[0001] METHOD AND APPARATUS FOR IMPLEMENTIMG H-ARQ IN A MIMO WIRELESS COMMUNICATION SYSTEM

[0002] FIELD OF INVENTION

[0003] The present invention is related to wireless communication systems. More particularly, the present invention is related to a method and apparatus for implementing hybrid automatic repeat request (H-ARQ) in a multiple-input multiple-output (MIMO) wireless communication system.

[0004] BACKGROUND

[0005] H-ARQ is a transmission scheme that is widely used in many wireless communication systems to ensure successful data transmission. In H-ARQ, a receiver sends feedback to a transmitter, indicating successful or unsuccessful receipt of a data packet, so that the transmitter retransmits a failed data packet.

[0006] MIMO is a technique used to increase data rate and system throughput. In a MIMO system, a transmitter and a receiver use multiple antennas for transmission and reception so that multiple data streams are transmitted simultaneously via multiple antennas.

[0007] Different H-ARQ transmission schemes have been proposed for MIMO systems. In a conventional simple repetitive H-ARQ scheme for a MIMO system, symbols are simply repeated in a subsequent transmission if the initial transmission fails. Table 1 shows signal transmissions in accordance with the conventional simple repetitive H-ARQ for a 2×2 MIMO system.

	Antenna 1	Antenna 2
first transmission	x_1	x_2
second transmission	x_1	x_2

Table 1

[0008] A space time block code (STBC)-based H-ARQ scheme for a MIMO system has been proposed for evolved universal terrestrial radio access

(EUTRA). Table 2 shows signal transmissions in accordance with the STBC-based H-ARQ for a 2×2 MIMO system.

	Antenna 1	Antenna 2
first transmission	x_1	x_2
second transmission	x_2^*	$-x_1^*$

Table 2

[0009] In a 2×2 MIMO system, as an exemplary MIMO system, a received signal may be expressed as follows:

$$\begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} = \begin{pmatrix} h_{11}(t) & h_{12}(t) \\ h_{21}(t) & h_{22}(t) \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \end{pmatrix}; \qquad \text{Equation (1)}$$

where t is an index in time, y_i, i=1,2, is received signals at receive antenna i, h_{ij}, i,j=1,2, is channel coefficients between receive antenna i and transmit antenna j, x_j, j=1,2, is transmitted signals at transmit antenna j, and n_i, i=1,2, is a noise at receive antenna i. It is assumed that the channel is quasi-static so that the channel coefficients are same during retransmission of the failed packet and the time index on the channel coefficients will be dropped hereinafter.

[0010] At a high signal-to-noise ratio (SNR), the SNR for the two data streams after linear minimum mean square error (LMMSE) detection is written as follows:

$$SNR\ (x_1) = \left(d_1 - \frac{|c|^2}{d_2} \right) \frac{E_s}{N_0}; \qquad \text{Equation (2)}$$

and

$$SNR(x_2) = \left(d_2 - \frac{|c|^2}{d_1} \right) \frac{E_s}{N_0}; \qquad \text{Equation (3)}$$

where E_s is symbol energy, N_0 is noise power spectrum density, and

$$d_1 = |h_{11}|^2 + |h_{21}|^2; \qquad \text{Equation (4)}$$

$$d_2 = |h_{12}|^2 + |h_{22}|^2; \text{ and} \qquad \text{Equation (5)}$$

$$c = h_{11}^* h_{12} + h_{22} h_{21}^*. \qquad \text{Equation (6)}$$

[0011] An SNR ratio between two data streams is:

$$\frac{SNR(x_1)}{SNR(x_2)} = \frac{d_1}{d_2}. \qquad \text{Equation (7)}$$

The SNR ratio in Equation (7) or its variation is used as criteria in assigning a modulation and coding scheme (MCS) for each of the data streams.

[0012] For the conventional simple repetitive H-ARQ transmission, the received signal in the retransmission is written as follows:

$$\begin{pmatrix} y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \qquad \text{Equation (8)}$$

[0013] Combining Equation (1) and Equation (8) results in:

$$\begin{pmatrix} y_1(t) \\ y_2(t) \\ y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \\ n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \qquad \text{Equation (9)}$$

[0014] At a high SNR, the SNRs for the two data streams, after LMMSE detection, are as follows:

$$SNR(x_1) = 2\left(d_1 - \frac{|c|^2}{d_2}\right)\frac{E_s}{N_0}; \qquad \text{Equation (10)}$$

and

$$SNR(x_2) = 2\left(d_2 - \frac{|c|^2}{d_1}\right)\frac{E_s}{N_0}. \qquad \text{Equation (11)}$$

The SNRs are 3 dB higher than initial transmission. The SNR ratio between the two data streams is the same as the initial transmission.

