A Reachability-Guaranteed Approach for Reducing Broadcast Storms in Mobile Ad Hoc Networks

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Abstract-* In this paper, a reachability-guaranteed approach for reducing broadcast storms in MANET is proposed. The approach is based on location awareness, which means each node in the network needs to equip the positioning device like GPS and exchanges location information in the HELLO message with its neighbors. Three mechanisms are included in the proposed approach: Relay Set (RS), Neighbor Coverage (NC), and Transmission Order (TO). Simulation results have shown that the proposed approach "RS+NC+TO" has a better performance than the threshold-based schemes and angle-based scheme in terms of 100% reachability, more saved rebroadcast, and shorter average latency to accomplish the broadcast process over the whole network.

Keywords: broadcast, mobile ad hoc network (MANET)

I. INTRODUCTION

The mobile ad hoc network (MANET) [1] has been an active research field in recent years. Routing [2-4] in a MANET is more difficult than the traditional wireless networks because of the nature of dynamic changing topology of the MANET. Thus, broadcasting is a common and important operation in MANETs for route finding, and it could be performed frequently. The most straightforward solution for broadcasting is *flooding* (*blind flooding*) in which every node rebroadcasts a message when the message is received at the first time. However, it had been pointed out in several articles [7-9] that blind flooding is improper in MANETs since it introduces lots of duplicate messages and consumes much network resources. Lots of duplicate messages imply serious redundancy in message transmissions and also lead to much contention and collision in mobile wireless networks, which was identified as the *broadcast storm problem* [7].

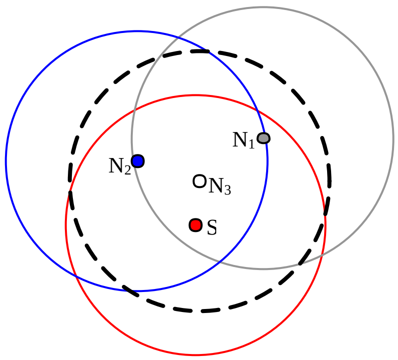
Several solutions for reduction of the broadcast storm problem in MANETs had been proposed in the literature [5-9]. One classification of these solutions is based on which is the decision maker for the rebroadcast. Mechanisms in which the sender of the broadcast message determines the rebroadcast nodes for relaying the message are called *sender-based* mechanisms. On the other hand, rebroadcast or not that is determined by the receiver of the message is called *receiver-based* mechanism.

Qayyum et al [5] proposed a sender-based mechanism called *MPR* (multipoint relay) for efficient broadcasting. The MPR technique restricts the number of retransmissions by selecting a small subset of neighbors which covers (in terms of one-hop radio range) the same network region that the complete set of neighbors does. The small subset of neighbors is called *multipoint relays* of a given network node. However, in order to calculate the multipoint relays, every node in MPR has to collect the set of one-hop neighbors and the two-hop neighbors, which results in heavy overhead. Moreover, the problem of finding an optimal multipoint relay set is NP-complete. Techniques of *self pruning* and *dominant pruning* proposed by Lim and Kim [6] are similar to MPR.

Ni et al [7] proposed several receiver-based solutions for the broadcast storm problem: the *counter-based*, *distance-based*, and *location-based* schemes. These schemes rely on various threshold mechanisms help a mobile node decide whether to rebroadcast or not. Adaptive versions of the schemes were also proposed [8] in which the threshold values are dynamically chosen according to a host's number of neighbors. It had been shown that if location information is available through devices such as GPS receivers, the location-based scheme is the best choice in terms of saved broadcast and reachability. However, all the threshold-based schemes mentioned above cannot reach 100% reachability and it degrades the performance of broadcasting-based route finding. Besides, it is difficult to find a good threshold value (or threshold function) suitable for any network situations.

