Retraction

Retracted: Simulation of Vehicular Network Use in Emergency Situations and Security Applications on a Pakistan Highway

Security and Communication Networks

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] A. T. Al-Douri, N. Mohammed Kadhim, A. A. H. Mohamad, and M. Abeyie, "Simulation of Vehicular Network Use in Emergency Situations and Security Applications on a Pakistan Highway," *Security and Communication Networks*, vol. 2022, Article ID 2902263, 10 pages, 2022.

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Research Article

Simulation of Vehicular Network Use in Emergency Situations and Security Applications on a Pakistan Highway

Asaad T. Al-Douri,[1] Noor Mohammed Kadhim,[2,3] A. A. Hamad Mohamad [ID],[4,5] and Melese Abeyie [ID][6]

[1]*Department of Dental Industry, College of Medical Technology, Al-Kitab University, Altun Kupri, Iraq*
[2]*Department of Medical Instruments Engineering Techniques, Al-Farahidi University, Baghdad 10021, Iraq*
[3]*Department of Medical Laboratory Techniques, Al-Turath University College, Baghdad 10021, Iraq*
[4]*Department of Medical Laboratory Techniques, Dijlah University College, Baghdad 10021, Iraq*
[5]*The University of Mashreq, Research Center, Baghdad, Iraq*
[6]*College of Natural and Computational Science, Department of Chemistry, Injibara University, Injibara, Ethiopia*

Correspondence should be addressed to Melese Abeyie; meleseabiye@inu.edu.et

VANETs (vehicular ad hoc networks), which are revolutionary techniques to enhance road safety, can be used to broadcast information about dangerous traffic conditions or accidents. However, distributing important information for driver safety and well-being has strict time and reliability requirements. This is because messages must be received by all cars involved in a potentially dangerous scenario for proper precautions to be taken to avoid the problem from materializing or intensifying. Because of the deterioration in conventional wireless communication system performance, ensuring that such requirements are met is a serious concern. To validate the concept before the actual installation of such systems and their absorption into the vehicle sector, it is therefore critical to employ simulation methodologies that are both reliable and thorough. This piece consists of large-scale, realistic security simulation research of an emergency situation based on actual road traffic data acquired on a Pakistan route. The study's findings are detailed in the following paragraphs. Aspects such as the incorporation of fixed communication units along a stretch of roadway and the performance of the vehicular network notifying all vehicles engaged in the various accident scenarios modeled on the same stretch of highway were evaluated. Both of these characteristics were designed to increase safety and security applications. After doing the investigation, it was observed that when fixed communication units are incorporated into the network infrastructure, there is a shorter delay in receiving the accident notification. This was the conclusion made after reviewing the findings. Drivers of vehicles located closer to the accident site will be able to respond in a timely and safe manner as a result of this improvement in network performance, and drivers security of vehicles located further away will have the option of exiting the highway to avoid potential congestion caused by increased road traffic.

1. Introduction

Pakistan's increasing urbanization at 3.3% per year and population growth of about 2% per year have contributed to the country's 18.3% increase in the number of motor vehicles registered during the last two decades [1]. Even though the country's road network has not increased significantly in recent years, there has been a significant increase in automotive collisions in Pakistan. In Pakistan, the accident death rate is 14.2 per 100,000 people [2], an unacceptably high figure. According to the Pakistan Bureau of Statistics [3], 48,828 individuals died due to traffic accidents in Pakistan. The authors assessed the performance of Het-Net, which combines Wi-Fi, DSRC, and LTE technologies for V2V and V2I communications, and found that using other wireless technology could reduce the need for expensive DSRC infrastructure by up to 55%. An application layer handoff method was created to enable Het-Net communication for

two CVT applications: traffic data collection [4]. The nation's network of highways and motorways carries most of the country's high-speed traffic. Several researchers have focused on the relationship analysis of accidents and numerous contributory components during the accident study done on roads and highways. Most of Pakistan's highways and other roadways are classified as either national highways or motorways [5].

The development of new wireless network technologies and the existence of low-cost embedded systems with high computational capacities gave rise to the emergence of vehicular networks, both in terms of research and of the market. This type of network enables the communication between vehicles (vehicle-to-vehicle (V2V)) and between them and the road infrastructure (vehicle-to-infrastructure (V2I)) [6].

The main interest in VANETs arises from using new road safety paradigms based on cooperation between the various entities involved in communication [7], which significantly improve road safety and promote sustainable mobility. However, given the criticality of this type of application, simulation studies are needed in large-scale environments and conditions as close as possible to reality. The potential advantages of the technology can be verified before starting its introduction in vehicles and infrastructures.

