Indoor Channel Capacity Measurement of 2 x 2 MIMO Polarization Diversity Antenna

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Article Info	**ABSTRACT**

This paper presents the channel capacity investigation and the polarization reconfigurable antenna analysis for MIMO system in an indoor scenario. A single and dual-port polarization reconfigurable antenna is used at the receiver end to study the effect of polarization diversity configurations towards the achievable performance of the channel capacity. The polarization reconfigurable antennas are developed through two techniques, which are slits perturbation for single-port and feeding network modification for dual-port. The benefits offered by the designed antennas are investigated when being used as a receiver in both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios. The results show the proposed antennas are suitable to be adopted and highly potential to improve the channel capacity of the MIMO systems.

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1. INTRODUCTION

A lot of people nowadays have used modern communication services in their daily life routines, thus contributed to the highly demanded for better data rate. One of the promising technologies that able to provide capacity improvement is Multiple-Input-Multiple-Output (MIMO) systems. As compared to traditional single-input single-output and single-input multiple-output systems, MIMO systems has higher diversity, ability to mitigate multipath fading and greater throughput without requiring more bandwidth and additional power [1], [2]. To further enhance the overall MIMO system performance with data rates increment, reconfigurable antennas (RAs) could be the solution. The use of RAs has been widely studied and investigated to produce much robust MIMO system in terms of channel quality, capacity and reliability [3]. The diversity feature, such as pattern [4], [5] and polarization [6], [7], or the combination of pattern-polarization diversities [8], [9] is exploited to increase the signal-to-noise ratio, which consequently improves the channel capacity. The use of polarization reconfigurable antenna (PRA) can achieve better capacities due to its ability to offer additional channels using several polarizations from different antennas element. Furthermore, the use of RAs also can offer compactness and cost reduction by arranging orthogonal polarized together instead of two physically space separation antennas [10], [11].

The authors have previously presented the compact single [12] and two ports [13] polarization diversity circular patch antenna. The antenna polarization mode is reconfigured using four RF switches embedded on the antennas radiating element and feeding network to shift the phase difference between two orthogonal modes existed on the patch, thus altering the polarizations of the antenna. Depending on the state of switching configurations, the polarization characteristics of these antennas can be reconfigured into multiple types of polarization modes–linear (LP), left-hand circular (LHCP) and right-hand circular polarization (RHCP).

In this paper, these antennas are used to investigate the performance of the system that utilized polarization diversity antenna in term of MIMO channel capacity enhancement. The field experiment in an indoor environment for both line-of-sight (LOS) and non-line-of-sight (NLOS) communication links is conducted to study the benefits offered by different polarization configurations at the receiver end. The analysis of the channel capacity measurement was done by using the scalar power correlation [14]. The performances comparison on the percentage of the channel capacity improvement or decrement is presented between reconfigurable versus non-reconfigurable antenna (reference) and between single-port (spatial diversity) against dual-port (polarization diversity) system.

2.   MIMO CHANNEL MODEL

The wireless MIMO system is consists of multiple antennas at the transmitter and receiver connected wirelessly through transmission medium. Consider x as the input signal and y as the output signal, the relationship between the input and output of the MIMO system is described using equation (1) below [15].

$$y = Hx + \eta \tag{1}$$

where η is the noise generated in the propagation system, and H is the MIMO channel matrix. The MIMO channel matrix is the transfer function between transmit and receive antenna that represented by correlation coefficients, which the mathematical expression as [16].

$$H = \begin{pmatrix} \rho_{11} & K & \rho_{1n} \\ M & O & M \\ \rho_{m1} & L & \rho_{mn} \end{pmatrix}_{MxN} \tag{2}$$

where ρ_{mn} is the power correlation coefficient of m transmit and n receive element. The correlation coefficient was calculated based on measurement data and can be defined into three different types: complex, envelope and power.

$$\rho_{mn} = \frac{cov_{mn}}{\sqrt{\sigma_{mm}^2}\sqrt{\sigma_{nn}^2}} \tag{3}$$

where is the covariance while σmm and σnn represents the variance of the input and output system, respectively. Equation (3) can be simplified, as shown in Equation (4) below [17]

$$\rho_{mn} = \frac{\sum_{m,n=1}^{N}(x_m - \bar{x})(y_n - \bar{y})}{\sqrt{\sum_{m=1}^{M}(x_m - \bar{x})^2 \sum_{n=1}^{N}(y_n - \bar{y})^2}} \tag{4}$$

where $\bar{x}$ is the mean average of the input signal, and $\bar{y}$ is the mean average of the output signal.

One of the methods to estimate the independent multiple channels between terminals is by using eigenvalue decomposition [18]. Here, the process diagonalizes matrix H and correlation matrix, R is represent by equation (5).

$$R = HH^H \text{ or } R = H^H H \tag{5}$$

where [.]H is the Hermitian Transposition (conjugate transpose). The purpose of calculating the R is to evaluate the received power for each Eigen channel.

