Visible Light Communication System Integrating Road Signs with the Vehicle Network Grid

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Abstract

Today, human life is threatened by road accidents inside the vehicle especially when driving in bad weather conditions such as rainy, icy, and foggy weather. These weather conditions can be treacherous if the driver does not have enough preparation and awareness of his vehicle for bad weather on the road. The driver must have preparations such as slowing down, increasing the following distance, keeping the light ON, breaking gently, and preparing for unexpected things happening on the road; all these need more attention on the road. Therefore, most vehicles today have a controller (ECU) (Engine Control Unit); it is like the human brain; the main job of the ECU is to collect the vehicle's information from sensors such as tire pressure, engine, brake, light, airbag, and collision. However, the important information for our project comes from collision sensors fixed on the front and back bumpers of the vehicle. The development of technology such as Visible Light Communication (VLC) is widely used for high-speed wireless data communication with a high data rate for different applications. The VLC technique is less affected by bad weather conditions and transmits data of different types over long distances at high speed. Therefore, this technology is used for numerous promising applications and is found suitable for outdoor and indoor applications. This article project uses visible light techniques to exchange information for all vehicle sensors with data centers through road sign grid networks. The main source of a transmitter and receiver by using a matrix LED light fixed on the Headlight or tail-light of the vehicle. In addition, all this information collected from different vehicles is processed in the Network Road Data Centre. The result will be a signal of attention and order to the Driver and ECU of the vehicle to reduce the speed and stop the vehicle. Finally, a new VLC transmission method is proposed in this article for communication between vehicles and environments to make intelligent roads and save human life. Moreover, the design uses VLC encoded by complex modulation techniques called recursive optical OFDM with a low FPGA power consumption, leading to an increase in vehicle response and a reduction in accidents compared with other methods.

Keywords- Visible Light Communication, Intelligent Transport System, Kintex-7 FPGA, Vehicle-to-vehicle communication, Road Network Grid.

I. INTRODUCTION

One branch of optical wireless communication is the VLC, which gathers a lot of attention from the general public and the research community. The VLC uses the luminance LED for optical wireless communications, and the white light is favorable in many promising ways such as long life, low power consumption, and high brightness. This technology is used for short-range optical wireless communication with a free frequency spectrum and has proven harmless to the human body[1]. Therefore, the exchange of vehicle information data at high speed and data rates between vehicles on the road and various elements in the environments such as Vehicle to Vehicles (V2V), Pedestrians (V2P), Infrastructures (V2I), Networks (V2N), and Vehicle to Everything Communications (V2X) which is used to reduce accidents and make safe human life and safety roads [2]. Therefore, the VLC is the best technique for communication between vehicle and environmental elements. The VLC used in vehicle-to-everything technology has attracted interest from academic researchers and vehicle industries because it improves vehicle and road safety [3]. In addition, these enable the key to the Intelligent Transportation System (ITS), which improves human life by reducing road accidents and vehicle congestion. As we know, road accidents have become the cause of people's deaths and injuries, according to a report from the World Health Organization

