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An Adaptive Multiple Antenna Transmission Scheme for an OFDMA System

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Abstract— We propose an orthogonal frequency division multiplexing frequency division multiple access (OFDMA) system with an adaptive multiple antenna transmission scheme for future wireless communication systems. In the system, both a transmit diversity scheme with high order modulation and a spatial multiplexing scheme with low order modulation are employed for the given spectral efficiency, between which the proper transmission scheme is selected according to the channel state. It is observed that the proposed system with a selection algorithm based on the post processing SNR reduce the average transmit power.

Keywords—Spatial Multiplexing, Transmit Diversity, OFDMA

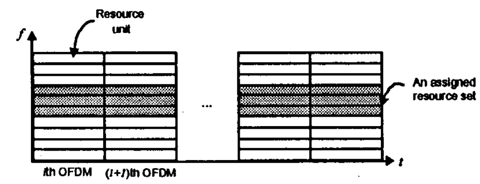

Figure 1. An example of resource allocation in an OFDMA system.

I. INTRODUCTION

In future wireless communication systems, high data rate and quality close to the wired environments are required to support increasing demands on various services such as video and audio streaming, file transfer, internet access, and so forth. Especially, demands on packet data service are increasing for ubiquitous internet access. OFDMA provides an efficient platform for high data rate packet transmission with its advantages of the robustness to multipath fading, granular resource allocation capability, no intracell interference, and etc. Thus, it has been adopted for wireless metropolitan area networks standards and considered as a successful candidate for future multiple access schemes [1].

Together with OFDMA, wireless communication using multiple antennas at both the transmitter and receiver has drawn a lot of attention due to its potential to achieve high spectral efficiency and performance enhancement [3]-[5]. Employing multiple antennas for antenna diversity is a practical, effective, and a widely applied technique for reducing the multipath fading. Transmit diversity scheme of [4] is particularly appealing because of its simplicity and performance. However, the modulation order should be increased to provide higher data rate in the system. On the other hand, spatial multiplexing with multiple transmit antennas can enhance the spectral efficiency even with low order modulation by increasing the number of transmit antennas [3]. However, its performance greatly varies according to spatial characteristics of the channel.

In this paper, we propose an OFDMA system with two modes of multiple antenna transmission for the given data rate. One mode is a transmit diversity coding scheme with high order modulation and the other is the spatial multiplexing with lower order modulation. The two transmission schemes can be considered as submodes of multiple adaptive modulation and coding (AMC) modes providing different data rates. Thus the selection between the two modes is performed according the spatial correlation and channel power asymmetry in a region of the same received SNR. We analyze the performance of the two transmission schemes and investigate the performance in a channel with different spatial correlation and channel asymmetry. With the results, we propose a selection algorithm based on the post processing SNR and investigate the performance gain with the proposed adaptive transmission via simulation. We will describe the overall system model of the proposed system in Section II and present a selection algorithm with performance analysis in Section III. In Section IV, analytical and simulation results will be shown and, finally, conclusions will be provided in Section V.

II. SYSTEM MODEL

Consider an OFDMA system with two transmit antennas for downlink, where data packets are assigned with orthogonal sets of time and frequency resources as illustrated in Figure 1. Theoretically, a subcarrier (frequency) of an OFDM symbol time can be a minimum unit for resource allocation. In this paper, we allocate a set of time and frequency resources which are coherent in time and in frequency for each data packet transmission.

The block diagram of the proposed system is depicted in Figure 2. The space block coding (SBC) modulator denotes the transmission scheme based on the Alamouti's transmit diversity block coding [4] with high order modulation and the spatial multiplexing (SM) modulator denotes the spatial multiplexing with low order modulation. Here, we give a generic name SBC to refer space time (or frequency) block coding since the OFDMA can assign block coded symbols either in time or in frequency. The SBC modulator maps the incoming bits to the modulation symbols x_l of constellation size M^2 and spatially encodes the modulation symbols such that the antenna symbol vector, transmitted at the allocated resource, is given by $\mathbf{x}_{2i} = (x_{2i}\ -x_{2i+1}^*)^T$ and $\mathbf{x}_{2i+1} = (x_{2i+1}\ x_{2i}^*)^T$. On the meanwhile, the SM modulator generates the modulation symbols x_l of constellation size M and multiplexes

