Broadband Channel Measurement for the High-Speed Railway Based on WCDMA

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***Abstract*—The paper describes the measurement campaigns for the broadband channel properties under the high-speed condition, which have been carried out on Zhengzhou to Xi'an (ZX) High-Speed Railway and Beijing to Tianjin (BT) High-Speed Railway. WCDMA with the bandwidth of 3.84MHz is employed as the excitation signal that is transmitted from the base station along the railway and received by the TSMQ by ROHDE & SCHWARZ inside the train. Different scenarios including plain, U-shape cutting, station and hilly terrain are chosen in the measurements and the parameters about the channel multipath properties are extracted, analyzed and briefly reported here. These results are informative for the system designers in the future wireless communication of High-Speed Railway.**

I. Introduction

In recent years, the High-Speed Railway (HSR) in China has attracted much attention, and it has been the focal point of the world with the commencement of commercial operation of Beijing to Shanghai High-Speed Railway with the top speed of 300km/h, on June 30, 2011 [1]. In contrast with the great progress of HSR, the wireless communication adapting to the high-speed condition is not fully developed. It is said that the signal is not so steady during the journey that the dropped call happens frequently [2].

As the major prerequisite condition of any wideband digital mobile radio system, the thorough knowledge of the propagation characteristics of the mobile radio channel is necessary especially under the high-speed condition. Currently, the classical channel models include the COST207, COST259, and ITU-R model, however, they all do not characterize the wireless channel under the high-speed condition accurately. Therefore, in order to validate the system performance, dedicated measurement campaigns are required to take to model exactly the propagation characteristics of wireless channel under high-speed condition.

Most measurement campaigns have been carried out for the broadband channel characteristics in different scenarios. The company Medav took the measurement on Intercity Express (ICE) between Siegburg and Frankfurt employing the channel sounder RUSK [3]. D. J. Cichon has employed ray-tracing to study the modeling in high-speed railway tunnels [4] [5]. The UMTS ROMES TSMQ (ROHDE & SCHWARZ) has been used to test the WCDMA signal to obtain the basic channel parameters in the case of stationary receiver in [6]. In [7], China Mobile Research Institute has conducted the channel measurement campaign for the environment inside the train and extracted some channel parameters comprising the path loss, delay spread and rice K factor. [8] gives some measurement results mainly about Doppler fast shift in rural high-speed railway in Taiwan by Propsound of Electrobit.

On the basis of the preceding discussion, there is an apparent scarcity of description for HSR wireless channel characteristics in the time delay domain. On one hand, the time dispersion properties are influenced by surroundings near the HSR and at odds with those in the urban environment. On the other hand, it appears much different among different scenarios during the journey. Due to the high-speed moving at the speed of 300km/h corresponding to 83.3m/s, the change of scenarios is rapid and brings about the performance degradation of wireless communication. Consequently, the paper focuses on the time dispersion of multipath in different scenarios around the high-speed railway.

The main contribution of this paper is to employ the dedicated WCDMA signal along the HSR by Chinese mobile telecom operator, which is 3.84MHz bandwidth at a center frequency of 2.1GHz, as the excitation signal to measure the wireless channel on ZX HSR and BT HSR respectively. UMTS ROMES TSMQ is employed which is a radio network analyzer made by ROHDE & SCHWARZ [9]. The parameters of time dispersion including root mean square (rms) delay spread, maximum delay, number of fingers, power difference and the K factor in different scenarios are extracted from the measurement data.

The paper is organized as follows. In Section II, the measurement system and environment are described, and also the laboratory calibration. Section III analyzes the raw data, shows the results of measurement and gives the corresponding explanation. At last, the conclusion is drawn in Section IV.

