Throughput Enhancement for MIMO–OFDM Systems Using Transmission Control and Adaptive Modulation

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***Abstract*— Future mobile communication systems will adopt the multiple antennas at both transmitter and receiver to improve system capacity and spectral efficiency. In such MIMO (Multiple Input Multiple Output) system, a channel separation method is indispensable because the parallel transmission is performed. When the ZF algorithm is used for the channel separation, serious signal quality degradation sometimes happens depending on the relation between the multiple channels. In such a case, the signal quality can be maintained with limiting the transmit channels. In this paper, we propose the transmission channel control scheme for the MIMO–OFDM systems. This scheme selects the transmit parameters (transmit antenna, modulation method, coding rate) so as to maximize the instantaneous system throughput based on the reception SNR of each channel. We show that the proposed scheme is effective in the system throughput enhancement through the computer simulation results.**

***Keywords*— MIMO, OFDM, Transmission control, Adaptive modulation, Throughput**

I. Introduction

This paper presents a new scheme of throughput enhancement for MIMO–OFDM (Multiple Input Multiple Output – Orthogonal Frequency Division Multiplexing) systems using a little feedback information.

Wideband mobile communication systems have been studied widely to transmit multimedia information. In the wideband communication systems, frequency-selective fading due to the multi–path channel becomes the severe problems in addition to the conventional Rayleigh fading. Multi–carrier techniques represented OFDM have been developed to overcome this problem. Recently, wireless LAN system has become popular and the transmission data rate which demanded by each user has increased. Therefore, the spectrally efficient wireless systems have attracted attention.

MIMO–OFDM is one of technologies for such spectrally efficient systems. This system transmits several data streams in parallel over multiple transmit antennas, and so it can increase the spectral efficiency of the wireless link remarkably. In MIMO system, the SDM (Space Division Multiplexing) scheme [1][2] and the STC (Space Time Coding) scheme [3,4] have been researched widely. In this paper, we deal with the first one.

In the SDM system, independent data streams are transmitted simultaneously form each antenna, and a channel separation at the receiver must be performed. Two major algorithms are known for the channel separation - the ZF (Zero forcing) algorithm and the MLD (Maximum Likelihood Detection) algorithm. In the ZF algorithm, the interference from undesired channels is eliminated using the difference of channel state among each antenna. This has low computational complexity and can be performed with the calculation of one time matrix inversion. On the other hand it has some weak points that we can not get diversity gain, can not separate received signal when each channel has the large correlation etc. In the MLD algorithm, the replicas of all possible transmit symbols are evaluated to determine transmitted data streams. This algorithm provides a superior transmission performance, however its complexity increases exponentially with the number of antennas. Therefore it is very difficult to realize the communication systems especially when the high order modulation is adopted. The complexity reduction scheme and evaluation of complexity are widely investigated [5-7].

In this paper, we consider the performance improvement for MIMO–OFDM systems with the ZF algorithm. The ZF algorithm shows the serious performance degradation when the large correlation among multiple channels appears. We can thus improve the system throughput by limiting the transmit channels adaptively. Several transmission channel control schemes have been studied [8-11]. In [8] some antenna selection criteria based on the received SNR are shown. In [9][10], optimum antenna set selection schemes with the adaptive power control which maximize the throughput in the BLAST system are reported. In [11] throughput enhancement scheme with the transmit antenna selection and the adaptive modulation in a single carrier system is described. We present the system throughput in the multi–carrier MIMO system with the adaptive antenna selection and modulation using a little feedback information.

This paper organized as follows. In Section 2 we describe the conventional SDM-MIMO system briefly, in section 3 proposed transmission channel control scheme is shown. In section 4 we present the system throughput obtained through computer simulation. Conclusions close the paper.

