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Safety Information Dissemination in Vehicular Networks using Facilities Layer Mechanisms

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Vehicle ad-hoc networks are considered as an essential building block of future intelligent transportation systems. One of the major roles of vehicular communication is the dissemination of information on the road in order to increase the awareness of the drivers and improve road safety. The facilities layer is a recently standardized component in the vehicular communication architecture, with an important role to play in the process of information dissemination. In this paper, we propose facilities layer-based mechanisms for information propagation and we show they outperform classical network layer solutions. We also demonstrate that previous studies that do not consider the cohabitation of different types of safety messages on the vehicular control channel highly under-estimate the dissemination delay, which can lead to unrealistic assumptions in the design of safety applications.

Keywords: vehicular networks, facilities layer, information dissemination

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1 Introduction

Vehicular ad-hoc networks (VANET) are distributed, self-organized, highly mobile networks of vehicles, in which moving cars are nodes that communicate with each other and, possibly, with a fixed infrastructure via the wireless media. This concept lays at the core of future Intelligent Transportation Systems (ITS), with the goal of increasing road safety and improving transport efficiency [1].

VANET-based applications can generally be classified as traffic safety and non-safety applications. Non-safety applications provide drivers and passengers with information related to traffic efficiency and entertainment. They can be further divided in comfort applications (e.g. content download [2], Internet on the road [3], social networking [4]) and general information service applications, such as traffic efficiency applications for better route selection, better traffic balance, lesser travel time, etc. [5]. This category includes not only applications used to deliver information to all the vehicles over large areas, but also applications that target small areas, for example in order to enable cooperative driving, or even individual vehicles, such as remote diagnostic and software update.

Safety applications on the other hand focus on improving road safety and attempt to increase the awareness range of the drivers by transmitting special messages. These messages are the result of monitoring the vehicle's own internal sensors, as well as the condition of other vehicles and the road. In case of an emergency, vehicles exchange messages and cooperate to help each other. Examples of critical traffic safety applications can be Collision Risk Warning, Cooperative Collision Avoidance, Pre- or Post-Crash Warning, etc. One of the most important safety application is Road Hazard Signaling, which requires a vehicle detecting an abnormal condition on the road (e.g. slow/stationary vehicle, emergency brake lights, wrong way driving, adverse weather condition, roadwork, humans/animals on road, etc.) to generate a special notification.

This safety information needs to be disseminated through a relevant portion of the vehicular network, over distances and directions that depend on the type of detected event. For example, the knowledge of a lane blocked by roadwork is significant for all the drivers using the corresponding road axis, up to a distance of several kilometers, that would allow choosing an alternative route. On the other hand, an animal detected on the highway is important for drivers moving in both directions, but only in a limited geographical region, close to the event.

Previous studies on special event dissemination in vehicular networks only considered a *one-to-one* scenario, where a single event is detected by a single vehicle. However, such hazardous events can be detected by numerous vehicles in a certain geographical area practically at the same time. Such a situation creates medium access problems that can have a significant effect on the performance of the safety application, due to the congestion in the medium created by redundant transmissions of the same information by several vehicles.

Moreover, previous works study the announcement of special events in isolation, without considering the cohabitation of different types of safety messages, thereby ignoring the standardized ETSI [6] and IEEE [7] VANET architectures, especially the recently proposed *facilities* layer [8].

In this paper, we study for the first time vehicular safety information dissemination in a realistic context, where multiple vehicles can simultaneously detect the same event, and where multiple types of safety messages coexist. We show that the impact of these multiple information flows is significant and we propose an intelligent dissemination mechanism that functions at the facilities layer and complies with the standardized vehicular communication architectures.

The remainder of this article is organized as follows : Section 2 discusses the approaches taken by previous studies. A brief introduction to the functioning of the facilities layer is given in Section 3, while the details of the proposed dissemination mechanism are presented in Section 4. Finally, the performance of the proposed solution is assessed in Section 5, before concluding this paper in Section 6.

2 Related Work

The problem of safety information dissemination in vehicular networks has been mostly investigated from the forwarder selection point of view. There are essentially two possible strategies to select the next relay node in a dissemination process : the selection can happen either at the source or at the receivers. Takano et al. [9] compare the two approaches and conclude that source-based forwarding is the better choice in low density networks, while receiver-based forwarding produces better results in a dense network.

