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Original Research Article

Vehicle-to-vehicle communication channel measurements on a vertical curve road

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ABSTRACT

Vehicle-to-Vehicle (V2V) communication channel measurements were carried out in different environments such as urban, suburban, rural, highway, tunnel, and overpass. The roads in these environments have generally flat terrain. However, there are horizontal or vertical curve roads that have been little focused in the literature. In this study, we performed two V2V measurements on a vertical-curve road in a rural environment to show how received signal strength changes with the distance between the transmitter and the receiver. The path loss exponent of log-distance path loss model was calculated by using the least-square method. According to the results, the path loss exponents were estimated as 7.53 and 7.61 with 78% and 83% fitting performances for two measurements. In literature, however, the path loss exponent for different propagation environments was obtained up to 6.13, especially in the straight road. Thus, our findings show that the vertical curve roads cause 15-20 dB more attenuation in the received signal strength than the straight roads. As a result, the vertical curve roads should be investigated and included in existing wireless communication simulators to better model real measurements. The authors contend that this study will aid in improving the channel modeling of V2V communication.

Keywords: Vehicle to vehicle communication, experimental measurement, channel model, path loss exponent, vertical curve road.

1. Introduction

Deaths from road traffic crashes have increased to 1.35 million a year. That's nearly 3 700 people dying on the world's roads every day [1]. In Vehicle-to-Vehicle (V2V) communication system, vehicles send message each other to prevent traffic accidents and reduce traffic congestion. The messages contain vehicles' location, speed, heading, etc. Vehicles generate warnings on the panel or mirrors with light or sound for the drivers after taking and processing the other vehicles' messages. Vehicles also send critical messages in an emergency, such as when a driver in front suddenly brakes. However, to do this, the sent message must be successfully received from the transmitter. This is directly dependent on the environment and conditions in which V2V communication takes place. Therefore, V2V communication channel measurements are carried out in different environments, such as highway, urban, suburban, rural, and so on to reveal how communication channel parameters change. The most of V2V communication channel measurement studies were used log-distance path loss model to calculate path loss exponent of the environment measurements made in. The path loss exponent is a parameter of the log-distance path loss model which indicates the rate at the path loss increases with the distance. The path loss exponent parameter is a unitless value ranging from 2 to 6 for classical wireless communication which is 2 for free-space environment [2].

In the literature, various V2V communication channel measurement setups were used. Generally, there are two types of measurement systems with respect to the capacity to analyze V2V communication channel parameters. One of them is able to analyze frequency-dependent channel parameters such as Doppler spread, power delay spread, coherence time while another measurement system is only record Received Signal Strength Indicator (RSSI) value at the receiver. An example of measurement system for the first one consists of a signal generator that is used as a transmitter and a vector signal analyzer which is used as a receiver. The other measurement system which records RSSI value at the receiver consists of commercially-available Dedicated Short-Range Communication (DSRC) On-Board Unit (OBU) radio devices on both at transmitter and receiver. In this study, only the results of the measurements using DSRC OBU devices, which are also used in our measurement setup, are discussed.

According to measurements carried out in urban environments, the calculated path loss exponent $n$value is changing from 1.51 to 3.91 in [3–8]. In suburban measurement environments, the obtained n value is between 1.53 and 2.22 in [4, 9, 10]. Measurements were performed on expressway, freeway, highway, and open road environments are considered together as highway because their environment similar to each other. In highway measurements, calculated n value is ranging from 1.77 to 2.85 in [3, 4, 11, 12]. There are also some specific measurement studies carried out in parking lots, intersections and on a ramp. In [3], measurements were also performed in a parking lot and n value is changing between 2.27 and 2.31. Another parking lot measurement were carried out in [13]. However, the authors used dual slope log-distance model instead of one slope log-distance model. In this model, there are two path loss exponent values.

n_1 value is between 1.9 and 2.18 while n_2 between 3.82 and 4.02. Intersection measurements were carried out in [14, 15] and n value is changing between 2 and 2.75. Lastly, a measurement performed at a ramp in urban environment, the obtained n value is between 4.8 and 6.13 in [16]. Although V2V communication channel measurements were performed in several environments, there are no studies related to curve roads to the best of our knowledge.

Horizontal curve roads may not significantly affect the V2V communication channel. However, vertical curve roads obstruct communication when there are no line-of-sight between the transmitter and the receiver. One of the main purposes of V2V communication is to prevent accidents occurring in blind spots especially at curve roads or at corners. The traffic accidents are unavoidable provided that the vehicles are not able to communicate in time on the curve roads. The aim of this study is to investigate the effect of the curve roads on V2V communication. For this purpose, we carried out some measurements on vertical curve roads in a rural environment. Then, the measurement results are modeled with log-distance path loss model and some important parameters such as path loss exponent and reference distance are presented.

