STBC-based ARQ Scheme for Multiple Antenna Transmission

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Abstract

In this paper, we present a new hybrid ARQ scheme based on space-time codes (STC) utilizing automatic repeat request (ARQ) over multiple-input multiple-output (MIMO) transmission in a slowly varying channel. The proposed scheme is based on Alamouti space-time coding and pre-combining of packets and exploits both spatial and time diversity of the MIMO channel. Simulation results confirms that this scheme is suitable in slowly varying channel and also provide reliable communication.

I. Introduction

The use of multiple-input multiple-output (MIMO) in wireless communication systems together with the recently developed space-time coding and signal processing techniques, has been shown to provide dramatic capacity increase over traditional single-input single-output (SISO) channels, especially over rich scattered environments. As a result, MIMO systems have become important and popular research subjects.

A major concern in packet data communication system is how to control the transmission errors caused by the channel noise and interferences such that data can be transmitted with a minimum error. The most common error control method used in data communication is ARQ which intends to ensure an extremely low packet error rate. Pure ARQ systems are easy to implement but lead to variable delays which are not acceptable for some real-time applications. It is well known that introducing packet combining into an ARQ scheme can improve the throughput remarkable. In [3], Chase introduced a packet combining scheme where the individual transmissions are encoded at some code rate R. If the receiver has P packets that have been requested for retransmission, the packet are concatenated to form a single packet of lower code rate R/P. In [4], Harvey et al. proposed a version of packet combining where L copies of the data packet are combined into a single packet of the same length as the original transmitted data packet by averaging the soft decision values from the consecutive copies.

Combined with hybrid ARQ, MIMO can potentially provide higher throughput packet data services with higher reliability. In [5], Nguyen and Ingram investigated hybrid ARQ protocols for systems that uses recursive space-time codes. In [6], Onggosanusi *et al.* investigated the possibilities to enhance the efficiency of HARQ in MIMO systems by employing either a zero-forcing (ZF) or minimum mean-square error (MMSE) receiver before (pre-combining) and after (post-combining) the interference-resistant detection. Their result showed that a pre-combining scheme outperform a post-combining scheme. Zheng *et al.* proposed in [7] a new ARQ scheme for MIMO systems where substreams emitted from various transmit antennas encounter different error statistics. By using per-antenna encoders, separating the ARQ process among the substreams, they obtained some throughput improvements. In [8], Gidlund proposed an ARQ scheme for multi-level modulation in MIMO-systems. The rationale with that scheme was that they changed the bit mapping in every retransmission and achieved significant diversity gain. In [10], a soft packet combining MIMO HARQ scheme is proposed in which the last two received packets are combined using joint Alamouti space-time decoding [2].

In this paper we consider a combination of the scheme presented in [6] and Alamouti space-time coding. We consider a case with two transmit antennas and M receive antennas, preprocessing is consider instead of multiplying with an unitary matrix when retransmitting subsequent packets. This results in that the decoding process will be simplified, especially for even transmissions. This is due to the MIMO channel diagonalization. The rest of the paper is organized as follows. In section II we discuss the used system model and in section III we briefly review the Alamouti scheme. The proposed hybrid ARQ scheme is described in section IV while in section V we give expressions for the soft decision statistics. In section VI numerical results is presented and we conclude the work in section VII.

Notation: Column vectors (matrices) are denoted by boldface lower (upper) case letters. Superscripts $(\cdot)^T, (\cdot)^*$ and $(\cdot)^H$ stand for transpose, conjugate, Hermitian transpose, respectively. We will use $\mathbf{I}_N$ to denote the $N \times N$ identity matrix.

II. System Model

For simplicity we consider a MIMO system with Q transmit antennas and M receiver antennas with L transmissions of the packet and for the lth transmission obtains

$$\mathbf{y}_l = \mathbf{H}_l\mathbf{s} + \mathbf{n}_l, \qquad l = 1, 2, \ldots, L \tag{1}$$

where $\mathbf{H}_l = [\mathbf{h}_{l,1} \cdots \mathbf{h}_{l,Q}]$ is the $Q \times M$ channel matrix experienced by the data at the l-th transmission, $\mathbf{s} = [s_1 \cdots s_Q]^T$ is the zero-mean Q-dimensional transmitted signal vector with $E[\mathbf{s}\mathbf{s}^H] = diag\{\lambda_1, \lambda_2 \cdots, \lambda_Q\} = \mathbf{\Lambda}, \mathbf{n}_l \sim \mathcal{N}_\rceil(\mathbf{0}, \sigma^2\mathbf{I})$ is the AWGN vector associated with the l-th transmission. In this paper we limit ourselves to $Q = 2$ transmit antennas and the composite MIMO channel gain can then be represented by the following matrix