(WHO) [4]. This report includes different victim categories, such as pedestrians, motorcyclists, cyclists, and other drivers. Therefore, the scientists are focused on the best method to improve vehicle safety in bad weather with poor road sight vision [5]. The manufacturer invests VLC (Visible Light Communication) techniques on vehicles with different network applications to reduce road accidents, making drivers and occupiers safer inside the car. These techniques gather more attention from the public and research community [6]. In addition, it is called a remarkable technology because it is a dual-use solid-state lighting source and data communications [7]. This technology is developing huge potential in pre-existing lighting infrastructure such as road signs. The opportunity provided by VLC is for fast and cost-efficient development and deployment, which provide low power consumption because the basic principle of VLC technology assumes that the data are carried by the visible light optical carrier with no additional power consumption required [8]. Finally, data information between vehicles and everything around them in the environment can be exchanged to make smart, intelligent road systems [9]. The communication technique uses VLC with complex encoding techniques such as OFDM, and optical OFDM [10][11]. Firstly, the vehicle bumper head and tail LED lights are used as a source of VLC transmitter and receiver for communication and exchange of information. The modern vehicle headlight and tail-light technology uses LED matrix lights with control light intensity [12]. This uses multi-LED as a matrix to generate light [13]. This research project uses this technology with an extra LED inside the matrix as a transmitter and receiver [14]. In addition, adaptive light intensity control can reduce power consumption [15]. The main goal of this research is to reduce the number of accidents that occur in foggy and icy weather when sight vision is very poor. This will lead to a lack of vision on the road due to misty weather and slippery roads and accidents happen especially on highway roads. The distance increase between transmitter and receiver data can be exchanged when using VLC between (V2V) and road sign. The driver's sight vision reaches between 2-11 meters day and night with bad weather conditions [16]. Therefore, the vehicle sends a signal, which includes a package of data about the car and road situation, and transmits it to the road sign network grid and other cars to give attention to the driver about the car-to-car accident happening and reduce it. This paper proposes a system model with an experiment that increases the distance of exchanging data information about vehicles and road signs through a road network grid during bad weather conditions. The data information will be exchanged between V2V, Road sign, Infrastructure, and Network Road Data Center. The design model uses VLC with recursive optical OFDM techniques. The designed model of the transmitter and receiver by a Kintex-7 FPGA evaluation board with a high-speed DAC/ADC converter connected to a matrix LED is used as a media source of the transmitter and receiver.

II. RESEARCH ELABORATIONS

A- Visible light communication based on vehicle-to-vehicle communication.

Modern communication uses RF frequency for communication vehicle to vehicles; some research depends on cellular network grids for communication, such as 5G but the limitation of this technology is affected by bad weather conditions and limited bandwidth spectrum. Therefore, The VLC is a form of wireless data communication of electromagnetic waves with frequencies from (400-800)THz. The implementation uses traditional light sources such as LED, which blinks at a rapid rate of up to 500Mb/s without humans perceiving this blinking; it is the same as a steady stream light. The (V2V) communication depends on Dedicated Short-Range Communication (DSRC) to provide reliable communication for short-range using LED. As we know, the modern car has an LED light as a basic light of the vehicle, street signs and traffic lights with a photodiode integrated to detect light intensity. The Visible light cannot interface with RF existing signal, which can increase usability and security. Therefore, the VLC is used to communicate data between vehicles. One important factor in the safety of roads during adverse weather conditions is the distance of communication between V2V through exchanging data information and sharing with network road grid data centers [17]. This will play an important part in improving road safety and making smarter roads lead to improved ITS. It can be seen when transferring information between vehicles and road signs to make transmission traffic flow information more efficient [18]. The investigation focuses on driving in different environment weather conditions, such as smoky, icy, and foggy, which affected the V2V transmission information and sight vision of the driver. The distance of the VLC transmission signal in V2X communications is affected by environmental conditions [19]. During bad weather conditions, vehicle drivers had a lack of sight vision of the road and another vehicle so the driver cannot take any action very fast when an accident happens on the road. During bad weather conditions, the driver will turn the switch on the fog lights, headlights, or both. Figure 1 describes data transmission information between (V2V)communication during bad weather based on VLC. As we know, the new LED light technology includes matrix LED with lenses to increase the distance of transmission and receiving VLC data [20]. Vehicle A has a transmitter Tx and receiver Rx on the headlamp in the front, and Vehicle B also has a receiver Rx and Tx on the back near the taillight. Therefore, two vehicles A and B, exchange information about road safety between each other. Most car accidents happen on highways [21]. Most of the data transmitted by the vehicle includes car speed, throttle position, an indicator of break stepping, tire pressure, collision status, and airbag system condition. All these data can be read from the Engine Control Unit (ECU) inside the vehicle, which looks like the brain of the vehicle. The (ECU) can store all the vehicle information inside it by using RAM and can be read at any time by a specialist technician to know the status of the vehicle. All the data stored inside the ECU could be transmitted as a package set between V2V and road signs at any time day and night during good and bad weather conditions using VLC [22].

