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Adaptive Modulation and Coding With Incremental Redundancy Hybrid ARQ in MIMO Systems: A Cross Layered Design.

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ABSTRACT

The present generation wireless systems has significant growth in the demand for reliable high-speed wireless communication links for multimedia applications like voice, video, e-mail, web browsing, etc. Attaining highly reliable links is a challenging task in wireless environment. MIMO exploits space dimension to improve the system capacity, range, and reliability. In this paper a cross layered approach with Adaptive Modulation and Coding (AMC) in the physical layer and Incremental Redundancy Hybrid Automatic Retransmission Request (IR-HARQ) in the data link layer is proposed for the fourth generation MIMO systems. The proposed model improves the transmission rate and also reliability of the MIMO system.

***Keywords* -** Adaptive Modulation and Coding (AMC), Incremental Redundancy Hybrid Automatic Repeat Request (IR-HARQ), Multiple Input Multiple Output (MIMO).

I. INTRODUCTION

For the present wireless communication systems, a novel direction proposed to resolve the capacity requirements in the challenging radio environment is the exploitation of MIMO systems. MIMO systems found the way into several standards for future wireless communication systems, especially in Wireless Local Area Networks (WLAN) and cellular networks such as IEEE 802.11, 802.16 and the 3rdGroup Partnership Project (3GPP) [1]. Diversity gain is achieved by Space-Time Coding (STC) at the transmit side, which requires only simple linear processing in the receiver side for decoding. Cross layer architecture is a design mechanism that brings together the layers in order to enhance the system spectral efficiency and throughput while still maintaining delay and performance constraints. Adaptive Modulation and Coding (AMC) is used in the physical layer to improve the system throughput by adapting the transmission rate to the time varying channel condition at the transmitter. However to achieve maximum reliability, it is required to restrict the transmission rates using small constellations. To mitigate this problem, Automatic Retransmission Request (ARQ) is used in conjunction with AMC [2][3]. To meet the delay requirements truncated ARQ is used where the number of retransmissions is limited [4].

A cross-layer design framework with AMC and HARQ is proposed in [5]. A new puncturing pattern for Rate-Compatible Low Density Parity Check codes (RC-LDPC) is used. The system proves to have improved spectral efficiency. To enhance system performance, cross layered design is proposed in [6] for QoS guaranteed traffic. The queuing behavior induced by both the truncated ARQ protocol and the AMC scheme is analyzed with an embedded Markov chain. The overall system throughput is maximized under the specified QoS constraints. However, their design indeed cannot guarantee the same BER performance at different transmission phases of the ARQ protocol. Hence cross layered design with AMC and IR-HARQ is proposed where in different transmissions, different code words are transmitted thus improving the reliability of the system. In section-2, the MIMO system model is presented. Section-3 gives the system modeling using IR-HARQ. Effective SNR and channel estimation is given in section-4.The obtained simulation results are shown in section 5. Finally, conclusion and future scope is given in section 6.

II. SYSTEM MODEL

The proposed model consists of MIMO system with T_N number of transmitting antennas and R_N number of receiving antennas as shown in Fig.1. Convolution Turbo coding (CTC) scheme is used to achieve diversity in the proposed system. Finite state machine is implemented to encode CTC long sequences of message bits using shift registers. The complexity of the code is determined by the memory of the encoder defined by the number of shift registers. If for each set of *k* information bits given to the encoder, n output bits are produced, then the code rate is *k/n.* Viterbi algorithm is used for the optimal decoding of a convolutionally coded sequence in AWGN modeled channel.

The diversity order for this system is given as:

