Article

Vehicular Communications Utility in Road Safety Applications: A Step toward Self-Aware Intelligent Traffic Systems

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Abstract: The potential of wireless technologies is significant in the area of the safety and efficiency of road transport and communications systems. The challenges and requirements imposed by end users and competent institutions demonstrate the need for viable solutions. A common protocol by which there could be vehicle-to-vehicle and vehicle-to-road communications is ideal for avoiding collisions and road accidents, all in a vehicular ad hoc network (VANET). Ways of transmitting warning messages simultaneously by vehicle-to-vehicle and vehicle-to-infrastructure communications by various multi-hop routings are set out. Approaches to how to improve communication reliability by achieving low latency are addressed through the multi-channel (MC) technique based on two non-overlaps for vehicle-to-vehicle (V2V) and vehicle-to-road (V2R) or road-to-vehicle (R2V) communications. The contributions of this paper offer an opportunity to use common communication adaptable protocols, depending on the context of the situation, coding techniques, scenarios, analysis of transfer rates, and reception of messages according to the type of protocol used. Communications between the road infrastructure and users through a relative communication protocol are highlighted and simulated in this manuscript. The results obtained by the proposed and simulated scenarios demonstrate that it is complementary and that the common node of V2V/V2R (R2V) communication protocols substantially improves the process of transmitting messages in low-latency conditions and is ideal for the development of road safety systems.

Keywords: inter-vehicle communications; hybrid networks; V2V; V2R; R2V; dedicated short-range communications; safety communications; road communications

1. Introduction

The demand for goods is constantly growing but also the need to transport and transit the world from one end to the other. It imprints a hallucinatory feature in terms of vehicle density, making it extremely difficult to control and implement efficient fluidization systems. Whether we are talking about road, sea, rail, or air transport, all of these face extremely many problems that are addressed by research institutes around the world, trying to remedy many shortcomings, highlighting comparative aspects between the types of transport and what could be directions. In addition, Vladimir Belokurov [1] and Enoch [2] try to propose and highlight certain deficiencies locally treated and to remedy them through solutions and mathematical models dedicated to the road sector. Recent studies have energized the literature through the works of Dulebenets [3] and Albayrak [4], who propose and analyze air transport and also local public transport, areas in continuous expansion. Some recent studies have highlighted the automotive and road transport sectors because they are the most used at the moment. The factors determined in the study and the focus on this area come from social and economic considerations because annually, road accidents cause damage in both sectors. Efficient management of infrastructure and communication networks can significantly reduce accident rates or congestion, delays, and

limitations. The social impact produced by road accidents cannot go unnoticed in terms of the loss of life that continues to cause about three deaths every minute.

Millions of road deaths occur globally every year, and drivers can avoid about 60–70% of them if they are informed at least half a second before a collision can occur. With approximately 1.3 million victims and over 50 million injured each year, this problem is extremely damaging to our society. Only from an economic point of view, these road accidents cause losses of between 1% and 5% of a country's gross domestic product, in addition to human and social losses. We can say that 90% of road accidents are caused by human error, lack of attention, driving under the influence of stress, fatigue, or delayed reaction times due to drivers taking other actions while driving. Due to a limited perception of drivers, they cannot react in time in the case of a possible accident; the cognitive reaction process in the case of a reaction to the visualization of taillights needs time to be processed between 0.7 s and 1.5 s [5,6]. Thus, the Intelligent Transportation System (ITS) department deals with the development of new protocols for communication and transmission of urgent messages to obtain short propagation times. The first reactions took place in 2003 when the American Society for Testing and Material (ASTM), a committee specialized in standardizing and supporting public and road safety, their priority being social safety, adopted the Dedicated Short-Range Communication (DSRC) standard. We can say that 5.9 GHz dedicated short-range communication (DSRC) is based on the IEEE 802.11p standard and can be considered a promising solution in the area of applicability of vehicle-to-vehicle (V2V), vehicle-to-road (V2R), and road-to-vehicle (R2V) communications, or more briefly infrastructure-to-vehicle I2V. Thus, DSRC uses orthogonal frequency-division multiplexing (OFDM) but also because of the wireless local area network (WLAN) standard implemented and defined in IEEE 802.11a [7,8]. At the level compared to IEEE 802.11a, DSRC has characteristics of robustness in interference and adaptability under conditions of continuous and fast movement. Therefore, the DSRC channel is divided into 7 channels with a frequency of 10 MHz, and each channel is divided into another 52 sub-channels. To comply with the requirements of data security, these sub-channels are classified into four priority categories. Consequently, important priority information about security applications is transmitted using the central channel. We can say that in the context of data collision prevention, DSRC uses carrier/sense multiple access with collision avoidance (CSMA/CA). Being a type of short- to medium-range wireless communication, this protocol has applicability in the concept dedicated to road safety systems and V2V or V2R (R2V) communications. Research in the field of V2V communications has been condensed into two main and existential areas, medium access control (MAC) and the forwarding of transmitted messages [9]. According to the literature, we can say that IEEE 802.11 MAC is considered the de facto protocol in DSRC, such as the case of time-division multiple access (TDMA) based on slotted MAC protocols, which are also ideal proposals. Regarding the main problem related to the latter approach is caused by the management of synchronization and allocation of slots dedicated to distribution in multihop networks, being conditions of high mobility in traffic on highways and heavily trafficked roads. Considerations and studies have concluded that proper optimization of IEEE 802.11 MAC could become a portable solution in DSRC applications, although there are performance limitations in the stability of the MAC protocol. The likelihood of causing IEEE 802.11 self-competition between adjacent nodes and data flow leads to a limitation of the flow path, although there is also the ability to route protocols such as the ad hoc distance vector (AODV) being considered useful in forwarding messages from DSRC applications [10,11].

2. Issues and Solutions Addressed in Vehicular Communications

Existence of emergencies, a source vehicle (e.g., crashed car) in the current stages cannot communicate in advance with other potential recipients based on identity (ID). We can say that unlike AODV, the routing that addresses the strict orientation to the products applicable to emergencies provides priority messages. The literature and research paper [12], highlights a protocol that broadcasts multiple and aims to limit the number of

packets in the network, so it can outline an inter-vehicular communication, even multiple in a situation where there is no nonplatoon driving.

We can say that V2V communication protocols not only include policies related to congestion control, services, and even a mechanism dedicated to differentiation but also ways to disseminate urgently warnings to obtain a low latency in the process of propagating messages. Biswas et al. present a general way of using and transmitting protocols applied in shaping cooperative management systems and road accident avoidance based on DSRC [9]. Problems related to the costs generated by the dissemination of protocols raise questions and outline techniques for mitigating these storms being proposed in [13,14], where each called node has the ability to transmit a message with some probability of reaching the receiver. These problems involve the academic community approaching new solutions to optimizing broadcasting storms and reducing the amount of heavy traffic, which with exaggerated transmissions may collide due to the excessive number of broadcast messages. The first step was to design a multi-channel (MC) wireless communication protocol to support commercial or infotainment-type communications. That may have high potential but requires high bandwidth to interconnect a network vehicle and the roadway or infrastructure, an area with a multi-channel hotspot band, and communication services, all of which have the ability of enabling vehicle-to-vehicle communication in critical situations on a separate safety channel [15]. Therefore, more precisely, when the contention-free period (CFP) is reached, a vehicle can transmit its signals without being disturbed, using the roadside units, while all other vehicles remain on stand-by. In the way that vehicles are in the containment period (CP), vehicles that are at the border of the regions where they can receive services can use the whole process using an ad hoc protocol. We deduce that safety messages are not delivered simultaneously, even if the vehicles are located in the nearby service area. The researches in [16–18] propose, based on IEEE 802.11p, a special way and mechanism designed to reduce long-term delays in establishing connections. We can say that the mechanism benefits from a station that works in wireless access in the average vehicle (WAVE). This way, the vehicle can communicate quickly with other interlocutors using a wildcard Basic Service Set Identification (BSSID) having the possibility to not involve authentication processes and association, considerably reducing the way the connection is set up and the delivery of messages that have a certain delay.

