Line-of-Sight-Polarized Wide-Band Mimo Measurements at 2-5 GHz

Muhehe D. J.[1*], Muia M. L.[2], Ogola W.[3]
[1]Department of Electrical and Communications Engineering, Masinde Muliro University of Science and Technology, P.O. Box 190-50100, Kakamega, Kenya.
[2]Department of Physics, Kenya Polytechnic University College, P. O. Box 52428-00100, Nairobi, Kenya.
[3]Department of Mechanical and Mechatronics Engineering, Kenya Polytechnic University College, P. O. Box 52428-00100, Nairobi, Kenya.
E-mail: muhehed@yahoo.co.uk, lavimuia@yahoo.com, wogola@hotmail.co.uk
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Abstract

A short- range line of sight (LOS) multiple-input multiple-output (MIMO) channel transfer function was measured for a 4x4 system between 2.0 and 5.0 GHz. Measurements were made for a fixed antenna spacing of 2λ for all the four antenna polarizations in an indoor environment. Capacity and spatial correlation were investigated and the maximum mean capacity loss of 7.18% was realized when the orientation of the receiving and the transmitting antenna arrays were transformed from co-polar to cross-polar configuration. Furthermore, a validity test was conducted and the empirical distribution was found to be the same and within the theoretical values.

Keywords: Spatial correlation, polarization, multi-input multi-output (MIMO), Non line of sight (NLOS), Line of sight (LOS), Capacity.

Introduction

Multiple antenna array technologies can significantly enhance the performance of radio systems. MIMO (Multiple-input multiple output) signaling techniques in particular offer diversity/multiplexing gains to provide considerably higher channel throughputs as compared to convectional single antenna systems (Teletar, 1995; Foshini and Gans, 1998). MIMO communications has been a topic of great interest by the international research community in the past few years. Whilst space- time coding and signal processing are essential to the implementation of MIMO technologies, often the radio propagation channel along with the antenna array type and geometry proves to be the major restriction in utilizing this technology (Molina *et al.*, 2008; Xu *et al.*, 1999). Thus, the experimental polarization characterization is vital in the development of MIMO technologies, which are intended for ad-hoc as well as for cellular systems (Kyritsi *et al.,* 2002; Zhao *et al.,* 2003). The aim of this work is to analyze the capacity and spatial correlation using wide-band measurements operated under fixed received power in the Ricean LOS scenario.

Materials and methods

The Environment

The measurements were carried out from the underground level of the Technical University of Cartagena (Spain), which consists of a 50-meter long corridor, three perpendicular corridors, and some laboratories. A plan view of the selected indoor environment is depicted in Figure.1. The walls of such a building are made of plasterboard while the floor and the ceiling are made of reinforced concrete.

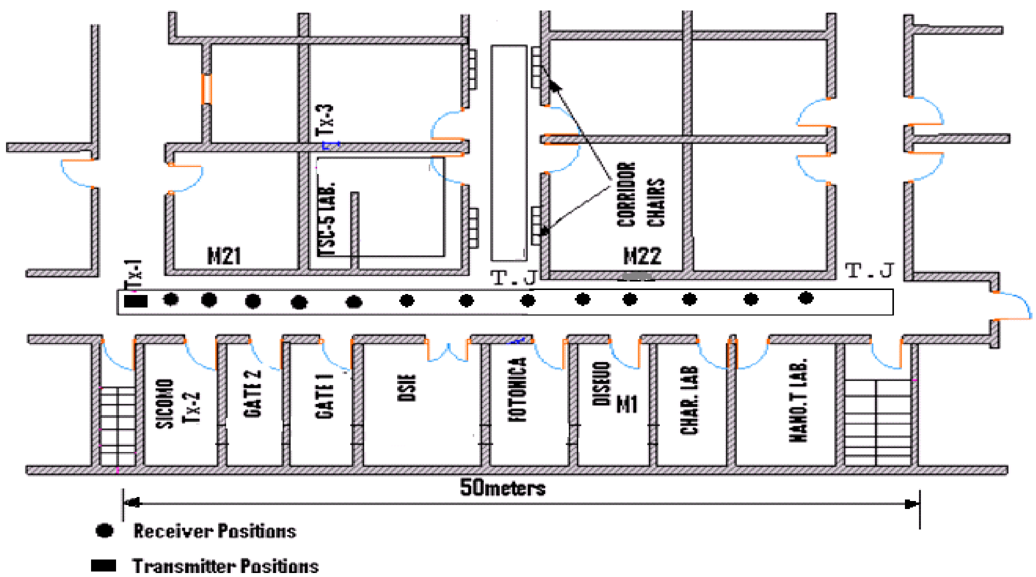

Figure 1: Block diagram of the MIMO Channel sounder (Molina *et al.,* 2008)

