# Statistical Modelling of a Radio Propagation Channel in an Underground Mine at 2.4 and 5.8 GHz

Mathieu BOUTIN[1,3], Sofiène AFFES[1,3], Charles DESPINS[1,2,3], Tayeb DENIDNI[1,3]

1 : INRS-EMT, Université du Québec, Montréal, Canada
2 : PROMPT-Québec, Montréal, Canada
3: LRCS (Laboratoire de Recherche en Communications Souterraines), Val d'Or, Québec, Canada

**Abstract—** ***This paper reports on the statistical modelling of a wideband radio propagation channel in an underground mine at 2.4 and 5.8 GHz. Both LOS and NLOS areas are considered. The amplitude for the paths of the experimental impulse responses is compared to the Rayleigh, Rice, Nakagmi, Weibull and Lognormal distributions. The arrival-time of these paths is compared to the Poisson, modified Poisson and Weibull distributions. The phase is considered a priori to be uniformly distributed. After comparing the experimental impulse responses to those generated by many simulations (based on the RMS delay spread), the best amplitude model is found to be Rice for LOS and Rayleigh for NLOS, and the best arrival-time model is modified Poisson, regardless of the frequency.***

**Key words—** ***Statistical modelling, indoor, underground mine, 2.4 and 5.8 GHz, method of moment, path arrival, amplitude, Kolmogorov-Smirnov, RMS delay spread.***

## I. INTRODUCTION

This work has been carried out by the Underground Communications Research Laboratory (LRCS), a university-industry partnership seeking to develop efficient communication techniques and novel applications, such as highly accurate wireless geolocation in underground mines. Building upon the sparse literature available on underground mine propagation characteristics and in order to support the development of these techniques and applications, propagation measurements were performed [1], [2] at 2.4 GHz and 5.8 GHz in a real mine in Val d'Or, Canada. As propagation characteristics specific to such confined environments with rough surfaces were observed [1], a deterministic model was developed [3] as an initial step to model the channel. However, this approach turned out to be very complex and limited in capturing the very specific nature of propagation in a confined gallery with rough surfaces.

This paper reports on the results of a statistical modelling approach for channel characterization in underground mines [7]. Statistical modelling is attractive in that it can quickly and reliably generate simulated impulse responses for a particular frequency and topography based on accurate models derived from experimental measurements. As opposed to the time-consuming process of gathering a huge amount of experimental impulse responses, simulated impulse responses can be readily available to test new applications for mines such as wireless geolocation [4]. To the best of our knowledge, this work is the first to propose a statistical model for indoor radio propagation in confined environments with rough surfaces, such as underground mines.

First, the measurement system used to extract the experimental impulse responses is presented (II). The mathematical model (III), path arrival modelling (IV), path amplitude modelling (V) and the simulation process (VI) will follow before the conclusion (VII).

## II. MEASUREMENT SYSTEM

Three separate areas of the mine gallery are considered - a line-of-sight area (LOS) and two non-line-of-sight areas (NLOS1 and NLOS2) of about 24 meters in length each as depicted in Figure 1 - to study the impact on the statistical channel model of both transmitter-receiver distance and the presence (or absence) of a LOS. A transmission antenna has been fixed at the beginning of the gallery, while a reception antenna took six samples (averaged over 10 impulse responses) at each meter. A total of 420 samples was thus obtained for each frequency, hence about 140 samples per area.

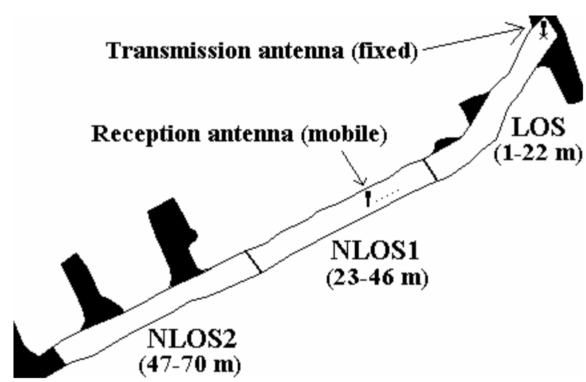


**Figure 1**-Topography of the underground mine gallery (only areas in white colour are modelled).

Before beginning the modelling process, the time axis of each impulse response is discretized in 8-ns time bins, as per the experimental protocol, by considering the peaks and the inflexions to find the paths of each impulse response [1] [2]. The path loss effect (due to tranmitter-receiver distance) is superfluous in this modelling process and was removed prior

0-7803-8887-9/05/$20.00 (c)2005 IEEE

to testing the candidate amplitude distributions with the experimental impulse responses. An example is shown in figure 2.

