Downlink Capacity Improvement Through Orthogonal Code Hopping Multiplexing and Multiple Scrambling Codes in CDMA Systems

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Abstract— **We compare the performance of the downlink capacity improvement schemes based on orthogonal code hopping multiplexing (OCHM) and multiple scrambling codes (MSC). Both OCHM and MSC have been proposed in order to overcome a code-limitation problem in CDMA downlink. However, both schemes exhibit different characteristics. In order to increase user capacity in CDMA downlink, OCHM allocates a random hopping pattern using a set of orthogonal codes instead of orthogonal code for each connection and MSC allocates a non-orthogonal codeword to each connection. In the OCHM scheme, *hopping pattern (HP) collisions* may degrade the system performance. The HP collisions in OCHM systems differ from the *hits* in frequency-hopping (FH) systems because it can be effectively controlled through synergy and perforation techniques. In OCHM, the receiver requires additional energy for a given frame error rate (FER) due to the HP collision. In the MSC scheme, *inner-cell interference* is induced by non-orthogonal codewords and it degrades the performance. Numerical examples show that the OCHM-based system is more effective than the MSC-based system.**

I. Introduction

Packet-type services, such as HTTP, FTP, and WAP, have gradually increased and may become dominant in future wireless communication systems. In contrast to voice traffic, these packet-based services have different characteristics. First, they exhibit high burstiness with low activity and second, packet-based traffic is generally concentrated on the downlink since mobile users often demand information from servers. Based on these characteristics, the demand for downlink code channels will increase for packet-based services in 3G and beyond 3G systems. However, orthogonal code allocation/de-allocation mechanisms in conventional CDMA systems are very inefficient for accommodating the bursty downlink packet-type traffic if code channels are allocated to mobile stations (MSs) by a base station (BS) at each session setup, and are released from the connection after each session termination. Many inactive periods of bursty traffic cause a waste of orthogonal code channels and the increased demand for orthogonal code channels may result in a lack of orthogonal codewords in spite of remaining BS power.

An orthogonal code hopping multiplexing (OCHM) system [1]–[5] has been proposed to accommodate a large number of mobile stations (MSs) with bursty traffic than the number of orthogonal codewords in downlink. It utilizes statistical multiplexing for orthogonal downlink in DS-CDMA systems. Since each MS 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 MS specific number, such as electronic serial number (ESN) and HP collisions among MSs may occur.

When an HP collision among MSs occurs in the conventional FH-CDMA systems, it is considered as an inevitable interference (*hit*) in case that all MSs are asynchronous with one another [6]. However, the HP collision can be detected and controlled by BS in a synchronous downlink environment. If an HP collision occurs in OCHM systems, BS compares 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, the collision does not need to be controlled and all the colliding symbols of different users are transmitted with a sum of all symbol energies, which results in an energy gain at the receiver. This effect is called *synergy* [1]. On the contrary, if all data with the same HP collision are not the same, all the corresponding data symbols are not transmitted during the symbol time. This effect is called *perforation*. Thus, in OCHM systems, the HP collision does not cause intra-cell interference (ICI), but perforation results in information loss. However, it can be recovered by a proper channel coding technique with additional energy. Therefore, HP collisions in OCHM systems also differ from the ICI, which is characterized by the cross-correlation function between non-orthogonal codewords, in the uplink of DS-CDMA systems.

Another method to overcome the code limited situation is to use multiple scrambling codes (MSC) [7]. It accommodates more MSs than the number of orthogonal codewords in downlink by using additional non-orthogonal code sequences. The MSC schemes [8] are specified in the WCDMA system and another type of multiple scrambling codes called quasi-orthogonal function (QOF) [9] is used in the cdma2000 (IS2000) system, in order to enhance the system capacity. MSC sets are generated by different masks multiplied by a Walsh code set. For example, the cdma2000 system specifies four different MSC sets each of which is generated by a distinct mask. Each mask corresponds to a row in a Walsh matrix of size 256. The masks selected by the cdma2000 standard are optimal in the sense that they minimize the cross-correlation between the generated MSCs and regular Walsh codes with the same length. Generally, MSC sets are found by exhaustive searches for this purpose [10]–[12]. As the number of MSC sets increases, the inner-cell interference also increases. Thus, it is obvious that the number of available MSC sets should be limited due to the corresponding inner-cell interference.

