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LAMD: Location-based Alert Message Dissemination scheme for emerging infrastructure-based vehicular networks

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Abstract

Requiring low dissemination delays and thorough vehicles coverage in the vicinity of an emergency event, Vehicular Ad-hoc NETWORKS (VANETs) were considered as the most adapted communication network to support alert messages dissemination. With the advent of Cooperative ITS services, emerging vehicular networks are expected to increasingly rely on Vehicle to Infrastructure (V2I) communication links, which are expected to be nominally available, with some transient and time-limited connectivity losses. The presence of V2I links paves the way to centralized network control, which can leverage vehicle-related and contextual information provided by the cloud to make more informed decisions. This paper proposes an effective alert message dissemination procedure called LAMD (Location-based Alert Messages Dissemination) for emerging vehicular networks that combines V2I broadcasts with selected V2V (Vehicle to Vehicle) rebroadcasts. The originality of our scheme lies in the selection process of V2V rebroadcasts, which is based on vehicles' location regarding predefined rebroadcast points selected by a centralized controller. This leads to very limited collisions, low delivery delays, and high information coverage with insignificant signaling and network overhead compared to legacy VANET based dissemination techniques.

Keywords: Vehicular communications, Alert message dissemination, Safety applications, SDN

1. Introduction

Future vehicular networks are moving away from the initial view, mainly centered on the Vehicular Ad hoc NeTwork (VANET) approach to encompass multi-access heterogeneous networks that combine different access technologies and network architectures, each commissioned to support different traffic and application services. Indeed, emerging Cooperative Intelligent Transportation System (C-ITS), which advocates for enriching the perception that vehicles have on their surrounding world and enlarging their perception horizon, are pushing towards enabling all kinds of vehicle connectivity under the umbrella of Vehicles-to-everything (V2X) communications [1, 2]. These latter notably include Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Network (V2N), and Vehicle-to-Cloud (V2C) communications, and are the core enablers of emerging C-ITS services whose objectives are to improve further road safety, traffic efficiency, and comfort and convenience to drivers and passengers. To name a few C-ITS services [?], we cite cooperative maneuver, bird’s-eye view, cooperative awareness (e.g., Emergency vehicle warning, Alert for an accident), etc.

Dedicated Short Range Communication (DSRC) and Long Term Evolution (LTE) are the two main complimentary access technologies considered for future vehicular networks. The former is foreseen for rapid dissemination and delivery of critical safety messages in a limited area of interest. At the same time, the latter is more suited for heavier and less stringent message exchanges [3]. Also, in line with the recent trends in communication networks and the progressive adoption of network softwarization, Software Defined Networking (SDN) is considered a promising paradigm for future vehicular networks. In addition, SDN paves the way for effective network control applications to unify the control of heterogeneous multi-access vehicular networks: it can leverage the vehicular network’s centralized, multi-level, and multi-access view with complementary vehicles, road, and route traffic-related information brought from the cloud. Moreover, SDN is a key paradigm for supporting the diverse Quality of Service QoS expectations (some of which are very stringent) of C-ITS services.

In this paper, we consider such an SDN-enabled multi-access vehicular network. Under this assumption, Vehicle to Infrastructure (V2I) wireless connectivity is nominally available, with agreed infrequent and time-limited connectivity losses. This holds for LTE access networks but also for DSRC based access networks where the V2I connectivity is achieved thanks to the

Road-Side Units (RSUs), as it is a prerequisite for the support of control traffic exchange between the SDN controller and the vehicles.

The presence of viable V2I wireless links is an appealing opportunity to reconsider how some core ITS services are implemented. This is, for instance, the case of the Alert Message (AM) dissemination service on an emergency or a risky situation (accident or vehicle breakdown) that we consider in this paper. The AM service broadcasts on an area of interest alarm messages for some period to let close-by vehicles react quickly and adequately to the risky situation [4]. Historically, alert message dissemination was carried out by a DSRC based VANET by inviting vehicles to rebroadcast the alert messages blindly. Unfortunately, this flooding causes a massive amount of unnecessary re-transmissions and collisions (known as the broadcast storm problem), thus wasting bandwidth, increasing dissemination delay, and lowering packet delivery ratio [5].

This paper extends our previous work [6]. It proposes a novel Location-Alert Message Dissemination scheme called LAMD for future vehicular networks that primarily exploits V2I links to widely broadcast alert messages complemented with parsimonious V2V rebroadcasts. V2V rebroadcasts selection is driven by a centralized network controller to reach the vehicles suffering from a potential loss of V2I connectivity while drastically controlling and reducing the number of rebroadcasts. It relies on the centralized view that the network controller builds on its coverage area and control as well as information related to road traffic and vehicles (their characteristics, and potentially their road trip). More precisely, the network controller computes rebroadcast locations (or rebroadcast points) to ensure that V2I broadcasts and V2V rebroadcasts lead to the full coverage of an area of interest. The selection process of vehicles allowed to rebroadcast an AM is finally based on their close vicinity to rebroadcast points. This alert message dissemination scheme offers highly controlled (ideally full) information coverage while drastically reducing the number of rebroadcasts compared to existing techniques. This drastically reduces the number of collisions and significantly saves network resources; useless rebroadcasts are avoided. Finally, our proposal induces insignificant network signaling overhead.

The rest of the paper is organized as follows: Section 2 introduces the problem of alert message dissemination and how it is historically addressed. Section 3 presents an overview of existing work that aims at improving AM dissemination. Section 4 describes the proposed location-based dissemination algorithm and the system model. Section 5 evaluates and discusses our

simulation results. Section 6 concludes the paper.

2. Alert Message dissemination in vehicular networks

AMs are used to urgently warn vehicles heading into a geographic area that hosts a hazardous situation or event (an accident, tricky weather/road condition, sudden break, etc.). AMs belong to the Decentralized Environmental Notifications Message (DENM) class of messages defined to convey the information related to different road events that need to be delivered to road safety applications of nearby vehicles [7]. They usually include the type of event, the coordinates of the event's position, an indication of the geographic area where the message should be distributed, and the sender. A road event is typically detected by one or multiple vehicles; in other words, multiple DENM messages related to the same event can be sourced from different vehicles. Also, an ITS application running behind the road infrastructure can detect the event and send DENMs down to vehicles. When a road event is detected, the corresponding DENM is periodically generated in an average of 10 messages per second for the period where the event remains present. The dissemination requirements of a DENM message are typically expressed in terms of a geographic area of interest, which delimits the area within which all the vehicles should receive the message and delivery/dissemination delays [7]. For instance, for AMs, the area of interest is a few kilometers from the event's location, meaning that multiple wireless transmission hops could be needed to cover the whole area, while the dissemination delay requirement is a few hundreds of milliseconds. Such reliability and delay expectations heavily depend on the performance of the wireless technology. Two main vehicular communication technologies based on the IEEE 802.11p amendment for vehicular networks are recommended: the Dedicated Short-Range Communications (DSRC) protocol [8] and the Intelligent Transportation System ITS-G5 protocol developed by the European Telecommunications Standards Institute (ETSI) [9]. Both operate on a dedicated 5.9GHz unlicensed band, split into one control channel (CCH) and 6 (or 5) Service channels (SCH). The CCH is used for DENM transmissions with another critical class of messages, namely CAM (Cooperative Awareness Message). CAMs are periodically broadcast by each vehicle to inform all their wireless one-hop away neighbors (vehicles and RSUs) of their current status, e.g., position, speed, heading, etc.