[0015] For the STBC-based H-ARQ, the signal received for the retransmission is written as follows:

$$\begin{pmatrix} y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} x_2^* \\ -x_1^* \end{pmatrix} + \begin{pmatrix} n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \qquad \text{Equation (12)}$$

[0016] Combining Equation (12) and Equation (1) results in:

$$\begin{pmatrix} y_1(t) \\ y_2(t) \\ y_1^*(t+1) \\ y_2^*(t+1) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ -h_{12}^* & h_{11}^* \\ -h_{22}^* & h_{21}^* \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \\ n_1^*(t+1) \\ n_2^*(t+1) \end{pmatrix}. \quad \text{Equation (13)}$$

[0017] At high SNR, the SNRs after LMMSE detector for the two data streams are as follows:

$$SNR(x_1) = SNR(x_2) \approx (d_1 + d_2)\frac{E_s}{N_0}. \quad \text{Equation (14)}$$

Comparing Equations (10), (11) and (14), it can be seen that STBC-based H-ARQ increases the total SNR across the two data streams compared to the simple repetitive H-ARQ when the cross term $|c| \neq 0$, which is generally true for a random MIMO channel.

[0018] However, in many practical systems, to achieve the maximum capacity offered by the MIMO channel, a data rate assigned to each spatial data stream is controlled separately according to its own SNR. This scheme is often referred to as per-antenna rate control (PARC).. At the initial transmission, the transmitter, (e.g., a Node-B), would allocate a higher modulation and coding scheme (MCS) to the antenna with a higher SNR and allocate a lower MCS to the antenna with a lower SNR. Since the MCS is often kept the same for each antenna when retransmission occurs, it is desirable to keep the same SNR ratio between the antennas after retransmissions. However, the STBC-based H-ARQ scheme equalizes the SNR across all data streams after packet combining as shown in Equation (14). Therefore, the STBC-based H-ARQ scheme is not suitable for systems that adaptively change data rate per spatial stream, (e.g., PARC).

[0019] SUMMARY

[0020] The present invention is related to a method and apparatus for implementing H-ARQ in a MIMO wireless communication system. A transmitter transmits at least two data packets via two or more antennas. If at least one of the data packets is not successfully transmitted, the transmitter retransmits the data packets while rearranging the data packets

in an orthogonal spreading manner. Alternatively, the transmitter may retransmit only the unsuccessfully transmitted data packet along with a new data packet while replacing a successfully transmitted data packet. The unsuccessfully transmitted data packet may simply be repeated without changing its format. When only the unsuccessfully transmitted data packet is retransmitted along with the new data packet, the transmissions may be combined to recover the retransmitted data packet and the new data packet simultaneously.

[0021] BRIEF DESCRIPTION OF THE DRAWINGS

[0022] A more detailed understanding of the invention may be had from the following description of a preferred embodiment, given by way of example and to be understood in conjunction with the accompanying drawings wherein:

[0023] Figure 1 is a block diagram of a transmitter configured in accordance with the present invention; and

[0024] Figure 2 is a block diagram of a receiver configured in accordance with the present invention.

[0025] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] The present invention may be implemented in any type of wireless communication systems including, but not limited to, wideband code division multiple access (WCDMA), frequency division duplex (FDD), time division duplex (TDD), long term evolution (LTE) of the third generation (3G) system, orthogonal frequency division multiplexing (OFDM), or any other wireless communication system.

[0027] Figures 1 and 2 are block diagrams of a transmitter 100 and a receiver 200 configured in accordance with the present invention. The transmitter 100 and the receiver 200 may be a wireless transmit/receive unit (WTRU) or a base station. The terminology "WTRU" includes but is not limited to a user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital assistant

(PDA), a computer, or any other type of user device capable of operating in a wireless environment. The terminology "base station" includes but is not limited to a Node-B, a site controller, an access point (AP), or any other type of interfacing device capable of operating in a wireless environment.

[0028] The transmitter 100 includes at least two antennas 102, an H-ARQ transmitter 104 and a controller 106. The H-ARQ transmitter 104 transmits at least two data packets simultaneously via the antennas 102 by implementing an H-ARQ mechanism. The H-ARQ transmitter 104 retransmits data packets if at least one of the data packets is not successfully transmitted. The controller 106 arranges data packets for retransmission in accordance with an orthogonal spreading H-ARQ scheme, a modified repetitive H-ARQ scheme or a modified STBC-based H-ARQ scheme in accordance with the present invention, which will be explained in detail hereinafter.

[0029] The receiver 200 includes at least two antennas 202, an H-ARQ receiver 204 and a data processor 206. The receiver 200 may optionally include a data combiner 208. Data transmitted by the transmitter 100 is received by the antennas 202. The H-ARQ receiver 204 receives the data by implementing an H-ARQ mechanism. The data processor 206 recovers data packets transmitted by the transmitter 100. If the transmitter 100 retransmits an unsuccessfully transmitted data packet along with a new data packet which replaces a successfully transmitted data packet when at least one data packet is not successfully delivered to the receiver 200 at an initial transmission, the data combiner 208 may combine retransmitted data and the initially received data after subtracting the successfully received data packet from the initially received data. The data processor 206 then simultaneously processes the unsuccessfully transmitted data packet and the new data packet that are transmitted together in retransmission. The transmit and receive processing will be explained in detail hereinafter.