For multiple transmitter and receiver antennas, the generalized formula for the average channel capacity, C of the system is denoted as [19].

$$C = \log_2\left(1 + \psi_n \frac{SNR}{N}\right) \quad\quad (6)$$

where ψ_n represents the eigenvalue and *SNR* is signal-to-noise-ratio. From the equation (6), it is realized that in order to improve the channel capacity of the MIMO, the eigenvalue is the variable that need to be manipulated. The unit for capacity is bits/s/Hz.

3.   MIMO EXPERIMENTAL SETUP
In this section, it is explained the results of research and at the same time is given the compreh The 2 x 2 MIMO channel capacity measurements using PRAs was conducted in the Microwave Laboratory, which consists of concrete wall, glass windows, tables, chairs, personal computers, cabinets and bookshelves. The size of laboratory is 14.4 meter width, 22.7 meter length and 3.4 meter height. This situation is set up to create and investigate the MIMO performances in a multipath and moderate density environment.

In particular, the MIMO performance is investigated when employed PRAs at the receiver end. Note that during the data being measured and captured, we were moved inside the technician room to minimize the interference come from human presence and activities, so that the testing environment is entirely static. For each antennas configuration, the changed solely made to the receiver part. Other than that, it remains the same to eliminate any factors that could possibly change the channel characteristics such as the position of the transmitter and receiver. For the single port antenna, the identical structure has been added and fabricated to demonstrate the spatial diversity 2 x 2 MIMO. In order to validate the improvement of the channel capacity by using PRAs, two monopole antennas are used at the receiver end for comparison (reference configuration).

To create and construct the NLOS scenario, a white board with a size of 2 m x 2.5 m is placed in front of the transmitter antennas at a distance of 2 meters to block the direct propagation path between transmitter and receiver, whilst the position of the transmitter and receiver remains unchanged. Both transmitter and receiver were located at the fix height of 1.5 m, and were separated at a distance of approximately 12 m. Note that the distance between transmitter and receiver can affect the channel capacity, due to the changes of the signal strength. The measurements were performed at 2.45 GHz, with 0 dBm power transmission at each antenna port (Pt=0 dBm). The antennas at the transmitter were placed using spatial diversity and physically/distance separated from each other at displacements of one λ (where λ is the wavelength at the operating frequency), or approximately 12.5 cm.
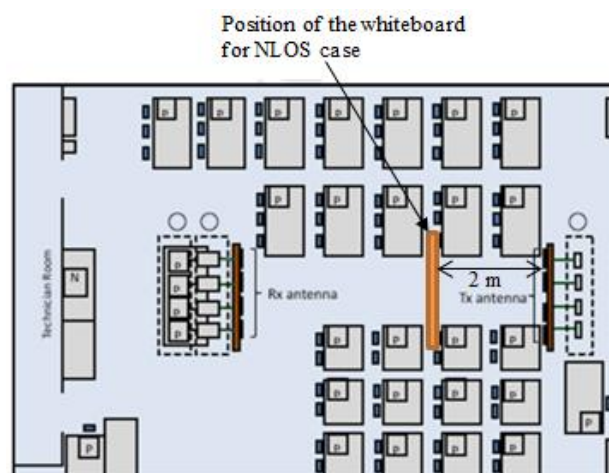

Figure 1. Floor layout of measurement campaign

The signal is generated (using Signal Generator Hittite HMC-T2000 700MHz-8 GHz) at the transmitter and is amplified (using Microwave Amplifier Agilent 87415A 2-8 GHz) at the receiver side and

being detected by the RF power sensor for every 1 second time intervals for 30 minutes. The power meter (using Amitec Microwave Power Sensor) displayed the power level and the data was recorded into the computer through the connected hyper terminal interface. The devices are connected together using 1 meter RF cable with a 1.3 dB cable loss. Then, the measurements data are imported and combined in the excel worksheet. The parameters H, ρ and ψ were calculated using programming coded developed in MATLAB software and finally the channel capacity value is determined. In this experimental campaign, the omni-directional monopole antenna was used at the transmitter.

4.   CHANNEL CAPACITY RESULTS AND DISCUSSIONS

In this section, the 2 x 2 MIMO channel capacity analysis and discussions using the proposed PRAs is presented. It is important to note that the results presented here is a site specific case, or in other words, the result is valid and true only for this specific measurement setup and conditions. Any changes and variations to the setup (except the replacement of the receiver antenna with PRAs) such as antennas distance, height or surroundings, could obviously give different results.

As discussed in the previous section, the MIMO channel capacity calculation was done using scalar power correlation method. Note that throughout the measurement campaign, the polarization of the antennas is switched manually. To investigate the benefits offered by each polarization configurations, Table I tabulate the channel capacity of the measurement 2 x 2 MIMO for all transmitter-receiver polarization configurations. The percentage of improvement or decrement for each configuration is calculated based on comparison with reference configurations.

