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# A broadband MIMO antenna's channel capacity for WLAN and WiMAX applications

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**ABSTRACT**

This paper describes the findings of a research into the multiple input multiple output (MIMO) channel capacity of a broadband dual-element printed inverted F-antenna (PIFA) antenna array. The dual-element antenna array is made up of two PIFAs that are meant to fit on a teeny-tiny and small wireless communication device that runs at 5 GHz. The device's frequency range is between 3.5 and 4.5 GHz. These PIFAs are also loaded into the device during the installation process. In order to investigate the channel capacity, the ray tracing method is employed in two different kinds of circumstances. For the purpose of carrying out this analysis of the channel capacity, both the simulated and measured mutual couplings of the broadband MIMO antenna are utilized.



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## 1. INTRODUCTION

Because of its capability to battle multipath fading and offer faster data rates, the technology known as multiple input multiple output (MIMO) has been regarded as a promising strategy for enhancing the capacity of wireless channels as well as their dependability [1]–[9]. However, the construction of numerous antennas on a tiny mobile terminal is a significant obstacle for the use of MIMO systems. This is due to the fact that doing so would enhance the mutual coupling and result in high correlation coefficients [10]–[12]. These antennas, which may be implemented using a variety of techniques [13]–[17], even if they are closely spaced, need to be capable of receiving signals independently, and the signals that are received need to be uncorrelated in order to attain a high capacity [18], [19]. Therefore, in order to get a higher MIMO channel capacity, it is necessary to have both adequate isolation between the antennas and appropriate radiation patterns.

The channel capacity and system link budget are studied in the work that has the reference number [20]. These calculations are based on measurements of the 28 GHz MIMO (4×4) channel that were carried out for both line of sight (LOS) and none line of sight (NLOS) situations. In order to accomplish this objective, a model of the MIMO channel capacity as a function of distance has been developed, and the study of the spatial correlation between antenna elements and channel capacity has been carried out. The findings indicate that there is a weakening of the correlation coefficient as the distance between the two points increases. And the uncorrelated channel has the potential to reach a larger capacity than either the partial or the complete correlated channels. The results of a simulation carried out by Wu [21] to determine the channel capacity of a MIMO system are presented. The simulation was carried out in MATLAB in accordance with a formula that was supplied for this purpose. The purpose of this research is to demonstrate that the channel capacity can be significantly improved by increasing the number of antennas while maintaining the same signal-to-noise ratio (SNR), which will result in a faster wireless transmission rate. This will be accomplished by proving the derived formula. Using the MIMO channel model in an indoor setting, Gao *et al.* [22] investigated the channel capacities of the modified dual-element printed inverted F-antenna (PIFA) array, the traditional dual-element PIFA, and two perfect dipoles. The conclusion drawn from this finding is that the channel capacity of the modified dual-element PIFA array with extremely low mutual coupling is quite similar to that of an ideal dipole array that does not have any mutual coupling at all. In addition to this, it has a higher mutual coupling strength than the traditional dual-PIFA, which has a strong mutual coupling.

Bakouchi *et al.* [23] presented a broadband PIFA antenna array for compact wireless communication device, which has provided a large bandwidth (670 MHz), a high isolation between its ports less than -26 dB with a good diversity performance. In this work, the channel capacity of this antenna array which operate at 5 GHz is investigated in a realistic indoor/outdoor and outdoor MIMO channel models, performed for NLOS scenario, by using a tool based on the ray tracing method. The ergodic and the outage channel capacity are studied in order to make a comparison between the performance of the broadband antenna array in the indoor/outdoor environment and the outdoor one, and to observe the improve of the wireless transmission rate.

## 2. RESEARCH METHOD

### 2.1. MIMO channel models

In this work, we made use of a ray tracing simulation program [24] in order to determine the MIMO channel response matrix H in both an indoor/outdoor and an outdoor wireless environment. This was accomplished by simulating the environment using rays. As the location for the indoor/outdoor wireless environment, the ground floor of the Department of Applied Physics in the Faculty of Sciences and Technologies of Marrakech has been selected. This hybrid indoor/outdoor setting is illustrated in Figure 1.

