Time-Varying Characteristics for V2V Channels in Complicated Scenarios

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Abstract

Wireless channel characterization and modeling is the foundation of vehicle-to-vehicle (V2V) communication systems. In this paper, the time-varying channel characteristics under three complicated scenes, namely, viaduct, tunnel, and cutting, are measured and studied. Specifically, based on the targeted 5.9 GHz channel measurements, a detailed analysis of the time-varying power and delay of multipath components (MPCs) is presented. The research in this paper is helpful to the investigation of V2V channel propagation mechanism and the design of communication systems.

1 Introduction

Wireless channel characterization and modeling is the foundation of communication systems [1, 2, 3, 4, 5]. However, most of the existing researches on vehicle-to-vehicle (V2V) channel are aimed at the traditional scenarios such as urban and suburban, and the researches on some complicated vehicular scenarios are insufficient. For example, little attention is paid to viaduct, tunnel, and cutting scenarios in vehicular communications, and these complex scenarios often become the high-incidence area of communication interruption, and then affect the overall performance of the vehicular communication system due to the bad and unique channel characteristics. Therefore, channel measurements and researches for these special scenarios are extremely necessary for V2V communication systems.

At present, a series of fruitful researches have been carried out on V2V channels in special scenarios. However, to the author’s best knowledge, the existing research still has the following gaps: i) There is a lack of research on tunnel, cutting and viaduct scenarios, which are common in V2V communications. Besides, although there have been researches on tunnels [6], cutting [7] and viaducts [8], almost all of them are oriented to railway or subway environment. In railway and subway scenarios, communication links generally exist between base stations (BSs) with high antenna heights and vehicles, which is obviously different from the links between vehicles in V2V communications. Therefore, the results presented by these related works can not well reflect the channel characteristics of V2V links. i)

Channel measurements for V2V applicable frequency is insufficient. At present, 5.9 GHz is considered as the most likely frequency band for V2V communications. However, the channel measurements for tunnels, cutting and viaducts are mostly at 930 MHz [9], 2.4 GHz [10] and 5 GHz [11]. In addition, there are some valuable geometry- or ray-tracing-based researches on V2V channels [12]. Although they are not limited by measurement ability and can be applied to 5.9 GHz. However, it is still necessary to carry out necessary channel measurements and provide some quantitative experimental results to verify and optimize them. iii) The research on time-varying channel characteristics needs to be enriched. Existing researches on special scenarios such as tunnels, cutting and viaducts mostly focus on statistical analysis and modeling of typical channel parameters such as path loss and delay spread. However, transmitters (TX) and receivers (RX) in V2V links are moving rapidly, which leads to strong non-stationariness. The existing research seldom involves the time-varying channel characteristics of V2V channels.

In this paper, to fill these gaps, time-varying characteristics of V2V channels in tunnel, cutting and viaduct scenarios are measured and studied. The remainder of this paper is organized as follows. Section II describes the 5.9 GHz V2V channel measurement campaigns. Section III and IV presents a detailed investigation of time-varying power and delay characteristics. Finally, Section V draws the conclusions.

2 Measurement Campaign

The schematic diagrams of measurement scenarios, including viaduct, tunnel and cutting, are shown in Fig. 1. Viaduct is a common scenario in highway and urban environments. The measurement vehicles run on a bridge about 12 meters high from the ground and about 25 meters wide. Therefore, trees, other vehicles, and low buildings on the ground are far away from TX and RX. Tunnel and cutting are widely built in mountainous and hilly areas. Their common feature is that there are walls on both sides of the road, which makes the tunnel and cutting become a semi-enclosed environment. This is obviously different from the open environment such as viaducts and ordinary urban ar-
Figure 1. Measurement Scenarios. (a) Viaduct. (b) Tunnel. (c) Cutting.

Figure 2. PDPs of three scenarios.

First of all, these three scenarios have a similar maximum delay, which is about 1800 ns, and the corresponding propagation distance is 540 meters. For signals whose propagation distance exceeds this value, the RX cannot capture useful signals from noise due to the path loss. It can be found that the number of multipath with large delay is small, and these multipaths have low energy, so the influence of these multipaths on channel characteristics is feeble.

