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NEW BINARY USER CODES FOR DS CDMA COMMUNICATION

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Abstract

Spread spectrum (SS) is a modulation technique in which the signal occupies a bandwidth much larger than the minimum necessary to send the information. A synchronized reception with the code at the receiver is used for despreading the information before data recovery. From a long period, Walsh codes and Gold codes have been used as spread spectrum codes in Code Division Multiple Access (CDMA) communications because of their ease of generation than the efficiency of these codes. Walsh codes are perfectly orthogonal binary user codes that have many popular applications in synchronous multicarrier communications although they perform poorly for asynchronous multi-user communications. Therefore, the nearly orthogonal Gold codes with their superior performance are the preferred user codes in asynchronous CDMA communications with small number of simultaneous users in the system due to their good auto-correlation (intracode correlation) and cross-correlation (inter-code) properties. Major drawback of these codes is that they are limited in number and in their lengths. In this paper, we performed MATLAB (7.1version) algorithm to obtain the new orthogonal sets of binary space for multiuser spread-spectrum communications. We compared their performance with existing codes like Gold and Walsh code families. Our comparisons include their time domain properties like auto and cross-correlations along with bit error rate (BER) performances in additive white Gaussian noise (AWGN) and Rayleigh channel for the synchronous and asynchronous DS-CDMA communications. It is shown that these codes outperform the Walsh codes significantly and they match in performance with the popular nearly orthogonal Gold codes closely for asynchronous multiuser communications in AWGN noise. It is also shown that all of the binary code families considered performed comparable for Rayleigh flat-fading channels. So these new codes can be used both for asynchronous and synchronous direct sequence spread spectrum CDMA communications. As a result, these can be used in both cases along with the advantage of their large availability and flexible code sizes.

Keywords: Spread spectrum, Direct sequence, Walsh code, Gold code, PN sequence Correlation, BER, AWGN, Rayleigh channel.

Nomenclatures

E_b	Bit energy
H_N	Hadamard matrix of order N
$h(t)$	Channel
J_0	Interference Power spectral density, W/Hz or dBm/Hz
L	Sequence length, bits
m, n	Time delay, bits
N_0	Additive white Gaussian noise
$R(t)$	Received signal
$R_c(m)$	Autocorrelation function

Abbreviations

AWGN	Additive white Gaussian noise
BER	Bit error rate
CDMA	Code division multiple access
DS-SS	Direct sequence-spread spectrum
ITU-T	International telecommunication union-telecommunication
Pdf	Probability density function
SS	Spread spectrum
W-CDMA	Wide band CDMA
WHT	Walsh-Hadamard transform

1. Introduction

Code division multiple access (CDMA) schemes have been considered as attractive multiple access schemes in the second-generation (2G), third-generation (3G) and future broadband wireless systems. CDMA has attractive features, such as antijam resistance, low probability of interception, resistance to multipath fading, and capability of random access [1]. Orthogonal codes are widely used for uplink and downlink transmissions of cellular DS-CDMA systems like cdma2000and WCDMA/UMTS. Many of the spreading codes used in wireless communication today are fixed power codes and are restricted in their power levels, the availability of the code family sizes. In traditional cellular networks, binary Walsh and Gold codes of 64 or higher length are used as CDMA spreading codes [2, 3]. Walsh codes are used for synchronous communications while Gold codes are widely employed for asynchronous communications. Longer distances in traditional cellular networks require higher processing gain, thus demanding longer spreading codes in CDMA. Popularity of these codes comes from the ease of their implementation using standard kernels [4].

1.1. Walsh code

Walsh codes are perfectly orthogonal codes and are used in synchronous communication from base station to the mobile hand-held user [3, 5, 6]. They perform poorly in asynchronous conditions due to poor cross correlation between the codes. Hadamard form of Walsh transform so called Walsh-Hadamard transform (WHT) is iteratively generated from the Kernels. Higher length Walsh code sets are iteratively generated from the lower length Walsh code sets using Kronecker product.

$$H_{2N} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{bmatrix}, \text{ where } \quad H_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \tag{1}$$

The simplicity of their generation and fixed power feature along with orthogonality property make them a good choice for the synchronous multiuser communications scenario [3, 5-7].