The rest of this paper is organized as follows: log-distance path loss model is described in section II, measurement setup, environment, and scenario are given in section III, measurement results are presented in section IV, modeling is given section V, and conclusion are given section VI.

2. Log-Distance Path Loss Model

Theoretical and measurements-based propagation models indicate that average received signal power decreases logarithmic with distance, whether in outdoor or indoor radio channels. The average large-scale path loss for an arbitrary transmitter-receiver separation is expressed as a function of distance by path loss exponent [2],

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\,log\left(\frac{d}{d_0}\right),\ d > d_0 \quad (1)$$

where n is the path loss exponent which indicates the rate at which the path loss increases with distance, d_0 is the close-in reference distance which is determined from measurements close to the transmitter, $\overline{PL}(d_0)$ is path loss at d_0, and d is transmitter-receiver separation distance.

The most important part of calculating path loss exponent is to determine optimum reference distance from measurement data. The reference distance is chosen a fixed value in most studies in the literature. This may cause deviation in path loss exponent value. Related to this problem, we proposed an approach in [17] to find optimum reference distance based on measurement data. According to this approach, the reference distance is chosen as minimum distance value in measurement data. Using this value and corresponding $\overline{PL}(d_0)$ value, which is also taken from measurement data, n value is calculated by using least-square method. Then, second distance value is chosen as a reference distance and this process is repeated for it and obtained another n value. In this way, this process is repeated for all distance values up to 100 m because reference distance is generally chosen between 1 m and 100 m [2]. The new log-distance path loss models (fitting curves) are generated with these n values. The errors between the generated models and measurement data are calculated. The n value with minimum error is determined as n_{best} value. The reference distance used to generate n_{best} is chosen as optimum reference distance. In this study, path loss exponent parameter is obtained by using this described approach.

3. Measurements

3.1. Measurement setup

The measurement setup was created with the same devices in both the transmitter and the receiver. The block diagram of the the measurement setup consisting of a laptop, a DSRC OBU (Cohda Wireless MK5 OBU), a camera, an inverter, and a cigarette lighter splitter is given in Fig. 1.

DSRC OBUs connected to the laptops are used for vehicles to communicate with each other. The measurement data are stored on Micro-SD card inside DSRC OBUs. Two 5.9 GHz omni-directional antennas and one GPS antenna are connected to the DSRC OBUs. The laptops are used to access interface of DSRC OBU to send start/finish messages. The cameras are used to record the environment and traffic during the measurements. The camera records are used when the measurement data needs to be analyzed in detail. The measurement setup is given Fig. 2. Basic parameter values of measurement system are given in Table 1.

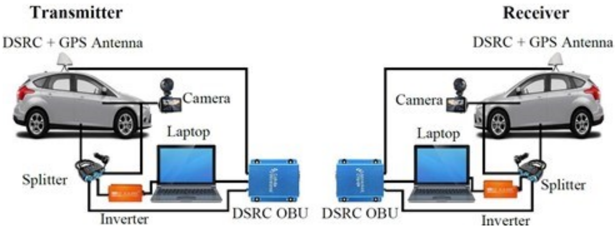

Fig. 1. Measurement setup block diagram.

Fig. 2. Measurement setup: a) The transmitter and the receiver vehicle b) Inside of the transmitter vehicle c) Inverter, lighter splitter, DSRC OBU and camera.

Table 1. Measurement system parameters.

Parameter	Value
Standard	IEEE 802.11p
Frequency Band	5.9 GHz
Data rates	3-27 Mbps
Transmit power	22 dBm
GNSS	2.5 m accuracy
Antenna gain	5 dBi
Antenna heights	1.48 m (T_x) – 1.44 m (R_x) (Vehicles) + 0.1 m (Antennas)
Receiver Sensitivity	−99 dBm at 3 Mbps

3.2. Measurement environment

Measurements were performed on a road in a rural environment in Gumushane, Turkey (GPS coordinates: 40.214580, 39.667389). There were no surrounding obstructions such as building or trees but there are traffic signs along the roadside. The season was winter, the weather was clear, and the temperature was 1°C during the measurements. The vertical curve road in the rural environment is depicted by screenshot of the camera inside the receiver vehicle and also the measurement environment map is given in Fig. 3.

