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ON THE PERFORMANCE OF MIMO SYSTEMS FOR LTE DOWNLINK IN UNDERGROUND GOLD MINE

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Abstract—This paper deals with the challenges related to evaluating the performance of Multiple Input Multiple Output (MIMO) antenna based on Long Term Evolution (LTE) system within an underground mine environment at 2.4 GHz. Actual measured channels parameters have been used in simulation tools based on Agilent SystemVue software. The results suggest that LTE is able in practice to support multi stream transmission with very high data rates in an underground mine gallery.

1. INTRODUCTION

LTE standard is considered as one of key candidates for the next generation wireless communications. The new evolution aims to reduce delays, improve spectrum flexibility and reduce cost for operators and end users [1]. To fulfill these targets, new enabling technologies need to be integrated into the current 4G radio network architectures. MIMO is one of the crucial enabling technologies in the LTE system to achieve the required peak data rate and the increase of the channel capacity [2].

Towards the characterization of MIMO wireless channels, tunnels and subways have always been special environments where wireless communications are needed. In [3, 4] Liénard et al. examine the possibilities of increasing the channel capacity through the use of

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MIMO techniques. However, to our knowledge, no measurements for the MIMO radio channel in underground mines have been reported in literature. In fact, this work presents measurements in a real underground mine of a MIMO system at 2.4 GHz combined with simulation using Agilent SystemVue software [5], along with a complete LTE physical layer library. The simulation results successfully match the standard requirement, and show a good performance in terms of capacity. Thus, it can be used for communication applications at 2.4 GHz, leading to operational enhancements and safety for the underground mining industry.

2. THE MEASUREMENT CAMPAIGN

2.1. Propagation Environment

Measurements were conducted in an underground gallery of a former gold mine located at 40 m deep underground level. The gallery stretches over a length of 75 m with a width and height both of approximately 5 m. It also has several branches of different sizes at variant locations. The humidity is still high, drops of water falling from everywhere and big pools of water cover the ground. A map of the underground gallery is shown in Figure 1.

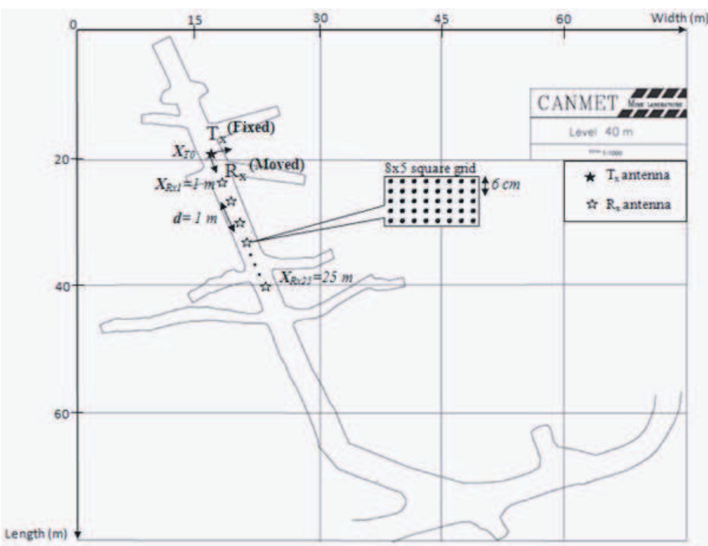

Figure 1. The underground gallery plan.

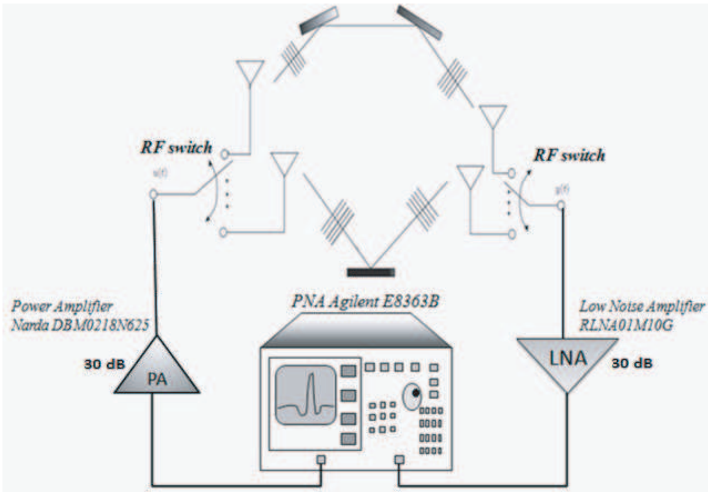

Figure 2. Measurement setup.

