URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Time-Varying Characteristics for V2V Channels in Complicated Scenarios

Mi Yang(1), Bo Ai*(1)(2), Ruisi He*(1), Zhangdui Zhong(1), Ruifeng Chen(3), and Haoxiang Zhang(4)
(1) State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China
(2) Peng Cheng Laboratory, Shenzhen, China
(3) Institute of Computing Technology, China Academy of Railway Sciences, Beijing, China
(4) China Academy of Industrial Internet, Ministry of Industry and Information Technology, Beijing, China

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 system.

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. ii) 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-

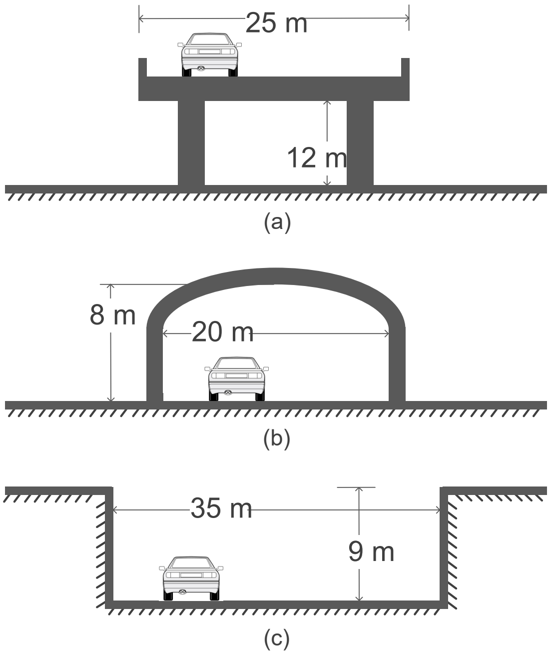

Figure 1. Measurement Scenarios. (a) Viaduct. (b) Tunnel. (c) Cutting.

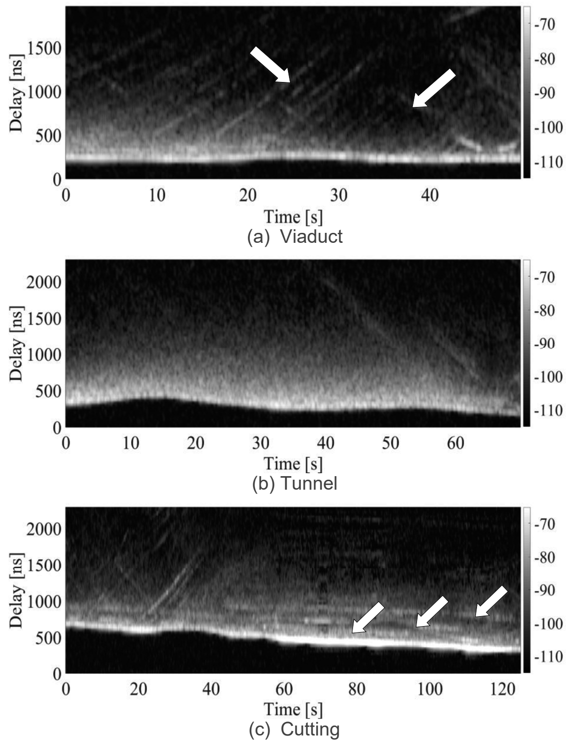

Figure 2. PDPs of three scenarios.

eas. Also, there are differences between tunnels and cutting. Firstly, due to the existence of ceilings, tunnels are more closed than cutting scenes, and secondly, the width of tunnels is generally smaller than cutting. In this paper, the measured tunnel is about 20 m wide and 8 m high, while the cutting is about 9 m deep and 35 m wide.

The measurement system is divided into TX and RX, which are deployed on two vehicles, respectively. The core equipment of TX is a vector signal transmitter, which can generate baseband measurement signals and up-convert then to 5.9 GHz band. Through a 30 dB gain power amplifier, the transmission power can reach 34 dBm. Correspondingly, at RX, a vector signal analyzer can down-convert radio frequency measurement signals to baseband and then perform data processing and analysis. In addition, to ensure the consistency of the reference clocks of all measurement devices, a set of GPS-tamed Rubidium clock at both TX and RX are used to provide 10 MHz reference clocks.