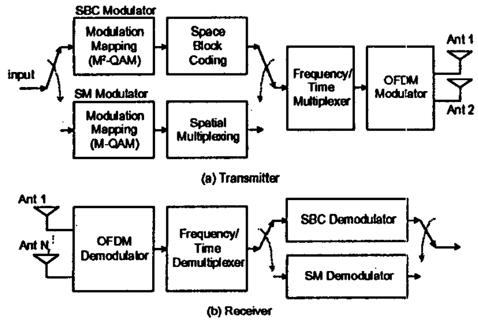

Figure 2. The transmitter of the proposed system.

the symbols such that the antenna symbol vector is given by $\mathbf{x}_i = (x_{2i}\ x_{2i+1})^T$. Since the SBC and SM modulators transmit $2\log_2(M)$ coded bits per allocated resource, they output the same data rate. The symbol vectors from one of the modulators are mapped to the time and frequency resources allocated for each data packet and the OFDM symbols are generated for transmission on two transmit antennas.

The channel is assumed to be quasi-static so that it does not vary over one data packet transmission and yet can vary over packet by packet. The channel is also assumed to be flat fading on the subcarriers assigned for a data packet. Thus the received vector from N_r receive antennas at the ith allocated resource is given by

$$\mathbf{r}_i = \sqrt{\frac{E_s}{2}}\mathbf{H}\mathbf{x}_i + \mathbf{n}_i, \tag{1}$$

where $\mathbf{r}_i$ is the $N_r \times 1$ received vector, $\mathbf{H} = [\mathbf{h}_1\mathbf{h}_2]$ is the $N_r \times 2$ complex matrix of the channel frequency response with $\mathbf{h}_q = (h_{1,q}h_{2,q}\cdots h_{N_r,q})^T$, and $\mathbf{n}_i$ is the $N_r \times 1$ additive white Gaussian noise (AWGN) vector with $E\{\mathbf{n}_i\mathbf{n}_i^H\} = N_0\mathbf{I}_{N_r}$. Here, the symbol energy is normalized by 2 so that the total transmitted energy over two transmit antennas per resource unit is E_s irrespective of modulation schemes. We further assume that the received power gathered from all channel branches is always the same such that $||\mathbf{H}||^2 = \sum_{p=1}^{N_r}\sum_{q=1}^{2}|h_{p,q}|^2 = 2N_r$. This assumption is based on that the two antenna transmission modes are considered as submodes supporting multiple AMC modes and the fading effect is compensated by selecting a proper AMC mode for the instantaneous SNR.

In the receiver, the received vector is processed according to the selection in the transmitter. In the SBC demodulator, the received vector is combined with channel gain such that

$$\hat{\mathbf{r}}_i = \mathbf{H}^H\mathbf{r}_i, \tag{2}$$

from which the signal component pertinent to the modulation symbol is extracted as

$$z_{2i} = \hat{r}_{1,2i} + \hat{r}^*_{2,2i+1}, \tag{3}$$

$$z_{2i+1} = -\hat{r}^*_{1,2i} + \hat{r}_{2,2i+1}. \tag{4}$$

Here, $\hat{r}_{k,i}$ is the kth element of $\hat{\mathbf{r}}_i$. With z_l, the constituent information bits of a modulation symbol x_l is detected. For the SM demodulator, several algorithms such as maximum likelihood (ML) detection, linear equalization based on zero forcing (ZF) or minimum mean square error (MMSE) criterion, and ordered successive interference cancellation can be utilized considering the complexity and performance. In this paper, we consider the ZF receiver for simplicity and the ML detector for optimal performance.

