# Directional Broadcast Forwarding of Alarm Messages in VANETs

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***Abstract*— The performance of general routing schemes for Vehicular Ad hoc NETworks (VANETs) is highly affected by the features of the specific Medium Access Control scheme the routing relies upon and by the mobility scenario. In this work, we address the design of position based routing solutions for the support of safety oriented applications in VANETs by focusing on the impact of the MAC layer on the performances of the routing strategies. Namely, we propose a simulation analysis in a realistic highway mobility scenario to assess the routing performance in the two cases where standard IEEE 802.11 technology and a dynamic TDMA scheme are adopted at layer 2 respectively. We discuss on the dimensioning of the routing parameters in both cases and we provide a comparative analysis of the two MAC/routing integrated solutions.**

## I. Introduction

The constant increase in the number of cars travelling along the roads worldwide calls for effective means to improve the road safety and the efficiency of the overall transportation infrastructure. To this end, the research community, the industries and the governments all over the world are investing much of their efforts and money in the development of integrated Intelligent Transportation Systems (ITS) based on wireless communication networks. The aim of ITS is of allowing vehicles, equipment on the road, service centers and intelligent sensors to exchange information in a prompt and cost effective way [1][2][3].

The creation of high-performance, highly reliable, highly scalable and secure Vehicular Ad hoc NETworks (VANETs) poses extraordinary challenges to the wireless research community related to the access to transmission channel [4], the information routing [5], the topology control by means of the transmission power [6], the support of the applications and the characterization of vehicular traffic both in terms of vehicles mobility and of service application requirements [7].

The applications in the field of vehicular communications may be roughly divided into two main categories: safety and non-safety applications. Non-safety applications include information retrieval, entertainment services, tolling services, etc. On the other hand, safety applications are mainly devoted to traffic control and vehicle collision avoidance services. Typical road safety applications include accident notification messages, collection and distribution of information on traffic and road conditions from sensors (on the road and on cars), virtual warning signs and even automatic traffic and routes management systems [8].

Road safety oriented communications have common characteristics: first of all the communications are often directed to a group of devices (vehicles, roadside network infrastructure, etc.), and the composition of the group of intended receivers (vehicles) may depend on their positions and direction. Moreover, a single transmission is not enough to target all the intended receivers due to the limited transmitter's range. Thus, the alarm message needs to be relayed by intermediate cars (multi-hop).

To this extent, position based routing [9] is commonly recognized to be one of the most promising solutions for VANETs [10] [5]. The aim of this work is to study the impact of the Medium Access Control (MAC) layer on the performance of geographical routing solutions, gathering general guidelines for the dimensioning of routing and MAC layer parameters. To this end, we consider a geographical routing scheme, named REACT (Routing for Emergency Applications in Car to car networks using Trajectories) [11] which belongs to the family of position based protocols but also incorporates the trajectory based routing paradigm [12]. Roughly speaking, in REACT the packet diffusion is implemented through one hop broadcast transmissions and is forced to follow specific trajectories, coded into the packets themselves.

The performance of REACT and of general position based routing solutions highly depends on the type of MAC scheme the routing relies upon. To this extent, the parameters of the routing schemes should be optimized with respect to the specific characteristics of the MAC layer. In this paper we compare through simulation the performance of REACT when varying the Medium Access Control solutions adopted at the lower layers. Namely, we test the cases where standard IEEE 802.11b [13] technology and a dynamic TDMA scheme, the ADHOC MAC [14], are adopted at layer 2 respectively. The performance analysis is carried out in a highway scenario where the vehicles move according to a realistic mobility model based on the concept of cellular automata [15].

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The remainder of the paper is organized as follows. Section II overviews the basis of the REACT scheme, whereas Section III discuss on the integration of REACT with IEEE 802.11 Distributed Coordination Function (DCF) and ADHOC MAC. In Section IV we present the topological scenario and the realistic vehicles' mobility model adopted in the simulation analysis which is reported in Section V. In Section VI we review some of the recent works carried out in the field of the design and performance evaluation of position based routing solutions for VANETs . Finally, concluding remarks and comments are given in Section VII.

## II. REACT BASICS: THE FORWARDING DECISION ALGORITHM

REACT conceptually features two functionalities: the *Forwarding Decision Algorithm* (FDA) and the *Topology Discovery Algorithm* (TDA). The former determines the next forwarder on the basis of the geographical/topological information provided by the latter.

The choice of the next forwarder is based on: (i) the position of the current node $i$, (ii) the type of information reported in the alert packet, such as the type of message and the type of trajectory coded in the packet, and (iii) positional information regarding neighboring vehicles. Indeed, the TDA provides each vehicle with a list of the neighboring vehicles ($NEIGH\_LIST(i)$), whose fields are the position and direction of motion. Details on how such information is distributed among the vehicles depend on the characteristics of the peculiar MAC level are discussed in Section III.

