Spectrally efficient multiple-ARQ scheme for MIMO channel

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Proposed is a multiple automatic repeat request (ARQ) scheme for the MIMO channel adopting the structure of space-time block codes (STBCs). With multiple transmissions accompanied by the proposed combing strategy, the input-output relationship of the Alamouti STBC is formed in the receiver. It is observed that the proposed ARQ scheme attains higher throughput than others at all SNR values.

Introduction: The multi-input multi-output (MIMO) system [1] and the automatic repeat request (ARQ) scheme, including hybrid ARQ, are considered promising solutions to attain high data rate as well as high reliability of wireless communications. As an ARQ scheme for a MIMO channel, single ARQ (MSARQ) and multiple ARQ (MMARQ) were proposed [2]. In MSARQ, the cyclic redundancy check (CRC) and the retransmission are conducted for the whole packet. On the other hand, in MMARQ, the CRC and the retransmission are conducted for individual subpackets. It is known that MMARQ attains higher throughput than MSARQ. Space-time block codes (STBCs) have been used to utilise the gain attained by a MIMO channel [3, 4]. Alamouti proposed an orthogonal STBC which can be decoded with low complexity [4]. Recently, an Alamouti-based hybrid ARQ, classified as MSARQ, was proposed for a static MIMO channel [5], in which odd columns and even columns of a STBC symbol matrix are transmitted alternately and the structure of the received signal of the STBC is formed in the receiver. To obtain higher throughput, however, it is required to design a MMARQ scheme utilising the good detecting performance of STBCs with a smaller number of channel uses. In this Letter, we propose a STBC-based MMARQ scheme with a novel transmission and combining strategy, which shows higher throughput than conventional schemes.

System model: Consider a MMARQ system depicted in Fig. 1 with the maximum number of total channel uses M allowing multiple transmissions over a static MIMO channel $\mathbf{H} \in \mathcal{C}^{N_r \times 2}$ with two transmit antennas and N_r receive antennas. The information frame $\mathbf{b}$ is demultiplexed into $\mathbf{b}_1$ and $\mathbf{b}_2$ which are independently CRC encoded as $\mathbf{c}_1$ and $\mathbf{c}_2$, respectively. By mapping bits in $\mathbf{c}_1$ and $\mathbf{c}_2$ to symbols, subpackets $\mathbf{x}_1 = [x_1(1)\, x_1(2)\, \cdots\, x_1(K)]$ and $\mathbf{x}_2 = [x_2(1)\, x_2(2)\, \cdots\, x_2(K)]$ are obtained, where K is the number of symbols in each subpacket and it is an even integer. Symbol matrices $\mathbf{S}_o$ and $\mathbf{S}_e \in \mathcal{C}^{2\times T}$ are constructed to be transmitted in odd and even transmission rounds, respectively, according to the feedback information sent from the receiver, where T denotes the number of channel uses per one transmission round. The received signals are combined with previously received signals to be used for detecting symbols as $\hat{\mathbf{x}}_1$ and $\hat{\mathbf{x}}_2$, which are demapped to $\hat{\mathbf{c}}_1$ and $\hat{\mathbf{c}}_2$, respectively. CRC decoding is conducted for each of $\hat{\mathbf{c}}_1$ and $\hat{\mathbf{c}}_2$, and the acknowledgement (ACK) or negative acknowledgement (NAK) signal for each corresponding subpacket is fed back to the transmitter. Let $\mathbf{y}^{(i)}(t) \in \mathcal{C}^{N_r\times 1}$, $\mathbf{s}^{(i)}(t) \in \mathcal{C}^{2\times 1}$ and $\mathbf{w}^{(i)}(t) \in \mathcal{C}^{N_r\times 1}$ denote received signals, transmitted symbols and circular symmetric complex Gaussian noises, respectively, at the tth channel used in the transmission round i. Then,

$$\mathbf{y}^{(i)}(t) = \mathbf{H} \times \mathbf{s}^{(i)}(t) + \mathbf{w}^{(i)}(t), \qquad 1 \le t \le T \tag{1}$$

where $\mathbf{s}^{(i)}(t) = \mathbf{s}_o(t)$ if i is odd and $\mathbf{s}^{(i)}(t) = \mathbf{s}_e(t)$ if i is even. Note that $\mathbf{s}_o(t)$ and $\mathbf{s}_e(t)$ correspond to the tth column of $\mathbf{S}_o$ and $\mathbf{S}_e$, respectively.