[0030] An orthogonal spreading-based H-ARQ scheme in accordance with the present invention is explained. Table 3 shows signal transmissions

in accordance with the orthogonal spreading-based H-ARQ scheme of the present invention for an exemplary 2×2 MIMO system. It should be noted that the 2×2 MIMO system is provided as an example, not as a limitation, and the present invention may be applied to a system employing more than two (2) antennas.

	Antenna 1	Antenna 2
first transmission	x_1	x_2
second transmission	x_1	$-x_2$

Table 3

[0031] A received signal for the retransmitted packet is written as follows:

$$\begin{pmatrix} y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ -x_2 \end{pmatrix} + \begin{pmatrix} n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \quad \text{Equation (15)}$$

[0032] Combining Equation (15) and Equation (1) results in:

$$\begin{pmatrix} y_1(t) \\ y_2(t) \\ y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{11} & -h_{12} \\ h_{21} & -h_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \\ n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \quad \text{Equation (16)}$$

[0033] An LMMSE receiver to estimate x_1 and x_2 from Equation (16) is as follows:

$$\begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \end{pmatrix} = \left(\overline{H}^H \overline{H} + \frac{N_0}{E_s} I \right)^{-1} \overline{H}^H \begin{pmatrix} y_1(t) \\ y_2(t) \\ y_1(t+1) \\ y_2(t+1) \end{pmatrix}; \quad \text{Equation (17)}$$

where

$$\overline{H} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{11} & -h_{12} \\ h_{21} & -h_{22} \end{pmatrix}.$$

[0034] At a high SNR, the post-MMSE SNR for the two data streams are as follows:

$$SNR(x_1) = 2d_1 \frac{E_s}{N_0}; \quad \text{Equation (18)}$$

and

$$SNR(x_2) = 2d_2 \frac{E_s}{N_0}. \quad \text{Equation (19)}$$

[0035] The total SNR across all data streams is increased compared to the conventional simple repetitive H-ARQ scheme. The SNR after retransmission is shown in Equations (18) and (19). The SNR ratio between the two data streams is the same as the initial transmission, which is a desired feature for PARC-enabled MIMO systems.

[0036] The orthogonal spreading-based H-ARQ scheme can be easily extended to more than two antenna systems. Assuming a symbol vector to be transmitted over N antennas is $X_0 = (x_1, x_2, \cdots x_N)$. The orthogonal spreading-based H-ARQ transmission pattern is determined by:

$$X = \sqrt{N} Diag(X_0) U_N; \quad \text{Equation (20)}$$

where U_N is an N×N unitary matrix. The n-th column of the matrix X is transmitted during the n-th transmission. Table 4 shows signal transmissions in accordance with the present invention for an exemplary 4×4 MIMO system.

	Antenna 1	Antenna 2	Antenna 3	Antenna 4
first transmission	x_1	x_2	x_3	x_4
second transmission	x_1	$-x_2$	x_3	$-x_4$
third transmission	x_1	x_2	$-x_3$	$-x_4$
fourth transmission	x_1	$-x_2$	$-x_3$	x_4

Table 4

[0037] In accordance with another embodiment of the present invention, when one of the transmitted data packets is not successfully received, only the failed data packet is retransmitted along with a new data packet. The new data packet replaces the successfully transmitted data packet. For example, in a 2×2 MIMO system, data packets x_1 and x_2 are transmitted via two antennas, and data packet x_1 is successfully received, but data packet x_2 is

not. In conventional systems, both packets x_1 and x_2 are retransmitted subsequently. In accordance with the present invention, only the failed packet x_2 is retransmitted and the successfully transmitted packet x_1 is not transmitted. Instead, a new data packet x_3 is transmitted along with the failed packet x_2.

[0038] Table 5 shows signal transmissions in accordance with the present invention and a conventional STBC-based H-ARQ scheme for an exemplary 2×2 MIMO system. In the conventional STBC-based H-ARQ, both packets x_1 and x_2 are retransmitted in different formats as shown in Table 5. In accordance with the present invention, a new data packet x_3 replaces the successfully received packet x_1 of the conventional STBC-based H-ARQ system, and the failed data packet x_2 and the new data packet x_3 are transmitted as in STBC-based H-ARQ scheme as shown in Table 5. It is assumed that no PARC type of rate adaptation is used in this case. To simplify receiver design, the format of the new packet x_3 may be identical to the data packet x_1 in the second transmission, (i.e., conjugated and inversed). Alternatively, the format for the new data packet x_3 may be different from data packet x_1.

