RCPT hybrid ARQ with limited number of retransmissions in DS-CDMA mobile radio

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The effect of a limited number of retransmissions is investigated for RCPT coded type I and II hybrid ARQ schemes in a DS-CDMA mobile radio. It is found by computer simulations that the type II scheme with minimum amount of parity bits transmitted in each retransmission gives the highest throughput. However if the signal energy is to be kept lowest, the best scheme depends on the maximum number of transmissions allowed: the type I scheme is the best for delay sensitive real-time applications and type II is suitable for delay tolerant applications like packet data communications.

Introduction: The rate compatible punctured turbo (RCPT) coded hybrid ARQ scheme has been shown to achieve enhanced throughput performance over an additive white Gaussian noise (AWGN) channel [1] and over fading and shadowing channels [2]. If the allowable number of transmissions is unlimited, the retransmissions continue until an error-free information sequence is recovered at the receiver. However in a practical system, the number of retransmissions allowed is limited to avoid unacceptable time delay before the successful transmission of a packet. When the number of allowable transmissions is limited to I_{max}, error-free reception is not guaranteed and residual error results. The average number of retransmissions (hence the additional redundancy bits transmitted) differs for different value of I_{max} even if the average received signal energy per coded bit-to-additive white Gaussian noise (AWGN) power spectrum density ratio, E_c/N_0, is the same. This causes the average required signal energy per information bit-to-AWGN power spectrum density ratio, E_b/N_0, defined as $E_b/N_0 = (E_c/N_0)/\eta$, to change as I_{max} changes, for the given residual bit error rate (BER). Here, η is the throughput defined as $\eta = N/N_{total}$, where N and N_{total} are the number of information bits and total number of bits transmitted, respectively. In this Letter, we consider type I and II RCPT coded hybrid ARQ schemes for a direct sequence code division multiple access (DS-CDMA) mobile radio. We evaluate by means of computer simulations the effect of a limited number of retransmissions on the throughput and the required E_b/N_0 to find which hybrid ARQ scheme maximises the throughput and minimises the required E_b/N_0.

RCPT coded hybrid ARQ: The various hybrid ARQ schemes considered in this Letter are obtained from the rate 1/3 turbo code by puncturing it with different puncturing period P. A rate 1/3 turbo encoder produces a systematic bit sequence (information bit sequence) of length N and two parity bit sequences, each of length N. The three sequences are punctured according to a puncturing pattern represented by a $3 \times P$ matrix. In the type I scheme, two parity bit sequences are punctured according to the puncturing matrix with $P = 2$:

$$\begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

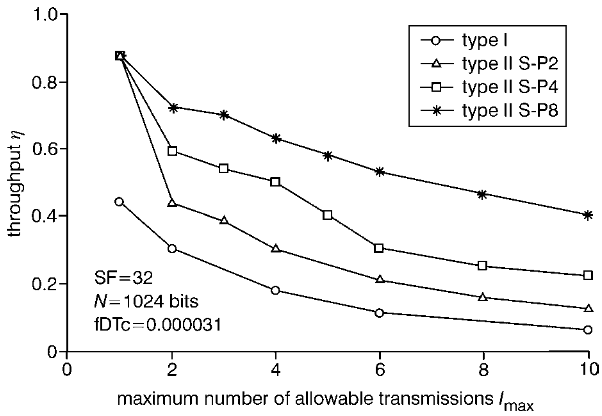

Fig. 1 *Throughput for residual BER = 10^{-4}*

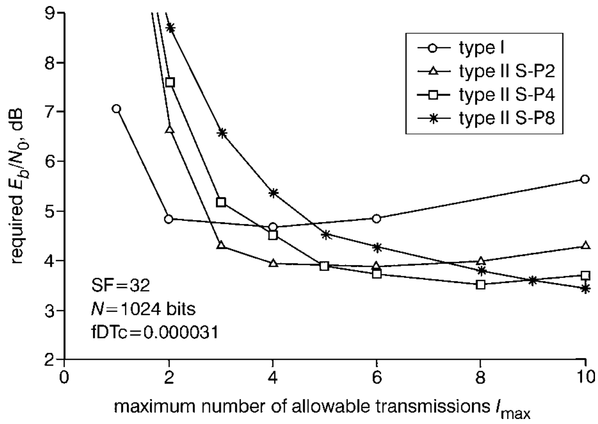

Fig. 2 *Required signal energy per information bit for residual BER = 10^{-4}*

and transmitted along with the systematic bit sequence. If the receiver detects errors in the decoded sequence, a retransmission of that packet is requested. The retransmitted packet uses the same puncturing matrix as the previous packet. In type II hybrid ARQ, we consider three schemes represented by S-PP (systematic-puncture period of P) with $P = 2$, 4, and 8. The puncturing matrices for the first transmission to $(P+1)$th transmission are as follows:

$$\begin{bmatrix} 1 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 \\ 0 & 1 \\ 1 & 0 \end{bmatrix} \quad \text{for S-P2}$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix} \quad \text{for S-P4}$$

$$\begin{bmatrix} 3 & 7 & 7 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 2 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 2 \\ 0 & 4 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$
$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 4 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 2 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 4 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 2 & 0 \end{bmatrix}$$
$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 2 \end{bmatrix} \quad \text{for S-P8 (in octal notation)}$$

