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Assessment of LTE-R using High Speed Railway Channel Model

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***Abstract*—Long Term Evolution for Railway (LTE-R) is commonly believed to be the next generation wireless communication system for high speed railway. The main objective of this paper is to assess the performance of LTE-R under realistic conditions using a hybrid high speed railway channel model involving WINNER II Channel Model that was refined and validated using measurements made within the WP1 Channel Model workpackage in Europe, high speed train channel model in 3GPP and large-scaled models based on a group of measurements on Zhengzhou- Xian passenger dedicated line in China. The paper presents a detailed evaluation of the BER and PSD for LTE-R suitably dimensioned for the high speed railway channel. The investigation includes analysis of the Doppler shift caused by the velocity of transmitter and receiver, the multipath interference due to reflections and diffractions from terrains in the radio service coverage area, and other serious impairing factors.The results show that LTE-R has promising potential to be used in a high speed railway environment.**

***Keywords*-high speed railway; LTE-R; MIMO; OFDM;**

I. Introduction

In recent years, to fulfill the increasing requirements for novel broadband mobile communication systems of high speed railway, Long Term Evolution for Railway (LTE-R) [1][2] has been presented based on the standard of Long Term Evolution (LTE) [3] and SAE (System Architecture Evolution) [4]. Since the major physical-layer key technologies of LTE-R [1][2] refer to LTE, OFDM [5] and MIMO [5] are the core of the novel system.

Orthogonal frequency division multiplexing (OFDM) presents an attractive solution for meeting the requirements of next generation wireless communication systems. The transmission bandwidth in OFDM is divided into many narrow subchannels, which are transmitted in parallel under fading channel, and inter-symbol-interference (ISI) can be almost completely avoided by adding a guard interval to each block of the data. So OFDM is considered as an effective technique in high-speed digital transmission [6]. Apparently, the proper dimension of guard interval is really crucial, since it determines whether LTE-R system can eliminate ISI and meanwhile is still a system with high spectral efficiency. Therefore, it is necessary to ascertain OFDM parameters in high speed railway scenario. Many research works have been reported on the performance and parameter configuration of OFDM in various channels [7][8][9]. However, no dissertation made the assessment and parameter design in a realistic high speed railway, particularly under a train speed up to 500 km/h.

For the other focal point - MIMO, previous research focus on the MIMO performance in a relatively short distance between transmitters or receivers, and this, is considerably different from the high speed railway situation. Thus, the performance of MIMO in LTE-R is needed to reassess under a realistic high speed train dimension.

In this paper,the performance of LTE-R has been accurately assessed under a hybrid realistic high speed railway channel model. The model consists of WINNER II Channel Model [10] supplying multipath fading channel suitable for high speed railway in Europe, high speed train channel model in 3GPP [11] providing Doppler shift profile and large-scaled models based on a group of measurements on Zhengzhou-Xian passenger dedicated line [12] offering path loss situation of high speed railway in China. Meanwhile, this paper also presents a detailed evaluation of the BER and PSD for a LTE-R dimension suitable for the high speed railway condition.

II. High speed railway channel model

In order to study the performance of LTE-R, it is essential that a realistic high speed railway transmission multipath propagation channel is characterized. D2a scenario of WINNER II Channel Model [10] is considered for the typical high speed railway multipath fading channel characterized by the number of paths, maximum time delay, fading of each path, AoA (Angle of Arrival) and AoD (Angle of Departure) of each path, i.e., as shown in Table I.

TABLE I
D2a scenario channel characteristics of WINNER II

No. of Paths	Delay [ns]	Power [dB]	AoD[°]	AoA[°]
1	0	0.0	0.0	0.0
2	55	-17.8	12.7	-80.0
3	60	-17.2	-13.6	86.0
4	85	-16.5	13.4	84.4
5	110	-18.1	-13.9	87.5
6	115	-15.7	-13.0	-82.2
7	130	-17.7	-13.9	87.5
8	210	-17.3	13.7	86.2

Propagation scenario D2 (Rural Moving Network) represents radio propagation in environments where both the AP (Access Point (BS)) and the UE (User Equipment (MS)) are moving, possibly at very high speed, in a rural area. The

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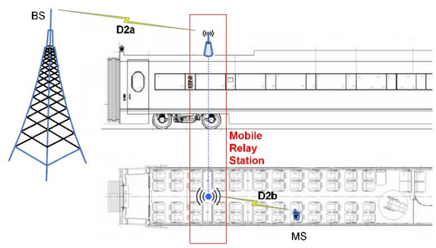

Fig. 1. D2 Scenario for high speed railway in WINNER II.

