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# Spread Spectrum Digital Communication System Using Chaotic Pattern Generator

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Chaotic signals and pseudo-noise sequences can have similar spectral and correlation properties, although chaos can be generate using simple difference equations. This feature can be employed in wireless digital communications based on spread spectrum, where information can be spread by chaotic signals. This paper compares conventional spread spectrum techniques and spread spectrum using chaotic signals in terms of power spectral density, autocorrelation sequence and bit error rate.

**Keywords: digital communication, spread spectrum, pseudo-noise, chaos**

## 1. Introduction

Reliability and availability of real time communication are imperative in the context of wireless communication services. A popular technique used in this scenario is Spread Spectrum (SS). In SS, the spreading process is accomplished using an *spreading code*. Conventionally, it is used a Pseudo-Noise (PN) sequence. These sequences are periodic with a long period and they have properties similar to noise. These properties are interesting when the safety of communications is a requirement of the system [Lathi-1998, Proakis-2000, Haykin-2001].

Besides the conventional method of PN periodic sequences generation, others methods can be used in SS systems. A promising one is the use of chaotic sequences as spreading codes [Li-1995, Mandal-2003, Wang-2005, Cong-2000].

A chaotic signal is deterministic, aperiodic and presents sensitive dependence on initial condition and these properties have increased the interest in using chaos in many fields of Science and Telecommunications [Kolumban-1996, Strogatz-2001, Alligood-1996, Halle-1993, Kurian-2006]. One of the reasons for using chaotic sequence is based on simplicity of its generation, because it can be created by simple rules [Li-1995, Heidari-1994, Heidari-1992]. Applications in SS are discussed, e.g. in [Rovatti-2004, Luca-2005, Volkovskii-2005].

This paper analyzes and compares the performances of the conventional method with a second approach - chaotic sequences as spreading codes. Autocorrelation, Power Spectral Density (PSD) and Bit Error Rate (BER) are considered in this comparison.

This paper is organized as follows: in Section 2 we describe the Direct-Sequence SS (DSSS) communication system. In Section 3 we address the use of PN and chaotic sequences. In Section 4 the application of chaotic sequence in SS is analyzed by computational simulations. Finally, Section 5 summarize results of this paper.

## 2. Direct-Sequence Spread Spectrum

A conventional SS communication system is show in Figure 1 [Proakis-1997].

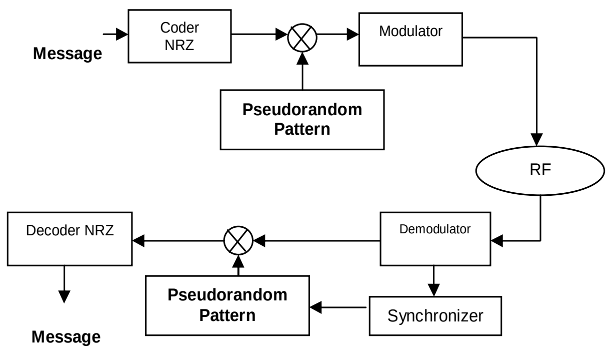


Figure 1. Spread Spectrum Communication System

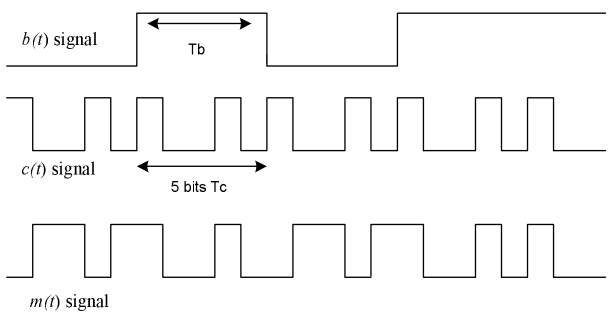


Figure 2. Examples of signals involved in DSSS for $N = 5$

In this system the SS process is accomplished using a periodic PN sequence before transmission. This sequence is independent of the message. The receiver works synchronized by the transmitter and uses the same PN sequence to recover the original message [Proakis-2000].

As a consequence of spreading, the transmitted signal occupies more bandwidth than the minimum required to transmit the original message. This is because the message bit duration $T_b$ is greater than the PN sequence bit duration $T_c$. This process leads to redundancy in each message bit transmitted, because for every bit $T_b$ there are $N$ bound bits $T_c$, expanding the bandwidth needed in $N$ times. Figure 2 shows examples of original message $b(t)$ and PN sequence $c(t)$. The resulting transmitted signal $m(t)$ is [Haykin-2001]

$$m(t) = b(t)c(t). \tag{2.1}$$

Spreading the message increases the security of transmitted information making it difficult to demodulate the signal for unwanted receivers that do not know the spreading code. In addition, SS provides immunity to narrowband interference, or *jamming*. This immunity is obtained at the receiver, because when the *jamming* is added in the channel the receiver decodes it as a SS signal [Sklar-2001].

