Path Loss Model Considering Doppler Shift for High Speed Railroad Communication

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Abstract— **In this paper, we propose the tuned free-space path loss modelling in high speed railroad considering Doppler effect. We use tuned free space path loss model which is utilized for measurement results at high speed railroad. The environment of high speed rail is mostly at viaduct and flatland over than 50 percent. The purpose of this paper is analyzing Doppler shift effect at viaduct and plain by using modified path loss model. Simulation results show that proposed path loss model considering estimated Doppler shift coincides with the free space loss model.**

Keywords— **Path loss, high speed railroad, Doppler shift, free space, propagation.**

I. Introduction

The demand for wireless communication consistently increases in high-speed mobile environment due to the development of high-speed railroad. It is important to provide better link quality be caused by the train's speed up and data rate increase. Beam-forming technique can be used widely in order to provide link quality as enhancing the strength of the transmitted signal or as reducing interference signal. But, getting the channel state information at base station is difficult, when high speed railroad communication uses beam-forming technique. Therefore, path loss model is very important in order to design consider diverse characteristic in high-speed train communication.

There are many models for analysing the path loss model nevertheless any path loss model can not apply to comprehensive. There have been studies on path loss between transmitter and receiver at urban and suburban environment [1-2]. However, there are few researches about path loss at viaduct and plain. But, path loss model is very important in the design of high-speed rail communication system, it is necessary to analyse accurately the Doppler shift effect.

There are a various path loss modelling methods such as using Ray tracing [3], concrete morphological and using building data [4], and previous model adding average residuals [5]. But, reference [5] has path loss exponent and actually path loss exponent is affected by obstacles between transmitter and receiver [6]. The Doppler effect is generated largely at high speed railroad. Therefore, there are needs to research about path loss modelling considering the Doppler effect.

In this paper, we propose tuned free path loss model considering Doppler shift at viaduct and plain in high-speed train environment. We confirm that there is almost no error between estimated model and tuned free space path loss model.

II. Measurement Environment

Path loss information is measured at train for path loss modelling of high speed railroad. Hence, maximum velocity of train is 340km/h. The flat land and viaduct have similar transfer characteristics because of low fluctuation. Measurement distances at viaduct and at flatland are 3km and 1.793km. Test frequency of railway network is downlink frequency with 200 KHz bandwidth from 930.2 MHz to 933.4 MHz range. Transmitting antenna on the line has 17dBi gain of beam which is the cross polarized 60° horizontal and 6.8° vertical beam width. Hence, antenna transmit power is 43dBm, and omni-direction receiver antenna is located 3.5m high above the train.

III. Tuned Free-Space Path Loss Model

Free-space path loss is calculated based on the following

$$L_0(dB) = 32.45 + 20\times\log_{10}(d) + 20\times\log_{10}(f) \quad (1)$$

where d is distance (km) between transmitter and receiver, f is carrier frequency (MHz). Path loss through measured data is calculated using the following equation

$$L_m = P_t + G_b - l_b - l_d - P_r \quad (2)$$

where P_r is $43dBm$ as receiver power and P_t is $43dBm$ as transmission power. G_b is $17dBi$ as transmitter antenna gain, l_b is a feeder loss at base band, l_d is as power divider. The difference between free-space and the measured path loss is given by

$$\triangle L = L_m - L_0 \quad (3)$$

Path loss is linearly proportional in log domain. Distance between the receiver and base station is only changed at each time. Therefore, tuned equation is defined as

$$\triangle L = K_1 \log_{10} d + K_2 \quad (4)$$

where K_1 is parameter about distance and K_2 is constant. Two parameters can be obtained by the Least-square criterion.

K_1 and K_2 are applied median value in [7]. The finally value is obtained as $K_1 = 6.26, K_2 = 9.855$ and

$K_1 = 14.19, K_2 = 12.72$ at viaduct and plain. Therefore, tuned free space path loss model at viaduct and plain can be expressed as

$$L = \triangle L + L_0 \tag{5}$$

$$L_{via} = 42.305 + 26.26 \times \log_{10}(d) + 20 \times \log_{10}(f) \tag{6}$$

$$L_{pla} = 46.17 + 34.19 \times \log_{10}(d) + 20 \times \log_{10}(f) \tag{7}$$

IV. Estimation Model Considering Doppler Shift

Variation the reception frequency is generated by Doppler effect due to movement of transmitter and receiver.

