LTE System Performance Evaluation for High-Speed Railway Environment Under Rician Channel

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Abstract. In high speed railway environment, the LTE system performance evaluation is of vital importance due to complexity of radio propagation scenario and high mobility. In this paper, the Hardware-in-the-Loop (HIL) simulation platform is built, which consists of radio channel emulator, LTE core network and so on. Based on this platform, the LTE system performance is tested under Rician channel with different parameters, such as the K-factor, the angle between the line-of-sight (LOS) and train's velocity. Finally, it is concluded that the LTE system performance degrades with the increase of moving speed, and the degree of degradation is related to the K-factor and the angle between the LOS path and velocity.

Keywords: LTE system performance evaluation · Channel emulator · Rician channel

1 Introduction

In recent years, with the rapid development of high-speed railway, GSM-R system will no longer meet people's needs of higher speed, higher bandwidth, smaller trans-mission delay and more business requirements. Therefore, the International Union of Railways (UIC) began to consider the evolution of the next generation mobile comm-unication system. At present, the industry has already reached a consensus that we will use Long Term Evolution (LTE) as the next generation mobile communication [1]. As an important application of the current LTE Scenario, high-speed railway has attracted an increasing amount of attention.

In the high-speed railway environment, users generally reflect that the throughput declines rapidly and the quality of transmission deteriorates seriously, which has become an urgent problem to be solved. To solve this problem, first of all, we need to evaluate the LTE system performance accurately, through which to discover the important parameters affecting the performance, and finally to provide support for performance enhancement techniques of high speed railway. As the pioneer of actual network formation, the laboratory simulation for LTE system performance in high-speed environment is of great significance.

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In 3GPP TSG-RAN WG4 Meeting, the Ericsson has simulated the PDSCH performance for EVA channels with a Doppler spread of between 200 and 850 Hz in different SNR, from which we can know the Doppler shift has great influence on the performance. In addition, some channel models such as two paths channel model, leaky cable propagation channel are proposed for the High Speed Scenario and the simulation of them have been done. However, there is little research on the performance of high speed railway under Rician channel. This paper focuses on it.

HIL simulation platform is built to evaluate the LTE system performance, this paper analyzes the performance under Rician channel with different parameters. The impact of K-factor and the angle between LOS path and velocity are the emphasis of our study, which provide an important basis for performance enhancement techniques. The paper is organized as follows: LTE channel model for high speed railway is described in Sect. 2. In Sect. 3, some environment parameters for HIL simulation platform is introduced and the performance evaluation is made. The measurement results are shown in Sect. 4. Finally, in Sect. 5, we draw some conclusions.

2 LTE Channel Model for High Speed Railway Scenario

Channel model is of vital importance for a communication system. Due to the signifi-cance of this topic, many researchers have spent much effort on the channel modeling and have got some achievements. Generally, we can divide these channel models into three types. First, the statistical channel model, such as Rician Model and Gaussian Statistical Model. Second, the deterministic channel model, which is based on the actual measurement of the channel circumstance. As to the semi-deterministic channel model, it includes COST 259, COST 273, Spatial channel Model (SCM), Spatial Channel Model Extension (SCME), WINNER Model and so on [2].

The semi-deterministic channel model contains delay and spatial characteristics, which makes the channel so complex that we can't make sure which parameters affect the performance of the system clearly. We choose Rician channel as the emphasis of this paper. On the one hand, in the realistic high-speed railway environment, the running route is linear, so there exists a LOS path and some non-LOS (NLOS) paths which can be describe as a Rician channel. On the other hand, high speed is a major characteristic of the channel, and the Doppler shift caused by high speed is crucial to wireless communication system. During the running way, the train will experience some scenarios, such as open suburb, cutting, viaducts and so on [3], which has different K-factors. What's more, with the relative position of BS and MS changing, the angle between LOS path and velocity differ causing different Doppler shift. Ricia-n channel has some simple but important parameters so that we can make a qualitative analysis of the influence of the angle between LOS path and velocity and K-factor on the system performance. Finally, find out which parameters affect the performance, how they do and what's the degree of the influence.

The Rician channel can be decomposed into a specular component for the LOS path and a scattering component subject to Rayleigh distribution for the NLOS path between the Tx and the Rx, where the K-factor is defined as the power ratio of the two [4].

