Propagation Characteristics for Modern Wireless System Networks in Underground Mine Galleries

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Propagation Characteristics for Modern Wireless System Networks in Underground Mine Galleries

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ABSTRACT

The propagation characteristics of electromagnetic waves in mine tunnels with roughness sidewalls have been addressed. The simulation results obtained using the ray tracing technique have been compared with a new approach known as Cascade Impedances Method (CIM). The measurements referred to have been taken in a real mine at 900 MHz.

1. INTRODUCTION

Underground mine galleries can be considered as complex transmission lines in wich multipath, attenuation, reflection, diffraction and scattering effects are dominants [1-16]. However, some companies have started to deploy modern wireless system networks in mine galleries with the objective is to increase safety and production. Recent studies [17-19] have introduced the concept of geolocation using wireless sensor networks based on random and mesh topology and various hybrid networks [12], as potential ways to help increase the safety of workers underground. There is a real need to know how to characterize the environment where these wireless systems are being deployed. In this paper we are addressing the characterization of propagation using the ray tracing technique. The simulation results have been predicted in difficult boundary conditions of roughness sidewalls and reflection coefficients and they have been compared with a new approach called Cascade Impedances Method CIM [1],[9]. The measurements have been taken in a real mine at 900 MHz.

2. RAY- TRACING TECHNIQUE APPROACH

Figure 1 represents a non canonical mine segment with six access points linked in a random topology [17-19], and eight mobile transceivers positioned randomly in the mine corridor.The challenge is to characterize the received signal in a mobile system (A) taking into account, the reflection from the rough sidewalls, the diffraction and the scattering of the signal from the corners and from the obstacles. In addition to the ray tracing technique we use the geometry and uniform GTD/UTD theory of diffraction [20-21]. The received signal at the trans-receiver (A) in figure 1 is:

$$[S_A(r)] = [f(a_i, b_i)] \cdot f_o \cdot \left| \sum_{i=1}^{N=AP=6} \left(\frac{e^{-jkr_{d_i}}}{r_{d_i}} \right) + \right.$$

$$+ \sum_{i=1}^{AP=6} \left(\sum_{j=1}^{J} \left(\sum_{p=1}^{Walls=P=4} \left[R_{g_j}{}^{(p)}(h,v) \right] \left(\frac{1}{r_j} \right) \cdot \left[e^{-j\Delta\Phi_j} \right] \right) \right)_{(i)} +$$

$$+ \sum_{i=1}^{AP=6} \left(\sum_{k=1}^{K} \left(\sum_{p=1}^{walls=P} \left(\left[R_{g_k}{}^{(p)}(h,v) \right] \frac{1}{r_k} \left[e^{-j\Delta\Phi_k} \right] \right) \left(f(\sigma_{sk}) \right) \right) \right)_{(i)} +$$

$$+ \sum_{i=1}^{AP=6} \left(\sum_{m=1}^{M} \left(\sum_{p=1}^{walls=P} \left(\left[R_{g_m}{}^{(p)}(h,v) \right] \frac{1}{r_m} \left[e^{-j\Delta\Phi_m} \right] \right) \left(f(\sigma_{sm}) \right) \left(D_m \sqrt{\frac{\rho_m'}{\rho_m (\rho_m + \rho_m')}} \right) \right) \right)_{(i)} +$$

$$+\sum_{i=1}^{AP=6}\left(\sum_{v=1}^{V}\left(\sum_{p=1}^{walls=P}\left(\left[R_{g_v}^{(p)}(h,v)\right]\frac{1}{r_v}\left[e^{-j\Delta\Phi_v}\right]\right)\left(D_v\sqrt{\frac{\rho_v'}{\rho_v\left(\rho_v+\rho_v'\right)}}\right)\right)\right)_{(i)}+\sum_{i=1}^{AP=6}\left(\left(\sum_{n=1}^{N}\left[\,R_{g_n}(h,v)\,\right]+1\right)D_n\sqrt{\frac{\rho_n'}{\rho_n\left(\rho_n+\rho_n'\right)}}\,e^{-jk\rho_n}\right)_{(i)}\Bigg|^2 \quad (1)$$

($f(a_i,b_i)$ and $R_g(h,v)$) are respectively the function of random dimensions of the mine tunnel segment and the reflection coefficient of the rough surface[1]. D_n is the diffraction coefficient [20-21] and $f(\sigma_{sm})$ is the scattering coefficient [22-23].

