Performance Analysis of LTE-R for High Speed Railways Inside a Tunnel

Kuldeep Gill, Alexander Arnold
Department of Electrical and Computer Engineering
Worcester Polytechnic Institute,MA 01609-2280,USA
Email:{ksgill,ararnold}@wpi.edu

***Abstract*—In this paper we do the performance analysis of high speed trains for LTE-R in tunnels. We are using WINNER II and 3GPP[SCM] for building our channel model for high speed trains in tunnel. We performed the analysis of large-scale and small-scale fading characterisitcs for HSTs in a tunnel. The theoretical Pe is calculated for both QPSK and 16QAM which are the essential part of LTE communication system. Lastly, we performed computer simulation to verify our theoretical results. The results clearly show that QPSK performs much better than 16QAM in tunnels where Line-of-Sight(LOS) is the most common path and can lead to high Ricean fading.To keep the mathematical analysis simple we ssumed single data link between transmitter and receiver.**

***Index Terms*—LTE-R,QPSK,16QAM,3GPP[SCM],HST.**

I. Introduction

IN recent years the use of trains has seen a tremendous rise in recent years due to their increasing speeds, increasing the demand for high speed and reliable wireless communication system. The development of a reliable wireless network for high speed trains is not a simple task and it is still an emerging technology. GSMR an existing wireless communication for trains was targeted for use in high speed trains, but it is not reliable enough and has several limitations. Therefore LTER has been proposed and looks promising in achieving broadband data rates in high speed trains and can overcome various GSM-R limitations.

LTE-R is the next generation high speed communication system which is based on the existing LTE system [1].To shed some light on LTE specifications, Table 1 lists the basic parameters of LTER that are planned to be implemented on HSR. As LTER is mostly based on LTE, SAE, MIMO and ODFM will be its key technologies. From our research in HSR communication system, there has not been any performance analysis of HSR within tunnels. This project will focus on evaluating performance of high speed railway communication systems when traveling in a tunnel. A lot of effort has been dedicated on implementing a channel model for LTE-R under high speed railway conditions, but not much focus is given on tunnel channel modelling. In [5], [6] and [7] measurements and studies has been carried out but they are not focusing on LTER. In this paper we are solely focusing on LTER for high speed trains in a tunnel.A lot of effort has been dedicated on implementing a channel model for LTE-R under high speed railway conditions, but not much focus is given on tunnel channel modelling. In [5], [6] and [7] measurements and studies has been carried out but they are not focussing on LTE-R. In this paper we are solely focusing on LTE-R for high speed trains in a tunnel. The development of a reliable wireless network is still an an emerging technology. Creating a dependable network for cellular use on high speed railways faces many additional challenges that normal cellular networks do not face. Another challenge that occurs is larger doppler shift.

Creating a dependable network for cellular use on high speed railways faces many additional challenges that normal cellular networks do not face. Additionally trains will frequently travel through tunnels or underground which causes even more challenges for a communication system. The main root of the challenges is a result of the high speeds of the trains which can range from 350 km/h up to 431 km/h. One challenge that has to be tackled is a way to handle frequent base station handovers, which can occur frequently as every 20 seconds. Another challenge that occurs is larger doppler shifting and spreading. Lastly the HSR channels are extremely time variant which make channel estimation and modeling exceptionally challenging.

In this paper, we propose a channel model for high speed trains in a tunnel environment with the use of leaky feeders. We then derive the mathematical performance analysis of the system followed up with simulated results.Additionally trains will frequently travel through tunnels or underground which causes even more challenges for a communication system. From our research in HSR communication system, there has not been any performance analysis of HSR within tunnels. This project will focus on evaluating performance of high speed railway communication systems when traveling in a tunnel.

The contents of this paper are organized as follows. In section II, we present our proposed system and channel models. In section III, we provide a mathematical derivation of the probability of error. In section IV, we our simulation results to verify our simulated results. Lastly we present our conclusion of our analysis of HSR in Section V.

