HARQ with variable spreading factor for multicode MC-CDMA

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A new hybrid automatic repeat request (HARQ) with variable spreading factor (VSF) suitable for multicarrier code division multiple access (MC-CDMA) is presented. A HARQ based on incremental redundancy strategy is considered. The throughput of MC-CDMA HARQ is a function of the frequency diversity gain, the coding gain and the inter-code interference. To effectively exploit the frequency diversity gain and the coding gain, the spreading factor is changed between the initial transmission and the succeeding retransmissions. It is shown by computer simulation that HARQ with VSF can provide better throughput performance than with fixed spreading factor.

Introduction: Next generation mobile communication systems require high-speed and high-quality packet transmission techniques. However, for high-speed data packet transmissions, the channel is severely frequency-selective owing to the presence of many interfering propagation paths with different time delays, resulting from the reflection or diffraction, by many obstacles between a transmitter and a receiver, of the transmitted signals. In a severe frequency-selective fading channel, multicarrier code division multiple access (MC-CDMA) is considered to be a promising wireless access [1]. An automatic repeat request (ARQ) combined with channel coding, called hybrid ARQ (HARQ) [2], is an inevitable technique for wireless packet-based transmission, since error-free transmission must be guaranteed for packet data services. The throughput performance of MC-CDMA HARQ is a function of the frequency diversity gain, the coding gain and the inter-code interference (ICI) owing to the orthogonality distortion [2]. As the spreading factor increases, the frequency diversity gain increases, but the coding gain decreases owing to less interleaving effect and the ICI gets stronger. Thus, the spreading factor plays an important role. We consider a HARQ based on incremental redundancy (IR) strategy [3] that gives higher throughput than a HARQ based on chase combining strategy. In IR-HARQ, an uncoded information packet is transmitted first and then a parity bit packet is transmitted if the first packet is received with errors. Since the first packet is uncoded, only the frequency diversity gain is expected. However, in the second transmission onwards, the parity bit packet is transmitted and thus the coding gain is obtained. Hence, the spreading factor should be optimised for the first transmission and second transmission onwards differentially. In this Letter, we propose a multicode MC-CDMA HARQ with variable spreading factor (VSF) for effectively exploiting the frequency diversity gain and the coding gain. Simulation results show that the proposed HARQ with VSF provides better throughput performance than with fixed spreading factor (FSF).

System model: We consider a multicode MC-CDMA with N_c subcarriers. The spreading factor SF_i is used at the ith ($i = 0, 1, 2, \ldots$) packet transmission. The code-multiplexing order at the ith transmission is denoted by C_i. We assume full code multiplexing (i.e. $C_i = SF_i$) and thus the transmission symbol rate is the same as in orthogonal frequency division multiplexing (OFDM); a total of SF_i data symbols are transmitted over SF_i subcarriers. The MC-CDMA HARQ transmission system model is illustrated in Fig. 1.

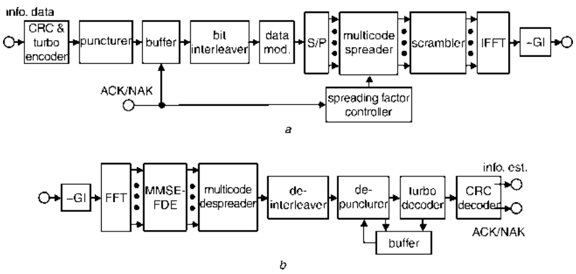

Fig. 1 *MC-CDMA HARQ transmission system model*

a Transmitter
b Receiver

At the transmitter, a cyclic redundancy check (CRC) coded sequence (we consider this sequence as the information sequence) is input to the turbo encoder and the turbo encoded output sequences (i.e. a systematic bit sequence and two parity bit sequences) are stored in the buffer for transmission. The systematic (or information) bit sequence or punctured parity bit sequence is block-interleaved and data-modulated. The data-modulated symbol sequence is serial-to-parallel (S/P) converted to C_i streams $\{d_c(n);\ c = 0 \sim C_i - 1,\ n = 0 \sim N_c/SF_i - 1\}$. C_i streams are spread using orthogonal spreading codes $\{c_c^{oc}(k);\ c = 0 \sim C_i - 1,\ k = 0 \sim SF_i - 1\}$, where $|c_c^{oc}(k)| = 1$, and then code-multiplexed. Finally, a long scramble code $\{c_{scr}(k);\ k = 0 \sim N_c - 1\}$ is multiplied. Then, an N_c-point inverse fast Fourier transform (IFFT) is applied to generate a multicode MC-CDMA packet signal having N_c subcarriers. The kth subcarrier component $S(k)$, $k = 0 \sim N_c - 1$, is expressed as

$$S(k) = \sqrt{\frac{2P}{SF_i}} \sum_{c=0}^{C_i - 1} d_c(\lfloor k/SF_i \rfloor)\, c_c^{oc}(k \bmod SF_i)\, c_{scr}(k) \tag{1}$$

where P represents the transmit power and $\lfloor x \rfloor$ is the largest integer smaller than or equal to x. The modulo operation, a mod b, finds the remainder of the division of a by b. After the insertion of an N_g-sample guard interval (GI), the resultant multicode MC-CDMA packet signal is transmitted over a frequency-selective fading channel.

