Research Paper

PERFORMANCE ANALYSIS OF CHAOTIC DS-CDMA WITH CSK MODULATION

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ABSTRACT

Direct sequence-code division multiple access (DS-CDMA) technique is used in cellular systems where users in the cell are separated from each other with their unique spreading codes. In recent times DS-CDMA has been used extensively. These systems suffers from multiple access interference (MAI) due to other users transmitting in the cell, channel inter symbol interference (ISI) due to multipath nature of channels in presence of additive white Gaussian noise (AWGN). Spreading codes play an important role in multiple access capacity of DS-CDMA system. M-sequences, gold sequences etc., has been traditionally used as spreading codes in DS-CDMA. These sequences are generated by shift registers and periodic in nature. So these sequences are less in number and also limit the security. This paper presents an investigation on use of new type of sequences called chaotic sequences for DS-CDMA system. These sequences are generated by chaotic maps. First of all, chaotic sequences are easy to generate and store. Only a few parameters and functions are needed even for very long sequences. In addition, an enormous number of different sequences can be generated simply by changing its initial condition. Chaotic sequences are deterministic, reproducible, uncorrelated and random-like, which can be very helpful in enhancing the security of transmission in communication. This paper investigates the performance of chaotic sequences along with chaotic modulation in DS-CDMA communication systems using various receiver techniques.

KEYWORDS CHAOTIC PN-SEQUENCE, CHAOTIC-CDMA, CORRELATION, CHAOS, NONLINEAR DIFFERENCE EQUATIONS.

1. INTRODUCTION

This Covert operation is required for a transmitter to protect the radio signals so that a commercial or military interceptor has difficulty in detecting the presence of the radio signals. Spread spectrum modulation can be used in a radio system to reduce the likelihood of intercept, as well as providing protection against jamming and interference [1]. Direct sequence spread spectrum is one of the spread spectrum techniques. Traditionally, a pseudo random (PN) sequence is used for direct-sequence code division multiple access (DS-CDMA) systems, but it lacks security due to fact that there are limited number of available PN sequences and they show periodic correlation properties. Studies in non-linear dynamical systems have developed chaotic theories. Chaotic sequences, based on chaotic theories, are non-binary and non-periodic sequences. The number of available chaotic sequences for DS-CDMA systems can be very large. It is very difficult for an interceptor to decipher the chaotic sequence even if a chaotic function is known. The properties of chaotic sequences provide advantages over the conventional PN sequences based systems.

In this paper, we investigate the bit error rate (BER) performance of a DS-CDMA system using chaotic sequences and chaotic modulation technique.

This paper is organized into five parts. Following this introduction, part II provides a more detail discussion on DS-CDMA system. Part III contains discussion on the background of PN sequence and chaotic nonlinear systems along with generation of chaotic sequences. In part IV, BER performance of DS-CDMA system with chaotic sequences generated using different chaotic maps and with different coherent and non-coherent receivers is evaluated and is compared. Finally part V provides concluding remarks.

2. DS-CDMA SYSTEM

2.1. Spread Spectrum Communication Techniques

Expansion of the bandwidth is not just sufficient to be termed as the spread spectrum, but the bandwidth expansion must be accomplished with the separate signature, or known as spreading sequence. Both transmitter and the receiver should have the knowledge of this spreading sequence. It is also independent of the data bits [2]. All the sequences are randomly distributed, and there is no correlation between any two sequences. Let the sequence of data bits x (n) have the period T_{bit} and the spreading sequence of length M generally called chips to distinguish them from the data bits have the frequency f_{chip} where $f_{chip} >> (1/T_{bit})$. In other words it is assumed that $f_{chip}>>f_{bit}$. From the above assumption that the transmitted data is random and independent, the power spectral density of the original un-spread signal is given by [3].

$$S_D(f) = T_{bit}\left(\frac{\sin\pi f T_{bit}}{\pi f T_{bit}}\right)^2$$

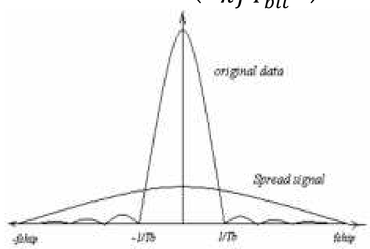

Figure 1. Spread spectrum concept in frequency domain.

And assuming that spreading sequence is pseudorandom in nature, and is given by

$$S_{ss}(f) = \frac{1}{f_{chip}}\left(\frac{\sin\pi f/f_{chip}}{\pi f/f_{chip}}\right)^2$$

The relationship between the above spectral densities is sketched in the Figure 1.

The increase in performance due to the bandwidth expansion and contraction process is termed as processing gain g_P .This processing gain can be represented as the ratio of bandwidth associated with the spread signal W_{SS} and that of the data signal W_D.