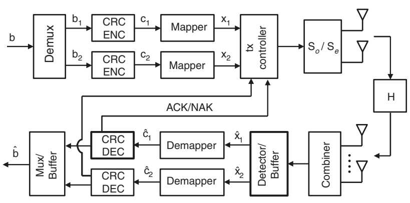

Fig. 1 *Block diagram of proposed MMARQ system*

Proposed transmission and combining strategy: For each transmission round, the following two cases exist: (a) both subpackets $\mathbf{x}_1$ and $\mathbf{x}_2$ are transmitted, or (b) only one subpacket is transmitted with another subpacket already acknowledged. Case (b) can occur only after case (a). We consider the ith transmission round.

First, consider case (a), in which $\mathbf{S}_o$ and $\mathbf{S}_e$ are formed as

$$\mathbf{S}_o = \begin{bmatrix} x_1(1) & x_2(2) & \dots & x_1(K-1) & x_2(K) \\ x_2(1) & x_1(2) & \dots & x_2(K-1) & x_1(K) \end{bmatrix} \tag{2}$$

and

$$\mathbf{S}_e = \begin{bmatrix} -x_2^*(1) & -x_1^*(2) & \dots & -x_2^*(K-1) & -x_1^*(K) \\ x_1^*(1) & x_2^*(2) & \dots & x_1^*(K-1) & x_2^*(K) \end{bmatrix} \tag{3}$$

where $T = K$. For each t, transmitting columns of $\mathbf{S}_o$ and $\mathbf{S}_e$ alternatingly with allowing multiple transmissions accompanied by combing at the receiver is equivalent to transmitting the Alamouti STBC. If $i = 1$, symbols are detected by a linear detection, e.g. maximum-likelihood (ML) detection. If $i \ge 2$, received signals in odd transmission rounds and those in even transmission rounds are combined separately. Let $\tilde{\mathbf{y}}^{(i)}(t)$ denote the combined signal up to the transmission round i, which is expressed as

$$\tilde{\mathbf{y}}^{(i)}(t) = \begin{cases} \dfrac{1}{\lceil i/2 \rceil} \sum_{n=\mathrm{odd},\, n\le i} \mathbf{y}^{(n)}(t) & \text{if } i \text{ is odd} \\ \dfrac{1}{\lfloor i/2 \rfloor} \sum_{n=\mathrm{even},\, n\le i} \mathbf{y}^{(n)}(t) & \text{if } i \text{ is even} \end{cases} \tag{4}$$

where $\tilde{\mathbf{y}}^{(0)}(t) = \mathbf{0}$ for all t. When $i \ge 2$, for each t, a pair of combined signals at two successive transmission rounds forms the input-output relationship of the Alamouti STBC as

$$[\tilde{\mathbf{y}}^{(\lfloor i \rfloor_o)}(t)\ \tilde{\mathbf{y}}^{(\lfloor i \rfloor_e)}(t)] = \mathbf{H} \times [\mathbf{s}_o(t)\ \mathbf{s}_e(t)] + [\tilde{\mathbf{w}}^{(\lfloor i \rfloor_o)}(t)\ \tilde{\mathbf{w}}^{(\lfloor i \rfloor_e)}(t)] \tag{5}$$

where $\lfloor i \rfloor_o$ and $\lfloor i \rfloor_e$ denote the greatest odd integer and the greatest even integer, respectively, that is smaller than or equal to i, and $\tilde{\mathbf{w}}^{(\lfloor i \rfloor_o)}(t)$ and $\tilde{\mathbf{w}}^{(\lfloor i \rfloor_e)}(t)$ denote the combined noise obtained by the same manner as in [4]. Since the matrix $\mathbf{s}_o(t)\, \mathbf{s}_e(t) \in \mathcal{C}^{2\times 2}$ forms the Alamouti STBC for each t, symbols $x_1(t)$ and $x_2(t)$ can be detected by Alamouti decoding with low computational complexity.

