Alerting for Vehicles Demonstrating Hazardous Driving Behavior

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ABSTRACT

Cooperative Collision Warning Systems (CCWSs) have become a major vehicle safety application in intelligent transportation systems. Vehicles organized in a vehicular ad-hoc network use a CCWS communication protocol to propagate emergency messages about hazardous events. Police cars, ambulances responding to incidents and speeding cars or motorcycles that constantly vary their speed, change lanes or commit other apparent traffic violations are examples of vehicles that demonstrate hazardous traffic patterns. Using their GPS and motion sensors, vehicles can detect those traveling in nearby avenue sections who constitute a threat.

In this paper, we propose a broadcasting protocol that alerts drivers about the presence of moving vehicles demonstrating hazardous driving behavior. In order to limit the volume of redundant transmissions, our approach selects the vehicles to be responsible for transmitting the emergency information for a hazardous vehicle. In this context, we provide mechanisms to create and maintain a chain of transmitters. This chain "covers" the road sections on which a hazardous vehicle is moving.

Our protocol attempts to increase the probability that an endangered vehicle does obtain timely information about a hazardous vehicle and reduce the total communication traffic imposed in urban environments where the vehicles' density is often high. We experimentally evaluate our suggested protocol by comparing it with two alternative CCWS broadcasting approaches and we ascertain the extent in which the above objectives are met.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols

Keywords

Collision Warning System, Hazardous Vehicles, VANETs

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1. INTRODUCTION

Over the last decade, we have witnessed a renaissance in terms of equipment that contemporary vehicles already carry aboard that includes multiple-type sensor devices, noteworthy computational resources and significant wireless communication capabilities. This trend is expected to continue and in a few years time all vehicles will display similar features. Such equipment enables vehicles to "perceive" their environment, exchange information with others and/or warn drivers about unpleasant and more importantly dangerous conditions in their vicinity. Using the above fixed vehicular infrastructure, a number of application services have been proposed such as vehicle navigation in congested road networks [15], cooperative discovery of available parking spaces [14] and cooperative collision avoidance [18, 12, 10, 16, 9, 2]. Recent automotive models incorporate such advances as part of their standard offering [4].

Safety systems that operate atop vehicular ad-hoc networks (VANETs) are now considered as one of the most critical applications in intelligent transportation systems (ITS). In this regard, a lot of research has been conducted over the last years in cooperative collision warning systems (CCWSs) [18, 12, 10, 16] and cooperative intersection collision warning systems (CICWSs) [9].

In this paper, we focus on communication protocols for CCWSs whose main aim is to propagate emergency messages related to hazardous events occurring on the road network. The major origin of such abnormal traffic situations is driving behavior largely deviating from driving patterns specified by local and federal traffic codes and regulations. Vehicles that constantly change lanes, abruptly accelerate and slow down, tailgate and pass over at very high speed are a source of worry for the majority of law-abiding travelers. In addition, police cars, ambulances, fire-trucks and/or municipal vehicles responding to emergency incidents may occasionally demonstrate unexpected driving behavior. The above traffic patterns constitute hazardous events on the road and travelers moving at the time ahead of the vehicle demonstrating such behavior should be properly alerted in a timely fashion. While existing CCWS communication protocols are designed to broadcast emergency messages to all endangered vehicles, they appear to be ineffective in the following aspects:

- The majority of existing protocols propagate emergency messages to the vehicles that follow [18, 16, 6, 3, 17]. However, the appearance of hazardous vehicles that frequently exceed posted speed limits has to be known predominantly to those traveling ahead. A plausible protocol must cover both dissemination directions as information has to be effectively passed not only to those tailing but more importantly to those finding themselves ahead of a reported event.

- A hazardous vehicle may generate tens or even hundreds of events while moving. Current approaches can literally drain the vehicular communication resources, by trying to disseminate all emergency messages for all detected events. The assumed high density of vehicles in urban environments amplifies this issue. A more elegant approach would have been to selectively designate vehicles responsible for propagating messages once a hazardous vehicle is identified. Subsequent updates for the status of the hazardous vehicle can be then broadcasted to all endangered vehicles by engaging only those responsible in the propagation process.
- There exist considerable problems in urban avenues that have numerous entry points not directly controlled by traffic lights (i.e., ramps). A vehicle entering through the ramp must be promptly warned about possible hazardous vehicles that are about to traverse the avenue segment running in parallel to the entry lane.