2.2. Channel Sounder and Methodology

Different techniques can be used for measuring the MIMO channel parameters. The most straightforward method would be to measure the radio channels between different transmit and receive antenna pairs separately using antenna switching at the TX and the RX. Both the TX and the RX of these sounders employ a synchronized switching to step through all the antenna elements. Such a technique is a simple extension of single-input single-output channel sounders. Thus every channel is measured sequentially. The measurement where all the T_X and R_X channels are measured is called a channel snapshot. The problem with this method is that if RF switching is used both at T_X and at R_X, the wireless channel has to be considered as static with no significant variations during one channel snapshot. In fact, the experimental setup as shown in Figure 2 consists of a network analyzer (Agilent E8363B), two sets of 2×2 conventional MIMO Patch antenna system vertically polarized and two amplifiers: power and LNA are used at the transmitter and the receiver respectively. Moreover, the parameters of the channel sounding measurements should be carefully selected in order to assure adequate multipath resolution and at the same time reducing the total time required for the frequency sweep. In fact, the PNA sweeps the frequency range from 2 GHz to 3 GHz for 6401 points and records the 6401 tones. So the frequency step is 156.22 kHz which corresponds to time domain duration of 6401 ns. In other words, the measurement system is capable of catching multipath components that arrive with a delay up to 6401 ns. This duration of impulse response is found to be long enough for such underground environment. However, before we take the channel measurement, the frequency domain channel sounding system needs to be as well calibrated. The calibration is performed with the transmitting (T_x) and receiving (R_x) antenna apart 1 m separation distance. This 1 m T-R separation distance d_0 is chosen to be the reference distance for the large scale path loss model. For all experiments, the transmitter remained fixed, while the receiver changed its position along the gallery, from 1 meter up to 25 meters far from the transmitter under line of site (LOS) conditions at steps of 1 m on an 8×5 square grid with a resolution $\Delta_d = 6$ cm. Therefore, at each measurement position the antenna pair is moved mechanically within the grid and 20 snapshots are performed. The local mean is then obtained by averaging static power measurements taken at these 20 different positions of the receive antenna around the specified locations. In fact, for each measurement position, the complex transfer function is:

$$G_{x,y,f} = A_{x,y,f} e^{j\theta_{x,y,f}} \tag{1}$$
$$x, y \in \{1, \dots, n_g\}, f \in \{1, \dots, n_f\}.$$

$A_{x,y,f}$ and $\theta_{x,y,f}$ are the measured magnitude and phase responses at frequency f on grid position (x, y).

During all measurements, the height of the transmitting and receiving antennas are maintained at 1 m above the ground level. The transmit power is set to 10 dBm and the received impulse response is obtained from the scattering parameter S_{21} measured over a certain bandwidth followed by the Inverse Discrete Fourier Transformation (IDFT). Furthermore, the MIMO antennas are separated by half the wavelength ($\lambda/2$), with a gain of 8 dBi and a fractional bandwidth of around 21% each.

3. POWER DELAY PROFILE

A wireless channel can be described by its impulse response. For any fixed location between transmitter and receiver, under static conditions, the overall average of the magnitude squared of the impulse response is referred to as the power delay profile (PDP) and is given by:

$$PDP(t) = \langle |h(t)|^2 \rangle \tag{2}$$

Thus, the power delay profile (PDP) is estimated by averaging 20 static measurements taken at 20 different positions of the receive antenna around the specified location. These 20 positions were separated

