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Decentralized Vehicle-to-Vehicle (V2V) Intelligent and Sustainable Communications for Improving Traffic Safety

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ABSTRACT Intelligent and sustainable vehicle networking (ISVN) is a promising new paradigm for transportation that leverages advances in vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication to enable vehicles to cooperate with each other and with the infrastructure to improve traffic safety and sustainability. Centralized V2V communication systems have limitations in terms of reliability and scalability, limiting their ability to meet the growing demands of ISVN. This paper proposes a decentralized V2V communication system that addresses the limitations of centralized systems by using a decentralized, collaborative, and intelligent approach. The proposed system consists of three main components: on-board vehicle units (OBUs), roadside units (RSUs), and a cloud server. The proposed system has the potential to significantly improve ISVN by enabling vehicles to cooperate with each other and with the infrastructure to improve traffic safety, efficiency, sustainability, and scalability. Specifically, the proposed system can improve traffic safety by reducing the number and severity of traffic accident. In addition, it will enhance traffic efficiency by enabling vehicles to optimize their routes and speeds. Also, it will elevate the scalability and reliability of ISVN by eliminating the need for a central fusion server. The proposed system is implemented using the Veins simulator, which is one of the most respected simulators for V2V communications systems. The proposed system outperforms other traditional centralized systems in several ways, including increased reliability and reduced latency.

Keywords: *V2V communication, Intelligent Transportation Systems (ITS), Intelligent and Sustainable Vehicle Networking (ISVN), Sustainable Transportation, Decentralization, and Collaboration.*

I. INTRODUCTION

Road accidents are a major cause of deaths and injuries worldwide, accounting for over 1.3 million fatalities each year. According to the World Health Organization, road accidents are the leading cause of death for young people aged 15-29 years [1]. Many of these accidents could be prevented if vehicles were able to communicate with each other and warn each other of hazards. Vehicle-to-vehicle (V2V) communication systems enable vehicles to communicate directly with each other without the need for a central infrastructure. This makes them more reliable and robust than traditional centralized systems. Decentralized V2V communication systems are a promising new technology for improving traffic safety. They allow vehicles to share information about their position, speed, and other relevant parameters, which can be used to warn drivers potential hazards and to coordinate braking and lane changes [2, 3]. One of the key benefits of decentralized V2V communication systems is that they can be used to warn vehicles of accidents. When a vehicle involved in an accident sends out a warning message, all other vehicles in the vicinity will receive the message and be able to take evasive action. This can help to prevent collisions and reduce the severity of accidents [4, 5]. Decentralized V2V communication systems can also be used to improve traffic flow and reduce congestion. By sharing information about their position and speed, vehicles can coordinate their movements and avoid jams. This can lead to shorter travel times and less fuel consumption [6, 7]. In addition to accident warning and traffic flow improvement, decentralized V2V communication systems can also be used for a variety of other applications, such as: Cooperative collision avoidance, Cooperative adaptive cruise control, Cooperative lane changing, Green light optimal speed advisory, and Vehicle platooning.

Decentralized V2V communication systems are still under development, but they have the potential to significantly improve traffic safety and efficiency [8]. A number of field trials and pilot researches are currently underway to evaluate the performance of decentralized V2V communication systems in real-world traffic conditions [9]. The Veins simulator [10] was used to evaluate the performance of the decentralized V2V communication system for accident warning. The Veins simulator is an open-source framework for running vehicular network simulations. It is based on two well-established simulators: OMNeT++, an event-based network simulator [11], and SUMO, a road traffic simulator. Veins extends these simulators to offer a comprehensive suite of models for IVC simulation [12]. The Veins simulator was chosen for this system because it is a widely used and well-respected simulator for vehicular network simulations. It offers a variety of features that are important for evaluating the performance of V2V communication systems, such as: Realistic modeling of vehicle movement and communication, support for a variety of V2V communication protocols, and the ability to simulate large and complex traffic scenarios [13].

This paper proposes a decentralized V2V communication system for intelligent and sustainable vehicle networking (ISVN). The proposed system leverages the principles of decentralization, collaboration, and intelligence to achieve high efficiency. The system architecture consists of three main components: on-board vehicle units (OBUs), roadside units (RSUs), and a cloud server. OBUs are responsible for V2V communication, sensor data processing, and intelligent decision-making. RSUs collect traffic data from vehicles and broadcast messages to vehicles to inform them of traffic conditions, accidents, and other important information. The cloud server stores and processes traffic data from RSUs and OBUs to generate insights into traffic patterns and trends, and to develop and deploy intelligent algorithms to RSUs and OBUs to improve the performance of the system. The proposed system's ability to connect vehicles and infrastructure promises a significant improvement in ISVN, enhancing environmental sustainability.