	Antenna 1	Antenna 2
first Transmission	x_1 (success)	x_2 (fail)
second transmission (conventional STBC-based H-ARQ)	x_2^*	$-x_1^*$
second transmission (present invention)	x_2^*	$-x_3^*$

Table 5

[0039] At the receiver, since data packet x_1 is received successfully, the decoded bits of data packet x_1 are reconstructed and subtracted from received data for the first transmission. The modified received data is then combined with the received data for the second transmission. Spatial diversity is achieved in the retransmitted data packet, (i.e., data packet x_2). This

arrangement improves an SNR of new data packet x_3 which will be explained hereinafter.

[0040] The received signal of the first transmission is as in Equation (1). After subtracting the successfully received data packet x_1 from the received data, it becomes as follows:

$$\begin{pmatrix} \tilde{y}_1(t) \\ \tilde{y}_2(t) \end{pmatrix} = \begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} - \begin{pmatrix} h_{11}(t) \\ h_{21}(t) \end{pmatrix} x_1 = \begin{pmatrix} 0 & h_{12}(t) \\ 0 & h_{22}(t) \end{pmatrix} \begin{pmatrix} x_3 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \end{pmatrix}. \quad \text{Equation (21)}$$

Packet x_3 is added into Equation (21) to facilitate description hereafter.

[0041] The received signal for the second transmission is written as follows:

$$\begin{pmatrix} y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11}(t+1) & h_{12}(t+1) \\ h_{21}(t+1) & h_{22}(t+1) \end{pmatrix} \begin{pmatrix} x^*_2 \\ -x^*_3 \end{pmatrix} + \begin{pmatrix} n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \quad \text{Equation (22)}$$

[0042] Combining Equations (21) and (22) results in:

$$\begin{pmatrix} \tilde{y}_1(t) \\ \tilde{y}_2(t) \\ y^*_1(t+1) \\ y^*_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{12}(t) & 0 \\ h_{22}(t) & 0 \\ -h^*_{12}(t+1) & h^*_{11}(t+1) \\ -h^*_{22}(t+1) & h^*_{21}(t+1) \end{pmatrix} \begin{pmatrix} x_2 \\ x_3 \end{pmatrix} + N. \quad \text{Equation (23)}$$

[0043] Equation (23) converts two 2×2 system into a virtual 2×4 system. Conventional LMMSE may be applied to demodulate packets x_2 and x_3 as follows:

$$\begin{pmatrix} \hat{x}_2 \\ \hat{x}_3 \end{pmatrix} = \left(\overline{H}^H \overline{H} + \frac{N_0}{E_s} I \right)^{-1} \overline{H}^H \begin{pmatrix} \tilde{y}_1(t) \\ \tilde{y}_2(t) \\ y^*_1(t+1) \\ y^*_2(t+1) \end{pmatrix}, \quad \text{Equation (24)}$$

where

$$\overline{H} = \begin{pmatrix} h_{12}(t) & 0 \\ h_{22}(t) & 0 \\ -h^*_{12}(t+1) & h^*_{11}(t+1) \\ -h^*_{22}(t+1) & h^*_{21}(t+1) \end{pmatrix}.$$

[0044] In quasi-static channel, spatial diversity is achieved on retransmitted data packet x_2 with reduced interference due to zero elements in the matrix above. Assuming quasi-static channel and dropping time index

t, at high SNR, the SNRs of the data streams for the second transmission are written as follows:

$$SNR(x_2) \approx \left(d_1 - \frac{|c|^2}{d_2} \right) \frac{E_s}{N_0}; \text{ and} \qquad \text{Equation (25)}$$

$$SNR(x_3) \approx \left(d_2 - \frac{|c|^2}{d_1} \right) \frac{E_s}{N_0}; \qquad \text{Equation (26)}$$

where $d_1 = |h_{11}|^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2$, $d_2 = |h_{12}|^2 + |h_{22}|^2$, and $c = -h_{11}h_{12}^* - h_{21}h_{22}^*$.

[0045] With respect to new data packet x_3, a conventional detection technique may be used, where packet x_2 is detected independently from two transmissions followed by a maximum ratio combining (MRC), and packet x_3 is detected only using the second transmission. In other words, conventional technique solves Equations (21) and (22) separately, then perform combining. In Equation (21), since all effective channel coefficients corresponding to x_3 equal to zero (0), only information on x_2 can be derived from Equation (21). With this detection technique, the SNRs are as follows:

$$SNR(x_2) \approx \left(d_1 - \frac{|c|^2}{d_2} \right) \frac{E_s}{N_0}; \text{ and} \qquad \text{Equation (27)}$$

$$SNR(x_3) \approx \left(d_2 - \frac{|c|^2}{d_1'} \right) \frac{E_s}{N_0}; \qquad \text{Equation (28)}$$

where $d_1' = |h_{11}|^2 + |h_{21}|^2$. The SNR of packet x_2 is identical in both techniques. However, a better SNR on x_3 is achieved in accordance with the present invention, when comparing Equations (26) and (28), and considering $d_1 > d_1'$.