3 Time-varying Power Distribution

Power delay profile (PDP) is widely used to describe the powers of the received multipath components (MPCs) with propagation delays. The instantaneous PDP is denoted as [13]

$$PDP(t,\tau) = \mid h(t,\tau) \mid^2, \tag{1}$$

where $h(t,\tau)$ is the channel impulse response (CIR) at time t with delay τ. Considering the actual environment and transmission power, there is generally a maximum delay, and PDP exceeding this maximum delay can be removed. Fig. 2 shows the measured PDPs in three kinds of scenarios. Following phenomena can be observed:

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

Table 1. Statistical parameters of channel characteristics.

Scenario	Viaduct	Tunnel	Cutting
RMS delay spread AVG μ [ns]	107.7	139.2	73.2
RMS delay spread STD δ [ns]	29.6	17.5	23.4
RMS delay spread 50% value [ns]	102.5	137.9	64.1
RMS delay spread 90% value [ns]	139.4	158.6	105.0

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.

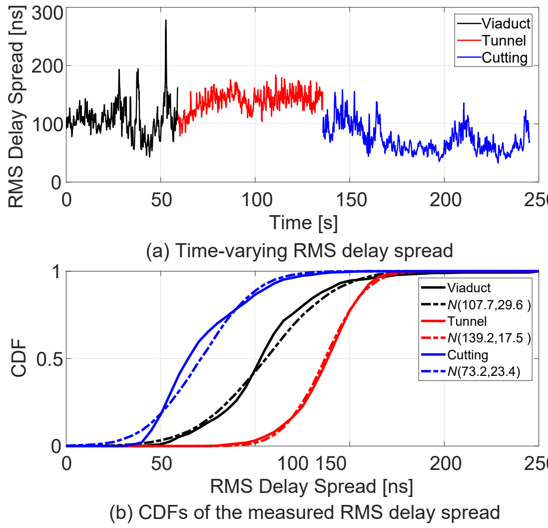

Figure 3. The time-varying RMS delay spreads and the corresponding CDFs of the three measured scenarios.

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.

5 Conclusion

Based on the 5.9 GHz channel measurements in V2V environments, this paper illustrates the difference between MPC energy and delay distribution in different scenarios through PDPs. It is found that there are a large number of indistinguishable MPCs in tunnels, and there are several long-lifetime MPCs with constant delay in the cutting scenario. These differences in MPC characteristics are due to the different types and positions of scatterers in the environment. In addition, these differences also affect the RMS delay spread. In tunnels, RMS delay spread is obviously larger than that in the other two scenarios because there are a 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.

6 Acknowledgements

This work was supported by the National key research and development program under Grant 2020YFB1806903, the National Natural Science Foundation of China under Grant 61725101, 61922012, 62001519, U1834210, and 61961130391, the State Key Lab of Rail Traffic Control and Safety under Grant RCS2020ZT008, RCS2019ZZ007, and RCS2020ZT010, the Royal Society Newton Advanced Fellowship under Grant NA191006, the Teaching reform project under Grant 134811522, the Fundamental research funds for the central universities under Grant 2020JBZD005 and I20JB0200030, the Open Research Fund from Shenzhen Research Institute of Big Data, under Grant No. 2019ORF01006, the project PCL Future Greater-Bay Area Network Facilities for Large-scale Experiments and Applications (LZC0019), and the Beijing Engineering Research Center of High-Speed Railway Broadband Mobile Communications.

References

[1] R. He, O. Renaudin, V. Kolmonen, K. Haneda, Z. Zhong, B. Ai, and C. Oestges, "A dynamic wideband directional channel model for vehicle-to-vehicle communications," *IEEE Transactions on Industrial Electronics*, **62**, 12, 2015, pp. 7870–7882, doi: 10.1109/TIE.2015.2459376.

[2] B. Ai, A. F. Molisch, M. Rupp and Z. -D. Zhong, "5G Key Technologies for Smart Railways," *Proceedings of the IEEE*, **108**, 6, June 2020, pp. 856–893, doi: 10.1109/JPROC.2020.2988595.