IEEE 802.11p is an instantiation of the IEEE 802.11 wireless LAN standard developed for vehicular networks. Some of the physical layer’s protocol parameters were adjusted to ensure satisfactory performance under fast-changing propagation channels due to vehicles mobility. Also, some functionalities were deactivated at the MAC layer, and some protocol parameters were adjusted to make 802.11p networks suited for the fast broadcast of short messages under the high mobility of vehicles. It relies on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) based on Enhanced Distributed Channel Access (EDCA) technique. EDCA provides a priority-based differentiated access to the transmission channel. It is enforced by controlling CSMA/CA parameters, namely the Arbitration Inter-frame Space (AIFS), which sets the free channel listening period, as well as the size of the min (resp. max) contention window size (resp. CW_{min} and CW_{max}) from which the random back-off times are derived.

Usually, AMs are relayed over multiple wireless hops to reach all vehicles within the geographic area of interest. However, rebroadcasting AMs leads to increased medium contention and transmission collisions among neighboring nodes and useless duplicate transmissions because of the shared wireless medium. This leads to inefficient use of radio resources and increased dissemination delays. In the case of high vehicle density, these are exacerbated due to excessive redundant and contending rebroadcasts (named in the literature as the broadcast storm problem). As a result, AMs delivery can be compromised for some time, disrupting the service provided by road safety applications.

3. Related Work

Alert message dissemination has been widely studied in a VANET/V2V context as referenced by survey papers [10, 11, 12]. All aim to address the "broadcast storm" problem and ensure high information coverage. The way they handle the problem can be broadly classified as follows. Either by controlling the flooding procedure, preventing systematic blind rebroadcasts from each receiving vehicle. Or by organizing vehicles in clusters and structuring the alarm message dissemination along these clusters avoiding the broadcast logic. Or, finally, using routing protocols to compute point-to-multi-point routes along which alarm messages are forwarded. Below, we dive further into the details of our classification and present, without being exhaustive, some representative papers that fall in each class.

3.1. Control of the Flooding Procedure

A lot of the proposed schemes try to control the flooding procedure of AMs either by reducing the number of rebroadcasters or by reducing the contention between transmitting vehicles. They are described hereafter.

3.1.1. Relay Selection

In these methods, only part of the vehicles is selected to relay the AMs. This selection is typically based on a combination of vehicles' characteristics, distance from the sender, local density, interests (e.g., the destination district), transmission power, etc., and helps to limit re-transmissions and contention at the cost of reduced information coverage.

Adaptive Data Dissemination Protocol (AddP)[13] selects forwarding nodes based on the local density of the forwarder and the positions of neighboring nodes. Since forwarding nodes are chosen during the dissemination of each multicast packet, the nodes closest to the boundaries of the communication range and the highest local density have priority to broadcast the message. AddP helps mitigate the broadcast storm problem (by reducing redundant messages and the hidden node problem) and frequent disconnections. However, the proposed mechanism may not be suitable for highly mobile and dense V2V networks in which local density and neighborhood of vehicles keep changing rapidly, and many vehicles are multicast recipients.

The idea of Liu and al. in [14] is to combine the advantages of various communications and cloud communication technologies to address the down-link data dissemination strategy from a remote server to a targeted area by ensuring reduced delays and high packet delivery rates. They propose a framework for the dissemination of alert messages within an integrated system which comprises a Hybrid VANET-Cellular architecture where the buses act as mobile gateways (vehicles with dual DSRC and Cellular interfaces, registered in the cloud) and a cloud infrastructure which enables rapid data acquisition of road traffic flow and the geographical position of all mobile gateways. This choice efficiently provides essential traffic information (accident, route recommendation, etc.) to the vehicles in the targeted area. Gateways play the role of rebroadcasters by relaying back and forth to the farthest receivers, which ensures that remote vehicles can immediately get the alert message. Since some gateways may broadcast the message simultaneously, the gateway relay selection process must be interrupted when the vehicles ahead detect that they have already received the message; thus, the

data redundancy can be considerably reduced. But this method remains restrictive because it requires that the nodes be spread over the targeted area of coverage.

Black-burst and Multi-channel-based Multi-hop Broadcast protocol BMMB [15] runs on different channels simultaneously. The black burst is based on splitting the communication range of the sender of the message into several segments via reiterative partitions; then, using the Request to Broadcast and Clear to Broadcast (RTB / CTB) mechanisms, a single relay vehicle is selected in the outermost non-empty segment to broadcast the emergency message on the next hop. This protocol minimizes the unwanted effects of the broadcast storm but assumes non-standard wireless technologies.

3.1.2. Adjusting of MAC Layer Parameters

In this second sub-class of methods, MAC level protocol parameters are adjusted on a vehicle basis for statistically assigning different back-off periods to vehicles. This choice reduces node contention and collisions, with no impact on information coverage. However, useless transmissions are not avoided.

In [16], Virdaus and al. propose a new model to calculate the survival probability of a single-hop broadcast packet. This model uses a forwarding mechanism in an emergency message dissemination application based on counting all the cases of contention window allocations to all the nodes simultaneously receiving a broadcast message. The proposed model improves the messages reception ratio. However, there is a significant increase in the dissemination delay.

In [17], the authors propose a protocol that minimizes the collision rate and therefore increases the broadcast reliability. A node can detect collisions and congestion by simply analyzing the sequence numbers of the recently received packets. Each node periodically broadcasts its status to its neighbors, e.g., relevant information on its position, speed, acceleration, etc.), and notably a report on the portion of packets it successfully received from each neighbor. Accordingly, each node dynamically adjusts its parameters, such as its Contention Window (CW) size and transmission rate, based on this feedback mechanism.

3.2. Vehicle Clustering Techniques

Another class of proposals set aside the flooding logic and guide AMs dissemination by organizing vehicles into clusters (groups of nodes) and defin-

ing how messages are propagated between and within clusters. Authors use many specific criteria for cluster formation and Cluster-Head CH selection as neighborhood, direction/destination, relative velocity, etc.

In [18], clusters are vehicles traveling in the same direction, with similar speeds (for cluster stability) and mutual radio coverage. The node with the highest link quality in the cluster is elected as CH, receiving messages from other CHs and retransmitting them to other cluster members. The proposed method considerably improves the emergency messages delivery ratio. However, there is a significant increase in the delivery time.

In [19], they define clusters as a set of vehicles around a nearby CH vehicle (i.e., with mutual radio coverage with CH), having the same direction, the same destination, and the same interests. Each CH maintains a list of neighboring CHs, including clusters from other roads. When a CH receives an emergency message with the same road ID as its own, it sends it to all of its cluster members and all neighboring CHs (within its transmission range R) moving in the opposite direction or on a different road ID. The information is exchanged through beacons with no beacon congestion control mechanism.

3.3. Routing Protocols

The third class is based on routing protocols that proactively or reactively compute point-to-multi-point routes to all known vehicles. As a result, they exhibit the most predictable information coverage and efficient resource usage, but their use creates a higher network overhead and an increased complexity embedded in vehicles.

The broadcast routing protocol developed in [20] provides security details to the VANET driver with a rear sensor. It detects messages for the neighbors with a simple procedure: to use one-hop intelligently depending on vehicles' speed and distance to define a front, a vehicle, and a rear vehicle. As multicast security message delivery occurs, an entry or relay is received when unrelated parties lose a safety note.