Besides the list of neighbors and the position of the current node $i$, the FDA takes in input: the position of the original message source ($S$), the trajectory ($T$), the target progression of the packet along the trajectory ($Pr_{tg}$), that is, the minimum distance the packet has to travel along the trajectory and the forwarding angle $\alpha$, representing the maximum allowed deviation from the trajectory.

Conceptually, the trajectory $T$ represents the direction along which the safety information needs to be propagated. For example, a car noticing an accident may spread this information to all the following cars travelling in the same direction on the same road, so that they can slow down and eventually take another road. Similarly, an ambulance may communicate its route to traffic light controllers in order to create a non-stop "all green" path to the destination.

A pseudo code for the FDA is reported in Algorithm 1. First of all, the algorithm evaluates the length of the progression along the trajectory starting from the source of the packet $S$ to the current forwarding node $i$, using the function $DistOnTrajectory(s, i, T)$. If this distance is greater than the target progression $Pr_{tg}$, the packet has already travelled enough and the selection of the next-hop is not necessary. Possible mechanism to keep the information within this area can be implemented [16]. Otherwise, a next forwarder selection is needed. In this case, FDA evaluates the progression along the trajectory for all its valid neighbors in list $NEIGH\_LIST(i)$ and estimates their deviation from the trajectory using the

**Algorithm 1** FDA(i,S,$\alpha$,$Pr_{tg}$,T,NEIGH_LIST(i))

1: progression(i) = DistOnTrajectory(i,S,T)
2: MaxProgr = progression(i)
3: NextHop = i
4: **if** MaxProgr $\geq Pr_{tg}$ **then**
5:    **return** Null
6: **else**
7:    **for all** j $\in$ NEIGH_LIST(i) **do**
8:    progression(j) = DistOnTrajectory(i,s,T)
9:    **if** (progression(j) $\geq$ MaxProgr **AND** AngleLimit(j,T,$\alpha$)) **then**
10:       MaxProgr = progression(j)
11:       NextHop = j
12:    **end if**
13:    **end for**
14: **end if**
15: **return** NextHop

function $AngleLimit(j, T, \alpha)$. Roughly speaking, this is used to eliminate from the decision those vehicles whose direction diverges from the trajectory. Finally, the node on the trajectory with the greater progression is chosen as the next-hop.

Since, the FDA basic operation can be affected by errors due to nodes' mobility, wireless channel fluctuations and connectivity holes, the routing entity must implement proper mechanisms for increasing the reliability of the chosen path.

The information stored in the $NEIGH\_LIST(i)$ can be out of date due to the high mobility of vehicles, and it may happen that a neighbor of vehicle $i$ stored in $NEIGH\_LIST(i)$ in the meanwhile is no longer reachable by vehicle $i$ itself.

In order to reduce the probability to select next-hops that are actually unreachable, REACT limits the decision range below the transmission range: i.e., the *decision range*, $R_d$, is defined as the maximum distance between a vehicle running the FDA and the potential next forwarder. Line 9 in the pseudo code is modified accordingly.

Further on, broadcast transmissions can be impaired by connectivity holes and collisions on the transmissions due to interference and wireless link fluctuation. These events, in turn, can abruptly interrupt the forwarding process before the packet life time has expired or the target progression along the trajectory has been reached. To this end, REACTS uses the concept of *implicit acknowledgement* according to which, the forwarding vehicle stores the message it has forwarded and sets a waiting timer $\tau$. If this timer expires without the packet rebroadcast has been performed by the selected next-hop, the last forwarding node re-runs the FDA to choose another next-hop and retransmits the packet (store and forward approach). The procedure is iterated until a valid forwarder is found or the message expiration time is reached, in this last case the message is dropped and an error signal is passed to the application.

A prototype format of the routing packet adopted by REACT is sketched in Figure 1. The header part contains: the

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| Source Position | Trajectory | Next Hop ID | Msg ID | Validity Time | Message |
|---|---|---|---|---|---|
| 4 byte | Y byte | 4 byte | 1 byte | 1 byte | X byte |

Fig. 1. *Format of the packet used by REACT.*

| Sender ID | Sender Position | Sender Direction | SN |
|---|---|---|---|
| 2 bytes | 4 byte | 4 bytes | 2 byte |

Fig. 2. *Format of the beacon signalling packets used to implement the TDA in IEEE 802.11.*

location of the original source of the message, the trajectory properly coded and the next forwarder ID, chosen by each forwarding node through the REACT algorithm. Then, the message includes the alert expiration time, based on the packet life time, that is set by the original source to limit the alert validity and the message life in the network, the message ID and the message payload which defines the type of alarm.

