UNDERGROUND WIRELESS COMMUNICATION CHANNEL MODELING AND SIMULATION USING 0.3GMSK MODULATION CONSIDERING PENETRATION AND SCATTERING LOSS

M.N.JAYARAM[1] & C.R.VENUGOPAL[2]

[1,2]Department of E&C, SJCE, Mysore570006, Karnataka, India
E-mail : jayaram_mn2002@yahoo.com , venu713@gmail.com

Abstract- Wireless communication inside mines and tunnels is very different from that in terrestrial environment because of the strong attenuation of signals. Here, we are developing an empirical model for the underground wireless communication channel based on experimental data which help in predicting the average received signal strength at a given distance from transmitter. The model aims at adding correction factors to the available outdoor and indoor propagation models such as Okumara-hata model, cost231 model, ITU indoor propagation models etc. Modeling is done by choosing the most appropriate model among the available ones and performing regression methods to the model based on experimental data. Correction factors are then added based on two parameters which we are considering namely- Penetration and Scattering loss for 0.3GMSK.

I. INTRODUCTION

Underground mines which are characterized by their tough working conditions and hazardous environments require fool-proof mine-wide communication systems for smooth functioning of mine workings and ensuring better safety. Proper and reliable communication systems not only save the machine breakdown time but also help in immediate passing of messages from the vicinity of underground working area to the surface for day-to-day normal mining operations as well as for speedy rescue operations in case of disaster. Therefore, a reliable and effective communication system is an essential requisite for safe working, and maintaining requisite production and productivity of underground mines. Most of the existing systems generally available in underground mines are based on line (wired) communication principle, hence these are unable to withstand in the disaster conditions and difficult to deploy in inaccessible places.

Therefore, wireless communication is an indispensable, reliable, and convenient system and essential in case of day-to-day normal duty or disaster situations.

The wireless communication systems used on surface cannot be applied straightaway in underground mines due to high attenuation of radio waves in underground strata, besides presence of inflammable gases and hazardous environment. Non symmetric mine topology, uneven mine structure and complex geological structures put further hindrance on the way of communication. Wireless communication in underground mine is a very complex technique.

We have used simple modulations like BFSK,BPSK &0.3GMSK .

II. AVILABLE PRACTCAL DATA, CALCULATION AND RESULTS

1. *Terrain Profile*

Underground mines consist of slopes, rocks, edges etc. This peculiar type of confined environment is characterized by very rough surfaces and a frequent absence of a line-of-sight between transmitting and receiving antennas. The resulting propagation characteristics differ from those frequently encountered in more typical indoor environments such as offices and corridors. This type of terrain profile limits the signal strength which makes it difficult for wireless communication. An approximate model of the underground channel taking such a terrain into consideration is done. Wireless communication in an environment which consists of soil or rock is more challenging than through air.

The approximate terrain profile inside mine is shown in figure 1.1

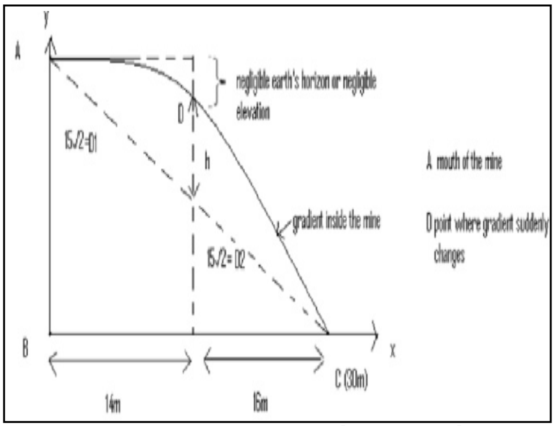

Figure 1.1: Approximate terrain elevation inside mine Power measurements are done at distances of 1m (point A), 14m (point D) and 30m (point C).These points are selected because these are critical points.

2. *Available Practical Data*

Measurements carried out in a gold mine using a high performance transceiver . probable losses that occurs at points A,D&C are listed in table 1.1 .

Table 1.1: The prominent losses at points A,D & C in the mine

Points	Losses considered during propagation
A	Penetration loss+ machinery loss+ power line interference loss
D	Penetration loss+ multi path loss+ power line interference loss.
C	Penetration loss+ multi path loss+ power line interference loss+ bending loss.