The Ad hoc On-Demand Distance Vector (AODV) routing protocol [21] supports on-demand, unicast, and multicast routing, using a sequence number for each route. AODV responds to link failure in the network because it is responsive. However, its major drawback is that this type of network can determine a route that is not necessarily the optimal route. Therefore, an enhancement to AODV, Ad hoc On-demand Multipath Distance Vector Routing (SD-AOMDV), is proposed in [22] to address the characteristics of

VANETs. SD-AOMDV adds additional criteria (speed and direction) to the field that determines the next hop during finding and building routes.

Our proposed method, LAMD, is a relay selection technique that differs significantly from other previous works because it considers only one parameter: the location of vehicles, making our method more efficient and simple. In addition, and as mentioned above, our dissemination scheme primarily exploits V2I transmissions and complements V2V re-transmissions to reach vehicles in white/gray areas, while the majority of the other work is solely concerned with V2V communications.

4. Location-based Alert Messages Dissemination Scheme (LAMD)

4.1. System Model

An SDN network controller is assigned to each region; it manages all the RSUs that provide V2I wireless connectivity within its region. Each controller identifies white and gray zones in its region and selects K rebroadcast zones where vehicles can rebroadcast an AM sent by an RSU to extend the V2I coverage and reach all the vehicles located in gray or white zones. These rebroadcast zones are defined by a rebroadcast point $P_i(x_i, y_i)$, $i \in [1, K]$, where x_i and y_i are the GPS coordinates of P_i , and a radius d_{max} in the order of a few meters from the rebroadcast point.

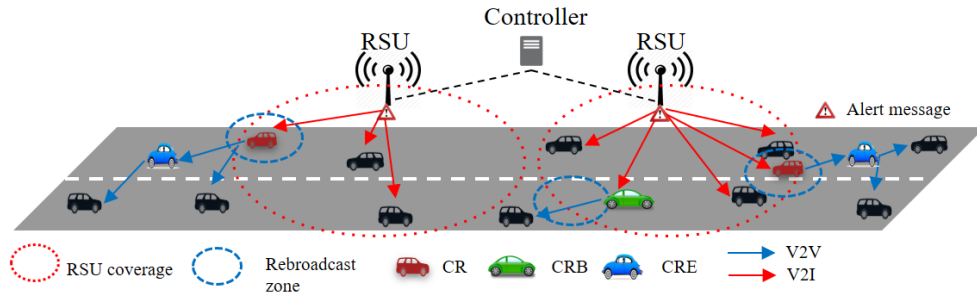


Figure 1: Location-based alert messages dissemination scenario

For illustration, Figure 1 depicts a road section involving two RSUs led by an SDN controller. The red dash ellipses represent RSUs' wireless coverage. All the other road portions are considered gray/white zones. Three

rebroadcast zones (delimited by the blue dashed ellipses) are defined. Vehicle transmissions from these rebroadcast zones are expected to cover the gray/white zones.

4.2. LAMD Key principles

LAMD is an alert message dissemination procedure designed for network-infrastructure-based vehicular networks, typically Software-defined vehicular networks (SDVN). It relies on V2I broadcasts from the network infrastructure (i.e., RSUs) complemented with vehicle-to-vehicle (V2V) rebroadcasts aiming to reach and cover all vehicles in a geographical area of interest notably those that do not fall under the coverage of the RSUs. The key principles of LAMD are as follows:

The network controller computes rebroadcast points/zones used to select vehicles allowed to undertake V2V retransmissions effectively. It shares these zones with vehicles during handover. As LAMD is focused on dissemination, it doesn't preclude any particular rebroadcast point placement method. This latter can be based on network planning, radio site surveying, or any form of prediction to cope with the dynamic nature of radio channels. A general simple default method is, however, proposed in section 4.2.1.

LAMD implements a distributed relay-vehicle selection method, which chooses among the vehicles that have received an AM, the most appropriate to ensure the full distribution of the alert message within the area of interest. This selection acts as a filter to avoid useless retransmissions. More precisely, on the advent of an alert message broadcast from an RSU, a receiving vehicle individually decides whether it is eligible for rebroadcast by checking its location regarding the rebroadcast points. The closer a vehicle is from a rebroadcast point, the better candidate it is for a rebroadcast. This distributed distance-based priority scheme is implemented by enforcing different waiting times before rebroadcast to vehicles, i.e., that linearly increase as a function of the distance vehicles have to their closest rebroadcast point. More precisely, vehicles sitting within a rebroadcast zone (which we name Candidate Relay (CR) vehicle) are invited to compute a waiting time as a function of their position with respect to the corresponding rebroadcast point within a time interval of $[0, W_{min} * T_s]$, where T_s is the time slot duration as defined in IEEE 802.11p and W_{min} is the minimum number of time slots.

To guard against road traffic situations where no vehicle is ideally positioned within a rebroadcast zone when an AM is broadcasted, as backup, vehicles

outside the broadcast zones but at a distance less than R_{max} from the corresponding point (which we name Candidate Relay Backup (CRB) vehicle) are invited to wait for a time period within the $[W_{min} * T_s, W_{max} * T_s]$ (where W_{max} is the maximum number of slots) time interval before a rebroadcast attempt. When the vehicle with the shortest waiting time rebroadcasts the AM, all the CRs and CRBs vehicles that receive the AM cancel their rebroadcast attempt. For those that have already finished their waiting process and requested transmission from the MAC layer, this request is resumed using the MLMEX-CANCELTX” service primitive [23]. This avoids redundant re-transmissions once a relay vehicle is notified that the AM was rebroadcasted by a better-positioned relay vehicle.

A last feature of LAMD is using a TTL (Time To Live) mechanism. Each AM conveys a TTL value initially set by the RSU when broadcasting the AM and then decremented at each rebroadcast. It hinders any rebroadcast when an AM message is received with a TTL is equal to zero. The initial value of the TTL is set by the controller for each RSU and allows extending the delivery coverage of an AM by allowing more than two-hops wireless paths. Indeed, in case of a vehicle receiving an AM from a relay vehicle having no wireless connectivity with the network infrastructure (i.e., RSUs), the vehicle is elected as an opportunistic relay (that we call Candidate Relay Exceptional (CRE), if the received TTL is not null, it enters the waiting time process with a time period set as a function of its distance to the sending vehicle and rebroadcasts the AM. This TTL mechanism can be tuned on an RSU or, even, an AM message basis, allowing the network controller to dynamically adjust the dissemination according to the wireless channel’s sudden and transient degradation. It can also be useful in case of ineffective or incomplete placement of rebroadcast points.

Figure 1 presents some examples of CR, CRB, and CRE vehicles with an illustration of their role in disseminating AMs.

4.2.1. *Rebroadcast point placement*

The number and the location of rebroadcast points and zones are inputs to the LAMD dissemination procedure. Therefore, different techniques could be considered deriving, either a static placement or even a dynamic one, that adapts the placement to the wireless channel conditions (number of vehicles, weather, etc.). We describe hereafter a general and simple static placement method, which takes as input performance measures of each RSU. These can be derived from some site surveying or simulation studies.