Implementation of SS communication system requires high processing capability at the transmitter and occupies more bandwidth than the necessary, however such costs are justified when the security of information is the main focus of a communication system [Li-1995, Haykin-2002].

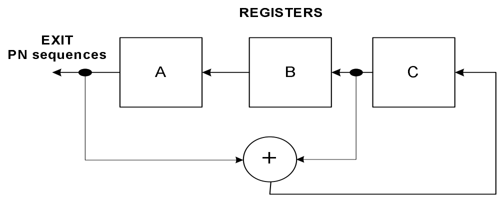


Figure 3. Circuit assembled by $m = 3$ registers.

## 3. Pseudo-random and Chaotic Sequences

The PN sequences can be created by shift-registers synchronized and connected to each other, with the output of one register as the input of the next one. Thus, these sequences are defined by the number of registers, the circuit initial condition and the logic of the interconnection of these registers [Haykin-2001]. These sequences are called Maximal-length sequences, or just *maxlength* [Proakis-1997]. Figure 3 shows an example of Maximal-length sequence generator.

If the initial condition in the circuit showed in Figure 3 is: 0 in register $A$, 0 in register $B$ and 1 in register $C$, after 7 shifts the output will be 0011101.

Being $m$ the number of registers, the output will be repeated after the period $L$ defined by:

$$L = 2^m - 1. \tag{3.1}$$

In DSSS applications, the binary sequence with elements $\{0, 1\}$ is mapped into a corresponding binary sequence with elements $\{-1, 1\}$. We shall call the equivalent sequence $\{c_n\}$ a *bipolar sequence*.

This way, *maxlength* sequences are deterministic and periodic. However, the name PN is applied due to their noise-like statical properties [Sklar-2001]:

1. In each period of a *maxlength* sequence the number of $1s$ is always one more than the number of $0s$. This is called the *balance property*.

2. The autocorrelation function of a bipolar *maxlength* sequence with period $L$ defined as

$$R_C(m) = \sum_{n=1}^{L} c_n c_{n+m} \tag{3.2}$$

is periodic with period $L$ and given by [Proakis-2000]

$$R_C(m) = \begin{cases} L, & m = 0 \\ -1, & 1 \leq m \leq L-1 \end{cases} . \tag{3.3}$$

The chaotic sequences generation is simpler than PN sequences generation, because chaotic signals are accomplished by simples rules (difference equations) while maxlength PN sequences need a large number of registers to obtain such properties [Faleiros-2007, Li-1995, Heidari-1994].

Figure 4 shows examples of PN and chaotic sequences spectrums. The signal in Figure 4(a) was coded by a PN maxlength sequence with $m = 12$ and period $L = 4095$. In Figure 4(b), it was used a chaotic signal generated by the logistic map:

$$g_a(x) = ax(1 - x) \tag{3.4}$$

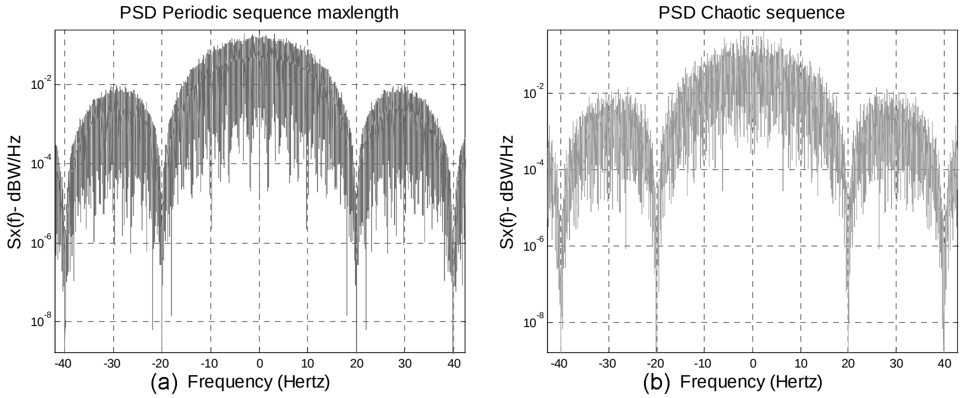


Figure 4. Spectrum of signals coded by (a) PN with $m = 12$ and (b) chaotic sequences

