Improved Orthogonal Code Hopping Multiplexing Using Both Division and Hopping

Jae Kyun Kwon*, Suwon Park**, Dan Keun Sung*** ***Regular Members***

ABSTRACT

We previously proposed an Orthogonal Code Hopping Multiplexing (OCHM) scheme for statistical multiplexing on a synchronous downlink. OCHM enables a large number of users to share a limited number of code channels through statistical multiplexing. We here improve the performance of OCHM by prioritizing encoded symbols according to their importance using both the conventional code division and the previously proposed code hopping multiplexing schemes. Prioritization is useful for channel coding schemes with different levels of importance for encoded symbols such as turbo-codes. Scheme performance is evaluated by simulation in terms of the required *Eb/N0* for a 1% block error rate.

Key Words : OCHM(Orthogonal code hopping multiplexing), Turbo-codes, Systematic Code, Priority, Statistical Multiplexing

Ⅰ. Introduction

CDMA downlink usually provides synchronous transmission among users by maintaining orthogonality through orthogonal code sets though it is partially impaired by delay spread. This is different from the case of uplink where interference is suppressed by low cross-correlation of PN(pesudo-noise) sequences. Since the number of orthogonal codewords in the downlink is generally limited, only a limited number of users can be assigned to dedicated downlink channels at the same time. In recent years, internet traffic has rapidly increased in wireless domains. Bursty downlink traffic is expected to be dominant in mobile communications. Low channel activity due to burstiness results in an inefficient use of dedicated code channels and a shortage of available channels in the downlink. Frequent channel reallocation or shared channel is attempted to overcome this inefficiency, but an additional signalling load cannot be neglected for bursty traffic. Conventional systems cannot avoid inefficiency due to complex access mechanisms and the signalling load in wireless internet environments.

Multi-Scrambling Code (MSC)[1] for W-CDMA and Quasi-Orthogonal Code (QOC)[2] for cdma2000 have been recommended in order to increase the number of downlink channels. More users can be accommodated, but orthogonality is lost. Orthogonal code hopping multiplexing (OCHM)[3,4] has been proposed as a new multiplexing scheme in which each user uses an orthogonal code hopping pattern from a limited number of orthogonal codewords, maintaining orthogonality symbol by symbol. In other words, OCHM does not assign a fixed code channel to a downlink user. Rather, an orthogonal code

---

※ This research was supported by the Yeungnam University research grants in 2006, and it also has been conducted by the Research Grant of Kwangwoon University in 2006.

* School of EECS, Yeungnam University (jack@yumail.ac.kr)

** Dept. of Electronics and Communications Engineering, Kwangwoon University (spark@kw.ac.kr; spark@ieee.org)

*** School of EECS, KAIST (dksung@ee.kaist.ac.kr)

논문접수 : KICS2007-10-486, 접수일자 : 2007년 10월 29일, 최종논문접수일자 : 2008년 2월 28일

hopping channel is assigned to the user. The receiver recovers symbols using the designated orthogonal code hopping pattern. Symbols among users may collide when they are active and their hopping patterns coincide with each other. Compensation for these collisions can be achieved by channel coding but severe collisions may limit the number of allocated users. Numerical results[3] have shown that OCHM allows more users in the downlink, compared to existing code division multiplexing when channel activity is low.

We applied the OCHM scheme to IS-95 and Wideband CDMA (W-CDMA) downlinks and compared the OCHM with the High Data Rate (HDR) system (1xEV-DO)[5]. The performance of OCHM was also compared with performance of the conventional code division multiplexing, herein refered to as Orthogonal Code Division Multiplexing (OCDM). OCHM can accommodate more users with a small degradation in the error rate. For example, with an activity factor of 0.1 and 64 orthogonal code channels in a single-code system, the number of allocable channels is 287 when a perforation probability of 20% is allowed. OCHM accommodates four times as many bursty data users than the given number of code channels under this condition[3]. We also obtained the optimal code rate for a varying traffic load in OCHM by simulation and proposed an adaptive code rate control scheme[6]. In addition, hybrid channel allocation of OCDM and OCHM[7] was studied. Besides, collision was mitigated by log-likelihood ratio conversion[8,9] and frame level control[10]. Later, the capacity of OCHM was analyzed[11], and multi-rate traffic was considered[12]. Recently, we devised schemes applying 16QAM to OCHM systems[13]. Furthermore, the above hopping multiplexing was applied[14] to OFDM air interface though it was originally proposed based on CDMA. It is natural since key points of the proposed hopping multiplexing are statistical multiplexing and collision resolution, and the only system requirement is that channels are orthogonal. In this sense, OFDM is better because there is no orthogonality impairment by delay spread.

