Measurement and Analysis of Fading Characteristics of V2V Propagation Channel at 5.9 GHz in Tunnel

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Abstract. In this paper, we present a vehicle-to-vehicle (V2V) wireless channel measurement at 5.9 GHz in the tunnel environments. The small scale fading characteristics are analyzed for outside and inside the tunnel, and the conjunction part in between. We evaluate the received signal magnitude inside the tunnel by comparing its distribution with five typical theoretical fading distributions. The best fit among the considered fading distributions is found to be Rician distribution that has the lowest Goodness of Fit (GoF) indicator. The K-factor calculated from measurements data inside the tunnel is lower than the values obtained outside the tunnel. Further, the K-factor is found to be dependent on the transmitter (Tx)-receiver (Rx) distance in the considered scenario.

Keywords: V2V · Propagation channel · Tunnel · Fading characteristics

1 Introduction

Internet of things (IOT) is a huge network of real-world various objects linked by the internet through information sensing equipments and realize the interconnection of people, machines and objects at any time and any place [1]. Internet of vehicles (IOV) is a specific application of IOT in urban intelligent transportation system. IOV uses the technologies of wireless communication and sensing detection to collect and interaction the information of vehicles, roads, environment through the Vehicle to everything (V2X) links, so as to realize an intelligent integrated network of traffic management control, vehicle control and dynamic information service [2,3].

V2X is mainly divided into three categories: vehicle-to-vehicle (V2V) [4], vehicle-to-infrastructure (V2I) [5], vehicle-to-pedestrian (V2P) [6], which forms the vehicular ad hoc networks (VANETs) by intercommunication. V2V communication is not limited to fixed base station, but a direct wireless communication between two moving vehicles from one end to another. V2V plays an important

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role in intelligent transportation system which can monitor "hidden" data such as the speed and position of other vehicles, and automatically predicts whether there will be a possible collision with other vehicles on the road. To better develop the V2V communication systems, it is essential to understand the V2V propagation channel.

Many measurement campaigns and channel modeling of V2V wireless channel have been performed in recent years for typical environments (e.g., rural, suburban, urban, and highway) [4,7–9]. Other particular environments such as underground parking and tunnel have also been investigated marginally. Particularly, the small scale fading in tunnel has not been thoughtfully studied. [10] presents a study on the statistical analysis of the small-scale fading of the V2V propagation channel at 5.9 GHz inside tunnels. The results of the paper shows that the Rice distribution to fit cumulative distribution function (CDF) and the mean K factor values outside the tunnel is higher than inside the tunnel. However, an insight into the other fading characteristics, e.g., Rayleigh, Weibull, etc. is needed.

In this paper, we present a channel measurement at 5.9 GHz in the tunnel environment. Based on the measurement data the small scale fading characteristics are analyzed for outside and inside tunnel, and the conjunction part in between. We compare the statistical characteristic of the received signal magnitude with 5 typical theoretical fading distributions. Based on the GoF indicator the best fit among 5 considered fading distributions is found to be Rician distribution. The K-factor is calculated and analyzed, that K-factor depends on the Tx-Rx distance.

The paper is structured as follows: in Sect. 2, the setup of the channel measurement campaign is addressed. Section 3 presents the data processing methods and the results. Finally Sect. 4 concludes the paper.

2 Channel Measurement

2.1 Measurement Setup

The channel measurement campaign was conducted with the BJTU channel sounder, which relies on National Instrument-PXI chassis based software defined radio system [11]. The channel sounder is consist of vector signal transmitter and receiver, clock module, power supply module, data storage, transmitting antenna/receiving antenna and other modules. At the transmitter side, the chassis NIPXIE-1082 and the vector signal transmitter NIPXIE-5673 are used to continuously transmit 5.9 GHz signal. Orthogonal Frequency Division Multiplexing (OFDM) sequence is adopted as the sounding signal of channel. A power amplifier is used to amplify the sounding signal at the transmitter, and then the signal is transmitted by a single transmit antenna mounted on the top of the vehicle. The receiver is composed of the chassis NIPXIE-1082 and the vector signal receiver NIPXIE-5663. During the measurement, both single-input single-output (SISO) and single-input multiple-output (SIMO) measurement were considered. For the former case, the same antenna as the transmit antenna was used

Fig. 1. Vehicles used for measurement: the van on the left side was used for transmitter and the car on the right hand side was used for receiver.

at the receiver; and for the latter case, we used an antenna array consisting of 16-elements, each of which is dual polarized. Each antenna unit of the antenna array was controlled by electronic switch, and data of each antenna channel was collected and stored in a time division manner. In both cases, the receive antennas were mounted on the rooftop of the receiver vehicle as shown in Fig. 1, where the van on the left side was used for transmitter and the car on the right hand side was used for receiver.