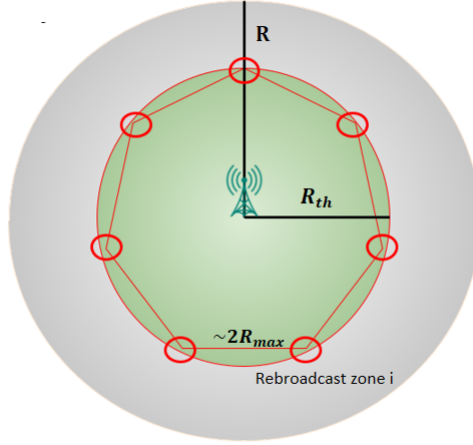


Figure 2: Rebroadcast zones

Real experiments in [3] show that the packet loss rate and delay significantly increase when the distance between vehicles and RSU exceeds a threshold R_{th} . We assume that the controller can define a threshold distance R_{th} for each RSU. From this threshold, the controller builds a regular polygon with r equal sides ($5 \leq r \leq 17$), each with a length greater than $2R_{max} \pm 100m$, where R_{max} is the maximum transmission range of vehicles (as shown in figure 2). This ensures reduced interference between relay vehicles associated with two adjacent rebroadcast zones. For each polygon vertices, the controller derives the closest point on a roadside that falls within a distance of d_{max} . If such a point exists, it is added to the set of rebroadcast points.

4.3. Dissemination procedure

The proposed AM dissemination scheme combines relay selection and contention management. Algorithm 1 describes the behavior of a vehicle when receiving an AM. In this scheme, each node V_j maintains a list of rebroadcast zones in its direction, shared by the controller during the handover. An AM is broadcast with the sender's position, and a time to live TTL is used to control the rebroadcasts of vehicles located in white zones, as explained above.

Let $P_i = F(pos(V_j), dir(V_j))$ a function which takes the GPS position of vehicle $pos(V_j) = (x_j, y_j)$ and its direction as parameters, and returns the closest rebroadcast zone in its direction.

Algorithm 1: Alert message dissemination

Input:

AM : Alert Message

 $P_i, i \in [1, k], d_{max}$: rebroadcast zones V_j : current node, $Pos(V_j)$: its position, $dir(V_j)$: its direction S : Sender

```
1 AM.Reception()                               /* AM received */
2 if  $S = RSU$  then
3    $P_i \leftarrow F(Pos(V_j), dir(V_j))$  /* find the nearest rebroadcast
   zone */
4   if  $d(P_i, V_j) \leq d_{max}$  then
5      $V_j \leftarrow CR$  /*  $V_j$  is a Candidate Relay */
6      $T \leftarrow T_1$  /* Calculate time to wait T */
7   else if  $d_{max} < d(P_i, V_j) \leq R_{max}$  then
8      $V_j \leftarrow CRB$  /*  $V_j$  is a Candidate Relay Backup */
9      $T \leftarrow T_2$ 
10 else
11   if ( $AlreadyReceive(AM) = True$ ) and ( $V_j = CR$  or  $V_j = CRB$ )
   then
12     if  $d(P_i, S) < d(P_i, V_j)$  then
13       Stop (t) and Discard()
14   else if ( $AlreadyReceive(AM) = True$ ) and ( $V_j = CRE$ ) then
15     Stop (t) and Discard()
16   else if  $V_j \notin \{RSU\}$  and  $TTL \neq 0$  then
17      $V_j \leftarrow CRE$  /*  $V_j$  is a Candidate Relay Exceptional */
18      $T \leftarrow T_3$ 
19   else
20     Discard ()
21 LaunchTimer (T)                               /* start timer */
```

As mentioned in Algorithm. 1, if a vehicle V_j receives an AM, first, it checks the sender:

- Step 1 [Lines 2-3] If the sender is an RSU, the node finds the closest rebroadcast point P_i from its location, and it checks its position according to the rebroadcast zone; otherwise, the message is received from a relay vehicle, go to step 4
- Step 2 [Lines 4-6] If V_j is in the rebroadcast zone, the node concludes that it is a Candidate Relay (CR) and then computes its waiting time T_1 as follows :

$$T_1 = W_{min} \frac{d(V_j, P_i)}{d_{max}} T_s \quad (1)$$

with $d(V_j, P_i)$ being the distance between vehicle V_j and rebroadcast point P_i , d_{max} is the radius of the rebroadcast zone, and W_{min} and T_s are respectively the minimum number of time slots and the time slot duration. As cited above, T_1 lies between 0 and $W_{min} * T_s$. Go to step 7, otherwise, go to step 3

- Step 3 [Lines 7-9] If V_j is beyond d_{max} but still within a distance R_{max} from the rebroadcast point, then, the node concludes that it is as Candidate Relay Backup (CRB) and computes the waiting time T_2 as follows :

$$T_2 = [W_{min} + (W_{max} - W_{min}) \frac{d(V_j, P_i)}{R_{max}}] T_s \quad (2)$$

where W_{max} is the maximum number of Time slots. T_2 is set between $W_{min} * T_s$ and $W_{max} * T_s$ to avoid collisions with nearby CR vehicles. This is particularly useful when the road traffic is low or sparse since, in case of no vehicle in a broadcast zone, a close-by vehicle is given the opportunity to rebroadcast the AM. Go to step 8, Otherwise discard the message

- Step 4 [Lines 10-11] If V_j receives the same message another time, and V_j is a CR or a CRB go to step 5, otherwise, go to step 6
- Step 5 [Lines 12-13] If V_j and the sender node are in the same rebroadcast zone, i.e. the distance between the rebroadcast point and the sender

is less than the distance between the rebroadcast point and V_j , if the waiting process has not elapsed yet, it is stopped and the AM discarded. Otherwise, it cancels the MAC layer transmission request. Then, the procedure exits

This condition ensures that once a CR has rebroadcast an AM, no other CR from the same rebroadcast zone is allowed to retransmit the AM. It also avoids the situation where a CR (or CRB) associated to a rebroadcast point is prevented from rebroadcasting if it receives a rebroadcast AM related to another rebroadcast point.

- Step 6 [Lines 14-15] If V_j receives the same message another time, and V_j is a Candidate Relay Exceptional (CRE), stop the timer, the procedure exits, otherwise, go to Step 7
- Step 7 [Lines 16-18] If V_j is not attached to any RSU and the $TTL > 0$, V_j is declared as CRE. In this case, the farthest vehicle from the sender, but still in its transmission range, has the highest priority to rebroadcast, so the waiting time T_3 is given by :

$$T_3 = W_{min} \left(1 - \frac{d(V_j, S)}{R_{max}}\right) T_s \quad (3)$$

Otherwise, discard message

- Step 8 [Line 21] Start the timer T

For completeness, it is worth noting that when V_j experiences a timeout, it updates the AM's TTL and then requests its transmission to the MAC layer.

4.4. Discussion

As explained above, LAMD focuses on message dissemination and takes a set of positioned rebroadcast points as input. Rebroadcast point placement is crucial to achieving the full performance of LAMD. But computing the optimal placement is not that easy as it requires an accurate propagation channel model on the area of interest, with varying characteristics and performance. One naive approach would resort to abusing the number of rebroadcast points, which raises scalability issues as the list of rebroadcast points that are reachable from an RSU must be provided to each vehicle during handover. It also adds contention between relay vehicles associated

with nearby rebroadcast points as it is likely that they would be in the transmission range of each other.