Trajectory coding and representation in the packet is out of the scope of this work. For the sake of simplicity we have presented the FDA considering a straight trajectory. In this case, $T$ = 5 bytes can be used to code the trajectory (4 byte to define a second point of the single line trajectory and 1 more byte to define the minimum progression along the trajectory). Obviously, as in classical source routing protocols, the length of the header depends on the number of parameters of the trajectory to be coded in it. The FDA can be extended also to the case of piecewise trajectories or trajectory trees [17].

## III. The Topology Discovery Algorithm

### A. REACT over 802.11

In case REACT relies upon the IEEE 802.11 technology, the TDA can be implemented exploiting the broadcast transmission service offered by such technology for the diffusion of signalling packets, named beacons in the following, carrying the required topological information. The format of a beacon is reported in Figure 2. Each packet carries the sender ID, the sender position and direction and a time stamp to assess the validity of the beacon itself.

Beacons must be transmitted periodically by the vehicles in order to refresh the topological information required by the FDA. The optimum value of the Beacon Interval (BI) obviously depends on the vehicles' mobility and density. From one hand, a low beacon interval is favorable to have fresh topological information, nevertheless, from the other side the lower the beaconing interval the higher the traffic load which may lead to high collision rate.

Upon reception of a valid beacon, a vehicles stores the beacon's sender information in the $NEIGH\_LIST$ or updates the entry corresponding to the sender with the new data. Indeed, a validity timer $\gamma$ is set for each entry of the neighbors' list and it is refreshed every time a new beacon is received by the specific vehicle. If no new information is received from the corresponding sender within $\gamma$ seconds, the sender is removed from the list.

### B. REACT over ADHOC MAC

ADHOC MAC [14] features a dynamic TDMA where each terminal, upon activation, acquires a Basic CHannel (BCH) which corresponds to a slot in a virtual frame (VF) and that is mainly used for MAC signaling. The very same BCH can be used also for broadcasting data to all the one-hop neighbors in a reliable way. ADHOC MAC adopts a distributed access algorithm for the acquisition of the BCH, which is named Reliable Reservation ALOHA (RR-ALOHA) [18]. The information needed for the RR-ALOHA correct operation is provided to all terminals by means of the BCHs. Each transmission on the BCH contains, besides data and header information, a control field named Frame Information (FI).

The FI is a vector with $N$ entries specifying the status of each of the $N$ slots preceding the current transmission, as observed by the transmitting terminal itself. The slot status can be either BUSY or FREE: it is BUSY if a packet has been correctly received from another terminal or transmitted by the terminal itself, otherwise it is FREE. In the case of a BUSY slot the identity of the transmitting terminal is reported. Consequently, the FIs report the information on the neighbors' activity of the sending terminal as perceived by the terminal itself in the previous VF.

Thus, a terminal receiving the FI from one of its neighbors gets aware of its neighbors'neighbors activity. Based on received FIs, each terminal marks a slot, say slot $k$, either as RESERVED, if slot $k-N$ is coded as BUSY in at least one of the FIs received in the slots from $k-N$ to $k-1$, or as AVAILABLE, otherwise. As in R-ALOHA, an AVAILABLE slot can be used for new access attempts.

Upon accessing an AVAILABLE slot, terminal $j$ will recognize in the next VF its transmission either successful, if the slot is coded as "BUSY by terminal $j$" in all the received FIs, or failed, otherwise. More details on ADHOC MAC with a proof of correctness of the aforementioned access algorithm can be found in [14].

The BCHs provided by the ADHOC MAC carry periodical signaling information which can be used to spread out the topological information needed by REACT. To this end, the BCH's header need to be enhanced and besides the usual FI other signaling fields should be added. Figure 3 shows the updated ADHOC MAC BCH format, including (i) the basic overhead (i.e. the FI), (ii) the transmitting vehicle's position (4 bytes for each coordinate) and (iii) the time-stamp (9 bytes), i.e., the time of position's survey. Another additional field, not directly related to REACT, is the protocol field, which is used to distinguish among different protocols of upper layers. The chosen size of the enhanced ADHOC MAC header is $35N + 144$ bits.