The paper is organized as follows: Section II reviews relevant prior work, Section III details the proposed system model, Section IV showcases performance evaluation findings, and Section V concludes by summarizing the work and suggesting avenues for future exploration.

II. Motivation

Decentralized vehicle-to-vehicle (V2V) communication systems for accident warning have been the subject of much research in recent years. A number of different approaches have been proposed, each with its own strengths and weaknesses. One of the most common approaches is to use a broadcast-based protocol [3]. In this type of protocol, all vehicles in a certain area are notified of an accident when it occurs. This approach is simple to implement and can be very effective in warning vehicles of nearby accidents. However, it can also be inefficient, as it can lead to a lot of unnecessary messages being sent [4]. Another approach is to use a cluster-based protocol [14]. In this type of protocol, vehicles are grouped into clusters. When an accident occurs, only the vehicles in the affected cluster are notified. This approach is more efficient than a broadcast-based protocol, but it can be more complex to implement and may not be as effective in warning vehicles of distant accidents [15]. A number of hybrid protocols have also been proposed [16]. These protocols combine elements of both broadcast-based and cluster-based protocols. For example, a hybrid protocol might use a broadcast-based protocol to notify vehicles of nearby accidents and a cluster-based protocol to notify vehicles of distant accidents [17]. In addition to the different protocol approaches, there are also a number of different MAC layer protocols that can be used for V2V communication [18]. One of the most popular MAC layer protocols for V2V communication is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). CSMA/CA is a simple and efficient protocol that allows vehicles to coordinate their transmissions and avoid collisions. Another popular MAC layer protocol for V2V communication is Time Division Multiple Access (TDMA). TDMA is a more complex protocol, but it can be more efficient than CSMA/CA in high-traffic scenarios [19].

III. Methodology

The proposed system achieves the key principles of decentralization, collaboration, and intelligence that are essential for building a robust and scalable system.

A. System Architecture

The system architecture is shown in Figure 1, it consists of three main components:

1. On-board vehicle unit (OBU): The OBU is a device installed in each vehicle. It is responsible for the following tasks:

   • V2V communication: The OBU communicates with other OBUs using a dedicated short-range communication (DSRC) protocol.

• Sensor data processing: The OBU processes data from the vehicle's sensors, such as radar, lidar, and cameras, to generate a local map of the vehicle's surroundings.

• Intelligent decision-making: The OBU uses the local map and other information to make decisions about the vehicle's speed, acceleration, lane changes, and other actions.

2. Roadside unit (RSU): The RSU is a device installed at strategic locations on the road. It is responsible for the following tasks:

• Collecting traffic data from vehicles: The RSU collects beacon messages from vehicles to generate a real-time view of traffic conditions.

• Monitoring traffic conditions: The RSU uses the collected traffic data to monitor traffic conditions and identify anomalies, such as congestion and accidents.

• Disseminating information to vehicles: The RSU broadcasts messages to vehicles to inform them of traffic conditions, accidents, and other important information.

3. Cloud server: The cloud server is a central repository for traffic data and intelligent algorithms. It is responsible for the following tasks:

• Storing and processing traffic data: The cloud server stores and processes traffic data from RSUs and OBUs to generate insights into traffic patterns and trends.

• Developing and deploying intelligent algorithms: The cloud server develops and deploys intelligent algorithms to RSUs and OBUs to improve the performance of the system.

• Storing and processing traffic data: The cloud server stores and processes traffic data from RSUs and OBUs to generate insights into traffic patterns and trends.

• Developing and deploying intelligent algorithms: The cloud server develops and deploys intelligent algorithms to RSUs and OBUs to improve the performance of the system.

