IMPROVED ANTENNA SELECTION TECHNIQUE TO ENHANCE THE PERFORMANCE OF WIRELESS COMMUNICATIONS CHANNELS

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ABSTRACT

The combination of space-time codes and a closed loop transmission diversity technique is currently receiving a lot of attention since it allows one to improve the performance of wireless communications channels. This paper proposes a simple closed loop transmission diversity technique to improve further the performance of the channels through proposing a structure of feedback information in order to reduce the time required for processing the feedback information at the transmitter. Calculations and simulations show that our technique performs especially well when it is combined with the Alamouti code.

1. INTRODUCTION

In wireless communications systems, the performance of downlink channels can be improved by transmission diversity techniques utilizing multiple transmit antennas at base stations. Various transmission diversity techniques have been proposed so far, including beamforming, antenna switching, delay transmission diversity [1, 2, 3, 4]. The combination of these techniques and the transmission diversity technique utilizing space-time block codes has been studied intensively. It provides a remarkable improvement in the performance of channels in both propagation environments, namely frequency nonselective and frequency selective Rayleigh fading.

One simple and interesting transmission diversity technique was proposed by M. Katz et. al. [5]. According to this technique, an M-antenna transmitter and one-antenna receiver are considered. The receiver measures M channel gains from M transmit antennas. Based on the measurements, the receiver informs the transmitter via a feedback loop about the N best channels ($N < M$). In [5], the authors also mentioned the optimal antenna selection and the restricted antenna selection. In the optimal antenna selection, the receiver uses $\lceil log_2(\binom{M}{N})\rceil$ ($\lceil . \rceil$ is the ceiling function) feedback bits to inform the transmitter about the N best channels out of M channels. Therefore, this technique is called N-out-of-M antenna selection. In the restricted antenna selection, the capacity limitation of the feedback loop was taken into account. The receiver in this case uses only one feedback bit to inform the transmitter about the N channels out of M channels. Let we take the case where M=4 and N=2 as an example. Based on the total power received from each antenna pair (1,2) and (3,4), the receiver informs the transmitter which pair should be selected. Obviously, this method is not optimal as the transmit antenna pair from which the received total power is greater than the other is not necessary the pair of the two best antennas. The disadvantage of these techniques is that a lot of additional transmit antennas have to be utilized, especially for large N and M. In a real scenario, it is difficult to sufficiently separate a large number of transmit antennas, in such a way that the transmission gains between the transmit and receive antennas are independent from each other.

As a result, in this paper, we concentrate on the N-out-of-(N+1) antenna selection technique as it provides a relatively good performance while utilizing only one additional transmit antenna. We propose an improved N-out-of-(N+1) antenna selection technique. This technique is similar to the N-out-of-(N+1) antenna selection technique proposed in [5] and, consequently, the proposed technique has the same performance as that of the N-out-of-(N+1) technique described in [5]. However, it takes a shorter time required for processing the feedback information due to the proposed structure of the feedback information. In addition, we also consider the capacity limitation of the feedback loop.

The rest of the paper is organized as follows: the theoretical basis for selecting transmit (and receive) antennas is recalled in Section 2. The proposed technique is presented in Section 3. In Section 4, some simulation results comparing the bit error probability of the proposed technique to that of the technique proposed in [5] are shown. The last section is the conclusion of the paper.

2. THEORETICAL BASIS FOR SELECTING TRANSMIT AND RECEIVE ANTENNAS

Let us consider a wireless system with N_T transmit antennas and N_R receive antennas. These antennas are assumed

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to be sufficiently separated from each other so that the transmission gains h_{ij} between the i^{th} (i=1..N_T) transmit antenna and the j^{th} (j=1..N_R) receive antenna are identically independently distributed (i.i.d) complex Gaussian random variables with zero means and unit variances. The channel is assumed to be quasi-static flat fading. In other words, the transmission gains remain constant during several transmission time slots. The channel model is then as follows:

$$Y=XH+N$$

where $Y_{(T\times N_R)}$, $X_{(T\times N_T)}$, $H_{(N_T\times N_R)}$ and $N_{(T\times N_R)}$ are the matrices of received signals, transmitted signals, transmission gains and noises respectively. Noises are assumed to be the independently complex Gaussian random variables with zero means and N_0 variances. T is the number of transmission time slots in each code block. Let E_S be the average energy per transmitted symbol and $\aleph$ the number of transmitted symbols in each code block. Then, at the receiver, we have $\aleph$ independent decision metrics for $\aleph$ transmitted symbols $\{x_k\}$ (k=1..$\aleph$) as follows [6]:

$$\hat{x}_k = \sum_{i=1}^{N_T}\sum_{j=1}^{N_R} |h_{ij}|^2 x_k + \Xi_k \tag{1}$$

where Ξ_k is a random variable with zero mean and $N_0 \times \sum_{i=1}^{N_T}\sum_{j=1}^{N_R} |h_{ij}|^2$ variance. From (1), one has the signal-to-noise ratio for the k^{th} decision variable as follows:

$$\gamma_k = \gamma_0 \sum_{i=1}^{N_T}\sum_{j=1}^{N_R} |h_{ij}|^2 \tag{2}$$

where $\gamma_0 = \frac{E_S}{N_0}$ is the signal-to-noise ratio of each transmitted symbol. Clearly, the optimal antenna selection is selecting N_T and N_R transmit antennas of which the transmission gains maximize the formula (2) [7]. This is the main basis for selecting transmission antenna techniques.

3. IMPROVED N-OUT-OF-(N+1) ANTENNA SELECTION TECHNIQUE

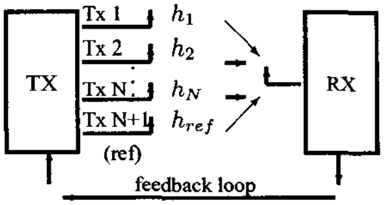

Fig. 1. The diagram of the proposed antenna selection scheme

To consider the principle of the proposed antenna selection technique, let us consider the diagram shown in Figure 1. The system comprises N default transmit antennas, one reference transmit antenna and one receive antenna. The receiver measures the transmission gains of (N+1) channels, including the reference channel. We denote these gains to be $\{h_1, ..., h_N\}$ and h_{ref}. The receiver searches for the minimum norm $|h|_{min}$ among $\{|h_1|, ..., |h_N|\}$ (assume that $|h|_{min} \equiv |h_i|$ ($i = 1, ..., N$)) and then compares it to $|h_{ref}|$. If $|h|_{min} \geq |h_{ref}|$ then the transmit antennas the transmitter should choose are $\{1, 2, ..., N\}$. Otherwise, the i^{th} antenna will be replaced by the reference antenna and the transmit antennas will be $\{1, 2, ..., i-1, ref, i+1, ..., N\}$. Hence, the reference antenna is used when the transmission gain of the reference antenna is not the worst. Essentially, this technique provides the same bit error property as that of the N-out-of-(N+1) antenna selection proposed in [5] since both techniques choose the N best channels out of (N+1) channels to transmit signals.

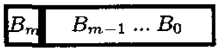

Fig. 2. The proposed structure of the feedback information

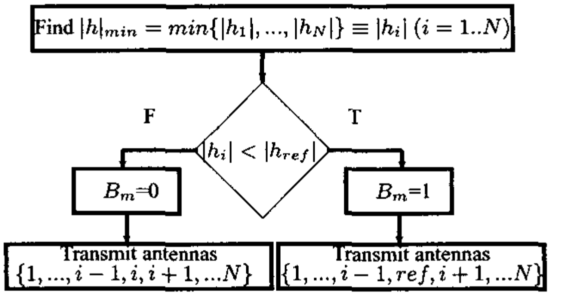

Fig. 3. The flow chart of the proposed antenna selection scheme

Next we consider the structure of the feedback information and the delay required for processing the feedback information at the transmitter. We assume that the feedback loop is error-free. Then, we propose the structure of the feedback information used for selecting transmit antennas as presented in Figure 2. The bit B_m is used to indicate whether the transmitter has to replace the i^{th} antenna with the reference antenna. The bit B_m is zero if the answer is no and B_m is unity otherwise. The m following bits indicate which antenna among N antennas should be replaced by the reference antenna. It is easy to realize that $m = \lceil log_2 N \rceil$. With this structure, the transmitter considers the bit B_m at first. As soon as it realizes that $B_m = 0$, the rest of the feedback information is not necessarily processed [1]. The transmitter will transmit signals via the default transmit antennas $\{1, 2, ..., N\}$. If $B_m = 1$, the transmitter uses the m following bits $B_{m-1}, ..., B_0$ to recognize which antenna

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[1] Theoretically, there is no need to transmit m bits $B_{m-1}, ..., B_0$ in the case $B_m = 0$

should be replaced by the reference antenna. Thereby, the delay for processing the feedback information is reduced. The flow chart for the proposed technique is presented in Figure 3.