All the schemes we have studied transmit all symbols by hopping(OCHM). We have compared these schemes with conventional code division multiple access(CDMA), herein called Orthogonal Code Division Multiplexing OCDM). OCHM can accommodate more users by statistical multiplexing. However, it suffers symbol collisions and degradation in channel coding performance. Encoded symbols are better transmitted by OCDM from the viewpoint of reliable symbol transmission. When a symbol is transmitted by OCHM, it is referred to as Hopping Mode(HM). Division Mode(DM) is used for OCDM. We adopt prioritization and transmit more important symbols by OCDM. This policy is useful in channel coding schemes with different levels of importance for encoded symbols. Turbo-codes[15] can be used for this situation. There are systematic bits and parity bits after turbo encoding, and the systematic bits are usually regarded more important than the parity bits[16].

This paper is organized as follows: We briefly introduce our previously proposed OCHM scheme in Section II. New combination of division mode and hopping mode is presented in Section III and the performance of the proposed scheme is evaluated by simulation in terms of the required E_b/N_0 for a 1% block error rate in the same section. Conclusions are presented in Section IV.

Ⅱ. Features of the OCHM Scheme

Several previous studies have analyzed code hopping schemes with various purposes in spread spectrum systems. Frequency hopping with a robust feature to narrow-band interference was applied to code hopping changing spreading codes[17]. Code hopping was also used to average multiuser interference in the uplink by code diversity[18,19]. It could be exploited to distinguish cells[20].

On the other hand, we proposed a multiplexing scheme base on orthogonal code hopping, here called OCHM and our proposed OCHM[3,4] can accommodate more downlink orthogonal channels than the number of orthogonal codewords through statistical multiplexing. OCHM does not reduce interference. However, it effectively utilizes the orthogonal codeword resource in the downlink. The number of dedicated orthogonal downlink channels in conventional Orthogonal Code Division Multiplexing (OCDM)-based systems, like IS-95, cannot exceed the number of codewords regardless of the downlink channel activity. It is also important to increase the use of orthogonal codewords within the maximum allowable total transmission power of the downlink in a cell. In order to increase the number of downlink channels, Multi-Scrambling Code (MSC)[1] for W-CDMA and Quasi-Orthogonal Code (QOC)[2] for cdma2000 have been recommended. These schemes do not support orthogonality of the downlink channels. However, the orthogonality is a valuable property of synchronous downlink, and OCHM increases the number of downlink channels without loss of orthogonality.

OCHM is a statistical multiplexing scheme for orthogonal downlink in spread spectrum systems based on a direct sequence. Fig.1 shows the transmitter structure of the OCHM scheme. It contains a hopping pattern generator and comparator & controller modules not found in conventional transmitters. The hopping pattern generator produces hopping patterns for users, and the comparator & controller module compares the user symbol information with the same hopping pattern in order to resolve collision problems. Since the OCHM scheme uses a mobile station (MS)-specific hopping pattern after an initial channel allocation from a base station (BS), signalling messages for allocation and de-allocation of orthogonal codewords during a call are less required for bursty traffic. The conventional CDMA (here called OCDM) system is a special case of the OCHM system because a constant hopping pattern allocated by a base station (BS) is the same as the fixed orthogonal codeword allocation, as specified in W-CDMA[1], cdma2000[2], and cdmaOne (IS-95)[21].