[0046] The present invention may be extended to systems with more than two antennas. Tables 6 and 7 show examples of extension to a four antenna system. Table 6 shows conventional STBC-based H-ARQ scheme and Table 7 shows an STBD-based H-ARQ scheme with the successfully transmitted packet being replaced with a new packet in accordance with the present invention.

	Antenna1	Antenna 2	Antenna 3	Antenna 4
Time 1	x_1	x_2	x_3	x_4
Time 2	$-x_2^*$	x_1^*	$-x_4^*$	x_3^*
Time 3	$-x_3^*$	$-x_4^*$	x_1^*	x_2^*
Time 4	x_4	$-x_3$	$-x_2$	x_1

Table 6

	Antenna1	Antenna 2	Antenna 3	Antenna 4
Time 1	x_1 (fail)	x_2 (fail)	x_3	x_4 (fail)
Time 2	$-x_2^*$	x_1^* (fail)	$-x_4^*$ (fail)	x_5^* (fail)
Time 3	$-x_5^*$	$-x_4^*$	x_1^*	x_6^* (fail)
Time 4	x_7	$-x_8$	$-x_6$	x_9

Table 7

[0047] Alternatively, the failed packet x_2 may be simply repeated and a new packet x_3 is transmitted along with the packet x_2 simultaneously. Table 8 shows signal transmissions in accordance with the present invention and a conventional simple repetitive H-ARQ scheme for an exemplary 2×2 MIMO system. In the conventional simple repetitive H-ARQ scheme, the spatial stream that is successfully received is left blank for retransmission. In accordance with the present invention, a new data packet x_3 is transmitted in place of the blank packet. Therefore, higher spectral efficiency is achieved.

	Antenna 1	Antenna 2
first Transmission	x_1 (success)	x_2 (fail)
second transmission (conventional simple repetitive H-ARQ)	0	x_2
second transmission (Present invention)	x_3	x_2

Table 8

[0048] The received signal of the first transmission is as in Equation (1). After subtracting data bits of the successfully received data packet x_1 from the initially received data, it becomes as follows:

$$\begin{pmatrix} \tilde{y}_1(t) \\ \tilde{y}_2(t) \end{pmatrix} = \begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} - \begin{pmatrix} h_{11}(t) \\ h_{21}(t) \end{pmatrix} x_1 = \begin{pmatrix} 0 & h_{12}(t) \\ 0 & h_{22}(t) \end{pmatrix} \begin{pmatrix} x_3 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \end{pmatrix}. \quad \text{Equation (29)}$$

[0049] The received signal for the second transmission is written as follows:

$$\begin{pmatrix} y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{11}(t+1) & h_{12}(t+1) \\ h_{21}(t+1) & h_{22}(t+1) \end{pmatrix} \begin{pmatrix} x_3 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1(t+1) \\ n_2(t+1) \end{pmatrix}. \quad \text{Equation (30)}$$

[0050] Combining Equations (29) and (30) results in:

$$\begin{pmatrix} \tilde{y}_1(t) \\ \tilde{y}_2(t) \\ y_1(t+1) \\ y_2(t+1) \end{pmatrix} = \begin{pmatrix} h_{12}(t) & 0 \\ h_{22}(t) & 0 \\ h_{12}(t+1) & h_{11}(t+1) \\ h_{22}(t+1) & h_{21}(t+1) \end{pmatrix} \begin{pmatrix} x_2 \\ x_3 \end{pmatrix} + N. \quad \text{Equation (31)}$$

[0051] Instead of solving Equations (29) and (30) followed by a combiner, the present invention applies LMMSE to solve Equation (31) as follows:

$$\begin{pmatrix} \hat{x}_2 \\ \hat{x}_3 \end{pmatrix} = \left(\overline{H}^H \overline{H} + \frac{N_0}{E_s} I \right)^{-1} \overline{H}^H \begin{pmatrix} \tilde{y}_1(t) \\ \tilde{y}_2(t) \\ y_1(t+1) \\ y_2(t+1) \end{pmatrix}; \quad \text{Equation (32)}$$

where

$$\overline{H} = \begin{pmatrix} h_{12}(t) & 0 \\ h_{22}(t) & 0 \\ h_{12}(t+1) & h_{11}(t+1) \\ h_{22}(t+1) & h_{21}(t+1) \end{pmatrix}.$$

[0052] At high SNR, the post-MMSE SNRs for x_2 and x_3 are as follows:

$$SNR(x_2) \approx \left(d_1 - \frac{|c|^2}{d_2} \right) \frac{E_s}{N_0}; \text{ and} \qquad \text{Equation (33)}$$

$$SNR(x_3) \approx \left(d_2 - \frac{|c|^2}{d_1} \right) \frac{E_s}{N_0}; \qquad \text{Equation (34)}$$

where $d_1 = 2\left(|h_{12}|^2 + |h_{22}|^2\right)$, $d_2 = |h_{11}|^2 + |h_{21}|^2$, and $c = h_{11}h_{12}^* + h_{21}h_{22}^*$.

