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Reduction of the broadcast redundancy by location awareness 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 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 mechanism requires a farther neighbor node away from the sending node to rebroadcast the message earlier than closer nodes so that a closer 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 existing solutions like threshold-based schemes and angle-based scheme in terms of 100% reachability, more saved rebroadcast, and shorter average latency.

Keywords: Broadcast; Mobile ad hoc network; Location awareness

1. 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 [5–12] 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* [9].

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Several solutions for reduction of the broadcast storm problem in MANETs had been proposed in the literature [5–12]. We classify these solutions into two types of mechanisms: *sender-based* and *receiver-based*. In sender-based mechanisms, the originator of a broadcast packet determines the relay nodes from its neighbors to rebroadcast the packet. Each node in the set of relay nodes further determines its relay nodes when receiving the broadcast packet from the originator, and so forth. In receiver-based mechanisms, a mobile node that has received a broadcast packet determines by itself whether or not to rebroadcast the packet. In the following, we briefly survey some existing solutions.

Qayyum et al. [5] proposed a sender-based mechanism called *multipoint relay* (*MPR*) 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 MPRs of a given network node. However, in order to calculate the MPRs, every node in MPR has to collect the set of one-hop neighbors and two-hop neighbors, which results in heavy overhead. Moreover, the problem of finding an optimal MPR set had been proved *NP-complete* in the paper.

Lim and Kim [6,7] proposed two techniques for reducing broadcast redundancy, namely *self-pruning* and *dominant pruning*. Self-pruning tries to reduce the flooding cost utilizing neighborhood information. The neighborhood information is piggybacked in the broadcast packet. A node receiving a broadcast packet checks whether all its neighbor nodes have received the packet. If so, the rebroadcast is cancelled. Self-pruning is thus classified as receiver-based. Dominant pruning extends the range of neighborhood information into two-hop apart nodes. A sending node in dominant pruning selects some of its neighboring nodes to relay the broadcast packet. As a matter of fact, the idea of dominant pruning is the same as MPR. Thus, dominant pruning is a sender-based mechanism. Peng and Lu [8] proposed a similar receiver-based scheme as self-pruning.

Ni et al. [9] proposed several receiver-based solutions for the broadcast storm problem: the *counter-based*, *distance-based*, and *location-based* scheme. These schemes rely on various threshold mechanisms help a mobile node to decide whether to rebroadcast or not. Adaptive versions of the scheme were also proposed [10] in which the threshold values are dynamically chosen according to the number of neighbors of a mobile node. It had been shown that if location information is available through devices such as GPS receivers, the *adaptive location-based scheme* (*ALB*) is the best choice among threshold-based scheme in terms of saved broadcast and reachability. However, all the threshold-based schemes mentioned above could not guarantee 100% reachability (i.e. the same level of reachability as blind flooding) and it degrades the performance of broadcast-based route finding. Besides, it is difficult to find a good threshold value (or threshold function) suitable for any network situations.

Chang and Ting [11] proposed a refined location-based (and receiver-based as well) scheme to get better control of broadcasting by using GPS system. In addition to the location information, the refinement further uses the moving velocity and direction to accurately predict the movement of the neighbors and to decide whether to rebroadcast or not. However, the proposed scheme is still threshold-based and cannot achieve 100% reachability.

A receiver-based scheme called *angle-based scheme* (*ABS*) had been proposed by Sun et al. [12]. Location information is used for ABS to achieve 100% reachability. In ABS, a mobile node receiving a broadcast packet waits a time period before determining whether to rebroadcast the packet or not. The mobile node may have received multiple copies of the same broadcast packet when the waiting time period ends. The mobile node does not rebroadcast the packet if the radio-transmitting area of the mobile node has been completely covered by the received copies of the broadcast packet. 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 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 approach 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 constantly knows the positions of its neighbors. Each node maintains a list of its neighbors and records/updates the location of each neighbor according to the information carried in the HELLO message. We also assume that the mobile nodes in a MANET have the same radio-transmitting range.

