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Experimental Characterization Of Antenna Location Effects At 60 Ghz In An Underground Mine

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ABSTRACT:*In this paper, an experimental characterization of a 60 GHz channel for an underground mining is reported. A frequencychannelsounder, with a passbandbandwidth of 2 GHz, is used to make measurements from 59 GHz to 61 GHz. The measurements are performed with two scenarios of antenna locations. The shapes of the power delay profiles are different when the transmitting and receiving antennas were placed in the center and on the right side of the gallery. Several statistical parameters such as the number delays, the delay spread, the mean excess delay and the path loss are extracted from the measurements in both scenarios. The distribution of the number of path is compared to a Poisson distribution. This distribution represents best the distribution of the number of path on the right side of the gallery. There is no relation between the delay spread and the transmitter receiver distance. Furthermore, the delay spread of scenario 2 is less than the one of scenario 1. These delay spreads are compared to some delay spread retrieved with measurements in the same gallery at 2.4 GHz. The path loss exponents in both scenarios are found to be less than 2. This is due to the nature of the underground mine environment. With the obtained results, the deployment of a wireless communication systems at 60 GHz is expected to be more reliable in an underground mine.*

KEYWORDS : *Channel characterization, delay spread, number of paths, path loss, underground mine.*

I. INTRODUCTION

The underground mining channel presents different challenges for wireless systems. This hostile environmentsuffersfrom multiple reflections, fadings and diffractions. Furthermore, there is no conventional underground mining channel as every mine exhibits different behaviors [1-3]. The characterization of this underground channel is therefore essential, as it will enable engineers to design high performance, efficient and low cost communication systems. This accurate model will allow development of wireless communication for the mining industry.The deployment of short range wireless link inside an underground mine is used to improve the security of workers and maximize the productivity through voice and video transmissions. The 60 GHz wireless technology is an ideal candidate for short range communication systems in underground mining environment. There is a massive amount of spectral space (5-7 GHz) available around the 60 GHz ISM frequency band [4]. By using this band, it is expected to achieve explicit high capacities in order to provide enhanced broadband services.

This ISM band presents two major drawbacks which are the propagation loss and the oxygen absorption. At 60 GHz, the propagation loss is 30 dB higher than at 2 GHz. The oxygen also attenuates the electromagnetic energy at 60 GHz. This absorption weakens 60 GHz signals over distance, so that signals cannot travel far beyond their intended recipient [4]. This will reduce the co-channel interference and will provide security to others wireless links in general and in particularly to other 60 GHz links.Different channel characterizations have been proposed for the 60 GHz unlicensed frequency band. The environments under study range from indoors [5-6], cars [7], tunnels [8] to hospitals [9]. The underground mining channel, which is different from the previous ones, has received little attention at 60 GHz. One recent publication is however found in the literature. This paper treats of the large scale characterization of a 60 GHz underground mining channel [10].In this contribution, the experimental characterization of a 60 GHz underground channel is presented. An accurate channel characterization and modeling can give valuable information to the wireless communication engineers. With the obtained channel parameters, an efficient communication system can thereby be designed. The analysis is based on channel measurements at 60 GHz. For the purpose of comparison, measurements campaigns at 2.4 GHz were also conducted in the same gallery. The effects of the antenna locations inside the gallery are taken in account.

II. MEASUREMENT TECHNIQUE

Measurement environment

Fig.1 shows the measurement setup inside the gallery of the underground mine at a depth of 70 meters. This gallery is approximately 3 meters wide and 2 meters high.The underground mine, called CANMET (Canadian Center for Minerals and Energy Technology) is located in Val d'Or, Québec,Canada. There are different galleries, corridors, curves and first aid stations inside the mine. The floor is uneven at different places, and one can notice the presence of some water puddles.