II. Channel Measurement Campaign

A. Measurement System

Abandoning using a dedicated channel sounding transmitter, we employ WCDMA as an excitation signal in the measurements, for the reason of the private network coverage along the HSR, and widest bandwidth in the actual 3G networks in China. As the direct-sequence (DS) CDMA technology using the Golden sequence for downlink, WCDMA takes up the bandwidth of 2130MHz-2145MHz with adjacent frequency interval of 5MHz. In WCDMA downlink, the length of one

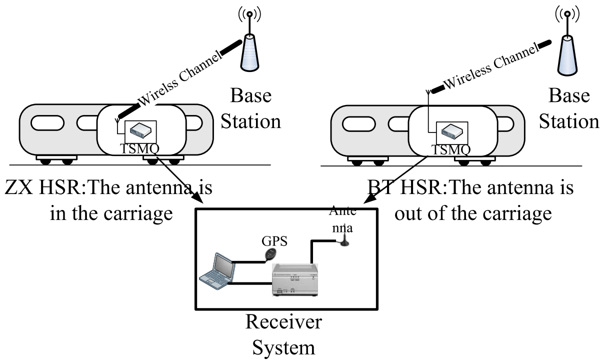

Fig. 1. A block of receiver system

frame (T_f) is 10ms consisting of 38400 chips. Common Pilot Channel (CPICH), as the fixed downlink physical channel, is broadcasted by the base station uninterruptedly, which is used for the cell recognition and channel estimation. The known pseudorandom sequences are transmitted in this channel.

As the measurement receiver, TSMQ utilizes a Rake receiver consisting of "fingers" each corresponding to one path delay of a received signal. Each RAKE finger independently receives the signal contribution of a single propagation path from a given cell; it performs this by correlating the received signal sample stream over a length of spreading factor samples with a time aligned copy of the scrambling and spreading codes [10].

During our measurement campaign, TSMQ is configured to work in UHS (Ultra-high-speed) mode with the top snapshot of 3ms, and 5ms is configured in reality. In each snapshot, the measurement data mainly includes latitude and longitude information, frequency, scrambling code, and the multipath information (the number, power and delay of fingers). Statistic characteristics of the channel condition will be extracted from the collected data.

Two antenna configurations are employed: (1) set inside the carriage and (2) use the train mounted antenna on the train roof. The 2nd antenna mode removes the penetration loss of the car body and the affection of seats, passengers and inter-wall of the carriage. A pure propagation condition can be obtained compared with the 1st configuration. The structure of the measurement system is shown as figure 1. The complete measurement apparatus is installed in the train consisting of TSMQ, computer terminal, GPS and receiver antenna. It is stressed that the measurement on ZX HSR follows the first program, i.e., the receiver antenna is inside the carriage. By contrast, on BT HSR, the antenna is located on the top of the train roof according to the configuration (2), with the gain of 8.5dBi. The received data corresponding to the geographical coordinates recorded by GPS are loaded to the computer terminal through 1394 firewire continuously.

B. Measurement Environment

Our measurement campaigns are planned with the purpose of characterizing the time dispersion properties in different scenarios along the HSR. The measurements are conducted on two railway lines (ZX HSR and BT HSR). The main length of ZX HSR is 484.518km. With the top speed of 350km/h (before July 1, 2011), the ZX HSR passes through 13 stations and abundant environments, such as plain, hilly terrain, U-shape cutting, viaduct, station and tunnel. Figure 2 shows four typical scenarios in which we take the measurements including plain, U-shape cutting, station and hilly terrain. BT HSR, regarded as the first passenger dedicated line in China, has a total length of 119.4km and 5 stations, and can reach the top speed of 350km/h. In fact, the measurement was conducted in the NO.0 High- Speed Integrated Inspection Train (NHSIIT) with the speed of approximately 240km/h in order to utilize the train-mounted antenna. NHSIIT is used to check the train system administrated by Ministry of Railway of China. This line mainly passes through the urban district composed of the viaduct and roadbed. The WCDMA network we measured is dedicated for the HSR, so the base station is along the railway with the vertical distance of about 30m, and the environment around it is almost the same as the railway.