In this paper, we analyze the user capacity of OCHM-based systems and compare it with the user cpacity of MSC-based systems in terms of various factors, such as user activity, the amount of outer-cell interference, orthogonality factor, and sectorization factor. The remainder of this paper is organized as follows: The user capacity of OCHM-based systems is analyzed in Section II. Numerical examples of user capacities of both systems are described in Section III. Finally, conclusions are presented in Section IV.

II. Downlink User capacity of OCHM-Based Systems

A. OCHM Mechanism, HP collisions, Perforation, and Synergy

The OCHM-based system utilizes a synergy and perforation scheme for HP collision control at BS. Fig. 1 shows the block diagram of the OCHM-based system deploying the synergy and perforation scheme. Furthermore, both the transmitted and received power levels for the specific user are shown. T_s denotes the symbol time. Each user changes the orthogonal codeword (OC) according to HP at each symbol time, during which an HP collision may occur. However, most of users may be inactive because of low channel activities when they demand data services. Users b and d are inactive in Fig. 1, but they follow their HPs during their sessions. 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 an HP collision among the *active* users occurs, a BS compares user data experiencing the HP collision and determines whether all user data with the same HP collision are the same or not. If all the corresponding data are the same, all the corresponding data symbols are transmitted with synergy, which results in an energy gain at the receiver. On the contrary, if all data with the same HP collisions are not the same, all the corresponding data symbols are not transmitted, in other words, perforated, during the symbol time. For example, user e experiences a synergy at $(n+2)T_s$ and a perforation at $(n+4)T_s$.

When a user experiences a synergy, BS allocates power to the user without any change. However, all the symbols experiencing the same synergy have an additional energy at the receivers because of other users' energy added by despreading process using the same OC. When a user experiences a perforation, BS does not allocate power to the perforated symbol and, thus, the user detects only noise during the perforated symbol time. Hence, the perforation degrades BER

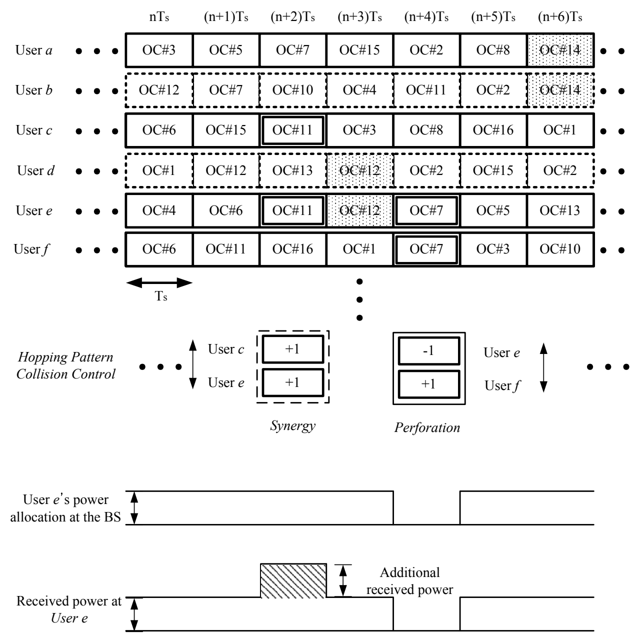

Fig. 1. Block diagram of the OCHM system

performance and additional energy may be required to trasmit for a target BER.

If an HP is randomly generated, the HP collision probability of the random-hoping OCHM-based system is expressed as:

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

where $\bar{\upsilon}$ is the channel activity, N_{OC} is the number of orthogonal codewords, and M is the number of users in a cell. For a given channel activity $\bar{\upsilon}$, P_c increases as the number of active users increases. The perforation probability of encoded symbols in the conventional random-hoping OCHM-based systems is written as:

$$P_p^{RH} = 1 - \left(1 - \frac{s-1}{s} \cdot \frac{\bar{\upsilon}}{N_{OC}}\right)^{M-1}, \tag{2}$$

where s is the number of symbol locations per dimension ($s = 2$ for BPSK and QPSK modulations).