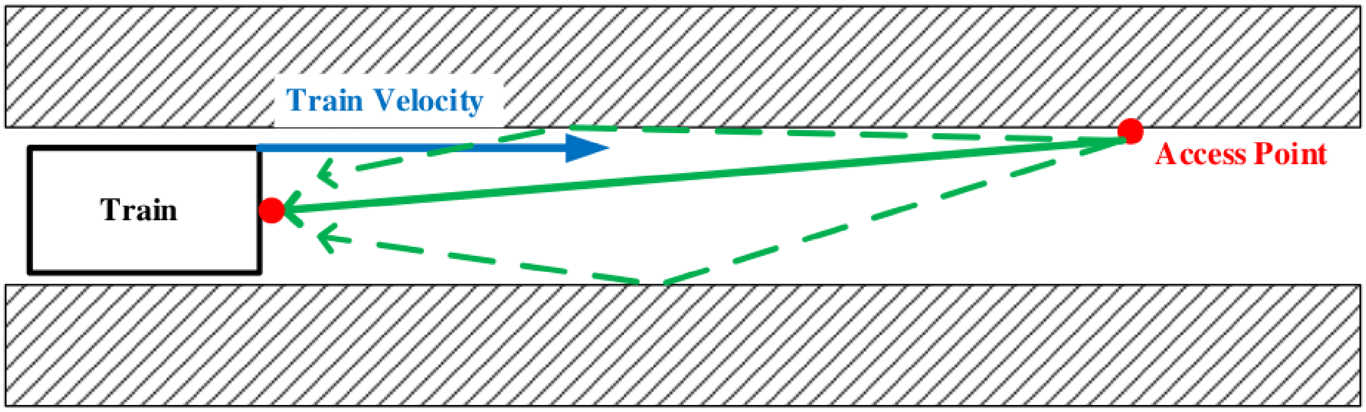

Fig. 1. High Speed Train in a Tunnel

TABLE I
BASIC PARAMETERS DEFINED IN LTE

Channel Coding	Turbo Codes with CRC
Channel Bandwidth	1.4MHz,3MHz,5MHz,10MHz,15MHz,20MHz
Modulation	QPSK,16QAM,64QAM
Multiple Access	OFDMA,SC-FDMA
MIMO	1x2,1x4,2x2,4x2,4x4
Latency	End-User Latency less than 10ms
Coverage	5-100 Kms

II. SYSTEM MODEL

In order to do the performance analysis of LTE-R, we need a realistic high speed railway channel model with multipath propagation characteristics. The WINNER II channel model [2] and 3GPP[SCM] [3] are two models which well be using in our project to come up with a channel model for trains in a tunnel. The WINNER II channel model has 12 different scenarios for various environments. We will be using D2 scenario for moving networks with multipath fading. The 3GPP Spatial Channel Model for high speed railways takes into consideration the Doppler shift in the channel. They have provided doppler shift for both open space and in a tunnel enviornment. Thus by using both these models we can realize a very good channel model for high speed railways with speed over 350 Km/hr. We have divided this section into 3 parts, 1st part deals with WINNER II channel model and 2nd part focuses on doppler shift profile of 3GPP[SCM] channel model. And lastly we explain in details our high speed railway channel model which encompasses both the channel models.

A. Winner II Channel Model

The goal of WINNER is to develop a single ubiquitous radio access system adaptable to a comprehensive range of mobile communication scenarios from short range to wide area. This will be based on a single radio access technology with enhanced capabilities compared to existing systems or their evolutions [2].In WINNER II channel model we will be focusing on D2 scenario which deals with high speed moving networks in rural areas. The model uses two data links, D2a for transmission between base station and moving relay node and D2b for transmission between MRS and user equipment. The Winner II channel model provides a very detailed measurement and analysis of large scale fading for moving networks. They haven't carried out any measurements in a tunnel, but have provided enough analysis that one can come up with a good estimate for channel model in a tunnel. The fig. 2 shows the power delay profile for moving networks for D2a network and the velocity of train is taken as 350km/hr.

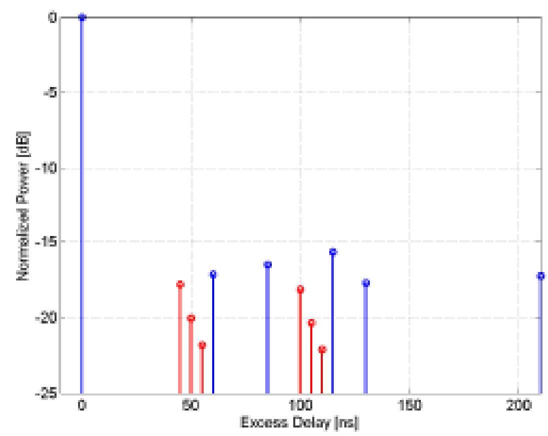

Fig. 2. Power Delay Profile for Moving Networks

B. 3GPP Spatial Channel Model

The 3GPP channel model is used for its Doppler shift profile in high speed railway environment. The measurements taken for Doppler frequency shift are implemented for 2 scenarios. Scenario 1 is for open space and scenario 3 is for tunnels using multiple antennas. There is also a Scenario 2 for high speed trains but that doesnt take Doppler shift into consideration. The doppler shift variation $f_s(t)$ is described by the equations below. The fig.3 shows the doppler shift profile as given in the channel model. The maximum doppler frequency is 1350Hz and it changes from the maximum positive value to the maximum negative value. The equation given below describes the doppler shift:

$$f_s(t) = f_d \cos\theta(t) \quad (1)$$

where f_d is max frequency and $\cos\theta(t)$ is defined below.

