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Performance Analysis CDMA Systems by Using Biorthogonal Codes

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배직교부호를 이용한 CDMA 시스템의 성능 분석

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ABSTRACT

In this paper, a new CDMA system is proposed, which is composed of very low rate convolutional codes and biorthogonal codes with good cross-correlation property. Convolutional encoder with rate 1/64 and constraint length 7 and 128 rows × 64 chips biorthogonal codes generated from Walsh codes with 64 rows × 64 chips are used for encoding and spreading. Viterbi decoder is used for demodulating newly designed CDMA system, whose branch metric values are not repeated by butterfly form but have different 128 values. The performance of the proposed CDMA system is analyzed and compared with conventional CDMA system and CDMA system with FEC and orthogonal modulation, which is similar to Qualcomm's CDMA system. The performance of the proposed CDMA system using biorthogonal code is better than of the CDMA system using and orthogonal modulation, and from the hardware complexity point of view, the amount of computation for implementing the proposed CDMA system is increased only a little.

要 約

본 논문에서는 오류정정 능력이 강한 부호율이 매우 낮은 길쌈부호와 상호상관 특성이 우수한 배직교부호를 결합한 새로운 CDMA 시스템을 제안한다. 제안된 시스템에서 사용된 배직교부호 변조기는 부호율이 1/64이고 구속장 길이가 7인 길쌈부호기와 64행×64칩의 Walsh 직교부호로 부터 발생된 128행×64칩의 배직교부호로 구성된다. 복조에 사용된 Viterbi 복호기의 가지 메트릭은 버터플라이 형태로 반복되지 않고 128개의 서로 다른 값을 가지게 된다. 제안된 CDMA 시스템의 성능은 일반적인 CDMA 시스템과, Qualcomm의 CDMA 시스템과 비슷한 FEC와 직교부호 변조를 이용한 DMA 시스템과 함께 비교 및 분석된다. 배직교부호를 이용한 CDMA 시스템의 성능은 FEC와 직교부호 변조를 이용한 CDMA 시스템보다 더 우수하며, 하드웨어의 복잡도 관점에서 고려할 때 구현에 대한 계산량이 다소 증가하지만 무시할 정도로 생각된다.

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Ⅰ. Introduction

Mobile communication service has been rapidly grown to saturate the capacity of system because of mobility, speed, globality and convenience since cellular communication systems has been introduced in early 1960s. As the capacity of current analog cellular communication system is gradually saturated because of consistently increasing number of subscribers, the development of the digital mobile communication is being accelerated to solve the capacity congestion problem. Although TDMA system is already being deployed in USA and Europe as a standard of digital cellular system, CDMA system which accommodates more users and better services is getting more attention from many countries[1]. Recently, CDMA system is adopted as a standard for next generation digital cellular system in Korea, and the commercial service by CDMA system will be stsred in a year.

CDMA communication system as a spread-spectrum multiple access system using spreading codes, can share the same carrier frequency among users, use soft-handoff between cells, and decrease performance degradation by multipath fading under mobile communication environment. Since fading phenomenon severely degrades voice quality by generating burst and random errors, error control technology is required[2][3].

In this paper, a new CDMA system is proposed, which is composed of very low rate convolutional codes and biorthogonal codes with good cross-correlation property. The performace of the proposed CDMA system is analyzed and compared with typical CDMA system and CDMA system using FEC and orthogonal modulation.

The proposed CDMA system using biorthogonal code and very low rate convolutional code turns out to have good performance enough to substitute the existing CDMA system using FEC and orthogonal modulation, and from the hardware complexity point of view, it makes it easy to implement CDMA digital cellular systems.

In section Ⅱ, we describe the entire configuration of the proposed CDMA system and introduce biorthogonal code modulator combined with very low rate convolutional code. Viterbi decoder is explained for demodulating the received signal modulated by biorthogonal codes in section Ⅲ, and for the performance comparison of this CDMA system, existing conventional CDMA system and CDMA system using FEC and orthogonal modulation are presented. From the simulation result, it turns out that the performance of the proposed CDMA system using biorthogonal codes is better than those of the other CDMA systems. Last, in section V, we conclude the paper.