Channel Sounder

Since our aim was to explore the channel response in a very wide frequency range band (2.0-5.0GHz). We chose to make the measurements in the frequency domain, so as to get larger and uniform dynamic range across the frequency spectrum. The complex channel transfer function between the transmitting (T_X) and receiving (R_X) antennas were obtained by measuring the S_{21} (Forward transfer Insertion gain) S-parameters using a multiport vector analyzer (MVNA), composed of an Agilent ENA E5071B and Multiport Test set E5091A, and a solid state fast switch,(Agilent 87406B, controlled by a switch driver Agilent 11713A) (Figure.2).

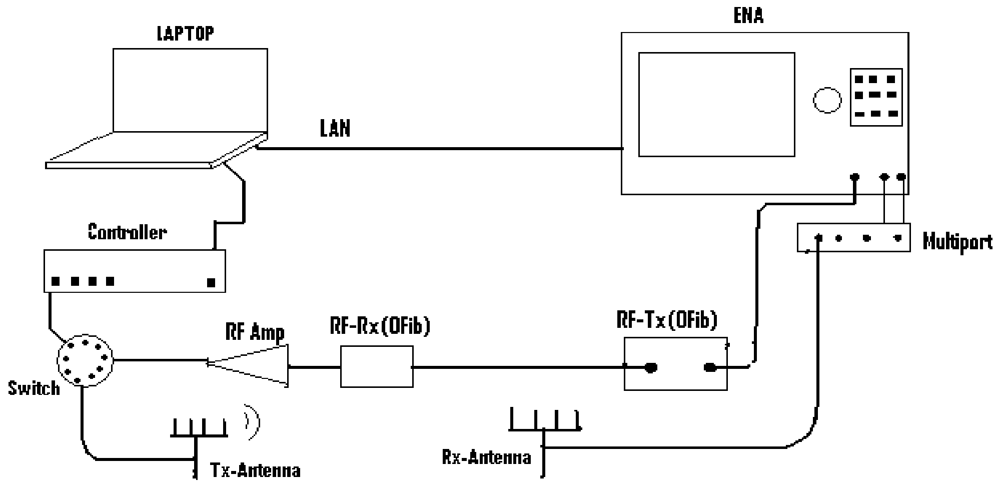

Figure 2: Block diagram of the MIMO Channel sounder (Molina *et al.*, 2008)

The receiving antennas were directly connected to the ports of the MVNA using a 4-meter long low loss coaxial cable. One port of MVNA is configured as a transmitter and connected to a fifty-meter long optical link (RF/OF) and (OF/RF), which carries the signal to the fast switch via a low noise 30dB RF Amplifier. Finally, the transmitting antennas were connected to the fast switch. Such optical link is composed of an optical fiber 50 meters long, a Ortel 3540A transmitter (RF/OF) and a Ortel 4510B optical receiver (OF/RF). Finally, the transmitting antennas are connected to the first switch, so that the signal from optical link is transmitted sequentially to each element of the transmitter array. The measurement process is controlled by a developed program executed from a laptop. The laptop is connected to the MVNA by a local area network (LAN) and subsequently connected to the first switch by the general- purpose interface bus (GPIB) port.

For measurements, we used eight Electro-metrics Omni directional mast mounted antennas (EM-6116) with a 1dBi gain over 2-10 GHz frequency band and XPD of 12 dB. The antennas were held on a mast that was 2- meters high. The phase stability of the fiber optics link was checked and the calibration of the MVNA takes frequency response of the amplifiers, cables, and optic coupler into account. The block diagram of the channel sounder is depicted in Figure 2.

