

ARQ strategies for 2×2 spatially multiplexed MIMO systems

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Abstract— This paper presents packet retransmission strategies for MIMO spatial multiplexing (SM) systems with independent coding and independent ARQ processes per stream. The received signals containing the retransmitted packets are kept in memory and combined. We present two methods to select the retransmission antennas. The first method is based on CSI: the optimization criterion is the minimization of the SNRs averaged over the outputs of a zero forcing linear equalizer. The second method is blind to CSI. When 2 packets are decoded with errors, retransmission follows a space time block code (STBC) structure, allowing a seamless switching between SM and STBC.

I. INTRODUCTION

A large number of techniques exists to perform Automatic Repeat Request (ARQ) in single input single output (SISO) systems. Nevertheless, the retransmission strategies in SISO systems are rather limited by the fact that there is a single spatial channel over which all the packets are transmitted. On the other hand, in Multiple Input Multiple Output (MIMO) systems, the data can be transmitted over multiple spatial channels simultaneously through Spatial Multiplexing (SM). The plurality of spatial channels increases the degrees of freedom that are available to retransmit the packets that have been received erroneously.

In this paper we introduce techniques to optimize the ARQ process for 2×2 MIMO systems when the data is transmitted through spatial multiplexing. The proposed retransmission strategies exploit the availability of spatial channels with different quality, induced by the presence of multiple antennas. We also propose another retransmission scheme which is oblivious with respect to the variable quality of the spatial channels and, consequently, has a lower computational complexity.

In [1], the authors show the advantage of independent coding with independent ARQ process per stream: this structure can bring a significant improvement compared with joint coding among streams and a unique ARQ process. In [1], however, packets get retransmitted from the same antenna. So, the link conditions are not taken into account to improve the performance of the ARQ process. Furthermore, this scheme does not benefit from the diversity improvement brought by switching the antenna assignment for retransmission.

In [2], antenna assignment is permuted circularly each time a packet is retransmitted. Like one of the schemes proposed in this paper, this ARQ method does not rely on channel conditions to select the retransmitting antenna. However, this method performs worse than the method proposed in this

paper. Indeed, when 2 packets are decoded with errors, we switch the antenna assignment but we also minimize inter-stream interference by complex conjugation or change of sign operation of the packets. The resulting diversity of our scheme is higher.

Other papers (see [3] for references) present the design of Space Time Block Codes (STBC) adapted to ARQ. Such schemes rely on joint coding of the streams and all the packets involved in the space time code are retransmitted even if some of them are detected without errors.

In the schemes developed in this paper, the spatially multiplexed streams are coded independently. Each transmit antenna sends a different packet. For each packet, the receiver can determine (a) whether the packet is correctly received and (b) from which transmit antenna the packet has been sent. Only packets detected with errors are retransmitted. Soft versions of the erroneously received packets are kept in the receiver's memory in order to be combined with the retransmitted packets and thus increase the probability of correct detection.

In the case when the transmitter considers the quality of the spatial channels, we assume that the Channel State Information (CSI) is available at the transmitter. Upon a notification for erroneously received packet, the transmitter should optimize the selection of the antenna through which the packet is retransmitted. If there is only one packet that needs to be retransmitted, then the other antenna is used to transmit a new packet, thus making efficient use of the available spatial dimension. The best antennas for retransmission are selected to minimize SNR averaged over the outputs of a zero forcing or Minimum Mean Squared Error (MMSE) linear equalizer.

This optimization results in the following. When only 1 packet is decoded incorrectly, then retransmission should be done from the weakest antenna. This can be intuitively understood as retransmission from the strongest antenna might represent an additional amount of information that is too large to decode the packet correctly, thus making inefficient use of the resources. When 2 packets are decoded incorrectly, then, in most cases, retransmission follows the structure of an STBC codeword: the antenna assignment is switched, the packets are complex conjugated and one of them gets its sign changed. This retransmission scheme minimizes inter-stream interference. Furthermore, diversity gets increased which is inherent to STBC transmission.

The second proposed method does not rely on CSI and is therefore applied when the CSI is not reliable or not available. This method follows the structure of an STBC codeword.