Studies conducted and the literature mentioned above focused on how to design and develop protocols to perform message forwarding, depending on the priority and mode of communication, whether we are talking about V2V or V2R (R2V) communication. In this paper, a common V2V/V2R (R2V) communication perspective is proposed and presented as a protocol and a way of simultaneous forwarding of messages in emergencies, prioritizing messages through these types of communications, thus not only improving the transmission ratio and message delivery but also obtaining improved delivery reports through low latency and operational capability through multi-route diversity. Moreover, we can say that MC techniques are ideas to be able to eliminate co-channel interferences between V2V and V2R (R2V) communication by assigning frequency bands with different characteristics. This paper addresses in Section 3 the common V2V/V2R (R2V) communication protocol and modeling and the design of an emergency message-forwarding architecture. Subsequently, the performances of the communication protocol proposal in its applicability in road safety scenarios on highways are analyzed. We can say that in the contexts mentioned above, this paper aims to provide a broad perspective on V2V and V2R (R2V) communications by exemplifying the way of modeling and application in the development of road safety applications and systems. This approach has huge potential by exposing conclusive results related to simulation scenarios based on real-life case studies. Therefore, vehicle-to-vehicle (V2V), V2R (R2V), and I2V communications can have a high degree of applicability in practical cases, solving over 80% of the problems mentioned above [19–21].

3. Vehicular Communications and Proposed Solutions

We can say that in the scenarios of road traffic that takes place on highways, when vehicles encounter other vehicles or abnormal movements, unexpected or improper movements, and even mechanical failures, a warning message is generated regarding the collision or emergency to the entire platoon of vehicles. In V2V communication, signals and warning messages regarding collisions or events from one vehicle to another are transmitted over several channels without the involvement of a roadside unit. At the same time, the warning messages in the V2R (R2V) communication area are first transmitted to a roadside unit and then retransmitted by that unit to the vehicles on the network. Vehicles receiving a warning message using V2V communication are required to transmit to a roadside unit, and if they have not received the warning message with the ID sent, they can request a new message to the roadside unit (RSU). The information that contains warning messages also contains the event ID, the car ID, the transmitter information, and the global positioning system (GPS)location, all generated to be able to get an overview in order to avoid a collision or an unpleasant event. We can say that the vehicle in the receiver position to identify whether a message has come from the opposite direction can use the location information, which is attached to the sender, or from the route traveled (front or rear). Therefore, when using V2V communication, vehicles will redirect warning messages in a selective way to the other vehicles in the network. Therefore, the characteristic of a high delivery ratio and low latency is extremely important for the process of transmitting warning messages. We can say that due to the degree of congestion and due to packet collisions but also to the reliability of the wireless channel, the part of scenarios in road traffic can suffer extremely much by delayed delivery in a timely manner [22]. Specifically, the wireless channel for communication between vehicles is disturbed by various propagating phenomena, such as multihop weakening or even signal shading. Multihop weakening can occur due to interference; in some cases, the factor is constructive, while sometimes, it can be destructive, often forming between two or more echoes of the signal that are transmitted, reaching the receiving area at different times. We can say that the phases of these multihop components are almost random, and the amount of their entire contribution varies greatly.

Therefore, the transmitted signal is sometimes diffracted and subsequently reflected by nearby infrastructure or by objects between vehicles, which leads to a multitude of versions of the transmitted signal and changes in reception times, even amplitudes. We conclude that this causes the signal and the sum of the received multiple signals to change in amplitude or in-phase and as a result, the reliability characteristics of the wireless channels are extremely degraded mobility conditions. We can say that in conventional broadcasting protocols, there is a probability of a general loss and dissipation of information in the network, concluding that the result of such a process is a lasting conflict and collisions with excessive packet loss. The difficulties mentioned in the previous sections can be addressed through a new common protocol on V2V and V2R or R2V communications, which is presented in this section and which addresses strictly the safety of motorway traffic. V2V and V2R or R2V communications are concatenated to not only more effectively incorporate their features but also suppress the impact of the reliability of wireless channels, all achieved through the exploitation of diversity and the management of several communication routes [23,24].

Another mechanism is one that finds similarities with the process of intelligent broadcasting but through the process of recognition and implicit confirmation of messages through redundant warnings to limit data packet collisions. Another feature can be exposed by MC techniques that aim to reduce and eliminate co-channel interference between V2V and V2R or R2V communications by assigning different bands with different frequencies. For a better perception of the way of operation and to understand more precisely traffic scenarios, a single lane was proposed in the first phase, as shown in Figure 1, to evaluate the common communication protocol V2V/V2R (R2V) as a proposal to increase road safety. We can assume that we have two independent transmitters operating in different frequency bands in channel 1, with the other for V2R or R2V communication being

on channel 2. Under the given conditions, vehicles are capable of obtaining simultaneous communications using V2V and V2R or R2V, as shown in Figure 1.

Figure 1. Single-lane, high-speed road traffic scenario: using vehicle-to-vehicle (V2V) and vehicle-to-road (V2R) or road-to-vehicle (R2V) communication protocols for road and public efficiency and safety.

The operation of transmitters and receivers on different channels, the transmission and reception of signals for V2V communication, and V2R or R2V communication can be processed by these transceivers simultaneously, without the likelihood of interference. We can say that in a specific communication way, their signals are processed separately in the physical layer (PHY) and MAC layer. Therefore, within the network layer, they are processed together, as shown in Figure 2, according to the common protocol in which we find the V2V/V2R or R2V communications presented and proposed [25–27].

We can say that when a car (for example, C1) has a mechanical-type fault or has intercepted a road hazard, a warning message is generated with a degree of urgency that includes characteristics and related information but at the same time keeps another set of data in its buffer for new retransmission regardless of the given situation. Subsequently, the messages do transmit to vehicles in the vicinity, as well as to the roadside unit, with the help of two receivers that are positioned properly and in different frequency bands (in the case of scenarios that occur on highways). In V2R or R2V communication, the source vehicle will periodically resend warning messages to the nearby roadside unit until a message with the event ID issued by the respective roadside unit is returned to it, warning via the V2V communication protocol other nearby vehicles until the message with the event ID for the rear vehicle is returned. When the road reception unit captures the warning message from the source vehicle, it reshapes the ID and replaces it with its own ID for later transmission to vehicles within the range of the roadside unit. It should be noted that the IEEE 802.11p standard, with a Basic Service Set Identification (BSSID) feature [25], is capable of a quick response in the communication process without engaging in authentication and association sessions, all in support of reducing overhead and also delays. Therefore, after the warning messages have been received, the vehicles have to go through the following steps that the messages contain.
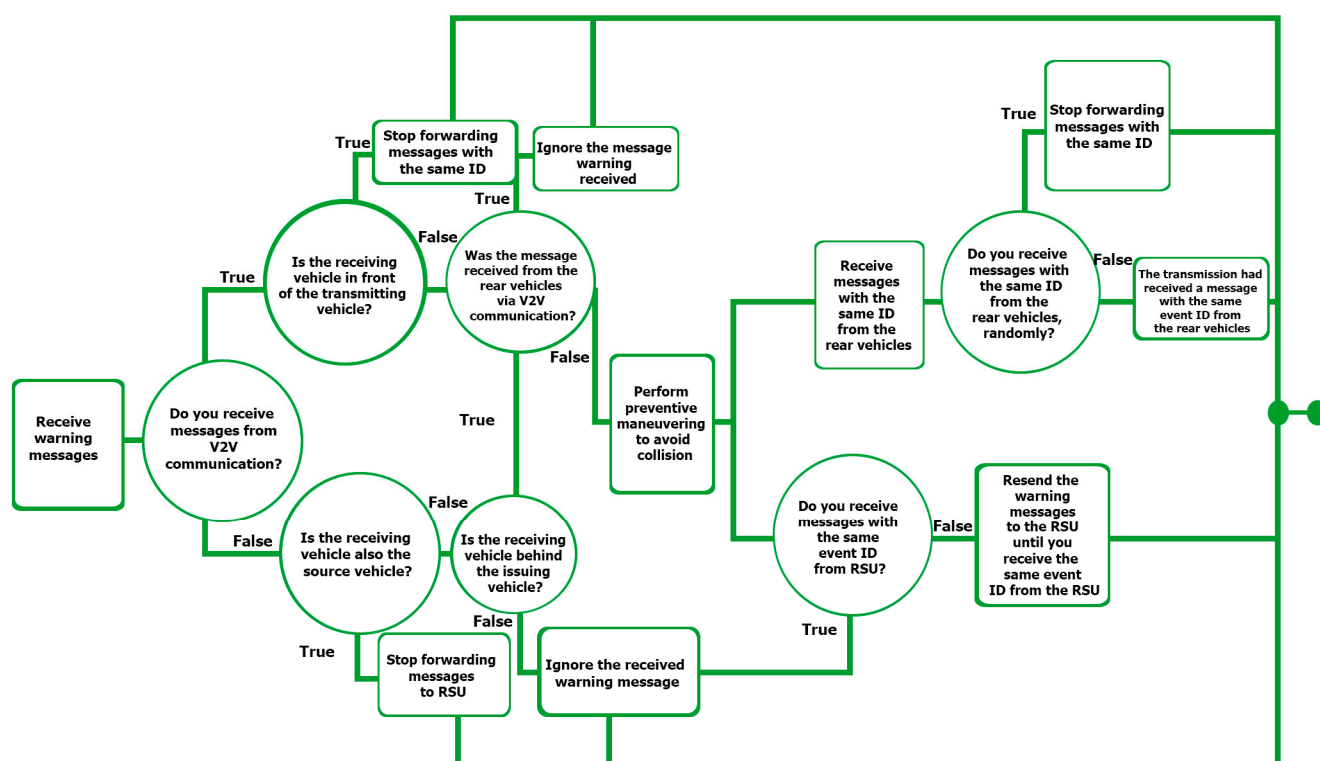
Figure 2. Flowchart in which the behaviors of the receiving vehicles are presented based on the assimilated information from the received warning message.

