

# A Bounding Algorithm for the Broadcast Storm Problem in Mobile Ad Hoc Networks

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**Abstract**—Many protocols used in Mobile Ad Hoc Networks rely on the broadcasting capability, especially when performing a route discovery process. However, an efficient broadcasting protocol should be devised to reduce the unnecessary redundant rebroadcasting at some nodes (redundancy) as well as to increase the coverage area as much as possible (reachability). A few approaches have been developed in the literature. We propose a bounding algorithm which is shown to be an efficient candidate to accommodate the two goals, that is to increase reachability while limiting redundancy.

## I. INTRODUCTION

An efficient and reliable solution for data broadcasting is a crucial goal in modern networks. The basic problem stands in acquiring feedback from the destination nodes to avoid network flooding. Reliable data broadcasting is even harder to obtain when we are dealing with wireless networks. These types of networks are highly unreliable, leading standards like IEEE 802.11 [1] to introduce MAC level acknowledgement when dealing with unicast data packets. Obviously, when dealing with broadcasting (or multicasting) any retransmission scheme would cause even more problems due to the access to the medium. A special case of wireless networks are the *mobile ad hoc networks (MANETs)* [2], [3]. A MANET consists of a collection of freely movable nodes which communicates using wireless links and which do not require any fixed infrastructure.

MANETs rely on the broadcasting capability or specialized flooding mechanism when performing route discovery or gathering some global information [4], [5]. For example, when on-demand routing protocols attempt to acquire a route between source and destination nodes, a *route discover* packet is sent by utilizing broadcasting mechanisms. However, the simple broadcasting without a rebroadcasting bounding mechanism at each node may result in an excess of redundancy, channel contention, and collisions. This phenomenon is called the *Broadcast Storm Problem* [6].

Redundancy indicates a situation where a node hears the same messages from more than one neighbors. Channel contention is due to the different nodes which are simultaneously trying to rebroadcast the received messages thus contending for the shared media, increasing the probability of collisions. To address redundancy, the decision whether or not rebroadcast must be controlled at each node receiving the message.

For contention and collision, all nodes trying to rebroadcast rely on backoff mechanism with randomly selected slots.

Y.-C. Tseng et al. [6] suggested several schemes to alleviate the broadcast storm problem, namely: the counter-based scheme, the distance-based scheme, and the location-based scheme. Although the authors indicates the location-based scheme as the best alternative, it requires all nodes to be equipped with a *global positioning system (GPS)* device to provide the appropriate accuracy of longitude and latitude. The distance-based scheme provides an higher level of reachability with respect to the counter-based scheme but it does not offer the same reduction of rebroadcast as its counterpart.

In this work we present a hybrid approach combining the advantages of distance-based and counter-based schemes in terms of reachability and saving of rebroadcasting without the overhead of equipping all nodes with GPS devices as required by the location-based scheme.

The rest of the paper is organized as follows. Section 2 describes the distance-based and counter-based approaches on which our proposal is based. Section 3 presents our algorithm whose performance is evaluated in Section 4. A few concluding remarks are given in Section 5.

## II. RELATED WORKS

The two most relevant solutions to the broadcast storm problem are based on the so called distance-based and counter-based schemes [6].

We first consider the distance-based approach in a simple topology like the one in Figure 1. When node A sends a broadcast message and node B tries to re-broadcast it, the additional area covered is equal to  $\pi r^2 - \text{INTC}(d)$ , where  $r$  indicates the nodes transmission range and  $d$  the distance between A and B.  $\text{INTC}(d)$  is defined as the intersection of the two nodes transmission areas. Therefore,  $\text{INTC}(d) = 4 \int_{d/2}^r \sqrt{r^2 - x^2} dx$ .