Ⅱ. Spread Spectrum Modulation using Biorthogonal Codes

Mobile communcation system is generally composed of forward link from base station to mobile station and reverse link from mobile station to base station[4]. Specially, in the reverse link, robust system design is required to compensate with degradation of performance due to multipath fading. Therefore, CDMA system using error correcting codes and orthogonal code modulation, can be used in the reverse link.

We proposed new CDMA system using biorthogonal codes, which can be used in CDMA system as Fig. 1. This system is composed of very low rate convolutional encoder using biorthogonal codes, PN sequence generator, PN chip soft-decision and Viterbi decoder.

Information bits are inputed at 9600bps to be transmitted through the reverse link. These input bits are transformed to 614.4Kcps rate symbols by very low rate convolutional encoder with code rate 1/64 and constraint length 7 and biorthogonal codes with 128 rows and 64 chips. That is, one input bit is transformed to biothogonal code of 64 chips selected by biorthogonal modulator. And each chip is spreaded by 2 and scrambled by two different PN sequences. Those PN sequences are long PN sequence and pilot PN sequence(short PN sequence) which have period $2^{42}-1$ and 2^{15}, respectively. The output chips of biorthogonal modulator are spreaded to to 1.2288Mcps transmission rate by long PN sequence and multiplied by pilot PN sequence and modulated in QPSK.

The transmitted signal is received through AWGN channel and multiplied by synchronized pilot PN sequence. Then, signals of I and Q channels are added and despreaded by synchronized by long PN sequence. After PN chip soft-decision, the symbols are inputed to Viterbi decoder, which is composed of branch metric calculation, add-compare-select, path metric memory and traceback depth operation for decoding the received signals.

Biorthogonal code set with total M codewords can be obtained from Walsh codes with $M/2$ signals as below[5].

$$B_k = \begin{bmatrix} H_{k-1} \\ \overline{H}_{k-1} \end{bmatrix} \quad (1)$$

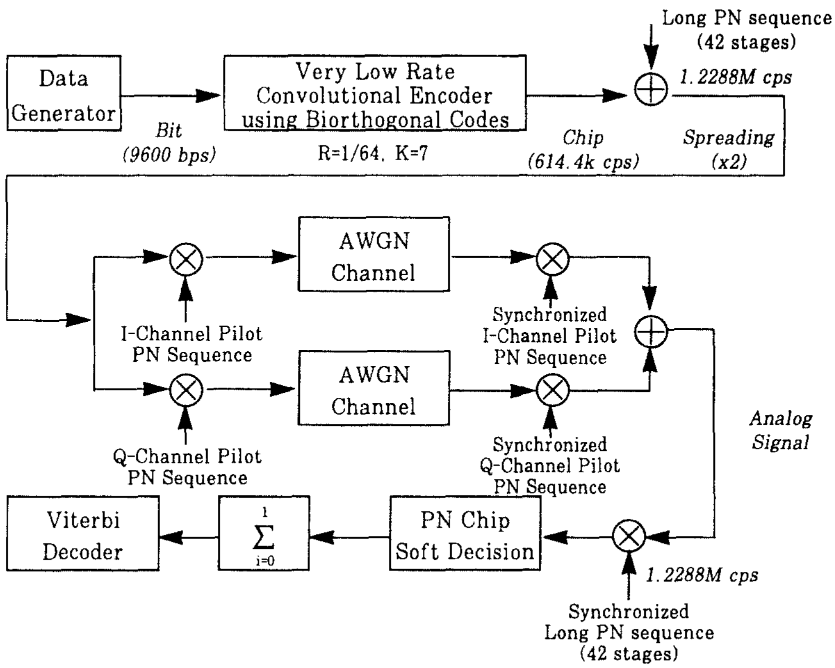

Fig. 1. Block diagram of CDMA system using biorthogonal codes

Here, Hadamard matrix H_{k-1} has a size of $2^{k-1} \times 2^{k-1}$ and can be generated as

$$H_{k-1} = \begin{bmatrix} H_{k-2} & H_{k-2} \\ H_{k-2} & \overline{H}_{k-2} \end{bmatrix} \quad (2)$$

where $\overline{H}_{k-2}$ is bit inversion of H_{k-2}. Biorthogonal code is composed of two sets of orthogonal codes, each codeword in one set has its antipodal codeword in another set. Biorthogonal codes, therefore, is organized by orthogonal and antipodal signal set.