[0053] For a conventional receiver, data is detected separately for each transmission before being combined. In other words, conventional detection solves Equations (29) and (30) separately, then combine post detected signal. Assuming LMMSE receiver is used to solve Equation (31), and a maximal ratio combining (MRC) is used to combine post-detection signal, the combined SNR for data x_2 and x_3 at high SNR can be written as:

$$SNR(x_2) \approx \left(d_1 - \frac{|c|^2}{d_2} \right) \frac{E_s}{N_0}; \text{ and} \qquad \text{Equation (35)}$$

$$SNR(x_3) \approx \left(d_2 - \frac{|c|^2}{d_1'} \right) \frac{E_s}{N_0}; \qquad \text{Equation (36)}$$

where $d_1' = \left(|h_{12}|^2 + |h_{22}|^2\right)$, $d_2 = |h_{11}|^2 + |h_{21}|^2$, and $c = h_{11}h_{12}^* + h_{21}h_{22}^*$.

[0054] By comparing Equations (33) and (35), it is shown that the SNR of the retransmitted data packet x_2 is identical for both the conventional scheme and the present invention. However, by comparing Equations (34) and (36), it is shown that the SNR of new data packet x_3 is improved using the present invention, since $d_1 > d_1'$.

[0055] Embodiments.

[0056] 1. A method for implementing H-ARQ in a MIMO wireless communication system.

[0057] 2. The method of embodiment 1, comprising a transmitter transmitting at least two data packets to a receiver.

[0058] 3. The method of embodiment 2, comprising the transmitter retransmitting the data packets to the receiver while rearranging the data packets in an orthogonal spreading manner for retransmission if at least one of the data packets is not successfully transmitted.

[0059] 4. The method as in any one of embodiments 2-3, wherein PARC is performed for transmitting the data packets.

[0060] 5. The method as in any one of embodiments 2-4, wherein both the transmitter and the receiver include two (2) antennas, and the transmitter transmits data symbols x1 and x2 via two antennas at initial transmission and transmits data symbols x1 and -x2 at retransmission.

[0061] 6. The method as in any one of embodiments 2-4, wherein both the transmitter and the receiver include four (4) antennas, and the transmitter transmits data symbols x1, x2, x3 and x4 via four antennas at initial transmission, and transmits data symbols x1, -x2, x3 and -x4 at a first retransmission.

[0062] 7. The method of embodiment 6, wherein the transmitter transmits data symbols x1, x2, -x3 and -x4 at a second retransmission.

[0063] 8. The method of embodiment 7, wherein the transmitter transmits data symbols x1, -x2, -x3 and x4 at a third retransmission.

[0064] 9. The method of embodiment 2, comprising if at least one of the data packets is not successfully transmitted at an initial transmission, the transmitter retransmitting the unsuccessfully transmitted data packet along with a new data packet which replaces a successfully transmitted data packet.

[0065] 10. The method of embodiment 9, comprising the receiver constructing the successfully transmitted data packet.

[0066] 11. The method of embodiment 10, comprising the receiver subtracting the successfully transmitted data packet from initially received data.

[0067] 12. The method of embodiment 11, comprising the receiver combining retransmitted data and the initially received data after subtracting

the successfully transmitted data packet.

[0068] 13. The method of embodiment 12, comprising the receiver performing a processing to obtain the unsuccessfully transmitted data packet at the initial transmission and the new data packet at the same time.

[0069] 14. The method as in any one of embodiments 9-13, wherein the unsuccessfully transmitted data packet is simply repeated without changing a format as in an initial transmission.

[0070] 15. The method as in any one of embodiments 9-13, wherein the unsuccessfully transmitted data packet and the new data packet are arranged in accordance with STBC-based H-ARQ scheme.

[0071] 16. The method as in any one of embodiments 9-15, wherein a format for the new data packet is identical to the successfully transmitted data packet.

[0072] 17. The method as in any one of embodiments 9-15, wherein a format for the new data packet is different from the successfully transmitted data packet.

[0073] 18. The method as in any one of embodiments 9-17, wherein PARC is performed for transmitting the data packets.

[0074] 19. A transmitter for implementing H-ARQ in a MIMO wireless communication system.

[0075] 20. The transmitter of embodiment 19, comprising at least two antennas.

[0076] 21. The transmitter of embodiment 20, comprising an H-ARQ transmitter for transmitting at least two data packets simultaneously via the antennas and retransmitting the data packets if at least one of the data packets is not successfully transmitted.

[0077] 22. The transmitter as in any one of embodiments 19-21, comprising a controller for rearranging the data packets in an orthogonal spreading manner for retransmission.

[0078] 23. The transmitter as in any one of embodiments 19-22, wherein PARC is performed for transmitting the data packets.

[0079] 24. The transmitter as in any one of embodiments 19-23, wherein both the transmitter and a receiver include two (2) antennas, and the controller transmits data symbols x1 and x2 via two antennas at initial transmission and transmits data symbols x1 and -x2 at retransmission.

