A Hybrid Space-time and Collaborative Coding Scheme for Wireless Communications

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Abstract: **This paper addresses at space-time coding techniques for broadband wireless communications. A brief overview of the space-time block coding and Collaborative Coding Multiple Access (CCMA) techniques is presented. A new coding scheme which combines the CCMA and space-time block coding techniques is proposed. The new coding technique with transmit diversity is simulated. Results are presented, which show that the hybrid coding technique is advantageous over the space-time block coding and CCMA techniques.**

I Introduction

Space-time coding has received much interest for broadband wireless and mobile communications [1]. Several interesting coding approaches have been suggested to combat the impairments in mobile fading channels. One interesting approach is space-time Trellis coding [2] which combines signal processing at the receiver with coding techniques appropriate to multiple transmit antennas and provides significant gain. The cost for this scheme is additional processing, which increases exponentially as a function of bandwidth efficiency and the required diversity order. For the simplicity of decoding, Alamouti provided a remarkable scheme for transmission using two transmit antennas [3]. Tarokh et al [4] introduced space-time block coding which generalizes the transmission scheme of Alamouti to an arbitrary number of transmit antennas and is able to achieve the full diversity promised by the transmit and receive antennas. These codes have a very simple maximum likelihood decoding algorithm based only on linear processing at the receiver.

In another research direction, a collaborative coding multiple access technique allows simultaneous communications by several users in the same bandwidth by means of special codes, known as collaborative codes, without subdivision in time, frequency or orthogonal codes [5-8]. This technique has theoretically been shown to achieve higher transmission rate than conventional multiple access techniques. The combining of signals to implement the multiple access channel (MAC) is reasonably simple to achieve at baseband, in which signals can be represented as voltages or currents which can add or combine appropriately. However, this combining of signals over mobile radio channel will introduce distortion due to channel fading and it then become less practical should no measures be taken to combat the effect of fading.

A new hybrid CCMA and space-time coding scheme is outlined in this paper to combine the advantages of these two kinds of coding. The principle of this novel scheme is that considering a T-user multiple access communication system with T independent users communicating simultaneously over a common MAC using a T-user collaborative code, the output of the T-user CCMA is phase mapped and space-time block code encoded, and the encoded symbol is divided into streams which are simultaneously transmitted using *m* transmit antennas. In the receiver side, the received signals are first space-time block decoded using a maximum likelihood algorithm, the result is then CCMA decoded to obtain the information from the T independent users.

II Space-Time Block Coding

Considering a mobile communication system with n antennas at the transmitter and m antennas at the receiver. At each time slot t, signals c_t^i, $i = 1,2,...,n$ are transmitted simultaneously from the n transmit antennas. The channel is assumed to be a flat Rayleigh fading channel and the path gain from transmit antenna i to receive antenna j is defined as $g_{i,j}$. The channel is assumed to be quasi-static so that the path gains are constant over a frame of length l and vary from one frame to another. At time t, the signal r_t^j, received at antenna *j*, is given by

$$r_t^j = \sum_{i=1}^{n} g_{i,j} c_t^i + \eta_t^j \quad (1)$$

where the noise samples η_t^j are independent samples of a zero-mean complex Gaussian random variable with variance $n/2$ per complex dimension. Assuming a perfect channel estimation, the receiver computes the decision metric and decides in favor of the code word that minimizes the sum.

$$\sum_{t=1}^{l} \sum_{j=1}^{m} \left| r_t^j - \sum_{i=1}^{n} g_{i,j} c_t^i \right|^2 \quad (2)$$

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A space-time block code is defined by a $p \times n$ transmission matrix Y. The entries of the matrix Y are linear combinations of the variables $x_1, x_2, ..., x_k$ and their conjugates. The number of transmission antennas is n, and we usually use them to separate different codes from each other. For example, for two transmit antennas, the transmission matrix is defined by

$$Y_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix} \tag{3}$$

Assume that transmission at the baseband employs a signal constellation with 2^b elements. At time slot 1, kb bits arrive at the encoder and select constellation signals $s_1, s_2, ..., s_k$. Let $x_i = s_i$, $i = 1,2,...,k$ in Y, we arrive at a matrix C with entries of linear combinations of $s_1, s_2, ..., s_k$ and their conjugates. The entry c_t^i represents the element in the *t*th row and the *i*th column of C. The entries c_t^i, $i = 1,2,...,n$ are transmitted simultaneously from transmit antennas $1,2,...,n$ at each time slot $t = 1,2,..., p$. So the *i*th column of C represents the transmitted symbols from the *i*th antenna and the *t*th row of C represents the transmitted symbols at time slot *t*.

