Modeling and Measurement of Wireless Channels for Underground Mines

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***Abstract*—This paper investigates wireless channel modeling for underground mines. The ray tracing and modal methods, which have been widely used for modeling radio propagation in tunnels, are applied to model wireless channels in underground mines. In addition, propagation measurements are taken in an underground hard rock mine at three different frequencies (455 MHz, 915 MHz, and 2.45 GHz). Simulation results based on the ray tracing and modal methods are compared to measurement results and show agreement. Challenges for modeling wireless channels in mines are discussed.**

I. INTRODUCTION

Understanding radio propagation in underground mines is critical for the design, deployment, and optimum performance of wireless systems in mining environments. Due to the complexity of the mining environments, statistics-based channel modeling methods are often employed to characterize wireless channels in underground mines [1-2]. While statistics-based channel modeling methods are useful, a deterministic channel model generally provides more physical insight into understanding the fundamental propagation mechanism and thus is preferred when available. In this paper, two deterministic channel modeling methods, the ray tracing and modal methods, are applied to model radio propagation in a hard rock mine. Measurement results taken in an underground silver mine are used to validate the modeling results.

II. DETERMINISTIC CHANNEL MODELING

A straight rectangular tunnel formed by four flat dielectric surfaces is considered. As shown in [3], for a given point source, the electrical field at an arbitrary point within the tunnel can be represented either by a summation of rays based on the ray tracing method, or by a summation of modes based on the modal method. The two methods have been shown to be accurate for modeling radio propagation in tunnels, for both vertically and horizontally polarized signals, at a variety of frequencies spanning from 455 MHz to 5.8 GHz [4]. The detailed mathematical formulations for the two methods can be found in [3] and thus will not be repeated in this paper.

III. MEASUREMENT

RF propagation measurements were performed in an underground silver mine shown in Fig. 1. The drift (i.e., the tunnel) selected for the measurements is relatively straight having approximate cross-sectional dimensions of 2.7 x 3.0 m (H x W) that vary along the drift axis. The ceiling, floor, and walls of the drift are comprised of rock with a significant amount of metal infrastructure present. A more detailed description of the environment and measurement setup can be found in [4].

Fig. 1. Radio propagation measurements in an underground silver mine

IV. SIMULATION SETUP

The ray tracing and modal methods introduced in [3] will be applied to model radio propagation in the silver mine where the propagation measurements were performed. The major parameters used for the simulations are given in table I.

Table I: Summary of the simulation's major parameters

Parameters	Value
Tunnel height	2.7 m
Tunnel width	3.0 m
Antenna height	1.22 m
Relative dielectric constant	30
Conductivity	0.01 S/m

V. RESULTS AND DISCUSSION

Fig. 2 shows a comparison of measured and simulated power attenuates along the drift axis at three different frequencies for vertically polarized signals. In each subfigure, the solid blue line is the measurement result, and the corresponding simulation results based on the ray and modal methods are represented by red and green lines, respectively. It is shown that simulation results at different frequencies match reasonably well with the measured results (<10% difference), with the exception of 455 MHz where the simulation gives an inflated power attenuation rate. This is most likely because the ray tracing and modal methods are analytical methods based on high-frequency approximations and thus are not accurate at low frequencies. In order to accurately compute modal attenuation rate at low frequencies, a new method based on numerically solving two complex equations derived from the boundary conditions has been investigated and the results published in [5].

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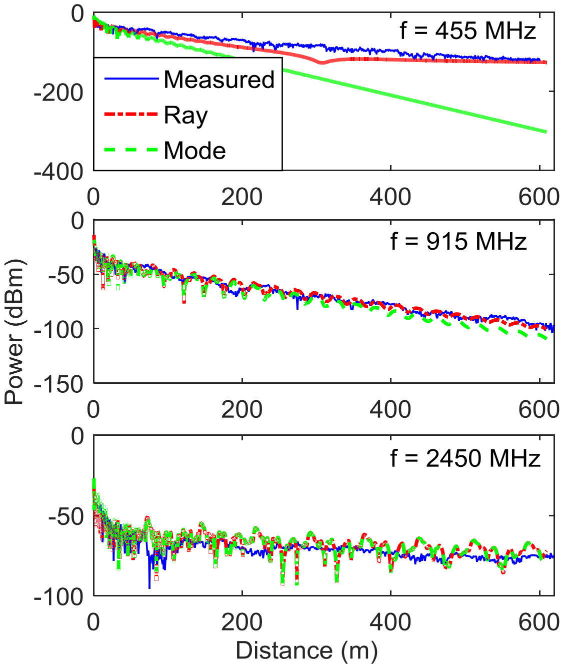

Fig. 2. A comparison of measured and simulated power attenuation along a silver mine drift at different frequencies.

Another observation from Fig. 2 is that the simulated results tend to show more short-term fast fluctuations as power decays with distance, while the measured results are "smoother" (less variation along the distance). It is known that these fast fluctuations are caused by multiple modes interacting with each other. The observation that the measured power decay profiles are smoother than the corresponding simulation results can be explained by the roughness effect investigated in [6]. It should be noted that for simplicity, surface roughness has not been considered in the simulated results shown in Fig. 2. Based on the analytical roughness model given in [6], simulations were revised by adding a Root Mean Square (RMS) roughness of 10 cm to each surface. A comparison of the simulation results with and without surface roughness at 2.45 GHz is shown in Fig. 3. It is evident from Fig. 3 that signals have less variation and are more heavily attenuated after the surface roughness is considered.

The results shown in Fig. 2 are for vertically polarized signals. Since the cross-sectional dimensions of the drift are approximately equal, the corresponding horizontal polarization results are very similar to those for vertical polarization and will not be shown here due to space limitations.

It should be noted that deterministically modeling radio propagation in complicated mining environments is challenging. One of the biggest challenges comes from the random variation of geometric dimensions which is common in underground mines. For example, it is shown in [4] that drift dimensions play a very important role in determining propagation behaviors. A small random variation of the dimensions might cause significant changes in propagation behavior.

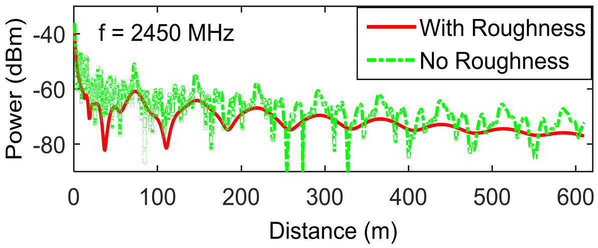

Fig. 3. A comparison of simulated power attenuations with and without surface roughness scenarios.

For results reported in this paper, both the transmitter and the receiver antennas were kept in the middle of the drift. We showed in [7] that the ray tracing and modal methods are also accurate when one or both of the antennas are off-center

VI. CONCLUSION

RF propagation measurements were conducted in an underground silver mine. Ray tracing and modal methods are shown to be valid for modeling radio propagation in mines. It is found that surface roughness present in typical mines introduces additional power attenuation as well a "smoothing" effect to radio signals. These effects should be considered in design and deployment of wireless systems in mines.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH).

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