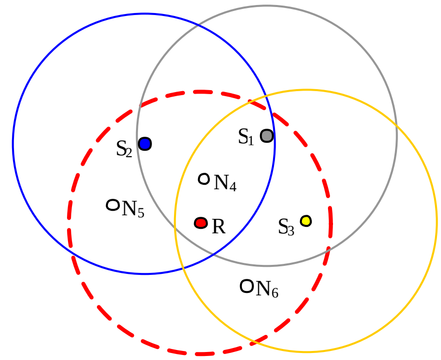
A receiver-based scheme namely *Angle-based Scheme* (*ABS*) has been proposed by Sun et al [9]. Location information is used for ABS to achieve 100% reachability. Moreover, in order to let a node covering more new area to rebroadcast the message earlier than the node covering less new area, the *Distance-based Defer Time Scheme* (*DBDT*) was also proposed to replace the random defer (waiting) time scheme used in other schemes. The authors claimed that the protocol combining ABS and DBDT enjoys high reachability and bandwidth efficiency.

In this paper, we propose a reachability-guaranteed scheme by *location-awareness* in which we assume (1) each node in the MANET is equipped with the positioning device, and (2) the HELLO message (the beacon packet) carries position information of the sending node such that each node knows the positions of its neighbors. The proposed scheme is a



S: the sending node N_1, N_2, N_3: neighbors
Relay set of *S*: {N_1, N_2}

Figure 1. E.g. determining the relay set



R has received the same broadcast message from S_1, S_2, S_3. *Since R's neighbors are all covered by the coverage of* S_1, S_2, S_3, *R decides not to re-broadcast the message.*

Figure 2. E.g. Neighbor Coverage

hybrid scheme of the sender-based and receiver-based mechanisms. Simulation study has been conducted and the result shows that better performance can be obtained by the proposed scheme over the threshold-based schemes and non-threshold-based scheme ABS+DBDT in terms of 100% reachability and saved rebroadcast.

The rest of the paper is organized as follows. The proposed sender-based mechanism is presented in section II, and two receiver-based mechanisms are proposed in section III. Simulation study for performance evaluation is presented in section IV. Finally, section V concludes this paper.

II. Sender-based Mechanism

A. Relay Set (RS)

Since each node in the MANET knows the positions of all its neighbors, the sending node of the broadcast message can determine the relay set of neighbors for rebroadcast by analyzing the radio coverage of its neighbors. The scheme is called *Relay Set* (*RS*) in the paper. The first step in the RS algorithm is to sort the neighbors by the distance of each neighbor to the sending node. Starting from the farthest neighbor, the sending node examines the radio coverage of each neighbor to identify the neighbors that do not create new radio coverage. These neighbor nodes, which are called exclusive nodes, may not be included in the relay set. Since the nodes in the relay set cover the radio coverage of the exclusive nodes, reachability of the RS algorithm is the same as blind flooding. One example of determining the relay set is shown in Figure 1. In the figure, Node N_3, whose radio coverage is totally covered by the radio coverage of the sending node *S* and the farther neighbors N_1 and N_2, is not included in the relay set of node *S*.

When receiving a broadcast message at the first time, the mobile node calculates the relay set for rebroadcast and appends the relay set to the message before broadcasting. Only the nodes in the relay set of the message rebroadcast the message and repeat the RS algorithm.

III. Receiver-based Mechanism

A. Neighbor Coverage (NC)

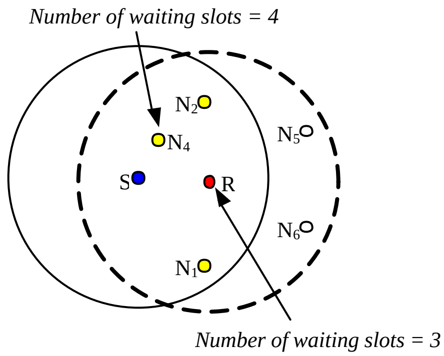
The basic idea of *Neighbor Coverage (NC)* is: if a mobile node receiving a broadcast message assures that all its neighbors have received the same broadcast message, rebroadcast of the message is actually redundant. Therefore, each node in the NC scheme needs to record the message ID as well as the sender of the broadcast message and calculate the neighbors that are not covered by the message. Calculation of the non-covered neighbors is easy since the mobile node knows the position of the sender of the message.

On receiving a broadcast message at the first time, the mobile node waits a random number of time slots before rebroadcast the message (i.e. invoke the underlying CSMA/CA module for broadcasting). Multiple copies of the same broadcast message may arrive during the waiting time. For the arrival of each copy of the same broadcast message, the mobile node updates non-covered neighbors for the message. If all neighbors are covered before the end of the waiting time, rebroadcast of the message is cancelled.

