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Performing the high bitrate visible light communications in the foggy weather to anticipate the interference on vehicle communications

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Abstract — Autonomous vehicle is the most advanced technology for driving on the road. Every autonomous vehicle should be able to communicate its information properly for any circumstances. Based on the title, we evaluate Visible Light Communication (VLC) for vehicles communication in several conditions. This research has simulated vehicle to vehicle (V2V) communication using high bitrate VLC. The objective of this research is to find and analyze how far information can be transmitted between vehicles in four scenarios. We considered the research method using four scenarios using the modulation of On-Off Keying Non-Return to Zero (OOK-NRZ) and bitrate up to 1 Gbps. These scenarios are (i) ideal conditions, (ii) interference from other vehicle lights, (iii) foggy conditions, and (iv) interference from vehicles and fog conditions. Based on the extensive simulation, the results obtained are that interference and fog conditions can increase error information, and it is represented by the value of the Bit Error Rate (BER). In addition, we also obtain an optimal distance of communication using BER less than 10^{-3} for four scenarios are 14.5 m, 13 m, 11.5 m, and 9 m, respectively.

Keywords – Vehicle safety, Visible Light Communication, Bit Error Rate, Signal to Noise Ratio.

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I. INTRODUCTION

Visible Light Communications (VLC) is an alternative communication that offers a speed rate reaching Gigabit per second (Gbps). Then bandwidth coverage is broader, has high data access speeds, and is license-free. VLC is also allegedly safer than RF for information sharing and access to communication/two-way communication. VLC technology is guided by the Institute of Electrical and Electronics Engineers (IEEE) 802.15.7 standard, including Physical, Mac and Application Layer. The security aspects are discussed in Mac Layer, but unlike the Radio Frequency (RF), the practices of security schemes have been carried out. Security on VLC is still rarely done, so the research area in VLC security is very potential to be developed, as has been reviewed by [1]. Besides securing communication, one aspect of security is the VLC potential that can be used on vehicle communication.

Vehicles of the future no longer need much control by humans but by intelligence and algorithms in cars. This intelligence is internal, meaning the car controls itself to get to the destination without accidents. Instead, future vehicles must have the ability to communicate between vehicles. This communication will reduce the number of vehicle accidents. In addition, the transfer speed of information between vehicles should be transmitted rapidly due to control and management information for safe riding.

VLC uses visible light as a high-speed transmission medium. The transmitter used in this study is a Light Emitting Diode (LED). The LEDs used are adapted to the existing LED components on the vehicle. LEDs with a transmit power of 60 W. LEDs have advantages: durability, blinking speed, and low power consumption [2]. The application of VLC outdoors allows it to be affected by the surrounding weather conditions. This study has transmitted data speeds of 1 Kbps, while the potential for sending data on visible light can be faster.

Paper [3] discussed the design and implementation of the VLC physical layer for the audio transmission system, where the input signal (audio signal) is not modulated or processed first by the Digital Signal Processing (DSP) device and is still pure in the form of analogue signals. It was carried out for verification by looking at the amplitude-phase of the audio signal received later than the sent signal. The bandwidth of the analogue front-end (AFE) receiver is 450 kHz when using the optical channel distance reference of 30 cm. This system can be used with 8 Watt LEDs.

Research [4], [5] has discussed V2V communication using radio frequency (RF). Researchers have found that RF-based communication requires a special license and complex structure, thus maximizing the popularity of LEDs on vehicles used as lighting into transmission media offers. LED-based V2V communication process offers a variety of profits such as lower costs and complexity. With unobstructed Line of Sight (LOS) propagation characteristics, the determination of the position of other vehicles can be obtained from V2V-based LEDs accurately.

V2V communication uses LEDs on rain, snow, and fog weather, studied by [6]. The study found that the weather outside was very influential in communication because the LED is a device that is very susceptible to a decrease in transmission quality that has high wavelengths. In addition, misty weather can reduce visibility or be very short, so LED communication becomes disturbed. The researcher also suggests that the fog is a kind of steam composed of water droplets; even though the size of the water droplets is tiny, the fog can make a journey deviation of light due to water or scattering events.

Research [7] has discovered that V2V-VLC can be easily implemented through the light-emitting diode (LED)-based headlamps, nowadays equipped in most modern cars, for short-range optical wireless communications. The results in this work indicate that cooperative communication protocols must be implemented to avoid communication disruption when moving along realistic curved roadway scenarios.

