleng, and V. Davies, "A Survey of Mobility Models for Ad Hoc Network Research," Wireless Communication & Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications, vol. 2, no. 5, pp. 483-502, 2002. 119

[14] P. Johansson, T.Larsson, N. Hedman, B. Mielczarek, and M.Dagermark, ôScenario Based Performance Analysis of Routing Protocols for Mobile Ad-Hoc Networks,ö in Proceedings of ACM Mobicom'99, Seattle, Washington, August 1999. 119