Fig. 1 depicts a speeding vehicle h going through the road segment next to entry point P that is not traffic light controlled. If a broadcasting protocol that uses time–out mechanisms and implicit acknowledgements is applied [18, 16, 3], a vehicle a entering through P may not get promptly alerted. Indeed, using the above type of protocol, a vehicle

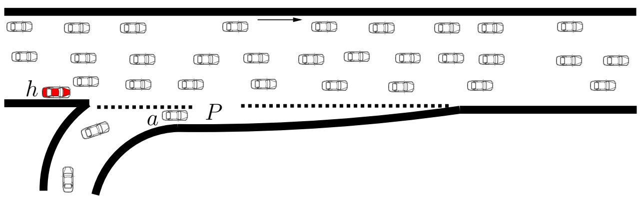

Figure 1: Entering through a ramp to a lane involving a hazardous vehicle

ceases transmission of emergency messages when it is in receipt of transmissions by others (implicit acknowledgement) and resumes transmitting when a time–out expires. It is thus likely that all vehicles in a's vicinity will be in a time–out period when a enters the avenue through P. Alternatively, a vehicle applying a message propagation protocol that uses a neighbor–list mechanism [10, 5] attempts to identify vehicles inside its transmission range that have not received an emergency message. In this case and in Fig. 1, all the vehicles in front of h that detect a, attempt to forward to a an emergency message about h, yielding redundant communication traffic. Another drawback of propagation protocols using neighbor–lists is the fact that vehicles must periodically broadcast their position to keep-alive their presence.

In this paper, we propose a dissemination protocol that tries to "cover" the area of interest with the minimum number of vehicles so that everyone either moving in or entering a dangerous zone gets notified properly. Fig. 2 outlines the solution of our protocol. The dangerous area DA extends in front of the speeding vehicle h; DA's length will be discussed in Section 3.3. The protocol specifies vehicles v_1, v_2, v_3, v_4 as the vehicles that are responsible for the periodic broadcasting of updates regarding the status of h. The four vehicles in question form the "broadcasting chain" that covers the entire area where dangerous incidents might occur. It is the responsibility of the broadcasting chain to inform all the vehicles traversing or entering the DA about the status of h.

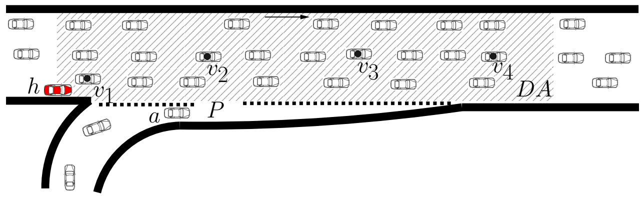

Figure 2: Outlining the operation of our dissemination protocol

Each of v_2, v_3, v_4 is close to the limit of the transmission range of the previous "broadcasting node" in the chain. The protocol continuously monitors the distance between each two consecutive nodes and re–assigns the broadcasting responsibilities in order to keep appropriate distances. Moreover, this re–assignment aims at ceasing the operation of redundant transmitters and maintaining one single chain over the extent of a DA.

Our approach fulfills two main objectives:

1. reduce the total communication traffic caused by the broadcasting of emergency messages issued for hazardous vehicles.
2. increase the probability that an endangered vehicle receives emergency messages in a timely manner.

In urban environments the density of vehicles traveling on avenues is high and the cases where a lot of safety messages must be broadcasted over the same space at the same time, are common. In those cases and as the percentage of vehicles equipped with communication resources is constantly increasing, the efficient utilization of the DSRC control channel [1] is of critical value.

In order to assess the performance of our protocol we compare it with two alternative approaches in a simulation environment, using different traffic congestion settings and wireless communication configurations. The results indicate that our approach yields a better outcome in terms of the two main objectives.

The rest of the paper is organized as follows: the assumptions for the protocol are provided in Section 2. Section 3 outlines the key aspects of our proposal, while Section 4 discusses our experimental results. Related work and concluding remarks are found in Sections 5 and 6, respectively.

2. ASSUMPTIONS

Our solution is based on two basic assumptions. The first assumption is the use of a positioning system by vehicles applying our broadcasting protocol, in order to determine their position. *Global Positioning System (GPS)* is the most common option, while *Differential GPS (DGPS)* can provide more accurate position estimations [8].

The second assumption is that each vehicle applies a detection method in order to discover cars, trucks or motorcycles within its vicinity that present a tangible threat. This detection can be accomplished through two ways:

1. *Detection–by–others :* in this case, a vehicle must use motion sensors [7] that provide relative–motion infor-

mation between the vehicle and a moving "obstacle". A detection–by–others method could build on the mechanisms proposed on [12, 2, 13, 18]. Essentially, vehicles applying such mechanisms can cooperatively estimate and predict the positions, speeds and future trajectories of their surroundings. Hence, a vehicle that moves at a high speed, tailgates, or constantly changes lanes, can be identified by its surroundings as hazardous.

2. *Self–Detection :* in this approach, a vehicle is responsible to start broadcasting when it realizes that it is likely to cause an accident. To this end, vehicles can use information provided by their Electronic Stability Control (ESC) system or GPS information about their position to indicate rapid lane changes and speed that exceeds the limit.

3. BROADCASTING PROTOCOL

3.1 Overview

When a hazardous vehicle h is detected, our protocol designates vehicles for the propagation of the emergency messages related to h. The selected vehicles form a *broadcasting chain* that extends over the entire dangerous area (DA). Each node in the chain is responsible for the broadcast of messages received from the previous node.

The space covered by the DA depends on the characteristics of the hazardous vehicle. A slow-moving or immobilized vehicle constitutes a threat to the ones moving behind. On the other hand, if a vehicle exceeds the speed limits, those ahead of the speeding vehicle (including those entering the same road) need to be alerted.

