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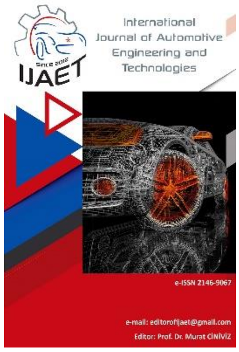

Original Research Article

Experimental measurements on the effect of vehicle movement direction on received signal power in V2V communication

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ABSTRACT

Vehicle-to-Vehicle (V2V) communication has been a popular topic in recent years. V2V communication channel measurements in different environments and scenarios have been performed to reveal the effect of different parameters such as vehicles, buildings, or trees. However, vehicle movement direction is generally neglected when the measurement data are analyzed. In this study, V2V channel measurements were carried out in open roads similar to a highway but with less traffic. The measurement data are divided into two groups: the vehicles approaching each other and moving away from each other. The effect of vehicle movement direction on the received signal power is indicated by comparing the received signal power values of these two groups. The results show that the received signal power differs depending on vehicle movement direction. However, according to our findings, it is not clear which movement direction causes more path loss. The authors suggest that vehicle movement direction should be taken into account in analyzing, modeling, and simulations of V2V communication channel.

Keywords: V2V, vehicle to vehicle communication, experimental measurement, channel model, vehicle movement direction

1. Introduction

Intelligent Transport Systems (ITS) are vital to increase safety and tackle Europe's growing emission and congestion problems. They can make transport safer, more efficient and more sustainable by applying various information and communication technologies to all modes of passenger and freight transport [1]. ITS allow vehicles to exchange information (among them and with the infrastructure) that alerts drivers to safety-related events or suggests actions to improve traffic flow. This is called as Vehicle-to-Vehicle (V2V) communication. V2V communication channel measurements should be performed to understand how different traffic environments affect communication channel. 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 latter measurement system is only record Received Signal Strength Indicator (RSSI) value at the receiver. The first measurement setup usually consists of a signal generator as a transmitter and a vector signal analyzer as a receiver. The latter measurement system comprises commercially-available Dedicated Short-Range Communication (DSRC) On-Board Unit (OBU) radio devices on both at the transmitter and the receiver. In this study, only the results of the measurements performed by using DSRC OBU devices are discussed because our measurement setup also consists of this.

In many V2V communication measurement studies, vehicle movement direction is not considered as a parameter when analyzing and modeling the data. To the best of our knowledge, there are only a few studies considered vehicle movement direction. In [2], the measurements were carried out in the opposite direction. However, there are no measurements or results related to the same direction. In [3], the measurements were performed which vehicles were driven in forward and reverse direction. An additional parameter was added to path loss models to account for the offset caused by vehicles' movement direction. However, the measurement distances are short for V2V communication and the measurement setup used is different from ours. In [4], the measurements were performed in the same and opposite direction, and the results were given as a table. The path loss exponents of the opposite direction measurements are higher than those of the same directions. However, there is discrepancy between path loss intercept of 2.3 GHz and 5 GHz measurements. The path loss intercept of the same direction in 2.3 GHz is higher than that of the opposite direction while 5 GHz measurement has a reverse situation.

In [5], the measurements were performed both in the same and opposite direction with different lanes in the road. However, the maximum measurement distance is restricted with 100 m, which is a very short distance for V2V communication channel measurements. In [6], the same and opposite direction measurement were carried out in different environments, and results were given both in a table and as a graphical. The results show that there are offset between forward and reverse direction measurements and it depends on the propagation environment. However, only one measurement result was compared graphically. The vehicle movement direction is not a parameter taken into account in path loss models. The aim of this study is to reveal the effect of vehicle movement direction on received signal power in V2V communication. For this purpose, we carried out measurements on open roads, which is similar to a highway but has less traffic. The measurement data were divided into two different data with respect to the vehicles' movement direction. Then, the divided data were compared and the differences between them were interpreted.

The rest of this paper is organized as follows: measurement setup, environment, scenarios are described in section II, measurement results are presented in section III, and conclusion are given section IV.

