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Spreading Codes Performance for Correlation Function Using MATLAB

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Abstract

In this paper we briefly describe spread spectrum systems, Code Division Multiple Access (CDMA) and types of spread spectrum systems and their properties. In this we study the generation of Spreading codes such as Non Orthogonal codes (Maximal lengths, Gold and Kasami sequences), Orthogonal codes (Walsh and Hadamard codes) and their functions in CDMA networks. The important properties of the sequences are examined. Auto and Cross Correlation properties of some codes are mentioned for performance in Spread Spectrum CDMA using MATLAB where it is seen that multiple access interference that is caused by the undesired users is directly related with the cross-correlation properties of the codes of these users so, and their correlation properties play a very important role in the detection.

Keywords: CDMA, Spreading Codes, Non Orthogonal Codes.

Introduction

Continuous growth in telecommunication industry in terms of users has led to utilize the available resources effectively and it provide maximum number of services. Spread spectrum (SS) is a technique where an already modulated signal or high frequency signal is modulated a second time in such a way as it produce interference in a barely noticeable way with some other signal operating in the same frequency band. So, in this interfering signals are transparent to spread spectrum signals and spread spectrum signals are transparent to interfering signals. Note that spread spectrum is not a modulation scheme. In this the main objective is preserved for generating PN sequence, like maintaining randomness, which is helpful to differentiate between users and also in generating noise like sequences, a very low correlation value, useful to avoid interference in the transmission channel and a high autocorrelation value to reject multipath fading.

Spread Spectrum System

Spread spectrum is 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 data and a synchronized reception with the code at the receiver is used for dispreading and subsequent data recovery. Different Spread spectrum techniques are distinguished according to the point in system at which pseudo- noise signal is inserted in communication channel. A direct sequence (DS) is best known spread spectrum technique. It is performed by multiplying a radio frequency (RF) carrier and a pseudo-noise (PN) digital signal. First the PN code is modulated onto the data signal, using one of several modulation techniques (e.g BPSK, QPSK, etc). Then the PN modulated data signal and the RF carrier are multiplied. This process causes that the RF signal to be replaced with a very wide bandwidth signal with the spectral equivalent of a noise signal. In the reception of the signal, the receiver must not only know the code sequence to despread the signal but also it requires to be synchronized with the code generator in the transmitter. The multiplication in the time domain of the data signal by the PN code sequence results in a signal with a frequency spectrum similar to the spectrum of the PN code signal (due to the fact that $T_c < T$, where T_c and T represent the duration of one chip in the PN code and one symbol in the data signal respectively). Therefore, the effects of increasing the data rate from R (symbol level) to Rc (chip level) are a reduction in the amplitude spectrum (from T to Tc) and an expansion of the signal in the frequency domain.

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Since the wide bandwidth of the PN codes allows us to reduce the amplitude spectrum to noise levels (without loss information), the generated signals appears as background noise in the frequency domain. From another perspective, the bandwidth of the data signal is basically spread by a factor N = T/Tc, which corresponds to the processing gain in the DS/SS system. In this type of systems the length of the code is the same as the processing gain. Several families of PN codes exist and some of them will be addressed in later sections.

Direct Sequence CDMA

Direct Sequence Code Division Multiple Access (DS-CDMA) is a method of multiplexing users by distinct codes and in this method all users use the same bandwidth. In DS-CDMA, each user has its own spreading code. The selection of a good code is important, because auto-correlation properties and length of the code sets bound on the system capacity. The code sets can be divided into two classes: orthogonal codes and non- orthogonal codes. Walsh sequences fall in the first category, while the other sequences (PN, Gold and Kasami) are shift-register sequences. When the user codes are orthogonal, the output of the correlation in the receiver is zero except the desired sequence.

