ITS-G5 Channel Models for High Speed Train-to-Train Communication

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Abstract. Train-to-train communication will be the key technology for future railway operation. An increase of safety and efficiency can be achieved by exchanging data between trains via ad hoc networks. For vehicle-to-vehicle communication the European standard is intelligent transport systems (ITS-G5). The usage of this standard for railways is hardly investigated. We investigate the performance of ITS-G5 for train-to- train communication at high speed conditions. ITS-G5 units were installed on two high speed trains and train-to-train (T2T) measurements were performed between Naples and Rome during four nights to cover different maneuvers. We present the analysis of the measurements data and resulting path loss models for tunnel and open field environments.

Keywords: T2T · Electronic coupling · ITS-G5 · Channel model · NGT

1 Introduction

On the path towards autonomous driving trains, electronic coupling is seen as the door opener application. Electronic coupled trains are connected with a wireless communication link, but without a mechanical coupler [1]. For this application, different T2T communication links are envisaged. We use three categories: short, mid and long range communication links. On short range of several hundred meters, ultra reliability and low latency are required to support precise distance control of the trains over wireless train control management system. For mid range communication between two trains, e.g. up to 2 km, a robust data link needs to be established which allows for a safe approach. Therefore, safety related information like movement information need to be exchanged with medium data rates under certain delay and error constraints. For long distances a terrestrial trunked radio (TETRA) based system could be used to ensure links up to a few tens of kilometers with low data rates as proposed in [2].

So far T2T is hardly investigated compared to train-to-ground communications. T2T channel models covering high speed scenarios and frequencies above 1 GHz are not discussed in literature. The necessity of investigations on short and mid range T2T links and related channel models is pointed out in [3]. A technology transfer from vehicular applications developed for road traffic like ITS-G5 to high speed trains in the railway domain needs to be verified.

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Based on previous measurements with commuter trains at speeds up to 140 km/h as presented in [4], we have set up an ITS-G5 system in two high speed trains (HSTs). This measurement campaign was performed in Italy in 2016 and is described in detail in [5]. In this paper we present an extended evaluation of the ITS-G5 link measurements in high speed railway (HSR) environments and deriving path loss channel models for certain railway environments.

2 Measurement Campaign

A comprehensive four days measurement campaign was planned and performed on the 220 km long HSR track between Naples and Rome in Italy. One night was used for intra-consist communication measurements (published in [6]) with one Trenitalia Frecciarossa ETR 500 HST [7] as shown in Fig. 1. In the following three nights, different T2T measurements with two of those HSTs were performed. Different measurement systems were installed. Next to an ITS-G5 communication link, a TETRA based communication system was installed and tested under high speed conditions as presented in [8]. The DLR RUSK channel sounder was used for intra-consist and T2T measurements at 5.2 GHz. For the movement tracking of both trains, global navigation satellite system (GNSS) receivers and inertial measurement units (IMUs) were mounted in the trains. More details on the campaign and the installed equipment can be found in [5].

2.1 ITS-G5 Equipment and Setup

Both HSTs were equipped with ITS-G5 Cohda Wireless MK-5 modules. The on board unit of Train 07 was set up as transmitter (Tx) and the unit of Train 28 as receiver (Rx). The general settings are listed in Table 1. The settings were chosen to ensure the most robust link. The radios were set up for the control channel 180 at 5.9 GHz with a bandwidth of 10 MHz. The output power of the Tx ITS-G5 module was set to the maximum of 23 dBm. On the Tx side, an additional amplifier was used to achieve in combination with the installed antenna an equivalent isotropically radiated power (EIRP) of 31 dBm. The data rate was set to 3 Mbit/s with BPSK modulation at a coding rate of 1/2. The packet length was 400 Byte with a repetition rate of 100 Hz.

To fulfill the safety regulations for railways, railway certified antennas were used. Huber+Suhner SWA-0859/360/4/0/DFRX30_2 omni-directional antennas were installed on the first coach after the locomotive of each train. These antennas support multiple bands up to 6 GHz and offer an integrated GNSS antenna.