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ \vdots & \vdots \\ h_{M1} & h_{M2} \end{bmatrix}. \quad (2)$$

At the encoder, the information bits are first encoded with a high rate code C_0 which is used for error detection and C_1 is a half rate $(2, 1, m)$ convolutional code C_1 used for error correction. The coded packets are then demultiplexed into two separate data streams from the two transmit antennas. The two data streams are digitally modulated and simultaneously transmitted. We denote the packet transmitted from antennas 1 as s_1 and the packet transmitted from antenna 2 as s_2. The received signal vectors are decoded at each transmission. If errors are detected, the erroneous packet is stored in a buffer, and the receiver sends a NACK to the transmitter and request for a new transmission of the packet. The retransmitted packet and the previous erroneous packet are then combined together at the symbol-level.

In this paper the following assumptions are made:

1) Channel states are available at the receiver.
2) Independent noise vector $\mathbf{n}_l$ is observed every transmission.
3) The channel matrix $\mathbf{H}_l$ can be the same or different for every transmission. In this paper slow fading channel is assumed ($\mathbf{H}_l = \mathbf{H}$).

III. Review of Alamouti Scheme

The Alamouti scheme provides full transmit diversity for systems with two antennas. At the space-time encoder each group of information bits is modulated and a block of two modulated symbols s_1 and s_2 are mapped to the transmit antennas according to a code matrix given by:

$$\mathbf{S} = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix}.$$

Signal transmission over the channels then proceeds such that in the first transmission period, two signals s_1 and s_2 are transmitted simultaneously from antenna one and antenna two, respectively. In the second transmission period, signal $-s_2^*$ and s_1^*. For a multiple receive antenna scenario, the received signals at the jth receive antenna at time t and $t + T$ can be written as:

$$r_1^j = h_{j,1}s_1 + h_{j,2}s_2 + n_1^j \quad (3)$$

$$r_2^j = h_{j,1}s_2^* + h_{j,2}s_1^* + n_2^j \quad (4)$$

where $h_{j,i} = 1, 2,\ i = 1, 2,\ j = 1, 2, \cdots, N$, is the fading coefficient for the path from transmit antenna i to receive antenna j, and n_1^j and n_2^j are the noise signals from receive antenna j at time t and $t + T$, respectively. Employing ML decoding, the decision rules is given by

$$\hat{s}_1 = \arg\min_{\hat{s}_1 \in S} \left[\left(\sum_{j=1}^{N} (|h_{j,1}|^2) + |h_{j,2}|^2 - 1 \right) |\hat{s}_1|^2 + d^2(\tilde{s}_1, \hat{s}_1) \right] \tag{5}$$

$$\hat{s}_2 = \arg\min_{\hat{s}_2 \in S} \left[\left(\sum_{j=1}^{N} (|h_{j,1}|^2) + |h_{j,2}|^2 - 1 \right) |\hat{s}_2|^2 + d^2(\tilde{s}_2, \hat{s}_2) \right] \tag{6}$$

IV. PROPOSED COMBINING SCHEME

A. Soft Packet Combining Scheme

In [10], an MIMO hybrid ARQ scheme was presented which employs soft combining of packets. Consider the first MIMO packet is sent as $[\mathbf{s}_1\ \mathbf{s}_2]^T$; If the packet contains error, the retransmission of the same packet is sent as $[\mathbf{s}_2^*\ \mathbf{s}_1^*]^T$ and the first and second transmissions are jointly decoded as an Alamouti space-time block code. If the packet still can not be correct decoded at the receiver, a new retransmission is requested and the third transmission is sent as $[\mathbf{s}_1\ \mathbf{s}_2]^T$. Then the second and third transmission are jointly decoded as Alamouti STBC.

The first and second space-time decoding output are combined together using classical Chase combining.

B. Proposed Hybrid ARQ Scheme

The proposed hybrid ARQ combining scheme is quite similar to the one presented in papers [9] and [10]. At the encoder the bits are space-time encoded and then mapped into a sequence. The transmitted coded data stream is then split into two subpackets and sent from the two transmit antennas. At the receiver, the received signal at the lth transmission is given by:

$$\mathbf{y}_l = \mathbf{H}\mathbf{s} + \mathbf{n}_l, \qquad l = 1, 2, \ldots, L \tag{7}$$

where $\mathbf{r}_l = [r_{1,l}, r_{2,l}, \cdots, r_{M,l}]^T \in \mathbb{C}^m$, $\mathbf{s}_l = [\mathbf{s}_1\ \mathbf{s}_2]^T$ and $\mathbf{n}_l = [n_{1,l}, n_{2,l}, \cdots, n_{M,l}]^T\ \mathbf{N}_{\mathcal{C}}[\mathbf{0}_M, \sigma^2\mathbf{I}_M]$.