Besides the TTL mechanism, which can be of help in the face of a non-optimal placement, we argue that thanks to the centralized control and the overall view of the network with additional information related to vehicles (their attributes, trip, etc.) brought from the cloud, effective dynamic placement can be devised and implemented by the controller. For instance, the controller could adjust the number and placement of rebroadcast points according to the number of available vehicles and their expected road trip (if available). Furthermore, at some rebroadcast points, the controller may instruct relay vehicles to transmit with a given transmission power or to direct the transmission towards a specific direction to increase the area of reach reliably. Such instructions could even be applied to a specific AM, as they can be piggybacked with the AM. Finally, the controller could also learn from its experience, reported by past vehicles, by employing reinforcement learning techniques to adjust its placement according to the current context.

Another salient feature of LAMD is nominally allowing one retransmission by a CR or CRB per rebroadcast point. This implicitly assumes that this single transmission or the next AMs of the same road event are expected to be delivered successfully for any vehicle in the targeted gray/white area within a brief delay. Nominally, this is the case, but it may take some time to notify the event when vehicle density is low in some cases. When the controller identifies such a situation, this latter may proactively adjust AMs dissemination to the situation by, for instance, allowing more than one single retransmission per rebroadcast point. In other words, a CR or CBR would resume its AM rebroadcast attempt only if it receives a pre-defined number of rebroadcasts.

This paper focuses on the downlink dissemination procedure (i.e., from the network infrastructure to the vehicles) since most performance gains lie there. In some scenarios, the vehicle may issue the AM that detects a road event. Then, the AM needs to be conveyed uplink toward the network infrastructure to benefit from the gains brought by the downlink dissemination. The uplink transmission in LAMD works as follows. If the vehicle has recently exchanged with an RSU (CAM or DENM messages or any other message on the SCH channels), it first invokes a unicast transmission to the RSU. If it fails or the vehicle has lost connectivity with its RSU, it broadcasts the AM stating that it is meant for uplink. Following the same logic as in downlink dissemination, any receiving vehicle computes its waiting time as a

function of its distance to its RSU and then starts its waiting process as part of a rebroadcast attempt. The closer a vehicle is from its RSU, the shorter is its waiting time.

5. Performance Evaluation

The goal is to assess the performance of LAMD regarding its ability: (1) to reach all the vehicles in the area of interest in a short time, (2) to avoid collisions and redundancy, and (3) to use network resources effectively. Also, our proposal is compared to the flooding technique [24], V2I broadcasts (with no V2V rebroadcasts) and the AddP [13] protocol.

This section presents and details the simulation environment, the performance metrics, and the obtained results.

5.1. Simulation Setup

In the experiments, an event-based network simulator Netsim is used. Simulation of Urban Mobility (SUMO) bi-directionally coupled with Netsim as described in [25] is used to make the most realistic simulations. SUMO is a microscopic road traffic simulator that allows creating a scenario by converting an existing map or using one of the external tools provided by the SUMO project itself (for example, NETGEN or NETCONVERT) [26]. Netsim includes implementations of IEEE 1609.4 and IEEE 802.11p communication standards. It also includes Basic Safety Message (BSM) handling and beaconing for cooperative awareness messages (CAMs).

In this work, we consider two urban scenarios with sparse, normal, and dense traffic conditions: in the first one, the roads form a symmetric Manhattan grid, while the second one corresponds to a part of a European-like city (namely, Toulouse, France) where the road structure is irregular. The vehicle density varied between 30 to 500 vehicles in the two scenarios. The duration of the simulation runs in 500 seconds. An average of 50 simulation runs is reported. The speed of vehicles is varied from 0 to 20 m/s, i.e., vehicles have different accelerations at different timestamps. We set the maximum transmission range of each vehicle to $R_{max} = 250m$.

In urban scenarios, signal shadowing effects heavily affect radio transmissions. The Netsim framework includes a log normal shadowing model. This model accurately captures large buildings' effect by blocking transmissions. For example, small walls block weak transmissions, while buildings only slightly hinder strong transmissions in the line of sight [13]. We use this

Table 1: Simulation configuration parameters

Parameter	Value
Simulation time	500 s
AM generation start	10 s
AM generation rate	10 packets/s
AM packet size	1024 bytes
Propagation model	Nakagami $m = 3$
Slot time	10 μ s
W_{min}	30
W_{max}	1023
d_{max}	16 m

model in our experiments. In all simulated scenarios, there were two RSUs separated by a distance of 1 to 2 km. Each one handles the transmission of alert messages to vehicles in its transmission range. The other simulation parameters are shown in table 1.

5.1.1. Manhattan Grid Model

We generate a 12×4 Manhattan Grid scenario with a SUMO simulator covering an area of $2km \times 1.5km$ with road segments of 300 meters long and two lanes in each direction. This scenario is commonly used to evaluate network protocols in urban environments [27, 28, 29, 30, 31]. This type of network is called Manhattan Grid because its road topology reproduces the Manhattan borough in New York City, USA. When reaching an intersection, a node can turn left, right, or go straight on, as in real life. So, in the Manhattan model, when the nodes reach the intersections, they move with 50% probability on the same street, 25% turning to left and 25% turning to the right, according to the scheme presented in [32].

Inter-Vehicle Communication (IVC) algorithms easily handle data dissemination in Manhattan Grid scenarios since predesigned algorithms can efficiently recognize the orthogonal road topology. Therefore, Manhattan Grid scenarios are usually used in the first experiment to verify the validity of our algorithm. If an IVC algorithm cannot handle Manhattan Grid scenarios, it will be impossible to handle more complex ones. Moreover, due to the simple road topology of Manhattan Grid scenarios, some design issues can be clearly exposed [33].

5.1.2. Toulouse City’s scenario

In this scenario, we assume a cross-section of Toulouse, France, with an area equal to $2km \times 2km$. The map has been retrieved from Open Street Map (OSM) project. Here, the roads are characterized by an irregular shape, and there are junctions—note that the number of junctions is slightly higher than in the regular scenario.

5.2. Rebroadcast point placement

We proceed as follows. We first identify the gray and white zones for both considered city maps. Then, we apply the default placement method of section 4.2.1.

A wireless transmission’s success depends on multiple factors: transmitter power, path loss, fading, receiver sensitivity, etc. Moreover, depending on the environment (highway, Urban, Obstructions, Line of sight), the transmission coverage of an RSU may vary widely, for example, from 100 to 700 meters, for the same transmission power as shown in [34, 35]. On the other hand, road safety applications, especially those concerning cooperative awareness, require high reliability, i.e., a PDR between 90 and 95% [?]. Therefore, for this study, the transmission coverage of a RSU is calculated as the maximum distance from the RSU where the PDR remains greater than 90% [36]. All the geographic areas that fall outside the transmission coverage of all RSUs are considered gray/white zones.

We have run several simulations to compute these zones where each RSU broadcasts a control message every 100 ms for 500s. After each packet, we record the distance of each vehicle from the sending RSU, the vehicles that received the message, and the packet status (success or error).