3.1. Receiving the Warning Message Confirmed by the Transceiver in V2R or R2V Communication Mode

➢ When the vehicle receives, it performs a verification of the source ID and the advertising message but does not send the message back to the roadside unit in order to reduce overhead in the network.

➢ When the receiving vehicle does not play the role of the source vehicle but is positioned in front of one that is the source, it has an obligation to avoid and ignore the message.

➢ When the vehicle acting as a receiver is positioned behind the source vehicle but has received warning messages that are identified with the same event ID from the V2V communication network, it must ignore the message.

➢ When the vehicle with the receiving role is positioned behind a source vehicle and does not receive the event ID, the transmission of procedures before the event and the prevention of a collision are performed, all the while waiting for confirmation of the warning message and event ID from the rear platoon.

According to the above steps, the processes that the proposed model goes through to optimize the association and identification sessions of the network hazards are highlighted. In the case of the last stage, there are two possibilities in the continuity of the process:

(a) If it receives a warning message containing the same event ID, then the process of retransmitting the warning message containing the event are stopped. This process facilitates fluid communication and also reduces costs.

(b) Otherwise, instances of periodic transmission of the message containing the warning characteristics are created until a warning message is returned containing the event ID from the vehicles located in the rear.

3.2. How to Receive Warning Messages from the Receiver That Processes the Information in the V2V Communication Module

➢ When the receiving vehicle is located in front of the vehicle broadcasting, it no longer has to retransmit the warning message regarding the event with the same ID. The aim is to reduce the number of messages broadcast on the network.

➢ When the receiving vehicle is positioned behind the broadcasting vehicle and the message has been reconditioned after, it must ignore the message.

➢ When the receiving vehicle is positioned behind the vehicle dedicated to broadcast and it receives the warning message as the first factor, it must perform the necessary measures and procedures to avoid a collision. At the same time, it has the role of verifying the validity of the message and whether an event with the same ID is not received from the roadside unit. If the information is not confirmed, it periodically sends the warning message to the roadside unit to obtain a warning message with the event ID. In parallel, the receiving vehicle has the quality of waiting for a random amount of time to filter the warning messages that have a similar event ID from the vehicles in the rest of the platoon.

According to the above steps, the processes that the proposed model goes through to optimize the warning processes in the V2V communication module and the dangers in the network are highlighted. In the case of the last stage, there are two possibilities in the continuity of the process:

(a) If such a message is received, the vehicle has the obligation to stop sending it regarding the same event. Commonly, again this method helps to reduce costs.

(b) If such a message is not received, the vehicle has the obligation to periodically send a warning message until an event ID is received from the vehicles behind the receiver.

According to the illustration in Figure 2, which represents the behavioral diagram of vehicles acting as receivers and using the common communication protocol V2V/V2R or R2V, a degree of difference in the behavior of receiving vehicles using V2R (R2V) or V2V communication but also the loss is illustrated in Figure 3 and respectively Figure 2. In the experimental realization, this paper proposes between six and nine intermediate receiving vehicles to have the guarantee that all vehicles within the platoon will have direct interaction with the messages on the network. According to the illustration in Figure 2, vehicles with intermediate status will receive warning messages with the same event ID not only from the roadside unit but also from vehicles in the vicinity by using V2R or R2V communication, respectively [26,27].

The operation of this mechanism supports the achievement of diversity on multiple wireless channels by increasing reliability in highly mobile environments so that a substantial improvement can be achieved in the process of delivering messages of interest to traffic participants. Detailed presentation of the vehicle illustration in Figure 4. We can say that the mentioned advantage is demonstrated by the results obtained and is presented in the simulations in Figures 5 and 6. Therefore, the demonstration reflects the premises of remarkable results, and we assume that when we obtain a higher delivery ratio of messages that subsequently leads to low latency, it becomes an ideal process at the level of overhead networks. At the same time, based on the observations made previously and also the presentation of the results from Figures 7–10, we can say that the proposed common protocol has the quality of achieving a low delay in the delivery of packages. This aspect substantially enhances the ability to achieve low latencies in message transmission.

4. Theory Principles and Simulation Results

4.1. Introduction to Theory Principles

This section will describe the performance of the proposal through the articulation of V2V/V2R or R2V communication in terms of communication protocols. Traffic scenarios will be detailed both on a single lane to highlight certain aspects and on three lanes to

increase the degree of complexity of scenarios to be able to implement in similar situations, in reality, even existing proposals or invoking the IEEE 802.11b standard [28,29].

We can say that in terms of the physical level, the sensitivity of the receiver can have values between -93.0 dBm and 98.0 dBm. In the case of simulations, standard values of -93.0 dBm were approached more precisely, and the data transfer rate in the case of IEEE 802.11b was between 1 Mbps and 11 Mbps; even in this case, the established values were standard ones. In addition, regarding the signal-to-noise ratio (SNR), we had a value of 10.0 dBm. Regarding the way of carrying out the data transmission and the cooperation of the V2V modules with the V2R or R2V modules, the average power received that has similarities for each vehicle is adjusted. We can say that the transmission power generated by transmitters dedicated to V2V communication can operate at a value between 10.0 dBm and 10.5 dBm, and the transmission power dedicated to V2R or R2V communication has a value between 9.0 dBm and 9.5 dBm. According to studies, omnidirectional antennas that have a loss factor of 0 dB are used in communications and mounted on vehicles, and for traffic units, large antennas are used that have a gain factor exceeding 20 dB. Therefore, the literature indicates a ratio of V2V communication in the transmission/reception process that exceeds 150m [30,31]. Another aspect is that when we talk about V2R and R2V communications, distances between 1300 m and 1500 m and proposed, an aspect that gives us the conviction that we can have coverage in terms of the roadside unit that includes distances of 1500 m. If we consider a general loss, the fading channels can be analyzed by the Rician distribution method, where the comparison of some K-type factors for the common information transmission protocol is studied. The Rician distribution model is based on a stochastic one to obtain radio propagation and analysis of propagation pathways, even if interferences are present. The Rician-type distribution has the probability of occurring in one of the propagation paths when a linear signal is stronger than the other. Thus, we can say that the K-type factor represents the ratio between the power of the direct path in the context with other paths, obtaining a scattering/dissipation factor [32,33].

$$f\left(x|v,\sigma\right) = \frac{x}{\sigma^2} \exp\left(\frac{-\left(x^2 + v^2\right)}{2\sigma^2}\right) I_0\left(\frac{xv}{\sigma^2}\right),\tag{1}$$

where $I_0(z)$ represents the Bessel function for zero-order operations.

In the context of accentuation by the Rician distribution method, the distribution can be represented by the expression of the parameter shape $K\frac{v^2}{2\sigma^2}$, which defines the ratio between the line-of-sight path contribution and the remaining multihop, and for the scale parameter $\Omega = v^2 + 2\sigma^2$, which represents the total power received by all possible means. In probability theory, variation is also analyzed, and we can even see the deviation of a random variation from the standard. This variation is treated by $f(x|v,\sigma)$, and the central area of incidence is analyzed, which also includes descriptive information, starting from a hypothesis that states that the data are sampled according to Equation (1). Subsequently, the information is exposed by $\frac{x}{\sigma^2}$, representing the emission between the blind area and the end of the platoon. The rest of the equation analyzes the square of the deviation from the standard on the central moments of distribution and also the covariation of the random variable, it being represented by the previous notation, exposing this random variable in the area of incidence from the moment of the event to the moment of receiving the message.

Therefore, in the MAC layer, we have an imposed limit of approximately eight for each item in the vehicle network, and the size of the warning message can be between 48 and 64 bytes. In the case of the process of periodic retransmission of messages from the source vehicle to the roadside information-processing unit, we have a set time interval of 0.03 s, and for communication and retransmission in the vicinity, the time is estimated of be 0.010 s [34–36].