The rest of the section is organized as follows. Section 3.2 presents the format of the broadcasted messages. Sections 3.3 and 3.4 describe the selection of the broadcasting nodes and the maintenance of the chain, respectively.

3.2 Message Format

Each broadcasted message contains information about the hazardous vehicle, together with data required by the vehicles to apply the protocol. Specifically, an emergency message m contains six fields:

- *BroadcasterStatus* contains the ID, the position, the speed and the direction of movement of the vehicle that broadcasts m.
- *SequenceNumber* corresponds to the sequence number in the broadcasting chain of the node that transmits m. The first broadcasting node in the chain sets 1 in this field. In the rest of the paper, we will designate as BN_i the i-th broadcasting node of the chain.
- *NextNode* denotes the ID of the vehicle that should act as the next node in the chain. This vehicle is chosen by the node BN_i that broadcasts m. Alternatively, BN_i can set in this field a point C to initiate the discovery of vehicles situated close to C that may become BN_{i+1}. This process is detailed in Section 3.3.
- *ConnectionBit* is a boolean field used to signal possible disconnections in the chain of transmissions. A node BN_i sets a 0 in this field if it has not received a message from BN_{i-1} for more than a time threshold T_{th}. The first node of the chain BN_1 sets a 0 in this field.
- *BroadcastTimestamp* is the timestamp of the message set by BN_1. The subsequent broadcasting nodes do not alter this value.
- *HazardReport* contains the latest information about the hazardous vehicle including the speed and the direction of movement.

The fields *BroadcasterStatus*, *SequenceNumber* and *NextNode* hold the information needed for the formation and maintenance of the chain of broadcasting nodes. Details are given in Sections 3.3 and 3.4. Fields *ConnectionBit* and *BroadcastTimestamp* are used for resolving which node must prevail in cases of redundant transmissions. The details are discussed in Section 3.4.

3.3 Formation of the Broadcasting Chain

The first step for constructing a chain of broadcasting nodes is to determine the first node of the chain. As mentioned in Section 2, a hazardous vehicle h equipped with self–detection mechanisms could autonomously start broadcasting emergency messages as BN_1.

If such mechanisms are not available, a vehicle v that detects h in its vicinity (and does not already receive the transmission of a preexisting broadcasting node) starts broadcasting. The assumed high density of vehicles in urban environments amplifies the probability that multiple vehicles will detect h and start broadcasting simultaneously. The message dissemination about h is performed by a single broadcasting chain. There are two criteria to decide which of the transmitters will dominate and become BN_1: *a)* the direction of movement of h, and *b)* the ID of each competing vehicle carried in the *BroadcasterStatus* of each message. The decision process is as follows. First, if there are competing vehicles moving in the same direction as h, the one with the highest vehicle ID prevails and becomes BN_1. Otherwise, all the competing vehicles travel in a different direction from h, and the one with the highest ID prevails.

After the first broadcasting node has been set, we need to create the broadcasting chain that will propagate the emergency messages within the DA. There are two key elements in this process: *a)* the direction of the propagation, and *b)* the distance between two consecutive nodes of the chain.

First, the direction of propagation is determined by the movement of the hazardous vehicle h. If h is a speeding vehicle, the chain must be formed in front of h in order to alert drivers traveling ahead of it. In contrast, if h is a slow-moving vehicle, the chain should lie behind h.

In our protocol, each broadcasting node is responsible for selecting the next vehicle in the chain. To this end, BN_1 calculates the point C the next node should preferably be close to. C is situated at a distance d_{PREF} in BN_1's axis of movement, and ahead or behind BN_1 depending on h's movement. Such point is indicated in the *NextNode* field of a broadcasted message. Consider the example in Fig. 3 that depicts a speeding vehicle h and the first node BN_1. Then, the resulting point C is situated ahead of BN_1 at a distance of d_{PREF}.

The value of d_{PREF} affects the performance of our broadcasting protocol. Clearly, if the distance between nodes is long, less nodes are required to cover the DA. The trade–off in this case is related to the stability of the broadcasting chain, since long distances between nodes could lead to frequent "disconnections" of the chain, especially if such distances are very close to the wireless transmission range. The stability and maintainance of the broadcasting chain are further discussed in Section 3.4.

Vehicles that receive the broadcast can infer their relative

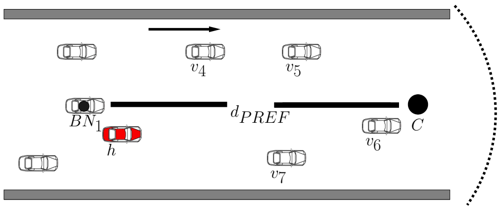

Figure 3: Selection of the next broadcasting node with $d_{PREF} = \frac{4}{5} * R$

position with respect to BN_1 by means of the *Broadcaster-Status* of the message. If C is in front of BN_1, the vehicles moving ahead of BN_1 will reply with a short response. Otherwise, only the vehicles traveling behind BN_1 respond. The response contains *a)* the ID, the position, the speed and the direction of movement of the responding vehicle, and *b)* the ID of the broadcaster, i.e., BN_1's vehicle ID.

