Symbol Repetition and Power Re-allocation Scheme for Orthogonal Code Hopping Multiplexing Systems

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Abstract— **We propose a symbol repetition and power re-allocation scheme to reduce a collision effect in orthogonal code hopping multiplexing (OCHM) systems. Each mapped symbol is repeated N times and an OCHM scheme is applied for downlink transmission. Through repetitions, the perforation effect is decentralized among the repeated symbols and the full perforation probability is significantly reduced. Transmit power is re-allocated among the repeated symbols to protect symbols regardless of the number of perforations in repeated symbols. Simulation results show that the proposed scheme saves the required energy by 4dB in independent Rayleigh fading channels for a frame error rate (FER) value of 1% when the perforation probability is 0.25.**

I. Introduction

Recently, data traffic has rapidly increased in wireless communication systems. From this trend, data traffic will be expected to be dominant in future wireless systems. Data traffic is inherently bursty and generally exhibits a low channel activity. Furthermore, there is more downlink traffic than uplink traffic. Several high speed downlink systems have been proposed to provide this data traffic in wireless link.

High speed downlink packet access (HSDPA) has been developed within 3GPP framework [1]. HSDPA provides downlink peak data rates up to 10Mbps and significantly reduces downlink transmission delay. In order to achieve high data rate transmission, several schemes have been proposed including adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ), fast cell selection (FCS), and multiple-input multiple-output (MIMO) antenna processing.

The cdma2000 1xEV-DO standard [2] provides a bandwidth efficient and high-speed wireless data service by supporting various data rates according to given channel conditions in both uplink and downlink. The data rate is determined by using feedback information from the receiver. This system provides only data traffic and uses time division multiplexing for downlink. Therefore, one user can receive data at a time.

Orthogonal frequency division multiplexing (OFDM) is the most promising technique for high-speed data transmission over frequency selective fading channels. In OFDM systems, a high-rate data stream is split into lower-rate data streams and these data are transmitted simultaneously [3]. Through parallel transmission over a frequency selective fading channel, the effective symbol duration becomes long, compared to delay spread and each subcarrier can be assumed to experience flat fading. Recently, many multiple access techniques based on OFDM have been proposed including OFDMA, FH-OFDMA, OFDM-TDMA, MC-CDMA, and OFDM-CDM [4]. Especially, a variable spreading factor (VSF)-OFCDM scheme which changes the sprading factor of OFCDM according to the given cell structure and radio link conditions is very attractive [5], [6].

An orthogonal code hopping multiplexing (OCHM) scheme has been proposed to accommodate more low-activity bursty users than the number of orthogonal downlink code words [7], [8]. It utilizes statistical multiplexing for orthogonal downlink in DS/CDMA systems. Since each user communicates with base station (BS) through a given orthogonal code hopping pattern (HP), signaling messages for allocation and de-allocation of orthogonal codewords are not needed during a session. HP can be randomly generated based on an user specific number, such as electronic serial number (ESN). Symbol collisions occur due to transmission of different symbols with the same orthogonal codeword during code hopping. These collisions are called perforations and the corresponding symbols are not transmitted. These perforations degrade the system performance. On the other hand, if all channel encoded data symbols spread by the same orthogonal codeword during code hopping and identical, then all the data symbols with code collisions can be transmitted without perforation. This effect is called synergy [7]. The conventional symbol collision mitigation methods use a strong coding gain of turbo codes or a log-likelihood ratio (LLR) re-computation according to the perforation probability [9]. In this paper, we propose a symbol repetition and power re-allocation scheme to reduce the perforation effect in OCHM systems. Simulation results show that the proposed scheme greatly reduces the perforation effect and saves the required E_b/N_0 for given frame error rates (FER). This paper is organized as follows: The proposed OCHM system is introduced in Section II. LLR computation for symbol repetition is described in Section III. The performance of the proposed scheme is evaluated in terms of the required E_b/N_0 for a 1% FER by simulation in Section IV. Finally, conclusions are presented in Section V.

