Channel Capacity of Ultra-Wide Band Systems with Interference

Wei Chien, Wei-Chun Hsiao, Chun-Liang Liu, Chien-Ching Chiu and Jhuo-Ru Li

***Abstract*—In this paper, channel capacity of multiple-input multiple-output ultra-wide band (MIMO-UWB) systems with single co-channel interference (CCI) is calculated. A ray-tracing approach is used to calculate wanted channel frequency response, and the channel frequency response is further used to calculate corresponding channel capacity. By the ray-tracing approach, two different antenna arrays are applied to our simulation to observe whether MIMO can reduce CCI. Also the effects caused by the two antenna arrays for desired system and CCI are quantified.**

***Index Terms*—MIMO-UWB, single CCI, ray-tracing approach and channel capacity .**

I. Introduction

For wireless communication systems, two main sources of performance degradation are the thermal noise present in the channel or generated in the receiver and unwanted signals emanating from the same or nearby stations. CCI is one of the unwanted signals and it appears due to frequency reuse in wireless channels. CCI reduction has been studied and used in a very limited form in wireless networks [1]-[3]. 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. Although using multiple antennas (SIMO and MISO) to reduce CCI has been proven effective in many literatures, it is not very sure that MIMO can be used to reduce CCI as well. Furthermore, capacity affected by CCI is still largely an unsolved problem [3] and corresponding literatures are few. As a result, it is worth to investigate whether MIMO can effectively reduce CCI on channel capacity calculation.

In a classical large cellular system, due to several interferers in different co-channel cells, the CCIs can be assumed as statistical random variables. Most studies have been made on effects of CCI based on the assumption in MIMO systems [4]-[6]. However, the assumption is not suitable for MIMO-UWB systems by the following reasons. First, in a small personal communication system (such as UWB systems), CCI are probably just caused by few signals from adjacent rooms. Second, the use of adaptive antennas and intelligent channel assignment techniques make the case of a large number of CCIs less probable.

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II. System Description and Channel Modeling

A matrix representation of the system is shown in Figure 1.An $N_t \times N_r$ UWB system can be represented by the three-dimensional matrix $\mathbf{H}^{\mathbf{UWB}} \in C^{N_r \times N_t \times N_f}$ such that $\mathbf{H}^{\mathbf{UWB}} = [\mathbf{H}_{\mathbf{f}}^{\mathbf{NB}}],\ f = 1,2,\cdots,N_f$, where $\mathbf{H}_{\mathbf{f}}^{\mathbf{NB}}$ is defined as a flat-fading channel matrix of narrowband MIMO system at the *f*th frequency component and N_f is the number of discrete frequency components of UWB system. When the frequency components of a wideband channel are uncorrelated to each other, it is possible to divide the wideband channel into several narrowband channels [7], [8]. As a result, MIMO capacity of UWB systems can be seen as the summation of several MIMO capacities of NB systems at every discrete frequency component, and it can be expressed as follows:

$$C^{UWB} = \sum_{f=1}^{N_f} C_f^{NB} \qquad \text{(bits/sec)} \tag{1}$$

where C_f^{NB} is the MIMO capacity of NB systems at the *f*th frequency component. More generally, the equation can be rewritten as follows:

$$C_{SE}^{UWB} = \frac{C^{UWB}}{BW} \qquad \text{(bits/sec/Hz)} \tag{2}$$

This equation expresses the achievable spectral efficiency through the MIMO channel and BW is the bandwidth of UWB system.

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

$$H(f) = \sum_{p=1}^{N_p} a_p(f) e^{j\theta_p(f)} \tag{3}$$

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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 pth phase shift and $a_p(f)$ is the pth receiving magnitude. Note that the channel frequency response of UWB systems can be calculated by equation (3) in the frequency range of UWB for both desired signal and interference signal.

