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Effective Coding Techniques in Spread Spectrum Communication Using MATLAB

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Abstract:

Multiple Users want to talk at the same time in the same geographical area especially, people want to talk at the same time in our locality using the same available resource (as in GSM). The problem statement in this study is “How to allow different users to share the same resources?” The research solution in this study is to divide them separately in time or in frequency or in combination of both or using separate codes. The study is completed based on the analysis on the Maximum length Pseudo Noise (PN) sequence. The results of generated m-sequence confirmed that the developed system could be utilized in spread spectrum communication systems. The analyses are carried with MATLAB language.

Keywords:

Coding Techniques, Spread Spectrum Communication, Digital Telecommunication System, MATLAB

1. Introduction

Channel codes are vital in fully exploiting the potential capabilities of spread spectrum communication systems. Although direct-sequence systems greatly suppress interference, practical systems require channel codes to deal with the residual interference and channel impairments such as fading. Frequency hopping systems are designed to avoid interference, but the hopping into an unfavorable spectral region usually requires a channel code to maintain adequate performance. A spread-spectrum signal is a signal that has an extra modulation that expands the signal bandwidth beyond what is required by the underlying data modulation. Spread-spectrum communication systems [1,2,3] are useful for suppressing interference, making interception difficult, accommodating fading and multipath channels, and providing a multiple-access capability. The most practical and dominant methods of spread-spectrum communications are direct-sequence modulation and frequency hopping of digital communications. There is some fundamental theoretical barrier to the effectiveness of spread spectrum communications. This remarkable fact is not immediately apparent because the increased bandwidth of a spread-spectrum signal necessitates a receive filter that passes more noise power to the demodulator. However, when any signal and white Gaussian noise are applied to a filter matched to the signal, the sampled filter output has a signal-to-noise ratio that depends solely on the energy-to-noise-density ratio. Thus, the bandwidth of the input signal is irrelevant, and spread-spectrum signals have no inherent limitations. At first it might seem that a spread-spectrum signal is counterproductive insofar as the receive filter will require an increased bandwidth and, hence, will pass more noise power to the demodulator. However, when any signal and white Gaussian noise are applied to a filter matched to the signal, the sampled filter output has a signal-to-noise ratio (SNR) that is inversely proportional to the noise-power spectral density. The remarkable aspect of this result is that the filter bandwidth and, hence, the output noise power are irrelevant. Thus, we observe that there is no fundamental barrier to the use of spread-spectrum communications [4,5,6,7,8].

The rest of the paper is organized as follows. Section II presents the background theory of spread spectrum communication systems. Section III gives the codes used in CDMA. Section IV mentions the implementation and results. Section V offers the discussions and conclusion of the works.

2. Background Theory

2.1. Dividing the Users in Frequency Domain: – FDMA

FDMA – Frequency Domain Multiple Access is a technique in which the users share the same resources but at different frequencies.

2.2. Advantages of FDMA

• No Inter Symbol Interference (ISI)

• Simple to design

• Easier synchronization

2.3. Disadvantages of FDMA

Frequency reuse is a problem in FDMA. We cannot allocate indefinite number of frequencies to the ever growing number of users. Since the spectrum is limited in bandwidth, a limited set of frequencies (Absolute Radio-Frequency Channel Number-ARFCN as in GSM) is reused over a given area. Need to take care of co-channel interference when using frequency reuse technique High Q filters are required at the receiver side to separate the frequency content of each allocated spectrum, or large guard bands are required to separate each user.

2.4. Dividing the Users in Time Domain: – TDMA

TDMA – Time Domain Multiple Access is a technique in which the users share the same resources but at different time slots. The time slots are so small that it is impossible for users to perceive the service disruptions.

Advantages of TDMA

• No need for High Q filters

• Suitable for digital data like PCM (Pulse coded modulation) data

Disadvantages of TDMA

• Need for tight synchronization circuits and guard time between time slots

• Equalizers are needed to cancel ISI effects.

• Susceptible to interference and multi-path effects.

2.5. Dividing the Users Using Codes: CDMA (Code Division Multiple Access)

Spread Spectrum Techniques:

The strict requirements of FDMA and TDMA are overcome by using spread spectrum techniques.

Spread Spectrum techniques do not require high Q analog filters, frequency reuse, guard bands (as in FDMA) and equalizers, strict synchronization circuits, guard time (as in TDMA).

Advantages:

• Low power spectral density however the transmitted bandwidth requirement is higher than the other two techniques.