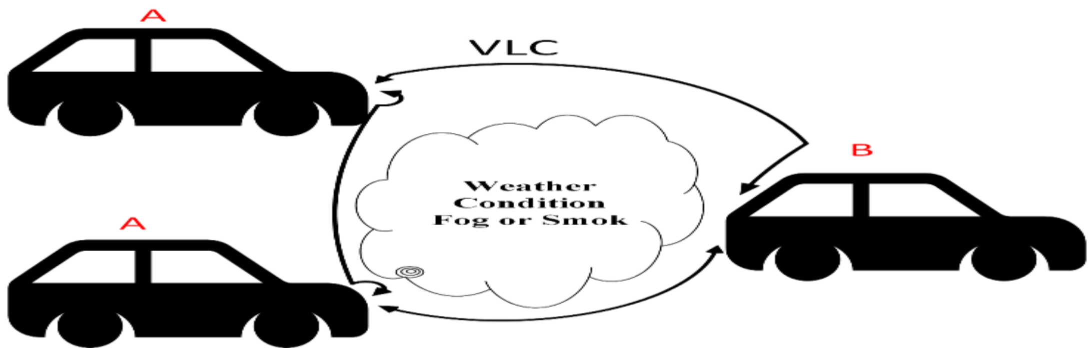

Figure 1. V2V Communication during bad weather conditions

B- Visible Light communications are used on the Vehicle-to-Road Network Grid.

Today, most infrastructures of highway roads, such as road signs in the highway street, contain an LED as a main component of light, such as road signs, traffic lights, headlights, and street lamps [23]. The LED can be invested in and used as a transmitter and receiver of the vehicle ECU to exchange information about road accidents, traffic jams, pedestrian crowds, vehicle status, and vehicle accidents. All the information above will be processed in road network data centers to reduce road vehicle accidents by applying different algorithms that improve road safety and efficiency [24][25]. In addition, providing attention warning information to the driver, especially in foggy weather conditions, has given information about crashes with multiple vehicles[26]. All this information will be transmitted from the road sign near the vehicle accident location and received from the vehicle or sent to the Network Road Data Center (NRDC) through the network grid of the road. The limitation comes from covering the sensor with snow when heavy snow weather. However, we covered this in our experiment by putting a sensor with a heater to clear the front of the LED and be ready to transmit and receive vehicle information in different weather conditions.

C- VLC in ITS (Intelligent Transport System)

VLC can play an important part in ITS, communicating between (V2V) and (V2I) to exchange information in different weather conditions [27][28]. The ITS system will have a positive effect on future mobility for people and vehicles[29] [30]. This system uses several technologies to communicate and exchange information. The technology uses the basics of communication and modern modulation techniques such as OFDM, WDM, and MIMO. In addition, the encoded signal uses basic encoding, such as OOK. QAM, ASK, and PSK [31]. The communication and information integration technology with road signs and vehicles leads to improved road safety, transportation time, fuel consumption, traffic efficiency, and driving pleasure [32][33]. Intelligent roads come from adding networks of sensors to the road infrastructure, such as road signs, traffic lights, and street lights. These sensors work as a transceivers to the other vehicles and data centers of the network grid.

III. RESULTS OR FINDING

In this project we will use a vehicle matrix LED light as a source of VLC transmitter and receiver in the media, which is integrated with road signs. In addition, the data communication technique is a recursive Optical-OFDM encoded by 16QAM as a base modulation technique. These techniques use the main component LED light in the transmitter and the receiver is attached to the road sign and vehicle head and tail light. The design depends on an electronic circuit using a Kintex-7 FPGA evaluation board from AMD Xilinx with an ADC /DAC high-speed converter as a daughter card from Avnet [34]. The board type KC-705 is called a 7K325T evaluation board with a high-speed data connector, FMC150, which is connected to the daughter card ADC/DAC from 4DSP [35][36]. Our experiment uses AMD Xilinx ISE 14.7 integrated with Matlab HDL coder. The main design of the modulation 16-QAM of the vehicle data set was done by an HDL coder and then downloaded to the Kintex-7 FPGA board through a JTAG USB cable. The recursive Optical-OFDM of the modulated signal occurs inside the FPGA board and generates the signal by adding a cyclic prefix to the recursive OFDM signal. The signal is converted to analog and then transmitted to the LED headlight using white light for the vehicle headlight and taillight. The data is transmitted for different weather conditions, starting from clear to rainy, icy, and foggy. The received VLC signal comes from the white light received by the photodiode and is then converted to digital through high-speed ADC fixed on the daughter card to process the received signal inside the Kintex-7 evaluation board. The signal received removes the cyclic prefix and is then processed inside FFT to remove the orthogonality of the recursive OFDM signal. Finally, the 16 QAM signal was de-encoded inside the HDL coder of Matlab to recover the original signal. The process used the communication channel for different weather conditions, which means repeating the experiment for different weather conditions, recording the results and comparing the results. In the experiment of communication between vehicle to vehicle, the information of the vehicle is collected from ECU for each vehicle on the road. That information is transmitted to the tail or head LED light of the vehicle through the optical cable to ensure high-speed transmission data with a wide spectrum. The information exchange between the head-light and tail-light of vehicles using LED white light. The channel of transmission using VLC with different weather conditions. However, the information about vehicles is transmitted to road signs fixed on the road, and those signs must have an LED light and photodiode to transmit and receive information about vehicles and the status of any accident or congestion on the highway road.