When 2 packets are decoded, the retransmission scheme is as described in the previous paragraph. When 1 packet is decoded incorrectly, then antenna assignment is switched. This scheme minimizes inter-stream interference and benefit from increased diversity.

Finally, there has been a considerable research effort [4] to find optimal criteria for multiplexing/diversity switching i. e. criteria to decide when the multi-antenna transmitter should use spatial multiplexing and when space-time block coding. An important dividend from our proposed schemes is that, when both packets need to be retransmitted, the spatial multiplexing is naturally resulting in space-time diversity transmission. Thus, by using a cross-layer design of the ARQ protocol and the MIMO transmission, we achieve a fine tuned seamless switching between spatial multiplexing and space time block coding.

II. SYSTEM DESCRIPTION

A. MIMO System

We consider a general MIMO system with 2 transmit and receive antennas, as depicted in Figure 1.

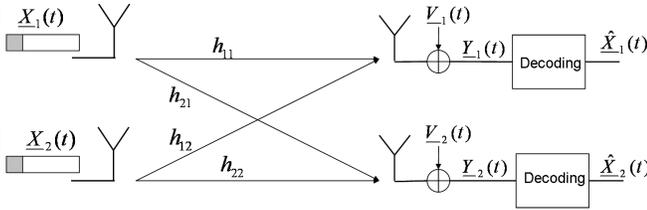


Fig. 1. 2×2 MIMO System

We define the following notations, where a vector \underline{V} indicates a row vector.

- $(\cdot)^*$, $(\cdot)^T$ and $(\cdot)^H$ denote respectively the conjugate, the transpose and the conjugate transpose operations.
- t is the packet index.
- We assume flat fading channels that are constant over a time of 2 packet durations. $H(t)$ is the 2×2 MIMO channel matrix at time t . $H(t) = [H_{A_1}(t) \ H_{A_2}(t)]$ where $H_{A_i}(t) = [h_{A_1, A_i}(t) \ \dots \ h_{A_2, A_i}(t)]^T$ is the channel from transmit antenna A_i to the receive antennas. $h_{A_j, A_i}(t)$ is the channel coefficient from transmit antenna A_i to receive antenna A_j . Channel estimation at the receiver is assumed perfect. We use indexes A_i to differentiate from the index of the packets (see below).
- The transmit power P_T is the same at each antenna.
- $\underline{X}_i(t)$, $i = 1, 2$ are the packets sent at time t . Note that $\underline{X}_i(t)$ is not necessarily sent from antenna A_i . $\hat{\underline{X}}_i(t)$ is the respective decoded packet at time t .
- $\underline{Y}_{A_j}(t)$ and $\underline{N}_{A_j}(t)$ denote respectively the received packet and the additive noise at receive antenna A_j at time t . The noise is assumed complex Gaussian, centered with same variance σ_N^2 at each antenna.
- For clarity of presentation, we assume here that $\underline{X}_i(t)$ is transmitted from antenna A_i , then the input-output

relationship of the MIMO system is:

$$\underline{Y}(t) = H(t)\underline{X}(t) + \underline{N}(t), \text{ where:} \quad (1)$$

$$\underline{X}(t) = \begin{bmatrix} \underline{X}_1(t) \\ \underline{X}_2(t) \end{bmatrix}, \underline{Y}(t) = \begin{bmatrix} \underline{Y}_{A_1}(t) \\ \underline{Y}_{A_2}(t) \end{bmatrix}, \underline{N}(t) = \begin{bmatrix} \underline{N}_{A_1}(t) \\ \underline{N}_{A_2}(t) \end{bmatrix}.$$

B. Retransmission Model

The packets are assumed to be independently coded and decoded across antennas. At each packet, a CRC is appended, so that the receiver can detect if a packet is received erroneously. A simple selective repeat ARQ protocol is used: the retransmitted packet has the same data content, but it can have a modified transmission format. The receiver sends an acknowledgment (Ack) or a non-acknowledgment (Nack), along with the corresponding packet identifier. We assume that the feedback messages are received with no errors at the transmitter. For the proposed CSI-based scheme, the transmitter is regularly updated with the channel coefficients and decides on the antennas used for retransmission; this decision could be centralized at the receiver if updated CSI is not available at the transmitter.