Generally, signal set with equal energy $s_i(t)$, i=1,2,..., M has orthogonality if equation (3) is satisfied.

$$z_{ij} = \frac{1}{E}\int_0^T s_i(t)s_j(t)dt = \begin{cases} 1 & \text{for } i = j \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where z_{ij} is called cross-correlation coefficient, and E is defined as

$$E = \int_0^T s_i^2(t)dt \quad (4)$$

Using z_{ij}, the cross-correlation of biorthogonal codes is calculated as the following.

$$z_{ij} = \begin{cases} 1 & \text{for } i = j \\ -1 & \text{for } i \neq j,\ |i-j| = M/2 \\ 0 & \text{for } i \neq j,\ |i-j| \neq M/2 \end{cases} \quad (5)$$

Biorthogonal codes used in orthogonal modulation of the proposed CDMA system in this paper are given as the biorthogonal code B_7 with size $128 \times 64(2^7 \times 2^6)$ generated by Hadamard matrix H_6 with size $64 \times 64(2^6 \times 2^6)$. The selection of biorthogonal code is determined by 7-bit output of shift registers in Fig. 2.

In biorthogonal code modulator, one bit information data is inputed and it outputs the modulated 64 chips by choosing one of 128 biorthogonal codes. Convolutional encoder in this CDMA system uses biorthogonal codes with code rate 1/64 and constraint lengh 7. We internally consider biorthogonal modulator as a convolutional encoder to generate address of biorthogonal codes according to input bits. The block diagram of very low rate convolutional encoder using biorthogonal codes is shown in Fig. 2.

(c_1, c_2, ..., c_7) denotes the address used in selecting one codeword in the table of biorthogonal code set. Upper part of convolutional encoder has the role of generating the address of biorthogonal code. Equation (6) represents its address calculation method as

$$\begin{aligned} \text{ADRS} &= \sum_{i=1}^{7} 2^{i-1} c_i \\ &= 2^0 c_1 + 2^1 c_2 + 2^2 c_3 + 2^3 c_4 + 2^4 c_5 + 2^5 c_6 + 2^6 c_7 \\ &= c_1 + 2c_2 + 4c_3 + 8c_4 + 16c_5 + 32c_6 + 64c_7 \end{aligned} \quad (6)$$

where ADRS is the address pointing one of

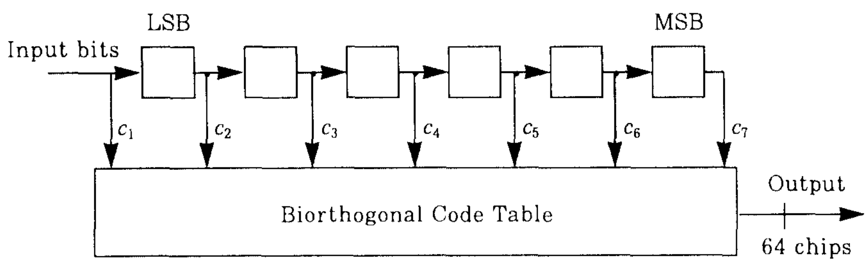

Fig. 2. Block diagram of very low rate convolutional encoder using biorthogonal codes

128 codes in the table of biorthogonal code set, and $c_i(i=1,2,\dots,7)$ is the output of shift registers in Fig. 2.

In order to generate the biorthogonal codes, we need 64-ary Walsh orthogonal codes. The upper half part of biorthogonal code table is composed of Walsh code itself and the lower half part is filled with bit inversioned Walsh code. Fig. 3 shows the biorthogonal code table.

In Fig. 3, $(i+64)$-th code is the 1's complement of i-th code. The ideal correlation of 64-ary Walsh code takes on the values, 0 or +64, however that of biorthogonal code using Walsh code takes on the values, -64, 0 or +64. Therefore, the correlation property of biorthogonal codes is better than that of Walsh codes.