The measured values of the total loss(transmitted signal strength – measured signal strength in dB) at A,D and C point considering three modulation formats BPSK, BFSK and 0.3-GMSK are given in Table 1.2:

Table 1.2: The measured values of losses at points A, D & C

Points	BPSK	BFSK	0.3GMSK
A	119.7185	119.7185	119.7185
D	137.4461	134.7918	132.5873
C	150.2984	147.9036	146.1967

3. *Modeling.*

Three basic models which are used in terrestrial communication are considered.

3.1 Selection of model

We consider 3 propagation models and then use one of them as the base for modeling.

- **<u>Cost231 model</u>**

Mathematical equation is given by equation(1.1)

$L=46.3+33.9\log f-13.82\ \log(h_B)-\ a(h_R)+(44.9-6.55\log h_B)$ ………… (1,1)

Where $a(h_R)=(1.1\log f-0.7)(h_R)-(1.56\log f-0.8)$, L=Median path loss in dB, f=Frequency of transmission in MHz, h_B =Base station antenna height in meter, d=Link distance in Km, h_R =Mobile station antenna height in meter and $a(h_R)$=Mobile station antenna correction factor.

In the GSM 900 MHz, receiving antenna height h_R =1m ,transmitting antenna height h_B = 50m and considering distance d in m, the losses at points A,D and C are given in Table:1.3

Table 1.3: Losses obtained from cost 231 model at A,D & C

Points	Loss(dB)
A(d=1m)	124.877
D(d=14m)	163.58
C(d=30m)	174.562

- <u>ITU model for indoor propagation</u>

Mathematical equation is given by

$L = 20\log\ f+N\ \log\ d+ Pf(n)-28$ ------------------- (1.2)

Where L= Total path loss in dB, f= Frequency of transmission in MHz, d= Distance in meter, N= Distance power loss coefficient, n= Number of floors between the transmitter and receiver, Pf(n)=Floor loss penetration factor. In GSM 900MHzband , floor attenuation factor Pf(n)=24, no of floors N=33 and considering distance d in m, the losses at points A,D and C are given in Table:1.4

Table 1.4: Losses obtained from ITU model at A,D & C

Points	Loss(dB)
A(d=1m)	55.462
D(d=14m)	93.285
C(d=30m)	104.2076

- <u>Log distance path loss model</u>

Mathematical equation is given by

$L= 20\log(4*\pi*d/\lambda) + 10*\gamma*\log(d/d_0) + X_g$ ------------(1.3) Where λ=Wavelength, d=Distance in meter, X_g =Fading factor, γ=Path loss exponent, d_0 =Reference distance. For Wave length in GSM 900MHz band , reference distance d_0 =1m, fading factor X_g =0,path loss exponent γ =2, the losses at points A,D and C are given in Table:1.5

Table 1.5: Losses obtained from Log distance path loss model at A,D & C

Points	Loss(dB)
A(d=1m)	55.462
D(d=14m)	93.285
C(d=30m)	104.2076

The best model for further calculations is found by comparing the measured values of loss with the losses obtained from model equations.

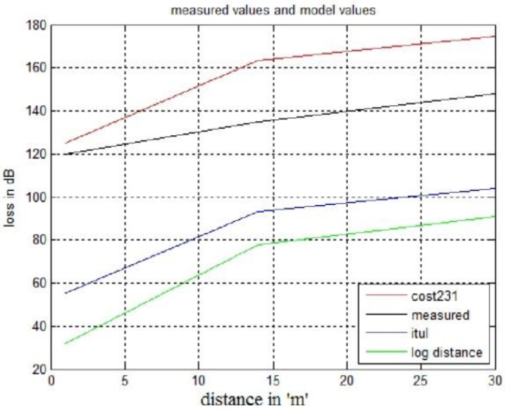

Figure 1.2 Measured & model path loss plot

3.2 Deviation of measured loss from model losses.

The deviation between the two losses are given in Table1.6

Table 1.6: The mean error from the differences of losses calculated from the models and measured losses

Models	Mean error
Cost231 model	20.202
ITU model	49.82
Log distance path loss model	67.253

Since Cost231 model has the lowest mean error. Hence, it is considered for all further calculations.

3.3 Calculation of correction factor to the selected model.

In the first step, correction factors w.r.t distance are added to the model using differences between model calculated and measured values.

Table 1.7: Differences between losses obtained from cost231 model and measured losses for 0.3GMSK modulation.