The hopping pattern may be based on an MS

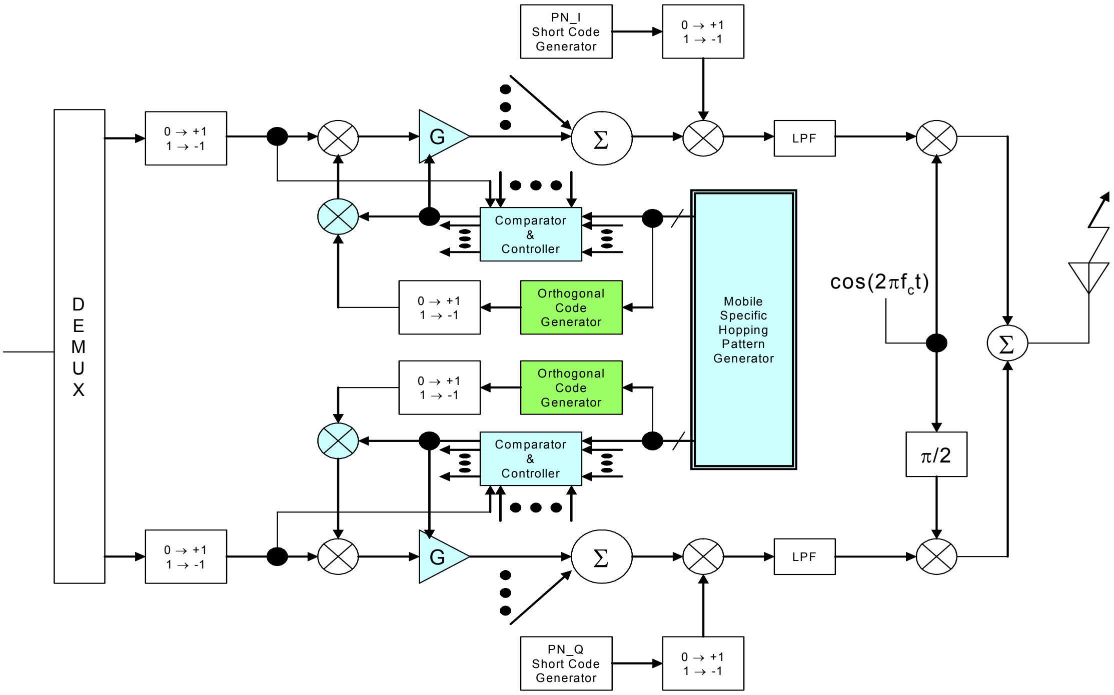


Fig. 1 Transmitter structure for OCHM

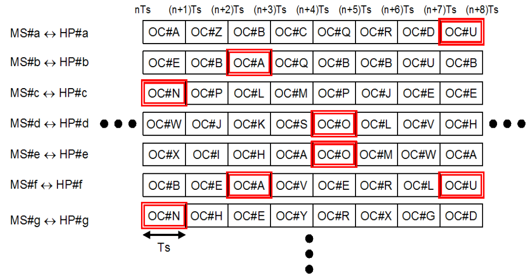


Fig. 2 MS-specific hopping patterns and collisions in OCHM

identifier (ID) using an electronic serial number (ESN). Since the number of available codewords in orthogonal code for OCHM is limited and the hopping patterns are mutually independent, orthogonal spreading codewords of two or more downlink active (data transmitting) channels may be identical at a symbol time (Fig.2). This event is called a collision of hopping patterns at that time. Encoded symbols with collisions are illustrated as double-lined boxes in Fig.2. For example, each MS transmits symbols according to a hopping pattern (HP). MS#c and MS#g are scheduled to send different symbols using the same orthogonal codeword OC#N at the *n*th time slot. Thus, their symbols collide.