Figure 1 shows the baseband representation of the two branch transmit diversity scheme. The scheme uses two transmit antennas and one receive antenna.

At a given symbol period *t*, two signals are simultaneously transmitted from the two antennas. The signal transmitted from antenna one is denoted as s_1, and s_2 from antenna two. During the next symbol period (*t+T*), signal $(-s_2^*)$ is transmitted from antenna one and s_1^* transmitted from antenna two. The channel at time t can be modeled by a complex multiplicative distortion $g_1(t)$ for transmit antenna one and $g_2(t)$ for transmit antenna two. Assuming that fading is constant across two consecutive symbols, we can obtain:

$$g_1(t) = g_1(t+T) = a_1 e^{j\theta_1} \qquad g_2(t) = g_2(t+T) = a_2 e^{j\theta_2} \tag{4}$$

where *T* is the symbol duration. The received signals can be expressed as

$$r_1 = r(t) = g_1 s_1 + g_2 s_2 + \eta_1 \qquad r_2 = r(t+T) = -g_1 s_2^* + g_2 s_1^* + \eta_2 \tag{5}$$

or in the matrix form

$$\vec{r} = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} + \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix}$$

$$\vec{r} = Y_{2, x_i = s_i} \vec{g} + \vec{\eta} \tag{6}$$

where r_1 and r_2 are the received signals at time *t* and *t+T* and η_1 and η_2 are complex random variables representing receiver noise and interference.

The combiner shown in Figure 1 creates the following two combined signals that are sent to the maximum likelihood detector:

$$\tilde{s}_1 = g_1^* r_1 + g_2 r_2^* \qquad \tilde{s}_2 = g_2^* r_1 + g_1 r_2^* \tag{7}$$

or by matrix

$$\vec{\tilde{s}} = \begin{bmatrix} \tilde{s}_1 \\ \tilde{s}_2 \end{bmatrix} = \begin{bmatrix} g_1^* & g_2 \\ g_2^* & -g_1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = (|g_1|^2 + |g_2|^2) \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} g_1^* & g_2 \\ g_2^* & -g_1 \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2^* \end{bmatrix} \tag{8}$$

These combined signals are then sent to the maximum likelihood detector to make a decision on which signal is dispatched.