From the above, the Doppler power density spectrum of Rician channel can be considered as the superposition of that of Rayleigh channel and a single pulse. The Doppler power density spectrum of Rayleigh channel is written as

$$S(f) = \begin{cases} \frac{\sigma_0^2}{\pi f_{\max}\sqrt{1-(f/f_{\max})}}, & |f| < f_{\max} \\ 0, & |f| \geq f_{\max} \end{cases} \quad (1)$$

where σ_0^2 is the power of NLOS path, $f_{\max}$ is the maximum Doppler shift of the LOS component. Doppler shift is as follows:

$$f_d = f\frac{v}{c}\cos\theta \quad (2)$$

where θ is the angle between LOS path and velocity. If v = 300 km/h and f = 2330 MHz, the maximum Doppler shift shall be 647.2 Hz.

The Doppler shift of the LOS path is changing with θ. When θ is 180°, the Doppler shift of the LOS path is maximum, while it is minimum for 90°. With θ equal to 180°, 90° and 45°, the maximum, minimum and median can be achieved, which represents a wider characteristics of Rician channel. Doppler shift of LOS path in different angles is given in Table 1.

Figure 1 shows the superposition of Doppler power density spectrum of Rayleigh channel and a single pulse. Doppler shift of LOS path for different angle is disparate. What's more, different K-factors correspond to different power allocation of LOS path and NLOS path.

Table 1. Doppler shift of LOS path

θ	Doppler shift f_d (Hz)
45°	457.7
90°	0
180°	−647.2

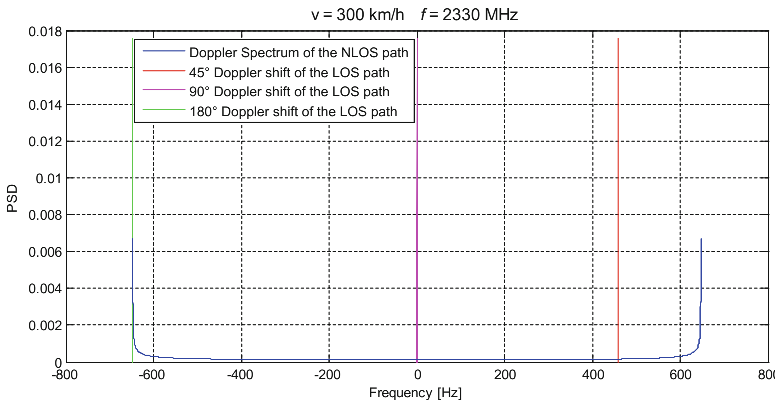

Fig. 1. Doppler power density spectrum in Rician channel

3 HIL Simulation Platform

We build the HIL simulation platform in the laboratory shown as Fig. 2, which consists of radio channel emulator, test mobile terminal (MS), base station (BS), LTE core network and Qos test software.

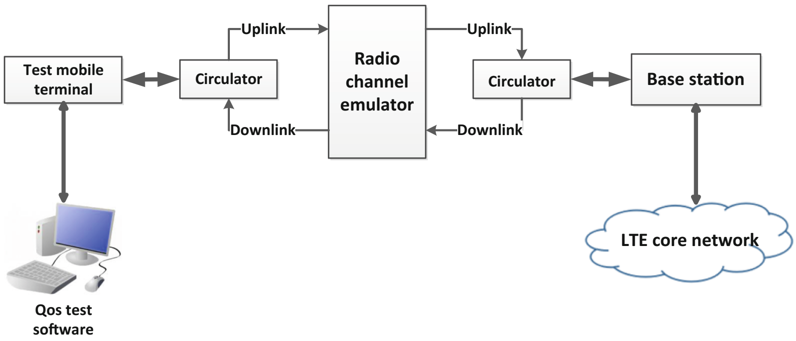

Fig. 2. HIL simulation platform for LTE system performance evaluation

The test mobile terminal is ZTE ME3760 supporting the frequency of 2.330 GHz under TDD duplex mode, and it achieves the function of network registration and data reception. The radio channel emulator C8 is used to emulate the radio propagation, which both has the flexibility of software simulation and the accuracy of the hardware emulation. As for the radio channel, the classical channel–Rician channel is used, what's more, the K-factor,the angle between LOS path and velocity and moving speed can be set flexibly on the platform, which provides the feasibility for the evaluation. The Qos software can test the UDP delay and throughput of the system.

In order to evaluate the performance, some environment parameters should be determined, such as configuration of base station, performance indicator, received power.

3.1 Parameters of Base Station

The base station configuration is given in Table 2.