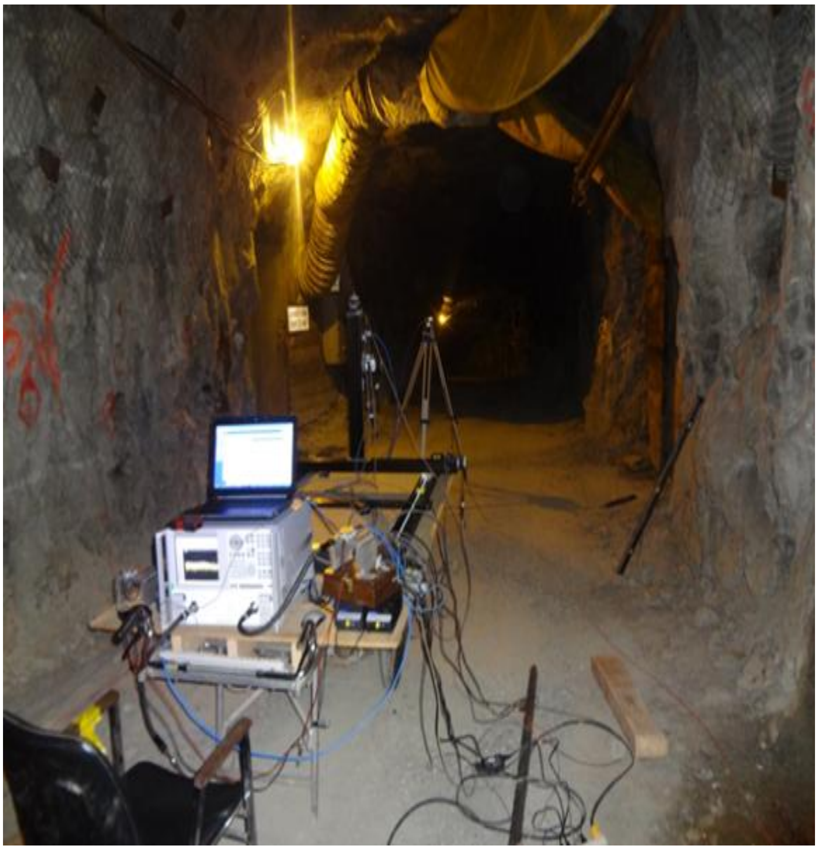

Figure 1. Photograph of the measurement inside the gallery of the mine

2.2 Measurements setup

As illustrated in Fig. 2, the measurement setup consists of a Vector Network Analyzer (VNA), a power divider, a local oscillator a power amplifier (PA), a low noise amplifier (LNA), frequency multipliers, filters, mixers, cables and antennas. The 54 GHz signalsat the local oscilator (LO) output of both mixers are obtained by multiplying the 2.25 GHz synthesizer signal through a CFM 0203X610-01 frequency sextupler and a CFM13 16X413-01 frequency quadrupler. The use of the lower frequency (2.25 GHz) for the LO before the power divider will give a better oscillator phase noise and will allow the use of simple circuits. The signal, which is between 5 GHz and 7 GHz, is generated by the port 1 of the VNA and thenupconverted to frequenciesbetween 59 GHz and 61 GHz. The upconverted signal output is filtered, amplified, and then transmitted through a directional antenna.The received signal, which is captured by the same kind of directional antenna, passes through a 60 GHz low noise amplifier and a 60 GHz bandpass filter. This radio frequency (RF) is downconverted , filtered, and converted to a baseband signal between 5 GHz and 7 GHz. This signal is connected to the second port of the VNA The LO at the frequency of 2.25 GHz and the VNA are synchronized through a 10 MHz reference clocks.Two directional horn antennas (CERNEX CRA15507520) are used. Their operating frequency ranges from 50-GHz to 75 GHz with a gain of 20 dB. Both 3-dB beamwidths in the azimuth and elevation planes are 12degrees. All antennas are vertically polarized in the operational frequency band.