The selection of modulation schemes can be performed at the receiver or the transmitter considering the AMC related issues such as available feedback channel capacity, other AMC mode selection, packet scheduling, and etc. One of easy implementation with the smallest feedback is to let the receiver decide the favorite transmission scheme and report the selection.

III. Transmission Scheme Selection Criterion

For the SBC, the post processing SNR for each modulation symbol is given by

$$\mathrm{SNR}_{SBC} = \frac{||\mathbf{H}||^2}{2}\frac{E_s}{N_0}, \tag{5}$$

from which the bit error rate (BER) performance can be evaluated for different symbol mapping. As an example, the BER for the SBC with 16-QAM under the given channel is as follows.

$$P_b = \frac{3}{4}Q\left(\sqrt{\frac{\mathrm{SNR}_{SBC}}{5}}\right) + \frac{1}{4}Q\left(3\sqrt{\frac{\mathrm{SNR}_{SBC}}{5}}\right), \tag{6}$$

where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-t^2/2}dt$. Thus, the SBC modulator provides us with uniform performance irrespective of channel matrix elements if $||\mathbf{H}||^2$ is same.

In case of the SM with the ZF receiver, the post processing SNR of the symbol from the qth transmit antenna is given by

$$\mathrm{SNR}_{SM,q} = \frac{1}{2[\mathbf{H}^H\mathbf{H}]^{-1}_{qq}}\frac{E_s}{N_0}. \tag{7}$$

Especially, for $N_r \geq 2$, it is simplified as

$$\mathrm{SNR}_{SM,q} = \frac{||\mathbf{h}_q||^2(1-\rho^2)}{2}\frac{E_s}{N_0}, \tag{8}$$

where $||\mathbf{h}_q||^2 = \sum_{p=1}^{N_r}|h_{p,q}|^2$ is the received power from the qth transmit antenna and $\rho = ||\mathbf{h}_1^H\mathbf{h}_2||/||\mathbf{h}_1||||\mathbf{h}_2||$ is the antenna correlation of the transmit part. Thus we can expect that even with a same value of $||\mathbf{H}||^2$, the SM modulator will produce widely different performance with channel antenna correlation ρ and the channel power asymmetry between $||\mathbf{h}_1||^2$ and $||\mathbf{h}_2||^2$. As an example, for the SM with QPSK, the BER with the ZF receiver is given by

$$P_b = \frac{1}{2}Q(\sqrt{\mathrm{SNR}_{SM,1}}) + \frac{1}{2}Q(\sqrt{\mathrm{SNR}_{SM,2}}). \tag{9}$$

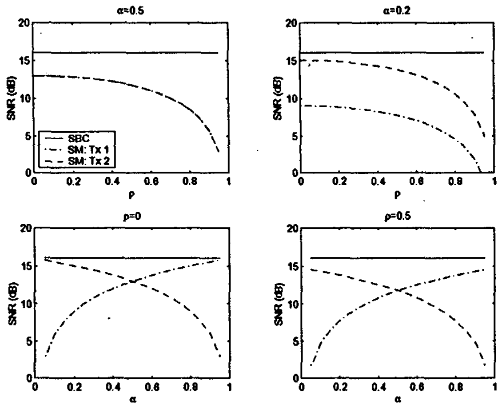

Figure 3. The post processing SNR of the SBC and SM modulators when $N_r = 2$, $||\mathbf{H}||^2 = 4$, and $E_s/N_0 = 13$dB.

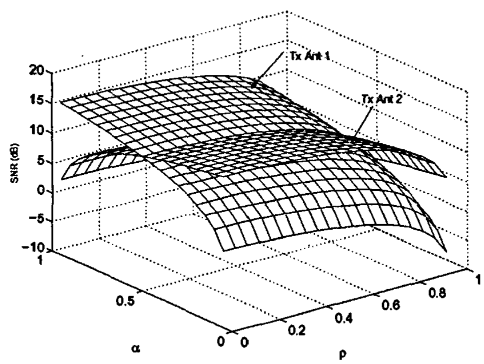

Figure 4. The post processing SNR per transmit antenna of the SM for various α and ρ when $N_r = 2$, $||\mathbf{H}||^2 = 4$, and $E_s/N_0 = 13$dB.

