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Code Selection with Application to Spread Spectrum Systems Based on Correlation Properties

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Abstract: Code Division Multiple Access (CDMA) have a key role in vast number of research activities. CDMA is a spread spectrum technology for the transmission of radio signals in telecommunication system. In CDMA multiple users can transmit the data simultaneously in a channel using same frequency. Each user is assigned with a unique code for transmission. The performance of any CDMA system can be determined by the choice of the spreading codes which are used as a signature code for the users in such a system. The choice of spreading code sequence is vital for resistance against interference with other areas and against interference with multiple users. Sequences of code that desires to be as different but at the same time can be easily reproduced at the reception signal can be recovered. This multiple access technique requires neither the frequency management nor the time management. This paper deals with the comparison of different spreading codes based on the autocorrelation and crosscorrelation properties. These spreading codes provide security for the data transmission.

Keywords: Spread spectrum, Spreading codes, Autocorrelation, Crosscorrelation, Code Division Multiple Access, Optical Code Division Multiple Access, Pseudo Noise code.

I. INTRODUCTION

Spread spectrum technique is defined as a means of transmission in which signal occupies a bandwidth in excess of the minimum necessary to send the information. The band spread is accomplished by a code which is independent of the data and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery. The code in this definition is a pseudorandom code that is mixed with the data to spread the signal. Thus for the spread signal to appear noise like, the codes need to be random but reproducible [1]. Inotherwords the spread spectrum is a transmission technique in which a pseudo-noise code, independent of the information data is employed as a modulation waveform to spread the signal energy over a bandwidth much greater than the signal information bandwidth. At the receiver signal is despread using a synchronized replica of pseudo-noise code [6].

A spread spectrum system is largely categorised by its coding scheme. The type of code employed, its length, and its chip-rate all define the overall system parameters. In order to alter the system's spreading capability it is necessary to alter the coding arrangement [2]. Also it is a means of signal modulation, in which the signal frequency is spread over a very wide bandwidth. Spread spectrum technology, which was initially used in military applications, is another approach to achieve multiple accesses. An important multiple-access technique in wireless networks and other common channel communication systems is CDMA. Each user shares the entire bandwidth with all the other users and is distinguished from the others by its signature sequence or code [6].

The sequences which are used in CDMA should possess the following properties:

- There must be a balance in the number of 1's and 0's.
- The autocorrelation should be a sharp two-valued function.
- The cross correlation should be as low as possible.

For achieving the spread spectrum it must fulfil the following requirements:

- Signal should occupy the bandwidth much in excess of the minimum bandwidth necessary to send information.
- Spreading is done by means of spreading code signal which is independent of the data.
- At the receiver, despreading is done by the correlation of the received spread signal with a synchronized replica of the spreading signal used to spread information [4].

II. TYPES OF SPREAD SPECTRUM

Based on the type of spreading modulation, spread spectrum systems are broadly classified as

- Direct sequence spread spectrum (DS-SS) systems
- Frequency hopping spread spectrum (FH-SS) systems
- Time hopping spread spectrum (TH-SS) systems.
- Hybrid system

A. Direct Sequence Spread Spectrum (DSSS)

In the first stage information signal in DSSS transmission is spread at baseband and then the spread signal is modulated by a carrier in second stage. Following this approach, the spreading operation is separate from the process of modulation. One of the important features of DSSS system is its ability to operate in presence of strong co-channel interference. A DSSS system can decrease the effects of interference on the transmitted information.

B. Frequency Hopping Spread Spectrum

Frequency hopping (FH) system, have constant frequency in each time chip; instead it changes from chip to chip. Frequency hopping systems can be classified into fast-hop or slow-hop. A fast-hop FH system is a system in which hopping rate is greater than the message bit rate and in the slow-hop system the hopping rate is smaller than the message bit rate.

C. Time Hopping Spread Spectrum

In a time hopping spread spectrum, signal is divided into frames, which in turn are subdivided into M time slots. When the message is transmitted, only one time slot in the frame is modulated with information (any modulation). This time slot is selected using Pseudo Noise (PN) generator. All of the message bits gathered in the previous frame are then transmitted in a burst during the time slot chosen by the PN generator. The PN code generator drives an on-off switch in order to process switching at a given time in the frame. This switch output is then demodulated appropriately. Each message burst is then stored and re-timed to the original message rate in order to recover the information. Time hopping is sometimes used in conjunction with other spread spectrum modulations such as Direct Sequence (DS) or Frequency Hopping (FH).