Through the ADHOC MAC header, vehicles gather topological information on neighboring nodes (positions and identifier) every VF, thus ADHOC MAC accomplishes the functionality of providing implicit beaconing of topological infor-

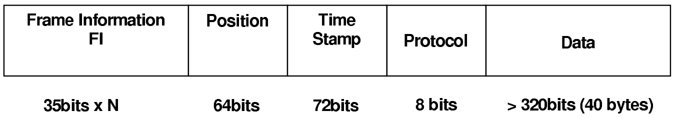


Fig. 3. *The new ADHOC MAC packet format.*

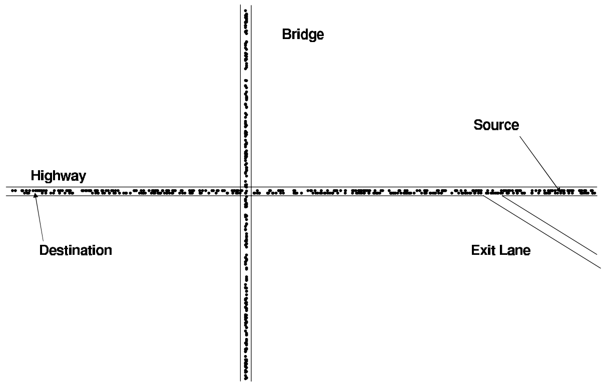


Fig. 4. *Scenario description.*

mation. Such beaconing is still periodical, as in the case IEEE 802.11 is adopted, and its period is equal to the VF duration. In this way, the node can fill its $NEIGH\_LIST$ following the very same rules discussed in the previous section.

Alert messages can be transmitted by the designated forwarders in their own BCHs and the corresponding acknowledgement/unacknowledgement is provided in the following frame: in fact, if the BUSY bit in the FI of the selected next-hop forwarder is equal to one, the next-hop forwarder has actually received the message and may rebroadcast it. If the BUSY bit is not set, the transmission toward the intended relay has failed (due to collision or vehicles' movement) and a new next-hop relay should be selected. In this last case, the next transmission attempt is performed in the next VF, thus the value of transmission timeout, as defined in Section II, is $\tau = T_f$, having called $T_f$ the time duration of a VF.

## IV. The Scenario Description

The simulation scenario considered in this paper represents a highway with a crossing bridge and an exit lane. Figure 4 shows the considered topology (i.e., the highway on the horizontal axis and the bridge on the vertical axis). An alert packet is transmitted at a given source point and should travel the target progression $Pr_{tg}$ along the trajectory as soon as possible. Table I summarizes the scenario parameters.

| Parameter | Value |
|---|---|
| Highway length | $10km$ |
| Bridge position | $4km$ on highway |
| Vehs' density on the bridge | $20vehs/km$ |
| Vehs' density on the highway | $5, 15, 25, 35, 45vehs/km$ |
| Vehs' speed on the bridge | $18.75m/s$ $(67.5km/h)$ |
| Vehs' speed on the highway | $31.25m/s$ $(112.5km/h)$ |
| Bridge length | $3km$ |
| Sender | $9.5km$ on highway |
| Exit position | $8.5km$ on highway |
| Bandwidth, C | $2Mbps$ |
| Radio communication range | $250m$ |

TABLE I

*Scenario parameters.*

In each lane, vehicles move accordingly to a realistic traffic mobility model that abstracts the real drivers behavior. In the following we restrict our attention to Cellular Automata (CA) models which have been increasingly used in the last decade [15][19] due to the good match exhibited by such models with empirical traffic measurements [20]. In these models, each *vehicle* $k$ is individually resolved by the couple $(x_k, v_k)$ describing the spatial location and the speed of the $k$-th vehicle along a one-dimensional road with wrap-around boundary conditions. The model then consists of a set of rules or equations to update these quantities over time, depending on the states of other vehicles around. CA models are discrete in both space and time: space is typically coarse-grained to the length that a car occupies in a jam, and time step is usually about one-second long. A side effect of this convention is that space can be measured in "cells", time in "steps" and usually these units are assumed implicitly and left out of the equations: e.g., a speed $v = 5$ means that the vehicle travels five cells per time step. As previously mentioned, many different models exist: we selected the Nagel and Schreckenberg automaton [15]. The set of update rules, performed in parallel for each vehicle, is as follows:

$$\begin{array}{ll} \text{1. Car-follow :} & v_k \leftarrow \min\{v_k+1, d(k-1,k), v_{max}\} \\ \text{2. Noise :} & v_k \leftarrow \max\{v_k-1, 0\} \quad \text{w.p.} \quad P_d \\ \text{3. Motion :} & x_k \leftarrow x_k + v_k \end{array}$$

The first rule describes deterministic car-following behavior: drivers try to accelerate by one speed unit except when the gap from the vehicle ahead is too small or when the maximum speed $v_{max}$ is reached. The second rule introduces random noise: with probability $P_d$, a vehicle ends up being slower than what calculated deterministically; this parameter simultaneously models effects of i) speed fluctuations at free driving, ii) over-reactions at braking and car-following, and iii) randomness during acceleration periods. In our evaluations we assume a $P_d$ value equal to 0.16.

