Inter-code Group Interference Cancellation Receiver for Downlink W-CDMA Communication Systems

Pisanu Korkiatpitak and Watit Benjapolakul
Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University, Phayathai Rd., Pathum Wan, Bangkok 10330, Thailand
Phone: +66(0)2218 6902, Fax: +66(0)2218 6912
E-mail: pisanu.k@student.chula.ac.th, watit.b@chula.ac.th

Abstract

In this paper, an inter-code group interference cancellation receiver is proposed for downlink wideband-code division multiple access (W-CDMA) communication systems. In a W-CDMA, orthogonal variable spreading factor (OVSF) codes are used to provide various data rates and maintaining the orthogonality between different spreading codes of different lengths. Accordingly, the proposed receiver can use the correlation property between mother codes and child codes of the OVSF codes to separate the codes into code groups. The mother code with desired user as a member of a code group is called the representative code of the desired code group and the other mother codes are called representative code of interfering code groups. No prior knowledge of users' spreading codes or even their spreading factors are required for estimating the representative codes of interfering code groups. The mobile receiver estimates the representative codes using fast Walsh transform (FWT) correlators and uses these codes to cancel the interference by successive interference cancellation (SIC). For a W-CDMA system and the IMT-2000 vehicular channel A model, a capacity increase of up to 100% of the original (without interference cancellation) system capacity is shown. Furthermore, the complexity of the proposed algorithm is low compared with other interference cancellation techniques.

1. Introduction

Third generation cellular systems are being designed to support wideband services like high speed internet access, video and high quality image transmission with the same quality as the fixed networks. Consequently, users will transmit their information signals using various data rates and their performance requirements will vary from application to application. In wideband-code division multiple access (W-CDMA), OVSF (orthogonal variable spreading factor) codes are used for variable spreading factor (SF) to provide various data rates and to maintain the orthogonality between different spreading codes of different lengths [1].

In W-CDMA downlink, the signals for different physical channels within a cell are transmitted synchronously by base stations. Typically, orthogonal spreading codes are assigned to distinct physical channels, thereby creating mutually orthogonal downlink signals. If these signals are transmitted through a multipath channel, the orthogonality can no longer be maintained at the receiver, giving rise to multiple access interference (MAI). Additionally, link capacity of W-CDMA is limited by interference. So if the MAI is reduced, the link capacity will be increased.

Several interference cancellation receivers [2-4] for downlink CDMA have been proposed. These receivers are assumed to know the spreading codes of other users. This assumption is not true for use in downlink where the mobile unit only knows its own spreading code. Moreover, these receivers are considered in a fixed spreading factor system which is not suitable for W-CDMA systems that are variable spreading factor systems or multirate systems. Nevertheless, the combined-interfering signals and subtractive cancellation receiver (reference receiver) in [5] is considered a multirate system and does not need to know the spreading codes of the other users. This receiver uses fast Walsh transform (FWT) correlators to estimate the interfering codes called effective spreading code (ESC). Then, this ESC is used to cancel the interference by successive inter-ference cancellation (SIC).

In this paper, an inter-code group interference cancellation receiver is proposed. This receiver uses the correlation property between mother codes and child codes of the OVSF codes to separate the codes into code groups. The mother code with desired user as a member of a code group is called the representative code of the desired code group and the other mother codes are called representative codes of interfering code groups. Both of the representative codes are estimated by FWT correlators in the same way as reference receivers. Then, the representative codes of interfering code groups are selected to be cancelled out from the received signal by subtractive cancellation.

This paper is organized as follows. In Section II, the signal model is specified. The proposed receiver and simulation results are presented in Section III and Section IV, respectively. Finally, Section V concludes the paper.

2. Signal Model

Signal models can be classified into two cases, fixed spreading factor case and variable spreading factor case [5].