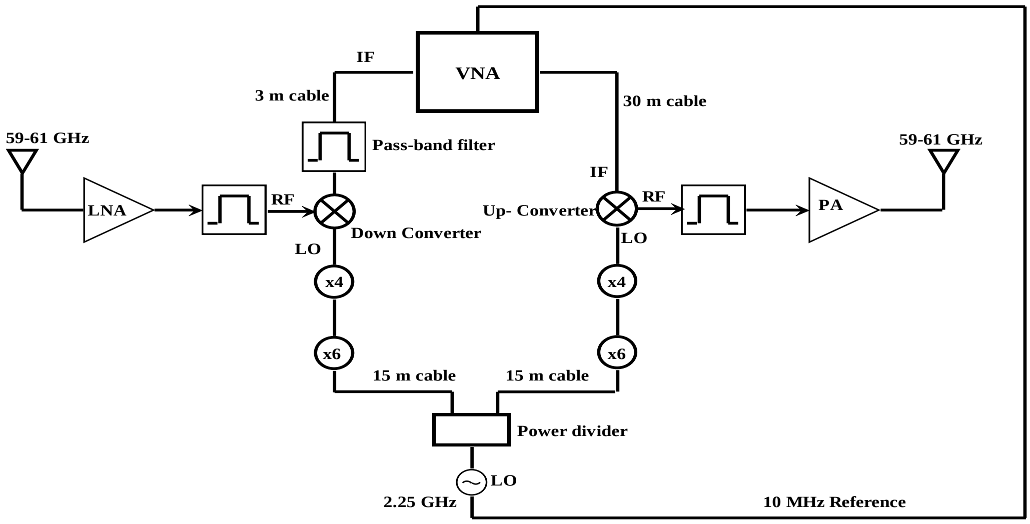

Fig.2 Measurement set-up

The Agilent E8363 VNA is used as both a transmitter and a receiver in the system. It measured the frequency transfer function with 6401 stepped frequency points in the range of 5 GHz to 7 GHz. Before the measurements were carried out, a Through Reflect Line (TRL) calibration was done. Then, a reference measurement was performed with the transmitting antenna and receiving antenna apart with 1 meter separation distance. Therefore, the impairment effects of the LNA, the PA, the cables, connectors and antennas were removed To characterize the propagation channel in small scale, the receiver is moved on a grid square with 9 points (3 X 3) where the distance between each adjacent point is equal to 2.50 cm, which is half of the wavelength in free space at the frequency of the 60 GHz. The antenna is accurately moved on this virtual array by using a VELMEX positioning system. A laser beam has been used to fix the height of the antennas from the ground at 1.5 meters. The measurements were done in light of sight (LOS) for a transmitter-receiver distance of 1 meter to 5 meters in two scenarios. In the first scenario, both the transmitting and receiving antenna are in the middle of the gallery, whereas in the second scenario, they are on the right side of the mine. All measurements were performed with minimal human movement and activity. In the all cases, ten consecutive sweeps were averaged at each distance to obtain an important statistical data of the channel and to also reduce the effects of random noise.

III. MEASUREMENTS RESULTS

Power delay profile

The power delay profiles (PDPs) of the underground channel are retrieved from the frequency channel responses by using an Inverse Fast Fourier transform (IFFT) with a Hanningwindowfunction to reduce the side lobe level.

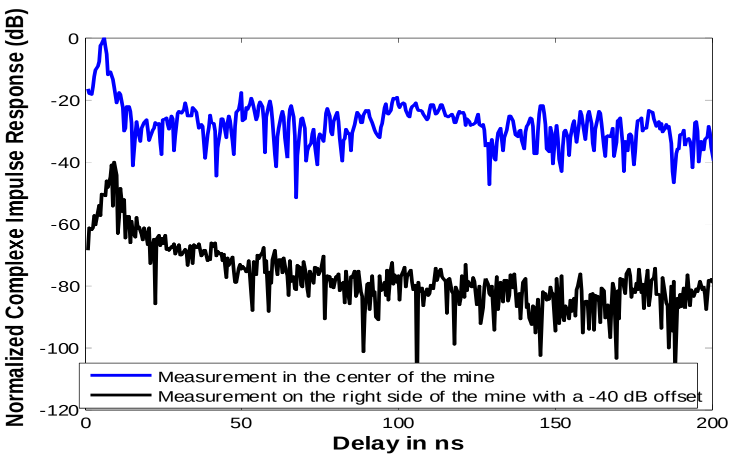

Fig 2 Normalized power delay profile at a distance of 1.6 meters for both scenarios.