In order to reduce the probability of vehicles responding simultaneously, each vehicle defers the transmission of the response depending on its distance from C. A similar technique is proposed in [11, 5]. The defer time is given by the expression $\frac{d_C}{2*R} * DT_{max}$, where d_C is the distance of the responding vehicle from C, R is the transmission range, and DT_{max} is a constant value expressing the maximum defer time. As a consequence, a vehicle closer to C will respond sooner than a vehicle farther from C. The value for the maximum defer time DT_{max} is strongly related to the density of vehicles traveling along the avenue, which can be estimated based on statistics stored on the vehicles' devices.

When BN_1 receives the responses, it chooses as BN_2 the responding vehicle that is positioned closer to C. Subsequent messages from BN_1 will have BN_2's ID in the *Next-Node* field. As soon as BN_2 receives a message containing its ID, it becomes part of the chain and starts broadcasting messages. Consider again the example of Fig. 3. Vehicles v_4, v_5, v_6 and v_7 respond to BN_1's broadcast. As v_6 is the closest vehicle to C, BN_1 chooses v_6 for becoming BN_2.

The subsequent nodes BN_i follow the same procedure for determining the next node BN_{i+1}. The end of the chain is decided based on the system parameter "Dangerous Area Extent" (DAE) that defines the extent of DA in time units, based on the speed of the hazardous vehicle. In particular, the node BN_l estimating that its current position will be reached by h in more than DAE seconds will be the last node of the chain; BN_l leaves the *NextNode* field empty in the messages it transmits. The estimation is based on the current position and speed of h contained in the *HazardReport* of the received broadcasted message.

The example in Fig. 4 illustrates a chain formed by four broadcasting nodes where each node is close to the limit of transmission range of the previous node. BN_4 becomes the last node of the chain after calculating that its current position will be reached by h in more than DAE seconds.

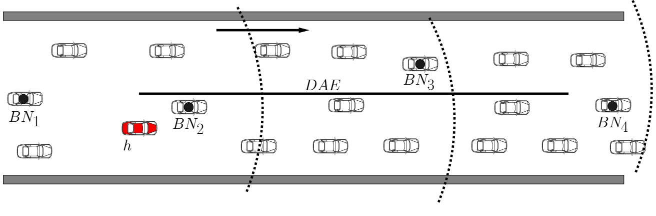

Figure 4: A Chain of four nodes

3.4 Maintenance of the Broadcasting Chain

In our protocol, we define a *transmission period* T_P for the broadcasting of messages, i.e., each broadcasting node transmits an emergency message every T_P seconds. The choice of T_P entails a trade–off between the frequency of updates the chain propagates and the number of messages broadcasted: a small T_P increases the probability an endangered vehicle will get promptly alerted, whereas a large T_P results in less redundant messages. A broadcasting node that does not receive a message from the previous or next node for more than T_{th} seconds, assumes that a disconnection occurred. We set $T_{th} = 4 * T_P$, i.e., a disconnection happens when a node misses four consecutive messages of the adjacent nodes.

After the broadcasting chain is formed, there are two main conditions that affect our protocol: *a)* the movement of the hazardous vehicle with respect to the broadcasting nodes, and *b)* the changes on the relative positions of the nodes. Both conditions are induced by the different speeds at which vehicles travel over avenues. Next, we present the techniques that handle each case.

3.4.1 Movement of the Hazardous Vehicle

We detail the case where the hazardous vehicle is a speeding one (an analogous mechanism applies for the case where the hazardous vehicle is a slow–moving one). Note that, if h is equipped with self–detection mechanisms, the movement of h is handled by the techniques presented in Section 3.4.2.

Our technique works as follows. As a hazardous speeding vehicle h moves faster than the broadcasting nodes, it first overtakes BN_1 and enters BN_2's scope. BN_2 then attempts to become the first node of the chain and replace BN_1. To this end, BN_2 adds an extra bit in the field *Broadcaster-Status* of the messages it broadcasts. Once BN_1 hears the extra bit in the broadcasts of BN_2, it acknowledges BN_2's request by setting the value 0 in the *SequenceNumber* of its own broadcasts. BN_2 can then become the new BN_1 upon receiving BN_1's acknowledgement. Alternatively, a disconnection (i.e., if BN_2 does not receive a response from BN_1 in T_{th} seconds) is also considered an acknowledgement.

3.4.2 Movement of the Broadcasting Nodes

Differences in the speed of the broadcasting nodes increase or decrease the distance between them, thus the broadcasting responsibilities need to be re–assigned accordingly.

Our maintenance protocol builds on algorithms Algs. 1 and 2. A broadcasting node applies Alg. 1 in order to decide about the next node. Each node waits for messages from the next node in the chain (line 4). If no messages are received (line 5), or if the distance of the current node to the next one is less than a *minimum distance threshold* d_{THRES} (line 12), the node tries to search for alternatives. The method `Find-Candidate-Nodes` searches for a new next node in the chain by applying the procedure discussed in Section 3.3.