A. Fixed Spreading Factor

In this case, the spreading factor is the same for all users. The spread signal for the k^{th} user, before scrambling can be written by [5]:

$$s_k(t) = \sum_{i=-\infty}^{\infty} b_k(i) c_k(t - iNT_c) \tag{1}$$

where $b_k(i)$ is the i^{th} data symbol for the k^{th} user; $c_k(t)$ is the spreading waveform of the k^{th} user; N is the spreading factor; and T_c is the chip duration. The combined and scrambled signal is given by [5]:

$$x(t) = a(t) \sum_{k=1}^{K} \sqrt{P_k}\, s_k(t) \tag{2}$$

where $a(t)$ is the scrambling code; K is the total number of users; P_k is the transmitted power for the k^{th} user signal. The received signal can be given by [5]:

$$r(t) = \sum_{l=1}^{L} \alpha_l x(t - \tau_l) + n(t) \tag{3}$$

where L is the number of paths; α_l and τ_l are the l^{th} complex path gain and delay, repec-tively; and $n(t)$ is the Gaussian noise component. A typical CDMA receiver consists of L fingers for despreading. Despread values are weighted and combined to form a decision statistic. Without loss of generality, let's assume the demodulation of $b_1(0)$ (bit number zero of the 1st user signal). From the l^{th} finger output $(l = 1,\ldots,L)$, the output of the multiuser interference terms can be written by [5]:

$$i_1^{(l)} = \int_{\tau_l}^{\tau_l + NT_c} \left(\sum_{\substack{p=1 \\ p \neq l}}^{L} \alpha_p a(t - \tau_p) \left(\sum_{k=2}^{K} \sqrt{P_k}\, b_k(0) \times c_k(t - \tau_p) \right) \right) a^*(t - \tau_l) c_1^*(t - \tau_l)\, dt \tag{4}$$

where * denotes complex conjugation.

B. Variable Spreading Factor

In W-CDMA, the OVSF codes are used to provide various data rates. The OVSF codes are illustrated in Fig. 1. The concept of effective spreading code (ESC) [5] is used to perform interference cancellation in a similar manner as in a single rate system. Using this concept, the intracell multiuser interference of the variable spreading factor case can be written to be [5]:

$$i_1^{(l)} = \int_{\tau_l}^{\tau_l + NT_c} \left(\sum_{\substack{p=1 \\ p \neq 1}}^{L} \alpha_p a(t - \tau_p) \left(\sum_{k=2}^{K} \sqrt{P_k}\, \hat{b}_k(0) \times \hat{c}_{k,0}(t - \tau_p) \right) \right) a^*(t - \tau_l) c_1^*(t - \tau_l)\, dt \tag{5}$$

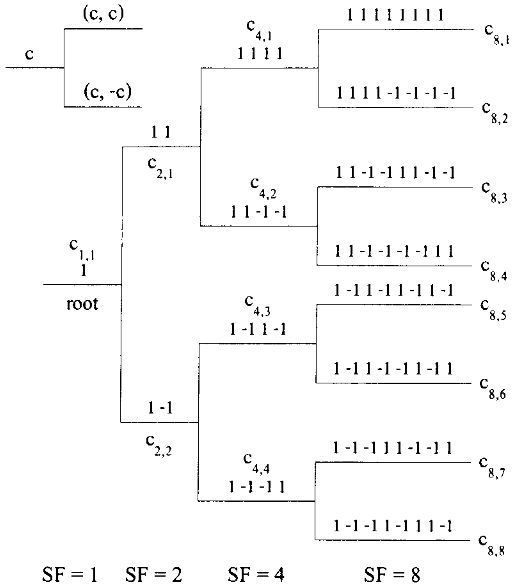

Fig. 1. Orthogonal variable spreading factor (OVSF) codes.

where $\hat{c}_{k,i}(t)$ and $\hat{b}_k(i)$ are the i^{th} symbol effective spreading code and effective data symbol of the k^{th} user, respectively.

In order to perform interference cancellation using the proposed technique, the correlation property between mother codes and child codes of the OVSF codes is introduced first. From Fig. 1, $c_{i,j}$ means the j $^{\text{th}}$ code in the ($\log_2$ i) $^{\text{th}}$ level. The child code is generated by the mother code, for example, $c_{8,3}$ = ($c_{4,2}$, $c_{4,2}$) and $c_{8,4}$ = ($c_{4,2}$, -$c_{4,2}$). The correlation between mother code $c_{4,2}$ and child code $c_{8,3}$ is (1,1) and the correlation between $c_{4,2}$ and $c_{8,4}$ is (1,-1). Thus, the child codes can be perfectly described by the mother code and their correlation value. In Fig. 1, $c_{4,4}$, $c_{8,5}$ and $c_{8,6}$ are members of a code group that has $c_{2,2}$ as the mother code. So, the mother code of the code group can be called the representative code and the child codes can be called members of the code group. Using these properties, the proposed interference cancellation decreases the code level from the desired code level to find other representative codes that interfere with the representative code of the desired code. To demon-strate this technique, the case that the spreading factor (SF) for desired user is 8 (in the 3rd level) and $c_{8,5}$ in Fig. 1 is the desired code. Assume the proposed technique decreases the representative code in one-step (SF=8 to SF=4). In SF=4 level, $c_{4,3}$ is the representative code with desired code as a member of code group. $c_{4,3}$ is called a representative code of the desired code group. On the contrary, other representative codes $c_{4,1}$, $c_{4,2}$ and $c_{4,4}$ are the codes that interfere with the representative code of the desired code group. These codes are called representative code of interfering code groups. According to this technique, the proposed interference cancellation receiver can be called an inter-code group interference cancellation recei-ver.