II. SDM-MIMO system overview

The SDM scheme improves the maximum transmission rate by sending the multiple data sequence simultaneously. Fig.1 shows the function blocks of the conventional two antennas MIMO–OFDM system. In the receiver, because two antennas receive the signals composed of data 1 and data 2, the signal combining between multiple antennas and the interference suppression are performed to divide two data sequences. The reception signal at the receive antenna k is given by

$$\begin{bmatrix} r_1^j \\ r_2^j \end{bmatrix} = \begin{bmatrix} h_{11}^j & h_{12}^j \\ h_{21}^j & h_{22}^j \end{bmatrix} \begin{bmatrix} x_1^j \\ x_2^j \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (1)$$

where j is the subcarrier number, h_{ki}^j is the branch gain from the transmit antenna i to the receive antenna k, x_i^j is the transmitted signal from the antenna i, n_k is the noise at the receive antenna k. "branch" means the channel from one transmit antenna to one receive antenna. Some estimation schemes to estimate the transmitted signal x_i^j are known. We adopt the ZF algorithm which use the inverse matrix $\boldsymbol{S}$ of the channel matrix $\boldsymbol{H} = [h_{ki}]$.

$$S^j = \begin{bmatrix} s_{11}^j & s_{12}^j \\ s_{21}^j & s_{22}^j \end{bmatrix} \quad (2)$$

The inverse matrix $\boldsymbol{S}$ is applied to the reception signal vector to obtain an estimate of x_{ki}

$$\begin{bmatrix} s_{11}^j & s_{12}^j \\ s_{21}^j & s_{22}^j \end{bmatrix} \begin{bmatrix} r_1^j \\ r_2^j \end{bmatrix} = \begin{bmatrix} x_1^j \\ x_2^j \end{bmatrix} + \begin{bmatrix} s_{11}^j & s_{12}^j \\ s_{21}^j & s_{22}^j \end{bmatrix} \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

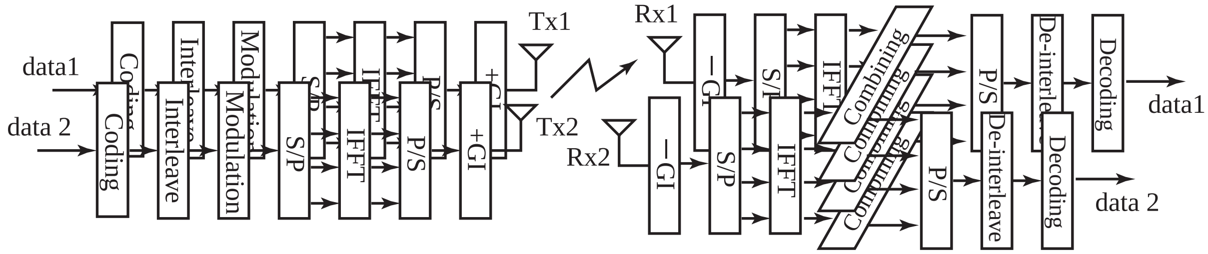

Fig. 1. Conventional MIMO–OFDM system function block

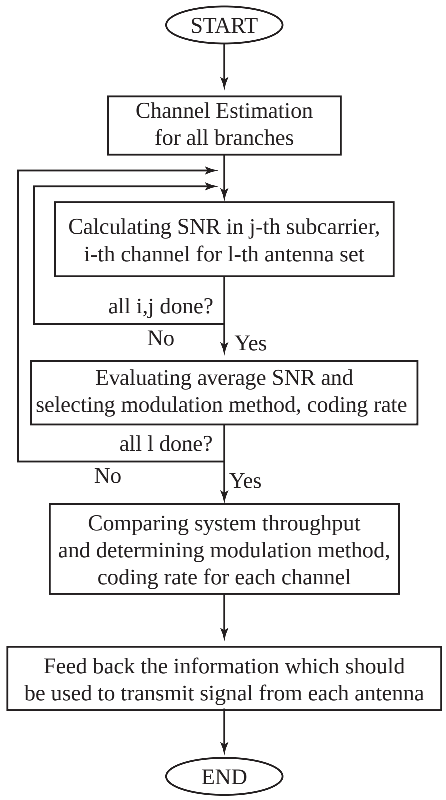

Fig. 2. A flow chart of the channel selection algorighm

Tab. 1. Channel selection pattern for 4 antenna systems

pattern number	ch1	ch2	ch3	ch4
0	·	·	·	·
1	·	·	·	
2	·	·		·
3	·		·	·
4		·	·	·
5	·	·		
6	·		·	
7	·			·
8		·	·	
9		·		·
10			·	·
11	·			
12		·		
13			·	
14				·