At the receiver, either zero-forcing or maximum-likelihood sequence estimator (MMSE) receiver can be employed to remove the interference for the lth transmission. Furthermore, we separate the two transmitted data packets and decoded them independently. If the received packet after decoding is error free, an acknowledgement is sent to the receiver. If the packet is not correct decoded a NACK is sent to the transmitter and request for a new transmission according to the Alamouti STC scheme, i.e. new packets composed of $[\mathbf{s}_2^*\ \mathbf{s}_1^*]^T$ are sent from the two transmit antennas. The received signal at the $(l+1)$th transmission is given as

$$\mathbf{y}_{l+1} = \mathbf{H}\mathbf{s}_{l+1} + \mathbf{n}_{l+1}. \tag{8}$$

Now, we take the conjugate of the new received packets and obtains

$$\mathbf{y}^*_{l+1} = \mathbf{H}^*\Theta\mathbf{s}_l + \mathbf{n}^*_{l+1}, \quad l = 1, \ldots, L \tag{9}$$

where

$$\mathbf{H}^* = \begin{bmatrix} h^*_{11} & h^*_{12} \\ \vdots & \vdots \\ h^*_{M1} & h^*_{M2} \end{bmatrix}, \boldsymbol{\Theta}_1 = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{10}$$

and

$$\mathbf{r}^*_{(l+1)} = [r^*_{1,(l+1)} \ r^*_{2,(l+1)} \cdots r^*_{M,(l+1)}]^T \tag{11}$$

By taking the conjugate of the received signal $\mathbf{r}_{(l+1)}$ it is clear that this operation is equivalent to re-sending the previous signal through the channel $\mathbf{H}^*\Theta$ that add time diversity effect.

At the receiver, we are using a linear receiver to process the received signal $\mathbf{r}_{(l+1)}$, first we multiply symbol wise by $(\mathbf{H}^*\Theta)^H = \Theta^T\mathbf{H}^T$ and then combine them on symbol level which provides the soft symbol decision $\mathbf{s}_l$. This operation is equivalent to combining the signal $\mathbf{r}^*_{(l+1)}$ with the previously received packet $\mathbf{r}_i$ using the pre-combining scheme of (1).

If the packet is correct decoded an ACK is transmitted, otherwise the transmitter resends the packets as in the l-th transmission, i.e. $\mathbf{s}_{(l+2)} = [s_1 \ s_2]^T$. The newly received packet $\mathbf{r}_{(l+2)}$ is then combined with $\mathbf{r}^*_{(l+1)}$ and $\mathbf{r}_1$. In even transmissions we send $[-s_2^* \ s_1^*]$ and for odd transmissions we use $[\mathbf{s}_1 \ \mathbf{s}_2]^T$. This procedure continues until a correct packet is decoded or the number of maximum retransmissions attempts is reached.

V. Soft statistics

We recall that for odd transmissions, the channel is given by $\mathbf{H}$ and for even transmissions $\mathbf{H}\Theta$. For either a ZF or MMSE receiver we can describe the soft decision statistic as:

$$\hat{\mathbf{s}} = (\mathbf{C} + \alpha\mathbf{I}_2^{-1})^{-1}\mathbf{x} \tag{12}$$

where $\mathbf{C} = \sum_{i=1}^{L} \mathbf{H}_l^H\mathbf{H}_l$ and $\mathbf{x} = \sum_{l=1}^{L} \mathbf{x}_l = \mathbf{C}\mathbf{s} + \mathcal{N}_{\mathcal{C}}(\mathbf{0}, \sigma^2\mathbf{C})$. The soft statistics after L transmissions can now be rewritten as

$$\hat{\mathbf{s}} = (\mathbf{C} + \alpha\mathbf{I}_2)^{-1}\mathbf{C}\mathbf{s} + \mathcal{N}_{\mathcal{C}}[\mathbf{0}_2, \sigma^2(\mathbf{C} + \alpha\mathbf{I}_2)^{-1}\mathbf{C}(\mathbf{C} + \alpha\mathbf{I}_2)^{-1H}] \tag{13}$$