2.2. DS-CDMA System

Spread spectrum signals for digital communications were originally invented for military communication, but nowadays are used to provide reliable communication in a variety of commercial applications including mobile and wireless communications, which provide resistance to hostile jamming, hide the signal by transmitting it at low power, or make it possible for multiple users to communicate through the same channel. In conventional DS-CDMA, in order to spread the bandwidth of the transmitting signals, the binary pseudo-noise (PN) sequences have been used extensively. It is a deterministic, periodic signal that is known to both transmitter and receiver, whose appearance has the statistical properties of sampled white noise. It appears, to an unauthorized listener, to be a similar to those of white noise [4].

DS-CDMA is a multiple access technique based on DS-SS in which multiple users can transmit their data on the same channel using orthogonal spreading sequences.

3. PSEUDO-RANDOM SEQUENCES

A pseudorandom (PN) sequence is a code sequence of 1's and 0's whose autocorrelation has properties similar to those of white noise. Some of the popular PN sequences are Maximal length shift register sequences (m-sequences), gold sequences etc.

3.1. Maximal length shift register sequences

Maximal length shift register sequences are by definition, the longest codes that can be generated by a given shift register or a delay element of a given length. In binary shift register sequence generators, the maximum length sequence is [2n-1] chips, where n is the number of stages in the shift register.

3.2. Gold sequences

For CDMA applications, m-sequences are not optimal. For CDMA, we need to construct a family of spreading sequences, one for each, in which the codes have well-defined cross-correlation properties. In general, m-sequences do not satisfy the criterion. One popular set of sequences that does are the Gold sequences. Gold sequences are attractive because only simple circuitry is needed to generate a large number of unique codes such as Gold sequence can be constructed by the XOR of two m-sequences with the same clocking.

3.3. Chaotic PN Sequence

By far, the maximum-length shift-register sequences (m-sequence) are the most widely known binary PN code sequences. The most undesirable property of m-sequence is that they are relatively small in number. Therefore, m-sequences are not suitable for DS-CDMA systems.

A chaotic sequence [4] is non-converging and non-periodic noise like sequence. A large number of uncorrelated, random-like, yet deterministic and reproducible signals can be generated by changing initial value. These sequences so generated by chaotic systems are called chaotic sequences. Chaotic sequences are real valued sequences. Since the spreading sequence in a Chaotic Spread Spectrum (SS) is no longer binary, the application of the chaotic sequences in DS-CDMA is thus limited. A further attempt to transform continuous values to binary ones by using digital encoding technique is therefore used to adopt it in DS-CDMA.

This paper proposes DS-CDMA system which uses chaotic PN sequences to spread the data along with chaotic shift keying for modulation. Some of the popular chaotic maps are logistic map, Hennon map, tent map etc. In this work, PN sequences are generated with both Logistic map [5] and Hennon Map [6]. Surprisingly, the maps can generate large number of noise-like sequences having low cross-correlations. These chaotic maps are utilized to generate infinite sequences with different initial parameters to carry different user paths. Per user path, the infinite chaotic sequences generated using a particular chaotic map with a particular initial condition, is divided into sequential subsets based on spreading rule. Similarly, the out-spreading detector which also knows the sequential rule of the subsets code can get back the transmitted information. Contrary to conventional CDMA, here individual bit is represented by different chip sequences and hence is more secure.

3.4. Generation of chaotic spreading sequence

One major difference between chaotic sequences and PN sequences is that chaotic sequences are not binary. Therefore chaotic sequences must be transformed into binary sequences [7]. Generation of PN sequence using chaotic map can be done in different ways. The real-valued trajectory of chaotic system is encoded to binary sequences by means of a quantization function to generate PN sequence. Quantization scheme can be through

- Two level / Multiple level quantization by comparison with zero thresholds.
- Quantization taking the mean value over continuous time E[X (t)] as threshold [8].

The sequences generated in this way are expected to have a low cross correlation.

The Fig.2 represents the generation on Chaotic spreading sequence:

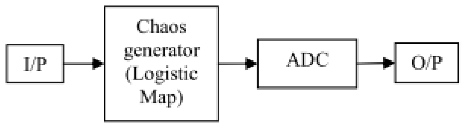

Figure 2. Chaotic PN Sequence generator

3.5. Chaotic modulation

In chaotic communication the digital bits or symbols are mapped onto sample functions of chaotic signals derived from chaotic attractors [9]. The key difference between a conventional carrier and a chaotic carrier is that the sample function for a given symbol is unstable, aperiodic and is different from one symbol interval to the next. As a result, the transmitted waveform is never the same, even if the same symbol is transmitted again and again. Because of this chaotic modulation has an inherent insensitivity to multipath propagation. One such chaotic modulation technique used in our work is chaotic shift keying.