The largest coverage area is obtained when  $d = r$ ; its value is approximately  $\pi r^2 - \text{INTC}(r) \approx 0.61 \pi r^2$ . This means that re-broadcasting provides an additional coverage equal to the 61%. The average value of  $\pi r^2 - \text{INTC}(d)$  is calculated using Equation 1:

$$\int_0^r 2\pi x[\pi r^2 - \text{INTC}(d)]/\pi r^2 dx \approx 0.41\pi r^2 \quad (1)$$

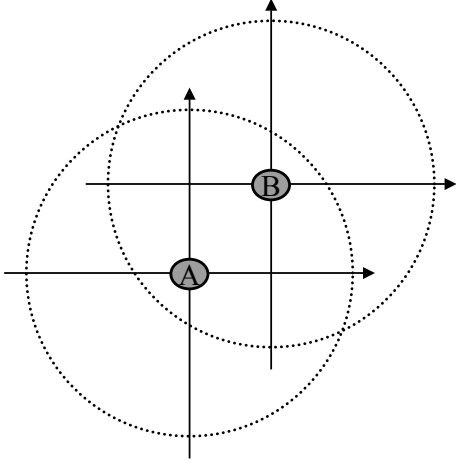


Fig. 1. Simple topology used as the reference example.

giving that a re-broadcast can provide only an additional 41% area on average.

As for counter-based approach, the benefit of a node re-broadcasting a message after hearing the message  $k$  times is observed and  $EAC(k)$ , Expected Additional Coverage is obtained according to  $k$  values. When  $k = 1$ , the  $EAC(1)$  is the largest. When  $k \geq 4$ , the  $EAC(k)$  is below 5% (refer to [6] for details).

#### A. Distance-Based Scheme

The distance-based scheme allows the receiving nodes located at a distance greater than a given threshold ( $D_{TH}$ ) to rebroadcast the message and prevents the others from rebroadcasting. An estimation of the distance can be easily extracted from the signal strength by using a simplified formula for the free space propagation model [7]. Let  $P_t$  and  $P_r$  be the power level for transmitting and receiving a message, respectively.  $P_r = (P_t * \lambda^2) / ((4\pi)^2 * d^2)$ , where  $\lambda$  and  $d$  represent the carrier's wavelength and the distance between two nodes, respectively. Therefore, the distance-based scheme has no need to provide the nodes with GPS devices unlike the location-based scheme.

- S1: When a broadcast message  $msg$  is heard, set  $d_{min}$  to the distance to the broadcasting host. If  $d_{min} < D_{TH}$ , proceed to S4.
- S2: Wait for a random number ( $0 \sim 31$ ) of slots. If  $msg$  is heard again, interrupt the waiting and return to S1. Otherwise, submit  $msg$  for transmission and wait until the transmission actually starts and proceed to S3.
- S3: The message is on the air. The procedure exits.
- S4: Cancel the transmission of  $msg$  if it was submitted in S2. The host is prohibited from rebroadcasting the same message in the future. Then the procedure exits.

The procedure  $db\_scheme$  is called every time a broadcast message  $msg$  is received. We suppose to have available a labelling function  $tcount(m)$  that, given packet  $m$  returns an

integer value which indicates the number of times that it has been received during the previous  $t_m$  ms.

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The distance-based algorithm