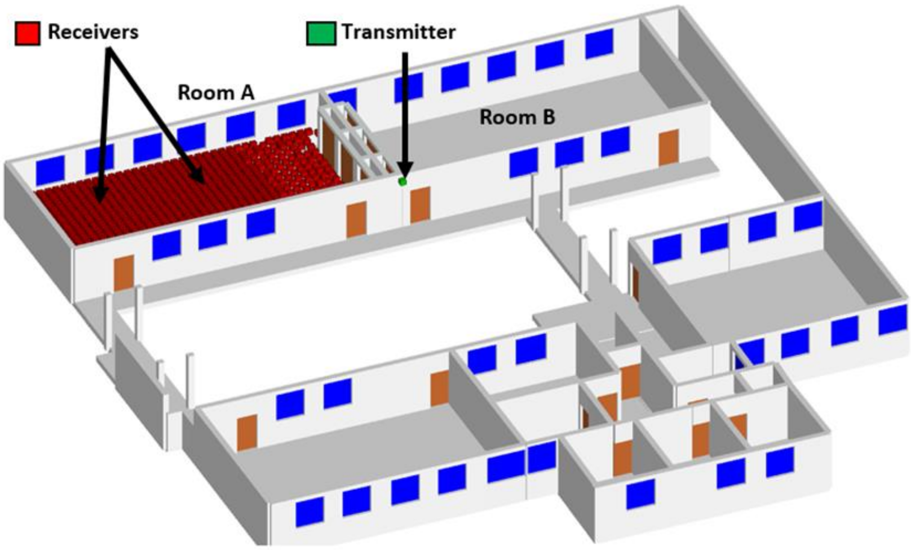


Figure 1. Indoor/outdoor wireless environment; Department of Applied Physics at Faculty of Sciences and Technologies of Marrakech

The transmitter (TX) is comprised of two perfect dipoles that are installed as a uniform linear array (ULA) antenna and are separated by a half wavelength from one another. It is hung on the ceiling of the corridor that is located outside of room A. Both the power level and the bandwidth come in at 20 dBm and 20 MHz respectively. The receivers (RX) are positioned in 1,000 spots, randomly, in rooms A at desktop height, in order to have the NLOS scenario [22], [25]. This allows for the generation of 1,000 different realizations. The grounds of the Faculty of Sciences and Technologies in Marrakech were selected to serve as the outdoor WiFi environment of choice. The wireless environment may be seen in Figure 2, which depicts the outside setting. An array of two perfect dipoles with a half wavelength of separation between them serves as the TX. These ULA antennas are mounted on the ceiling of one of the high buildings. Both the power level and the bandwidth have been set to 20 MHz each. The power level is 20 dBm. The RX are randomly positioned in one thousand spots [26] at a height of 1.5 meters above the ground.

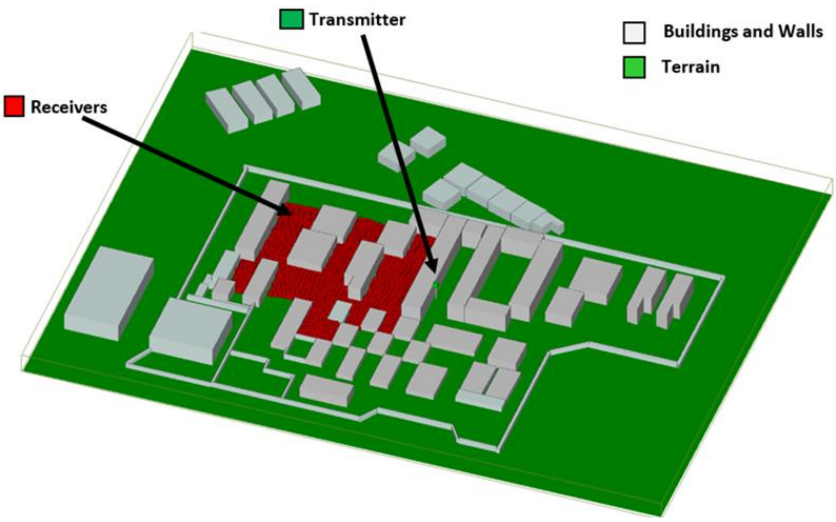


Figure 2. The outdoor wireless environment; Faculty of Sciences and Technologies of Marrakech

The ray tracing simulator is used to collect data such as the received power, time delay, and ray length. This data is then used to generate the channel response. Modeling the channel response involves calculating the vector sum of all of the rays that arrive at the sites of the receiving antennas. In (1) is used to compute the results of this system [22]. Knowing that M is the number of the rays, $P_k$ is the received power, $f_o$ is the carrier frequency, $l_k$ is $k_{th}$ ray length, $\lambda$ is wavelength, and $\tau_k$ is $k_{th}$ ray time delay.