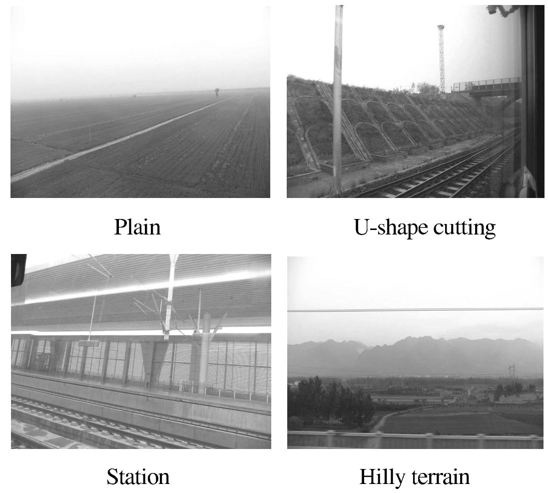

Fig. 2. Four typical scenarios on ZX HSR.

C. Laboratory Calibration

With the purpose to detect the veracity and sensitivity of the apparatus, laboratory calibration should be carried out under the emulator self-defined fading channel before taking the measurement campaign. And the diagram of calibration processing is shown as Figure 3. TSMQ receives the signal from the vector signal generator (SMU-200A by ROHDE & SCHWARZ), which exports the special signal that has suffered self-defined fading, and then the power delay profile of the fading condition can be obtained. Additionally, the power spectrum of the transmitted signal is shown by he signal analyzer (FSQ by ROHDE & SCHWARZ) connected with the vector signal generator. The performance parameters of TSMQ can be determined through the calibration as follows, the maximum delay and the minimum fading that TSMQ can detect are $20\mu s$ and 20dB respectively.

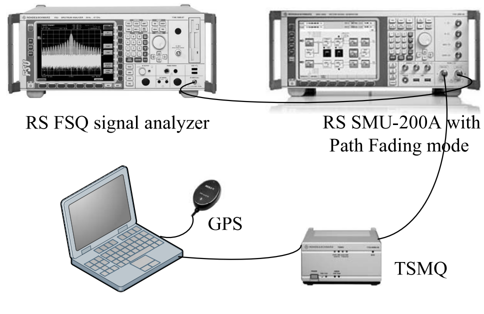

Fig. 3. Elementary diagram of calibration.

III. Results and Analysis

The statistical data is mainly about the multipath delay spread to evaluate the small-scale fading of wireless channel. The PDFs (Probability Density Function) and CDFs (Cumulative Distribution Function) of rms delay spread, maximum delay, and number of fingers are shown as the basic parameters in this part. Additionally, the power distribution of the first finger relative to the second one is also considered. The time dispersive properties of broadband multipath channels are most commonly quantified by rms delay spread which is defined as the square root of the second central moment of the power delay profile and calculated as [11]

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\overline{\tau})^2} \tag{1}$$

where $\overline{\tau}$ and $\overline{\tau^2}$ are the first and second moments of the instantaneous power-delay profile respectively, and can be calculated as

$$\overline{\tau} = \frac{\sum\limits_k P(\tau_k)\,\tau_k}{\sum\limits_k P(\tau_k)} \tag{2}$$

$$\overline{\tau^2} = \frac{\sum\limits_k P(\tau_k)\,\tau_k^2}{\sum\limits_k P(\tau_k)} \tag{3}$$

where τ_k and $P(\tau_k)$ represent the delay and corresponding delay power of the kth finger respectively. It is measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$. And the value does not depend on the absolute power level of $P(\tau_k)$, but only the relative amplitudes of the multipath components within $P(\tau_k)$. Especially for BT HSR, the main scenario is viaduct and the receiver antenna is mounted on the train roof, therefore it is probable that the dominate ray is line-of-sight (LOS). The received signal envelop has a Ricean distribution with the corresponding probability density function given by [12]:

$$P(r) = \frac{r}{\sigma^2} \cdot \exp\left(-\frac{r^2+s^2}{2\sigma^2}\right) \cdot I_0\left(-\frac{rs}{\sigma^2}\right) \tag{4}$$

