Frame Level Control for Collision Mitigation in Orthogonal Code Hopping Multiplexing

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Abstract— **We have recently proposed an orthogonal code hopping multiplexing (OCHM) scheme which is based on a statistical multiplexing scheme for orthogonal downlink in direct sequence spread spectrum systems. This is a feasible candidate for accommodating a large number of bursty packet-based users with good backward compatibility. In OCHM, code-collisions which degrade channel coding performance and result in an increase in the required E_b/N_0 are inevitable for obtaining a statistical multiplexing gain. In this paper, we lower code-collision probability by discarding or delaying excessive frames whose number is larger than a threshold value. It reduces the required E_b/N_0 at the transmitter and saves system power. However, there is an increase in BLER (Block Error Rate) or delay. Therefore, there exist trade-offs between the required E_b/N_0 and BLER (or delay). We can determine an operating point which can reduce the required E_b/N_0 by considering how much BLER or delay the system requires as a target value.**

I. INTRODUCTION

In orthogonal code allocation/de-allocation mechanisms of conventional CDMA systems, code channels are allocated by a base station (BS) to mobile stations (MS's) at each initial call setup, and released from the connections after each call termination. Since bursty downlink packet-type traffic may be dominant in future wireless communications, code channels are wasted by many inactive periods within a call, and thus, an increase in the number of low activity users may yield a lack of available downlink channels.

For solving this channel inefficiency problem for bursty traffic, one approach is to develop new physical layer techniques for downlink, such as 1xEV-DO (HDR) [1] and high speed data packet access (HSDPA) [2], which have maximum data rates up to 10 Mbps. Time division multiplexing (TDM) with a scheduler at BS increases channel efficiency. The scheduler monitors all downlink channels based on channel quality information (CQI) from MS's and allocates a transmission opportunity to a specific MS considering the channel condition and fairness. The scheduling-based schemes may exhibit rather good throughput performance. However, inaccuracy and delay of CQI may yield a degradation in throughput performance and fairness issues are always with the scheduling-based systems [3]. In addition, the complexity of the scheduling schemes may increase exponentially as the number of parameters considered and the number of active users increase [4].

Orthogonal code hopping multiplexing (OCHM) [5] is another approach for supporting packet services efficiently without big changes in conventional systems. Downlink multiplexing using code hopping in OCHM results in a statistical multiplexing gain. Thus, OCHM can accommodate more downlink channels than that in conventional CDMA systems. A large statistical multiplexing gain of OCHM can be achieved with a large spreading factor and low channel activity traffic. At the beginning stage of packet services, the required data rate of each subscriber may range from several tens kbps to several hundreds kbps. Therefore, OCHM can be a good candidate technique for medium rate (several hundreds kbps) and low data rate (several tens kbps) services.

However, if two or more downlink channels have the same orthogonal codeword during a modulation symbol time, code hopping of downlink channels yields a code-collision. As the number of allocated downlink users increases, the number of code-collisions increases. According to previous studies [5–7], these code-collisions in OCHM degrade channel coding performance and result in an increase in the required E_b/N_0. Moreover, a time-varying feature in the required E_b/N_0 requires more transmit power than that actually needed for keeping a margin. This large transmit power of BS increases inter-cell interference and decreases the system capacity. The CDMA system capacity is determined by a minimum value between code-limited and power-limited capacities [1]. OCHM which is applicable to increasing the code-limited capacity may not be useful if power-limited capacity becomes relatively small due to the increased transmit power of BS. Therefore, to increase the power-limited capacity, it is desirable to reduce the required E_b/N_0 caused by a large number of code-collisions. Thus, the objectives of this paper are as follows:

- To introduce three frame level control mechanisms for collision mitigation
- To evaluate the effect of transmit power saving for these mechanisms
- To evaluate the performance in terms of BLER (Block Error Rate) and delay for these mechanisms
- To determine the available operating points by considering both transmit power of E_b/N_0 at transmitter and BLER (or delay)