Receiver-based relay selection uses MAC layer contention mechanisms to determine the next forwarding node. In the classical strategy, described by Fussler et al. [10], every receiver calculates the distance to the transmitter node and sets a back-off time in order to give priority to the farthest relay. However, Amoroso et al. [11] argue that the farthest relay is not necessarily the optimal solution, and use neighborhood information to assign the smallest contention time to the farthest spanning relay. Other possible strategies propose using as preferential forwarders parked cars [12] (for caching purposes) or large vehicles [13] (to fight against radio propagation problems).

It is important to notice that all these mechanisms take place at the MAC or network layer. With access only to the corresponding headers, they need to take forwarding decisions without access to the actual safety data. We argue that these solutions, despite being usually presented by their authors as *information dissemination* mechanisms, are in fact focused simply on *packet dissemination*.

The in-depth study by Scheuermann et al. [14] shows that data aggregation is essential for information propagation in a VANET. They show that, as information is disseminated through the vehicular network, the bandwidth it consumes should reduce faster than the square of the covered distance. As the actual safety data remains unknown in packet dissemination mechanisms, data aggregation is not possible in this case. This shows that, although more efficient than simple flooding, the solutions discussed above are not appropriate in a vehicular context, as they require, at best, constant bandwidth to propagate information.

Unlike previous works, we study actual information dissemination, taking place at the upper layers, more precisely at the recently standardized facilities layer. This allows us to propose appropriate mechanisms, able to reduce channel congestion and safety information propagation delay.

3 The Facilities Layer

As previously explained, our solution is designed to function at the facilities layer, standardized in the ETSI ITS architecture [8]. However, an equivalent *message sub-layer* exists in the IEEE Wireless Access in Vehicular Environment (WAVE) framework [7], making the principles advocated in this paper generic.

Facilities Layer Dissemination

The ETSI facilities layer contains functionalities from the OSI application layer, presentation layer (encoding, decoding, encryption) and session layer (e.g. inter host communication), with amendments specially conceived for ITS. The facilities layer provides three types of services : application support, information support, and communication support.

Information support services are focused on common data and database management, handling the local dynamic map of the vehicular environment and the different station capabilities. Communication support provides services to lower layers, such as selecting addressing mode, congestion control, session support, or mobility management. In the application support category, the facilities layer provides common services and functionalities for the execution of a basic set of applications (e.g. Human Machine Interface support, time synchronization, service announcement, etc.). An essential application support service is the management of the two common messages used by safety applications : Decentralized Environment Notification Message (DENM) and Cooperative Awareness Messages(CAM).

CAMs, also called beacons, are regular, time or distance triggered messages broadcast by the facilities layer, distributed within the network by vehicles in order to provide information about their presence, position and basic status to neighboring vehicles that are located within a single hop distance. By receiving CAMs, a vehicle is aware of other vehicles in its neighborhood along with their positions, movement and basic sensor information. This allows vehicles to present drivers with relevant information that increases their awareness about road traffic.

Information distributed by CAMs is commonly used by several important applications, therefore the CAM management is a mandatory facility to be presented in vehicles. Safety applications like Collision Warning or Intersection Management are typical cases which benefit from beacons. The CAM frequency is between 1-10 Hz, and is determined by the communication management entity, taking into account the operating requirements of the supported safety applications, the transport layer requirements, the current channel load, etc.

A DENM is used to provide information related to an event that has a potential impact on road safety. Unlike CAMs, DENMs are not regular, but are triggered following the detection of some events. DENMs are mainly used by applications like Road Hazard Warning (RHW) in order to alert road users of the detected event.

Upon detection of an event that corresponds to a RHW use case, vehicles immediately broadcast a DENM to other vehicles located inside a geographical area (called relevant area) which should be concerned by the event. In general, an event is characterized by an event type, a geographical position/area, the detection time and duration. However, these attributes may change over space and over time.

