Performance Analysis of CDMA Systems by Using Biorthogonal Codes

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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. 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. The performance of proposed CDMA system using biorthogonal codes is better than that of the CDMA system using FEC 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.**

I. Introduction

Mobile communication service has been rapidly grown to saturate the capacity of system, because of mobility, speed, globality and convenience since celluar system has been introduced in early 1960s. As the capacity of current analog celluar communication systems is gradually saturated because of consistently increasing number of subscribers, the development of the digital mobile communications 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 celluar system, CDMA digital celluar system which accommodates more users and better performance, is getting more attention from many countries[1]. Recently, CDMA system is adopted as a standard for next generation digital celluar system in Korea, and the commercial service by CDMA system will be started in a year.

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 performance of proposed CDMA system is analyzed and compared with typical CDMA systems and CDMA system using FEC and orthogonal modulation. The proposed CDMA system 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 celluar systems.

In section II, we describe the entire configuration of 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 proposed CDMA system using biorthogonal codes is better than those of the other CDMA systems in section IV. In section V, we conclude the paper.

II. Spread Spectrum Modulation Using Biorthogonal Codes

We proposed new CDMA system using biorthogonal codes, which can be used in the reverse link of 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 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 biorthogonal 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 1.2288Mcps transmission rate by long PN sequence and multiplied by pilot PN sequence and modulated in QPSK.

Transmitted signal is received through AWGN channel and multiplied by synchronized pilot PN sequence. Then, signals of I and Q channels are added and is despreaded by synchronized 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 operation for decoding the received signals.

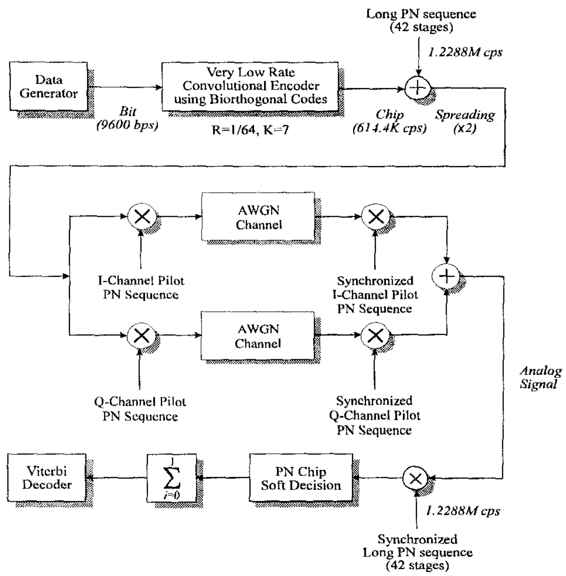

Fig. 1. Block diagram of CDMA system using biorthogonal codes.

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

$$\mathbf{B}_k = \begin{bmatrix} \mathbf{H}_{k-1} \\ \overline{\mathbf{H}}_{k-1} \end{bmatrix} \tag{1}$$

where $\mathbf{H}_{k\text{-}1}$ is Hadamard matrix of dimension $2^{k-1} \times 2^{k-1}$ and $\overline{\mathbf{H}}_{k-1}$ is an inversion of $\mathbf{H}_{k-1}$. Biorthogonal code is composed of two sets of orthogonal codes, each codeword in one set has its antipodal codeword in another set. Biorthogonal code, therefore, is organized by orthogonal and antipodal signal set.

The cross-correlation of biorthogonal codes is calculated as follows.

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

Biorthogonal codes used in orthogonal modulation of proposed CDMA system in this paper are given as the biorthogonal code $\mathbf{B}_7$ with the dimension 128 × 64 generated by Hadamard matrix $\mathbf{H}_6$ with the dimension 64 × 64($2^6 \times 2^6$) in Fig. 2.

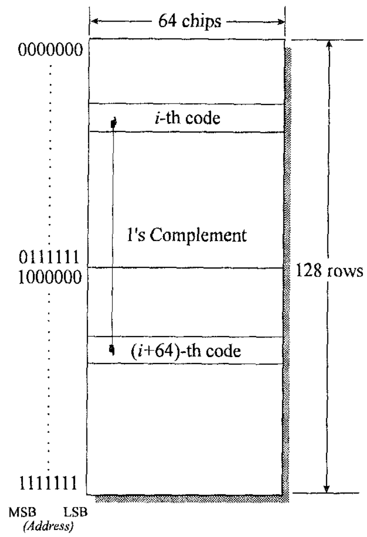

Fig. 2. Structure of biorthogonal code table.

