Recovering VANET Safety Message in Transmission Holes

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Abstract

The core concern in vehicular ad hoc networks (VANETs) is the reliable transfer of safety-related messages to all endangered vehicles on the road. The recent discovery of the presence of transmission holes in the VANET communication range poses a serious challenge in the safety-message propagation. In this work, a technique for recovering the safety message for vehicles located in the transmission holes is proposed. Each vehicle that successfully receives the safety message actively estimates propagation loss for its immediate neighbors. If the receiving vehicle determines one of its neighbors being located in a coverage hole, the safety message is rebroadcast by the receiving vehicle. The propagation-loss estimation makes use of the topology information appended in the periodic beaconing messages. The proposed technique is evaluated in the ns-3 simulator. The simulation results suggest that the proposed technique improves the overall message-dissemination reliability over the existing techniques.

Keywords: Transmission holes, VANETs, Safety message, Routing, Packet reception rate, Received signal strength.

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INTRODUCTION

Vehicular ad hoc network (VANET) is a collection of vehicles equipped with wireless communication capability, spontaneously forming a network while moving on the road. Vehicles cooperate to deliver safety-related information through multi-hop paths without the need for central administration. The dissemination of safety-related information among vehicles on the road helps drivers to anticipate hazardous events and maneuver accordingly to avoid potential dangerous events. With timely and reliable wireless communication between vehicles, VANET is aimed at providing passenger safety by exchanging real-time traffic-hazard messages among vehicles. In addition to safety-related services, VANET can also offer infotainment services by providing high-speed Internet connectivity onboard the vehicle.

The distinctive VANET topology and its dynamic wireless-signal environment pose a serious challenge in VANET communication. Vehicle movements are bound by street maps, traffic signals and regulations, and the movement of surrounding vehicles. Consequently, the distribution of vehicles is highly non-uniform, and the connectivity among them is highly random. Furthermore, the inevitable use of common control channel for safety applications makes communication immensely vulnerable to collisions and interference from both visible and hidden nodes. The unique VANET characteristics cause challenging research concerns in information propagation and routing.

The low height of antennas onboard the vehicles causes the optical line-of-sight (LOS) to be obstructed by obstructions, in particular by the mobile obstructions, causing transmission holes in the transmission range.

Most of the existing studies consider static obstructions as the only source of obstruction in the message-propagation path (Otto et al. 2009, Cheng et al., 2007). However, since the significant portion

of vehicle-to-vehicle signal propagation is bound to the road surface, it is imperative to consider surrounding vehicles on the road as obstacles in the LOS path between two communicating nodes. Recent studies on safety-message propagation (Meireles et al. 2010, Boban et al., 2011) suggest that a single vehicle as an obstacle in the LOS path can cause signal attenuation by as much as 20 dB. Consequently, in traffic with a large density of public transportation and commercial vehicles, it is highly probable that there exist a number of coverage holes in the transmission range. The existence of coverage holes causes several vehicles to be completely unaware of the ongoing safety-message transmission. In such a scenario, the use of a feedback-triggered recovery is not possible because the given vehicle located in the transmission hole can not request recovery as it is completely oblivious of the activity in the channel. The lack of feedback from vehicles located in holes makes reliability a serious challenge in the safety-message propagation. To the best of our knowledge, this is the first work that addresses the issue of covering transmission holes in VANET safety-communication scenario. We present a message recovery technique that takes advantage of the topology information contained in periodic beacon messages. Simulation results using ns-3 simulator show that the proposed technique nearly guarantees the delivery of VANET safety messages.

The proposed technique for the coverage of holes

Message origination and forwarding

The safety-message origination and forwarding to the next hop is carried by the base routing protocol. In this explanation of the proposed algorithm, the urban multi-hop broadcast (UMB) [Korkmaz et al. 2004] is considered as an example base protocol. However, as described above, the proposed reliability technique is flexible to be incorporated on top of any base routing method.

After sensing a hazardous event on the road, the original node initiates the safety-message transfer. The node broadcasts the safety alert message within its one-hop transmission range. In case the message is intended for multiple hop distance, then one of the receivers rebroadcasts the message to the next hop after following an elimination mechanism.

The general elimination mechanism used by most of the routing protocols is based on a sectoring method. The transmission range of the sender node is divided into multiple sectors based on the distance from the sender node and the density of vehicles. The back-off assignment is carried in a way that the furthest nodes in the transmission range receive the smallest back-off values. Therefore, a node furthest from the sender rebroadcasts (or forwards) first. After the rebroadcast is carried by the node, the remaining nodes with higher back-off values overhear the rebroadcast and quit their rebroadcast process. During the message propagation when the broadcast transmission takes place in each hop, the critical role of the proposed technique come in to play to ensure that the message is received by every node in the intended distance. The proposed technique tracks the delivery of the message at each node individually and guarantees the reception of the message.

