Uplink Capacity Improvement Through Orthogonal Code Hopping in Uplink-Synchronized CDMA Systems

Bang Chul Jung, *Member, IEEE*, Sung Soo Cho, and Dan Keun Sung, *Senior Member, IEEE*

***Abstract*—We propose an orthogonal code hopping multiple access (OCHMA) scheme in order to improve the capacity of an uplink-synchronized code division multiple access (CDMA) systems. When orthogonal codes (OCs) are used for channelization in uplink-synchronized CDMA systems, a finite set of OCs tends to severely limit the capacity gain of the uplink-synchronized CDMA systems. The OCHMA system allows each user to use a different OC for each symbol according to an allocated hopping pattern (HP). It also allows multiple users to use the same OC at a specific symbol time, which is called an HP collision. Thus, the proposed OCHMA scheme can accommodate more users than the number of available OCs. We analyze the capacity of the OCHMA scheme and compare the performance of the OCHMA with that of conventional schemes including the system using multi-scrambling codes (MSC) which have also been proposed to overcome a code-limited situation.**

***Index Terms*—Channelization code restriction, orthogonal code hopping multiple access, noise rise, uplink capacity, uplink synchronization.**

I. Introduction

In code division multiple access (CDMA) systems, uplink capacity is mainly limited by multiple-access interference (MAI). The uplink-synchronized CDMA systems have been proposed to reduce MAI [1]–[3], and they use orthogonal codes (OCs) for channelization in order to discriminate their own users. Previous studies demonstrated that it is possible to achieve accurate symbol synchronization in the uplink [4]–[6]. A time-division-synchronous code-division multiple access (TD-SCDMA) system was proposed by the Chinese Academy of Telecommunication Technology (CATT) in 1998 [7] and was standardized by the 3G Partner Project (3GPP) as a low chip-rate (LCR) time division duplex (TDD) mode of the Universal Terrestrial Radio Access (UTRA) in March 2001. Recently, the TD-SCDMA system has been evolved to provide higher data rates and better quality-of-service (QoS) [8].

Previous studies [9], [10] focused on the user capacity of uplink-synchronized CDMA systems in a single cell environment. The result showed that uplink synchronous transmission can significantly increase the uplink capacity since it can suppress the MAI from other users. However, the user capacity of the uplink-synchronized CDMA systems can be limited by the maximum number of orthogonal codes in a cell. This code-limited situation can occur when a system accommodates a large number of users with low channel activity in a small other-cell interference environment. This limitation can be mitigated by introducing multi-scrambling codes (MSC) [11]. They circumvent the code limitation, but they increase the MAI because signals transmitted with different scrambling codes are non-orthogonal to each other. Furthermore, the capacity gain achieved through the introduction of MSC decreases as channel activity decreases because the probability that users tend to use OCs in different MSC groups increases. If the user channel activity approaches zero, the capacity of the uplink-synchronized CDMA system with MSC is close to that of the conventional asynchronous CDMA systems.

In this letter, we propose an orthogonal code hopping multiple access (OCHMA) scheme in order to improve the capacity of uplink-synchronized CDMA systems. Especially, we focus on a data communication environment with low user-channel activity because data traffic, such as HTTP, FTP, and WAP, has gradually increased and may become dominant in future wireless communication systems. Furthermore, we assume that each user sends signaling information for indicating the data transmission when there is a data packet for transmission. If the signaling information is not transmitted, a BS should decode all data from users with connections. The rest of this correspondence is organized as follows: In Section II, we introduce the system model and propose an OCHMA scheme. In Section III, we mathematically analyze the user capacity of the proposed OCHMA scheme. In Section IV, we illustrate numerical examples and compare the performance of the proposed scheme with that of the conventional schemes. Finally, conclusions are presented in Section V.

II. OCHMA Scheme

A. OCHMA Mechanism and HP collisions

Fig. 1 shows the block diagram of an OCHMA scheme for uplink-synchronized CDMA systems. We assume that the symbols from all users within the same cell are perfectly time-synchronized. T_s denotes the symbol time. Each user changes an orthogonal code (OC) according to a pre-allocated hopping pattern (HP) at each symbol time, during which an HP collision may occur in case of allocation of the same OC to multiple users. However, most users may be inactive in a low channel-activity environment when they demand data services. Inactive users may transmit control information like transmit power control information even when they do not have data to transmit. However, we assume that inactive users do not

