Orthogonal Chaotic Sequence for Use in Wireless Channels

Anamika Sarma, Kandarpa Kumar Sarma, Nikos Mastorakis

Abstract— Chaotic sequences are effectively used for secure communication. Generation of chaotic sequences continues to be an evolving area. Recently, stress has been given to the generation of orthogonal chaotic codes. In this paper, a chaotic spreading sequence based direct sequence/spread spectrum (DSSS) communication system is proposed. Here, a logistic map is used for generation of chaotic sequences used as a spreading factor in a DSSS system in Rayleigh fading channel. We discuss a method to make the chaotic code orthogonal to mitigate several disadvantages of the channel. The paper also includes a detail explanation of all the experimental work done in order to use orthogonal chaotic code as a spreading factor in various channels and related results and discussion. The bit-error rate (BER) and symbol error rate (SER) of the proposed system is compared with Gold code. Results show that the proposed system has a significant improvement in BER and SER. The mutual information, autocorrelation function and computational time of the system are also analyzed.

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Keywords— **Logistic map, Chaotic code, Orthogonal code, Gold code, DSSS, Rayleigh fading**

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I. INTRODUCTION

All the conventional wireless communication methods based on spread spectrum (SS) principle relies upon an efficient generation of spreading sequences for use in faded channels. In frequency domain, several communication methods use spreading techniques to expand the bandwidth of the system much more than it actually requires. These methods are called spread spectrum (SS) communication systems. These are used for a variety of reasons, such as the establishment of secure communications, increasing protection against interference etc. There are several SS communication schemes. One of them is to use SS system with direct sequence (DS) approach. In this technique, the transmitted binary data is directly multiplied with orthogonal (or nearly orthogonal) spreading sequences [1], [2], [3]. Multiplication has a significant effect on the transmitted signal as it spreads the baseband bandwidth of the signal. Similarly, the received data signal is multiplied with same set of sequences for correct reception. Nowadays, the most commonly used spreading sequences in DSSS communication systems are pseudo-noise (PN) sequences such as m and Gold sequences. It is evident that they have proper correlation properties. But, they can be reconstructed by linear regression methods and hence, they are not preferable for secure communications [1], [2]. Hence, it is suitable to replace these non-zero cross-correlation PN code with orthogonal codes. Fading related distortions like co-channel interference (CCI) can be conveniently mitigated by using orthogonal spreading codes. Most of the common spreading sequences are non-orthogonal, which fail to mitigate CCI observed during transmission. Orthogonal codes have zero cross-correlation property. Hence, these codes can mitigate interference between data streams [2], [10].

In this paper, a new DSSS communication scheme is proposed. Here, a logistic map based chaotic sequence is used as a spreading factor in a Rayleigh fading channel. In this work, a chaotic sequence is generated using logistic map and the sequence is used for spreading. The chaotic code is made orthogonal to improve the performance of the system. The chaotic sequence is made orthogonal with the help of complement of the code. The details of the method is described in Section 3. The bit error rate (BER) and symbol error rate (SER) of the proposed system is compared with conventional Gold and convolutional codes. Results show that the proposed system has a significant improvement in BER and SER. The mutual information, autocorrelation function and computational time of the system are also analyzed. This paper is organized as follows. The generation of spreading sequences and direct sequence spread spectrum methods are described in Section 2. Section 3 explains the model of the proposed orthogonal chaotic sequence generation for use in DSSS. Then, in Section 4, a detailed discussion on the experimental results is given. Section 5 discusses the conclusion of the paper.

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II. SPREADING SEQUENCE GENERATION AND SPREAD SPECTRUM

Here, we briefly discuss the fundamental concepts related to the spreading sequence generation.

A. m-Sequences and Gold Sequences

Conventional DSSS systems use the PN sequences such as m-sequences (maximum length sequences) and Gold sequences as spreading sequences. Most commonly, m sequences are bit sequences generated using maximal linear feedback shift registers. They are periodic and reproduce every binary sequence that can be represented by the shift registers i.e., for length-m registers they produce a sequence of length 2^m-1. An m-sequence is also sometimes called an n-sequence or an maximum length sequence (MLS). M-sequences are spectrally flat, with the exception of a near-zero DC term [1], [10]. The generation of m-sequence is more distinct in Figure 1.

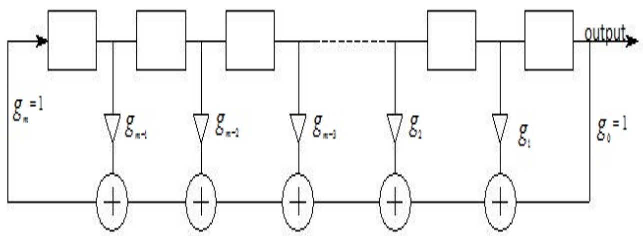

Figure 1: Generation of m-sequence using maximal linear feedback shift register

Practical applications for m-sequences include measuring impulse responses. They are also used as a basis for deriving pseudo-random sequences in digital communication systems that employ DSSS and frequency-hopping (FH) spread spectrum transmission systems. m-sequences are inexpensive to implement in hardware or software, and relatively low-order feedback shift registers can generate long sequences; a sequence generated using a shift register of length 20 is 2^20-1 samples long. There are several important properties of m-sequences such as Balance property, Run property, Correlation property etc. Balance property indicates that the occurrence of 0 and 1 in the sequence should be approximately the same. The autocorrelation function of an m-sequence is a very close approximation to a train of delta function [2].