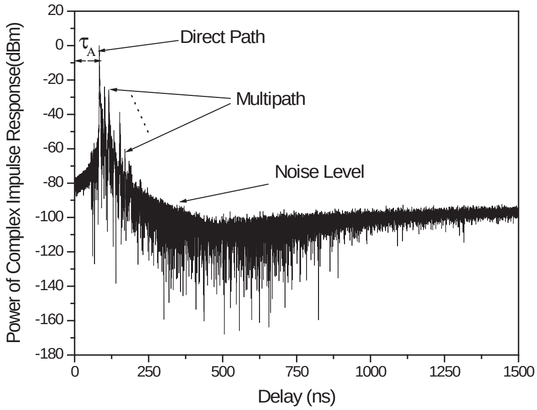

Figure 3. Normalized PDP sample.

from each other approximately by a half wavelength, so as to obtain independent measurements. After that the *PDP* was normalized to its maximum power.

Different types of radio propagation environments produce differently shaped PDPs. For instance, Figure 3 shows the normalized PDP measured in a separation distance of 4 m in the underground mine.

4. SYSTEMVUE

4.1. Definition

Agilent SystemVue is a powerful, electronic system level (ESL) design environment that allows system architects and algorithm developers to innovate the physical layer (PHY) of next-generation wireless. It provides unique value to RF, DSP and FPGA/ASIC implementers who rely on both RF and digital signal processing to deliver the full value of their hardware platforms that adhere to the physical layer of modern emerging standards. Thus, it replaces general-purpose analog, digital and math environments by offering a dedicated platform for ESL design and signal processing realization. In fact, SystemVue Models full WINNER (Wireless World Initiative New Radio) and WINNER-II channel fading for 4G link-level simulation and throughput scenarios [6]. In addition, it allows fully-configurable up to 8x8 MIMO array needed for LTE Advanced, arrays, with importation of 2D antenna patterns for realistic MIMO crosstalk and propagation effects.

4.2. LTE System Results

SystemVue offers design tools which, later in the design process, can be interfaced with test instrumentation to provide a mixed hardware and simulation environment. Figure 4 shows the top level schematic for LTE downlink 2 × 2 MIMO throughput measurements. T_X_DL and R_X_DL represent the subnetwork of physical layer baseband

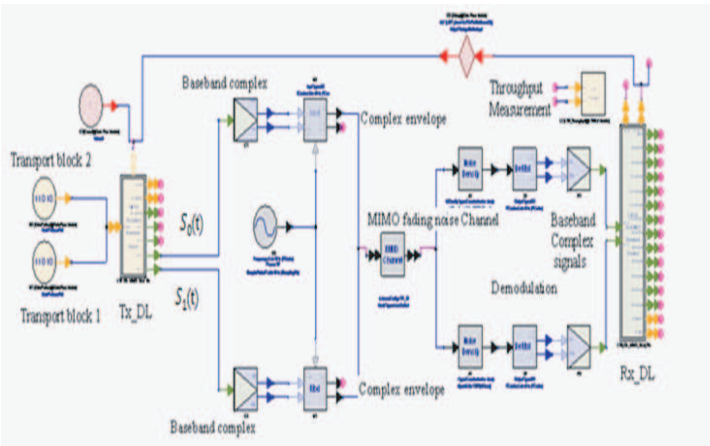

Figure 4. Layout of a complete transmitter and receiver with faded MIMO channel using Agilent SystemVue software.

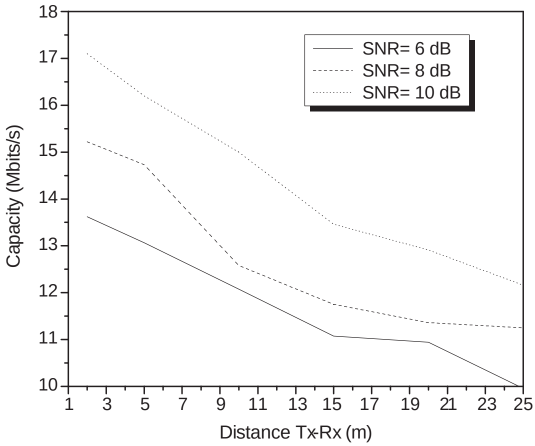

Figure 5. Capacity of LTE-MIMO system for SNR = 6, SNR = 8, SNR=10.