$$D \overset{\triangle}{=} T_N R_N \tag{1}$$

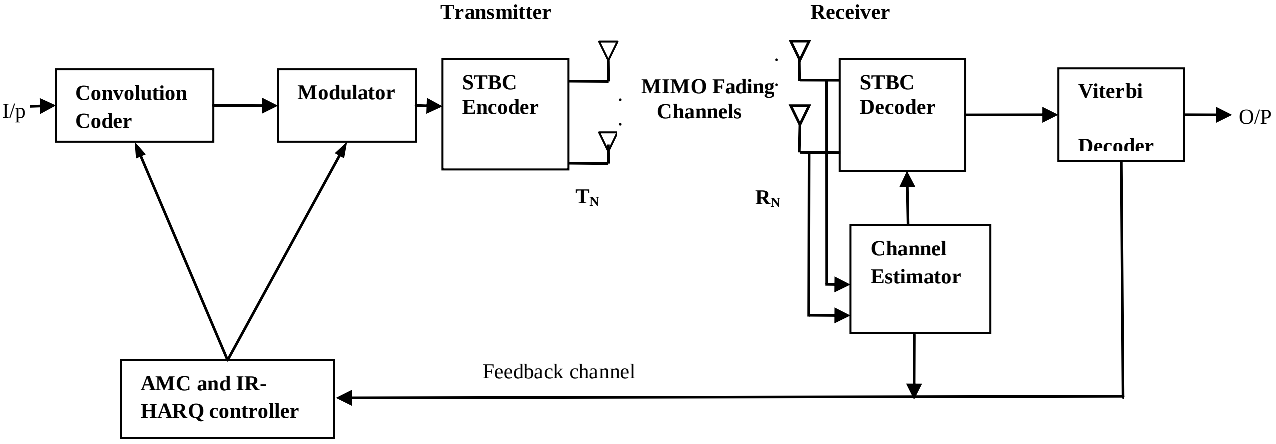

Fig.1. Block Diagram of the Proposed System

The cross layer approach connects physical layer and data link layer to enhance the performance of MIMO network. Through MIMO fading channels, the coded symbols are forwarded in the physical layer on a frame by frame fashion subsequently using Space Time Block Coding (STBC). Various modulation and coding schemes (MCS) are used in the physical layer. The receiver computes the Signal to Noise Ratio (SNR) and sends back to the AMC controller. If Y is the received symbols matrix of order $R_N \times nS$ and X is the transmitted symbols matrix of order $T_N \times nS$ and N is the noise matrix of order $R_N \times nS$, the matrix elements are designed as i.i.d. complex circular Gaussian random variables having zero mean and unit variance. *nS* stands for number of symbols per antenna. The controller selects a suitable MCS for the next transmission. If ds is the data sequence, it is encoded into z_i codewords where i= 0,1,…..z-1.Therefore more than one code words z_i may contain the part of information in ds. The technique makes use of Convolution Turbo Code (CTC) for encoding *ds* through a rate-1/3 mother code, which is punctured to generate the z_i. Diverse z_i may enclose common systematic or parity bits of the mother code. The length of codewords (Le_i) may not be equal [7]. For the codeword z_i forwarded at every transmission, the received signal is specified as,

$$Y_{i,j} = h_{i,j} x_{i,j} + N_{i,j} \tag{2}$$

Here, block flat fading is considered in which channel remains constant during the transmission of one symbol. If the channel is known only at the receiver, the receiver tries to decode the received data. If no error detected or the decoder corrects the errors then the successful reception is indicated to the transmitter. Then, the system progresses on transmitting a new data sequence ds. Upon a failure, a retransmission is invoked. Previously transmitted data are tracked at the receiver in order to associate the decoding, since the channel is known only at the receiver.

III. IR-HARQ

In the time varying wireless channel redundancy of the system may be more than the optimum value though the channel condition is good for non AMC system. On the other hand, if the channel is poor, more errors are expected to occur than those which can be handled by the capability of the error-correcting code. Consequently, too many retransmissions are requested, and the throughput falls down. Thus, in order to achieve optimum performance, the rate of the error-correcting code should be matched to the prevailing channel conditions [8][9]. Hence IR-HARQ is proposed in the data link layer to reduce the number of retransmissions and to meet the delay constraints for 4G systems. At each retransmission, different code words z_i are forwarded in IR-HARQ. The modeling of IR-HARQ is shown in figure-2.A Maximal Ratio symbol Combining (MRC) approach is used at the receiver. An optimal decision rule is used where the received signals are linearly combined through different diversity branches after co-phasing and weighting them with their respective channel.

The obtained symbols are then given to a Maximum-Likelihood (ML) receiver [10].

