The Application of Semi-Deterministic Method on High-Speed Railway Cutting Scenario

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Abstract

Some channel characteristics in high-speed railway, such as path loss and Ricean K factor, have been intensively studied in several certain scenarios. Due to the limitation of channel measurement, some small-scale channel properties, especially the DoA (Angle of Departure) and AoA (Angle of Arrival) information, which is important for a MIMO channel model, are difficult to estimate from the current data. In this paper, the semi-deterministic method based upon geometry-based stochastic channel modeling is applied on cutting scenario. Some channel parameters are extracted from the Zhengxi high-speed railway measurement. The other part of the model is based on cutting geometry and cluster analysis. The cluster size is determined by the channel parameters. And the variation of the cluster size over the distance from the train is investigated.

Index Terms

Geometry-based stochastic model; High-speed railway; MIMO; cluster size

I. Introduction

Currently, lots of literatures about channel measurement in high-speed railway have been published. The properties of path loss [1, 2], Ricean K factor [3, 4], and delay [5] in some certain scenarios of high-speed railway are discovered, which is beneficial to build a channel model for railway. Though the related researches have been done a lot, the spatial characteristics, i.e., the angle of departure (AoD) and angle of arrival (AoA), have rarely been mentioned. The spatial channel model for high-speed railway is also attractive. For example, the 5G is a hot topic at present, and the angle information of multipath is important for the massive Multiple-Input Multiple-Output (MIMO) system [6]. Also the MIMO application in high-speed railway will bring diversity gain to reduce the failure of handover [7].

There are mainly three methods to measure the angle of multipath [8], which are based on direction-finding antenna arrays, synthetic aperture radar technique, and highly directional antennas. However, when these methods are applied in high-speed railway, there will be some constraints in operation. The real high-speed railway situation is difficult to reproduce. In the transmitter side, the BS towers should be very high and able to cover the whole measured area. In the receiver side, due to the high velocity of the train, which means the channel is highly time-variant, the rotated directional horn antenna scheme is inappropriate. Meanwhile, to ensure the safety of the running train, the extra antennas are forbidden to set up on top of the train. Besides, the environment of high-speed railway is different from the urban, or suburban based on the existing measurements [1, 9], and there are some special scenarios in high-speed railway, such as viaduct and cutting. Therefore, the measured results in these scenarios can not be used in high-speed railway directly.

To solve this problem, this paper proposes a semi-deterministic channel modeling method. The remainder of this paper is organized as follows. Section II gives a brief description of this channel modeling idea and the procedure. Section III describes an example of channel model in cutting scenario. Also the relationship between the cluster size and the channel parameters is discussed. Finally, Section IV presents our conclusions.

II. Semi-Deterministic Channel Model

The typical double-directional channel impulse response is expressed as [10]:

$$h(t, \Omega_t, \Omega_r) = \sum_{k=0}^{n} a_k e^{j\phi_k} \delta(\Omega_t - \Omega_{t,k}) \delta(\Omega_r - \Omega_{r,k}) \tag{1}$$

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where a_k, ϕ_k, $\Omega_{t,k}$, $\Omega_{r,k}$ are the amplitude, phase, AoD and AoA for each path, respectively. Obviously, the channel impulse response needs the statistic information of AoD and AoA, which are the information we short of. Then we start from the propagation mechanism and geometry analysis of scenario. An example of cutting scenario is given in the following.

Fig. 1. The cutting scenario in high-speed railway.

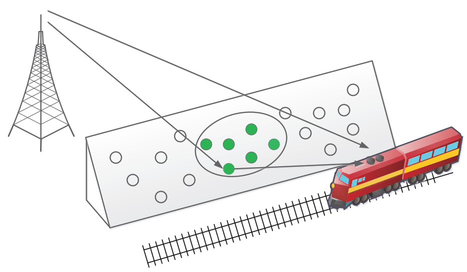

Fig. 2. The channel model for the cutting scenario.

A real cutting scenario is shown in Fig. 1 with two slopes composed of concrete and grass. According to the previous measurement [11], the multipath in cutting is rich. It can be assumed that the cutting surface are full of scatterers like in [12]. However, not all of the power scattered by the scatterers will be received by the train. Therefore, the effective scatterers, whose power can arrive at the train, are modeled as a scattering cluster as shown in Fig. 2. The scattering cluster locates on each slope and is assumed to be elliptical. The scatterers distribute uniformly within the cluster.

The receiving signals mainly consist of Line-of-Sight (LOS) and Non-LOS (NLOS) parts. The whole channel impulse response can be expressed as:

$$h = h_{LOS} + h_{NLOS} \tag{2}$$

The complex path amplitude of LOS path is modeled as [12, 13]:

$$a_{LOS} = e^{j\phi_p} G_{0,p}^{1/2} \left(\frac{d_{ref}}{d_p} \right)^{n_p/2} \tag{3}$$

where n_p is the LOS pathloss exponent, $G_{0,p}$ is the received power at a reference distance d_{ref}. d_p is the distance between BS and the train. n_p, $G_{0,p}$ can be extracted from the measurement data. ϕ_p is the random phase shift of the LOS path, uniform over $[0, 2\pi)$.