In synchronous DS-CDMA systems the code sequence in the receiver is exactly same with that in the transmitter, so there is no time shift between the users. When the user codes are orthogonal in the synchronized systems, there is no multiple access interference between the users after dispreading. In practice, it is difficult to realize synchronized DS-CDMA systems and time shifts between users decrease the system's capacity. The most important measures that specify the codes performance are, the orderly low values of cross-correlation between codes and the rate of effect of auto-correlation values from time shifts.

Pseudonoise (PN) Sequence

A pseudo noise (PN) sequence is a binary sequence of 1's and 0's and it is periodic. Some of its characteristics that are similar to random binary sequences(having equal # of 0's and1's), very low correlation between any two shifted version of the sequence and low cross correlation between any two sequences. Pseudo-Random sequence is not random (deterministic) but it looks randomly for the user who doesn't know the code. The larger the period of the PN spreading code, will be more random binary wave and it is harder to detect it.

A PN Sequences are the largest codes that can be generated using a linear feedback shift register. The generator polynomial governs all the characteristics of the generator It consist of a shift register made up of m flip-flops and a logic circuit. The flip-flops in the shift register are regulated by a single timing clock. Binary sequences are shifted through the shift registers and the output of the various stages are logically combined and feedback as the input to the first stage.

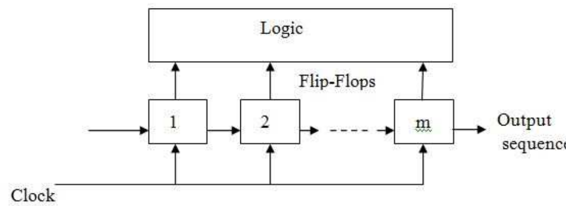

Figure 1: Feedback Shift Register.

The initial contents of the flip-flops determine the contents of the memory. The generated PN sequence is determined by mainly three factors that are length m of the shift register, flip-flop's initial state and the feedback logic. The number of possible states of the shift register is at most 2mfor a m flip- flops. So the generated PN sequence must become periodic with a period of at most 2^m.

When the feedback logic consists of Exclusive-OR gates, the shift register is called a linear and in such a case, the zero state is not permitted. Therefore the period of a PN sequence produced by a linear m-stage shift register cannot exceed $2^m - 1$. When a sequence of period 2m − 1 generated, it is called a maximal – length (ML) sequence.

Maximal-length sequences satisfy the following three properties.

***Balance Property*:**

In each period of maximum-length sequence, the number of 1s is always one more than the number of 0s. So there must be 2^m-1 ones and $2^{m-1}-1$ zero in a full period of the sequence.

***Run Property*:**

Here, the 'run' represents a subsequence of identical symbols (1's or 0's) within one period of the sequence. The length of this subsequence is the length of the run. Among the runs of 1's and 0's in each period of a maximum-length sequence, one-half the run of each kind are of length one, one-fourth are length two, one-eighth are of length three etc. For a maximum-length sequence generated by a linear feedback shift register of length m, the total number of runs is (N+1)/2 where $N=2^m - 1$.

Correlation Property:

The autocorrelation function of a maximum-length sequence is periodic, binary valued and has a period $T=NT_c$ where T_c is chip duration. This property is called the correlation property. The autocorrelation function is[2]

$$R_c(\tau) = \begin{cases} 1-\frac{N+1}{NTc}|\tau| & ,|\tau| \\ -\frac{1}{N} & \text{For the remainder of the period} \end{cases}$$

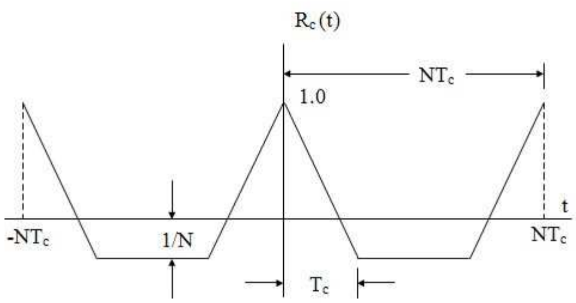

Figure 2: Autocorrelation function for a maximum-length sequence with chip duration Tc and period NTc.