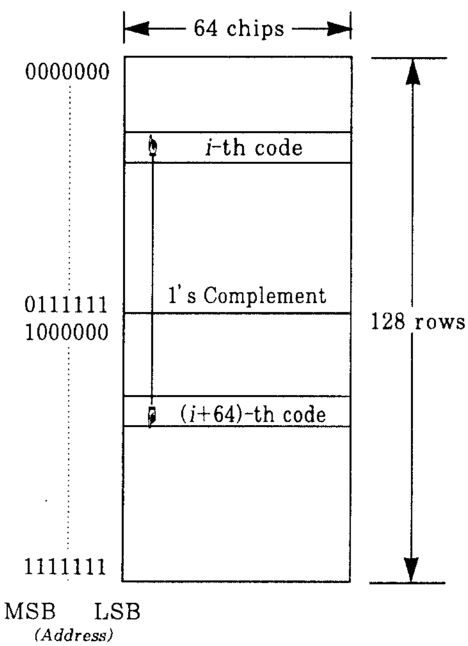

Fig. 3. Structure of biorthogonal code table

Ⅲ. Demodulation using Viterbi Decoder

The received signal which was spreaded and scrambled by long and pilot PN sequence and modulated by QPSK, is quantized by soft-decision before it is inputed to Viterbi decoder. The received signal can be represented as follows.

$$r = \pm\sqrt{E_s} + n \tag{7}$$

where E_s is signal energy per transmitted code symbol, and n is additive white Gaussian noise with zero mean and double sided noise power spectral density $N_0/2$.

The received analog baseband signal r is inputed to Viterbi decoder as quantized digital symbol $y_1, y_2, \dots y_Q$ according to soft-decision threshold values $b_1, b_2, \dots, b_{Q-1}$.

It is well known that if the number of soft-decision bit is 4, the optimal full scale value for soft-decision is represented as

$$f_s = 8.0 \times 0.6 \times \frac{1}{\sqrt{\frac{E_b}{N_0} \times D}} \tag{8}$$

where 8.0 means that each symbol is assigned to 8-level because decision level Q is 16, and 0.6 is experimental value for the best performance of Viterbi decoder. And D is the parameter for the optimal full scale.

The implementation of Viterbi decoder for decoding the proposed CDMA system is different from common Viterbi decoder. That is, when we calculate path metric, the branch metric values are not repeated by certain butterfly from but obtained from different 128 branch metric values. Fig. 4 shows the trellis diagram of very low rate convolutional code using biorthogonal codes.

First, 128 different branch metric values are calculated when the outputs of PN chip

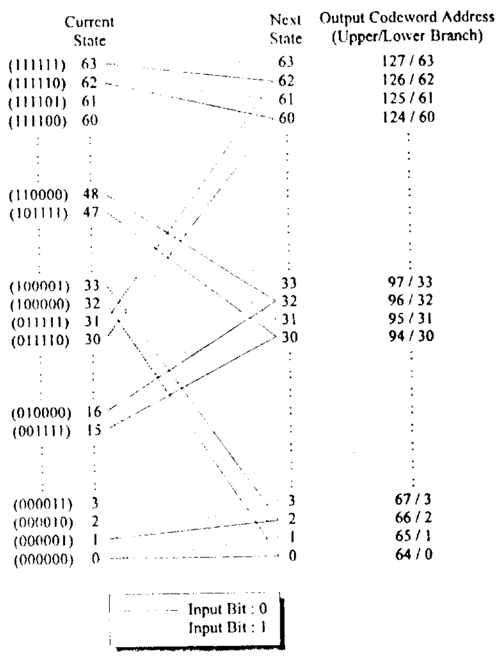

Fig. 4. Trellis diagram of very low rate convloutional code using biorthogonal codes

soft-decision are inputed to Viterbi decoder.

The soft-decisioned symbol is used for calculation of branch metric by measuring the Euclidean distance between quantized symbols and 128 codewords in biorthogonal code set. All 128 branch metric values are calculated by repeating this process for the quantized symbols and all different 128 biorthogonal codewords.

