RMS Delay Spread and Coherence Bandwidth Measurements in Underground Mining Environments at 2.4 and 5.8 GHz

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ABSTRACT

This paper presents the experimental set-up and results of channel impulse response measurements conducted in an underground mining environment at center frequencies of 2.4 GHz and 5.8 GHz. The rms delay spread and the coherence bandwidth are estimated and compared for the two bands. The measurements showed that in the underground gallery considered and in the two frequency bands, random reflections have the effect of flattening the relationship between the rms delay spread and distance. In the 2.4 GHz band, the rms delay spread is less than or equal to 9.92 nanoseconds for 90% of all measurement locations. The corresponding value for the 5.8 GHz is 8.55 nanoseconds. It has been shown that the coherence bandwidth is highly variable as a function of the location of the receiver. No clear relationship is observed between the rms delay spread and the coherence bandwidth but a concentration of the coherence bandwidth values occurs when the delay spread is below 10 ns at both frequency bands. In general, it has been observed that underground radio channel characteristics are influenced by the configuration of this peculiar environment.

1. INTRODUCTION

Measuring and characterizing the impulse response parameters of mobile radio channels is important in the design and implementation of efficient mobile systems. In particular, a good communication system in underground mines can largely increase safety and production output. To date, however, there are few studies available in the literature which consider this special environment [1-6].

This paper details the results of wideband propagation measurements at center frequencies of 2.4 GHz and 5.8 GHz, made in the CANMET (Canadian Center for Minerals and Energy Technology) experimental mine in Val d'Or (Québec). The two frequencies are compared by evaluating the rms delay spread and the coherence bandwidth.

In our study the radio channel sounding was carried out in the frequency domain. This technique is based on sweeping the measured bandwidth with a single sine wave signal. In a post-processing step, the recorded radio channel frequency responses are inverse-Fourier transformed to get the channel impulse responses. Finally, the channel characterization is obtained from the impulse responses.

This paper is organized as follows. Section II provides a description of the underground environment and of the channel measurement system. In section III the analysis of the collected data is performed. Section IV draws out the conclusions of this work.

2. DESCRIPTION OF THE ENVIRONMENT AND CHANNEL MEASUREMENT SYSTEM

Experiments were conducted in an underground gallery of a former gold mine, the laboratory mine CANMET in Val d'Or, 500 kilometers north west of Montreal, Canada. Located at a 70 m underground level, the gallery stretches over a length of 70 meters with 2.5 to 3 meters of width and approximately 3 meters of height. A plan of the gallery is provided in *Figure 1*. Due to the curvature of the gallery, the existence of a non-line-of-sight (NLOS) cases is visible. Moreover, the walls are very rough, the floor is not flat and it contains some large puddles of water.

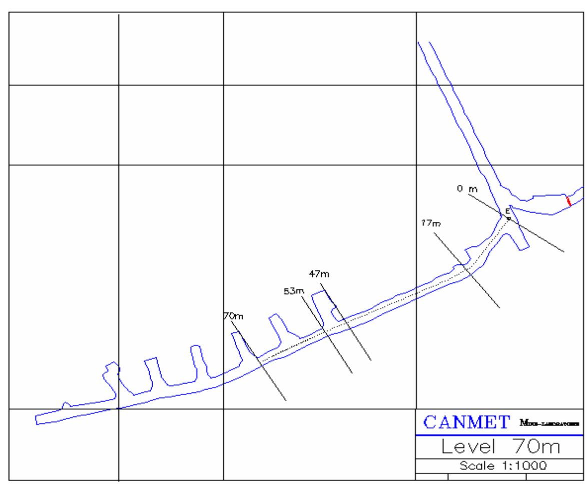


Figure 1: Map of the underground gallery.

To investigate the statistical behavior of the channel, experiments were conducted in which the channel impulse response structures in the two bands of interest were compared for 420 different receiver locations along 70 meters of the gallery, while the transmitter remained fixed. For each location, a temporal average has been performed on a set of ten complex-transform- function measurements at different observation times.

The wideband measurement setup consisted of a Vector Network Analyser with fixed and moving omnidirectional antennas to act as the receiver and transmitter, respectively. The transmitting port swept the channel in the frequency band 2.3-2.5 GHz (5.7-5.9 GHz resp.) and the receiving port recorded the channel output with the signal attenuation and phase shift introduced by the channel in the frequency domain. The received data was then transformed to the time domain using the Fourier transform to obtain the time delay profile. The frequency step was 200 MHz between the frequency band 2.3-2.5 GHz (5.7-5.9 GHz resp.) and consequently in the time domain a theoretical resolution of 5 ns was obtained (in practice, due to the use of windowing, the time resolution is estimated to be around 8 ns).