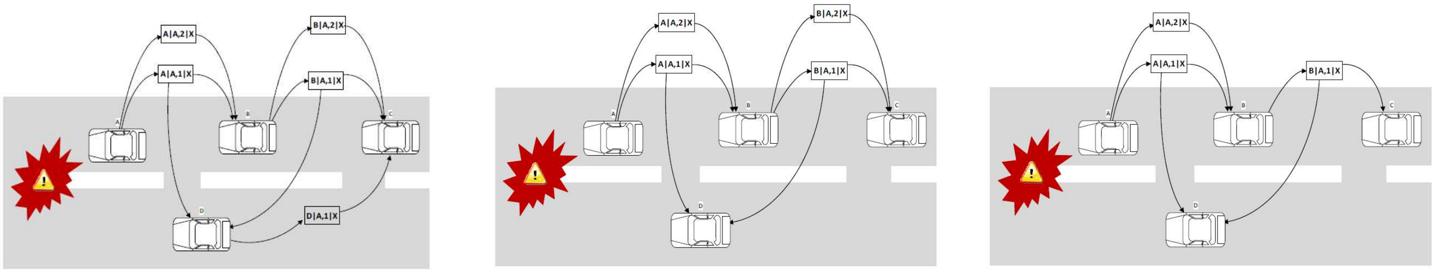
The transmission of a DENM is repeated with a certain frequency, within a certain range depending on the event. DENM broadcasting persists as long as the event is present. This broadcast can be a single hop or multi hop, with the aim to cover as many vehicles as possible in the relevant area. Vehicles which receive DENMs process the information and decide to present appropriate warnings or information to users, as long as the information in the DENM is relevant for the vehicle. If the DENM has to be re-forwarded, the vehicle checks for the necessity and re-broadcasts it.

With respect to safety information dissemination, the facilities layer plays a central role, through information and communication support services. The relevance of the received DENMs is assessed by information support functionalities, and integrated in the local dynamic map, where it becomes available to the different applications. Information support mechanisms also decide if the safety data needs to be forwarded to other vehicles, in which case the communications support facility handles channel contention and transmission parameters.

Despite this major role, the facilities layer has been completely ignored by previous studies on safety information dissemination, which focused instead on basic MAC or network layer solutions.

4 Intelligent Dissemination

As DENMs and CAMs coexist on the vehicular control channel, the process of safety information dissemination in a VANET requires MAC layer mechanisms in order to handle the access to the media of the different network nodes. However, this requirement for channel access coordination should not be confused



(a) MAC layer-based information dissemination. (b) Network layer-based information dissemination. (c) Facilities layer-based information dissemination.

FIGURE 1: Different strategies of vehicular information dissemination.

with the actual decision of disseminating a certain information. Indeed, the mechanisms involved in this decision process can be implemented at different layers in the network architecture, as shown in Figure 1 and discussed below.

In Figure 1, the red area is a hazard which is detected by vehicle A which is nearest to the hazard. Upon detection, it starts transmitting DENMs. Each special notification message is shown with 3 fields : the last-hop forwarder, the DENM initiator with message sequence number and lastly the hazard ID. Node A broadcasts the first DENM, with sequence number 1 and event code X, as $(A|A,1|X)$ to surrounding nodes B and D. Several strategies are possible in this case at receivers B and D :

MAC layer-based information dissemination. If the forwarding decision is taken at the MAC layer, the dissemination mechanism can only access information from the MAC layer header, such as the last forwarding node. An example of this strategy is given in Figure 1a. Nodes B and D receive this message and begin a distance-based back-off in order to select the best forwarder. B, being the farthest receiver, wins the contention and rebroadcasts the message to node C and D as $(B|A,1|X)$. However, as the decision is taken at the MAC layer, node D only has information on the last forwarder, not enough to allow the cancellation of the back-off for the original message. Therefore, node D also redundantly rebroadcasts the same message received from B. This solution is simple, as all the required mechanisms take place at the MAC layer, but can result to significant broadcast storm problems.

Network layer-based information dissemination. Acknowledging that cross-layer mechanisms are required in order to distinguish between channel access and the forwarding decision, previous research studies propose to base the dissemination process at the network layer. In this case, the possible forwarders have access to layer 3 information, such as the IP address of the initiator, allowing them to better evaluate their decision, as shown in Figure 1b. In this case, when node D receives the message $(B|A,1|X)$, forwarded by node B, it can match it to the previously received message $(A|A,1|X)$. This allows node D to cancel the on-going back-off timer and remove the message from the MAC layer transmission queue.