The branch metric, $BM_n(t)$ (n=0,1,2,...,127), can be calculated as the Euclidean distance between 128 biorthogonal codes and the received signal $y=(y_0, y_1, y_2, \ldots, y_{63})$ whose bits are quantized by 4 bits.

$$BM_n = \sum_{i=0}^{63} a_i, \quad n = 0, 1, \ldots, 127 \tag{10}$$

where a_i is given as

$$a_i = \begin{cases} y_i & \text{if } B_i = 0 \\ 15 - y_i & \text{if } B_i = 1 \end{cases} \tag{11}$$

where B_i is the i-th bit in a biorthogonal code.

In add-compare-select, the current path metric values are calculated by using 128 branch metric values and the past path metric values. The number of states in the proposed system is 64 because the constraint length of convolutional code 7. Therefore, the path metric values at time t are given as

$$PM_0(t), PM_1(t), PM_2(t), \ldots, PM_{62}(t), PM_{63}(t) \tag{12}$$

Using the trellis diagram in Fig. 4, the new 64 path metric values are calculated, where the branch metric values are not repeated as below.

$$\begin{aligned} PM_0(t) &= \min\{PM_0(t-1)+BM_0(t), PM_{32}(t-1)+BM_{64}(t)\} \\ PM_1(t) &= \min\{PM_0(t-1)+BM_1(t), PM_{32}(t-1)+BM_{65}(t)\} \\ &\vdots \\ PM_{62}(t) &= \min\{PM_{31}(t-1)+BM_{62}(t), PM_{63}(t-1)+BM_{126}(t)\} \\ PM_{63}(t) &= \min\{PM_{31}(t-1)+BM_{63}(t), PM_{63}(t-1)+BM_{127}(t)\} \end{aligned} \tag{13}$$

The path meric values increase as the time t increases. In order to avoid the overfolw of path metric memory, the normalization of path metric is needed. The minimum path metic value should be found at each time and all path metric values are substracted by the minimum path metric value. That is,

$$\begin{aligned} PM_{min}(t) &= \min_i\{PM_i(t)\} \\ PM_i(t) &\leftarrow PM_i(t) - PM_{min}(t) \end{aligned} \tag{14}$$

After normalization, the mimimum path metric becomes always zero.