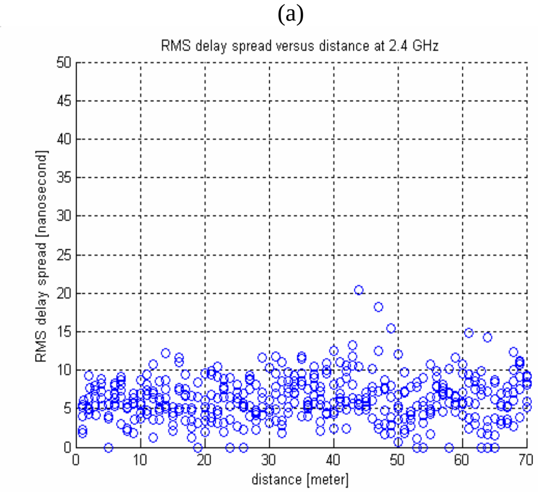
During the measurements, transmit and receive antennas were both at a height of 1.8 meters.

3. RMS DELAY SPREAD AND CHANNEL COHERENCE BANDWIDTH

The rms delay spread τ_{rms} and the coherence bandwidth were computed, and their statistics were then extracted from the magnitude of the complex impulse response of the channel in the two bands of interest, at all 420 measurement locations by using predefined thresholds for the multipath noise floor [1].

Figures 2(a) and *2(b)* plot τ_{rms} against transmit-receive antenna separation at 2.4 GHz and 5.8 GHz, respectively.

(a)



(b)

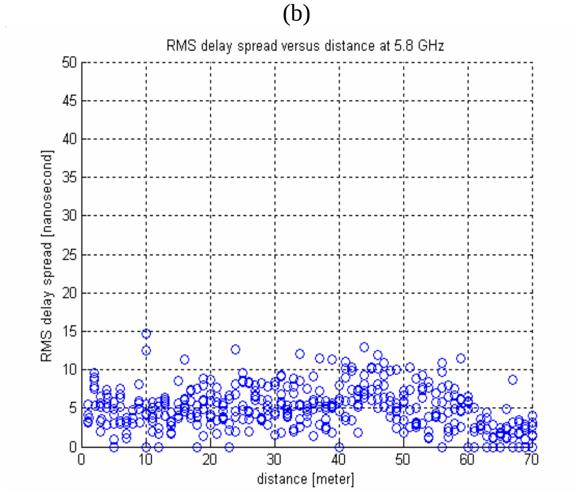


Figure 2: RMS delay spread as a function of distance at (a):2.4 and (b):5.8 GHz.

For the underground gallery considered and in the two frequency bands, random reflections have the effect of flattening the relationship between the rms delay spread and distance. In contrast, we have not seen the same phenomenon at the 40 m level of the mine [6], where the gallery is 5 meters large. In both cases, the profiles observed differ from those commonly found in indoor building environments [7] [8].

Results thus show that indoor underground multipath characteristics can vary considerably depending upon the gallery dimensions and the transmit/receive distance.

In *Figure 3*, the cumulative distribution function (CDF) of τ_{rms} for both bands shows the percentage of receive locations for which the rms delay spread is less than a specified value.

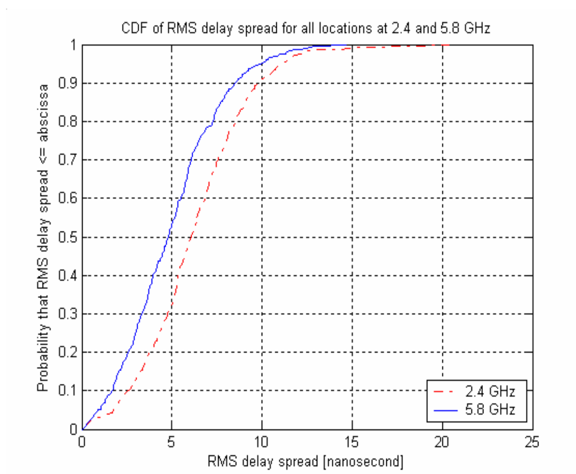


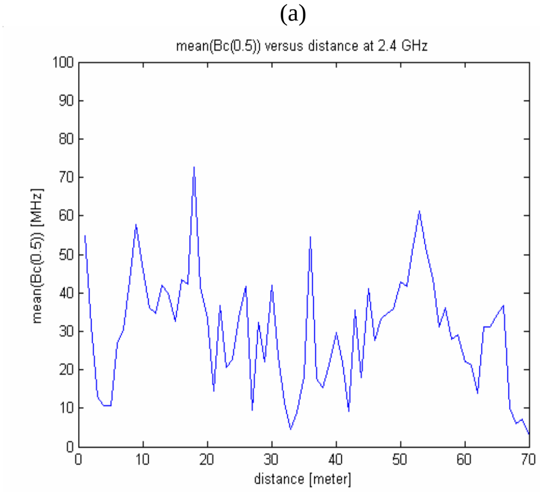
Figure 3: Cumulative Distribution Function of τ_{rms} at 2.4 and 5.8 GHz.