Note that, due to the parallel update, an implicit reaction time of the order of the time step is introduced; however, rather than representing the actual driver's reaction time, which would be much shorter, the reaction time is a measure of the time elapsed between the stimulus and the action of the vehicle.

## V. Performance Evaluation

The performance of REACT over ADHOC MAC and IEEE 802.11b is tested hereafter using $ns2$ simulator [21] in the topological scenario described in Section IV. The performance statistics gathered from the simulation analysis are:

- the Delivery Failure Probability, i.e., the probability for a packet not to cover the target progression,
- the conditional delivery delay, i.e., the delivery delay of those packets which are actually delivered,

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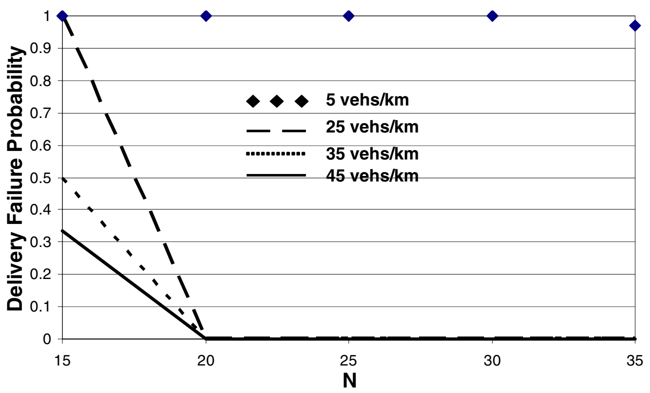


Fig. 5. *Delivery Failure Probability versus the number of slots N in the ADHOC MAC virtual frame.*

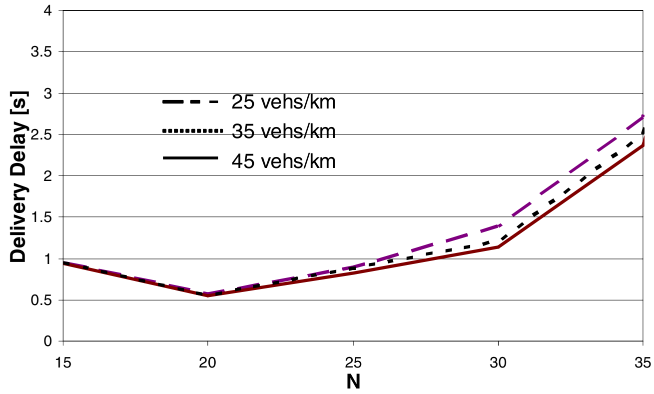


Fig. 6. *Delivery Delay versus the number of slots N in the ADHOC MAC virtual frame.*

- the packet collision probability.

Results reported in the following are obtained with a confidence level of 99% and a confidence interval of 2%.

| Parameter | Value |
|---|---|
| Decision range, $R_d$ | $50, 100, 125, 150, 175, 200, 225, 250m$ |
| Forwarding angle, $\alpha$ | $60deg$ |
| Target Progression, $Pr_{tg}$ | $8.5Km$ |
| Packet Lifetime | $10s$ |
| Validity Timer $\gamma$ | $3s$ |

TABLE II

SIMULATION PARAMETERS.

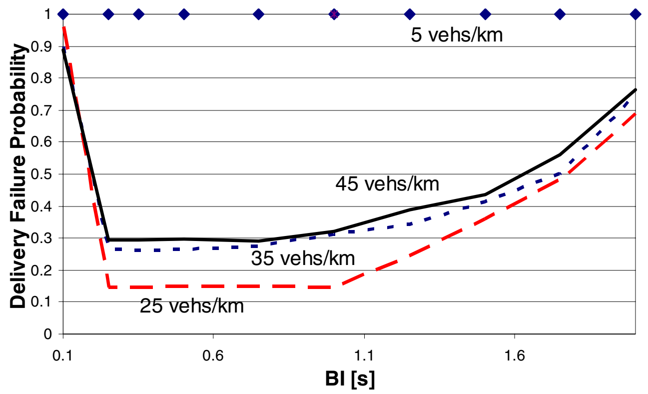


Fig. 7. *Delivery Failure Probability versus the beacon interval BI in IEEE 802.11b.*

The parameters values that ADHOC MAC and 802.11b share are summarized in Table II. In our reference scenario, the IEEE 802.11b Distributed Coordination Function (DCF) is implemented at the MAC layer. The DCF parameters are set to the standard values and broadcast transmissions are used for the alarm packets.

In the following results a single alarm packet is generated and relayed according to REACT rules until either the target progression has been matched or the packet lifetime expires.