1) Even Number of Transmissions: When the total number of transmissions L is even, it can be showed that $\mathbf{C} = \frac{N}{2} h^2 \mathbf{I}_2$ where $H^2 = \sum_{k=1}^{M} |h_{k1}|^2 + |h_{k2}|^2$. The soft decision statistic $\hat{\mathbf{s}}$ can now be expressed as

$$\hat{\mathbf{s}}_{(even)} = \beta \mathbf{s} + \mathcal{N}_{\mathcal{C}}[\mathbf{0}_2, \sigma^2 \frac{\frac{L}{2} h^2}{(\frac{L}{2} h^2 + \alpha)^2}], \tag{14}$$

where β is a scalar and given as

$$\beta = \frac{\frac{L}{2} h^2}{\frac{L}{2} h^2 + \alpha}.$$

Since no matrix inversion is needed, which basically means that ZF and MMSE processing is unnecessary. We can express the signal-to-noise ratio as

$$SNR_{(even)} = \frac{\beta^2}{\sigma^2} \frac{\frac{L}{2} h^2}{(\frac{L}{2} h^2 + \alpha)^2} = \frac{\frac{L}{2} h^2}{\sigma^2}. \tag{15}$$

For an even number of transmissions, the performances of zero-forcing and MMSE receivers are the same. This is due to the channel is diagonalized by the Alamouti space-time coding (interference is already cancelled). It is also observed that the SNR performance is proportional to the number of transmission. This implies that with increasing number of transmissions, the performance will increase.

2) Odd Number of Transmissions: In the case of odd number of retransmissions, the decision statistic for an ZF receiver is given by

$$\hat{\mathbf{s}}^{ZF}_{(odd)} = \mathbf{s} + \mathcal{N}_{\mathcal{C}}(\mathbf{0}_2, \sigma^2 \mathbf{C}^{-1H}_{odd}) \tag{16}$$

and for MMSE receiver

$$\hat{\mathbf{s}}^{MMSE}_{(odd)} = (\mathbf{C}_{odd} + \sigma^2 \mathbf{I}_2)^{-1} \mathbf{C}_{odd} \mathbf{s} + \mathcal{N}_{\mathcal{C}}[\mathbf{0}_2, \sigma^2 (\mathbf{C} + \alpha \mathbf{I}_2)^{-1} \mathbf{C} (\mathbf{C} + \alpha \mathbf{I_2})^{-1H}], \tag{17}$$

where

$$\mathbf{H} = \begin{bmatrix} a_1^2 & b \\ b^* & a_2^2 \end{bmatrix}. \tag{18}$$

$$a_1^2 = \frac{N+1}{2} \sum_{k=1}^{M} |h_{k1}|^2 + \frac{N+1}{2} \sum_{k=1}^{M} |h_{k2}|^2$$

$$a_2^2 = \frac{N+1}{2} \sum_{k=1}^{M} |h_{k2}|^2 + \frac{N-1}{2} \sum_{k=1}^{M} |h_{k1}|^2$$

$$b = \sum_{k=1}^{M} h_{k1}^* h_{k2}. \tag{19}$$

With the above expressions in mind we can give SNR expressions for both ZF and MMSE.

$$SNR^{(1)}_{(odd)ZF} = \frac{1}{\sigma^2[\mathbf{C}^{-1H}_{(odd)}]_{2,2}} = \frac{(a_1^2a_2^2 - |b|^2)}{\sigma^2 a_1^2} \tag{20}$$

$$SNR^{(2)}_{(odd)ZF} = \frac{1}{\sigma^2[\mathbf{C}^{-1H}_{(odd)}]_{1,1}} = \frac{(a_1^2a_2^2 - |b|^2)}{\sigma^2 a_2^2}, \tag{21}$$

where $SNR^{(p)}_{(odd)ZF}$, $p = 1, 2$ is the signal-to-noise ratio corresponding to the p-th detected packet. Note that we have a signal enhancement by the term $(a_1^2a_2^2 - |b|^2)$ and a noise enhancement by a_1^2 for $SNR^{(1)}_{(odd)ZF}$ and a_2^2 for $SNR^{(2)}_{(odd)ZF}$.