Facilities layer-based information dissemination. However, even with access to network layer information, the dissemination process can still be considered as *packet dissemination*. In order to provide actual *information dissemination* in a vehicular network, the proposed mechanisms should have access to the safety data. With the introduction of the facilities layer, such solutions are possible. In the particular example shown in Figure 1c, a facilities layer based mechanism can help further alleviate the congestion in the medium by reducing the number of redundant retransmissions by a node of duplicate messages describing the same hazard. By having access to facilities data, such as the identifier code of the detected event, its geographical position and detection time, can be extremely useful in this sense.

First of all, this allows a potential forwarder to establish whether two packets with the same initiator are describing the same event. Indeed, when a vehicle detects a hazard, it will transmit several DENMs about the event in order to notify the neighboring nodes. The neighbors that receive this information might decide to forward it to their own neighbors. However, it is fair to assume that the importance of the event decreases as it propagates in the network. A possible strategy at the facilities layer can be in this case to only forward the first DENM announcing the event, while also adding the information regarding the hazard to future CAMs. This allows a fast dissemination in the network by the immediate retransmission of the initial DENMs, while also covering reception gaps in this first step with the information added to the CAMs.

The facilities layer can also improve the dissemination process by the use of the local dynamic map which keeps an accurate image of the neighboring vehicular environment through the reception of CAMs and DENMs. In practice, some events can be detected by several vehicles simultaneously (e.g. a pedestrian on the highway can be detected by the on-board sensors of multiple vehicles in that area), and DENMs can be initiated from different sources. A layer 3 strategy that only uses the IP address of the initiator can not distinguish the fact that different packets are announcing the same event, therefore the same information is propagated in the network through multiple message flows. At the facilities layer, the information is added to the local dynamic map at the first received DENM, and propagated through a DENM retransmission or by adding supplementary information to a CAM. Therefore, when the same information is received from a different source, the vehicle is able to check its existence in the local dynamic map.

In the next section, we show that this increased intelligence can significantly improve the performance of the dissemination process in a safety vehicular network.

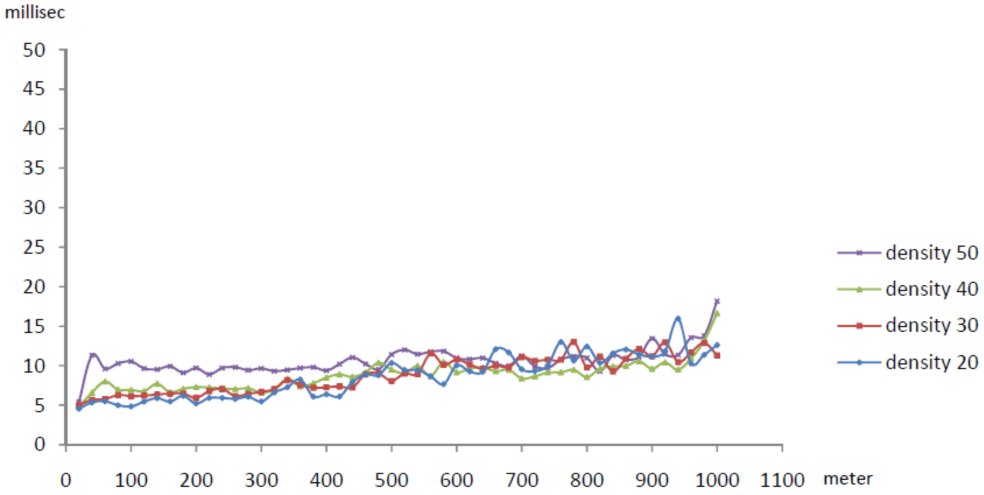


FIGURE 2: Information propagation delay as a function of the distance to the detected event for different vehicular densities when no CAM traffic is present in the background.

5 Performance Evaluation

As our study if focused on high density vehicular networks, an actual deployment is onerous and the best alternative in this case is to make use of a simulation tool. In our case, we decided to use the JiST/SWANS simulation framework [15]. JiST is a high performance discrete event simulation engine that runs over a standard Java virtual machine. It outperforms existing simulation engines both in time and memory consumption. SWANS is a scalable wireless network simulator which is built on top of JiST, containing independent software components that can be composed to form a complete wireless ad hoc network.