### *A. Parameters Dimensioning*

First of all, we investigated the impact of the parameters to be specifically set using ADHOCMAC or 802.11b. In order to have a fair evaluation of the impact of these parameters on REACT, we fix the dimension of the alarm packet to be delivered $P = 256$ bytes.

When ADHOC MAC is adopted the actual data rate $R$ available for the spreading of alarm packets is given by:

$$R = P/T_f = \frac{CP}{(P + H)N},$$

where $C$ is the data rate of the physical channel, $N$ is the number of slots within the VF and $H$ is the BCH header length.

In this scenario, we investigated the impact of the number of $N$ slots per frame on the performance of the routing protocol. The results are reported in Figures 5 and 6 which show respectively the delivery failure probability and the conditional delivery delay versus the number of slots in ADHOC MAC virtual frame. The curves have been obtained setting the decision range $R_d = 200$ m and the one in Figure 5 limits the range of $N$ to those value ensuring the actual packet delivery for the values of vehicles' density considered, that is, $N \geq 20$. The results reported by the two figures show that the optimum value of $N$ comes from a trade off between two distinct effects: if from one hand a low number of slots speeds up the delivery time since shorter frames are used, on the other hand a low number of slots increases the collision probability and probability of failure in acquiring a BCH. Thus, all the results presented in the following are obtained using, for each vehicles' density, the lower number of $N$ ensuring null delivery failure probability, i.e., $N$ =20.

On the other side, when 802.11 supports REACT, the parameter to be optimized is the beacon interval (BI). Figure 7 reports the delivery failure probability versus the beacon interval for different vehicles' densities. As clear form the figure, the delivery failure probability never goes to zero for any values of the beacon interval. However, it has a minimum which comes from a trade off choice between the need of having fresh topological information (frequent beacons) and the one of limiting congestion due too frequent beacons. As

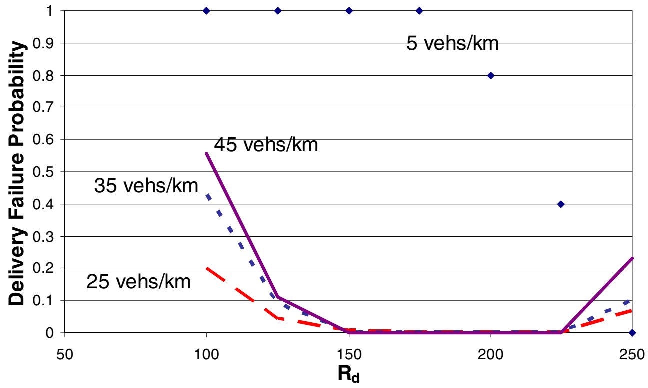


Fig. 8. *ADHOCMAC: Delivery failure probability versus the decision range value for different vehicles' density.*

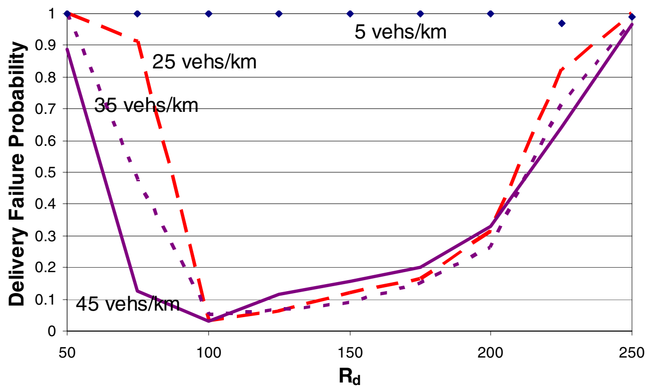


Fig. 9. *802.11b: Delivery failure probability versus the decision range value for different vehicles' density.*

for ADHOC MAC, all the results presented in the following are obtained using the optimized BI value for each value of vehicles' density, i.e., $BI = 1$ s.

### *B. Performance Comparison*

As mentioned in the previous section, the performance of the routing scheme depends also on the value of the decision range, $R_d$. Here we aim at evaluating the impact of such parameter in the configurations of the routing algorithm gathered from the previous dimensioning analysis (optimum values of N and BI).

Figures 8 and 9 show the delivery failure probability, versus the decision range when adopting ADHOC MAC and standard IEEE 802.11 respectively.

The first observation coming from the figures is that, in the case ADHOC MAC is used, the delivery is always successful for vehicles' density above 5 vehs/km when considering the decision range values between 150 m and 250 m. This suggests that the main factor determining the efficiency of the routing is the network connectivity, rather than packet collisions (which increases with the vehicles' density) or non-consistent choices of the next forwarders (which increases with the decision range).