The impairments encountered in V2V-VLC channels are mitigated in reproducing kernel Hilbert space (RKHS) by a minimum symbol error-rate post-distorter using a low dimensional approximation of random Fourier features (RFF) has studied by [8]. It also shows that it facilitates computationally simple post-distortion under a finite memory budget. The proposed post-distorter convergence and BER-performance are analyzed over realistic V2V VLC channels obtained via raytracing. The proposed post-distorter's analysis and computer simulations exhibit equivalent convergence characteristics and error rates over reasonable distances, with much lower computational complexity.

Study [9] has analyzed for optical OFDM (O-OFDM) along with adaptive modulation scheme is investigated in VLC for the vehicle to vehicle (V2V) communications in outdoor. The outdoor VLC channels vary fast and experience multipath scattering and reflection, resulting in time domain dispersion. Also, outdoor VLC links are subjected to high ambient noise levels, especially from the sun.

Study [10] has found that vehicles' interference with light from other vehicles increases disorders, namely increasing thermal noise. Also, the weather whose weather change is very influential on VLC's performance compared to stable conditions. One of the weather conditions that had been analyzed was foggy weather.

We found that research to determine the safety distance for communication has not been analyzed from the literature reviewed. Our study has a contribution that uses bits up to 10000 and high bitrate up to 1 Gbps to present the estimated error communication. We conduct simulation research in extreme misty weather conditions to analyze the influence of fog on VLC performance. We also have aimed for this research to examine optimal distance in V2V communication. In addition, we have done extensive simulations using Python programming.

This research was divided into several parts to clarify the flow of discussion. Part 2 shows the method proposed and provides broad exposure regarding channel models. We also express and consider the parameters used in the simulation. Part 3 explains the results of research from simulations that have been carried out. Also, in this section, we analyze the impacts on V2V communication. Part 4 discusses the final results of the simulations. Finally, we conclude all the research results in Part 5 in comprehensive.

II. RESEARCH METHOD

A. Simulation Model

From the selection of visible light, we are considering using Light Emitting Diode (LED) as a light source. LED is one of the electronic components with semiconductor materials and is a diode technology that can emit light. In general, the LED has a spectral width of 40 nm at a wavelength of 850 nm and 80 nm at 1300 nm [11], [12]. One of LED's advantages is having an energy efficiency of 80% to 90% [13]. In addition, LEDs have been widely used in vehicles; thus, increasing the ability as a medium of communication is a relevant proposal.

We propose using the photodetector that has a function to convert light signals into electrical signals for the receiver side. One type of photodetector we use is positive intrinsic negative (PIN). The working principle of the PIN is to change the input photon into an output current based on Photo Voltaic Effect and requires a reverse bias with a value of 5-20 volts to describe the current carrier that comes out of the intrinsic area [14].

This study divides two types of channel models used in simulations. The Line of Sight (LOS) transmission channel is where the signal is transmitted from the transmitter to the receiver directly without the barrier. The non-line of sight (NLOS) channel model illustrates the presence of particles such as water, dust, crystal fog, and others as an obstacle. The LOS channel has a higher data delivery speed than the NLOS channel, and this speed reaches hundreds of Mbps [15].

Fig 1. illustrates the Direct-LOS (DLOS) and non-DLOS channel models used in this research model. Vehicles from behind or in front of other vehicles emit light modelled with N-DLOS. In general, the LOS channel has another advantage; this channel has no barrier and has a lower error probability level. The LOS channel equation is explained by [16]:

$$H = \frac{(m+1)A\cos^{m+1}(\phi)}{2\pi d^2}, \tag{1}$$

where A is the area on the receiver and d is the receiver distance on the transmitter. While ϕ is a light output angle on the transmitter. Whereas the value of m is equality of Lambertian, which is defined by [16]:

$$m = -\frac{\ln 2}{\ln(\cos(\phi_{\frac{1}{2}}))}. \tag{2}$$

Then the power received by the receiver is formulated by [16]:

$$P_r = P_{tot} \cdot H, \tag{3}$$

where P_{tot} is transmitted power from the LED.