From Eqn.(3) we can get SNR of each estimated signal,

$$w_1^j = \frac{1}{\left\{\left|s_{11}^j\right|^2+\left|s_{12}^j\right|^2\right\}\sigma^2} \quad (4)$$

$$w_2^j = \frac{1}{\left\{\left|s_{21}^j\right|^2+\left|s_{22}^j\right|^2\right\}\sigma^2} \quad (5)$$

where w_i^j is the SNR of estimated signal at the subcarrier j transmitted from the Tx antenna i, σ^2 is the noise power. The average transmitted signal power $|x|^2 = 1.0$ is supposed. This SNR information is used as a metric weight for the viterbi decoding. If the inverse matrix $\boldsymbol{S}$ dose not exist, the viterbi decoding is performed with the metric weight equal 0.

III. Transmission Control

As we described previous section, the received SNR at each channel can be estimated if the noise power and the branch gain between all transmit antennas and receive antennas are observed. If we use the ZF algorithm, the serious throughput degradation sometimes occurs with the channel condition. In this paper, we propose the selection scheme of the transmit channel, coding rate and modulation method in the instantaneous throughput maximization criteria. In this algorithm, only the modulation method and coding rate information of each channel are fed back. In order to reduce the control data, the channel information is not fed back.

Fig.2 shows the flow chart of the proposed scheme. The channel selection algorithm of this scheme is as follows,

1) Channel Estimation
In the MIMO system, the orthogonal sequences are transmitted as the pilot signals in each channel. The branch gains of each subcarrier between transmit antennas and receive antennas h_{ki}^{j} are estimated with the pilot signals at the receiver.

2) Calculation of Average SNR
The SNR in each subcarrier, in each channel is calculated as a previous section. The SNR is calculated about all the conbinations we can realize. There are 15 selection patterns in the case of 4 transmit antennas and 4 receive antennas as Table 1. We define "ch X" as the channel which is transmitted using the transmit antenna X. The average SNR v_m is the moving average of the SNR in each subcarrier.

$$v_m = \frac{1}{N_c}\sum_{j=1}^{N_c} w_m^j \quad (6)$$

where N_c denotes the number of subcarriers, m denotes the channel number.

3) AMC set selection and throughput calculation
Selecting AMC set for each channel in each selection pattern based on the average SNR and the AMC set selection table. AMC set is “Adaptive Modulation and Coding set” that is a combination of the modulation method and coding rate. From this information,

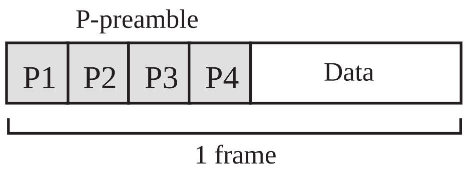

Fig. 3. Frame structure in the computer simulation

Tab. 2. Simulation parameters

Modulation method	QPSK, 16QAM, 64QAM
Coding rate	R=1/2, 3/4
Number of FFT points	64
Guard interval	16
Number of subcarriers	52
FFT clock	25MHz
Frame length	12 OFDM symbols
Packet length	1 frame
Number of antennas	Tx:4, Rx:4
Synchronization	Ideal
Feedback	Ideal
Channel	18 path Rayleigh fading exponential decay RMS delay spread 50ns

Tab. 3. AMC set selection table

Modulation	Coding rate	Throughput	Channel estimation	Threshold
QPSK	1/2	1.0	Ideal	10.7dB
			Pilot	11.8dB
16QAM	3/4	3.0	Ideal	23.0dB
			Pilot	23.8dB
64QAM	3/4	4.5	Ideal	28.7dB
			Pilot	29.5dB

the system throughput in each selection pattern is calculated. We define the throughput as the number of transmit bits per subcarrier.