Message recovery

The scenario for recovering the safety message in a transmission hole is illustrated in Figure 1. Three vehicles (X, Y and Z) are assumed as being completely obstructed in the line-of-sight (LOS). Therefore, the nodes X, Y and Z are oblivious of the original broadcast from node A, these vehicles are termed as the nodes in holes. The remaining nodes within the broadcast range are assumed to receive the safety message successfully. After the reception of the safety message by the remaining nodes, each receiver node checks the reception at its immediate neighbors to determine the need for any recovery rebroadcast.

The immediate neighborhood is defined as the area around a given node a, covered by a circle of radius r, such that there exist two nodes b and c, where $r = \|a - c\|$ *and* $\|a - b\| \leq \|a - c\|$.

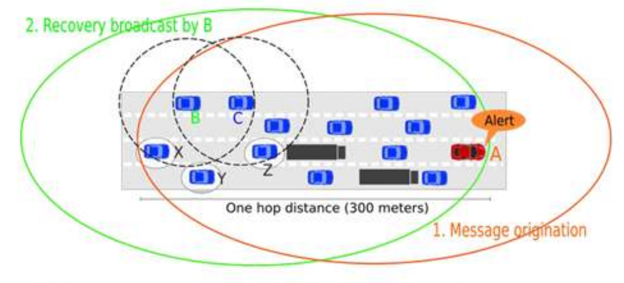


Figure 1: Recovering the message loss in a hole using the proposed technique.

Moreover, $r \leq \|a - z\|$ for any node x where $x \neq a \neq b \neq c$. Therefore, r is the smallest radius around a given node that can house two other neighboring nodes. A single neighboring node may be suffice as a rescuer, the reason for keeping two nodes in the immediate neighborhood is to provide additional reliability at the recovery stage.

Each node maintains the topology information of the surrounding broadcast range. The topology information is gathered from beacon messages that are received periodically from all the surrounding nodes. The beacon message is also appended with vehicle-type information, which is used in estimating the attenuation effect of the vehicle. Moreover, as described earlier, each node is equipped with a GPS and a digital map. The assumption is congruous with most of the studies on VANET communication. To determine the need for a recovery rebroadcast, each node generates the road topology with nodes located on the map by using the respective location, the speed, and the direction information of the nodes; all acquired from the periodic beacon messages. The node can then determine its respective immediate neighbors and runs the received-signal strength (RSS) estimation for each the immediate neighbors. The RSS estimation is carried using the angle between the given immediate neighbor and the original sender. A node located in the LOS path between the sender node and the receiver node is counted as an obstruction, with an attenuation effect on the signal depending on the obstructing-vehicle type (Meireles et al., 2010, Boban et al., 2011). The loss caused by the road surroundings can also be considered for additional accuracy in the RSS estimation (e.g., the recommendations in (Otto et al., 2009, Giordano et al., 2011).

In Figure 1, the process for determining the need for recovery rebroadcast is depicted only for node B and node C. The immediate neighborhood of node B and node C is depicted with the help of dashed circles. Both the nodes, upon the reception of the message from node A, perform the RSS estimation for the nodes in their immediate neighborhood. As shown in the figure, both node B and node C detect one neighbor located in a hole (i.e., the RSS value estimated for the neighbor is below the receiver sensitivity threshold). Consequently, node B and node C contend to rebroadcast the safety message to cover each of their neighbors located in a hole. Significantly, in such a case of multiple rescuers, the proposed technique ensures unique rebroadcast to avoid collision, and at the same time, a single recovery rebroadcast is performed for multiple nodes in holes. Thus, node B and node C wait for one rebroadcast cycle (to allow for self-recovery by normal forwarding rebroadcast); and then follow the sectoring-based elimination process as followed in a normal forwarding rebroadcast. In the figure, node B is the furthest node from the original sender node, thus, node B rebroadcasts the safety message in the entire broadcast range. The rebroadcast is also overheard by the other two nodes previously located in transmission holes. Upon receiving the recovery broadcast, only the receiver nodes that are ready for recovery rebroadcast previously (node C in Figure 1) repeat the RSS estimation step to confirm the reception at its uncovered immediate neighbor. The details of the proposed hole detection and recovery mechanism are summarized in Algorithm 1.

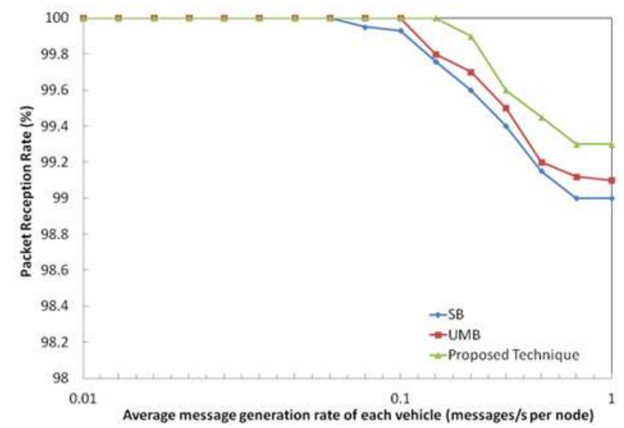
Algorithm 1 Pseudo-code for the NSN-H algorithm.