• Privacy due to use of separate codes for each users

• Possibility of jamming the signal is very low

• Reduced multi-path effects

• Immune to interference effects

There exist different techniques to spread a signal: Direct-Sequence (DS), Frequency-Hopping (FH), Time-Hopping (TH) and Multi-Carrier CDMA (MC-CDMA). It is also possible to make use of combinations of them.

Direct-Sequence (DS) spread spectrum:

In DS spread spectrum technique, the user data is spread over much higher bandwidth by multiplying with a maximum length PN sequence called chips. Always the user data rate (Rb) is relatively low compared to the rate of the PN sequence (called "chip rate" – Rc).The spread signal looks like a noise when transmitted over a radio interface. "Spreading Factor" or "Processing Gain" determines number of users that can be allowed in a spread spectrum system, the amount of multi-path effect reduction, the difficulty to jam or detect a signal etc.

It is defined as the ratio of chip rate to the user data rate. Higher the spreading factor, greater is the capability to detect user data. Spreading factor may also be considered as a "gain" and is known as "Processing Gain" given by 10log10 (chip rate/user rate). If the processing gain of a CDMA system is 20dB and if a Eb/N0 ratio of 5dB is needed at the receiver for satisfactory operation , the signal-to-interference ratio can be as low as -15dB, the user signal can still be recovered from the received signal (in presence of the interference signal). This is because the de-spreading benefits from the processing gain of 20dB. In a typical WCDMA system, the chip rate is 3.84×106 chips/second (3.84 Mcps) and the user data rate is 12.2 Kbps, which equates to a processing gain of 10log (3.84M/12.2K)=24.9dB.

3. Codes used in CDMA

IS-95 CDMA Standard uses three types of codes namely (1) Long code (2) Short code and (3) Walsh Hadamard codes.

Long Code:

Long codes run at 1.2288 Mb/s and are 42 bits longs (created using a 42 bit LFSR register). It takes approx. 41.2 days to repeat a long code at this rate. It is used for both encryption and spreading. Encryption is achieved by using a mask called Long Code mask which is a created using a 64-bit authentication key called A-key (assigned by CAVE protocol) and Electronic Serial Number (ESN – assigned each user based on the mobile number). The Long code changes each time a new connection is created.

Short Code:

Short code is an m-sequence of length 215-1 (created using a 15 bit LFSR register) and is used for synchronization purpose in the forward as well as reverse links. The short code is also used to identify cell/base station connection in the forward link. It repeats approx. 75 times in 2 seconds. Each base station is assigned a cyclically shifted version of same short code sequence to differentiate the base stations. This is also called PN offset in CDMA jargon. Since the cyclically shifted versions of the same m-sequence offer poor correlation, it is easier to differentiate between different base station links. During the initial call setup stage, a mobile phone tries to find a base station (in 2 seconds max allowed time), if it find a base station, the mobile phone is validated using a database by the base station and is assigned a PN Short code sequence. This PN short code sequence uniquely identifies the connection between the particular base station and the mobile devices served under that base station. In reality two short code sequences are used; one for I channel and another for Q channel (used in spreading and de-spreading).

Walsh Hadamard Code:

CDMA uses another type of code called Walsh Hadamard Code. In IS-95 CDMA, 64 Walsh codes are used per base station. This enables to create 64 separate channels per base stations (i.e. a base station can handle maximum 64 unique users at a given time). In CDMA-2000 standard, 256 Walsh codes are used to handle maximum 256 unique users under a base. Walsh codes are created by transformation of Hadamard Matrix. The codes under a family of Walsh codes, possess a beautiful property of being orthogonal to each other.

The first matrix in a Hadamard transform is

$$H_1 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

The subsequent matrices are formed iteratively using

$$H_{N+1} = \begin{bmatrix} H_N & H_N \\ H_N & \bar{H}_N \end{bmatrix}$$

The H_2 matrix will be

$$H_2 = \begin{bmatrix} H_1 & H_1 \\ H_1 & \bar{H}_1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

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Each row of a Hadamard matrix represents a unique Walsh code and all the Walsh codes in a given matrices are orthogonal. The length of the row of the matrix (number of columns otherwise) is the code-length of the Walsh codes. To get a 64-Walsh code matrix we need to transform the matrices till H8 (this matrix contains 64 rows – representing 64 Walsh codes and each code are of 64 bits length).