Alg. 2 provides the rules each node applies in order to decide if it must continue or stop broadcasting. Intuitively, in Alg. 2, a node waits for messages from the previous node in the chain (line 5). If such messages are received, but indicate a node other than the current one as the next one in the chain, the current node must stop broadcasting (line 12). If messages from the previous node are not sensed, the node analyzes all the other messages it received to detect if it is a redundant node (lines 15–27).

Next, we illustrate some representative examples of the

Algorithm 1 `Next-Node`

Begin

1: I := The sequence number of this broadcasting node
2: BN_I := This broadcasting node
3: BT_I := The *BroadcastTimestamp* of the last broadcast received from BN_{I-1}
4: **Wait for** a broadcast with:
SequenceNumber $= I + 1$ AND *BroadcastTimestamp* $\leq BT_I$
for T_{th} seconds
5: **if** no such broadcast was received **then**
6: /* The next node has been disconnected; find another node */
7: `Find-Candidate-Nodes`
8: **else**
9: Pos := The position reported in the *BroadcasterStatus* of the received broadcast
10: ID := The vehicle ID reported in the *BroadcasterStatus*
11: $Distance$:= The distance between BN_I and Pos
12: **if** $Distance \leq d_{THRES}$ **then**
13: /* The next node is too close; find another node */
14: `Find-Candidate-Nodes`
15: **else**
16: Set ID in the *NextNode* of your next broadcast
17: **end if**
18: **end if**

End

application of our algorithms. First, consider the case depicted in Fig. 5. The node BN_i travels faster than BN_{i+1}, thus the distance between them constantly decreases. When the distance is smaller than d_{THRES}, BN_i needs to find a new BN_{i+1} near point C that is on the limit of BN_i's transmission range (lines 12–14 of Alg. 1). When the new BN_{i+1} is found, i.e., vehicle v_1, the previous BN_{i+1} must stop transmitting. BN_{i+1} analyzes the messages received from BN_i indicating v_1 as the next node in the chain. Therefore, BN_{i+1} stops broadcasting (lines 10–13 of Alg. 2).

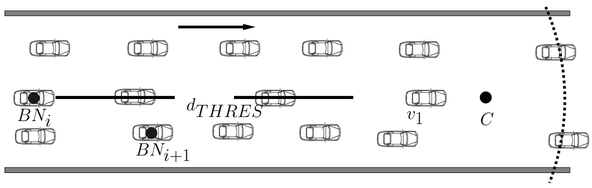

Figure 5: The distance between two consecutive nodes decreases

The next example is depicted in Fig. 6. BN_i moves slower than BN_{i+1}, thus the distance between them constantly increases. BN_i needs to find a new BN_{i+1} close to C (lines 5–7 of Alg. 1), i.e., v_1. After becoming the new BN_{i+1}, v_1 searches for a new node to act as BN_{i+2}. Using the technique presented in Section 3.3 v_1 detects v_2. Finally, the previous BN_{i+1} hears the transmissions of v_2 (lines 15–23 of Alg. 2) and stops transmitting emergency messages.

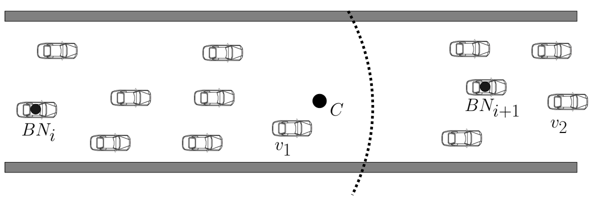

Figure 6: The distance between two consecutive nodes increases

Fig. 7 depicts a case where a broadcasting node BN_{i+1} slows down suddenly and moves next to BN_{i-1}. Then, suppose that BN_{i+1} cannot hear the messages sent by BN_i. In

Algorithm 2 `Broadcast-Decision`

Begin

1: $I + 1$:= The sequence number of this broadcasting
2: BN_{I+1} := This broadcasting node
3: ID_{I+1} := The vehicle ID of this broadcasting node
4: BT_{I+1} := The *BroadcastTimestamp* of the last broadcast received from BN_I
5: **Wait for** a broadcast with:
SequenceNumber $= I$ AND *BroadcastTimestamp* $\geq BT_{I+1}$
for T_{th} seconds
6: **if** the broadcast BRC_I was received **then**
7: **if** the *NextNode* of BRC_I is ID_{I+1} **then**
8: /* normal flow */
9: **return** "CONTINUE BROADCASTING AS BN_{I+1}"
10: **else**
11: /* the previous node has updated the chain */
12: **return** "STOP BROADCASTING AS BN_{I+1}"
13: **end if**
14: **else**
15: **for** any other broadcast BRC received with:
SequenceNumber $\neq I$ **do**
16: CB := The *ConnectionBit* of BRC
17: BT := The *BroadcastTimestamp* of BRC
18: ID := The vehicle ID in the *BroadcasterStatus* of BRC
19: /* Resolve conflict */
20: **if** CB=1 OR $BT > BT_{I+1}$ OR (BT=BT_{I+1} AND $ID > ID_{I+1}$) **then**
21: /* The other node prevailed */
22: **return** "STOP BROADCASTING AS BN_{I+1}"
23: **end if**
24: **end for**
25: /* You prevailed or no redundant messages were found */
26: **return** "CONTINUE BROADCASTING AS BN_{I+1}"
27: **end if**

End

this case, BN_{i+1} will have to analyze all the other messages it receives, in order to decide if it contributes to the propagation of emergency messages or if it is a redundant node (lines 15–27 of Alg. 2). The messages sent by BN_{i-1} that have a *ConnectionBit* set to 1 will be used by BN_i to infer that it should stop transmitting (lines 20–22 of Alg. 2).