The proposed approach is a hybrid scheme that includes sender-based as well as receiver-based mechanisms. Simulation study has been conducted for performance evaluation of the proposed scheme. Performance comparison for the proposed scheme and two existing solutions, ALB and ABS + DBDT, has also been made. The results have shown that a better performance can be obtained by the proposed scheme over the threshold-based scheme ALB and the non-threshold-based scheme ABS + DBDT in terms of *reachability*, *saved rebroadcast*, and *average latency*.

The rest of the paper is organized as follows. A sender-based mechanism is proposed and presented in Section 2. Two receiver-based mechanisms are proposed in Section 3. Simulation study for performance evaluation is presented in Section 4. Finally, Section 5 concludes this paper.

2. Sender-based mechanism

2.1. Relay Set

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-transmitting area 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 distance of each neighbor to the sending node. Starting from the farthest neighbor, the sending node examines the radio-transmitting area of each neighbor to identify the neighbors that do not create new radio coverage. These neighbor nodes, which are called *exclusive nodes*, are actually the redundant nodes of rebroadcast and may not be included in the relay set. Moreover, since the overall radio-transmitting area of the nodes in the relay set completely covers the radio-transmitting area of the exclusive nodes, the reachability of the RS algorithm is the same as blind flooding (i.e. 100% reachability).

It is worth mentioning that calculation of the radio-transmitting area of a neighbor node in the RS algorithm is

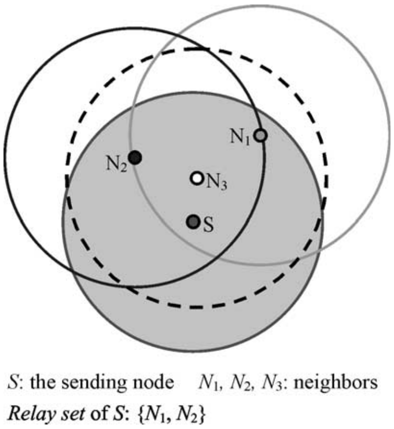

Fig. 1. Example determining the relay set.

similar to that of ABS [12]. However, as mentioned in Section 1, ABS is a receiver-based scheme in which a mobile node determines whether or not to rebroadcast a packet.

One example of determining the relay set for a mobile node is shown in Fig. 1. In the figure, since its radio-transmitting area is totally covered by the radio-transmitting area of sending node S and two farther neighbors N_1 and N_2, node N_3 is not included in the relay set of node S. The algorithm of RS is summarized in Fig. 2.

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

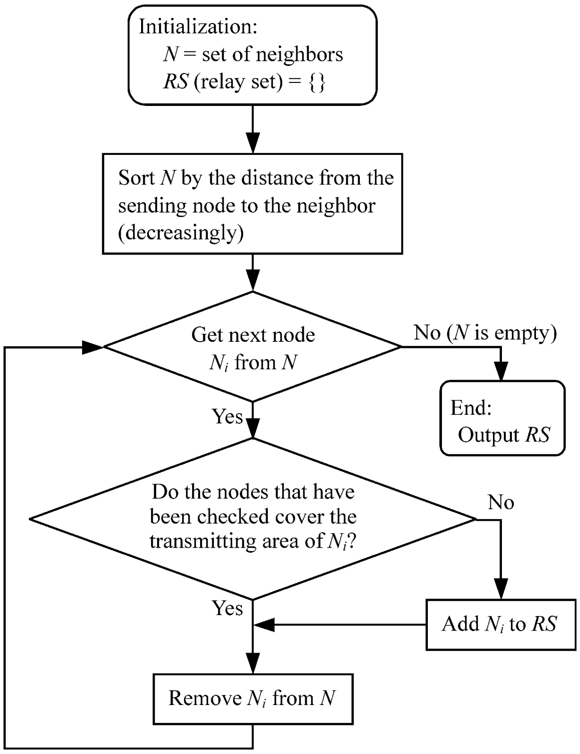

Fig. 2. The algorithm of RS.

3. Receiver-based mechanisms

3.1. Neighbor Coverage

The basic idea of *Neighbor Coverage* (*NC*) is: if a mobile node receiving a broadcast packet assures that all its neighbors have received the same packet, rebroadcast of the packet is actually redundant. Each node in the NC scheme records the packet ID as well as the neighbors from which one copy of the broadcast packet has been transmitted and calculates the neighbors that are not covered by the broadcast packet. Calculation of the non-covered neighbors is based on the copies of the broadcast packet received by the mobile node and the location of the neighbors that has sent the node one copy of the packet.