When there exist collisions among the hopping patterns of active downlink channels, a comparator and controller at the transmitter of a base station (BS) performs one of two operations. First, if at least one channel-encoded data symbol is different from the others, all data symbols colliding at the moment are *perforated* and are not transmitted. The channel decoder of the corresponding MS can recover the perforated data symbols of each channel if the number of perforated data symbols is less than a threshold value. The transmission power during the encoded and perforated data symbol time is zero for all related channels. Second, if all channel encoded data symbols are identical, all the data symbols with collisions are transmitted without perforation. This situation yields an E_s/N_0 gain at the receiver, referred to as *synergy*. The transmission power during the encoded data symbol time for each channel is the sum of the assigned transmission powers for all related downlink channels, or the maximum power among the assigned transmission powers. A high perforation probability degrades the performance of channel decoding.

For a given perforation probability, the number of allocable dedicated downlink channels can exceed the number of orthogonal codewords if the channel activity is low. The allowable perforation (or collision) probability depends on the channel coding scheme. A more powerful channel coding scheme allows a higher perforation (or collision) probability. If the channel activity of downlink channels is 0.1 and the allowable perforation probability is 20%, then the number of allocable downlink dedicated orthogonal channels with 64 orthogonal codewords is approximately 287[3].

OCHM in a wide sense includes conventional OCDM because OCHM with a constant hopping pattern is the same as conventional OCDM. OCHM here means OCHM in a narrow sense excluding conventional OCDM for brevity's sake in this paper.

Ⅲ. Combination of Division and Hopping Mode

An encoded symbol can be transmitted through either OCHM or OCDM. OCHM can suffer symbol collisions and degradation in channel coding performance. However, a large number of downlink users can be accommodated by OCHM statistical multiplexing[3]. OCHM and OCDM can be selectively applied to user symbols depending on the importance of the symbols. Herein, OCHM is renamed the Hopping Mode (HM) of OCHM in a wide sense and OCDM is renamed the Division Mode (DM) of OCHM in a wide sense.

DM performs better than HM for encoded symbols when neither statistical multiplexing nor bandwidth efficiency is considered. DM provides higher reliability for transmission of symbols. Therefore, priority is given to DM, and more important symbols are transmitted by DM. This feature is useful in channel coding schemes with different levels of importance for encoded symbols.

Turbo-codes[15] can be used for channel coding schemes. There are systematic bits and parity bits after turbo encoding, and the systematic bits are usually regarded more important than the parity bits. Therefore, we will apply DM to the systematic bits and HM to the parity bits. Fig.3 illustrates this concept.

Simulation environments are described assuming perfect channel estimation, phase equalization, and BPSK/QPSK. Wireless channels are also assumed to experience either AWGN or independent (uncorrelated) Rayleigh fading. No specific code hopping patterns are designated and symbol perforations occur randomly. Recursive Systematic Convolutional-type Parallel Concatenated Convolutional Codes(PCCC), which are widely used in the third generation wireless communication systems, are considered as an encoder. Turbo coding in 3GPP specifications is considered with the decoder using the Soft Output Viterbi Algorithm (SOVA)[22]. A 1% BLER (Block Error Rate)[23] is assumed as a performance measure. The size of an encoder block is 1,000 bits and the number of encoder blocks used in the simulation is 10,000.

The three types of multiplexing referred to as MUX Types I to III can be applied depending on the use of DM and HM.

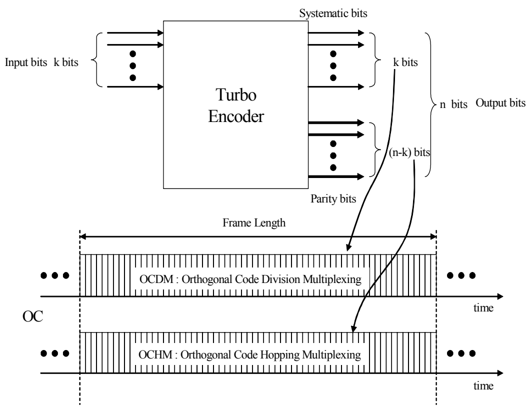


Fig. 3 Combination of Division Mode and Hopping Mode

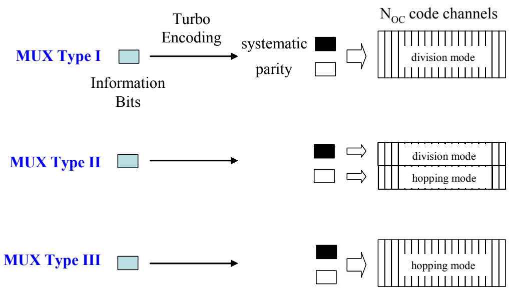


Fig. 4 Three Mux Types

- MUX Type I: only DM
- MUX Type II: systematic bits by DM & parity bits by HM
- MUX Type III: only HM