The complex path amplitude of a diffuse scattering component is modeled as [12, 14]:

$$a_s = G_{0,DI}^{1/2} \cdot c_s \cdot \left(\frac{d_{ref}}{d_{T\to r} \times d_{r\to R}} \right)^{n_{DI}/2} \tag{4}$$

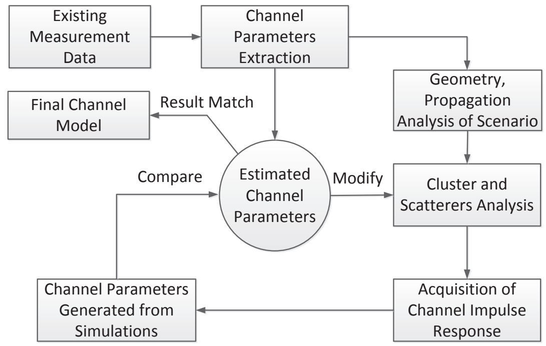

Fig. 3. The flow chart of channel modeling.

where c_s is the zero-mean complex Gaussian variable. n_{DI} and $G_{0,DI}$ are scattering pathloss exponent and the reference power respectively. It is assumed n_{DI} and $G_{0,DI}$ are the same for all diffuse scatterers. $d_{T\to r}$ is the distance between BS and the scatterer. Meanwhile, $d_{r\to R}$ is the distance between the scatterer and the train.

The path gain for each part can be estimated from the previous Zhengxi high-speed railway measurement [2, 4]. The rest parameters are obtained from the semi-deterministic analysis. Once the final channel impulse response is obtained. It is crucial to test whether this channel model is suitable or not. We can use the simulated channel impulse response to generate a certain channel parameter which can also be estimated from the measurement data, then these two parameters can be compared. The flow chart is described in Fig. 3.

III. Example Comparison with Measurement

In this section, the example of cutting analysis and the result of comparison with measurement are shown. The Ricean K factor is chosen as a standard parameters to test the channel model, for it can be estimated from the current data and generated from simulations. The cluster size on each size is a crucial factor, and the semimajor and semiminor-axes of elliptical cluster a and b are set as in [15]. The scatterers are generated uniformly on two slopes with the density $\chi_{DI} = 2$ per meter within the cluster. The modification of the channel model can be the cluster resizing in Fig. 2. The clusters of different sizes contain different numbers of scatterers and generate different Ricean K factor. The comparison result is shown in Fig. 4 that the channel model agree well with the data after setting the appropriate size of cluster.

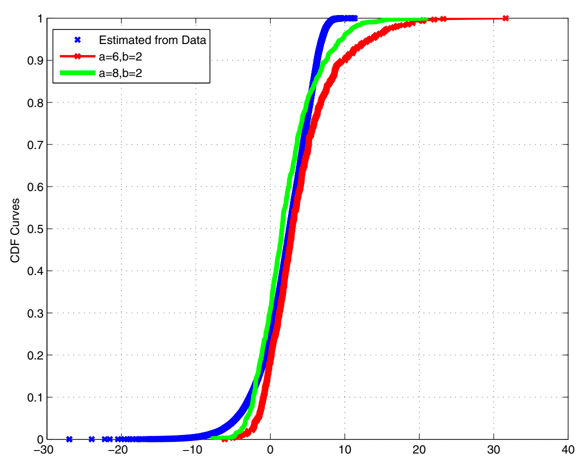

Fig. 4. CDF comparison of K factors of different cluster size with ones estimated from measurement data.

Then, we focus on the discipline of the cluster size coefficient ab varying with the distance d_R, which is short for $d_{r\to R}$.

Their relationship curve is shown in Fig. 5. The coefficient ab, also means the size of cluster, is different when the cluster changes the location between BS and the train. According to Fig. 5, the cluster size is symmetrical around the midpoint $d_p/2$. Depending on the Mean Inequality Theorem, the power loss is the biggest when the cluster is in the midpoint. Therefore, the cluster size is large to include more scatterers to increase the power. However, the cutting surface is limited to exist a large cluster. For the cutting situation, the BS tower is high and installed with a directional antenna. The area beneath the BS is out of the main lobe of the antenna, and the reflected and scattering components are sparse. So it is reasonable to put the cluster in the range of $(0, d_p/2)$ in channel model.

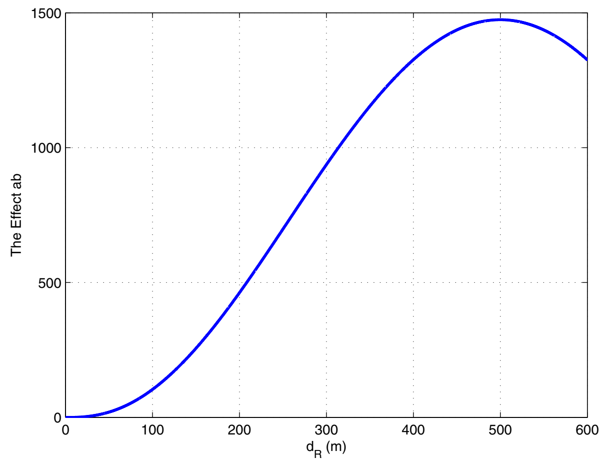

Fig. 5. The relationship between cluster size coefficient ab and d_R.

IV. Conclusions

In this paper, the semi-deterministic method based upon geometry-based stochastic channel modeling for high-speed railway is proposed. The idea and procedure of this semi-deterministic method is shown. An example of special scenario in high-speed railway - cutting is given. It shows that the modeled channel impulse response agree well with the measurement data. Finally, an analysis of the relationship between the cluster size and the distance d_R is given.

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