Adaptive Code Rate for Orthogonal Code Hopping Multiplexing(OCHM) in Synchronous Downlink

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***Abstract*— We previously proposed an Orthogonal Code Hopping Multiplexing(OCHM) scheme as a new statistical multiplexing scheme in synchronous downlink. OCHM enables a large number of users to share a limited number of code channels through statistical multiplexing. In this paper, we obtain the optimal code rate in several traffic load environments by simulation and summarize the appropriate traffic load region for each code rate as the optimal code rate. An adaptive code rate control scheme is proposed and the base station adaptively changes the code rate according to traffic environments in order to save power.**

***Index Terms*— Orthogonal Code Hopping Multiplexing, OCHM, adaptive code rate, optimal code rate, perforation, statistical multiplexing.**

I. Introduction

Orthogonal Code Hopping Multiplexing(OCHM) [1], [2] is a new statistical multiplexing scheme in downlink, which enables a large number of users to share a limited number of code channels through statistical multiplexing. Orthogonality is preserved and however, some user symbols may collide occasionally by code hopping. We can control the number of allowable users according to their activity and the required error rate. Channel coding gain can vary to compensate for collisions. However, collisions degrade channel decoding performance when collision probability is high. A collision mitigation scheme [3] is proposed to mitigate degradation due to collisions. There is no admission control[1] on packet transmission.

We applied the OCHM scheme to IS-95 and Wideband CDMA(W-CDMA) downlink, and compared OCHM with the High Data Rate (HDR)[2] system [4]. The performance of OCHM was compared with that of the conventional code division multiplexing here called the Orthogonal Code Division Multiplexing(OCDM). OCHM can accommodate a large number of users with little degradation in 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% was allowed. OCHM accommodates bursty data users four times more than the given number of code channels in this condition.

In typical communication schemes including code division multiplexing, code rate determines information rate within limited bandwidth and limited chip rate. The optimal code rate is based on channel conditions and coding schemes. Varying code rates causes to change information rate, and thus, finding the optimal code rate is to maximize the information rate satisfying the required bit or block error probability in given channel environments. On the other hand, information rate is fixed and varying code rates causes to change the required transmission power in OCHM. In this paper, we obtain the optimal code rate minimizing the required transmission power for each traffic load condition in OCHM. From these results, we can adaptively control the code rate for the time-varying traffic load.

This paper is organized as follows. Section II outlines the OCHM scheme. Section III describes the problem statement and obtains the optimal code rate in several traffic load environments by simulation. Section IV summarizes the appropriate traffic load region for each code rate as the optimal code rate and proposes an adaptive code rate control scheme. Section V presents conclusions and further studies.

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[1] It means the initial admission control for packet transmission. Retransmission control like automatic repeat request(ARQ) is possible.

[2] 1xEV-DO is the new name for HDR.