where $I_0(\cdot)$ is the 0th-order modified Bessel function of the first kind, r denotes the envelope of the received signal, σ^2 represents the variance of the diffuse components, and s^2 is the power of the direct LOS path. Any moment of the Ricean distribution can be given as

$$\begin{aligned}\mu_n &= E\left[r^n\right] \\ &= \left(2\sigma^2\right)^{\frac{n}{2}} \exp\left(-k\right) \Gamma\left(1+\tfrac{n}{2}\right) F_1\left(1+\tfrac{n}{2};1;k\right)\end{aligned} \tag{5}$$

where $\Gamma(\cdot)$ is the gamma function, and $F_1(\cdot)$ is the confluent hypergeometric function. The close form of even moment can be written as

$$\hat{\mu}_2 = E\left[r^2\right] = s^2 + 2\sigma^2\left(K+1\right) \tag{6}$$

$$\hat{\mu}_4 = E\left[r^4\right] = 8\sigma^4 + 8\sigma^2 s^2 + s^4 \tag{7}$$

Then the estimated K factor can be obtained as

$$\hat{K}_{2,4} = \frac{-2\hat{\mu}_2^2 + \hat{\mu}_4 - \hat{\mu}_2\sqrt{\hat{\mu}_2^2 - \hat{\mu}_4}}{\hat{\mu}_2^2 - \hat{\mu}_4}. \tag{8}$$

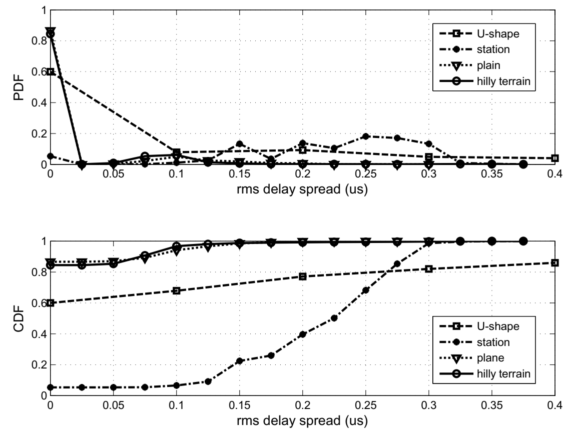

Fig. 4. rms delay spread in different scenarios on ZX HSR.

A. ZX HSR measurement results

In figure 4, the time dispersive property is assessed by rms delay spread in the four different scenarios. From the statistic curves, it can be obtained that plain and hilly terrain have similar distribution that up to 95% of rms is less than 0.1μs and 84% is 0μs; it means that the single path plays the leading role in the two scenarios, and the fact is also verified later in the literature. By contrast, U-shape cutting and station appear richer reflection and scattering. U-shape cutting has the largest rms delay spread of more than 0.4μs. In station scenario, 95% of rms delay spread is less than 0.3μs, and more than half of them vary in [0.15, 0.3]μs.

Figure 5 depicts the maximum delay in the four scenarios. In plain and hilly terrain scenarios, probability when the maximum delay is less than 0.4μs is 98%. U-shape cutting has the largest multipath delay which is likely more than 1.4μs. It is noted that the maximum delay of each snapshot in the station region ranges from 0.3μs to 0.7μs, and about half of them is 0.6μs, for the reason that the surroundings of the station are closed and stationary resulting in more reflection than plain and hilly terrain.

Figure 6 shows the PDF and CDF of the path number. The statistical curves show that only one or two figures occupy the dominant position in both plain and hilly terrain scenarios.