In general, foggy conditions usually form in cold and cool places. Water droplets that make up this fog can disturb the VLC used by water and air with different medium refractive indexes. We find that different medium refractive indexes can cause light absorbed or refracted by the fog. In this study, we consider visibility due to fog by 0.2 km and applied for calculating attenuation coefficient (dB/km) as [2]

$$\gamma(\lambda) \simeq \frac{17.35}{V}\left(\frac{\lambda}{550}\right)^{-\mu}, \tag{4}$$

where V is the level of visibility, and λ is the wavelength of LEDs. The value of μ is a variable that is influenced by visibility, as intended in Table 1 [17].

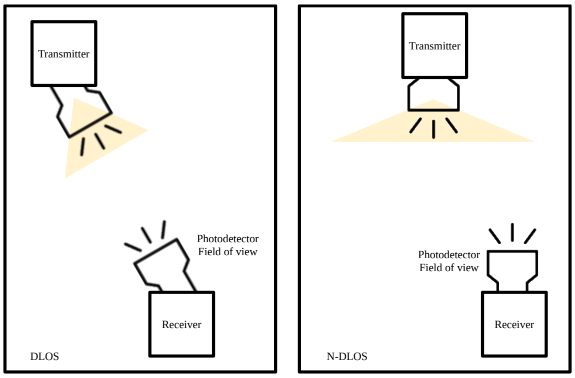

Fig.1. Illustration of communication channel model line of sight.

The coefficient for the fog channel, we define it as a H_{fog} that can be determined through Beer's law [18]. The law describes light scattering and absorption on a media. The equation can be explained as follows [19]

$$H_{fog} = e^{-\gamma(\lambda)d}, \tag{5}$$

where d is the transmission distance. After getting a power received that has passed the transmission media, we calculated the magnitude of the signal-to-noise ratio (SNR). SNR is a comparison ratio between the power signal received with the power noise. SNR is generally widely used to be a standard size of signal quality on a communication system. Information signals through a medium in communication experience many disorders that damage the information signal itself and reduce the quality of the signal. The quality of the information signal received can be calculated [20].

$$SNR = \frac{{I_p}^2}{{I_{pi}}^2 + 2q\,B(I_p + I_D) + \frac{4\,K_b T B}{R_l}}, \tag{6}$$

where I_p is primary photocurrent, q is the electron charge, B is bandwidth, I_d is dark current, T is photodiode temperature, K_b is Boltzmann constants, and R_l is the load resistance. Interference from other vehicle lights is I_{pi} as defined [20]

$$I_{pi} = P_{ri} \times R, \tag{7}$$

where R is responsivity.

Table 1. Parameters of μ against fog visibility.

μ value	Visibility range
1.6	V>50 Km
1.3	6 Km<V<50 Km
0.16+0.34	1 Km<V<6 Km
V-0.5	0,5 Km<V<1 Km
0	V<0.5 Km

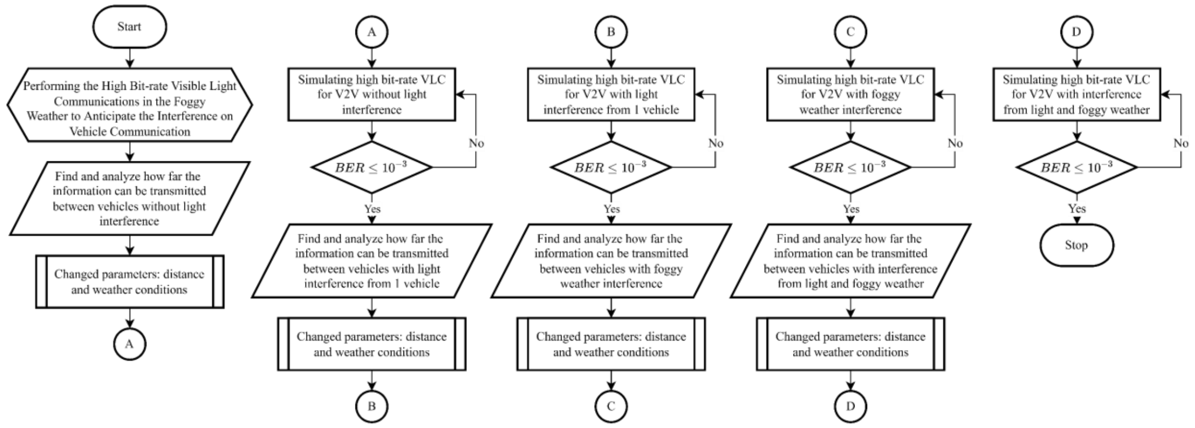

Fig.2. Flowchart for V2V research.

