COMPUTATIONAL ELECTROMAGNETIC ANALYSIS OF A RECONFIGURABLE MULTIPORT CIRCULAR PATCH ANTENNA FOR MIMO COMMUNICATIONS

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Abstract: This paper uses near field and far-field computational electromagnetic analysis to demonstrate a novel reconfigurable multi-port circular patch antenna that uses pattern diversity to improve the performance of a MIMO system. Different modes of the circular patch antenna can be excited by varying its radius. A 2x2 MIMO system employing such reconfigurable antennas was analyzed using computational electromagnetic ray tracing software for an outdoor environment. The results show an improvement in the achievable throughput while reducing the size of the antenna array.

INTRODUCTION

Recent studies have shown that reconfigurable antennas improve Multiple Input Multiple Output (MIMO) system performance [1, 2]. In this paper we propose a reconfigurable multi-port circular patch antenna (RMCPA) whose size can be reconfigured through switches. The RMCPA provides a high degree of pattern diversity while being physically compact. The different spatially orthogonal radiation patterns excited between the different antenna ports are determined by the possible antenna configurations. The overall goal of a system employing this RMCPA would be to adaptively choose the optimal configuration based on environment/channel conditions to decrease MIMO spatial channel correlation and subsequently maximize link capacity.

ANTENNA DESIGN

The geometry of the proposed two port circular patch antenna is shown in Fig. 1(a) [3]. The radius of this antenna can be changed by turning the switches on and off. Therefore it is possible to define two configurations for this antenna: one in which all the switches are turned off and the electromagnetic mode TM_{13} is excited ("mode 3" configuration) and another in which they are turned on and the electromagnetic mode TM_{14} is excited ("mode 4" configuration). The antenna is fed through two coaxial ports located such that the radiation patterns excited simultaneously at the two ports are spatially orthogonal to each other. The isolation between the two ports is higher than 20 dB. The design uses a single antenna that allows for reduced space occupation by the antenna on the communication device while acting as a two element array.

The antenna structure was analyzed and simulated using the finite-difference time-domain method HFSS antenna design software. The switches were modeled as microstrip lines having low insertion losses (<1dB) in the ON configuration and as an air gap in the OFF configuration.

The antenna is designed to resonate at 2.46 GHz, a typical frequency for 802.11-like MIMO-aware local area networks. However the antenna's ports are matched at this frequency only for the "mode 4" configuration for a target return loss of 10 dB, and hence a separate matching network is required to match the ports for the "mode 3" configuration.

The resulting far-field radiation patterns in the azimuthal plane for the two modes excited by the two different antenna configurations at both its ports, both matched at 2.46 GHz, are shown in Fig 1(b). It can be observed that the radiation patterns excited by "mode 3" and "mode 4" configurations are different, thus resulting in pattern diversity. The patterns excited at the two ports for the same configuration are also different in that they are spatially orthogonal to each other. Therefore employing this antenna at the receiver and transmitter in a communications link, with both the ports excited, effectively forms a 2x2 MIMO system. For a given multi-path environment we can choose particular RMCPA configurations at the receiver and transmitter which would decrease MIMO spatial channel correlation and maximize channel capacity.

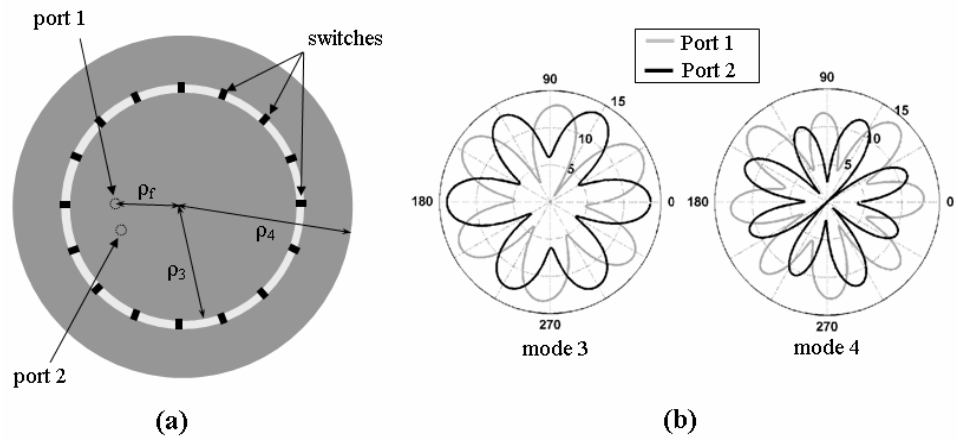

Figure 1: (a) Geometry of the RMCPA (ρ_f =2.2cm, ρ_3 = 3.48cm, ρ_4 = 4.42 cm, angular separation between the ports = 25º, substrate dielectric constant ε_r = 6.15) (b) azimuthal far-field radiation patterns (in dB) of the RMCPA in the two configurations for both the antenna ports at 2.46 GHz.