Because of these aspects, the characteristic of transmitting warning messages, from vehicles behind the platoon with a time interval between 0 and 0.005 s, should not be neglected. We can also take into account the aspect of delays caused by the process gener-

ated by authentication and association, but these aspects were removed in the simulations performed, with the margin of error already introduced in the model described. This aspect is largely based on the assumption that when transmitting information via V2V or R2V communication, vehicles can send warning messages to the unit at the boundary of the running surface and be subject to association processes under restrictions and elements imposed by IEEE 802.11 standards [37,38].

Fading channel models are used in all test models that are performed on the basis of electromagnetic effects both for information transmitted in the air within cellular networks and in the case of diffuse communications. Fading channel models are also used in communications that model the distortion caused by various perturbations, elements that are analyzed according to the block diagram of the proposed multipath channel model in Figure 3.
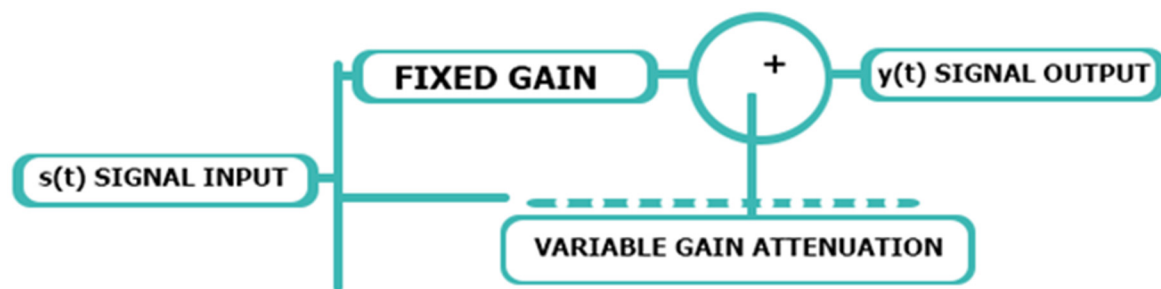

Figure 3. Multihop fading channel structure.

We performed simulations by analyzing the input signal by two different gains, one being a fixed gain and the other being a variable gain, which are caused by the volatility given by the areas of incidence and the flow of vehicles either from the platoon. The detailed model presupposes the analysis of the signals passing through a communication medium and the analysis of the random variation, this being blurred by the previously presented distribution or by the Rayleigh distribution under compromise conditions:

$$y(t) = g_1 \times s(t) + 0.5 \left[\tau \times g_2 \times s(t) \right] + 0.25 \left[\tau \times g_2 \times s(t) \right] + n(t) \quad (2)$$

Therefore, $y(t)$ is the signal from the output, $s(t)$ is the signal from the input, with τ being the delay or even the change in direction/phase, g_1 is the notation for the fixed gain and g_2 is that for the gain variable, and $n(t)$ is noise. This alternative comes to the aid of the previous stochastic model being a statistical model having the contribution of an intense propagation medium on the radio signal, extremely ideally mediating wireless devices. To analyze and generate the noise that we found in the section dedicated to simulations, the following function was used:

$$Syntax: y = AWGN(x, SNR, ' measured') \quad (3)$$

According to the Rician distribution model, this function adds a white Gaussian background to vector x. Thus, the scalar SNR returns the total signal-to-noise ratio for a segment in dB variation. When x becomes complex, additive white Gaussian noise (AWGN) also adds complex noise. The syntax is also used in MatLab simulations, which assume that the power of x is 0 dB. AWGN then calculates and measures the power of x before noise is added. We can say that the relative power of the noise in the case of a dissipated channel is described by small quantities such as:

(1) signal-to-noise ratio (SNR) analyzed for a sample;
(2) bit-analysis-type ratio for the sectional-type density of the noise power (Eb/N_0); and
(3) power-to-noise symbol-type ratio for spectral density power (Es/N_0).

Thus, a Bit error rate (BER) is relative to the number of bits analyzed and received incorrectly in balance with the total number of bits transmitted in a set time interval. The signal-to-noise ratio is defined by the signal strength and the noise power that disturbs or corrupts the signal. We can say that the presented and simulated model also efficiently compares the desired signal level by canceling the background noise through the iterations and constraints imposed by the common node.

$$SNR = \left(P_{signal} / P_{noise} \right) = \left(A_{signal} / A_{noise} \right)^2 \qquad (4)$$

We can say that when the effect of the BER is found on the SNR, and we have results that show that in a BER, the performance is clearly superior when we have a low SNR. When we have white Gaussian noise that is assumed to reflect the degree of environmental imperfection and traffic interference, the error dominates the BER, which is improved by simplifying the SNR. Thus, when BER performance is lower in fading channels and selective fading channels, the best alternative is AWGN. Therefore, a channel can be physically modeled when calculating the processes aimed at modifying the transmitted signal; in the case of simulations and scenarios performed, the sources are unlimited and can congest the transmission channels at any time. For example, in wireless communication, the channel can allow modeling by calculating the reflection of each object in the environment being identified in context in a scatter plot consistent with the x signal. We consider the interpretation of a complex vector and analyze the dissipation diagram that interprets the real part and the imaginary part into quadrature components. When x becomes real as a vector, the diagram shows the interpretation as a real signal in the case of simulations.

4.2. Practical Scenarios and Simulations Results

Consequently, approximately five scenarios were outlined in which various aspects were simulated to obtain the best results that were later taken into account to be discussed in this paper. Following the simulations in which we had one busy lane and the other free, the number of vehicles in circulation was 20 and they had a speed of 50 m/s. In the scenario in which the number of cars tripled, reaching approximately 55 vehicles, the speed was also kept at approximately 50 m/s and the width tread totaled about 5 m. According to the regulations imposed by the legislation and applying the preventive conduct between vehicles, a distance of approximately 50 m was kept, taking into account the length of each car of approximately 4 m [39]. Here is a detailed presentation of the vehicle illustration in Figure 4a,b, and the response of the receiving vehicles during the use of V2V or V2V communication:

(a) Illustration of the behavioral scheme of the receiving vehicles in the case of the V2R communication protocol, where the source vehicle sends warning messages to the RSU, waiting for the return of the messages with the event ID from the roadside unit;

(b) Illustration of the behavioral scheme of the receiving vehicles in the case of the V2V communication protocol, where the vehicles periodically send messages to other cars in nearby areas until the event ID is returned from the rear vehicles;

Experimental achievements based on numerical simulations are based on the theory and implementation method by which Jiang et al. [40] provided a starting point for calculating the coverage radius and the maximum length that a junction can cover. Data on road traffic and the number of lanes on which the protocol performance analysis is performed depending on the exposure of the Rician channel are predetermined, inserting a determining K-type factor that can vary from 20 to 60, depending on the degree of load of the junction. The simulation results validate the possibility of using a common node and emphasize that there is a guarantee of a stable connection and the ability to cover sufficient distances.