Two normalized PDPs at a distance of 1.6 meters are presented in Fig.3. For clarity reasons, the PDP in scenario 2 is offset by -40 dB. In both scenarios, the LOS path is always present, and it is followed by several multipath components. In the case of scenario 1, the multipaths decay faster. However, after 50 ns, there is a multipath which is less than -20 dB of the strongest component. For the second configuration, the directive antenna filtered the different paths. The delays, after the LOS component, decay also rapidly in amplitude.
With the time of arrival (TOA) of the shortest path, the experimental distance can be found, and therefore, the measurement system accuracy can be verified. The distance is calculated as follows:

$$d = c * \tau_1 \qquad (1)$$

where c is the speed of the light in free space and τ1 is the TOA of the shortest delay. For scenarios 1 and 2, TOAs are found to be 5.9991 ns and 5.4973 ns, respectively. The corresponding experimental distances are 1.7997 meters and 1.6492 mm. This correspond to errors of 0.1997 meters and 0.0492 for scenarios 1 and 2, respectively. This could be attributed to the fact that the ground plane in the underground mine environment is uneven at different places.

a. Number of paths

The impulse response (IR) of the underground channel can be written as:

$$h(t) = \alpha_k \sum_{k=0}^{N-1} \delta(t - t_k) e^{j\theta_k} \qquad (2)$$

where N is the number of multipath components, α_k, t_k and $\theta_k$are the random amplitude, arrival-time and phase of the k^{th} path, respectively, and δ is the delta function. The phases θ_k are assumed to be an independent uniform random variables over [0, 2π].

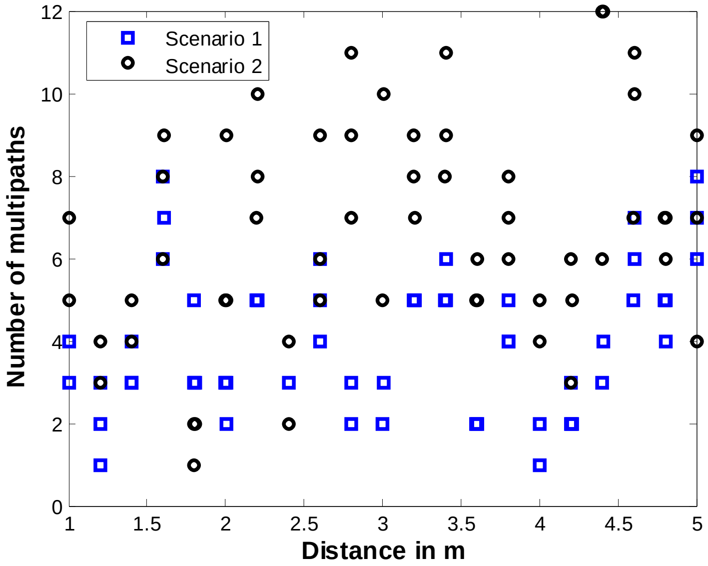

Figure 2. Number of multipath components in both scenarios

The number of paths are obtained by simply counting the number of paths on the power delay profile with the multipath components with amplitude within 20 dB of the peak value of the PDPs. Fig. 4 depicts the results of the number of paths in the center and right side scenario in function of the distance. As expected, the presence of the antennas near the wall will create more paths. The average values for the number of paths in scenario 1 and scenario 2 are 3.98 and 6.31, respectively.These two values are higher than the mean value of number path of 3.5 and 2.2, obtained at 60 GHz in a hall and a corridor, and published in [6]. The reflective nature of the underground mine is thereby illustrated. The numbers of multipath distributions in both scenarios have been fitted to the Poisson one, which is given by:

$$P(N) = \frac{\eta^{N_T - N}}{(N_T - N)!} e^{-\eta} \qquad (3)$$

where N, N_T, and η are a random variable, the maximum value and the mean of number of paths. N_T is equal to 8 and 12 for scenarios 1 and 2, respectively