The rest of this paper is organized as follows: our previously proposed orthogonal code hopping multiplexing (OCHM) scheme is briefly introduced in Section II. In Section III, three

[1] Generally, in 2G and 2.5G CDMA systems, system capacity is limited by power because major target services of 2G and 2.5G are based on voice with relatively high activity. However, packet-based services in 3G CDMA systems will be served in a code-limited situation

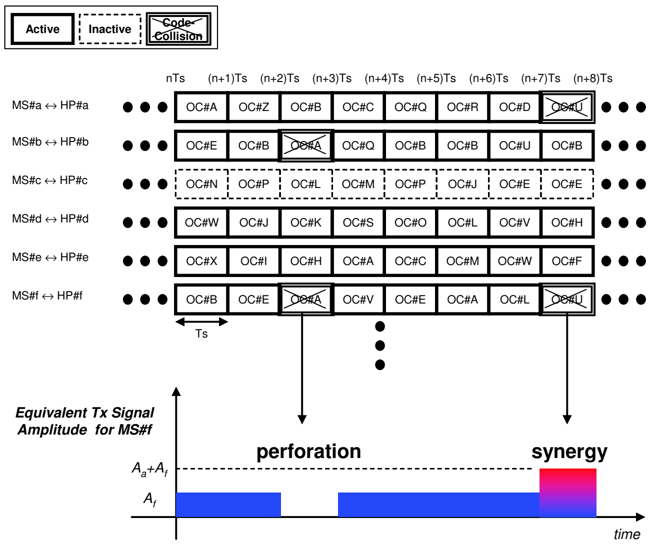


Fig. 1. Orthogonal Code Hopping Multiplexing (OCHM)

frame level control mechanisms for collision mitigation are proposed, and the performance is evaluated through simulation. Finally, conclusions are presented in Section IV.

II. Orthogonal Code Hopping Multiplexing

Previously, there were several studies on code hopping methods based on spread spectrum systems [8–10]. These previous studies were mainly focused on showing that code hopping systems perform better than conventional spread spectrum systems in BER performance because co-channel interference is reduced by *code diversity* [9] [2]. However, OCHM is distinguished from these previous code hopping methods because code hopping in OCHM includes downlink multiplexing for increasing the utilization of code channels.

Fig. 1 shows the basic operation of OCHM. In conventional CDMA, each modulation symbol is spread during a modulation symbol time T_s by a specific orthogonal codeword (OC). During a call of each MS, an orthogonal codeword allocated to the MS is maintained regardless of the inactive periods. Thus, orthogonal codeword resources are wasted in a bursty traffic environment.

On the other hand, OCHM allows to change the orthogonal codewords in every modulation symbol time T_s and to multiplex more MS's than the number of orthogonal codewords, as shown in Fig. 1. For example, MS #f changes an orthogonal codeword for each modulation symbol based on a hopping pattern (HP) indexed by #f. An MS-specific hopping pattern is generated based on an MS identifier (ID), such as an electronic serial number (ESN) at an initial channel allocation time.

From the random hopping of orthogonal codewords, BS can multiplex more downlink channels than the number of orthogonal codewords. However, as described in introduction, code-collisions between codewords are inevitable for higher utilization of orthogonal codewords. Fortunately, BS can monitor all information of downlink channels. BS compares each channel to the others during multiplexing for finding which symbols collide, and deals with the colliding symbols before transmitting.

When a code-collision occurs among the hopping patterns of active downlink channels, a comparator and controller in the OCHM transmitter performs one of the following two operations: *perforation* and *synergy*.

- *Perforation* : If code-collision symbols do not have an identical symbolic value, i.e., $+1$ or 0 for BPSK, then none of the data symbols colliding during a symbol time of T_s are transmitted.
- *Synergy* : If code-collision symbols have an identical symbolic value, the transmission signal amplitude of the orthogonal codeword during the symbol time is the sum of the signal amplitudes assigned for all of the corresponding downlink channels.