Hence, the synergy probability is given as:

$$P_s^{RH} = P_c^{RH} - P_p^{RH}. \tag{3}$$

Recently we have proposed a new code hopping method to mitigate HP collision effect, which is called a group-mode hopping (GH) strategy [14]. In the GH strategy, the down-link channels are divided into collision-free groups (CFGs), and there are $\lfloor \frac{M}{N_{OC}} \rfloor$ groups with N_{OC} orthogonal code-words within each group, and one last group with a size of $\left(M - \lfloor \frac{M}{N_{OC}} \rfloor \cdot N_{OC}\right)$, if the size is not equal to zero. Within a CFG, the exclusively assigned HPs do not collide each other. In other words, they prevent intra-group collisions. Thus, HP collisions occur only among users in different CFGs. If we use a group-mode hopping strategy, Eq. (1) through Eq. (3)

can be rewritten as:

$$P_c^{GH} = \left\{1-(1-\bar{\nu})^{\left\lfloor \frac{M}{N_{OC}}\right\rfloor -1}\cdot\left(1-\frac{\bar{\nu}N_{last}}{N_{oc}}\right)\right\} + \frac{N_{last}}{M}\left\{1-(1-\bar{\nu})^{\left\lfloor \frac{M}{N_{OC}}\right\rfloor}\right\} \quad (4)$$

$$P_p^{GH} = \left\{1-\left(1-\frac{s-1}{s}\cdot\bar{\nu}\right)^{\left\lfloor \frac{M}{N_{OC}}\right\rfloor -1}\cdot\left(1-\frac{s-1}{s}\cdot\frac{\bar{\nu}N_{last}}{N_{oc}}\right)\right\} \cdot\left(\frac{M-N_{last}}{M}\right)+\frac{N_{last}}{M}\left\{1-\left(1-\frac{s-1}{s}\cdot\bar{\nu}\right)^{\left\lfloor \frac{M}{N_{OC}}\right\rfloor}\right\} \quad (5)$$

$$P_s^{GH} = P_c^{GH} - P_p^{GH}, \quad (6)$$

where N_{last} is the number of users in the last CFG. The GH strategy reduces the HP collision probability in the given M.

B. BER Performance of the OCHM system

We first consider the coded bit error probability of the OCHM system with a convolutional code (CC). CC is one of the most commonly used channel coding schemes in wireless communication systems. We assume that BPSK modulation is used for transmitting symbols over an AWGN channel with one-sided power spectral density N_0. For a soft-decision Viterbi decoder the bit-error probability bound in OCHM systems with the convolutional code is expressed as [15]:

$$P_{b,CC}^{OCHM} < \sum_{d=d_{free}}^{\infty} B_d \sum_{i=0}^{d} \binom{d}{i} (1-P_p)^i P_p^{d-i} \cdot Q\left(\sqrt{\frac{2i^2 R_c E_b}{dN_0(1-P_p)}}\right) \quad (7)$$

where B_d and R_c denote the total number of non-zero information bits on all weight-d codewords and the code rate, respectively. d_{free} indicates the free distance of CC.

When a turbo code (TC) is used for the OCHM system, we can approximate the bit error probability using error floor analysis or truncated union bound analysis. Basically, the bit error probability analysis of TC is similar to that of the CC case except the computation of distance spectrum coefficients. From the previous analysis of the CC, the bit error probability of TC is expressed as:

$$P_{b,TC}^{OCHM} \approx \frac{B_{d_{free}}}{L_{frame}} \cdot \sum_{i=0}^{d_{free}} \binom{d_{free}}{i} (1-P_p)^i P_p^{d_{free}-i} \cdot Q\left(\sqrt{\frac{2i^2 R_c E_b}{d_{free} N_0(1-P_p)}}\right), \quad (8)$$

where L_{frame} and $B_{d_{free}}$ indicate the frame length and the information bit multiplicity of the free distance, respectively.

A reasonable approximation for FER of a channel coding scheme is given by

$$FER \simeq 1-(1-P_b)^{L_{frame}} \simeq P_b \cdot L_{frame}, \quad (9)$$

where $P_b(P_b \ll 1)$ denotes the bit error probability of a channel coding scheme.

C. Downlink power allocation for the OCHM system

In the OCHM system, the downlink power which is allocated for a specific MU is determined by the perforation probability, P_p, as well as the channel environment. The perforation probability varies according to both the number of users in a cell and the user activity at the specific time. In downlink, BS can know the exact number of perforated symbols in a frame of each MU at the time. Through the BER performance analysis shown in Section II-B, BS can determine the allocated power for a specific MU in downlink. If the BER or FER performance analysis does not exist, the link-level simulation results are required in each case.