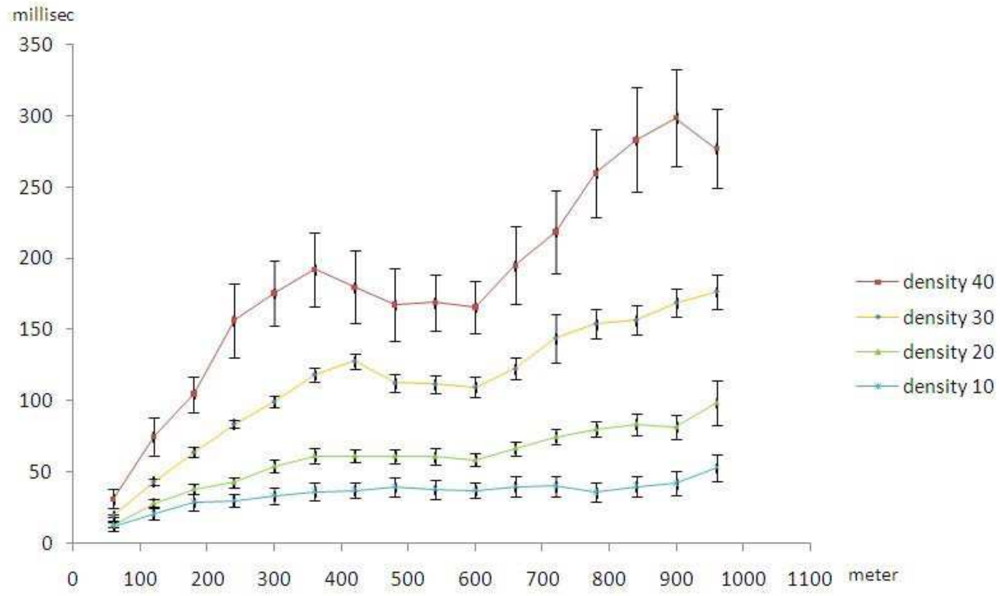


FIGURE 3: Information propagation delay as a function of the distance to the detected event for different vehicular densities when using intelligence level 1 mechanisms (95% confidence intervals are also shown).

In this framework, the Street Random Waypoint (STRAW) [16] mobility model is used. STRAW is a car-following model that uses real maps from the TIGER database (developed by the US Census Bureau) as the source of street plans. We have chosen to simulate a 10km2 area that includes a 4.5km long highway segment.

In this context, a hazard is defined by its starting time, duration and geographical location. A vehicle detects the event if he is situated or enters the geographical area where the hazard was produced and transmits 5 consecutive DENMs, with a period of 10ms. We simulate hazards at random placements on the highway segment, and we study the dissemination information on the highway over a distance of 1km in both directions. Throughout all the simulations, background CAM messages are transmitted by all the vehicles with a frequency of 10Hz.

Regarding the physical layer of the vehicular network, the propagation of radio waves is based on the model proposed by Dhoutaut et al. [17], basically a classical shadowing probabilistic radio propagation model where the fast fading factor depends on the vehicular density.

At the MAC layer, we use the IEEE 802.11 protocol with parameters corresponding to the IEEE 802.11p amendment. A distance-based forwarding mechanism is also implemented to select the best forwarders among the different contenders in the dissemination process.

We simulate medium and heavy vehicular traffic scenarios, with a density varying between 10 and 40 veh/lane/km. Every simulation begins with a warm-up period of 100s in which only the mobility model is active. Communication is then enabled and CAMs are exchanged, followed by the hazard detection and DENM transmission. Each point is the average of 30 to 50 simulation runs, and 95% confidence intervals are also shown in the figures.

Facilities Layer Dissemination

In the following, we compare network layer-based information dissemination (presented as *intelligence level 1* mechanisms) and facilities layer-based information dissemination (*intelligence level 2*).

In a first step, we compare the information propagation delay as a function of the distance to the detected event. Figure 3 shows the results obtained for intelligence level 1 mechanisms for different levels of vehicular densities.

The first observation in this figure is that the dissemination delay sharply increases with the vehicular density. This can be attributed to the fact that, with higher vehicular density, the medium is more congested, so more and more nodes contend to emit their DENMs (as well as CAMs), causing more and more collisions, which naturally increases the delay for the information to be propagated to farther away nodes.

It is noteworthy that previous studies on safety information dissemination discuss the benefits of increased node density, considering this increases the network connectivity and reduces the number of forwarders. However, these studies consider DENM transmission in isolation, without the background beaconing traffic. In Figure 2, we present results from a scenario without CAM exchanges. The results indeed show that, for dissemination distances of more than 600m, higher vehicular densities decrease the dissemination time through an increased connectivity. However, it is important to notice that the dissemination delay is 10 times smaller than in the case when CAMs are also transmitted. These values are the consequence of practically no contention at the MAC layer, as DENM traffic is the only one considered in the network.