$$\cos\theta(t) = \frac{\frac{D_s}{2} - vt}{\sqrt{D_{min}^2 + ((\frac{D_s}{2}) - vt)^2}}, 0 \leq t \leq \frac{D_s}{v} \quad (2)$$

$$\cos\theta(t) = \frac{-1.5D_s + vt}{\sqrt{D_{min}^2 + (-1.5D_s + vt)^2}}, \frac{D_s}{v} \leq t \leq \frac{2D_s}{v} \quad (3)$$

$$\cos\theta(t) = \cos\theta(tmod(\frac{2D_s}{v})), t \geq \frac{2D_s}{v} \quad (4)$$

$D_s/2$ is initial distance of train from BS.
D_{min} is BS-Railway track distance
v is velocity of train in mps.

C. Channel Model For HSTs in a Tunnel

We are doing performance analysis of high speed trains in a tunnel by breaking the channel model into small scale fading and large scale fading. The equation given below describes the time-variant channel model:

$$H(t,\tau) = \sum_{i=1}^{L} \alpha_i(t).\delta(t - \tau_i(t)) \quad (5)$$

where $\alpha_i(t)$ is a complex amplitude which consists of small scale and large scale fading parameters.

$$\alpha_i(t) = \alpha_l(t) \times \alpha_s(t) \quad (6)$$

where $\alpha_l(t)$ is the large scale fading parameter and $\alpha_s(t)$ is small scale fading parameter.

In [4] it is shown that the large scale fading model describes the large scale variations which includes shadow fading and path-loss, whereas small scale fading consists of multipath fading. Since we are evaluating the performance in a tunnel, the line-of-sight(LOS) is the dominant component and hence the fading is best described by Ricean fading model.

III. Error Performance Analysis

This section is divided into 2 parts, 1st part deals with the probability of error for QPSK,16QAM modulation schemes under ricean fading which is small scale fading model. And in 2nd part we do the analysis of large scale fading model, and based on measurements of WINNER II model we can get a good estimate of α_l. we will be deriving the closed form solution for theoretical probability of error for QPSK and 16QAM modulation schemes. LTE uses QPSK, 16QAM and 64QAM for data communication, so in this paper we will be leaving out 64QAM. If one wants to derive probability of error for 64QAM, one can build upon the work in [8].

A. Small Scale Fading Model

We start we probability of error of QPSK under AWGN channel

$$P_b = Q(\sqrt{2x}) \quad (7)$$

where x is Signal-to-noise(SNR) ratio. Now as we have already established that in a tunnel the small scale fading channel can be estimated by ricean multipath fading model. So, lets derive the probability of error for QPSK under ricean fading channel. Let α_s be the small scale fading parameter,

$$P_b = Q(\sqrt{2\alpha_s^2 x}) \quad (8)$$

Now to calculate the probability of error we need to average out the α_s .

$$P_b(x) = \int_0^\infty Q(\sqrt{2x})p(x)dY \quad (9)$$

where $p(x)$ is ricean pdf and is given by the equation below.

$$p_{\bar{Y}_b}(x) = \frac{(1+K)}{\bar{Y}_b} e^{-K} I_o(\sqrt{\frac{4K(1+K)x}{\bar{Y}_b}}) e^{-\frac{(1+K)x}{\bar{Y}_b}} \quad (10)$$

$\bar{Y}_b$ is the average SNR and is given by

$$\bar{Y}_b = \frac{E_b}{N_o} \times E(\alpha_s^2) \quad (11)$$

For simplifying the mathematical analysis we'll be assuming the mean as unity. The average probability of error is given by the equation below as,

$$P_b(x) = \int_0^\infty Q(\sqrt{2x}) \frac{1+K}{\bar{Y}_b} I_o(\sqrt{\frac{4K(1+K)}{\bar{Y}_b}}) e^{-\frac{(1+K)x}{\bar{Y}_b}} \quad (12)$$