Figure 3 shows the computed PDR as a function of the distance to the RSU for both scenarios. It can be observed that the PDR falls below 90% when the distance between the vehicle and the RSU is strictly greater than $R_{th}^T \simeq 600m$ for the Toulouse’s scenario and $R_{th}^M \simeq 500m$ for the Manhattan’s scenario. From there, first, for the Toulouse’s scenario, we build a regular octagon for each RSU with 8 sides of $459m(0.765R_{th}^T$ [37]) in length and 8 vertices representing our rebroadcast points. Then, for Manhattan’s scenario, we build a regular heptagon for each RSU with 7 sides of $434m$ lengths and 7 vertices representing the rebroadcast points in the Manhattan map. In fact, as mentioned above, we have placed the rebroadcast points at the edge of the road closest to each vertex. Also, we do not consider all the rebroadcast points as the RSUs are in the corners. As a result, we get 13 rebroadcasts

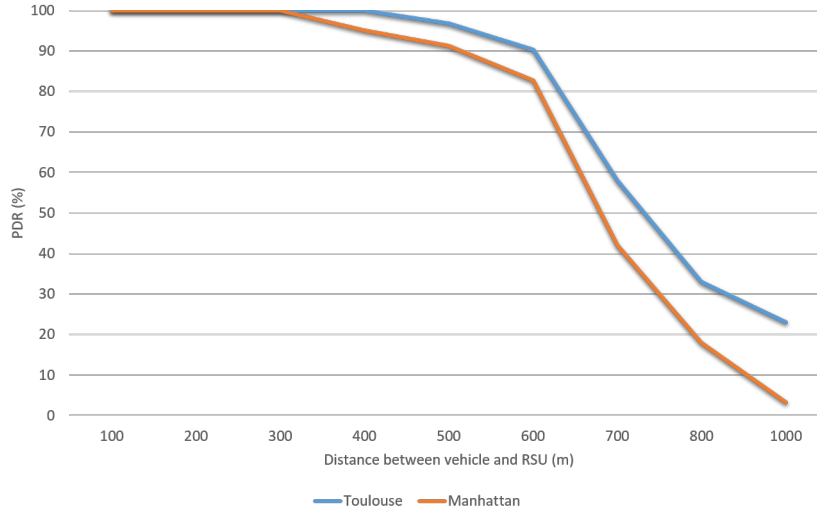


Figure 3: PDR versus the distance between vehicles and RSU

zones in both Toulouse’s scenario and Manhattan’s scenario, as shown in Figure 4 and 5.

5.3. Performance metrics

The following three performance metrics are used to assess the effectiveness of LAMD in disseminating AMs.

- **Information Coverage (IF):** computed as the total number of vehicles that successfully receive ($NumVehRecMsg$) an AM at the end of the simulation divided by the number of vehicles ($TotalNumVeh$) averaged on all generated AMs. This metric shows how successful the dissemination is after a decent period of time.

$$IC = \frac{NumVehRecMsg}{TotalNumVeh} \quad (4)$$

- **Packet Delivery Ratio (PDR):** is the ratio between the number of AMs ($NumRecMsg$) successfully received by each vehicle and all transmitted AMs ($NumTransMsg$) during the vehicle lifetime within the area of interest averaged on all the vehicles of the area of interest. This metric is important since it measures the sustained effectiveness

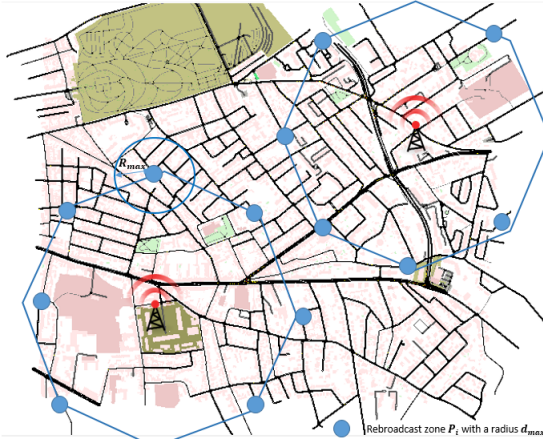


Figure 4: Toulouse's city scenario

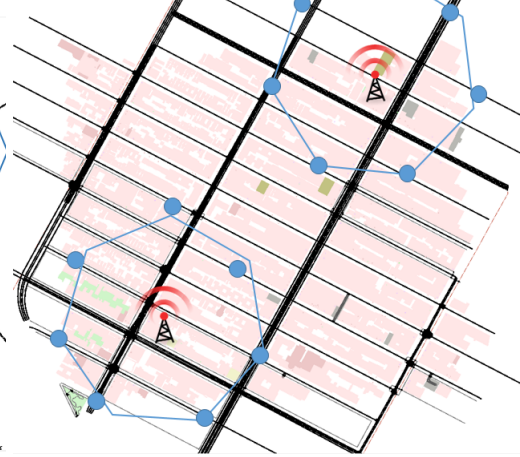


Figure 5: Manhattan's city scenario

of the dissemination.

$$PDR = \frac{NumRecMsg}{NumTransMsg} \quad (5)$$

- **Dissemination delay:** The dissemination delay is the total time required to deliver the AM to all the vehicles in the area of interest that receive the AMs. The vehicles that do not receive any AM are excluded from the computation. This metric measures how fast the dissemination can reach the vehicles within the area of interest.

The following two performance metrics measure the network overhead induced by the dissemination in terms of collisions and redundant successful transmissions.

- **Collision Ratio (CR):** The collision ratio is the percentage of MAC collisions (NumCollisionPkts) divided by the number of packets sent (NumSentPkts) computed over the simulation duration.

$$CR = \frac{NumCollisionPkts}{NumSentPkts} \quad (6)$$

- **Redundancy Rate (RR):** The average number of AM rebroadcasts or duplicate transmissions (i.e., NumDuplicPkts) out of all sourced (generated) AM (NumSPkts) [38].

$$RR = \frac{NumDuplicPkts}{NumSPkts} \quad (7)$$

5.4. Performance Analysis

This section details the performance results for Toulouse and Manhattan scenarios under various vehicle densities.

5.5. Effectiveness of LAMD dissemination procedure

5.5.1. Information Coverage

Figure 6 presents the Information Coverage as a function of vehicle density for LAMD, flooding, V2I, and AddP when applied to the scenario of Toulouse city. The results show that starting from a vehicle density of 225 vehicles, LAMD achieves full vehicle coverage at the end of simulation time. In comparison, AddP achieves full coverage with the same vehicle mobility, starting from a vehicle density of 420 vehicles (almost twice the density with LAMD). This is because LAMD combines V2I and V2V transmissions while AddP relies exclusively on V2V transmissions. These latter depend on the vehicle density as vehicles must be in mutual radio coverage to support a V2V transmission.

For the considered experiments, the flooding dissemination never achieves a full-coverage even under high densities, despite all vehicles being allowed to rebroadcast an AM. Worse, when the density increases, the IC decreases. In fact, the increase in vehicle density increases transmission collisions, and redundant rebroadcasts. Both consume the scarce radio resources in place of constructive rebroadcasts. This is a typical illustration of the negative effect broadcast storm problem cited above.

The IC of V2I also decreases when vehicle density increases. By increasing density, more vehicles are likely to be located outside of the RSU coverage. The results show that with the vehicle mobility generated by SUMO on average, more than 20% of the vehicles do not fall within reach of an RSU for the entire simulation period (500s) or their lifetime. Despite this important portion of far away from vehicles, even under very low vehicle densities where the presence of vehicles within or around rebroadcast zones is not guaranteed, LAMD achieves an IC of more than 92%. Moreover, as shown in Figure 7, which plots the IC as a function of time for low vehicle density scenarios (35, 75, 225 vehicles), the maximum achievable IC is reached in less than 500ms.

