Path Loss Models in Viaduct and Plain Scenarios of the High-speed Railway

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Abstract— This paper focuses on propagation path loss modeling in viaduct and plain scenarios of the High-speed Railway. The data used for modeling comes from measurement on Zhengzhou-Xi'an passenger dedicated line with the maximum moving speed of 340Km/h. Based on the measurement data, tuned Free-space path loss models in these two scenarios are proposed. The performance of the tuned models is compared with that of the Hata model. The evaluation of the models is in terms of mean error, root mean square error and standard deviation of the residuals between the models and measurement. The simulation results and related analysis show better performance of the proposed tuned models compared with the conventional Hata model.

Index Terms— path loss; modeling; High-speed Railway; viaduct; plain

I. Introduction

With the rapid development of the High-speed Railway, more and more attention has been paid to the characteristics of the wireless channel in railway scenarios. Among all the characteristics of the High-speed Railway, path loss is a basic one which is of great importance in the design of the High-speed Railway Communication System.

As we all know, there are lots of models based on the statistical and theoretical analyzes. But none of them are universally applicable. The Hata model is widely used in macro-cell scenarios. And also, a lot of work is done to predict the propagation path loss between the transmitter and the receiver in such scenarios as urban or suburban [1], [2]. Unfortunately, some typical scenarios of the High-speed Railway, such as viaduct, plain and cuttings, are few considered.

The propagation path loss modeling methods are in varied forms. Although ray tracing[3] is a more precious method, it's time and memory consuming in the modeling of large-scale propagation. Similarly, reference[4] suggests improving the performance of the model by using detailed morphological and building data. But the detailed information needed is hard to obtain. Therefore, statistical models are frequently used. Reference[5] suggests adding the average residual to the present model. However, the path loss exponent remains the same in this way. In practice, obstructions between the transmitter and receiver as well as multipath propagation will have effects on the value of the path loss exponent[6]. Therefore, the path loss exponents are so important that should be tuned in different scenarios. Most of the references such as[7]-[10] present the path loss exponent and the shadowing to show the large-scale propagation characteristics of some typical scenarios based on measurement. Though precious, these models lose the universality.

To meet the needs of the path loss modeling in the scenarios of the High-speed Railway, model tuning is done based on the measurement data of the Zhengzhou-Xi'an(Zhengxi) High-speed Railway. In this paper, firstly, measurement environment and the system are introduced. Then, based on the measurement data, tuned Free-Space path loss models are presented in viaduct and plain scenarios, respectively. Finally, performance evaluation is made to check whether these two models can predict the path loss in these two scenarios well.

II. Measurement Environment and the System

A. Measurement Environment

The measurement has been carried out in Zhengxi High-speed Railway with a total length of 458Km. And the speed of train is up to 340Km/h. Usually, there are some typical scenarios along the high speed railway, such as viaduct, cuttings, plain and mountain area. Along Zhengxi railway line, viaduct ,which is built highly above the ground, occupies more than 50% of all the scenarios. The viaduct scenario is showed in Fig.1. As the figure shows, the surface of the viaduct is almost flat. And it is higher than most of the surroundings.

Fig. 1.   Viaduct scenario   Fig. 2.   Plain scenario

In plain scenario, the fluctuate of the ground is small, just like that of the surface of the viaduct. Therefore, the propagation characteristics have something like in these two

scenarios. Fig.2 shows a typical plain scenario in Zhengxi High-speed Railway.

B. Test System

The measurement has been taken in the present network on Zhengxi passenger dedicated line. Therefore, the testing frequency is the same as the downlink frequency, which ranges from 930.2MHz to 933.4MHz with a bandwidth of 200KHz. The transmitting antennas on the line are mainly cross-polarized with 17dBi Gain, 65° horizontal and 6.8^o vertical beam width. The transmitting power of the antennas is 43dBm. And the receiving antenna which is omni-directional is placed on the top of the train, with a height of 3.5m.

The receiving system , which is shown in Fig.3, is composed of the receiver Griffin, the software and the GPS. The receiving power collected by Griffin and the position information collected by the GPS are given to the software to do some analysis. The sampling rate of Griffin is one sample per 52cm. And the receiving data between two base stations is called a group in this paper.
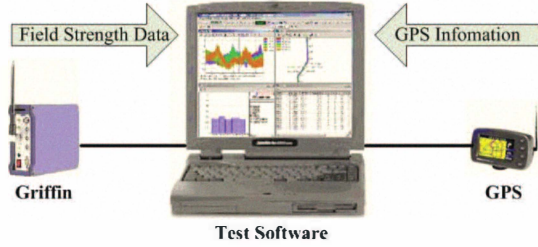

Fig. 3.   Test system

III. MODELING OF THE PATH LOSS IN VIADUCT AND PLAIN SCENARIOS

A. Measurement Results and Analysis

Fig.4 and Fig.5 show the receiving power with log-distance in viaduct and plain scenarios. And the unit of the distance is Km. The measurement distances are 3Km and 1.793Km in these two pictures, respectively. The fast fading is smoothed out according to Lee's law[11].