As the delay spreads were greater at 2.4 GHz in several locations (*Figures 2 (a)* and *(b)*), the CDF plot for that band is consequently below that for the 5.8 GHz. It can be seen that in the 2.4 GHz band, the rms delay spread is less than or equal to 9.92 nanoseconds for 90% of all locations. The corresponding value for the 5.8 GHz band is 8.55 nanoseconds.

For wideband radio systems in such an environment, performance levels under static conditions would be marginally better in the 5.8 GHz band, since delay spreads are slightly smaller in this band than at 2.4 GHz. But coverage would be about the same for both bands.

Plots against distance of the mean and the maximum of the coherence bandwidth for a correlation level of 0.5, for all the six positions of the gallery width located at a distance *d* from the transmitter, and for both bands, are shown in *Figures 4* and *5*, respectively.

(a)



(b)

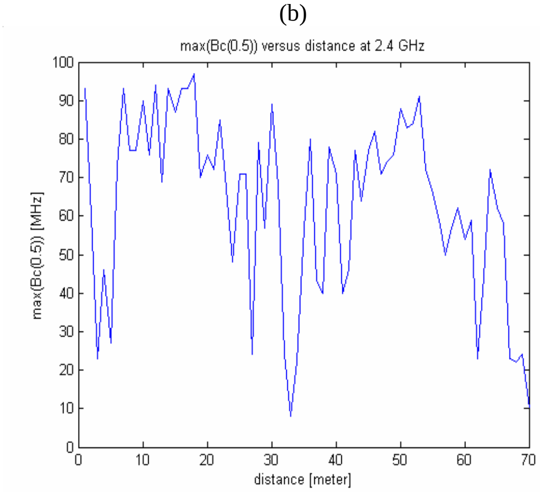
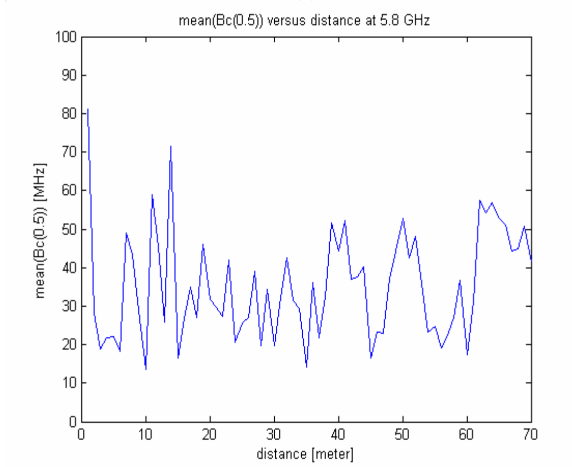


Figure 4: Mean (a) and maximum (b) of coherence bandwidth for a correlation level of 0.5 at 2.4 GHz.

(a)



(b)

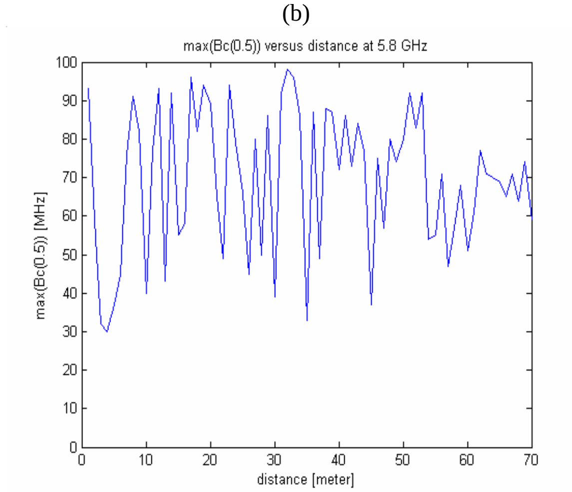


Figure 5: Mean (a) and maximum (b) of coherence bandwidth for a correlation level of 0.5 at 5.8 GHz

The coherence bandwidth is random and is highly variable with the transmit-receive antenna distance. It is appreciably larger for the 5.8 GHz band. This is consistent with the τ_{rms} results and the relationship between these two parameters. The coherence bandwidth represents the minimum frequency separation to have the components of the radio signal sufficiently uncorrelated. It is also a relevant parameter in the design of frequency diversity systems.