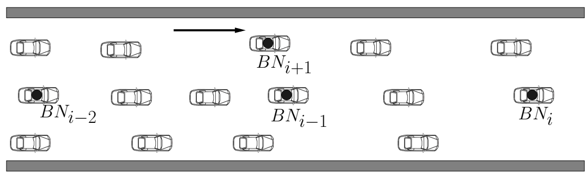

Figure 7: Redundant node inside a chain

Besides the cases discussed in Figs. 5–7, there are numerous other cases where we may end up with redundant nodes transmitting inside a chain. These cases are brought up due to abrupt vehicle acceleration/deceleration or package collisions and physical obstacles that affect wireless communication. When there are two (or more) redundant nodes sensing each other's transmissions, they apply the following criteria to resolve the conflict (lines 20–23 of Alg. 2): First, nodes connected to a previous node (indicated by *ConnectionBit*) prevail. Second, nodes that transmit the most recent messages (i.e., with the newest *BroadcastTimestamp*) prevail. Finally, the node with the higher ID prevails.

4. EVALUATION

The evaluation of our protocol was performed on a simulator we developed on *Java6*. For our experiments, we used a portion of the Manhattan road-network that was imported to the simulator using the *OpenStreetMap XML* format.

We divided the avenues into main and secondary avenues. Throughout the experiments, we uniformly distribute regular (i.e., law abiding) vehicles across each segment of the road network while placing a hazardous/speeding vehicle per main avenue. In order to produce hazardous situations on avenue junctions, we assume that the crossings of main with secondary avenues are not traffic light controlled and priority is given to those traveling on main avenues. The speed of each regular vehicle varies during an experiment, but still remains within the interval $[40, 80]$ km/h. The speed of the hazardous vehicles ranges within $[80, 120]$ km/h.

We compared our *BroadcastChain* protocol with two alternative approaches for emergency CCWS broadcasting:

1. the *ImpACK* approach: vehicles apply an implicit acknowledgement mechanism, similar to those suggested in [18, 16, 3], to decide when they must stop or start transmitting. This approach is the main alternative approach found in the related work that fits adequately to the problem discussed in this paper. In detail, when a vehicle v detects a hazardous one, it starts transmitting emergency messages. Vehicles that move in front of v and receive its transmission will, in turn, start broadcasting. Once v receives a broadcast from a vehicle in front, it ceases transmission and enters a time–out period. Upon receipt of subsequent transmissions from vehicles in front, v resets the time–out counter. When the time–out expires, v will resume broadcasting. The same rules are applied by all the vehicles located on the *DA*. The duration of the time–out period is designated as "Implicit Acknowledgement Time–out" (`IAT`).
2. the *NoACK* approach: all the vehicles found on the *DA* act as transmitters. A transmitter broadcasts one emergency message every "Transmission Period No Acknowledgement" (`TPNA`) seconds. Moreover, each transmitter uses a specific time–slot within period `TPNA`. This time–slot is determined by the last two digits of the respective vehicle's id.

In order to evaluate the effectiveness of the three methods in discussion, we employ the following metrics:

- the *"Incident Probability" (IP)* metric, which is related to the probability of an endangered vehicle not receiving an emergency message on time. We consider that an *Incident* happens when a hazardous vehicle h comes closer than the *incident threshold* τ_I to a vehicle that has not received any warning for it. To the contrary, if v has been warned about h we consider it as a *Notified-Vehicle*. The fraction: $\frac{Incidents}{Incidents+NotifiedVehicles}$ expresses the *Incident Probability* metric.
- the *"Warnings Received per Hazardous Vehicle" (WRHV)* metric, related to the total communication traffic caused by the broadcasting of emergency messages. Every vehicle records the hazardous vehicles for which it has been alerted and the number of emergency messages received for each of those vehicles. Based on these recordings, we compute the average number of messages received per hazardous vehicle. Ideally, each vehicle should receive just one emergency message for each of the hazardous vehicles that enter its vicinity.

Table 1 summarizes the main parameters of our simulation and the range of values used in the experiments. In addition, due to space limitations, we only include the experiments that correspond to the following values of the system parameters: d_{THRES} and d_{PREF} are set to $\frac{3}{5}*$`R` meters and $\frac{4}{5}*$`R` meters, respectively, *DAE* is set to 12.6 meters, and τ_I is set to 9 seconds.