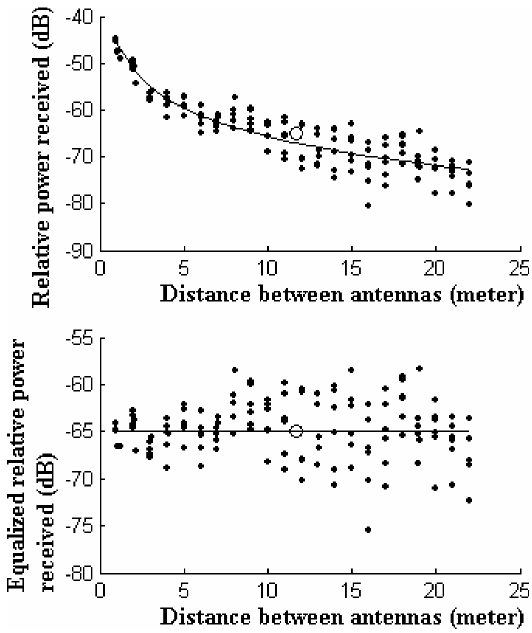


**Figure 2**-Example of path loss effect removal (at 2.4 GHz, NLOS2).

However, this path loss effect is reinserted during the simulation process in order to reflect the real propagation environment, although it has no effect on the rms delay spread [7].

## III. MATHEMATICAL MODEL

A radio propagation channel can be completely characterized by its random impulse response *h(t)* as per:

$$h(t)=\sum_{k=0}^{N-1}\alpha_k\delta(t-t_k)e^{j\theta_k}\,, \qquad (1)$$

where $N$ is the number of multipath components, $\alpha_k$, $t_k$ and $\theta_k$ are the random amplitude, arrival-time and phase of the $k^{\text{th}}$ path, respectively, and $\delta$ is the delta function.

The amplides $\alpha_k$ and the path arrivals $t_k$ are modelled in the following sections by comparing them to some already known distributions frequently used in the literature. The phases $\theta_k$ are assumed to be, a priori, statically independent uniform random variables over [0, 2π).

## IV. PATH ARRIVAL MODELLING

The modelling process considers the following distributions for path arrivals, which are the most commonly used in the literature [5]: Poisson, modified Poisson and Weibull.

The parameters of each of these distributions are estimated from experimental results by seeking to minimize the mean square error (MMSE) between the probability distribution function and the experimental distribution, for each time bin. An example is shown in figure 3.

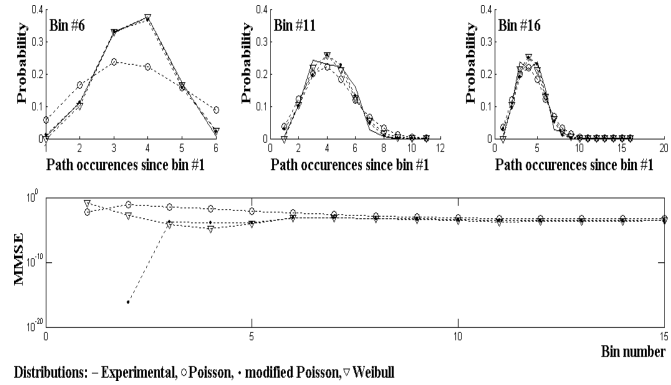


**Figure 3**-Example of parameter estimation for the path arrival ditributions (at 2.4 GHz, NLOS1).

Results suggest that the modified Poisson distribution offers the best fit, for all areas and both frequencies.

By examining all the experimental impulse responses collected, we observe no path clustering effect, in contrast to what was reported previously for more conventional indoor environments with smooth surfaces [6]. Hence, there is no need to model cluster arrivals.

## V. PATH AMPLITUDE MODELLING

The most popular distributions for path amplitude, especially for indoor environments, are considered as candidate models [5]: Rayleigh, Rice, Nakagami, Weibull and Lognormal.

The method of moments is used to estimate the parameters of each candidate distribution, at each time bin, based on experimental results. Decreasing exponential curves (of the form $y=Ae^{-(x-1)/B}+C$ [8]) for both amplitude average and standard deviation, as a function of time bins, are obtained by curve-fitting. An example is shown in figure 4.