Table 2. Configuration of base station

Parameter	Value
Duplex mode	TDD
Carrier frequency	2.33 GHz
Bandwidth	10 MHz
Transmit power	17.8 dBm
Timeslot allocation	2 [1:3]
Special timeslot allocation	7 [10:2:2]

3.2 Performance Indicator

The performance of a wireless communication system mainly includes effectiveness, reliability and real-time performance. This paper focuses on the two aspects of effectiveness and real-time performance, so the system performance indicators are throughput and UDP delay, from which the throughput can measure the effectiveness of the system, and UDP delay does in real-time performance.

Throughput: It is defined as the amount of data uploaded or downloaded in a unit time, which is significant to a system. There are many factors that affect the throughput, including bandwidth, timeslot allocation, special timeslot allocation, control channel over, service type and so on.

UDP delay: It is defined as the time interval of the data packet transmitting from the user to Gi interface of GGSN.

3.3 Receiving Power

In the 3GPP specification, the Signal Receiving Power Reference (RSRP) and Received Signal Strength Indicator (RSSI) are related to the received power.

RSRP is defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth. The reference point for the RSRP shall be the antenna connector of the UE [5]. It can reflect the useful signal of the cell. Figure 3 is a schematic diagram of the RSRP calculation method. R_0 is cell-specific reference signals [6].

RSSI comprises the linear average of the total received power (in [W]) observed only in OFDM symbols containing reference symbols for antenna port 0, in the measurement bandwidth, over N number of resource blocks by the UE from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc. [5]. Although it is also the average value, it contains other interference signals from the outside, which makes the average value of measurement higher than that of the useful signal. As a result, RSRP is used as the indicator of received power.

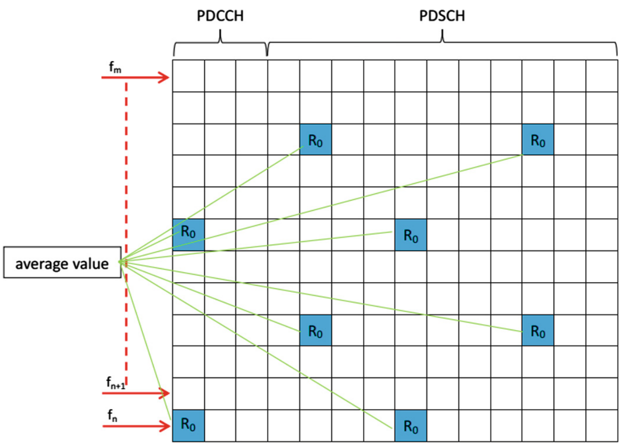

Fig. 3. Schematic diagram of the RSRP calculation method

Measure RSRP and RSSI using the base station analyzer. And the corresponding relationship is shown in Table 3.

Table 3. Relationship between RSRP and RSSI

RSSI (dBm)	RSRP (dBm)
−50	−68.28
−51	−69.48
−52	−70.41
−53	−71.29
−56	−74.28
−66	−84.92
−71	−91.43
−72	−92.51
−73	−93.11
−74	−93.75

When the RSRP is lower than −93.75 dBm, RS signal constellation is so indistinguishable that it cannot be demodulated correctly shown as Fig. 4. Therefore, this paper uses the RSSI value for −52 dBm and −73 dBm, that is, the corresponding RSRP value for the −70.41 dBm and −93.11 dBm, which makes the evaluation of the system more reasonable.

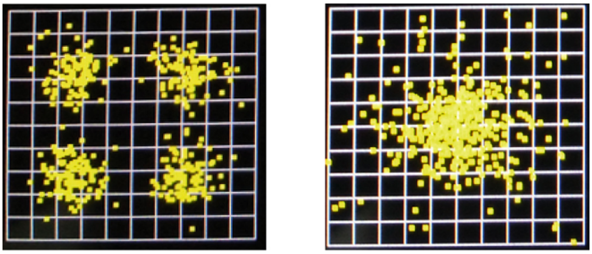

Fig. 4. RS signal constellation diagram with RSRP is −96.98 dBm (the right figure) and −92.51 dBm (the left figure)

4 Measurement Results

Key parameters haven been described in Sect. 3. In this section, the LTE system performance for high-speed railway is measured on the platform. Measurement results are as follows.

The relationship of system performance and θ is shown in Figs. 5 and 6 for two aspects of throughput and UDP delay, from which the influence of the received power is apparent.