D. Hybrid System: DS/FH

The DS/FH Spread Spectrum technique is a combination of direct-sequence spread spectrum and frequency hopping schemes. In this one data bit is divided over several carrier frequencies. As the FH-sequence and the PN-codes are coupled, a user can use a combination of an FH-sequence and a PN-code [6].

III. SPREADING CODES

In CDMA systems the code selection is so important for resistance against interference with other areas and against interference with multiple users. Sequences of codes that should be different but at the same time can be easily reproduced at the reception signal can be recovered. There are two important properties of spreading sequences: Autocorrelation and cross correlation.

Even if a single code sequence is assigned to each user, the user signal still interferes with that of another user when the environment is accessible at the same time, this interference being called multiple access interference. This interference can be decreased by choosing sequences of code that have a small cross correlation. To cope with such interference, it must meet several requirements:

- Each code sequence should be periodic with a constant length.
- Each code sequence should be easy to distinguish from its time –shifted code.
- Each code sequence should be easy to distinguish from other code sequences.

The first two requirements are important due to the effects of multiple propagation paths that occur in the external environments and mobile internal radio. The third requirement is important due to the ability to access multiple communication systems [6].

Properties of spreading code:

- It should appear deterministic
- It should appear random to a listener
- The correlation (cross correlation) of two different codes should be small.
- The correlation of a code with a time delayed version of itself (autocorrelation) must equal zero for any time delay other than zero for rejecting multi-path interference [1].

Similarity between two sequences is defined by correlation. When two sequences compare different, they are said to have cross correlation and when same then autocorrelation. The correlation of two sequences x and y as a function of time delay i is:

$$r(i) = \sum_{k=0}^{L-1} x_k y_{k+i}$$

The correlation function r(i) of any PN sequence of length N is defined by

$$r(i) = \begin{cases} 1, & i = 0 \\ -\frac{1}{N}, & 1 \leq |i| \leq N-1 \end{cases}$$

It has been seen that the length of the code, autocorrelation and cross-correlation properties will help us to determine the best suitable code for any particular communication environment. Therefore here the cross-correlation and auto-correlation properties of different codes are analysed [2].

A. Barker codes

PN sequence can also be a periodic. Such sequences are called as Barker sequences. Barker codes, that are subsets of PN sequences, are commonly used for frame synchronization in digital communication systems. Barker codes can have length at most 13 and have low correlation sidelobes. Barker sequences are too short for practical use of spectrum spreading. The correlation of a codeword with a time-shifted version of itself is said to be correlation sidelobe. The correlation sidelobe, Ck for a k-symbol shift of an N-bit code sequence, {Xj} is defined as

$$C_k = \sum_{j=1}^{N-k} X_j X_{j+k}$$

Here, Xj is an individual code symbol taking values +1 and -1, for 0<j<N, and the adjacent symbols are assumed to be zero [4].

B. Chaotic codes

Chaotic sequences are generated by discrete chaotic functions. One of the most common utilizing is the logistic maps that can be given by the two equations as:

$$X_{n+1} = rX_n(1-X_n) \quad (1)$$

$$X_{n+1} = 1-2X_n^2 \quad (2)$$

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In equation (1) X_n €] 0,1 [(n=0,1..) and $0<r\leq 4$ is known as the bifurcation parameter, for r €]3.57,4] the sequence generated from (1) is chaotic. Whereas in equation (2)) X_n €]-1,1[(n=0,1..). The concept of sensitivity of chaotic maps given by equations (1) and (2) to initial conditions can be defined giving two close values of initial value *x0*, after a few iterations, the two sequences generated by each equation will look completely uncorrelated [3].