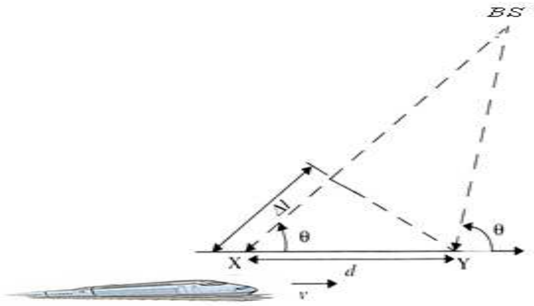

Figure 1. Doppler shift effct.

Doppler shift effect is related to the velocity of mobile device and angle between reception radio wave and the moving direction in figure 1. If variation of received frequency occurs, it is possible as variation factor of carrier frequency recognize as a loss of received signal without compensation for Doppler effect.

When train with v velocity moves from X to Y, difference of paths $\triangle l$ is defined as

$$\Delta l = d\cos\theta = v\Delta t\cos\theta \tag{8}$$

where θ is incoming angle between base station and trans. Phase change $\triangle\varphi$ is given by

$$\Delta\varphi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi\Delta t}{\lambda}\cos\theta \tag{9}$$

Therefore, frequency variation by Doppler effect can be expressed as

$$f_d = \frac{1}{2\pi}\frac{\triangle\phi}{\triangle t} = \frac{v}{\lambda}\cos\theta = v\frac{f_c}{c}\cos\theta \tag{10}$$

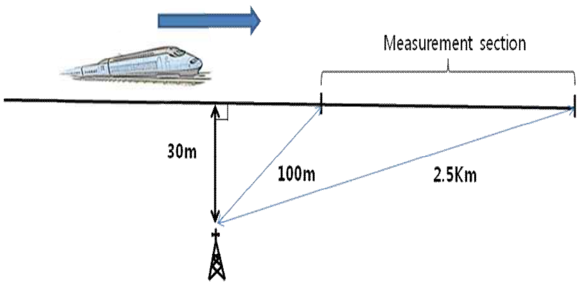

Figure 2. Simulation condition.

Fig. 2 shows simulation environment for estimation model considering Doppler shift. In this paper, we assume distance between base station and the rail is 30m. Also, we measure at 100m unit from 100m to 2.5km about distance from base station to train in order to improve reliability of results. Therefore, we estimate novel estimation model with minimum error between estimated novel path loss model values and tuned path loss model values. Carrier frequency f_c is 930MHz and maximum velocity of trains is 340Km/h (=94.4m/s).

High speed train's channel model is changed by location of transceiver, the height of the viaduct, and antenna location. We can estimate free space path loss model of viaduct and plain considering these points. But there are the difference between the free-space path loss and the measurement values. We confirm that these two models have difference at measurement range of simulation environment in figure 3. Therefore, tuned free space model is need.

Tuned path loss model represents the sum form of median values of measurement values at existing free space path loss model. Residuals have $K_1 \times \log_{10}(d) + K_2$ form, K_1 and K_2 are obtained through measurement results.

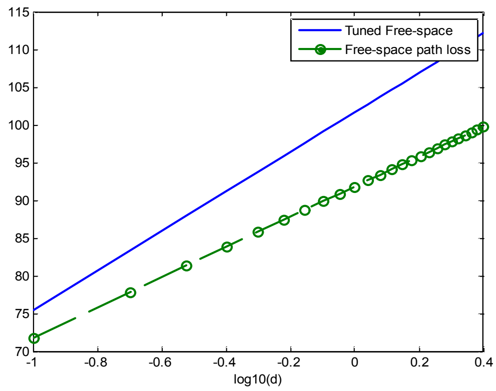

Figure 3. Tuned Free space model and path loss model at viaduct.