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

For example, node R in Fig. 3 has received three copies of a broadcast packet from its neighbors S_1, S_2, and S_3. Since node R knows the locations of all its neighbors, it is easy to know if there are other neighbors of node R that are not covered by the radio-transmitting area of nodes S_1, S_2, and S_3. In the case of Fig. 3, since all neighbors are in the coverage of radio transmission of the three senders, node R decides not to rebroadcast the packet.

The idea of NC is similar to the self-pruning scheme [7]. However, because of the introduction of location awareness in NC, information of neighbor nodes does not need to be carried in the broadcast packet, which reduces the overhead of transmission.

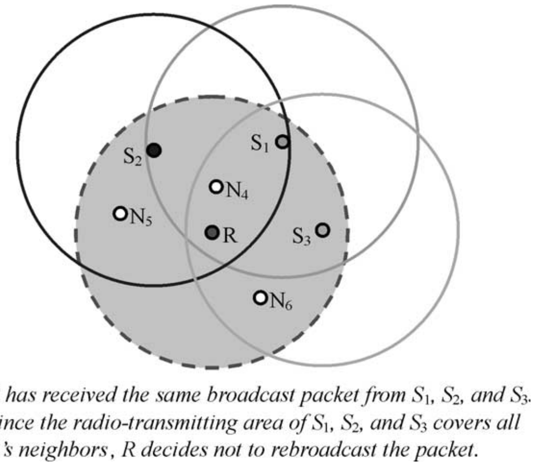

Fig. 3. Example Neighbor Coverge.

3.2. Transmission Order

When all neighbors have received a broadcast packet transmitted by a mobile node, neither the RS scheme nor the NC scheme has a designate rebroadcast order for the neighbors. However, according to the rule of thumb for rebroadcast, a farther neighbor node should rebroadcast the packet earlier than closer neighbor nodes so that the closer nodes have more chance to find that it is redundant to rebroadcast the packet and cancel the rebroadcast operation. The idea is called *Transmission Order* (*TO*) in the paper.

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

The idea is: upon receiving a broadcast packet from a sending node, a farther neighbor node waits fewer time slots before rebroadcasting the packet than closer nodes. More specifically, when a mobile node *R* has received a broadcast packet from a sending node *S*. Node *R* calculates its transmission order for rebroadcast among the common neighbors of *R* and *S*. The number of waiting time slots of *R* is set the value of its transmission order. For example, node *R* in Fig. 4 identifies itself the third one (N_1 is the first and N_2 is the second) to rebroadcast the packet transmitted by *S*. The waiting time of *R* is set to three time slots. Similarly, the waiting time of node N_4 is four time slots.

The idea of TO is similar to DBDT [12], but TO adopts a different way to compute the waiting time of rebroadcast than DBDT. DBDT is associated with receiver-based ABS that considers the radio-transmitting area of nodes as mentioned in Section 1. Notice that in ABS if the radio-transmitting area of a mobile node is not completely covered by the node's received copies of the same broadcast packet, the mobile node still rebroadcasts the packet even if all its neighbors has received the packet. In such case, the rebroadcast is actually redundant. On the other hand, TO is integrated with NC. Instead of considering the radio-transmitting area, a mobile node in NC directly monitors the receiving status of its neighbors for a broadcast packet. Thus, the mobile node does not rebroadcast the packet in the case mentioned above, which means more rebroadcast can be saved by integration of TO and NC than ABS + DBDT.

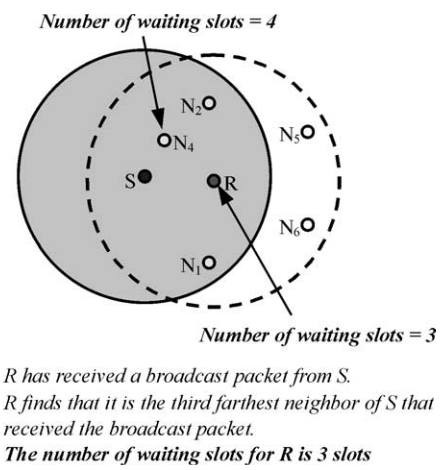

Fig. 4. Example Transmission Order.