This work intends to analyze the feasibility of using vehicular networks in highway scenarios to respond to accident situations. Three different aspects are intended to be evaluated:

(i) The impact of roadside units (RSUs) in the accident notification process is to assess the need to invest in their installation.

(ii) The ability to give timely warning to vehicles close to the accident zone to avoid chain collisions.

(iii) The ability to warn vehicles far from the affected region to ensure that they can choose an alternative route, minimizing traffic congestion.

The study presented in the simulation is based on the real case of the Pakistan motorway AH1/M-2 (Islamabad to Lahore motorway), which connects the capital, Islamabad, to Lahore. AH1/M-2 is located in Pakistan; the Lahore-Islamabad Motorway is a highway that runs from north to south and connects Rawalpindi/Islamabad to Lahore. This motorway is one of the several motorways under the responsibility of Pakistan road safety [8].

2. Review of Literature

2.1. Security Applications. The development of vehicular networks enables the development of new types of road safety applications. These applications are based on cooperation and information sharing between vehicles and the surrounding environment and aim to alert the driver of situations that affect safety and mobility conditions throughout the journey.

In [9], characterization of the different types of applications was carried out, and it was concluded that safety applications should be used essentially to support accident situations, provide information at intersections, and avoid traffic congestion. However, many options regarding the most appropriate protocol architecture and communication mechanisms are left open.

The study presented in [10] further characterizes the types of road safety applications, defining applications for five different purposes:

(i) Alert for dangerous infrastructure features.

(ii) Alert for abnormal traffic conditions.

(iii) Warning of collision danger.

(iv) Warning of impending shock.

(v) Accident notification.

According to the same study, this type of application requires the use of new communication mechanisms that allow sending information to an unspecified set of nodes: dissemination within a geographic area (Geocast) and periodic dissemination to adjacent nodes (Beaconing). Multihop communication and store-and-forward are also used to guarantee the reception of information by nodes that are outside the initial range and correlation to reduce data traffic, especially in situations of a high density of vehicles.

A crucial aspect of the performance of these applications is related to the definition of the scope of the Geocast and the validity time of the security information. In [11], the authors stipulate 250 m as an acceptable value for a maximum range of a Geocast communication and 10 s as a time limit for the validity of the information. However, an experimental study carried out in the context of the European Cooperative Vehicle-Infrastructure Systems (CVIS) project with a set of safety applications developed by the consortium concluded that the warning time should not exceed 5 s [11].

For applications aimed at alerting drivers to potential accidents, there are other determining factors for their success, such as the accuracy of the vehicle's location and the prediction of its movement, which are directly related to the time period between beacons. Studies reported in [12] show that a frequency of 5 Hz guarantees an adequate performance for this type of application.

Several authors have also carried out performance studies on applications to avoid accidents at intersections [12, 13]. However, these studies do not apply to a motorway scenario, given the scenario's different mobility patterns and characteristics.

2.2. Safety Applications for Emergency Situations. A potentially dangerous situation can trigger the transmission of messages generated by various road safety applications, of which the most relevant for an accident scenario are

(i) Sudden braking warning (emergency electronic brake lights (EEBL)).

(ii) Post-crash warning (PCW).

(iii) Cooperative collision warning (CCW) alert.

The EEBL application allows a vehicle to notify vehicles behind it when it suddenly brakes. It is especially useful in

poor visibility conditions where vehicles may not be aware in time that the vehicle in front has braked/activated the brake lights. The PCW application notifies vehicles approaching an accident scene of the presence of an immobilized vehicle due to an accident or mechanical failure. Finally, the CCW application mitigates the occurrence of collisions by sending periodic information about the position, speed, acceleration, and direction of each vehicle.

According to [14, 15], these applications can be characterized according to different parameters, as shown in Table 1.

3. Characterization of the Scenario

3.1. General Information. The AH1/M-2 highway is considered one of the most congested highways in the country since it is one of the two main access routes to the city of Islamabad. The 25 kilometers between Islamabad and Lahore on the AH1/M-2 include 12 intersections with 60 access routes.

In terms of technology, AH1/M-2 is a highway equipped with an advanced infrastructure, made up of a backbone, which interlinks a set of sensors, video surveillance cameras (CCTV), and variable message boards (PMVs). The CCTV poles are placed laterally in locations that offer good visibility, and the PMVs are placed on raised porches perpendicular to AH1/M-2. In any two cases, these systems are spread over the entire length of the highway, being placed at about 6 m height. There are sensors at the entrances and exits and sensors located along two different sections of the AH1/M-2. Currently, this infrastructure is used to collect traffic information, identify dangerous situations, detect accidents, and provide information to drivers about traffic conditions. All information is centralized at the operational coordination center—CCO, which manages all highways concessioned by the SKB Engineering group.