Gold Sequences

The particular class of PN sequences called Gold sequences. They can be chosen such that, the cross-correlation values between the codes over a set of codes are uniform and bounded. Gold codes can be generated by modulo-2 addition of two maximum-length sequences with the same length. The code sequences are added chip by chip by synchronous clocking. The generated codes are of the same length as the two m-sequences which are added together.

In addition to their advantages Gold codes generates large number of codes. To define a set of Gold codes, preferred pairs of m sequences are used. If a is an m-sequence of length N, the second sequence a` can be obtained by sampling every qth symbol of a. The second sequence is called decimation of the first sequence.

The following conditions are sufficient to define a preferred pair a and à of m-sequences:

$n \neq 0$; that is, n is odd or n=2 (1)

à =a[q] where q is odd and either (2)

$q= 2^k + 1$ or $q= 2^{2k} - 2^k + 1$

gcd(n, k) ={ 1, for n odd; (3)

2, for n=2.}

The decimation of an m-sequence may or may not yield another m-sequence. The set of Gold codes for this preferred pair of m-sequence is defined by {a, à, a+a, a+Dà, a+D2à, ..., a+D N-1 à}where D is the delay element.

Shift-Register Length, m	Period (Code Length)	Cross-Correlation
m odd	$N=2^m-1$	$-1/N$ $-(2^{(m+1)/2}+1)/N$ $(2^{(m+1)/2}-1)/N$
m even and not divisible by 4	$N=2^m-1$	$-1/N$ $-(2^{(m+2)/2}+1)/N$ $(2^{(m+2)/2}-1)/N$

Kasami Sequences

Properties of Kasami sequence are very similar to the preferred sequences used to generate gold codes. Kasami sequence sets are one of the important types of binary sequence sets because of their very low cross-correlation. Kasami codes are based on PN codes of length $N=2^m-1$ where m is an even integer. There are two different sets of Kasami sequences. Generation of a small set of Kasami sequences is similar to the generation of Gold sequences with M=2n/2 binary sequences of period N=2n-1, where n is even. To generate a Kasami sequence, first of all the sequence a' is found by selecting every $(2^{n/}2+1)^{st}$ bit of an m-sequence a. The resulting sequence a' is an m-sequence. The first Kasami Sequence can be found by adding (modulo-2 addition) the sequences a and a'. Then by adding all $2^{n/2}$-2 cyclic shifts of the sequence a' with the sequence a, a new set of Kasami sequences can be formed. A Kasami codes have better cross correlation and auto correlation properties

Hadamard-Walsh (Orthogonal) Codes

Walsh codes are orthogonal codes. These codes are used in DSSS systems and also in FHSS systems to select the target frequency for next hop. The Hadamard-Walsh codes are generated in a set of $N=2^n$ codes with length $N=2^n$. The generating algorithm is as follows

$$H_{2N} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{bmatrix} \quad (4)$$

where N is a power of 2 and over score denotes the binary complement of the bits in the matrix. The smallest set of N=0 is $H_0=[1]$ with the length 1. The rows or columns of matrix H_N are the Hadamard-Walsh codes since the matrix H_N is symmetric. The sets of 2 and 4 codes are shown below

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \quad (5)$$

$$H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \quad (6)$$

As shown above, in each set, the first row of the matrix consist all 1's and rest of the rows contains N/2 0's and N/2 1's. Also row N/2 starts with N/2 1's and ends with N/2 0's. Orthogonality is the most important property of Hadamard-Walsh codes. Because of this orthogonality property, the cross-correlation between any two Hadamard-Walsh codes of the same set(matrix) is zero, when system is perfectly synchronized.

Walsh codes are not maximal length or PN type codes for spread spectrum. Although the members of the set are orthogonal, they do not give any spreading. They are used in forward channel of IS-95 CDMA type system for their orthogonality. Walsh code spreading can be used if all users of the same channel are synchronized in time, because the cross-correlation between deferent shifts of Walsh codes is not zero.