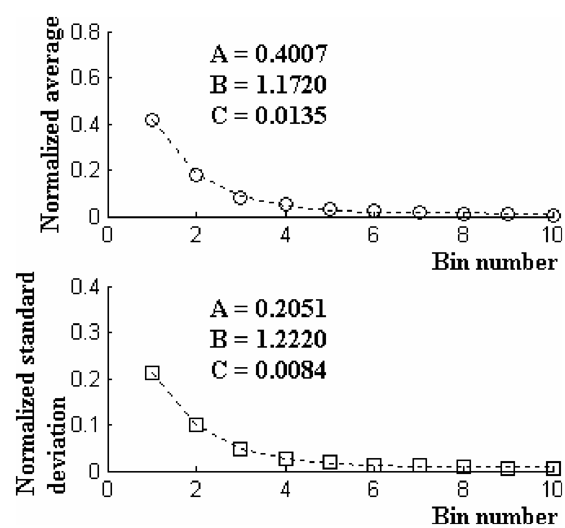


**Figure 4**-Example of decreasing exponential curves used by the method of moments (at 5.8 GHz, LOS).

With these two statistical properties, the resulting first and second fitted moments are used to approximate the parameters of the five amplitude distributions for each bin. An example is shown in figure 5.

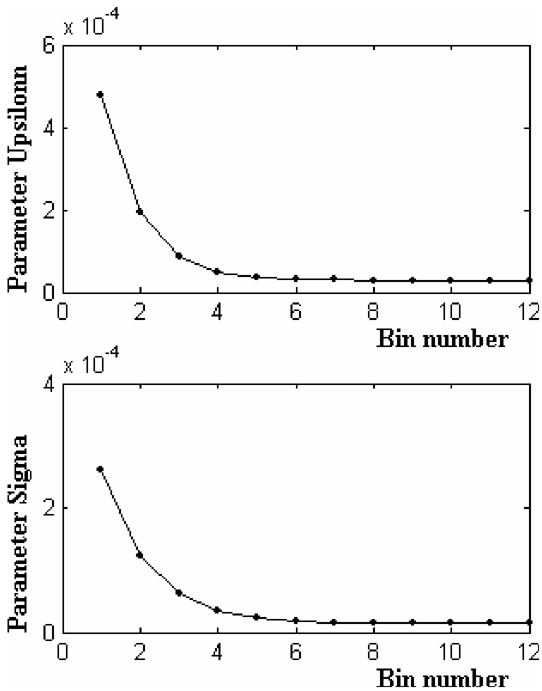


**Figure 5**-Example of parameters approximation (Rice distribution at 2.4 GHz, LOS).

However, the simulation process is required to determine which of these distributions is the most appropriate to model the channel.

## VI. SIMULATION PROCESS

The simulated impulse responses are obtained in three steps. First: a set of path arrivals (including all the time bins) is generated following the modified Poisson distribution with its optimal parameters for each bin found during modelling. Second: five sets of path amplitudes are generated following the Rayleigh, Rice, Nakagami, Weibull and Lognormal distributions, with their optimal paramaters for each bin found during modelling. Finally, each of the generated sets of path amplitudes is combined with the set of path arrivals, resulting in a simulated impulse response.

The RMS delay spread of each simulated impulse response is extracted and compared with those obtained experimentally. The Kolmogorov-Smirnov test is used to identify the distribution which best represents the experimental results, based on the most commonly used propagation characteristic, namely the RMS delay spread. An example is shown in figure 6.

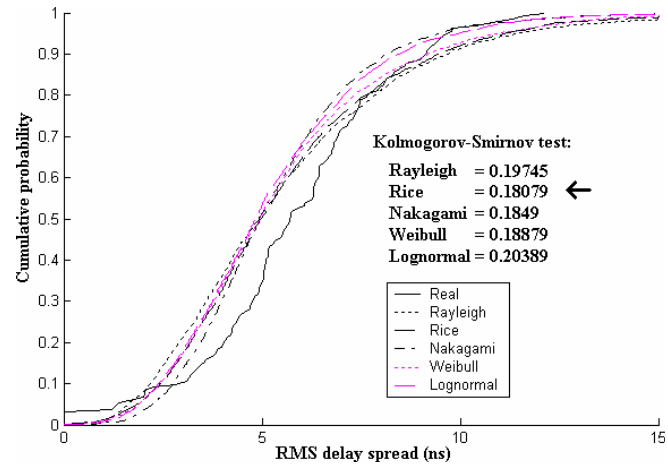


**Figure 6**-Example of the use of the Kolmogorov-Smirnov test on the RMS delay spread (at 2.4 GHz, LOS).

After comparing a set of 100 simulations to the experimental results (each simulation including 3000 impulse responses), the best amplitude distribution for each area of the mine gallery and for each frequency is shown in Table 1, where the performance score of each distribution is reported.