All the highway road signs are connected through the network grid by optical wireless communications or by optical cable for long distances. Those signs are connected together to the data center to process the data of each vehicle on the highway road in addition to the accident status. The road data center divides the highway road into sections, and each section has a number of sub-roads; each one has a number to assign, and each vehicle has a number ID to identify the status of it. Therefore, the road data center analyses the information according to specific algorithms and programs and gives a result to reduce the accident by reducing the speed of the vehicles on the accident road or stopping it for a distance far away from the accident locations.

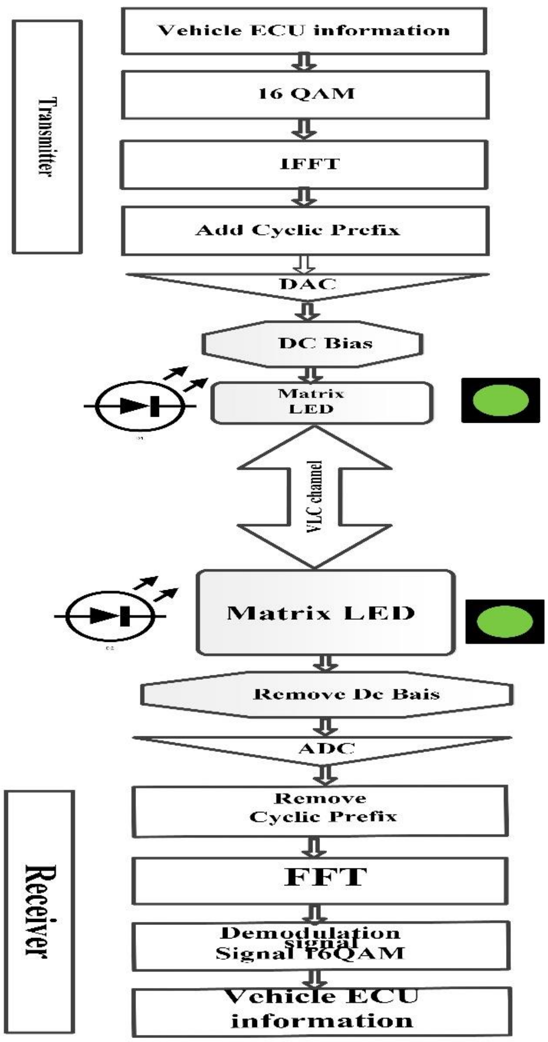

Figure 2. System Design Flowchart

In this article, the main component of VLC used to communicate between vehicles and road signs is a matrix LED light, which is used as a source of Tx and Rx. The flowchart of the design model transmitter and receiver is shown in Figure 2 above. The vehicle information included speed, RPM, break status, tire pressure, vehicle-to-vehicle distance, collision status, and ECU information, including all vehicle sensors with identified numbers. All the vehicle information is transmitted by optical cable to the transmitter |(head and tail light), which is encoded by 16-QAM modulation to generate a subcarrier that multiplexed subcarriers by IFFT to make orthogonality between subcarriers and generate recursive OFDM. In addition, a cyclic prefix was added to prevent the overlapping between the orthogonal subcarriers, DC bias was added, and then the digital card was converted to analog by the daughter card from 4DSP called DAC3283. The recursive OFDM signal includes all information on the vehicle and road status. The signal transmitted is received from another vehicle or road sign and sent to the road data center to process and give decisions about road safety.

