# MODELLING OF WAVE PROPAGATION IN ROUGH MINE TUNNELS

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## ABSTRACT

A new technique is applied to the modelization of radio waves propagation in mine tunnel having lossy dielectric side walls of random roughness. The resultant model takes into account the spatial variability of the electromagnetic waves in non canonical rough mine tunnels and makes use of the cascade impedance method (CIM) to predict the propagation behavior. Two (2-D) and three dimensional (3-D) propagation models were obtained and compared with experimental data.

## I. INTRODUCTION

In the last few years, several kinds of wireless communication systems and propagation models have been studied and used in many type of environments. The prediction of electromagnetic waves propagation in underground mines with canonical shapes, i.e. semi-circular or cylindrical has also been characterized using classical approaches such as ray-tracing techniques or geometrical theory of diffraction. However, this not the case for many mines that are diverging considerably from these canonical shapes. Evidences come immediately that any classical strategy will fail in a rigourous attempt to model the propagation characteristics in these environments for systems design. It is, however, a major issue since it is in those difficult environments where the use of modern technology, such as wireless LAN with radio-localization, appears to be of the utmost importance.

Our paper presentation will address the propagation problems of millimetric waves in this non-standard type of environments, using 2-D and 3-D propagation models. The models are developed using a new method that has been named the Cascade Impedances Method [1]. In order to be able to compare with the few available analytical or experimental results for waves propagation in highly diffractive media, the model takes in account the spatial variability of millimetric waves in the case of canonical and non canonical segment of mine tunnel. Using modern mapping techniques, a 2-D and 3-D representation of the fields that build up within the confined walls is obtained using a statistical model of the wall roughness. Our approach has been initially calibrated by modeling a classical rectangular waveguide with perfectly smoth side walls to establish a confidence level for the proposed method.

## II. THE MODEL

Recent investigations [1] have shown that in spite of the multiple reflections, diffraction and attenuation due to roughness and complexity of the mine tunnel, it can still be considered as a transmission line.

To characterize waves propagation inside a long non canonical mining tunnel, the method known as Segmental Statistical Method (SSM) [2] is applied. Using this method, the tunnel is divided into N segments. These are then resegmented into transversal and horizontal sections of (i,j) cells which can be assimilated to cascades impedances showing the necessary parameters to predict the ultimate performance of wireless transmission systems, such the roughness and reflexion coefficients.

For a mining tunnel segment walls (figure 1) of length *z*, variable heights $y_i$ and width $(a_i\ ,\ b_i)$ and a transmitter source S, the cascade method (CIM) yield the model of Figure 2

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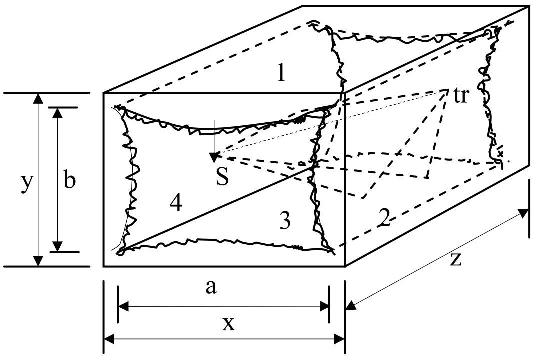


Figure1: Geometrical discrete representation of the mine

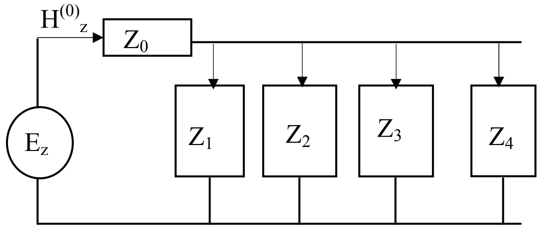


Figure 2: Impedance model

where the impedances of the walls are espressed as:

$$Z_1 = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} \cdot a \cdot z \cdot G_1(x,y,z)\ ,\quad Z_2 = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} \cdot b \cdot z \cdot G_2(x,y,z),$$

$$Z_3 = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} \cdot b \cdot z \cdot G_3(x,y,z)\ ,\quad Z_4 = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} \cdot b \cdot z \cdot G_4(x,y,z)\ , \tag{1}$$

and $G_1(x,y,z)$, $G_2(x,y,z)$, $G_3(x,y,z)$, $G_4(x,y,z)$, are Gaussian roughness functions and the equivalent impedance of the walls are espressed as:

$$Z_{eq} = Z_1 // Z_2 // Z_3 // Z_4 \tag{2}$$

The reflexion coefficients of the four walls are then expressed as:

$$|\Gamma_1| = \left|\frac{Z_1 - Z_0}{Z_1 + Z_0}\right| \ ,\quad |\Gamma_2| = \left|\frac{Z_2 - Z_0}{Z_2 + Z_0}\right| \ ,\quad |\Gamma_3| = \left|\frac{Z_3 - Z_0}{Z_3 + Z_0}\right| \ ,\quad |\Gamma_4| = \left|\frac{Z_4 - Z_0}{Z_4 + Z_0}\right| \tag{3}$$

and the equivalent reflexion and transmission coefficients are given by:

$$|\Gamma_{eq}| = \left|\frac{Z_{eq} - Z_0}{Z_{eq} + Z_0}\right| \ ,\quad |T_{eq}| = 1 + |\Gamma_{eq}| \tag{4}$$

The description of how these parameters and others such as reflexion and transmission coefficients when a non-canonical situation is considered will be explained in full details at the conference.