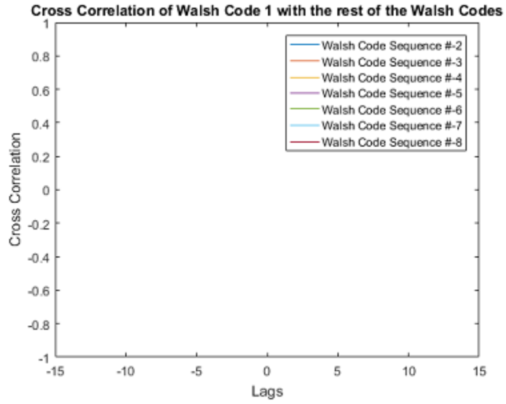

Figure 1. *Cross Correlation with lags based on different code sequences.*

Walsh codes possess excellent cross-correlation property (cross correlation of one Walsh code with another is always zero) and therefore possess excellent orthogonality property. The auto-correlation property of Walsh code is very poor and so it is used only in synchronous CDMA networks, which maintains a synchronizing mechanism to identify the starting of the codeword. Actually in IS-95, out of the 64 available Walsh codes, Walsh code 0 is reserved for pilot channel, 1 to 7 are assigned for synch channel and paging channels and the remaining 8-63 are assigned for users (traffic channel). Figure 1 shows the Cross Correlation with lags based on different code sequences. Figure 2 illustrates the Auto Correlation with lags based on Simulation and Theory.

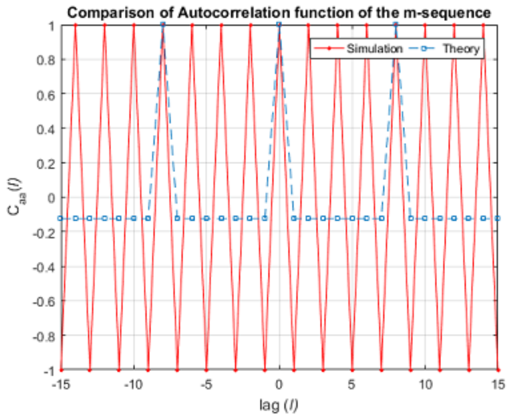

Figure 2. *Auto Correlation with lags based on Simulation and Theory.*

4. Implementation of Maximum Length Sequences (m-sequences) and Results

In spread spectrum communications, typically in CDMA, the user data is multiplied with a spreading sequence to achieve spreading. When the signal is received, the spreading is removed from the desired signal by multiplying it with the same sequence that was exactly synchronized to the transmitted PN signal. When a de-spreading operation is applied to the interferer's signals, it spreads the interference signal over a wider bandwidth, thereby reducing its effective power. This reduction in the interference power translates as processing gain. In CDMA, each user is assigned a predetermined spreading sequence which has low cross correlation property with other user's spreading sequences. Spreading sequences are chosen based on their characteristics like autocorrelation, cross correlation properties, etc… Some of the spreading sequences are listed below

- Maximum length Pseudo Noise (PN) sequence
- Gold sequences
- Kasami sequences
- Walsh Hadamard sequences

In this study, we only focus on the Maximum length Pseudo Noise (PN) sequence.

Maximum Length PN sequences (m-sequences):

Maximum Length PN sequence generators are binary sequence generators that are capable of outputting all possible combinations of binary sequences in 2m-1 cyclic shifts, where m is the size of the LFSR (Linear Feedback Shift Registers) used in generating such sequences. Terms like Pseudo- Random Binary Sequences (PRBS) or pseudo-noise sequences are also used to refer m-sequences.

To generate an m-sequence, feedback connections of LFSRs are done according to a primitive polynomial (generator polynomial).

Primitive Polynomials:

A generator polynomial is said to be primitive if it cannot be factored (i.e. it is prime), and if it is a factor of (i.e. can evenly divide) xN+1, where N = 2m-1 (the length of the m-sequence). If we wish to construct an m-sequence generator using 3 registers (m=3), then the primitive polynomial that determines the feedback connection can be determined as follows.

$$N = 2^n - 1$$

$$x^7 + 1 = (x+1)(x^3 + x + 1)(x^3 + x^2 + 1)$$

In the above equation, the three primitive polynomials are $(x+1), (x^3 + x + 1)$, and $(x^3 + x^2 + 1)$.

Since the number of registers are m=3, we have to choose a primitive polynomial that is of degree 3. From the above factorized equation, we have two choices for m=3, i.e. $(x^3 + x + 1)$ and $(x^3 + x^2 + 1)$. These polynomials are often represented as [3 1 0] and [3 2 1] respectively. Some of the primitive polynomials used for generating m-sequences are given below.

