Performance Analysis of a Reconfigurable Antenna Array in WLAN Channel Models

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***Abstract*—This paper presents a performance evaluation of a pattern reconfigurable antenna array in a clustered MIMO channel model. Using the IEEE 802.11 TGn and TGac standard channel models, the effect of pattern diversity is investigated in both single-user and multi-user MIMO systems. The numerical results show that the additional degrees of freedom provided by a pattern reconfigurable array can mitigate the effects of co-channel interference and provide a significant gain in system capacity.**

I. Introduction

The rapid growth of wireless communications technology in recent years has led to the proliferation of mobile devices and applications requiring larger amounts of bandwidth. Multi-antenna technologies such as single-user (SU) and multi-user (MU) multiple-input single-output (MIMO) have been adopted into the 802.11 n/ac standards to increase the communication spectral efficiency in rich multipath environments. Furthermore, it has been shown that pattern reconfigurable antenna (RA) technology can be employed in MIMO arrays to enhance the capacity performance of wireless systems. [1], [2]

Although, the performance improvement of MIMO systems equipped with RA has been extensively studied in literature [1]–[3], most of these studies have focused on measurements with array designs or ray tracing simulations and do not give a clear insight on the performance of the array employing RA as a function of the antenna radiation patterns. In order to clearly demonstrate the relationship between the system performance and array radiation patterns, analytical or simulation studies that are based on widely accepted channel models are required. The authors in [4] provide an analytical study of the benefits of RA but their work does not consider the effects of co-channel interference or multi-user systems. Since 802.11 networks are largely interference limited, it is crucial to study the role of RA in mitigating interference.

In this paper, we present a performance evaluation of a RA array in the 802.11n/ac standard channel model [5], [6]. Specifically, we demonstrate that our array, consisting of the reconfigurable Alford loop antenna (RALA) [7] is capable of using its pattern diversity to enhance link quality and reduce the impact of interference in the context of SU-MIMO with varying power levels and directions of co-channel interference along with combating interference leakage in MU-MIMO.

II. System Model

A. Channel Model

In this section, we provide a brief overview of the clustered MIMO channel model for indoor propagation as specified in the 802.11 TGn/ac channel model. [5], [6] Consider a MIMO system with N_t transmit antennas and N_r receive antennas and the narrowband equivalent received signal is given as

$$y = \sqrt{\frac{\text{SNR}}{N_t}}\,\mathbf{H}\mathbf{x} + \mathbf{n} \tag{1}$$

where the SNR is the signal-to-noise ratio, $\mathbf{y} \in \mathbb{C}^{N_r \times 1}$ is the received signal vector, $\mathbf{x} \in \mathbb{C}^{N_t \times 1}$ is the transmit signal vector, $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$ is the MIMO channel matrix and $\mathbf{n} \in \mathbb{C}^{N_r \times 1}$ is the zero-mean additive Gaussian noise vector. For non-line-of-sight channels, TGn channel model specifies channel matrix as

$$\mathbf{H} = \mathbf{R}_r^{1/2}\mathbf{H}_w\mathbf{R}_t^{1/2} \tag{2}$$

where $\mathbf{R}_r$ and $\mathbf{R}_t$ represent the recieve and trasnmit spatial correlation matrices respectively and $\mathbf{H}_w \in \mathbb{C}^{N_r \times N_t}$ is a matrix of independent zero mean, unit variance, complex Gaussian fading coefficients.

B. Capacity Calculation

For the case of SU-MIMO with co-channel interference, the capacity is derived in [8] and is given by:

$$C_{\text{SU-MIMO}} = \mathbb{E}\Bigg\{\log_2 \det \Bigg[\mathbf{I}_{N_r} + \mathbf{H}\mathbf{H}^* \left(\sum_{k=1}^{K} \frac{N_t}{N_t \text{SIR}_k}\,\mathbf{H}_k\mathbf{H}_k^* + \frac{N_t}{\text{SNR}}\,\mathbf{I}_{N_r}\right)^{-1}\Bigg]\Bigg\} \tag{3}$$

where K represents the number of interference sources, SIR represents the signal-to-interference ratio and $\mathbf{H}_k$ represents the interference channel matrix. The expression in (4) for computing the capacity the MU-MIMO system using minimum mean squared error (MMSE) precoding is obtained from [9].