Ⅳ. Simulations

A. Various CDMA Systems

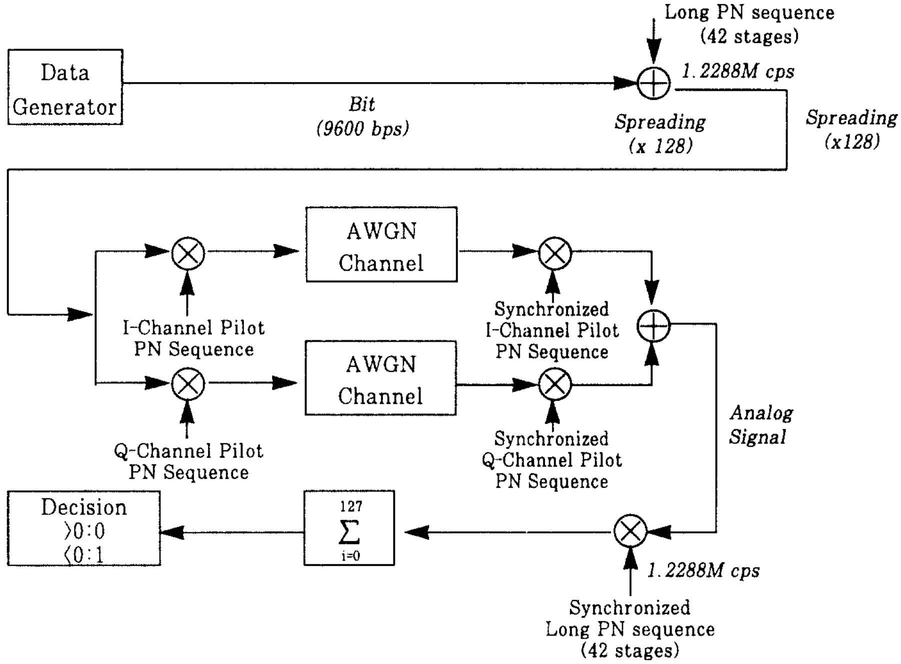

Fig. 5. Block diagram of conventional CDMA system

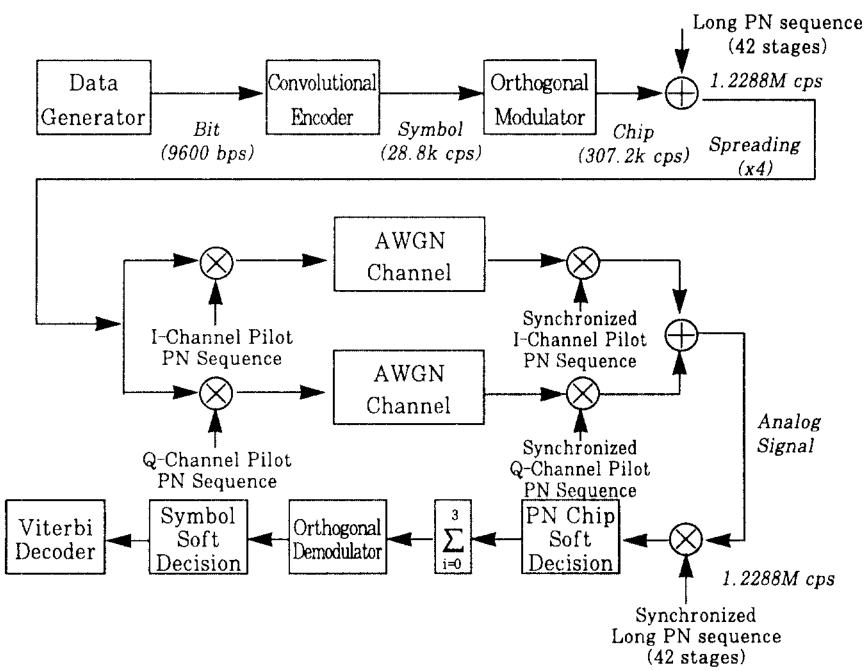

Fig. 6. Block diagram of CDMA system using FEC and orthogonal modulation

The performance of the proposed CDMA system is compared with two different types of CDMA system such as a conventional CDMA system in Fig 5, which is composed of spreading and despreading, and CDMA system with orthgonal modulation and FEC in Fig. 6.

The performance of conventional CDMA system is the same as that of coherent BPSK system. In the conventional CDMA system, the input bit rate is 9600bps and the chip rate of PN sequence is 1.2288Mcps. Therefore, the spreading ratio is 128 and that is, the processing gain is 21dB. The modulation scheme has been chosen as QPSK.

The second system is almost the same as Qualcomm's CDMA system except the constraint length of convolutional code, where the constraint length of 7 has been chosen instead of 9, because the convolutional code in our proposed CDMA system is 7. The code rate of convolutional encoder is 1/3 and constraint length 7. Two information bits are convolutionally encoded into 6 symbols, then these symbols are modulated to 64 walsh chips. The orthogonally moduated symbols are spreaded by long PN sequence by 4. Therefore this CDMA system also has the processing gain of 21dB.

The three different CDMA systems including the proposed CDMA system do have the same processing gain of 21dB and the constraint length fo convolutional encoder is 7.

B. Performance Analysis and Comparison

Three different CDMA systems are implemented using Borland C on IBM-PC. The input file has the varible parameters, such as E_b/N_0, frames, traceback depth, full scale, and number of soft-decision bits, and etc and the output file includes the number of errored bits and bit error rate together with input parameters listed above.