C. Gold codes

Gold sequences form an important class of periodic sequences, which gives larger set of sequences with good periodic cross-correlation. A set of Gold sequences of period N = 2n –1, consists of N+2 sequences for which we have good cross-correlation properties [4]. A set of Gold sequences can be generated from appropriately selected maximum length sequences as described below

Therefore, in order to generate a Gold-sequence set for a given order n, we can use the following methodology:

- Find a preferred pair of primitive polynomials h(x) and g(x) having order n
- By utilizing the shift-register architecture, implement the sequences u and v corresponding to the polynomials h(x) and g(x), respectively.
- Use the N different phases of either u or v, in order to find each of the N+2 Gold sequences which is given by the equation

$$G(u\ v) = \{u, v, u\oplus v, u\oplus Tv, u\oplus T^2v, \ldots, u\oplus T^{N-1}v\}$$

D. Hadamard codes

A Hadamard Matrix H having order n is an nxn matrix of 1s and 0s in which $HH^T = nI_n$. (I_n is the n × n identity matrix.). It has the following properties:

- Hadamard matrix having order 1 is [1].
- If H is a Hadamard matrix of order n, then $\begin{bmatrix} H & H \\ H & -H \end{bmatrix}$ is a Hadamard matrix will have an order 2n. Where entries, –H are the negation of their corresponding entry in H [2].

E. Kasami codes

Following a procedure similar to that used to generate Gold codes will produce a smaller set of binary sequences known as Kasami sequences. A set of Kasami sequences includes $M = 2^{m/2}$ binary sequences with a period of $n = 2^m - 1$, provided that m is even. Starting with an m-sequence, say A, a second sequence, B, can be produced by taking every $2^{m/2} + 1$ bit of A, or in other words, sequence B is generated by decimating A by $2^{m/2} + 1$. It can be shown that the final sequence is periodic with period $2^{m/2} - 1$. By taking of $n = 2^m - 1$ bits of the sequences A and B, a new set of sequences is produced by modulo-2 adding the bits from A and the bits from B, and all the $2^{m/2} - 2$ cyclic shifts of the bits from B. By including A in the set, a set of $2^{m/2}$ binary sequences of length $n = 2^m - 1$ is produced. The auto and cross correlation functions of Kasami sequences can have values from the set $\{-1, -(2^{m/2} + 1), 2^{m/2} - 1\}$. Therefore the maximum value of cross correlation for any pair of sequences from the set is $2^{m/2} + 1$ [2].

F. Pseudo Noise (PN) codes

A pseudo-noise sequence is a periodic sequence which consists of the combination of binary 1's and 0's. The PN sequences have the following three properties; Balance, run and autocorrelation properties. Due to these properties, PN sequences are found to be efficient for data encryption. PN sequences are defined by the help of a polynomial of degree n:

$$P(x) = \sum_{i=0}^{n} a_i x^i$$

where $a_i \in F_2$ and $a_n = a_0 = 1$. The PN Sequence corresponding to this will satisfy the below recursion:

$$P_{n+k} = \sum_{i=0}^{n} a_i p_{k+i}$$

over the field F_2. p(x) = 0 is the characteristic equation of the mentioned recursion [2].

G. Walsh codes

The Walsh code is a linear code that maps binary strings of length n to binary codewords of length 2^n. Moreover these codes are mutually orthogonal. Walsh codes can be produced from Hadamard matrices of orders which are a power of 2. The rows of the matrix having order 2^N constitute the Walsh codes which encodes N bit sequences. Here instead of 1 and -1 consider 1 and 0. That means considering the matrix and the codes over the field F2 or modulo 2. As Walsh codes are linear codes, there exist a generator or a transformation matrix for the same [2].

IV. PERFORMANCE MEASUREMENT OF DIFFERENT CODES

The transmission performance is only dependent on the auto-correlations and cross-correlations values of the PN sequences. The correlations will have a direct impact on the Inter Symbol Interference (ISI) and the Multiple Access Interference (MAI).

TABLE I: AUTOCORRELATION AND CROSS CORRELATION OF SPREADING CODES

Codes	Code length	Auto correlation	Cross correlation
Barker	11	0.5000	$-2.4980*10^{-16}$
Chaos	8	0.5000	$1.9429*10^{-16}$
Gold	8	135	-89
Hadamard	8	0.5000	$-2.7756*10^{-17}$
Kasami	8	0.9666	-0.2224
PN	8	0.5000	$-1.3878*10^{-16}$
Walsh	8	0.5000	$-8.3267*10^{-17}$