Regardless of perforated symbols, the channel decoder in the receiver of the corresponding MS can recover the transmitted data. The synergy operation allows the code-collision symbols to maintain and share their transmission powers in common. Thus, a synergy operation results in a transmission power gain.

Perforation/syerngy scheme for code-collision in code hopping system is a unique and distinguished concept. Synergy compensates the OCHM system for some loss in E_b/N_0 due to code-collisions. This effective statistical multiplexing of OCHM yields a significant increase in the number of allocatable users at the cost of a slight increase in E_b/N_0. The detailed performance improvements are evaluated in [5, 11, 12].

III. Proposed Schemes for Collision Mitigation

Perforations in OCHM degrade the channel coding performance and result in an increase in the required E_b/N_0. Each user is statistically active and, thus, the number of active users varies in time and follows a certain probability distribution. It means that the required E_b/N_0 also varies in time since it is highly related to the number of active users. A base station (BS) should keep a margin to manage these variations and to transmit at the required E_b/N_0 value. For reducing power consumption, it is needed to reduce the required value of E_b/N_0 increased due to sporadic code-collisions. It can be accomplished by limiting the number of multiplexed users (or limiting code-collision probability).

Fig. 2 shows three collision mitigation mechanisms in OCHM. Each input is a data stream spread by orthogonal codeword hopping according to its own hopping pattern (HP). In pure OCHM, code-hopped frames of each user are directly delivered to a comparator & controller module. Then, the comparator & controller module compares all spread data streams, decides the code-collision/perforation/synergy, and determines the transmit power. However, as previously mentioned, an increase in the number of multiplexed users yields a large degradation in channel coding performance due to an increase in code-collisions. We can reduce the performance degradation using three mechanisms shown in Fig. 2. Therefore, in this paper, we describe these three mechanisms and evaluate how many frames have to be discarded or delayed to obtain a new operating point of E_b/N_0 at transmitter.

[2] Code-diversity averages the interference of all mobiles to a common moderate value.