The additional required E_b/N_0 at an MS due to perforations can be expressed as:

$$\Delta(E_b/N_0) = f(FER_{req}, P_p) - f(FER_{req}, 0), \quad (10)$$

where $f(A,B)$ denotes the function of the required E_b/N_0 at MU for given requirements: $FER_{req} = A$ and $P_p = B$, and it is derived from Eqs. (7), (8), and (9). The last term in Eq. (10) indicates the required E_b/N_0 for $P_p = 0$. FER_{req} denotes the required FER at receiver. The allocated symbol power for a specific MS at BS is determined as:

$$P_T = \frac{f(FER_{req}, P_p)\cdot \mu R_c \cdot I_{total}}{T_s \cdot L_{path}}, \quad (11)$$

where μ, I_{total}, T_s, and L_{path} denote the encoded bits per modulated symbol, the total interference at MS, the symbol time, and the path-loss between BS and the MS, respectively. As P_p increases, the required energy at the receiver, $f(FER_{req}, P_p)$, increases and the allocated power, P_T, also increases.

D. User capacity analysis

Recently, we have analyzed the downlink user capacity of the OCHM system and have compared it with the user capacity of the conventional CDMA system [4]. In [4], we defined code and power capacities independently like as the conventional CDMA systems. Thus, the overall user capacity is derived as the minimum value of the two capacities. Code capacity of the OCHM system with random hopping is defined as the maximum number of HPs allocated for a given P_p, which is expressed as:

$$M_c^{RH} = 1 + \frac{\ln(1-P_p^{RH})}{\ln\left(1-\frac{(s-1)\cdot\bar{\upsilon}}{s\cdot N_{OC}}\right)}. \quad (12)$$

It is derived from Eq. (2). When we utilize the group mode hopping at BS, the code capacity of the OCHM system is similarly defined by using Eq. (5). Power capacity is defined as the maximum number of users under the condition that the allocated power is less than or equal to the maximum available power at BS, and it is expressed as:

$$M_p \le \frac{E_{s,max}\cdot \bar{L}_{path}}{\bar{\upsilon}\cdot\left(\frac{E_b}{I_0}\right)_{target}^{OCHM}\cdot \mu R_c \cdot I_{total}}, \quad (13)$$

where $E_{s,max}$, $\bar{L}_{path}$, and $(E_b/I_0)_{target}^{OCHM}$ denote the maximum symbol energy for data traffic at BS, the average path-loss at an MS, and the target (E_b/I_0) for a given FER at

TABLE I
SYSTEM PARAMETERS FOR NUMERICAL EXAMPLES.

Parameter	Value	Parameter	Value
ρ	0.2	$E^{(t)}_{s,max}$	$\frac{15\times SF}{1.2288\times 10^6}\,[J]$
N_{oc}	64	N_0	$-174\,[dBm]$
R_e	1000$[m]$	λ	$1, 1/3$
γ	4	β_{QOS}	$\frac{1}{N_{oc}}$
α	$0.7\sim 1$	R_c	$\frac{1}{3}$
N_{adj}	6	μ	2 (QPSK)

MS, respectively. In [4], we have illustrated the user capacity which is the minimum value of Eqs. (12) and (13) for varying $(E_b/I_0)^{OCHM}_{target}$ and P_p. $(E_b/I_0)^{OCHM}_{target}$ was evaluated through computer simulations for several cases in [4]. However, as we noted in Section II-C, the additional required energy at MS increases as P_p increases. The allocated power for a specific MS in downlink at BS also increases as P_p increases. Thus, the $(E_b/I_0)^{OCHM}_{target}$ value in Eq. (13) is dependent on P_p. In fact, $(E_b/I_0)^{OCHM}_{target} = f(FER_{req}, P_p)$ and the power capacity of the OCHM system is expressed as:

$$\tilde{M}_p \leq \frac{E_{s,max}\cdot \bar{L}_{path}}{\bar{\upsilon}\cdot f(FER_{req}, P_p)\cdot \mu R_c \cdot I_{total}}, \qquad (14)$$

where $f(FER_{req}, P_p)$ is determined by the channel coding capability.

In the OCHM system, P_p increases as the number of users in a cell increases and the required E_b/N_0 at MS, $(E_b/I_0)^{OCHM}_{req}$, increases as P_p increases. Thus, the transmitted energy for an MS increases and the user capacity can be limited. As noted before, the required E_b/N_0 at MS, $(E_b/I_0)^{OCHM}_{req}$, is determined by the channel coding capability in the OCHM system. Furthermore, the perforation probability, P_p varies according to the hopping pattern generation method. If we use the group mode hopping instead of the random hopping, we can reduce the P_p value for a given number of users.