3.3. Measurement scenario

The measurement scenario is sketched in Fig. 4. The transmitter vehicle (T_x) was fixed on a

Fig. 3. The vertical curve road in rural environment and the aerial map.

straight ground of the road and was not moved during the measurements. The receiver vehicle (R_x) was moved from bottom of vertical curve toward the transmitter vehicle. There is no traffic that obstructs the communication between T_x and R_x during measurements. At the beginning of measurements, there is no line-of-sight between vehicles, and the communication link is blocked by the vertical curve road and the piece of land under it. Line-of-sight communication occurs after the receiver vehicle crossed the vertical curve on the road. The measurements were terminated just after line-of-sight occurred.

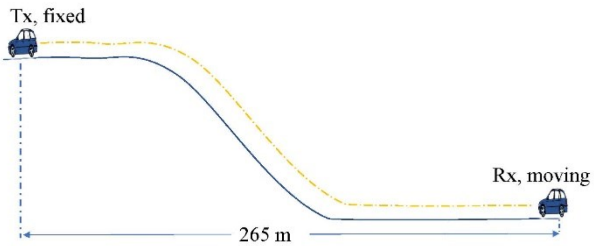

Fig. 4. Measurement scenario.

4. Measurement Results

The received raw data recorded by DSRC OBUs processed in MATLAB. The received data includes GPS coordinates both the transmitter and the receiver, RSSI values of both antennas, vehicle speeds, packet sequence sent, coding rate, etc. GPS coordinates of the transmitter and the receiver are used to calculate the distance between them. The RSSI values of antennas are combined to obtain single RSSI value. Hereafter, this single RSSI value is called as the received power. The measurement distance between Tx and Rx is ranging from 72 m to 265 m for first measurement. The received power value against the distance for first measurement is given Fig. 5. It can be said that there are two different path loss characteristics before and after about 150 m. This situation can be explained as follows. The path loss caused by the vertical curve road and the piece of land under it is more dominant than path loss caused by distance. Therefore, the received power values are lowest until the receiver vehicle starting to cross the vertical curve road corresponding about 150 m. The other portion of Fig. 5, in other words before 150 m, the received power is sharply increasing, which means that path loss is decreasing. This is because that as the receiver vehicle approaches to the transmitter, the amount of the piece of land that obstructs communication decreases.

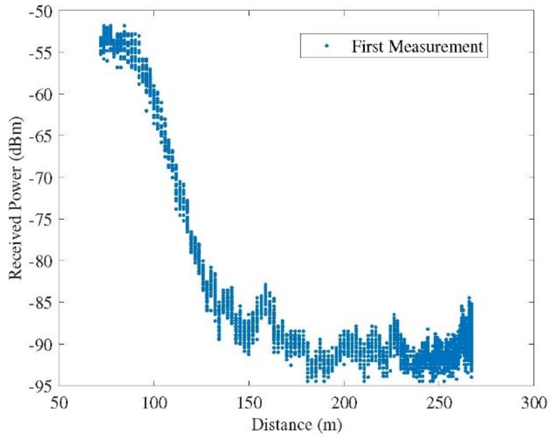

Fig. 5. Received power versus T_X–R_X distance of first measurement.

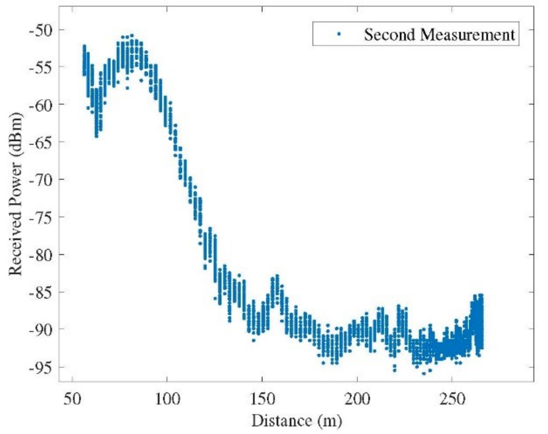

Fig. 6. Received power versus T_X–R_X distance of second measurement.

The second measurement was carried out in same location with the same scenario. The received power versus distance is given in Fig. 6. The measurement distance between T_x and R_x is changing from about 55 to 265 m. It can be seen that almost the same path loss characteristic is exhibited. However, there are some received power values between 60 and 70 m that more attenuated than the expected value. This fact is called as signal strength drops in [11]. The drops in received power values between 60 and 70 m are due to the groundreflected ray which is one part of the two-ray ground reflection path loss model.

5. Modeling

The modeling is performed with log-distance path loss model because of the most used model in V2V communication channel. The path loss exponent values are obtained using approach described in Section–II.