Now the closed form solution is derived in [8] and is given by

$$\bar{P}_e = \int_0^{\frac{\pi}{2}} \frac{e^-K}{\pi} \frac{(1+K)\cos^2\theta}{(1+K)\cos^2\theta + \bar{Y}_b} e^{-\frac{K(1+K)\cos^2\theta}{(1+K)\cos^2\theta + \bar{Y}_b}} d\theta \quad (13)$$

Similarly we can drive the P_e for 16QAM. Below are steps to calculate P_e for 16QAM. The probability of error for AWGN channel is given as

$$P_b = \frac{3}{4} Q(\sqrt{\frac{4x}{5}}) \quad (14)$$

Following the similar steps as we did for QPSK, the final equation can given as

$$P_b(x) = \int_0^\infty \frac{3}{4} Q(\sqrt{\frac{4x}{5}}) \frac{1+K}{\bar{Y}_b} I_o(\sqrt{\frac{4K(1+K)}{\bar{Y}_b}}) e^{-\frac{(1+K)x}{\bar{Y}_b}} \quad (15)$$

And P_e for 16QAM is given by

$$\bar{P}_e = \int_0^{\frac{\pi}{2}} \frac{e^-K}{\pi} \frac{(1+K)\cos^2\theta}{(1+K)\cos^2\theta + \bar{Y}_b} e^{-\frac{K(1+K)\cos^2\theta}{(1+K)\cos^2\theta + \bar{Y}_b}} d\theta \quad (16)$$

TABLE II
LOS CLUSTERED DELAY LINE MODEL FOR D2 NETWORK

Cluster	Delay[ns]	Power[dB]	AoD[^{o}]	AoA[^{o}]	Ray power[dB]
1	0	0.0	0.0	0.0	-0.12^{*} -28.8^{**}
2	45 50 55	-17.8 -20.1 -21.8	12.7	-80.0	-27.8
3	60	-17.2	-13.6	86.0	-30.2
4	85	-16.5	13.4	84.4	-29.5
5	100 105 110	-18.1 -20.4 -22.1	-13.9	87.5	-28.1
6	115	-15.7	-13.0	-82.2	-28.7
7	0	0.0	0.0	0.0	-30.8
8	210	-17.3	13.7	86.2	-30.3

* Power of dominant ray, ** Power of scatterer ray.

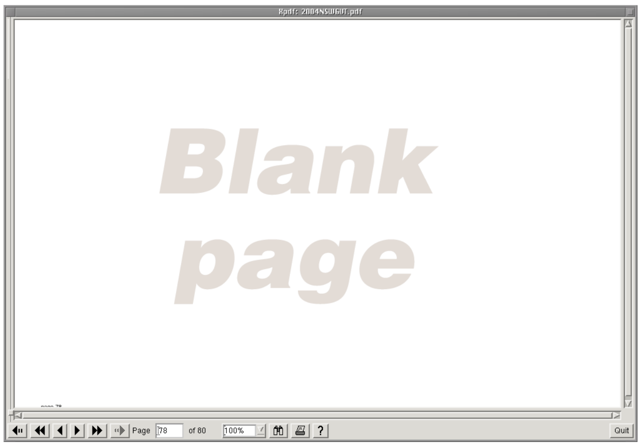

Fig. 3. Path Loss in a tunnel

B. Large Scale Fading Model

The large scale fading model plays an important role in a tunnel channel modelling. Depending on the path-loss and shadowing factor a proper channel estimation can be done. In this section we'll take a look at various parameters defined by WINNER II model.

The below table shows the LOS Clustered delay line model for MRS-MS in high speed train.

$$\alpha_l(t) = 10^{\frac{40log(v\times t)+10.5-18.5log(h_{BS})-18.5log(h_{MS})+1.5log(f_c/5)}{10}} \tag{17}$$

The equation above gives the large scale fading parameters where v is the velocity of train in mps, h_{MS} is the height of train and MRS, h_{BS} is the height of leeky feeder cable lines and f_c is the centre frequency.

Assuming v=350km/hr, h_{MS}=1.5m,h_{BS}=5m. The large scale fading profile can be generated by substituting the given values into above equation. ort, we broke it down into the five sections. For the next two weeks we will be completing the introduction and background sections of the paper. Starting April 3rd to April 14th we will be writing the proposed channel section of the paper. From April 14th April 23rd will write the performance analysis section of the paper. Lastly from April 24th to April 30th we will write the conclusion, giving us the final weekend for editing the paper.