The variety of sensorization equipment available enables the collection of data of a variety of types, including traffic intensity and density, class, the combined weight of two vehicles, and average speed, Het-Net might offer extra supplemental connectivity for safety applications to notify upstream vehicles to take preventative measures to avoid issue spots. This information is delivered and processed to central systems for statistical processing before being sent, in quasireal time, to PMVs to avoid problem locations.

3.2. Characterization of Traffic. A historical record of traffic information allows modeling the traffic in a macroscopic way [14]. This record indicates the average intensity of traffic in different locations, measured every 10 minutes. In addition, there is also a record of the origin-destination matrix for every two accesses of AH1/M-2. Based on the analysis of the registered information, it was possible to determine the intensity of traffic in different sections throughout the day. The values were obtained from the three most representative locations in different periods of the day: *o* period of less traffic (2:00-3:00 a.m.), *o* period of higher traffic (8:00-9:00 a.m.), and a period of medium traffic (13:00-14:00).

Table 1: Characterization of road safety applications.

	EEBL	PCW	CCW
Communication mode	Geo-broadcast	Geo-broadcast	Geo-broadcast
Cardinality	Unidirectional	Unidirectional	Unidirectional
Type of communication	V2V	V2I, V2V	V2V
Transmission mode	By event	By event	Periodically
Freq. min. messages (Hz)	~10	~1	~10
Maximum latency (s)	0.1	0.5	0.1
Reach (m)	~300	~300	~150

3.3. Characterization of the Accident Conditions. For the history of traffic, SKB Engineering also has information that allows for identifying the locations most prone to accidents and defining the most frequent causes. According to the data made available by SKB Engineering, there are five most critical areas [15].

In the first zone, it occurs in the Islamabad to Lahore section, between departures 9 and 10. The main cause of accidents consists of strong winds and excessive speed, which results in the vehicle not being misled and, possibly, in an accident. The second area is located next to CREL, near exit 6, not in the Islamabad to Lahore direction. In this area, the accidents are caused mainly by the sudden variation in traffic density on the curve that immediately precedes a departure. Drivers who dislodge at excessive speed are not aware of the rapid formation of a queue next to the exit and are forced to reduce speed abruptly. The following two locations are located close to the departure point for the National Stadium: a sharp curve, combined with the excessive speed of two vehicles, is the main cause of accidents. The last area is located near Exit 5, not in the Islamabad to Lahore direction, in the direction of Islamabad to Lahore. More than once, the main cause of the accident was excessive speed [16]. Even though they occur often, road accidents are the worst thing that may happen to a road user. The most regrettable aspect is that we don't learn from our on-the-road errors. The majority of road users are generally relatively aware of the general norms and safety precautions when using the roads; it is only the road users' slack attitude due to overspeeding, drunk driving, driver distractions, red light jumping, and avoiding safety equipment such seat belts and helmets. . Still, in certain situations, accidents occur in high-traffic conditions, which can occur even when the traffic is heavy. Likewise, it is essential to model the occurrence of accidents in different traffic conditions.

4. Vehicle Support Network for Emergency Applications

4.1. Architecture of the Vehicular Network. Two fundamental aspects to be balanced do not design a vehicular network with the need to use fixed communication units (RSUs) properly positioned to increase the coverage of communication in order to ensure better connectivity.

In the case of AH1/M-2, there is already a network infrastructure, so it is relatively easy to find suitable locations to place the aforementioned RSUs, namely, locations with better visibility, where the CCTV cameras or PMVs are currently located. Still, it is necessary to guarantee that there is a significant improvement in performance, which justifies the investment to carry out the RSUs. Likewise, two different scenarios will be considered:

(i) Vehicular network without RSUs that supports only vehicle-to-vehicle (V2V) communication.

(ii) Vehicle network with RSUSs that also supports vehicle-to-infrastructure (V2I/I2V) communication.

Figure 1 represents the complete case, with a network containing RSUs allowing V2V and V2I/I2V communication.

In a real situation, the vehicles and the RSUs may be equipped with antennas with different characteristics. V2I is used where an RSU is available, and V2V multihop communication is used where the RSU's communication range cannot reach, with the knowledge that the antennas of the RSUs have a greater range and that they are located above the height of two vehicles to prevent them from acting as an obstruction to the propagation of the signal, this method could be successful for roads and highways with sparsely distributed RSUs. As can be seen, the subject of this study is V2V multihop communication because it is crucial to EM broadcasting for accident prevention [17].