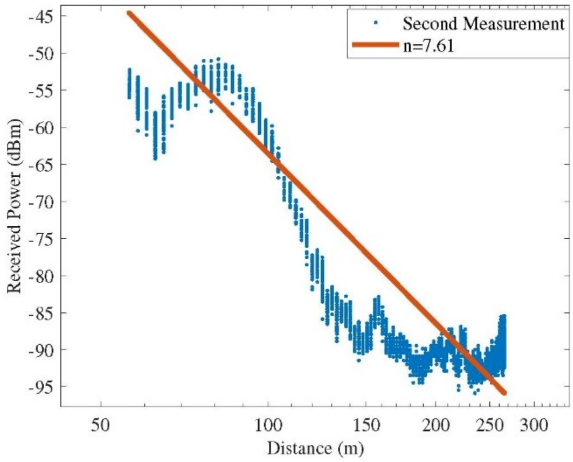

Fig. 7. Received power versus Tx–Rx distance of second measurement.

The effective isotropic radiated power (EIRP) which is used for calculating path loss is 26 dBm (22 dBm + 5 dB – 1 dB) transmit power, antenna gain, cable loss, respectively). Path loss value is calculated as 26 dBm – RSSI. For first measurement, optimum reference distance d_0 and corresponding $\overline{PL}(d_0)$is calculated as 96.87 m and 84.56 dB, respectively. For second measurement, d_0 and corresponding $\overline{PL}(d_0)$ is calculated as 74.14 m and 79.66 dB, respectively. After these values are substituted in (1), path loss exponent, n can be calculated. For first and second measurement, the obtained n values are 7.53 and 7.61, respectively. Using these calculated parameters, log-distance path loss model can be customized for our measurements as follows;

$$\begin{aligned} PL(d_1) &= -64.98 + 75.29\log(d_1) \\ PL(d_2) &= -62.69 + 76.12\log(d_2) \end{aligned} \quad (2)$$

where $PL(d_1)$ and $PL(d_2)$ are customized models for first and second measurement, respectively. The raw measurement data and customized path loss models of both first and second measurements are shown in Fig. 7 and Fig. 8, respectively.

The obtained parameters for the measurements are summarized in Table II. M-1 and M-2 is abbreviation of first and second measurement, respectively. R-square (R^2) value, which is in range 0–1, is used to indicate how the customized path loss model fits the raw data well. The higher R^2 value means that the model fits the raw data better. It should be noted that $PL(d_0)$ values in Table II are path loss values. It must be subtracted from 26 dBm to obtain the received power value.

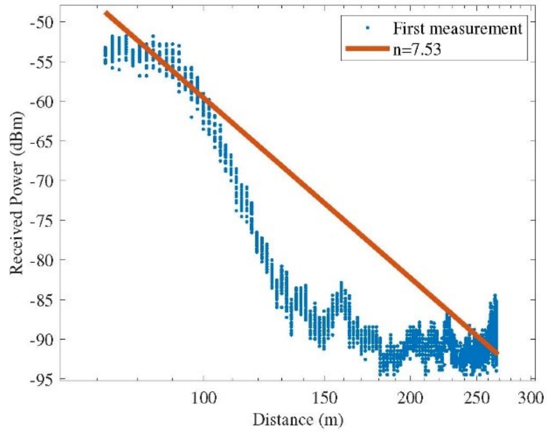

Fig. 8. Received power versus Tx–Rx distance of second measurement.

Table 2. Obtained Parameters.

	M-1	M-2
d_0	96.87 m	74.14 m
$PL(d_0)$	84.56 dB	79.66 dB
n	7.53	7.61
Distance	72-265 m	55-265
R^2	0.78	0.83

6. Conclusion

Experimental measurements of V2V communication channel are crucial to understand the effect of various environment. Although there are many studies carried out in urban, suburban, rural, and highway environments, vertical curve roads have not been investigated adequately. In this study, experimental measurements were performed on a vertical curve road in rural environment. The reference distance was chosen according to the approach mentioned in section II and the path loss exponent in log-distance path loss model was calculated. The measurement data and customized log-distance path loss models are given both in formulas and figures. Additionally, the all extracted parameters from the measurement data according to log-distance path loss model were given in Table II.

In [3–16], path loss exponent was obtained between 1.51 and 6.13, while it is calculated as 7.53 and 7.61 in our vertical curve road measurements. Results show that the vertical curve roads in our measurements attenuate the received signal strength more than the other measurements in the literature. The authors also observed that the vertical curve road in this study sharply attenuated received signal strength by 30 dB a 50 m distance between 100 m and 150 m. However, the received signal strength was attenuated by 5 dB a 50 m distance between 150 m and 200 m because of only distance-dependent path loss. It is suggested that the vertical curve roads should be considered for V2V communication channel modeling and included in wireless communication simulators to better model real measurements.

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