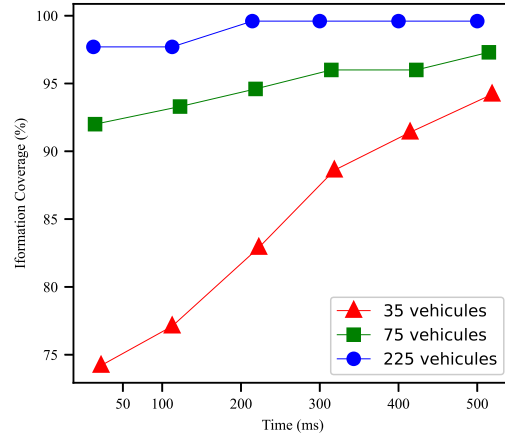
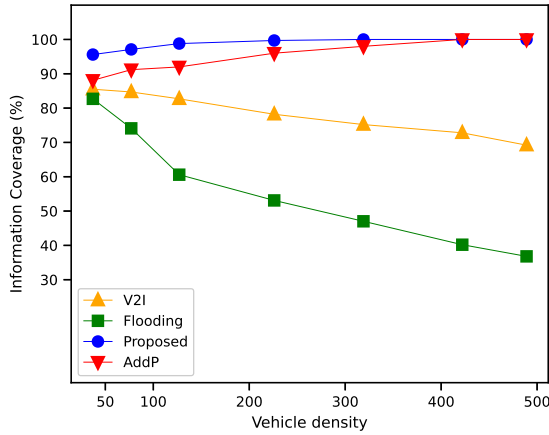


Figure 6: Information Coverage - Toulouse Figure 7: Information Coverage - Toulouse

As shown in figure 8, the evolution of IC as a function of vehicle density for Manhattan’s scenario is quite similar to Toulouse’s scenario. However, we notice an expected slight difference because the road layout is different. Notably, with LAMD, full vehicle coverage is achieved starting from a lower density of vehicles, i.e., with a density of 125 vehicles (vs. 225 vehicles for Toulouse’s scenario).

5.5.2. Packet Delivery Ratio

Figure 9 and Figure 10 present the PDR for all dissemination procedures, respectively, for Toulouse’s city scenario and Manhattan’s city scenario under different vehicle densities. The results show that LAMD sustainably delivers AM messages to almost all vehicles (with a PDR of 96%). Notably, in comparison, AddP exhibits a significantly lower PDR (around 70%). This shows that LAMD distributes AMs more effectively by presumably selecting more suitably relay vehicles and inducing fewer packet losses over the overall simulation period. This comparison also holds with flooding, whose poor packet delivery ratio is caused by the collisions generated by the broadcast storm.

5.5.3. Dissemination Delay

Figure 11 and Figure 12 show the dissemination delays versus vehicle density respectively in Toulouse’s city and Manhattan’s city scenario. The results show that the dissemination delays with LAMD and AddP are signif-

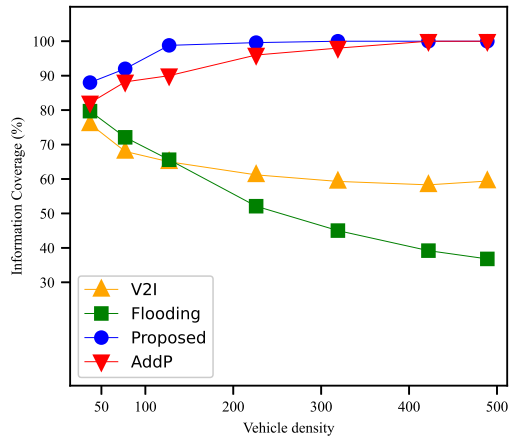


Figure 8: Information Coverage - Manhattan

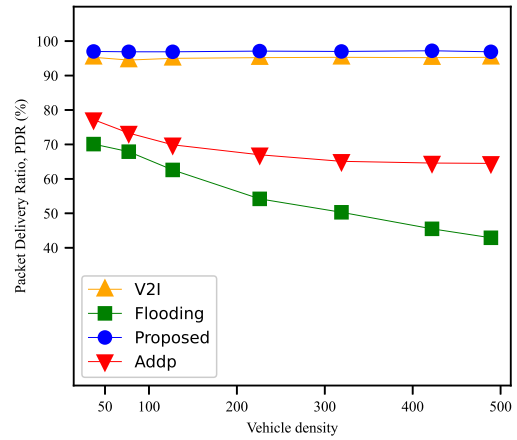
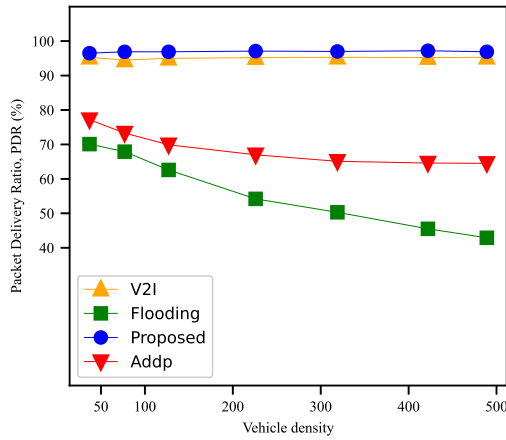


Figure 9: Packet Delivery Ratio - Toulouse Figure 10: Packet Delivery Ratio - Manhattan

icantly lower than the delays observed with Flooding and V2I approaches, especially for high traffic densities.

The results show that LAMD delivers the first copy of an AM to all vehicles within a few AM periods. For high vehicle densities, relay vehicles always exist, which quickly rebroadcast the AM to the vehicles outside the RSUs coverage, leading to a dissemination delay below twice the AM period. For low vehicle densities, fewer vehicles are available in the network, the presence of vehicles around each rebroadcast zone is hence not guaranteed for the first AMs. Nevertheless, LAMD can still deliver an AM to all the vehicles within 5 AM periods (i.e., $500ms$). For instance, for a vehicle density of 30 vehicles, the total time required is $315.28ms$ in Manhattan’s city scenario, with over 75% of vehicles served within $100ms$.

AddP exhibits similar results thanks to its relay selection method, which favors far away relay vehicles with the highest neighborhood. This helps speeding the full dissemination of AMs.

Even if all vehicles are allowed to rebroadcast an AM with the potential of fastly reaching all the vehicles, the flooding dissemination suffers from the effect of the broadcast storm. AM rebroadcasts experience collisions and increased contention, delaying their successful delivery.

For the V2I approach, it takes quite a long time to reach all the vehicles in the area of interest, as these latter need to be under the coverage of an RSU to receive an AM. As the average speed of vehicles is between 7 and 13 m/s, i.e., the vehicle can only move approximately 1m in $100ms$. So, it may take some time before a vehicle comes under the coverage of an RSU. This is the reason why V2I offers by far the worst dissemination delays.

5.6. LAMD network overhead

5.6.1. Collision Ratio

Figure 13 and Figure 14 show the collision ratio as a function of vehicle density respectively for Toulouse’s city scenario and Manhattan’s city scenario. The results are similar in both scenarios. It is worth noting that even for high vehicle densities, the collision ratio remains very low with LAMD (about 0.001%). In comparison, we observe that the collision ratio reaches 59% for flooding and ranges from 22% to 34% for AddP (yet AddP also relies on some form of relay selection to limit contention to the wireless medium).