4.2. Architecture. Figure 2 illustrates the architecture for all of us on the network, which must be similar for all of us and adaptable to various types of applications. Also, vehicles and RSUs support a set of road safety applications, with the information generated by these applications being disseminated within a given geographic area using an unreliable transport protocol and a geographic routing protocol or GPSR (Greedy Perimeter Stateless Routing) [18]. The geographic routing protocol was modified to support communication within a geographic area, limited or not, to a restricted set of us, the performance of vehicular networks on highways, taking into account aspects such as the feasibility of placing RSUs along with the infrastructure and its impact on this same performance. In terms of access to the medium and physical transmission of data, the protocols implemented in the IEEE 802.11p standard are used, on which the WAVE (wireless access in vehicular environment) systems are based [17].

4.3. Emergency Applications. In the event of an accident, it is crucial to ensure that, firstly, the accident does not escalate and, secondly, to avoid the formation of long and lengthy traffic queues, whose tails can also imply sudden braking, leading to second accidents.

It is considered that, immediately after the accident, the vehicle notifies those approaching from its rear if the damage caused by the accident does not make it impossible. Vehicles approaching the accident site may be at a point on the

motorway that precedes an exit, so they can anticipate their departure from the motorway upon receiving the warning. Vehicles that are very close to the accident scene, to the point of having to drastically reduce their speed when they perceive a dangerous approach to the vehicle in front, must transmit sudden braking/risk of imminent collision in the rear warnings to the other vehicles.

This modeling will allow analyzing the coexistence of several road safety applications and their impact on communication in an emergency scenario.

From an application point of view, it is necessary to support the three applications, namely,

(i) PCW application—used to notify the occurrence of an accident. The crashed vehicle generates notifications for a short time. These notifications are resent by the vehicles that receive them in order to ensure that the information reaches quickly beyond the affected area. However, in order to avoid broadcast storm situations, such as those described in [19], these notifications are only resent the first time they are received through a simple correlation mechanism.

(ii) EEBL application—used to warn vehicles of sudden braking by the vehicle in front. The braking vehicle generates messages for a short time at a relatively high rate. These messages are not forwarded by the vehicles that receive them.

(iii) CCW application—used to detect potential collision situations based on the location information it periodically receives from its neighbors. The messages generated by each node have an exclusively local character, not being forwarded to nodes that are not adjacent to it.

For an effective response to an emergency situation, it is essential to ensure that, despite the coexistence of road safety traffic from different applications, it is possible to fulfill the requirements previously stipulated for each of them, namely, in terms of the ability to notify vehicles of a situation of an accident.

5. Accident Scenario Modeling

5.1. Characterization of the Accident Scenario. In order to obtain reliable results, an attempt was made to reproduce an accident scenario in simulation. Among the various types of cases identified in Section 3.3, the first was chosen, as it was the one where the most accidents were reported. This location (Jhelum, Punjab, Pakistan, (32.675778, 72.755291), shown in Figure 3, is located on the Islamabad to Lahore (direction: Islamabad), close to k22.1 km, and in an area where the motorway has three lanes where accidents often happen there. The distance between the exit immediately before the accident site (10th exit) is approximately 1.2 km (red spot marker in the figure). To take advantage of the existing infrastructure, the RSUs must be placed next to the CCTV poles or next to the PMVs (marked in the figure with blue markers). However, since the distance between them is
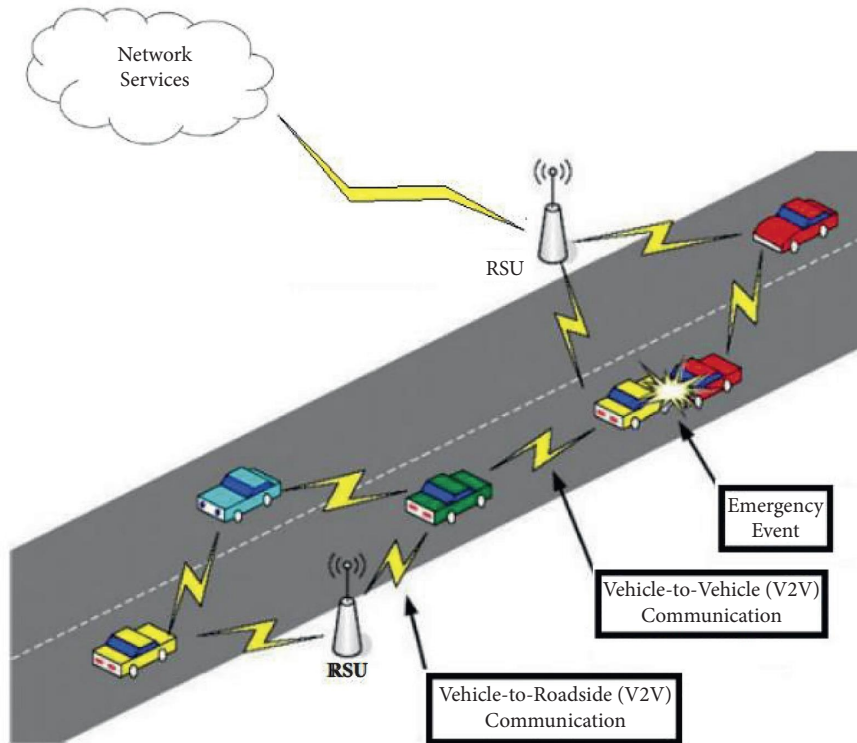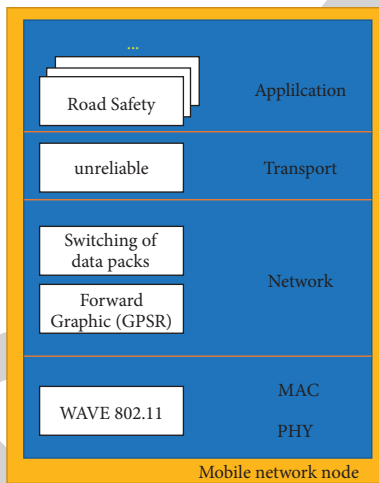
Figure 1: Proposed VANET architecture.