transmitter and receiver models respectively. The baseband complex-valued signals $S_0(t)$ and $S_1(t)$ generated from T_X_DL are modulated, transmitted through fading and noisy channel, and then demodulated. The upper feedback path models the feedback from R_X_DL to T_X_DL to maintain the system synchronous. However, it is interesting to investigate for certain signal to noise ratio, the effect of the distance upon the channel capacity. SystemVue uses the theoretical capacity for a uniform distributed transmitted power with a signal to noise ratio of ρ which is expressed as [7]:

$$C = \log_2 \left(\det \left[I_N + \left(\frac{\rho}{M} H H^* \right) \right] \right) \text{(bit/s/Hz)} \tag{3}$$

where I_N is the identity matrix $N \times M$, $()^*$ is the complex conjugate function, and H is the Frobenius normalised transfer function. In our case the number of input $N = 2$ and output $M = 2$. Hence, the measurements data uploaded into the systemvue software are basically composed of: the PDP (Power Versus Delay). Figure 5 shows the throughput performance of the LTE system for various SNR = 6 dB, 8 dB and 10 dB. Due to path loss, the capacity is obviously a decreasing function of distance. Consequently, we can expect a decrease of MIMO performance for wider signal coverage. In fact, it can be seen that a channel capacity of 12,01 Mbits/s can be achieved at $d_{Tx\text{-}Rx}$ =25 m for an SNR of 10 dB compared to 11.23 Mbits/s and 9.75 Mbits/s for SNR of 8 dB and 6 dB, respectively. Therefore, the curve of the higher SNR gets more throughput. However, a changing gradient of the channel capacity at SNR=6 dB with increasing distance is noticeable between 15 m and 20 m. This can be explained by the multipath richness at that zone. Therefore, lower channel correlation is guaranteed, which improves the MIMO channel capacity. Consequently, lower slope value is observed at the specified zone comparing to other positions in the undertaken measured gallery.

5. CONCLUSION

This paper analyses the experimental results obtained from a measurement campaign in order to characterize the 2 × 2 MIMO channel at a frequency of 2.4 GHz in underground mining gallery. Channel measurements are extracted and implemented to simulate the LTE-MIMO system using SystemVue software. Results show propagation behaviour that is specific for these underground environments. Hence, the achievable MIMO capacity gain depends on the multipath characteristics of the propagation channel. The MIMO system in LTE standard presents a good performance in terms of capacity. Therefore, it can ensure a channel capacity higher than

12 Mbits/s for an SNR = 10 dB for a coverage distance up to 25 m which is enough for short range communication to improve miners productivity and safety whom are working in the same area. Thus, the LTE-MIMO system is useful for underground mining communication.

REFERENCES

1. "LTE Physical Layer — General Description (Release 8)," 3rd Generation Partnership Project, Tech. Rep. TS 36201, V8.1.0, Nov. 2007.
2. Wei, N., A. Pokhariyal, T. B. Sorensen, T. E. Kolding, and P. E. Mogensen, "Performance of MIMO with frequency domain packet scheduling in UTRAN LTE downlink," *IEEE VTC*, 2007.
3. Molina-Garcia-Pardo, J.-M., M. Liénard, E. Simon, and P. Degauque, "On the possibility of applying polarization diversity in tunnels," *Proc. MSWIM Conf.*, 392–395, Tenerife, Spain, Oct. 26–30, 2009.
4. Liénard, M., P. Degauque, J. Baudet and D. Degardin, "Investigation on MIMO channels in subway tunnels," *IEEE J. on Selected Areas in Communications*, Vol. 21, No. 3, 332–339, Apr. 2003.
5. LTE-Advanced Signal Generation and Measurement Using SystemVue: http://www.agilent.com/find/eesof-systemvue.
6. Ndzi, D. L., K. Stuart, S. Toautachone, B. Vuksanovic, and D. A. Sanders, "Wideband sounder for dynamic and static wireless channel characterisation: Urban picocell channel model," *Progress In Electromagnetics Research*, Vol. 113, 285–312, 2011.
7. Noori, N. and H. Oraizi, "Evaluation of MIMO channel capacity in indoor environments using vector parabolic equation method," *Progress In Electromagnetics Research B*, Vol. 4, 13–25, 2008.