The multiuser interference of the proposed technique can be derived from Fig. 2, an example with three users using different spreading factors. The spreading factors for users 1, 2, and 3 are 16, 8, and 4, respectively. Let N, $N/2$, and $N/4$ be the spreading factors for users 1, 2, and 3, respectively. The spread data signal of these users can be written as [5]

$$s_1(t) = \sum_i b_1(i)c_1(t - iNT_c) \tag{6}$$

$$s_2(t) = \sum_i b_2(i)c_2(t - \frac{iNT_c}{2}) \tag{7}$$

$$s_3(t) = \sum_i b_3(i)c_3(t - \frac{iNT_c}{4}) \tag{8}$$

Assume user 1 is the desired user and a receiver uses the proposed technique with one-step decreased level $(n = 1)$, that decreases the level from SF=16 to SF=8. Thus, the received signal in 1 bit (16 chips) is divided into 2 parts (or 2^n parts, each part is numbered by u where $u = 0,1,2,...,2^n - 1$). In this case, there are 8 chips per part and the duration of each part is $8T_c$ (or $NT_c/2^n$). The signal of user #2 in Eq. (7) can be written as:

$$s_2(t) = \sum_i \sum_{u=0}^{1} \hat{b}_2^{(i)}(u)\hat{c}_{2,u}^{(i)}(t - \frac{uNT_c}{2}) \tag{9}$$

where $\hat{b}_2^{(i)}(u) = b_2(u + 2i)$ and $\hat{c}_{2,u}^{(i)}(t)$, the representative code that has user #2 as a member of code group in part $\# u$ for the i^{th} symbol of user #1, is:

$$\hat{c}_{2,u}^{(i)}(t) = c_2(t) \tag{10}$$

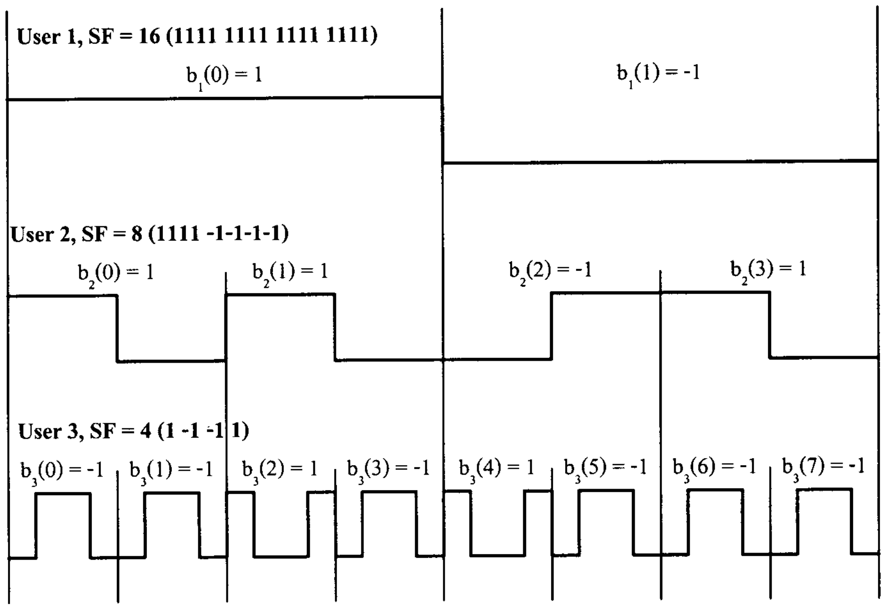

Fig. 2. Examples of various spreading factor cases.

