Propagation of millimetric waves in rough sidewalls mining environment

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***Abstract*- This paper presents the modelisation of propagation of millimetric waves along lossy dielectric side walls of random roughness found in a mining environment. Two (2D) and three dimensional (3D) representations are obtained with a new analytical method, the Segmental Statistic Method (SSM). It employs mathematical and geometric approaches linked to magnetic vectors projection representation, with the use of ray technique and the segmentation of the mining tunnel. Results are shown to be in accordance with those obtained using the classical Rayleigh roughness indicator. This new approach makes possible to predict propagation performance in extreme condition in long mining corridor.**

Index Terms-**Rough sidewalls, mining environment, tunnel mine, propagation, rough surface.**

I. INTRODUCTION

Modern exploitation of mineral resources requires that efficient communication means be deployed in mining facilities to achieve remote control of production machines and to insure security of personal with cellular phones, high speed modems and video transmission. Some studies [1-2] of propagation mechanisms in mining environments are available but they mostly deal with either rectangular or semi-circular mine tunnels. The problem of electromagnetic scattering and propagation conventional or slightly rough surfaces tunnels has been intensively adressed. To resolve the problem created by random rough surfaces, many algorithms and approximate analytical methods has also been proposed. Among them, inhomogenous and homogenous approaches [3-4], the tangent plane aproximation [5], the small perturbation method (SPM) [6] are used for specifics cases types of rough surfaces and conditions.Another approach for the characterization of rough surfaces uses the Monte Carlo simulation. This method requires an enormous memory and computational time. Very recent studies [7-8] suggest that the Parabolic equation and the traditional method of moment (MoM) in conjunction which Galerkin's approximation are potentially applicable techniques to solve the difficult problem of scattering by these lossy irregular rough surfaces. It does not exist however an adequate analytical solution for the evaluation of random rough side walls mining environment. In this paper, an original model is considered. It proposes the use of an analytical efficient approach to solve the problem of modelisation of wall roughness at millimetric waves, where diffraction effects are important and not easily predic-table using a new combination of the Segmental Statistic Method (SSM) and the Finite Difference Time Domain method (FDTD). In this approach, the wall roughness is modeled using mathematical and geometric approaches linked to magnetic vectors projection representation using a ray technique and the segmentation of the mining tunnel.

II. ANALYTICAL FORMULATION

A) Projection of magnetic vectors

The geometry of the problem under consideration is shown in Figure 1 .

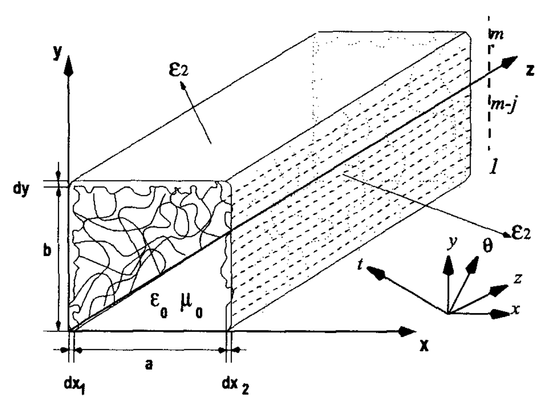

Figure1: A rectangular mine tunnel

The SSM method is applied to two parallel rough rock walls as shown in Figure 2 ,which are divided into i segments.The roughness of the tunnel is modeled as a function of the maximal cutoff wavelength λ_{cm} , the orientation θ_i of each segment and the distance of rough rock walls a_i . It can be assumed that an antenna located at an origin point emitting two rays (1) and (2) will let us determine a couple ($\vec{E_1}$, $\vec{E_2}$) ($\vec{H_1}$,$\vec{H_2}$) of electromagnetic vectors of reflected rays. By projection of magnetic vectors , two triangles (ABC) and (ADB) at the level of the walls can be obtained. For an infinity of rays , an infinite number of triangles can be obtained.

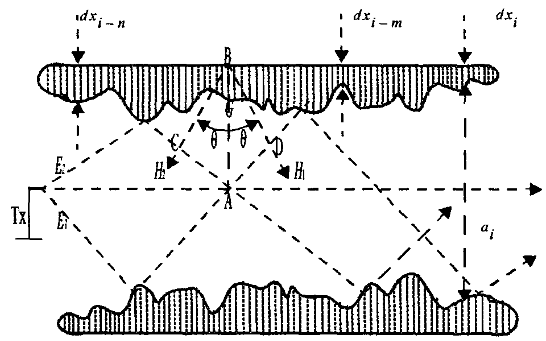

Figure 2: Two parallel rough rock walls

Using the geometrical optics applicable to the reflexion to an infinity of rays and the height of each segment can be shown to be

$$Rg_{x_i} = dx_i = \sum_{i=1}^{N}\left(\frac{n_i\lambda_{cm}}{g\sin\theta_i} - \frac{a_i}{k_i}\right) \quad (1)$$

$$Rg_{y_i} = dy_i = \sum_{i=1}^{N}\left(\frac{n_i\lambda_{cm}}{g\sin\theta_i} - \frac{b_i}{k_i}\right) \quad (2)$$

where k_i , g and n_i are integers.