3.5.1. Chaos Shift Keying

The operating principle can be described as follows. Denote the bit duration by T_b. The transmitter consists of two chaos generators f and g, producing signals □c (t) and □c (t), respectively. During the l bit duration, i.e., $[(l-1)\, T_b, lT_b]$, if a binary "+1" is to be sent, □c (t) is transmitted, and if "−1" is to be sent, □c (t) is transmitted.

Figure 3. shows the block diagram of a typical CSK digital communication system.

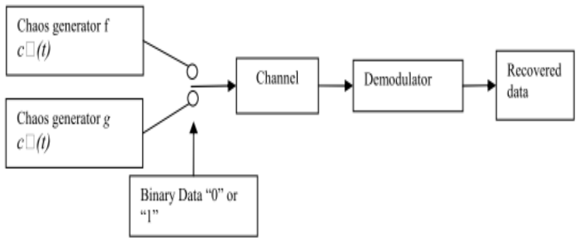

Figure 3. CSK digital communication system

Chaos-based communication systems can be broadly classified into coherent and non-coherent based on the type of the demodulation technique used. Coherent systems require an exact replica of the chaotic carrier to be reproduced at the receiver, there are two Coherent receivers:

- Coherent receiver based on Correlation: In a Correlator type coherent CSK demodulator, two correlator's are employed to evaluate the correlations between the received signal and the two recovered chaotic signals.
- Coherent receiver based on Error Calculation: The first demodulation method proposed for CSK is based on the synchronization error. In this demodulation scheme, decision can be made based on the synchronization errors between the received signal and the estimated signals regenerated at the receiver.

In a Non-coherent demodulation the demodulator determines the bit energy. Because the information is carried by non-periodic chaotic signal segments, the received energy per bit appearing at the input of the decision circuit is a random variable, even in the noise-free case. Such a demodulator is known as Non-Coherent demodulator.

3.6. Chaotic DS-CDMA system

The implementation of chaotic signals within chaos based DS-CDMA systems is possible due to the fact that the chaotic signals are approximately mutually orthogonal.

In this work we have used a unique chaotic PN-sequence that is generated using logistic map in order to spread the message from each user , the spread signal from each user is modulated using chaotic shift keying technique, this modulated signal from each user in the system are combined together, then the composite N-user signal passes through an analog communication channel as shown in Figure 4, where it is corrupted by background noise w(t), which is additive, white and Gaussian. The individual signals are separated at the receiver by exploiting the orthogonality property of the chaotic signals used as PN-sequence. Namely, two chaotic signals will have a cross-correlation product of zero. Thus with proper synchronization, correlating the composite received signal, x (t), with each user's unique chaotic PN signal will recover each user's original message, with minimal interference from the other users signals. The recovered signal for each user is further demodulated using any chaotic demodulation technique. The output of the demodulator is given to the threshold decision circuit which finally makes an estimate of the data symbol transmitted for each user.

3.6.1. Chaotic DS-CDMA Transmitter

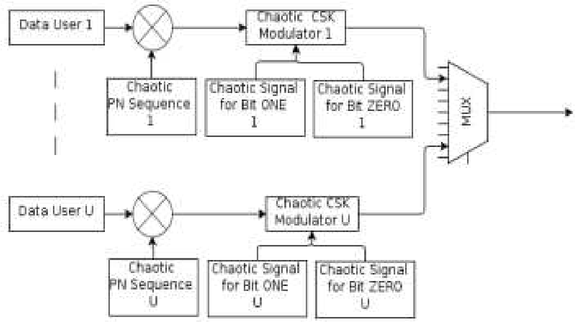

Figure 4. Chaotic DS-CDMA transmitter

In the chaotic DS-CDMA transmitter the binary data from each user is first spread using chaotic PN-Sequence and then modulated using chaotic shift keying technique. The resulting modulated signal from all the users are multiplexed and transmitted over the signal channel.

3.6.2. Chaotic DS-CDMA receiver

The received signal r(t) is first de-modulated then de-spread to obtain the data from each user that was multiplexed at the transmitter end. Based on Coherent and Non-coherent there are 3 different receivers for a DS-CDMA system they are:

3.6.2.1. Coherent Correlator based DS-CDMA receiver

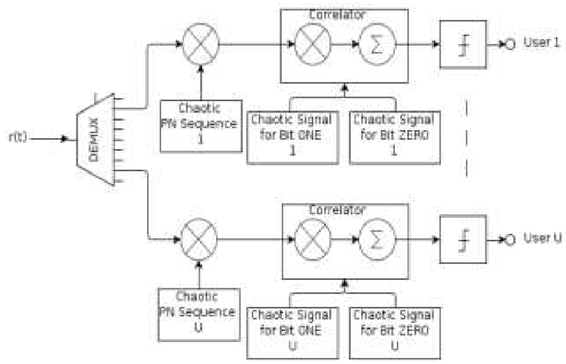

Figure 5. Coherent Correlator based DS-CDMA receiver.