II. Proposed Repetition and Power Re-allocation Scheme for OCHM Systems

A. Repetition and Power Re-allocation Mechanism

The OCHM system utilizes a user specific random hopping pattern to allocate a code channel to a new user. An orthogonal

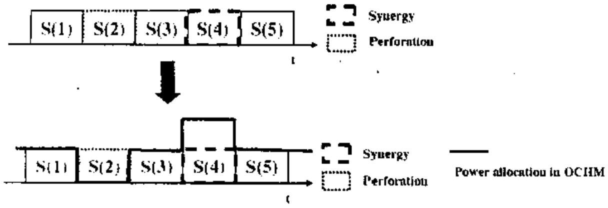


Fig. 1. Synergy, perforation, and power allocation in the conventional OCHM system

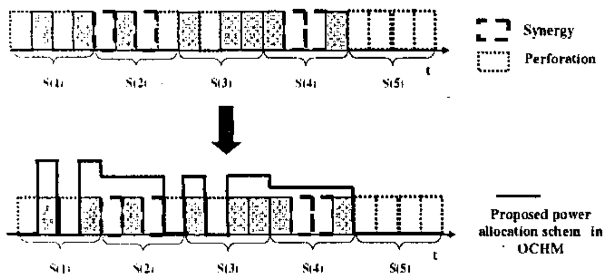


Fig. 2. Synergy, perforation, and power allocation in the proposed OCHM system

code hopping pattern allocated to a user is independent among users and may cause a *hopping pattern collision* between two or more users with the same code channel at a specific time during code hopping, which can be detected by the BS in downlink. If the hopping pattern collision occurs, BS compares user data and determine whether it results in *synergy* or *perforation*. When all the symbols of the users with a colliding hopping pattern are not the same, a perforation occurs and all data symbols collided are not transmitted during the symbol time [7].

Fig. 1 shows a synergy, perforation, and the power allocation process in the conventional OCHM system. The perforation and synergy occur in Symbols 2 and 4, respectively. The energy of Symbol 4 becomes large due to the synergy effect. The perforated symbols are removed from the frame in the conventional OCHM system, which causes performance degradation.

If a symbol is repeated, the same information may exist in a frame when perforations occur randomly. Fig 2 shows a synergy, perforation, and the power allocation process in the proposed OCHM system using symbol repetitions. Each symbol is repeated 4 times and the repeated symbols may be perforated. Symbols 1 and 2 have two and one perforations, respectively. Repeated symbols from Symbol 5 are all perforated. We define a *partial perforation* in which the repeated symbols are perforated less than the number of repetitions (e.g. Symbol 1,2,and 3) and a *full perforation* in which all repeated symbols are perforated (e.g. symbol 5). If a symbol experiences the partial perforation, the remaining symbols are used for decoding the original symbol. However, if a symbol suffers from the full perforation, the original symbol can not be recovered without any channel coding scheme and it causes performance degradation. Note that the power allocated to Symbol 1 is different from that of Symbol 2. Since two symbols have a different number of perforation symbols, the number of remaining symbols is also different. We propose to adjust the power level of remaining symbols to have the same energy regardless of the number of perforations, in order to recover the original symbol at the receiver. Through this process, we can protect all symbols equally unless the symbol experiences a full perforation.

B. Hopping Pattern Collision Probability of the proposed systems

The hopping pattern collision probability of the conventional OCHM system can be expressed as:

$$P_c = 1 - \left(1 - \frac{\bar{v}}{N_{OC}}\right)^{K-1} \tag{1}$$

where $\bar{v}$ is channel activity, N_{OC} is number of orthogonal codewords, and K is the number of active users in a cell. For a given channel activity $\bar{v}$, P_c increases as the number of active users increases.

C. Perforation Probability of Encoded Data Symbols in the Proposed Scheme

The perforation probability of encoded symbols in the conventional OCHM systems is written as:

$$P_p = 1 - \sum_{i=0}^{s-1} \pi_i \left(1 - \frac{(1-\pi_i)\bar{v}}{N_{OC}}\right)^{K-1}. \tag{2}$$

where π_i is the probability of modulation symbol $i \in \{0, 1, 2, ..., s-1\}$. For BPSK, there are 2 symbols ($s = 2$).