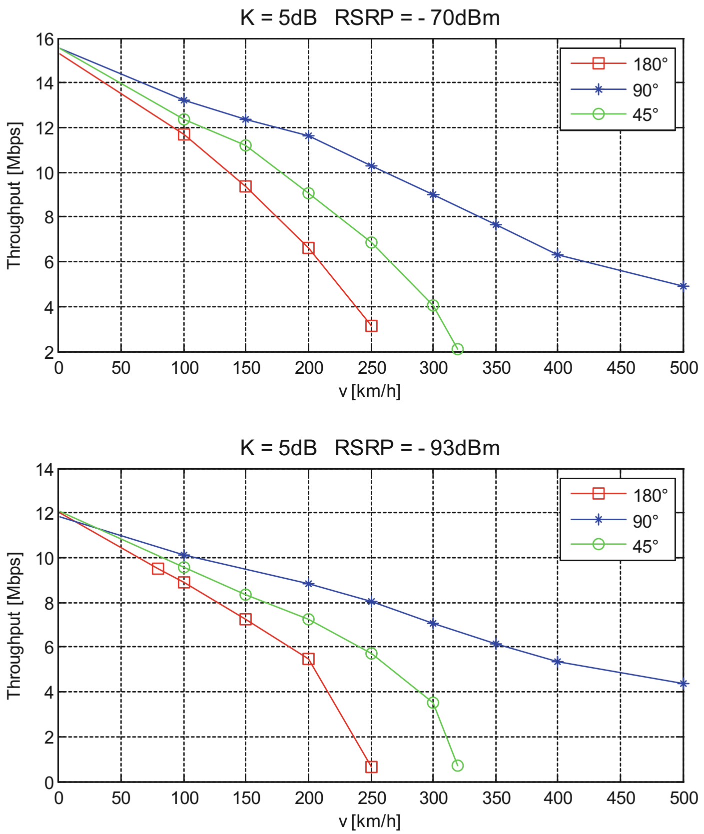

Fig. 5. The throughput with θ = 180°, 90° and 45°

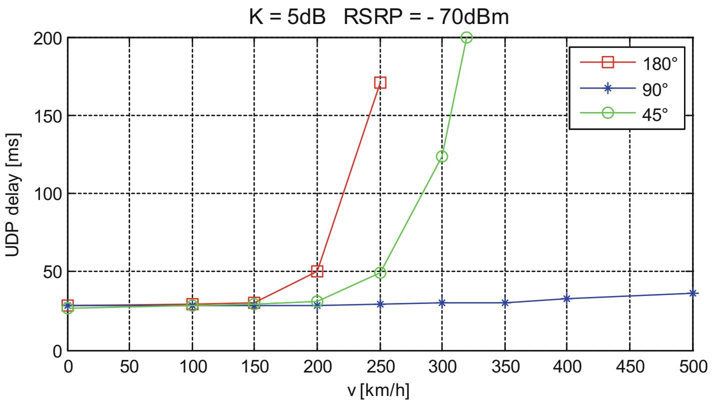

Fig. 6. The UDP delay with θ 180°, 90° and 45°

Shown as above, the LTE system performance degrades with the increase of moving speed. What's more, it deteriorates most rapidly for 180°, and performs well for 90°. To be precise, the system performance is excellent with high throughput and

