Implementation of LTE-R Transceiver and the Performance with WINNER D2a Channel Model

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***Abstract*—With the rapid development of high-speed railway, the train speed can reach up to 350 km/h. Much more technical demands for high-speed railway mobile communication system are put forward. As the next generation wireless communication technology of 3GPP, Long Term Evolution for railway, known as LTE-R, is proposed to provide railway communication services including railway control, passenger services, wireless surveillance video, etc. The main goal of this paper is to evaluate the detailed performance of LTE-R on the WINNER D2a channel model which has been presented as an appropriate choice for the wireless channel model in high-speed scenario, and implement a LTE-R transceiver based on LabVIEW software and National Instruments Universal Software Radio Peripheral 2920 (NI USRP2920) platform for further research. The experimental results show that LTE-R has promising potential to be used in high-speed railway scenario.**

Keywords-MIMO; OFDM; WINNER D2a CHANNEL; LabVIEW; USRP;

I. INTRODUCTION

GSM for Railway (GSM-R) communication platform has been utilized in China for a long time, the data rate of voice services can reach up to 9.6kbps, which can't meet the increasing demands of high-rate data transmission in railway communication. In that case, the evolution of the high-speed railway communication has been more and more urgent. Long Term Evolution for Railway (LTE-R) [1] is commonly considered as a new railway wireless communication system based on LTE/System Architecture Evolution (SAE), which can provide high data rate, simple network architecture, high service quality, flexible bandwidth allocation and high spectral efficiency [2].

The two major physical-layer technologies, i.e., Multiple-Input Multiple-Output (MIMO) as well as Orthogonal Frequency Division Multiplexing (OFDM) in LTE can also be adopted as key technologies in LTE-R system [3]. OFDM is a special multi-carrier modulation technology, the high-speed data streams will be modulated to a number of parallel mutually orthogonal narrow sub-channels, so the frequency selective channel can be transformed into flat fading sub-channel from the perspective of frequency domain, which can resist the frequency selective fading. The cycle prefix is usually used as a guard interval, it is inserted between the two OFDM symbols to avoid the inter-symbol interference (ISI), because the length of guard interval is longer than the maximum value of time delay spread. Due to its capability in providing spatial multiplexing and diversity gains without increasing the system bandwidth, MIMO technology has attracted a lot of attention [4]. Given the advantage of OFDM and MIMO technologies, the combination of OFDM and MIMO is a popular wireless access scheme and it has been adopted in the LTE and LTE advanced (LTE-A) systems as well as in many other wireless communication systems [5]. As a consequence, the evaluation of MIMO-OFDM performance in LTE-R plays a significant role for the next generation railway wireless communication technology, what's more, the design and implement of LTE-R transceiver will provide much facilities for further research.

This paper is organized as follows: Section II introduces the high-speed railway channel model and the architecture of LTE-R transceiver; then design and implement a LTE-R transceiver with the WINNER D2a channel model based on LabVIEW software and National Instruments Universal Software Radio Peripheral 2920 (NI USRP2920) platform in Section III. Section IV presents the experimental results and gives the performance analysis in detail. Finally, conclusions are drawn in section V.

II. SYSTEM MODEL

A. High-Speed Railway Channel Model

The high-speed railway channel has a huge difference with the one in traditional public mobile communication network. The influence of Doppler shift plays a more significant role in high-speed scenario. WINNER D2a channel model has been presented as an appropriate choice for the wireless channel model for high-speed railways [6]. Cluster is the basic unit in WINNER D2a channel model, the number of clusters depends on the scenario and varies from 8 to 24, the delay of the nth cluster is given by [7]

$$\tau_n = -\gamma_\tau \sigma_\tau \ln(x_n) \tag{1}$$

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Where τ_n describes the delay of the cluster, γ_τ is the delay coefficient of the cluster, and σ_τ is the root mean square (RMS) of delay spread, X_n is a random number of the standard normal distribution, In the D2a scenario, the value of γ_τ is 3.8ns, and σ_τ is 40ns. Set the minimum value of τ_n to zero then sorts them in ascending order

$$\tau'_n = sort(\tau_n - \min(\tau_n)) . \quad (2)$$

As the line of sight (LOS) path always existing in the D2a scenario, we revise the value of τ'_n as

$$\tau''_n = \frac{\tau'_n}{0.7705 - 0.0433k + 0.0002k^2 + 0.000017k^3} . \quad (3)$$