The original symbol perforation probability of the proposed OCHM system using the symbol repetitions can be expressed as:

$$P_{p,N} = 1 - (1 - P_p)^N \tag{3}$$

where N is the number of symbol repetitions. The original symbol indicates a coded symbol before the symbol repetition process. Eq. (3) represents the probability that the original symbol has more than one perforation among N repeated symbols.

The partial perforation probability of an original symbol is written as:

$$\begin{aligned} P_{pp,N}^{m} &= P(m \text{ perforations} \mid N \text{ repetitions}) \\ &= \binom{N}{m} (P_p)^m (1 - P_p)^{N-m}, 0 < m < N. \end{aligned} \tag{4}$$

Eq. (4) has a binomial distribution with an event probability of P_p. The partial perforation effect can be mitigated through the power re-allocation process, as shown in Section II-A.

The full perforation probability of an original symbol is given as:

$$P_{fp,N} = (P_p)^N. \tag{5}$$

If a symbol experiences a full perforation, the symbol cannot be recovered at the receiver with any channel coding scheme

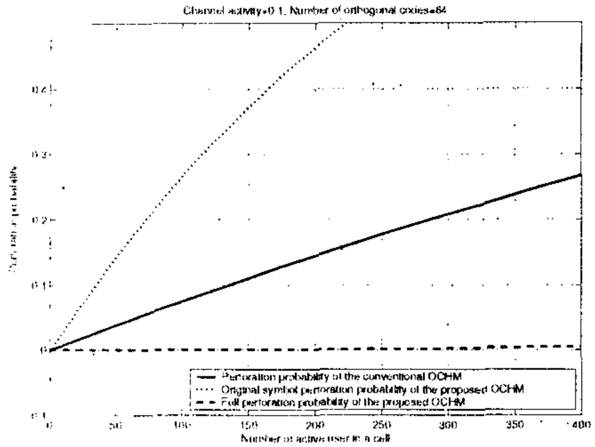


Fig. 3. Perforation probability according to the number of active users for the proposed OCHM system

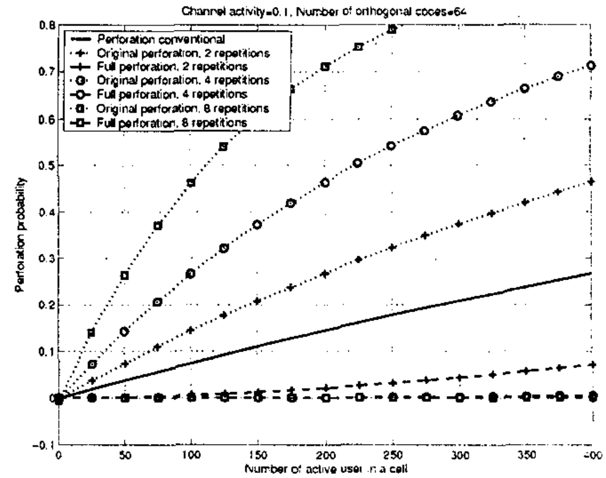


Fig. 4. Perforation probability for varying the number of symbol repetitions

and it causes performance degradation. As the number of repetitions increase, the full collision probability significantly decreases.

The effective number of repeated symbols in perforation is written as:

$$N_{eff,N} = \sum_{i=0}^{N} i \cdot \binom{N}{i} (P_p)^i (1-P_p)^{N-i} - N \cdot P_p \quad (6)$$

From Eq. (6), the effective perforation probability of a symbol ($N_{eff,N}/N$) is the same as the symbol perforation probability in the conventional OCHM systems.

Fig 3 shows the perforation probability of the proposed OCHM system. The perforation probability increases as the number of active users increases. In this figure, we assume that the number of repetitions is 4 and the channel activity is set at 0.1. The number of orthogonal code channels is 64. The original symbol perforation probability as noted in Eq. (3) is larger than symbol perforation probability of the conventional OCHM system, but the full perforation probability is much smaller than for the conventional one. If the number of active users is 350, the symbol perforation probability is 0.24 in the conventional OCHM system. However, in the proposed OCHM system, the full perforation probability is approximately 0.