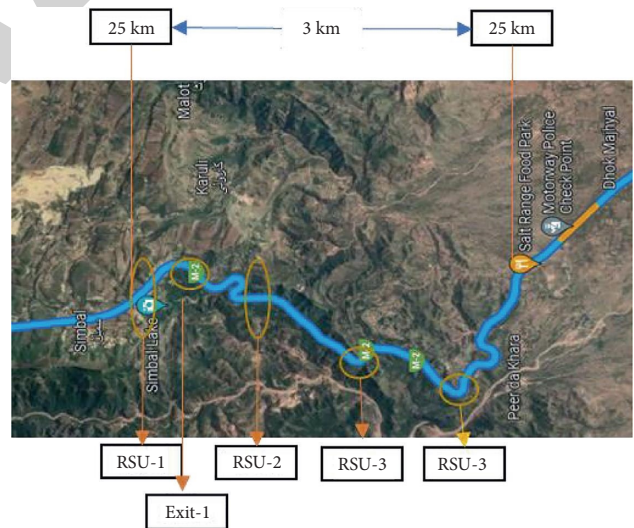Figure 2: Architecture of a network node.

Figure 3: Islamabad to Lahore section of the AH1/M-2 motorway.

only a few hundred meters, there will be no need to install RSUs in all locations. The vehicle moves at the maximum permitted speed (120 km/h), so the RSUs must be placed next. Therefore, it was decided to include in the scenario, modeling only MSWs with an average distance between them of about 1 km (MSW 1, 2, and 3) for to be safe and avoid a collision, and this is a relatively simple representation of reality since it does not consider the natural distribution of vehicle departure times and their movement.

As mentioned earlier, the most frequent cause of accidents is speeding. However, accidents can occur in situations of high-traffic intensity or even in situations of low intensity. Any of these scenarios can have a strong impact on the performance of the vehicular network, as the first can lead to an overload of data traffic, and the second can lead to a lack of connectivity in the network. In order to better assess the impact of these two extreme cases, it was decided to select the values recorded section for the period with the highest traffic. At this stage, if your resource does not show up in the Endpoint list and you created both your hosted zone and the

TABLE 2: Characterization of the highway section of the AH1/M-2.

Length of the section (m)	3000 (22 km to 25 km)
Direction of traffic	Islamabad to Lahore
Number of ways	02 to 03
Speed limit (km/h)	120

TABLE 3: Location of the most relevant points.

	Real position (km)	Position MOVE (m)
Local accident	22.075	2925
First departure	23.23	1770
MSW 1	24.84	160
MSW 2	23.79	1210
MSW 3	22.6	2400

resource to which you are directing traffic using the same AWS account, make sure the following: verify that the record type you selected is supported, specific to the resource you are routing traffic to, for instance, you must select A — IPv4 address for the record type if you want to direct traffic to an S3 bucket.