[0080] 25. The transmitter as in any one of embodiments 19-23, wherein both the transmitter and a receiver include four (4) antennas, and the controller transmits data symbols x1, x2, x3 and x4 via four antennas at initial transmission, and transmits data symbols x1, -x2, x3 and -x4 at a first retransmission.

[0081] 26. The transmitter of embodiment 25, wherein the transmitter transmits data symbols x1, x2, -x3 and -x4 at a second retransmission.

[0082] 27. The transmitter of embodiment 26, wherein the transmitter transmits data symbols x1, -x2, -x3 and x4 at a third retransmission.

[0083] 28. The transmitter of embodiment 20, comprising an H-ARQ transmitter for transmitting at least two data packets via the antennas and retransmitting data packets if at least one of the data packets is not successfully transmitted at an initial transmission.

[0084] 29. The transmitter of embodiment 28, comprising a controller for controlling the H-ARQ transmitter such that only the unsuccessfully transmitted data packet is retransmitted along with a new data packet which replaces a successfully transmitted data packet.

[0085] 30. The transmitter as in any one of embodiments 28-29, wherein the unsuccessfully transmitted data packet is simply repeated without changing a format.

[0086] 31. The transmitter as in any one of embodiments 28-30, wherein a format for the new data packet is identical to the successfully transmitted data packet.

[0087] 32. The transmitter as in any one of embodiments 28-30, wherein a format for the new data packet is different from the successfully

transmitted data packet.

[0088] 33. The transmitter as in any one of embodiments 28-31, wherein PARC is performed for transmitting the data packets.

[0089] 34. A receiver for implementing H-ARQ in a MIMO wireless communication system.

[0090] 35. The receiver of embodiment 34, comprising at least two antennas.

[0091] 36. The receiver of embodiment 35, comprising an H-ARQ receiver for receiving data from a transmitter, the transmitter retransmitting an unsuccessfully transmitted data packet along with a new data packet which replaces a successfully transmitted data packet when at least one data packet is not successfully delivered to the receiver at an initial transmission.

[0092] 37. The receiver of embodiment 36, comprising a data processor for recovering data packets transmitted by the transmitter.

[0093] 38. The receiver of embodiment 37, comprising a data combiner for combining retransmitted data and an initially received data after subtracting the successfully received data packet from the initially received data, wherein the data processor processes the unsuccessfully transmitted data packet and the new data packet that are transmitted together in retransmission simultaneously.

[0094] 39. The receiver as in any one of embodiments 36-38, wherein the unsuccessfully transmitted data packet is simply repeated without changing a format.

[0095] 40. The receiver as in any one of embodiments 36-39, wherein a format for the new data packet is identical to the successfully transmitted data packet.

[0096] 41. The receiver as in any one of embodiments 36-39, wherein a format for the new data packet is different from the successfully transmitted data packet.

[0097] Although the features and elements of the present invention are described in the preferred embodiments in particular combinations, each

feature or element can be used alone without the other features and elements of the preferred embodiments or in various combinations with or without other features and elements of the present invention. The methods or flow charts provided in the present invention may be implemented in a computer program, software, or firmware tangibly embodied in a computer-readable storage medium for execution by a general purpose computer or a processor. Examples of computer-readable storage mediums include a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs).

[0098] Suitable processors include, by way of example, a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), and/or a state machine.

[0099] A processor in association with software may be used to implement a radio frequency transceiver for use in a wireless transmit receive unit (WTRU), user equipment (UE), terminal, base station, radio network controller (RNC), or any host computer. The WTRU may be used in conjunction with modules, implemented in hardware and/or software, such as a camera, a video camera module, a videophone, a speakerphone, a vibration device, a speaker, a microphone, a television transceiver, a hands free headset, a keyboard, a Bluetooth® module, a frequency modulated (FM) radio unit, a liquid crystal display (LCD) display unit, an organic light-emitting diode (OLED) display unit, a digital music player, a media player, a video game player module, an Internet browser, and/or any wireless local area network (WLAN) module.

* * *

CLAIMS

What is claimed is:

1. A method for implementing hybrid automatic repeat request (H-ARQ) in a multiple-input multiple-output (MIMO) wireless communication system, the method comprising:

a transmitter transmitting at least two data packets to a receiver; and

the transmitter retransmitting the data packets to the receiver while rearranging the data packets in an orthogonal spreading manner for retransmission if at least one of the data packets is not successfully transmitted.

2. The method of claim 1 wherein per-antenna rate control (PARC) is performed for transmitting the data packets.

3. The method of claim 1 wherein both the transmitter and the receiver include two (2) antennas, and the transmitter transmits data symbols x_1 and x_2 via two antennas at initial transmission and transmits data symbols x_1 and $-x_2$ at retransmission.

4. The method of claim 1 wherein both the transmitter and the receiver include four (4) antennas, and the transmitter transmits data symbols x_1, x_2, x_3 and x_4 via four antennas at initial transmission, and transmits data symbols x_1, $-x_2$, x_3 and $-x_4$ at a first retransmission.

