ON THE MODELLING OF A RADIO PROPAGATION CHANNEL FOR LOS AND NLOS AREAS IN A MINE TUNNEL

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

1: INRS- EMT, Place Bonaventure, 800 de la Gauchetiere Ouest, suite 6900
Montreal, Qc, Canada, H5A1K6
Tél: (514) 875-1266 ext 2011. Fax: (514) 875-0344
2 : PROMPT-Québec, Montréal, QC, Canada
3 : LRCS (Laboratoire de Recherche en Communications Souterraines), Val d'Or, QC, Canada
Email:{ mboutin*, affes, denidni }@ inrs-emt.uquebec.ca, cdespins@promptquebec.com*

ABSTRACT

This paper reports on the statistical modelling of a wideband radio propagation channel in a mine tunnel for LOS and NLOS areas. Both frequencies of 2.4 and 5.8 GHz are considered. The arrival-time for the paths of the experimental impulse responses is compared to the Poisson, modified Poisson and Weibull distributions. While the phase is considered a priori to be uniformly distributed, the amplitude of these paths is compared to the Rayleigh, Rice, Nakagmi, Weibull and Lognormal distributions. The experimental impulse responses are compared to those predicted by simulations, considering the potential models whith their extracted parameters. For the LOS area case, the best arrival-time model is modified Poisson and the best amplitude model is Rice. For the NLOS area case, the best arrival-time model is modified Poisson as well, but the best amplidute model is Rayleigh. However, the parameters of these models depend on the operating frequency.

1. 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 mine tunnel propagation characteristics and in order to support the development of these techniques and applications, propagation measurements have been performed [1], [2] in LOS and NLOS areas in a real mine in Val d'Or, Canada. As propagation characteristics specific to such confined environments with rough surfaces have been observed [1], a deterministic model has been 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 mine tunnels [7]. Statistical modelling is attractive so 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. In fact, 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 mine tunnels.

First, the measurement system used to extract the experimental impulse responses is presented. Then, the mathematical model, path arrival modelling, path amplitude modelling and the simulation process will thus follow. Finally, concluding remarks are given.

2. MEASUREMENT SYSTEM

The mine tunnel has been separated in three areas: 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. Hence, the impact on the statistical channel model of both transmitter-receiver distance and the presence (or absence) of a LOS can be studied. While a transmission antenna is fixed at the beginning of the tunnel, a reception antenna takes six samples at each meter (averaged over 10 impulse responses). A total of about 140 samples is thus obtained for each area with each frequency.

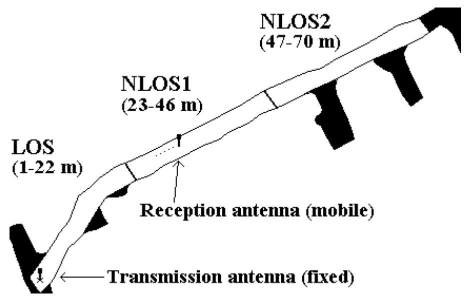

Figure 1. Areas of the mine tunnel (only areas in white colour are modelled).

Prior to beginning the modelling process, the time axis of each experimental impulse response is discretized in 8-ns time bins (as per the experimental protocol) by considering the inflexions and peaks to find the multiple paths of each impulse response [1] [2]. Before testing the candidate amplitude distributions with the experimental impulse responses, the path loss effect due to transmitter-receiver distance has to be removed. An example is shown in Figure 2.

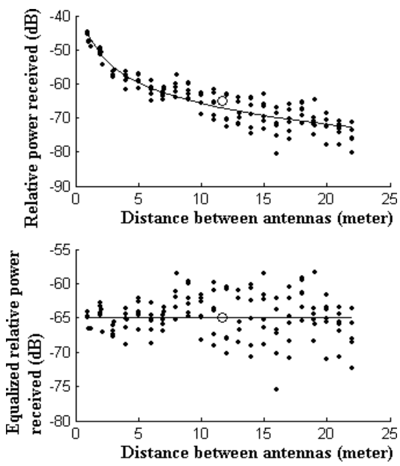

Figure 2. Example of path loss effect removal (at 2.4 GHz, NLOS2).

In order to reflect the real propagation environment, this path loss effect is reinserted during the simulation process [7].

3. MATHEMATICAL MODEL

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

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

where N is the number of multipath components, α_k, t_k and θ_k are the random amplitude, arrival-time and phase of the k^{th} path, respectively, and δ is the delta function.