Measurement Procedure

The 4x4 MIMO system was configured as follows:- a (2 – 5GHz) frequency wide band was selected for measurements. We measured over 801 equal spaced points five times so as to ensure the stationarity of the channel. and also to improve the SNR of the measurements. An intermediate frequency of 3 KHz was chosen and the frequency resolution is Δf = 3.75 MHz. The coherence bandwidth is defined as the range of frequencies over which the channel is can be considered flat (Rappaport, 2002). When the correlation function is above 0.9, the coherence bandwidth was found to be around $WB_c \approx$ 25MHz. This value is much higher than the frequency resolution Δf, validating thereby, the correct frequency sampling of the measured frequency sampling of the measured channel transfer functions within the bins of width Δf .The transmitted power from each antenna was 0dbm and the noise floor was -100dBm; the attenuation of the antenna cables was -5dB coupled with 30dB gain of the R.F Amplifier. Therefore, the dynamic range of the channel sounder was greater than 90dB enough to ensure a high signal to noise ratio (SNR) in most measurements.

The transmitter Tx_1 (Black square) was positioned in the middle of the corridor next to the SICOMO laboratory while the receiver (Black circles) was moved along the corridor and measurements were recorded at every 2 meters distance. Thirteen positions were considered which translated to a total distance of 26 meters.

The gain of the R.F amplifier was manually adjusted in order to compensate for the path losses. For each position (Pair transmitter-receiver), four combinations of uni-polarized arrays were measured in the LOS scenario. If we define V as the vertical polarization and H as the horizontal polarization for the elements of the array, then the mentioned four combinations are VV, HH, HV and VH, where the first letter is for the transmitter and the second letter is for the receiver (Figure 3). We can then define the G matrix for each polarization. The large size of the antennas meant we were unable to establish a separation between elements of the array of less than 4cm. Therefore, the antenna spacing had to be set to 2λ = 6cm (with λ referred to f_{max}). During the measurement campaign, there was no movement in the laboratory, so the channel was assumed quasi-stationary.

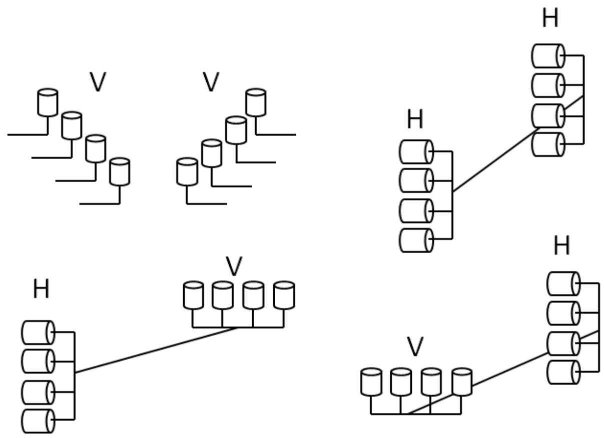

Figure 3: Different polarization for the antenna arrays

So at each position between the transmitter and the receiver, $G_{4x4x801x5}$ matrices were obtained, whose dimensions express the number of receiving antennas , transmitting antennas, analyzed frequencies and the time snapshots. This means that for every frequency sample, 4x4x5 matrices were analyzed.

Results and discussions

Capacity

The maximum theoretical capacity for a uniform distributed power MIMO given by equation (1). Here the entries in the H matrix are assumed to be independent and identically distributed (i.i.d) complex Gaussian variables with zero-mean and unit variance (Foschini and Gans, 1998).

$$C = \log_2 \det\left[I_m + \left(\frac{SNR}{n} \right) HH^H \right] bps / Hz, \quad (1)$$

Where:- I_m = m x m identity matrix,
SNR = received signal to noise ratio,
m = no. of received antenna elements in the array,
n = no. of transmit antenna elements in the array,
H = Frobenius normalized matrix (Channel transfer Matrix)
H^H = Complex Transpose conjugate operation

Correlation

The environment is essential to reach good MIMO performances, which implies rich scattering environment and low correlation between the antenna elements. We analyze correlation independently at both the transmitter and the receiver (Eggers *et al.,* 1993). The complex correlation coefficient at a frequency *f* for the k^{th} time realization between the reception antennas *p* and *q* can be computed as:

$$\rho^{pq}(f,k) = \frac{E\left[h^{p}(f,k)h^{q}(f,k)^{*}\right]}{\sqrt{E\left[\left|h^{p}(f,k)\right|^{2}\right]E\left[\left|h^{q}(f,k)\right|^{2}\right]}} \tag{2}$$

Where E[ ] is the expectation operation value for all the transmitting elements antennas. The correlation coefficient between the transmitting antennas is calculated similarly, by swapping the rows and the columns on the matrix (Molina *et al.,* 2008). Table I shows the summary of the mean capacity values and the respective mean correlation coefficient for all configurations.