When the ML detection is used for the SM modulator, it is complicated to define the post processing SNR . We instead estimate it with the post processing SNR of the ZF receiver.

Figure 3 compares the post processing SNR of the SM and SBC, when $N_r = 2$, $||\mathbf{H}||^2 = 4$, and $E_s/N_0 = 13$dB. In the figure, α ($= ||\mathbf{h}_1||^2/||\mathbf{H}||^2$) represents the channel asymmetry: if $\alpha = 0.5$, $||\mathbf{h}_1||^2 = ||\mathbf{h}_2||^2$. We also provide the post processing SNR per transmit antenna of the SM for various α and ρ in Figure 4, with the same conditions as in Figure 3. In case of the SM modulator, the post processing SNR decreases as ρ increases and the difference between the post processing SNRs of two transmit antennas becomes larger as α deviates from 0.5. If the difference between SNR_{SBC} and $\text{SNR}_{SM,q}$ is less than the SNR gain of the M-QAM used in the SM over the M^2-QAM used in the SBC, the SM will outperform the SBC. Moreover, the BER is dominated by the symbols in a bad state and a transmission selection criterion can be therefore obtained as

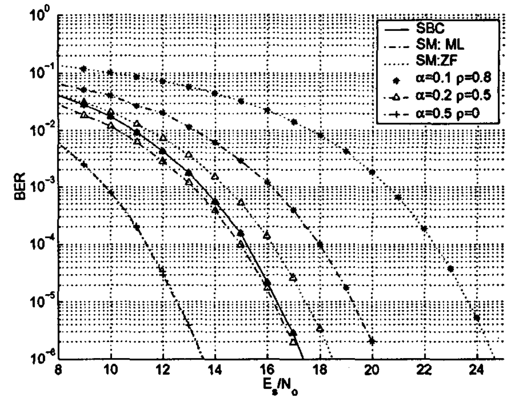

Figure 5. The BERs of the SBC modulator with 16-QAM and the SM modulator with QPSK in fixed channels with different α and ρ.

$$\text{Select} \begin{cases} \text{SBC}, & \text{if } \text{SNR}_{SBC} > \text{SNR}_{SM,\min} + T \text{ (dB)}, \\ \text{SM}, & \text{otherwise}, \end{cases} \tag{10}$$

where $\text{SNR}_{SM,\min} = \min_q \text{SNR}_{SM,q}$ and a threshold T can vary with the modulation schemes used in the SM and SBC.

IV. Performance Evaluation

In this section, we investigate the performance of the proposed system via analytical results and Monte Carlo simulations. A data packet of size 1536 is mapped to 16-QAM symbols for the SBC and QPSK symbols for the SM. Thus total 384 coherent resource units are allocated for a packet data transmission. At the receiver, the number of receive antennas is 2 for all simulations.

To begin with, we compare the performance of the SM and SBC modulators in a fixed channel with different (α, ρ) in Figure 5. We provide analytical results for the SBC and the SM with the ZF receiver while simulation results fort the SM with the ML receiver. The SBC modulator exhibits the same performance irrespective of (α, ρ) while the SM exhibits more than 6dB SNR variation with the ML receiver and more than 20 dB SNR variation with the ZF receiver at the BER of 10^{-3} for three (α, ρ) values. When the channel has no antenna correlation and is symmetric, we can obtain up to 3.6dB SNR gain by selecting the SM instead of the SBC. Moreover, we can obtain a large SNR gain by choosing the SBC instead of the SM in a fairly asymmetric channel with severe antenna correlation. Another observation from the performance of $(\alpha, \rho) = (0.5, 0)$ is that QPSK has a SNR gain of 7dB over 16-QAM at the BER of 10^{-3}. Thus we expect that the optimal threshold will be a value near 7dB.