Initialize
$R_i \leftarrow$ one-hop transmission range of node i;
$r_i \leftarrow$ radius of immediate neighborhood of node i;
$I_i \leftarrow$ set containing nodes in the immediate neighborhood of node i;
$N_i \leftarrow$ rebroadcast sectors around node i;
$rs_i \leftarrow$ rebroadcast sector of node i;
$\omega \leftarrow$ contention window of each sector;
$RSS_i \leftarrow$ estimated received signal strength for node i;
$rss_{th} \leftarrow$ receiver sensitivity threshold;
$H_i \leftarrow$ set containing nodes located in holes detected by node i;

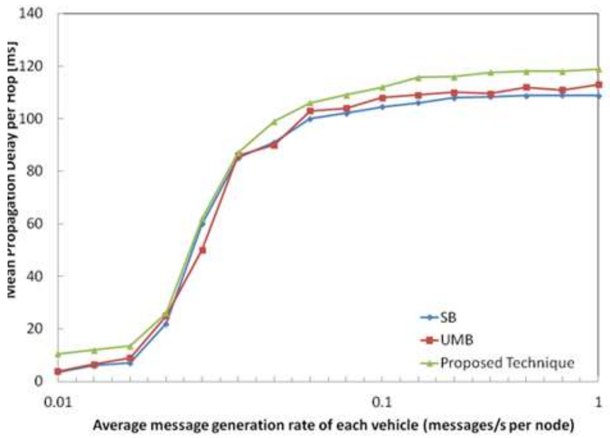
Event new safety alert message received from node s
foreach $n \in R_s$ **do**
  if (to_nack = set) **then**
    cancel to_nack;
  else
    compute $\|n - s\|$;
    choose rs_i corresponding to $\|n - s\|$;
    schedule_rebroadcast with random_backoff $N_s.\omega - rs_i.\omega + \text{random}(\omega)$;
  foreach i r_n **do**
      compute RSS_i;
      if $(RSS_i < rss_{th})$ **then**
        set to_rescue;
        $H_n \leftarrow H_n \cup \{i\}$;

Event new beacon message received
  compute $\|n - s\|$;
  if $(\|n - s\| \leq r_i)$ **then**
    $I_i \leftarrow I_i \cup \{s\}$;
  else if $(s \in I_i)$ **then**
    $I_i \leftarrow I_i \backslash \{s\}$;
Event copy of safety alert message received by n from node s
    if (to_rescue = set) **then**
      foreach $i \in H_n$ **do**
        compute RSS_i;
        if $(RSS_i \geq rss_{th})$ **then**
          cancel to_rescue;
          $H_n \leftarrow H_n \backslash \{i\}$;

Event unrecoverable signal received by node i
set to_nack;
wait for rebroadcast_cycle;
Event rebroadcast_cycle expires for node i
if (to_nack = set) **then**
  broadcast nack in r_i;
else
  if (to_rescue = set) **then**
    broadcast recent message in R_i;



(a) Packet reception rate.



(b) Mean propagation delay.

Figure 2: Packet reception rate and propagation delay of NSN, UMB and SB methods.

Simulation analysis

To analyze the performance of the proposed technique, we have fully implemented the proposed technique on top of the UMB protocol in the ns-3 simulator, version 3.9 (nsnam 2011). For details about the simulation setup, the reader is encouraged to refer to our work in (Khan et al., 2011).

In Figure 2(a), the packet-reception rate (PRR) for one-hop distance is shown against the average message generation rate of each node. The packet reception by a node is the final reception of the message regardless of the number of rebroadcasts resulting from the recovery mechanism. The figure shows that the reliability gain of the proposed technique outperforms the UMB and SB methods, particularly in the high message generation rate region. In Figure 2(b), we show the evaluation of the proposed technique in terms of the average message-propagation delay in each hop. The comparison result shows that the proposed technique, despite its recovery mechanism overhead, incurs a minimal overhead delay of below 5 ms even in the worst case scenario.

CONCLUSION

In this work, we have addressed the problem of covering transmission holes in VANET safety- message communication. We have proposed a new technique that tracks the safety message to individual node level to ensure message delivery. The technique makes use of the existing periodic beacon messages to maintain immediate-neighborhood information. Based on the available topology information each receiving node determines a neighbor located in the transmission hole, and efficiently recovers the safety message for the neighbor. ns-3 simulation results show that the proposed technique promises guaranteed delivery of safety messages, and incurs a minimal overhead delay of below 5 ms even in the worst case scenario.

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