The Cohda MK-5 modules offer a dual transceiver radio. For these measurements, only radio A was activated and connected to the measurement antenna. The internal GNSS receiver was used to log the train positions for each received signal strength indication (RSSI) measurement.

The Tx data included a header with a sequential packet number, the movement information of the Train 07 and dummy payload data. The movement

Table 1. Cohda MK5 radio settings

Channel	180
Carrier frequency	5.9 GHz
Bandwidth	10 MHz
EIRP	31 dBm
Data rate	3 Mbit/s
Modulation	BPSK
Coding rate	1/2
Packet length	400 Byte
Repetition rate	100 Hz

information of Train 07 and Train 28 and the RSSI measurements were stored together with the GPS time stamp on the Cohda module at Train 28.

2.2 Environment and Scenarios

The measurement campaign was performed at night from midnight to 5 am out of scheduled operation time in spring 2016. The environment along the track varies from urban and suburban areas around Naples to rural areas before arriving in Rome. A map of the HSR track is plotted in Fig. 2 and marked in red. Open field, forest, hilly sections and tunnels alternate in the rural area.

Nowadays, typical HST maneuvers include mainly crossing and sometimes overtaking. An overtake maneuver is comparable with an approaching maneuver for electronic coupling. Therefore, the overtaking maneuver was specially performed in all characteristic environments for different speeds. The low speed measurements were performed at 50 km/h and the high speed at 250 km/h average absolute velocity. The combination of environments and maneuvers with different velocities lead to the measurement scenarios listed in Table 2. For all measurements, the trains were driving on different parallel tracks.

For the analysis in Sect. 3 we are focusing on open field and tunnels at high speed. We present one overtake maneuver for each environment.

Table 2. Measurement scenarios

	Slow	Fast
(Sub-) urban	x	
Rural	x	x
Tunnel		x

Fig. 1. Trenitalia Frecciarossa ETR 500 HST.

Fig. 2. HSR track Naples-Rome. Image by Google, Map Data 2016 NOAA, U.S. Navy, NGA, GEBCO Image Landsat (2015). (Color figure online)

3 Data Analysis

3.1 Path Loss Models

Two path loss models were chosen to estimate the losses in different environments. The free-space path loss equation

$$FSPL(d) = 20 \cdot log_{10}(\frac{4\pi d \cdot f}{c}) \quad (1)$$

was used as reference. d represents the distance between Tx and Rx antenna, f the carrier frequency and c the speed of light.

The log-distance path loss model was used to model line of sight (LOS) and non LOS conditions. In addition to a reference path loss at a distance $d_0 = 1\,\text{m}$, a relation of the actual distance d and d_0 times a path loss exponent n is added. The power variations due to shadowing and multi path effects are modeled as normal distributed vector $\chi_\sigma \sim \mathcal{N}(0, \sigma)$.

$$PL(d) = FSPL(d_0) + 10 \cdot n \cdot log_{10}(\frac{d}{d_0}) + \chi_\sigma \quad (2)$$

3.2 Scenarios

Figures 3, 4, 5, 6, 7, 8, and 9 show the measurement analysis in open field and tunnel environment. In general, the received power, the distance and speed of the trains over time are plotted in Figs. 3 and 7. The received power and the fitted path loss of the log-distance model are plotted in Figs. 4 and 8. Figures 5 and 9 show the probability density of the fading effects in case of the log-distance model.

Open Field: First, we present an approaching maneuver in a rural environment. As shown in Fig. 3, the Tx Train 07 is between 300 m and 400 m in front of the Rx Train 28. Both trains are accelerating from 100 km/h to 250 km/h. In this phase of the maneuver both trains could be seen as one electronically coupled consist. Up from 200 s the Rx is accelerating up to 300 km/h and reducing the gap, finally overtaking the Tx train. Out of the top chart of Fig. 3 we can derive, that fades are less related to the speed than to the distance between Tx and Rx.