With MRC, the received symbols are collaborated as,

$$\tilde{Y}_0 = \sum_{i=0}^{n-1} h_i^* Y_i = \tilde{h}_0 x_0 + \sum_{i=0}^{n-1} h_i^* n_i = \tilde{h}_0 x_0 + \tilde{z}_0 \tag{3}$$

Where, $\tilde{h}_0 = \sum_{i=0}^{n-1} h_i^* h_i$ and n stands for the number of transmissions. To measure the Log-Likelihood Ratios (LLRs), the ML receiver uses $Y_0' = \frac{1}{\sqrt{\tilde{h}}} \tilde{Y}_0$ and $\sqrt{\tilde{h}}$, which will be transmitted to the decoder so as to estimate the information sequence *ds*.

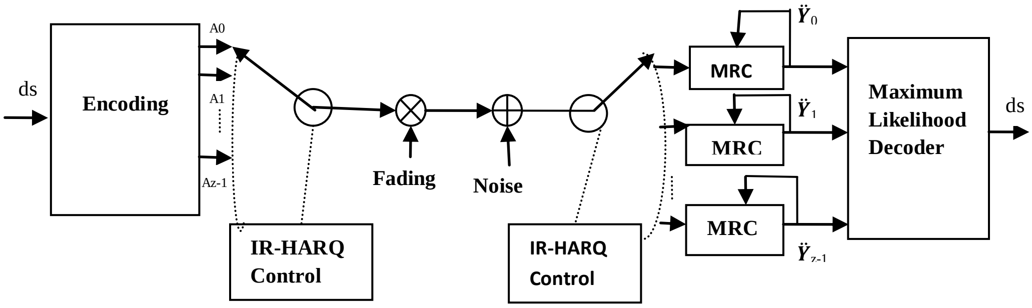

Fig.2.System Model for IR-HARQ

If n transmissions are processed then each codeword will be forwarded n_i times, where, i = 0,1,…,z-1, with $\sum_{i=0}^{Z-1} n_i = n$. The measurement of the LLRs and the decoding uses the sequences Y_i' that results from n_i combining operations. If A is the set of symbols containing bit β ,it can be represented as

$$A = \{a_0, a_1, \ldots, a_{n(\beta)-1}\} \tag{4}$$

Its corresponding MRC-combined symbols are given as $\left\{\tilde{Y}_0, \tilde{Y}_1, \tilde{Y}_{n(b)-1}\right\}$ (5)

IR-HARQ makes use of bit level combining. The operation of IR-HARQ is mathematically expressed as follows

$$LLC_{BLC}(\beta) = \sum_{i=0}^{n(\beta)-1} LLR_i \tag{6}$$

$$= \sum_{i=0}^{n(\beta)-1} L\left(b_\beta \mid Y_i', \sqrt{\tilde{h}_i} \right) \tag{7}$$

$$= \sum_{i=0}^{n(\beta)-1} In \frac{\Pr\left\{ b_\beta = 1 \mid Y_i', \sqrt{\tilde{h}_i} \right\}}{\Pr\left\{ b_\beta = 0 \mid Y_i', \sqrt{\tilde{h}_i} \right\}} \tag{8}$$

$$= \sum_{i=0}^{n(\beta)-1} In \frac{\sum_{x_i^{(1)} \in \delta_\beta^{(1)}} \Pr\left\{ Y_i' \mid x_i^{(1)}, \sqrt{\tilde{h}_i} \right\}}{\sum_{x_i^{(0)} \in \delta_\beta^{(0)}} \Pr\left\{ Y_i' \mid x_i^{(0)}, \sqrt{\tilde{h}_i} \right\}} \tag{9}$$

$$= \sum_{i=0}^{n(\beta)-1} In \frac{\sum_{x_i^{(1)} \in \delta_\beta^{(1)}} \exp\left\{ - \| Y_i' - \sqrt{\tilde{h}_i}\, x_i^{(1)} \|^2 \right\}}{\sum_{x_i^{(0)} \in \delta_\beta^{(0)}} \exp\left\{ - \| Y_i' - \sqrt{\tilde{h}_i}\, x_i^{(0)} \|^2 \right\}} \tag{10}$$

sequences that could In equations 9 and 10, $\delta_\beta^{(1)}$ ($\delta_\beta^{(0)}$) are the sets of all possible symbol be forwarded on the channel when the value of β is equal to 1 (0).