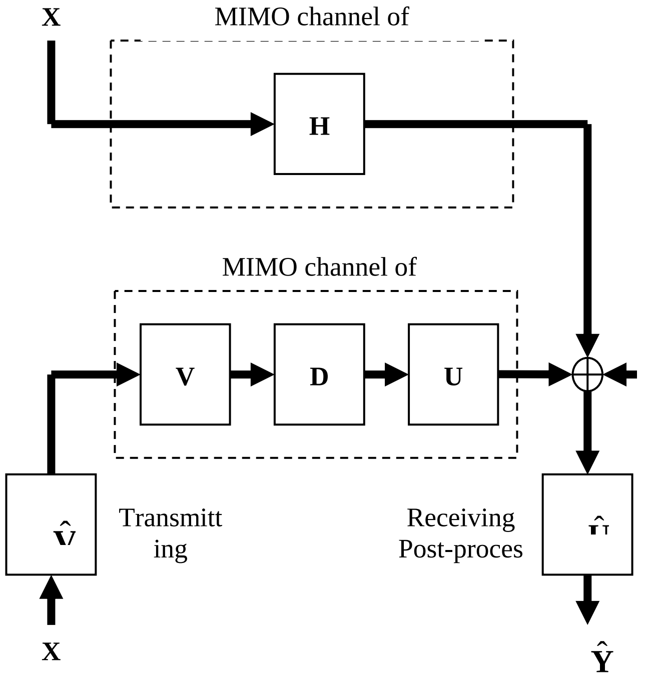

Fig. 1 A matrix representation of MIMO-NB system with single CCI

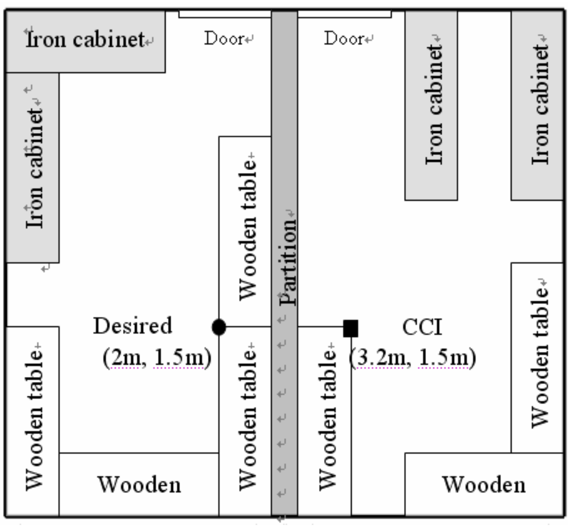

Fig. 2 Layout of a small personal communication environment

III. NUMERICAL RESULTS

Layout of a small personal communication environment is shown in Figure 2. In the figure, 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. Furthermore, some furniture is in the rooms, including wooden doors, wood tables and iron cabinets. Sizes of the wooden table and the iron cabinet are 1.5m (length) × 0.5m (width), and heights of the wooden table and the iron cabinet are 1m and 2m respectively.

The transmitter of desired signal (2.m, 1.5m, 1.2m) and the transmitter of interference signal (3.2m, 1.5m, 1.2m) are located in Room 1 and Room 2, respectively. Moreover, 236 receivers are located on the four wooden tables in Room 1 with equal distance of 0.1m. All antennas of both transmitter and receiver are omni-directional radiation. Furthermore, two different antenna arrays, spatial array (SA) and polar array (PA), are considered as shown in Figure 3(a) and Figure 3(b) respectively.

In the simulation, the channel is assumed to have $N_f = 1501$ discrete frequency points over the $BW = 7.5\,GHz$ wideband from $f_l = 3.1\,GHz$ to $f_H = 10.6\,GHz$ with $B \approx 5\,MHz$ resolution. The inter-element separation $d = 0.06\,\mathrm{m}$ is chosen in order to achieve low spatial correlation, while the largest wavelength is $\lambda_l = c / f_l \approx 0.1\,m$, where $c = 3\times10^8$ m/s is the speed of light. Finally, note that strict time stationary is maintained by ensuring complete physical isolation and absence of any mobile objects.