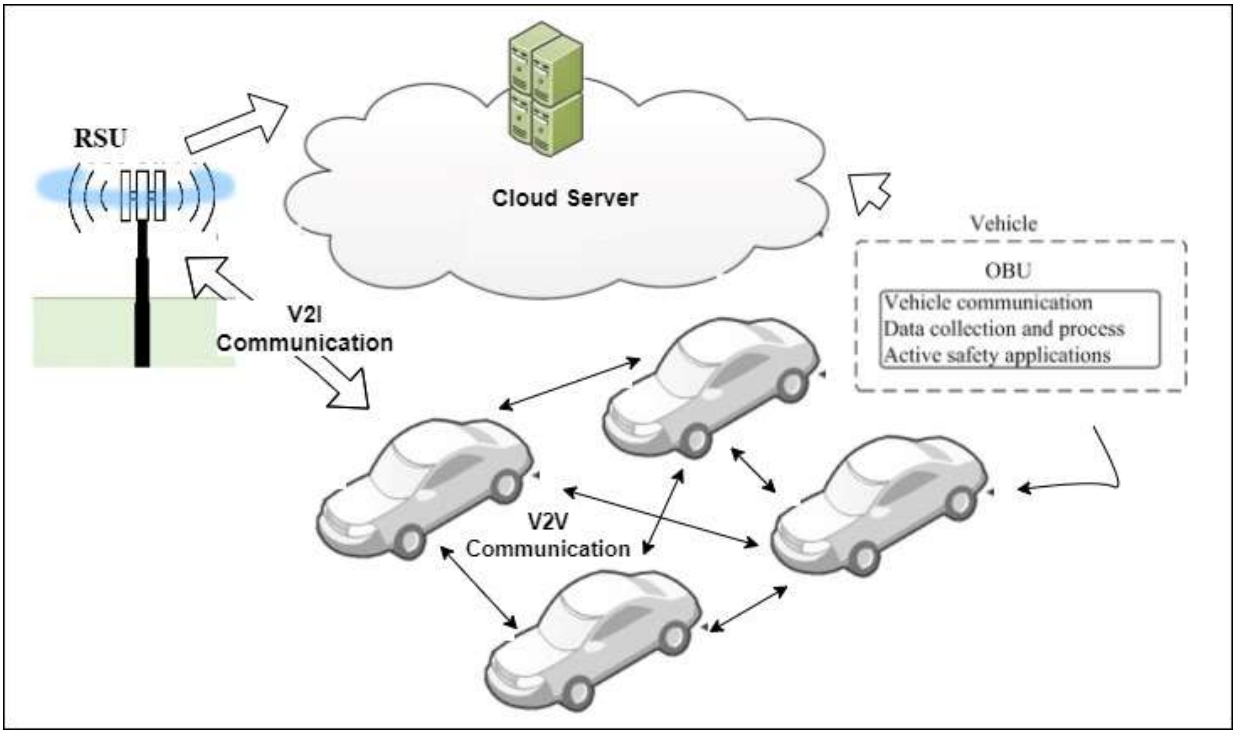


FIGURE 1: **Proposed System Model**

B. System Operation

The system operates with three main components: on-board vehicle units (OBUs), roadside units (RSUs), and a cloud server. Specifically, Figure 1 shows that OBUs communicate with each other directly using V2V communication. The arrows between the components indicate the flow of information between them OBUs also communicate with RSUs, which collect traffic data from vehicles and broadcast messages to vehicles to inform them of traffic conditions, accidents, and other important information. The cloud server stores and processes traffic data from RSUs and OBUs to generate insights into traffic patterns and trends, and to develop and deploy intelligent algorithms to RSUs and OBUs to improve the performance of the system.

The system also handles the different types of information that are exchanged between the components of the system. For example, OBUs exchange beacon messages with each other to share their position, speed, and direction of travel. RSUs collect beacon messages from vehicles and use them to generate a real-time view of traffic conditions. The cloud server stores and processes traffic data from RSUs and OBUs to generate insights into traffic patterns and trends. We can summarize the system operation in the following way:

1. Vehicles periodically broadcast beacon messages containing their position, speed, and direction of travel.
2. Vehicles receive beacon messages from other vehicles and use them to construct a local map of their surroundings.
3. Vehicles use the local map to make intelligent decisions about their speed, acceleration, lane changes, and other actions.
4. RSUs collect beacon messages from vehicles and use them to generate a real-time view of traffic conditions.
5. If an RSU detects an anomaly in traffic conditions, such as congestion or an accident, it broadcasts a message to vehicles in the area.
6. Vehicles receive messages from RSUs and adjust their behavior accordingly.