Regarding the simulation process, the road infrastructure was designed using dedicated AnyLogic software; subsequently, the scenarios were considered and the parameters were set, according to which the following results were obtained.
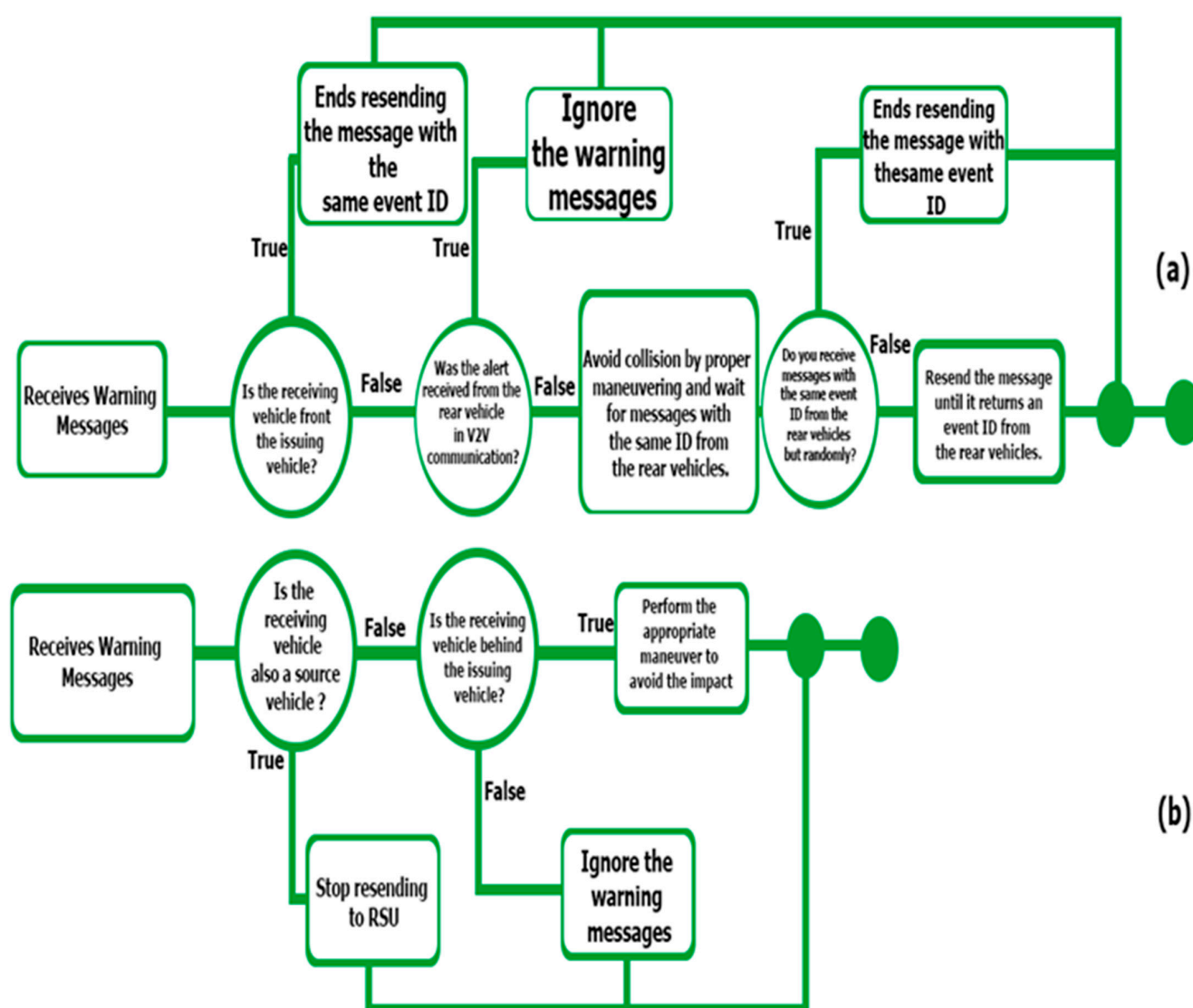
Figure 4. Flowchart showing the response of the receiving vehicles while using V2R or V2V communication. (**a**) V2R communication protocol; (**b**) V2V communication protocol.

An aspect that is not taken into account in this paper is related to the braking process, because the main objective is to manage and perform in the area of improving the delivery ratio of data packets or messages, reducing delays, and exploiting diversity and transmission factors on various channels. Simulations are performed in one direction and a certain direction, the process is similar in both cases, but the model can expand the area and can analyze a much wider road segment. When vehicles receive messages about a possible accident including location information, they can also identify the direction of travel of the problem vehicle. We can also say that in Figure 1, the guarantee of the performance of the V2V/V2R or R2V joint communication protocol is the analysis in a running scenario with the circulation on a single lane. This scenario provides a message delivery report for the three communication protocols, namely the protocol that uses V2V communication, as described in Figure 4a, which uses only V2V or R2V communication. As shown in the two components, there is also a common V2V/V2R or R2V protocol being studied and exposed in Figure 4, where we obtain the factor F related to the Rician channel, which has a value of 50, but also in Figure 5, where the exposed K-type factor has a value of 20. We can say that these two constants show that V2V and V2R or R2V protocols have the quality of significantly improving the message delivery process. and this can later achieve enhanced performance. Thus, it is demonstrated that a communication that is based on the

diversity of transmission routes and through complementary protocols can overcome the elements that distort and create insecurity of the wireless channel in extremely complex environments with high mobility. If we make an objective comparison between the results presented in Figures 5 and 6, we can reach the first stage of conclusions that present a series of notable and reasonable elements of how reliable the wireless channel is; it has a higher rate of penetration and transmission of messages [41].

However, the effect of latencies on these protocols was also analyzed and is shown in Figures 7–10, where delays in the message delivery process are reported and durations in the delay interval are defined. Here, the generation time for the source vehicle and also the whole process by which the information is dissipated and reaches the final destination in an appropriate form are included. We can see that in these illustrated simulations, it is reported that the common protocol, through its complementary features, achieves high performance and that the model reports delays in the delivery of data packets and messages with a duration of less than ≤ 5 ms and 9 ms, with small deficiencies for vehicles further away.

We can say that not only does the proposal reproduce all the necessary characteristics and can achieve low latencies in the transmission of messages but also we can have a new direction of research and implementation in real scenarios. Therefore, in the future, V2V and vehicle-to-everything (V2X) systems developed by Cohda Wireless will be used, and these systems will work simultaneously, as in the exposed simulations and according to the proposed scenarios. The systems benefit from elements dedicated to a platoon of 6–9 vehicles and a roadside unit (RSU) for the centralization of information.
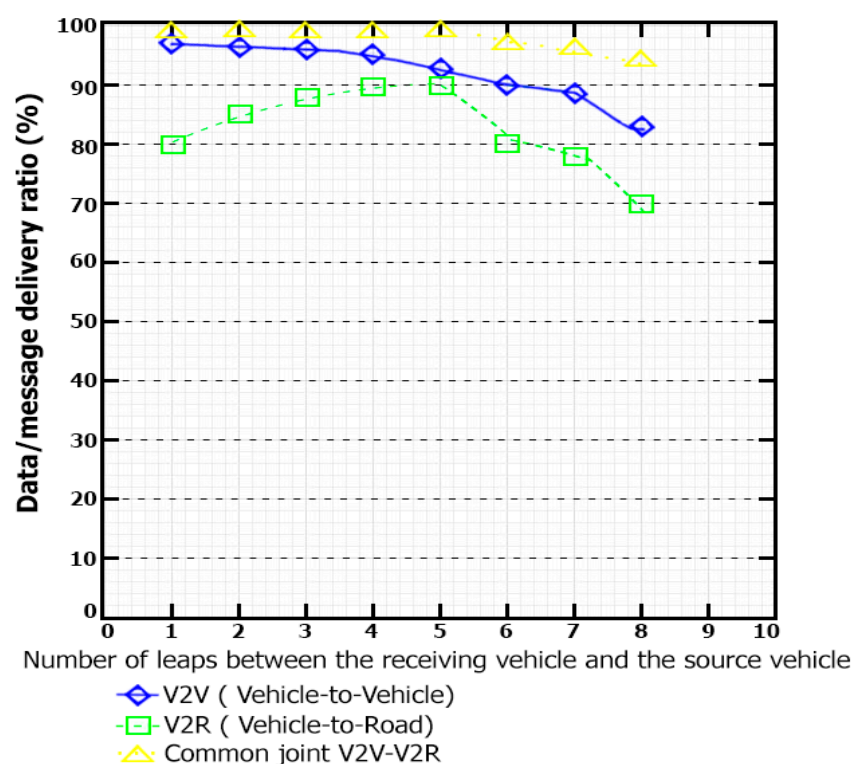