Secondly, there are some MPCs with strong energy and large lifetime in these scenarios, and this kind of MPC is most apparent in the viaduct, such as the signal marked by the white arrow in Fig. 2 (a). These signals show an obvious dynamic process: delay from small to large with energy from strong to weak, and vice versa. These MPCs originate from static scatterers in the environment, such as buildings and traffic signs. When the measurement vehicles pass through the scatterer, the short propagation path brings the MPCs with small delay and strong energy. As the vehicles gradually move away, the increase of propagation distance leads to decreased energy and the increase of delay. Because of its transparent change process, the source of this kind of MPCs is traceable. Therefore, it can be speculated that there will be more such MPCs in a scenario with denser scatterers, and this phenomenon can be observed in [14].

Thirdly, there are a lot of indistinguishable MPCs in tunnels. The wall and ceiling in the tunnel will cause multiple reflections of signals so that RX can capture many multipath signals. These MPCs are superimposed, which makes
it difficult to distinguish them in the power-delay domain. The relative delay of these MPCs is in the range of 0 to 1500 ns. Unlike the large delay MPCs in cutting scenarios mainly from distant scatterers, the large delay MPCs in tunnels come from multiple reflections.

Fourthly, there are several long-lifetime MPCs with constant delay in the cutting scenario, as indicated by the white arrow in Fig. 2 (c). The relative delay of these persistent MPCs is 100-400 ns, and the corresponding propagation distance is 30-120 meters. The sources of these MPCs are single or multiple reflections from the walls on both sides of the cutting. The measurement vehicles are constantly moving, but because the distance between the vehicles and the walls is basically unchanged, the delay of these MPCs is also stable. Also, it is found that there are some interruptions in these MPCs, which may be due to some vehicle obstructions. An interesting phenomenon is that although there are walls in tunnels, similar MPCs are not observed. The reason is that the distance between the walls of a tunnel is closer, and the existence of the ceiling will lead to more complex and dense MPCs, so it is difficult to distinguish these persistent MPCs from a large number of received signals.

According to the above observation, it can be concluded that the difference in scenarios has a significant influence on the energy and delay of MPCs. Specifically, scatterers such as buildings, walls, and surrounding vehicles are the sources of MPCs, and the differences in their types, numbers, and positions lead to the channel characteristics differences between scenarios. For the three typical V2V scenarios concerned in this paper, viaducts have more static-scatterer-caused MPCs with delay and energy varying with vehicle movement. Moreover, there are a lot of indistinguishable MPCs in tunnels because they have the most abundant scatterers. The striking feature of cutting scenarios is several MPCs with a constant delay caused by wall reflection.

## 4 Time-varying Delay Dispersion

Root-mean-square (RMS) delay spread is the square root of the second central moment of PDPs and is widely used to characterize the delay dispersion of channels. Fig. 3 shows the time-varying RMS delay spreads and the corresponding cumulative distribution functions (CDFs) for measured scenarios. The statistical values are summarized in Table 1. The average values in these three scenarios are 107.7 ns, 139.2 ns, and 73.2 ns, respectively. And standard deviations values are 29.6 ns, 17.5 ns, and 23.4 ns, respectively. It can be found that there are obvious differences in RMS delay spread among these three scenarios. In tunnels, RMS delay spread is obviously higher than that in the other two scenarios, because there are a large number of dense reflection paths, and these MPCs still have strong energy in large delay.

In the cutting scenario, although there are several strong reflection paths, their delay is small, so the RMS delay spread is not significantly increased. At the same time, the cutting scenario also lacks high-delay and strong-energy MPCs existing in viaducts, so the cutting scenario has the lowest RMS delay spread. The differences in RMS delay spread between scenarios may affect the design of communication systems, such as inter-symbol interference elimination and diversity technology.

### Table 1. Statistical parameters of channel characteristics.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Viaduct</th>
<th>Tunnel</th>
<th>Cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS delay spread AVG $\mu$ [ns]</td>
<td>107.7</td>
<td>139.2</td>
<td>73.2</td>
</tr>
<tr>
<td>RMS delay spread STD $\delta$ [ns]</td>
<td>29.6</td>
<td>17.5</td>
<td>23.4</td>
</tr>
<tr>
<td>RMS delay spread 50% value [ns]</td>
<td>102.5</td>
<td>137.9</td>
<td>64.1</td>
</tr>
<tr>
<td>RMS delay spread 90% value [ns]</td>
<td>139.4</td>
<td>158.6</td>
<td>105.0</td>
</tr>
</tbody>
</table>

Figure 3. The time-varying RMS delay spreads and the corresponding CDFs of the three measured scenarios.
large number of dense reflection MPCs with strong energy. The quantitative results presented in this paper are helpful to deepen the understanding of V2V channels.

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