5.2. Mobility Model. The mobility simulator MOVE1 (Mobility Model Generator for Vehicular Networks) was used for the mobility simulation since it fits the scenario under study. This road traffic generator allows the modeling of scenarios with a high number of nodes, taking into account both aspects of macro and micro-mobility [2], and allows the interconnection to the used network simulator—the ns-32.

Based on the scenario described above, a section was defined in MOVE's Map Editor with the characteristics indicated in Tables 2 and 3. It should be noted that MOVE does not allow the creation of complex profiles with curves and unevenness, so it is not possible to represent the geography of the section in question accurately.

To model the mobility of the nodes, we used vehicle movement generator based on previously defined traffic intensity values. The RSUs were represented using fixed nodes located at the exact coordinates of the previously selected CCTV systems. The mobility model used by MOVE is the car-following model [20, 21], managing to model the acceleration, braking, or lane change following the approach of other vehicles and the constant speed that allows for maintaining the minimum safety distance from the front vehicle. However, it does not consider the drivers' response to stimuli, which could be interesting for modeling accident situations. In the model used, at the initial instant, the vehicles are all at the starting point, corresponding to the entrance to the highway. The departure time of each vehicle is randomly defined, following a uniform distribution, with values between the initial time and the final time of the simulation (180 s). The vehicle starts moving at the maximum permitted speed (120 km/h). This is a relatively simple representation of reality since it does not consider the real distribution of vehicle departure times and their movement, thus being able to condition the traffic density that is obtained and, consequently, the network's performance.

However, the existing real data do not allow a more detailed characterization.

The modeling of the accident scene was carried out considering two different situations: in the first situation, the vehicle victim of the accident is stopped, preventing circulation in one of the carriageways; in the second situation, the three lanes are blocked, one by the injured vehicle and the others, e.g., by assistance vehicles.

5.3. Vehicle Network Modeling. The simulation of the accident scenario was performed using the ns-3 network simulator. The choice of this simulator was due to the fact that it is a free-to-use tool widely used by the scientific community, which allows complex simulations to be carried out with a level of detail that allows the reproduction of real results in a very reliable way.

The vehicular network architecture is implemented by importing the MOVE output file, which contains the position of each node at each instant of simulation time. In simulations involving V2I/I2V communication, RSUs are special nodes whose position coordinate is maintained throughout the simulation. Vehicle entry and movement are carried out according to the mobility model described above.

The fact that ns-3 does not yet have all the modules necessary to simulate a node with the proposed architecture (Figure 2) led to the need to make adaptations to the model proposed previously.

The previously considered applications are modeled through CBR (constant bit rate) traffic generators, with different time configurations between message generation. For the sake of simplicity, all messages have the same size (480 bytes), which was defined in order to ensure that the security information is already included in the packet, following the indications defined in [17–19].

As previously mentioned, information from the PCW application has to reach all nodes quickly, which is achieved by having the receiving nodes resend the information received for the first time, while the information from the other applications has a local character. This behavior was modeled by defining the time to live (TTL) field in the message, which allows controlling the number of times the message is retransmitted. Therefore, for the PCW application, a value was selected that allows the message to be retransmitted the number of times necessary to allow its reception by nodes that are before the exit at the moment of the accident. This value must be parameterized for the different scenarios that may be considered. In order to respect the functional principles defined above, the PCW and EEBL applications only start when an accident occurs. The values used are shown in Table 4.

The simulation model developed uses the UDP protocol as an unreliable transport protocol at the transport level. At the routing level, a module was used that implements the GPSR geographic routing protocol [20], with a location service similar to the one used by Karp and Kung in the specification of the protocol itself.

At the MAC layer level, the biggest limitations arise since ns-3 does not yet support the 802.11p protocol [17]. Thus, it

TABLE 4: Parameterization of traffic generators.

	PCW	EEBL	CCW
Size of messages (B)	480	480	480
Frequency (Hz)	8	8	2
Destiny	All	All	All
TTL	60	2	2
Start time (s)	T_{accident}	T_{accident}	0
End instant (s)	$T_{\text{simulation}}$	$T_{\text{simulation}}$	$T_{\text{simulation}}$

TABLE 5: Parameterization of propagation models and antennas.