Figure 5. Simulation of a high-speed road traffic scenario on a single band, which analyzes the performance of the message delivery process by using the three types of communication protocols exposed in a Rician channel that has a determined K-type factor of 50.
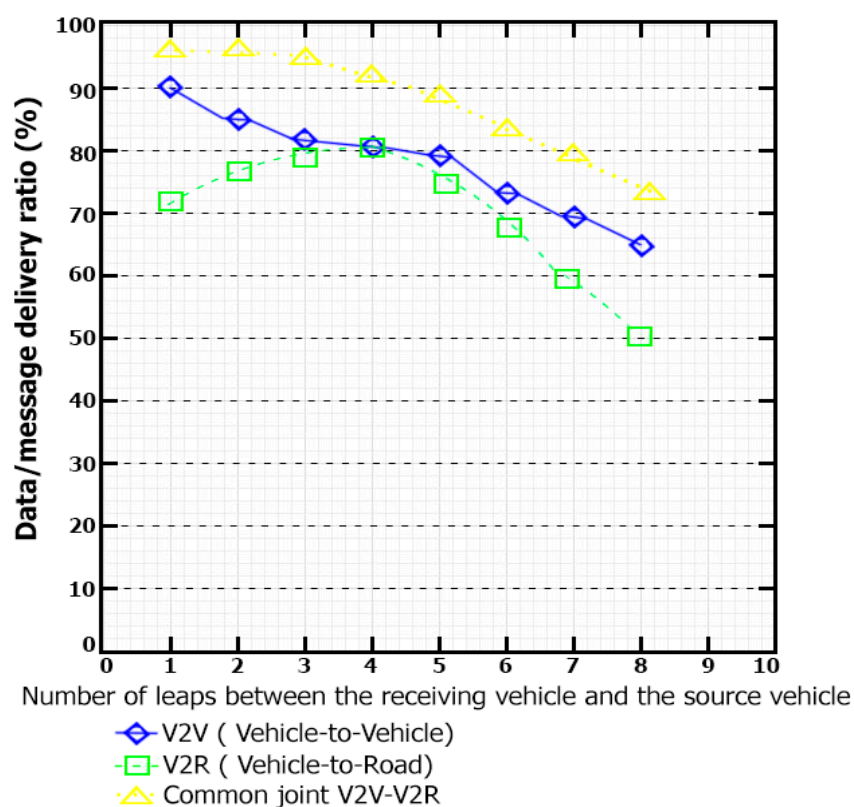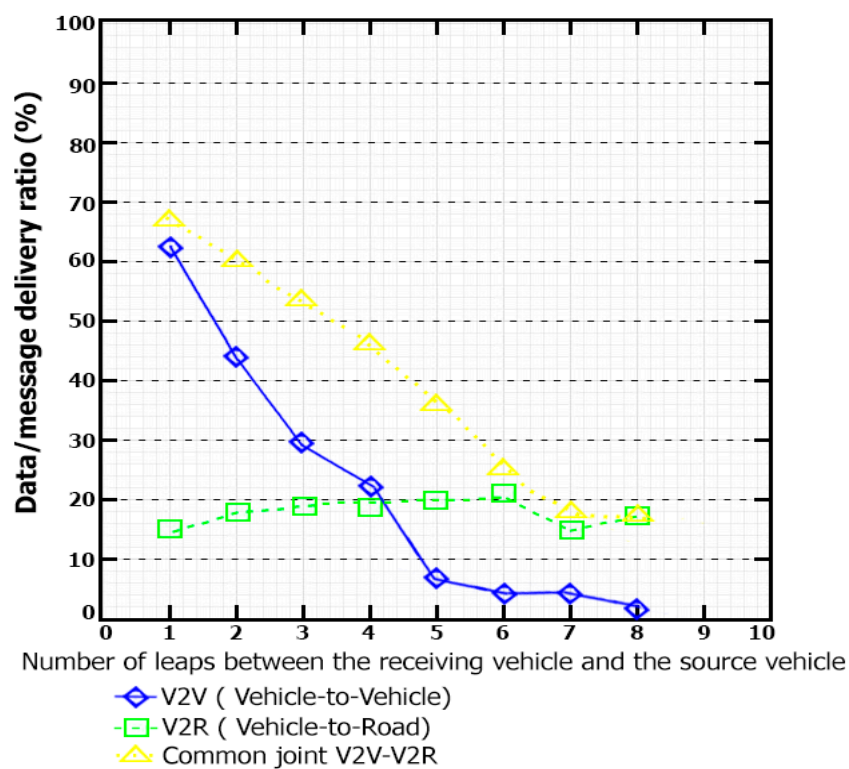
Figure 6. Simulation of a high-speed road traffic scenario on a single band, which analyzes the performance of the message delivery process by using the three types of communication protocols exposed in a Rician channel that has a determined K-type factor of 30.

Figure 7. Simulation of a high-speed road traffic scenario on a single lane, with a delay ratio of <5 ms in the message delivery process when using the three communication protocols exposed in a Rician channel that has a determined K-type factor of 60.
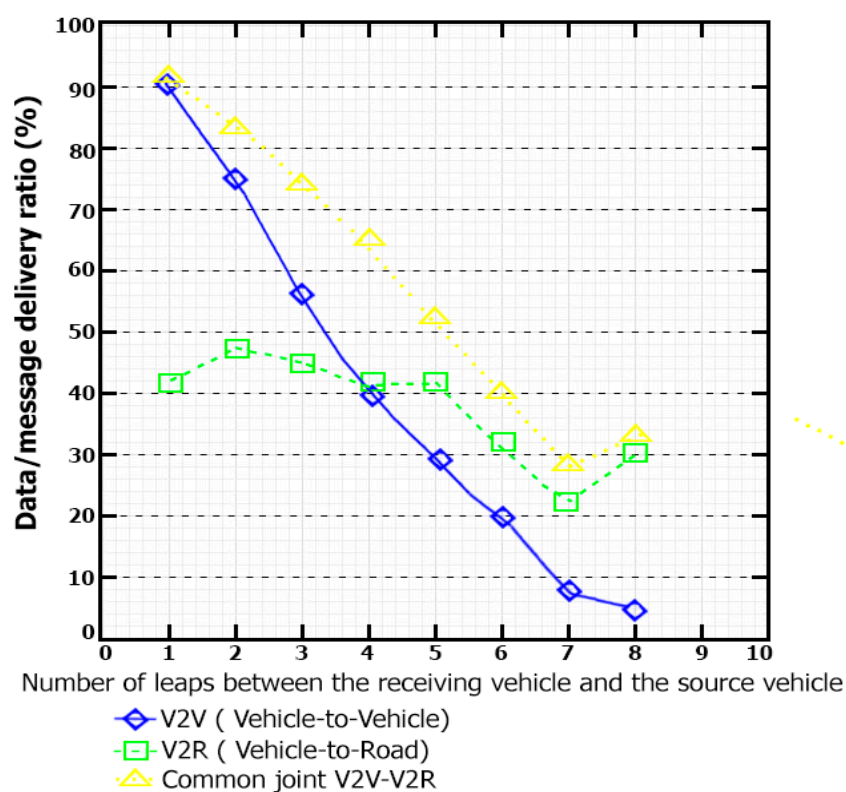
Figure 8. Simulation of a high-speed road traffic scenario on a single lane, with a delay ratio of <9 ms in the message delivery process when using the three communication protocols exposed in a Rician channel that has a determined K-type factor of 60.
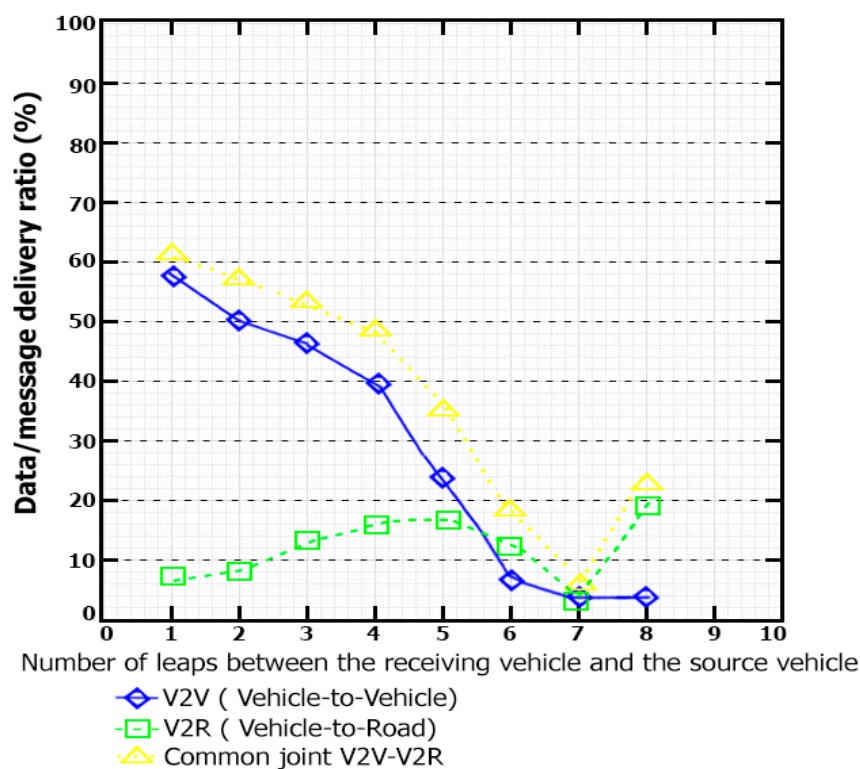

Figure 9. Simulation of a high-speed road traffic schedule on a single lane, with a delay ratio of <5 ms in the message delivery process when using the three communication protocols exposed in a Rician channel that has a determined K-type factor of 30.

