Measurement-Based V2V Channel Characteristics at 5.9 GHz on Urban Crossroad

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Abstract. This article present single-input-single-output (SISO) measurement results of vehicle-to-vehicle (V2V) radio channel in an urban crossroad scenario at 5.9 GHz, where the measurement vehicles driving in vertical direction. Besides, radio channel characteristics include power delay profile (PDP), channel gain and delay spread also were conducted. Moreover, the lack of line of sight (LOS) path due to the roadside buildings can cause 9 dB attention loss in channel gain and around 130 ns increase in root mean square (RMS) delay. The influences of roadside buildings on V2V radio channels cannot be ignored. All the conclusions drawn in this article have guiding significance for the design of Intelligent Transportation System (ITS).

Keywords: V2V Communication, Channel Characteristic, Channel Gain, Delay Spread

1. Introduction
Vehicle-to-vehicle communication has a significant impact on intelligent transportation system (ITS) [1], [2]. ITS need a dynamically exchange to improve safety, especially interest is collision avoidance system. Therefore, the link quality of V2V radio channel becomes more prominent, particularly in urban crossroad and changing lanes scenarios. The Line-Of-Sight (LOS) path is mostly obstructed by the roadside buildings. Previous research [3] find the channel properties has influences on communication performance, so that it is essential to study characteristics of V2V radio channel.

Over the past few years, many V2V measurement campaigns had been conducted in suburban street, expressway and urban canyon scenarios [2]. But only a small part of the literatures have studied crossroads scenario [4]. Paper [5] studied the channel characteristics of four urban intersections at 5.9 GHz, and the reliable communication ranges were determined. Paper [6][7] discuss the large-scale path loss and small-scale fading for urban intersections in Non-Line-Of-Sight (NLOS) conditions. Paper [8] gave the 4×4 MIMO radio channel measurement campaign in highway scenario at 5.2 GHz. In paper [9], the large scale propagation properties and delay spread in indoor environment at 5.9 GHz had been provided. The analysis of delay spread and angular dispersion in crossroad scenarios at 5.3 GHz can be found in [10].
However, most of the measurement campaigns were conducted in Europe and United States close to 5.9 GHz. The V2V measurement campaigns under Asia at 5.9 GHz is rarely. To fill the gaps, we conduct a measurement campaign in urban crossroad of Wuhan, China at 5.9 GHz.

The rest of this paper is structured as follow: we describe the measurement equipment and the measurement campaign in section II. In section III we present the channel characteristics include power delay profile, channel gain and delay spread. Finally, the conclusions are presented in section IV.

2. Measurement Equipment and Environment

2.1. Measurement Equipment
The channel sounder provided by Super Radio AS that preforms signal-in-signal-output (SISO) measurements in urban crossroad. For the measurements, two compact cars were used. Global Positioning System (GPS) part and the omni-directional antenna were installed on the roof of the cars, shown in Figure 1(a).

![Figure 1](image)

(a) (b)

Figure 1. Measurement scenario and vehicle. (a) is the measurement vehicle. (b) is the measurement vehicle scenario.

The height of transmit antenna (TX) and receive antenna (RX) was 1.50m and 1.77m, respectively. The transfer function $H(f, t)$ were estimated over 100 MHz with a center frequency of 5.9 GHz, which is approaching the 802.11p standard. The channel sounder emitted 1933 chirp signals per second (i.e. the chirp repetition time was 517.3 us) with 16 dBm TX power, and there were 2560 samples per chirp with 10 ns delay resolution (i.e. the test signal length was 25.6 us). During the whole measurement process, both GPS part and channel sounder were connected to the portable computer to record the GPS position information and Channel Impulse Responses (CIRs) data. The main parameters are shown in Table 1.

| Parameters                  | Value         |
|-----------------------------|---------------|
| Center frequency, $f_c$     | 5.9 GHz       |
| Bandwidth, $B_W$            | 100 MHz       |
| Test signal length, $\tau_{\text{max}}$ | 25.6 us       |
| Chirp repetition time, $T_{\text{rep}}$ | 517.3 us       |
| Sample number, $N$         | 2560/chirp    |
| Delay resolution, $\tau_{\text{min}}$ | 10 ns       |
| TX antenna height, $h_{\text{TX}}$ | 1.50 m       |
| RX antenna height, $h_{\text{RX}}$ | 1.77 m       |
| TX power, $P_{\text{TX}}$  | 16 dBm        |
| TX gain, $G_{\text{TX}}$   | 2 dBi         |
| RX gain, $G_{\text{RX}}$   | 2 dBi         |
2.2 Measurement Environment
Apart from the contributions shown in paper [5], [11] and [12] that estimated the V2V radio channel in Germany, Sweden, and the United States, we measured the V2V radio channel in China, which fill the gap of measurement data. The measurement site was located on the intersection of Bridge South Road and Jian’an Street, Wuhan, China (114°19’12.52” E, 30°30’19.33” N). During the measurement campaign, the measurement vehicles were driving with perpendicular direction in an urban crossroad as shown in Figure 1(b). The TX vehicle drove from east to west, meanwhile the RX vehicle drove from south to north. For the measurement process, the TX vehicle was driving at a speed of 0-6 m/s because of the bad traffic condition, meanwhile the RX vehicle was driving at a speed of 5-11 m/s.