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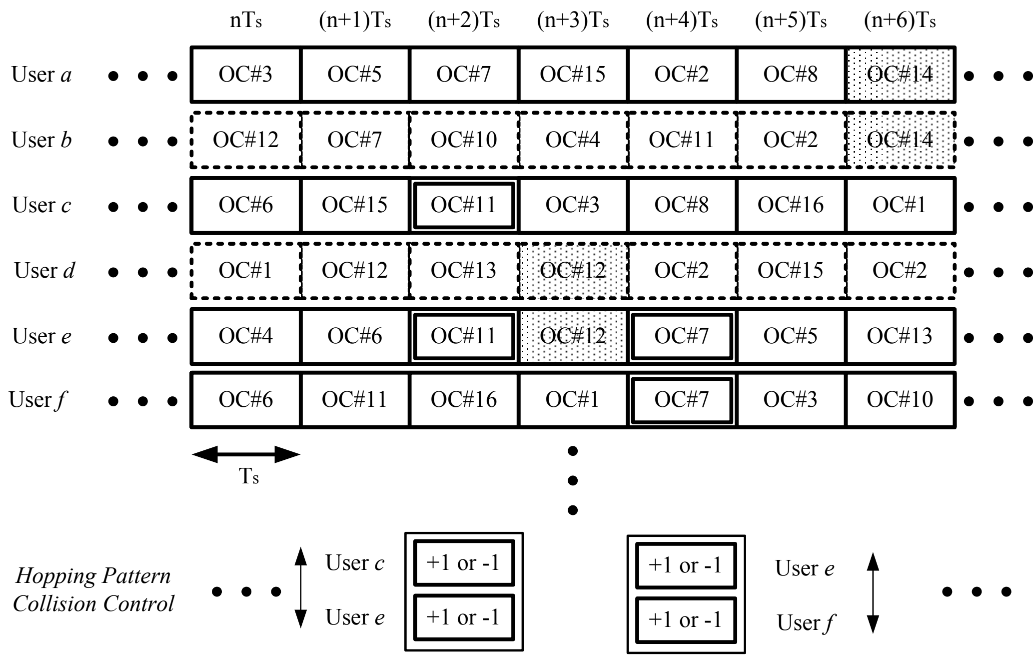


Fig. 1. Block diagram of an OCHMA scheme.

transmit at all because we focus the data transmission part rather than the control information in this figure. Users b and d are inactive in Fig. 1, but they follow their HPs during their sessions regardless of data transfer. In this case, HP collisions between an active user group and an inactive user group do not affect the performance of the *active* user group. The shaded parts in Fig. 1 indicate this type of collision. When the number of users in a cell is smaller than that of available OCs, an HP can be generated without collisions. Furthermore, we can make a *collision-free group* (CFG) within which any OCs are exclusively allocated to users. Thus, HP collisions occur only among users in different CFGs. This CFG concept is similar to MSC. An OC allocated during a symbol period in a CFG may collide with other OCs in a different CFG. This causes an HP collision.

When an HP collision among the *active* users occurs, a BS should deal with the collision. As noted before, we assume that the BS knows the pre-determined HPs of all users and the existence of uplink data from users. Thus, the BS can detect the users using the same OC during each symbol time. For example, the BS knows that users c and e use the same OC during $(n+2)T_s$. In Fig. 1, we assume that all users use binary phase shift keying (BPSK) as a modulation scheme. That is, each user transmits symbols, s ($s \in \{+1, -1\}$). In this section, we assume a wireless channel with frequency-flat fading for mathematical simplicity and we consider the multi-path fading effect on the performance in Section III. The matched filter output of the k-th received symbol of the i-th user at the BS can be expressed as Eq. (1). In Eq. (1), L represents the number of users experiencing the same HP collision, $s_{l,k}(1 \leq l \leq L)$ denotes the l-th user signal experiencing the same HP collision with the other $(L-1)$ user signals during the k-th symbol time, $\theta_{i,k}$ represents the phase shift of k-th symbol of i-th user due to fading. The term $a_{i,k}$ represents the amplitude of fading coefficient and $E_{i,k}$ is the transmit symbol energy of k-th symbol of i-th user. The terms $a_{i,k}$ and $\theta_{i,k}$ are known at the BS through channel estimation, and $n_{i,k}$ denotes the thermal noise at the BS.

When an HP collision does not occur during the k-th symbol time of the i-th user, the log-likelihood ratio (LLR) for $s_{i,k}$ is expressed as [13]:

$$\Lambda(s_{i,k}) = L_c \cdot e^{j\theta_{i,k}} \cdot y_{i,k} = \frac{2a_{i,k}\sqrt{E_{i,k}}}{\sigma^2} \cdot e^{j\theta_{i,k}} \cdot y_{i,k} \quad (2)$$

where σ^2 and L_c denote the noise variance at the BS and the channel reliability, respectively.