Points	Loss(dB)
A(d=1m)	5.159
D(d=14m)	30.993
C(d=30m)	28.57

First a plot of the differences vs. log d is drawn as in Fig 1.3 below.

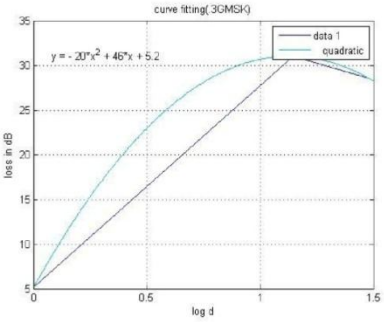

Fig 1. 3 loss vs logd curve

Polynomial regression is then performed by using the basic fitting tool in mat lab to obtain correction factor.

Thus, we obtain a correction factor

$C1=5.2+41(\log_{10} d)-18(\log_{10} d)$ (1.4)

Incorporating in eq(1.1) ,

we have

$L=46.3+33.9\log f-13.82\log(h_B)-a(h_R)+(44.9-6.55\log h_B)$

$-C1$ -- (1.5)

Figure 1.4 shows the corrected cost231 model w.r.t distance

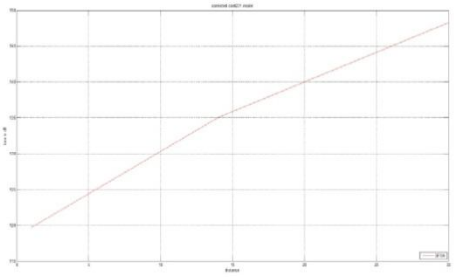

Figure 1.4: Plot of corrected cost231 model vs. distance

III. ANALYSIS OF PARAMETERS

Further corrections in the model are obtained by considering two parameters: penetration & scattering losses. Multi path loss is assumed to be 40 dB , using Fresnel's model bending loss 34.63 dB & power line loss is 57.9 dB (measured using magnetic dipole).

1. Penetration loss.

There was a 35 cm thick concrete brick wall at the entrance which results in penetration loss.

For lossy dielectric medium $\gamma^2 =(\alpha+j\beta)^2 =(\sigma+j\omega\epsilon)(j\omega\mu)$………...(1.6)

So Attenuation constant $\alpha \approx \sigma/2\sqrt{(\mu/\epsilon)}$ Dielectric constants at 900MHz GSM band are listed in table1.8.For concrete this loss is 16 dB .

Table 1.8: Value of constants.

Type of wall	Permittivity Farad/meter	Permeability Henry/meter	Conductivity Ampere/meter^2	Thickness Centimeter
Concrete thin wall	9	1	0.1	35
Wooden	5	1	1*10^-15	3
Glass	2.4	1	1*10^-12	0.3
Copper	1	1	5.7*10^7	1.3

Now at point C the losses considered are:

Penetration loss+ multipath loss+ bending loss+ power line interference loss, We take penetration loss to be variable , let it be given by some term k3 ,hence the total loss becomes:

L=K3 +40+34.63+57.9

The correction factors are derived using the basic fitting tools in MATLAB. Thus, we obtain a second correction factor $C2=10.58\log_{10}f-173$

Adding it to the already corrected cost231 model we get the final cost231 model as, $L=46.3+33.9\log f-13.82\log(h_B)-a(h_R)+(44.9-6.55\log h_B)\log d-C1-C2$ ------(1.7)

Scattering loss:
At point C total loss is L=Penetration loss+ multipath loss+ power line interference loss. Considering multipath loss (MPC) as variable we have L= 16+40+57.9+MPC
Using polynomial regression method we use MATLAB for curve fitting and find the third correction factor as
C3=-0.01*d^2+0.45*d-40
Adding it to already corrected Cost 231 model we get the model after scattering correction as:
$L=46.3+33.9\log f-13.82\log(h_B)-a(h_R)+(44.9-6.55\log h_B)\log d-C1-C2-C3$.
The final plot of corrected model is as in Fig 1.4

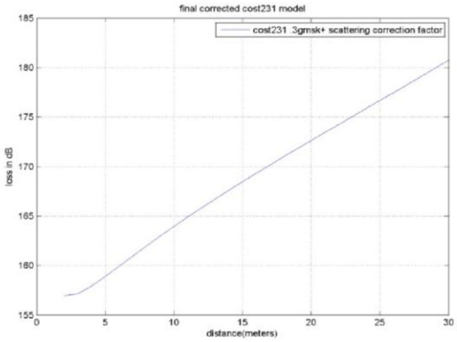

Figure 1.4: Shows the Plot of final corrected cost231 model.