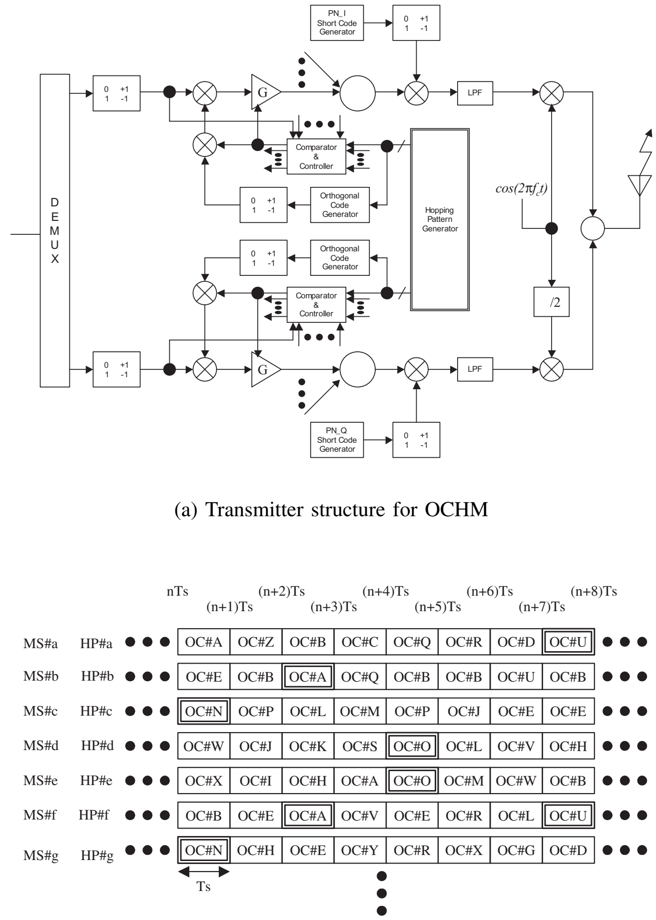
II. FEATURES OF THE OCHM SCHEME

OCHM [1], [2] is to accommodate more downlink orthogonal channels than the given number of orthogonal codewords for mobile stations through statistical multiplexing. The number of dedicated orthogonal downlink channels in the conventional OCDM-based systems like IS-95 cannot exceed the number of codewords in the orthogonal code regardless of downlink channel activity. Since orthogonal codewords are valuable resources for synchronous downlink of Code Division Multiple Access(CDMA) systems, it is important to increase the utilization of orthogonal codewords within the maximum allowable total transmit power of the downlink in a cell. In order to increase the number of downlink channels, Multi-Scrambling Code(MSC) [5] for W-CDMA and Quasi-Orthogonal Code(QOC) [6] for cdma2000 have been recommended. These schemes do not support the orthogonality of downlink channels. However, the orthogonality is a very valuable property of synchronous downlink.

OCHM is a statistical multiplexing scheme for orthogonal downlink in spread spectrum systems based on direct sequence. Fig. 1(a) shows the transmitter structure for the OCHM scheme. It additionally requires a hopping pattern generator and comparator & controller modules compared to conventional transmitters. The hopping pattern generator is used to generate user-specific hopping patterns, and the comparator & controller module compares the symbol information of users with the same hopping pattern and resolves collision problems. Since the OCHM scheme uses a mobile station (MS)-specific hopping pattern after an initial channel allocation from 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 [5], cdma2000 [6], and cdmaOne (IS-95) [7]. We also studied the hybrid channel allocation [8] of OCDM and OCHM as call admission policies.

The hopping pattern may be based on MS identifier(ID) using electronic serial number(ESN) as an example. Since the number of available codewords in an 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, as shown in Fig. 1(b). This event is called a collision of hopping patterns at that time, and the encoded symbols with collisions are illustrated as double-lined boxes in Fig. 1(b). For example, each MS transmits symbols according to its hopping pattern (HP). MS#c and MS#g are scheduled to send different symbols using the same orthogonal codeword, OC#N at the nth time slot, and then their symbols collide.

When collisions among the hopping patterns of downlink



(a) Transmitter structure for OCHM

(b) MS-specific hopping patterns and their collision

Fig. 1. Orthogonal Code Hopping Multiplexing(OCHM)

active channels occur, a comparator and controller at the transmitter of a base station(BS) takes one of the following two operations: If at least one channel-encoded data symbol is different from others, then all data symbols colliding at the moment are *perforated*[3] 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. The transmit power during the encoded and perforated data symbol time is zero for all related channels. If all channel encoded data symbols are identical, then all the data symbols with collisions are transmitted without perforation. This situation yields an E_s/N_0 gain at the receiver and we call it *synergy*. The transmit power during the encoded data symbol time for each channel is the sum of the assigned transmit power for all related downlink channels

[3]The term, *puncturing* [2] was chosen to describe the condition, but it may cause confusion with puncturing used to increase the code rate. Therefore, we adopt *perforation* which has the same lexical meaning.

or the maximum among the assigned transmit power. We studied collision mitigation schemes to improve performance by reducing the degradation due to perforation [3].

For a given perforation probability, the number of allocable dedicated downlink channels can exceed that of orthogonal codewords if the channel activity is low. The allowable perforation (or collision) probability depends on the channel-coding scheme. As a channel coding scheme is more powerful, the higher perforation (or collision) probability is allowable. 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 in a single-code system is approximately 287 [1].

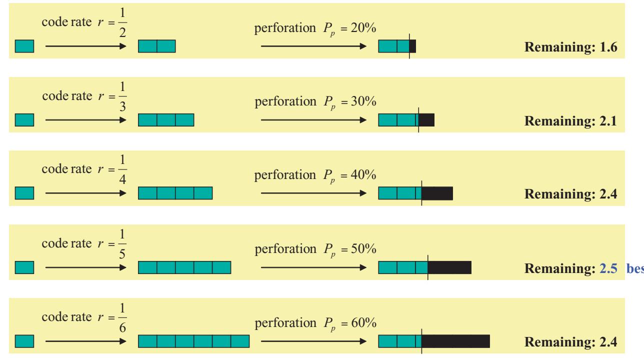


Fig. 2. Example of optimal code rate

III. Optimal Code Rate

A. Problem Statements

In typical communication schemes including code division multiplexing, code rate is determined considering the channel conditions, available bandwidth, power, and information rate. Low code rate (or strong coding) requires a wider bandwidth but commonly less power. Thus, we need to lower the code rate (or strengthen coding) within a limited bandwidth. On the other hand, the used bandwidth is fixed in OCHM systems. Strong coding results in an increase in symbol collisions. We will investigate trade-offs between coding gain and collisions.