## III. RESULTS

Figure 3 represents two vertical Gaussian rough walls mine tunnel segment. The simulation parameters are a length of 16 m and maximun transversal and vertical dimensions of $X_0$ =2.5 m, $Y_0$=3 m. A random roughness excursion for the four side walls of [ 0-25 cm] is accepted. The dielectric of walls is $\varepsilon_r$=2.5 and the conductibility is $\sigma$=0.001 S/m.

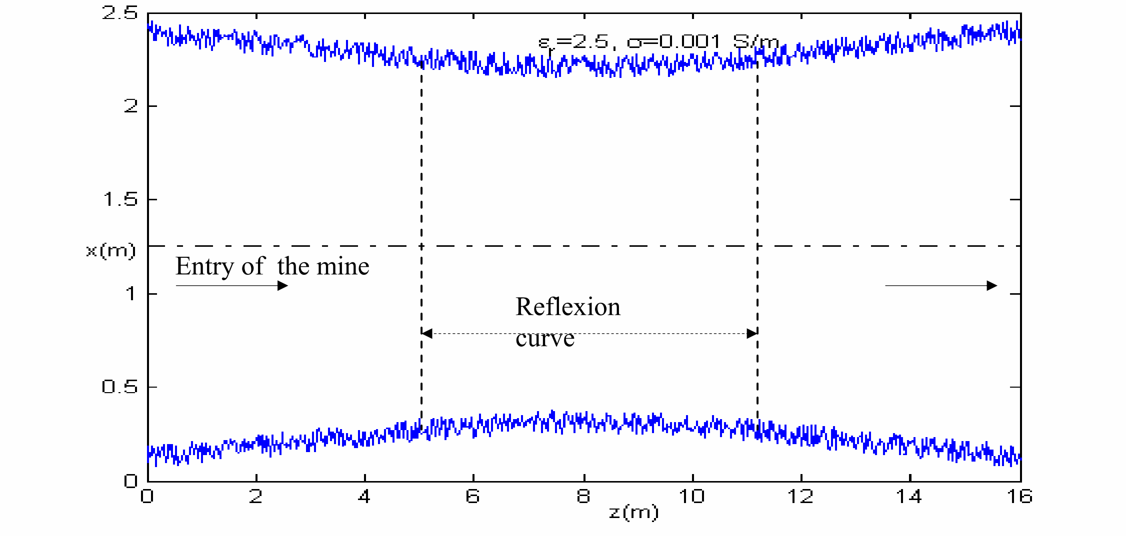


Figure 3: Two vertical rough walls mine tunnel showing Gaussian roughness.

Figure 4 presents the simulated field for the Gaussian rough mine tunnel segment of Figure 3. The frequency of the signal is 2.4 GHz and the longitudinal step is $\Delta z=\lambda/12$.

