Channel Capacity with Channel Interference in MIMO-WLAN Systems

Chien-Hung Chen [1]
Department of Information Technology and Mobile Communication, Taipei College of Maritime Technology,
New Taipei City, Taiwan, R.O.C.
e-mail:f1092@mail.tcmt.edu.tw

Chia-Ying Yu[2]
Electrical Engineering Department, Tamkang University,
New Taipei City, Taiwan, R.O.C.
e-mail:imjarvinia@hotmail.com

Wei-Siang Gu[3]
Electrical Engineering Department, Tamkang University,
New Taipei City, Taiwan, R.O.C.
e-mail: zzz129@yahoo.com.tw

Chien-Ching Chiu[4]
Electrical Engineering Department, Tamkang University,
New Taipei City, Taiwan, R.O.C.
e-mail:chiu@ee.tku.edu.tw

Shu-Han Liao[5]
Advanced Communication System Center, Smart Network System Institute, Institute for Information Industry,
Taipei, Taiwan, R.O.C.
e-mail:shliao@iii.org.com

***Abstract*- The channel capacity of multiple-input multiple-output (MIMO) wireless local area network (MIMO-WLAN) systems with co-channel interference (CCI) is calculated in this paper. The ability to combat CCI for the MIMO-WLAN simple uniform linear array (ULA) and polarization diversity array (PDA) are investigated. The channel frequency response, which is further used to calculate the corresponding channel capacity is calculated by ray-tracing approach. Numerical results show that MIMO-PDA is better than those of MIMO-ULA when interference is present.**

Keywords*- *MIMO-WLAN; ray-tracing approach; channel capacity

I. Introduction

In recent years there has been a growing interest in the development of potentially mass-producible application systems using millimeter waves, such as wireless LAN (local area networks) systems [1]. This paper addresses basic issues regarding the wireless LAN systems that operate in the 60 GHz band which provides 7 GHz of unlicensed spectrum with a potential to develop wireless communication systems with multi Gbps throughput as part of the fourth-generation (4G) system [2]. For wireless communication systems, CCI is one of the unwanted signals and it appears due to frequency reuse in wireless channels. The use of directional antennas and antenna arrays has long been recognized as an effective technique for reducing CCI, since the differentiation between the spatial signatures of the desired signal and CCI signals can be exploited to reduce the interference when multiple antennas are used.

In a classical large cellular system, due to several interferers in different co-channel cells, the CCIs can be assumed as statistical random variables. In this paper channel capacity of multiple-input multiple-output wireless LAN (MIMO-WLAN) systems with CCI is calculated at the 60GHz band. Simple uniform linear array and polarization diversity array are applied to the desired system and the CCI respectively to observe the effects caused by the two antenna arrays. The remainder of this paper is organized as follows. In Section 2, system description and channel modeling are presented. Several numerical results are given in Section 3. Section 4 concludes the paper.

II. SYSTEM DESCRIPTION AND CHANNEL MODELING

A. *System description*

A time-invariant narrowband MIMO system with CCI can be described as follows:

$$\mathbf{Y} = \mathbf{H_d X_d} + \mathbf{H_i X_i} + \mathbf{W} \tag{1}$$

where $\mathbf{Y}$, $\mathbf{X_d}$, $\mathbf{X_i}$ and $\mathbf{W}$ denote the $N_r \times 1$ received signal vector, the $N_t \times 1$ desired transmitted signal vector, the $N_i \times 1$ interference signal vector and the $N_r \times 1$ zero mean additive white Gaussian noise vector at the symbol time, respectively. In (1), $\mathbf{H_d}$ is the $N_r \times N_t$ channel matrix for the desired signal, and the element h_{xy} of the channel matrix $\mathbf{H_d}$ denotes the complex channel gain from the *y*-th transmitting antenna to the *x*-th receiving antenna, $\mathbf{H_i}$ is the $N_r \times N_i$ channel matrix for interference signal, and the h_{xi} which denotes the complex channel gain from the *i*-th interference antenna to the *x*-th receiving antenna is the element of the channel matrix $\mathbf{H_i}$.