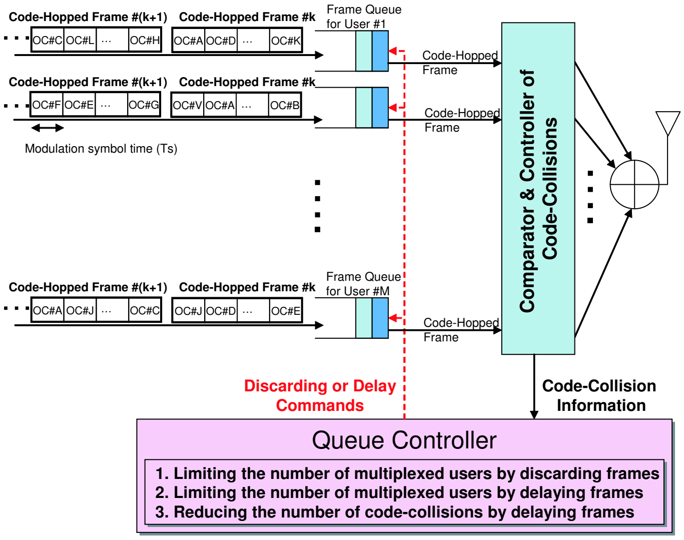


Fig. 2. Collision mitigation mechanisms in OCHM

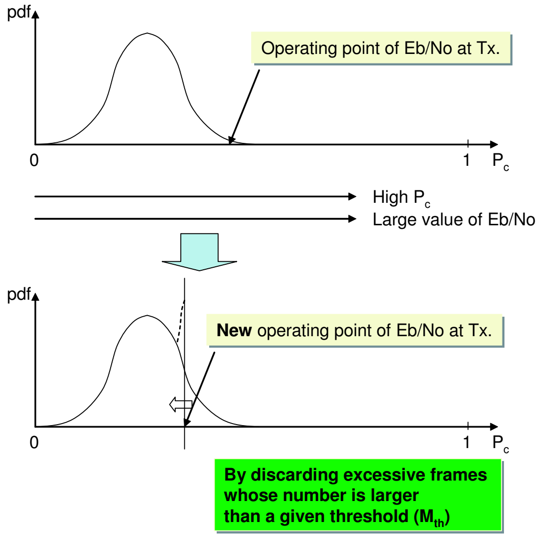


Fig. 3. Distribution of code-collision probability

A. Limiting the Number of Multiplexed Users by Discarding Frames

If the number of frames which will be delivered to the comparator & controller module in a frame time is larger than a threshold, a system considered here is to discard excessive frames in order to limit the number of multiplexed users (or active users in a frame time).

As shown in Fig. 1, each OCHM user has its own channel activity. Thus, the number of active users in a frame basis is time-varying in OCHM. Especially, since code-collision probability P_c is a function of the number of active users, N in OCHM, P_c is also time-varying. The average code-collision probability is calculated as:

$$P_c = 1 - \left(1 - \frac{1}{N_{OC}}\right)^{N-1} = f(N) \ , \qquad (1)$$

where N_{OC} is the number of orthogonal codewords.

The time-varying feature in the number of active users may yield a code-collision probability distribution. Fig. 3 shows an example of code-collision probability distribution. We need to lower this operating point from the viewpoint of E_b/N_0 by discarding excessive frames whose number is larger than a given threshold. If we restrict the number of active users in a frame time to M_{th}, where M_{th} is the threshold value, the largest average code-collision probability is determined by Eq. (1) with $N = M_{th}$.

System parameters and notations for analysis and simulation are introduced as follows:

- $M = 128$: the number of users
- $N_{OC} = 64$: the number of orthogonal code channels
- $\nu = 0.1$: mean channel activity
- M_{th}: threshold for the maximum number of transmitting users
- $r = \frac{1}{3}$: code rate (Turbo codes, MAP)
- Interleaver size : 2000
- Data modulation: BPSK / QPSK
- Wireless channel: AWGN

Since frames are discarded at the transmitter, BLER (Block Error Rate) or FER (Frame Error Rate) is considered as a performance measure. We use both block and frame to express the same meaning. Even if there is no frame discard in the transmitter, there is a possibility the receiver cannot successfully receive all frames and a BLER value of 1% typically occurs at the receiver due to wireless channel. Therefore, the overall BLER is a weighted sum of block error rates at the transmitter and the receiver.

$$BLER_{rx} = BLER_{tx} + (1 - BLER_{tx})BLER_{rx|tx} \ , \qquad (2)$$

where $BLER_{tx}$ is the BLER at the transmitter due to discarding, $BLER_{rx|tx}$ is the BLER for transmitted frames at the receiver, and $BLER_{rx}$ is the overall BLER considering both block discards at the transmitter and block losses at the receiver. It is expected that BLER characteristic does not differ among users and, thus, we obtain only the mean BLER.

Several discard schemes[3] have been proposed for excessive user frames. However, their performance is similar in the mean BLER. Therefore, we apply a random selection scheme without a queue for convenience. It randomly selects frames to be discarded if the number of active users in a frame time is larger than M_{th}. Then, BLER at the transmitter is given as follows:

$$P\{\text{active} = k\} = p_{act,k} = \binom{M}{k} \nu^k (1-\nu)^{M-k} \ , \qquad (3)$$

where M is the number of users and ν is the channel activity.

[3] Random Early Detection (RED) [13] and Early Packet Discard (EPD) [14] schemes discard excessive user frames in buffer systems. However, they consider both delay and loss. They can be used for further studies when we take both BLER and delay into account at the same time.