C. Scenarios

The system can be used to support a variety of scenarios, including:

1. Vehicle test for obstacle and message broadcast: In this scenario, a vehicle detects an obstacle and broadcasts a warning message to other vehicles in its vicinity. Other vehicles receive the warning message and take appropriate action, such as slowing down or changing lanes.
2. Accident detection and response: In this scenario, an RSU detects an accident and informs all vehicles in the area. Vehicles receive the message and take appropriate action, such as slowing down or taking an alternative route.
3. Emergency vehicle passing: In this scenario, an emergency vehicle needs to pass other vehicles on a highway with no empty lanes. The emergency vehicle broadcasts a priority message to other vehicles in its vicinity. Other vehicles receive the priority message and take appropriate action, such as slowing down and moving to the side of the road.

D. Statistical Measurements

The following statistical measurements can be collected to assess the performance of the system:

- Response time of vehicles to warning messages
- Speed and acceleration of vehicles before and after receiving warning messages
- Distance between vehicles and obstacles when warning messages are received
- Number of vehicles that take alternative routes to avoid accidents
- Speed and acceleration of vehicles before and after receiving emergency vehicle passing requests
- Compute when, where and how Radio Media transmissions and noises arrive at receivers

E. Simulator Structure

The simulator should model the following components:

- Vehicle movement and dynamics: The simulator should model the movement and dynamics of vehicles in a realistic way.
- V2V communication channel: The simulator should model the V2V communication channel, including factors such as latency, bandwidth, and interference.
- RSU operation and accident detection: The simulator should model the operation of RSUs, including their ability to detect accidents.

- Accident response behavior of vehicles: The simulator should model the accident response behavior of vehicles.

The Veins simulator was used to evaluate the performance of the decentralized V2V communication system for accident warning. The Veins simulator is an open-source framework for running vehicular network simulations. It is based on two well-established simulators: OMNeT++, an event-based network simulator, and SUMO, a road traffic simulator. Veins extends these simulators to offer a comprehensive suite of models for IVC simulation. The Veins simulator was chosen for this project because it is a widely used and well-respected simulator for vehicular network simulations. It offers a variety of features that are important for evaluating the performance of V2V communication systems, such as:
Realistic modeling of vehicle movement and communication support for a variety of V2V communication protocols the ability to simulate large and complex traffic scenarios

The *Veins* simulator was used to simulate three highway scenarios:
Scenario I: A vehicle encounters an obstacle in the road and warns other vehicles of the obstacle as shown in Figure 2.

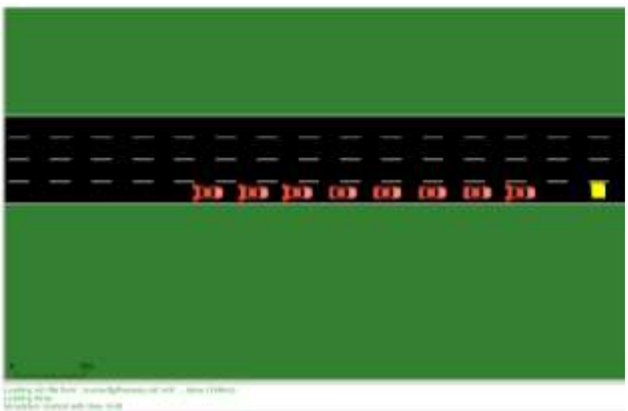


FIGURE 2: ***Sumo-gui's Appearance for Scenario I***

Scenario II: A vehicle makes an accident and warns other vehicles of the accident.

FIGURE 3: **The Vehicles before the Accident.**

Scenario III: An emergency vehicle needs to pass other vehicles on a highway with no empty lanes as shown in Figure 3 and 4 for two deferent test cases.