In simulation, we chose the parameter values as

• Convolutional code : R=1/64, K=7

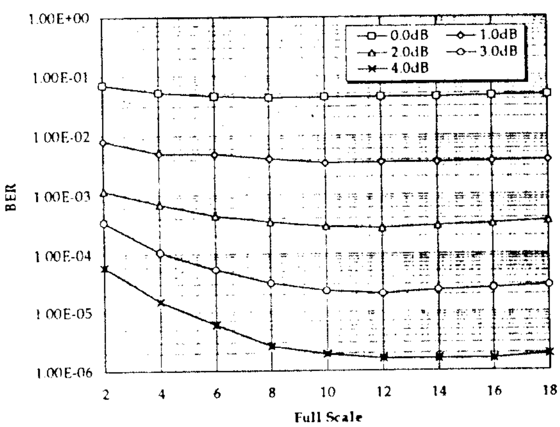

Fig. 7. Performance of the proposed CDMA system using biorthogonal codes with variation of full scale parameters

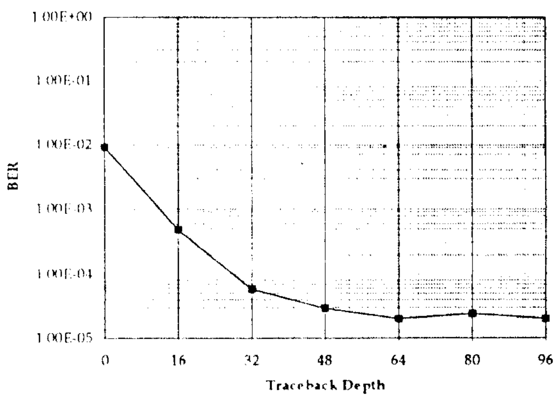

Fig. 8. Performance of the proposed CDMA system using biorthogonal codes with variation of traceback depth of Viterbi decoder(E_bN_o=3dB, fs=12)

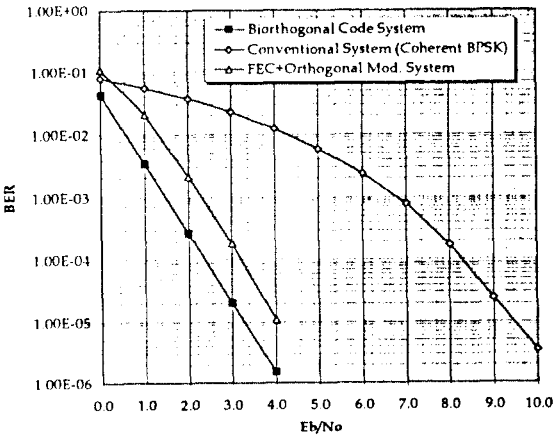

Fig. 9. Performance comparison of CDMA systems

- Biorthogonal code : 128×64
- Modulation : QPSK
- Channel : Additive White Gaussian Noise
- PN sequence : Long PN sequence of period 2^{42}-1
  Pilot PN sequence of period 2^{15}
- Soft-decision : 4 bits
- Demodulation : Viterbi decoder

Fig . 7 and Fig. 8 show the performance of the proposed CDMA system using biorthogonal codes with variation of full-scale and traceback depth, respectively.

The performance comparison of the three different CDMA systems are presented in Fig. 9. The performance of conventional CDMA system is almost the same as that of coherent BPSK. The CDMA system of FEC and orthogonal modulation is little inferior to the Qualcomm system by 0.4dB, because its constraint length is 7, which is shorter than that of Qualcomm CDMA system by 2. The performance of the proposed CDMA system is better than that of the CDMA system with FEC and orthogonal modulation by 0.8dB at BER=10^{-5} with the little increase of hardware complexity.

V. Conclusions

In this paper, the new CDMA system using very low rate convolutional codes and biorthogonal codes is proposed. The proposed CDMA system can be considered as a combining of spreading and forward error correcting code.

The code rate of convolutional code is 1/64 and biorthogonal codes with 128 by 64 are used. From the simulation, result it is proved that bit error performance for the proposed CDMA system is better than that of conventional CDMA system with forward error correction by 0.8dB at BER=10^{-5}. The increase of hardware complexity of the proposed CDMA system can be ignorable. In the band and power limited channel such as cellular system, the proposed system can be used as a suitable candidate for modulation scheme of CDMA.

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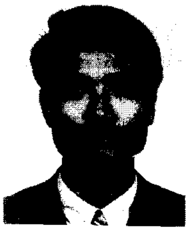

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