The average capacities of UWB systems calculated from 236 receiving locations for both MIMO-SA and MIMO-PA with and without single CCI are shown in Figure 4. It is seen that the capacities without single CCI for spatial array MIMO (MIMO-SA) are larger than that for polar array MIMO (MIMO-PA). This is due to the fact that MIMO-SA exhibits approximately equal sub-channel power gain, while in MIMO-PA, the sub-channel with vertical to vertical polarization, for example, is weaker than horizontal to horizontal polarization. However, the capacity with single CCI for MIMO-SA is smaller than that for MIMO-PA when SNR_t is large enough, and the opposite results can be seen when SNR_t is small. The reason is that when MIMO-SA use spatial array to break a multipath channel into several individual spatial channels to enhance capacity, these individual spatial channels also import extra interference power at the moment. In contrast to MIMO-SA, MIMO-PA use tri-polar array to enhance capacity, implying the interference power is reduced when antenna polarizations of receiving antenna and interference antenna are not the same. In other words, when MIMO-PA system breaks a multipath channel into several individual spatial channels to enhance capacity, not all individual spatial channels are affected by interference.

A parameter is defined to check whether MIMO compared to SISO can be used to reduce degradation of capacity while single CCI exist, and it is expressed as

$$VR_c = \frac{\text{Average capatity with single CCI}}{\text{Average capacity without single CCI}} \times 100\% \quad (4)$$

Note that the more value of VR_c increase, the more degradation of capacity reduces. In other words, larger VR_c

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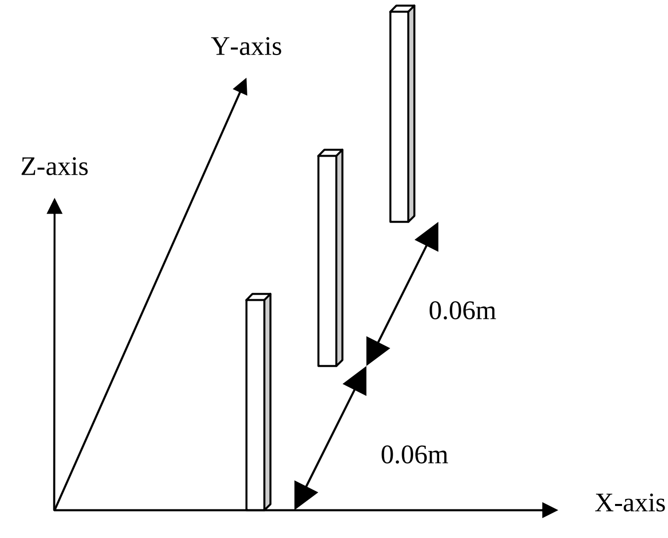
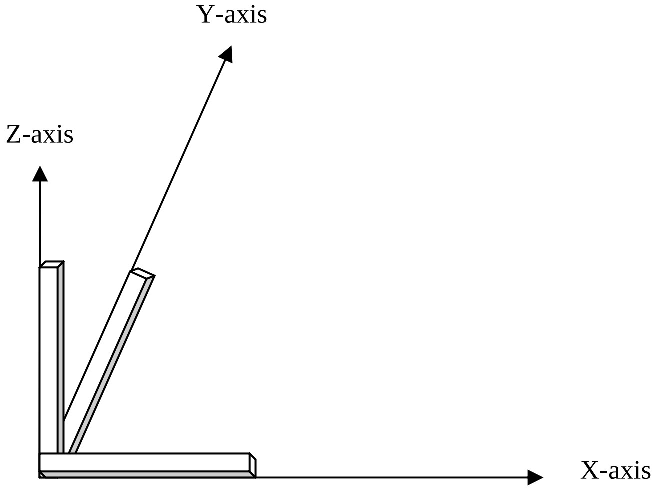
expresses the system can obtain more channel capacity while CCI exist. VR_c for MIMO-SA, MIMO-PA and SISO are shown in Figure 5. It is seen that MIMO-PA can effectively reduce the effect of CCI but MIMO can not. The results obtained in Figure 5 are as same as that obtained in Figure 4.