As listed in Table 1, it can be noted that the channel capacity improvement with the proposed antennas varies as a function of the different receiver configurations. It is found that the channel capacity for LOS scenario is better than NLOS as the channel correlation is relatively low, which result in increased of eigenvalue and consequently channel capacity. For spatial diversity configuration, the proposed antenna outperforms a conventional references one wavelength separated monopole antenna in configuration 1E for LOS scenario. Meanwhile, for NLOS scenario, the best channel capacity is achieved through configuration 1C. Other configurations (configuration 1B, 1D and 1E) guarantees higher channel capacity than reference configuration. It is also observed that the capacity with spatial diversity PRAs did not improved significantly when the receiver and transmitter in LOS scenario as the channel conditions are relatively good. Configuration 1A (LP-LP) and 1F (RHCP-RHCP) is generally the worst configurations in both LOS and NLOS scenarios as it shown capacity reduction as referred to typical configuration.

Table 1. Channel Capacity Results of the 2 x 2 MIMO as Respect to Reference Configurations

Transmitter-Receiver Polarization Configurations			Channel Capacity (bits/s/Hz)		Percentage of improvement/ decrement (±%)	
			LOS	NLOS	LOS	NLOS
		Reference	1.0091	0.1274	NA	NA
Spatial diversity	1A	LP-LP	0.2867	0.0866	-71.6	-32.0
	1B	LP-LHCP	0.0144	0.2430	-98.5	+90.7
	1C	LP-RHCP	0.4652	**0.3688**	-53.9	+189.5
	1D	LHCP-RHCP	0.0075	0.3463	-99.3	+171.8
	1E	LHCP-LHCP	**1.9463**	0.1787	+92.9	+40.3
	1F	RHCP-RHCP	0.3332	0.0605	-67.0	-52.5
Polarization diversity	2A	Orthogonal LPs	0.0441	**0.1793**	-95.6	+40.7
	2B	Orthogonal CPs	**1.5938**	0.0981	+57.9	-23.0

For polarization diversity PRAs against reference performance, channel capacity improvement of approximately 50% is obtained in configuration 2B for LOS and configuration 2A for NLOS scenarios. The achievable channel capacity results showed that it is very effective to have a configuration that exploits polarization diversity to improve the performance gains of the MIMO systems due to its consistent behavior, especially for multipath NLOS scenarios. This is due to the facts that, instead of employing fix polarization at the receiver, the antennas are capable to function with multiple type of polarization mode providing additional channels in MIMO system. Hence, by using PRAs at the receiver, the polarizations could be switched for selecting the best polarization configuration to enable an increase in SNR that eventually improve the channel capacity.

Based on the findings, it shows that not all configurations of PRAs will provide better channel capacity than reference configuration. For some transmitter-receiver polarization configurations, the channel capacity obtained are lower than non-reconfigure antennas. In this specific measurement setup, the best configuration is 1E (LHCP-LHCP), as it shows consistent behavior with channel capacity improvement in both LOS and NLOS scenarios. Moreover, as predicted, spatial diversity technique works well with better percentage of improvement (92.9% for LOS and 189.5% for NLOS) as compared with polarization diversity technique. Even though the capacity of improvement for the polarization diversity is not that good as spatial diversity technique, it contributes significant improvement of capacity (improved by 40.7% for LOS and 57.9% for NLOS) with better space optimization - less space occupied. It is also observed that the PRAs performed well in NLOS scenario due to the fact that PRAs unique capability to cater the multipath fading rich attributed by transmission scattering and reflections phenomenon.

It is found that spatial diversity has been identified can provide better performance in term of capacity compared to polarization diversity. The spatial degree of freedom is extremely potential to increase the MIMO channel capacity. However, this method only will be very useful for the system which has no restrictions in term of space and volume. Spatial diversity is impractical to be applied for limited space system. In this type of system, polarization diversity is more efficient and suitable for due to the compactness of the multi-elements structure.

5. CONCLUSION

In this paper, the channel capacity measurement campaign and performance investigation of the 2 x 2 MIMO systems when exploiting the polarization diversity characteristic is presented. The designed antennas of single and dual port PRAs are used at the receiver end, while space-separation omni-directional monopole antennas are used as transmitter antenna. We showed that channel capacity is improved as compared to non-reconfigure antenna (typical configuration) when polarization diversity which offering multiple type of polarizations is applied at the receiver end. Configuration 1E (LHCP-LHCP) and 2B (orthogonal CPs) is the best configurations for LOS scenario with percentage capacity improvement of 92.9% and 57.9%, respectively. Meanwhile, in the NLOS scenario, the configurations 1C (LP-RHCP) for spatial diversity and 2A (orthogonal LPs) performs better than other configurations. The results proved the use of reconfigurable antennas is an effective solution to obtain good communication link capacity for the systems that have constraints on the space such as handheld devices and limited-space MIMO system.

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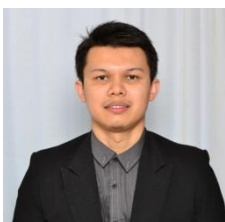
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