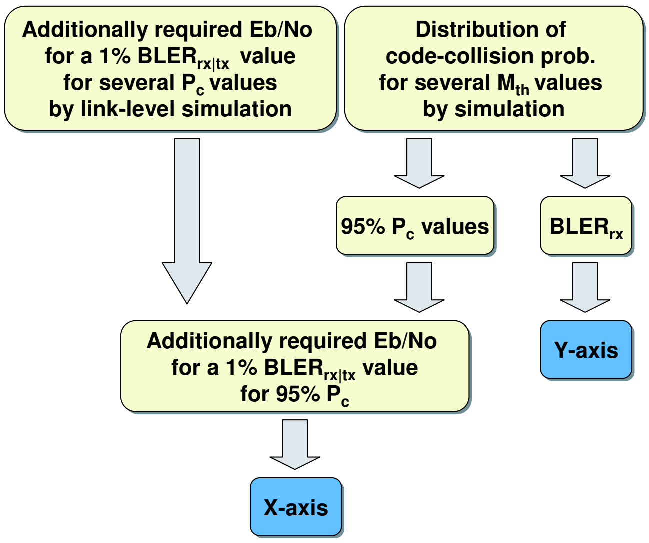


Fig. 4. Simulation procedures

$$
\begin{aligned}
BLER_{tx} &= \frac{\sum_{i=M_{th}+1}^{M}(i-M_{th})p_{act,i}}{\sum_{i=0}^{M} i p_{act,i}} \\
&= \frac{\sum_{i=0}^{M}(i-M_{th})p_{act,i} + \sum_{i=0}^{M_{th}}(M_{th}-i)p_{act,i}}{M\nu} \\
&= \frac{M\nu - M_{th} + \sum_{i=0}^{M_{th}}(M_{th}-i)p_{act,i}}{M\nu} \quad .
\end{aligned} \tag{4}
$$

Now, we can analytically obtain the overall BLER by setting $BLER_{rx|tx}$ at 1% in Eq. (2).

In order to determine a lower operating point of E_b/N_0 by limiting the number of downlink users, we need to investigate the relationship between the additionally required E_b/N_0 and the overall BLER, and find the appropriate M_{th} value for the new operating point. "Additional" here means an increment from the E_b/N_0 value in code-collision free case.

These values can be obtained following the steps shown in Fig. 4. First, the required E_b/N_0 values for a $BLER_{rx|tx}$ value of 1% are obtained for several given code-collision probabilities by link-level simulation. Then, we obtain the distributions of code-collision probability for several M_{th} values by simulation. A 95% P_c value represents the code-collision probability, in which the cumulative distribution function (CDF) value is 0.95. A 95% P_c value becomes higher as M_{th} increases since the code-collision probability deviates more. All of the 95% P_c values can be mapped into the additionally required E_b/N_0 values because we obtain the required E_b/N_0 for a 1% BLER value for a 95% P_c value by interpolation from the previous link-level simulation results in Table I.

Fig. 5 shows the overall BLER for varying the additionally required E_b/N_0 and M_{th}. The horizontal axis represents the additionally required E_b/N_0 values in dB at the base station due to a deviation of code-collision probability. We can also observe the variation of $BLER_{rx}$ and $\Delta E_b/N_0$ with M_{th}. The overall BLER and the additionally required E_b/N_0 values converge to 0.01 and 0.79, respectively, for M_{th} values