When an HP collision occurs for $s_{i,k}$, the log-likelihood ratio (LLR) is expressed as [15]:

$$\Lambda(s_{i,k}) \quad = \quad \log \frac{\sum_{m=1}^{2^{L-1}} \exp\left\{-\frac{(y_{i,k}-b_{+1,m})^2}{2\sigma^2}\right\}}{\sum_{m=1}^{2^{L-1}} \exp\left\{-\frac{(y_{i,k}-b_{-1,m})^2}{2\sigma^2}\right\}}$$

$$y_{i,k} = \begin{cases} a_{i,k}e^{-j\theta_{i,k}}\sqrt{E_{i,k}}s_{i,k} + n_{i,k} & \text{without HP collisions} \\ a_{i,k}e^{-j\theta_{i,k}}\sqrt{E_{i,k}}s_{i,k} + \sum\limits_{l=1,l\neq i}^{L} a_{l,k}e^{-j\theta_{l,k}}\sqrt{E_{l,k}}s_{l,k} + n_{i,k}, & \text{with an HP collision} \end{cases} \quad (1)$$

$$\simeq \log \frac{\max_m \left[\exp \left\{ -\frac{(y_{i,k}-b_{+1,m})^2}{2\sigma^2} \right\} \right]}{\max_m \left[\exp \left\{ -\frac{(y_{i,k}-b_{-1,m})^2}{2\sigma^2} \right\} \right]}, \quad (3)$$

where $b_{+1,m}$ and $b_{-1,m}$ represent the realization of the received symbols conditionally $s_{i,k} = +1$ and $s_{i,k} = -1$, respectively. The approximation in Eq. (3) results from a well-known exponential approximation given as [13]:

$$\sum_i A_i \exp(B_i) \approx \max_i A_i \exp(B_i). \quad (4)$$

We illustrate the LLR value of the k-th symbol of the i-th user in Eq. (3). As we noted in Eq. (1), there can be L data symbols including the data symbol of the i-th user when an HP collision occurs. For the remaining $L-1$ symbols, the same LLR computation is required. For example, when two users experience the same code collision ($L = 2$) and the other user is assumed to be the l-th user, the LLR for $s_{i,k}$ is expressed as Eq. (5). The LLR can be similarly derived for QPSK or high order modulations. The complexity of LLR computation exponentially increases as the modulation order increases. However, the receiver, i.e., BS can support the complexity in general.

When a transmit power control (TPC) technique is applied to MSs, the term $\left(a_{i,k} \cdot \sqrt{E_{i,k}}\right)$ becomes a constant at the BS in a slow fading environment. If the channel varies faster than the TPC interval (fast fading environment), then the received power at the BS may keep track of the average path-loss due to the propagation loss and shadowing. In this section, we consider the signal model in single cell environment, and thus the TPC technique also consider the received signal power, while typical TPC scheme keep the received signal-to-interference-and-noise (SINR) to be maintained in practical systems.

When an HP collision occurs, the LLR computation method for the above OCHMA scheme can be regarded as a kind of multi-user detection (MUD) technique and its computational complexity may be increased at the BS [14]. The MUD complexity increases exponentially as the number of the involved MSs increases and the probability of detection error also increases as the number of involved MSs increases. However, in the OCHMA scheme, the MUD technique is required only when the HP collision occurs among MSs, while the MUD technique is required for all symbols in the conventional PN-based uplink scheme. Furthermore, most HP collisions occurs between two MSs in the OCHMA scheme and the complexity of MUD in the OCHMA scheme is much lower than that of the conventional MUD scheme because all active users are involved in the conventional MUD scheme for all symbols.

Basically, we do not need to assume that multi-cells coordinate or synchronize each other for the proposed scheme, because the proposed scheme only requires that the users in a cell are synchronized. Uplink soft handover is an important mechanism for most (W)CDMA systems. However, as for the soft handover case, we need to consider the received signal from the specific user at multiple cells. The user in soft handover process cannot make his signal be received with other users' signals at the same time in both cells. Hence, the challenging issues of soft handover in the proposed scheme are left and the mathematical analysis and numerical results proposed in this paper are valid only for hard handover cases. Despite this, in data services which are main target services in this paper, hard handover will be enough to satisfy the quality-of-service (QoS).