**Table 1**: Match results in % based on the RMS delay spread.

| | LOS | NLOS1 | NLOS2 |
|---|---|---|---|
| **2.4 GHz :** | | | |
| Rayleigh | 0 | 88 | 92 |
| Rice | 91 | 0 | 0 |
| Nakagami | 2 | 4 | 2 |
| Weibull | 7 | 6 | 5 |
| Lognormal | 0 | 2 | 1 |
| **5.8 GHz :** | | | |
| Rayleigh | 1 | 90 | 94 |
| Rice | 89 | 2 | 1 |
| Nakagami | 2 | 4 | 3 |
| Weibull | 8 | 2 | 1 |
| Lognormal | 0 | 2 | 1 |

The results shown in Table 1 clearly suggest that the best amplitude distribution, regardless of frequency, is Rice for a line-of-sight propagation, and Rayleigh for a non-line-of-sight situation. The best distribution for path arrivals is the modified Poisson, as mentioned previously.

## VII. CONCLUSION

The statistical modelling has been done for the three areas of the underground mine gallery: LOS, NLOS1 and NLOS2, for the 2.4 GHz and 5.8 GHz frequencies. It turned out that the best distributions are modified Poisson for the path arrival, and Rice and Rayleigh for the amplitude, in LOS and NLOS respectively. This is true for both frequencies. The phase has been considered, a priori, to be uniformely distributed.

The RMS delay spread has been used to compare the simulated impulse responses resulting from the studied models with those obtained experimentally, using the Kolmogov-Smirnov test. Many simulations have been realized and the more performant models are those which have got the largest number of sucessful Kolmogorov-Smirnov tests.

The simulations obtained from the most relevant models could be used in many upcoming projects that need a large impulse response data base representing the studied mine gallery. Further work will seek to compare results of this statistical modelling approach with those of deterministic modelling.

## ACKNOWLEDGMENT

The authors wish to thank M. Ahmed Benzakour [2] who performed the measurement campaign, without which this paper could not have been realized.

## REFERENCES

[1] C. Nerguzian, C. Despins, S. Affes and M. Djadel "Radio Channel Characteritization of an Underground Mine at 2.4 GHz", to appear in IEEE Transactions on Wireless Communications.

[2] A. Benzakour, S. Affes, C. Despins, and P.-M. Tardif, "Wideband channel characteristics at 2.4 and 5.8 GHz in an underground mining environment", *Proc. of IEEE VTC'04-Fall*, Los Angeles, California, USA, September 26-29, 2004.

[3] M. Ndoh, and G.Y. Delisle, "Underground Mines Wireless Propagation modelling", *Proc. of IEEE VTC'04-Fall*, Los Angeles, California, USA, September 26-29, 2004.

[4] C. Nerguizian, C. Despins and S. Affes, "Geolocation in Mines with an Impulse Response Fingerprinting Technique and Neural Networks", to appear in IEEE Transactions on Wireless Communications.

[5] H. Hashemi, "The Indoor Radio Propagation Channel", Proceedings of the IEEE, vol. 81, no. 7 (July), pp. 943-968. 1993.

[6] A. A. Saleh and R. A. Valenzuela, "A Statistical model for indoor multipath propagation," IEEE Journal on Selected Areas in Communications, vol. 5, pp. 128-137, February 1987.

[7] Boutin M. Modélisation statistique de la propagation radio dans une mine souterraine à 2.4 et 5.8 GHz. Master thesis, Institut national de la recherche scientifique : énergie, matériaux et télécommunications (INRS-EMT), to be published . 2005 (french).

[8] Ganesh R. et Pahlavan K. "Statistical modelling and computer simulation of indoor radio channel". Communications, Speech and Vision, IEE Proceedings I, vol. 138, no. 3 (June), pp. 153-161. 1991.