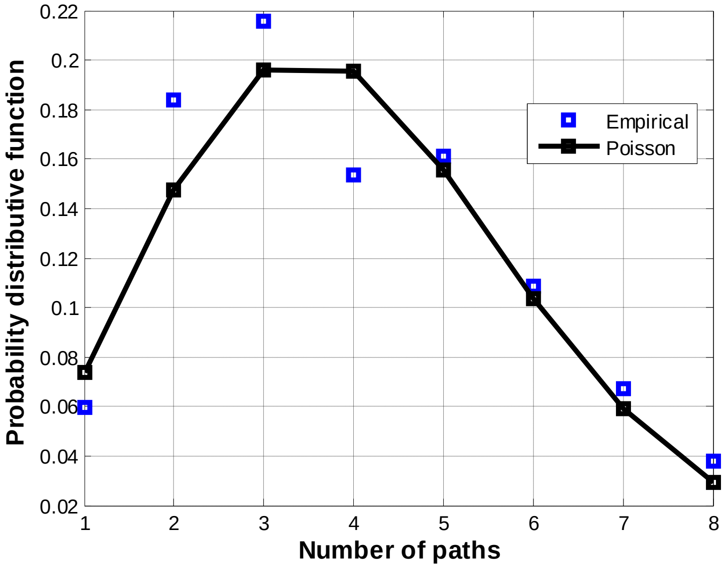

Figure 3. Probability distribution function of the number of paths for scenario 1.

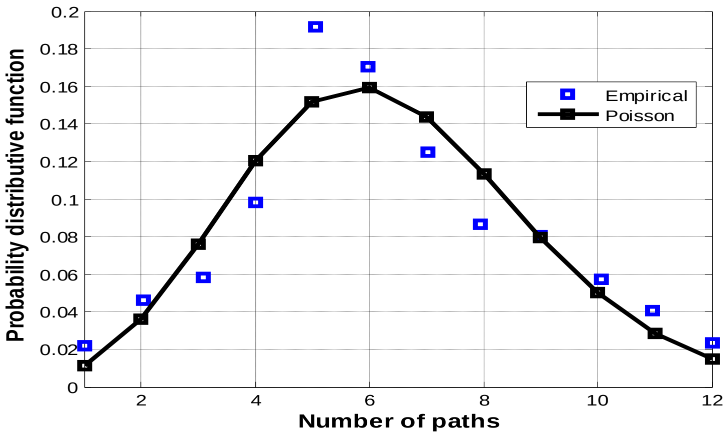

Figure 4. Probability distribution function oof the number of paths of scenario 2.

From Fig 5, it can be seen that the Poisson's distribution moves away from the distribution of number path in scenario 1. The distribution of Poisson represents best the distribution of number of path in scenario 2, as shown in Fig. 6. The same results have been reported by Geng and al in a corridor at 60 GHz [6]. When the mean of number of path is lower, its distribution deviates from the Poisson one, whereas for higher values ofnumber of paths, there is a concordance between the two distributions.

Delay spread and mean excess delay

In this underground mine; there are different obstacles such as the walls, the electric wires, the telecommunications cables, the ventilation systems and the pipes… All these elements will cause some reflection and scattering. The received signal will suffer from multipath fading, which come from the vectorial sum of the different multipath.Two keys time dispersion parameters that can be obtained from the PDPs are the mean excess delay and the delay spread. The mean excess delay is the first moment of the PDP, and the delay spread is the square root of the second central moment of the PDP. They are defined as [12]:

$$\tau_{rms} = \sqrt{\overline{\tau^2} - \bar{\tau}^2} \qquad (4)$$

$\bar{\tau}$, the first moment is defined as:

$$\bar{\tau} = \frac{\sum_k a_k^2 \cdot \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k) \cdot \tau_k}{\sum_k P(\tau_k)} \quad (5)$$

and

$$\bar{\tau}^2 = \frac{\sum_k a_k^2 \cdot \tau_k{}^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k) \cdot \tau_k{}^2}{\sum_k P(\tau_k)} \quad (6)$$

where a_k, $P(\tau_k)$, and τ_k are the gain, power, and delay of the k^{th} path, respectively