B. OCHMA vs OCHM

An orthogonal code hopping multiplexing (OCHM) system [12], [13], [16] has been proposed to accommodate a larger number of mobile stations (MSs) with bursty traffic than the number of orthogonal codes in ***downlink***. In downlink, if an HP collision is present, a BS examines the user data experiencing the HP collision and determines whether all user data with the same HP collision are identical or not. If all the corresponding data are identical, all the colliding symbols of different users are transmitted with a sum of all symbol energies (synergy). On the other hand, if all data with the same HP collision are not identical, then all the corresponding data symbols are not transmitted during the symbol time (perforation). This type of HP collision control is possible because the BS has all the data toward all MSs in downlink. An MS does not know which symbol experiences the HP collision and decodes its data regardless of HP collisions in this case. If the MS knows the probability of the HP collision in a specific frame, the *LLR conversion* scheme [13] can be used for a channel decoder at the recever (MS). However, the MS does not still know which symbol experiences HP collision and it uses the possibility of the HP collision to compute the LLR.

On the other hand, the transmitter (each MS) cannot know which symbol experiences an HP collision because it does not know the HP of other transmitters (other MSs) and their data transmission at a specific time in ***uplink***. Hence, each MS cannot control the HP collision and transmits the data without consideration about the HP collision. Since a BS is assumed to keep track of the HPs of all MSs in its own cell, and to know which MS transmits data in the uplink, the BS can exactly detect which symbol experiences an HP collision when the BS receives uplink frames from MSs. If the BS detects an HP collision, then it computes the exact LLR for the symbol using Eq. (3). The computed LLR values are delivered to the decoder and the information bits are obtained through the decoding process.

C. Hopping Pattern Collision Probability

When HPs are randomly generated, the HP collision probability of the OCHMA system based on random hopping (RH) is expressed as:

$$P_c^{RH} = 1 - \left(1 - \frac{\bar{\upsilon}}{N_{OC}}\right)^{M-1}, \quad (6)$$

where $\bar{\upsilon}$ is the average user channel activity [12], N_{OC} is the available number of orthogonal codes (OCs) in the uplink, and M is the number of users having connections in a cell. If we use a CFG-based hopping scheme, the HP collision probability is derived as:

$$P_c^{GH} = \frac{M - N_{last}}{M} \left\{ 1 - (1-\bar{\nu})^{\left\lfloor \frac{M}{N_{OC}} \right\rfloor - 1} \cdot \left(1 - \frac{\bar{\nu} N_{last}}{N_{oc}}\right) \right\} + \frac{N_{last}}{M} \left\{ 1 - (1-\bar{\nu})^{\left\lfloor \frac{M}{N_{OC}} \right\rfloor} \right\} \quad (7)$$

$$\Lambda(s_{i,k}) = \log \frac{\exp\left\{-\frac{(y_{i,k}-\sqrt{E_{i,k}}a_{i,k}e^{-j\theta_{i,k}}-\sqrt{E_{l,k}}a_{l,k}e^{-j\theta_{l,k}})^2}{2\sigma^2}\right\} + \exp\left\{-\frac{(y_{i,k}-\sqrt{E_{i,k}}a_{i,k}e^{-j\theta_{i,k}}+\sqrt{E_{l,k}}a_{l,k}e^{-j\theta_{l,k}})^2}{2\sigma^2}\right\}}{\exp\left\{-\frac{(y_{i,k}+\sqrt{E_{i,k}}a_{i,k}e^{-j\theta_{i,k}}-\sqrt{E_{l,k}}a_{l,k}e^{-j\theta_{l,k}})^2}{2\sigma^2}\right\} + \exp\left\{-\frac{(y_{i,k}+\sqrt{E_{i,k}}a_{i,k}e^{-j\theta_{i,k}}+\sqrt{E_{l,k}}a_{l,k}e^{-j\theta_{l,k}})^2}{2\sigma^2}\right\}}. \quad (5)$$

where each CFG is allocated to N_{OC} users and N_{last} is the remaining number of users allocated in the last CFG. For a given average user channel activity $\bar{\upsilon}$, the collision probability increases as the number of active users increases. As the collision probability increases, the required E_b/I_0 also increases and simulation results will be shown in Section IV.