The software platform of the channel sounder is based on the programming environment of Laboratory Virtual Instrument Engineering Workbench (LabVIEW), which can efficiently program and control the hardware equipment of the channel sounder. With suitable setting the software, extracting data collected by the receiver for real-time processing, storage and displaying can be achieved.

To synchronize the transmitter and receiver, Rubidium clock disciplined by the timing information obtained from Global Positioning System (GPS) receivers as the frequency norm standards were used on both sides. To provide power to the channel sounder, the high-power inverter was used to convert the 12 V DC power of the vehicle battery into 220 V AC power. To prevent the power interruption and unstable current, the uninterruptible power supply was used between the inverter and the channel sounder. Table 1 shows the 5.9 GHz channel sounding system parameters.

2.2 Measurement Environment

The measurement campaign was conducted in a tunnel in the south region of Xi'an city. Both vehicles travelled in the same direction with similar speeds. The

Table 1. 5.9 GHz channel sounding system parameters.

Centre frequency f_c	5.9 GHz
Measurement type	SISO and SIMO
Bandwidth B	30 MHz
Transmit power	max. 34 dBm
Test signal	OFDM signal
Transmit and receive antenna speed	$\sim 40^{\mathrm{km/h}}$

Fig. 2. Rectangular tunnel with two lanes

measurement was started at the street cross shortly before the entrance of the tunnel, such that the channel propagation characteristics can be obtained for outside tunnel, inside tunnel and the conjunction part in between. During the measurement campaign, there always exists a direct line-of-sight (LoS) between the transmitter and the receiver. Figure 2 shows the picture of the rectangular tunnel consisting of a two lanes. Figure 3 visualizes the received power for the measurement where the vehicles started from the street cross. The received power is varying distributed between −55 dBm and −30 dBm. In the beginning, the received power varies insignificantly. It is due to the fact that both vehicles were waiting for the traffic light changing from red to green. It can be seen that there is a large decreasing in the received power while two vehicles traveled towards the tunnel with increasing distance between transmit and receive antennas. The fading depth of received signal outside the tunnel is smaller than inside tunnel.

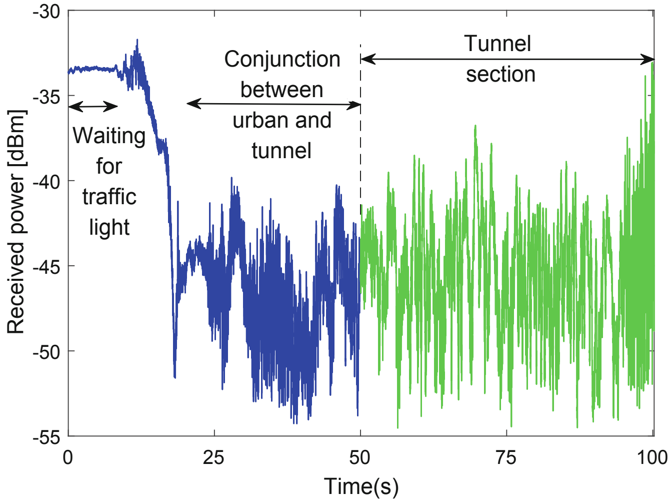

Fig. 3. Received power outside and inside the tunnel for measurement (Color figure online)

3 Small-Scale Fading Analysis

In order to evaluate the small scale fading in the tunnel, the received signal strength is normalized to mitigate the large scale fading effect, i.e., distance dependent path loss. Similar to [12–14], a sliding window is used to calculate the large scale fading by moving average method. The received power is normalized to the average power taken over a certain measurement samples where the channel is regarded to be stationary. In this paper, the window length is set to 200 consecutively measured samples. Figure 4 visualizes the normalized magnitude of the received signal inside the tunnel.

In the statistical characteristics of describing small scale fading, there are usually two probability distribution functions assumed for V2V communication channel: Rician distribution and Rayleigh distribution, but other distributions such as Nakagami-m and Weibull have also been proven to well fit the fading behavior. More specifically, the Rice and Weibull distributions have been used in paper [12]. The Weibull distribution is a more generalized distribution model, which is identical to the Rayleigh distribution when the shape parameter $k = 2$. If the shape parameter of the Weibull distribution is larger than two, the Weibull distribution becomes similar to the Rician distribution.