III. NUMERICAL EXAMPLES

We assume that the maximum transmission symbol energy of a BS is given by $\frac{15\times SF}{1.2288\times 10^6}\,[J]$ which is typically used for the cdma2000 system, where SF is the spreading factor [9]. In addition, we let the cross-correlation between two code sequences in the different code set be $\frac{1}{\sqrt{N_{oc}}}$ which is the optimal cross-correlation bound. Thus, the interference factor due to the introduction of MSCs is $\beta_{QOS} = \left(\frac{1}{\sqrt{N_{oc}}}\right)^2 = \frac{1}{N_{oc}}$ which is the square value of the cross-correlation. Furthermore, we vary the data channel activity values from 0.1 to 0.5. The system parameters are listed in Table I. Under this environment, we analyze the system from the average point of view. ρ and R_e indicate the proportion of power allocated to common control channels and the cell radius, respectively. γ and α represent the path-loss exponent and the orthogonality factor [16] of the OC. N_{adj} and λ denote the number of adjacent cells and the sectorization factor, respectively. In this paper, we consider the outer-cell interference comes from the first tier cells.

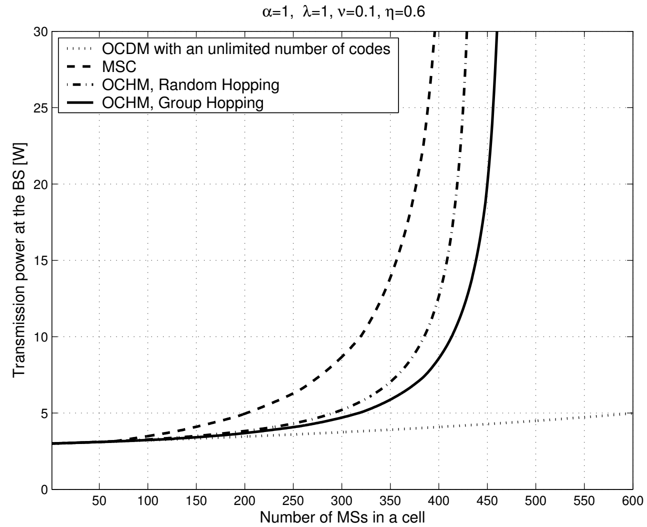

Fig. 2. Downlink transmit power at the BS according to the number of MSs for four different system with CC

A. Required power at the BS of each system

Fig. 2 shows the downlink transmit power at the BS according to the number of MSs in a cell for four different system with CC: orthogonal code division multiplexing (OCDM) with an unlimited number of codes (ideal case), multi-scrambling code system, random hopping-based OCHM, and group hopping-based OCHM. η represents the power ratio between home BS and an other cell BS. All systems require more power at the BS as the number of MSs in a cell increases. The OCHM-based system can be operated in either a group-mode hopping or random hopping. If we use the group-mode hopping, the performance of the OCHM system can be improved. In the MSC-based system, if the number of MSs in a cell is equal to 350, the required power at the BS is larger than $13W$ while it is approximaely $6W$ in the OCHM-based system with group-mode hopping. Therefore, the OCHM-based system yields better performance than the MSC-based system. The dotted line in Fig. 2 represents the performance of the system that has an unlimited number of orthogonal codes. In this system, there exist no code limitation in the downlink and thus, it does not induce any inner-cell interference and additional energy at MS.

Fig. 3 shows another example of the downlink transmit power at the BS for four different system with TC [17]. If we use TC as a channel coding scheme, the performance of the OCHM-based system can be improved since additional energy at MS due to symbol perforations decreases.

B. User capacity comparison

Fig. 4 shows the user capacities of the MSC-based system and the OCHM-based system according to the other-cell interference (η) and channel activity. In Fig. 4, we use the CC as a channel coding scheme. If the channel activity is equal to 0.5 like voice service, the MSC-based system yields better performance than the OCHM-based system with random hopping (RH) patterns. However, as the channel activity decreases, the OCHM-based system with RH patterns yields

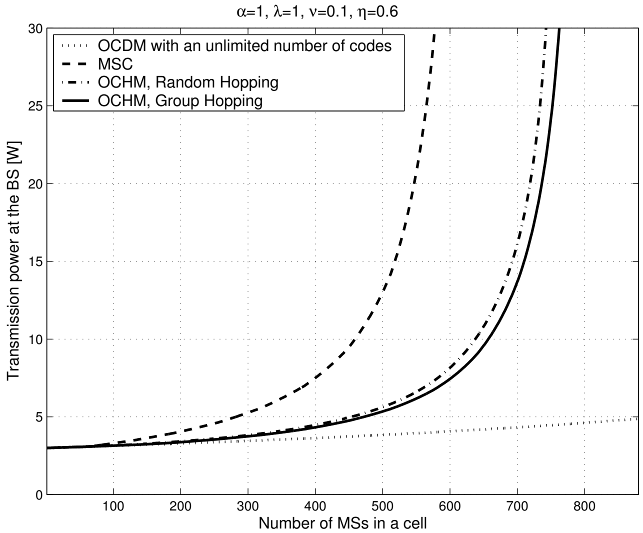

Fig. 3. Downlink transmit power at the BS according to the number of MSs for four different system with TC