$$h_{ij} = \sum_{K=1}^{M} \sqrt{P_k}\, e^{i\left(\frac{2\pi}{\lambda}\right)l_k} e^{i2\pi f_0 \tau_k} \tag{1}$$

Then, the capacity of channel is determined using (2) [22], [27]:

$$C(\mathbf{H}) = \log_2 \det\left(I_{N_R} + \frac{\rho}{N_T}\mathbf{H}\mathbf{H}^H\right) \; bits/s/Hz \tag{2}$$

where $I_{NR}$ is the identity matrix, H is the coefficient matrix of channel, $\rho$ is the SNR, the superscript $(.)^H$ denotes conjugate transpose, and det (.) is the determinant. $N_T$ is the transmitter's number, and $N_R$ is the receiver's number. In this case, this model is applied to investigate the channel capacity of antenna arrays with two elements that work at 5 GHz.

### 2.2. Broadband MIMO system design

Figure 3 [23] shows the dual-element antenna array used in this study, it is a broadband dual-element PIFA antenna array for MIMO application. The symmetrical back-to-back antenna elements are placed 2.7 mm from top and 3 mm from side on the system printed circuit board (PCB). An FR4 substrate of size of 100×60×0.8 mm$^3$ is used as a PCB ($\varepsilon_r$=4.4 and tanδ=0.018), on which the system ground plane of size 100×60 mm$^2$ is printed below. The antenna is fed by the RG402/U coaxial cable. The dimensions of the PIFA element are WS=5 mm, LT=10.5 mm, and T=0.3 mm. And the high of the antenna (H) is equal to 4 mm. The two PIFAs are placed with a separation of 40 mm (more than half wavelength λ=53.95 mm, 40 mm=0.74 λ). And to increase the isolation between the PIFAs, a small ground plane and a parasitic element are placed between the radiating plate and the PCB. It was made by collecting a rectangular plate with dimensions of WG=7 mm, LG=12 mm, and T=0.3 mm, to a parasitic element (WG=7 mm, HPE=2.7 mm, and T=0.3 mm). They are used also to widen the bandwidth.

As a consequence of this, more than 26 dB of isolation has been obtained across the operational bandwidth thanks to the fact that the two PIFA antennas have been located 0.74 l apart on the PCB. Bakouchi *et al.* [23] provided a comprehensive presentation of the MIMO antenna's underlying architecture. Both the wireless local area network (WLAN) frequency bands (5.15–5.35 GHz and 5.725–5.825 GHz) and the worldwide interoperability for microwave access (WiMAX) frequency bands (5.25–5.85 GHz) are utilized by the antenna during operation. In addition to preserving the high level of isolation, the tiny ground plane makes a contribution to the breadth of the bandwidth, which enables it to span the appropriate frequency ranges for WLAN and WiMAX.

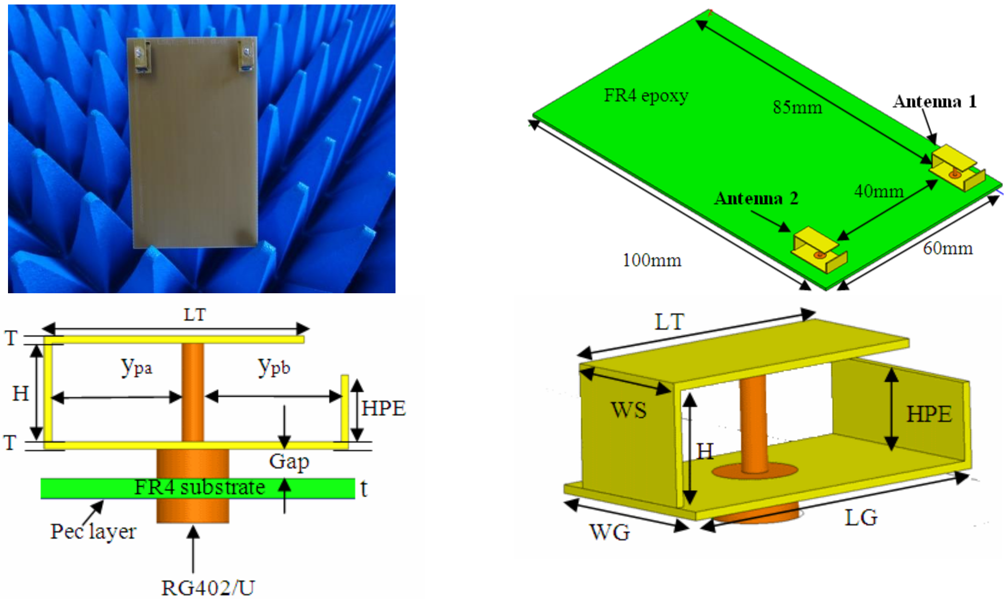


Figure 3. Broadband MIMO antenna for WLAN and WiMAX applications [23]