In this study, we added interference parameters of other light and accumulated them with noise [19]. The results reduce comparison values between signal power and noise power. We analyzed the difference between the scenario in this study with SNR calculation. Bit error rate (BER) is the number of bits that errors in particular time intervals are divided by the number of bits sent in the same interval. For optical wireless communication, it is accurate, which is less than 10^{-3} [21].

B. Flowchart Diagram

Fig 2. shows the flowchart research in general that has been done. First, we initiate vehicles that play a signal transmitter, signal receiver and signal interference. We calculate the gain channel to get a receipt on the vehicle that receives the signal. This research changes the distance between vehicles which affects the output variable. In addition, we have considered the variable noise fog and interference from vehicles in different scenarios.

The changed variables are distances between transmitter and receiver, weather, and interference values from the vehicle. We also make illustrations of scenarios without interference and bright weather conditions. Then, experimenting for interference from vehicle light, with conditions still in bright weather. We also experimented with changing the weather to be foggy without any interference from other vehicles—finally, trials where there is interference from vehicles and misty weather conditions. We have calculated, simulated, and analyzed for these four experiments to get a maximum distance worth less than or equal to 10^{-3}.

C. Research Scenario

We use four scenarios in this simulation. We consider all simulation conditions at night, where the sun interference can be ignored. We consider the analysis when interference conditions from other vehicles. The scenario is shown in Fig 3. illustrates the communication process between vehicles without any light interference. The communication process between vehicles does the second scenario with additional light interference from the vehicle around, assuming a vehicle interference, as in Fig 4. Fig 5. describes the communication process with noise or disruption from the fog weather with a 0.2 km visibility rate. Finally, Fig 6. illustrates the communication process with additional interference and noise fog with a visibility rate of 0.2 km.

D. Communication System Diagram

Fig 7. describes the VLC system in this study. The first information signal in bits (0 and 1) enters the modulator section. The modulator section modulates the signal using the line coding on-off keying non-return to zero (OOK-NRZ). Then, the modulated signal is emitted by the LED with a signal in the form of light. The light signal is then transmitted in a channel by air. After going through the channel, the light goes to the photodiode as a light signal receiver, then converted into an electrical signal again. After that, the signal towards the demodulator separates the information signal and the carrier signal. In the following process, the signal is forwarded until it reaches the receiver and is converted into an information signal.

This study uses several parameters considered to support and become references in the calculation and analysis process. The parameters that have been used are listed in Table 2.

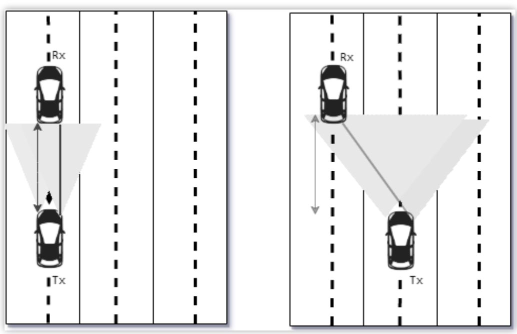

Fig.3. Communication between vehicles without light interference.

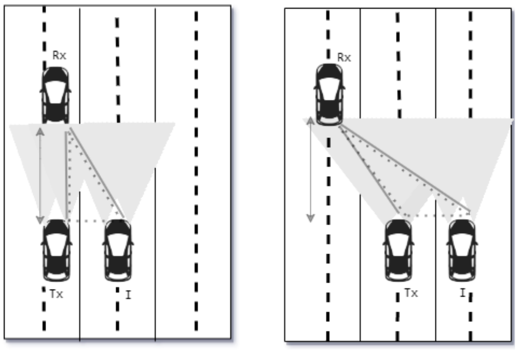

Fig.4. The process of communication between vehicles plus light interference from one vehicle.

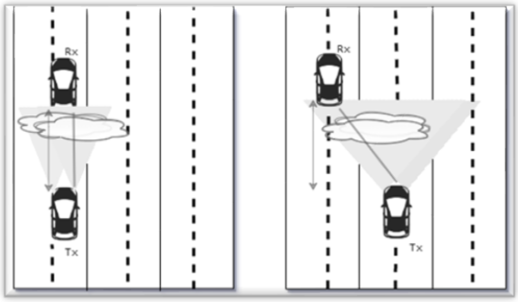

Fig.5. The process of communication with interference from the fog weather.