5. The method of claim 4 wherein the transmitter transmits data symbols x_1, x_2, $-x_3$ and $-x_4$ at a second retransmission.

6. The method of claim 5 wherein the transmitter transmits data symbols x_1, $-x_2$, $-x_3$ and x_4 at a third retransmission.

7. A method for implementing hybrid automatic repeat request (H-ARQ) in a multiple-input multiple-output (MIMO) wireless communication system, the method comprising:

a transmitter transmitting at least two data packets to a receiver; and

if at least one of the data packets is not successfully transmitted at an initial transmission, the transmitter retransmitting the unsuccessfully transmitted data packet along with a new data packet which replaces a successfully transmitted data packet.

8. The method of claim 7 further comprising:

the receiver constructing the successfully transmitted data packet;

the receiver subtracting the successfully transmitted data packet from initially received data;

the receiver combining retransmitted data and the initially received data after subtracting the successfully transmitted data packet; and

the receiver performing a processing to obtain the unsuccessfully transmitted data packet at the initial transmission and the new data packet at the same time.

9. The method of claim 7 wherein the unsuccessfully transmitted data packet is simply repeated without changing a format as in an initial transmission.

10. The method of claim 9 wherein the unsuccessfully transmitted data packet and the new data packet are arranged in accordance with space time block coding (STBC)-based H-ARQ scheme.

11. The method of claim 9 wherein a format for the new data packet is identical to the successfully transmitted data packet.

12. The method of claim 9 wherein a format for the new data packet is different from the successfully transmitted data packet.

13. The method of claim 7 wherein per-antenna rate control (PARC) is performed for transmitting the data packets.

14. A transmitter for implementing hybrid automatic repeat request (H-ARQ) in a multiple-input multiple-output (MIMO) wireless communication system, the transmitter comprising:

at least two antennas;

an H-ARQ transmitter for transmitting at least two data packets simultaneously via the antennas and retransmitting the data packets if at least one of the data packets is not successfully transmitted; and

a controller for rearranging the data packets in an orthogonal spreading manner for retransmission.

15. The transmitter of claim 14 wherein per-antenna rate control (PARC) is performed for transmitting the data packets.

16. The transmitter of claim 14 wherein both the transmitter and a receiver include two (2) antennas, and the controller transmits data symbols x_1 and x_2 via two antennas at initial transmission and transmits data symbols x_1 and $-x_2$ at retransmission.

17. The transmitter of claim 14 wherein both the transmitter and a receiver include four (4) antennas, and the controller transmits data symbols x_1, x_2, x_3 and x_4 via four antennas at initial transmission, and transmits data symbols x_1, $-x_2$, x_3 and $-x_4$ at a first retransmission.

18. The transmitter of claim 17 wherein the transmitter transmits data symbols x_1, x_2, $-x_3$ and $-x_4$ at a second retransmission.

19. The transmitter of claim 18 wherein the transmitter transmits data symbols x_1, $-x_2$, $-x_3$ and x_4 at a third retransmission.

20. A transmitter for implementing hybrid automatic repeat request (H-ARQ) in a multiple-input multiple-output (MIMO) wireless communication system, the transmitter comprising:

at least two antennas;

an H-ARQ transmitter for transmitting at least two data packets via the antennas and retransmitting data packets if at least one of the data packets is not successfully transmitted at an initial transmission; and

a controller for controlling the H-ARQ transmitter such that only the unsuccessfully transmitted data packet is retransmitted along with a new data packet which replaces a successfully transmitted data packet.

21. The transmitter of claim 20 wherein the unsuccessfully transmitted data packet is simply repeated without changing a format.

22. The transmitter of claim 20 wherein a format for the new data packet is identical to the successfully transmitted data packet.

23. The transmitter of claim 20 wherein a format for the new data packet is different from the successfully transmitted data packet.

24. The transmitter of claim 20 wherein per-antenna rate control (PARC) is performed for transmitting the data packets.

25. A receiver for implementing hybrid automatic repeat request (H-ARQ) in a multiple-input multiple-output (MIMO) wireless communication system, the receiver comprising:

at least two antennas;

an H-ARQ receiver for receiving data from a transmitter, the transmitter retransmitting an unsuccessfully transmitted data packet along with a new data packet which replaces a successfully transmitted data packet when at least one data packet is not successfully delivered to the receiver at an initial transmission;

a data processor for recovering data packets transmitted by the transmitter;

a data combiner for combining retransmitted data and an initially received data after subtracting the successfully received data packet from the initially received data, wherein the data processor processes the unsuccessfully transmitted data packet and the new data packet that are transmitted together in retransmission simultaneously.

26. The receiver of claim 25 wherein the unsuccessfully transmitted data packet is simply repeated without changing a format.

27. The receiver of claim 25 wherein a format for the new data packet is identical to the successfully transmitted data packet.

28. The receiver of claim 25 wherein a format for the new data packet is different from the successfully transmitted data packet.