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procedure  $db\_scheme(msg)$ 
if  $tcount(msg) == 1$  then
   $d_{min} = d_S$ 
  if  $d_{min} \geq D_{TH}$  then
    wait for a random number ( $0 \sim 31$ ) of slots
    send  $msg$ 
  else
    inhibit  $msg$  rebroadcasting
  endif
else
  if waiting_to_send then
    suspend_waiting
    if ( $d_{min} > d_S$ ) then
       $d_{min} = d_S$ 
    endif
    if  $d_{min} < D_{TH}$  then
      cancel_waiting
      inhibit  $msg$  rebroadcasting
    else
      resume_waiting
    endif
  endif
endif

```

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where  $d_S$  is the distance from the sending node.

#### B. Counter-Based Scheme

In the counter-based scheme, the basic idea is that for a node hearing the same message an increasing number of times from the neighboring nodes decreases the additional coverage benefit from having the node to rebroadcast. Therefore, when a node hears the same message a given amount of times, indicated by threshold  $C_{TH}$ , the node is prohibited from rebroadcasting the message. According to [6], a  $C_{TH}$  value of 3 or 4 can save a high percentage of retransmission with better reachability than simple flooding.

- S1: Initialize counter  $c = 1$  when a broadcast message  $msg$  is heard for the first time.
- S2: Wait for a random number ( $0 \sim 31$ ) of slots. If  $msg$  is heard again, interrupt the waiting and perform S4. Otherwise, submit  $msg$  for transmission and wait until the transmission actually starts and proceed to S3.
- S3: The message is on the air. The procedure exits.
- S4: Increase  $c$  by one. If  $c < C_{TH}$ , go back to S2. Otherwise, if  $c = C_{TH}$ , proceed to S5.
- S5: Cancel the transmission of  $msg$  if it was submitted in S2. The host is prohibited from rebroadcasting the same message in the future. Then the procedure exits.

The counter-based scheme can be formally represented as follows:

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The counter-based scheme

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**procedure** *cb\_scheme(msg)*

**if** tcount(*msg*) == 1 **then**

wait for a random number (0 ~ 31) of slots  
send *msg*

**else**

suspend\_waiting  
**if** tcount(*msg*) <  $C_{TH}$  **then**  
    resume\_waiting

**else**

cancel\_waiting  
inhibit *msg* rebroadcasting

**endif**

**endif**

---

From the simulation results described in [6], we can observe that the counter-based scheme is better than the distance-based one with respect to the amount of avoided re-broadcasted message, because rebroadcasting is inhibited when a node hears the same message  $k$  times. However, in the distance-based scheme, all nodes tend to rebroadcast the same message only if they are located above  $D_{TH}$ . Hence, the distance-based scheme provides more additional coverage than the counter-based one.

### III. THE BOUNDING ALGORITHM

The counter-based and distance-based schemes can be candidate solutions to efficiently address the well-known broadcast storm problem. Moreover, location-based approach, despite being a better option, is only meaningful when all nodes have GPS devices. In this paper, we propose a re-broadcasting bounding algorithm which is based on both schemes to obtain an increase in reachability while highly reducing the amount of packets re-broadcasted.