In order to see how large the time benefit gained by the proposed technique, we compare the average processing time required for our method and for the method proposed in [5]. It is worth to recall that we consider the optimal antenna selection technique. Let us now assume that the transmit antennas are sufficiently separated from each other so that the fading affecting them is independent. In other words, $h_1, h_2, ..., h_N$ and h_{ref} are i.i.d complex Gaussian random variables. Therefore, the probability of the event where the transmission gain of the i^{th} channel (i=1..(N+1)) is the worst is the same for every antenna, including the reference one. Although, there is a fact that the time for processing the feedback information does not necessarily linearly increases with the number of feedback bits, it is easier to calculate the time benefit of the proposed method when the average processing time is assumed to increase linearly with the number of feedback bits. Obviously, the result we derive as follows is only aimed at providing the readers with the lower bound of the average processing time saved by our technique in comparison with that of the technique proposed in [5]. The probability of the event in which h_{ref} is the worst transmission gain ($B_m = 0$ in this case) is $\frac{1}{(N+1)}$. When $B_m = 0$, the transmitter has to process one bit (bit B_m) only. The probability of the event in which h_{ref} is not the worst transmission gain is $1 - \frac{1}{(N+1)} = \frac{N}{N+1}$. In this case, the transmitter has to process $(m+1) = (1 + \lceil log_2 N\rceil)$ bits. Let t be the average processing time for one feedback bit, then the average time required for processing feedback information in our method is:

$$\tau_1 = \frac{1}{N+1}t + \frac{N}{N+1}\,(1 + \lceil log_2 N\rceil)t.$$

On the other hand, in the N-out-of-$(N+1)$ technique proposed in [5], the transmitter always has to process

$$\lceil log_2 \binom{N+1}{N} \rceil = \lceil log_2(N+1)\rceil$$

bits. Therefore, the average processing time is:

$$\tau_2 = \lceil log_2(N+1)\rceil t$$

It is easy to realize that when N is the power of 2, for instance $N = 2, 4, 8$, one has:

$$\lceil log_2 N\rceil + 1 = \lceil log_2(N+1)\rceil \qquad (3)$$

Hence, the relative reduction of the average processing time between two techniques is:

$$\frac{\triangle\tau}{\tau_2} = \frac{\tau_2 - \tau_1}{\tau_2} = \frac{\lceil log_2 N\rceil}{(N+1)\lceil log_2(N+1)\rceil} \qquad (4)$$

The formula (3) shows that our method uses the same number of feedback bits for selecting transmit antennas as the N-out-of-(N+1) technique proposed in [5], while the formula (4) shows that the time required for processing the feedback information in the former is shorter than that of the latter. The average processing time reductions for some particular values of N =2, 4 and 8 are 16.7, 13.33 and 8.33 % respectively. We realize that the proposed technique allows the transmitter to reduce noticeably the time required for processing the feedback information in the case for $N = 2$, such as when the Alamouti code [8] is utilized. It is worth to recall that the time reduction is probably much greater than the above figures if we take its non-linear proportionality with the number of feedback bits into consideration.

Finally, we consider the capacity limitation of uplink channels used for transmit diversity purposes in WCDMA mobile communication systems. The feedback information used for transmit diversity purposes is usually transmitted in the D bit field of the Feedback Information field in the uplink Dedicated Physical Control Channel (DPCCH). According to the standard of WCDMA systems [9], the rate for the feedback information used for closed loop mode transmit diversity is limited to 1500 bits/sec (the maximal number of feedback bits per time slot is 1). Hence, $m + 1$ bits used for selecting transmit antennas are transmitted during $m + 1$ consecutive slots. In order to keep the transmitter updated with a small delay on the best channels, we suggest that the number of feedback bits should not be greater than 4 (corresponding to N=8 transmit antennas).