This is obviously an important advantage of LAMD since radio resources are saved and made available to other AMs or CAM messages. This is

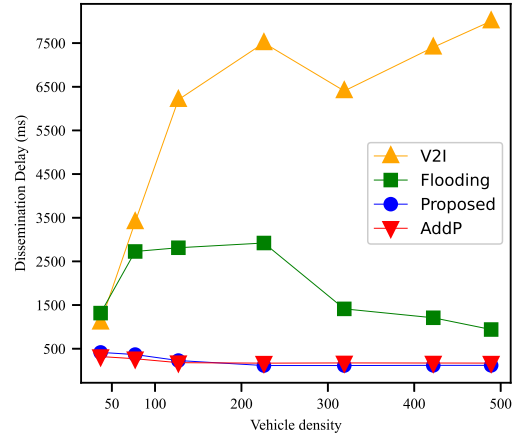
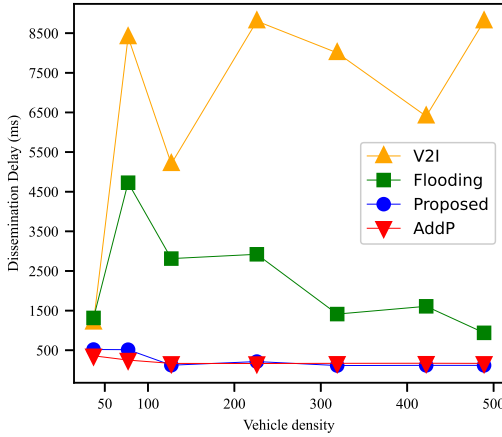


Figure 11: Dissemination Delay - Toulouse Figure 12: Dissemination Delay - Manhattan

achieved thanks to the selection method, which limits the set of candidate relays to those close to rebroadcast points and then further reduces rebroadcast contention by assigning different waiting periods to candidate relays. However, some rare collisions may still occur, either because of a simultaneous transmission from two or more nearby candidate relays associated to different rebroadcast points, or the back-off procedure of the CSMA/CA technique, which if the wireless medium was sensed busy, introduces a random back-off time when the vehicle accesses the medium.

5.6.2. Redundancy Ratio

Figure 15 and Figure 16 show the number of duplicated AM transmissions for all techniques successively in Toulouse’s city scenario and Manhattan’s city scenario under different vehicle densities. As expected, Flooding is the protocol with the highest redundancy because no mechanism limits AM rebroadcasts. Compared to other techniques, LAMD induces the smallest redundancy ratio (below 50%). The redundancy gain with respect to the other dissemination schemes increases as the vehicle density increases and reaches one third less redundancy than AddP (as explained above, also uses a relay selection method that reduces transmission redundancy).

This low redundancy is achieved thanks to the ability of LAMD to correctly select only a small set of relay vehicles to fully disseminate an AM, and also to the fact that a candidate relay that observes an AM rebroadcast resumes its rebroadcast attempt.

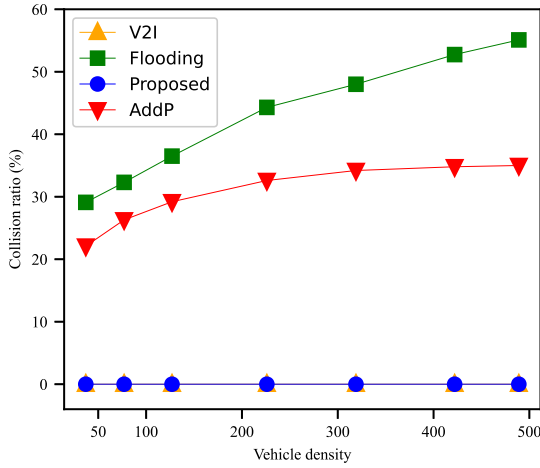


Figure 13: Collision ratio - Toulouse

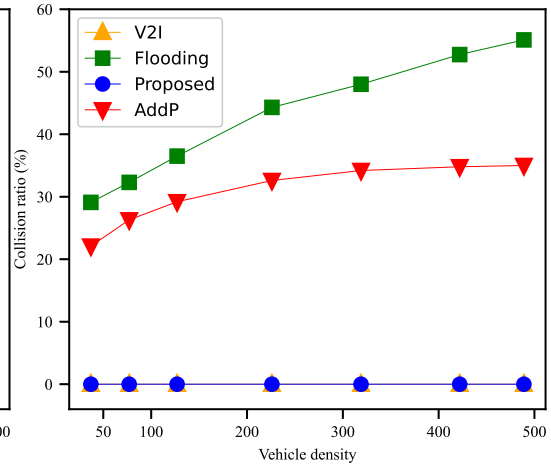


Figure 14: Collision ratio - Manhattan

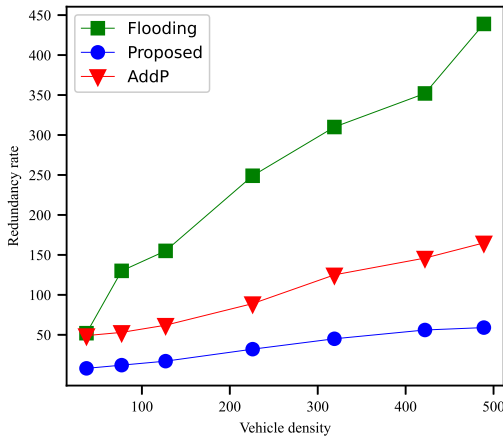


Figure 15: Redundancy Ratio - Toulouse

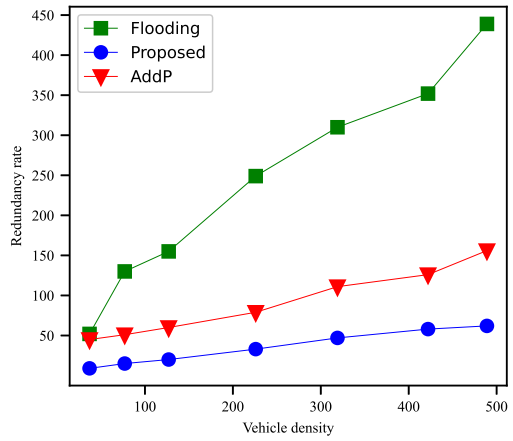


Figure 16: Redundancy Ratio - Manhattan

6. Conclusion

This chapter proposes an alert message dissemination scheme based on vehicle locations to provide high coverage, fast delivery, and minimal network overhead. The main peculiarities of our solution are: First, the combination of V2I transmissions and V2V re-transmissions, where first, RSUs broadcast alert messages, and then, some selected relay vehicles rebroadcast the messages after a personalized waiting time. Second, the definition of broadcast zones by the SDN controller where relay vehicles may rebroadcast the message to reach all vehicles that are located in the area of interest, particularly those in white and/or poorly covered areas. To that end, we have proposed a static default method that computes rebroadcast points.

The performance results prove the effectiveness of our scheme by providing a high delivery ratio, limiting packet collisions, minimizing redundancy, and ensuring rapid dissemination and high information coverage.

One important perspective of this work is to define a dynamic placement method of rebroadcast zones that adapts to radio channel conditions and the actual locations of the gray/white zones, as well as to road traffic conditions.

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