The receiver collects the signals containing the transmitted packets decoded with errors until time $t - 1$ from which the contribution of the correctly decoded packets has been removed. Those past signals are combined with the received signal at time t . Based on this combination, the transmitted packets at time t can be decoded correctly with higher probability.

We define $H_{[\underline{X}_i(t)]}(t')$ as the channel from the antenna transmitting $\underline{X}_i(t)$ at time t' . $H_{[\underline{X}_i(t)]}(t') = 0$ if $\underline{X}_i(t)$ is not transmitted at time t' . The combined received signal at time t is denoted $\mathcal{Y}(t) = [\bar{Y}(t-L)^T \ \dots \ \bar{Y}(t-1)^T \ Y(t)^T]^T$. $\bar{Y}(t-k)$, $k > 0$, is the received signal from which the contribution of the correctly decoded signals has been removed. L denotes the memory of the ARQ process.

$$\mathcal{Y}(t) = \mathcal{H}_1(t)\underline{X}_1(t) + \mathcal{H}_2(t)\underline{X}_2(t) + \mathcal{N}(t) \quad (2)$$

where $\mathcal{N}(t) = [\underline{N}(t-L)^T \ \dots \ \underline{N}(t)^T]^T$ groups all the noise samples and:

$$\mathcal{H}_i(t) = [H_{[\underline{X}_i(t)]}(t-L)^T \ \dots \ H_{[\underline{X}_i(t)]}(t)^T]^T. \quad (3)$$

An example of this process for a 2×2 system is as follows:

$$\mathcal{Y}(t) = \begin{bmatrix} H_{A_1}(t-1) \\ H_{A_2}(t) \end{bmatrix} \underline{X}_1(t) + \begin{bmatrix} 0 \\ H_{A_1}(t) \end{bmatrix} \underline{X}_2(t) + \mathcal{N}(t). \quad (4)$$

Here $\underline{X}_1(t)$ is newly transmitted at time $t-1$ from antenna A_1 and retransmitted at time t from antenna A_2 . $\underline{X}_2(t)$ is newly transmitted at time t from antenna A_1 .

We assume that $\underline{X}_1(t)$ is decoded with errors and $\underline{X}_2(t)$ is decoded correctly, unless stated otherwise. The contribution of error free $\hat{\underline{X}}_2(t)$ is removed from the combined received signal $\mathcal{Y}(t)$ to get:

$$\bar{\mathcal{Y}}(t) = \mathcal{Y}(t) - \mathcal{H}_2(t)\hat{\underline{X}}_2(t) = \mathcal{H}_1(t)\underline{X}_1(t) + \mathcal{N}(t). \quad (5)$$

Decoding of $\underline{X}_1(t)$ is then performed again based on $\bar{\mathcal{Y}}(t)$. The probability of error free decoding of $\underline{X}_1(t)$ is now higher.

If $\underline{X}_1(t)$ is decoded correctly, 2 new packets are transmitted at time $t + 1$, otherwise the antenna from which to retransmit $\underline{X}_1(t)$ must be properly selected.

III. CSI-BASED RETRANSMISSION SCHEME

A. Retransmission strategies

We present next the different retransmission strategies when 1 or 2 packets are decoded with errors. To simplify the presentation, we give up here the time index t for the packets. Note that in the case where 2 packets are decoded incorrectly, we restrict ourselves to 2 choices for retransmission: the reason is that those 2 schemes minimize inter-stream interference when the number of retransmission of both packets is even. A criteria based on CSI will decide of the best choice among the 2 schemes.