Fig. 2 conceptually describes why the optimal code rate exists in OCHM as an example. For various code rates with the same information rate, the numbers of encoded symbols are different. Low code rate produces more encoded symbols and results in a higher coding gain when there is no perforation. However, we suffer from more symbol perforations when we attempt to transmit more symbols within a limited bandwidth in OCHM. Perforation probability (P_p) increases as code rate decreases, and the number of well-transmitted or well-received symbols decreases. The number of well-transmitted symbols may pass through a maximum value as the code rate decreases. Even though the number of well-transmitted symbols does not directly mean the coding gain, they are at least positively correlated. In this example, the optimal code rate may be decided as $\frac{1}{5}$.

We will obtain the optimal code rate according to traffic environments. Either variable spreading factor or multi-codes can be chosen when code rates vary. Both variable spreading factor and multi-codes are different in operations, but equivalent in collision probabilities and data throughput. We here assume multi-code environments to facilitate understanding. $\frac{1}{r}$ code channels are used for a code rate of r. For example, a user data is transmitted through three code channels if the code rate is $\frac{1}{3}$. Some traffic parameters are introduced as follows:

- N_{OC}: the number of orthogonal code channels
- ν: mean channel activity
- r: code rate

The number of channels is fixed and an active user occupies r^{-1} channels. As r^{-1} increases, more collisions (or perforations) occur and the number of transmitted symbols decreases. In fact, the number of transmitted symbols does not increase any more for low code rates. Collisions result in this cutoff and the trade-off point is determined by the traffic load. We will obtain the optimal code rate according to traffic load and investigate the applicability of optimal code rate in slowly varying traffic environments.

B. Simulation Results

Simulation environments are described as follows:

- Data modulation: BPSK / QPSK
- Wireless channel: AWGN, independent (uncorrelated) Rayleigh fading
- Collision & perforation: random perforation with a probability of P_p
- Turbo codes [9]

Perfect channel estimation and equal gain combining [10] are assumed. We first consider BPSK, however, simulation results can be applied to QPSK because QPSK can be characterized as two orthogonal BPSK channels [11]. Wireless channels are assumed to experience AWGN or independent (uncorrelated) Rayleigh fading. No specific code hopping patterns are designated and random hopping patterns are considered, and thus, collision and perforation of symbols occur randomly.

Recursive Systematic Convolutional (RSC)-type Parallel Concatenated Convolutional Codes (PCCC) in 3GPP specifications are considered as an encoder as widely used in third generation wireless communcations. The decoder adopts the Soft Output Viterbi Algorithm (SOVA) [12]. The number of decoding iterations is adaptive and restricted within 10. Automatic Repeat Request (ARQ) [13] is commonly used to improve performance for delay-insensitive data communication instead of increasing E_b/N_0. Thus, 1% Block Error Rate (BLER) [14] is assumed as a performance measure, and the size of an encoder block is $1,000$ and the number of encoder blocks used in simulation is $10,000$. The code rate