III. Capacity Approximation of the OCHMA System

We derive the expected uplink capacity of the OCHMA scheme. We assume that all users are operated with the same transmission bit rate. Noise rise (NR) at the BS is known to be a robust measure of the uplink load of CDMA systems, and it is defined as $\zeta = P_{tot}/P_{noise}$ where P_{tot} denotes the total average received power at a BS and P_{noise} represents the thermal noise power at the BS. The uplink loading factor can be expressed as $\eta = (\zeta-1)/\zeta$ [17]. The total average received power of the OCHMA scheme at the BS can be expressed as

$$\begin{aligned} P_{tot} &= P_{own} + P_{other} + P_{noise} = P_{own}(1+\delta) + P_{noise} \\ &= \bar{\upsilon} N_{OCHMA} \cdot P_{OCHMA}(1+\delta) + P_{noise}, \end{aligned} \quad (8)$$

where P_{own} and P_{other} denote the received power from its own-cell and the received power from other cells, respectively, and δ denotes the ratio of P_{other} to P_{own}. P_{own} is equal to $\bar{\upsilon} N_{OCHMA} \cdot P_{OCHMA}$, where $\bar{\upsilon}$, N_{OCHMA}, and P_{OCHMA} represent the average user channel activity, the number of users in a cell, and the received power from each user, respectively. On the other hand, the required E_b/I_0 in the OCHMA scheme is written as:

$$\gamma_H = \frac{G \cdot P_{OCHMA}}{P_{tot} - \alpha P_{own}} = \frac{G \cdot P_{OCHMA}}{P_{tot} - N_{OCHMA} P_{OCHMA} \bar{\upsilon} \alpha}, \quad (9)$$

where α indicates the orthogonality factor and G represents the processing gain [11], [17]. Using Eq. (9), Eq. (8) can be rewritten as:

$$\begin{aligned} P_{tot} &= N_{OCHMA} \cdot \frac{\bar{\upsilon}\gamma_H P_{tot}}{G + \gamma_H N_{OCHMA} \bar{\upsilon} \alpha} \cdot (1+\delta) \\ &\quad + P_{noise}. \end{aligned} \quad (10)$$

Therefore, the NR of the OCHMA scheme is given as:

$$\zeta_{OCHMA} = \left[1 - (1+\delta)\frac{\gamma_H N_{OCHMA} \bar{\upsilon}}{G + \gamma_H N_{OCHMA} \bar{\upsilon} \alpha}\right]^{-1} \quad (11)$$

In general, the required E_b/I_0 for satisfying a certain error requirement depends on many parameters such as modulation and coding scheme (MCS), wireless channel condition, channel coding scheme, and so on. In the OCHMA scheme, the required E_b/I_0, γ_H, increases as the HP collision probability increases when the other parameters affecting the error performance are fixed. Hence, when the number of users in a cell increases, the HP collision increases and the required E_b/I_0 increases. This causes an increase in the NR value of the OCHMA scheme.

The NR of the conventional asynchronous uplink CDMA which uses pseudo-noise (PN) sequences is expressed as [17]:

$$\zeta_{PN} = \left[1 - (1+\delta)\frac{\gamma_D N_{PN} \bar{\upsilon}}{G}\right]^{-1}, \quad (12)$$

where γ_D denotes the required E_b/I_0 which is equivalent to the required E_b/I_0 in the OCHMA system without HP collisions. Furthermore, the NR of the MSC-based uplink-synchronized CDMA system is expressed as [11]:

$$\zeta_{MSC} = \left[1 - (1+\delta)\sum_{j=1}^{J} \frac{\gamma_D N_{MSC}^j \bar{\upsilon}}{G + \gamma_D N_{MSC}^j \bar{\upsilon}\alpha}\right]^{-1}, \quad (13)$$

where J is the number of scrambling code groups within a cell ($J = \lceil M/N_{OC} \rceil$) and N_{MSC}^j indicates the number of users under scrambling code group j. For example, if the number of users in a cell and the number of available OCs in a cell are set to $M = 80$ and $N_{OC} = 64$, respectively, J is equal to 2, $N_{MSC}^1 = 64$, and $N_{MSC}^2 = 16$. Therefore, $N_{MSC}^j = N_{OC}(1 \le j \le J-1)$ for a given J.

The capacity gain of the OCHMA scheme over the conventional uplink-asynchronous CDMA scheme is expressed as:

$$\begin{aligned} C_{gain}^{OCHMA} &= \frac{C_{OCHMA} - C_{PN}}{C_{PN}} \\ &= \frac{R_b \bar{\upsilon} N_{OCHMA} - R_b \bar{\upsilon} N_{PN}}{R_b \bar{\upsilon} N_{PN}} \\ &= \frac{N_{OCHMA} - N_{PN}}{N_{PN}}, \end{aligned} \quad (14)$$

where R_b represents the information bit rate of each user. N_{OCHMA} is derived from Eq. (11) for a given uplink loading factor (η^*). N_{OCHMA}, N_{PN}, and C_{gain}^{OCHMA} are expressed as:

$$N_{OCHMA} = \frac{\eta^* G}{[(1+\delta) - \eta^*\alpha]\gamma_H \bar{\upsilon}}, \quad (15)$$

$$N_{PN} = \frac{\eta^* G}{(1+\delta)\gamma_D \bar{\upsilon}}, \quad (16)$$

and

$$C_{gain}^{OCHMA} = \frac{1+\delta}{\frac{\gamma_H}{\gamma_D}(1+\delta-\eta^*\alpha)} - 1. \quad (17)$$

Therefore, the ratio γ_H/γ_D should be minimized in order to maximize the capacity gain of the OCHMA system. Furthermore, the capacity gain of the OCHMA system increases as the orthogonality factor increases.