Within the measurement data, starting from the 50 s, both vehicles entered the tunnel. Therefore, the measured data inside the tunnel was considered to determine the small-scale fading distribution type in the tunnel. Figure 5 shows the CDF curves of the signal magnitude taking into account five typical theoretical distributions for fitting, including Normal distribution, Rayleigh distribution, Rician distribution, Weibull distribution, and Log-Normal distribution.

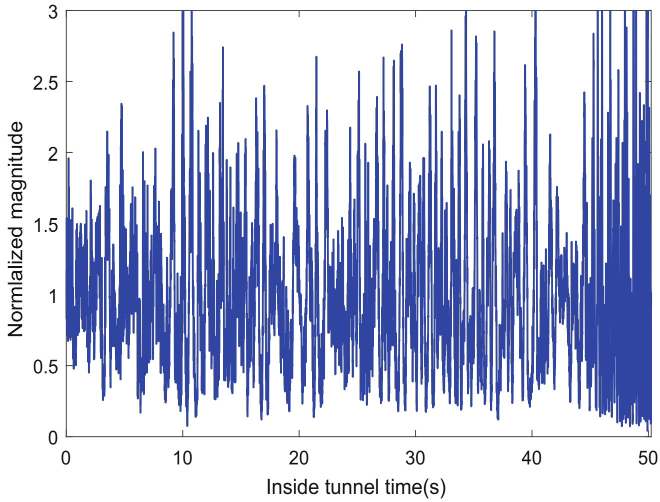

Fig. 4. Normalized magnitude of the received signal.

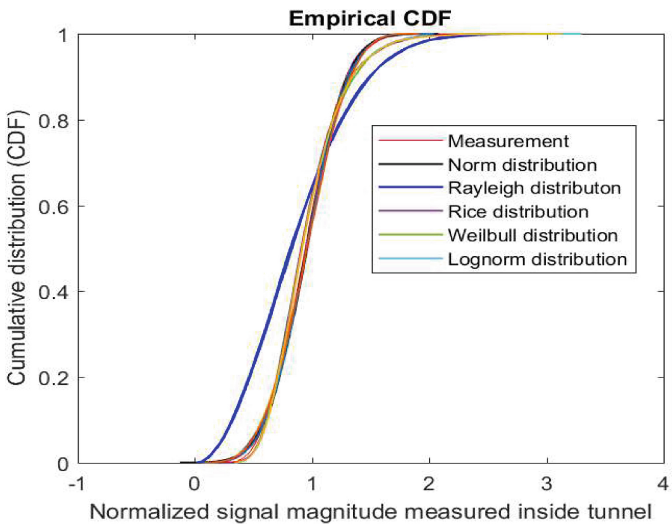

Fig. 5. Distribution conditions for fitting

A popular approach to characterize the distribution is the Kolmogorov-Smirnov (KS) test statistic serving as a GoF indicator [12–14]. The so-called test statistic ρ is calculated as:

$$\rho = \sup_{x} |F_X(x) - F(x)| \tag{1}$$

Table 2. GoF values of considered distributions.

Distribution	ρ
Norm	0.0269
Rayleigh	0.2049
Rice	0.0215
Weibull	0.0313
Lognorm	0.0518

where $\sup_x$ is the supremum operator, $F_X(x)$ and $F(x)$ are the empirical and theoretical CDFs of x, respectively. A lower value for ρ indicates a better fit of the distribution to the empirical CDF calculated using the measurement samples. Table 2 lists the GoF indicator ρ for the different distributions. It can be seen that the value of ρ for the normal distribution, Rician distribution and Weibull distribution fits are close to each other. Particularly, the value of ρ for Rician distribution is the lowest. Considering the fact that Tx-Rx distance were generally short during the measurement, and the LoS path existed during the measurement, it is reasonable to consider the Rician fading to approximate the small scale fading characteristics of the magnitude inside tunnel.