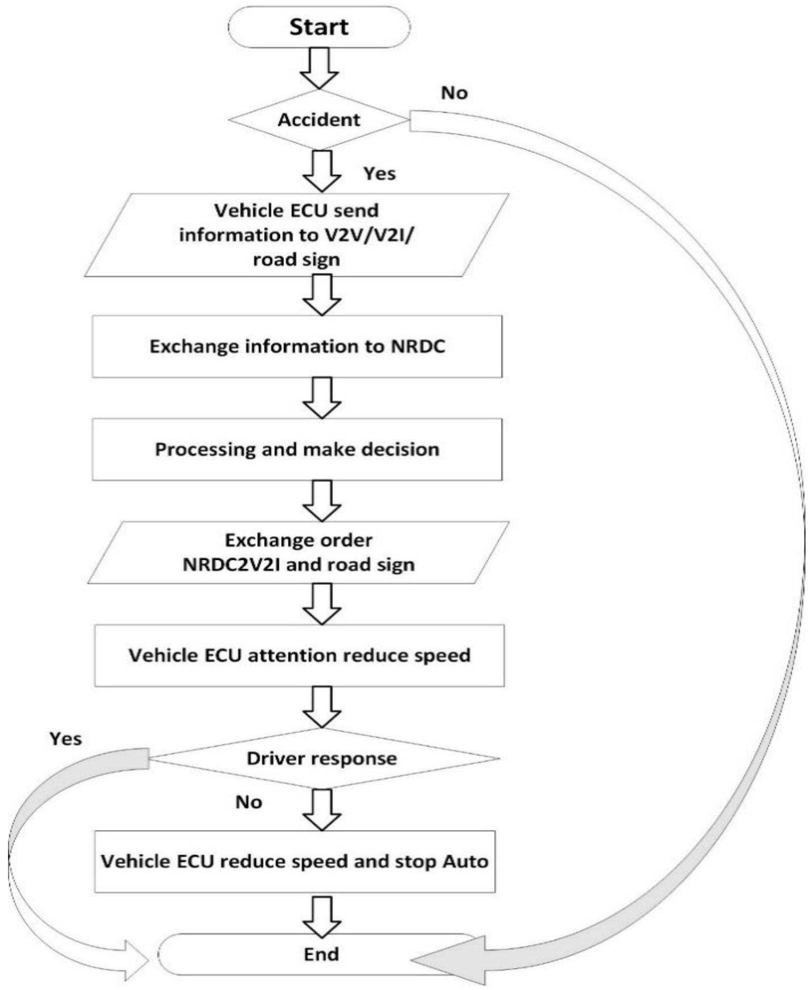

Figure 3. Signal flow process

The analog signal is transmitted to other vehicles or infrastructures road signs through matrix LED headlights. The signal is transmitted in the media for different weather conditions with a distance of 100-200 meters to the other vehicle or road sign. On the receiver side, which is a road sign, each one includes a small electronic circuit used to demodulate the received signal. The recursive Optical-OFDM signal received by photodiode integrated with matrix LED put on vehicle tail-light or road sign. This signal is converted to digital by ADC connected on FMC150 from 4DSP called ADC62P49, which removes the DC bias. Finally, the original signal can be recovered through the Demodulator 16-QAM. The signals collected from multiple vehicles is sent to the network road data center for processing through road signs using optical cable or wireless optical VLC techniques. After processing the information, the new signals will be sent back to the multiple vehicles on the road through the road sign. This signal included information about road suggestions to reduce accidents after processing by using a special algorithm to solve the congestion and make roads and driving safer during bad weather. This signal goes directly to the ECU (Engine control unit). First, the driver should be given attention to reduce the speed; if not, the ECU becomes the auto driver and reduces the speed. The flow chart of the system design is shown in Figure 3. This flow chart describes the system's process when an accident happens on the road. First, collect the data information from Vehicles ECU and infrastructures road sign. After collection, the information is sent to the Network Road Data Centre (NRDC), which processes the information. The output order signal generated depends on the road congestion situation. However, if there is an accident on the highway the Road Data Centre sends a signal to the road sign to reduce the vehicle speed. If the driver does not respond, the vehicle ECU will control the speed of the vehicle automatically and become an auto driver through the ABS by reducing the vehicle's speed and stopping the vehicle. A multi experiment is done with an accident of multiple vehicles that happened on the highway. Firstly, in clear weather, rainy, heavy snowing, and foggy, the sight vision distance is very short, less than 2 meters, because of foggy and icy weather. Therefore, the driver cannot respond very quickly to stop the vehicle or reduce the speed to prevent crashes. The ECU inside the crash’s vehicle knows the accident through the sensors and sends signals to the road sign about the vehicle situation through the headlight or taillight using matrix LED by VLC OFDM techniques. In addition, send a signal of the GPS location of the accident and ID number of the vehicles.