Table 1. Primitive Polynomials with Respective Degree

Degree (m)	Length of m-sequence (N)	Primitive Polynomials
1	1	$(x+1)$
2	3	$(x^2 + x + 1)$
3	7	$(x^3 + x + 1)$

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4	15	$\left(x^4+x+1\right)$
5	31	$\left(x^5+x^2+1\right)$
6	63	$\left(x^6+x+1\right)$
7	127	$\left(x^7+x+1\right)$
8	255	$\left(x^8+x^7+x^2+x+1\right)$
9	511	$\left(x^9+x^4+1\right)$
10	1023	$\left(x^{10}+x^3+1\right)$
11	2047	$\left(x^{11}+x^2+1\right)$
12	4095	$\left(x^{12}+x^6+x^4+x+1\right)$

Following is an example of generating an m-sequence of length 7. Generator polynomial = [3 1 0] which can be represented as G= [1 0 1 1] (G=[X3 X2 X1 X0]). The LFSR feedback connections are connected as follows. Figure 3 demonstrates the Maximum length Pseudo Noise (PN) sequence.

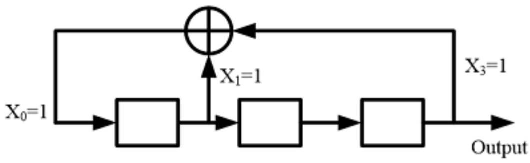

Figure 3. *Maximum length Pseudo Noise (PN) sequence.*

Autocorrelation Property of m-sequences:

The discrete autocorrelation of an m-sequence is computed by,

$$C_{aa}(l)=\frac{1}{N}\sum_{k=0}^{N-1}a_k a_{k-l}$$

Since m-sequences are periodic with period N, the autocorrelation is also periodic with period N.

$$C_{aa}(l)=C_{aa}(L+N)$$

Theoretically the autocorrelation of an m-sequence is a two valued function given by

$$C_{aa}(l)=\begin{cases}1, l=kN \\ \frac{1}{N}, l\neq kN\end{cases}; k=0,1,2,\ldots,N$$

The maximum length PN sequence is generated using a primitive polynomial of degree 6. The generator polynomial used is [6 1 0]. Since m=6, N=63 (2m-1). Therefore, the generated m-sequence will be periodic with period N=63 i.e., all the values and autocorrelation repeats after 63 samples. An NRZ coder is used to convert the generated output to polar format. The autocorrelation of the m-sequence is two valued: 1 and 0.0158 (because 1/N=1/63=0.0158).

Figure 4 mentions the Comparison of Autocorrelation Function of the m-sequence. According to these results, we could easily observe the simulation results as well as theory of fundamental concepts. There has not been much difference between two results. Figure 5 offers the Generated m-sequence. Based on the results of generated m-sequence, the discrete format and polar format of those sequences could be utilized in spread spectrum communication systems for digital telecommunications.

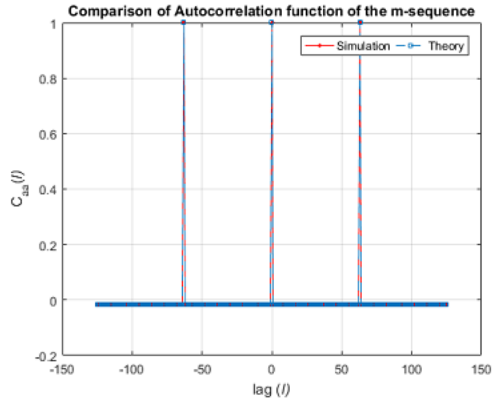

Figure 4. *Comparison of Autocorrelation Function of the m-sequence.*

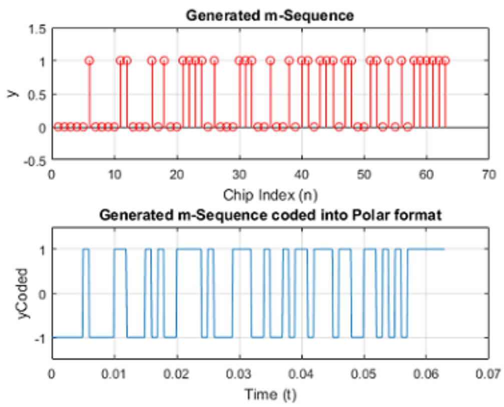

Figure 5. *Generated m-sequence.*

5. Discussions and Conclusion

The main purposes of this study are effective coding techniques in spread spectrum communication using MATLAB. The study was accomplished based on the coding techniques with Maximum length Pseudo Noise (PN) sequence. The numerical results show that the generated m-sequence could be utilized in spread spectrum communication systems. The research solution in this study has been solved for dividing the different users separately in time or in frequency or in combination of both or using separate codes.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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