The Rician distribution can be represented as

$$f(x) = \frac{2(K+1)}{\Omega} \cdot e^{-K-\frac{(K+1)^2}{\Omega}} \times I_0\left(2\sqrt{\frac{K(K+1)}{\Omega}}x\right) \tag{2}$$

where x stands for the magnitude, I_0 is the $0th$ order modified Bessel function of the first kind, $\Omega = E\{x^2\}$, and K is the Rician K-factor, i.e., the power ratio of the dominant path to the multipath components. In general, K-factor is defined as

$$K = \frac{A^2}{2\sigma^2} \tag{3}$$

where A denotes the peak amplitude of the dominant component and σ the root mean square value of the amplitude. To calculate K the moment-based method [15] with

$$K = \frac{\sqrt{1-\gamma}}{1-\sqrt{1-\gamma}} \tag{4}$$

and

$$\gamma = \frac{\mathrm{Var}\{x^2\}}{(E\{x^2\})^2} \tag{5}$$

is widely used. The notations Var and E stand for the sample variance and expectation estimators, respectively. To use the sample variance and expectation estimators, a spatial window length has to be considered that is no longer than the window length for removing the large scale fading. Therefore, a window length of around 180 magnitude samples is used to calculate the K-factor.

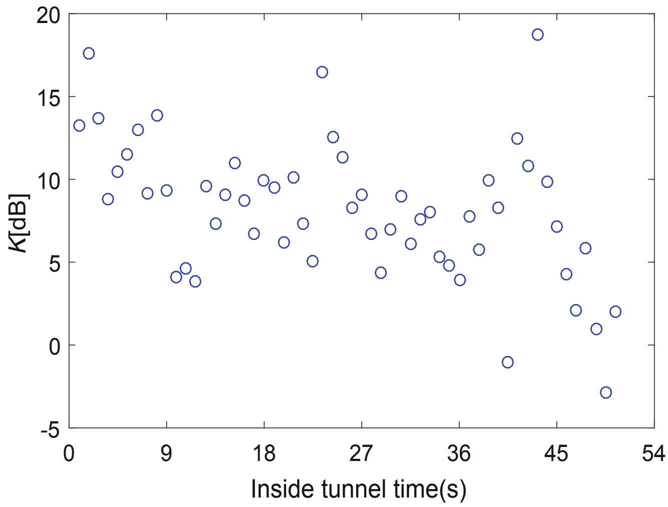

Fig. 6. Variation of the K-factor for measurement inside tunnel.

Figure 6 shows the estimated K-factor values versus the measurement index inside the tunnel. Since there exists a direct LoS component, the K-factor values are relatively large. The change of K-factor in the figure probably because the multipath component inside tunnel varies in power due to the changing environment, e.g., moving cars, resulting in the variation in power of the multipath component. While both vehicles moved inside the tunnel, the K-factor decreases in average as seen from Fig. 6. It is probably due to the fact that the distance between transmitter and receiver slightly increases. The obtained mean and standard deviation values of the K-factor are 8.1 and 4.2, respectively.

As a comparison, the K-factor estimated for outside the tunnel is calculated as well and visualized in Fig. 7. It can be noticed that in the beginning both vehicles were stable with a distance of about 5 m and, thus, the fading depth is insignificant which results in very large k-factors. While the distance between the transmitter and the receiver increased to about 50 m from the 7th second, the k-factor decreases. Thus, in considered scenario where the transmitter and the receiver is not separated far away, the k-factor shows a dependency on the distance between the transmitter and receiver.

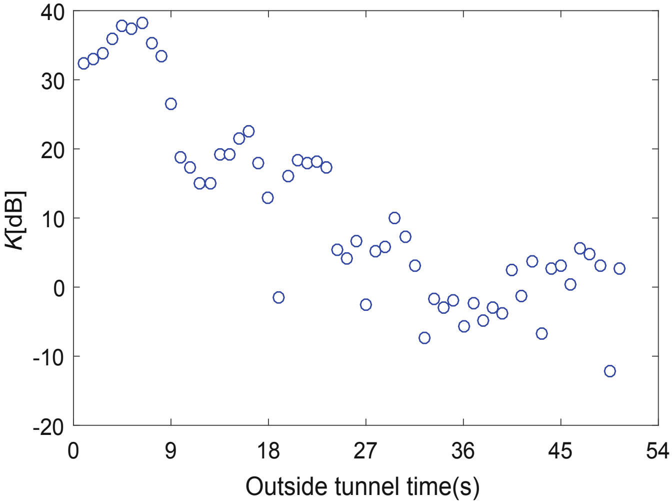

Fig. 7. Variation of the K-factor for measurement outside tunnel.