The first transmission consists of transmitting only the systematic bit sequence. The number of bits transmitted in the second transmission onwards differs depending on the puncturing period and is $2N/P$. As the number of retransmissions increases, the resultant code rate decreases. After each retransmission, turbo decoding is performed at the receiver. Presence of errors even after the $(P+1)$th transmission causes the sequences of systematic bits, and punctured parity bits to be transmitted again in the subsequent transmissions.

Computer simulation: In this Letter, the single user case is considered (or the other user interference is approximated as a Gaussian noise and thus combined with the AWGN). The information bit length $N = 1024$ is assumed. The RCPT coded sequence to be transmitted is block-interleaved by a channel interleaver and then transformed into binary phase shift keying (BPSK) data symbol sequence. For channel estimation, four known pilot symbols are time-multiplexed every 32 data symbols. Spreading is implemented by multiplying the pilot-inserted BPSK sequence with the long pseudorandom (PN) chip sequence. Spreading factor (SF) is taken to be 32. The spread signal is transmitted via a 4-path Rayleigh fading propagation channel with uniform power delay profile and normalised maximum Doppler frequency $f_D T_c = 3.1 \times 10^{-5}$, where T_c is the chip interval of spreading sequence. The receiver has a 4-finger coherent RAKE combiner, in which channel estimation is performed based on the pilot symbol assisted $K = 2$ WMSA channel estimation [3]. After BPSK demodulation the soft decision sample sequence is de-interleaved and RCPT decoded using log-MAP algorithm. A retransmission is requested if errors are detected. An error-free reverse channel and perfect error detection are assumed throughout the Letter.

We first discuss the throughput performance and then the required E_b/N_0. Fig. 1 shows the throughput η for the different hybrid ARQ schemes against I_{max} for a residual BER of 10^{-4}. It can be seen in the Figure that the type I scheme has the lowest throughput followed by the type II S-P2, S-P4 and S-P8 schemes. S-P8 scheme has the highest throughput at all times as the redundancy bits transmitted with each retransmission is the least. The required E_b/N_0 $(=(E_c/N_0)/\eta)$ is computed from the knowledge of residual BER and throughput. First, the E_c/N_0 needed for the required residual BER is found and η for that E_c/N_0 is obtained. The values of E_b/N_0 are then calculated and shown in Fig. 2 against I_{max} for a residual BER of 10^{-4}. It can be seen that for each hybrid ARQ scheme, there exists an optimum I_{max} that attains a minimum E_b/N_0. The reason for this is explained below. The increase in I_{max} reduces the residual BER and thus, decreases the required average E_c/N_0 causing the E_b/N_0 to reduce. However if I_{max} is too large, a slow decrease in the required average E_c/N_0 is approached, while the average number of redundancy bits increases causing the E_b/N_0 to increase. For delay sensitive systems, e.g. packet voice communications, $I_{max} \leq 2$ may be required and hence, the type I hybrid ARQ scheme is the most favourable as it requires the minimum E_b/N_0. For packet data transmissions, the delay is not so critical, and the type II hybrid ARQ scheme may be utilised. For each type II scheme, the minimum required E_b/N_0 is attained after all the parity bits are transmitted. Hence, the optimum puncture period P that minimises E_b/N_0 depends on I_{max}. When $I_{max} = 4$, the minimum E_b/N_0 is 4 dB and is achieved by S-P2. When I_{max} can be as large as 5 or 6, S-P4 is the best. However if $I_{max} > 8$ is allowed, S-P8 is the most desirable scheme.

Conclusion: The performance of RCPT coded hybrid ARQ for DS-CDMA in a frequency selective Rayleigh fading channel was evaluated when the number of allowable retransmissions is limited. It has been found that the type II hybrid ARQ S-P8 is the most favourable in order to maximise throughput. If signal energy is to be kept low, the best scheme depends on the maximum number I_{max} of transmissions allowed: the type I scheme is the best for delay sensitive real-time application and type II is suitable for delay tolerant applications such as packet data communications. In type II ARQ schemes, the minimum required E_b/N_0 is attained after all the parity bits are transmitted and depends on P. Therefore the optimum P depends on I_{max}.

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