Simulations and Results

As it can be seen from figure 3, the auto-correlation properties of PN and Gold codes are exactly same. These properties are very similar to the orthogonality properties since the correlation values between codes for the time shifts which are less than 1 chip are very low($7.8\text{x}10^{-3}$). In figure 4, the cross-correlation values are shown for the interval [-$2T_c$,$2T_c$]. It is clear that while the cross-correlation values are bounded by three values, PN codes have higher and multi values. Since the PN codes are chosen from the same set, the cross correlation properties are similar with the shifted autocorrelation properties.

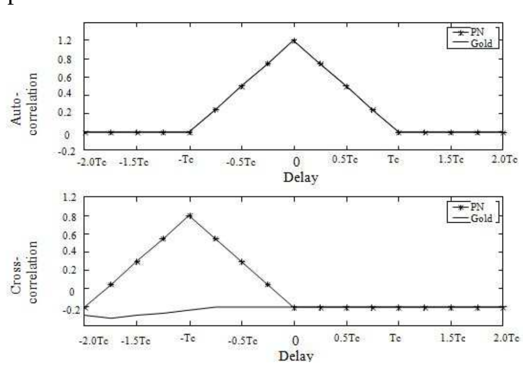

Figure 3: Correlation values of [7 1] PN-code and [7 3]-[7 3 2 1] Gold code. N=127. Initial contents of flip-flops: 1000000

Time shifts less than one chip are modeled by increasing the resolution four times. In the new generation of DS-CDMA systems, Gold codes are preferred since cross-correlation properties are required. Especially for the case of asynchronous, the cross-correlation values of PN codes are high which cause multiple access interference (MAI).

In figure 1.3, the correlation values of PN and Gold sequences are shown for the case of higher time shifts[-$10T_c$,$10T_c$](PN codes are chosen from the same set). The highest cross-correlation value of Gold code is 0.134. In figure 5, the cross-correlation of two PN sequences are shown which are chosen from two different sets that are produced by different feedback connections. In the IS-95 standards, DS-CDMA systems, a long code is produced ($N=2^{42}-1$) and the parts of this code are used as spreading codes for different users. In figure 6 auto and cross-correlation 27.

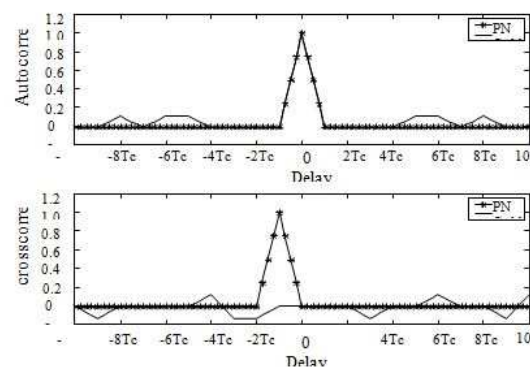

Figure 4: Correlation Values Of [7 1]Pn-Code And [7 3]-[7 3 2 1]Gold Code. N=127. Initial Contents of flip-flops:1000000

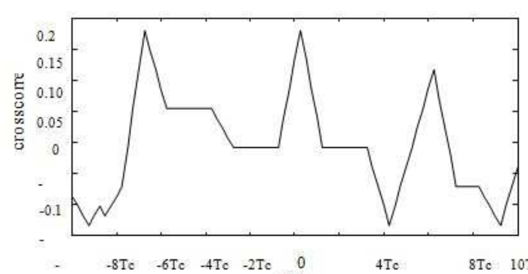

Figure 5: Correlation values of PN-codes chosen from the sets of [7 1]and[7 6 5 4]. N=127. Initial contents of flip-flops:1000000

Initial contents of flip-flops:1

Given a set of N sequences of period L, a lower bound on their maximum cross-correlation is[1]

$R_{max} \geq L\sqrt{\frac{N-1}{NL-1}}$ (7)

values of Kasami sequences are shown. It is clear that, they have higher auto-correlation values for the time shifts which are greater than one chip as compare to PN and Gold sequences. It's maximum cross-correlation value is around 0.333(absolute value).