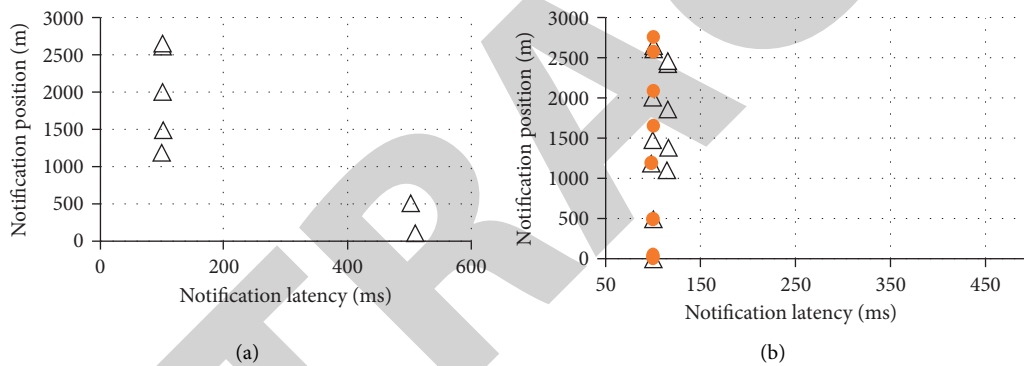|			Vehicle	RSU
Nakagami model	Nakagami m-factor	$m0$		1.5
		$m1$		0.75
		$m2$	0.5	
Two-ray ground model	Height (m)		1.7	6.3
Antennas	Transmission power (dBm)		5	18
	Hook (dBi)		2	9

(a)

(b)

FIGURE 4: (a) Low vehicle intensity: the notification latency is in the order of 100 ms. (b) High vehicle intensity: the notification latency is in the order of 100 ms.

was necessary to resort to the module that implements 802.11 communication in ad hoc mode. With this solution, there is no support for quality of service and switching between channels, which are essential mechanisms for the coexistence of security applications with other types of applications. The fact that applications other than those related to emergency scenarios are not being considered strongly reduces the impact of this limitation. It may, however, happen that, due to the inability to differentiate the various applications in use, the performance of the most critical application—PCW—is affected.

The physical layer already has support for the 802.11p standard, and this was the model used. In order to obtain simulation results that approximate the real conditions as closely as possible, special care was taken in the choice of propagation models. We chose to use a model that accounts for losses due to signal attenuation with distance (path loss) and another that accounts for losses due to the effects of signal dispersion (multi-path fading). Therefore, the two-ray ground reflection and Nakagami [22] models are used. The range of the different types of antennas was modeled using

the configuration of transmission power and antenna gain. The values used are shown in Table 5.

6. Results and Discussion

6.1. Test Scenario. The tests carried out are intended to assess whether the most critical application (PCW) requirements can be guaranteed, taking into account that there is traffic coming from other security applications in circulation. This assessment was carried out in several different scenarios:

(i) Communication with and without MSW.

(ii) One-way or three-way blocking.

(iii) Traffic with low and high intensities.

6.2. Evaluation Metrics. To measure the performance of the PCW application, application-level and network-level metrics were stipulated. From an application point of view, the following metrics were defined:
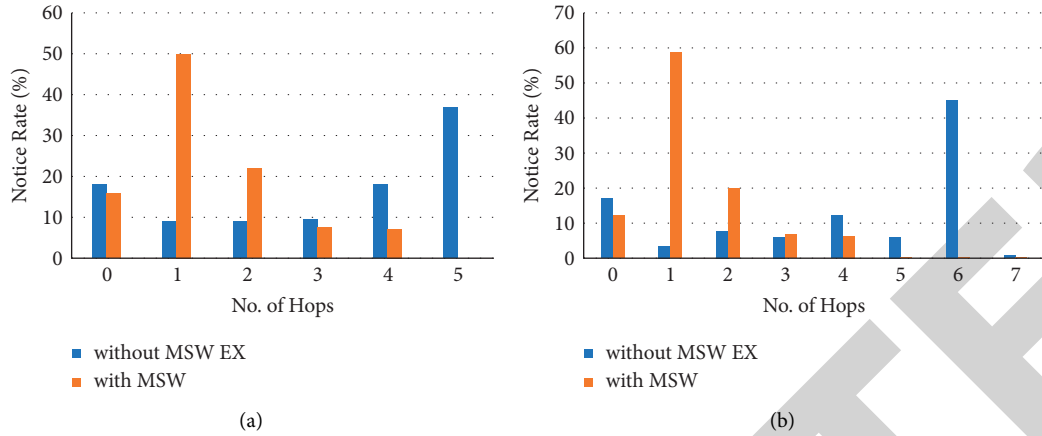
FIGURE 5: Low vehicle intensity; V2V and V2I communication; 1 blocked way (a) and high vehicle intensity; V2V and V2I communication; 1 blocked way (b).

TABLE 6: Results for the different post-accident conditions.

Global statistics	Total	Before you leave	Accident area
Notice fee	100%	100%	100%
Useful notice fee	100%	100%	86%
Minimum notification latency (ms)	102.75	102.75	102.75
Average notification latency (ms)	107.14	107.32	104.22
Maximum notification latency (ms)	133.92	133.92	111.79

(i) Warning rate: the percentage of vehicles in circulation that received an accident notification.