Furthermore, we can observe that the delivery failure probability decreases when increasing the decision range until 225 m for a fixed vehicles' density value, since greater decision range values increase network connectivity, i.e., the probability of finding a proper next-hop. On the other side, if the connectivity is assured (i.e., densities bigger than 10 vehs/km), the delivery failure probability increases when increasing the vehicles' density; in fact, in this case many vehicles do not acquire a BCH, thus, with small decision ranges, the probability of missing the next forwarder increases. If we further increase the decision range (up than 225 m) misleading choices on the next hop and collisions appear thus increasing the failure probability.

When the IEEE 802.11 is considered(Figure 9), there is no value of decision range for which the delivery failure probability is null. Even when the network is fully connected, the collisions among the beacons lead to routing failure due to inconsistent topological information. This is well portrayed by Figure 10 which captures the packet collision probability versus the decision range for different vehicles' density in the cases the ADHOC MAC and the IEEE 802.11 are adopted. The curve referring to IEEE 802.11 accounts for alarm to beacon, beacon to beacon and alarm to alarm collisions, whereas in ADHOC MAC the only possible collisions are among alarm packets. As clear from the figure, ADHOCMAC is very effective in avoiding collisions in all the decision ranges considered, thus the performance of the routing are mainly affected by the network topology only. On the other side, the collision probability characterizing IEEE 802.11 is never null and much higher, thus affecting the routing reliability in those cases where the network is potentially connected.

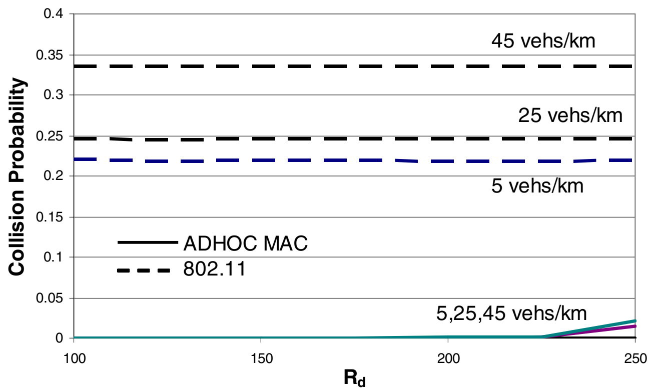


Fig. 10. *The packet collision probability versus the decision range value for different vehicles' density*

An important performance parameter for safety application is the reliability in terms of degree of diffusion of the information. To this end, Figure 11 presents the delivery failure probability versus the target progression along the trajectory. This figure shows that ADHOC MAC provides null delivery failure probability at high vehicles' density for any target progression value considered, since the network is fully connected and collisions are limited. Conversely, at the density

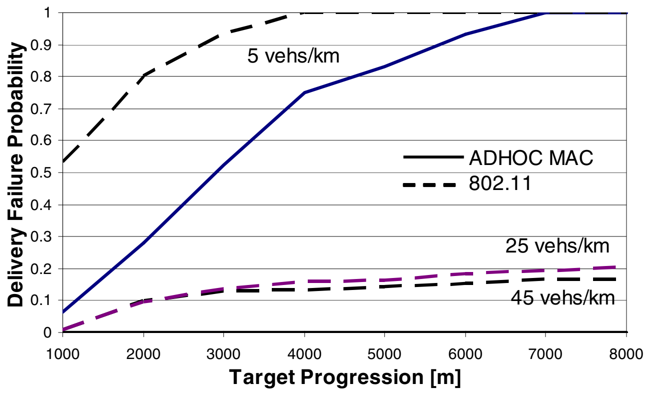


Fig. 11. *Delivery failure probability versus the distance between source and destination for different vehicles' density.*

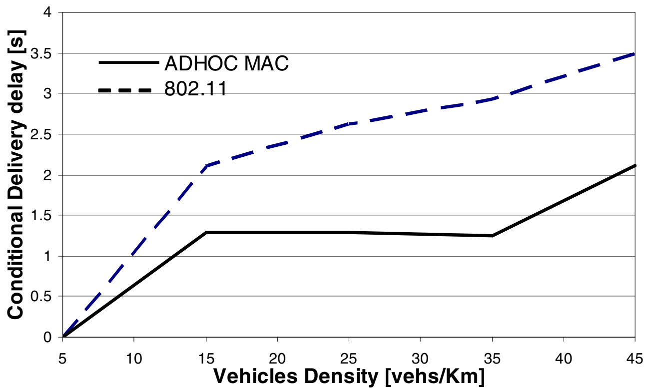


Fig. 12. *The packet delivery delay versus the decision range value for different vehicles' density.*

of 5 vehs/km, an increasing distance to be covered raises the delivery failure probability since on longer portions of the road gaps in the connectivity are more likely to appear. On the other side, as expectable from the discussion on the previous figures, in case IEEE 802.11 is used, the delivery failure probability is not null even at high vehicles' density values.