B) Ray-optical projection

In this second approach, the geometry of the problem is shown in Figure 3.Two rays are projected from a source to two parallel rough rock walls with incidence angles θ_1 and θ_2 , dielectric ε_2 , the free space dielectric ε_0 and integer g_0 .Lets us consider the distance $\overline{D_1P_1}$,$\overline{D_2P_2}$ as a refraction of rays in the rough rock walls. For this ray-tracing model used here , the problem consist of determining the distance $\overline{D_1C_1}$, $\overline{D_2C_2}$ who represents the height of each point of rough. According to the

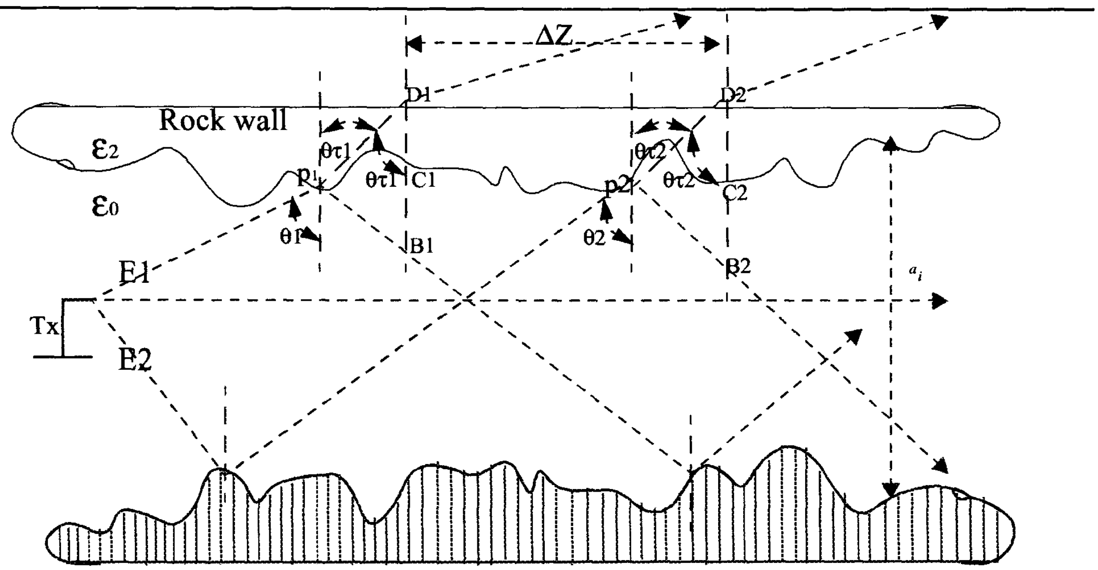

Figure 3: Details of the geometry used

Snell's law and to ray geometry projection, some distances can be shown to be

$$\overline{B_1C_1} = \frac{a_1}{k_1},\ \overline{B_2C_2} = \frac{a_2}{k_2}$$

and $g = g_o \cdot \frac{\varepsilon_0}{\varepsilon_2}$

$$\overline{D_1C_1} = \left(\frac{n_1 \lambda_{cm}}{g_o \cdot \frac{\varepsilon_0}{\varepsilon_2} \cdot \sin\theta_1} - \overline{B_1C_1} \right) \quad (3)$$

$$\overline{D_2C_2} = \left(\frac{n_2 \lambda_{cm}}{g_o \cdot \frac{\varepsilon_0}{\varepsilon_2} \cdot \sin\theta_2} - \overline{B_2C_2} \right) \quad (4)$$

For an infinity of rays, the height of each segment can be expressed as

$$Rg_{x_i} = dx_i = \sum_{i=1}^{N} \left(\frac{n_i \lambda_{cm}}{g \sin\theta_i} - \frac{a_i}{k_i} \right)^{(m)} \quad (5)$$

$$Rg_{y_i} = dx_i = \sum_{i=1}^{N} \left(\frac{n_i \lambda_{cm}}{g \sin\theta_i} - \frac{b_i}{k_i} \right)^{(m)} \quad (6)$$

with m tranversal segments as shown in Figure 1

Equations (5 and 6) are random rough coefficients. Using the Lagrange interpolation technique,a wall roughness function ψ_{Rgx} can be obtained as

$$\psi_{Rgx} = \sum_{i=u}^{i=u+v} Rgx_i \cdot \xi \quad (7)$$

$$\xi = \frac{(y - y_u)(y - y_{u+1})\ldots\ldots(y - y_{u+v})}{(y_i - y_u)(y_i - y_{u+1})\ldots\ldots(y_i - y_{u+v})}$$