4. SIMULATION RESULTS

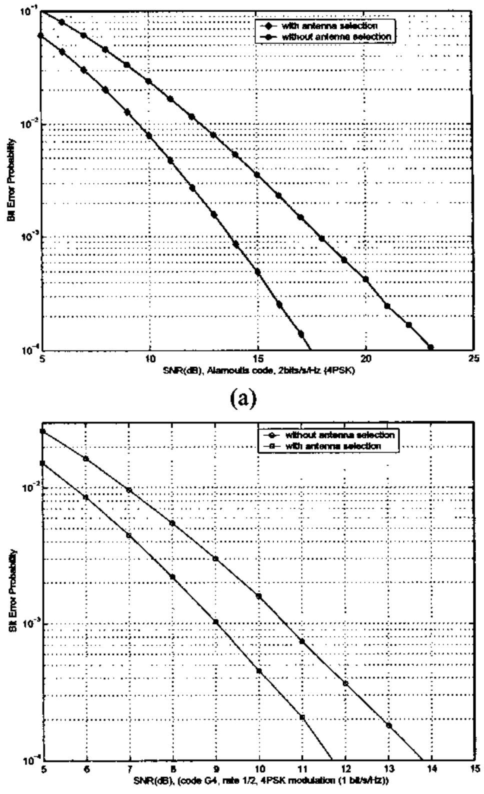
In this section, we compare the bit error probability of space-time block codes transmitted via channels with and without our proposed transmit antenna selection technique. The signal-to-noise ratio SNR is defined as the ratio of the total power of the received signals and the power of noises at the receiver per each transmission time slot (each symbol period). Figure 4 (a) shows the bit error probability of the Alamouti code (N=2) modulated by a 4PSK constellation with our antenna selection technique (2-out-of-3 antenna selection with 2 feedback bits). It can be seen from the figure that the signal-to-noise ratio advantage gained by our method is about 5.5 dB at BER=10^{-4} compared to the case without antenna selection. Figure 4 (b) presents the bit error probability of the 1/2-rate space-time block code proposed by Tarokh et. al. [6] ($N = 4$) and compares to that in the case without antenna selection. In this simulation, we use a 4PSK signal constellation and the 4-out-of-5 transmit antenna selection scheme. The SNR advantage in this case is about 2 dB at BER=10^{-4}. The summary of the comparison between our technique and the technique proposed in [5] is presented in Table 1.

Table 1. Comparison between the proposed technique and the technique proposed in [5].

Proposed technique	vs. N-out-of-($N+1$) in [5]
Performance	the same
Number of feedback bits	the same
Number of transmit antennas	the same
Average processing time	shorter (16.7% for $N = 2$)

5. CONCLUSIONS AND DISCUSSIONS

In the paper, the authors propose a simple antenna selection technique to improve the performance of down links in wireless communication systems. Essentially, our technique is similar to the N-out-of-(N+1) antenna selection technique proposed in [5]. Both techniques use the same number of feedback bits and have the same performance. An advantage of the N-out-of-(N+1) antenna selection technique is that it provides a relatively good performance while utilizing a minimum number of additional transmit antennas (one more antenna only). This property is important because of the fact that it is difficult to separate a large number of transmit antennas from each other so that the spatial correlation between them can be neglected. A main advantage of our technique over the technique proposed in [5] is the remarkable reduction of time required for processing the feedback information. The reduced average processing time is a specially important advantage in fast fading channels to avoid outdating the feedback information by the time it is applied at the transmitter. This advantage is due to our proposed structure of the feedback information and the principle in which the transmitter selects the transmit antennas in such a way that the reference antenna is used to replace the default transmit antenna which is corresponding to the worst transmission gain. Simulations show that the proposed technique gains a great SNR advantage over the systems without antenna selection. The capacity limitation of the feedback loop in the third generation mobile communication systems WCDMA is also considered in the paper. According to the standard of WCDMA systems, the number of feedback bits in our technique is limited to 4.



(a)

(b)

Fig. 4. BER vs. SNR of the code Alamouti and $G4$ [6] with and without antenna selection.

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