Table 1: Summary of the correlation coefficients and capacity values for LOS measurements

	LOS (SNR=10dB)		
Polarization	**Mean (T_X correlation)**	**Mean (R_X_correlation)**	**Capacity (b/s/Hz)**
HH	0.5242	0.4519	11.1503
HV	0.5942	0.5226	10.3634
VV	0.4873	0.4603	10.8047
VH	0.4989	0.4764	10.8896

If we consider a fixed received power of say, 10dBm at LOS, the HH position posted the highest mean capacity and the least correlation coefficient at the receiver followed by VH, VV and HV configurations respectively. This is attributed to the fact that the relative permittivity of the ceiling and concrete floor is stronger than that of the plastered brick wall. A higher relative permittivity or the dielectric constant of a material implies higher values of reflection coefficient on incident waves (Suzuki and Mohan, 2000). There is a maximum mean capacity loss of 7.18% when cross-polar polarization is selected. Appendix A1-A4 shows the scatter plot and the respective regression line based on the least squares regression model (A1) for various modes of propagation.

From the estimated regression line analysis, it is evident that the capacity increases with the distance and this can be attributed to the increase in the decorrelation between the spatial channels (Molina *et al.,* 2008). However, in Figure A5 for the VH configuration, the trend is completely different. This may probably be attributed to the impact of clusters and the ricean K-factor, which outweighs the benefits of increasing delay spread in this mode of propagation (Tang and Sanagavarapu, 2005).

The mean correlation values, when using (Kyritsi *et al.,* 2003) show that the ricean channel can be considered highly decorrelated and this can be attributed to the multiple obstacles existing along the corridor. A mean correlation lower than 0.7 is realized in almost all cases. Furthermore, the mean correlation coefficients at the receiver were found to be lower than that at the transmitter. This phenomenon is attributed to the presence of scatterers that contribute to fading between the spatial channels.

Validity Test

Kolmogorov-Smirnov test was conducted in order to compare the complementary cumulative distribution function (CCDF) of the empirical data to that of the theoretical data, i.i.d. (Panahandeh *et al.,* 2005). The *p*-test statistic was conducted at 95% confidence level. In all the polarization tests, the *p*- values for different combinations posted values greater than 0.05, which confirms the normality of the empirical data about the mean. The probability density function of the measured capacity plotted against the respective capacity values is depicted in Figure 4. At CCDF=0.5, it is observed that the i.i.d mean supersedes the means of the measured data.

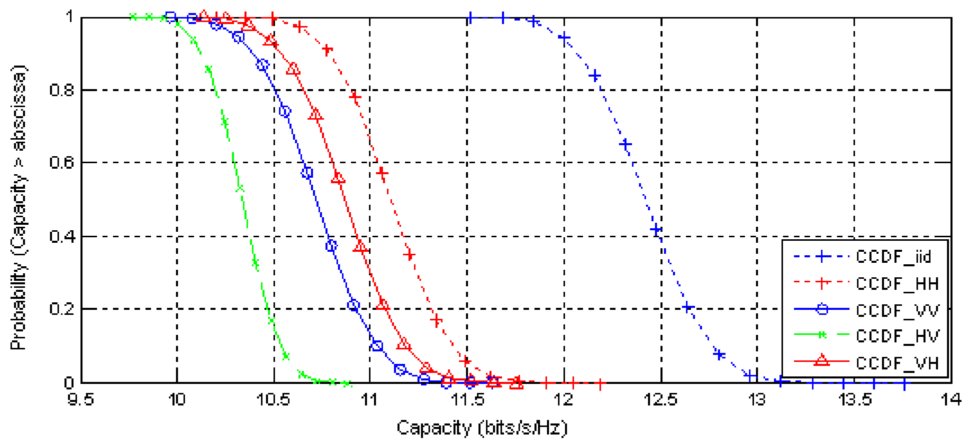

Figure 4: CCDF of the capacities per polarization dimension for the group of measurements in the LOS position for T_{X1} and $M_{21,}$ at SNR = 10dB together with the i.i.d channel

Conclusions

In this research a 4 x 4 MIMO in the line-of-sight (LOS) indoor measurement campaign at (2 -5GHz) has been reported. The Wireless channel response was measured for different polarization schemes at a fixed SNR . Measurements were made using Omni's whose gain is 1dBi over 2-

10GHz bandwidth. The following conclusions were made regarding the LOS measurements.