Similarly, the capacity gain of an MSC-based uplink-synchronized CDMA system over the conventional uplink-asynchronous CDMA scheme is given as [11]:

$$C_{gain}^{MSC} = \frac{1+\delta}{\eta^*}\left[\frac{\gamma_D \bar{\upsilon}}{G} \cdot N_{OC}(J-1) + \frac{\eta_J}{1+\delta-\eta_J\alpha}\right] - 1, \quad (18)$$

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Channel coding scheme	Convolutional codes
Code rate	1/3
Coding block size	640 bits
Modulation scheme	BPSK
Wireless channel	Rayleigh fading channel
Number of receiver antennas	1
Receiver type	LLR-based optimal receiver proposed in Eqs. (2) and (3)

where

$$\eta_J = \eta^* - \frac{(1+\delta)\gamma_D \bar{\upsilon} N_{OC}(J-1)}{G + \gamma_D \bar{\upsilon} \alpha N_{OC}}. \qquad (19)$$

IV. NUMERICAL EXAMPLES

We perform link-level simulations for evaluating the BER performance of the OCHMA system. The detailed simulation parameters are summarized in Table I.

Fig. 2 shows the BER performance of a convolutional code (CC) in the OCHMA-based system when the channel is slowly varying. In this case, the transmit power control (TPC) scheme works well and the channel is assumed to be perfectly known to the receiver (BS). A single-path fading channel is assumed. We use a convolutional code with a code rate of $1/3$ and a constraint length of 9 ($K = 9$) using a generator polynomial $(557, 663, 711)$ in octal number. The convolutional code introduced above was used in the IS-95 uplink system [18]. The solid line represents the BER performance of the CC in case that $P_c = 0$, and the solid lines with marks represent the BER values for $P_c > 0$. The BER values increase as the collision probability increases. When the P_c value is set to 0.5, the additional required E_b/I_0 is approximately 1.0dB for a BER of 10^{-4}. As the number of active users in a cell increases, the required E_b/I_0 increases. Thus, the channel coding performance is important in the performance of the OCHMA system.

Fig. 3 shows the BER performance of a CC in the OCHMA-based system when the channel is fast varying. In this case, we assume that the channel varies fast, in other words, the fading coefficient varies independently for each modulated symbol. The channel coefficient is also assumed to be perfectly known to the receiver. The receiver computes the LLR value of each modulated symbol using the Eqs. (2) and (3). The required E_b/I_0 increases due to the fast fading, compared to the performance in Fig. 2. However, the additional E_b/I_0 because of the HP collision is similar to that of the slow-fading case. When the P_c value is set to 0.5, the additional required E_b/I_0 is approximately 1.0dB for a BER of 10^{-4}.

Fig. 4 compares the NR values of the OCHMA scheme with that of the conventional schemes when the average user channel activity values are set to 0.5 and 0.2. This result is obtained by applying the results in Figures 2 and 3 to Eqs. (11), (12), and (13). By using Figs. 2 and 3, we can estimate the required E_b/I_0 (γ_H) for a given HP collision probability. When we compute the NR for a given number of users in a cell in Fig. 4, we first estimate the HP collision probability for a given number of users in a cell using the Eqs. 6 and 7, and then, compute the required E_b/I_0 (γ_H) according to the HP collision probability using the results of Figs. 2 and 3. Finally, the NR is obtained by applying the estimated γ_H for a given number of users to Eqs. (11), (12), and (13).

In the OCHMA scheme, HPs can be randomly generated (random hopping, RH) or in a collision-free group-based manner (group hopping, GH). The group hopping-based OCHMA scheme yields the best performance. As the number of users in a cell increases, the required E_b/I_0, γ_H, increases in the OCHMA schemes, while the intra-cell interference increases in the conventional uplink schemes. Note that the performance gain of the OCHMA scheme increases as the average user channel activity decreases. Therefore, the OCHMA scheme can be more effective when the channel activity of data traffic is relatively low. Furthermore, a code-limited situation occurs more frequently when the user channel activity is low and the user traffic is bursty.