4. Performance evaluation

4.1. Simulation environment and performance criteria

The transmission radius for each mobile host is 500 m in the simulation. A geometric area named a *map* that contains one hundred mobile hosts is simulated. A map can be of size 1×1, 3×3, 5×5, 7×7, 9×9, and 11×11 units, where a unit is of length 500 m. 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 s, and the speed from 0 to 20 m/s (72 km/h).

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.

4.2. Simulation results and discussions

In order to properly separate NC and NC + TO for performance comparison, we denote by *pure NC* the *zero waiting time* version of NC, which means that a mobile node has to determine whether to rebroadcast the packet or not right after one copy of a broadcast packet is received. Thus, in pure NC, a mobile node does not rebroadcast a packet only when it has a common set of neighbors with the sender of the broadcast packet. Simulation results of SRB for proposed scheme are shown in Fig. 5. Note that in Fig. 5, 'pNC' denotes pure NC, 'NC + TO' denotes the NC scheme integrated with TO, and 'RS + NC + TO' denotes the hybrid scheme combining all proposed mechanisms. In Fig. 6, we compare the values of SRB and RE of the proposed scheme RS + NC + TO with two existing solutions, ALB (adaptive location-based scheme, denoted

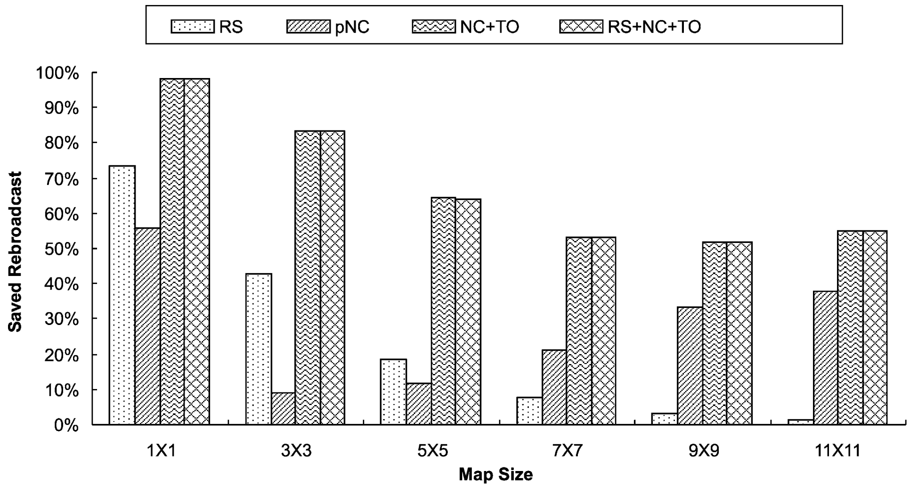

Fig. 5. SRB of the proposed schemes.

by 'ALB' in the figure) and ABS + DBDT (angle-based scheme + distance-based defer time, denoted by 'ABS' in the figure). Simulation results of average latency are displayed in Fig. 7.

We have some observations from the simulation results.

(1) Values of RE for proposed scheme (RS, pNC, RS + NC + TO) are all 100% since all the schemes only save unnecessary rebroadcasts. On the other hand, the threshold-based scheme ALB cannot guarantee 100% reachability. Moreover, RS + NC + TO has a better performance than ALB and ABS in terms of a larger *SRB* regardless of the density of the map (Fig. 6).

(2) Since neither RS nor pure NC introduces waiting time before rebroadcasting the packets, the average latency of RS and pure NC is smaller than that of RS + NC + TO as shown in Fig. 7. Moreover, Fig. 7 also shows that the average latency of RS + NC + TO is smaller than that of ALB and ABS. The reason for the smaller latency of RS + NC + TO is two-folded as explained in the following.