In the large-scale propagation modeling, the near field data should be deleted. The two figures given here and other measurement results show that the receiving power suffers large fluctuation within 300m. So only the data farther than 300m is considered in the data process.

B. Tuned Free-space Pass Loss Models

In viaduct and plain scenarios, the transmitting and receiving antennas are much higher than most of the surroundings. The power of the line of sight of the radio propagation in viaduct scenario is stronger, while that of the multipath is relatively weaker. On account of this, Free-space path loss model can be used to predict the path loss of viaduct and plain scenarios. However, the difference between the measurement and Free-space path loss exists, although not big. Therefore, tuned Free-space path loss models are needed.
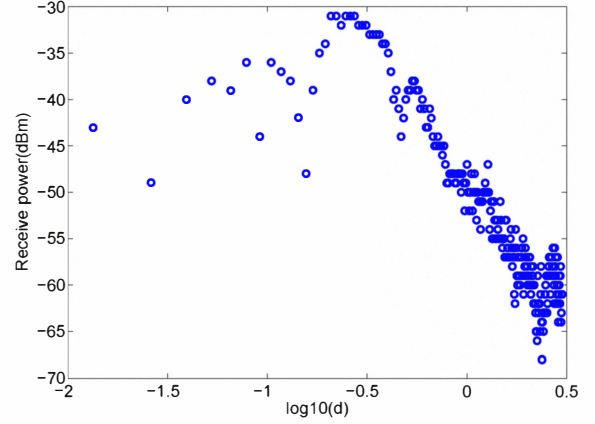

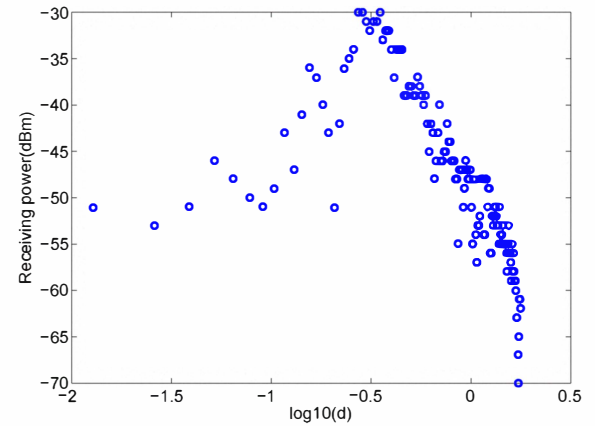Fig. 4.   Receiving power in viaduct scenario

Fig. 5.   Receiving power in plain scenario

Free-space path loss is calculated as:

$$L_0(dB) = 32.45 + 20 \times \log_{10}(d) + 20 \times \log_{10}(f) \quad (1)$$

Where, d denotes distance between the transmitter and the receiver in Km, and f denotes carrier frequency in MHz.

The receiving power is:

$$P_r = P_t + G_b - l_b - l_d - L_m \quad (2)$$

Where, P_r is the receiving power; P_t is the transmitting power, $P_t = 43dBm$; G_b is the gain of the transmitting antenna, $G_b = 17dBi$; l_b is the loss of the base station's feeder, $l_b = 3.3dB$; l_d is the loss of the Power-divider, $l_d = 3.5dB$; L_m is the measured path loss.

Then, the path loss of the measurement data can be obtained:

$$L_m = P_t + G_b - l_b - l_d - P_r \quad (3)$$

The difference between the Free-space and measured path loss is:

$$\Delta L = L_m - L_0 \quad (4)$$

On the one hand, in the measurement of each time, only the distance between the base station and the receiver changs. On the other hand, pass loss is linearly related to the distance

in log-domain. So, the tuned equation is defined as follows:

$$\Delta L = K_1 \lg d + K_2 \qquad (5)$$

Where, K_1 is the parameter about distance; K_2 is the constant. The two parameters are obtained by Least-square criterion.

In the modeling process, 274 groups in viaduct and 30 groups in plain of measured data are used. As the measurement data of the receiving power may sometimes invalid, the parameters K_1 and K_2 are invalid consequently. The 3σ criterion is introduced to eliminate the invalid values of the two parameters. σ and $|\Delta v_i| = |v_i - \bar{v}|$ denote the standard deviation and absolute value of the residuals between the data and their mean value, respectively. If the condition $|\Delta v_i| > 3\sigma$ is satisfied, the criterion detects the invalid data. After the detection, 260 and 30 groups left in viaduct and plain scenarios. Then, the parameters' median value, mean value and standard deviation of 260 groups of K_1 and K_2 in viaduct scenario are given in Table I. And those of 30 groups of K_1 and K_2 in plain scenario are given in Table II.

