Radio Propagation Simulation and Measurement Inside a Curved and Sloped Subway Tunnel

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Abstract – **For the introduction of CBTC systems to subways, there is a demand to understand the radio propagation characteristics inside tunnels in order to properly design base station intervals. Propagation loss from measurements and ray launching simulations at 2.5 GHz were compared. Simulations were done for curved and sloped tunnels with rectangular and 8-sided cross sections, and straight tunnel with rectangular cross section. It was found that all propagation loss simulation errors are within 10 dB and the tunnel model which included curves and slopes with rectangular cross section gives the smallest error of 4.9 dB.**

Index Terms — **Radio propagation, ray launching, tunnel propagation, railway signaling.**

1. Introduction

In railway networks, there is increasing expectation for train control systems using wireless communications such as the Communications-Based Train Control (CBTC) system [1]. As compared to traditional systems, CBTC is believed to be advantageous in terms of maintenance of field equipment. On the other hand, there is dissatisfaction in terms of the communication speed. To remedy this, CBTC based on IEEE 802.11 are being implemented to take advantage of the speed of IEEE 802.11. One disadvantage though, is the interference from mobile Wi-Fi routers which uses the same frequency [2].

In the future, demand for mobile communications is expected to increase. To properly design CBTC systems, appropriate estimation of interference and signal coverage are important. Measurements can be done but this can be expensive as the measurements increase. Another approach is to use simulations. The authors have compared simulations for straight tunnels using FDTD and ray tracing methods [3]. In this paper, propagation loss inside a curved and sloped subway tunnel taken from measurements and simulations using ray launching are compared.

2. On-Site Measurement

Radio propagation measurements were conducted inside a subway tunnel in Harbin City, China. This tunnel is still under construction and therefore it is not yet open to the public and there are no additional equipment. Because of this, propagation effects only from the tunnel can be measured.

The tunnel cross section is shaped like a horseshoe as shown in Fig. 1(a). Looking from the top, the tunnel is curved as shown in Fig. 1(b). Furthermore, the tunnel height gradually slopes down by around 7 m in the middle and then slopes up again by around 8.2 m at the other side as shown in Fig. 1(c).

Measurements were conducted at 2.5 GHz in a 1200 m section at a walking speed of 1 m/s, with the transmitter (Tx) located at 3 m from the ground, and the receiver (Rx) located at 2 m from the ground. Both Tx and Rx are positioned at the center of the cross section of the tunnel. The IQ function of a real-time spectrum analyzer was used to record the received level. To verify the locations, the time record at every 100 m of Rx is checked. Around 180 m from Tx, there is no more line-of-sight (LoS). The rest of the measurement parameters are listed in Table I.

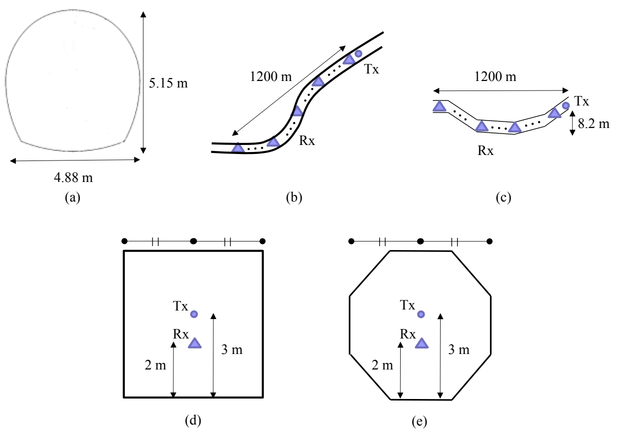

Fig. 1. (a) Actual tunnel cross section. (b) Top view of tunnel with location of Tx and Rx. (c) Side view of tunnel. (d) Rectangular cross section and (e) 8-sided cross section used in simulation.