$$C_{\text{MMSE}} = \sum_{m=1}^{M} \log_2\left(1 + \frac{|\mathbf{h}_m\mathbf{w}_m|^2}{\sum_{j\neq m}|\mathbf{h}_m\mathbf{w}_j|^2 + M\sigma_2/P}\right) \tag{4}$$

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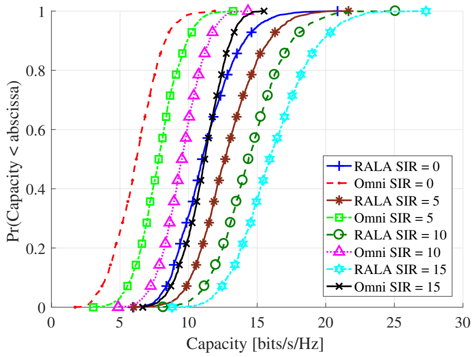

Fig. 1. CDF of SU-MIMO capacity for various SIR (dB) levels

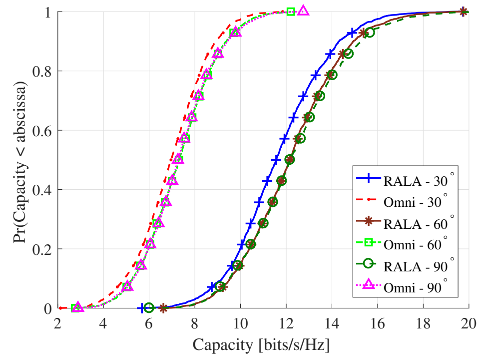

Fig. 2. CDF of SU-MIMO capacity for various interference directions

III. Simulation Setup

The simulation environment selected for our study was an indoor small office environment, which corresponds to Model E of the delay profile describe in the TGn standard. As specified in the model, the rms delay spread for this profile is 100 ns. The number of clusters used for all simulations was four. The angle-of-arrival (AOA) and angle-of-departure (AOD) were independently generated from a uniform distribution over $[-180°, 180°]$. The azimuth angular spread of each cluster was generated from a uniform distribution over $[20°, 40°]$. The power angular spectrum was assumed to have a truncated Laplacian distribution with the angular spread as the standard deviation. The spatial correlation matrices for the transmitter and receiver are calculated based on the power angular spectrum and the antenna patterns with the linear array assumption, where the inter-element spacing is $\lambda/2$. The signal-to-noise ratio for all simulations is set to 20 dB.

IV. Results

Our simulation focuses on three different downlink transmission scenarios where the transmitter is equipped with an array of 3 RALA and the receivers are equipped with omni-directional antennas. The capacity performance of the RALA array is benchmarked against a traditional omni-directional antenna. First we consider a 3x3 SU-MIMO with co-channel interference, and evaluate the capacity performance at various levels of SIR, where the angle of the interference source is fixed to 90 degrees with respect to the desired transmitter. The cumulative distribution function (CDF) of the capacity for this scenario is displayed in Fig. 1. Next, we study the same 3x3 SU-MIMO system but we fix the SIR to 3 dB and vary the direction (angle) of the co-channel interference source with respect to the desired signal. Fig. 2 shows the capacity CDF curves for this scenario. Finally, we consider the 3-user 3x1 MU-MIMO system, where the transmitter has 3 RALA and each of the 3 receivers have 1 omni-directional antenna and show the performance in Fig. 3.

V. Conclusion

Our simulation study has showed that the directional gain and pattern diversity provided by the RALA array make it possible to minimize the effects of interference at varying powers and angles by exploiting appropriate directional patterns to realize more effective channel matrices. Furthermore, the additional degrees of freedom provided by the various directional patterns provide the transmitter suitable channels to precode the spatial streams and reduce the effects of interference leakage from one stream to others in MU-MIMO systems.

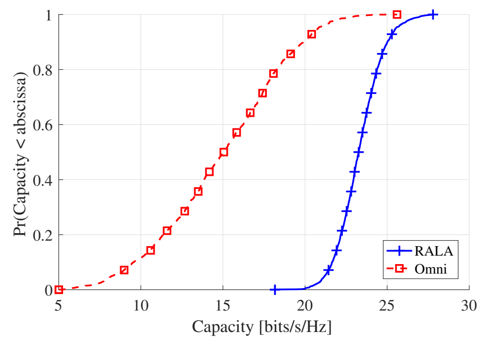

Fig. 3. CDF of MU-MIMO capacity with MMSE precoding

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