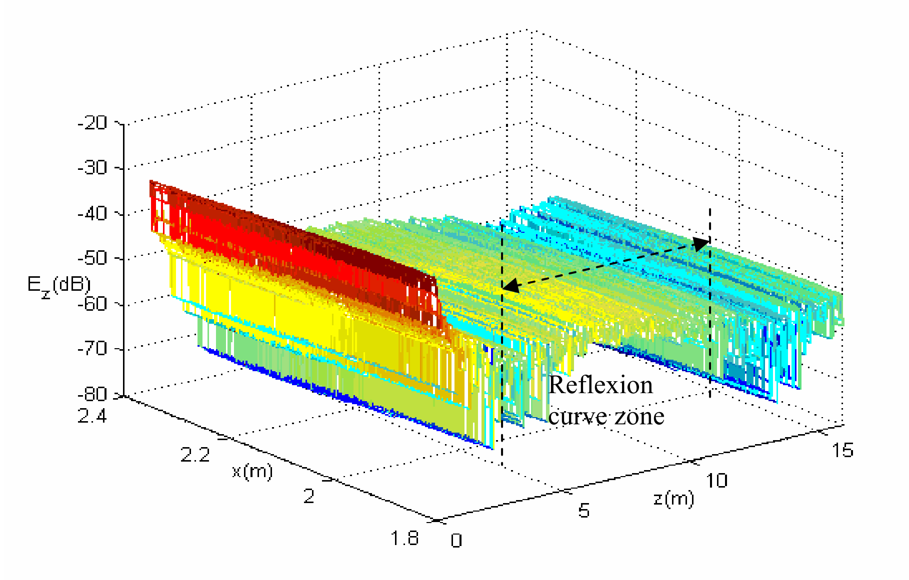
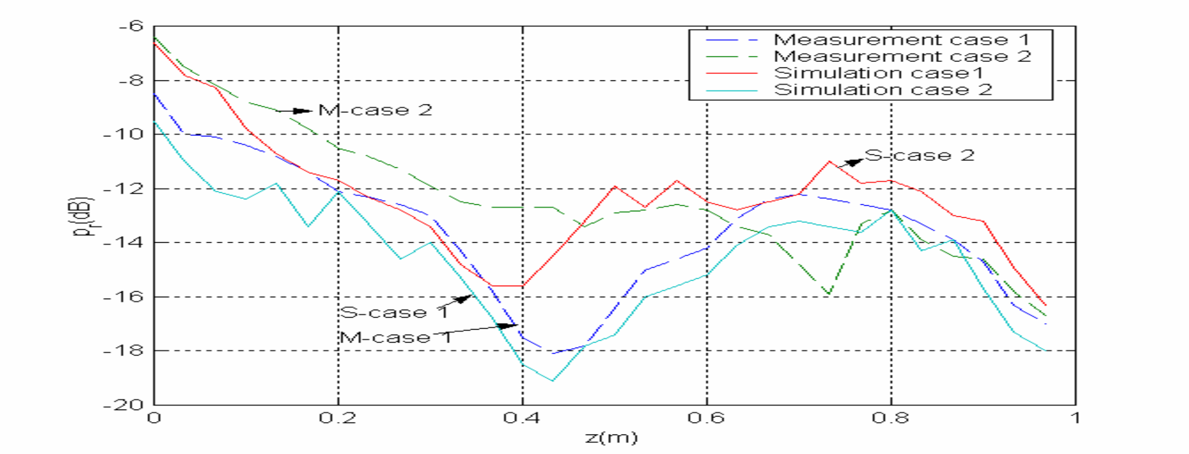


Figure 4: Simulated received power from the Gaussian rough mine tunnel.

It can be noticed that, after diffraction and reflexion has occurs on the rough walls, the signal is also reflected several times on the ground because the form of walls. This large reflexion amplitude, followed by many other beats of smaller amplitudes, appears in the reflexion zone. The received signals shown in figure 4 clearly indicates additional losses due to the rough walls. It can seen from the figure 4 ( reflexion curve zone ) that the influence of the form of roughness walls tunnel is very difficult to predict unless the impedance model can accurately takes into account all the detailed parameters. This effect also changes low fading signals to fast fading signals. In order to validate our theoretical results, measurements were taken in a scale model of a gold mine of dimensions a=b=30 cm, L=1m. The comparison of the received signals shown in figure 5 clearly indicates that the rough walls contribute to increase the radio wave signal reflexions losses.



V-polarization -case 1 , H- polarization -case 2 ,

Figure 5: Measurement- Simulation power at 2.4 GHz , transmit power =14dBm ,Gr=Gt=10dB.

## IV. CONCLUSION

The numerical results presented in this paper is promising for a reasonably accurate modeling of waves propagation in various, short or long, canonical or bending mining corridors if an appropriate choice of modeling sections is done, even for various complex confined media.The perfomance of the our model has been verified theoreticaly and valided experimently with several measurements. The proposed modeling is applicable for the simulation of millimetric waves propagation in canonical or non canonical mine tunnel and it is clear that for wireless communications in mining tunnels, the frequency, polarization, and the antennas will play a significant role in the reduction of attenuation caused by the wall roughness.

REFERENCE

[1] M.Ndoh, G.Y.Delisle and R. Le “ Modélisation des conditions de propagation dans un environnement complexe, ’’ Journées Internationales de Nice sur les Antennes ( *JINA 200)* , Nice France 12-14, Nov 2002, CD Proceedings, 4 pages.

[2] M.Ndoh, G.Y.Delisle, “A moderm Appoach to Complex Propagation Problems in confined media ”,*2002 URSI* General Assembly, Maastricht Netherlands,17-24 Aug 2002, CD Proceedings, 4 pages .

[3] M.Liénard and P.Degauque, “Natural Wave Propagation in Mine Environments,”*IEEE Trans.Antennas Propagat.,*vol.48, no.9, pp- 1326-1339 Sept 2000.

[4] M. Ndoh, G. Y. Delisle, “ Propagation of millimetric waves in rough sidewalls mining environment”, IEEE Veh. Technol. Conf., VTS- 2001, Rodos, Greece, 6-9 May 2001, CD Proceedings, 5 pages.

[7] A.G.Emslie, R.L.Lagace andP.F.Strong, “Theory of Propagation of UHF Radiowaves in Coal Mine Tunnels,” in Proc., Trough-the Earth Electromagnetics Workshop, Colorado School of Mines, Golden,Colo., 15-17 Aug. 1973.

[8] S.F.Mahmoud,J.R.Wait, “Geometrical Optical Approach for Electromagnetic Propagation in Rectangular Mine Tunnels,” *Radio., Sci*., vol. 9 no.12 pp.1147-1158, 1974.