Mathematically it is proven that, for the large L and m odd, the maximum value of the cross-correlation function between any pair of Gold sequences is $R_{max}=\sqrt{2L}$, for even $R_{max}= 2\sqrt{L}$.

For the Kasami sequences, maximum cross-correlation value is found as $R_{max} = \sqrt{L}$.

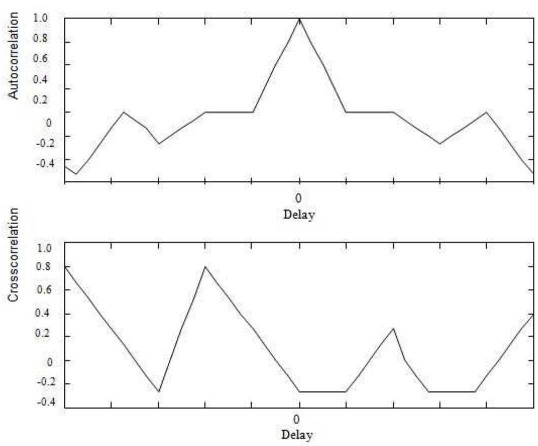

Figure .6. Correlation values of Kasami codes. N=127. Initial contents of flip-flops:1111

Maximum value of the cross-correlation function between any pair of Gold sequences, it is clear that Gold sequences are slightly suboptimal. On the other hand, it is observed that Kasami sequences satisfy the lower bound for large values of L. Because of all these properties, we can conclude that Gold & Kasami sequences are appropriate for CDMA applications.

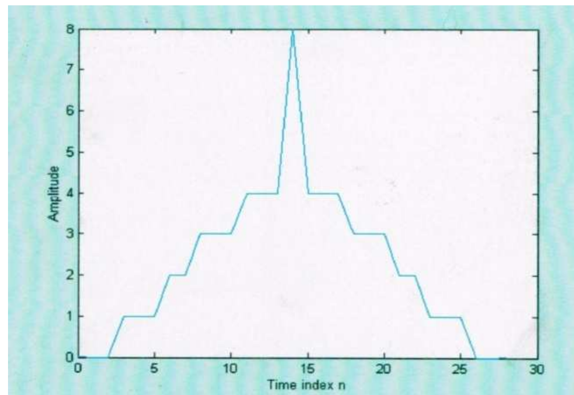

Figure .7 Auto correlation function of the PN SEQUENCE

PN =

0 1 1 1 0 1 0 1 1 0 0 1 0 0

Autocorrection =

0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	2.0000	2.0000
3.0000	3.0000	3.0000	4.0000	4.0000	4.0000	8.0000	4.0000
4.0000	4.0000	3.0000	3.0000	3.0000	2.0000	2.0000	1.0000
1.0000	1.0000	0.0000	0.0000	0.0000			

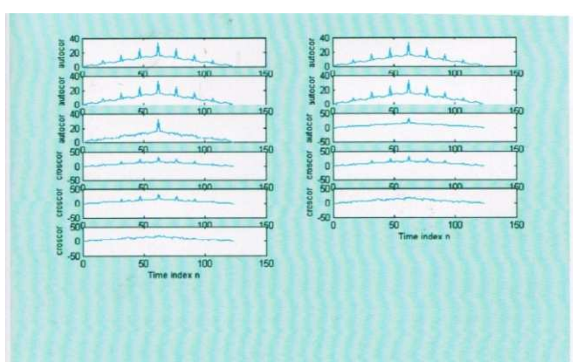

Figure .8 Graph reveling the Auto-correlation and Cross-correlation of the generation PN SEQUENCE