For example, node *R* in Figure 2 has received three copies of a broadcast message from its neighbors S_1, S_2, and S_3. Since node *R* knows the positions of all its neighbors, it is easy to know if there are other neighbors of node *R* that are not covered by S_1, S_2, and S_3. In the case of Figure 2, since all neighbors are in the coverage of the three senders, node *R* decides not rebroadcast the message.

B. Transmission Order (TO)

Neither the RS scheme nor the NC scheme has a designate rebroadcast order for neighbors of the sending node. However, according to the rule of thumb for rebroadcast, a farther neighbor node away from the sending node should rebroadcast the message earlier than nearer nodes so that the nearer nodes may have more chances to detect that it is redundant to



R has received a broadcast message from S.
R finds that it is the third farthest neighbor of S that received the broadcast message.
The number of waiting slots for R is set to 3

Figure 3. E.g. Transmission Order

rebroadcast the same message and cancel the rebroadcast operation. The idea is called *Transmission Order (TO)* in the paper.

The sending node of a broadcast message seems to be in the best position to set the rebroadcast order for its neighbors since the sending node can compute the distance of the neighbors according to their positions. However, it is improper for the sending node to ask its neighbors to follow the rebroadcast order since some neighbors might decide not to rebroadcast the message due to the NC scheme and thus break the order. Instead, we modify the random waiting time of the NC scheme for Transmission Order as explained in the following.

The idea is: a farther node that has received the broadcast message waits a shorter time than nearer nodes. When a mobile node *R* has received a broadcast message from sender *S*. Node *R* has to calculate its sequence number of rebroadcast among the common neighbors of *R* and *S*. The waiting time of *R* is then set as the value of its sequence number. For example, node *R* in Figure 3 identifies itself the third one (N_1 is the first and N_2 is the second) to rebroadcast the message from sender *S*. The waiting time of *R* is set to 3 time slots. Similarly, the waiting time of node N_4 is 4 time slots.

The idea of TO is similar to *Distance-based Defer Time Scheme* (DBDT) [9], but TO adopts a different way to compute the waiting time. Moreover, TO is associated with NC, which takes into consideration the receiving node's neighbor relationship. On the other hand, DBDT is associated with ABS that only considers the radio coverage of the receiving node. If there are no other neighbor nodes except the sending node of the message for a receiving node, the receiving node will still rebroadcast the message according to the algorithm of ABS, which is actually redundant.

IV. PERFORMANCE EVALUATION

The transmission radius for each mobile host is 500 meters in the simulation. A geometric area named a *map* that contains one hundred mobile hosts is simulated. A map can be of size 1x1, 3x3, 5x5, 7x7, 9x9, and 11x11 units, where a unit is of length 500 meters. Each host roams around randomly in the map during the simulation. The roaming pattern of each host consists of a series of *turns*. In each turn, the direction, speed, and time interval are randomly generated. The direction is uniformly distributed from degree 0 to 359, the time interval from 1 to 2000 seconds, and the speed from 0 to 20 meters per second (72 km/hr).

The criteria for performance evaluation include:

1. *REachability* (*RE*): the number of mobile hosts receiving the broadcast message divided by the total number of mobiles that are reachable, directly or indirectly, from the source node.
2. *Saved Rebroadcast* (*SRB*): $(r - t)/r$, where r is the number of hosts receiving the broadcast message, and t is the number of hosts actually transmitted the message.
3. *Average latency*: the interval from the time the broadcast was initiated to the time the last host finishing its rebroadcast.

Simulation results of *RE* (lines in the figure) and *SRB* (bars in the figure) for the proposed schemes are shown in Figure 4, in which the scheme "RS+NC+TO" is the hybrid scheme combining all proposed schemes. Note that ALB (adaptive location-based scheme) in Figure 4 is the best threshold-based scheme proposed in [8], and AB denotes the scheme "ABS+DBDT" proposed in [9]. Moreover, the random waiting time for the receiver in NC is set to 0 time slot in the simulation, which means the receiver cancels the rebroadcast only when all its neighbors are covered by the broadcast message it just received. Average latency of these mechanisms is displayed in Figure 5.