4) Selection of Transmit Scheme
The system throughput is compared among all selection patterns and the AMC set with the maximum throughput is selected. This AMC set information is shared between the transmitter and the receiver through the feedback channel. At the receiver, demodulation process is performed with this information. The SNR information in each subcarrier w_m^j is used for the weight in the viterbi decoding.

IV. Simulation Results

In this section, we present the numerical results about the MIMO–OFDM system performance. The system throughput is evaluated in 64 carriers MIMO–OFDM system with 4 transmit antennas and 4 receive antennas. Table 2 shows the major simulation parameters and Fig.3 shows the frame structure. Each transmit frame is composed of the preamble parts and the data part. P-preamble contains the orthogonal signals which are 4 OFDM symbols [12].

A. AMC set selection table

In the proposed scheme, the AMC set selection table must be prepared to select the modulation method and coding rate in each channel. We set the threshold level so as to achieve PER=1% (Packet Error Rate) in the SISO-OFDM system under the frequency selective fading environment. Three AMC sets are evaluated in this study as displayed in Table 3. Fig.4 shows the PER performances in the SISO-OFDM system from which we derive Table 3. In this figure, ”Ideal” means the perfect channel estimation and ”Pilot” means channel estimation using the pilot signals. Generally, under the fading environment, burst error occurs when the reception SNR falls down. In other words, most errors happen when the reception SNR is less than the average SNR. (A notch of frequency response can be compensated with the interleave and FEC) Therefore, we can get the greater PER performance than 1% using this selection table. If the reception SNR is less than all the threshold levels in Table 3, no signal is transmitted from the transmit antenna.

Tab. 4. Example of the throughput calculation

Pattern number	ch1	ch2	ch3	ch4	Throughput
0	19.3 QPSK	22.8 QPSK	18.2 QPSK	19.6 QPSK	4.0
1	22.5 QPSK	25.0 16QAM	21.6 QPSK	—	5.0
2	25.3 16QAM	25.4 16QAM	—	23.0 16QAM	9.0
3	23.4 16QAM	—	21.0 QPSK	22.3 QPSK	5.0
4	—	26.7 16QAM	23.8 16QAM	22.8 QPSK	7.0
5	27.1 16QAM	27.1 16QAM	—	—	6.0
6	25.2 16QAM	—	23.6 16QAM	—	6.0
7	26.8 16QAM	—	—	25.0 16QAM	6.0
8	—	28.1 16QAM	26.0 16QAM	—	6.0
9	—	27.5 16QAM	— 16QAM	25.0	6.0
10	—	—	24.6 16QAM	24.4 16QAM	6.0
11	28.2 16QAM	—	—	—	3.0
12	—	28.8 64QAM	—	—	4.5
13	—	—	26.7 16QAM	—	3.0
14	—	—	—	26.4 16QAM	3.0

Table 4 shows an example of AMC set assignment for one burst using the selection table when average SNR=21dB and the perfect channel estimation are assumed. We calculate the reception S/N in each channel, in 15 antenna selection patterns respectively, and assign the AMC set to each channel with the selection table. And so we can get the instantaneous system throughput in each selection pattern. In this table, the 2nd to 5th columns present the instantaneous reception SNR and the selected modulation method in each channel, the 6th column presents the instantaneous system throughput. In the case of Table 4, the pattern 2 has the maximum throughput 9.0 bit/subcarrier.

B. System throughput evaluation

We show the system throughput calculated by the computer simulation. Fig.5 is the result with perfect channel estimation, and