TABLE I

STATISTICAL VALUES OF K_1 AND K_2 IN VIADUCT SCENARIO

Parameter	Median(dB)	Mean(dB)	Std(dB)
K_1	6.26	6.9152	6.019
K_2	9.855	7.33	12.38

TABLE II

STATISTICAL VALUES OF K_1 AND K_2 IN PLAIN SCENARIO

Parameter	Median(dB)	Mean(dB)	Std(dB)
K_1	14.19	12.82	10.28
K_2	12.72	14.9	5.339

In this paper, the median values of the K_1 and K_2 are employed. The mean value is calculated by averaging the values of different groups. One situation that can make the things get worse is when there exits several higher values. Fortunately, the median value can avoid this problem. So, the values of K_1 and K_2 are obtained finally.

In viaduct scenario: K1=6.26, K2=9.855
In plain scenario: K1=14.19, K2=12.72
The tuned Free-space path loss model is:

$$L = \Delta L + L_0 \qquad (6)$$

$$L = K_1 \times \log_{10}(d) + K_2 + 32.45 + 20 \times \log_{10}(d) + 20 \times \log_{10}(f) \qquad (7)$$

Then, the models in viaduct and plain scenarios are repressed as:

$$L_{via} = 42.305 + 26.26 \times \log_{10}(d) + 20 \times \log_{10}(f) \qquad (8)$$

$$L_{pla} = 46.17 + 34.19 \times \log_{10}(d) + 20 \times \log_{10}(f) \qquad (9)$$

IV. PERFORMANCE EVALUATION

In this section, performance evaluation of models is done to analyze whether the tuned models can adjust the measurement

data or not. To do this, open area scenario in Hata, similar to viaduct and plain scenarios of the High-speed Railway, is used for comparison. And the groups that used for model evaluation are 180 and 30 in viaduct and plain scenarios, respectively.

A. Hata Model in Open Area and Introduction of the Evaluation Terms

In open area, the Hata model is expressed as following:

$$L_{urban} = 69.55 + 26.26 \times \log_{10}(f) - 13.82 \times \log_{10}(h_b)$$
$$- \alpha(h_m) + (44.9 - 6.55 \times \log_{10}(h_b))\log_{10}(d) - K \qquad (10)$$

$$\alpha(h_m) = (1.1 \times \log_{10}(f) - 0.7)h_m - (1.56 \times \log_{10}(f) - 0.8) \qquad (11)$$

$$K = 4.78 \times (\log_{10}(f))^2 - 18.33 \times \log_{10}(f) + 40.94 \qquad (12)$$

Where, f donates frequency; h_b donates the height of the base station; d donates the distance between the transmitter and the receiver; $\alpha(h_m)$ donates the correction factor of the height of the mobile station; K donates the correction factor for open area.

To evaluate the performance of the models, the residuals of the path loss between the measurement and the models are studied. And the expression is shown below:

$$\Delta L = L_m - L = \{\Delta L_1, \Delta L_2, ... \Delta L_i, ... \Delta L_N\}$$
$$i = 1, 2 ... N \qquad (13)$$

Where, L_m is the measurement path loss; L is the corresponding path loss of the models for comparison; N is the total number of the sampling points in the group.

The mean value (M) of the residuals is defined as:

$$\overline{\Delta L} = \frac{\sum\limits_{i=1}^{N} \Delta L_i}{N} \qquad (14)$$

The standard deviation (STD), which reflects the fluctuations of the residuals between the path loss of the measurement and the Hata model, is defined as:

$$\sigma = \sqrt{\frac{\sum\limits_{i=1}^{N} (\Delta L_i - \overline{\Delta L})^2}{N - 1}} \qquad (15)$$

Reference[12] points out that the tuned model can be used when STD is lower than 10dB.

And the root mean square error (RMS) is obtained as following:

$$s = \sqrt{\frac{\sum\limits_{i=1}^{N} (\Delta L_i)^2}{N}} \qquad (16)$$

B. Performance Evaluation of the Two Models

Firstly, the residuals between the tuned Free-space model and Hata model are calculated. Then, the evaluation indexes M, RMS and STD can be obtained. To observe the performance of the tuned model clearly, statistical values of M, RMS and STD in viaduct and plain scenarios are listed in Table III and Table IV.