Likewise, the signal of user #3 in Eq. (8) can be re-written as:

$$s_3(t) = \sum_i \sum_{u=0}^{1} \hat{b}_3^{(i)}(u)\hat{c}_{3,u}^{(i)}(t - \frac{uNT_c}{2}) \qquad (11)$$

where $\hat{b}_3^{(i)}(u) = b_2(2u+4i)$ and $\hat{c}_{3,u}^{(i)}(t)$, the representative code that has user #3 as a member of the code group in part $\#u$ for the i^{th} symbol of user #1, is:

$$\hat{c}_{3,u}^{(i)}(t) = c_3(t) + b_3(2u+4i)b_3(2u+4i+1)c_3(t - \frac{NT_c}{4}) \qquad (12)$$

Using this concept, the intracell multiuser interference is divided into 2 parts and can be shown to be:

$$i_{1,0}^{(l)} = \int_{\tau_l}^{\tau_l + \frac{NT_c}{2}} \left(\sum_{\substack{p=1 \\ p \neq l}}^{L} \alpha_p a(t - \tau_p) \left(\sum_{k=2}^{K} \sqrt{P_k}\,\hat{b}_k^{(0)}(0) \times \hat{c}_{k,0}^{(0)}(t - \tau_p) \right) \right) a^*(t - \tau_l)c_1^*(t - \tau_l)dt \qquad (13)$$

and

$$i_{1,1}^{(l)} = \int_{\tau_l + \frac{NT_c}{2}}^{\tau_l + NT_c} \left(\sum_{\substack{p=1 \\ p \neq l}}^{L} \alpha_p a(t - \frac{NT_c}{2} - \tau_p) \left(\sum_{k=2}^{K} \sqrt{P_k}\,\hat{b}_k^{(0)}(1) \times \hat{c}_{k,1}^{(0)}(t - \frac{NT_c}{2} - \tau_p) \right) \right) \times a^*(t - \frac{NT_c}{2} - \tau_l)c_1^*(t - \frac{NT_c}{2} - \tau_l)dt \qquad (14)$$

where $\hat{c}_{k,u}^{(i)}(t)$ is the representative code of an interfering code group that has the k^{th} user as a member of code group in the uth part for the i th symbol. From this example, the generalized