2. Measurements

2.1. Measurement Setup

The measurement setup was created with the same devices in both the transmitter and the receiver. The block diagram of 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.

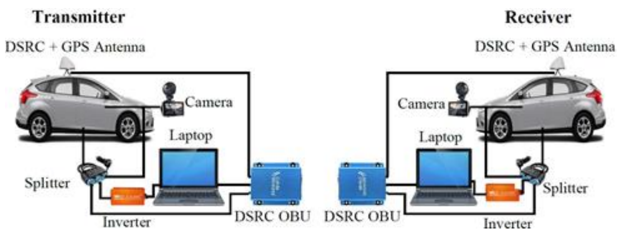


Figure 1. Measurements setup block diagram

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. The basic parameter values of measurement system are given in Table 1.

Figure 2. Measurement setup: a) The transmitter and the receiver vehicle b) Inside of the transmitter vehicle c) Inverter, cigarette lighter, 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

2.2. Measurement Scenario

The measurement scenario is sketched in Fig. 3. The vehicles were located at the maximum distance in the opposite direction on the different lanes before starting to the measurements. At first, the vehicles were driven toward each other, meet in the middle of the road (minimum distance in measurements), then they were moving away from each other. The transmitter and receiver vehicles were both moving during measurements. The vehicles were keep following the blue route and this was repeated many times without stopping. The same scenario was carried out on both open road environments. The communication was just a few times obstructed by other vehicles during whole measurements. In other words, the measurement studies were performed with no traffic on the open roads.

3.3. Measurement Environment

The measurements were carried out in two different open road environments. There are no large scale obstructions, such as mountain and buildings surrounding the open roads. One of the open roads (OR1) is a road with two lanes (one in each direction) and no surrounding objects such as traffic lamps, buildings or trees, but there are some traffic signs at the roadside. The other open road (OR2) is a road with four lanes (two lanes in each direction) surrounded by a few trees and a three-story apartment about 50 m from the middle of the road. GPS coordinates of OR1 94 and OR2 are ”40.135366, 39.490248” and ”40.096944, 39.465583” as latitude and longitude, respectively. Measurement environments of OR1 and OR2 are depicted in Fig. 4.

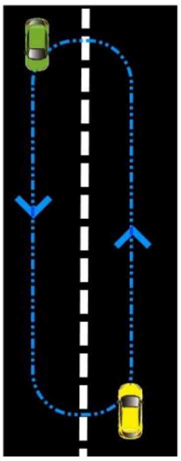


Figure 3. Measurement scenario

Figure 4. Open Road-1 (OR1- two lanes) and Open Road-2 (OR2-four lanes)

3. Measurement Results

255355 data packets were collected on OR1 in about 11 minutes measurement, while 243818 data packets collected on OR2 in about 10 minutes. The measurements data are given in Fig. 5. The measurement data recorded in

DSRC OBUs are processed via MATLAB. The x-axis indicates the distance between the transmitter and the receiver, while the y-axis indicates the received signal strength corresponding to the distance.

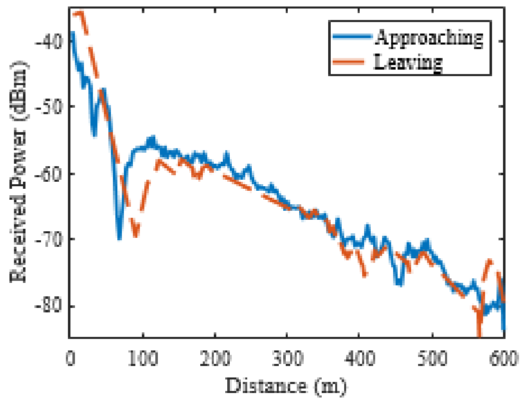
The measurements data are divided into two groups: Approaching in the Opposite Direction (AOD), which vehicles are moving towards each other in the opposite direction; and Leaving in the Opposite Direction (LOD), which vehicles are moving away from each other in the opposite direction. AOD and LOD data were compared to show the change in received signal strength due to the vehicle movement direction.