The road network data center sends an attention signal to other vehicle drivers on the highway to reduce the vehicle speed because of an accident. However, if the driver does not respond to the attention, the vehicle's ECU sends a signal to the ABS (anti-lock braking system) to reduce the vehicle's speed or stop with a warning sign. Figure 4 shows the description of system design communication between road signs and vehicles when an accident happens.

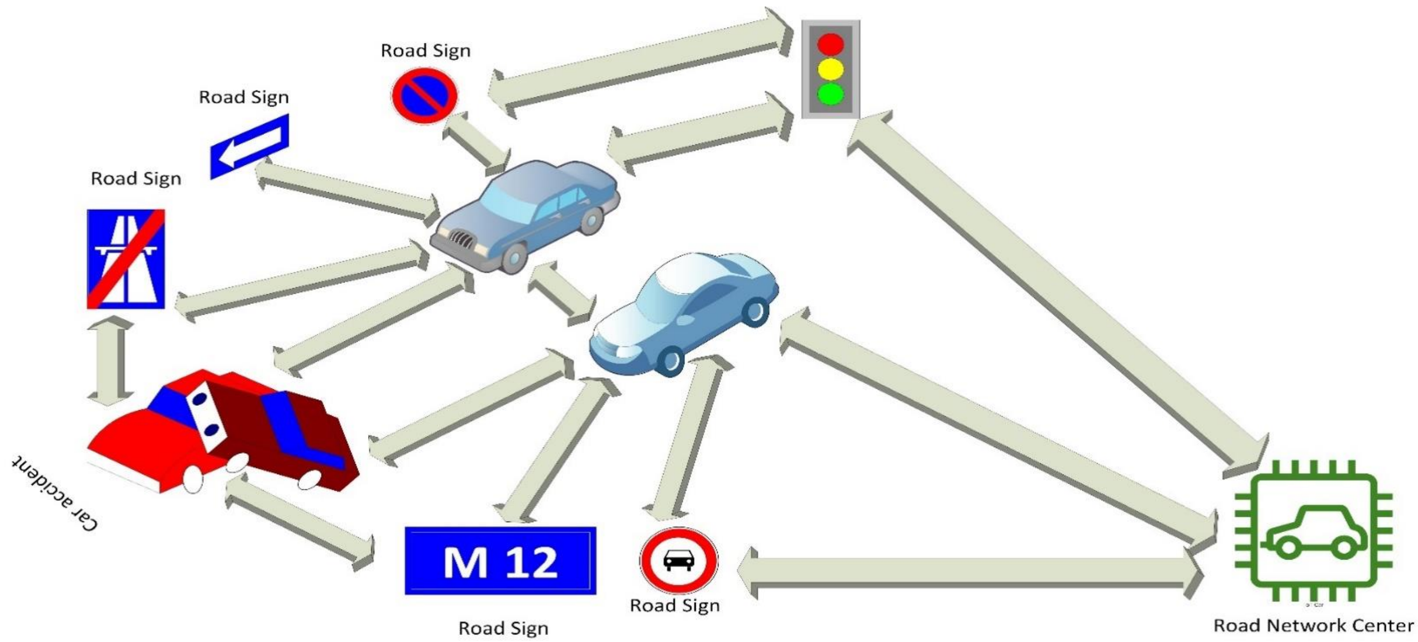

Figure 4. System flow accident description

The location of the transmitter and photodiode receiver of the recursive OFDM signal, which transmits the information by VLC through the LED fixed on the road sign using the road network grid as shown in Figure 5. This shows the LED light fixed on the top of a road sign, especially on the highway street and the main road. All smart signs and traffic light are connected through network grid by optical wire or optical wireless to exchange the information with high speed and free spectrum using LED light.