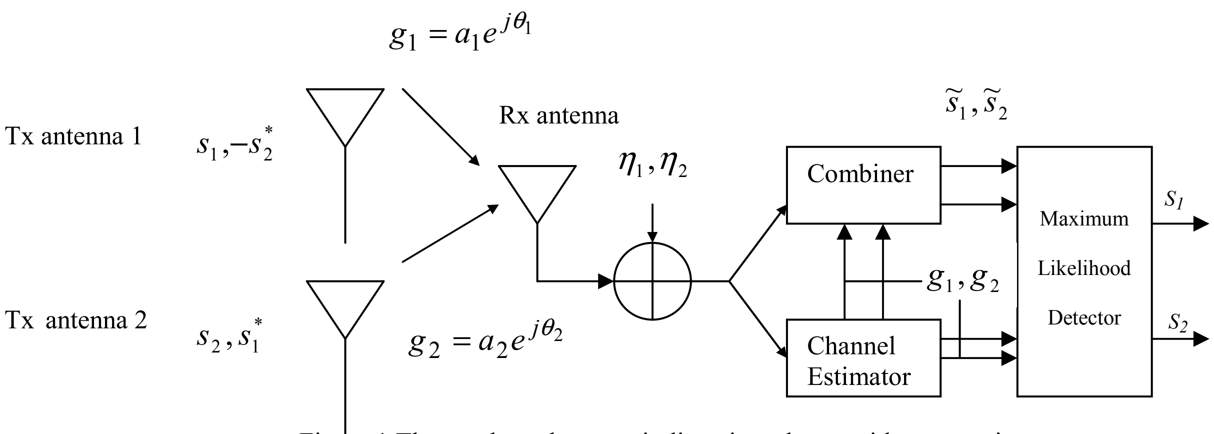

Figure 1 The two branch transmit diversity scheme with one receiver

III Collaborative Coding Multiple Access

In a situation where the bandwidth is a restricted resource such as radio frequency bands, it is necessary to study efficient ways of sharing it between as many users as possible. Furthermore, it is of considerable importance to use a simple and effective multiple access coding technique capable of error control. CCMA is an attractive proposition since it allows a substantial increase in the number of users that can access the channel simultaneously leading to a higher combined information rate. CCMA techniques exist which lie between the two extreme cases of TDMA and CDMA and offer in certain circumstances the possibility of rate sums higher than unity with modest synchronisation requirements [6]. There are two main approaches for the CCMA code design for the discrete adder channel. The first one focuses on achieving the bounds promised by multiple access information theory where all the users are active [5, 6]; the second approach aims at code construction for T active users out of M multiple access systems where the primary goal of code construction is not to achieve channel capacity [9]. Previous work has covered both approaches to the CCMA coding [5, 7, 8].

Code constructions for CCMA schemes are restricted since the composite code resulting from the individual user's code combinations have to be uniquely decodable. A composite code is said to be uniquely decodable if it can decode each of the component codes uniquely and deliver the corresponding sink information reliably to their intended destinations. Various block codes have been designed to meet the unique decodability criteria . It was found that the best rate sum would be achieved if block length N is kept to a minimum [10]. The rate sum decreases with increase in N tending to unity. Code constructions in this instance are based on the multiple access information theory (MAIT) approach which began with a coding theorem developed in [11]. The search for codes in this case is complicated by the fact that at least one of the component codes must be non-linear in order to achieve a rate point near the boundary of the capacity region of the MA adder channel. A similar approach based on achieving channel capacity asymptotically as the number of users (M) goes to infinity is also described. Here, each user gets two codewords and the overall rate sum is M/N (bits/channel use). The original model of such a scheme was proposed by [10] and represents a uniquely decodable code pair of block length $N=2$, as is shown in Table 1.

Table 1: 2-user Block Code

User1 \ User 2	**00**	**11**
00	00	11
01	01	12
10	10	21

User one has two code words $C_1=(00,11)$ and User two has three code words $C_2=(00,01,10)$. The individual rates for User one and User two are $R_1=0.5$ and $R_2=0.792$ respectively. The composite coding scheme, shown in Table 1, has a total rate sum $R_T=R_1+R_2=1.292$ (bits/channel use).

The rate of a component code is expressed as

$$R_i = \frac{\log_2 W_i}{N} ....(bits / channel \quad .use) \tag{9}$$

where W_i is the number of distinct codewords in component code C_i and N is the block length. The rate sum $R_T(M)$ of an M-user code $(C_1, C_2, ..., C_M)$ is defined as:

$$R_T(M) = R_1 + R_2 + ... + R_M .(bits / channel.use) \tag{10}$$

The simple coding scheme above can be extended to length N, where C_1 is the two N-tuples $(000... 0)$ and $(111... 1)$, and C_2 is the N-tuples $(000... 0)$ and all the other N-tuples except the all one vector. The omission of the all one vector from C_2 is made in order to maintain unique decodability. It is clear that User one code is a repetition code that has one message symbol which is repeated N times. The total rate sum of a 2-user scheme based on this construction can be seen to decrease with increase in N tending to unity.

IV Hybrid Coding Scheme Combining CCMA and STC

In this section, a hybrid CCMA/space-time coding is introduced to combine the advantages of these two kinds of coding. The principle of this new scheme is that considering a T-user multiple access communication system with T independent users communicating simultaneously over a common multiple access channel using a T-user collaborative code, the output of the T-user CCMA is phase mapped and space-time block code encoded. The encoded symbol is divided into streams which are simultaneously transmitted using m transmit antennas. On the receiver side, the received signals are first combined using the method described in Section 2, and the combined signals are then sent to the maximum likelihood decoder to obtain the sink signals of the T-users. Figure 2 shows the proposed hybrid coding scheme corresponding to a two-user CCMA, two transmit antennas and one receive antenna system.