1) 1 packet out of 2 decoded incorrectly:

At time $t+1$, packet \underline{X}_1 is retransmitted from either antenna A_1 or antenna A_2 ; a new packet \underline{X}_{new} is transmitted. The received signal $\underline{Y}(t+1)$ is combined with $\underline{\bar{Y}}(t)$. Decoding of \underline{X}_1 and \underline{X}_{new} is performed based on the combined received signals:

$$\begin{bmatrix} \underline{\bar{Y}}(t) \\ \underline{Y}(t+1) \end{bmatrix} = \begin{bmatrix} \mathcal{H}_1(t) & 0 \\ H_{A_i}(t) & H_{A_j \neq A_i}(t) \end{bmatrix} \begin{bmatrix} \underline{X}_1 \\ \underline{X}_{new} \end{bmatrix} + \begin{bmatrix} \mathcal{N}(t) \\ \underline{N}(t+1) \end{bmatrix} \quad (6)$$

When $i = 2$, we denote the composite channel matrix in (6) as \mathcal{H}_{switch} : indeed, in this case, the antenna assignment of retransmitted packet \underline{X}_1 is switched from antenna A_1 to antenna A_2 . When $i = 1$, the matrix is denoted $\mathcal{H}_{no\ switch}$.

2) Both Packets decoded with errors:

At time t , the general form of the combined received signal is:

$$\underline{\mathcal{Y}}(t) = \begin{bmatrix} \mathcal{H}_1(t-1) & \mathcal{H}_2(t-1) \\ H_{A_1}(t) & H_{A_2}(t) \end{bmatrix} \begin{bmatrix} \underline{X}_1 \\ \underline{X}_2 \end{bmatrix} + \mathcal{N}(t) \quad (7)$$

here $\mathcal{H}_1(t) = [\mathcal{H}_1(t-1)^T \ H_{A_1}(t)^T]^T$ and $\mathcal{H}_{A_2}(t) = [\mathcal{H}_2(t-1)^T \ H_{A_2}(t)^T]^T$. We consider 2 choices for retransmission.

a) *Switching*: $\underline{X}_1^*(t)$ is retransmitted from antenna A_2 and $-\underline{X}_2^*(t)$ from antenna A_1 , as:

$$\begin{bmatrix} \underline{\mathcal{Y}}(t) \\ \underline{Y}(t+1) \end{bmatrix} = \begin{bmatrix} \mathcal{H}_1(t-1) & \mathcal{H}_2(t-1) \\ H_{A_1}(t) & H_{A_2}(t) \\ -H_{A_2}^*(t+1) & H_{A_1}^*(t+1) \end{bmatrix} \begin{bmatrix} \underline{X}_1 \\ \underline{X}_2 \end{bmatrix} + \mathcal{N}(t). \quad (8)$$

When the ARQ memory is 1 ($\mathcal{H}_1(t-1) = \mathcal{H}_2(t-1) = 0$), the 2 transmissions at t and $t+1$ form a 2x2 Alamouti STBC.

b) *No Switching*: $-\underline{X}_1(t)$ is retransmitted from antenna A_1 and $\underline{X}_2(t)$ from antenna A_2 , as:

$$\begin{bmatrix} \underline{\mathcal{Y}}(t) \\ \underline{Y}(t+1) \end{bmatrix} = \begin{bmatrix} \mathcal{H}_1(t-1) & \mathcal{H}_2(t-1) \\ H_{A_1}(t) & H_{A_2}(t) \\ -H_{A_1}(t+1) & H_{A_2}(t+1) \end{bmatrix} \begin{bmatrix} \underline{X}_1 \\ \underline{X}_2 \end{bmatrix} + \mathcal{N}(t). \quad (9)$$

When both packets are decoded with errors, we will denote as \mathcal{H}_{switch} and $\mathcal{H}_{no\ switch}$ the equivalent channel in (8) and (9) respectively.

For both strategies, if the number of retransmissions of the same 2 packets is even, then the columns of \mathcal{H}_{switch} and $\mathcal{H}_{no\ switch}$ are orthogonal (we recall that the channel is assumed constant over 2 packet durations). In addition to having computational complexity advantages, it also removes the inter stream interference.

B. Retransmission Criteria

At time t , the transmitter selects the retransmitting antennas based on the ARQ matrix \mathcal{H} , where \mathcal{H} is either $\mathcal{H}_{switch}(t+1)$ or $\mathcal{H}_{no\ switch}(t+1)$. The transmitter buffers the values of the channel coefficients up to time t . However, it does not have access to the channel coefficients at time $t+1$: as the channel is assumed constant over the duration of 2 packets, the channel estimate at time t will be considered as valid at time $t+1$.