IV. CONCLUSION

1. Point C (at a depth of 30m) is selected because it is the critical point in the terrain .
2. 0.3 GMSK modulation is used .
3. High power of is used to overcome penetration loss at entrance .
4. Beyond 30m as more than 75% of the received signal was attenuated measurements was not possible.
5. We have used super position while modeling i.e for penetration loss we have assumed scattering loss as constant 7 vice versa .
6. Model can be updated by considering antenna height loss (due different planes of TX &RX) , bending loss, low frequency interference loss as variables .
7. Parameters like loss due to fan, blowers, lighting , ground reflection can be considered .
8. This model may not work in other mines due to change in geometry.

REFERENCES

[1]. Theodore.S. Rappaport, Wireless communications, Principle and practice, Eastern Economy Edition, 2nd ed, 2002.

[2]. William C.Y.Lee, Mobile communications engineering, Theory and applications

[3]. Gilles, Y. Delisle. School of information technology & engg, University of Ottawa, Canada Underground mine wireless propagation modeling

[4]. Signal propagation techniques in underground mines. http://www.ece.gatech.edu/research/labs/bwn/surveys/underground09.pdf

[5]. Helchel. IEEE transaction on antenna & propagation, ‘Comparison of 900 MHz band and 800 MHz band indoor propagation ‘vol 54, No 12, Dec 2006

[6]. Shi Lihua, Xu Qiwei, Chan Bin Gao Cheng Measurement of the frequency dependent Dielectric constant of concrete materials by TDR & wavelet modeling method Asia pacific Conference on environmental electromagnetic. CEEM 2003, Nov 4 – 7.

[7]. Hindawi Publishing Corporation , International Journal of Antennas and Propagation , Volume 2008, Article ID 806326, 10 pages,doi:10.1155/2008/806326

[8]. Raj Jain, “Channel models a tutorial, Feb 1,2007”

[9]. About Modulation Format. http://en.wikipedia.org/wiki/Modulation

[10]. C. Nerguizian, C. L. Despins, S. Aff`es, and M. Djadel, “Radiochannel,characterization of an underground mine at 2.4GHz,”,IEEE Transactions on Wireless Communications, vol. 4, no. 5,pp. 2441–2453, 2005.

[11]. Zhi, S. and I. F. Akyildiz, \Channel modeling of wireless net-works in tunnels," IEEE Global Telecommunications Conference,(GLOBECOM'08), New Orleans, LA, Nov. 30{Dec. 4, 2008).

[12]. Empirical formula for propagation loss in land mobile radio service, IEEE transactions on Vehicular Technology, VOL. VT-29, NO.3, AUGUST 1980

[13]. About Radio Propagation Models. http://en.wikipedia.org/wiki/Radio_ propagation model

[14]. About Path Loss. http://en.wikipedia.org/wiki/Path_loss

[15]. Bertoni, H. L., Radio Propagation for Modern Wireless Systems Prentice Hall, Englewood Cli®s, NJ, 2000.

[16]. M. Boutin, A.Benzakour, C.Despins and S. Affes. (2008). Radio wave characterization and modeling in underground mine tunnels, IEEE. Transaction. on Antennas and Propagation, 2:540-549.

[17]. 17. M.Lienard and P.Degauque. (2000). Natural Wave Propagation in Mine Environments, IEEE Transaction on Antennas and propagation, 48(9): 1326-1339.

[18]. 18. W.E.Pakala and V.L.Chartier Radio noise measurements on overhead power lines from 2.4to 800kv,

[19]. M.Ndoh and G.Y.Delisle. (2004). Underground mines wireless propagation modeling, 60th IEEE Vehicular Technology Conference, Los Angeles, CA, 3584-3588.

[20]. Kjeldsen, E. and M. Hopkins, \An experimental look at RF prop-agation in narrow tunnels," Proc. IEEE Military CommunicationsConf. (MILCOM'06), Washington D.C., Oct. 23{25, 2006

[21]. Li Wenfeng, Lv Yingli, Li Baiping. (2008). Experiment on characteristic of radio propagation in mine. Journal of Xi an University of Science and Technology, 2:327-330 (in Chinese.

◆◆◆