TABLE I
ADDITIONALLY REQUIRED E_b/N_0 FOR A 1% $BLER_{rx|tx}$ VALUE BY LINK-LEVEL SIMULATION

P_c	0.1	0.2	0.3	0.4
$\Delta E_b/N_0$	0.25	0.57	0.98	1.37

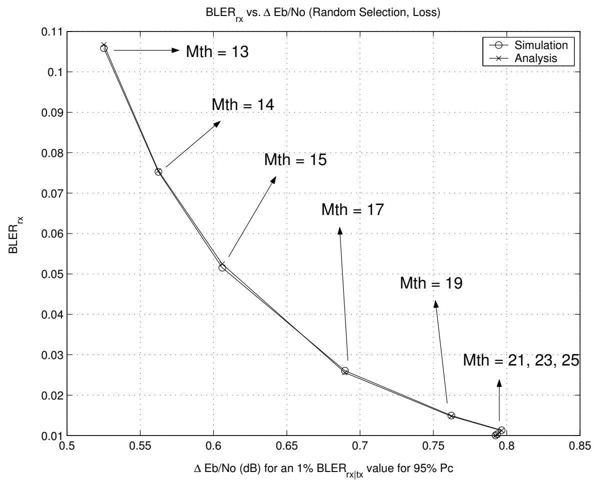


Fig. 5. Overall BLER vs. additionally required E_b/N_0

larger than 21 because the probability that the number of active users is larger than 21 are very rare. It implies that M_{th} values larger than 21 is not applicable as a threshold. We can determine a proper operating point from this figure by considering the required BLER target value [4] and the additionally required E_b/N_0 allowed in OCHM.

B. Limiting the Number of Multiplexed Users by Delaying Frames

In the previous section, we lowered the required E_b/N_0 value by increasing BLER. Here, we observe a scheme which allows some delay by queueing per user without increasing BLER. Since we need to determine which frame is served first, various types of scheduling schemes can be adopted.

Four scheduling schemes are taken into account:

- Random selection (RS)
- Round robin (RR)
- Longest queue first (LQF)
- Longest wait first (LWF)

The random selection (RS) scheme randomly selects users to be delivered to the comparator & controller module and was adopted in the previous section. The round robin (RR) scheme is to sequentially offer an opportunity to be transmitted for fairness. The longest queue first (LQF) scheme gives priority to a user having the longest queue. Finally, the longest wait first (LWF) scheme is to serve frames which have waited longer. Among four schemes, only RS or RR can be used as a discard scheme of excessive frames in the previous section. LQF and LWF are devised to minimize delay due to queueing. In this situation, we do not need to use any algorithm like the proportionally fair algorithm [16] considering both user diversity and fairness since user traffic characteristics are identical.

[4] A BLER value of 10% is not low but sometimes becomes a target value [15].

C. Reducing the Number of Code-Collisions by Delaying Frames

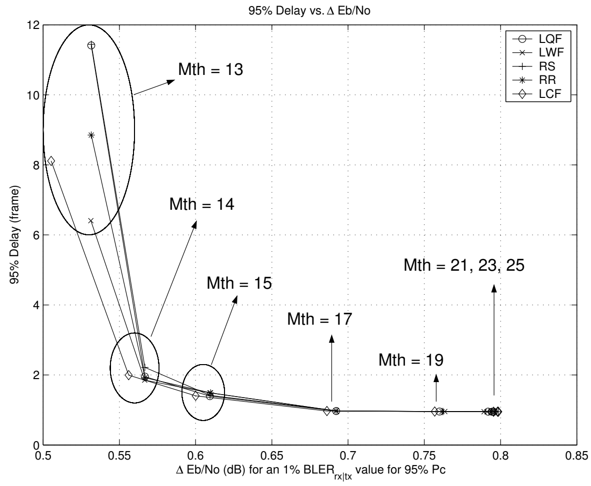
Thus far, we have reduced the number of frames (blocks) by counting only the number of active users. We consider code-collision probability for each frame when we need to discard or delay frames. For competing frames, the number of code-collisions in each frame is counted if the number of active users in a frame time is larger than M_{th}. The number of code-collisions are obtained per user per frame. Then, excessive frames with more code-collisions are delayed in descending order of the number of code-collisions. As a matter of fact, the instantaneous number of code-collisions in a frame is related to other frames and, thus, the number of code-collisions is changed after discarding (delaying) the frame with the largest number of code-collisions. Therefore, we need to count the number of code-collisions repeatedly for every removing (delaying). Since this process adds complexity of one more loop, we just count the number of code-collisions once at the beginning of a frame. This scheme is called a less code-collision first (LCF) scheme. The most obvious advantage of LCF is that it yields a much smaller code-collision probability P_c than the other schemes because LCF selects frames with less code-collisions.