Figure 5. Road sign with LED

The design diagram of the design model, as shown in Figure 6, describes the communication between vehicles, road signs, and Network Road Data Centre. All data communication will be exchanged by matrix LED using optical-recursive OFDM techniques. The ECU sends the vehicle information to the road sign in two ways: by sending it and receiving it through an LED light using Recursive OFDM with a 16QAM encoding signal. The signal received is sent to the road data center to process the vehicles information and status of road accidents, then produces an output signal depending on a protocol algorithm stored in the data center to produce the best solution to reduce the highway accident and solve the road congestions. The produced signal is sent back to the road sign and back to vehicles depending on the roads with the decisions of reduce speed or stop warning signal; if the driver does not respond, the vehicles reduce the speed and stop depending on ECU in cooperation with ABS.

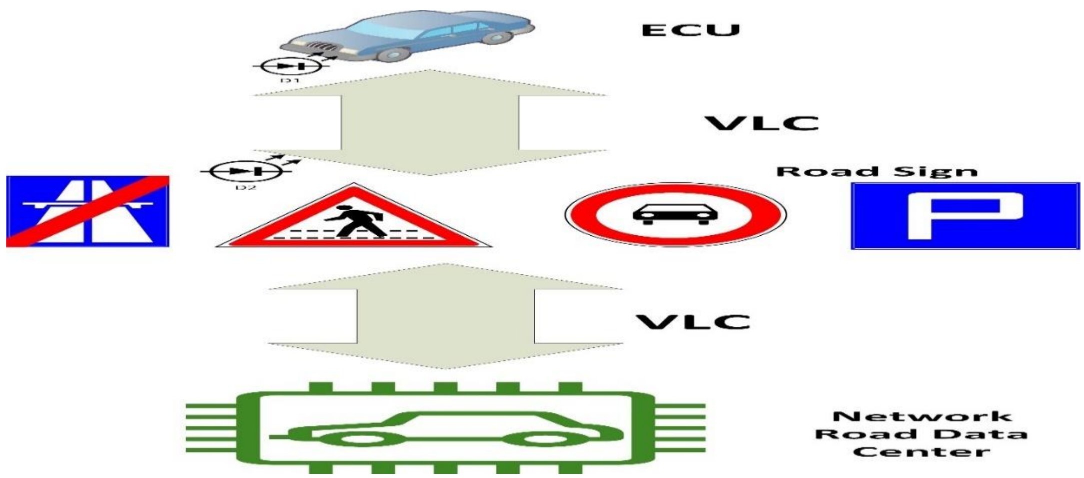

Figure 6. Exchange information of the system

From the experiment above, we see the number of accidents reduced by 70% when compared with the highway without a design model, as shown in Figure 7. The figure above shows the number of accidents increases in the winter especially in months (11,12,1,2) and then decreases. In the orange line vehicles with the applied model, we see a reduction in the number of accidents by approximately 70% when compared with vehicles without a model.