For a MMSE receiver we found the SNR as

$$SNR^{(1)}_{(odd)MMSE} = \frac{[a_1^2(a_2^2+\sigma^2) - |b|^2]^2}{a_1^2a_2^4 + 2a_1^2a_2^2\sigma^2 + a_1^2\sigma^4 - |b|^2a_2^2 - 2|b|^2\sigma^2} \tag{22}$$

$$SNR^{(2)}_{(odd)MMSE} = \frac{[a_2^2(a_1^2+\sigma^2) - |b|^2]^2}{a_2^2a_1^4 + 2a_2^2a_1^2\sigma^2 + a_2^2\sigma^4 - |b|^2a_1^2 - 2|b|^2\sigma^2}. \tag{23}$$

VI. Numerical Results

To asses the performance of the proposed scheme in MIMO environments, we simulated a 2×2 MIMO system using QPSK modulation is used for symbol mapping. The data is encoded with a $R_c = 1/2$ convolutional code (133,171) with constraint length 7 and minimum code distance 10. It was assumed that the channel remains constant for L transmissions and the channel gains are i.i.d. complex Gaussian random variables and with uniform power.

In Fig. 1 the bit error rate is plotted versus E_b/N_0 for different number of transmissions and compared to the soft packet combined scheme in [10]. For equal number of transmissions, it is shown that the performance is the same for ZF and MMSE which was expected since the Alamouti STC removes the interference. Moreover, no matrix inversion is needed which reduces the complexity. At a BER of 10^{-2} the performance gain is 3db compared to Chase combining and 2.2db to the soft packet combined scheme in [10]. In Fig. 2, the bit error rate for different number of transmissions for a Zero-forcing receiver is shown.

VII. Conclusion

In this paper, we propose a MIMO-ARQ scheme based on the Alamouti scheme which both exploits the space-time coding gain and the time diversity gain. The proposed method simplifies the computation of the decision statistic when the total number of transmissions is even since the Alamouti code take care of cross interference. For odd number of transmissions, the interference is removed by a linear ZF or MMSE receiver. The simulation results show that this scheme performs well in slow varying channels.

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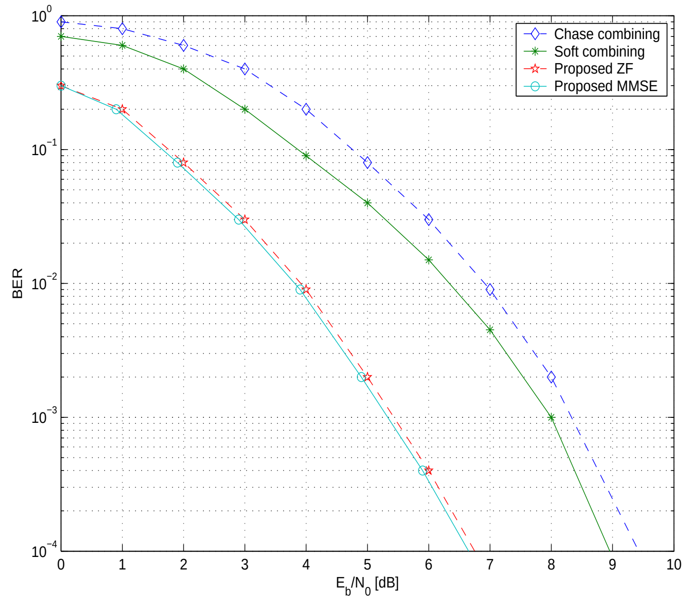

Fig. 1. BER Performance for the proposed scheme compared to Chase combining and soft packet combining for $L = 2$ transmissions

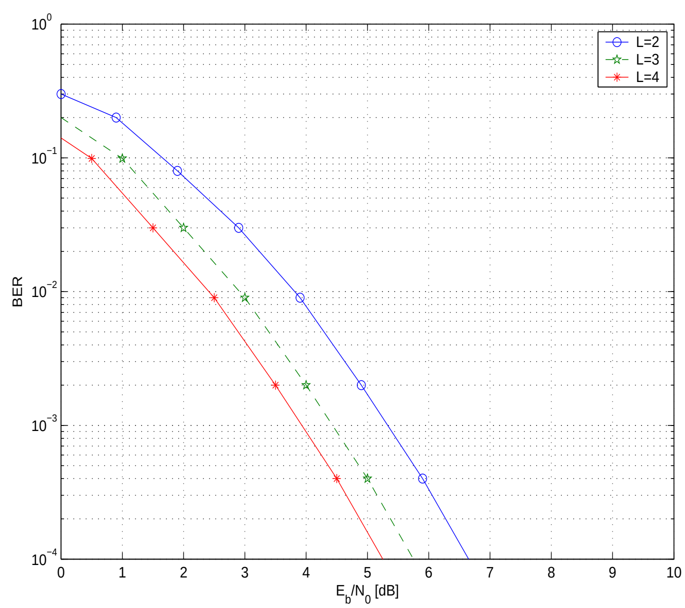

Fig. 2. BER Performance of the proposed scheme employing zero-forcing receiver for different number of transmissions.