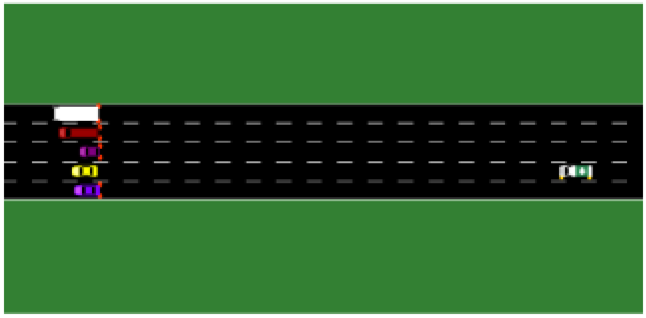


FIGURE 4: **Emergency Scenario test I.**

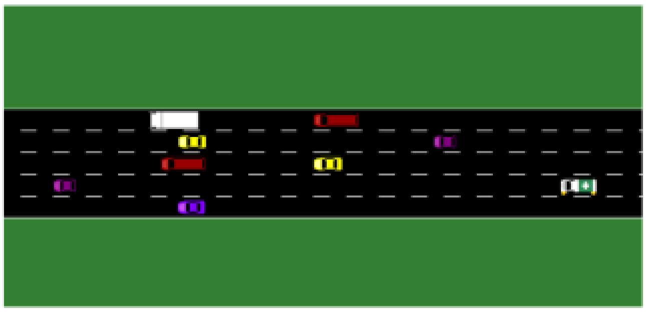


FIGURE 5: **Emergency Scenario test II.**

IV. PERFORMANCE EVALUATION

A. Scenario I

Figure 6 shows the output results from the simulator related to scenario 1, Running of Sumo and Omnet++ of Highway with the following parameters:

- The vehicles are moving at a speed of 100 km/h.
- The vehicles are decelerating at a rate of 8 m/s2.
- The Airframe11p is transmitted with a delay of less than 1 ms.

FIGURE 6: **Running of Sumo and Omnet++ of Highway Scenario I**

The Figure 6 shows the following:

- The positions of the vehicles on the highway.
- The speed of each vehicle.
- The acceleration of each vehicle.
- The distance between each vehicle.

Also the below are the Airframe11p details, which includes the following:

- Source vehicle ID.
- Destination vehicle ID.
- Frame sequence number.
- Frame size.
- Frame transmission delay.

It shows that the Airframe11p is transmitted with a very high speed, with barely noticeable delay between the message arrival to the next node and the last node. This is because the Airframe11p is transmitted using a dedicated short-range communication (DSRC) protocol, which is designed for high-speed communication between vehicles, also shows that the vehicles are able to decelerate quickly when they see an obstacle. This is because the vehicles are communicating with each other using the decentralized V2V communication system, which allows them to warn each other of obstacles and accidents.

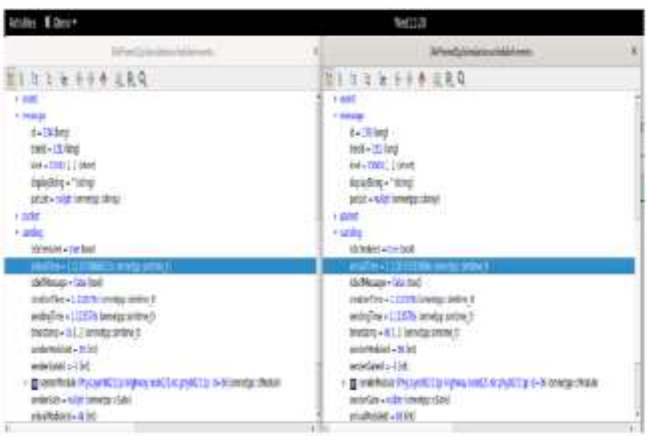


FIGURE 7: ***The AirFrame11p Details I***

As shown in Figure 7, the Airframe is transmitted with a very high speed. The delay between the message arrival to the next node and the last node is barely noticeable, which is to be expected given the high speed of DSRC communication. This is a significant advantage of the decentralized V2V communication system, as it allows vehicles to communicate with each other very quickly and efficiently. This is essential for applications such as obstacle avoidance and accident warning, where vehicles need to be able to react to changes in the traffic environment in real time. Once the first vehicle sees an obstacle it starts to decelerate till it stops and send a frame to the other vehicles to warn them and the other vehicles starts to decelerate with rate 8 Mps.

The following is the statistics of the speed, acceleration, and distance between all the 8 nodes of the cars.