Figure 3 shows instead that, when the CAM messages are also considered, the benefits of increased connectivity are not significant compared to the increased channel congestion.

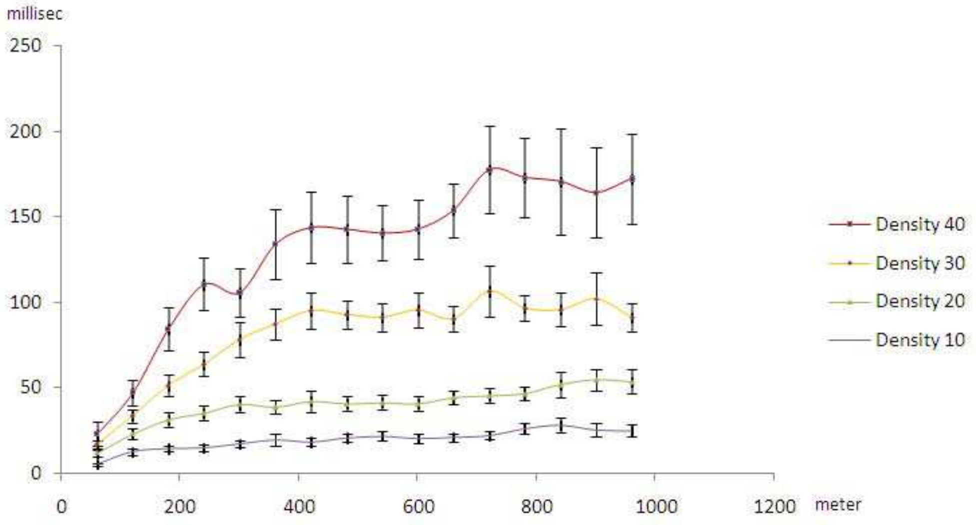


FIGURE 4: Information propagation delay as a function of the distance to the detected event for different vehicular densities when using intelligence level 2 mechanisms (95% confidence intervals are also shown).

The same relationship between dissemination delay and vehicular density can be noticed in Figure 4, where the results for an intelligence level 2 mechanism are shown. However, by comparing the results with those presented in Figure 3, we can notice that the delay when using a facilities layer approach is much smaller than when only network layer mechanisms are implemented. While for the first 100 meters the difference between the two mechanism is not significant, for higher distances the delay can be even halved by moving to a more intelligent strategy. It is noteworthy that, in both scenarios, all the vehicles withing the 2km coverage area have been notified about the event.

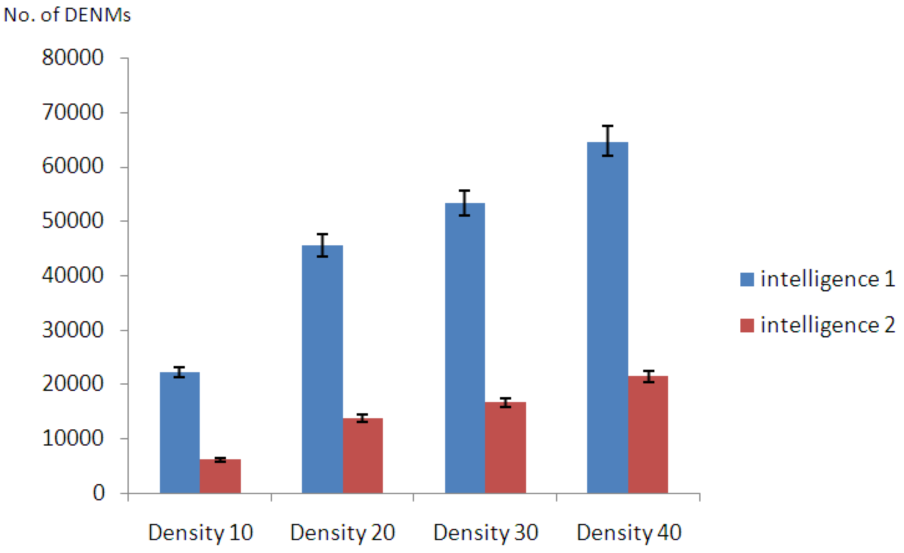


FIGURE 5: Number of transmitted DENMs for different vehicular densities and dissemination strategies.