Table 1: Simulation Parameters

Name	Description	Values
`RVS`	Regular Vehicle Speed in km/h	$[40, 80]$
`HVS`	Hazardous Vehicle Speed in km/h	$[80, 120]$
`R`	Transmission Range in meters	$[17.5, 560]$
`TP`	Transmission Period for the *BroadcastChain* in seconds	$[0.63, 10.08]$
`TPNA`	Transmission Period for the *NoACK* approach in seconds	$[2.52, 20.16]$
`IAT`	Implicit ACK Time–out for the *ImpACK* approach in seconds	$[2.52, 40.32]$
`VD`	Vehicle Density : Number of vehicles per km per lane	$[20, 120]$

Figs. 8 and 9 depict how each of the three methods responds to an increase in the density of vehicles traversing the road network. `R` is fixed to 70 and `TP` is fixed to 2.52. We use two different settings for the *ImpACK* approach:

- *ImpACK1*, where `IAT`$= 2*$`TP`
- *ImpACK2*, where `IAT`$= 8*$`TP`

and two different settings for the *NoACK* approach, namely:

- *NoACK1*, where `TPNA`$= 2*$`TP`
- *NoACK2*, where `TPNA`$= 8*$`TP`

In Fig. 8, *NoACK1* demonstrates the best *IP* in all the six `VD` settings examined. However, this performance comes with a cost of a high number of *WRHV*, as Fig. 9 shows. As `VD` increases from 20 to 120, the *WRHV* for *NoACK1* grows from 10 to 56. Very close to the *IP* performance of *NoACK1* is the performance of our *BroadcastChain* protocol, in Fig. 8. Furthermore, the *BroadcastChain* draws the lowest *WRHV* in all six `VD` settings, in Fig. 9. Our approach noticeably keeps *WRHV* at the same lowest level regardless of the `VD`, because it attempts to identify only one transmitter every $d_{PREF} = \frac{4}{5}*$`R` meters, as discussed in Section 3.

ImpACK1 has an *IP* of below 10 percent, in all the six `VD` settings of Fig. 8. In contrast, *NoACK2* and *ImpACK2* give an *IP* between 15 and 25 percent. The fact that *NoACK2* and *ImpACK2* have a large value for `TPNA` and `IAT`, respectively, explains why the *IP* is high in these cases. Additionally, from Fig. 9 we may infer that the *NoACK* approach is considerably more expensive than the other two approaches, since it has a lot more overhead, even for *NoACK2* where a large value for `TPNA` is used.

In the experiments depicted in Figs. 10 and 11, `VD` is fixed to 60 and `R` is fixed to 70. Through these experiments we intent to measure the performance of *BroadcastChain* and *ImpACK* for different values of the `TP` and `IAT` parameters. The x-axis expresses the value of `TP` and for each case, we set `IAT`$= 4*$`TP`. For both methods of Fig. 10, the *IP* increases as the `TP` and `IAT` increase. Nevertheless, *BroadcastChain* consistently demonstrates significantly lower *IP*. The trade–off for the low *IP* is the high *WRHV*, as in Fig. 11 the overhead for both methods decreases when the `TP` and `IAT` increase. Again, *BroadcastChain* proves to be more efficient since the attained *WRHV* is consistently lower.

In Figs. 12 and 13, `VD` is fixed to 60, `TP` to 2.52 and `IAT` to 10.08 while `R` ranges from 17.5 to 560. Fig. 12 shows that

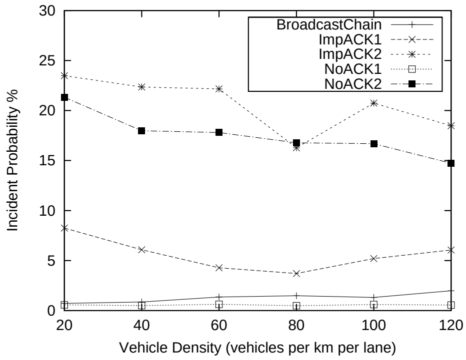

Figure 8: *Incident Probability* for different Vehicle Densities

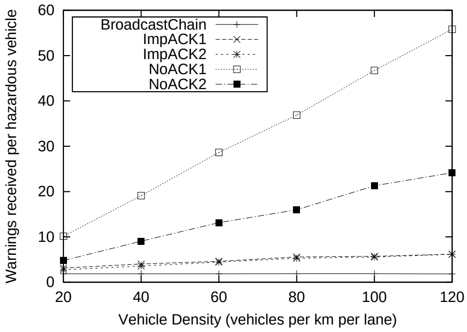

Figure 9: *Warnings Received per Hazardous Vehicle* for different Vehicle Densities

BroadcastChain achieves a lower *IP* only when R is less than 280. The cost of having a low *IP* for the *ImpACK* method, when R increases, is the overhead, indicated by the large values of *WRHV* in Fig. 13. In contrast, *BroadcastChain* has, once more, a lower *WRHV*, which will not exceed 3 even when R is 560. The *WRHV* of *BroadcastChain* does not follow the increase of R as the distance between consecutive broadcasting nodes is proportional to R.