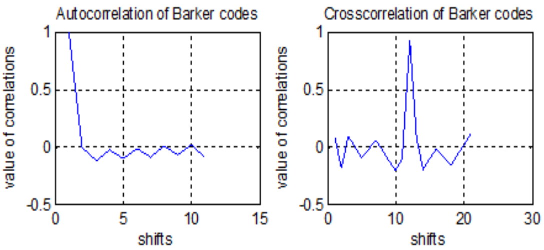

Fig. 1 Autocorrelation and Crosscorrelation of Barker codes

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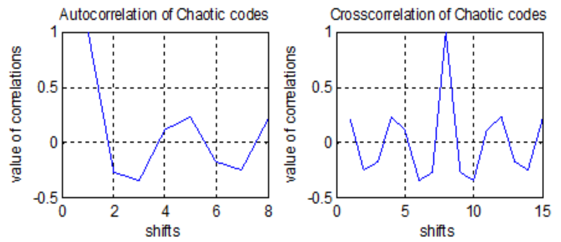

Fig. 2 Autocorrelation and Crosscorrelation of Chaotic codes

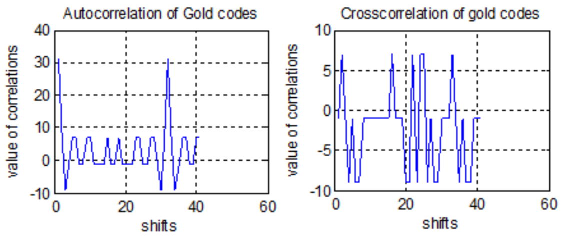

Fig. 3 Autocorrelation and Crosscorrelation of Gold codes

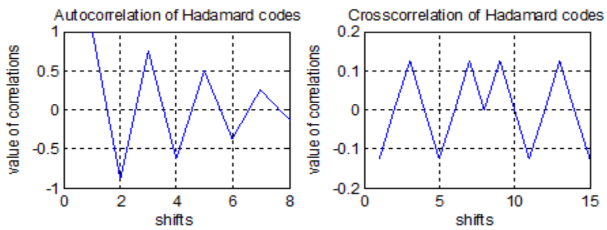

Fig. 4 Autocorrelation and Crosscorrelation of Hadamard codes

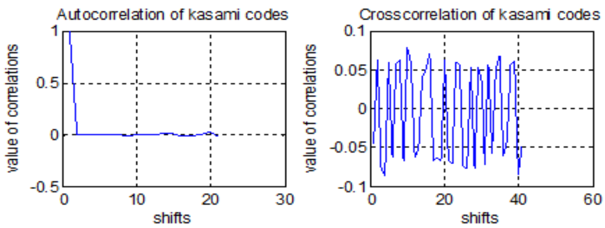

Fig. 5 Autocorrelation and Crosscorrelation of Kasami codes

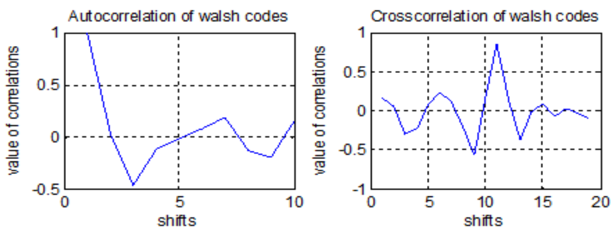

Fig. 6 Autocorrelation and Crosscorrelation of Walsh codes

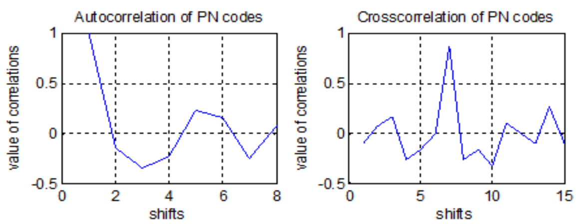

Fig. 7 Autocorrelation and Crosscorrelation of PN codes

V. CONCLUSION

The performance measurement of different codes based on the autocorrelation and crosscorrelation are analysed. For a good code the autocorrelation should be high and crosscorrelation should be low. This paper finds the spreading code with suitable autocorrelation properties along with low cross-correlation values. And as a result the gold codes are found to have good autocorrelation properties and are the pairs with the low crosscorrelation so that they can be used in multi-user environment and thereby prevent the Multiple Access Interference. Spreading codes find their application in CDMA and Optical Code Division Multiple Access (OCDMA) for secure data transmission.

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BIOGRAPHY

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