1.2. Gold code

Gold codes are product codes achieved by the exclusive or-ing (modulo-2 adding) of two maximum-length sequences with the same length. The code sequences are added chip by chip by synchronous clocking [6, 8-10]. Every change in phase position between the two generated *m*-sequences causes a new sequence to be generated. When specially selected *m*-sequences, also called *preferred m-sequences* are used, the generated code is called the Gold code (Fig. 1). The algorithm for the generation of 31-bit Gold Code is shown in Fig. 2. Gold codes are well known for the lowest cross correlation values between the codes and are ideal for asynchronous, uplink communication from the mobile hand-held unit to the base station [2, 10, 11]. Gold sequences are defined for lengths of 2^n-1, where n is not a multiple of 4. That means, Gold sequences are not defined for lengths of 15,255, etc. These codes are simple to generate, but sizes of the available codes are limited for multi user communications.

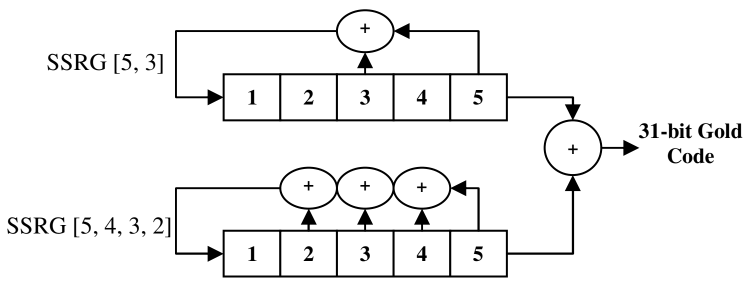


Fig. 1. 31-bit Gold Code Generator [8].

2. Analytical Approach

Walsh functions exhibit the features of orthogonality, DC basis function, linear phase, unique zero crossings inherently [3, 4]. Spread spectrum applications do not require such stringent conditions for their basis functions. In my simulation approach, the restriction of unique zero crossings on the nature of basis functions for the new proposed code generation has been left.

2.1. New proposed code generation

The binary sample space for the design of *New Proposed Code* set will comprise only two properties, i.e., zero mean and linear phase (either symmetric or asymmetric about the middle of the code). Hence, for the case of 8-bit (length 8) codes, binary sample space consists of 22 unique codes, and for 16-bit codes there are only 326 candidate codes, and similarly, for 32-bit codes there are about 38,000 potential codes [7]. From this binary sample space, the orthogonal code sets [12] are iteratively searched as per following algorithm:

(1) Select the first basis function of the orthogonal set from the corresponding integer in the sample space. Represent the integer number in binary representation and convert to bipolar notation.
(2) Select the next basis function by sequentially converting the integers in the sample space into binary codes and checking for orthogonality of codes with the first basis function.
(3) Repeat this process n-1 times to get n-1 orthogonal codes, checking each time for the orthogonality. Lastly the DC code is added in order to make it a (*n*-dimensional) complete binary set.
(4) By choosing a different integer number as first basis function, number of independent orthogonal code sets can be generated.

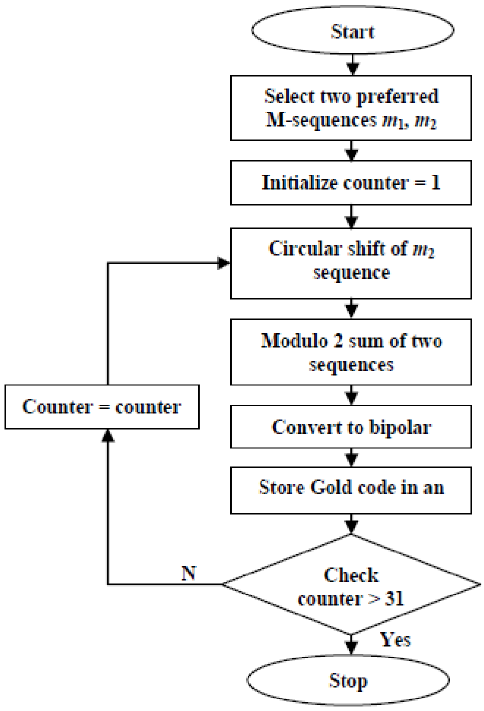


Fig. 2. Flowchart for 31-bit Gold Code Generator.

Using the above said algorithm, I have made a MATLAB simulation program for 32-bit code. Firstly, I found the binary sample space from 2^{32} available values by checking each number for linear phase and zero mean condition. From this available binary sample space, for any corresponding number 31-orthogonal pairs were found and the DC code is added. Thus, by using a different number as the first basis function, a number of different orthogonal pairs can be formed.