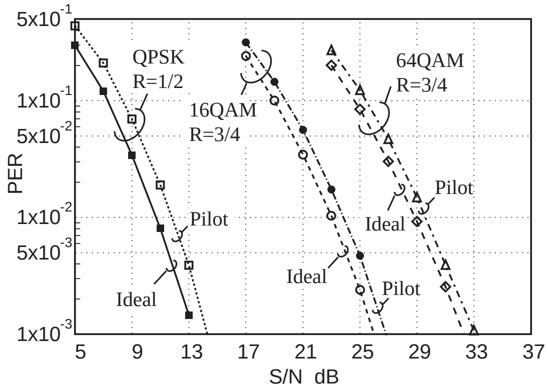

Fig. 4. PER performance in the SISO–OFDM system

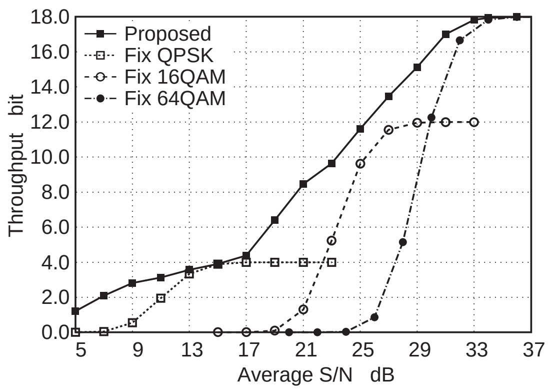

Fig. 5. System throughput in the MIMO–OFDM system (Perfect channel estimation)

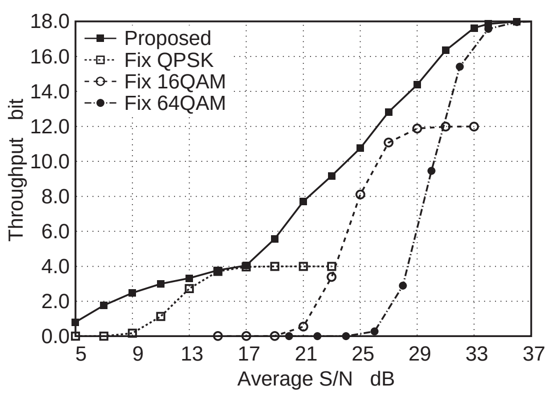

Fig. 6. System throughput in the MIMO–OFDM system (Channel estimation with pilot signal)

Fig.6 is the one with channel estimation using the pilot signals. In these figure, ”proposed” means the performance result with the proposed transmission channel selection scheme, ”Fix QPSK”, ”Fix 16QAM”, ”Fix 64QAM” mean the results with the conventional scheme that the signals are always transmitted from 4 antennas with the fixed modulation method and coding rate. They correspond to (QPSK R=1/2), (16QAM R=3/4), (64QAM R=3/4) respectively. The horizontal axis denotes the average SNR in each branch. When the signals are transmitted from the multiple antennas, the total signal power thus is proportional to the number of antennas.

According to these results, the system throughput can be improved effectively with the proposed scheme. Major two reasons of this throughput enhancement are as follows,

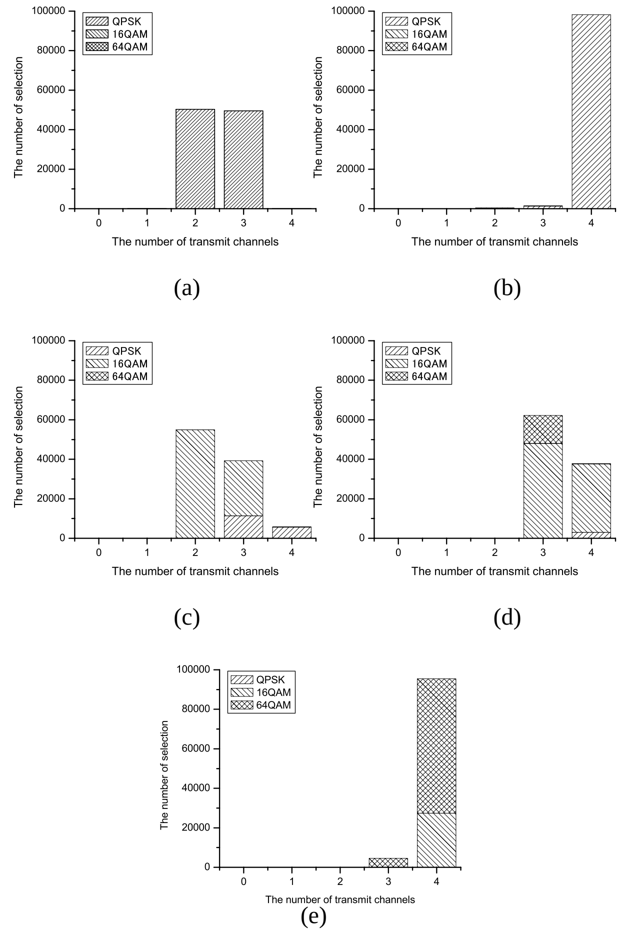

Fig. 7. The channel assignment of the proposed transmission control(a)SNR=5dB (b) SNR=15dB (c) SNR=19dB (d) SNR=24dB (e)SNR=30dB