The choice of retransmission between \mathcal{H}_{switch} and $\mathcal{H}_{no\ switch}$ leaves the receive energy unchanged, which means that trace $\mathcal{R}(\mathcal{H})$ is a constant c , where :

$$\mathcal{R}(\mathcal{H}) = \mathcal{H}^H \mathcal{H} = c. \quad (10)$$

This will be the constraint for the proposed optimization design.

Next, we present several equivalent criteria used to select the retransmission antennas.

1) Equalization of MSE for ZF (or MMSE) receiver:

The MSE of the estimation error for packet \underline{X}_i is:

$$E(\hat{\underline{X}}_i - \underline{X}_i)(\hat{\underline{X}}_i - \underline{X}_i)^H = \left[\mathcal{R}(\mathcal{H})^{-1} \right]_{ii} I \quad (11)$$

where $[M]_{ii}$ denotes the element (i, i) of matrix M and I is the identity matrix with appropriate dimension. The MSE averaged over the 2 outputs of the ZF equalizer, $\overline{MSE}(\mathcal{H})$ is:

$$\overline{MSE}(\mathcal{H}) = \frac{1}{2} \frac{\text{trace } \mathcal{R}(\mathcal{H})}{\det \mathcal{R}(\mathcal{H})}. \quad (12)$$

Then, minimization of \overline{MSE} is equivalent to:

$$\max_{\substack{\mathcal{H} \in \{\mathcal{H}_{switch}, \mathcal{H}_{no\ switch}\} \\ \text{s.t. trace } \mathcal{R}(\mathcal{H}) = c}} \det \mathcal{R}(\mathcal{H}) \quad (13)$$

This result holds also for a linear MMSE receiver.

It can be easily proven that this criterion is also equivalent to equalizing the MSE of both outputs of a ZF equalizer.

2) Equalization of SNR for ZF (or MMSE) receiver:

We can prove that (13) is also equivalent to equalizing the SNRs of both streams or maximizing the average SNR over both outputs of a ZF equalizer.

3) Equalization of Packet weights:

- We define the weight of antenna A_i :

$$W(A_i(t)) = \|H_i(t)\|^2 \quad (14)$$

- We define the weight of transmitted packet $\underline{X}_i(t)$ at time t :

$$W(\underline{X}_i(t)) = \sum_{k=0}^{L-1} W(A_{[\underline{X}_i(t)]}(t-k)) \quad (15)$$

where $A_{[\underline{X}_i(t)]}(t-k)$ is the antenna transmitting $\underline{X}_i(t)$ at time $t-k$.

The weight can be seen as a measure of the information available to decode the packet. The more a packet has been transmitted or the strongest the antenna from which it is retransmitted, the larger his weight will get.

Criterion (13) is equivalent to choosing the retransmission which equalizes the most the weights of the packets. We will see that this notion of packet weight will be useful when 2 packets are decoded incorrectly.

C. Optimization Results

1) 1 packet out of 2 decoded with errors:

Some computations lead to:

$$\begin{aligned} \overline{MSE}(\mathcal{H}_{no\ switch}) &\leq \overline{MSE}(\mathcal{H}_{switch}) \Leftrightarrow \\ \|H_{A_1}(t+1)\|^2 &\leq \|H_{A_2}(t+1)\|^2. \end{aligned} \quad (16)$$

This means that the erroneous packet should be retransmitted from the weakest antenna. When both streams have the same strength, then the retransmitted packet can be assigned to any antenna. However, in the latter case, it is preferable to switch antenna assignment to increase the diversity order. Intuitively, if retransmission is done from the strongest antenna, then the information exploited for retransmission might be unnecessarily large, so resources are lost for the new retransmission.