Fig.4 describes the three MUX Types. For MUX Type I, only the number of users not exceeding the number of code channels can be accommodated within the total transmission power of the BS. MUX Types II&III typically accommodate more users through HM statistical multiplexing. Therefore, the comparison is accomplished between MUX Types II&III by investigating how much SNR (Signal to Noise Ratio) gain MUX Type II achieves, compared with MUX Type III. The number of orthogonal code channels, N_{OC} is 64 and the channel activity, ν is 0.1~0.5. MUX Types II cannot accommodate more users when only systematic bits occupy all the code channels through DM. We assume that a user with a code rate of 1/2 occupies a code channel resource. Then, MUX Type II can accommodate up to $64\times(1/2)^{-1}=128$ users. The main difference between MUX Types II&III is that systematic and parity bits may experience perforations in MUX Type III, while only parity bits are affected by perforations in MUX Type II.

For the hopping mode of MUX Type II, the collision and perforation probabilities are as follows:

$$P_c = 1 - \left[1 - \frac{\nu}{2\left(N_{OC} - \frac{M}{2}\right)}\left(r^{-1} - 1\right)\right]^{M-1}, \quad (1)$$

$$P_p = 1 - \left[1 - \frac{\nu}{4\left(N_{OC} - \frac{M}{2}\right)} \left(r^{-1} - 1\right) \right]^{M-1}, \quad (2)$$

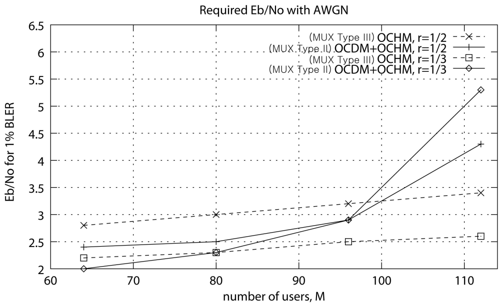
where *M* is the number of users and *r* is the code rate. *M* is given between 64 and 128, and *r* is set to 1/2 or 1/3. The collision and perforation probabilities for MUX Type III are as follows:

$$P_c = 1 - \left(1 - \frac{\nu}{2N_{OC}} \frac{1}{r}\right)^{M-1}, \quad (3)$$

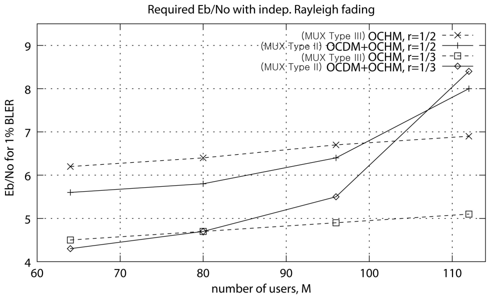
$$P_p = 1 - \left(1 - \frac{\nu}{4N_{OC}} \frac{1}{r}\right)^{M-1}. \quad (4)$$

Certainly, the collision(or perforation) probability of parity bits of MUX Type II is higher than that of MUX Type III since systematic bits of MUX Type II experience no collision.