Figure 10. Simulation of a high-speed road traffic schedule on a single lane, with a delay ratio of <9 ms in the message delivery process when using the three communication protocols exposed in a Rician channel that has a determined K-type factor of 30.
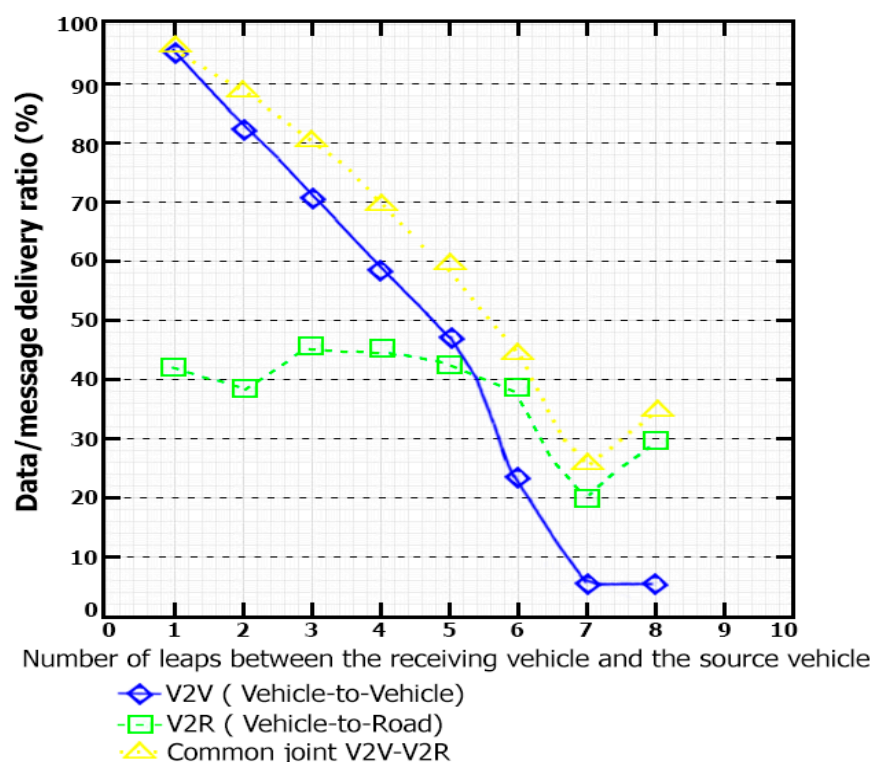
For a more efficient presentation of the proposals in this manuscript, scenarios with heavy traffic were also considered, in addition to a higher traffic flow in which the proposed common protocol was simulated using the V2V/V2R common communication protocol and vice versa, as can be seen in Figure 11 [42,43]. Thus, the results of the simulations are notable and correspond to the requirements being presented by the simulations in Figures 12 and 13, which demonstrate the performance of the V2V/V2R common communication protocol and vice versa and can be seen including the degree of medium to low delay in the delivery of simultaneous messages.

Therefore, the proposed scenarios expose the capacity of the V2V/V2R common communication protocol and the achievement of low latencies concerning message delivery. As can be seen in Figure 14, this proposed common protocol has the necessary capacity to meet all requirements but at the same time to exceed a standard V2V communication, even when an emitter or a source vehicle does not have the ability to interact and communicate with data collection units. We can say that Figure 15 is an additional investigation to confirm the proposals in the multilateral scenario presented in Figure 11 when the source vehicle has the ability to communicate with roadside units on the road.
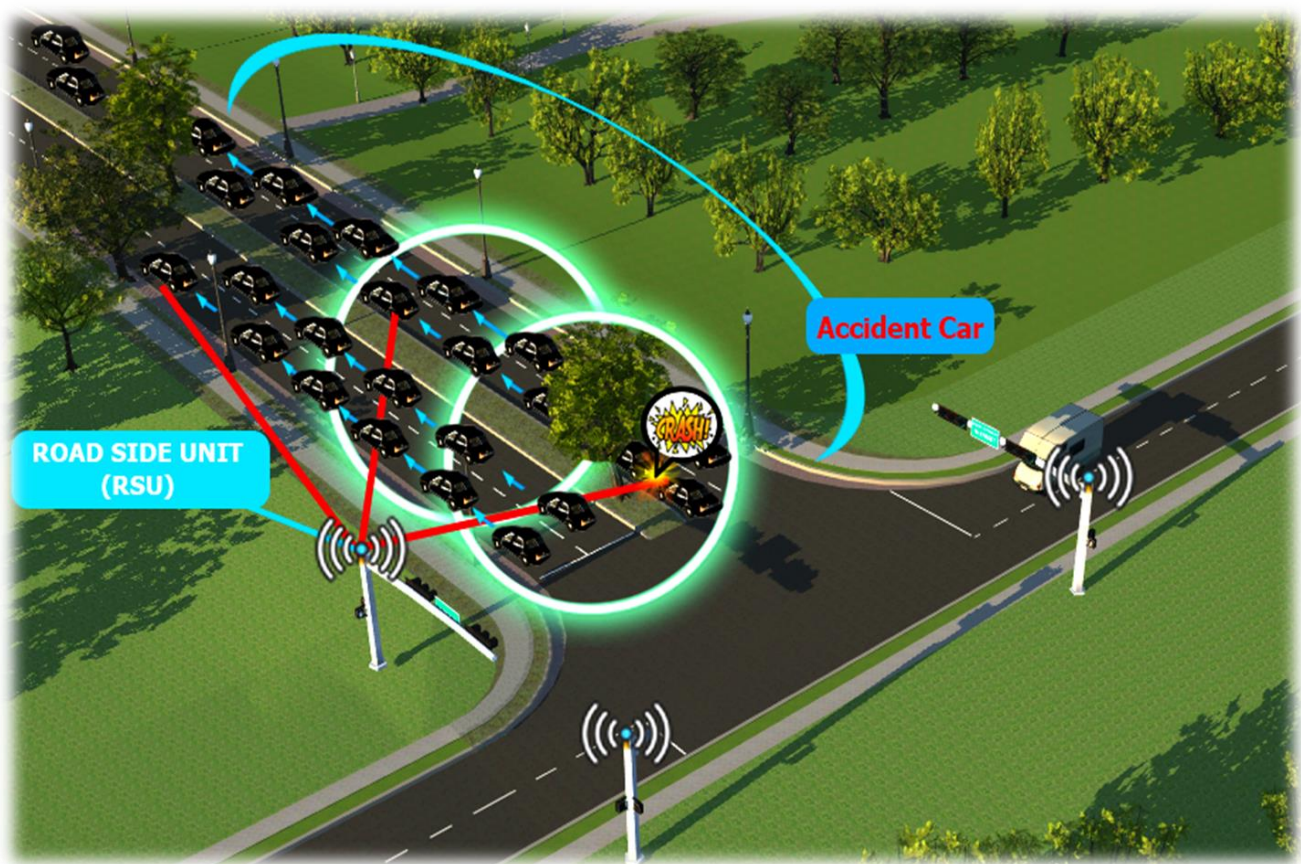
Figure 11. Illustration of a traffic scenario on a high-speed road with more lanes and more cars, the communication also being based on V2V and V2R or R2V communication protocols to increase the degree of public and road safety.
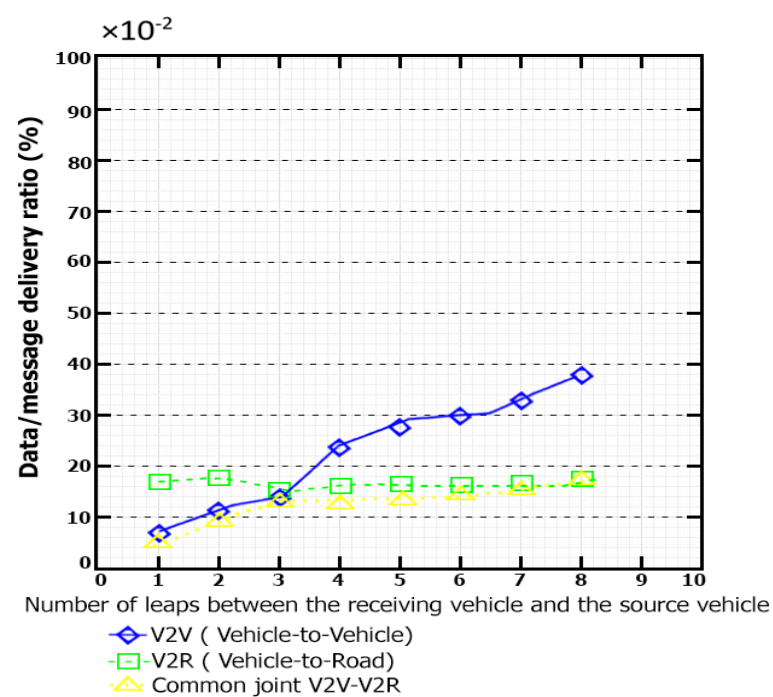

Figure 12. Simulation of a high-speed road traffic program on several lanes, analyzing the delay and performance in the case of using the three communication protocols by managing a Rician channel that has a determined K-type factor of 60.

