Optimal Antenna Selection Scheme with Transmit Adaptive Array for Wideband CDMA Systems*

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Abstract: Transmit diversity schemes are an effective capacity improvement method for down link of wideband code division multiple access (W-CDMA) systems. In this paper, we propose to use transmit antenna subset selection scheme in conjunction with closed loop transmit adaptive array (TxAA). The proposed scheme selects N_S optimum antennas among $N_T(>N_S)$ transmit antennas in order to maximize diversity gain from selected antennas, and also reduces the cost of RF chains by employing two different types of RF modules for the selected and the unselected antenna group, respectively. Computer simulation results show performance improvement by the proposed scheme over the conventional TxAA when considering up link control information feedback.

1. Introduction

Since future mobile communication services are expected to require higher capacity on down link rather than on up link, it becomes increasingly important to consider techniques that can improve the capacity of the down link channels[1,2,3]. In this aspect, base station (BS) transmit diversity utilizing multiple antennas has been identified as a promising technique. Among various transmit diversity schemes, the closed loop TxAA[1] which is adopted in IMT-2000 W-CDMA systems[4,5], is shown to provide good performance.

In the TxAA, the mobile station (MS) utilizes down link channel measurements to exploit the optimal transmit antenna weights which maximize the received signal-to-noise ratio (SNR) at the MS. These optimal weights are determined and fed back to the BS for controlling the individual weight for each transmit antenna. When utilizing multiple transmit antennas at the BS, cost of transmit RF chains such as high power amplifiers (HPAs) is a significant limiting factor. To relieve this problem, space-time block coding (STBC) combined with antenna selection has been proposed and analyzed in [3], where STBC is applied only to those two best channels that are determined at the channel estimator of the MS. The results show that the scheme in [3] effectively provides a trade-off between system cost and performance.

In this paper, we propose to use transmit antenna subset selection scheme in conjunction with the TxAA for down link of W-CDMA systems. In the proposed scheme, N_S "best" antennas among $N_T(>N_S)$ transmit antennas are selected to maximize diversity gain of selected antennas, and also reduces the cost of RF chains by employing two different types of RF modules for the selected and the unselected antenna group, respectively. Simulation results show that the proposed scheme is a very cost-effective transmit diverisity solution for down link of W-CDMA in the presence of feedback bandwith limitation, feedback information delay and Doppler spread.

The remaining of the paper is organized as follows. Section 2 describes the proposed transmit diversity scheme which combines antenna selection and TxAA. Section 3 presents simulation results, followed by concluding remarks in Section 4.

2. Proposed Transmit Diversity Scheme

Figure 1 shows block diagram of W-CDMA system employing the proposed transmit antenna subset selection scheme with the TxAA. In the figure, we assume N_T transmit and $N_R=1$ receive antenna topology, where TxAA is applied to $N_S=2$ antennas with the best channel measurements. In the transmitter, we consider distinct orthogonal pilot sequences $P_i(i=1,\cdots,N_T)$ such as CPICH in 3GPP W-CDMA[4] for the transmit antennas, which are utilized for channel estimation in the MS. Thus, there are two different types of RF chains: The first type of RF chains is for those two selected antennas with the pilots and the data, while the other type is for those (N_T-N_S) antennas only with the pilots. Note that since pilot sequences have constant envelopes, we do not have to employ an expensive RF chain such as an HPA with very good linearity for (N_T-N_S) antennas not selected. This contributes to significant reduction of the BS system cost by the proposed selection.

We consider a quasi-static flat fading channel which is represented by a channel matrix $\mathbf{H}$ of size $N_R \times N_T$ given in (1) whose component $h_{i,j}$ is complex fading coefficient of the link from the j-th transmit antenna to i-th receive antenna.

$$\mathbf{H}=\begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,m} & \cdots & h_{1,n} & \cdots & h_{1,N_T} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,m} & \cdots & h_{2,n} & \cdots & h_{2,N_T} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ h_{N_R,1} & h_{N_R,2} & \cdots & h_{N_R,m} & \cdots & h_{N_R,n} & \cdots & h_{N_R,N_T} \end{bmatrix} \quad (1)$$