We compare the above five schemes (RS, RR, LQF, LWF, and LCF) by simulation. The simulation environment is identical to Section III-A, but the performance measure is delay instead of BLER. We observe the maximum delay and 95% delay from CDF. The additionally required E_b/N_0 for 95% P_c is also used in the horizontal axis. We assume that even a frame transmission without queueing yields a transmission delay of one frame.

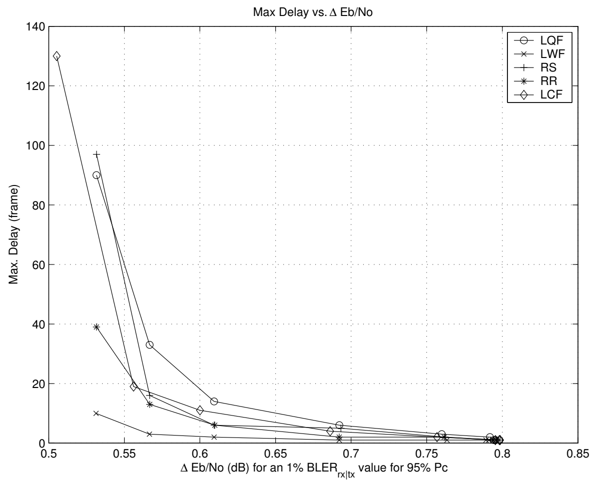
Fig. 6(a) shows 95% delay for five schemes by simulation. Delay values decay as $\Delta E_b/N_0$ (or M_{th}) increases. For small values of $\Delta E_b/N_0$, LCF performs the best, LWF is the second, and the other three schemes show the worst in performance. However, difference in performance becomes negligible for large values of $\Delta E_b/N_0$. Moreover, as expected, LCF shows smaller additionally required E_b/N_0 values than these of the others with given M_{th} values. This is because LCF guarantees the smallest code-collision probability. It means that for a given required E_b/N_0, LCF serves higher transmission rate than that of the others as the cost of scheduling complexity.

Fig. 6(b) illustrates the maximum delay for the five schemes. The performance of the five schemes is similar to that in Fig. 6(a), but difference in performance is significant and still exists for large $\Delta E_b/N_0$ values (or large M_{th} values). These results show that LWF is the best among the five schemes in terms of delay. This is because the measures represent large values of delay and LWF first serves frames with large delay values. Therefore, LWF can be a competing alternative when choosing a suitable scheme according to system requirements.

From these results, we can find the operating point reducing the required E_b/N_0 by considering how much delay the system permits from the figures. For example, 0.57 dB is additionally required for two frames of 95% delay, i.e., one frame of queueing delay after considering one frame of transmission delay. This saves 0.23 dB compared to the additionally required E_b/N_0 value of 0.8 dB for large M_{th} values and is realized by setting M_{th} at 14.



(a) 95% delay vs. additionally required E_b/N_0



(b) Max delay vs. additionally required E_b/N_0

Fig. 6. Delay for five delay schemes (RS, RR, LQF, LWF, and LCF)

IV. Conclusion

In this paper, we lower the code-collision probability by discarding or delaying excessive frames whose number is larger than a threshold value. It reduces the required E_b/N_0 at the transmitter and saves system power. However, there is an increase in BLER (Block Error Rate) or delay. Therefore, there exist trade-offs between E_b/N_0 and BLER (or delay). We can determine an operating point reducing the required E_b/N_0 by considering how much BLER or delay the system requires as a target value.