In communications, correlation is a generic process that is used to evaluate the "likeness" between two signals. For the CSK system, if the chaotic carriers used at the transmitter for transmitting the data can be recovered exactly at the demodulator, the transmitted symbol can be identified by evaluating the correlation of the transmitted signal and the regenerated chaotic carriers followed by a decision maker, as shown in Figure 5.

3.6.2.2. Coherent Error-based DS-CDMA receiver

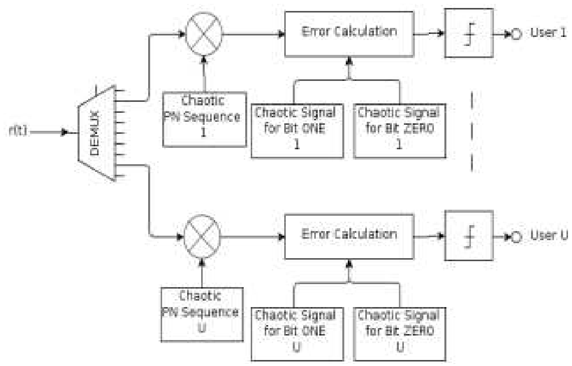

Figure 6. Coherent Error-based DS-CDMA receiver.

In the original CSK systems demodulation of the received signal is based on the synchronizing property of chaotic systems [10]. The structure of such a demodulator is shown in Figure .6. The chaotic signals used at the transmitter end are regenerated at the receiver. The difference (error) between the incoming signal and the regenerated chaotic signal is calculated, and then using a comparator the transmitted symbol can be estimated.

3.6.2.3. Non-Coherent Bit-energy based DS-CDMA receiver

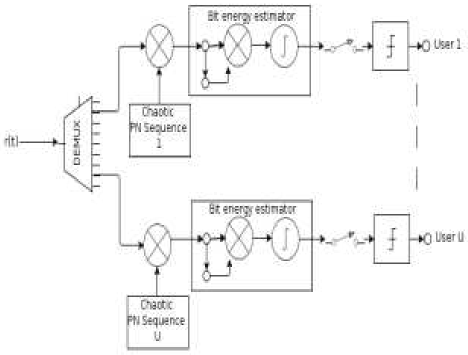

Figure 7. Non-Coherent Bit-energy based DS-CDMA receiver.

4. SIMULATION RESULTS

Numerical results of the performance for a chaotic DS-CDMA system with two users which uses chaotic PN-Sequence and chaotic shift keying as modulation is presented below.

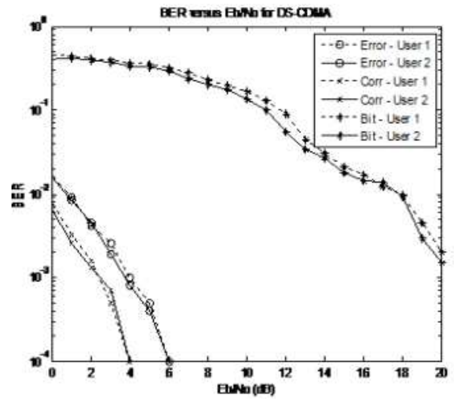

Figure 8. Synchronous Error based receiver; Synchronous Correlation based receiver; Asynchronous receiver.

The chaotic PN-sequence is generated using logistic map which is given as:

$x_{n+1} = ax_n^2-1$

This map depends on only one parameter, 'a' which we have taken as 3.3 for User1 and 3.7 for User2.

Along with this we have taken CSK as chaotic modulation scheme which uses Hennon map for the generation of chaotic signals given as:

$x_{n+1} = y_{n+1}-ax_{n2}$

$y_{n+1} = bx_n$

This map depends on two parameters, 'a' and 'b', for which we have taken 'a' as 1.1 for message bit-1, & 0.85 for message bit-0 and 'b' is kept constant as 0.3.

We have taken the spreading factor as 16 and 30 CSK samples per information symbol.

In general, an increase in the spreading factor will provide better BER performance, as seen in conventional DS-CDMA technique. Out of the three different detection techniques used the Coherent based techniques give better performance compared to non-coherent technique.

5. CONCLUSIONS

The performance of a chaotic DS-CDMA system is studied in this paper. The BER is evaluated for chaotic DS-CDMA system that uses both coherent/non-coherent CSK detection techniques. Analytical results shows chaotic DS-CDMA systems based on Coherent Correlator receiver have better performance than the coherent error based technique. But both coherent detection techniques give better performance than the non-coherent energy based detection and also it can be seen that the system has to sacrifice its communication quality to maintain its performance.

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