Fig.5 illustrates the required E_b/N_0 performance for MUX Types II and III for varying the number of users when the block error rate (BLER) is 1% and the user activity is as low as 0.1. Solid lines represent the performance of MUX Type II and dotted lines indicate the performance MUX Type III. In Fig.5(a), the curves of MUX Types II and III intersect when the number of users is approximately 100 at a code rate of 1/2 under AWGN channels. This means that the proposed MUX Type II yields better performance than MUX Type III for the number of users less than 100. The E_b/N_0 degradation of MUX Type II is still acceptable whthin 1dB when the number of users is 112. On the other hand, two curves meet at 80 users for a code rate of 1/3. Since we assume that a user with a code rate of 1/2 occupies a code channel resource, doubled parity bits with a code rate of 1/3 cause many collisions especially in the hopping mode of MUX Type II. Therefore, the performance degradation results for MUX Type II, and it will be restored if we assume that a user with a code rate of 1/3 occupies a code channel resource. Recently, the use of higher code rates and aggressive H-ARQ becomes common to achieve high spectral efficiency. Then, MUX Type II will be better than MUX Type III for much higher number of users. We also observe that two curves of MUX Type II intersect at 96 users. For a small number of users, many parity redundancy produces high coding gain and, however, it causes many collisions for a large number of users. Therefore, high code rate is effective for a large number of users and low code rate can be better for a small number of users. The best code rate can vary according to the number of users. Fig.5(b) shows the result in independent Rayleigh fading channels. The trend is similar to Fig.5(a).



(a) AWGN channels



(b) Independent Rayleigh fading channels

Fig. 5 Required Eb/N0 according to the number of users when the user activity is 0.1

Performance of MUX Types II and III for varying the user activity is illustrated in Fig.6 when the number of users is 96. The proposed MUX Type II is always better than MUX Type III for 96 users. In addition, the performance difference becomes larger as the user activity increases.

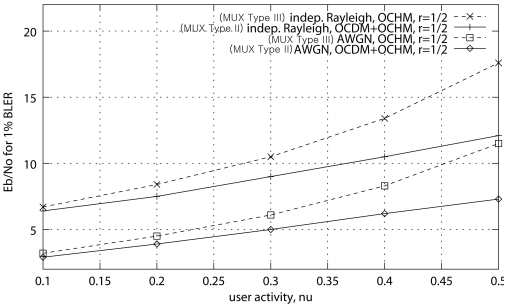


Fig. 6 Required Eb/N0 according to the user activity when the number of users is 96

Ⅳ. Conclusions

An orthogonal code hopping multiplexing (OCHM) scheme was proposed[3] as a novel statistical multiplexing scheme for orthogonal downlink to accommodate more low-activity bursty users than the number of orthogonal downlink codewords. The Hopping Mode (HM) of OCHM enables the system to accommodate more users but requires more energy due to symbol collisions. Consequently, conventional Division Mode(DM) is more reliable for symbol transmission than Hopping Mode(HM). This prioritization can be applied to channel coding schemes with different levels of importance for encoded symbols. We propose that the more important systematic bits are transmitted by Division Mode(DM) and parity bits are transmitted by Hopping Mode(HM) in turbo-codes. The proposed scheme still enables to accommodate more users than the number of code channels as the previously proposed OCHM does, and yields better E_b/N_0 performance.

References

〔1〕 3GPP, *3rd Generation Partnership Project: Technical Specification Group Radio Access Network*, 3GPP TS 25 series, 2001.

〔2〕 TIA/EIA, *Physical Layer Standard for cdma2000*, Proposed Ballot Version, TIA/EIA/IS-2000.3, Mar. 1999.

〔3〕 Suwon Park and Dan Keun Sung, "Orthogonal Code Hopping Multiplexing," *IEEE Communications Letters*, Vol. 6, No. 12, pp. 529-531, Dec. 2002.

〔4〕 Suwon Park and Dan Keun Sung, "Orthogonal Code Hopping Multiplexing for Downlink in Spread Communication," *Proceeding of MDMC 2001*, Pori, Finland, pp. 365-372, Jun. 2001.

〔5〕 Jae Kyun Kwon, Suwon Park, Dan Keun Sung, and Mun Geon Kyeong, "Performance Comparison of Orthogonal Code Hopping Multiplexing (OCHM) and HDR Schemes in Synchronous Downlink," *Proceeding of WCNC 2002*, Orlando, U.S.A., pp. 200-205, Mar. 2002.