Figures 6 and 7 compare the BERs of the proposed system with the ZF receiver and the ML receiver, respectively, for the SM demodulator. In the figures, the channel elements $h_{p,q}$ are randomly generated from the complex normal distribution and

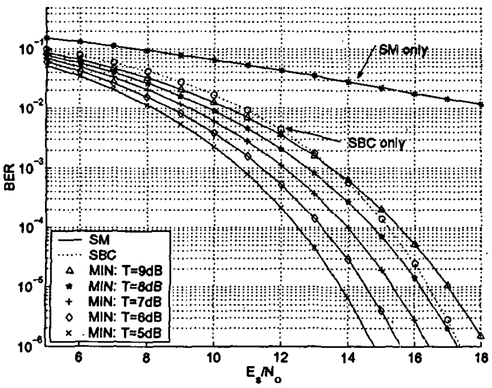

Figure 6. The BERs of the proposed system when the ZF receiver is employed for the SM.

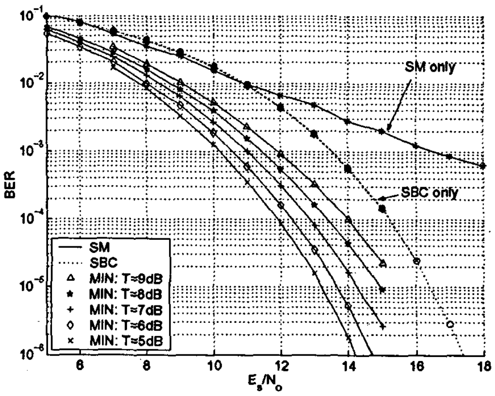

Figure 7. The BERs of the proposed system when the ML detector is employed for the SM.

TABLE I
THE EFFECTIVE SNR GAIN WITH ADAPTIVE TRANSMISSION SCHEME.

SM receiver	T	G_{sm}	λ	G_a
ZF	5 dB	2.6 dB	0.11	0.29 dB
ZF	6 dB	2.0 dB	0.22	0.44 dB
ZF	7 dB	1.4 dB	0.33	0.46 dB
ZF	8 dB	0.7 dB	0.43	0.30 dB
ML	5 dB	3.3 dB	0.11	0.36 dB
ML	6 dB	3.0 dB	0.22	0.67 dB
ML	7 dB	2.5 dB	0.33	0.83 dB
ML	8 dB	2.2 dB	0.43	0.95 dB
ML	9 dB	1.7 dB	0.53	0.90 dB

normalized as $||\mathbf{H}||^2 = 4$. The bit errors due to the SM selection and due to the SBC selection are separately collected to show the effect of the adaptation. While the SM outperforms the SBC in some cases of (α, ρ) as shown in Figure 5, the former shows worse performance than the SBC in average since the worst case dominates the performance. By adaptively selecting the transmission scheme proper for the channel, the BER due the SM is much lower than that due to the SBC. While the $T = 5$dB shows the best performance in the figures, the selection rate is much lower than the system with other threshold values. For fair comparison, we define the effective gain with adaptive transmission scheme as

$$G_a = \lambda G_{sm}, \tag{11}$$

where λ is the selection rate of the SM and G_{sm} is the SNR gain obtained by selecting the SM instead of the SBC. Table I compares G_{sm}, λ, and G_a at the BER of 10^{-3} for the ML and ZF receiver with several threshold values. From the table, we can obtain a best performance with the ML detection at the threshold value around 8 dB and reduce the transmit power by 1 dB in average.

V. CONCLUSIONS

In this paper, an OFDMA system with two multiple antenna transmission schemes has been considered. We analyzed the performance of the SBC modulator and SM modulator according to the spatial characteristics. With the results, it was shown that the system with the SM modulator produced widely different performance with the channel antenna correlation and channel asymmetry while the system with the SBC modulator exhibited uniform performance. From the observation, we proposed an adaptive antenna transmission scheme with a selection algorithm based on the post processing SNR. With the proposed method, we can reduce the transmit power both in nomadic applications by automatically configuring one transmission mode suitable for the channel characteristics and in low speed mobile applications by adaptively selecting the proper mode for the channel state.

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