TABLE III

STATISTICAL VALUES OF THE RESIDUALS OF THE TUNED MODEL AND THE
HATA MODEL IN VIADUCT SCENARIO

Model	M(dB)	RMS(dB)	STD(dB)
$Tuned\ Free-space$	1.436	5.765	3.442
$Hata$	6.546	8.26	4

TABLE IV

STATISTICAL VALUES OF THE RESIDUALS OF THE TUNED MODEL AND THE
HATA MODEL IN PLAIN SCENARIO

Model	M(dB)	RMS(dB)	STD(dB)
$Tuned\ Free-space$	2.603	6.379	4.18
$Hata$	13.55	14.09	3.694

As the table shows, in viaduct scenario, the mean values of M, RMS and STD of the tuned model are 1.436dB, 5.765dB and 3.442dB, while those of Hata are 6.546dB, 8.26dB and 4dB. The mean error is improved by 5.1dB. The improvement of RMS and STD are 2.5dB and 0.6dB, respectively. And the term STD is lower than the maximum tolerated value of 10dB. Therefore, the tuned model can adjust the measurement data well.

In plain scenario, the mean values of M, RMS and STD of the tuned model are 2.603dB, 6.379dB and 4.18dB, while those of Hata are 13.55dB, 14.09dB and 3.694dB. Though the term STD of the tuned model is increased by 0.5dB, it shows that M and RMS decrease significantly after tuning process, which are 11.0dB and 7.7dB respectively.

For the mean error, -10dB to 10dB is the interval that should be paid attention to. In viaduct scenario, the probability in this interval is 0.933 for tuned model and 0.812 for Hata model. In plain scenario, the probability in this interval is 0.933 for tuned model and 0.333 for Hata model. In plain scenario, however, STD of the tuned model turns higher. But the maximum of STD is 6dB, which is lower than the tolerated value of 10dB. And as mentioned above, it only increases by 0.5dB. The cost is low compared to the decrease of the mean error and the root mean square error.

Fig.6 and Fig.7 present two examples to make comparison between the tuned models and the classical Hata model in viaduct and plain scenarios. The two pictures show that the tuned models work better than Hata.

V. CONCLUSION

In this paper, propagation measurement data in viaduct and plain scenarios of Zhengxi High-speed Railway is analyzed and discussed. Based on these measurement data, tuned Free-space path loss models are made in viaduct and plain scenarios. Finally, the tuned models are compared to the Hata model, which is widely used in GSM network. Evaluation results show that the mean errors of the tuned models are decreased by 5.1dB in viaduct scenario and 11.0dB in plain scenario compared to the Hata model. And the tuned models' root mean square errors are decreased by 2.5dB in viaduct scenario, 7.7dB in plain scenario. Consequently, these models will be
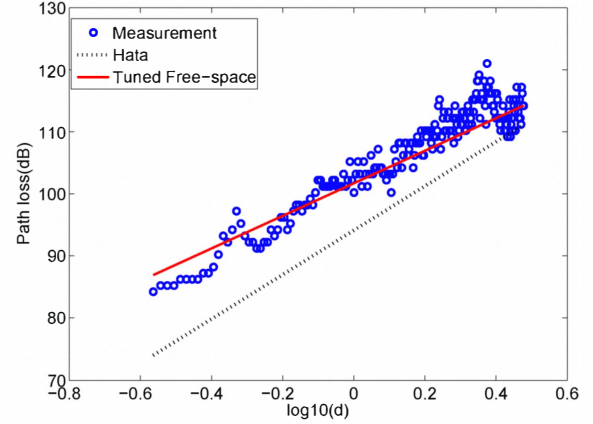

Fig. 6. Comparison of the path loss of the tuned Free-space model in viaduct, Hata model in open area and the measurement
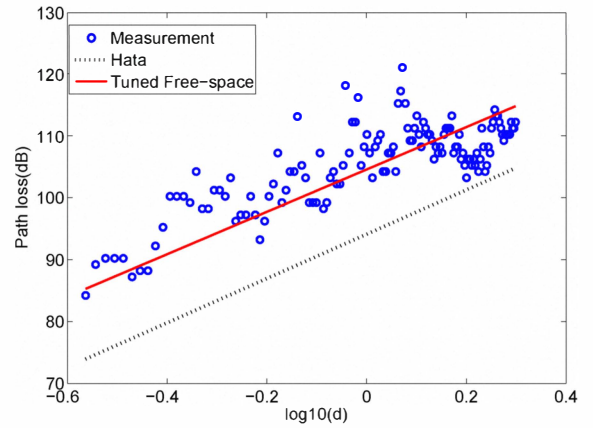

Fig. 7. Comparison of the path loss of the tuned Free-space model in plain, Hata model in open area and the measurement

useful for predicting the propagation path loss in viaduct and plain scenarios of the High-speed Railway.

VI. ACKNOWLEDGMENT

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