Analysis of V2V Communication Performance on Roads and Tunnels Surrounded by Mountains

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***Abstract*—In this paper, communication performance analysis is conducted for driving scenario using IEEE 802.11p wireless access in vehicular environments (WAVE), a vehicle communication standard. Since vehicle communication is linked to advanced driver assistance systems such as safety and autonomous driving, it is very important to maintain stable communication performance. However, in the vehicle communication environment, it is difficult to ensure a stable performance because the communication terminal moves at high speed and there are various communication interference factors such as changes in the surrounding environment. Therefore, in this paper, scenarios are set for actual vehicle communication environments and the vehicle communication performance is analyzed for each situation based on actual measurement experiments. In the actual measurement experiment, the basic safety message (BSM) of the vehicle is transmitted and received in real-time using two vehicles with two WAVE devices. The received signal strength of the signal is analyzed while exchanging BSM messages. In this experiment, various scenarios are set up and the signal strength for each scenario is analyzed. This paper conducted a performance comparison using the received signal power of messages transmitted and received by driving conditions in the road environment by experimenting with vehicle-to-vehicle communication.**

***Index Terms*—Autonomous driving system, Vehicle to everything (V2X) communication, Wireless access in vehicular environments (WAVE)**

I. Introduction

Four core technologies required for autonomous driving are perception [1], control [2], path planning [3] and V2X communication [4]. Among them, V2X refers to a technology in which a vehicle exchanges or shares information with surrounding vehicles and road infrastructure using wired/wireless communication networks. It includes communication between vehicles to infrastructure (V2I), between vehicles and pedestrians (V2P), and between vehicles and mobile devices (V2N) [5]. By using the V2X communication technology, it is possible to overcome the limitation of the recognition range of the sensor mounted on an autonomous vehicle and to recognize the surrounding environment even in situations where it is difficult to recognize the surrounding environment.Representative V2X communication methods include WAVE [6] based on wireless LAN technology and cellular Vehicle-to-everything (C-V2X) based on mobile communication technology (LTE and 5G) [7]. WAVE is a wireless communication technology suitable for automobile driving environments based on the IEEE 802.11a [8] wireless LAN technology. 1609.4 [9] and the 1609.2 [10] are developed as a secure communication standard and set as communication standards for vehicles. Testing the performance of autonomous driving algorithms on the road has many limitations and high risk of accidents. Therefore, each country is encouraging the development of autonomous driving technology and supporting performance verification by establishing a test bed for testing autonomous driving algorithms. Representative test beds include M-city in the US [11], AstaZero [12] in Sweden and J-town in Japan.

As such, although various communication technologies are supported in Daegu, Korea no research has been conducted on the transmission/reception environment that can predict the communication performance within Daegu test Road.

In this paper, a study on the vehicle-to-vehicle (V2V) communication in highway environment is conducted by analyzing the reception strength on various driving routes in Daegu demonstration road through basic safety message (BSM) transmission and reception by installing a terminal for V2V communication in a vehicle. In this paper, V2V communication was conducted through a total of four scenarios and the performance of each scenario was analyzed.

Section II describes the configuration of the environment for conducting the experiment, and Section III describes the communication parameters of the communication used in the experiment. Section IV explains the results of the experiment and concluding remarks are in Section V.

II. V2V Communication Configuration

In order to proceed with the V2V communication experiment, Section II.A describes the performance of the on board unit (OBU), antenna, and the configuration of the test vehicle for the communication test, Section II.B describes the communication test demonstration road and explains how to proceed with communication. The communication experiments are conducted on a straight road, a tunnel road, a straight road with obstacles, and a tunnel road with obstacles in a total of four scenarios.

A. Test Environment and Vehicle Configuration

Fig. 1 shows that one WAVE terminal and antenna are installed in the test vehicle for the V2V communication. For the WAVE terminal, it is used in the red box on the right as showed in Fig. 1. Terminal supports IEEE1609.2/3/4, SAE J2735 protocols [13] and two channel bands of 10 MHz and 20 MHz. The role of the terminal OBU is to support vehicle safety messages and platooning. Terminal OBU includes two communication channels, a global positioning system (GPS) receiver [14]. The BSM message [15] is transmitted by generating vehicle location information, speed, driving direction, route history, and route prediction information based on GPS signals. The test vehicle consisted of two OBUs, and 2 pairs of antennas. The test vehicle used are a sedan and a small SUV. The height of the antenna from the ground is 1.41 m from the sedan, and the height of the antenna of the small SUV is 1.56 m. The height difference between the antennas was 0.15 m.