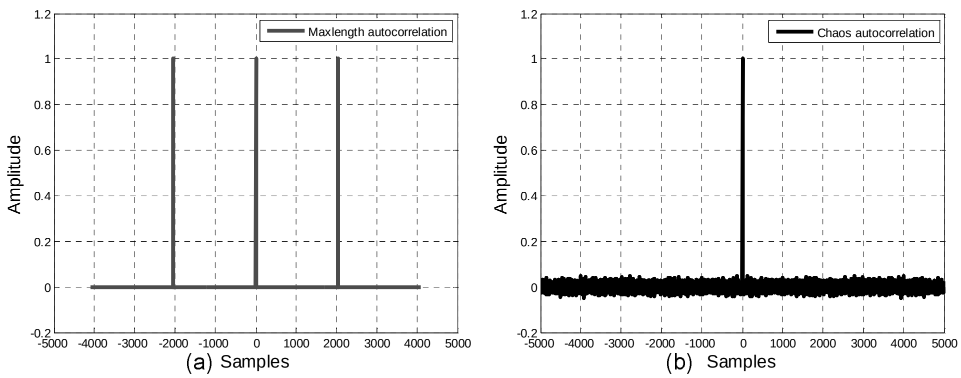


Figure 5. Autocorrelation of (a) maxlength and (b) chaotic sequences.

with initial condition 0.2, $a = 4$ and 1000 points. To use a chaotic signal as spreading code the points created by logistic map should be quantized to take $\pm 1$ values.

Figure 5 shows the respective normalized autocorrelation sequences. For PN sequences, autocorrelation assumes lower values but periodicity make periodic pulses to appear. This situation does not occur with the chaotic sequence.

## 4. Chaotic Sequence in Spread Spectrum

In this section we compare the use of PN sequences and chaotic sequences when it comes to Bit Error Rate (BER) in an Additive White Gaussian Noise (AWGN) channel.

Three SS systems were simulated varying the generation of spreading sequences: the first uses maxlength sequence with $m = 16$; the second uses chaotic sequence generated by the logistic map defined by Eq. (3.4) and the third one uses a computer generated random sequence. The same conditions were established at the transmitter and receiver. The signals were quantized and normalized to take $\pm 1$ values.

Figure 6 shows our results in addition to the theoretically expected curve [Lathi-1998]. No significant differences between the analyzed sequences were found in BER curves,

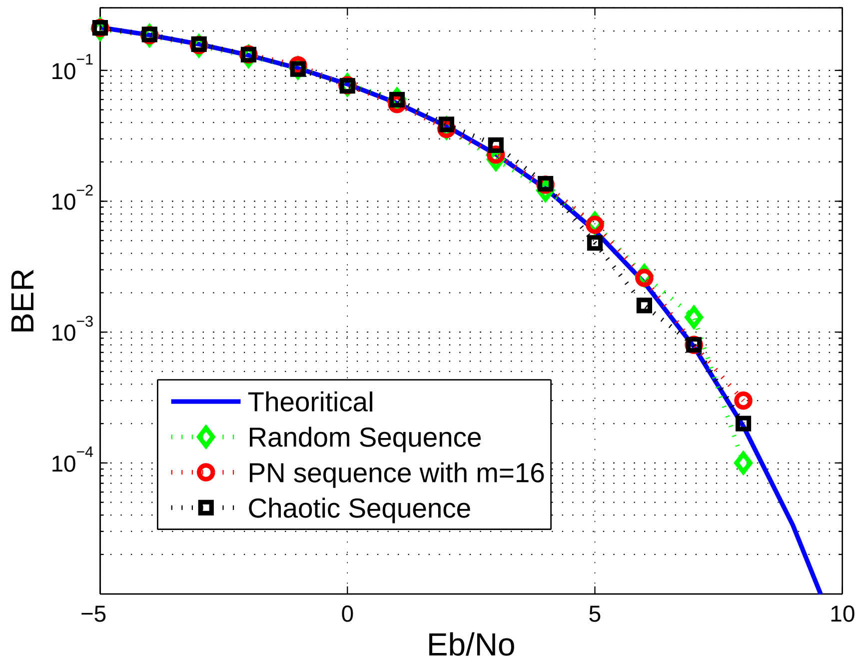


Figure 6. BER in AWGN channel for PN, chaotic and random DSSS systems

as shown in Figure 6. This happens because the channel is only AWGN and the addition of white noise equally affects the transmitted signals.

These results show that chaotic sequences can be applied as spreading code, but another channels with different interferences must be simulated. Chaotic spreading code system must to be analyze face interference from multi-user and multi-path.

## 5. Conclusion

Chaotic sequences present broadband and noise-like properties. This features show that chaotic sequences can be applied in Telecommunication systems where PN sequences are used as spreading code.

The presented results were obtained on AWGN channel. In this scenario chaos and PN sequence perform identically in terms of BER. However, the generation of chaotic sequences is simpler than maxlength sequences, because chaotic sequences is not limited by the number of registers.

In continuity with this work we are studying the behavior of SS by chaotic spreading code in multi-user and multi-path channel [Sklar-2001, Li-1995].The goal is to compare the performance of sequences analyzed in these environments.

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