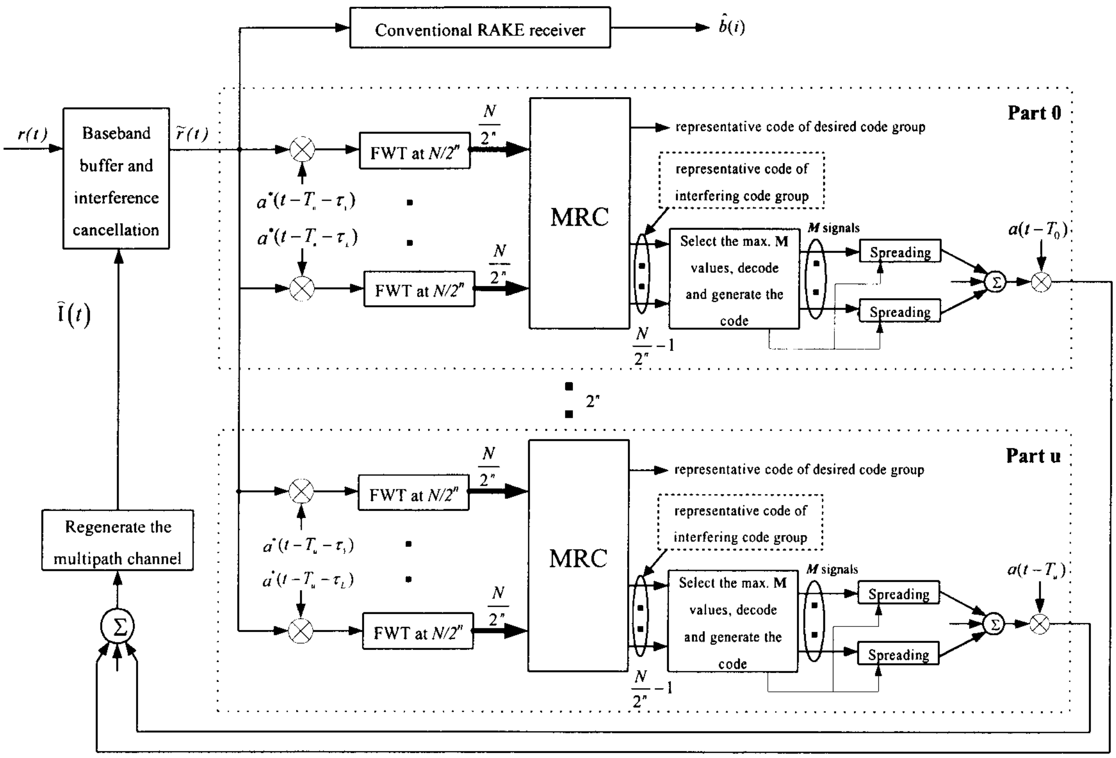

Fig. 3. Inter-code group interference cancellation receiver.

form of the intracell multiuser interference in the u th part for the i th symbol can be written as:

$$\hat{i}_{1,u}^{(l)} = \int_{\tau_l+T_u}^{\tau_l+T_{u+1}} \left(\sum_{\substack{p=1 \\ p\neq l}}^{L} \alpha_p a(t-T_u-\tau_p) \left(\sum_{k=2}^{K} \sqrt{P_k} \hat{b}_k^{(i)}(u) \times \tilde{c}_{k,u}^{(i)}(t-T_u-\tau_p) \right) \right)$$

$$\times a^*(t-T_u-\tau_l) c_1^*(t-T_u-\tau_l) dt \qquad (15)$$

where $T_u = uNT_c/2^n$, $u = 0,1,2,...,2^n-1$ and n is the decreased level. The interference from all parts (2^n parts) are combined together and can be written to be:

$$\hat{i}_1^{(l)} = \sum_{u=0}^{2^n-1} \hat{i}_{1,u}^{(l)} \qquad (16)$$

3. Inter-code Group Interference Cancellation Receiver

The proposed receiver structure is shown in Fig. 3. The main idea of this receiver is successive interference cancellation (SIC). The received signal is divided into 2^n parts that depend on the decreased level (n). In each part, the received signal is passed on through a RAKE receiver, but instead of using a conventional correlator at each finger, this receiver uses a fast Walsh transform (FWT) to correlate against all $(N/2^n)$ orthogonal codes. Then, the receiver combines the $(N/2^n)$ correlation values from L fingers according to the maximum ratio combining (MRC) principle [1]. In the $(N/2^n)$ correlation values from MRC, only one correlation value is the correlation for the representative code of the desired code group, the other $(N/2^n)-1$ correlation values are the correlation for representative codes of inter-fering code groups that should be cancelled out from the received signal by selecting the maximum M correlation values. Then, the selected correlation values are decoded, spread, and scrambled at the end of each part. The signals from all parts are combined together and then pass on to a regenerated version of the multipath channel, generating an interfering signal to be cancelled out from the received signal. The cancellation process uses the subtraction technique that can be given by

$$\tilde{r}(t) = r(t) - \hat{I}(t) \quad (17)$$

where $r(t)$ is the received signal; $\hat{I}(t)$ is the regenerated interfering signal; and $\tilde{r}(t)$ is the modified received signal. After the cancellation process, the receiver has the choices to stop or continue cancellation. The receiver performs the same process as before if the receiver chooses to continue cancellation. But, if the receiver chooses to stop, the modified received signal is detected by a conventional RAKE receiver.

4. Simulation Results

In this section, the results from computer simulations are presented. The parameters for simulation are as follows [5]. There are K users simultaneously transmitting their information data signals with different symbol rates. Each user is assigned a Walsh code with different spreading factors (SF). Note that the same E_b / N_0 is used for all physical users (mobile terminals) regardless of their data rates. Accordingly, the high data rate users have higher average power than the low data rate users. For instance, the average power of a user with data rate MR is M times that of the single user, therefore, an M-rate user can be considered as M single rate users (M effective users). In the simulation, both AWGN (additive white Gaussian noise) and multipath fading channels are also considered. The simulated frequency-selective fading channel uses the IMT-2000 vehicular channel A model [6], which is the low delay spread case that occurs frequently, at the carrier frequency of 2 GHz and 100 km/h with correlated coefficients generated using Jake's model [7]. The multipath channel parameters are shown in Table 1. QPSK modulation is used for data with spreading factors ranging from 128 (voice) to 8 (data). The frame length is 10 ms. The scrambling code is a truncated Gold se-quence of length 40,960 chips. The RAKE receiver has six fingers. Finally, perfect channel estimation is assumed.