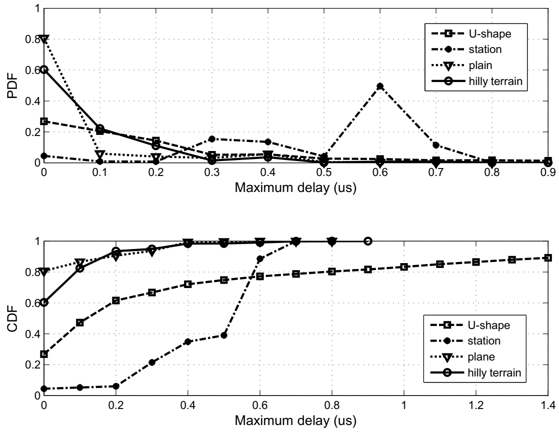

Fig. 5. Maximum delay in different scenarios on ZX HSR.

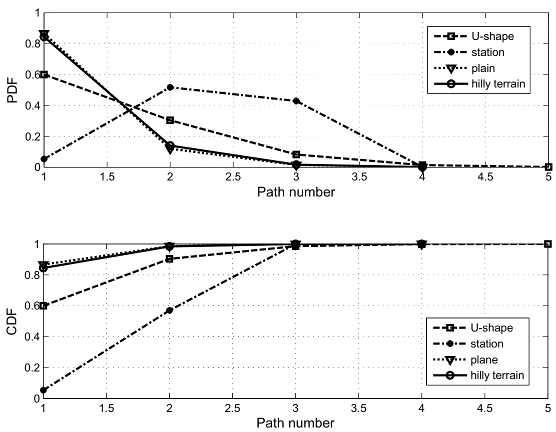

Fig. 6. Path number in different scenarios on ZX HSR.

It is more than 80% when only one finger is detected and approximately 10% for two fingers; the result is identical with the rms delay spread analyzed before. Under station condition, the multipath performance is more obvious than the other scenarios. The probability is just 5% when only one finger is detected, yet it is more than 90% when the TSMQ receiver detects two or three fingers.

If there are two or more fingers in one snapshot, we can obtain the power difference between the first finger and the second one, as presented in figure 7. It is possible that the second finger is stronger than the first one, and in this case, the second component is regarded as the dominant one in the wireless channel. Similar results have been found in [6]. Plain and hilly terrain have the similar curves showing that the difference varies in [-7.5, -2.5]dB and [2.5, 17.5]dB, with the largest PDF of 19% when the power difference is 7.5dB. In U-shape cutting scenario, the value ranges in [-7.5, 15]dB. In station region, the power difference distribution is more concentrated, ranging in [-5, 5]dB, with the largest probability of 37% when the first component is stronger 2.5dB than the second one.

TABLE. I lists the results of time dispersion for the four scenarios. From the statistical data in the table, it is clear that the plain and hilly terrain exhibit the similar results in the delay spread domain. For the rms delay spread, the plain and hilly terrain has the minimum value of 95% with less than $0.1\mu s$. Considering that the rms delay spread is inversely proportional to the coherent bandwidth, the two scenarios have the largest coherent bandwidth. Except for U-shape cutting, the maximum delays of other three scenarios, which are similar to each other, are less than or equal $0.7\mu s$. The worst delay of $2.5\mu s$ occurs in U-shape cutting snapshot samples for the reason that there are more reflectors; the maximum number of resolved echo waves in U-shape cutting is 4, while 2 fingers can be extracted in the plain scenario. The station and hill terrain have the similar maximum path number of 3. It is because that the communication space is limited due to its semiclosed structure, thus more echoes take place compared with the other scenarios.

On the basis of the preceding discussion, we conclude that the plain and hilly terrain have similar multipath behaviors, and the station and U-shape cutting show much stronger multipath effects than the other two scenarios. We try to give the explanation as follows. Under the mountainous condition, one side of the railway is plain and the other side is Huashan Mountain; because of the limit of the sensitivity of TSMQ (the maximum delay is $20\mu s$, the maximum path gain is -20dB), the reflected wave from the large distance is so weak that it can not be detected after the penetration loss. Therefore, the multipath property of the mountainous region we detected has little difference from that in the plain scenario. In the station scenario, the newly-built roof and wall are made of metal

