Highway and Rural Propagation Channel Modeling
for Vehicle-to-Vehicle Communications at 5.9 GHz

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Introduction

Recent advances in computing and wireless communication technologies have increased interest in outdoor vehicular networks. Dedicated Short Range Communications (DSRC) systems have been proposed to support safety and service operations for vehicular networks. In North America, the Federal Communications Commission has allocated 75 MHz of spectrum at 5.9 GHz for DSRC based information exchange between vehicles [1]. Because vehicular networks bring significant potential for a wide range of services and applications, there exists a need to gain a detailed understanding of various vehicle-to-vehicle (V2V) propagation channels that cover diverse and rapidly changing on-road environments.

This paper reports channel measurements made using an on-road vehicular testbed equipped with programmable laboratory instruments. In particular, this location-aware channel sounding platform allows us to conduct statistical measurement campaigns for the outdoor V2V propagation channel as a function of location. Relevant Antenna effects are also discussed.

Reported experimental studies include narrow-band measurements conducted at 5.2 GHz described in [2], joint Doppler-delay power profile measurements at 2.4 GHz presented in [3], and vehicle-to-vehicle channel measurements and modeling at the 5.9 GHz band reported in [4].

Measurement Campaigns

Simultaneous mobility and RF measurements are desired as the vehicles traverse different environments. The RF platform we developed in [5] was improved by using Rubidium clocks to prevent the carrier drift. This is particularly useful for long time measurements. The experiments used roof mounted antenna on both vehicles. Fig. 1 depicts snapshots of the highway and rural environments during the measurement campaigns. The highway data presented here was measured on interstate highway route 79 located north of Pittsburgh, Pennsylvania. This segment of interstate highway consists of two and three lane segments with moderate traffic. During the experiments, the two vehicles were moving steadily at high speed, along with other vehicles with similar speeds. There exist cases
when the two vehicles changed lanes and overtook each other. There were in general no nearby buildings, but occasional overpasses were observed. The rural data was acquired as the vehicles traversed the rolling country side north of Pittsburgh, PA. This area is characterized by sections of open road interspersed with towns and intersections. The traffic was very light on these 2-lane roads, and the vehicles did not pass one another. Nearby clutter consisted of different kinds of low-height vegetation. Remote trees and hills were also commonly observed.

(a) Highway        (b) Rural
Fig. 1: Snapshots of the highway and rural environments.

Channel Modeling

Owing to the complexity of the real environment, empirical channel models are desired in large-scale vehicle-to-vehicle network simulations to ensure realistic results. Here we provide parameters for a dual-slope log-normal pathloss model extracted from our measurements. While the statistical variations in V2V channels are generally not normally distributed owing to the line-of-sight component [5], the normal distribution is an attractive approximation owing to its simplicity.

The received signal strength was computed from the frequency spectrum of the signals. We obtained the signal strength in each sweep by taking the difference between the total power in a fixed bandwidth with and without a signal present. For implementation details we refer the readers to [5].

We now describe the large-scale pathloss and shadowing model as a function of distance between the transmitter and receiver. We fit the measured pathloss to a log-distance pathloss model, as shown in Fig. 2. The slopes of the first segment are close to 2. For the second segment, the slopes are observed to be around 4. Given the transmit and receive antenna heights, the breakpoint distance calculated using the first Fresnel zone at 5.9 GHz is \( d_c = 225 \text{m} \). Referring to Fig. 2, the breakpoint distances that gave the best results are very near this value. It is interesting to compare these results with our previous suburban studies in [7], where a breakpoint of around 100m gave the best fit to the data. The shorter critical distance may be caused by more densely distributed objects like vehicles
and pedestrians on the road, creating reflections from points higher than the ground [5]. Since there are fewer pedestrians and other objects on the road in rural or highway areas compared to suburban areas, the likelihood of having reflections from objects above the ground is much smaller compared to the suburban case.

Fig. 2: Pathloss measurements and approximate large-scale models. (a) Highway. Dual-slope model with $\gamma_1=1.9$, $\sigma_1=2.5$ dB; $\gamma_2=4.0$, $\sigma_2=0.9$ dB; and $d_c=220$ m. (b) Rural. Dual-slope model with $\gamma_1=2.3$, $\sigma_1=3.2$ dB; $\gamma_2=4.0$, $\sigma_2=0.4$ dB; and $d_c=226$m. Here $\gamma_i$, $\sigma_i$ are the pathloss exponent and standard deviation for the $i$th segment, and $d_c$ is the breakpoint distance.

Next consider the spread of measured values about the average. We observe that in the suburban environment, the $\sigma_2$ values (standard deviations beyond the breakpoint) reported in [5] are larger than highway and rural environments reported here. This difference may result from a greater number of nearby objects such as houses and buildings in the suburban environment than in rural or highway environments.

In addition to the above comparison and analysis, it is interesting to note that in the highway data, we observe data points with much shorter vehicle separations than observed in the rural case (as short as 2 meters). These correspond to the case when the vehicles pass one another on the two-lane or three-lane highway segments. This situation is not observed in the rural measurements with one lane in each direction.

In the case of vehicles passing, variations can also arise from the radiation pattern of the antennas. Fig. 3 shows the measured antenna pattern above a simple ground plane for the actual antennas used for these measurements. In the on-road experiments, the roof-mounted antennas were placed with their direction of low-gain to the right side of the vehicle to ensure the best gain when the two vehicles were in car-following scenarios (majority of the cases). However, when a vehicle passes another, the gain of the passing vehicle antenna can vary rapidly as the angle between the vehicles changes. This suggests that measurements made during vehicle passing should be corrected for changes in antenna gain before inferring changes with distance.
**Conclusion**

In this article, we have reported experimental studies of signal strength as a function of vehicle separation for outdoor vehicle-to-vehicle propagation at 5.9 GHz. Statistical measurement campaigns were conducted in highway and rural driving environments. These measurements were used to obtain parameters for a dual-slope log-normal propagation model. The effects of antenna pattern variations for passing vehicles were also discussed.

![Radiation Pattern at 5.9 GHz](image)

Fig. 3: Measured antenna pattern above a ground plane (not mounted on vehicle).

**References**

[1] Standard specification for telecommunications and information exchange between roadside and vehicle systems - 5GHz band dedicated short range communications (DSRC) medium access control (MAC) and physical layer (PHY) specifications.