First, each node in ALB needs to set a random waiting time from 0 to 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. Furthermore, in TO, the number of neighbors of a mobile node has been taken into consideration when computing the waiting time for the node. The waiting time of a mobile node in DBDT is directly converted from the distance of the mobile node to the packet sender (a shorter distance makes a longer waiting time), which always results in a longer waiting time than that of TO. For instance, if there is no common neighbors between the mobile node and the packet sender, and the mobile node is very close to the sender, the waiting time calculated by DBDT would be close to the maximum waiting time (Max_Defer_Time) defined by DBDT, but the waiting time in TO would be zero time slots. 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.

(3) As shown in Fig. 5, RS is better than pure NC in terms of SRB for denser maps like 1×1, 3×3, and 5×5. However, as the map is getting sparse (7×7, 9×9, and 11×11), pure NC is instead better than RS. The reason is explained as follows. RS can save more rebroadcasts when

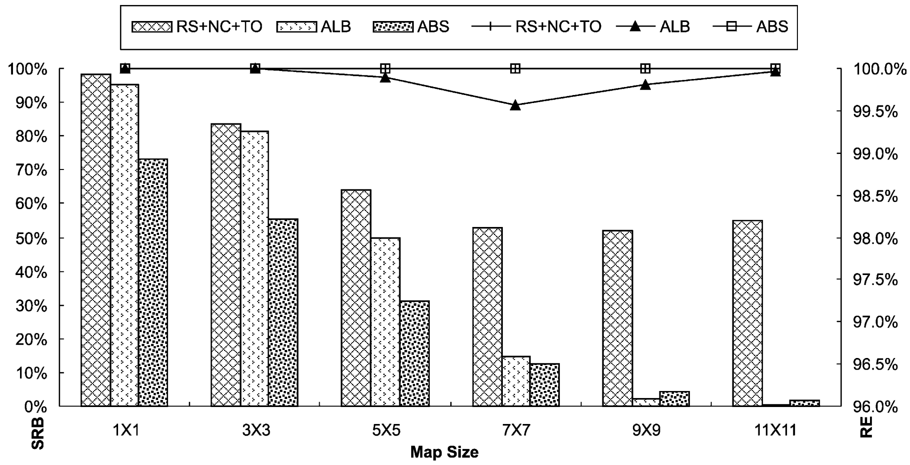

Fig. 6. Comparing the proposed scheme (RS + NC + TO) with two existing schemes.

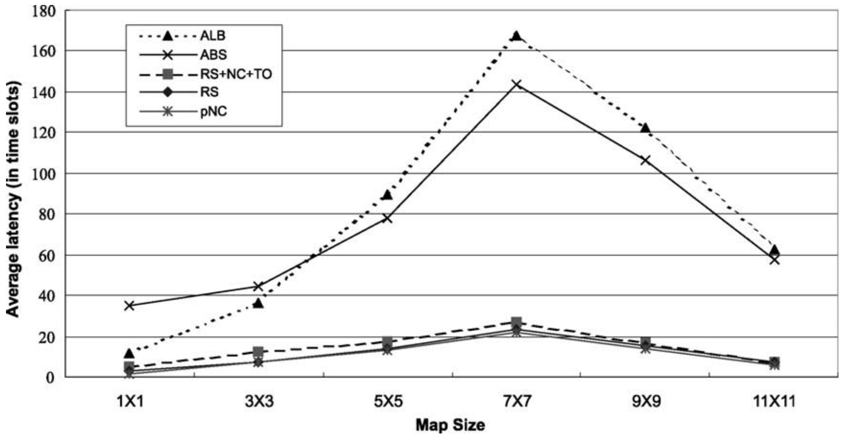

Fig. 7. Simulation result: average latency.

the map is denser, since there are more neighbors for a sender. As the map is getting sparse, almost all the neighbors of a sender need to rebroadcast because of little overlap of the radio-transmitting area of the neighbors. Hence, SRB of RS is decreasing when the map is getting sparse. On the other hand, in the case of pNC for sparser maps, a receiver has more chance to save its rebroadcast since there are very few neighbors (even no neighbors) for the receiver. Therefore, SRB of pNC is even increasing when the map is getting sparse.