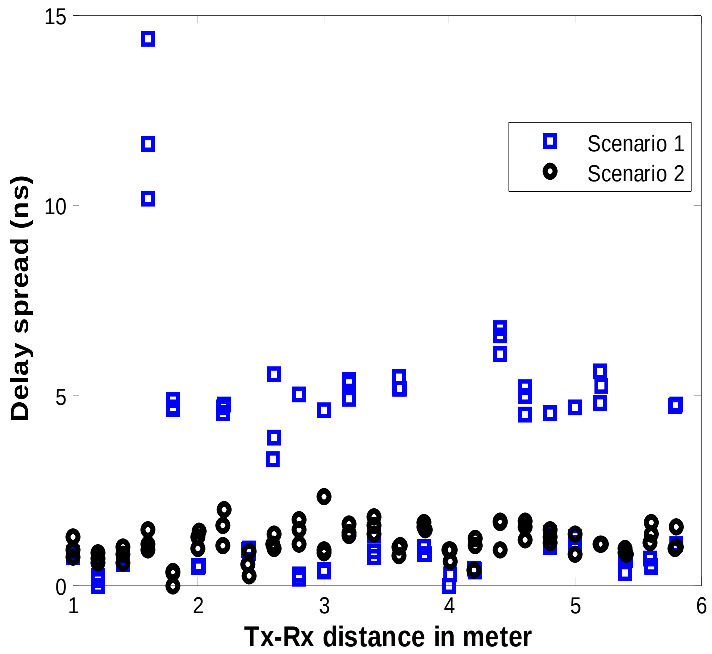

Figure 5. Delay spread in both scenarios.

The time dispersion parameters were calculated by taking the multipath components with amplitudes within 20 dB of the peak value of the PDF, for both scenarios. The variation of the delay spread in function of the distance has been plotted in Fig. 7. As mentioned in previous works in confined area, this parameter has been found not to be correlated to the distance between the transmitter and the receiver [1-3]. The same results are obtained in these measurement campaigns. The delay spread changes significantly between scenarios. For scenario, the delay spread varies from 0.15 ns to 14.13 ns, with a mean value of 2.84 ns. In the other hand for scenario 2, the delay spread is between 0.13 ns to 2.32 ns. A mean value of delay spread is found to be 1.13 ns. The same kinds of results have reported previously in an indoor measurement campaigns similar at 60 GHz [4]. The author uses some high gain directive antennas, and the delay spread is less than 2 ns with a dynamic range of 30 dB. For a threshold of 20 dB, like in this case, the delay spread should even be less.The results obtained in this current characterization are due to the spatial filtering capacity of the directive antennas and to the high received power in scenario 1. The mean, maximum and the standard deviation of the delay spread and the mean excess are summarized in Table I. This values are compared to a results obtained at 2.4 GHz in the same mine, over the same distance and in the center of the gallery. All the values of the different time dispersion metrics are higher than those obtained at 60 GHz. One can conclude that the 60 GHz frequency band can offers some transmission with rates of someGbps.The mean excess delay has also been computed for the samethresholdlevel of 20 dB. It can be seen that, for scenario 1 and scenario 2, that the mean excess delay varies from 3.99 ns to 99.45 ns and from 5.50 ns to 33.48 ns, respectively. The average values for scenario 1 and scenario 2 are 35.20 ns and 16.7ns, respectively. The result obtained in Fig. 3 can be a good indication of the difference of values for both scenarios.

TABLE I. MEAN, STANDARD DEVIATION (STD), AND MAXIMUM FOR THE DELAY SPREAD AND THE MEAN EXCESS DELAY FOR SCENARIO 1, SCENARIO 2 AND RESULTS AT 2.4 GHZ

	Delay spread (ns)			**Mean excess delay (ns)**		
	Mean	***Std***	***Max***	***Mean***	***Std***	***Max***
Scenario 1	2.84	2.81	14.38	35.20	25.14	99.45
Scenario 2	1.12	0.41	2.31	16.7	6.27	33.48
Results at 2.4 GHz	12.74	5.83	26.48	69.07	33.31	152

Path loss

The path loss is a critical factor in the design of wireless communication systems. In addition, it can indicate the area covered by this radio frequency system. In the underground mine, the path loss of electromagnetic waves affects he received power and the link budget of the system. The average path loss can be estimated from the measurements using [11]:

$$PL(d)_{dB} = \frac{1}{M\ N}\sum_{i=1}^{M}\sum_{j=1}^{N}|f(i,j,d)|^2 \qquad (7)$$

where |f(i,j,d)| is the measured complex frequency response deduced from the measurements. M and N are the number of data points (which is 6401).