So, by using this approach we tried to enlarge our search area to get a large number of orthogonal pairs and there by fulfilling the demand of large number of simultaneous users for present multiuser CDMA communication. Table 1 shows the typical set of ***32-bit New Proposed codes***. Figure 3 shows the plot of typical 31-bit Gold, 32-bit Walsh and 32-bit new proposed codes.

Table 1. 32-bit New Proposed Codes.

Ser. No.	Binary Notation	Ser. No.	Binary Notation
1	11111111111111111111111111111111	17	00101110001100010111001110001011
2	00000000010110110010010111111111	18	01101010110101101001010010100101
3	00100101100000101011111001011011	19	00001011111010001110100000101111
4	01000111000111001100011100011101	20	00010010001001101001101110110111
5	01110010001001111110010001001110	21	00011010100110111101100101011000
6	01100001011001010101100101111001	22	00011100011101011010111000111000
7	00111100010011001100110111000011	23	00100011010111011011101011000100
8	00000110111011100111011101100000	24	00101001101101100110110110010100
9	00111111001010000001010011111100	25	00110111111111110000000000010011
10	01010110110000010111110010010101	26	01000111101100011000110111100010
11	01101110010100100100101001110110	27	01001100101011110000101011001101
12	01011011110001000010001111011010	28	01001101000011111111000010110010
13	00011001100101010101011001100111	29	01010001011110100101111010001010
14	00110101110000111100001110101100	30	01011101011100101011000101000101
15	01110100100111000011100100101110	31	01111011000010110010111100100001
16	01110000101110001110001011110001	32	01101000111010011001011100010110

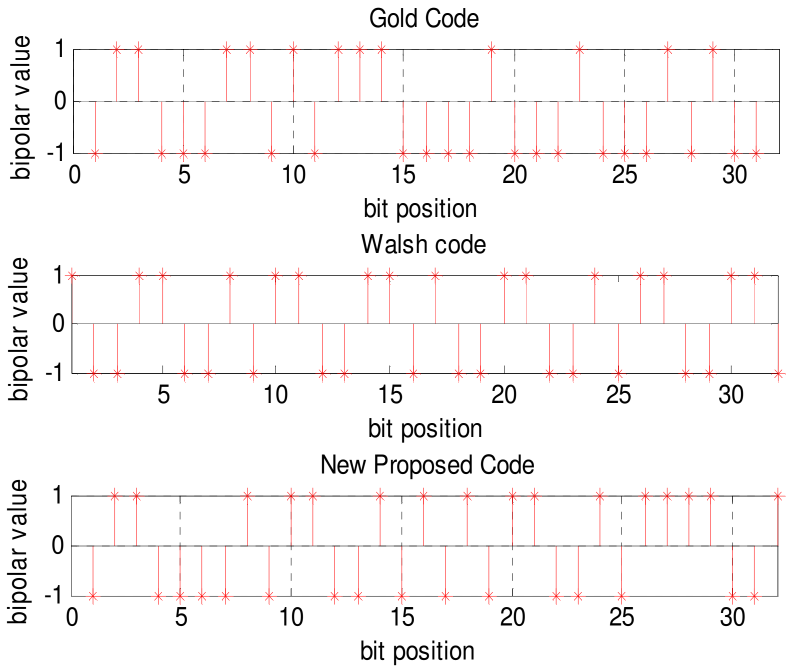


Fig. 3. Typical 31-bit Gold, 32-bit Walsh and New Proposed Codes.

3. Performance Comparison

For the DS-SS application [11] we require unique coding of the different user signals that occupy the same transmission bandwidth in a multi-access system and synchronization for W-CDMA systems where there is no global timing reference. In order to achieve these objectives, the coding sequences require special correlation properties referred to as auto correlation, and cross correlation.

3.1. Auto Correlation [13-15]

Auto correlation is a measure of how well a signal $C(n)$ can differentiate between itself and every time-shifted variant of itself. Auto correlation for a finite, discrete signal is defined in Eq. (2)

$$R_c(m) = \sum_{n=1}^{L} C_n C_{n+m}, \qquad 0 \le m \le L-1 \qquad (2)$$

where m is a time delay and L is the sequence length.

A correlation of zero indicates a signal that is orthogonal to a time-shifted version of itself. It is observed from Fig. 4 that autocorrelation of the new codes is maximum for L=0 shift while for L≠0 it has lower value (comparable to Gold code) which shows that they exhibit orthogonality [16] with their time delayed version. Whereas Walsh codes have poor auto-correlation so cannot be used in asynchronous communication.