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

4. PATH ARRIVAL MODELLING

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

Estimation of the parameters of each of these distributions is done 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.

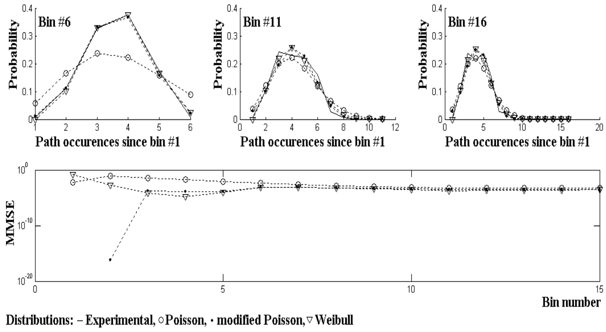

Figure 3. Example of parameters estimation for the path arrival ditributions (at 2.4 GHz, NLOS1).

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

In contrast to what was reported previously for more conventional indoor environments with smooth surfaces [6], no path clustering effect was observed by examination of all the experimental impulse responses collected. Hence, there is no need to model cluster arrivals.

5. PATH AMPLITUDE MODELLING

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

In order to estimate the parameters of each candidate distribution at each time bin, the method of moments is used with the experimental results. A curve-fiting technique is used to obtain 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. An example is shown in Figure 4.

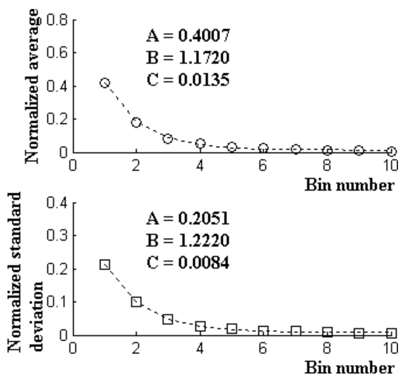

Figure 4. Example of decreasing exponential curves used by the method of moments (at 5.8 GHz, LOS).

The first and second fitted moments can be used to approximate the parameters of the five amplitude distributions for each bin, with these two statistical properties. An example is shown in Figure 5.

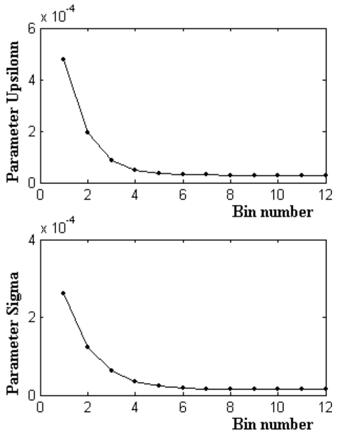

Figure 5. Example of parameters approximation (Rice distribution at 2.4 GHz, LOS).

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

6. SIMULATION PROCESS

Three steps are needed in order to simulate impulse responses. 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 arrivals is combined with the sets of path amplitude, resulting in a simulated impulse response.

The RMS delay spread beeing the main comparison criteria, it is extracted from both simulated and experimental impulse responses. The Kolmogorov-Smirnov test is then used to identify the distribution that represents the experimental results well, based on this most commonly used propagation characteristic. An example is shown in Figure 6.

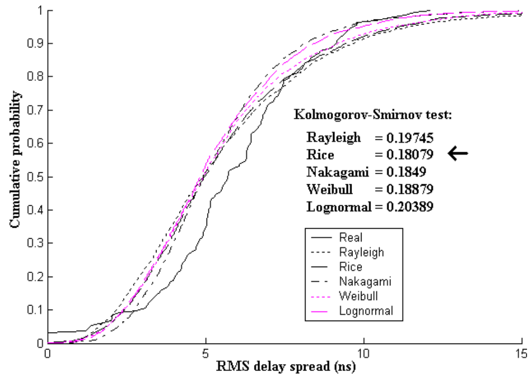

Figure 6. Example of the use of the Kolmogorov-Smirnov test on the RMS delay spread (at 2.4 GHz, LOS).

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 tunnel 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 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.

7. CONCLUSION

Statistical modelling has been performed for the three areas of the mine tunnel: 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 carried out and the more relevant models are those which have obtained the largest number of sucessful Kolmogorov-Smirnov tests.

The most relevant models could provide simulations that could be used in many upcoming projects that need a large impulse response data base representing the studied mine tunnel. Further work will deal with comparing 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 work 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. <u>Modélisation statistique de la propagation radio dans une mine souterraine à 2.4 et 5.8 GHz</u>. 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.