## 3. RESULTS AND DISCUSSION

### 3.1. Channel capacity if broadband MIMO antenna

In both of the MIMO channel models, research was conducted on the channel capacity of the broadband MIMO antenna. This model makes use of both the observed 2D radiation pattern of the twin PIFA antennas as well as the simulated pattern that was generated by HFSS. Figures 4 and 5 show the MIMO channel capacities of the broadband MIMO antenna when used as receivers in the indoor/outdoor realistic propagation environment (Department of Applied Physics at the Faculty of Sciences and Technologies of Marrakech in Figure 1) and in the outdoor realistic propagation environment, respectively (Faculty of Sciences and Technologies of Marrakech in Figure 2). The results of the channel capacity calculations derived from the simulated radiation pattern of the two PIFA arrays are compared to the radiation pattern calculations obtained from the measurements made in both settings.

### 3.2. Ergodic channel capacity

Figure 4 illustrates the total capacity of the ergodic channel. It has come to our attention that the capacity of the measured broadband MIMO antenna, which has a low mutual coupling of 26 dB, is more than that of the one that was simulated (where the mutual coupling is equal to 16.32 dB). When the SNR is equal to 20 dB, the channel capacity of the simulated dual PIFA antenna is equal to 28.7 bits/s/Hz in the environment that combines interior and outdoor spaces. In addition, the measured broadband MIMO system was able to boost its throughput to 29.5 bits/s/Hz. The difference in channel capacity between the simulated and the observed PIFA arrays is around 0.8 bit/s/Hz when the SNR is equal to 20 dB. When the SNR is equal to 20 dB, the channel capacity for the simulated broadband MIMO antenna is equal to 28.8 bits/s/Hz when operating in an outdoor setting. In terms of the broadband MIMO antenna that was tested, this value comes out to 29.2 bits/s/Hz. The difference in channel capacity between the simulated and the observed PIFA arrays is around 0.4 bit/s/Hz when the SNR is equal to 20 dB.

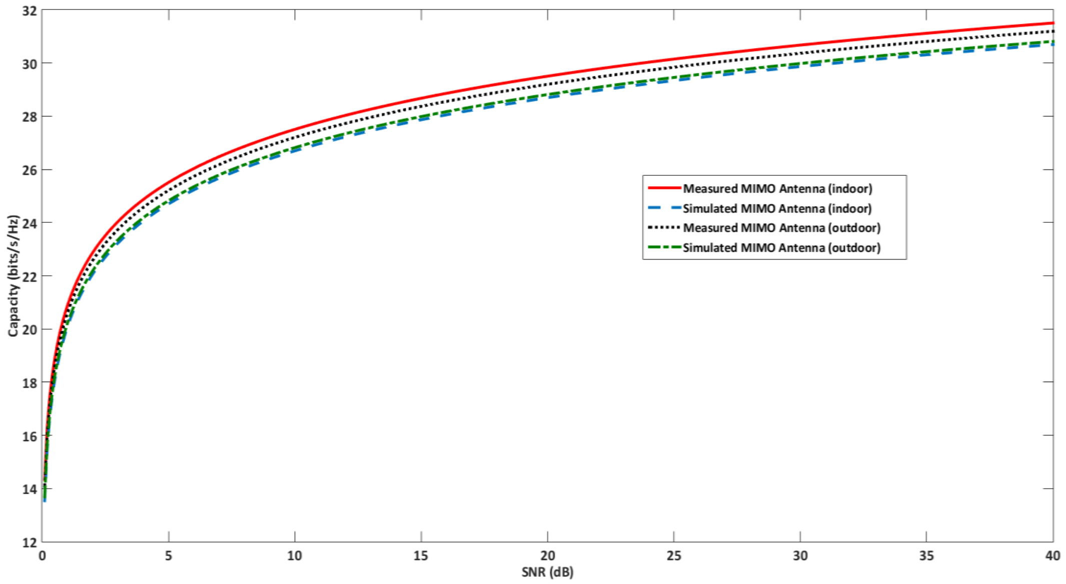


Figure 4. Ergodic channel capacity in the indoor/outdoor environment and in the outdoor environment