According to the distance-based scheme, when a broadcast packet is sent, the receiving nodes re-send it only if the node is located farther than  $D_{TH}$ . However, we would like to put the counter-based requirement on the nodes located above the threshold in order to avoid excessive rebroadcasting. In this latter situation, a small counter threshold avoids the nodes passing the distance threshold test from rebroadcasting the message though the decreasing reachability. Therefore, we carefully make use of a larger counter threshold when applying the counter-based scheme to the nodes located above the distance threshold. The bounding algorithm is the following:

- S1: Set  $d_{min}$  to the distance to the broadcasting host. If this is the first time message *msg* is received initialize counter  $c = 1$ , otherwise increment  $c$  by one.
- S2: if  $d_{min} < D_{TH}$ , proceed to S5. If  $c < C_{TH}$ , proceed to S3. If  $c = C_{TH}$ , proceed to S5.
- S3: Wait for a random number (0 ~ 31) of slots. If *msg* is heard again, interrupt the waiting and return to S2.

Otherwise, submit *msg* for transmission, wait until the transmission actually starts and proceed to S4.

S4: The message is on the air. The procedure exits.

S5: Cancel the transmission of *msg* if it was submitted in S3. The host is prohibited from rebroadcasting the same message in the future. Then the procedure exits.

Or, formally:

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The bounding algorithm

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**procedure** *bounding(msg)*

$d_{min} = d_S$

**if** (tcount(*msg*) == 1) **then**

**if** ( $d_{min} < D_{TH}$ ) **then**  
    inhibit *msg* rebroadcasting

**else**

wait for a random number (0 ~ 31) of slots  
send *msg*

**endif**

**else**

**if** (tcount(*msg*) <  $C_{TH}$ ) and ( $d_{min} < D_{TH}$ ) **then**  
    wait for a random number (0 ~ 31) of slots  
    send *msg*

**else**

cancel\_waiting  
inhibit *msg* rebroadcasting

**endif**

**endif**

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Suppose two nodes A and B receiving a message broadcast by a sending node S. They are located farther than  $D_{TH}$  from node S. If the expiration of node A waiting timer allows it to rebroadcast the message before node B timer expires, and they are respectively located within  $D_{TH}$ , node B is also prohibited from rebroadcasting without being affected by the counter threshold. As shown in Figure 2, node S initially broadcasts a message to the nodes within its transmission range. Then, they decide whether or not to rebroadcast the message according to the distance between themselves and node S. While the nodes within  $D_{TH}$  from node S are prohibited from rebroadcasting, the others (the nodes in the shaded area as shown in Figure 2) determine their random waiting timers. Suppose that the waiting timer of node N1 expires first. Then, node N5 is also refrained from rebroadcasting because it is located within  $D_{TH}$  with respect to node N1. However, node N2 can be given a chance to rebroadcast the message because it is located above the distance threshold from node N1.

If the waiting timers of nodes N2 and N3 expire earlier but not simultaneously than that of node N4, in addition to the message sent by node S, when node N4 hears the same message from nodes N2 and N3 before its waiting timer expires, it determines whether or not to rebroadcast according to its counter value. For example, if  $C_{TH}$  is set to 3, the node N4 cannot rebroadcast the message. Otherwise, if  $C_{TH}$  is greater than 3, the node is allowed to rebroadcast the message.