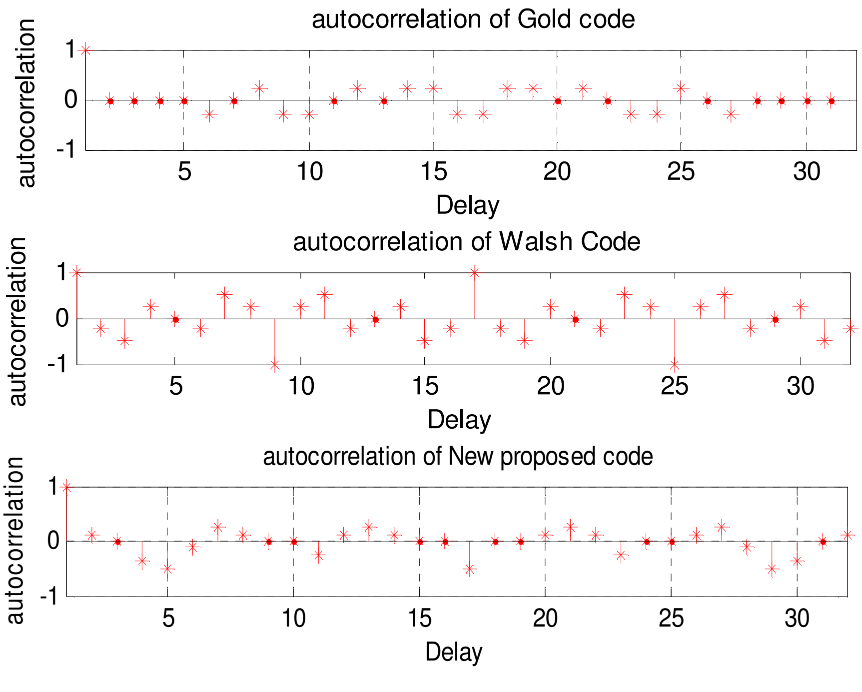


Fig. 4. Comparative Autocorrelation Analysis of 31-bit Gold Code, 32-bit Walsh Code, and 32-bit New Proposed Code.

3.2. Cross correlation [11, 14]

Cross correlation is defined as the correlation between two different signals. Ideally, each code should be orthogonal to other codes for any time delays, i.e., its value should be zero. Cross correlation for finite length discrete signals is defined in Eq. (3)

$$r_{xy}(T) = \sum_{n=0}^{L} x(n)\, y(n-T) \tag{3}$$

From Fig. 5 it is observed that new codes have lower cross-correlation values (comparable to gold codes) for different time delays, while Walsh code have higher cross-correlation values. So the new codes can be used in the multiuser environment.

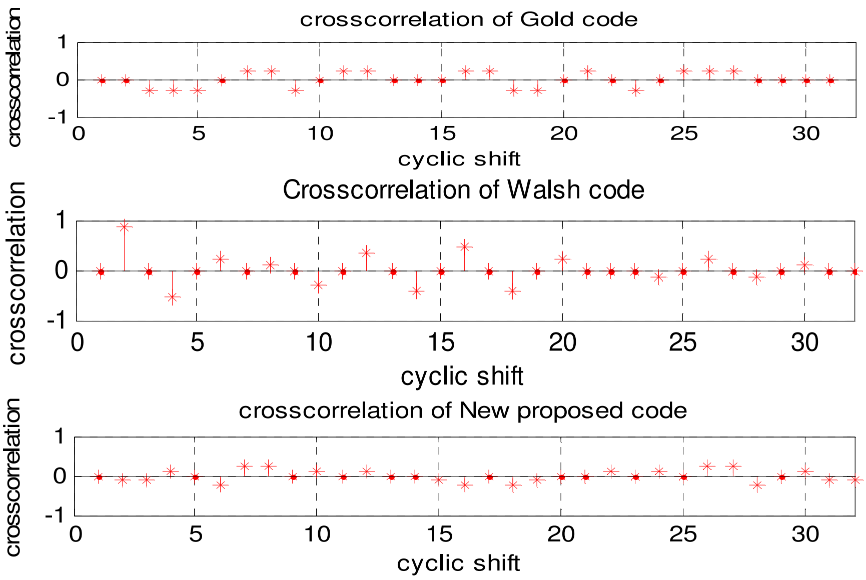


Fig. 5. Comparative Cross-Correlation Analysis of 31-bit Gold Code, 32-bit Walsh Code, and 32-bit New Proposed Code.