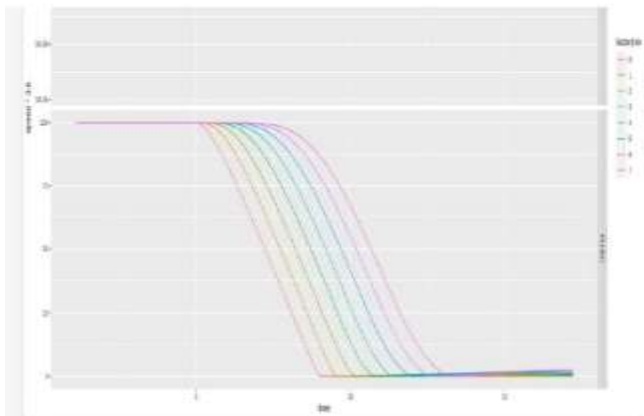


FIGURE 8: **Speed Statistics of node [0 ... 7]**

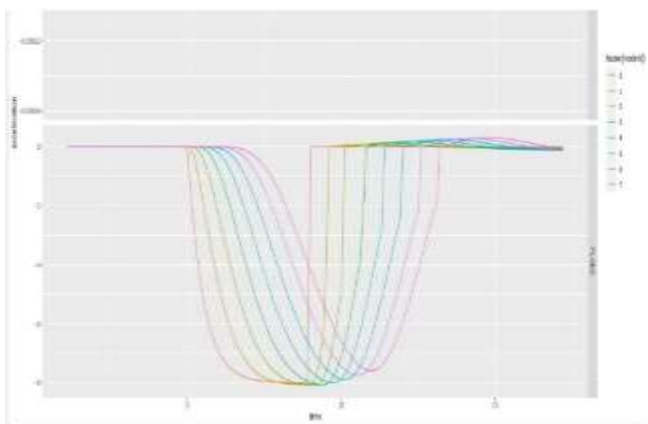


FIGURE 9: **Acceleration Statistics of node [0 ... 7]**

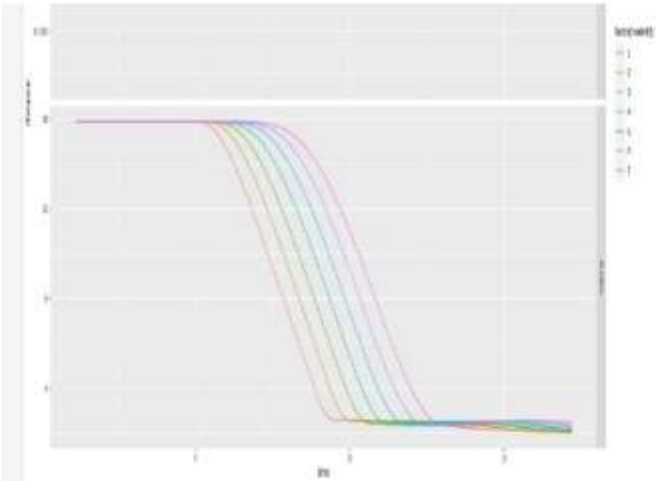


FIGURE 10: **Distance Statistics of node**

- Speed: The speed of the vehicles decreases as they approach the obstacle. The first vehicle stops completely, and the other vehicles slow down to a safe speed as shown in Figure 8.
- Acceleration: The acceleration of the vehicles is negative, indicating that they are decelerating. The deceleration rate is highest for the first vehicle, and it decreases for the subsequent vehicles as shown in Figure 9.
- Distance: The distance between the vehicles increases as they decelerate. This is because the vehicles are maintaining a safe following distance as shown in Figure 10.
- The speed of the vehicles decreases from 100 km/h to 0 km/h within a distance of about 50 meters.
- The deceleration rate of the first vehicle is approximately 8 m/s2.
- The distance between the vehicles increases from about 10 meters to about 20 meters as they decelerate.

Overall, the statistics show that the vehicles are responding to the obstacle in a safe and controlled manner. The decentralized V2V communication system is effectively warning vehicles of the obstacle and allowing them to take evasive action.

B. Scenario II

The second scenario of the evaluation of the decentralized V2V communication system, which is targeting accidents that may occur on the road. The RSU is acting as a decision maker and is deciding which vehicle will go through the same route or will change it through broadcast messages.

FIGURE 11: **The Vehicles Responses to the Accident**

Figure 11 shows that the RSU successfully broadcast the message to all vehicles on the road. The vehicles that were able to receive the message were able to avoid the accident site and take alternative routes. In order to illustrate the proposed methodology, the simulator output may be discussed as follows:

- Vehicle [5]: Received broadcast message and took alternative route.
- Vehicle [16]: Received broadcast message and continued on original route (no other option).
- Vehicle [17]: Received broadcast message and took alternative route.
- Vehicle [26]: Received broadcast message and took alternative route.

The simulator output shows that the RSU-based broadcast message system is an effective way to warn vehicles of accidents and help them to avoid accidents. All vehicles in the radio range of the RSU received the broadcast message. They were able to receive the message were able to avoid the accident site and take alternative routes or continue on their original routes.