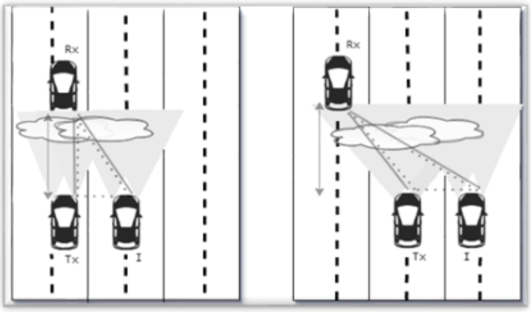

Fig.6. Communication process plus interference and fog.

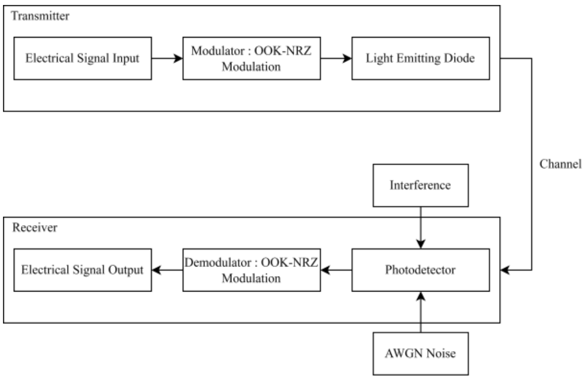

Fig.7. Diagram of communication systems between vehicles.

Table 2. Parameter of simulation.

Parameter		**Value**
Transmitter	Light source	LED
	Transmit power	60 Watt
	Number of LED	1
	Number of bits	100000
Receiver	Photodiode	PIN
	Responsivity	0.85 A/W
	Area detector	1 cm^2
	FOV	70°
Interference	Number of vehicles	1
	Transmit power	60 W
Others	Line coding	OOK-NRZ
	Bit rate	1 Gbps
	Visibility	0.2 km
	Bandwidth	2 GHz

III. RESULT

A. SNR performance based on distance

Fig 8. explains that interference added to the channel affects the resulting SNR value. Interference can reduce the SNR value, so system performance decreases. This study observed the safe distance between vehicles, precisely 10 m. In the first scenario, obtain an SNR value of 23.6524 dB. The second scenario produced an SNR value of 11.1435 dB by adding interference to the vehicle around. The third scenario has an SNR value of 16.1475 dB with fog in the channel. Finally, added interference and channel fog, the SNR value at the same distance is 10 m, equal to -7.78326 dB. From the results of research that has been done, we analyzed that the more distance, the SNR value fell linearly. The ideal SNR is when the comparison value between signal power and noise power is more than one. The SNR that obtains a negative value will be complicated to detect because the power of noise is more significant. We also found that interference has no significant effect of decreasing the distance between 7.5 m until 17.5 m for SNR value. We analyzed that signal received power has more significant than noise and interference for a distance less than 17.5 m. After that, the power received signal decreases until it has a similar value with interference power. In addition, the result shows that the fog conditions and other vehicle interference resulted in a very low SNR.

The channel value can be analyzed without adding vehicles' interference, and fog is still better. Based on Fig 8. we found that scenarios 2 and 3 have the same tangent point. At a distance before 11 m, we noticed that the channel added to the fog noise has better quality than the channel, which is only added with interference. In addition, by calculating the distance of more than 11 m, the value of SNR in Scenario 2 is higher.

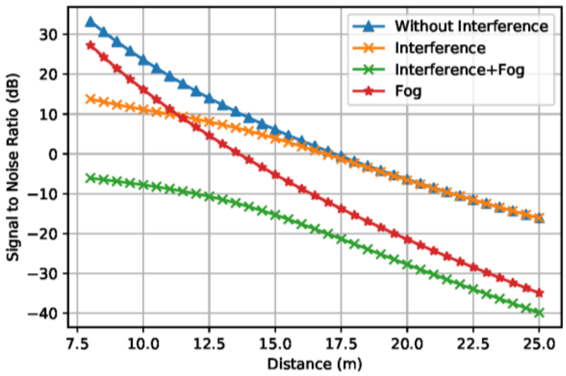

Fig.8. Comparison of various scenarios for SNR value.