This paper, novel tuned path loss model considering Doppler shift effect can be expressed as

$$L = K_1 \times \log_{10}(f_d) + K_2 \times \log_{10}(d) + K_3 + \underbrace{32.45 + 20 \times \log_{10}(d) + 20 \times \log_{10}(f)}_{Free-space\ path\ loss\ model} \tag{11}$$

where frequency change occurs due to Doppler shift.

In order to determine parameters K_1, K_2 and K_3, we select optimum values with the minimum error between tuned path loss model and measured data, where step size is 0.1. The final parameters at viaduct and at plain represents as

$$K_1 = 6.2,\ K_2 = 12.5,\ K_3 = 4.0\ in\ Viaduct \tag{12}$$

$$K_1 = 5.0,\ K_2 = 19.2,\ K_3 = 9.0\ in\ Plain \tag{13}$$

The estimated path loss model considering Doppler shift can be expressed as

$$L_{via} = 6.2 \times \log_{10}(f_d) + 32.5 \times \log_{10}(d) + 20 \times \log_{10}(f) \tag{14}$$

$$L_{pla} = 5.0 \times \log_{10}(f_d) + 39.2 \times \log_{10}(d) + 20 \times \log_{10}(f) + 41.45 \tag{15}$$

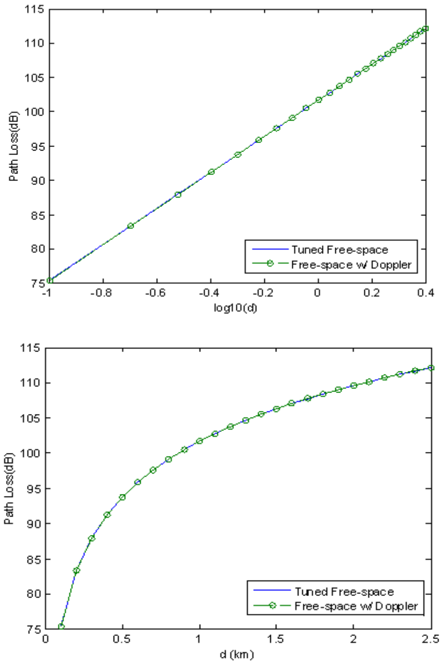

Figure 4. Comparison of the path loss of tuned Free-space model and Free-space model with Doppler shift in Viaduct.

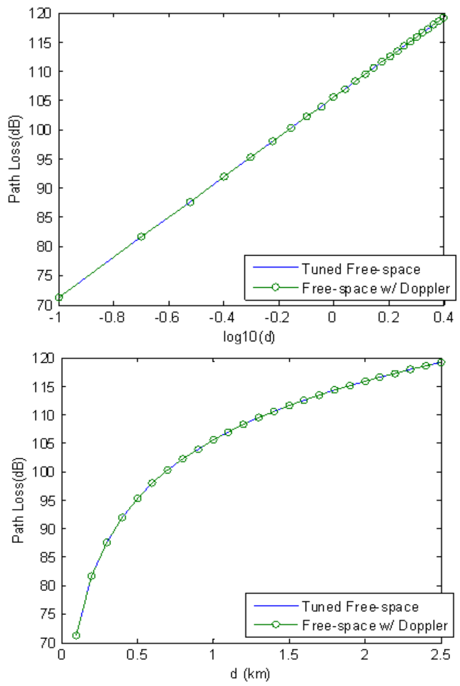

Figure 5. Comparison of the path loss of tuned Free-space model and Free-space model with Doppler shift in Plain.

Fig. 4 and Fig. 5 show difference of reference [7] and proposed path loss consider Doppler shift at viaduct and plain respectively. Simulation results shows that the proposed path loss estimation model is generally accurate compare to previous schemes.

V. Conclusion

In this paper, we investigate the propagation model considering Doppler effect by using measured data of high speed railroad at viaduct and plain in the free space. We confirm that the estimated model is almost similar the tuned free space path loss model. However, the influence of path loss model due to Doppler shift is very small actually. In the future work, we consider more variety of environments for accurate estimation of path loss model in high speed railroad.

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