3.3. BER performance comparisons

Bit error rate (BER) performance is simulated under AWGN noise and Rayleigh flat fading channel for asynchronous and synchronous communication for DS-CDMA. Probability of error for DS-SS is given by Eq. (4) where E_b is bit energy, N_0 and J_0 are AWGN and interference Power spectral density respectively [14, 15].

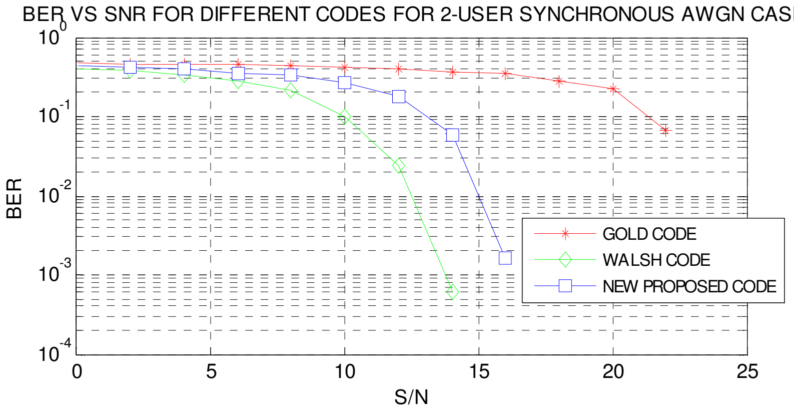
$$P_b = Q\sqrt{\frac{2E_b}{N_0 + J_0}} \tag{4}$$

User generates binary valued data samples and allotted unique orthogonal spreading code. User data bit streams are multiplied with the corresponding spreading codes and Channel noise is added to the data at defined SNR levels. At the receiver, matched filter is used to despread and detect the incoming data stream. Detected data samples are verified with the transmitted data samples to calculate the bit error rate (BER) performance.

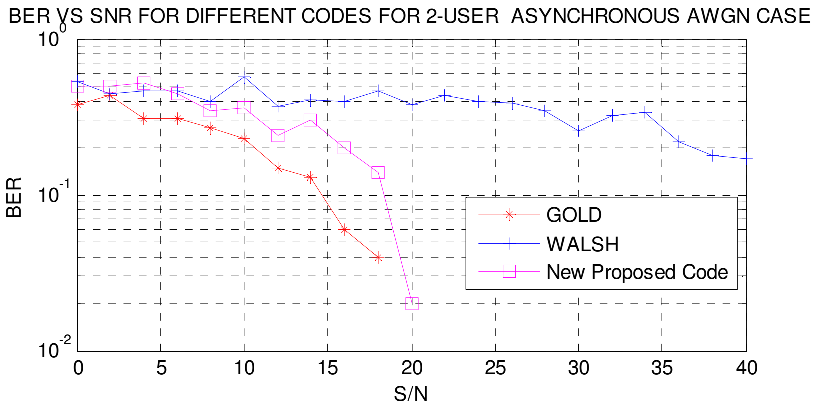
For asynchronous communication, we assume that at receiver the user data approaches with certain delay (equal to the code length) and despreaded by the unique code to get the information signal.

3.3.1. For AWGN case

As shown in Fig. 6 the BER analysis shows that the New codes perform comparable to Gold codes in asynchronous case (outperforms Walsh codes) and perform comparable to Walsh codes in synchronous case (outperforms Gold codes). Hence, these new codes can be used simultaneously for both cases for AWGN channel.



(a)



(b)

Fig. 6. BER Performance Analysis of 31-bit Gold Code, 32-bit Walsh Code, and 32-bit New Proposed Code in (a) Synchronous and (b) Asynchronous AWGN Environment.

3.3.2. For Rayleigh flat fading case

In wireless mobile communication system, a signal can travel from transmitter to receiver over multiple reflective paths; this phenomenon is referred to as multipath propagation. The effect can cause fluctuations in the received signal's amplitude, phase, and angle of arrival giving rise to the terminology multipath fading. The received signal consists of large number of multiple reflective paths and when there is no line-of-sight signal component it is called Rayleigh fading because the envelope of the received signal is described by a Rayleigh pdf (probability density function) [17].