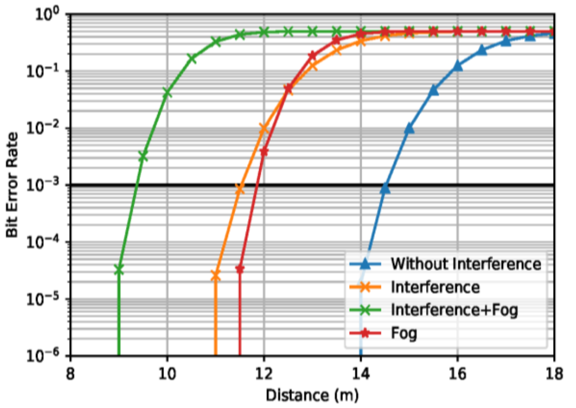

Fig.9. Comparison of various scenarios for distance performances.

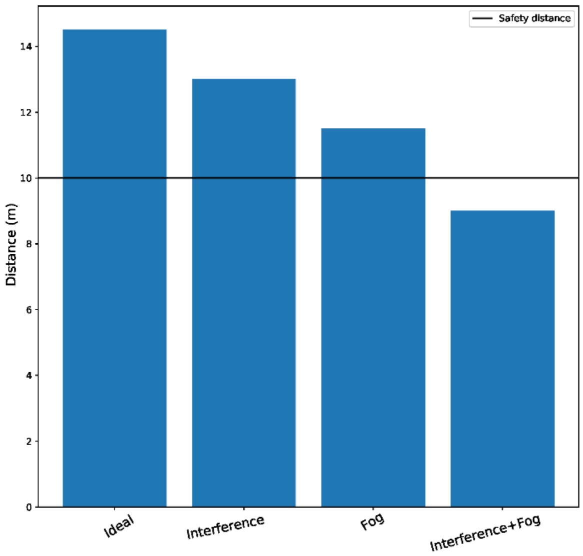

Fig.10. Comparison of transmission distances on various channel simulation models.

B. BER performance based on distance

Fig 9. describes that scenario 1 has a higher value than other scenarios. The value in scenario 1 began to be detected at 14 m for $2.3x10^{-5}$ BER performance. However, based on the value of what has not exceeded the threshold value, the system can still communicate optimally up to 14.5 m. While scenario 2 applies interference to the VLC system, the value is detected at 11 m for $1.7x10^{-5}$ BER performance. The value of scenario 3, which adds a fog noise of $2.5x10^{-5}$, begins to be detected at 11.5 m. Scenario 4, which is the addition of the interference of vehicles around and noise fog, can run a scenario well up to 9 m. At 9.5 m, the resulting value equals 0.003356 and has exceeded the threshold, so the system run on scenario 4 is not optimal. In addition, our research has better performance for high-speed bit rate up to 1 Gbps instead of 1 Kbps in research [2].

IV. DISCUSSION

Based on the experiment results, the influence of fog with a visibility rate of 0.2 km in decreasing the value is still more significant than the influence of vehicle interference carried out by the scenario. Thus, the optimal distance in the implementation of the communication process of each scenario sequentially is 14.5 m for the first scenario, 13 m, and 11.5 m for the second and third scenarios, respectively, as shown in Fig 10. Finally, the scenario that does not meet the safe distance for the vehicle's communication is the fourth scenario with a maximum distance of 9 m. The decrease in transmission distance is caused by noise from weather and interference, and we find that communication on vehicles can still be done in a range of 14 – 11.5 m.

V. CONCLUSION

We have done simulations for various conditions on visible light communication. Communication scenarios between vehicles without other vehicle interference and without fog weather obtain an ideal performance. Of all scenarios, interference and weather fog reduce performance in communication. The condition in the fog with a 0.2 km visibility rate has a more significant influence on the process of communication between vehicles compared to the addition of interference from other vehicles. It is evident from the difference in SNR values in the interference scenario (scenarios 2) and foggy conditions (scenarios 3). SNR in scenario 3 is higher up to 11 m and afterwards obtain a value that continues to decline compared to scenario 2. The scenario of additional interference from other vehicles and the mist weather resulted in the value of the error probability in very high information. It shows that scenario 4 is the worst system in communication between vehicles.

This study has many potentials to be the recommendation for future work by changing the more power-efficient modulation such as the Pulse Position Modulation (PPM). We also continued this study by considering various speed vehicles while communicating. So that further research enriches analysis of power efficiency to modulation and performance of various scenarios of vehicle speed differences.

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