As the number of symbol repetitions increases, the original symbol perforation probability itself increases in the proposed OCHM system, but the full perforation probability exponentially decreases as noted before. Fig 4 shows the perforation probability for varying the number of symbol repetitions. In this figure, we assume that the number of symbol repetitions varies from 2 to 8, and the channel activity is 0.1. The number of orthogonal code channels is 64. The dashed lines and dotted lines represent the original symbol perforation probability ($P_{p,N}$) and the full perforation probability ($P_{fp,N}$) of the repetition scheme, respectively. The solid line shows the perforation probability of the conventional OCHM system (P_p). The original symbol perforation probability increases, but the full perforation probability decreases as the number of symbol repetitions increases.

If N symbol repetitions are used at the transmitter, the data rate is reduced by $1/N$. This is the same data rate as the system with a N-times larger spreading factor. If we use a larger spreading factor, the number of available codewords increases and the perforation probability decreases. For a given data rate requiring a spreading factor of N_{sf}, we can choose a spreading factor of N_{sf}/N with N symbol repetitions or a spreading factor of N_{sf} with no symbol repetitions. Fig 5 compares the full perforation probability of the proposed OCHM system with the perforation probability of the conventional system with the same data rate. The full perforation probability directly affects the system performance in the proposed OCHM system because the partial perforation effect can be mitigated through the power re-allocation scheme. The dotted lines and solid lines indicate the full perforation probabilities of the proposed OCHM systems and the perforation probabilities of the conventional OCHM systems with the same data rate, respectively. The proposed OCHM system yields lower perforation probabilities than the conventional OCHM system.

III. LLR Computation for the Proposed OCHM Systems

A soft-input decoder of turbo codes requires a channel modulator output as a form of likelihood function [10], [11]. If we transmit x and receive y in conventional BPSK/QPSK, the LLR is expressed as:

$$\begin{aligned} L(x|y) &= \log \frac{P(x=+1|y)}{P(x=-1|y)} \\ &= \log \frac{P(y|x=+1)}{P(y|x=-1)} + \log \frac{P(x=+1)}{P(x=-1)} \\ &= L(y|x) + L(x), \\ &= L(y|x), \ \text{for equi-probable symbols} \quad (7) \end{aligned}$$

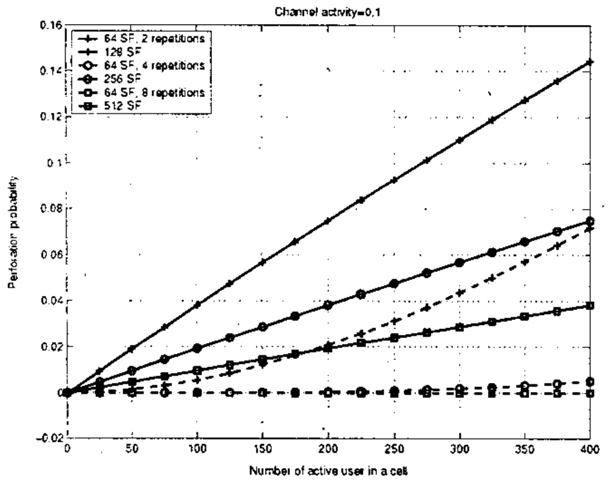


Fig. 5. Comparison full perforation probability of the proposed OCHM system and the perforation probability of the conventional system with the same data rate

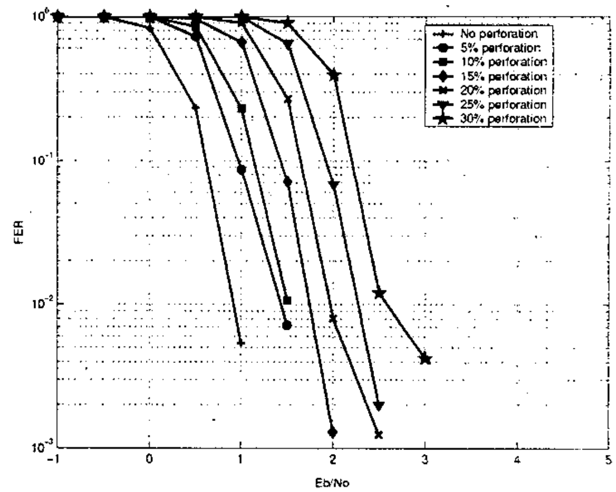


Fig. 6. FER performance of the proposed OCHM system in AWGN channels

The LLR for an AWGN channel can be computed as:

$$L(x|y) = \frac{2}{\sigma^2} \cdot y, \tag{8}$$

where σ^2 represents the noise variance. The LLR is proportional to the received symbol amplitude y in AWGN channels.

If the channel experiences fading, the LLR is computed as:

$$L(x|y) = a \cdot \frac{2}{\sigma^2} \cdot y \tag{9}$$

where a represents the fading amplitude.

In the proposed OCHM system, the modulated symbols are repeated N times. Therefore, N channel modulator outputs are combined together to generate an LLR for the corresponding symbol. The probability of $\vec{y}$ conditioned x in AWGN channels can be expressed as:

$$\begin{aligned} P(\vec{y}|x) &= \prod_{i=1}^{N} p(y_i|x) \\ &= \prod_{i=1}^{N} \frac{1}{\sqrt{2\sigma^2}} \exp\left(-\frac{(y_i - x)^2}{2\sigma^2}\right), \end{aligned} \tag{10}$$

where y_i is the i-th repeated symbol and N is the number of symbol repetitions. For a BPSK, x is $+1$ or -1. We compute the LLR of the proposed OCHM system using Eq. (10). The LLR with N symbol repetitions in AWGN channels is written as:

$$L(x|\vec{y}) = \frac{2}{\sigma^2} \sum_{i=1}^{N} y_i. \tag{11}$$

The LLR is proportional to the summation of the repeated symbol amplitude. Similarly, the LLR in fading channels is expressed as:

$$L(x|\vec{y}) = \frac{2}{\sigma^2} \sum_{i=1}^{N} a_i y_i. \tag{12}$$

where a_i is the fading amplitude of the i-th repeated symbol. Through the symbol repetitions, the diversity gain can be achieved at the receiver, as shown in Eq. (12). If the fading is independent between symbols and there are no collisions among N repeated symbols, then the diversity order reaches N.

IV. Simulation Results

Simulations are performed in both AWGN channels and Rayleigh fading channels. BPSK modulation is used and turbo codes are used for a channel encoder. The length of a frame is 1024 bits and the code rate is 1/3. Turbo coding in 3GPP specifications is considered with a decoder using a maximum-a-posteriori (MAP) algorithm with maximum iteration number 8. Symbol perforations are assumed to occur randomly.

Fig. 6 illustrates the FER performance of the proposed OCHM system versus E_b/N_0 for various levels of perforation probability in AWGN channels. The number of symbol repetitions is 4. The required E_b/N_0 to meet a given FER requirement also increases as the perforation probability increases. Fig 6 shows the FER result in AWGN channels. The merit of the OCHM system is that it has no control overhead to allocate or de-allocate channel to users and can support more users than the maximum number of available orthogonal channels in the system. However, the perforation effect degrades the overall system performance including an increase in the required E_b/N_0 for a given FER. Therefore, the design objective for the OCHM systems is to reduce the additional energy to satisfy a given FER performance when the perforation probability increases.

Fig. 7 shows the FER performance of the proposed OCHM system using four repetitions for different values of perforation probability in fading channels. In this simulation, we assume that the channel is an independent Rayleigh fading channel. If the perforation probability is 30%, the required E_b/N_0 is about 3.2dB and then additional 3dB energy is needed, compared