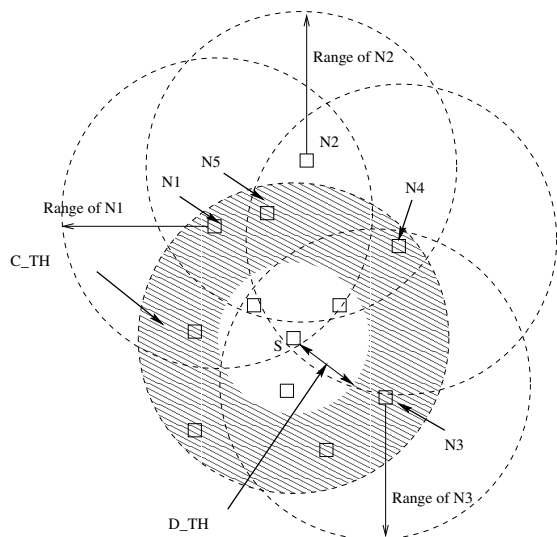


Fig. 2. Graphical representation of the proposed algorithm.

Figure 3 shows an extreme case where some nodes (those located within the solid-line in the figure) cannot receive the broadcast message. When the waiting timers of nodes N1, N2, N3 and N4 expire, not simultaneously, but before the timer at node N0, the rebroadcasting of node N0 is refrained if the count of reception of the message exceeds  $C_{TH}$ . However, the number of nodes which cannot receive the broadcast message can be reduced because other nodes located within the transmission ranges of nodes N1 and N4 are allowed to have some chance to rebroadcast the message.

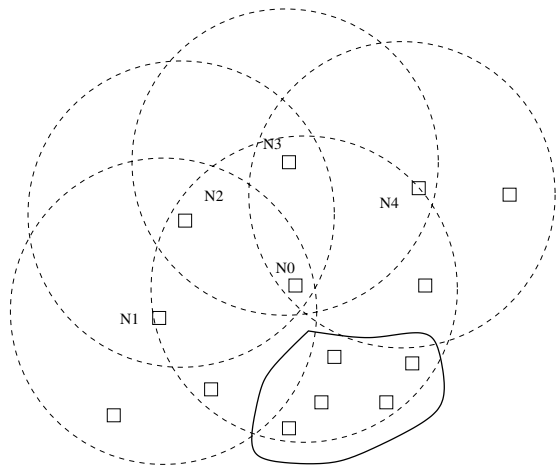


Fig. 3. Example of the Worst Scenario: situation where a group of nodes cannot receive the broadcasted packet.

#### IV. SIMULATION RESULTS

We developed a discrete event-driven simulator to measure the performance of our proposed scheme against distance-based and counter-based ones. In the simulations, all nodes have the same transmission range of 500 meters. We considered a network with a moderate density, consisting of 100 mobile nodes randomly placed in a  $6 \text{ km} \times 6 \text{ km}$  area.

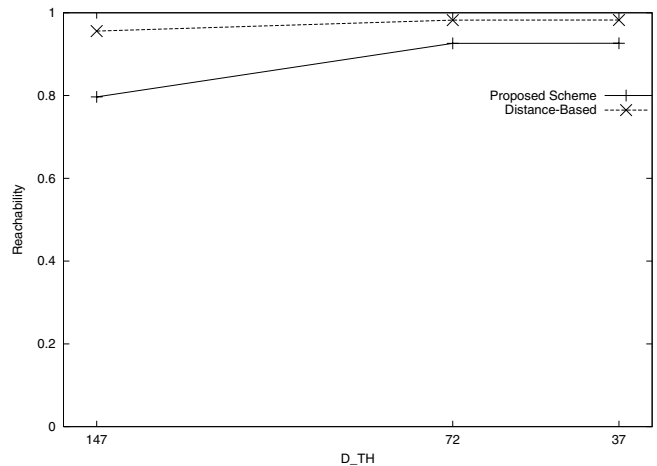


Fig. 4. Comparison of the proposed protocol with the Distance-Based approach in terms of reachability.

The performance comparison of our protocol with distance-based and counter-based schemes was done in terms of reachability and savings of rebroadcasting. The reachability is represented by the number of mobile hosts which received the broadcast message. The saving of rebroadcasting is indicated by simply calculating the actual total number of rebroadcasting activity performed by the corresponding nodes.

The IEEE 802.11 standard doesn't support any mechanism for reliable broadcast unlike the unicast packet transmission using RTS/CTS handshaking before packet transmission. Therefore, for simplicity, to emulate the loss of packet broadcast as well as to include packet collision, we assumed a random packet loss at the receiving nodes. We obtained the results averaged after running the transmission of 10,000 packets from a broadcast source node. One run means that one packet is broadcast by a source node and the run stops when there is no further broadcasting activity in the network.

We first of all evaluated the performance results by comparing our scheme with the distance-based approach in terms of reachability and savings of rebroadcasting. We used a fixed value for the  $C_{TH}$  parameter equal to 4. The  $D_{TH}$  value is varied within 147, 72 and 37 meters. We adopted the same threshold values used in [6] to make a reasonable comparison among the schemes.

Distance-based scheme can achieve almost 100% coverage. All nodes located above  $D_{TH}$  have always the chance to rebroadcast the same message, resulting in high reachability. In our proposed scheme, we can see that some nodes are unable to rebroadcast the message when they are controlled by the counter threshold even if rebroadcasting can increase the additional coverage. In addition, the decreased  $D_{TH}$  provides the nodes located above the threshold with more chance to rebroadcast the same message, resulting in the increased reachability rather than high  $D_{TH}$  (see Figure 4).

However, even if the distance-based shows better perfor-

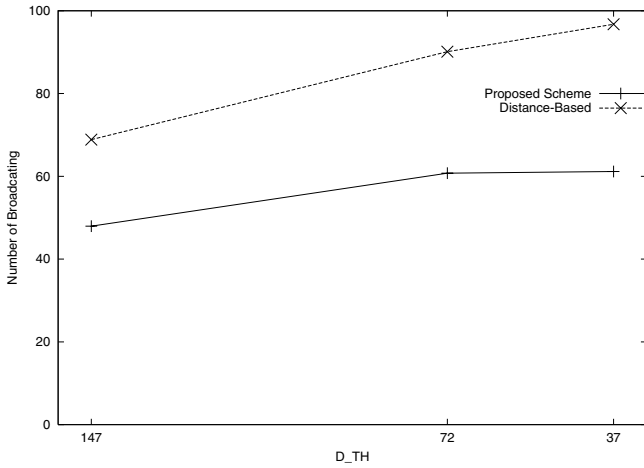