Besides the geographical diffusion degree, it is also interesting to give some insights on the delivery delay. Figure 12 reports the delivery delay with a target progression $Pr_{tg} = 8500$ m conditioned to actual delivery versus the vehicles' density when adopting optimum configuration ($R_d$, N, and BI) for ADHOC MAC and IEEE 802.11. ADHOC MAC provides lower delivery delay values for all the tested vehicles density values. To wrap up the results of Figures 11 and 12, IEEE 802.11 does not guarantee the actual delivery of an alarm packet and, even in the cases it does, the measured delivery delay is higher than the one provided by ADHOC MAC. Similar results not reported here for the sake of brevity have been obtained with other values of the target progression along the trajectory.

## VI. Related Work and Contributions

Within the general framework of "pure" position based routing for VANETs, a good deal of work has already been carried out in the recent past and several routing/forwarding solutions have been proposed [22], [23], [24].

Reference [25] proposes a geocast algorithm for the support of virtual warning sign, whose target is to distribute the information within a defined geocast zone. The proposed scheme adopts a unicast routing to reach the destination area according to which each forwarding node chooses as next forwarder the neighbor which is closest to the final destination. The aforementioned mechanism has some contact points with REACT since both need topological information on the neighboring nodes and both implement a greedy algorithm for the choice of the next forwarder. However, one substantial difference exists: REACT is more tailored for applications requiring a directional broadcast rather than a real geocast support at the network layer. In fact, REACT uses broadcast transmissions and try to follow a specific trajectory rather than the shortest feasible path to the destination. Reference [16] follows up the aforementioned work by focusing on different techniques to store the geocast information within the final destination area, so that it is periodically broadcasted to new come nodes.

Within the same field, Yang *et al.* [26] focus on the design of position based solutions for the support of cooperative collision warning among vehicles, with the specific target of developing distributed congestion control algorithms to limit the impact of multiple collision warning messages on the overall system performances. Collision warning services are addressed also in reference [27], which presents a directional broadcasting protocol using geographical information. Different form REACT, the proposed mechanism implements a receiver oriented next forwarder choice. Each receiving node sets up a timer on the basis of its own position and its distance to the destination, according to the qualitative criteria that nodes in better positions will have shorter timers. Upon timer expiration, the receiving node forwards the packet and all the nodes overhearing this transmission simply abort their own. The proposed solution has two main drawbacks: multiple unwanted transmissions of the same packet can happen if nodes do not overhear packet transmission and no recovery procedure is implemented. Conversely, in our solution the transmitter chooses the next forwarder and recovery procedures are implemented to cope with temporary forwarding failures (lack of connectivity).

All the works referenced above and the most of the works carried out in the past evaluate the performance of the several proposed routing/forwarding schemes in the case IEEE 802.11-oriented technology is used at layer 2, whether the basic form, IEEE 802.11b [28], [4], or enhancements, DSRC [29], [30]. To the best of our knowledge, very few works study the interaction of position based routing with dynamic TDMA MAC schemes and none of them provides a comparative analysis of integrated MAC/Routing solutions. To this extent, the novel contributions of the present work can be summarized in the following points:

- integration of position based routing with dynamic TDMA scheme,

- dimensioning guidelines for the integration of position based routing solutions both with standard IEEE 802.11 technology and with dynamic TDMA based one,
- qualitative analysis of the two integrated solutions in a realistic highway mobility scenario.

## VII. Conclusions

In this paper we have addressed the issue of designing routing solutions to support safety applications in vehicular networks. To this end, we have focused on a directional broadcast solution which leverages the position based routing paradigm and the trajectory based one, and bases the routing/forwarding decision heuristic on both classical geographical information (neighboring vehicles' positions and directions, current vehicle's position, destination's position, etc...) and information on physical trajectories which should be followed by the flow of alarm packets.

The necessary topological information to be spread to support the routing/forwarding decision can be achieved either with a "ad hoc" signaling protocol based on periodical beacon exchange among nodes, or adopting specific MAC schemes able to distribute such information at layer 2. To this end, we have compared through simulation the performance of the routing scheme in a realistic highway mobility scenario when implemented respectively on top of standard IEEE 802.11 technology and on top of a dynamic TDMA based MAC scheme, the ADHOC MAC, which is able to distribute topological information at layer 2.

The results we gathered outline that the performance of position based routing based on standard IEEE 802.11 technology can be greatly impaired by the overhead traffic used for recovering topological information which each transmitter bases its routing decision on. Within this field, we are planning of extending the same analysis carried out in this paper to the case where the routing/forwarding decision is moved from the transmitter to the receiver, in which case the signalling overhead can potentially be reduced.

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