The selection of biorthogonal code is determined by 7-bit output of shift registers in Fig. 3. 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 length 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. 3.

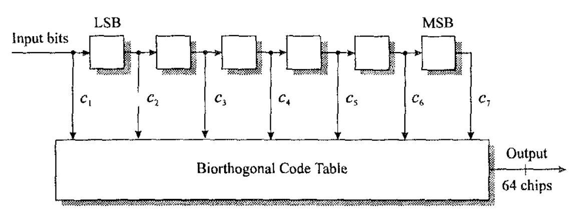

Fig. 3. Block diagram of very low rate convolutional code using biorthogonal codes.

$(c_1, c_2, \ldots, c_7)$ in Fig. 3 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 (3) represents its address calculation method.

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

where ADRS is the address pointing one of 128 codes in the table of biorthogonal code set, and $c_i(i=1, 2, \ldots, 7)$ is the output of shift registers in Fig. 3.

In Fig. 3, $(i+64)$-th code is the 1's complement of i-th code. The ideal cross-correlation in 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 cross-correlation property of biorthogonal codes is better than that of Walsh codes.

III. Demodulation using Viterbi Decoder

The received signal which was spreaded and scrambled by the 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 the follwing equation[3].

$$r = \pm\sqrt{E_s} + n \quad (4)$$

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 $N_0/2$.

It is well known that the optimal full scale value for soft-decision is represented as

$$f_s = 8.0 \times 0.6 \times \frac{1}{\sqrt{\frac{E_b}{N_0} \times D}} \quad (5)$$

where 8.0 means that each symbol is assigned to 8-level because decision level is Q=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 type but obtained from different 128 branch metric values. Fig 4 shows the trellis diagram of very low rate convolutional encoder using biorthogonal codes.

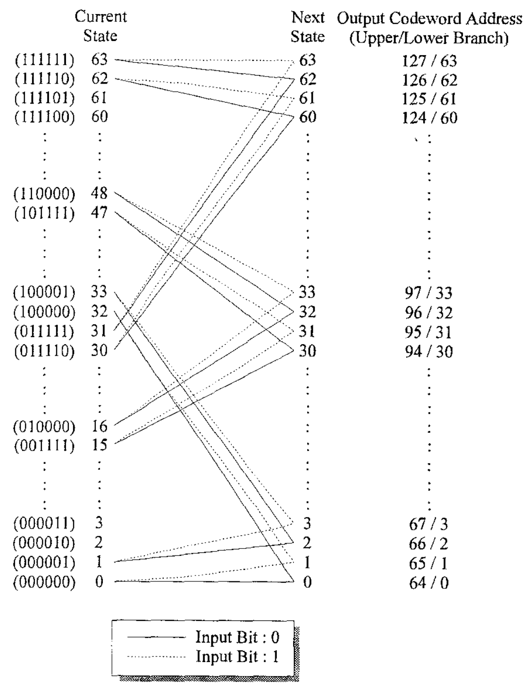

Fig. 4. Trellis diagram of very low rate convolutional code using biorthogonal codes.

First, 128 different branch metric values for the received signal are calculated when the outputs of PN chip soft-decision are inputed to Viterbi decoder.

The soft-decisioned symbols are used for calculation of branch metric by measuring the Euclidean distance between quantized symbols and 128 codeword 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, $\mathrm{BM}_n(t)$ (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.

$$\mathrm{BM}_n = \sum_{i=0}^{63} a_i, \quad n = 0, 1, \ldots, 127 \quad (6)$$

where a_i is given as

$$a_i = \begin{cases} y_i & \text{if } B_i = 0 \\ 15 - y_i & \text{if } B_i = 1 \end{cases} \quad (7)$$

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

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

$$PM_0(t),\ PM_1(t),\ PM_2(t),\ ...,\ PM_{62}(t),\ PM_{63}(t) \tag{8}$$

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.

$$\begin{aligned}
PM_0(t) &= \min\{PM_0(t\text{-}1)+BM_0(t),\ PM_{32}(t\text{-}1)+BM_{64}(t)\} \\
PM_1(t) &= \min\{PM_0(t\text{-}1)+BM_1(t),\ PM_{32}(t\text{-}1)+BM_{65}(t)\} \\
&\vdots \\
PM_{62}(t) &= \min\{PM_{31}(t\text{-}1)+BM_{62}(t),\ PM_{63}(t\text{-}1)+BM_{126}(t)\} \\
PM_{63}(t) &= \min\{PM_{31}(t\text{-}1)+BM_{63}(t),\ PM_{63}(t\text{-}1)+BM_{127}(t)\}
\end{aligned} \tag{9}$$

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

IV. SIMULATIONS

A. Various CDMA Systems

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

The performance of conventional CDMA system is the same as that of coherent BPSK system.