[3] R. He, C. Schneider, B. Ai, G. Wang, Z. Zhang, D. A. Dupleich, R. S. Thomae, M. Boban, J. Luo, Y. Zhang, "Propagation Channels of 5G Millimeter-Wave Vehicle-to-Vehicle Communications: Recent Advances and Future Challenges," *IEEE Vehicular Technology Magazine*, **15**, 1, March 2020, pp. 16–26, doi: 10.1109/MVT.2019.2928898.

[4] M. Yang, B. Ai, R. He, L. Chen, X. Li, J. Li, B. Zhang, C. Huang, and Z. Zhong, "A cluster-based three-dimensional channel model for vehicle-to-vehicle communications," *IEEE Transactions on Vehicular Technology*, **68**, 6, 2019, pp. 5208–5220, doi: 10.1109/TVT.2019.2911929.

[5] R. He, B. Ai, G. L. Stber, G. Wang, and Z. Zhong, "Geometrical-based modeling for millimeter-wave mimo mobile-to-mobile channels," *IEEE Transactions on Vehicular Technology*, **67**, 4, 2018, pp. 2848–2863, doi: 10.1109/TVT.2017.2774808.

[6] R. He, Z. Zhong, B. Ai, G. Wang, J. Ding, and A. F. Molisch, "Measurements and analysis of propagation channels in high-speed railway viaducts," *IEEE Transactions on Wireless Communications*, **12**, 2, 2013, pp. 794–805, doi: 10.1109/TWC.2012.120412.120268.

[7] V. Savic, J. Ferrer-Coll, P. ngskog, J. Chilo, P. Stenumgaard, and E. G. Larsson, "Measurement analysis and channel modeling for TOA-based ranging in tunnels," *IEEE Transactions on Wireless Communications*, **14**, 1, 2015, pp. 456–467, doi: 10.1109/TWC.2014.2350493.

[8] R. He, Z. Zhong, B. Ai, J. Ding, Y. Yang, and A. F. Molisch, "Short-term fading behavior in high-speed railway cutting scenario: Measurements, analysis, and statistical models," *IEEE Transactions on Antennas and Propagation*, **61**, 4, 2013, pp. 2209–2222, doi: 10.1109/TAP.2012.2235399.

[9] B. Zhang, Z. Zhong, R. He, F. Tufvesson, and B. Ai, "Measurement based multiple-scattering model of small-scale fading in high-speed railway cutting scenarios," *IEEE Antennas and Wireless Propagation Letters*, **16**, 2017, pp. 1427–1430, doi: 10.1109/LAWP.2016.2626303.

[10] T. Zhou, C. Tao, S. Salous, and L. Liu, "Measurements and analysis of angular characteristics and spatial correlation for high-speed railway channels," *IEEE Transactions on Intelligent Transportation Systems*, **19**, 2, 2018, pp. 357–367, doi: 10.1109/TITS.2017.2681112.

[11] J. Li, Y. Zhao, J. Zhang, R. Jiang, C. Tao, and Z. Tan, "Radio channel measurements and analysis at 2.4/5GHz in subway tunnels," *China Communications*, **12**, 1, 2015, pp. 36–45, doi: 10.1109/CC.2015.7084382.

[12] H. Jiang, Z. Zhang, L. Wu, J. Dang, and G. Gui, "A 3D non stationary wideband geometry-based channel model for MIMO vehicle to vehicle communications in tunnel environments," *IEEE Transactions on Vehicular Technology*, **68**, 7, 2019, pp. 6257–6271, doi: 10.1109/TVT.2019.2918333.

[13] T. K. Sarkar, Zhong Ji, Kyungjung Kim, A. Medouri, and M. Salazar Palma, "A survey of various propagation models for mobile communication," *IEEE Antennas and Propagation Magazine*, **45**, 3, 2003, pp. 51–82, doi: 10.1109/MAP.2003.1232163.

[14] M. Yang, B. Ai, R. He, G. Wang, L. Chen, X. Li, C. Huang, Z. Ma, Z. Zhong, J. Wang, Y. Li, and T. Juhana, "Measurements and cluster based modeling of vehicle to vehicle channels with large vehicle obstructions," *IEEE Transactions on Wireless Communications*, **19**, 9, 2020, pp. 5860–5874, doi: 10.1109/TWC.2020.2997808.