(i) For a constant received power, the effect of spatial correlation is much more important than the received SNR. In the LOS scenario, the HH configuration for the Omni multi antenna array dominated other configurations in terms of efficiency. If we consider the wide-band LOS measurements along the corridor, there was a maximum mean capacity loss of 7.18% when the cross- polar polarization was selected.

(ii) Mean correlation values at the transmitter and at the receiver were calculated and in all cases, the channel is considered to be as highly de-correlated, since the correlation lower than 0.7 is observed in almost all cases.

(iii) The mean correlation at the receiver is lower than the transmitter and the capacity was found to increase with distance in most of the propagation modes.

(iv) The empirical CCDF in the LOS for the group measurements along the corridor were found to be normally distributed about the mean.

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APPENDIX: LINEAR REGRESSION

Linear regression for various polarization measurements in the LOS along the corridor. The regression model based on Least squares method was used to model the estimated regression line.

$$\hat{Y} = b_0 + b_1 x \qquad \textbf{(A1)}$$

Where

$\hat{y}$ = Is the estimated regression line

b_0 = y-intercept of the estimated regression line

b_1 = slope of the estimated regression line

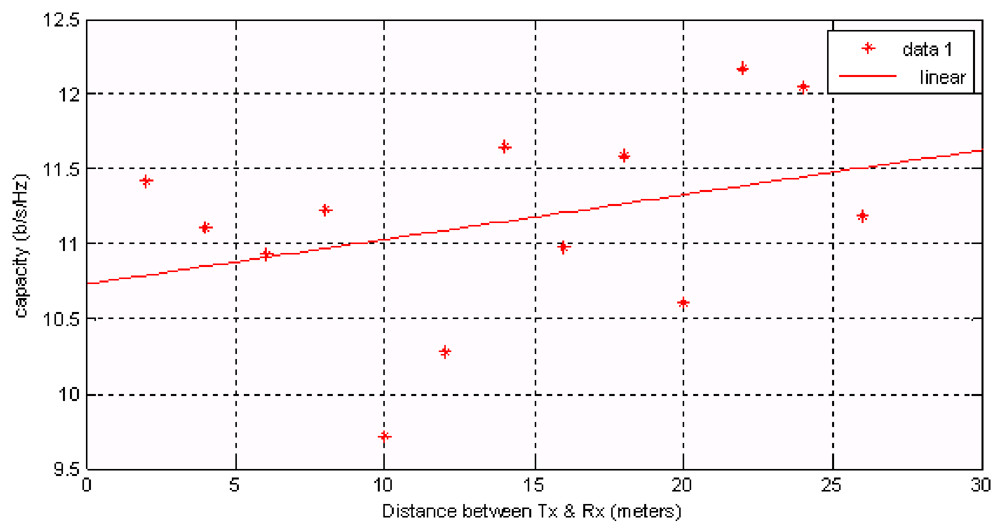

Figure A1: Scatter diagram and the estimated regression line for Capacities verses Distance(Tx_Rx) for HH polarization, LOS measurements at SNR=10dB