### 3.3. Outage channel capacity

Figure 5 illustrates the outage channel capacity determined by the empirical CDF in the indoor/outdoor and outdoor contexts for the broadband MIMO systems that were simulated and tested. An outage of 19.78% is required in the indoor and outdoor environment that is reproduced by the dual-element PIFA array in order to have the channel capacity equal to or lower than 25 bits/s/Hz. And according to the PIFA array that was tested, an outage of 12.31% is required in order to have the channel capacity that is equal to or lower than 25 bits/s/Hz. Therefore, using the broadband MIMO system, 87.69% of the possible channel realizations have the potential to attain a channel capacity that is greater than 25 bits/s/Hz.

In the outdoor environment, in the simulated dual-element PIFA array, an outage of 20.84% is specified to have the channel capacity equal or less than 25 bits/s/Hz. And by the measured PIFA array, an outage of 18.54% is specified to have the channel capacity equal or less than 25 bits/s/Hz. So, with the broadband MIMO system, 81.46% of channel realizations can achieve a channel capacity higher than 25 bits/s/Hz.

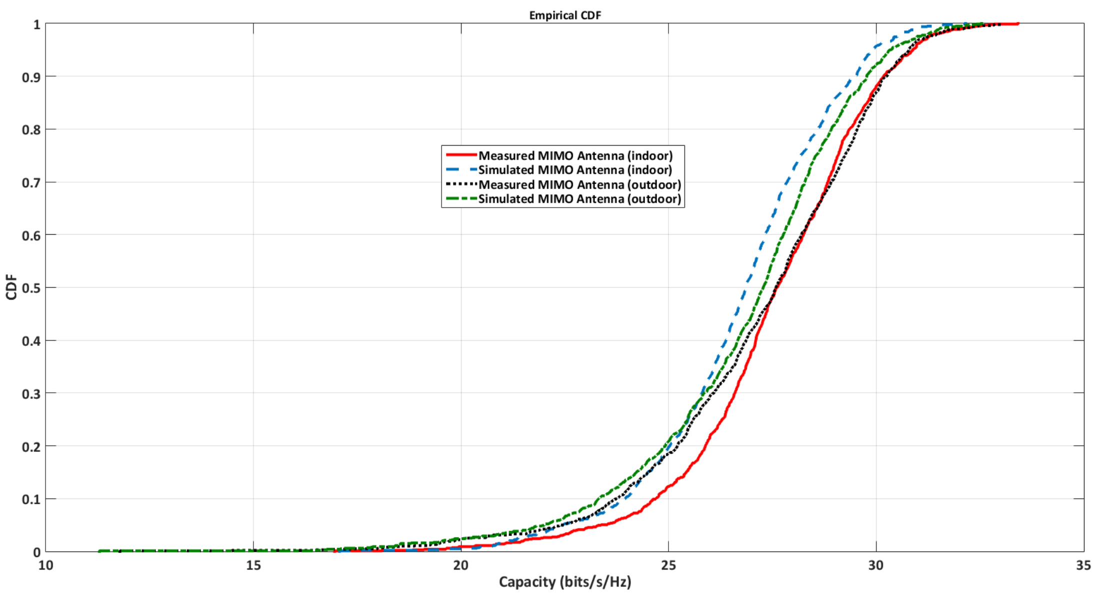


Figure 5. Outage channel capacity (empirical CDF) in the indoor/outdoor and the outdoor environments

## 4. CONCLUSION

We studied the channel capacity of the broadband MIMO system of two PIFAs for WLAN/WiMAX applications in real MIMO channel models based on an indoor/outdoor propagation environment and another purely external environment. And in both models, we found that the results given by the measured MIMO system of two PIFA are near to that given by the simulated MIMO system. By the result of the ergodic and the outage capacity, we found that a good channel capacity performance of the broadband MIMO system in the indoor/outdoor environment and the outdoor one is similar, with a good wireless transmission rate. There is just a little increase in channel capacity when moving from an indoor setting to an outdoor environment. As a consequence of this, the MIMO broadband antenna with strong isolation and a decent diversity parameter operates well in both of these different kinds of situations.

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