4 Conclusion

Tunnel is a safety-critical environment for applications of intelligent transportation system in terms of wireless based communications and navigation. To investigate small scale fading characteristics for in tunnel V2V propagation channel, a channel measurement campaign at 5.9 GHz with a bandwidth of 30 MHz was performed. In this paper, a detailed description of the channel measurement campaign and analysis of the small scale fading characteristics are presented. The results show that the received signal experiences a Rician fading due to the presence of a direct LoS path. Inside the tunnel the mean and standard deviation of the K-factor values are 8.1 and 4.2, respectively. As the distance between transmitter and receiver is not large, a distance dependency between the distance and the K-factor has been found. To model the distance dependent K-factor is the next research direction.

References

1. Muntjir, M., Rahul, M., Alhumyani, H.A.: An analysis of Internet of Things (IoT): novel architectures, modern applications, security aspects and future scope with latest case studies. Int. J. Eng. Res. Technol **6**(6), 422–447 (2017)
2. Contreras, J., Zeadally, S., Guerrero-Ibanez, J.A.: Internet of vehicles: architecture, protocols, and security. IEEE Internet Things J. **5**(5), 3701–3709 (2017)
3. de Ponte Mueller, F.: Survey on ranging sensors and cooperative techniques for relative positioning of vehicles. Sensors **17**(2), 271 (2017)
4. Molisch, A., Tufvesson, F., Karedal, J., Mecklenbrauker, C.: A survey on vehicle-to-vehicle propagation channels. IEEE Wirel. Commun. Mag. **16**(6), 12–22 (2009)

5. Belanovic, P., Valerio, D., Paier, A., Zemen, T., Ricciato, F., Mecklenbrauker, C.F.: On wireless links for vehicle-to-infrastructure communications. IEEE Trans. Veh. Technol. **59**(1), 269–282 (2010)
6. Anaya, J.J., Merdrignac, P., Shagdar, O., Nashashibi, F., Naranjo, J.E.: Vehicle to pedestrian communications for protection of vulnerable road users. In: IEEE Intelligent Vehicles Symposium Proceedings, pp. 1037–1042 (2014)
7. Cheng, L., Henty, B.E., Stancil, D.D., Bai, F., Mudalige, P.: Mobile vehicle-to-vehicle narrow-band channel measurement and characterization of the 5.9 GHz dedicated short range communication (DSRC) frequency band. IEEE J. Sel. Areas Commun. **25**(8), 1501–1516 (2007)
8. Sen, I., Matolak, D.W.: Vehicle-vehicle channel models for the 5-GHz band. IEEE Trans. Intell. Transp. Syst. **9**(2), 235–245 (2008)
9. Fernandez, H., Rubio, L., Rodrigo-Penarrocha, V.M., Reig, J.: Path loss characterization for vehicular communications at 700 MHz and 5.9 GHz under LOS and NLOS conditions. IEEE Antennas Wirel. Propag. Lett. **13**, 931–934 (2014)
10. Susana, L., del Castillo, A., Fernández, H., Rodrigo-Peñarrocha, V.M., Reig, J., Rubio, L.: Small-scale fading analysis of the vehicular-to-vehicular channel inside tunnels. Wirel. Commun. Mob. Comput. **2017** (2017)
11. Yang, M., et al.: A cluster-based three-dimensional channel model for vehicle-to-vehicle communications. IEEE Trans. Veh. Technol. **68**(6), 5208–5220 (2019)
12. Bernado, L., Zemen, T., Tufvesson, F., Molisch, A., Mecklenbrauker, C.: Time- and frequency-varying K-factor of non-stationary vehicular channels for safety-relevant scenarios. IEEE Trans. Intell. Transp. Syst. **16**(2), 1007–1017 (2015)
13. He, R., Zhong, Z., Ai, B., Ding, J., Yang, Y., Molisch, A.: Short-term fading behavior in high-speed railway cutting scenario: measurements, analysis, and statistical models. IEEE Trans. Antennas Propag. **61**(4), 2209–2222 (2013)
14. Wang, W., Raulefs, R., Jost, T.: Fading characteristics of maritime propagation channel for beyond geometrical horizon communications in C-band. Ceas Space J. **11**(1), 95–104 (2017). https://doi.org/10.1007/s12567-017-0185-1
15. Greenstein, L.J., Michelson, D.G., Erceg, V.: Moment-method estimation of the Ricean K-factor. IEEE Commun. Lett. **3**(6), 175–176 (1999)