3. Results and Analysis

3.1 Average Power Delay Profile and Channel Gain
To analysis the impact of time variations on the received signal power and scatters, we derive the instantaneous time-varying power delay profile (PDP) of each time sample. Meanwhile, in order to filter the impacts of small scale fading, we average the instantaneous time-varying PDP within a 10-wavelength sliding window according to the Wide-Sense Stationary Uncorrelated Scattering (WSSUS) assumption [13]. The average PDP (APDP) is derived as formula 1:

$$P(t, \tau) = \frac{1}{N_{avg}} \sum_{n=0}^{N_{avg}-1} |h(t+nT_{rep}, \tau)|^2$$

(1)

Where $t= (0, N_{avg}T_{rep}, 2N_{avg}T_{rep}, \ldots)$, for $N_{avg}$ is the chirp number over 10-wavelength sliding window, which value equals 58 and calculated as $N_{avg}=\lfloor 10\mu/s T_{rep} \rfloor$. Here, $T_{rep}$ is equal to 517.3 us denotes the chirp repetition time and $\nu$ is the relative speed of TX and RX vehicle. And $h(t+nT_{rep}, \tau)$ is the time varying channel impulse responses (CIRs). Besides, the time-varying channel gain is calculated as $CG=PL$, and the $PL$ is calculated by equation 2.

$$PL = P_{RX} + G_{RX} + G_{TX} - P_{TX} - G_{loss}$$

(2)

In formula 2, $P_{RX}$ is the received signal power calculated as $P_{RX}(t)=\sum P(t, \tau)$, $G_{TX}$ and $G_{RX}$ represent the TX gain and RX gain in dBi, respectively. $G_{loss}$ denotes the cable loss of the measurement system, the detailed value of the parameters in formula 2 are shown in TABLE 1.
Figure 2. APDP and channel gain. (a) is APDP. (b) is channel gain in dB scale

Figure 2 shows the APDP and the corresponding channel gain. In Figure 2(a) we saw a clear LOS component at time of 0-2.2s, and the LOS component disappear in the time of 2.2–5s. Besides, we can see there were number of scatterings in the whole measurement campaign which can provide the high lever channel gain even though lack of LOS component.

By analyzing the GPS coordinates of measurement vehicles and the corresponding satellite map, at 2.2s the RX vehicle was driving in the north of the intersection, meanwhile the TX vehicle was driving in the east of the intersection. So that the LOS path was obstructed by the roadside buildings as shown in Figure 1(b) marked by the red circle. The impact of surrounding buildings blocking the LOS path on the wireless channel is not only reflected in the APDP. Figure 2(b) shows a 9dB decrease in channel gain at about 2s. In the propagation of wireless signals, the LOS path contains a large amount of energy, and the absence of the LOS path will cause a large decrease in channel gain. By analyzing Figure 2, we can conclude that the decrease of channel gain is due to the lack of LOS path. Therefore, the obstruct of roadside buildings would case about 9dB attenuation loss on the received signal level.

3.2 Delay Spread

The root mean square (RMS) delay is the key parameters for the application of V2V wireless communication system, which providing a compact description for delay and frequency dispersion of a channel [1], and the frequency selectivity of a channel also described by RMS delay.

A great number of research results have been proven that delay spread has a direct impact on the error floor [1], [13]. Therefore, there is a great significance to analysis the characteristics of delay spread. The mean delay $\tau_\infty$ is calculated as normalized first-order moment of PDP and RMS delay $\tau_{\text{rms}}$ is the normalized second-order central moment :

$$\tau_\infty(t) = \frac{\int_{-\infty}^{\infty} P(t, \tau) \tau d\tau}{\int_{-\infty}^{\infty} P(t, \tau) d\tau}$$

$$\tau_{\text{rms}}(t) = \sqrt{\frac{\int_{-\infty}^{\infty} P(t, \tau) \tau^2 d\tau}{\int_{-\infty}^{\infty} P(t, \tau) d\tau} - \tau_\infty^2(t)}$$

As shown in Figure 3, there is around 130 ns increase of RMS delay. In this situation, the LOS link was obstructed by the roadside buildings between TX and RX vehicles. Therefore, only scatterings can arrive at the RX. Those scatterings were provided by multiple reflections of roadside buildings, the rich scatterings result a higher RMS delay.

Figure 3. Time varying RMS delay
4. Conclusions
This article presents V2V radio channel characteristics at 5.9 GHz on urban crossroad in Wuhan, China. The statistic characteristics in power domain and time domain include APDP, channel gain and delay spread were analyzed. One of the great contributions of this paper is the center frequency we measured is 5.9 GHz, which is accord with the 802.11p standard. Therefore, the results we got can provide an exact guidance for the design of ITS.

Based on WSSUS assumption, the APDP and channel gain shows the absence of LOS path would result in 9dB attention loss in receive signal lever and 130ns increase in RMS delay spread.

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