It was found from the results that MIMO-SA compared to MIMO-PA can be used to obtain the largest capacity while CCI does not exist. However, MIMO-SA is not the best choice while single CCI exist, since it can not reduce the degradation of capacity caused by the CCI. In contrast to MIMO-SA, MIMO-PA can be used to reduce the degradation of capacity even though it provide less capacity compared to MIMO-SA while CCI does not exist. It is concluded that MIMO-PA provides somewhat lower gain in SNR and capacity than does the MIMO-SA, but offers a feasible alternative for miniaturized UWB devices owing to its compact, collocated antenna structure, and it keep a good immunity against the CCI.



(a) Spatial linear array



(b) Tri-polar array

Figure 3 Layouts of SA and PA

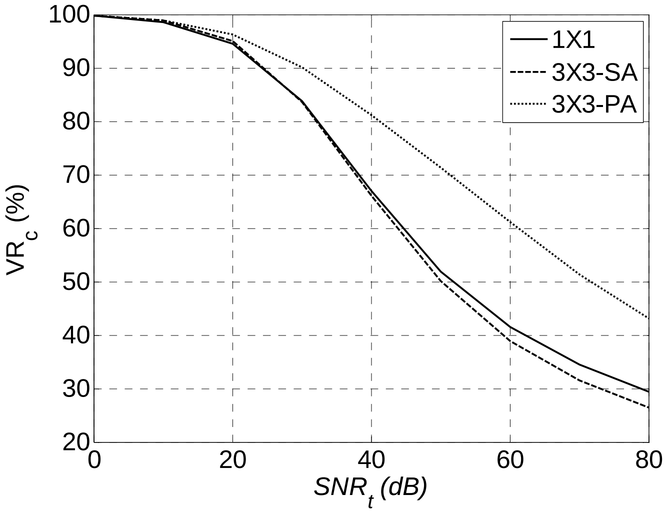


Fig. 4 The average capacities of UWB systems for both MIMO-SA and MIMO-PA with and without single CCI

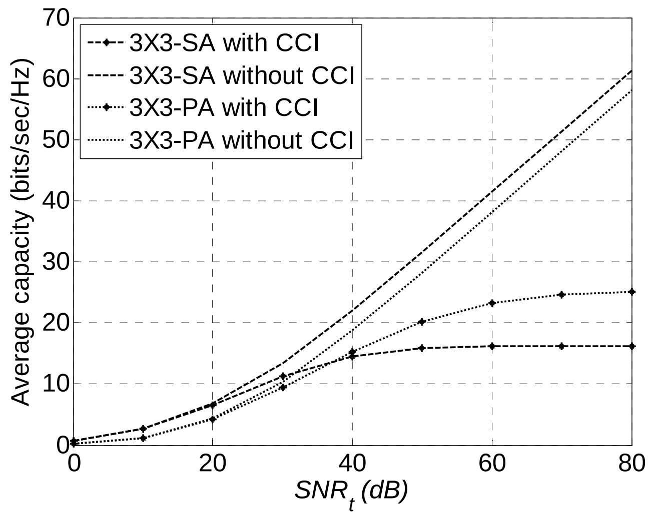


Fig. 5 VR_c for MIMO-SA, MIMO-PA and SISO

IV. CONCLUSION

The analyses of the MIMO capacity of UWB systems with single CCI have been investigated. By the ray-tracing channel model, the average capacities of both MIMO-UWB system and SISO-UWB system with and without single CCI are calculated while the transmitter of the CCI equips only one antenna, and the results are used to decide whether MIMO can effectively reduce CCI on capacity performance. Furthermore, considering the transmitter of the CCI equips multiple antennas and applying SA and PA to desired system and the CCI respectively, the average capacities of MIMO-UWB system with and without the CCI are calculated to show the effects caused the two antenna array.

Numerical results show that MIMO-PA provides somewhat lower gain in SNR and capacity than does the MIMO-SA, but offers a feasible alternative for miniaturized UWB devices owing to its compact, collocated antenna structure, and it keep a good immunity against the CCI. Moreover, the immunity against CCI for MIMO-PA is better than that for MIMO-SA system does, and the immunity will increases when antenna arrays of desired system and CCI are different.

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