connection to the trains is arranged by using a moving relay station (MRS) mounted on the roof of the carriage. As shown in Fig. 1, D2a means the sub-scenario that the connection from the AP to the MRS. In D2a scenario of WINNER II Channel Model, the time varying channel impulse response can be given in the Eq. (1):

$$h(t,\tau)=\sum_{i=1}^{L}E_i(t)\cdot\delta(t-\tau_i(t)) \tag{1}$$

In this expression the complex amplitude for each path as well as its delay are time varying. In the coefficients $E_i(t)=E_{li}\times E_{si}$, two different components can be distinguished, E_{li} describes the large-scaled fading (long-term variations) and E_{si} describes the large-scaled fading (short-term variations), whilst $\tau_i(t)$ describes the delay of the ith path.

The large-scaled fading model E_{li} can be given by:

$$E_{li}(t)=10^{\frac{P_t[dBm]+G-PL(t)[dB]-PL_{other}+X_\sigma}{20}} \tag{2}$$

where $PL(t)$ is the ensemble average of all possible path loss values for a given value of t ; P_t is the power of transmitted signal$G$ is the gain, PL_{other} is the attenuation caused by devices and feeder lines (in dB). X_σ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB). The log-normal distribution describes the random shadowing effects on the propagation path, which is referred to as log-normal shadowing.

Using the path loss model based on the measurements on Zhengzhou- Xian passenger dedicated line, $PL(t)$ can be expressed as:

$$PL(t)_{via}[dB]=42.305+26.26\times\log_{10}(v\cdot t)+20\times\log_{10}(f) \tag{3}$$

$$PL(t)_{pla}[dB]=46.17+34.19\times\log_{10}(v\cdot t)+20\times\log_{10}(f) \tag{4}$$

where $PL(t)_{via}$ and $PL(t)_{pla}$ are path loss in viaduct and plain of high speed railway, respectively; f is operating frequency and v represents the velocity of train.

The small-scaled fading model E_{si} can be given by:

$$E_{si}(t)=\sum_{j=1}^{N}a_{ij}e^{j\varphi_{ij}}e^{j\cdot 2\pi f_s\cdot t\cdot\cos\alpha_{ij}} \tag{5}$$

where a_{ij} is the amplitude of each path; φ_{ij} is the initial phase of each path, which forms the uniform distribution over the interval $[-\pi,\pi]$; α_{ij} represents the incident angle of each path. f_s is the Doppler shift variation given by 3GPP [11]:

$$f_s(t)=f_d\cos\theta(t) \tag{6}$$

where $f_s(t)$ is the Doppler shift and f_d is the maximum Doppler frequency. The cosine of angle $\theta(t)$ is given by:

$$\cos\theta(t)=\begin{cases}\frac{D_s/2-vt}{\sqrt{D_{\min}^2+(D_s/2-vt)^2}}, 0\le t\le D_s/v\\ \frac{-1.5D_s+vt}{\sqrt{D_{\min}^2+(-1.5D_s+vt)^2}}, D_s/v<t\le 2D_s/v\\ \cos\theta\left(t \mod (2D_s/v)\right), t>2D_s/v\end{cases} \tag{7}$$

where $D_s/2$ is the initial distance of the train from BS, and $D_{\min}$ is BS-Railway track distance, both in meters; v is the velocity of the train in m/s, t is time in seconds.

III. LTE-R DIMENSION CONFIGURATION

The LTE-R system parameters are calculated based on choosing the maximum delay spread from Table I, which is found to be $\tau_{\max}=210ns$. In general, any signal arrives in the CP interval will be discarded by the receiver so the CP should be kept as short as possible since in the terminology of the information theory, it is a redundant part of the channel capacity. Normally, the length of cp equals 4 times of $\tau_{\max}$ [13], thus in this case, $T_{cp}=4\cdot\tau_{\max}=840ns$. In the case of OFDM systems employing a CP the spectral efficiency is written by:

$$\eta=H\cdot(1-T_{cp}/T_u) \qquad bits/s/Hz \tag{8}$$

where H is the entropy of the source, T_{cp} is the CP length and T_u is the OFDM useful time duration. In practice $(T_{cp}/T_u)\le 0.25$, and consequently $\eta\ge 0.75\beta$, which implies a reduction in spectral efficiency by up to 25% [14]. The spectral efficiency (η) is maximized for critical time-frequency density, ($T_u f_{sc}=1$), which ensures the orthogonality between sub-carriers. Therefore, the subcarriers spacing is the inverse of the OFDM symbol time duration. The target of LTE-R is proposed as 20 Mbps bit rate in a frequency spectrum of 5-20 MHz, thus LTE-R system parameters can be computed based on the maximum delay spread of the hybrid high speed railway multipath fading channel, as listed in Table II

TABLE II
LTE-R DIMENSION SUITABLE FOR HIGH SPEED RAILWAY

$T_{cp}=4\cdot\tau_{\max}$	840 ns		
$T_u=4\times T_{cp}$	3.36 μs		
$f_{sc}=1/T_u$	297.6 KHz		
$T_t=T_{cp}+T_u$	4.2 ns		
Modulation	64QAM	16QAM	QPSK
$N_d=(R_b\times T_t)/\log_2 M$	14	21	42
$N=2^{ceil(\log_2 N_d)}$	16	32	64

Where T_t is the OFDM symbol time duration and N is the number of sub-carriers.