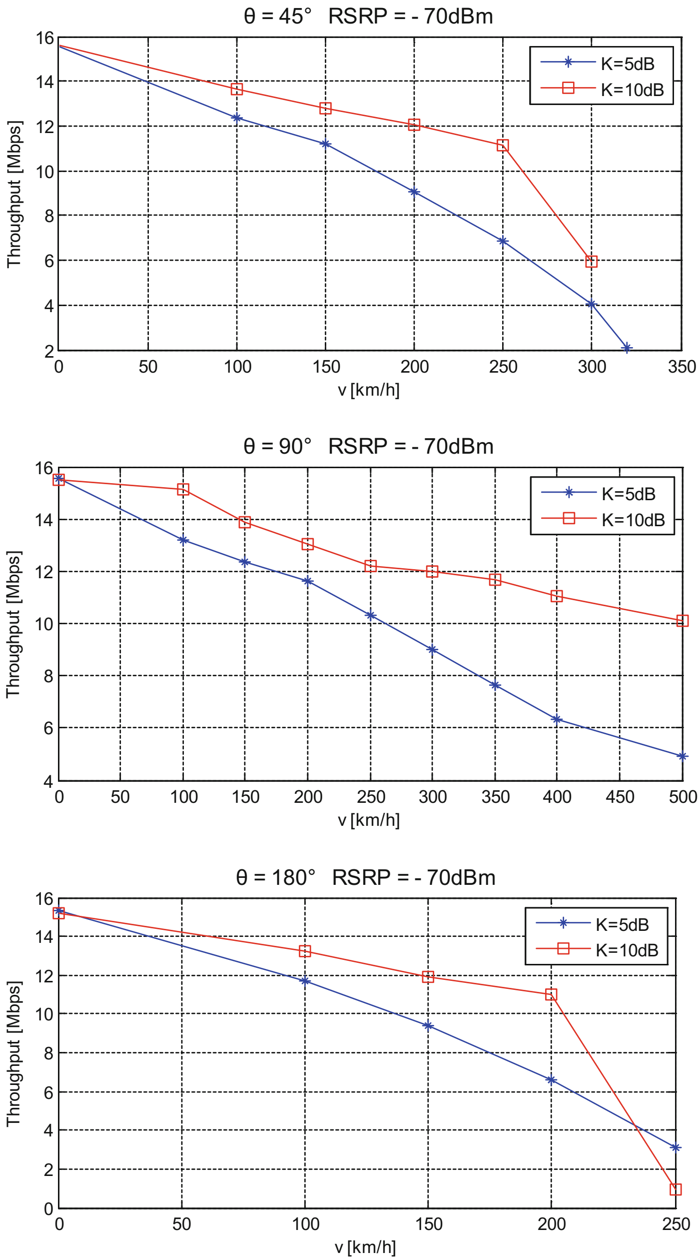

Fig. 7. The throughput with K = 5 dB and 10 dB

small UDP delay for low moving speed and θ has almost no influence on performance. On the contrary, it is poor with low throughput and large UDP delay for high moving speed and θ has a great influence on performance. When θ is 180°, the Doppler shift of LOS path is maximum which leads to poor performance that MS cannot attach the network if moving speed is up to 280 km/h. And for θ equal to 45°, there exists a Doppler shift of LOS path but not large, and when moving speed is up to 330 km/h, MS cannot attach the network. As for 90°, there is only the Doppler shift of NLOS path which obeys rayleigh distribution. The proportion of NLOS path is so small in power that the performance changes little with the increase of moving speed.

In the figures with RSRP covering −93 dBm and −70 dBm, no matter what θ and K-factor are, the performance is better in higher RSRP. For higher RSRP, in the same environment, we can get higher signal-to-noise ratio (SNR). That is, if possible, we can increase power properly to improve the system performance.

The relationship of system performance and K-factor is shown in Figs. 7 and 8 for two aspects of throughput and UDP delay.

From the figures above, when moving speed is 0, the K-factor has no effect on the system performance. Under the condition of low speed, the greater the K-factor is, the better the performance is. But for high speed, when θ is 45°and 90°, the performance is better for greater K-factor, while it deteriorates for 180°. To explain this phenomenon, first we know that the power of LOS path is higher for greater K-factor, which makes the performance well. But at the same time, in the condition of high speed for 180°, the higher the power of LOS path is, the higher proportion of the maximum Doppler shift accounts for, it has such a great influence that the performance decreases.

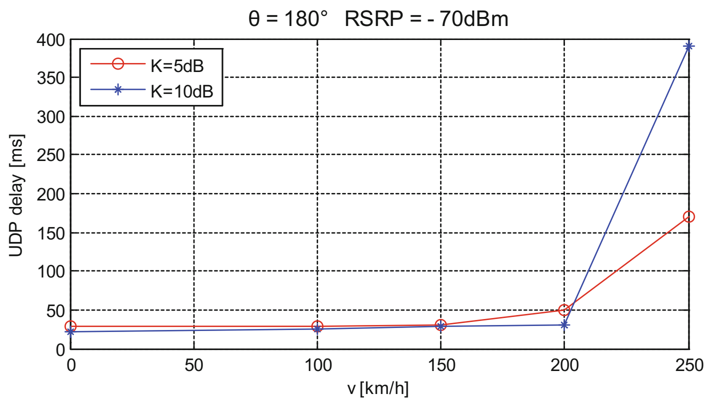

Fig. 8. The UDP delay with K = 5 dB and 10 dB

5 Conclusion

In the paper, we evaluate the LTE system performance for high-Speed railway environment under Rician channel on the HIL simulation platform. From the simulation results, the conclusions can be made on three aspects. In general, the LTE system performance degrades with the increase of moving speed. More specifically, in the condition of high speed, θ has a great influence on the performance. When θ is 180°, the performance is worst that MS can't attach the network for the speed up to 280 km/h. What's more, the performance is better under the Rician channel with greater K-factor in low speed. However, in the case of high speed and θ of 180°, when moving speed reaches a certain value, which is almost 230 km/h, the greater the K-factor is, the worse the performance is. As for the received power, we can achieve better performance in higher received power. These conclusions can make contributions to performance enhancement techniques.

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