2) Both packets decoded with errors:

It can be proven that:

$$\overline{MSE}(\mathcal{H}_{no\ switch}) \leq \overline{MSE}(\mathcal{H}_{switch}) \Leftrightarrow$$

$$(\|\mathcal{H}_1(t)\|^2 - \|\mathcal{H}_2(t)\|^2) (\|H_{A_2}(t+1)\|^2 - \|H_{A_1}(t+1)\|^2) \geq 0. \quad (17)$$

Assume $\|H_{A_1}(t+1)\|^2 \leq \|H_{A_2}(t+1)\|^2$. If $\|\mathcal{H}_1(t)\|^2 \geq \|\mathcal{H}_2(t)\|^2$, there is no switching, otherwise there is switching. For $\|\mathcal{H}_1(t)\|^2 = \|\mathcal{H}_2(t)\|^2$ or $\|H_{A_1}(t+1)\|^2 = \|H_{A_2}(t+1)\|^2$, then both switching or no switching strategy can be adopted.

These results tell that the packet with the higher weight should be assigned to the antenna with the weaker strength. Thus, the weights of the 2 packets at time $t+1$ gets equalized. In the case of 2 packets in error, this gives an easy way to select between the 2 choices for retransmission.

IV. CSI-BLIND RETRANSMISSION SCHEME

In this section, we present a scheme where no CSI is available to predict the best retransmission configuration. This scheme can also be applied when the antennas have the same strength.

Furthermore, this type of retransmission is more simple than the previously described one and does not require use of CSI and computation of the packet weights. It can also be applied to the general case where the antennas have different strength. In the simulation section, we will see that this scheme performs well compared with the CSI-based scheme.

Retransmission will follow the structure of a 2×2 space time block code. For a 2×2 , the Alamouti transmits the following codeword:

$$C = \begin{bmatrix} \underline{X}_1 & -\underline{X}_2^* \\ \underline{X}_2 & \underline{X}_1^* \end{bmatrix} \quad (18)$$

Let us assume that packets $\underline{X}_1, \underline{X}_2$ are transmitted at time t : this corresponds to the first column of the code below.

- 1 packet in error: suppose that \underline{X}_1 is decoded with errors, then \underline{X}_2 is retransmitted from antenna 1.
- 2 packets in error: $-\underline{X}_2^*$ is retransmitted from antenna 1 and \underline{X}_1^* is transmitted from antenna 2.

This scheme inherits the good properties of STBC. It minimizes the inter-stream interference: if the number of retransmission of 2 same packets is even, then the inter-stream interference is completely eliminated. The scheme also inherits from the diversity advantages of STBC. The 2×2 spatial multiplexing scheme has diversity order 1; the 2×2 Alamouti scheme has diversity order 2. Our scheme will have a diversity order between 1 and 2. Schemes that do not minimize the inter-stream interference will have a diversity order smaller than our scheme.

V. SIMULATION RESULTS

The coefficients of the MIMO channel are assumed independent and identically distributed, with a Gaussian distribution: $h_{A_i, A_i} \sim \mathcal{CN}(0, 1)$. The length of the packets is 1000 bits. A new independent channel is considered every 4000 packets. Over this 4000 packets, the channel can be time-invariant or time-variant: in the latter case, the channel will vary from block to block according to Jakes model. The constellation is QPSK and is the same for all the streams. No coding is done. The receiver is a ZF equalizer; the contribution of correctly decoded packets is removed as explained above.

We plot the throughput defined as $b \frac{N_{correct}}{N_{total}} N_{streams}$: $b = 2$ is the number of bits of the constellation, $N_{correct}$ is the number of packets decoded correctly, N_{total} is the total number of packets transmitted. We compare the following schemes:

- (1) CSI-based scheme
- (2) CSI-blind scheme.
- (3) The erroneous packets are retransmitted from the same antenna.

For schemes (3), the packets are retransmitted unmodified (no conjugation or sign change). Performance are shown in figure 2 and figure 3. In figure 2 the channel is assumed time invariant. We observe that the CSI-based scheme performs the best; however, the performance of the CSI-blind scheme come close to the CSI based scheme.

Figure 3, the channel is highly time variant: the correlation of the channel from 1 block to the following is $\rho = 0.5$. We observe that the performance of all the schemes become

equivalent. The CSI-based scheme appears to perform slightly better than the other ones.