OR1 and OR2 measurements have eight and nine laps, respectively. The corresponding results are given in sub-figures and named as from OR1-1 to OR1-8 for OR1 and from OR2-1 to OR2-9 for OR2. In all sub-figures: the x-axis shows the distance between the transmitter and the receiver, which is calculated using GPS logs; and the y-axis shows the received signal power, which is calculated combining both RSSI values of DSRC antennas.

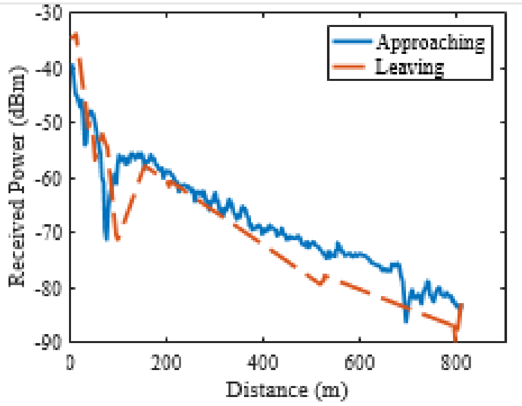
The received signal power values in Fig. 5a and Fig. 5b are averaged at intervals with a distance of three meters. Three meters was preferred to have a greater value than the GPS accuracy (2.5 m) and to minimize the above average deviation. The comparing results of averaged received signal powers are given in Fig. 6 for OR1 and in Fig. 7 for OR2. Firstly, some general characteristics related to the results are presented. For OR-1 results, first 150 m of AOD and LOD data exhibit two-ray ground reflection path loss model [10] as large-scale fading. It is similar for OR2 results but at first 100 m. After that distances, OR1 and OR2 data follow log-distance path loss model [10] as large-scale fading. However, there are some significant deviations on received power values that are not related to the vehicle movement direction. After carefully examining the camera records, it is understood that these serious deviations are originating from exactly the angular position of the vehicles. The vehicles are moving in the opposite direction and returning from a certain point of the road to follow the blue route in Fig. 3. These deviations appeared during the rotation of the vehicles and can be clearly seen in some sub-figures. For example, it appeared at AOD data between 450 and 650 m in both OR1-3 and OR1-5. The other remarkable situation is that AOD and LOD data is changing place after a distance in some results such as OR2-5, OR2-7 or OR2-9. In other words, while the received signal strength is above that of the other, it falls below after a certain distance. This could possibly be related to critical distance, which is used in [7–9]. Even so, by analyzing these results in that way, it is not possible to explain which vehicle movement direction attenuates the received signal more, in other words, causing more path loss.

4. Conclusion

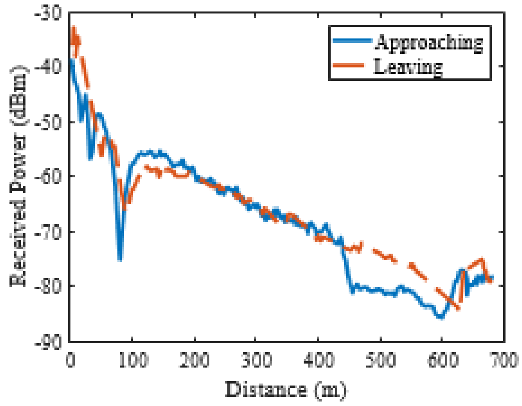
In V2V communication channel measurements, the vehicle movement direction is an important factor that has not been taken into account in most cases. The main idea behind this study is to indicate the effect of the vehicle movement direction on the received signal power. For this purpose, we carried out V2V communication channel measurements in two different open area environments. The measurement data are divided into two groups according to their directions: vehicles are approaching each other and vehicles are moving away from each other. The results show that the data of approaching and leaving are different from each other. However, it is not possible to explain which vehicle movement direction attenuates the received signal more, in other words, causing more path loss. In addition, in some results, it can be said that the received signal power of approaching data is more than that of leaving up to a specific distance. After this distance, the received signal power of leaving data is more than that of approaching. In other words, the difference between the received signal power of approaching and leaving data is reversing after a specific distance. Determination of this specific distance may be similar to critical distance which is calculated at [7–9]. As future work, further study and analysis will be conducted to incorporate the impact of vehicle motion on V2V communication into models and simulations.