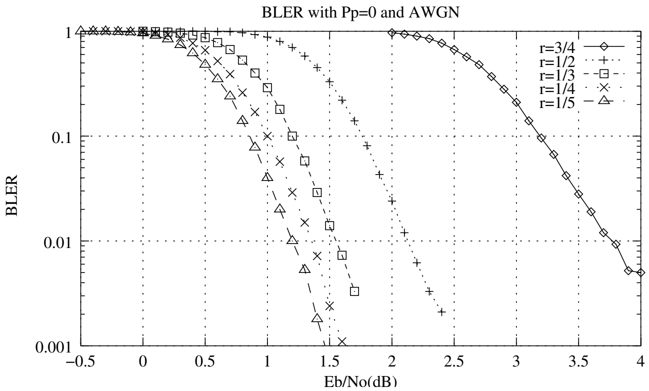


Fig. 3. Coding gain in AWGN channels

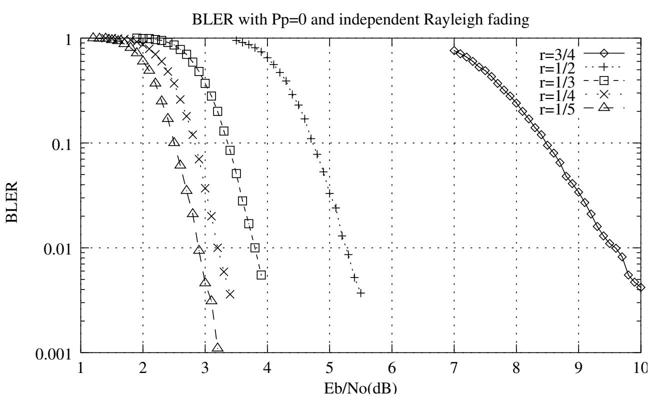
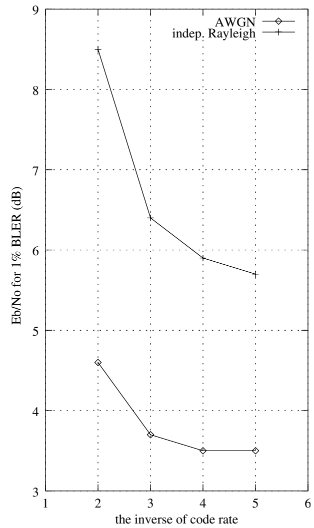


Fig. 4. Coding gain in independent Rayleigh fading channels

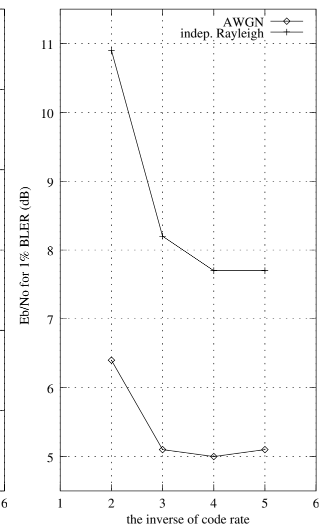
r of Turbo encoder is $\frac{1}{5}$ and higher code rate is realized by puncturing.

Figs. 3 and 4 show the coding gain in Turbo coding. Redundancy in low code rates enables the transmitter to decrease transmission power. In Fig. 3, the required E_b/N_0 is reduced as the code rate decreases in AWGN channels. Moreover, the difference in the required E_b/N_0 becomes smaller as the code rate decreases. Fig. 4 shows the required E_b/N_0 in independent Rayleigh fading channels. The trend is similar, but more gains are achieved in independent Rayleigh fading environments because time diversity becomes useful for strong coding.

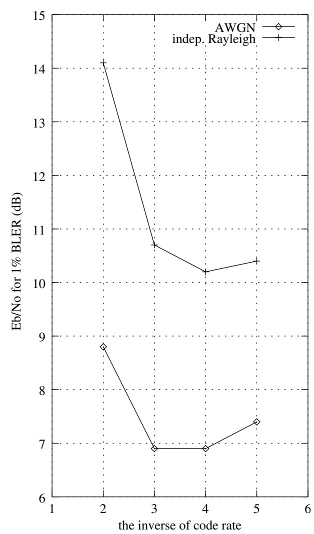
We now investigate the optimal code rate for $N_{OC} = 256$ and $\nu = 0.1$. 256 is not large as the number of channels because it is equivalent to 64 if $r = \frac{1}{4}$ is adopted in a single-code system. We obtain block error rates for several code rates with collisions in AWGN or independent Rayleigh fading environments. Then, the required E_b/N_0 values are summarized for 1% BLER according to code rate and the number of users. Fig. 5 illustrates the code rate versus the required E_b/N_0 for 1% BLER for several different number of users. Low code rate (or high redundancy) yields low E_b/N_0 when traffic load is low for a small number of users



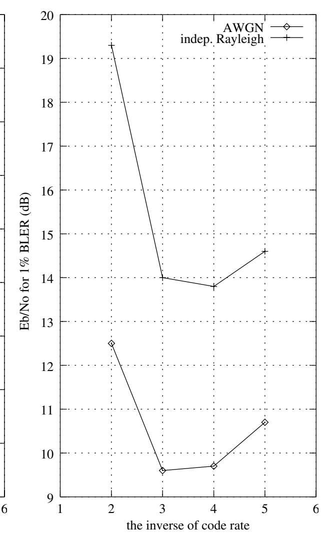
(a) 400 users



(b) 600 users



(c) 800 users



(d) 1000 users

Fig. 5. Code rate vs. the required E_b/N_0 for 1% BLER

in Fig. 5(a). On the other hand, the high code rate system performs well when traffic load is high in Fig. 5(d). This is because low traffic load environments accommodate more redundant encoded symbols without severe collisions and achieve higher coding gain. For high traffic load environments, properly high code rate is required to avoid severe collisions. The performance of $r = \frac{1}{2}$ is not good because coding gain is poor compared to lower code rates in Figs. 3 and 4. We performed simulation only for several code rates in Fig. 5, and the exactly optimal code rate may be achieved by smoothing curves from more simulation results. Intermediate code rates