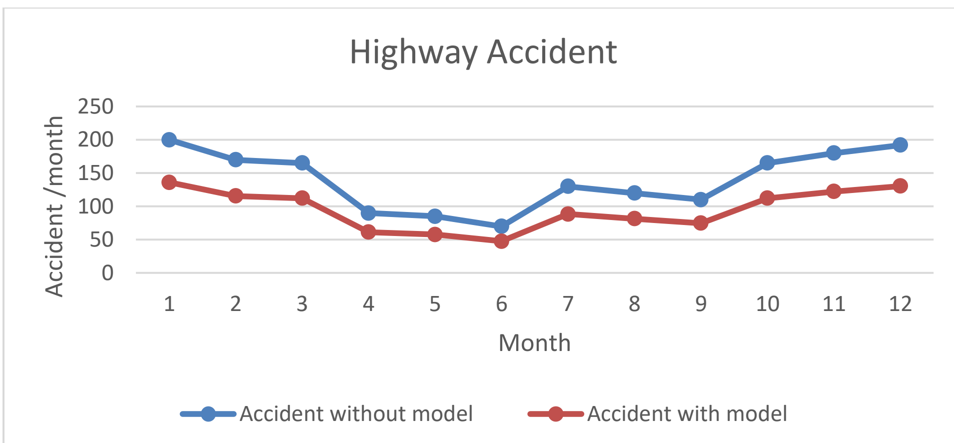

Figure 7. Accident analyses

The distance of the Vehicle response to VLC depends on the condition. Figure 8 shows the distance of communication between vehicle to vehicle or road sign. The result shows that if the weather conditions are foggy or icy, the distance from exchange information is reduced by 50% to 70%. In clear weather, the exchange of information reaches 170 meters, but in snowy and heavy foggy weather, it is reduced to 100-120 meters. In rainy weather, the distance of exchange information is between 150-130 meters, and in light foggy, the distance is 160-150 meters, as shown in Table 1. In addition, in the applied model, we see the distance of data exchange increased when compared with the vehicle without the model, and the distance can be increased depending on the signal amplifier fixed on the electronic circuit for Tx. Moreover, the transmission and receiving of information are reduced when the weather is heavily foggy and snowing, and the sight-vision is very poor over a few meters; our proposed project recovers this problem and covers this gap.

TABLE I. – Exchange information for different weather conditions

Weather condition	***VLC communication distance (meters)***
Clear	170
Foggy	160-150
Rainy	150-130
Heavy snowing and foggy	100-120

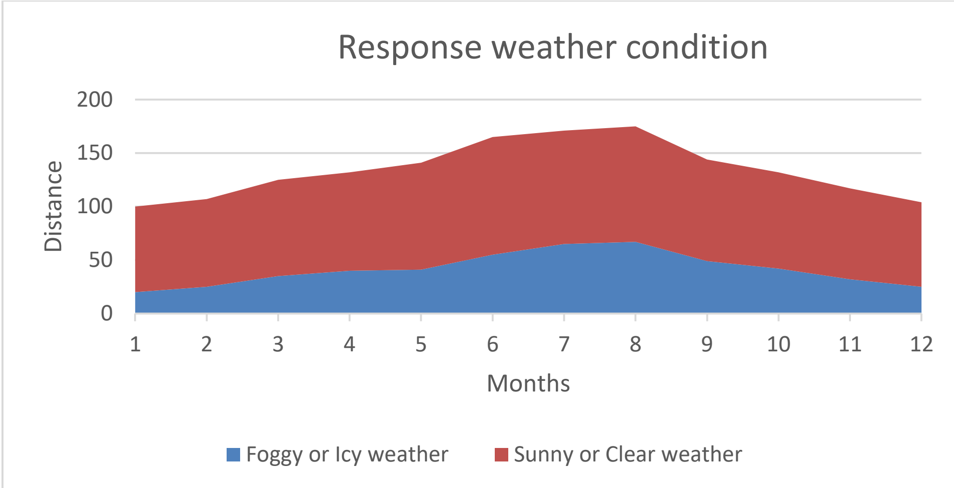

Figure 8. The response distance of the vehicle depends on the weather

IV. CONCLUSION

Human life inside the vehicle or on the street is hazardous without attention from vehicle drivers. In this project, the intelligent transport system is studied and developed by adding more safety to the driver and other people's lives inside the vehicle, especially when driving in foggy weather and icy streets when the sight vision is very poor and the driver cannot recognize other vehicles accident or things in the road. The development of using VLC with optical recursive OFDM increases the safety of ITS roads, especially on highway streets when in bad weather conditions, and reduces the number of accidents by 70% when compared with vehicles without a model. Future work will increase the distance of VLC transmission by changing transmission techniques using NOMA (Non-Orthogonal Multiple Access) with advanced modulation techniques based on recursive OFDM. This technique will reduce the power and increase the distance of transmission by using laser light when compared with VLC using Recursive OFDM techniques.

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