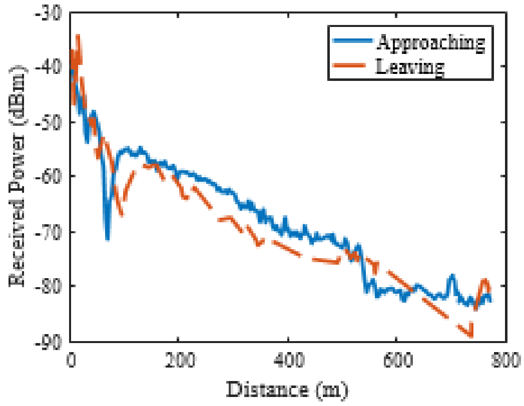
(a) OR1-1



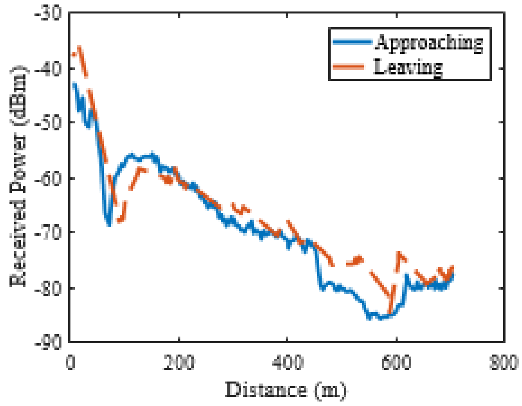
(b) OR1-2



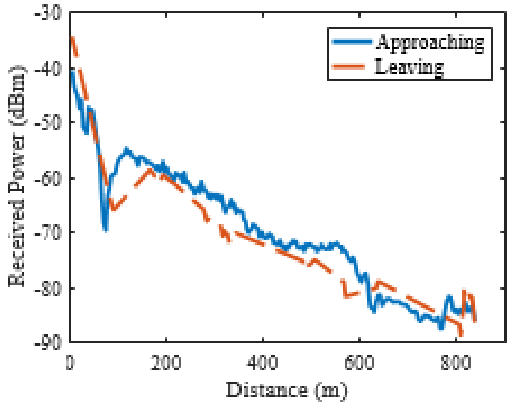
(c) OR1-3



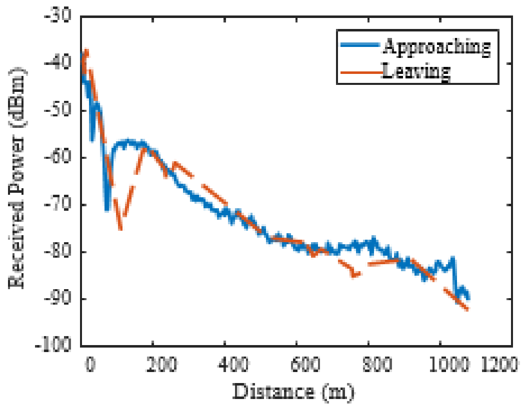
(d) OR1-4