In Fig. 4 the measured received power is plotted over distance in green. The related FSPL model and log-distance model are plotted in red and black. As already mentioned before, up from a distance of 200 m deeper fades can be observed; this is caused by a higher probability of non LOS components. Even in open field environment, catenary, pylons or the signaling system can cause multi path components (MPCs). More information on multi paths in railway environments can be found in [3,5]. As expected for open field there is high probability for LOS. Therefore, FSPL model fits quite well to the measured received power. At higher distances the log-distance model with a path loss exponent of $n = 2.1$ fits better than the FSPL model.

The shadowing was analyzed as well and fitted to a normal distribution as shown in Fig. 5. The log-distance model parameters are listed in Table 3.

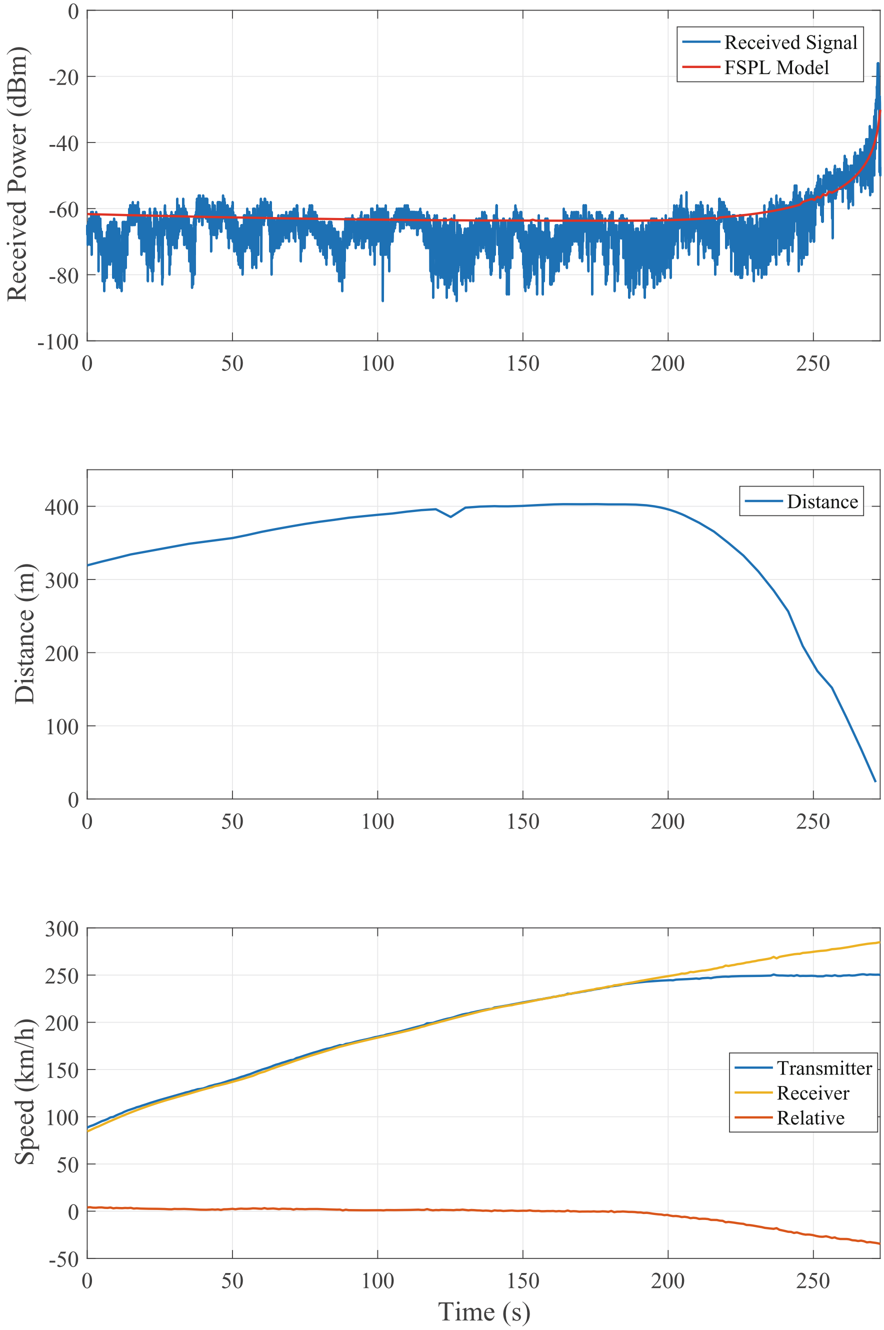

Fig. 3. High speed maneuver in open field

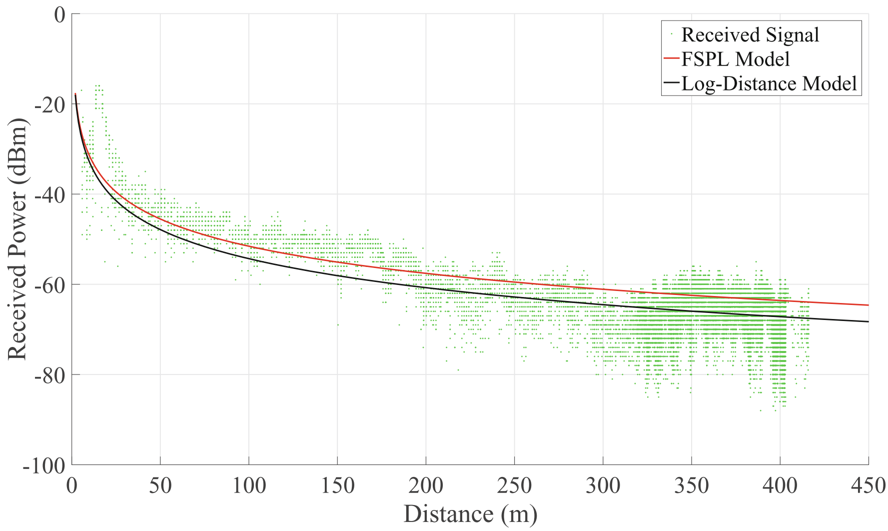

Fig. 4. Path loss model for open field (Color figure online)