IV. SNR EVALUATION

At the transmitter, the complex modulated symbols (R) are mapped by STBC encoder into T_N orthogonal complex symbol sequences of length *nS*. These mapped symbol sequences are forwarded concurrently by T_N. As a result, the coding rate (C_R) of a STBC is given as

$$C_R = \frac{R}{nS} \tag{11}$$

Let *AvgP* be considered as the average transmits power for every stream or antenna. Before the computation of maximum likelihood (ML), the received symbol *Y* can be described as per the effective SISO channel model for STBC as

$$Y = \|\mathbf{H}\|_F^2 \, s + N \tag{12}$$

Where, the real and imaginary part of the transmitted complex symbol is represented as *s*, $\|\cdot\|_F^2$ is the squared matrix of Frobenius norm and the channel coefficient $\|\mathrm{H}\|_F^2$ is given as,

$$\|\mathbf{H}\|_F^2 = \sum_{i,j} h_{ij}^2 \tag{13}$$

The SNR at the receiver can be calculated as follows

$$\gamma = \frac{AvgP}{\sigma^2}\|\mathrm{H}\|_F^2 = \frac{tP}{\sigma^2 T_N C_R}\|\mathrm{H}\|_F^2 = \frac{\bar{\gamma}}{T_N C_R}\|\mathrm{H}\|_F^2 \tag{14}$$

Here, *tP* is the total transmission power transmitted at antennas of T_N or every symbol duration. The average pseudo SNR ($\bar{\gamma}$) is given as,

$$\bar{\gamma} = \frac{tP}{\sigma^2} \tag{15}$$

The probability density function (PDF) of γ can be described with the consideration that $\|\mathrm{H}\|_F^2$ is the sum of 2D i.i.d χ^2 random variables. Thus, γ is described as,

$$P_\gamma(\gamma) = \frac{\gamma^{D-1}}{\Gamma(D)} \left(\frac{T_N C_R}{\bar{\gamma}} \right)^D \exp\left(- \frac{T_N C_R}{\bar{\gamma}} \gamma \right), \gamma \geq 0 \tag{16}$$

Here, $\Gamma(\cdot)$ symbolizes the Gamma function. Assuming that the computation of the minimum mean square error (MMSE) in the channel is carried out by the receiver, the channel coefficient is described as

$$\mathbf{H} = \hat{\mathbf{H}} + E_{er} \qquad (17)$$

In equation (17), $\hat{\mathbf{H}}$ denotes approximation of channel matrix and E_{er} is the approximation error.The proposed technique presumes that $\hat{\mathbf{H}}$ and E_{er} are uncorrelated. Elements in E_{er} are i.i.d, which are the zero mean circulatory symmetric complex Gaussian distributed random variables with variance of σ_{er}^2 .The value of variance is given as,

$$\sigma_{er}^2 = E_{er}\left(h_{ij}^2\right) - E_{er}\left(\hat{h}_{ij}^2\right) \qquad (18)$$

The relationship between assessed SNR $\hat{\gamma}$ and instantaneous SNR γ is defined as

$$\hat{\gamma} = \frac{1-\sigma_{er}^2}{1+\sigma_{er}^2 tP}\gamma \qquad (19)$$

Accordingly the PDF of assessed SNR $\hat{\gamma}$ is given as,

$$P_{\hat{\gamma}}(\hat{\gamma}) = \frac{\lambda^D}{\Gamma(D)}\hat{\gamma}^{D-1} e^{-\lambda\hat{\gamma}}, \text{ where } \gamma \geq 0 \qquad (20)$$

The value of λ is,

$$\lambda = \frac{T_N C_R\left(1+\sigma_{er}^2 tP\right)}{\left(1-\sigma_{er}^2\right)\gamma} \qquad (21)$$

The correlation involves among h_{ij} and assessed $\hat{h}_{ij}$ is expressed as:

$$cl = \frac{E_{er}\left(h_{ij}\,\hat{h}_{ij}\right)}{\sqrt{E_{er}\left(h_{ij}^2\right)E_{er}\left(\hat{h}_{ij}^2\right)}} = \frac{1}{\sqrt{1+\sigma_{er}^2}}$$

Equations given in (19) to (22) represents the quality of channel estimation. If σ_{er}^2 =0, then $\hat{\gamma} = \gamma$ and cl=1.