Subsequently, the FDTD method can be used to obtain the wall roughness functions:

$$\frac{\partial^4 \Psi_{Rgu,v}}{\partial x^2 \partial y^2} \approx \frac{1}{(\Delta x)^2 (\Delta y)^2} \bullet \Psi \quad (8)$$

with

$$\Psi = 4\Psi_{Rgu,v} - 2(\Psi_{Rgu+1,v} + \Psi_{Rgu-1,v} + \Psi_{Rgu,v+1} + \Psi_{Rgu,v-1}) + (\Psi_{Rgu+1,v+1} + \Psi_{Rgu+1,v-1}) + \Psi_{Rgu-1,v+1} + \Psi_{Rgu-1,v-1}$$

C) Roughness power density function.

If it is assumed that the roughness power density function for all tunnel's is a set of random and gaussians rough functions linked with a roughness

$$\left| R^{(m)}_{g_M}(\theta) \right| = \begin{bmatrix} \left[\left[R^{(m)}_{gx,z}(\theta_1) \ldots R^{(m)}_{gx,z}(\theta_n) \right]\right] & \left[\left[R^{(m)}_{gy,z}(\theta_1) \ldots R^{(m)}_{gy,z}(\theta_n) \right]\right] \\ \left[\left[R^{(m)}_{gx',z}(\theta_1) \ldots R^{(m)}_{gx',z}(\theta_n) \right]\right] & \left[\left[R^{(m)}_{gy',z}(\theta_1) \ldots R^{(m)}_{gy',z}(\theta_n) \right]\right] \end{bmatrix} \quad (9)$$

coefficient.In this case, a roughness coefficient for four sidewalls, tunnel can be expressed as equation (9) below where *m* is transversal segments as shown in Figure 1, and $M=4$ for four sidewalls. This coefficient can be used for the propagation of electromagnetics waves in tunnel's mine environment with modal, ray-tracing, scattering and diffraction theory.

III. VALIDATION AND RESULTS

The roughness coefficient as proposed by equations (5,6) is validated by the Rayleigh roughness indicator for one sidewall only. To find a relation existing between the roughness coefficient proposed and the classical Rayleigh roughness indicator,it is assume that

$$\frac{a_i}{ki} = \frac{b_i}{ki} = 0 \ , \ n_i = \frac{\Delta\varphi_{1,2}}{\pi} \text{ and } g=4$$

as given by equations(5,6) where $\Delta\varphi_{1,2}$ is the phase difference between rays 1 and 2.
According to Rayleigh , the mean heigth is obtained using

$$Rg_i = x_i = \sum_{i=1}^{N} \left(\frac{\Delta\varphi_{1,2}\lambda}{\pi \sin\theta_i} \right) \qquad (10)$$

If phase shift is $\Delta\varphi_{1,2} = \frac{\pi}{2}$, then $S_i < \frac{\lambda}{8\sin\theta_i}$

which is considered as a condition for a smooth

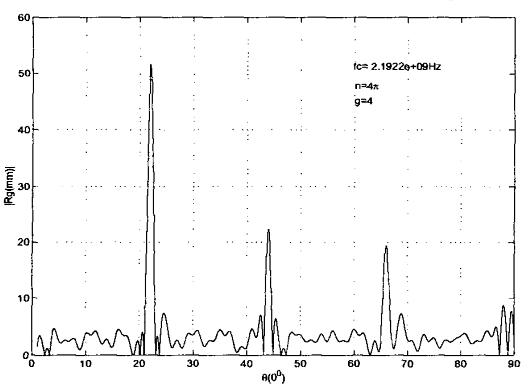

Figure 4: Tunnel's roughness coefficient vs incidence angle (degrees)

surface . This coefficient can be compared to the Rayleigh's coefficient if the preceding conditions are respected. Figure 4 illustrates results obtained by simulation of the roughness coefficient and attests the variation of purely random sidewalls asperities distribution. It was simulated with Matlab with parameters such as the material with dielectric constant of 2.5, the cutoff frequency, *n* and *g* an as mentionned on the plot. The tunnel's walls dimensions were 1<a<10 m ,1<b<10 m, z=20 m and 1<k<4 .

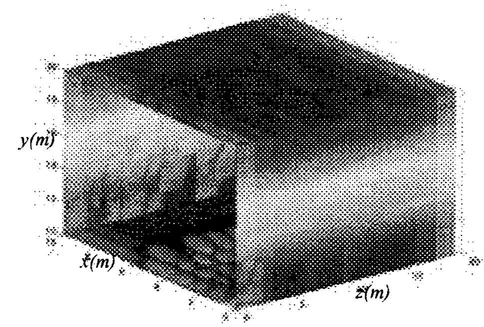

Figure 5 : Soft walls rectangular tunnel model

Figure 5 is a soft walls rectangular tunnel model ; it has been simulated with out roughness coefficient. Figure 6 and 7 were simulated using roughness coefficient equation (9) , and some functions have been generated which.