(ii) Useful warning rate: the percentage of vehicles in circulation that received the accident notification within the latency and range limit characteristic of the PCW application.

(iii) Notification latency: time that elapses from when the accident occurs until the vehicle is notified.

(iv) Notification position: position of the node when it receives the accident notification, measured about the input coordinate.

At the network level, the metrics considered were

(i) Number of hops: number of nodes used to relay the message.

6.3. Results Obtained: General Case.

The information of each vehicle at the moment of the accident notification is represented through a set of XY-type graphs. The X coordinate describes the notification latency and the Y coordinate describes the notification position. Figures 4(a) and 4(b) illustrate the values obtained in the situation of low vehicular intensity, and Figure 5 illustrates the case where the intensity is high.

Except for vehicles that are further away from the accident, in a low traffic intensity with V2V communication, most vehicles receive the notification very quickly, with the notification latency in the order of 100 ms. However, more distant vehicles have higher latencies (about 500 ms), although they can be warned when they are still far from the accident site. As shown in Figure 4(b), the existence of RSUs (dots illustrated in red) makes it possible to reduce the latency value for more distant vehicles. When the traffic intensity is high, there is a greater variation in the notification conditions, which translates into a greater dispersion of the notification position. Regarding the notification latency, although there are variations in value, the maximum observed latency is much lower (about 135 ms) since more vehicles are capable of retransmitting the notification. The existence of RSUs allows more nodes to receive the notification faster, which is visible by the higher concentration of points along the Y-axis. It is also verified that the number of distant nodes that receive the notification earlier increases. This situation is particularly evident in the case of MSW 2 ($Y = \sim 1210$ m). The results presented in Figures 5(a) and 5(b) illustrate the number of hops used histogram and confirm the previous conclusions. The use of RSUs reduces the number of communication hops, which reduces the notification latency since the RSU has a greater range and allows the transmission of information to distant nodes more quickly.

6.4. Results Obtained: Post-Accident Conditions.

Based on the information received, it is also possible to assess how the notification would allow drivers to react promptly to the accident situation. Two different situations must be considered:

(i) Drivers in the accident area must be warned quickly to react in time to avoid secondary accidents.

(ii) Drivers who are en route to the accident area but still have time to receive the alert so that they can deviate follow an alternative route, avoiding congestion.

Based on these assumptions, the warning rate, the useful warning rate, and the notification latency were measured for the general case and for each of the situations identified above. Table 6 presents the results obtained for each of these metrics. In this study, it was considered that, in the general case and in the case of nodes before the exit, the warning was only useful if it arrived before 500 ms. In contrast, the maximum acceptable value for nodes in the accident region was 105 ms (the latency value defined for the EEBL application with a margin of 5%).

7. Conclusions and Recommendations

In the present work, the performance of vehicular networks on highways was analyzed, taking into account aspects such as the feasibility of placing RSUs along with the infrastructure, its impact on this same performance, and the ability to enable the timely receipt of warnings regarding emergencies, to minimize second collisions and mitigate traffic congestion. Different aspects were analyzed using the modeling and simulation of mobility and communication between vehicles and, additionally, between vehicles and road infrastructure—the RSUs.

The results obtained allow us to conclude that the use of RSUs improves the performance of road safety applications, as it reduces the latency in receiving information. From the analysis of the same data, it is still possible to conclude that it is not necessary to install the RSUs mentioned above in all locations where there are currently CCTV poles or PMVs, which will have significant cost advantages.

From the results in a post-accident phase, referring to high-intensity conditions, with three blocked lanes and the inclusion of RSUs, it appears that vehicles far from the accident zone, at a point that precedes an exit, are all warned in time. If the alert appeared before 500ms, it was beneficial. In contrast, if the maximum acceptable value for nodes in the accident region was 105 ms, it would be not useful. All vehicles in the accident zone, i.e., within the maximum range of 300 m, received the notification. However, only about 86% of them received it within the latency limit, i.e., 105 ms. However, considering the 500 ms of the PCW application, all nodes under study received the notification successfully, with a latency below this value.

In future work, we intend to evaluate this situation in a small-scale experimental prototype, which allows us to assess to what extent the results obtained by simulation are representative of the real situation. This study will make it possible to determine the importance of aspects that cannot be modeled in simulation, such as the presence of obstacles on the motorway and the actual geometry of the motorway itself (levels, bridges, and curves, among others).

Data Availability

The data underlying the results presented in the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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