Where k is the Rice factor in dB, τ''_n is the revised delay of the cluster. So the time varying channel impulse response of WINNER D2a channel model can be given by [3]

$$h(t,\tau''_n) = \sum_{n=1}^{L} E_{Ln}(t) E_{Sn}(t) \delta(t - \tau''_n) . \quad (4)$$

Where L is the number of clusters, $E_{Ln}(t)$ is the large-scaled fading coefficient, $E_{Sn}(t)$ is the small-scaled fading coefficient. $E_{Ln}(t)$ can be expressed as

$$E_{Ln}(t) = 10^{\frac{P(t) - P_L + G_n}{20}} . \quad (5)$$

Where P(t) is the power of the transmitted signal in dBm, P_L is the value of path lose in dB, G_n is a random variable in dB forming zero-mean Gaussian distribution. The P_L model in D2a scenario can be expressed as

$$P_L = 40\log_{10}(d) + 10.5 - 18.5\log_{10}(h_{bs}h_{ms}) + 1.5\log_{10}(f_c/5) \quad (6)$$

Where d is the distance between the train and the Basic Station (BS), h_{bs} and h_{ms} are the heights of the BS and the User Equipment (UE). f_c is the operation frequency. $E_{Sn}(t)$ is the coefficient of the small-scaled fading , which can be expressed as

$$E_{Sn}(t) = \sum_{n=1}^{L} A_n e^{j\varphi_n} e^{j2\pi f_s(t)\cdot t\cdot\cos(\alpha_n)} . \quad (7)$$

Where A_n and φ_n describes the amplitude and the initial phase of each cluster, α_n is the incident angle of each cluster, $f_s(t)$ denotes the Doppler shift as [8]

$$f_s(t) = f_d \cos\theta(t) \quad (8)$$

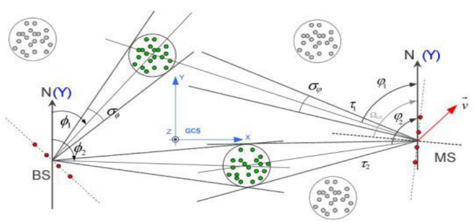

Figure 1. WINNER D2a channel model

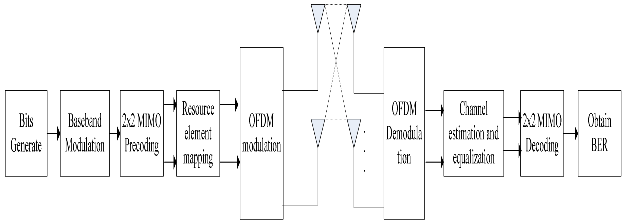

Figure 2. Block diagram of the LTE-R Transceiver

Where $f_d = f_c \cdot v$ / c is the maximum Doppler shift frequency, v is the speed of the train, and c is the speed of light.

B. Architecture of LTE-R Transceiver

The whole architecture of LTE-R transceiver is shown in Fig. 2. Bits generate module is used to generate the bits for baseband modulation. Baseband symbols are mapped to different antenna ports in 2x2 MIMO pre-coding module. With the resource element mapping module, baseband symbols are mapped to different time-frequency grid location of an OFDM frame. The OFDM symbols are generated in OFDM modulation module as

$$S(t) = \sum_{i=0}^{N-1} q_i e^{j2\pi f_i(t)} \quad (9)$$

Where q_i is the baseband symbol, N is the number of q, f_i is the carrier frequency. The pilot symbols are placed in the OFDM time-frequency grid for channel estimation at certain intervals, the location of the pilot symbols is shown in Fig. 3. The pilot sequence is generated by:

$$r_{L,n_s}(m) = \frac{1 - 2\cdot c(2m) + j(1 - 2\cdot c(2m+1))}{\sqrt{2}}$$

$$m = 0, 1, 2\ldots 2R-1 \quad (10)$$

Where n_s is time slot index in a frame, c(m) is the pseudo-random sequence, L is the OFDM symbol index in a time slot, R is the number of the resource block in an OFDM symbol. We can find that the pilot sequence is the pseudo-random sequence with QPSK modulation in actual, so we can use QPSK modulation to achieve the generation of the pilot sequence.

In receiver, the received signal R(t) of each antenna is expressed as

$$R(t) = S(t) * h(t, \tau''_n) + n \quad (11)$$

Where n is the noise of the channel, in the channel estimation module, there are several channel estimation algorithms based on the pilot symbols: Least-Squares (LS) channel estimation algorithm, Minimum Mean Square Error (MMSE) channel estimation algorithm. In MIMO decoding module, the symbols from two different antennas are combined and decoded to bits. We can get the bit error rate in the obtain BER module.