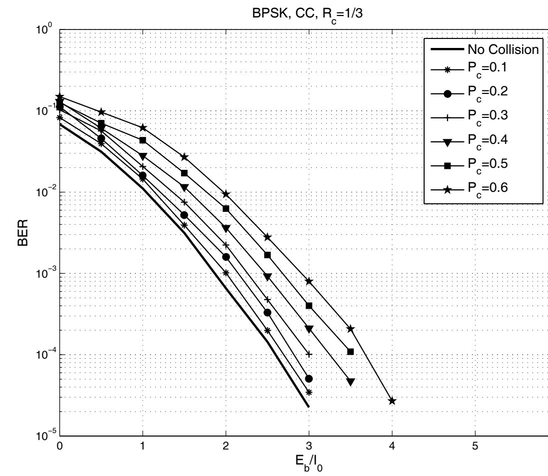


Fig. 2. BER performance of CC with $K = 9$ and $R_c = \frac{1}{3}$ in a slow fading environment.

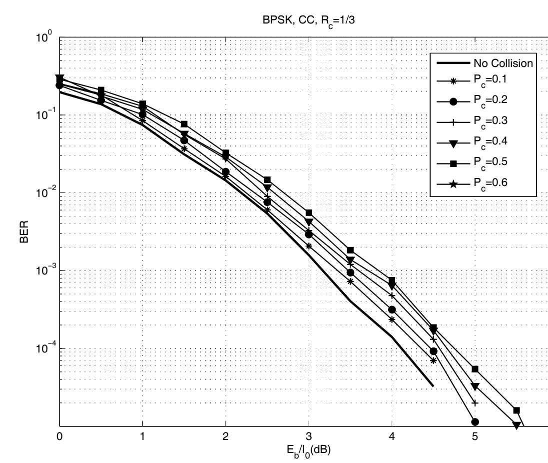
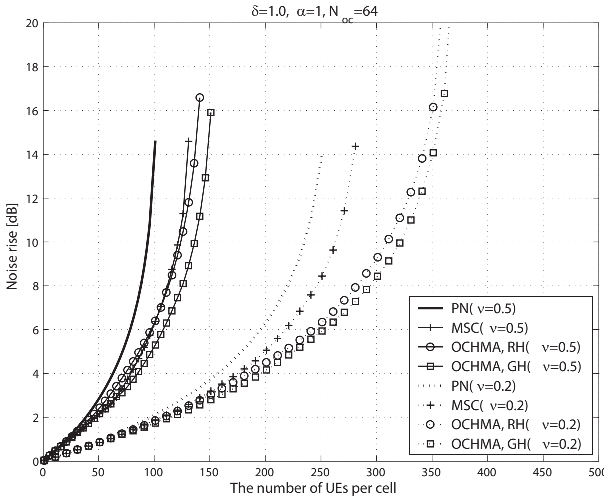
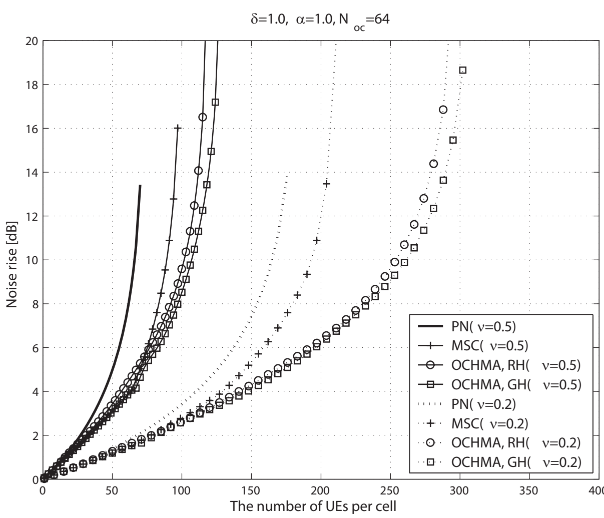


Fig. 3. BER performance of CC with $K = 9$ and $R_c = \frac{1}{3}$ in a fast fading environment.



(a) Slow fading channel



(b) Fast fading channel

Fig. 4. Noise rise of the OCHMA scheme according to the number of users in a cell.