1) We can use the appropriate modulation method depends on the reception SNR by the adaptive modulation.
2) If it is difficult to perform the channel separation with the ZF algorithm, we can continue the signal transmission through part of the channels by limiting the transmit channels.

First one is a well known effect of the adaptive modulation. Additionally the transmission channel control comes to the great factor for the throughput enhancement in the MIMO–OFDM system. Especially this effect appears remarkably at the severe SNR condition.

Fig.7(a)∼(e) present the channel assignment of the proposed transmission control scheme at several reception SNRs. The horizontal axis means the number of transmit antennas. The vertical axis denotes how many times it is chosen in 100000 times attempt. These bar graphs also show the ratio of the modulation scheme assigned to the channel. When the reception SNR is very small, 4 channel parallel transmission is very difficult. In this situation (Fig.7(a)), the channel assignment is performed so as to keep the enough SNR for QPSK in the limited channels. The parallel transmission becomes possible with increasing reception SNR (Fig.7(b)). If we get higher SNR, the high order modulation scheme can be selected. 16QAM R=3/4 has the throughput three times as high as QPSK R=1/2 has. Hence the proposed scheme assigns the high order modulation scheme with reducing the number of transmit channels. Fig.7(c) displays this situation. We can see that the transmit channels are reduced and 16QAM is selected. Fig.7(d) and (e) show the results in the case of sufficient reception signal

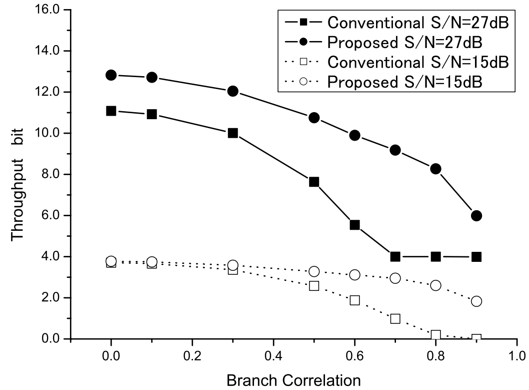

Fig. 8. Throughput comparison in the correlated fading environment

power. In this case, the parallel transmission is selected with the high order modulation scheme.

C. Evaluation in the correlated fading environment

In the MIMO–OFDM systems using the ZF algorithm, system throughput rapidly degrades as the branch correlation increases. The branch correlation α between branch a and branch b is defined as

$$\alpha = \frac{|E[f_a(t) \cdot f_b^*(t)]|}{\sqrt{E\left[|f_a(t)|^2\right]} \cdot \sqrt{E\left[|f_b(t)|^2\right]}} \quad (7)$$

where f_a, f_b denotes the path gain which has the same delay time. There is no correlation between the paths which have deferent delay time. All paths satisfy Eqn.(7).

Fig.8 shows the system throughput in the correlated fading environment when the SNR=15dB and 24dB. In this figure ”Conventional” means the 4 channel parallel transmission with the fixed modulation method which has the maximum throughput in each condition. We see that the proposed scheme maintains superior throughput compared with conventional one if the branch correlation increases.

V. Conclusion

We have proposed a transmit channel control scheme with a little feed back information in the MIMO–OFDM systems. In this scheme, the modulation method and coding rate are selected so as to maximize the instantaneous system throughput based on the estimated SNR. The simulation results have been shown for the 4 antennas MIMO–OFDM system in the uncorrelated and correlated fading environment. This scheme can attain the throughput enhancement compared with the conventional fixed transmit scheme in the wide SNR condition. Therefore proposed scheme is effective to improve the MIMO–OFDM system performance.

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