TABLE I
Measurement and Simulation Parameters

Description	Value
Center frequency	2.5 GHz
Transmitter signal	Unmodulated carrier
Transmitter power	10 dBm
Antennas	Half-wave dipole
Polarization	Vertical
Measurement distance	1200 m
Ray launching simulation parameters	20 maximum reflections
	0.05 degree ray spacing
	1 m receiver spacing
	Concrete material (relative permittivity: 6.2, conductivity: 0.069 S/m, thickness: 0.2 m)

3. Simulations using Ray Launching

Ray launching is one of the typical methods used to simulate tunnels [4]. In our work, we used a commercial ray tracing software [5] and simulated 4 models. Among these 4 models, 2 are curved and sloped tunnels with rectangular cross section as shown in Fig. 1(d) and another one with 8-sided cross section as shown in Fig. 1(e). The other 2 models are straight tunnels with rectangular cross section, one with LoS results, and another one taking out the LoS results to account for the non-LoS (NLoS) locations. The reason for making 4 models is to check how much one needs to model the tunnel to get comparable results with measurement.

The simulation parameters are shown in Table I. 20 maximum reflections were set to ensure results exist at NLoS locations far from Tx. Each model takes around 1 hr to finish in a core i7 computer.

4. Analysis of Results

Fig. 2 shows the moving median of propagation loss versus the distance travelled from Tx. The length of moving median used is 100 wavelengths equivalent to 12 meters at 2.5 GHz. For comparison, the free space propagation loss is also included in the figure.

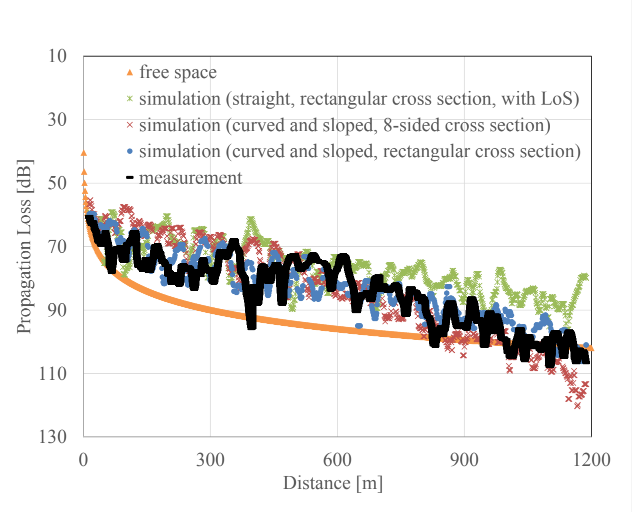

Fig. 2. Measurement and simulation results.

The results from the straight tunnel taking out the LoS results is not included in Fig. 2, because the results did not vary much with the straight tunnel with LoS results for distances greater than 100 m. This is because the reflections have greater contributions than the LoS path at distances greater than 100 m. Table II lists down the corresponding errors of each model with respect to the measurement. The error is defined as the average of the absolute difference between medians of simulation and measurement for every 100 wavelength.

From Fig. 2 and Table II, the curved and sloped model with rectangular cross section (blue dot) gives the least error of 4.9 dB. The error of the other models are within 10 dB. The straight tunnel results (green *) predict a higher propagation loss especially on distances greater than 600 m. This suggests that modeling the curve and slope portions of the tunnel when doing simulation give more accurate results. On the other hand, the curved and sloped model with 8-sided cross section (red x) predicts a higher propagation loss before 500 m. This suggests that a rectangular cross section is enough to represent the horseshoe shape of the actual tunnel.

TABLE II
Errors of Simulation Model

Simulation Model	**Error [dB]**
Straight, rectangular cross section, with LoS result (green *)	9.2
Straight, rectangular cross section, without LoS result	9.3
Curved and sloped, 8-sided cross section (red x)	6.8
Curved and sloped, rectangular cross section (blue dot)	4.9

5. Conclusion

Radio propagation measurements were performed inside a curved and sloped subway tunnel. Moreover, ray launching simulations with up to 20 reflections were done for curved and sloped tunnels with rectangular and 8-sided cross sections, and straight tunnel with rectangular cross section. It was found that all propagation loss simulation errors are within 10 dB and the tunnel model which included curves and slopes with rectangular cross section gives the smallest error of 4.9 dB. This suggests that a rectangular cross section is enough to represent the horseshoe shape of the actual tunnel.

This kind of accurate path loss simulation is very important to CBTC systems for the prediction of communication coverage. In the future, tunnels with structures and branches will be considered.

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