As discard or delay schemes, we investigate the random selection, the round robin, the longest queue first, and the longest wait first schemes. The longest wait first scheme is the best among the above four schemes from the viewpoint of maximum delay and 95% delay. In the above four schemes, the number of active users is considered every frame. Each user frame may have a different number of code-collisions and, thus, we can reduce the number of code-collisions by delaying excessive frames with more code-collisions. This scheme is called the less code-collision first scheme. It reduces the code-collision probability for a given M_{th} value. The less code-collision first scheme performs better than the random selection scheme, but competes with the longest wait first scheme in terms of maximum delay and 95% delay.

As a further study, combination of both loss and delay will be studied by considering finite queue size and delay limit. It is expected to significantly reduce maximum delay with a little increase in BLER. Besides, more simulations are required for high traffic load environments.

REFERENCES

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

[2] 3GPP, *3rd Generation Partnership Project: Technical Specification Group Radio Access Network,* 3GPP TS 25 series, June 2001.

[3] J. K. Kwon, S. Park, D. K. Sung, and M. G. Kyeong, "Performance Comparison of Orthogonal Code Hopping Multiplexing (OCHM) and HDR Schemes in Synchronous Downlink," *in Proceeding of WCNC 2002,* Orlando, U.S.A., pp. 200-205, March 2002.

[4] M. Kazmi et. al., "Scheduling Algorithms for HS-DSCH in a WCDMA Mixed Traffic Scenario", *Proceeding of PIMRC 2003*.

[5] S. Park and D. K. Sung, "Orthogonal Code Hopping Multiplexing," *IEEE Communications Letters,* Vol. 6, No. 12, pp.529-531, Dec. 2002.

[6] J. K. Kwon, S. Park, and D. K. Sung, "Log-Likelihood Ratio(LLR) Conversion Schemes in Orthogonal Code Hopping Multiplexing," *IEEE Communications Letters,* Vol. 7 No. 3, pp. 104-106, Mar. 2003.

[7] J. K. Kwon, S. Park, D. K. Sung, and Heesoo Lee, "Adaptive Code Rate for Orthogonal Code Hopping Multiplexing(OCHM) in Synchronous Downlink," *in Proceeding of WCNC 2003*, New Orleans, U.S.A., pp. 855-859, Mar. 2003.

[8] T. Onizawa and T. Hasegawa, "The Spread Spectrum Code Hopping System ," *in Proceeding of ISSSTA 1994,* vol. 1, pp. 287-291, July 1994.

[9] B. Unal and Y. Tanik, "Capacity Improvement by Code-Hopping in S-CDMA Systems," *in Proceeding of ICC 1998,* vol. 2, pp. 989-993, June 1998.

[10] B. Unal and Y. Tanik, "Code-Hopping as a New Strategy to Improve Performance of S-CDMA Celluar Systems," it in Proceeding of Globecom 1996, vol. 2, pp. 18-22, Nov. 1996.

[11] S. Park and D. K. Sung, "Orthogonal Code Hopping Multiplexing for Downlink in Spread Spectrum Communications," *in Proceeding of MDMC'01,* Pori, Finland, pp.365-372, June 2001.

[12] S. Park, S. H. Moon, J. K. Kwon, and D. K. Sung, "Orthogonal Code Hopping Multiplexing for Downlink Statistical Multiplexing," *in Proceeding of ISSSTA 2002,* Prague, Czech Republic, pp. 588-592, Sep. 2002.

[13] S.Floyd and V. Jacobson, "Random Early Detection Gateways for Congestion Avoidance," *IEEE ACM Trans. on Networking,* Vol. 1, No. 4, pp. 397-413, Aug. 1993.

[14] A. Romanow and S. Floyd, "Dynamics of TCP Traffic over ATM Networks," *IEEE Journal on Selected Areas in Communications,* Vol. 13, No. 4, pp. 633-641, May 1995.

[15] IEEE, *IEEE Std. 802.11a-1999: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications; High-Speed Physical Layer in the 5GHz Band,* 1999.

[16] Jack M. Holtzman, "Asymptotic Analysis of Proportional Fair Algorithm," *Procedding of PIMRC 2001,* San Diego, USA, Sep.-Oct. 2001.