IV. LTE-R PERFORMANCE SIMULATION

The whole simulation process is: Transmission bits generation $\rightarrow$ Base band modulation $\rightarrow$ MIMO 2×2 precoding

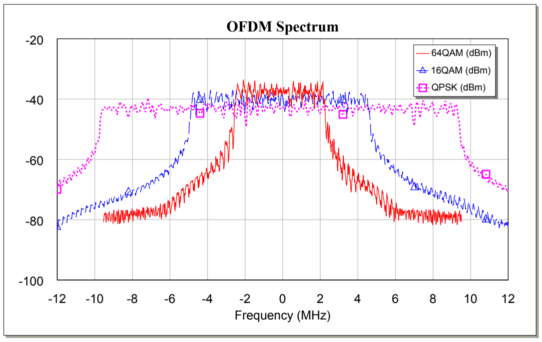

Fig. 2. Power Spectral Density of the OFDM transmitted signal with 64QAM, 16QAM and QPSK, respectively.

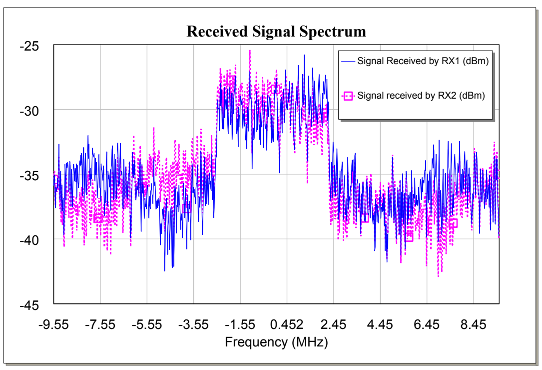

Fig. 3. Power Spectral Density of the signal received by different antennas. Modulation is 64QAM.

$\rightarrow$ Resource element mapping $\rightarrow$ OFDM modulation $\rightarrow$ High speed railway channel propagation $\rightarrow$ OFDM demodualtion $\rightarrow$ Channel estimation and equalization $\rightarrow$ Detection $\rightarrow$ Obatian BER. Fig. 2 shows the Power Spectral Density function of the OFDM transmitted signal using 64QAM, 16QAM and QPSK modulation, respectively. The effect of the frequency selective fading is shown on the received signal PSD function. Since the length of each carriage or a train is dozens of meters or hundred meters which is hundreds of times the wavelength of operating frequency, 2×2 MIMO system can support sufficiently low correlated wireless MIMO channels. As shown in Fig. 3, Fig. 4 and Fig. 5, the signal PSD received by each single receiving antenna when the train is running in a speed of 500 km/h, using 64QAM, 16QAM and QPSK modulation, respectively. Apparently, the signal received by different antennas experiences different frequency selected fading. Thus, combination of the signals received by two antennas can overcome the frequency selective fading of the wireless channel; and this effect is more obvious particularly in LTE-R system.

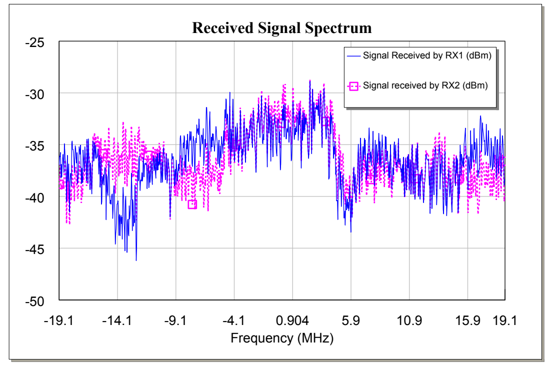

Fig. 4. Power Spectral Density of the signal received by different antennas. Modulation is 16QAM.