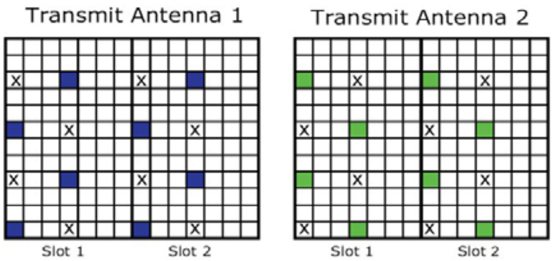

Figure 3. The location of the pilot symbols of two antennas

III. IMPLEMENT THE LTE-R TRANSCEIVER

One way of evaluating the detailed performance of LTE-R system under the WINNER D2a channel model is to use both virtual and real platforms with LabVIEW software and NI USRP2920.

According to the LTE-R Transceiver described in Section II, the design and implement of LTE-R transceiver can be described as follow:

First, generate bits used for baseband modulation in transmitter. Since the railway communication pays a lot of attention to public safety, one way to achieve this goal is to adopt Alamouti 2x2 MIMO Space-Frequency Block Coding (SFBC) scheme in [9], the SFBC scheme shown in Fig. 4 treats two baseband modulated symbols as a group, the two original symbols are transmitted at two different frequencies in one antenna, and the two conjugated or negated symbols are transmitted at the same two different frequencies in another antenna, which can get the diversity gain to improve the reliability of the LTE-R transceiver. So we map the baseband symbols to the different antenna ports according to SFBC scheme. Then add the pilot sequence to symbols, with the IFFT transformation and adding cyclic prefix (CP), and now OFDM symbols are generated. We also add training sequence at the beginning of each OFDM symbols in order to make sure the transmitter and receiver are in synchronism, the structure of the transmitted symbols is shown in Fig. 5.

As the actual channel environment in laboratory can't be adapted to the WINNER D2a channel model, we generate channel impulse response matrix of WINNER D2a channel model in virtual platform, and convolve the matrix over OFDM symbols before transmitting the OFDM symbols to USRP. The USRP converts the symbols to radio frequency and transmits symbols by two transmitting antennas.

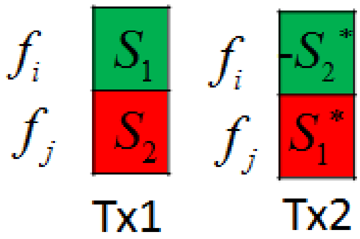

Figure 4. Alamouti SFBC scheme

Figure 5. the structure of the transmitted symbol

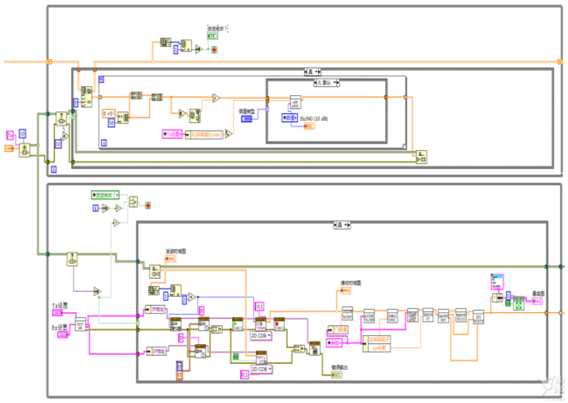

Figure 6. The main program diagram of the LTE-R Transceiver

In receiver, we receive radio frequency symbols from two receiving antennas in USRP and convert them to baseband frequency, then, we use training symbols to accomplish the synchronization with the classical algorithms, such as: Moose algorithm used for carrier frequency synchronization, early-late gate algorithm used for symbol synchronization, and Schmidl & Cox algorithm for frame synchronization. After finishing the synchronization and removing CP, we use the pilot sequence in received OFDM symbols to complete the channel estimation with MMSE algorithm in frequency domain. With the SFBC decoding algorithm, we combine the symbols in Maximal Ratio Combining (MRC) diversity technology and get the bits from transmitter.

So far, the design and implement of LTE-R transceiver has been accomplished as described before. The main program diagram of the LTE-R transceiver is shown in Fig. 6, and the front panel of the LTE-R transceiver is shown in Fig. 7.