Fig. 5. Comparison of the proposed protocol with the Distance-Based approach in terms of number of broadcasting.

mance with respect to reachability, it produces much overhead of rebroadcasting performed. Since all nodes distanced above the distance threshold are allowed to rebroadcast irrespective of hearing the same message from their neighboring nodes, the total number of rebroadcasting increases as the threshold decreases. It implies that a node rebroadcasts the message even if the rebroadcasting doesn't cover additional area. However, the proposed scheme reduces this overhead by prohibiting nodes from rebroadcasting due to the counter threshold (see Figure 5).

Second, we also compared our proposed scheme against counter-based one in terms of reachability and saving of rebroadcasting. In this comparison, the  $D_{TH}$  value used in our scheme is 147 meters. Then, we varied the  $C_{TH}$  value from 3 to 6 to see how to improve the performance. We don't use the same counter threshold in both our protocol and counter-based scheme since the nodes located below the distance threshold has been already excluded as broadcasting nodes. Hence, we would like to give some nodes located above the threshold more chance to rebroadcast in order to expand the set of reachable nodes by using a higher counter threshold than that of counter-based scheme.

As shown in Figure 6, when our proposed scheme uses a counter threshold one greater than the counter-based one (e.g.,  $C_{TH} = 4$  in our protocol,  $C_{TH} = 3$  in the counter-based scheme), we experience better reachability than the counterpart. Even when using the same counter threshold, we achieved similar results for reachability, also reducing the number of rebroadcasting (Figure 7).

## V. CONCLUSIONS AND FUTURE WORKS

The simple packet flooding without a careful decision of a controlled rebroadcasting may produce an excessive redundancy of incoming packets, a greater channel contention, and an higher collision rate. This paper presented a bounding

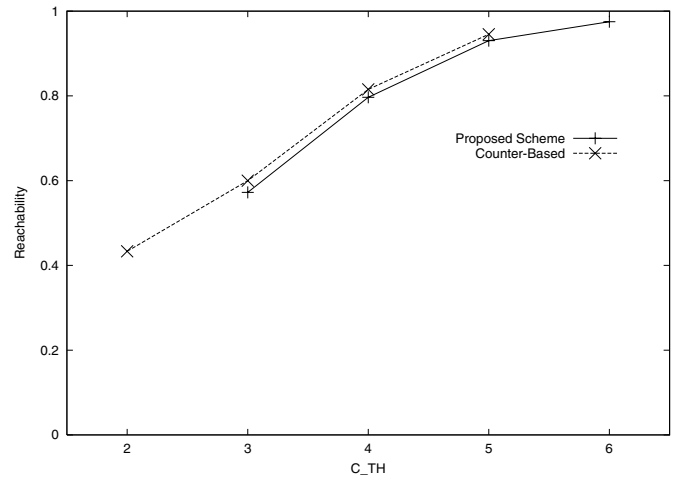


Fig. 6. Comparison of the proposed protocol with the Counter-Based approach in terms of reachability.

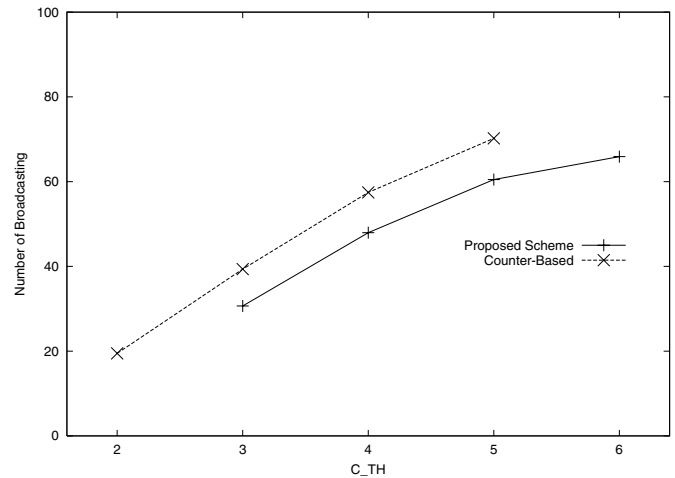


Fig. 7. Comparison of the proposed protocol with the Counter-Based approach in terms of number of broadcasting.

algorithm to limit the influence of the problem of broadcast storm in mobile ad hoc networks.

Many protocols used in MANETs rely on the broadcasting capability, especially when performing a route discovery process. To alleviate the broadcast storm problem various solution are already available. The most promising are the: counter-based, distance-based, and location-based schemes.

Our work is a hybrid approach combining the advantages of distance-based and counter-based schemes in terms of reachability and saving of rebroadcasting without the overhead of equipping all nodes with GPS devices as required by the location-based scheme. We use the counter-based constraint on the nodes located above the threshold to avoid excessive rebroadcasting. Through simulations we showed that our approach can be a candidate solution to satisfy two goals, namely high reachability and low redundancy. This is anyway a first step.

We are more thoroughly evaluating our proposal trying to devise its behavior under many different topologies and mobility patterns. We are also evaluating the implementation and execution cost of the bounding algorithm on standard MANET routing protocols.

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