〔6〕 Jae Kyun Kwon, Suwon Park, Dan Keun Sung, and Heesoo Lee, "Adaptive Code Rate for Orthogonal Code Hopping Multiplexing (OCHM) in Synchronous Downlink," *Proceeding of WCNC 2003*, New Orleans, U.S.A., pp. 855-859, Mar. 2003.

〔7〕 Suwon Park, Sung Ho Moon, Jae Kyun Kwon, and Dan Keun Sung, "Orthogonal Code Hopping Multiplexing for Downlink Statistical Multiplexing," *Proceeding of ISSSTA 2002*, Prague, Czech Republic, pp. 588-592, Sep. 2002.

〔8〕 Jae Kyun Kwon, Suwon Park, and Dan Keun Sung, "Log-Likelihood Ratio (LLR) Conversion Schemes in Orthogonal Code Hopping Multiplexing," *IEEE Communications Letters*, Vol. 7, No. 3, pp. 104-106, Mar. 2003.

〔9〕 Jae Kyun Kwon, Suwon Park, and Dan Keun Sung, "Collision Mitigation by Log-Likelihood Ratio (LLR) Conversion in Orthogonal Code Hopping Multiplexing," *IEEE Trans. on VT*, Vol. 55, No. 2, pp. 709-718, Mar. 2006.

〔10〕 Sung Ho Moon, Jae Kyun Kwon, and Dan Keun Sung, "Frame Level Control for Collision Mitigation in Orthogonal Code Hopping Multiplexing," *Proceeding of WCNC 2005*, New Orleans, U.S.A., Mar. 2005.

〔11〕 Sung Ho Moon, Suwon Park, Jae Kyun Kwon, and Dan Keun Sung, "Capacity Improvement in CDMA Downlink with Orthogonal Code Hopping Multiplexing," *IEEE Trans. on VT*, Vol. 55, No. 2, pp. 510-527, Mar. 2006.

〔12〕 Sung Ho Moon, Jin Hu, Junsu Kim, Jae Kyun Kwon, and Dan Keun Sung, "Multi-Rate Transmission in Orthogonal Code Hopping Multiplexing," *Proceeding of APCC 2005*, Perth, Australia, Oct. 2005.

〔13〕 Sung Ho Moon, Jae Kyun Kwon, and Dan Keun Sung, "Synergy/Perforation Control for 16QAM in Orthogonal Code Hopping Multiplexing," *IEEE Trans. on VT*, Vol. 56, No. 4, pp. 1704-1715, July 2007.

〔14〕 Sung Ho Moon, Jun-Su Kim, and Dan Keun Sung, "Performance Analysis of Orthogonal Frequency and Code Hopping Multiplexing," *IEEE Trans. on Wireless Com.*, (accepted for publication).

〔15〕 C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-Codes," *Proceeding of ICC '93*, Geneva, Switzerland, pp.1064-1070, May 1993.

〔16〕 S. Parkvall, E. Dahlman, P. Frenger, P. Beming, M. Persson, "The Evolution of WCDMA Towards Higher Speed Downlink Packet Data Access," *Proceeding of VTC 2001-Spring*, Rhodes, Greece, pp. 2287-2291, May 2001.

〔17〕 T. Onizawa and T. Hasegawa, "The Spread Spectrum Code Hopping System," *Proceeding of ISSSTA 1994*, Oulu, Finland, pp. 287-291, July 1994.

〔18〕 B. Unal and Y. Tanik, "Code-Hopping as a New Strategy to Improve Performance of S-CDMA Cellular Systems," *Proceeding of Globecom 1996*, London, U.K., pp. 1316-1319, Nov. 1996.

〔19〕 B. Unal and Y. Tanik, "Capacity Improvement by Code-Hopping in S-CDMA Systems," *Proceeding of ICC 1998*, Atlanta, U.S.A., pp. 989-993, June 1998.

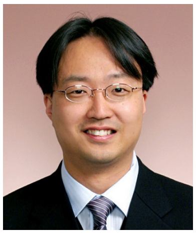
〔20〕 I. G. Kim, K. Kim, and B. W. Lim, "A Fast Cell Search Algorithm for Inter-Cell Asynchronous W-CDMA System Using Code Hopping Method," *Proceeding of Globecom 1998*, Sydney, Australia, pp. 1373-1377, Nov. 1998.