For example, assuming C_1 = (00, 11) and C_2 = (01, 10), the output of the adder of C_1 and C_2 is uniquely decodable. The BPSK (Binary Phase Shift Keying) output of C_1 is $S_{11}S_{12}$ = (11, -1-1), the BPSK output of C_2 is $S_{21}S_{22}$ = (1-1, -1 1), and the BPSK output of both C_1 and C_2 has four possibilites, that is C=($C_{11}C_{12}$, $C_{21}C_{22}$, $C_{31}C_{32}$, $C_{41}C_{42}$)= (2 0, 0-2, 0 2, -2 0). Let $S_1=S_{11}+S_{21}$ and $S_2=S_{12}+S_{22}$. Following the same process as in Section 2, we can obtain decoded $\widetilde{S}_1$ and $\widetilde{S}_2$. We then compute the following distances:

$$d_k^2 = \sum_{i=1}^{2} \left| \widetilde{S}_i - C_{k,i} \right|^2 , k = 1,2,3,4 \tag{11}$$

Selecting the smallest distance and getting thecorresponding $C_{k,i}$, we can follow the look-up table to sink information to complete the decoding process.

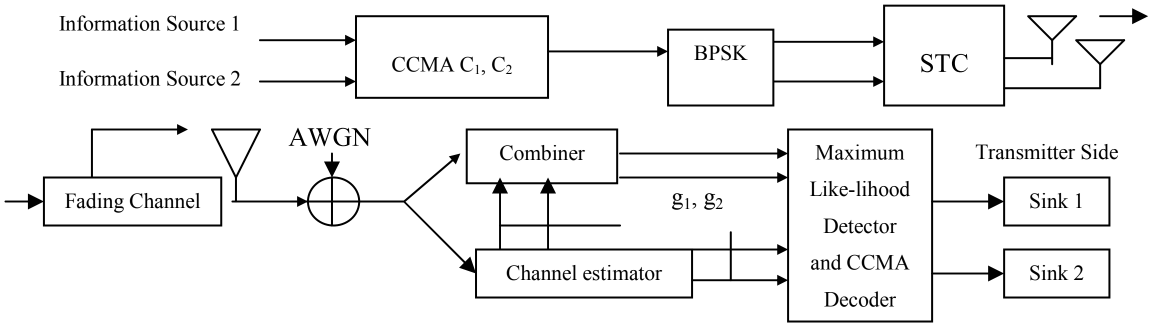

Figure 2: Hybrid CCMA and STC Scheme

V Simulation Results

In this section we provide simulation results for the performance of the hybrid CCMA/space-time coding scheme described in Section 4 (Figure 2 illustrates a block diagram of the proposed system). The main simulation parameters which we used were a data rate 9.6 kbit/s and a maximum Doppler frequency 100 Hz. Figure 3 shows the bit error performance of CCMA coding with and without space-time coding. The results demonstrate that significant gain can be achieved by transmit antenna diversity.

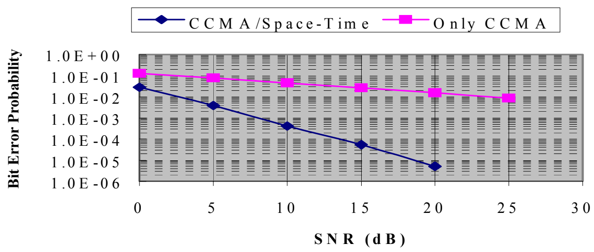

Figure 3: Performance of Hybrid Coding Compared with CCMA

Figure 4 shows the bit error rate of the proposed hybrid 2-user CCMA/space-time block coding with two transmit antennas and one receive antenna. From Figure 4 it can be seen that the combined CCMA/space-time coding system can give about 3dB improvement at bit error probability 10^{-5} with very little additional coding and decoding complexity compared with the space-time block coding with coherent BPSK.

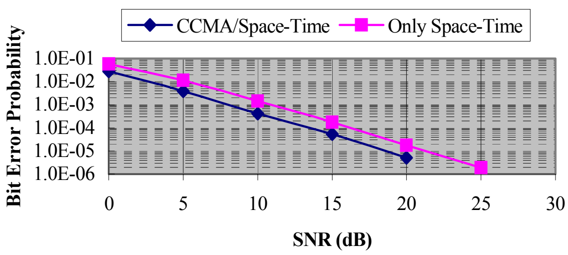

Figure 4: Performance of Hybrid Coding Compared with STC

VI Conclusions

Space-time block coding and collaborative coding multiple access techniques have been briefly discussed and a new coding scheme which combines the collaborative coding multiple access and space-time block coding techniques has been presented. The new coding technique with transmit diversity has been simulated. Initial results have been presented which show that the hybrid coding technique is advantageous over the space-time block coding and CCMA techniques.

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