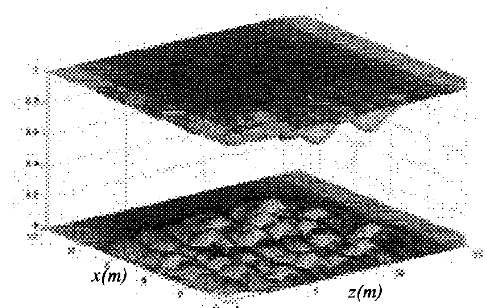

Figure 6: Two walls of the rough tunnel

Figure 8 gives a representation of the computed results for the whole tunnel . It is the union of four independant walls and propagation conditions in this type of random waveguide can ultimately be represented by a cascade of transmission lines with specific impedances.These results will be discus and fully interpreted at the conference.

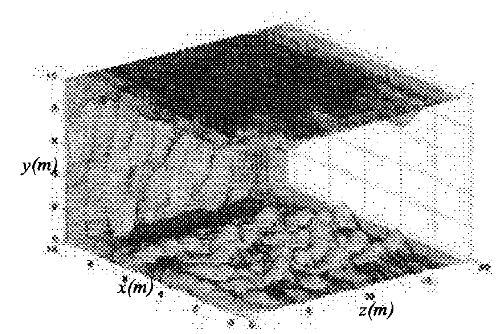

Figure 7: Three walls of the rough tunnel

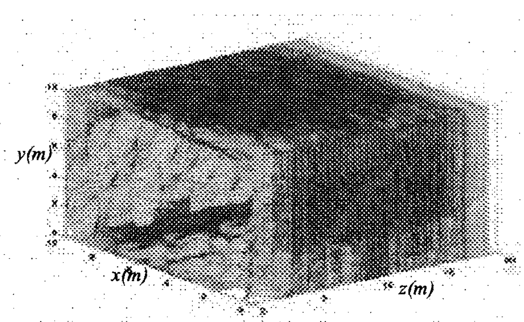

Figure 8: The entire rough tunnel model

IV. CONCLUSIONS

It has been demonstrated that the roughness of walls as seen in mining tunnels may be considered as an ensemble of gaussian and non gaussian functions. This study allowed us to model the tunnel's roughness density according to his intrinsic characteristics by the statistical segmental method (SSM).
The numerical results obtained so far shows that it is possible to model adequately the roughness indicator , a necessary parameter to predict the ultimate performance of wireless transmission systems.

References

[1] A.G.Emslie, R.L.Lagace , P.F.Strong, "Theory of the propagation of UHF radiowaves in coal mine tunnels", IEEE Trans .Antennas Propagat., vol.AP-23, pp.192-205, March. 1975.

[2] Q. Li,et al., "Bistatic scattering and emissivities of random rough dielectric lossy surfaces with the physics-based two-grid method in conjunction with the sparse-matrix canonical grid method",IEEE Trans.Antennas and Propagat., Vol.48,No.1,pp.1-11, Jan.2000.

[3] K.Sarabandi ,Y.Oh,and F.T.Ulaby ,"A numerical simulation of scatering from one-dimensional inhomogebeous dielectric random surfaces", IEEE Trans.Geosci.Remote Sensing,vol.34,pp.425-432. March.1996.

[4] M.Nieto -Vesperinas ,"Depolarisation of electromagnetic waves scatered from slightly rough random surfaces-A study by means of the extinction theorem,"J.Opt.Soc.Amer.,vol.72.pp.539-537,1982.

[5] P.Beckman and A.Spizzichino,The Scattering of Electromagnetic Waves from Rough Surfaces.Norwood,MA:Artech House,1987.

[6] S.O.Rice ,"Reflection of electromagnetic waves by slightly rough surfaces,"Commun.Pure Appl.Math.,vol.4,pp.357-378,1951.

[7] D. Zahn, et al.,"Numerical simulation of scattering from rough surfaces : a wavelet-based approach",IEEE Trans.Antennas and Propagat., Vol.48,No.2,pp.246-253 , Feb.2000.

[8] D. J. Donohue, "Propagation modeling over terrain using the parabolic ware equation", IEEE Trans. Antennas and Propagat., Vol.48,No.2, pp. 260-277, Feb.2000.

[9] R.P.Tores,et al., "An accurate and efficient method to estimate the local fading statistical from ray-tracing" , IEEE V ehic .Technol., pp.92-101, Sep 19-22,1999.