The flat Rayleigh fading channel refers to the multiplicative distortion of the transmitted signal [18-20].

$$R(t) = s(t).h(t) + n(t) \quad (5)$$

where $R(t)$ is the received waveform, $s(t)$ is the transmitted signal, $h(t)$ is the channel waveform and $n(t)$ is the AWGN noise.

As shown in Fig. 7 we find that for Rayleigh channel case, the New proposed codes are suited for synchronous (perform comparable to Walsh codes) environment while inferior in asynchronous environment. Also gold and Walsh codes are also worse in asynchronous Rayleigh environment.

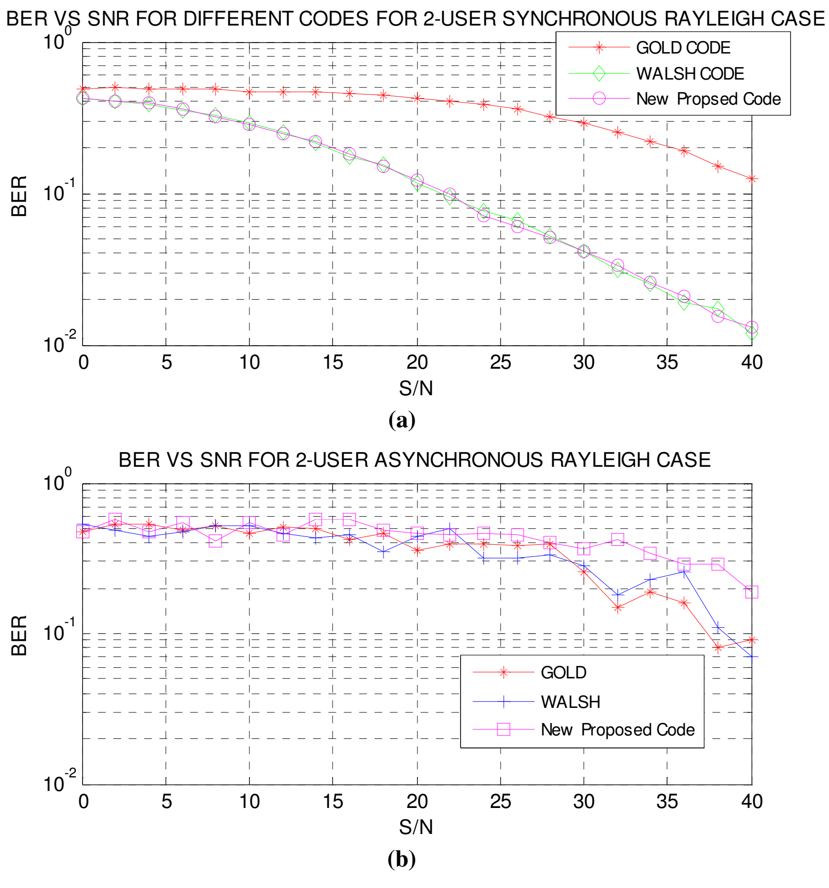


Fig. 7. BER Performance Analysis of 31-bit Gold Code, 32-bit Walsh Code, 32-bit New Proposed Code in (a) Synchronous and (b) Asynchronous Rayleigh Flat Fading Environment.

In conclusion, the new proposed codes are very well suited for AWGN channel while suited for Rayleigh channel only for synchronous environment.

4. Conclusions

CDMA technology [1, 15] is a fast growing technology in the field of Wireless Communication. The ultimate aim of service providers is to accommodate the maximum number of users in the available bandwidth as allotted by ITU-T. CDMA technology is identified by its spreading capability through the spreading codes for multiple accessing various users information. In this paper, a comprehensive study is carried out to analyze different spreading codes for a DS-CDMA system, and an objective way has been presented to search new orthogonal code sets. It is observed that the new proposed orthogonal codes have better correlation properties and have improved BER performance. The growing demand for orthogonal, fixed power (binary/antipodal) user codes challenged us to design additional orthogonal codes [21] to be employed in the emerging and future applications of spread spectrum communications with flexible code sizes and power requirements than the ones used in the current wireless technologies. Future generations of wireless mobile systems will aim to support a wide range of service and bit rates by employing a variety of techniques capable of achieving the highest possible spectrum efficiency [22]. As dynamic utilization of spreading code libraries consisting of multiple orthogonal sets brings additional network security at the code level, we expect spreading code rich system solutions in the future [4].

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