The received multicode MC-CDMA packet signal is perturbed by the additive Gaussian noise (AWGN). The N_g-sample GI is removed and N_c-point FFT is applied to decompose the received packet signal into N_c-subcarrier components $\{R(k);\ k = 0 \sim N_c - 1\}$. The kth subcarrier component can be expressed as

$$R(k) = S(k)\, H(k) + N(k) \tag{2}$$

where $H(k)$ is the channel gain and $N(k)$ is the noise component at the kth subcarrier. Minimum mean square error (MMSE) based frequency-domain equalisation (FDE) is performed before multicode despreading. The decision variable for the data symbol $d_c(n)$ after despreading can be expressed as

$$\hat{d}_c(n) = \frac{1}{SF_i} \sum_{k=nSF_i}^{(n+1)SF_i - 1} R(k)\, w_i(k)\, \{C_c^{oc}(k \bmod SF_i)\, C_{scr}(k)\}^* \tag{3}$$

where $*$ denotes the complex conjugate operation and $w_i(k)$ is the MMSE-FDE weight for the kth subcarrier at the ith packet reception. Since $C_i = SF_i$, $w_i(k)$ is given by [1]

$$w_i(k) = \frac{H^*(k)}{|H(k)|^2 + (E_s/N_0)^{-1}} \tag{4}$$

where E_s/N_0 is the average received symbol energy to the AWGN power spectrum density ratio. Following the same procedure as in [4], the log-likelihood ratio (LLR) is computed for turbo decoding. Then, the LLR sequence is de-interleaved, de-punctured and input into the turbo decoder.

Optimisation of SF_i: The hybrid ARQ considered in this Letter is obtained from the rate 1/3 turbo code. A rate 1/3 turbo encoder produces a systematic bit (information bit) sequence and two parity bit sequences. The three sequences are punctured according to puncturing matrices $\{p_i\}$ for the ith packet transmission as follows:

$$P_0 = \begin{bmatrix} 1 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad P_1 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad P_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \\ 1 & 0 \end{bmatrix} \tag{5}$$

where the first row corresponds to the information bit sequence and the 2nd and 3rd rows correspond to the parity bit sequences. '0' means the deletion of the bit at the corresponding position. At the first transmission ($i = 0$), only the information packet is transmitted. If packet error is detected, the 2nd transmission ($i = 1$) is requested; the parity bit packet is transmitted for turbo decoding. If packet error is still detected, the different parity bit packet is transmitted at the 3rd transmission ($i = 2$). As the number of retransmissions increases, the resultant code rate decreases and thus the coding gain increases. In the proposed HARQ with VSF, the spreading factor at the first transmission ($i = 0$) is set to be the largest possible, i.e. $SF_0 = N_c$, so that the largest frequency diversity gain can be achieved (the degradation owing to the ICI can be offset by the diversity gain). In each retransmission ($i \geq 1$), the coding gain owing to the turbo decoding is obtained besides the frequency diversity gain. By computer simulation, we found that $SF_i = 1$ ($i = 1, 2, 3, \ldots$) provides the best throughput.

Simulation result: We evaluated by computer simulation the throughput performance of the multicode MC-CDMA HARQ with VSF. The maximum number of retransmissions is assumed to be infinite. A rate-1/3 turbo code, having constraint length 4 and two (13, 15) recursive systematic component encoders, is used. The information sequence length K is assumed to be $K = 2048$ bits and 64×32 block-interleaver is used. $N_c = 256$, $N_g = 32$ and 16QAM data-modulation are assumed. We consider a frequency-selective Rayleigh fading channel having a 16-path uniform power delay profile with a time-delay spacing of one FFT sample. At the receiver, log-MAP decoding with eight iterations is carried out. Perfect error detection is assumed.

The simulated throughput performance of multicode MC-CDMA HARQ with VSF is shown in Fig. 2. For comparison, throughput curves with FSF of $SF = 256$ ($C = 256$) and $SF = 1$ ($C = 1$) are also plotted. It is seen from Fig. 2 that, for HARQ with FSF, the use of $SF = 256$ (1) attains the best throughput in a high (low) E_s/N_0 region. Since the use of larger spreading factor increases the probability of the first packet being correctly received, $SF = 256$ is the optimum value in a high E_s/N_0 region. Alternatively, in a low E_s/N_0 region, since two or more retransmissions are always necessary, $SF = 1$ provides the best throughput. However, it is seen from Fig. 2 that the proposed HARQ with VSF offers almost the best throughput performance over a wide range of E_s/N_0. It should be noted that the received E_s/N_0 measurement is not necessary for changing the spreading factor in HARQ with VSF.

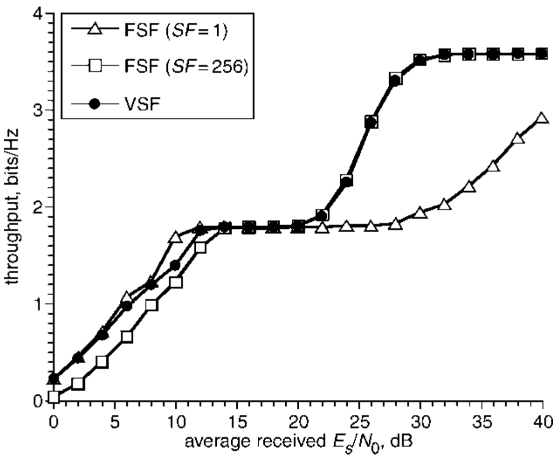

Fig. 2 *Throughput performance*

Conclusions: In this Letter, we have presented HARQ with VSF to effectively exploit the frequency diversity gain and the coding gain for multicode MC-CDMA. The achievable throughput performance in a frequency-selective Rayleigh fading channel was evaluated by computer simulation to show that the proposed HARQ with VSF provides better throughput performance than with FSF.

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