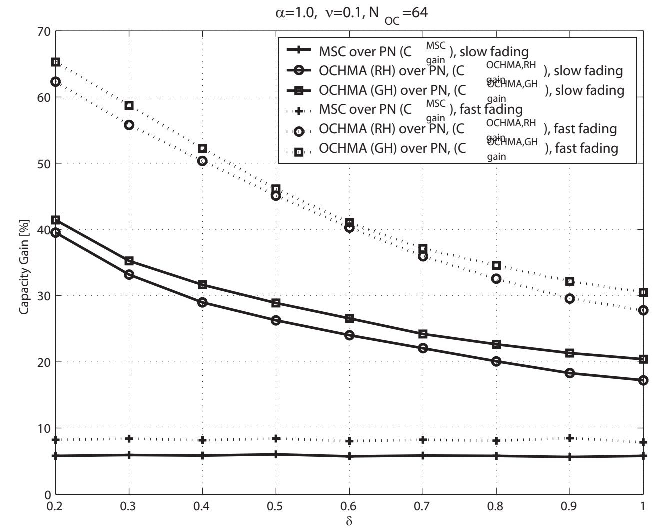


Fig. 5. Capacity gain of both the OCHMA system and the MSC-based CDMA system over the conventional asynchronous-uplink CDMA scheme.

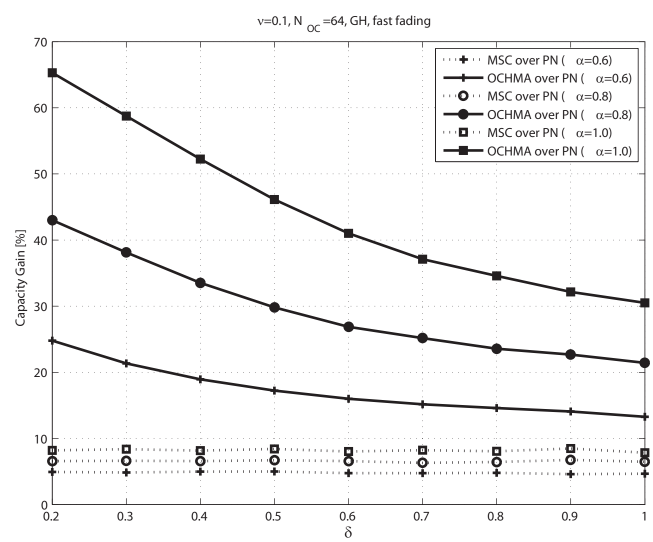


Fig. 6. Effect of orthogonality on the capacity gain of both the OCHMA system and the MSC-based CDMA system.

Fig. 5 shows the capacity gains of both the OCHMA scheme (C_{gain}^{OCHMA}) and the MSC-based synchronous-uplink scheme (C_{gain}^{MSC}), compared with that of the conventional asynchronous-uplink CDMA system. The result of Fig. 5 can be obtained by applying the results of Fig. 4 to Eqs. (17) and (18). The target NR value is set to 4dB [17]. The capacity gain of the OCHMA scheme is larger than for the MSC-based scheme regardless of the ratio of other-cell interference to the inner-cell interference (δ). When $\delta = 0.6$, C_{gain}^{OCHMA} with GH is approximately 41% for fast fading channels, while C_{gain}^{MSC} is approximately 8%. The capacity gain for slow fading channels is little lower than that for fast fading channels. C_{gain}^{MSC} has a nearly constant value for varying the proportion of other-cell interference (δ). However, C_{gain}^{OCHMA} decreases as the proportion of other-cell interference (δ) increases. Note that there is much less of a relative gain between RH and GH, which might imply that the actual code hopping scheme that is used does not make a significant difference to the performance, even though the OCHMA scheme provides a noticeable gain over the other schemes that it is compared against.

Fig. 6 shows the effect of the orthogonality factor on the capacity gain of both the OCHMA system and the MSC-based CDMA system. The orthogonality factor decreases as the multipath fading becomes severe. As we noted in Section III, the capacity gain decreases as the orthogonality factor decreases. The proposed OCHMA system still outperforms the MSC-based CDMA system. However, it is more sensitive to the orthogonality factor.

V. Conclusions

In this letter, we propose an OCHMA system in order to improve the capacity of the synchronized-uplink CDMA systems under channelization codes restriction. Since the synchronized-uplink CDMA system utilizes orthogonal codes for user channelization, the user capacity can be limited due to the available number of orthogonal codes. The OCHMA scheme can overcome the code-limited situation by allowing HP collisions among users. However, HP collisions increase the required E_b/I_0 at a BS in the OCHMA system. The

OCHMA scheme yields a larger capacity than the MSC-based synchronized-uplink scheme, especially in an environment with low user-channel activity, low other-cell interference, low dispersive wireless channel. In this correspondence, we focused on the fixed resource allocation scheme in the proposed OCHMA system and the conventional systems. When a dynamic OC or power allocation scheme can be applied to both the conventional CDMA systems and the proposed OCHMA system, it can improve the performance of those systems. We leave it for further study.

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