Next, consider case (b) with the assumption that $\mathbf{x}_2$ is acknowledged earlier and only $\mathbf{x}_1$ is retransmitted at the ith transmission round, where $i \ge 2$. The extension of the proposed scheme to the case when $\mathbf{x}_2$ is retransmitted with $\mathbf{x}_1$ already acknowledged is straightforward. If the ACK signal for $\mathbf{x}_2$ was made at the $(i-1)$th transmission round, the signal components corresponding to symbols in $\mathbf{x}_2$ are cancelled from the previously combined signals. If the ACK signal has been made earlier than the $(i-1)$th transmission round, the cancellation process is not required at the round i. For each t', $t' = 1, \cdots, K$, the cancellation is conducted as

$$\tilde{\mathbf{y}}^{(\lfloor i-1 \rfloor_o)}(t') \leftarrow \tilde{\mathbf{y}}^{(\lfloor i-1 \rfloor_o)}(t') - \mathbf{H} \times \hat{\mathbf{s}}_o(t')$$

$$\tilde{\mathbf{y}}^{(\lfloor i-1 \rfloor_e)}(t') \leftarrow \tilde{\mathbf{y}}^{(\lfloor i-1 \rfloor_e)}(t') - \mathbf{H} \times \hat{\mathbf{s}}_e(t')$$

where $\hat{\mathbf{s}}_o(t')$ and $\hat{\mathbf{s}}_e(t')$ denote the t'th column of $\hat{\mathbf{S}}_o$ and $\hat{\mathbf{S}}_e$, respectively, which are defined by

$$\hat{\mathbf{S}}_o = \begin{bmatrix} 0 & \hat{x}_2(2) & \dots & 0 & \hat{x}_2(K) \\ \hat{x}_2(1) & 0 & \dots & \hat{x}_2(K-1) & 0 \end{bmatrix} \tag{6}$$

and

$$\hat{\mathbf{S}}_e = \begin{bmatrix} -\hat{x}_2^*(1) & 0 & \dots & -\hat{x}_2^*(K-1) & 0 \\ 0 & \hat{x}_2^*(2) & \dots & 0 & \hat{x}_2^*(K) \end{bmatrix} \tag{7}$$

Then, we generate a reformed signal by

$$\tilde{\mathbf{y}}_R^{(j)}(t) = \tilde{\mathbf{y}}^{(j)}(2t-1) + \tilde{\mathbf{y}}^{(j)}(2t), \qquad t = 1, \cdots, K/2 \tag{8}$$

where $j = \lfloor i-1 \rfloor_o$ or $\lfloor i-1 \rfloor_e$. It follows that $\tilde{\mathbf{y}}_R^{(\lfloor i-1 \rfloor_o)}(t) = \mathbf{H} \times [x_1(2t-1)\, x_1(2t)]^T +$ 'noise' and $\tilde{\mathbf{y}}_R^{(\lfloor i-1 \rfloor_e)}(t) = \mathbf{H} \times [-x_1^*(2t)\, x_1^*(2t-1)]^T +$ 'noise'. Then, we construct $\mathbf{S}_o$ and $\mathbf{S}_e$ for the ith transmission round as

$$\mathbf{S}_o = \begin{bmatrix} x_1(1) & x_1(3) & \dots & x_1(K-1) \\ x_1(2) & x_1(4) & \dots & x_1(K) \end{bmatrix} \tag{9}$$

and

$$\mathbf{S}_e = \begin{bmatrix} -x_1^*(2) & -x_1^*(4) & \dots & -x_1^*(K) \\ x_1^*(1) & x_1^*(3) & \dots & x_1^*(K-1) \end{bmatrix} \tag{10}$$

where $T = K/2$. The received signal $\mathbf{y}^{(i)}(t)$ obtained by (1), (9) and (10) is combined with previously received and reformed signals as

$$\tilde{\mathbf{y}}_R^{(i)}(t) = \begin{cases} \dfrac{1}{\lceil i/2 \rceil}\left(\dfrac{\lceil i-2 \rceil}{2} \times \tilde{\mathbf{y}}_R^{(i-2)}(t) + \mathbf{y}^{(i)}(t)\right) & \text{if } i \text{ is odd} \\ \dfrac{1}{\lfloor i/2 \rfloor}\left(\dfrac{\lfloor i-2 \rfloor}{2} \times \tilde{\mathbf{y}}_R^{(i-2)}(t) + \mathbf{y}^{(i)}(t)\right) & \text{if } i \text{ is even} \end{cases} \quad (11)$$