Assuming that the m and n-th antennas are selected for the TxAA($N_S=2$), the received signal is

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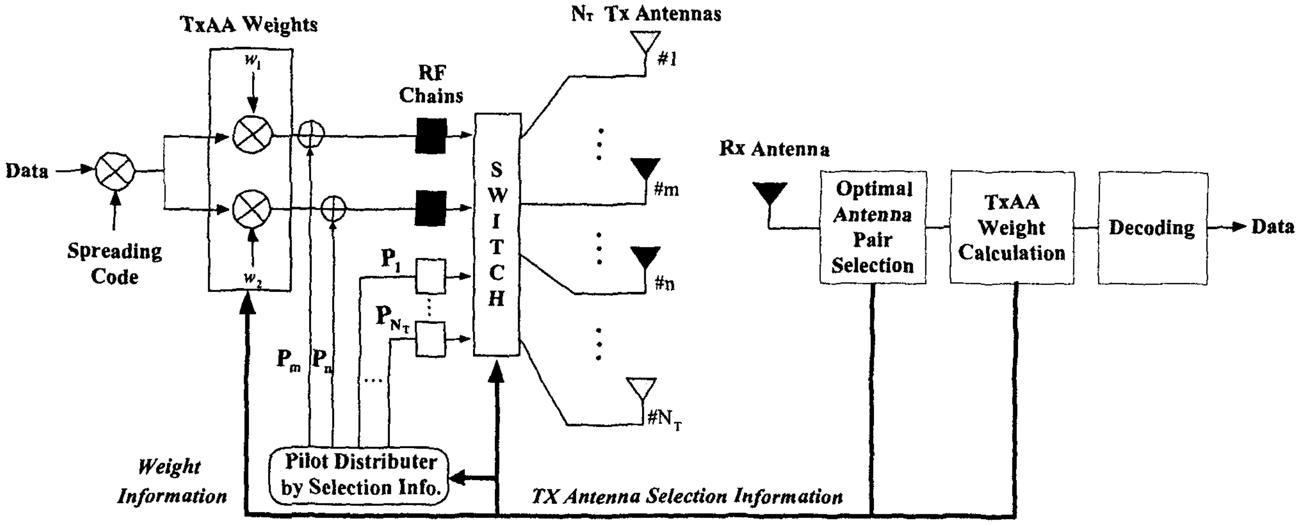

Figure 1 : proposed transmit antenna subset selection schemes with TxAA.

$$r(t) = \sum_{k=1}^{N_R} [d(w_1 h_{k,m} + w_2 h_{k,n}) s(t-\tau_0)] + n(t) \quad (2)$$

where d is the data symbol with $E[|d|^2]=1$, $s(t)$ is user-specific spreading waveform, τ_0 is the propagation delay, $w_i (i=1,2)$ are complex TxAA weights for the two selected antennas, and $n(t)$ is additive white Gaussian noise with variance $N_0/2$. Assuming that downlink channel parameters are perfectly estimated at the MS, the output r_k of the k –th receive antenna after de-spreading and channel compensation becomes

$$\begin{aligned} r_k &= \int_0^T r(t) \cdot s^*(t-\tau_k) \cdot (w_m h_{k,m} + w_n h_{k,n})^* dt \\ &= d\, |w_m h_{k,m} + w_n h_{k,n}|^2 \\ &+ \int_0^T n(t) \cdot s^*(t-\tau_k) \cdot (w_m h_{k,m} + w_n h_{k,n})^* dt \\ &= d_k + n_k \quad (k = 1, \cdots, N_R) \end{aligned} \quad (3)$$

where d_k and n_k are defined as

$$d_k \equiv d\, |w_m h_{k,m} + w_n h_{k,m}|^2 \quad (4)$$

$$n_k \equiv \int_0^T n(t) \cdot s^*(t-\tau_k) \cdot (w_m h_{k,m} + w_n h_{k,n})^* dt \quad (5)$$

Thus, the output SNR γ_k of the k –th receive antenna becomes

$$\gamma_k = \frac{E\left[|d_k|^2\right]}{E\left[|n_k|^2\right]} = \frac{|w_m h_{k,m} + w_n h_{k,m}|^2}{\sigma_n^2} \quad (6)$$