The reason for this important difference in information dissemination delay can be better understood using the results shown in Figure 5. This figure shows the average number of transmitted DENMs in the two scenarios : network layer or facilities layer-based dissemination. We can notice that, by using intelligence level 2, the number of DENMs can be reduced up to 5 times. This highly reduces the congestion level and speeds up the dissemination process.

Finally, we also studied the impact of DENM dissemination on the reception ratio of CAM messages. These results are presented in Figure 6 for a density of 30 veh/lane/km, but other densities show a similar behavior. First of all, it is important to notice the relatively low beaconing reception ratio, regardless the transmission of supplementary safety data through the means of DENMs. This low reception ratio under high vehicular density confirms the findings of previous studies [18] that argue for adaptive techniques to alleviate channel congestion. However, we can observe that, when DENMs are transmitted using intelligence level 1 mechanisms, the CAM reception ratio reduces with around 5% recent. This difference is significant if we consider that CAM reception is measured on the entire map, while DENM dissemination is restricted to only a part of the simulated geographical area. The results for facilities layer-based dissemination are not shown on the figure, but they are practically identical with those obtained without DENMs, showing once again that the proposed solution manages to reduce the extra-congestion created by the transmission of special event notifications.

To summarize, the results presented in this section help us make two important observations :

- Facilities layer-based information dissemination mechanisms can highly improve the propagation of safety information in a vehicular network ;
- Ignoring the background safety beaconing messages in the study of vehicular information dissemination results in highly unrealistic results, that misguide the design of the network architecture and mislead the expectation of safety applications.

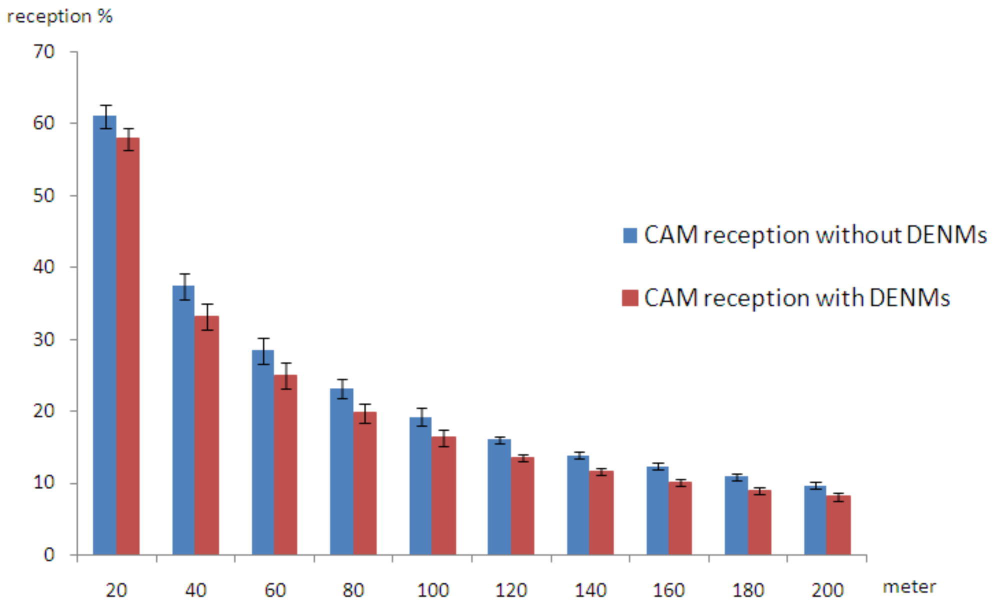


FIGURE 6: Impact of DENM transmission on the CAM reception ratio for a vehicular density of 30 veh/lane/km when intelligence level 1 dissemination is used.

6 Conclusion

Efficient safety information dissemination is essential for the future deployment of vehicular ad hoc networks. In this paper, we study for the first time the role of the recently standardized facilities layer in this dissemination process.

Through a thorough simulation study, we show that intelligent facilities layer mechanisms can result in a 50% shorter dissemination delay, by reducing the number of redundant DENM transmission. Moreover, we argue that previous studies that ignore the background beaconing traffic result in artificially small dissemination delays and over-evaluate the role of improved connectivity.

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