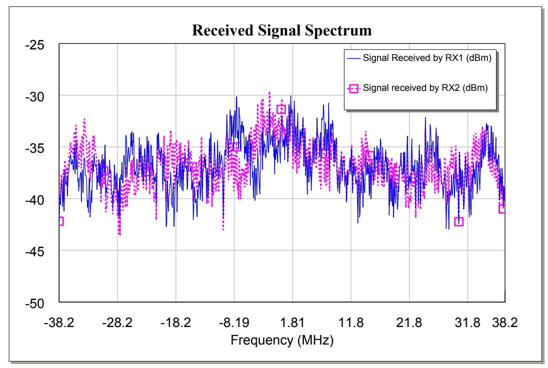

Fig. 5. Power Spectral Density of the signal received by different antennas. Modulation is QPSK.

V. Simulation Results

The simulation results in this section are based on the parameters calculated in the previous section. Simulations for the BER vs. Eb/No in different correlation MIMO configurations, different mobile velocities and different modulations.

Fig. 6 shows the BER vs. Eb/No of LTE-R system using 64QAM modulation and 2×2 MIMO. Obviously, when the channel equalization is implemented, Doppler shift resulted from the mobility of train can be eliminated to a great extent. Hence, BER performance is just slightly different among the cases of the speed of 200 km/h, 350 km/h and 500 km/h. Nevertheless, the correlation situation of the MIMO system affects BER performance. As Clearly demonstrated in Fig. 6, the BER is much higher when the MIMO channels have high correlation than low correlation. Fortunately, train or each carriage is sufficiently long and this can help the antennas on-train to be deployed far away enough rendering MIMO channels uncorrelated.

Similar BER performance situations can be seen in Fig. 7 and Fig. 8, which illustrate the BER vs. Eb/No of LTE-R system using 16QAM and QPSK modulation in the cases of the speed of 200 km/h, 350 km/h and 500 km/h, respectively.

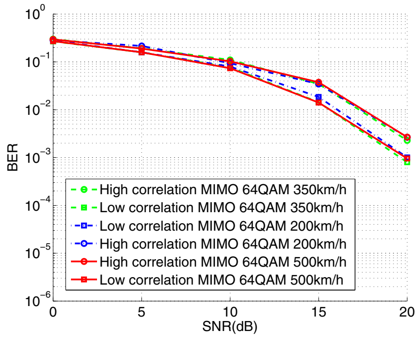

Fig. 6. BER performance of LTE-R system using 64 QAM modulation. Comparison between high and low correlated MIMO channels when the speed is 200 km/h, 350 km/h and 500 km/h.

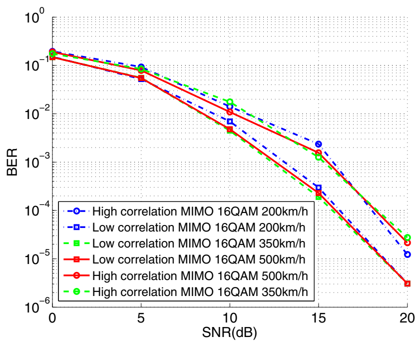

Fig. 7. BER performance of LTE-R system using 16 QAM modulation. Comparison between high and low correlated MIMO channels when the speed is 200 km/h, 350 km/h and 500 km/h.

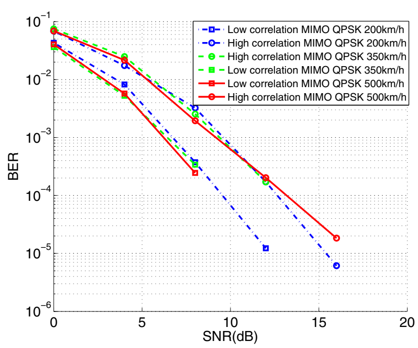

Fig. 8. BER performance of LTE-R system using QPSK modulation. Comparison between high and low correlated MIMO channels when the speed is 200 km/h, 350 km/h and 500 km/h.

Comparing Fig. 6, Fig. 7 and Fig. 8, we can find that higher-order modulation can save more frequency resource, but more easily to generate error than lower-order modulation. As an example of quantifying the BER performance difference among three modulations, LTE-R with 16QAM shows an improvement of about 8 dB than with 64QAM when the BER achieves 10^{-3}; while this number changes into approximate 6 dB when we compare QPSK to 16QAM.

VI. Conclusion

The performance including BER and PSD of Long Term Evolution for Railway (LTE-R) has been assessed using a realistic hybrid high speed railway channel model involving WINNER II Channel Model in Europe, high speed train channel model in 3GPP and high speed railway large-scaled fading models in China. A proper LTE-R dimension suitable for the high speed railway channel has been computed and assessed. The results indicate LTE-R can provide good performance with advanced channel estimation and dispersedly deployed antennas on-train. Thus, LTE-R is a very promising solution for the next generational broadband mobile communication systems of high speed railway.

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