The total SNR at the output of the receiver can be written as[2]

$$\gamma = \sum_{k=1}^{N_R} \gamma_k = \frac{\mathbf{w}^H \mathbf{H}_{m,n}^H \mathbf{H}_{m,n} \mathbf{w}}{\sigma_n^2} \quad (7)$$

where superscript H denotes conjugate transpose of a matrix, $\mathbf{w} = [w_1 \ w_2]^T$ is the transmit antenna weight vector constrained to be normalized, i.e., $\|\mathbf{w}\|^2 = |w_1|^2 + |w_2|^2 = 1$, and

$$\mathbf{H}_{m,n} = \begin{bmatrix} h_{1,m} & h_{1,n} \\ h_{2,m} & h_{2,n} \\ \vdots & \vdots \\ h_{N_R,m} & h_{N_R,n} \end{bmatrix} \quad (8)$$

is the channel matrix whose component is the complex fading coefficient of the link from the m -th and n -th transmit antenna to the i -th receive antenna. The SNR in (7) is *maximized by selecting* $\mathbf{w}$ *as the eigenvector* corresponding to the largest eigenvalue $\lambda_{\max}$ of the channel correlation matrix $\mathbf{H}_{m,n}^H \mathbf{H}_{m,n}$ [2,3]. The optimal TxAA weights are calculated for these two selected antennas through eigen-analysis. After appropriate quantization, both antenna selection information and TxAA weight information are to be fed back to the BS on up link control channels such as 3GPP DPCCH[4]. For flat fading channels, $\mathbf{H}_{m,n}^H \mathbf{H}_{m,n}$ becomes singular, and the proposed scheme achieves the optimal SNR of

$$\gamma_{\max} = \frac{\lambda_{\max}}{\sigma_n^2} = \frac{1}{\sigma_n^2} \sum_{k=1}^{N_R} (|h_{k,m}|^2 + |h_{k,n}|^2) \quad (9)$$

Thus, in the receiver of the proposed scheme, instantaneous channel coefficients are estimated by utilizing the pilot sequences, then a pair of optimal transmit antennas with the two largest estimates are selected.

In (9), m and n denote the columns of $\mathbf{H}$ with the highest and second highest norms, respectively. The squared column norms are i.i.d. gamma distributed random variables (r.v.s), that is

$$f_x(c_i) = \frac{1}{(N_R - 1)!} c_i^{N_R - 1} e^{-c_i} \quad (10)$$

where c_i is the square of the i -th column norm. Hence we are able to diectly utilize the 'order statistics' approach to solve the problem as described in [3]. Following similar analysis given in [3] for the antenna selection scheme with STBC, we obtain the gain by the antenna selection scheme as

$$\text{gain} = 10 \log_{10} \left(\frac{E(X_{N_T} + X_{N_T - 1})}{2 N_R} \right) \text{ [dB]} \quad (11)$$

which is the gain in average SNR of the selection scheme over the TxAA with no selection. Here, $E(X_{N_T})$ and $E(X_{N_T-1})$ are the first moments of the largest and the second largest squared column norms, respectively, and are given in [3]. Note that the gain in (11) is only valid in ideal channel conditions not considering various impairments such as feedback bandwidth limitation and feedback delay.

With q -bit quantization for each TxAA weight, the conventional TxAA scheme for all N_T transmit antennas requires $q \cdot N_T$ feedback bits. On the other hand, the proposed scheme requires $2 \cdot q$ bits for TxAA and $\left|\log_2\left({}_{N_T}C_2\right)\right|$ bits for the antenna selection. For instance, with $q = 4$ as in 3GPP TxAA mode 2 specification[2], the conventional TxAA needs 16 and 24 feedback bits, while the proposed scheme only requires 11 and 12 bits for $N_T =$ 4 and 6, respectively.

3. Simulation Results

To verify the performance of the proposed scheme, computer simulations have been performed. In the simulation, flat fading channels are considered. Based on W-CDMA air interface specifications[4,5], the carrier frequency, chip rate and spreading factor are set to be 2 GHz, 3.84 Mcps and 32, respectively. The random complex spreading code that is regarded as a combination of channelization and scrambling codes, is considered. All the parameters for the simulation are summarized in Table 1.