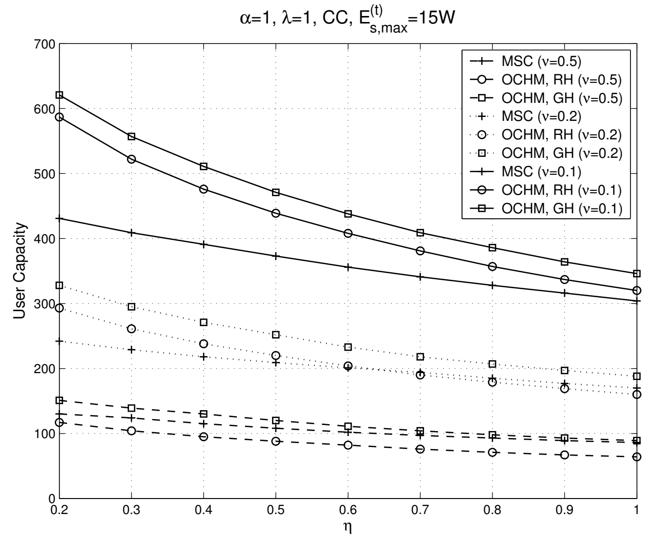

Fig. 4. Downlink user capacity comparison according to other-cell interference (η) and activity (ν) with CC

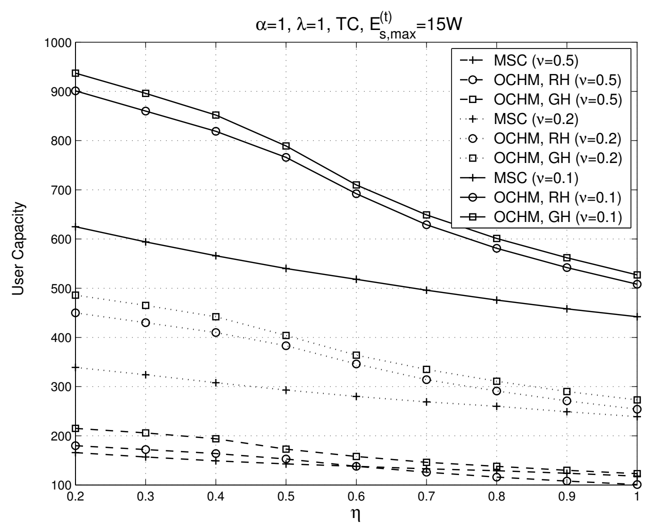

Fig. 5. Downlink user capacity comparison according to other-cell interference (η) and activity (ν) with TC

better performance than the MSC-based system. The OCHM-based system relatively has a larger capacity than the MSC-based system when other-cell interference is small. Since a code-limited situation occurs more frequently when channel activity is low and other-cell interference is small [4], the OCHM-based system is more effective than the MSC-based system. When the other-cell interference is large or the channel activity is high, the power capacity may be smaller than the code capacity, i.e., the maximum number of available codes in a cell. Furthermore, if we use the OCHM-based system with group-mode hopping (GH), the OCHM-based system is better than the MSC-based system regardless of the channel activity. Note that the user capacity of the OCHM-based system with GH is equal to 438 when $\eta = 0.6$ and it is much larger than a code limit of 64 in the conventional CDMA systems.

Fig. 5 shows the downlink user capacities of the MSC-based system and the OCHM-based system when a turbo code is used as a channel code. The OCHM-based system can accommodate more users than the MSC-based system. The OCHM-based system becomes effective as the channel activity decreases. If η is equal to 0.6 and the channel activity is eqaul to 0.1, the downlink user capacities of the MSC-based system, the OCHM-based system with RH, and the OCHM-based system with GH are 518, 692, and 789, respectively. The capacity gain of the OCHM-based system over the MSC-based system decreases as η increases.