The path loss in terms of the distance in dB can be written as a random log normal distribution:

$$PL_{dB} = PL_{dB}(d_0) + 10\ \mathrm{n}\log(d/d_0) + \delta_\sigma \qquad (8)$$

where$PL_{dB}(d_0)$ is the path loss at the reference distance.n is the path loss exponent, δ_σ is a Gaussian random variable with zero-mean (in dB) and a standard deviation σ also in (dB).

$PL_{dB}(d_0)$and n are estimated by using a linear least mean square fit method. Fig. 8 shows the path loss as a function of the distance in both scenarios. Table II gives the path loss exponent and the standard deviation of the random variable in all cases. In both scenarios, the path loss is much lower than the one in free space. For scenario 1 and scenario 2, the values of and σ are (n = 1.65, σ = 2.5 dB) and (n = 1.51, σ = 3.24 dB), respectively. The values of path loss exponent obtained are due to the wave guiding effect of the underground mine and to the use of directive antennas. These results are compared to those obtained in the same mine, but in another gallery [10]. The obtained path loss exponent is around 1.65 at the frequency of 60 GHz in the center of the gallery. This is due of the difference in the dimensions of the gallery used in these measurements.

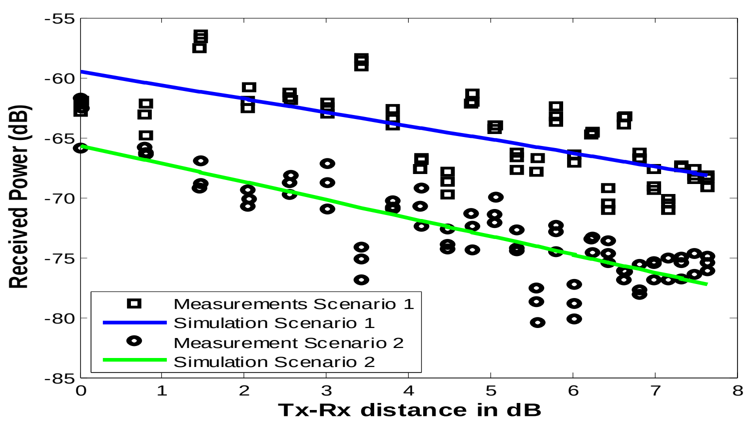

Figure 6. Path loss results in both scenarios.

TABLE II. MEAN, STANDARD DEVIATION (STD), AND MAXIMUM FOR THE DELAY SPREAD AND THE MEAN EXCESS DELAY FOR SCENARIO 1, SCENARIO 2 AND RESULTS AT 2.4 GHZ

Scenario	**1**	**2**
n	1.15	1.51
PL(do) in dB	-59.50	-65.65
Sigma (dB)	2.5	2.3

IV. CONCLUSION

In this paper, a 60 GHz propagation channel has been studied in an underground mine in line of sight configurations. The effects of the antenna locations have been investigated. Different statistical parameters have been presented. The shapes of the power delay profiles were affected by the antenna placements. The number of paths exhibits a Poisson distribution for large value of number of paths. It has also been demonstrated that the RMS delay spread is not correlated to the distance between the transmitter and the receiverbecause of multimodes nature of the underground mine. The RMS delay spread on the right side of the gallery, and near the wall, is less than the one measured in the center of the gallery. The delay spread varies between 0.13 ns and 2.30 ns with a mean value of 1.23 ns for scenario 2, which is the measurement on the right side of the gallery, for a threshold of 20 dB. For comparison reasons, a 2.45 GHz underground channel has also been characterized. The multipath nature and the wave guiding effects of the real underground mine were shown by the value of the path loss exponent, which is less than the one of free space in LOS. Therefore, with such performances, The 60 GHz frequency band can be used in in mining industry to transmit data rates over someGbps.

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