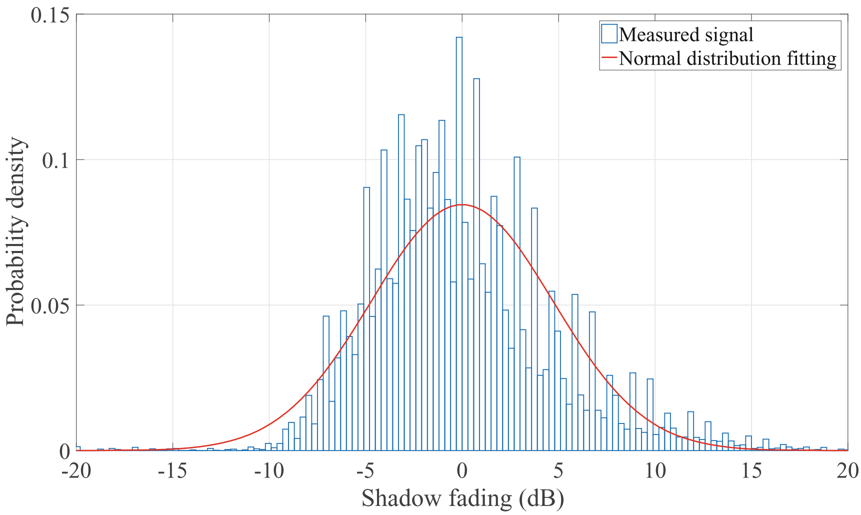

Fig. 5. Probability density of shadow fading for open field

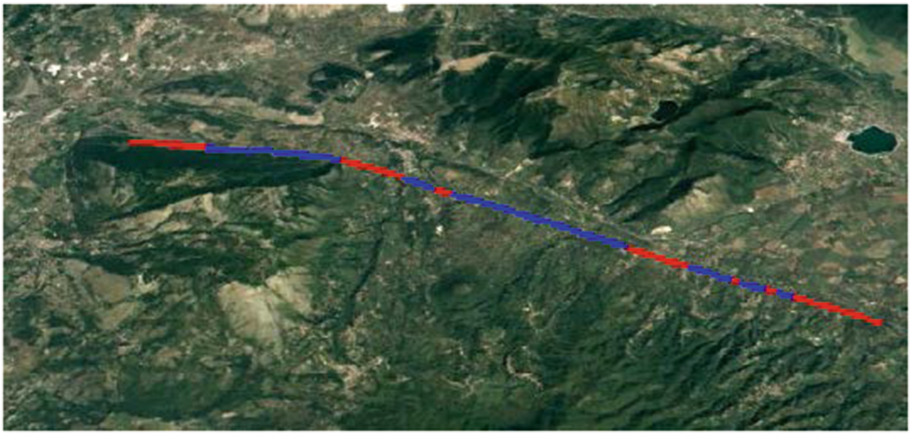

Fig. 6. Track for tunnel section, blue indicates tunnels. Image by Google, Map Data 2016 NOAA, U.S. Navy, GEBCO Image Landsat (2015). (Color figure online)

Tunnels: The second maneuver is a departure and approaching in a hilly environment with several consecutive tunnels. In Fig. 6 the tunnels are marked in blue; the trains are driving from right to left side of the figure. Hence, at least one train was always in a tunnel and several times, Tx and Rx were in the same tunnel or in two consecutive tunnels. This is illustrated with colored bars in the top chart of Fig. 7.

The analysis of the maneuver starts at 0 s when Rx is overtaking Tx with a speed of 140 km/h and accelerates to 200 km/h. Rx runs ahead till 165 s up to a maximum distance of 2.1 km. Tx is accelerating from 50 km/h to 270 km/h and catching up to Rx at 275 s.

While both trains were driving through the longest tunnel marked in orange, the distance was above 2 km. Up from around 250 s, both trains were in a same tunnel again (brown tunnel). For both events, the received power was 18 dB above the FSPL model. This gain is caused by a wave guiding effect inside the tunnels. Around 50 s and 70 s similar effects can be observed with a gain of 15 dB. In these sections the trains were in different, but very close tunnels.

For constellations with large areas of open field between different tunnels (e.g. 90–120 s or 210–240 s), only one train was inside a tunnel. In these sections the received power is 15–20 dB beneath the FSPL model, because diffraction at the tunnel entry causes extra loss [2].

Figure 8 shows the received power over distance for two cases. At the first and general case at least on train is in a tunnel (marked in green). This case is modeled by the free-space path loss (FSPL) model in red. Second case marked with blue dots, both trains are in the same or very close tunnels. This case is modeled by the log-distance model in black. For both cases, strong wave guiding effects can be observed for distances beneath 500 m and above 2000 m. If at least one train is in a tunnel, deep fades can be observed for distances above 500 m.