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The received signal can be expressed as follows:

$$\hat{\mathbf{Y}} = \hat{\mathbf{U}}(\mathbf{UDV^*})\hat{\mathbf{V}}\mathbf{X_d} + \hat{\mathbf{U}}\mathbf{H_i X_i} + \hat{\mathbf{U}}\mathbf{W} \tag{2}$$

where $\mathbf{U}$ and $\mathbf{V^*}$ are the $N_r \times N_r$ and $N_t \times N_t$ unitary matrices, $\mathbf{D}$ is a $N_r \times N_t$ rectangular matrix whose diagonal elements are non-negative real values and other elements are zero, $\hat{\mathbf{V}}$ and $\hat{\mathbf{U}}$ are linear signal processing operation. If channel state information (CSI) is known at both transmitting side and receiving side, the processing operations, $\hat{\mathbf{V}}$ and $\hat{\mathbf{U}}$, can be expressed as $\mathbf{V}$ and $\mathbf{U}^*$, respectively. Then, equation (2) can be rewritten as follows:

$$\hat{\mathbf{Y}} = \mathbf{DX_d} + \mathbf{SX_i} + \hat{\mathbf{W}} \tag{3}$$

where $\mathbf{S} = \mathbf{U^* H_i}$ denotes a $N_r \times N_i$ equivalent channel matrix for the interference, $\hat{\mathbf{W}} = \mathbf{U^* W}$ is still a zero mean additive white Gaussian noise vector.

Finally, the equation can be organized as follows:

$$C_f^{NB} = B\sum_{x=1}^{N_m}\log_2\left(1+\frac{\frac{SNRt}{N_m}\times\lambda_x}{\frac{SNRt\times ISR}{N_i}\sum_{y=1}^{N_i}s_{x,y}^2+1}\right) \tag{4}$$

where ISR is the ratio of the total transmitting power of the interference signal to that of the desired signal and SNRt denotes the ratio of the total transmitting power of the desired signal to noise power of the receiver. To assume that the total transmitting power of desired signal is the same as the power of the interference signal, we set the ISR=1.

B. *Channel modeling*

Using ray-tracing approaches to predict channel characteristic is effective and fast, and the approaches are also usually applied to MIMO channel modeling in recent years [5]. Thus, a ray-tracing channel model is developed to calculate wanted channel matrix of MIMO-WLAN system.

By using these images and received fields, the channel frequency response can be obtained as following [6]

$$H(f) = \sum_{p=1}^{N_p} a_p(f) e^{j\theta_p(f)} \tag{4}$$

where p is the path index, N_p is the number of paths, f is the frequency of sinusoidal wave, $\theta_p(f)$ is the *p*-th phase shift and $a_p(f)$ is the *p*-th receiving magnitude. Note that the channel frequency response of WLAN systems can be calculated by equation (4) in the frequency range of WLAN for both desired signal and interference signal.

III. NUMERICAL RESULTS

Layout of a small personal communication environment is shown in Figure 1. The dimensions of the two rooms are both 2.5m (length) × 4.0m (width) × 2.5m (height), and the partition with dimensions of 0.2m (thickness) × 4.0m (width) × 2.5m (height) is between the two rooms. Materials of the ceiling, the walls, the partition and the ground are all concrete block. The dielectric constant and conductivity of the different materials are shown in Table I. [7].

The transmitter of desired signal located at x=2m, y=1.5m, z=1.2m and the transmitter of interference signal located at x=3.2m, y=1.5m, z=1.2m are placed in Room1 and Room2, respectively. Moreover, 236 receiving antennas are located on the four wooden tables in Room1 with equal distance of 0.1m.

The antennas of both transmitter and receiver belong to vertically polarization and omni-directional dipole antenna for SISO.

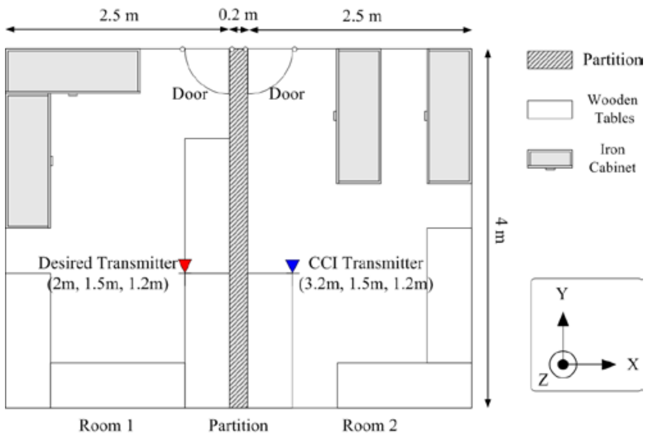

Figure 1. Layout of a small personal communication environment

While the largest wavelength is $\lambda_l = c / f_l \approx 0.005\ m$, and the inter-element separation, d=0.0025m, is chosen to achieve low spatial correlation. Note that strict time stationary is maintained by ensuring complete physical isolation and absence of any mobile objects.