〔21〕 TIA/EIA, *Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System*, TIA/EIA/IS-95, Jul. 1993.

〔22〕 J. P. Woodard and L. Hanzo, "Comparative Study of Turbo Decoding Techniques: An Overview," *IEEE Trans. on VT*, Vol. 49, No. 6, pp. 2208-2233, Nov. 2000.

〔23〕 Qualcomm, *1xHDR: 1x Evolution (1xEV) Airlink Overview*, Aug. 2000.

Jae Kyun Kwon Regular Member



Feb. 1996 : B.S. degree in Dept. of Electrical Engineering, KAIST (minor degree in Mathematics)

Feb. 1998 : M.S. degree in Dept. of Electrical Engineering, KAIST

Aug. 2003 : Ph.D. degree in Dept. of Electrical Engineering and Computer Science, KAIST

Aug. 2003~Aug. 2006 : Senior Researcher, ETRI

Oct. 2004~Now : Secretariat, Air Interface Working Group, NGMC Forum

Sep. 2006~Now : Full-Time Lecturer, School of Electrical Engineering and Computer Science, Yeungnam University

Oct. 2006~Feb. 2008 : Invited Researcher, ETRI

<Research Interests> inter-cell interference, OFDM / CDMA air interface, relay-based cellular systems, code hopping systems

Suwon Park Regular Member

Feb. 1994 : B.S. degrees in Dept. of Electrical Engineering and Dept. of Mathematics (double-major), KAIST

Feb. 1996 : M.S. degree in Dept. of Electrical Engineering, KAIST

Feb. 2003 : Ph.D. degree in Dept. of Electrical Engineering and Computer Science, KAIST

Mar. 1994~Sep. 1998 : Research Engineer, Samsung Electronics Co., Ltd.

Sep. 1998~Feb. 1999 : Full-Time Entrusted Researcher, KAIST

Mar. 1999~May 2002 : Part-Time Entrusted Researcher, ETRI

June 2002~Feb. 2006 : Senior Engineer, Samsung Electronics Co., Ltd.

Mar. 2006~Feb. 2007 : Full-Time Lecturer, Dept. of Electronics and Communications Engineering, Kwangwoon University

Mar. 2007~Now : Assistant Professor, Dept. of Electronics and Communications Engineering, Kwangwoon University

<Research Interests> CDMA/OFDM/OCHM/ORHM radio transmission technologies, coding theory, SDR/CR technologies, radio resource management, power control, PAPR reduction, interference/coexistence problems

Dan Keun Sung Regular Member

Feb. 1975 : B.S. degree in Dept. of Electronics Engineering, Seoul National University

Aug. 1982 : M.S. degree in Dept. of Electrical and Computer Engineering, The University of Texas, Austin

May 1986 : Ph.D. degree in Dept. of Electrical and Computer Engineering, The University of Texas, Austin

1977~1980 : Research Engineer, ETRI

1986~Now : Professor, School of Electrical Engineering and Computer Science, KAIST

1993~1994 : Research Project Coordinator in Switching Systems, IITA

1996~1999 : Director, Satellite Technology Research Center

1998~Mar. 2007 : Division Editor/ Editor, JCN International Journal

2002~Now : Editor, IEEE Communications Magazine

2003~2005 : General Conference Chair, TPC Vice-Chair, IEEE ICC 2005(Seoul)

2003~2004 : Steering Committee Chair, JCCI

1992 : National Order of Merits, Dongbaek Medal

1997 : MoMuC Paper Award, KAIST Research Achievement Award

2000 : APCC 2000 Best Paper Award, KAIST Academic Excellence Award

2004 : This Month's Scientist Award by MOST and KOSEF

<Research Interestss> radio resource management, mobile communications systems & networks, multi-service switching, wired/wireless IP networks, traffic control, ad hoc networks, UWB networking, etc.