In summary, two different principles for saving rebroadcast are adopted in RS and pNC: RS is based on the calculation of *radio-transmitting area*, but pNC is considering *receiving status of neighbors* for the same broadcast packet. Mechanisms considering radio-transmitting area like RS and ABS can get a good performance for dense maps but bad for sparse maps. However, mechanisms considering neighbor's receiving status like pNC can get a good performance even for sparse maps.

(4) Both RS and ABS ('ABS + DBDT') consider radio-transmitting area, but the performance of ABS is always better than RS in terms of SRB. The reason for the better performance of ABS is because DBDT is associated with ABS, which increases the chance for a node to save rebroadcast. However, the average latency of RS is always smaller than ABS (Fig. 7) since there is no waiting time introduced by RS before rebroadcast.

(5) In order to investigate the effect of TO on the NC scheme, we compare the performance of pure NC with NC + TO. We find in Fig. 5 that the performance of NC + TO is much better than pure NC in terms of SRB, which proves the correctness of the idea of TO that a farther neighbor node away from the sending node should rebroadcast the packet earlier than closer nodes so that the closer nodes have more chances to detect that it is redundant to rebroadcast the same packet. In summary, NC + TO saves much more rebroadcast than pure NC at the expense of slight increase in average latency (Fig. 6).

As mentioned in Section 3.2, DBDT is similar to TO but adopts a different mechanism in calculating the waiting time. However, the performance of ABS + DBDT is not as good as we expect (in comparing with the performance of NC + TO). The reason is because DBDT is associated with ABS, and ABS is based on the analysis of radio-transmitting area, which is unsuitable for sparse maps as explained in point (3). Therefore, a larger value of SRB is obtained by NC + TO than ABS.

(6) In Fig. 7, there are two phases of the change of average latency for each scheme. First, the value of average latency goes up from map size 1×1 to 7×7. However, the value of average latency starts to go down from map size 9×9. The reason for increasing average latency in the first phase (1×1 to 7×7) relates to the value of SRB. In the first phase, the value of SRB for each scheme (Fig. 6) goes down which means more mobile nodes needs to rebroadcast. Because of that, it takes a longer time to complete a broadcast process in the whole network. But if the map size is too large (9×9 and 11×11), the network is divided into several isolated parts each containing fewer mobile nodes. It takes a shorter time to complete a broadcast process when there are fewer mobile nodes in the network. This is the reason why the value of average latency goes down in the second phase.

(7) The value of SRB (Fig. 5) of RS + NC + TO is almost the same as that of NC + TO, which implies the redundant nodes detected by RS in a MANET can always be detected by NC + TO. But surprisingly, simulation study also shows that there are some cases in which the performance of RS + NC + TO (with RS) is better than NC + TO (without RS). The reason is explained as follows. In NC + TO, we expect a farther node (maybe two hops away from the sending node) to rebroadcast the packet earlier so that a closer neighbor node of the sending node can save its rebroadcast. However, in RS + NC + TO, some neighbors of the sending node are excluded from rebroadcast due to the RS algorithm and thus the transmission order of the neighbors has changed, which sometimes results in a redundant rebroadcast issued by a closer neighbor node. We give an example for illustrating the special phenomenon in Fig. 8.