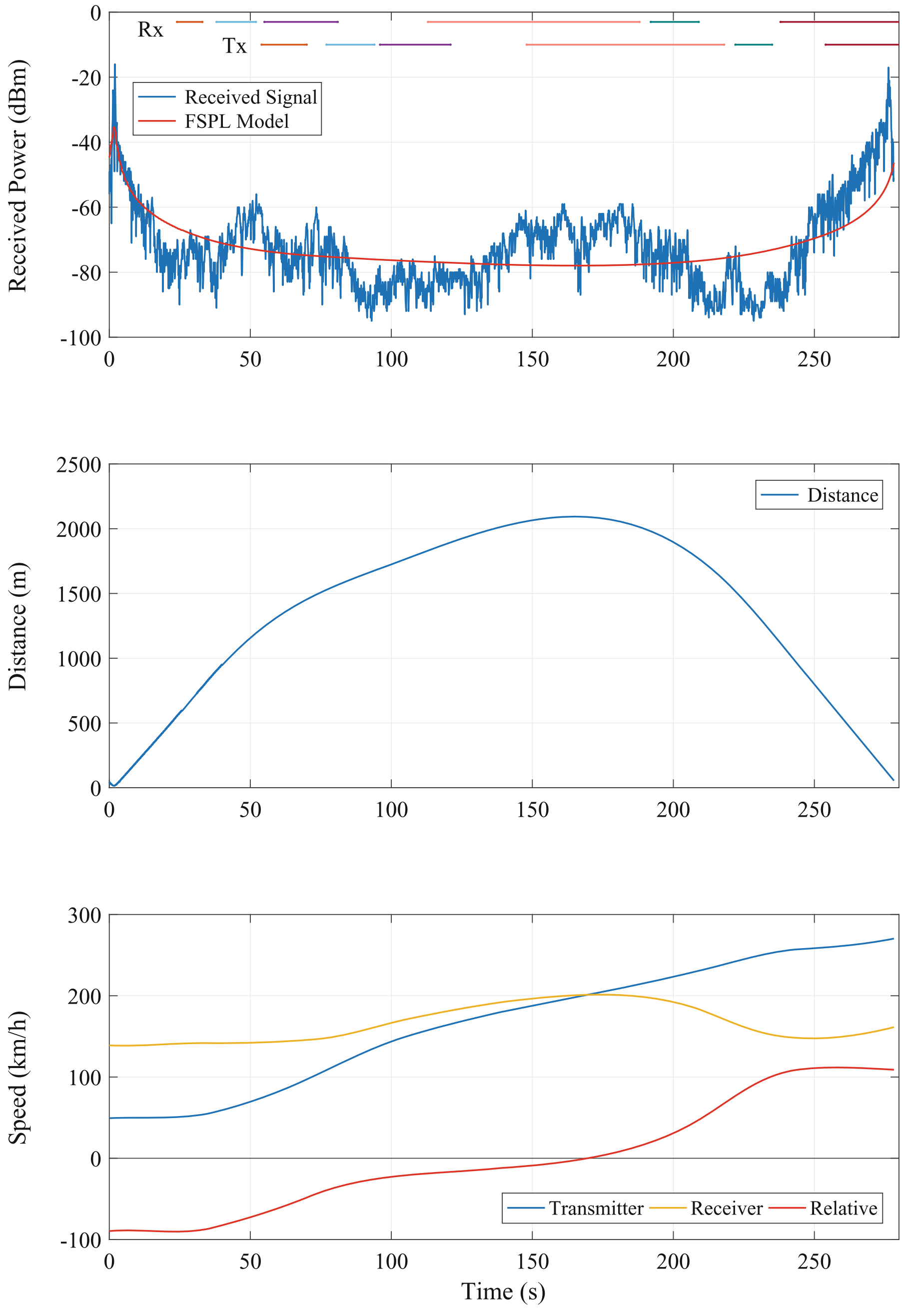

Fig. 7. High speed maneuver in tunnels (Color figure online)