Table 1 : Simulation parameters

Parameters	Settings
Channel model	Quasi-static flat fading
Frame format	3GPP W-CDMA DPCH
Spreading factor	32
Carrier frequency	2 GHz
Chip rate	3.84 MHz
Modulation	QPSK
Mobile speed	3 ~ 120km/h
Feedback info. bandwidth	1 bit/slot
Propagation & processing delay	1 slot
Weight info. quantization	4 bits/weight
Selection info. quantization	$\left\lceil \log_2 \binom{N_T}{2} \right\rceil$ bits
Spreading code	Random complex code

3.1 Ideal situation

Figure 2 shows bit error rate (BER) performances of the conventional TxAA with all the N_T antennas, and the proposed scheme with the selection of two antennas. This case is considered to be "ideal situation" in the sense that all the required information for TxAA and/or antenna selection is assumed to be perfectly available at the BS without any undesirable effect of information feedback such as quantization error, feedback bandwidth limitation, feedback information delay and error. As expected, it is observed from the figure that the conventional TxAA scheme utilizing all the N_T transmit antennas ("TxAA(N_T)") outperforms the proposed scheme ("TxAA(N_T)+Selection(N_S)") which selects $N_S = 2$ best antennas from N_T antennas. However, we also observe that the proposed scheme shows significantly better performance than the conventional TxAA scheme with 2 transmit antennas due to selection diversity gain. Figure 3 also shows BER performances of the TxAA with all the N_T antennas, and the proposed scheme with $N_S = 3 \sim 5$ in ideal situation. In the figure, we observe that as the number of selected antenna increases, performance of the proposed scheme becomes larger, as expected.

3.2 Non-ideal situation

In this subsection, we consider more realistic up link information feedback conditions. Here, the control information is assumed to be fed back to the MS by one bit per slot, and $q = 4$ bits are used for quantization of each antenna weight with the same up link signaling scheme of 3GPP TxAA mode 2 specification[5]. Thus, we consider in this case the effects of quantization, feedback delay and feedback bandwidth limitation, but not feedback bit errors. Note that detailed quantization scheme for the feedback information of TxAA with more than two transmit antenna is not yet standardized in the 3GPP specification. Moreover, different quantization scheme may result in quite different system performance. Thus, we assume 4-bit quantization per weight in order to impose up link feedback bandwidth limitation, however, in the simulation optimum unquantized weights are supposed to be utilized for TxAA scheme at the BS.

As stated above, the selection information of the proposed system is $\lceil \log_2({}_6C_2) \rceil = 4$ in case that N_T is 6. The feedback information bits of "TxAA(6)" and the proposed scheme "TxAA(6)+Selection(2)" are 24 and 12, respectively. Also, feedback intervals of total weights and/or selection bits of "TxAA(6)" and the proposed scheme "TxAA(6)+Selection(2)" are 1920 and 960 symbols, respectively, when considering the parameters in Table 1. If these symbol time intervals are regarded appoximately as coherence times caused by Doppler spreads, then mobile speeds corresponding to these coherent times are easily calculated as 33km/h and 67km/h, respectively. These values may be considered as rough estimates of the mobile speeds at which the systems begin to exhibit severe performance degradation.

Figure 4 depicts the BER performances of both schemes where $N_T = 6, N_S = 2$ and the MS speed was set to 3, 20 and 120 km/h. We observe that the proposed scheme shows comparable or even better performance than the conventional TxAA at the most of mobile speeds, and these results highlight the effectiveness and good performance of the proposed scheme in realistic situations. Figure 5 depicts the BER performances of both schemes where $N_T = 6, N_S = 3$ and the MS speed was set to 3, 20 and 120 km/h. We observe that performance of the proposed scheme with $N_S = 3$ is slightly better than that with $N_S = 2$ at low mobile speed, however, at higher mobile speed it no longer holds due to increase of feedback information bits.