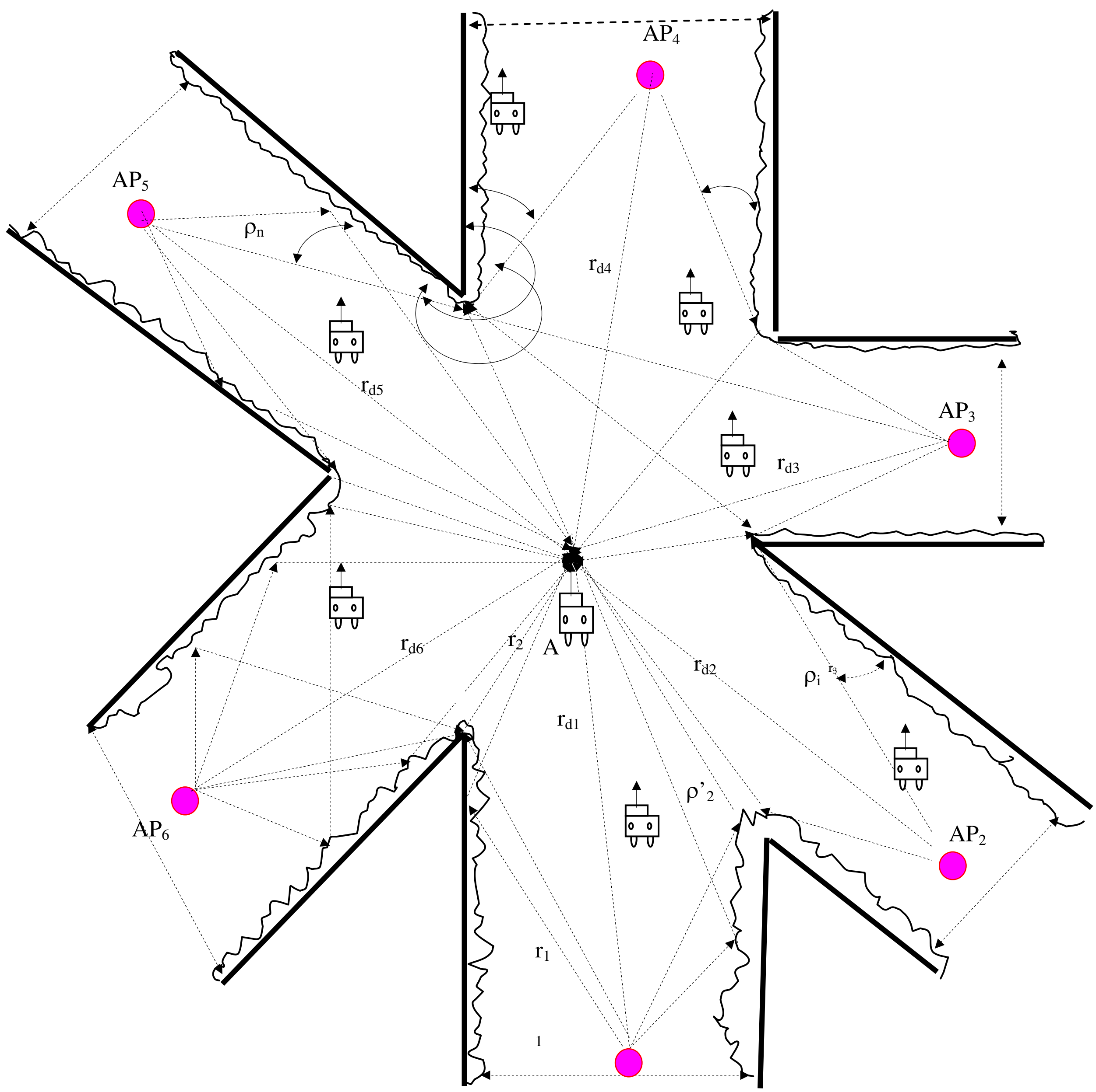

Figure 1: A non canonical segment with six access points in mesh topology

The first term of the equation (1) represents all the direct paths. The second term is the reflected components of the signal which will reach the trans-receiver (A) without involving scattering or diffracting phenomena. The third term represents all the reflected paths which will reach the trans-receiver (A) after scattering on the obstacles. The fourth term represents all the reflected paths which will reach the trans-receiver (A) after scattering and diffracting on the obstacles and rough corners of mine corridors. The fifth term represents all the components of the signal which will reach the trans-receiver (A) after involving the reflection and the diffraction from the rough side walls and diffraction on the corners.

3. RESULTS

Figure 2 represents the simulated rays inside a two dimensional mine segment with several rough sidewalls. This result confirmed that, depending on the form of the segment and the position of the transmitter, one can obtain many zones. In this particular case, there are three propagation zones (M,N,Q) and other zones (A,B,C,D, E, F,G,H,K) called zones of uncertainty or neutral zones. The importance of these zones has been given by [1-2],[9].