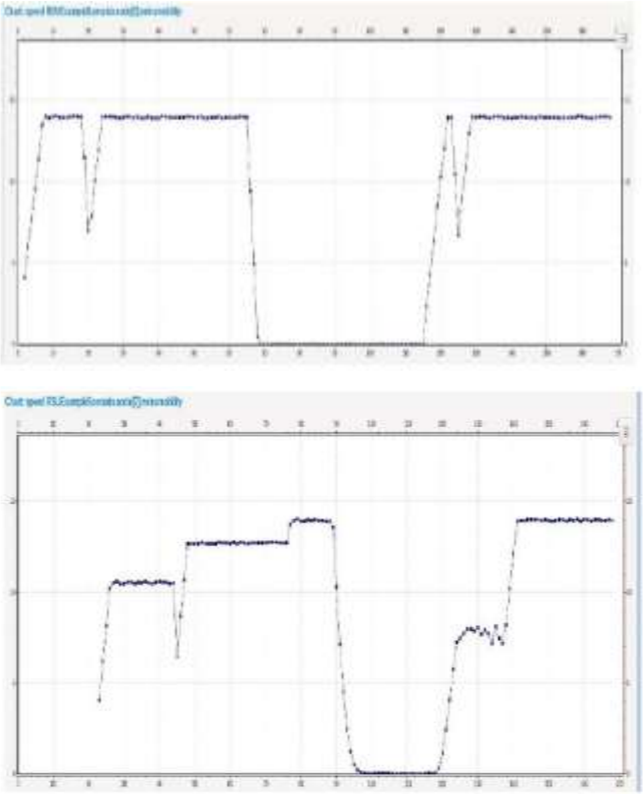


FIGURE 12: **Speed Statistics of the first node and a random node**

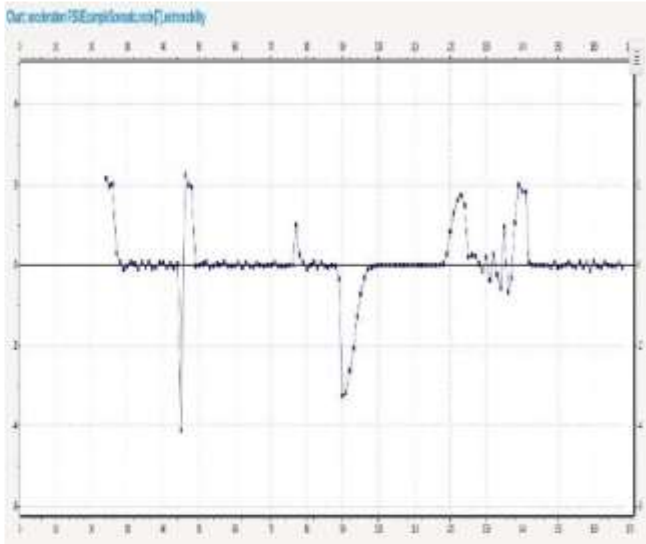
Figures 12 and 13, show the Speed/Acceleration statistics of the first node and a random node. Overall, the speed and acceleration statistics show that the vehicles are responding to the accident warning message in a safe and controlled manner. The decentralized V2V communication system is effectively enabling the vehicles to coordinate their responding and decelerate at a safe rate.

C. Scenario III

In this scenario, the emergency scenario will be investigated. So, RSU will send a broadcast message to all other vehicles (node [0-5]) on the highway road. The broadcast message will contain the following information:

- Type of emergency vehicle (police car, ambulance, fire engine, etc.)
- Current position of the emergency vehicle
- Direction of travel of the emergency vehicle
- The broadcast message will be sent using a V2V communication protocol, such as DSRC or LTE-V.

Once the other vehicles on the highway road receive the broadcast message, they will react accordingly. For example, if the emergency vehicle is approaching from behind, the other vehicles may slow down or change lanes to allow the emergency vehicle to pass.



D.