The cumulative distribution function (CDF) of the coherence bandwidth is computed for each frequency band and the level below which Bc stays for a given percentage of time is determined. The 0.5, 0.7 and 0.9 coherence bandwidths obtained for 90% of receiver positions are given in *Table 1*.

	Coherence Bandwidth [MHz]		
	Bc(0.5)	*Bc(0.7)*	*Bc(0.9)*
2.4 GHz	74.2	31.3	7.1
5.8 GHz	78.7	34.8	9

Table 1: The level below which the Coherence Bandwidths stay for 90% of receiver position for 0.5, 0.7 and 0.9 correlation at 2.4 GHz and 5.8 GHz.

The coherence bandwidth for a correlation level of 0.5 against τ_{rms}, at both bands, is given in *Figure 6*. A relation of the form $Bc = k\,e^{-n\,\tau_{rms}}$, where Bc expressed in [MHz] and τ_{rms} in [ns] has been considered [9]. A regression line is fitted to the scatter plot of pairs (τ_{rms} , log(Bc)). The results of the fit are given in *Figure 6*, with (log(*k*),*n*) = (4.1515,-0.2361) at 2.4 GHz and (log(*k*),*n*) = (3.9467,-0.1948) at 5.8 GHz.

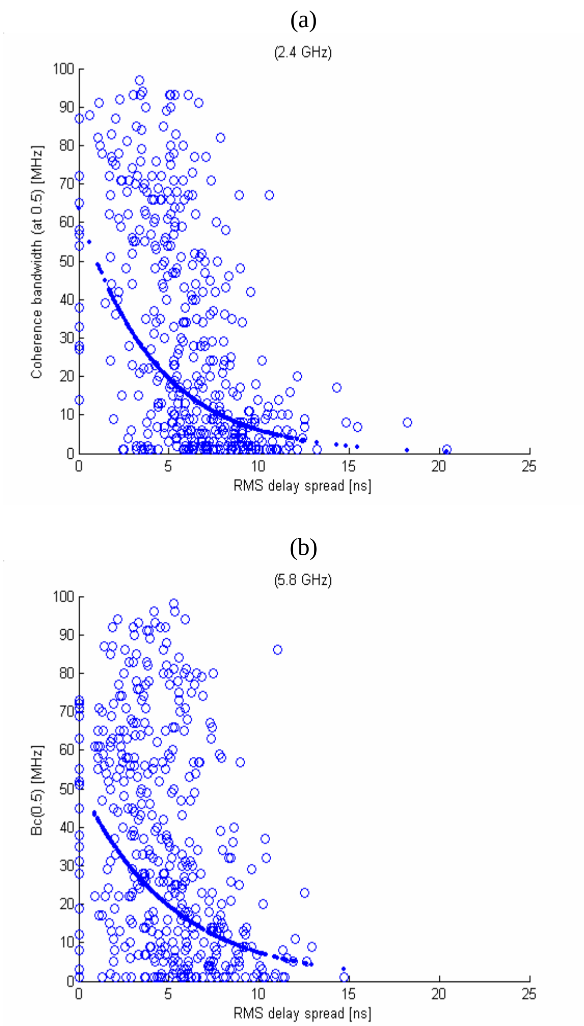


Figure 6: Coherence bandwidth at level of 0.5 as a function of distance with their dependence curve at (a): 2.4 GHz and (b): 5.8 GHz.

4. SUMMARY AND CONCLUSION

In order to characterize radio channels in underground mines, measurements were performed at 2.4 and 5.8 GHz using a vector network analyzer. Frequency responses were obtained for one transmitter location and 420 receiver locations in an underground gallery. The inverse Fourier transform was used to convert the frequency domain data to corresponding time domain responses.

Results show that indoor underground multipath characteristics can vary considerably depending upon gallery dimensions and the transmit/receive antenna separation. They also suggest that random reflections have the effect of flattening the relationship between the rms delay spread and distance in the gallery considered at both frequency bands of 2.4 and 5.8 GHz.

It has been shown that the coherence bandwidth is highly variable as a function of the location of the receiver. As well, a concentration of the coherence bandwidth values occurs when the delay spread is below 10 ns for both frequency bands.

For the studied environment, performance levels under static conditions would be marginally better (assuming that multipath diversity is not exploited) in the 5.8 GHz band, but coverage would be about the same for both bands.

The results presented herein are currently exploited in the design of wireless local area networks and for radiolocation applications [10] in an underground mining environment.

5. REFERENCES

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