Fig. 1. Environment of communication data collection.

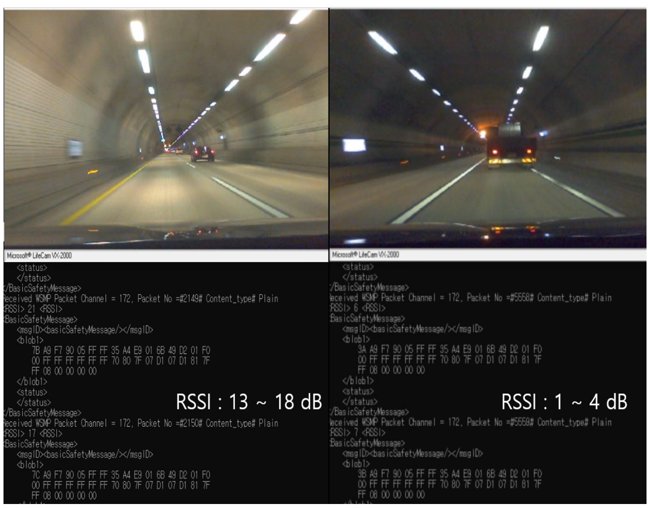
B. Driving Scenario

Fig. 2 shows the vehicle path for sending and receiving BSM messages in WAVE communication. The vehicle path is marked with a red dotted line. The route consists of a total of 13.64 km in length. It also consists of 6 tunnels, 2 underpasses, 9 bridges, and 3 interchanges. The daily traffic volume of this road is about 40,000 units, and it is a road with many underpasses. There are four driving scenarios. The first scenario analyzes the transmission/reception strength of BSM messages between vehicles driven at a speed of 60 km/h to 80 km/h while maintaining the distance between vehicles at 100 m or less. This scenario analyzes OBU transmit/receive strength. The second scenario measures received signal strength indicator (RSSI) by placing an obstacle, such as a truck, between vehicles in the first scenario environment. The third scenario analyzed the transmission/reception strengths of BSM messages in the tunnel while maintaining the first scenario. The last scenario analyzes the BSM transmission/reception strength in the tunnel environment in the second scenario.The RSSI measurement in straight road proceeds as shown in Fig. 3 that shows examples of two experiments. On the left, two test vehicles are sending and receiving BSM messages. The speed of the vehicle was set between 60 km to 80 km. The RSSI strengths in Fig. 3(a) is transmitted/received strength 15 to 20 dB as shown in the figure below. Fig. 3(b) shows a scenario in which an obstacle between vehicles is included in the situation on Fig. 3(a). In Fig. 3(b), the change in reception strength can be confirmed by inserting obstacles between vehicles. When an obstacle is added, it can be seen that the RSSI reception strength is reduced by about 10 dB compared to Fig. 3(b) reduction 1 to 7 dB. In Fig. 4, V2V communication is carried out in a tunnel environment. In Fig. 4(a), V2V communication is carried out while maintaining the vehicle distance within 100 m in the tunnel. The RSSI of the BSM message is 13 – 18 dB. It can be seen that there is a difference of about 5 dB from the environment of Fig. 3(a). Fig. 4(b) is the result of measurement with obstacles between vehicles in the tunnel. BSM RSSI is 1 – 4 dB, so it can be seen that communication is not good in the tunnel situation. Compared with Fig. 3(b), it can be seen that the signal strength intensity of about 3 dB is lower.

Fig.2. Daegu Demonstration test bed.

(a) (b)

Fig.3. RSSI for BSM in (a) the line-of-sight and (b) blocked by a truck on a straight road.



(a) (b)

Fig.4. RSSI for BSM in (a) the line-of-sight and (b) blocked by a truck on a straight road in tunnel.

III. Communication Parameters

Table I shows the communication parameters used in the experiments. The vehicle communication system used in the experiment follows the WAVE standard and has a frequency of 5.855 - 5.925GHz. The transmission speed is 6.9 Mbps, the BSM transmission period is 102 ms, the maximum size of the sending BSM is 250 bytes, and the size of the receiving BSM is 150 bytes. The receive sensitivity is -95 dBm in the absence of multipath. Among the communication parameters, the strength of a signal received, P_r , theoretically at a distance considering only the transmission power, cable loss, antenna gain, and visible signal can be calculated as

$$\begin{aligned} P_r[\text{dBm}] = P_t[\text{dBm}] + G_t[\text{dB}] + G_r[\text{dB}] \\ -P_L[\text{dB}] - C_{Lt}[\text{dB}] - C_{Lr}[\text{dB}] \end{aligned} \quad (1)$$

where P_r is the received signal strength, P_t is the transmit power G_t, G_r is the transmit and receive antenna gain, respectively, C_{Lt} and C_{Lr} are the cable losses connected to the transmit and receive antennas, respectively, and ϕ is the free space loss at the distance d m. λ stands for wavelength. The free space loss is 20 log$(4\phi d/\lambda)^2$.