IV. EXPERIMENTAL RESULTS

In this section, we provide the performance of the implemented LTE-R transceiver with WINNER D2a channel model, the configuration of the platform is shown as Table I:

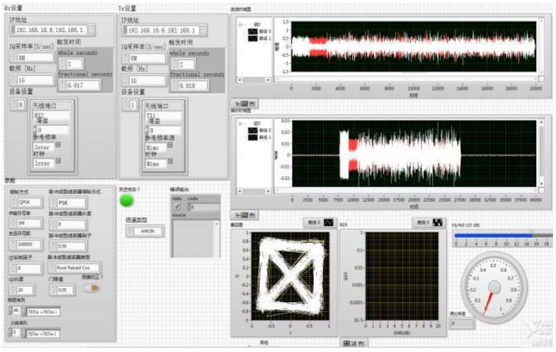

Figure 7. The front panel of the LTE-R Transceiver

TABLE I. THE CONFIGURATION OF THE PLATFORM

	Modulation type	
	QPSK	***16QAM***
transmitting bits numer	100,000	200,000
IFFT number	512	512
transmitting bits numer	100,000	200,000
train speed	350Km/h 500Km/h	350Km/h 500Km/h
antenna height	32m	32m
the distance between base station and track	50m	50m
multi-path number	8	8
carrer frequency	1GHz	1GHz

Fig. 6 indicates Bit Error Rate (BER) vs. Signal-to-Noise Ratio (SNR) of LTE-R transceiver using 16QAM modulation and QPSK modulation at the speed of 350Km/h, and 500Km/h. Obviously, the Doppler shift dues to the mobility of train can be restrained to a great extent with channel estimation. Therefore, BER performance is slightly varies at different speed. Compare with the different modulation methods, we can easily figure out that high-order modulation can improve the availability of transceiver, however, it may bring more bit errors than low-order modulation. LTE-R transceiver with QPSK modulation shows an improvement of about 5 dB than with 16QAM when the BER achieves 10^{-3}. The constellation graph of received modulated signals is shown in Fig. 7 and Fig. 8.

V. CONCLUSION

The performance of LTE-R transceiver with WINNER D2a channel model has been evaluated by BER. The experimental result shows that LTE-R can provide good reliability for the next generation railway communication system. The implemented LTE-R transceiver with Labview and NI USRP 2920 is effective, and it can be used for deeper study of LTE-R in the future.

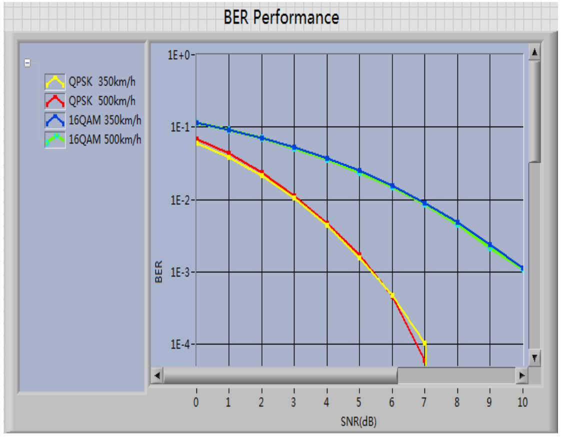

Figure 6. BER of the implemented LTE-R transceiver with 16QAM and QPSK at the speed of 350km/h and 500 km/h

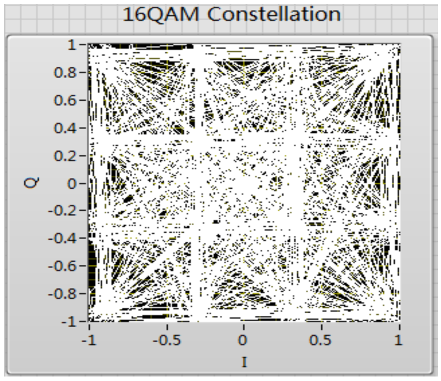

Figure 7. Constellation of received signal with 16QAM modulation

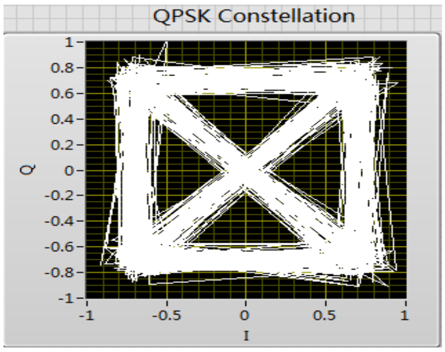

Figure 8. Constellation of received signal with QPSK modulation

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