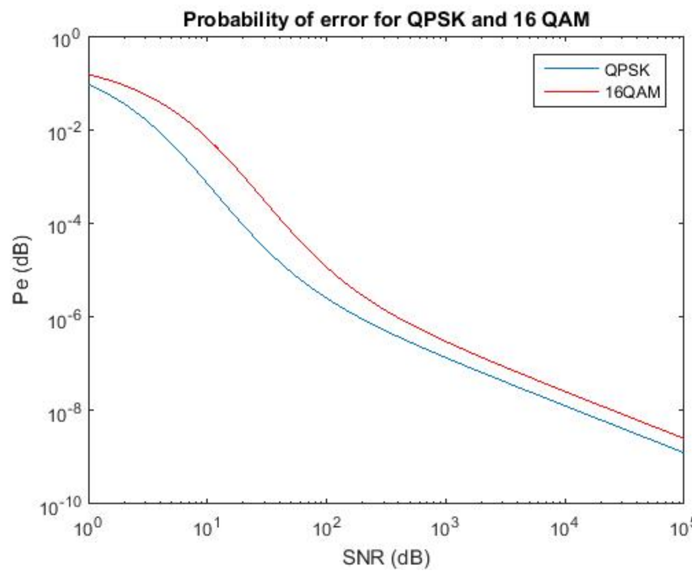

Fig. 4. BER Vs SNR(dB) for QPSK and 16QAM

IV. SIMULATIONS AND RESULTS

We have carried out the computer simulations in matlab to verify our theoretical results. In this section we provide the simulation results for high speed trains in a tunnel. We have analyzed the SNR(db) vs BER for both QPSK and 16QAM. With OFDM and MIMO better results can be achieved, but they are not studied in this paper.

V. CONCLUSION

To complete this project we broke it up into the performance analysis and the report. For the remainder of the current week will be finishing up our proposed channel model for HSR in tunnels. Starting next week and until April 16th we will be calculating the probability of error. We start by first determining the upper and lower bounds in the first week and then calculating the actual probability of error for the following two weeks. Starting the week of April 10th we will also be starting our Matlab simulation to verify the probability of error. This will overlap with our calculation of the probability of error so that we could have some breathing room for the last week of classes.

REFERENCES

[1] LTE/SAE -The Future Railway Mobile Radio System? Long-Term Visions on Railway 14.09.2009.

[2] IST-4- 027756 WINNER II D1.1.2 V1.0 WINNER II Channel Models,2007.

[3] 3rd Generation Partnership Project; technical specification group radio access network;spatial channel model for MIMO simulations, 3GPP TR 25.996 V6.1.0,2003

[4] Ke Guan, Zhangdui Zhong and Bo Ai, "Assessment of LTE-R using High Speed Railway Channel Model", IEEE 2011,p.462.

[5] J.-M. Molina-Garcia-Pardo, M.Lienard, A.Nasr and P.Degauque, "Wide-band Analysis of Large Scale and Small Scale Fading in Tunnels", IEEE 2008.

[6] A. Hrovat, G. Kandus and T. Javornik, "Four-slope channel model for path loss prediction in tunnels at 400 MHz, Microwaves, Antennas & Propagation", IET.vol.4,Issue:5, pp:571-582,2010.

[7] Ruisi He, Zhangdui Zhong and Cesar Briso, Broadband Channel Long Delay Cluster Measurements and Analysis at 2.4GHz in Subway Tunnels, IEEE 2011.

[8] Mahrokh G. Shayesteh and Abbas Aghamohammadi,"On the Error Probability of Linearly Modulated Signals on Frequency-Flat Ricean, Rayleigh, and AWGN Channels", ITC.vol.43, pp:1454-1466, 1995.

[9] D. G. Dudley, M. Lienard, S. F. Mahmoud and P. Degauque, Wireless Propagation in Tunnels, IEEE Antenna and Propagation Magazine, vol. 49, no. 2, pp. 11-26, April 2007.

[10] P. Delogne, Leaky Feeders and Subsurface Radio Communications, Stevenage, Herts; New York: P. Peregrinus, August 1982

[11] C. Cerasoli, RF Propagation in Tunnel Environments, In Proceedings of IEEE Military Communications Conference, 2004 - MILCOM 2004, vol. 1, pp. 363- 369, November 2004.

[12] Ruisi He, Zhangdui Zhong and Bo Ai, Path loss measurements and analysis for high-speed railway viaduct scene, IWCMC2010-Proceedings of the 6th International Wireless Communications and Mobile Computing Conference, p 266-270, 2010.

[13] Jose-Maria Molina-Garcia-Pardo,Jos-Victor Rodrguez and Leandro Juan-Llcer, Wide-band measurements and characterization at 2.1ghz while entering in a small tunnel, IEEE Transactions on Vehicular Technology, vol. 53, no. 6, November 2004.