TABLE I
Communication Parameters

Parameters	Values
Frequency	5.85 - 5.925 GHz
Bandwidth	10 MHz
Transmission rate	6.9 Mbps
Transmission interval	102 ms
Transmit BSM size	250 bytes
Reception BSM sizel	150 bytes
Receiver sensitivity	No multipath : -95dBm
Cable loss	2.3dB
Transmit power	23 dBm
Antenna gain	4 dBi
Antenna height	1.41 m - 1.56m

IV. Experiment Result

A total of 2 vehicles were used for V2V communication. As shown in Fig. 2, BSM messages were transmitted and received at a location of demonstration road. Since the driving scenario includes curved roads with various curvatures as well as straight roads, the vehicle's driving speed was within about 30 - 80 km/h. Table II shows the reception level of the BSM transmitted in the environment of 4 scenarios. There are 4 scenario, and the BSM signal strength was analyzed in tunnels and general highways. RSSI is the received signal strength, and refers to the number of power received from the receiving OBU. The BSM message RSSI in the transmitting vehicle OBU is 30 dBm. It can be seen that the received RSSI averages 20 - 30 dBm in the normal straight section, and about 5 - 10 dBm loss occurs compared to the transmit RSSI. In contrast, when an obstacle called a tunnel was added in the same straight section of the tunnel, it received 15 - 20 dBm. The RSSI loss rate within the tunnel is about 33% - 55%. It can be seen from these figures that communication in the tunnel is not as good as in the general road. When there is an obstacle such as a truck or a car between vehicles in a straight section, 5 - 10 dBm is received. It can be seen that the signal strength of 15 - 20 dBm is lowered compared to the existing straight section. It can be seen from this fact that the presence or absence of obstacles becomes a factor in communication obstruction in the vehicle-to-vehicle communication environment. In the last scenario, if there is an obstacle between test vehicles in the tunnel, it can be confirmed that it is 0 - 5 dBm. It is 10 - 15 dBm lower than the value measured in the existing tunnel scenario, it can be confirmed that the communication is not good in this situation. Therefore, it can be confirmed that V2V communication is weak when there is an obstacle between vehicles in the tunnel.

TABLE II
BSM SIGANL STRENGTH ANALYSIS IN EACH SCENARIO

Scenario	**RSSI Signal Strength** (dBm)
Tunnel road	15 - 20
Tunnel road (blocked by a truck)	0 - 5
Straight road	20 - 30
Straight road (blocked by a truck)	5 - 10

V. CONCLUSION

In this paper, WAVE terminals were installed in two vehicles to predict the V2V communication performance on the Daegu Technopolis, an autonomous driving experimental city. One vehicle transmits BSM from a location around the receiving vehicle, and the other vehicle receives the BSM message while driving along the technopolis route. The RSSI signal level of the receiving OBU is distributed from a maximum of 30 dBm to a minimum of 3 dBm, and it was confirmed that the BSM message was well received up to about 600 m. Above 600 m, the BSM message was not well received due to a decrease in received signal strength and an invisible path due to obstacles such as surrounding tunnels. In addition, regardless of the location of the transmitting vehicle, it can be seen that the BSM message is well received up to about 300 m from the transmitting vehicle, which is a result that satisfies the standard. It is thought that application can be applied in Korea as well. For the experimental scenario, the RSSI of the BSM message was analyzed by separating the cases for each situation on the demonstration road for each vehicle. As a result of the analysis, it can be confirmed that the communication performance in the actual tunnel is lower than the communication performance of the general roadwalk. As such, by analyzing the V2V message delivery range and received signal strength on the route of the Daegu Arboretum in Daegu Technopolis, the V2V communication environment in the demonstration road could be confirmed. Through these research results, it is expected that it can be used to predict and evaluate the communication performance required for the development and experiment of various safety scenarios using V2V communication on the demonstration road. In this paper, although V2V communication performance was analyzed in a test bed composed of obstacles such as multiple tunnels and surrounding vehicles, a study related to communication performance evaluation considering various actual vehicle driving environments in an not typical environment in order to prepare domestic communication safety standards in the future will need.

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