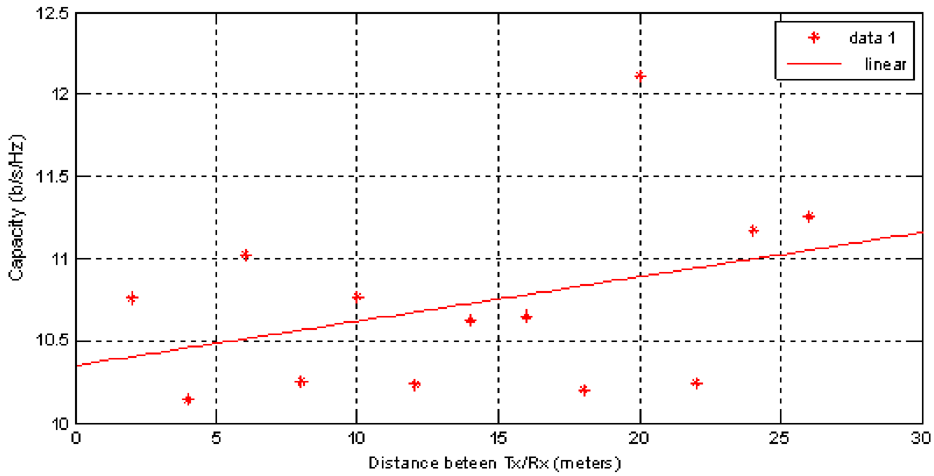

Figure A2: Scatter diagram and the estimated regression line for Capacities verses Distance (Tx_Rx) for VV polarization, LOS measurements at SNR=10dB

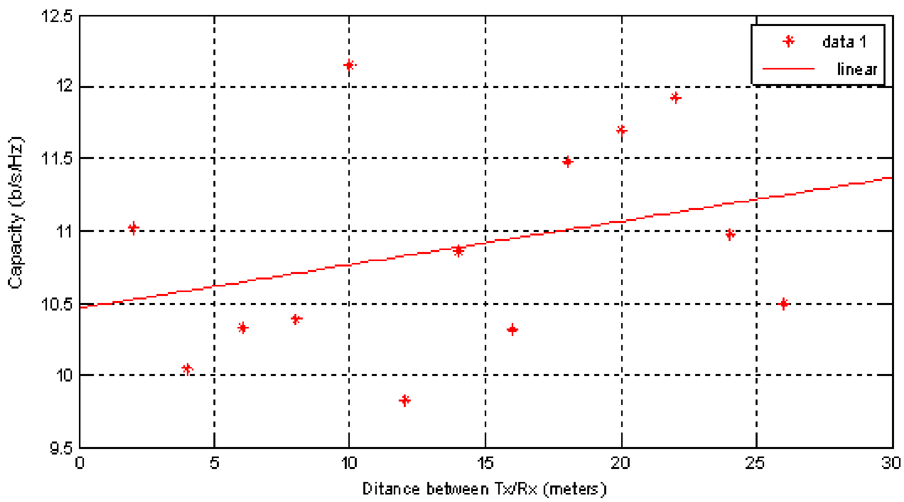

Figure A3: Scatter diagram and the estimated regression line for Capacities verses Distance (Tx_Rx) for VH polarization, LOS measurements at SNR=10dB

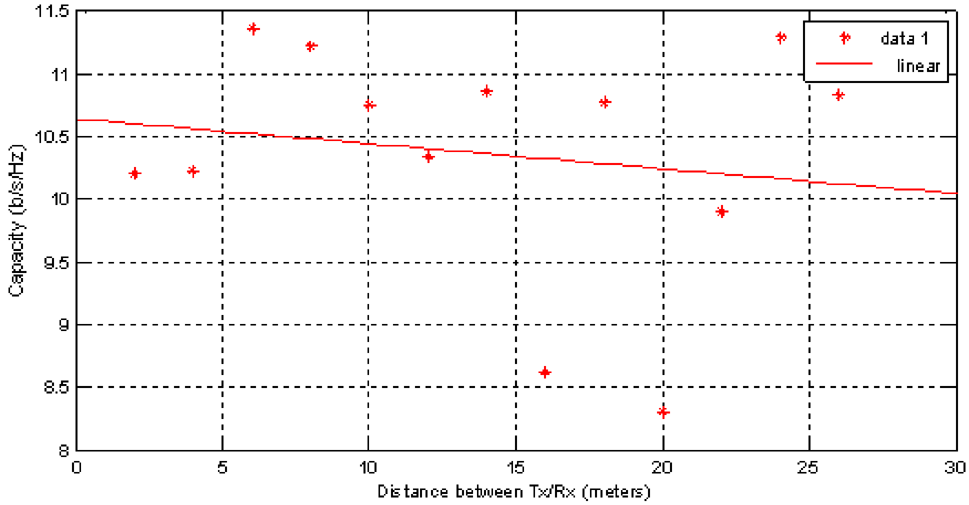

Figure A4: Scatter diagram and the estimated regression line for Capacities verses Distance (Tx_Rx) for HV polarization, LOS measurements at SNR=10dB