TABLE I

APPROPRIATE NUMBER OF USERS

Code rate (r)	AWGN	Independent Rayleigh fading
$\frac{1}{5}$	$1 \sim 320$	$1 \sim 630$
$\frac{1}{4}$	$320 \sim 770$	$630 \sim 1100$
$\frac{1}{3}$	$770 \sim$	$1100 \sim$

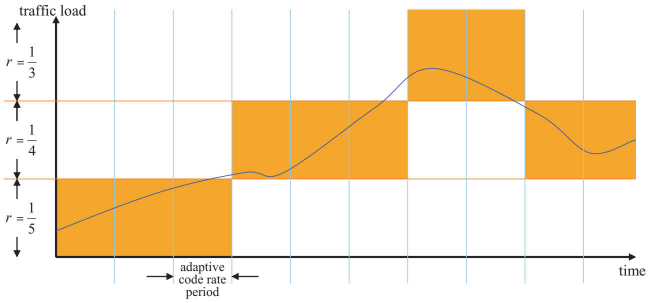


Fig. 6. Adaptive code rate

can be realized by puncturing (or hopping) in time axis based on lower code rate and it is for further study.

IV. Adaptive Code Rate

From simulation, we obtain the optimal code rate for each traffic load situation. Each code rate has its traffic load region as the optimal code rate. Table I summarizes the appropriate region of each code rate for varying the number of users from simulation. The base station may control the code rate according to the number of connecting users from the table. We can slowly change the code rate according to traffic load as shown in Fig. 6 and save system power. The base station intermittently observes the system traffic load every specific period and controls the optimal code rate.

V. Conclusions

An orthogonal code hopping multiplexing (OCHM) scheme was proposed [1], [2] as a novel statistical multiplexing scheme for orthogonal downlink to accommodate more low-activity bursty users than the number of orthogonal downlink codewords. We obtain the optimal code rate for varying the traffic load in OCHM by simulation, and propose an adaptive code rate control scheme. It intermittently changes the code rate according to traffic environments to save power. We can find appropriate traffic load regions for each code rate by simulation. Low code rate (or high redundancy) yields low E_b/N_0 when traffic load is low for a small number of users and high code rate performs well when traffic load is high. For a further study, intermediate code rates can be realized by puncturing (or hopping) in time axis based on lower code rate. Besides, it is helpful to analyze the relationship between coding gain and the number of well-transmitted symbols.

Acknowledgments

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References

[1] Suwon Park and Dan Keun Sung, “Orthogonal Code Hopping Multiplexing,” *IEEE Communications Letters*, Vol. 6, No. 12, Dec. 2002.

[2] 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.

[3] Jae Kyun Kwon, Suwon Park, and Dan Keun Sung, “Log-Likelihood Ratio (LLR) Conversion Schemes in Orthogonal Code Hopping Multiplexing,” *IEEE Communications Letters*, (accepted for publication).

[4] 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.

[5] 3GPP, *3rd Generation Partnership Project: Technical Specification Group Radio Access Network*, 3GPP TS 25 series, 2001.

[6] TIA/EIA, *Physical Layer Standard for cdma2000*, Proposed Ballot Version, TIA/EIA/IS-2000.3, Mar. 1999.

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

[8] Suwon Park, Sung Ho Moon, Jae Kyun Kwon, and Dan Keun Sung, “Orthogonal Code Hopping Multiplexing for Downlink Statistical Multiplexing,” accepted for presentation in *ISSSTA 2002*, Prague, Czech Republic, Sep. 2002.

[9] 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.

[10] Jhong Sam Lee and Leonard E. Miller, *CDMA Systems Engineering Handbook*, Artech House, 1998.

[11] B. Sklar, *Digital Communications: Fundamentals and Applications*, Prentice Hall, 1988.

[12] 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.

[13] S. Lin and D. J. Costello, Jr., *Error Control Coding: Fundamentals and Applications*, Prentice Hall, 1983.

[14] Qualcomm, *1xHDR : 1x Evolution (1xEV) Airlink Overview*, Aug. 2000.