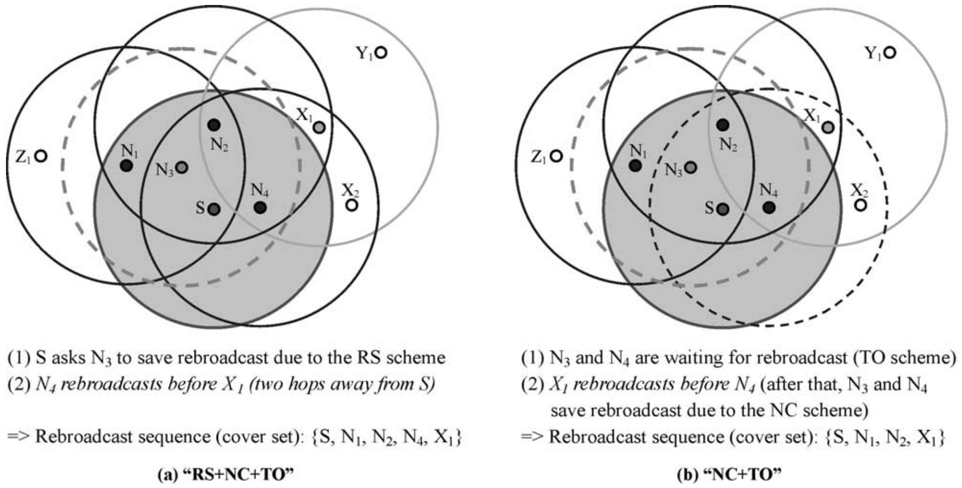

Fig. 8. Example NC + TO is better than RS + NC + TO.

Node S in Fig. 8 is the originator of a broadcast packet. One possible broadcast sequence for RS + NC + TO is illustrated in Fig. 8(a), which is explained in the following. The RS algorithm excludes node N_3 from rebroadcast, so node N_4 waits fewer time slots than the case without excluding node N_3. Notice that node X_1 receives a copy of the packet after N_2 rebroadcasts the packet. Normally X_1 rebroadcasts the packet before N_4 due to the TO scheme. However, a shorter waiting time possibly makes N_4 to rebroadcast before X_1. (We do not mean that N_4 always rebroadcasts before X_1, but there is a possibility for the case to occur) As a consequence, nodes of rebroadcast in RS + NC + TO for the topology are $\{S, N_1, N_2, N_4, X_1\}$.

On the other hand, for NC + TO, N_3 is not excluded from rebroadcast. If the case occurs that X_1 rebroadcasts before N_3. After receiving the copy of the packet from X_1, both N_3 and N_4 find that it is redundant to rebroadcast the packet due to the NC algorithm. As a consequence, only nodes $\{S, N_1, N_2, X_1\}$ rebroadcast as shown in Fig. 8(b), which is better than RS + NC + TO.

5. Conclusion

Broadcast storm problem in MANETs is addressed in this paper. Existing solutions in the literature are surveyed and classified into two types of mechanisms: sender-based or receiver-based. The idea of location awareness is adopted and a hybrid approach combining both sender-based and receiver-based mechanisms to reduce broadcast storm but maintain the same reachability level as blind flooding are proposed in the paper. Location awareness means each node in the network needs to be equipped the positioning device like GPS and exchanges location information in the HELLO message with its neighbors.

The proposed sender-based mechanism is called Relay Set (RS), in which the sending node of the broadcast message determines the relay set of the neighbors for rebroadcast by analyzing the radio-transmitting area of its neighbors. The neighbors that do not create new radio coverage are not included in the relay set of the sending node. The proposed receiver-based mechanism is called Neighbor Coverage (NC), in which a node receiving a broadcast packet does not have to rebroadcast the packet if all its neighbors have received the same packet. One mechanism called Transmission Order (TO) is combined with NC to further improve the performance. A designate rebroadcast order among neighboring nodes is assigned by the TO algorithm, in which when a sender node transmits a broadcast packet, a farther neighbor node of the sender should rebroadcast the packet earlier than closer neighbor nodes so that the closer nodes have more chance to find that it is redundant to rebroadcast the packet and save the rebroadcast.

Simulation study has shown that the performance of the hybrid scheme RS + NC + TO as well as the scheme NC + TO have a significant improvement over exiting solutions such as threshold-based scheme (ALB) and ABS in terms of 100% reachability, more saved rebroadcast, and shorter average latency. From the investigations and observations on the simulation results as well as performance comparisons, we conclude the following three important principles for broadcast storm reduction under the requirement of 100% reachability:

(1) The sending node of a broadcast packet is in the best position to determine the relay set among its neighbors by considering the radio-transmitting area of the neighbors.
(2) For a mobile node that has received a broadcast packet, it is better for the node to consider the receiving status of its neighbors for the same packet when determining whether to rebroadcast or not, instead of merely considering the radio-transmitting area of the neighbors.
(3) Regulation of the rebroadcast order such that a farther neighbor node of the packet sender rebroadcasts earlier

than closer nodes can significantly improve the performance in terms of saved rebroadcast.

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