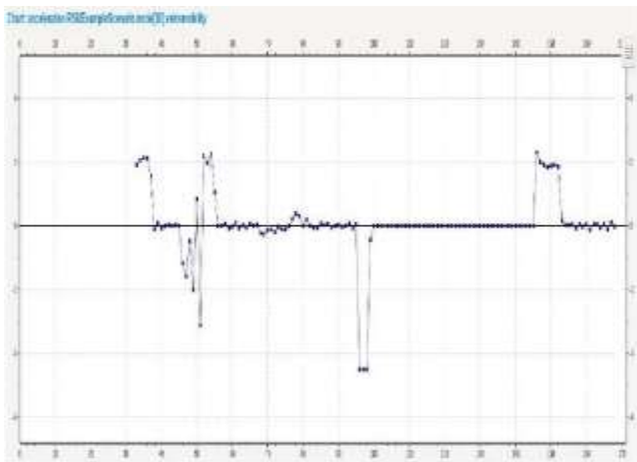


FIGURE 13: **Acceleration Statistics of the First Node with Random Node**

The medium model describes the shared physical medium where communication takes place. It computes when, where and how transmissions and noises arrive at receivers. It also efficiently provides the set of interfering transmissions and noises for the receivers. The number of received frames as shown in Figure 14 is much higher than the number of sent frames, indicating that the radio medium is congested. Aso, the number of interference cache hits is high, indicating that the radio medium is noisy. In addition, the number of interference computation counts and reception computation counts are high, indicating that the vehicles are having to work hard to process and interpret the noisy radio signals. In Figure 15, the SNIR (signal-to-noise ratio) is low, indicating that the radio medium is noisy. Overall, the statistics of the radio medium indicate that it is congested and noisy. This is likely due to the fact that there are a large number of vehicles transmitting data simultaneously. The vehicles are having to work hard to process and interpret the noisy radio signals, which is reducing their throughput and efficiency. All Used Aspects for Emergency Scenario are shown in Table 1.

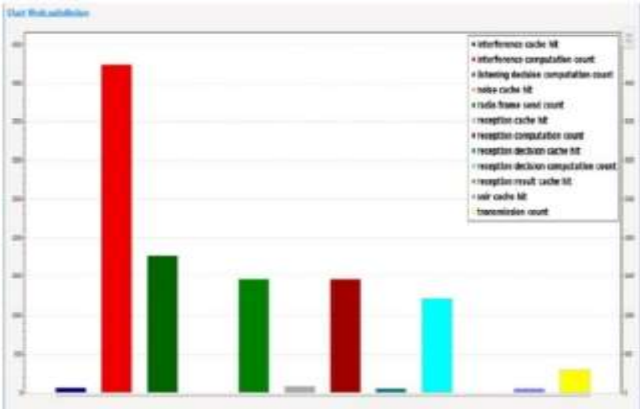


FIGURE 14*:* **Radio Medium Statistics I**

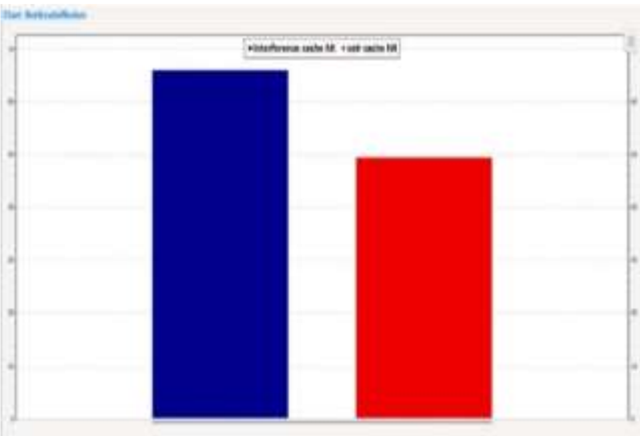


FIGURE 15*:* **SNIR and Interference Statistics I**

Table 1*:* **Used Aspects for Emergency Scenario**

Antenna	Isotropic Antenna
Frequency	5.9GHz
Bandwidth	10MHz
Transmitter	IEEE80211 ScalarTransmitter/OFDM
Receiver	IEEE80211 ScalarReceiver
Channel Model	IEEE80211 Channel, Ch=180
Radio Medium	IEEE80211 Scalar RadioMedium

V. CONCLUSION

The decentralized vehicle-to-vehicle (V2V) communications systems for accident warning has the potential to significantly improve traffic safety. The system is able to effectively warn vehicles of accidents in different highway scenarios. The system is also able to handle a large number of vehicles and to broadcast messages efficiently. The simulation results showed that the decentralized V2V communication system outperforms the other methodologies via prevention of a significant number of collisions. The system is also able to reduce the severity of collisions that do occur. Overall, the decentralized V2V communication system is a promising new technology for improving road safety and traffic efficiency. The system has the potential to save lives and reduce injuries. The proposed system is still under development, but it has the potential to make a significant contribution to improving ISVN. There are a number of areas where future work on the decentralized V2V communication system for accident warning could be investigated. These areas may include: developing more sophisticated algorithms for detecting and predicting accidents, improving the efficiency of the message broadcasting protocol, and developing methods for integrating the system with other traffic safety systems, such as road traffic signals and intelligent transportation (ITS) systems.

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