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 constraint length of convolutional code in our proposed CDMA system is 7. The rate of convolutional encoder is 1/3 and constraint length 7. Two information bits are convolutionally encoded into 6 symbols, which are orthogonal modulated to 64 Walsh chips. The orthogonal modulated symbols are spreaded by long code PN sequence by 4. Therefore, this CDMA system also has the processing gain of 21dB.

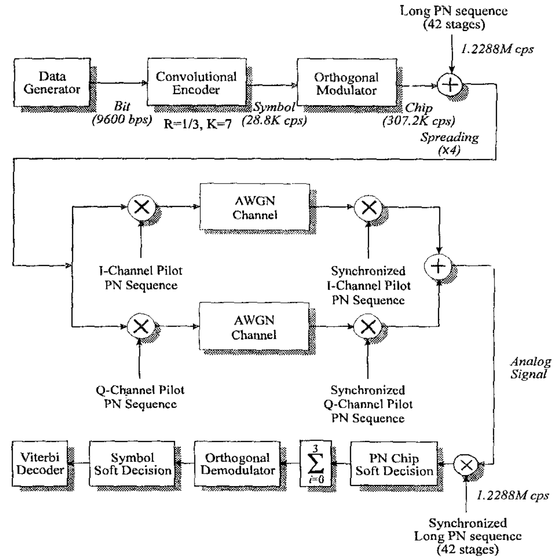

Fig. 5. Block diagram of CDMA system using FEC and orthogonal code modulation.

The three different CDMA systems including the proposed CDMA system do have the same processing gain of 21dB and the constraint length of 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 variable parameters, such as E_b/N_0, number of frames, traceback depth, full scale, and number of soft-decision bits, etc and the output file includes the number of errored bits and bit error rate together with input parameters listed above.

In our simulation, we chose the parameter values as

- Convolutional encoder rate : 1/64
- Constraint length : 7
- 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. 6 shows the performance of the proposed CDMA system using biorthogonal codes with variation of traceback depth.

The performance comparison of the three different CDMA systems are presented in Fig. 7. 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, 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 limited and power limited channel such as celluar system, the proposed system can be used as a suitable candidate for modulation scheme of CDMA.

References

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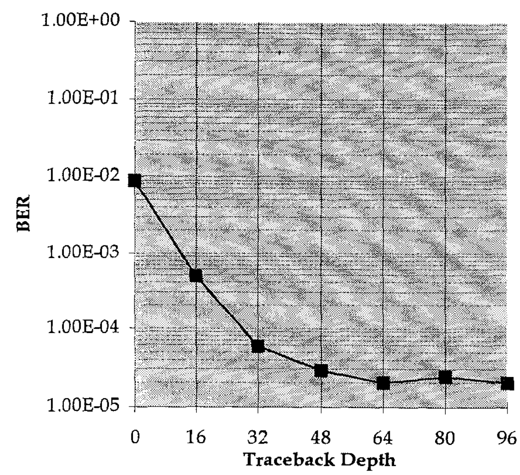

Fig. 6. Performance of the proposed CDMA system using biorthogonal codes with variation of traceback depth of Viterbi decoder.

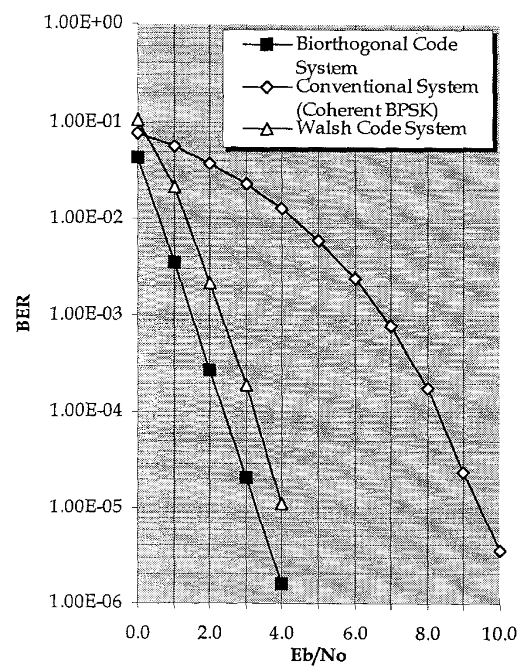

Fig. 7. Performance comparison of all CDMA systems.