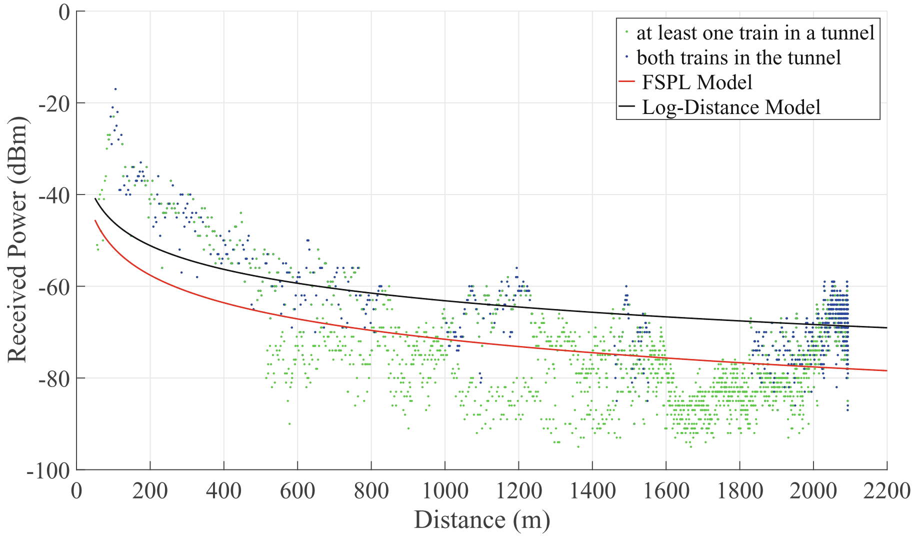

Fig. 8. Path loss model for tunnel environment (Color figure online)

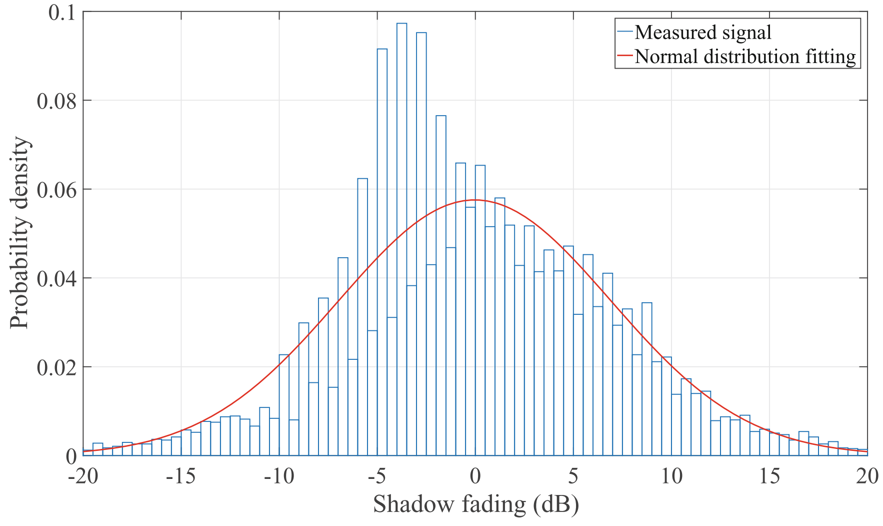

Fig. 9. Probability density of shadow fading for both trains in a tunnel (Color figure online)

Table 3. Log-distance model parameters

	$PL(d_0)$ dBm	n	σ dB
Open field	47.8	2.1	4.72
Tunnels	47.8	1.72	6.93

The probability density of the shadowing is plotted in blue in Fig. 9 for the case where both trains are inside a tunnel. A normal distribution is fitted to the measured signal with the parameters listed in Table 3.

4 Conclusion

In this paper we presented an analysis of ITS-G5 as T2T link under HSR conditions. The performance at open field environment and tunnels at high speed were investigated in detail. For both environments, the received power was measured while performing overtaking maneuvers with two HSTs.

In detail, deep fades can be observed for link distances above 200 m in open field and above 500 m in tunnels. If Tx and Rx are in the same tunnel or close tunnels, a wave guide effect with a maximum gain of 18 dB can be observed. For mixed environments with tunnels and open field, alternating strong fading effects and shadowing affect the link significantly. Nevertheless, stable links could be achieved for distances up to 2 km. The high speed ($\geq$200 km/h) has no significant effect on the data transmission.

For both environments, log-distance models were derived and the parameters presented. In comparison to car-to-car communication, larger communication ranges can be achieved by similar data rates. Furthermore, the dynamic of trains is smaller than for road vehicles. As already presented in [4] the update delay is sufficient for electronic coupling application. Hence, the ITS-G5 standard is suitable for mid range communication for electronic coupling applications.

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