PN =

0 1 0 1 1 1 1 0 0 0 1 0 0 1 1 0 1 0 1 1
1 1 0 0 0 1 0 0 1 1 0 1 0 1 1 1 1 0 0 0
1 0 0 1 1 0 1 0 1 1 1 1 0 0 0 1 0 0 1 1
0 1 0

PN =

0 1 0 1 1 1 1 0 0 1 0 1 0 0 0 1 1 0 0 0
0 1 0 0 0 0 0 1 1 1 1 1 1 0 1 0 1 0 1 1
0 0 1 1 0 1 1 1 0 1 1 0 1 0 0 1 0 0 1 1
1 0 0

PN =

0 0 0 0 0 0 0 0 0 1 1 1 0 1 1 1 0 0 1 1
1 0 0 0 0 1 0 1 0 0 1 0 1 1 0 1 0 0 1 1
1 0 1 0 1 1 0 1 1 0 0 1 1 0 0 0 0 0 0 0
1 1 0

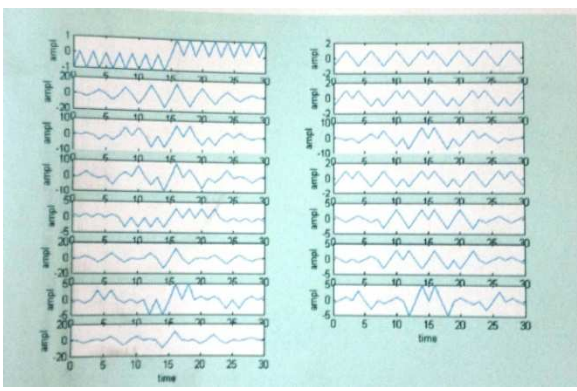

Figure .9 Walsh Hadamard Code Sequences Cross-correlation Output

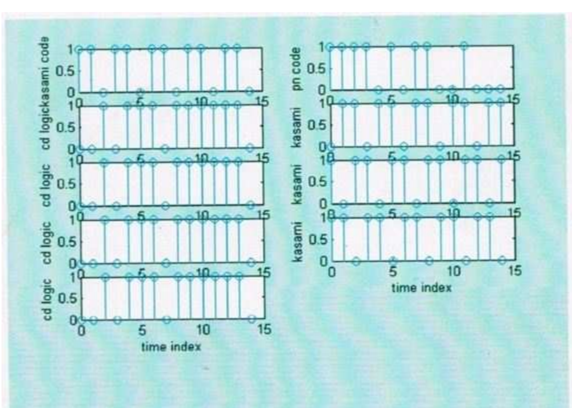

Figure .10 Generation of Kasami Codes and Other Codes Using Kasami and PN Codes

Conclusion

This paper give a general overview about different spreading codes used in DS-CDMA. Here it has been tried to focus on generation and properties fulfilled by different classes of codes. We may support a multitude of users over a common communications channel in spread spectrum environmental by using a technique known as Code Divison Multiplexing (CDM) which relies on the use of PN Codes with different generators for the individual users. However, an important phenomenon arises in CDMA is the partial cross-correlations of PN Sequences, which manifest itself as a result of crosstalk between any two users sharing a common radio environmental. This work illustrates several CDMA Codes generations and gives a detail view of improvement PN sequences and its correlations natures. It has been found the probability of error of a desired user in the direct sequence spread spectrum system with K multiple access users can be defined as

$P(E)=f(P_k, \varphi_k, \Delta_k)$, where it is a function of power of the k^{th} user P_k

Phase shift of the k^{th} user caused by modulation φ_k, and the amount of shift of k^{th} user caused by the asynchronous system Δ_k. The received signal will consist of sum of K different transmitted data (one is desired user and $K-1$ undesired users).

Reception is achieved by correlating the received data with the desired code sequence to produce a decision variable. So here we get that each code has its own advantage like m-sequence gives very long pseudo random sequence, Gold and Kasami codes provide with a large number of codes and because of their good correlation and rapid synchronization features they are used in many 3G applications. Walsh codes are useful in WCDMA applications because of their low cross correlation.

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