In this paper, the average capacity versus SNRt for the MIMO-WLAN simple ULA and PDA is calculated. In truth, the capacity in equation (8) can be calculated by equal transmitting powers for both MIMO-ULA and MIMO-PDA cases. SNRt is the ratio of total transmitting power to noise power for 236 receiving points. As a result, the channel realizations for various receiving locations are combined into one ensemble with 236 samples.In other words, we have calculated the SNR in all receiving positions.

The average capacities of WLAN systems calculated from 236 receiving locations with CCI-ULA, CCI-PDA and without CCI for MIMO-ULA and MIMO-PDA are shown in Figure 2 and Figure 3 respectively. Note that the CCI-ULA and the CCI-PDA denote the CCI with simple uniform linear array and polarization diversity array, respectively. In the two figures, the capacity for MIMO-ULA with CCI-PDA is larger than that with CCI-ULA, and the capacity for MIMO-PDA with CCI-ULA is larger than that with CCI-PDA, when SNRt is large enough. This is due to the fact that the received CCI power becomes large when antenna arrays of desired system and CCI are the same, and the opposite results can be obtained when antenna arrays of desired system and CCI are different.

IV. CONCLUSION

Numerical results show that MIMO-PDA provides somewhat lower gain in SNR and capacity than MIMO-ULA for the interference free case, but offers a feasible alternative for miniaturized WLAN devices owing to its compact, collocated antenna structure, and it keeps a good immunity against the CCI. The immunity against CCI for MIMO-PDA is better than that for MIMO-ULA

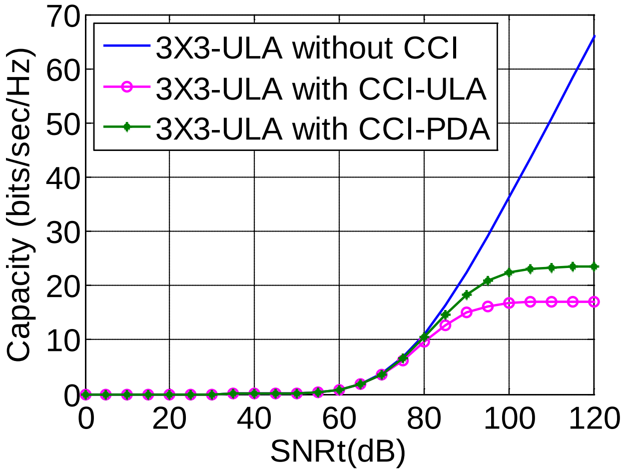

Figure 2. The average capacities of WLAN systems for MIMO-ULA with CCI-ULA, CCI-PDA and without CCI

TABLE I Dielectric properties of different materials

MATERIALS	Relative Permittivity			
	Real	**Imaginary**	**Conductivity**	**Tan loss**
	ε'	ε''	σ	**Tan(δ)**
Concrete (Ceiling, Walls, Partition, Ground）	6.4954	0.4284	1.43E+00	6.60E-02
Wood (Wooden Doors, Wood Tables）	1.5	0.09	3.00E-01	6.00E-02

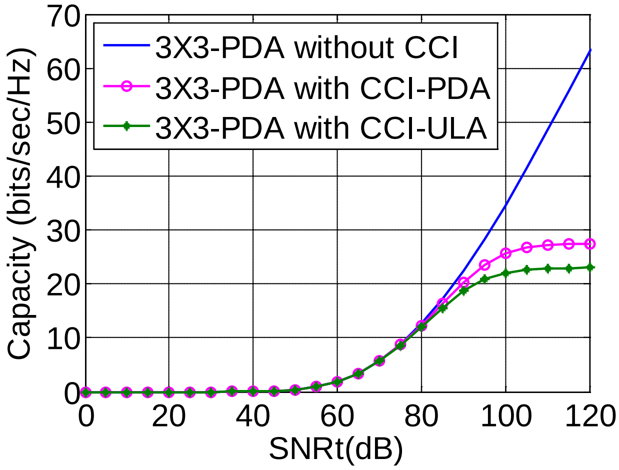

Figure 3. The average capacities of WLAN systems for MIMO-PDA with CCI-PDA, CCI-ULA and without CCI

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