where $\tilde{\mathbf{y}}_R^{(0)}(t) = \mathbf{0}$. Then, for each t, a pair of reformed signals at two successive transmission rounds forms the input-output relationship of the Alamouti STBC as

$$\left[\widetilde{\mathbf{y}}_R^{(\lfloor i \rfloor_o)}(t) \;\; \widetilde{\mathbf{y}}_R^{(\lfloor i \rfloor_e)}(t)\right] = \mathbf{H} \times \begin{bmatrix} x_1(2t-1) & -x_1^*(2t) \\ x_1(2t) & x_1^*(2t-1) \end{bmatrix} + \left[\widetilde{\mathbf{w}}_R^{(\lfloor i \rfloor_o)}(t) \;\; \widetilde{\mathbf{w}}_R^{(\lfloor i \rfloor_e)}(t)\right] \quad (12)$$

where $\tilde{\mathbf{w}}_R^{(\lfloor i \rfloor_o)}(t)$ and $\tilde{\mathbf{w}}_R^{(\lfloor i \rfloor_e)}(t)$ denote reformed circular symmetric complex Gaussian noises obtained by the same manner as in (8). It follows that $x_1(2t-1)$ and $x_1(2t)$ for each t can be detected by Alamouti decoding.

As presented above, for all possible scenarios, the combined signals in the receiver at any transmission round except the initial round can be regarded as the received signal of the Alamouti STBC. Thus, Alamouti decoding can be used to detect all symbols, resulting in good detecting performance and thus high throughput with low computational complexity.

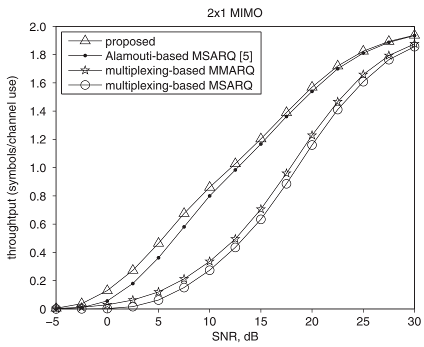

Fig. 2 *Throughput performances of ARQ schemes over 2 × 1 Rayleigh fading channel, where K = 100, M = 5K and QPSK modulation is used*

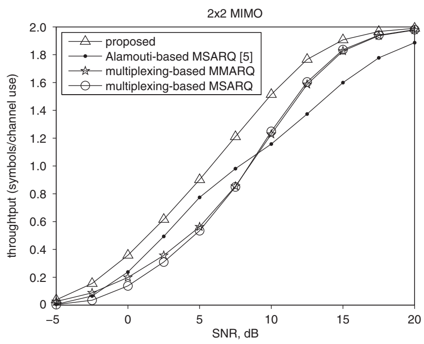

Fig. 3 *Throughput performances of ARQ schemes over 2 × 2 Rayleigh fading channel, where K = 100, M = 5K and QPSK modulation is used*

Numerical results: We consider 2×1 and 2×2 static Rayleigh fading channels. The ANSI-CRC code with the generator polynomial $g(x) = x^{16} + x^{15} + x^2 + 1$ is used and M is fixed as $5K$, where K=100. The QPSK modulation is used for bit-to-symbol mapping. In Figs. 2 and 3, we plot the throughput performance of the proposed MMARQ scheme obtained by simulations. The throughput is defined by the number of acknowledged symbols over the total number of channel uses by multiple transmissions. For comparison, we also plot the performances of the Alamouti-based MSARQ scheme [5], the multiplexing-based MMARQ scheme and the multiplexing-based MSARQ scheme, where ML detection is used for these schemes. Note that the proposed scheme uses ML detection in the initial transmission round and Alamouti decoding since the second round. It is observed that the proposed scheme shows higher throughput than other schemes at all SNR values.

Conclusion: We propose a spectrally efficient STBC-based MMARQ scheme for a $2 \times N_r$ static MIMO channel. After the combining process in the receiver, we obtain the form of the input-output relationship of the Alamouti STBC, although the STBC is not actually transmitted. The proposed ARQ scheme enables one to attain high throughput with low computational complexity.

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