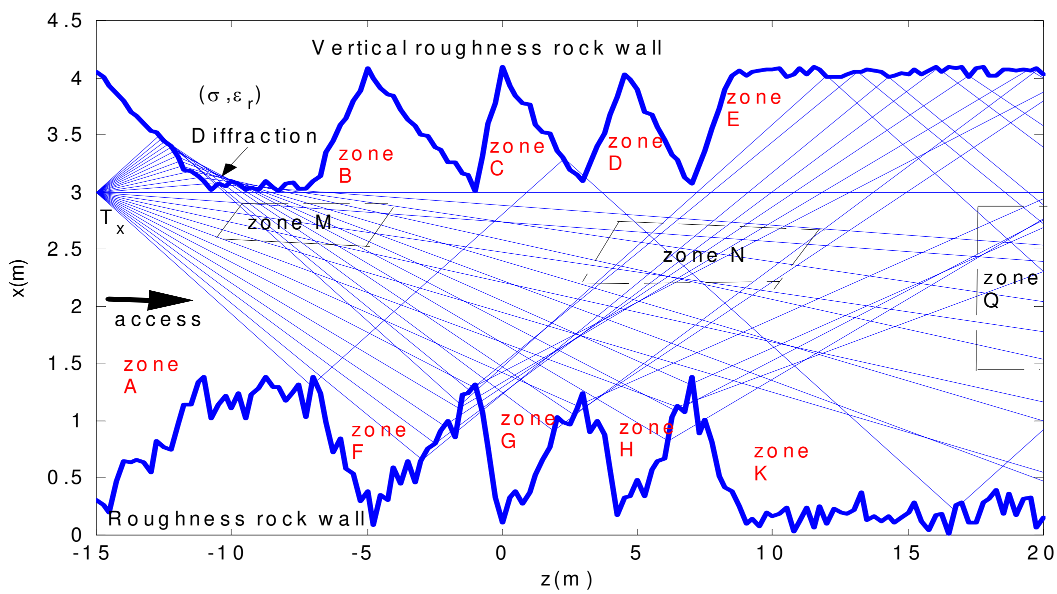

Figure 2. 2D simulated segment with rays.

Figure 3 illustrates predicted received power in a segment of tunnel mine at 900 MHz.

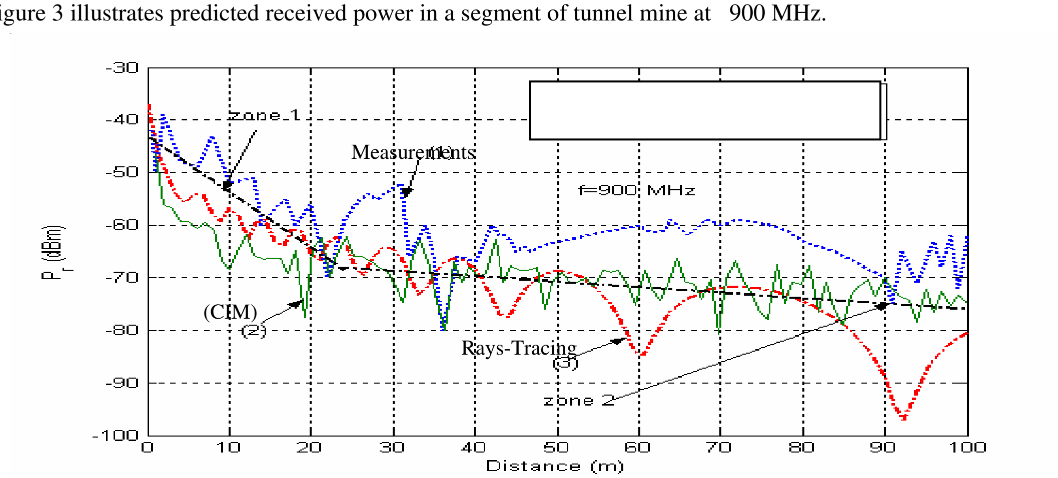

Figure 3: A 2 -D Comparison between simulations of both methods and measurements at 900 MHz.

4. CONCLUSION

In this paper, we characterized the radio waves propagation in a non standard mine segment using the Ray Tracing Approach. The efficiency of the model has been proven by the comparison of theoretical simulation with the Cascade Impedances Method (CIM), as well as measurements taken in a real mine segment at 900MHz. The results obtained in this study confirmed that the diffraction, reflection and multipath are dominant in complex rough mine corridors. However, wireless systems can be deployed by using advanced mesh or hybrid network architectures and topologies.

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