We have some observations from Figures 4 and 5.

(1) Values of *RE* for proposed schemes (RS, NC, RS+NC+TO) are all 100% since all the schemes only save unnecessary rebroadcasts. On the other hand, the threshold-based scheme like ALB cannot guarantee 100% reachability. Moreover, "RS+NC+TO" has a better performance than ALB and AB in terms of a larger SRB regardless of the density of the map.

(2) RS is better than NC in terms of *SRB* for denser maps like 1x1, 3x3, and 5x5. However, as the map is getting sparse (7x7, 9x9, and 11x11), NC is instead better than RS. The reason is explained as follows. RS can save more rebroadcasts when the map is denser, since there are more neighbors for a sender. As the map is getting sparse, almost all the neighbors for a sender need to rebroadcast because the little overlap of the radio coverage of the neighbors. Hence, *SRB* of RS is decreasing when the map is getting sparse. On the other hand, in the case of NC for sparser maps, a receiver can have more chance to save its

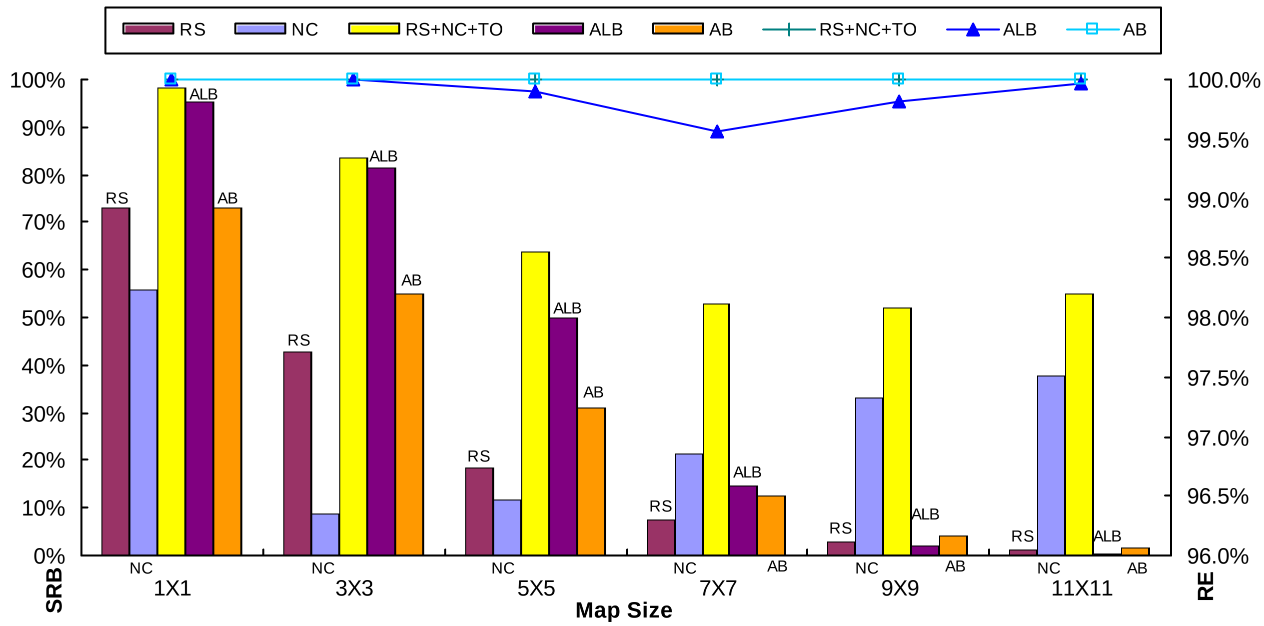


Figure 4. Simulation result: SRB and RE

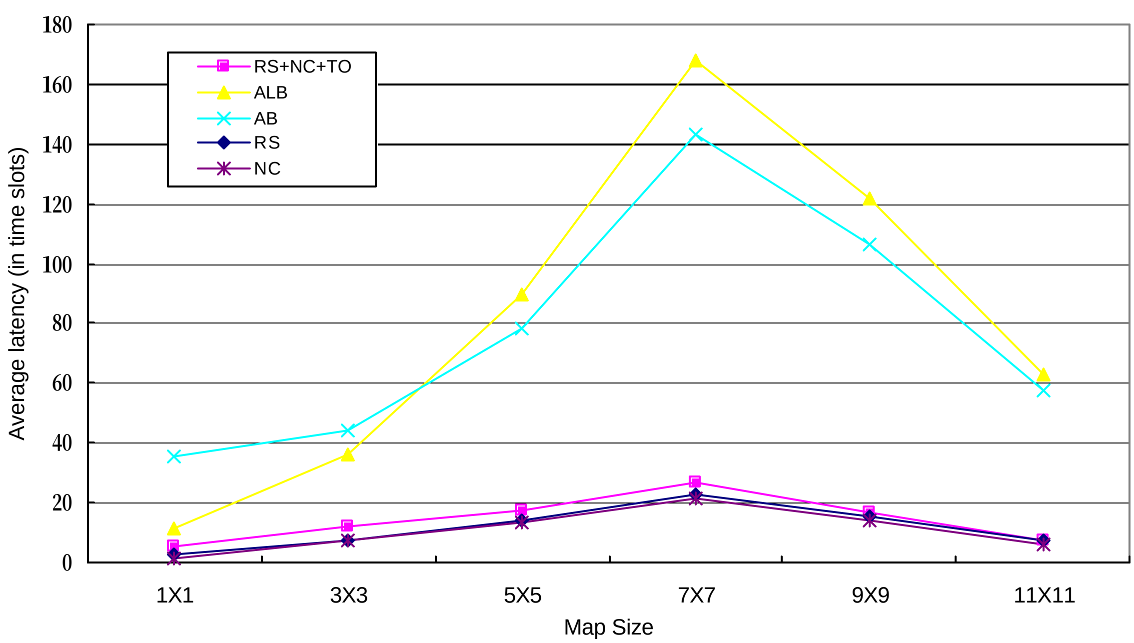


Figure 5. Simulation result: Average latency

rebroadcast since there are very few neighbors (even no neighbors) for the receiver. Therefore, *SRB* of NC is even increasing when the map is getting sparse.

(3) Since neither RS nor NC (w/ waiting time = 0) introduces waiting time before re-broadcasting the messages, the average latency of RS and NC is smaller than that of "RS+NC+TO" as shown in Figure 5. Moreover, Figure 5 also shows that the average latency of "RS+NC+TO" is smaller than that of ALB and AB. The reason for the smaller latency of "RS+NC+TO" is two-folded:

First, each node in ALB needs to set random waiting time from 0 ~ 31 time slots before rebroadcast, while each node in "RS+NC+TO" only needs to wait a couple of time slots before rebroadcast according to the transmission order of the node. On the other hand, since TO has considered not only the distance of each node from the sending node but also the number of neighbors, the waiting time generated by TO is smaller than that of DBDT in AB. Second, the larger *SRB* of the proposed approach also speeds up the broadcast process over the whole network, since fewer nodes are involved in rebroadcast.

V. Conclusion

In this paper, a reachability-guaranteed approach for reducing broadcast storms in MANET is proposed. The approach is based on location awareness of each node, which means each node in the network needs to equip the positioning device like GPS and exchanges location information in the HELLO message with its neighbors. Three mechanisms are included in the proposed approach: Relay Set (RS), Neighbor Coverage (NC), and Transmission Order (TO).

RS is a sender-based mechanism in which the sending node of the broadcast message determines the relay set of its neighbors for rebroadcast according to the radio coverage of the neighbors. The idea of the received-based NC is: a node receiving a broadcast message does not have to rebroadcast the message if all its neighbors have received the same message. TO requires a farther neighbor node away from the sending node to rebroadcast the message earlier than nearer nodes so that the nearer node may have more chances to save the rebroadcast.

Simulation results have shown that the proposed approach "RS+NC+TO" has a better performance than the threshold-based schemes (Adaptive Location Based scheme) and Angle-Based scheme in terms of 100% reachability, more saved rebroadcast, and shorter average latency.

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