Figure 13. Simulation of a high-speed road traffic program on several lanes, analyzing the delay and performance in the case of using the three communication protocols by managing a Rician channel that has a determined K-type factor of 30.
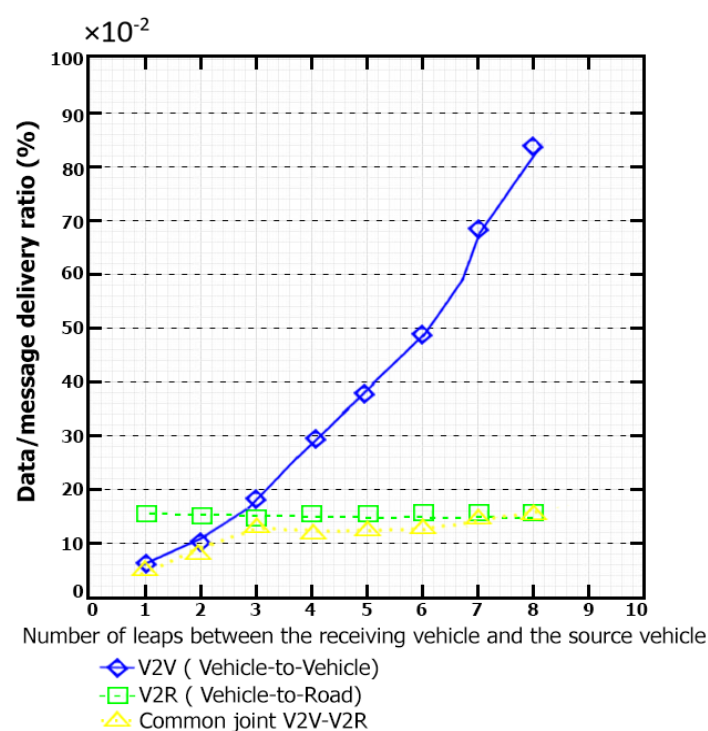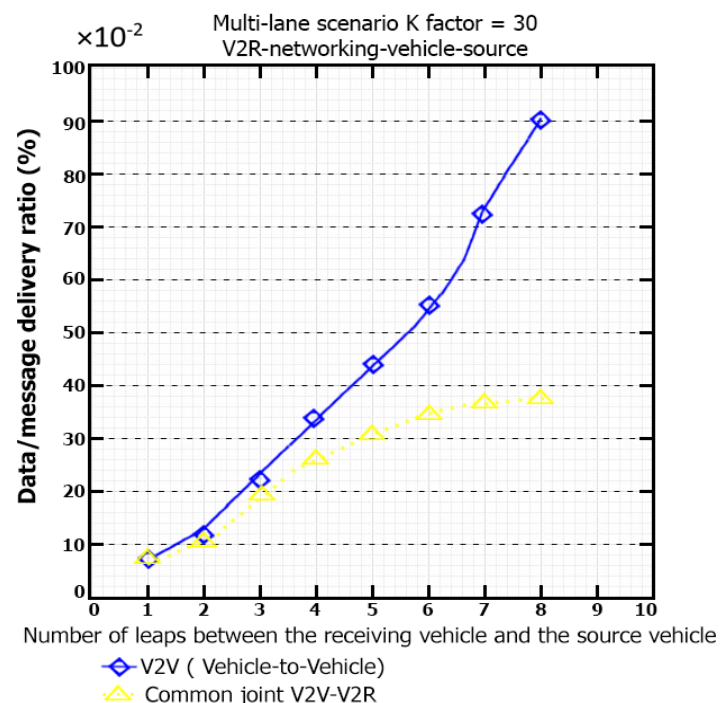

Figure 14. Simulation of a high-speed traffic scenario on several lanes, analyzing a vehicle that is the source but is not able to communicate with the roadside unit (RSU) installed.

5. Discussion

In this paper, a common communication method was proposed through the use of V2V and V2R communication protocols, and also vice versa, incorporating these communications in the road and social infrastructure for a flexible cooperation process, dedicated to

the issues set out in the introductory sections. Another aspect was to demonstrate through simulation scenarios the degree of reliability of communication and how to obtain low latencies if we use the two protocols in a single mechanism, exploiting the capacity and diversity of how data are transmitted. This analysis highlighted that communication based on diversity and several communication channels included in a common protocol offer flexibility and achieve results outlining more future possibilities. The mode of communication can eliminate the impact of the wireless channel by leading everything in a perfectly controllable environment with increased mobility, which offers the ability to improve the process of sending messages. We can say that the studies performed and the simulated processes provide a clear answer in terms of the delivery report of warning messages on account of the results on low latencies and the way of delivery structured on dense levels without generating losses in networks. Therefore, the study also analyzed experimental data and simulations performed in previous research on optical communications based on communication protocols such as visible light communication (VLC), DSRC, and V2X communication [44,45].

The study highlights that the average delay in warning messages transmitted using the proposed communications is between 0.08 and 0.011 s, taking into account the distance factor between the vehicle reception area and the source vehicle. The scenarios were outlined on real criteria and were determined following the analysis of some traffic processes. The average delay obtained provides a guarantee of the direct process of reducing the delay in the process of flashing messages, even for vehicles at a distance of three lengths. In a subsequent process, the information is condensed and introduced in a simulation act that provides a complex scenario in which the density of vehicles is unlimited and without setting a certain direction in terms of communication.

Figure 15. Illustration regarding a traffic scenario with several lanes in each direction without communication protocols, highlighting the extension and blockages produced by the lack of controlled road traffic.

This aspect is presented in Figure 15, where you can see the degree of congestion and traffic jams generated by poor control and traffic management if there is no communication protocol or intelligent transport system [46–50].

6. Conclusions

We can say that in the context of highlighted concerns and the development of solutions to substantially improve the safety of urban traffic and high-speed traffic, this paper addressed some of the issues in current systems and proposed elements with adequate symmetry to solve those issues. The paper also investigated the opportunity to use common and adapted communication protocols, depending on the context of the situation, coding techniques, and scenarios based on real data, analysis of transfer rates, and reception of messages according to the type of protocol used. Therefore, this article offers remarkable results and outlines an important research direction, so this type of common communication contributes to diminishing the problems that the current society faces. These simulations managed to adequately expose the distribution and transmission of information based on V2V and V2R communication protocols or vice versa. These simulations are a continuation of the previous stages of study in the direction of road safety and the reduction in the degree of congestion, with solid notions and practical cases considered. However, due to the current limitations and technology and also the communication frequency legislation, there may be transmission delays and sometimes packet losses in V2V or V2R communication and those related to infrastructure. These may make the transmission process more difficult, and some vehicles may not receive messages in a timely manner. Therefore, one of the future directions in our studies aims to analyze and create scenarios highlighting the considerations created by traffic flow characteristics marked by factors that generate delays or elements that disrupt the sending and loss of packets in the communication process.

Future work in this direction involves expanding measurements and scenarios by conducting practical experiments based on dedicated communication platforms. According to the specifications of this article, in the future, experimental measurements will be performed with the help of equipment based on V2X–V2I and/or V2V–V2R communication (produced by Cohda Wireless). In the perspective of future developmental needs, it is necessary to put into practice the simulated scenarios and appropriately highlight of the characteristics that underlie the complementarity of a common node based on V2V and R2V communication protocols. Evaluation and real analysis of the adaptability of the systems and also of the way in which the technique of receiving messages adapts according to the context are important. Implementation of a reconfigurable system and multi-core units in order to increase the processing power in order to properly evaluate vehicular communications is also important. A challenge but also a need is testing the capacity of robustness and performance under conditions of massive congestion and urban traffic. This direction will aim at analyzing and improving the robustness of systems and increasing communication distances and latencies. Another aspect is the development of reconfigurable V2V and V2I architectures adaptable to the context. The aims of future work are to fully demonstrate and confirm the need for such communications to be used for road and automotive applications [51].

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Abbreviations

VANET	Vehicular ad hoc network
MC	Multi-channel
V2V	Vehicle-to-vehicle
V2R	Vehicle-to-road
R2V	Road-to-vehicle
ITS	Intelligent transportation system
DSRC	Dedicated short-range communication
ASTM	American Society for Testing and Materials
OFDM	Orthogonal frequency-division multiplexing
CSMA/CA	Carrier/sense multiple access with collision avoidance
MAC	Medium access control
TDMA	Time-division multiple access
AODV	Ad hoc distance vector
ID	Identifier
CFP	Contention-dree period
CP	Containment period
WAVE	Wireless access in the average vehicle
BSSID	Basic Service Set Identification
RSU	Roadside unit
GPS	Global Positioning System
PHY	Physical layer
SNR	Signal-to-noise ratio
V2X	Vehicle-to-everything
VLC	Visible light communication
V2I	Vehicle-to-infrastructure
AWGN	Additive white Gaussian noise

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