5. RELATED WORK

During the last decade, a number of detection approaches for vehicles with hazardous traffic patterns and pertinent communication protocols have been proposed in both CCWSs [18, 12, 10, 11, 5, 16] and CICWSs [9]. Based on the speed of vehicles about to traverse an intersection, the algorithm in [9] estimates the likelihood of a collision. In [12], vehicles use differential *GPS*-units as well as motion sensors to predict future trajectories of adjacent fellow travelers. Predictions for developing trajectories as well as future positions help identify potential collisions.

The CCWS dissemination protocol in [11] determines that only the vehicles close to the limit of the wireless communication range of a transmitter must re–broadcast a message they receive. The dissemination approach taken in [5] is different as each vehicle v maintains one set for the vehicles that are inside its transmission range and one set of vehicles that have transmitted a message m. Before re–transmitting m, v decides the time period to wait. Once the waiting period ends, and if there are vehicles within the range of v that have not transmitted m, v re–transmits m. In [10], a message distribution mechanism that identifies zones around the

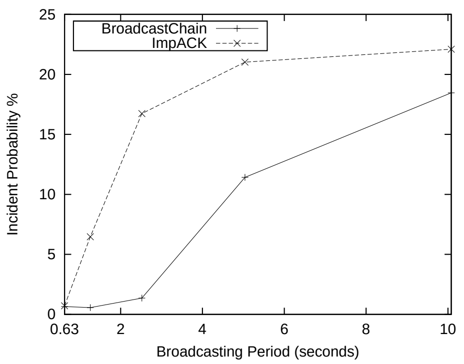

Figure 10: *Incident Probability* for different Transmission Periods

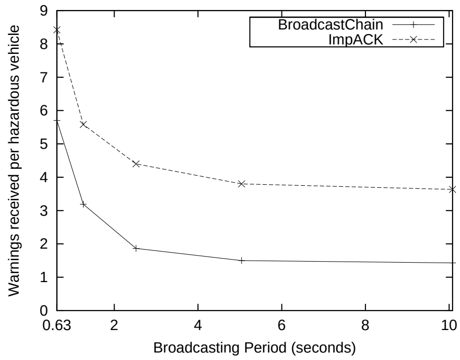

Figure 11: *Warnings Received per Hazardous Vehicle* for different Transmission Periods

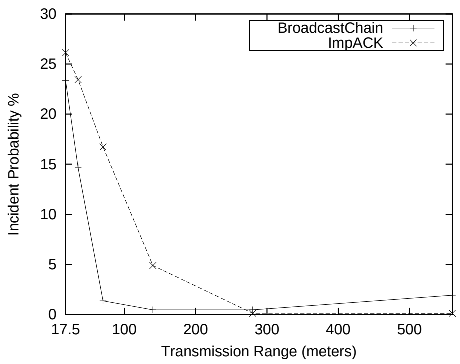

Figure 12: *Incident Probability* for different Transmission Ranges

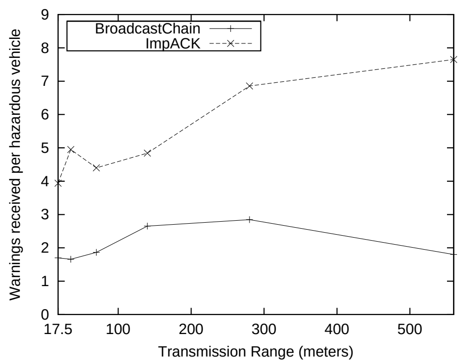

Figure 13: *Warnings Received per Hazardous Vehicle* for different Transmission Ranges

location of a hazardous incident, is outlined. Each vehicle bases its message forwarding decisions according to the zone it finds itself in at any time.

In [16] a communication protocol is proposed for emergency warning dissemination. Vehicles applying the protocol decide in which rate they should transmit warnings. Furthermore, vehicles use implicit acknowledgements and time–out mechanisms in order to understand when they must cease or restart transmitting. A related approach is discussed in [18]. Again, the communication protocol is based on implicit acknowledgements and time–out mechanisms, but it differentiates traffic scenarios and emergency events to operate more efficiently.

6. CONCLUSIONS

In this paper, we propose a protocol for the dissemination of information related to moving vehicles that display hazardous behavior in urban environments. Vehicles equipped with motion sensors can detect nearby travelers that deviate from expected driving patterns complying with traffic legislation. Once hazardous behavior has been identified, others who may move in-range might be alerted about this developing incident.

Instead of using an all-out effort by disseminating vehicles, our protocol exploits the smallest possible number of vehicles geographically covering a vicinity of the incident; these vehicles use their transmitters to pass emergency messages to all interested travelers. Our approach simultaneously minimizes the total communication traffic and maximizes the probability that a vehicle in danger receives emergency notifications in a timely manner.

Through detailed simulation experiments we have compared the performance of our proposal with those of two competing alternatives: the first uses implicit acknowledgements and a timeout mechanism and the second has each vehicle transmit emergency messages on a time-slot determined by the ID of the vehicle. We investigate all above approaches while taking into account diverse settings in the density of moving vehicles, their wireless range and the required period of transmission. Our protocol ensures the timely notification of travelers in danger while consistently expends minimal communications costs in all settings.

Acknowledgment

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