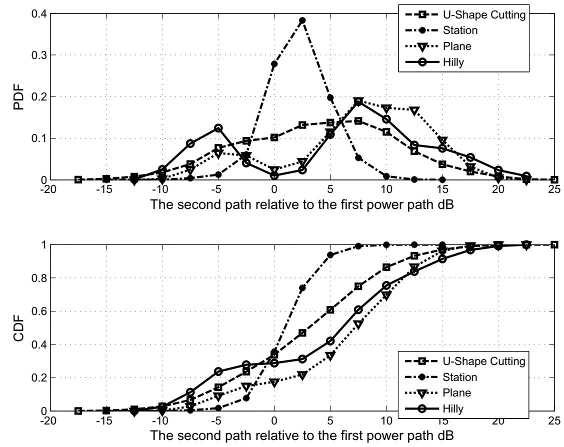

Fig. 7. Power difference in different scenarios on ZX HSR.

TABLE I
CHANNEL PROPERTIES FOR THE FOUR SCENARIOS

Scenario	rms delay spread 95 %	Max delay	Path number
Plain	$< 0.1\mu s$	$0.35\mu s$	2
Station	$< 0.3\mu s$	$0.7\mu s$	3
Hill terrain	$< 0.1\mu s$	$0.3\mu s$	3
U-shape cutting	$< 0.8\mu s$	$2.5\mu s$	4

materials having a strong reflection. So the multipath property is more obvious. While the U-shape cutting has cement slopes beside the two sides, the wave will undergo the reflection many times, further more, the cement has a stronger diffuse reflection than metal materials. For this reason, the U-shape cutting behaves to have the richest multipath characteristics than the other scenarios.

B. BT HSR measurement results

TABLE II
CHANNEL PROPERTIES FOR BT

Scenario	rms=0	Max number of path
BT HSR plain A	98 %	2
BT HSR plain B	91 %	2

TABLE II lists the channel delay parameters in the two different plains. In most cases there is only one finger, i.e., rms delay spread is zero in the snapshots with the probability of 98% and 91% in the two scenarios, respectively. The reason is that the BT Line is mainly composed of the plain area, and the train-mounted antenna on the roof is applied, which can receive the signal directly from the base station without any effect from the penetration fading, reflection and scattering inside the train.

TABLE III
RMS COMPARISON FOR BT

Type	ZX plain	BT plain A	BT plain B
rms $< 0.1\mu s$	$\approx$ 94 %	100 %	$\approx$ 99 %

TABLE III gives the rms delay spread comparison between the ZX and BT for the plain scenario. We mainly emphasize on the probability when the rms delay spread is less than $0.1\mu s$ in the plain scenario. We can draw the conclusion that by use of the antenna outside the train, multipath delay spread can be diminished.

TABLE IV
K FACTORS FOR BT

Measurement Section	A	B	C
K factor (dB)	4.8	5.2	2.5

Table IV shows the K factor that we get in three different measurement sections. Each value is the average K factor for every measurement section, varying from terrain to terrain. Section A and B are the viaduct models, exhibiting stronger LOS, with the K factor of 4.8dB and 5.2dB respectively. By contrast, section C is where in the town appearing richer reflection and scattering, corresponding to the little K factor of about 2.5dB. Actually, the K factor is around 5dB in most instances in the whole measurement campaign on BT HSR.

IV. CONCLUSIONS

In this paper, we described the measurement campaigns and the corresponding results for the wireless communication channel under high-speed condition. Channel measurement were made on two High-Speed Railways (ZX HSR and BT HSR), respectively, and data were collected in various scenarios. The multipath delay spread were presented and analyzed. On ZX HSR, owing to the terrain feature and apparatus accuracy, the channel properties of the hilly terrain we extracted is similar to that of plain; the station reveals its own propagation properties due to the metal structure construction. For BT HSR, because of the position of the receiver antenna, the rms delay spread is less than that of ZX even in the same scenario. Specially, the K factor is obtained on BT HSR, which is about 5dB for most cases.

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