Table 1. IMT-2000 vehicular channel A model para- meters

Path number	Delay (ns)	Average Power (dB)
0	0	0
1	310	-1
2	710	-9
3	1090	-10
4	1730	-15
5	2510	-20

A. Performance Evaluation

In this simulation, there are seven users with spreading factors of 128, 128, 64, 16, 16, 8 and 8 (52 effective users) at SNR (signal to noise ratio) = 20 dB. The average BER (bit error rate) of a single rate user (SF=128) versus the number of iterations is plotted in Fig. 4 which results from using the proposed receiver with one-step decreased level $(n=1)$. The number of correlation values (M), that are selected in each part, are chosen to be $M = 2$, $M = 4$, and $M = 6$ for illustration. It is observed when iteration is not higher than three that the proposed receiver performs better if the value of M increases. However, in the case of $M = 6$, when the iteration is higher than three, the performance may be worse than that in the case of $M < 6$, for example, the performance in the case of $M = 6$ is worse than that in the case of $M = 2$ in the 6th iteration. This problem occurred because the behavior of BER tends to diverge and is a so-called over cancellation [5] or ping-pong effect [8]. Consequently, for the case of $n=1$, it is better to choose $M=1$ or $M=2$ so that over cancellation or a ping-pong effect will be avoided. Fig. 5 presents simulated results the same as Fig. 4, but in the case of two-step decreased levels $(n=2)$. The same behavior as in the case of $n=1$ is observed. In this case, however, the over cancellation or ping-pong effect is likely to occur. It is suggested to use the number of iterations which is less than the value that makes BER start to diverge. Nevertheless, if the required BER is the same, the case of $n=2$ needs a lower number of iterations than the case of $n=1$ to

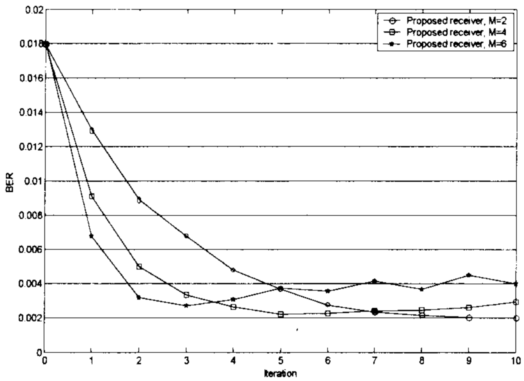

Fig. 4. Performance evaluation of the proposed receiver with one-step decreased level $(n=1)$.

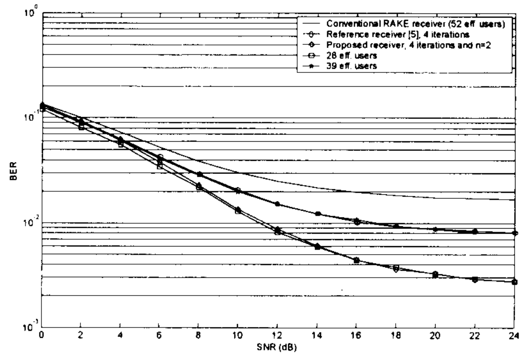

Fig. 6. Capacity enhancement using the reference receiver and the proposed receiver $(n=2)$ with $M=2$ and iteration $=4$.

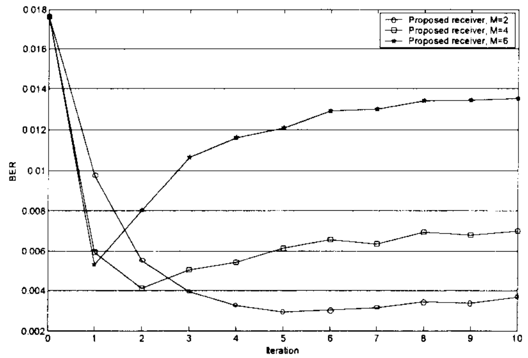

Fig. 5. Performance evaluation of the proposed receiver with two-step decreased levels $(n=2)$.