V. PERFORMANCE EVALUATION

The performance of the system is evaluated in terms of average throughput and bit error rate. The various parameters used in the simulation are tabulated in Table I.

MCS is based on the SNR values. It is assumed that the channel state is known at the receiver. The SNR is feedback to the MCS controller to select an optimal Modulation and Code rate.SNR mapping Modulation and Coding Scheme (MCS) is shown in Table II.

The simulation results for the proposed system in terms of average transmission rate and bit error rate are shown in figure 3 and 4 resp. The proposed IR-HARQ with AMC is compared with the performance of the system using ARQ AMC. It is evident that that by changing the MCS during retransmissions, the throughput of the system is significantly improved as shown in Fig.3

Table I.
Simulation Parameters

Parameters	**values**
Transmitters (Nt)	2
Receivers (Nr)	2
Modulation	2,4,16,64
Rate	1/2,1/3,2/3
Number of packets	100
Coding technique	convolutional

Table II:
MCS SNR Mapping

SNR (γ)dB	**MCS Scheme**
-5< γ < 5	M=2, R=1/2
5≤ γ <10	M=4, R=1/2.
10≤ γ <15	M=16, R=1/3.
15≤ γ <21	M=64, R=2/3

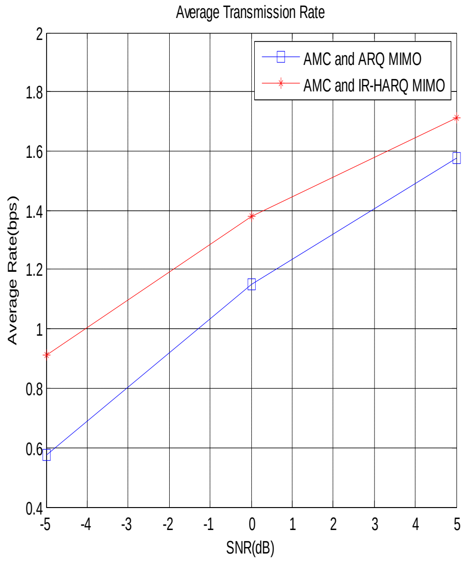

Fig.3. Average Transmission Rate (AMC-ARQ Vs AMC-IR-HARQ).

It is evident from figure-4 that bit error rate is appreciably reduced especially when the channel is good. In AMC and ARQ MIMO, BER decreases to 10^-2 at 25 db whereas for the AMC and IR-HARQ MIMO bit error rate reduces to 10^-3. However the error rate is slightly increased when the channel is very poor.

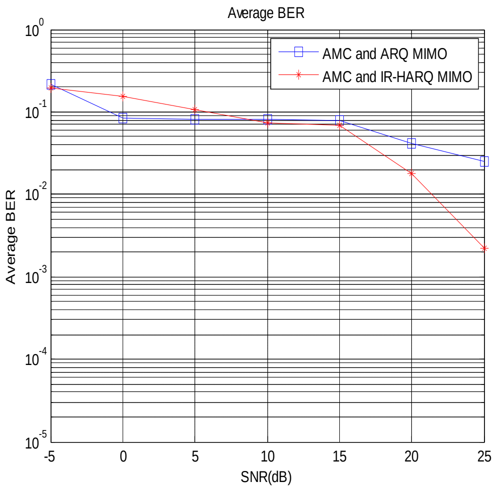

Fig.4. Average BER. (AMC-ARQ Vs AMC-IR-HARQ).

Hence for the system with AMC and IR-HARQ, the throughput is increased and the error rate is significantly reduced when the channel is adequate.

VI. CONCLUSION AND FUTURE SCOPE

MIMO using AMC controller is used in most of the fourth generation wireless communication systems. Cross layered design using AMC in the physical layer and IR-HARQ is used in the data link layer is used in the proposed system to increase the reliability of the system. The simulation result shows that the average transmission rate is improved with reduced bit error rate. The performance of the system is better than the existing system using ARQ in terms of throughput thus making the system more compactable for multimedia services.

The future scope of this work can be emphasized on improving the performance of the system at all channel conditions.

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