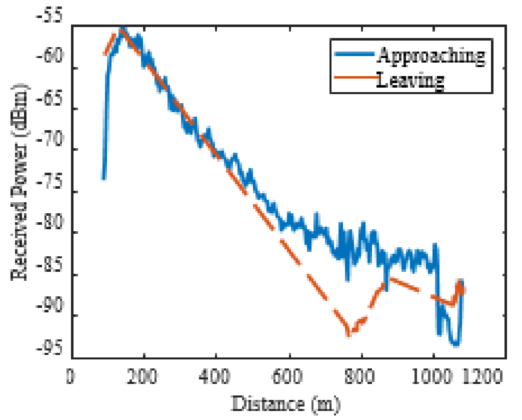
(e) OR1-5



(f) OR1-6



(g) OR1-7



(h) OR1-8

Figure 6. AOD and LOD data in OR1

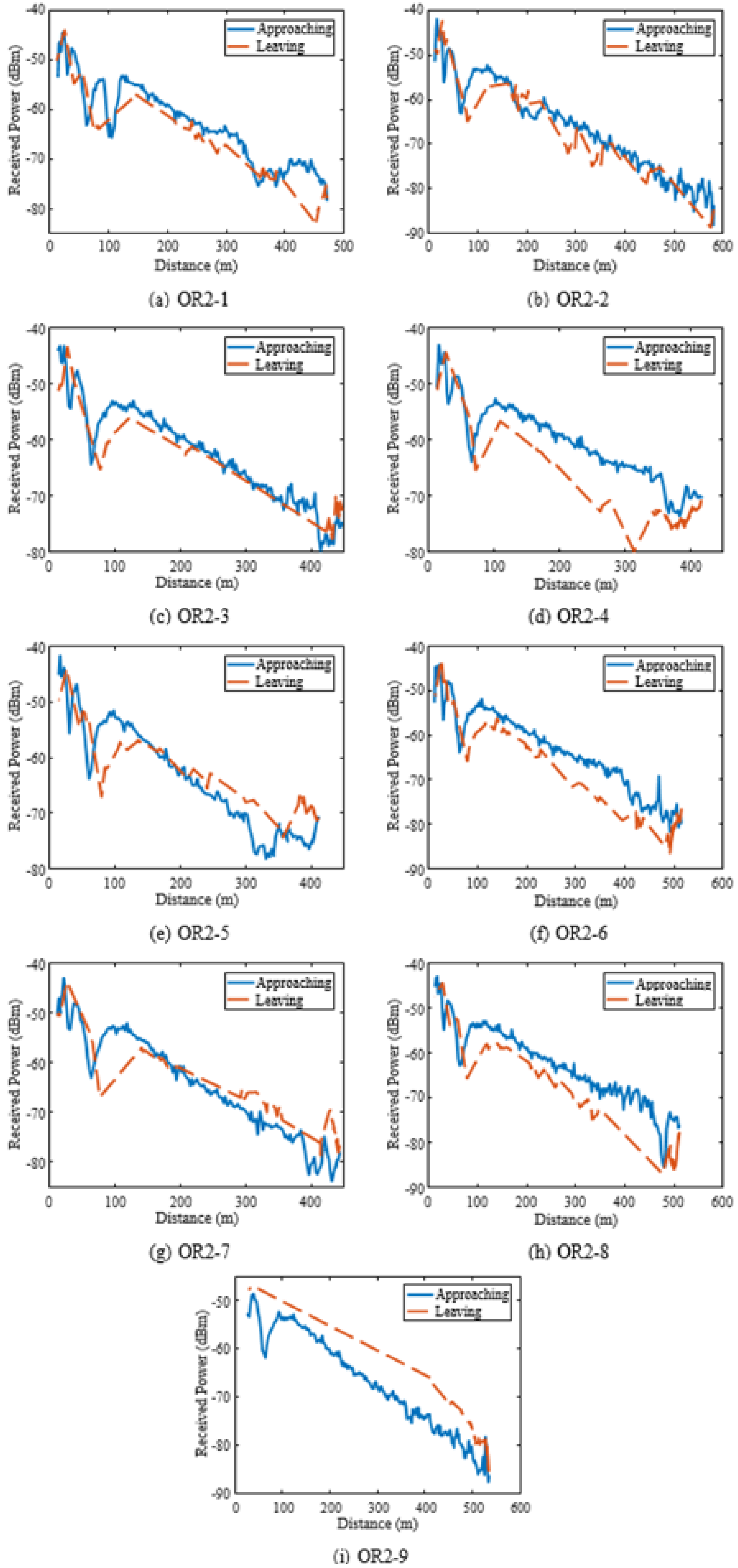


Figure 7. AOD and LOD data in OR2

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