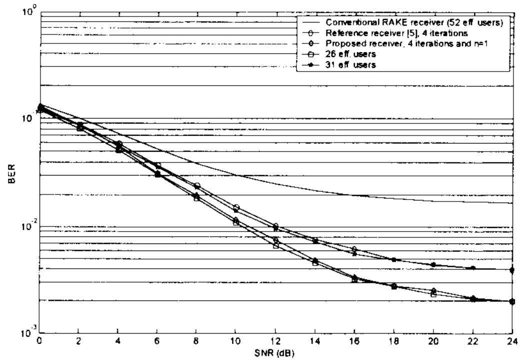

Fig. 7. Capacity enhancement using the reference receiver and the proposed receiver $(n=1)$ with $M=4$ and iteration $=4$.

achieve that BER. For example, in the case of $M=2$ and required BER = 0.004, the case of $n=1$ needs five iterations to achieve this requirement, but the case of $n=2$ just needs three iterations.

B. Capacity Enhancement

The increase of capacity, as a result of using interference cancellation receivers, i.e., the proposed receiver, and the combined-interfering signals and subtractive cancellation receiver (reference receiver) [5], are shown in this section. There are 52 effective users in the system, the same as in the previous section. In Fig. 6, the BER has been plotted as a function of the SNR. Both reference receiver and proposed receiver use $M=2$ and iteration = 4. In addition, the proposed receiver decreases two steps of the code level $(n=2)$. The performance of applying a conventional RAKE receiver to 52 effective users , 39 effective users, and 28 effec- tive users have been plotted to demonstrate capacity increase. From the plots, using the reference receiver and the proposed receiver, the system capacity is increasel when compared with using conventional RAKE receiver (52 effective users) by about 33% and 85%, respectively. So the proposed receiver gives a better performance than the reference receiver by about 52%. Plots in Fig. 7 compare the reference receiver with the proposed receiver with one-step decreased level, using $M=4$ and iteration = 4. Again, the BER versus the SNR and the performance of applying conventional RAKE receiver to 52 effective users, 31 effective users, and 26 effective users have been plotted. From these results, using the reference receiver the system capacity is increasel when compared with using conventional a RAKE receiver (52 effective users) by about 67% but using the proposed receiver increases the capacity by about 100%

which is higher than that of the reference receiver by about 33%.

C. Complexity Comparison

This section compares the computational complexity of the reference algorithm and the proposed algorithm by counting up how many operations (addition, subtraction, multiplication, division, or modulo) are required for detecting the data in one symbol. This method is known as a flop (floating point operation) count and the unit of flop count is called flop. So the complexity in this case is flops per symbol (flops/symbol). In Fig. 8, the complexity has been plotted as a function of iteration. The reference algorithm and the proposed algorithm use $M = 4$. The decreased level for the proposed algorithm is chosen to be $n = 1$, $n = 2$, $n = 3$, and $n = 4$. From the plots, it is clear for both reference and proposed algorithms that the complexity increases when increasing the iteration. Furthermore, the reference algorithm is more complex than the proposed algorithm in all decreased levels because the proposed algorithm reduces the complexity in FWT correlators from $N \log_2 N$ to $(N/2^n)\log_2(N/2^n)$ where N is the spreading factor of desired user and n is the decreased level. Thus, higher decreased level reduces complexity.

V. Conclusion

In this paper, an inter-code group interference cancellation receiver is proposed. The concept of this receiver is to estimate the representative codes of interfering code groups that should be cancelled out from the received signal. From the simulation results, the problem of over cancellation or ping-pong effect can be observed in the BER. Accordingly, it is important to choose the numbers of M, n, and iterations that do not make the BER diverge. Nevertheless, using the proposed receiver can increase the capacity of up to 100% of the original (without interference cancellation) system capacity. Because of the problem of over cancellation or ping-pong effect, in future work, the cancellation process will be changed from subtractive technique to a projection technique in order to avoid this problem.

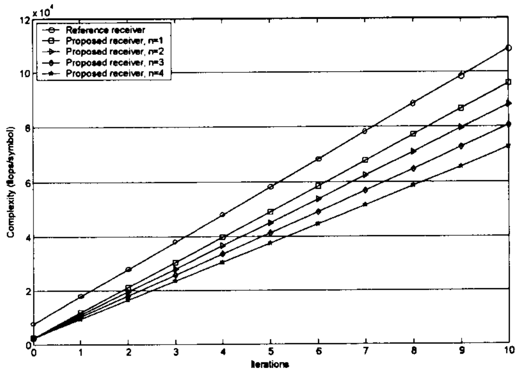

Fig. 8. The complexity of different receivers.

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