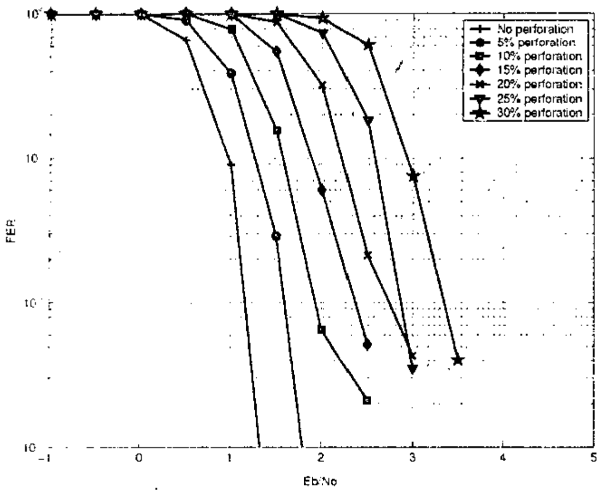


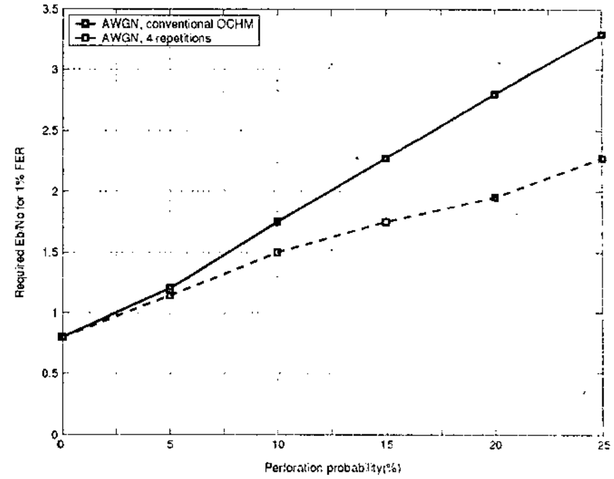
Fig. 7. FER performance of the proposed OCHM system in fading channels

with that the system with no perforation. The proposed OCHM system is appropriate especially for accommodating many medium- and low-rate data users.

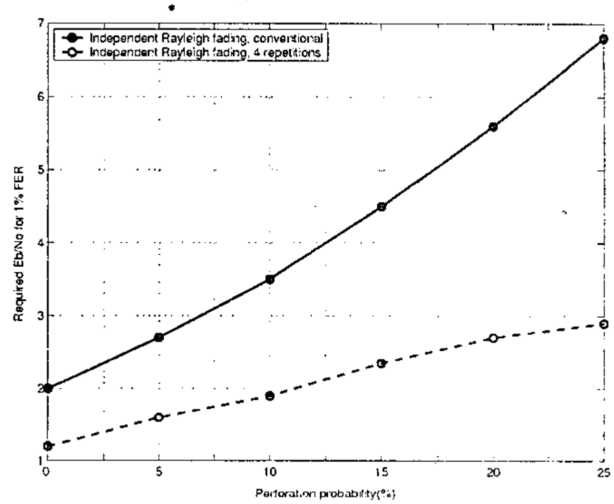
Fig. 8 compares the required E_b/N_0 for an FER requirement of 1% between the conventional OCHM system and the proposed OCHM system. The solid and dotted lines indicate the performance of the conventional OCHM system and the proposed OCHM system, respectively. The relative performance improvement in fading channels is larger than that in AWGN channels due to a diversity effect, even though the required E_b/N_0 in fading channels is generally higher than that in AWGN channels. When the perforation probability is 25%, the saved energy from the proposed OCHM system is 1dB and 4dB in AWGN and independent Rayleigh fading channels, respectively. As the perforation probability increases, the performance improvement also increases.

V. Conclusions

The OCHM system is a novel statistical multiplexing system for orthogonal downlink to accommodate more low-activity bursty users than the number of orthogonal downlink channels. The performance of OCHM systems is limited by the collision effect among symbols. We proposed a symbol repetition and power re-allocation scheme that reduces the collision effects of the conventional OCHM systems. The LLRs for the repeated symbols are computed. Simulation results show that the proposed OCHM system saves the required energy more, compared with the conventional OCHM system, especially, in independent Rayleigh fading channels.



(a) AWGN channels



(b) Independent Rayleigh fading channels

Fig. 8. Comparison required E_b/N_0 for 1% FER in AWGN channels and independent Rayleigh fading channels

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