The capacity gain of the OCHM-based system over the MSC-based system is defined as:

$$C_{gain}^{OCHM} = \frac{C_{OCHM} - C_{MSC}}{C_{MSC}}, \tag{15}$$

where C_{OCHM} and C_{MSC} indicate the user capacities of the OCHM-based system and the MSC-based system, respectively. Fig. 6 shows the capacity gain of the OCHM-based system over the MSC-based system. In Fig. 6, GH is used as a hopping pattern generation method in the OCHM system. When an omni-antenna is used at BS, capacity gain increases as the channel activity decreases. If η and the channel activity are set at 0.6 and 0.1, respectively. C_{gain}^{OCHM} with CC and TC are equal to 23% and 37%, respectively. When a 3-sector antenna is used at BS, the capacity gain is much larger than that with an omni-antenna. When a 3-sector antenna is used at BS, η is set at 0.6, and channel activity is 0.1, C_{gain}^{OCHM} with CC and TC are equal to 71% and 87%, respectively. The capacity gain increases as we use a more powerful channel coding scheme since the additional energy decreases at MS in the OCHM-based system. Thus, TC is a more attractive coding scheme in the OCHM-based system. Furthermore, the capacity gain decreases as the other-cell interference increases.

Thus far, we assumed that α is equal to 1, that is, orthogonality is perfectly restored among orthogonal codes. In real environments, the orthogonality factor varies according to channel. Fig. 7 shows the capacity gain of the OCHM-based

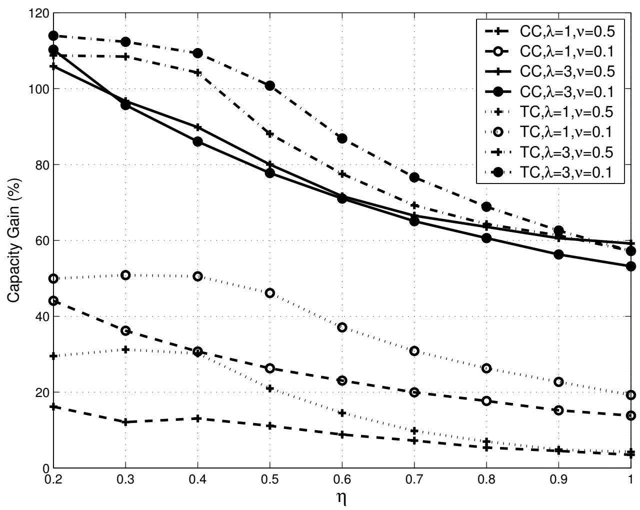

Fig. 6. Capacity gain of OCHM-based system over MSC-based system

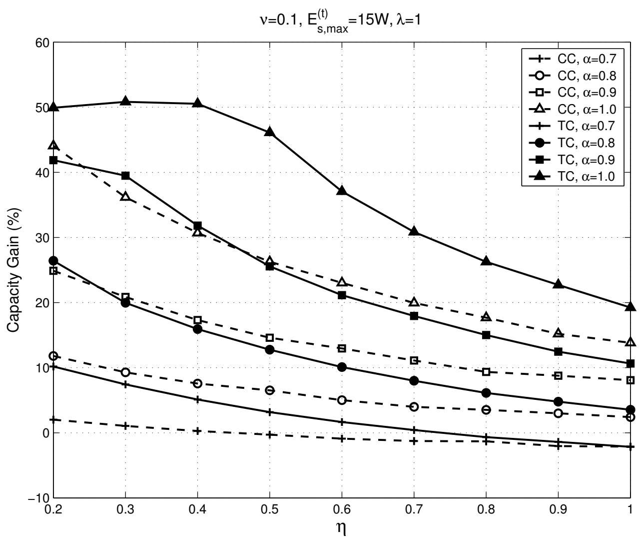

Fig. 7. Capacity gain of OCHM-based system over MSC-based system for varying orthogonality factor

system over the MSC-based system for varying the orthogonality factor (α). The OCHM-based system is more sensitive to the orthogonality factor than the MSC-based system because all active users in the OCHM-based system induce the inner-cell interference due to multi-path fading. In the MSC-based system, the active users in the same code set induce the inner-cell interference due to multi-path fading, but the active users in the different code set induce only the inner-cell interference due to non-zero correlation between different code sets which is independent of orthogonality factor. However, the OCHM-based system yields better performance than the MSC-based system in most situations although the capacity gain decreases as the orthogonality factor decreases.