SIMULATION RESULTS

The RMCPA was studied in terms of MIMO channel capacity. FASANT [4], a deterministic electromagnetic ray tracing program based on geometric optics and the uniform theory of diffraction was used for numerical computation of channel capacity. A 3D model of Austin downtown was simulated as the geometry input of FASANT. The transmitter was fixed at the center of the model at a height of 1.5m, while the receiver, whose height was fixed at 1.5m was moved along the streets as shown in Fig. 2(a), occupying 3000 different locations. The 3D radiation patterns obtained from HFSS for the different configurations of the RMCPA were used in the ray tracing simulation at both ends of a 2 × 2 MIMO system. The channel matrix **H** was computed as in [5] and the following equation was used to estimate the link capacity [6]:

$$C = \log_2\left[\det\left(\mathbf{I}_{N_{RX}} + \frac{SNR}{N_{TX}}\mathbf{H}\mathbf{H}^{\dagger}\right)\right], \tag{1}$$

where N_{TX} is the number of transmit antennas, N_{RX} is the number of receive antennas and $(\dagger)$ is the transpose operator. A 10 dB SNR at the receiver was assumed for the calculation.

The channel capacity was calculated this way for each possible configuration of the transmitting and receiving RMCPAs, for a total of 4 different configurations per position. We took the optimal antenna configuration as the one which yielded the highest channel capacity at each point. The channel capacity achieved using this reconfigurable antenna was then compared with that of a 2x2 MIMO system that employs half wavelength dipoles spaced half wavelength (lambda/2) and

one wavelength (lambda) apart. Based on the data collected from the simulations, a cumulative distribution function (CDF) for the capacity was numerically obtained and is shown in Fig. 2(b), where one curve represents the CDF relative to a system where the reconfigurable antenna solution was used, and the others were relative to systems where the array of half wavelength dipoles with different spacing were used. The improvement achievable using the RMCPA is significant: there is a probability of 50% that the gain achieved with the RMCPA is at least of 0.8 bps/Hz and 1.7 bps/Hz for a SNR of 10 dB with respect to a system employing half wavelength dipoles with separation of one wavelength and half wavelength respectively.

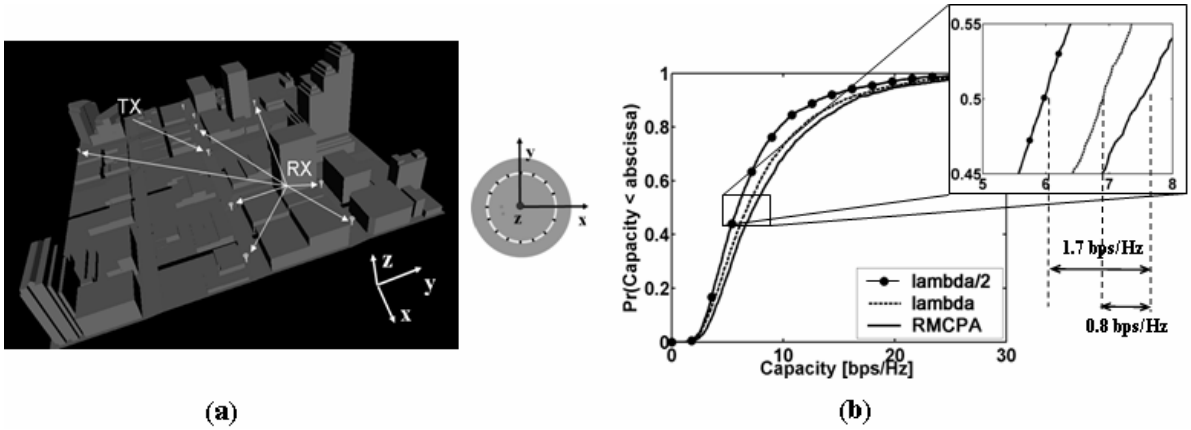

Figure 2: (a) 3D model of downtown Austin (TX location is shown with some of the RX locations and the orientation of the RMCPA in the environment), (b) CDF of capacity for the RMCPA and the array of half wavelength dipoles with a spacing of half wavelenght and one wavelength in the simulated outdoor environment.

CONCLUSION

A novel reconfigurable antenna that can be used as part of a reconfigurable MIMO system has been proposed. Simulation results have shown how the reconfigurable antenna solution described in this paper can provide a considerable improvement in capacity with respect to a system which does not have this capability. Moreover the proposed antenna occupies less space than conventional antenna arrays because of its compact design and is thus an attractive solution for handheld devices.

REFERENCES

[1] D. Piazza and K. R. Dandekar, "Reconfigurable antenna solution for MIMO-OFDM systems," *Electronics Letters,* vol. 42, pp. 15-16, 2006.

[2] B. A. Cetiner, H. Jafarkhani, J.-Y. Qian, H. J. Yoo, A. Grau, and F. De Flaviis, "Multifunctional reconfigurable MEMS integrated antennas for adaptive MIMO systems," *IEEE Communications Magazine,* vol. 42, pp. 62-70, 2004.

[3] R. G. Vaughan, "Two-port higher mode circular microstrip antennas," *IEEE Transactions on Antennas and Propagation,* vol. 36, p. 3, 1988.

[4] M. F. Catedra, J. Perez, A. Gonzalez, O. Gutierrez, and F. Saez de Adana, "Fast computer tool for the analysis of propogation in urban cells," *Annual Wireless Communications Conference, Proceedings,* pp. 240-245, 1997.

[5] J. Perez, J. Ibanez, L. Vielva, and I. Santamaria, "Capacity estimation of polarization-diversity MIMO systems in Urban microcellular environments," Barcelona, Spain, 2004, pp. 2730-2734.

[6] A. F. Molisch, M. Steinbauer, M. Toeltsch, E. Bonek, and R. S. Thoma, "Capacity of MIMO systems based on measured wireless channels," *IEEE Journal on Selected Areas in Communications,* vol. 20, pp. 561-569, 2002.