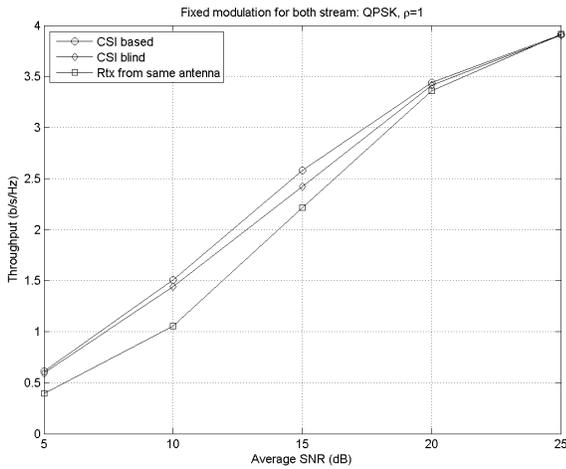


Fig. 2. Throughput curves for 2×2 random channels: time invariant case

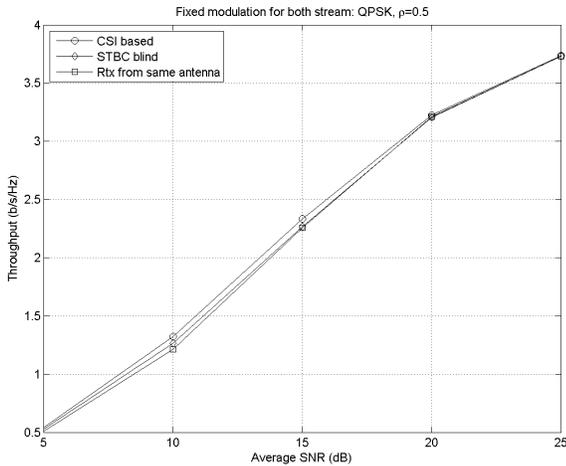


Fig. 3. Throughput curves for 2×2 random channels: time variant case

VI. DISCUSSION

The CSI-free ARQ scheme can be generalized to a MIMO system with more than 2 transmit and receive antennas: the retransmission will then follow the structure of an adapted STBC codeword. For the CSI-based schemes, the criterion which consists in minimizing the average MSE at the output of the ZF equalizer is still valid. In the 2×2 case, this criterion leads to simple results as the choice of the retransmission antenna is based on the antenna strength and packet weights. For a MIMO system with more than 2 transmit antennas, the different retransmission configurations can be tested and the one minimizing the criterion can be chosen: it is however computationally expensive as all the permutations, sign change, conjugation need to be incorporated. Simple retransmission schemes have to be found for a MIMO system with more than 2 transmit antennas.

Furthermore, this work assumes identical modulation and coding for the packets sent from both antennas. Many papers have shown that it is advantageous to adapt the modulation and coding independently for both antennas based on CSI. When the available CSI is not outdated, then the packet error probability will be low at the receiver and few retransmissions will be necessary. In this case, the selection of the retransmission antenna will not have a big influence.

Let us consider the example of a communication link between a base station and a mobile station, where the BS gets regular CSI updates from the MS. The CSI gets outdated because of the delay between CSI estimation and reception of the packet which modulation and coding level has been decided on the estimated CSI. This delay can be due to several reasons:

- The delay is due to the duplexing mode: this is the delay between 2 DL transmissions in TDD mode.
- Reduction of the frequency of CSI feedback might be essential. .
- The delay is due to the scheduling: a MS might not be scheduled on every frame because his channel is temporarily bad or because it is no data to be sent to the BS. In this case the CSI for this user available at the BS could be totally outdated. If the BS uses this CSI, decoding errors at the MS will occur.

Proper ARQ schemes have to be found in all these cases.

VII. CONCLUSION

We have proposed ARQ schemes for a 2×2 MIMO system that are adapted or blind to the link conditions. When retransmission relies on CSI and 1 packet out of 2 is decoded with errors, then it should be retransmitted from the weaker antenna. When 2 packets are decoded with errors, most of the time, they are retransmitted following an STBC structure. When the CSI is not available, then retransmission follow the STBC structure all the time. The performance of the CSI-blind scheme is close to the performance of the CSI-based scheme. The proposed schemes consider the same modulation and coding for both streams: proper ARQ schemes have to be studied when adapted modulation and coding based on CSI is applied. Furthermore, another natural extension of this work is consideration of MIMO systems with more than two antennas.

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