IV. Conclusions

In this paper, we compared two systems which have been proposed to accommodate more users than the maximum number of available orthogonal codes in CDMA downlink. The OCHM-based system does not induce inner-cell interference but it requires more energy at MS in order to compensate for the information loss in BS. The MSC-based system uses non-orthogonal sequences which involves inner-cell interference for improving the downlink user capacity. Numerical examples show that OCHM-based system can accommodate more users than the MSC-based system. The capacity gain of OCHM-based system increases as the other-cell interference decreases and the channel activity decreases. Thus, the OCHM-based system is a more effective scheme than the MSC-based system considering that a code-limited situation occurs more frequently in the case of low other-cell interference and low channel activity. However, the OCHM-based system is more sensitive to orthogonality factor.

Acknowledgments

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References

[1] S. Park and D. K. Sung, "Orthogonal code hopping multiplexing," *IEEE Communi. Lett.*, Vol. 6, No. 12, pp.529-531, Dec. 2002.

[2] J. K. Kwon, S. Park, and D. K. Sung, "Log-likelihood conversion schemes in orthogonal code hopping multiplexing," *IEEE Commun. Lett.*, Vol. 7, No. 3, pp.104-106, Mar. 2003.

[3] J. H. Chung, S. Park, and D. K. Sung, "Symbol perforation reduction schemes for orthogonal code hopping multiplexing," *IEICE Trans. on Commun.*, Vol. E88-B, No. 10, pp. 4107-4111, Oct. 2005.

[4] S. H. Moon, S. Park, J. K. Kwon, and D. K. Sung, "Capacity improvement in CDMA downlink with orthogonal code hopping multiplexing," *IEEE Trans. on Vehicular Technology*, Vol. 55, No. 2, Mar. 2006.

[5] J. K. Kwon, S. Park, and D. K. Sung, "Collision mitigation by log-likelihood ratio (LLR) conversion in orthogonal code hopping multiplexing," *IEEE Trans. on Vehicular Technology,(Accepted).*

[6] E. A. Geraniotis and M. B. Pursley, "Error probability for slow-frequency-hopped spread-spectrum multipel-access communications over fading channels," *IEEE Trans. Commun.*, Vol. 30, No. 5, pp.996-1009, May 1982.

[7] 'Quasi-Orthogonal Sequences for Code-Division Multiple Access Systems,', *IEEE Trans. on Info. Theory*, Vol. 46, No.3, pp. 982-993, May. 2000.

[8] *'3GPP, Third Generatin Partnerssship Project: Technical Specification Group Radio Access Network,'*, 3GPP TS 25 series, June 2001.

[9] *'TIA/EIA, Physical Layer Standard for cdma2000 Spread Spectrum Systems,'*, 3GPP2 C.S0002 Version 3.0, June 15, 2001.

[10] L. Korowajczk, et al, *Designing cdma2000 Systems*, Wiley, 2004.

[11] A. G. Shanbhag and J. Holtzman., "Optimal QPSK Modulated Quasi-Orthogonal Functions for IS-2000," *IEEE Sixth International Symposium on Spread Spectrum Tech & Appli.,*, Vol. 2, pp. 756-760, Sept. 2000.

[12] J. O. Carnero, K. I. Pederson and P. E. Mogensen, 'Capacity Gain of an Uplink-Synchronous WCDMA System under Channelization Code Constraints,', *IEEE Trans. Veh. Technol.,* Vol. 53, pp. 982-991, July, 2004.

[13] S. Tsai, F. Khaleghi, S. J. Oh and V. Vanghi, 'Allocation of Walsh codes and Quasi-Orthogonal Functions in cdma2000 Forward Link,', *in Proc. of IEEE VTC'01 Fall,* Vol. 2, pp. 747-751, Oct., 2001.

[14] S. H. Moon, S. Park, J. K. Kwon, J. H. Chung, and D. K. Sung, "Group Mode Hopping for Collision Mitigation in Orthogonal Code Hopping Multiplexing," *IEEE Trans. on Vehicular Technology*, (Submitted, Oct. 2005)

[15] B. C. Jung, H. Jin, D. K. Sung and S. Y. Chung, "Performance Analysis of Orthogonal Code Hopping Multiplexing Systems," *IEEE ICC2006*, (Accepted, Jan. 2006)

[16] S. Burger, H. Buddendick and G. Wolfle, "Location Dependent CDMA Orthogonality in System Level Simulations," *in Proc. of IEEE VTC'05 Spring,*, May, 2005.

[17] *'Physical layer aspects of UTRA High Speed Downlink Packet Access (Release 4)'*, 3GPP TR25.848 V4.0.0, Mar. 2001.