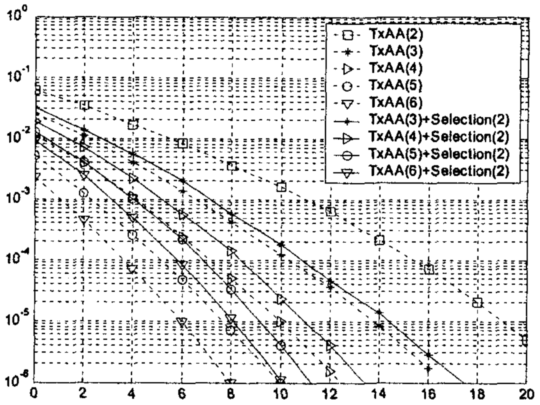

Figure 2 : BER performances of the conventional TxAA ($N_T = 2 \sim 6$) and the proposed scheme in ideal situation ($N_R = 1, N_S = 2$).

4. Conclusion

In this paper, we propose a transmit antenna subset selection scheme in conjunction with closed loop TxAA. The proposed scheme selects optimum antennas among transmit antennas in order to maximize diversity gain of selected antennas and also reduces the cost of RF chains by employing two different types of RF modules for the selected and the unselected antenna group, respectively. Simulation results show that the proposed scheme exhibits better performance than the conventional TxAA at the most of mobile speed in realistic realistic up link information feedback conditions.

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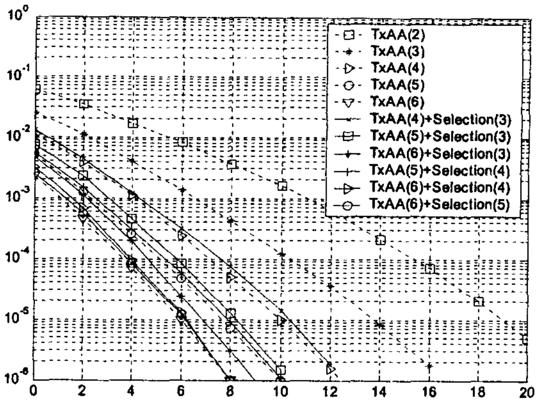

Figure 3 : BER performances of the conventional TxAA ($N_T = 2 \sim 6$) and the proposed scheme in ideal situation ($N_R = 1, N_S = 3,4,5$).

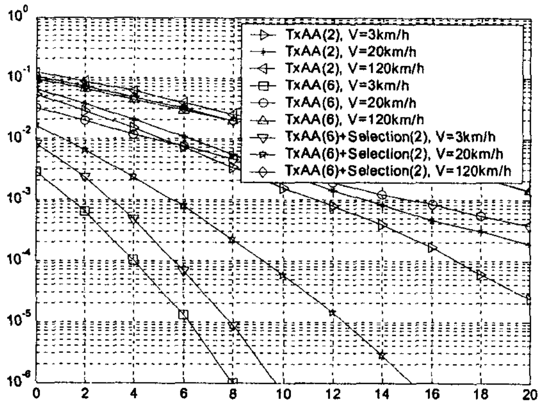

Figure 4 : BER performances of the conventional TxAA ($N_T = 2 \sim 6$) and the proposed scheme in non-ideal situation ($N_R = 1, N_S = 2$).

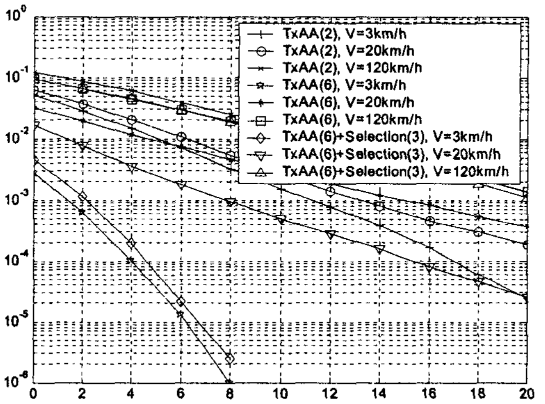

Figure 5 : BER performances of the conventional TxAA ($N_T = 2 \sim 6$) and the proposed scheme in non-ideal situation ($N_R = 1, N_S = 3$).