A Gold sequence is a type of binary sequence, used in telecommunication (CDMA) and satellite navigation (GPS). Gold codes are named after Robert Gold. Gold codes have bounded small cross-correlations within a set, which is useful when multiple devices are broadcasting in the same frequency range. A set of Gold code sequences consists of 2^N-1 sequences each one with a period of 2^N-1 [1]. Gold sequences can be generated by linear combination of two m-sequences; but the condition is that they must have same degree. All pairs of m-sequences cannot be used to generate Gold codes. Those which can generate Gold codes are called preferred pairs [1], [2]. The generation of Gold code is shown in Figure 2.

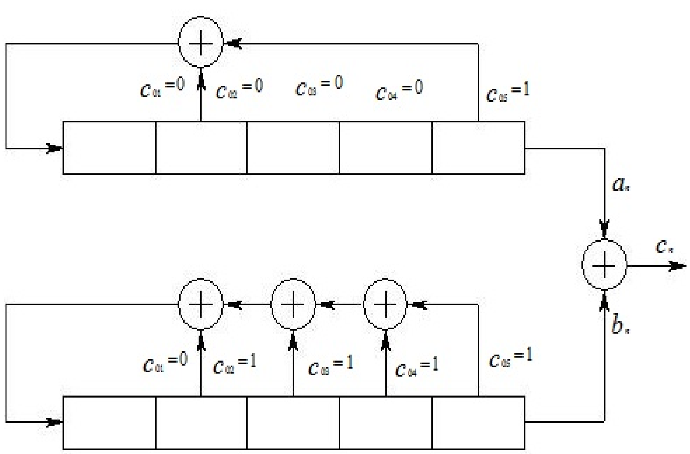

Figure- 2: Gold sequence generator

The xor of two different Gold codes from the same set is another Gold code in some phase. Within a set of Gold codes about half of the codes are balanced the number of ones and zeros differs by only one. Other sequences like Walsh sequences, Kasami sequences etc. can also be used as spreading sequences [5].

B. Design of Spreading Sequence with Logistic Map

Logistic map is used to generate a chaotic sequence. The logistic map is a polynomial mapping of degree 2. It produces chaotic behavior from simple non linear dynamical equation. Mathematically, a logistic map can be expressed as-

$$x(n+1) = r * x(n) * (1 - x(n)) \qquad (1)$$

where, $x(n)$ is a number between zero and one, and represents the ratio of existing population to the maximum possible population at year n. Hence, $x(o)$ represents the initial ratio of population to maximum population (at year 0). Further, r is a positive number, and represents a combined rate for reproduction and starvation.

By varying the parameter r, the following behavior is observed [1], [2]:

- With r between 0 and 1, the population will eventually die, independent of the initial population.
- With r between 1 and 2, the population will quickly approach the value $r - 1/r$, independent of the initial population.
- With r between 2 and 3, the population will also eventually approach the same value $r - 1/r$, but first will fluctuate around that value for some time. The rate of convergence is linear, except for r=3, when it is dramatically slow, less than linear.
- With r between 3 and 3.44949), from almost all initial conditions the population will approach permanent oscillations between two values. These two values are dependent on r.
- With r between 3.44949 and 3.54409 (approximately), from almost all initial conditions
the population will approach permanent oscillations among four values.
- With r increasing beyond 3.54409, from almost all initial conditions the population will approach oscillations among 8 values, then 16, 32, etc. The lengths of the parameter intervals which yield oscillations of a given length decrease rapidly.
- At r approximately equal to 3.56995 chaos behavior is observed. From almost all initial conditions, we can no longer see any oscillations of finite period. There is a little variation in the initial population and it shows huge variation in results over a specific time. It is a specific characteristic of chaos.
- Most values beyond 3.56995 exhibit chaotic behavior, but there are still certain isolated ranges of r that show non chaotic behavior. These are called islands of stability.
- The development of the chaotic behavior of the logistic sequence as the parameter r varies from approximately 3.56995 to approximately 3.82843 is sometimes called the Pomeau- Manneville scenario.

The simplicity of logistic map makes it an excellent method to generate chaotic sequences.

Chaotic systems exhibit a great sensitivity to initial conditions, a property of the logistic map for most values of r

between about 3.57995 and 4 (as noted above). A common source of such sensitivity to initial conditions is that the map represents a repeated folding and stretching of the space on which it is defined. In the case of the logistic map, the quadratic difference eq. (1) describing it may be thought of as a stretching-and-folding operation on the interval (0, 1) [1], [2].

C. Spread Spectrum Modulation

In telecommunications, spread spectrum is a technique in which a signal is transmitted on a bandwidth much more than the frequency content of the original information.There are two main principles of spread spectrum modulation namely direct- sequence and frequency hopping techniques. In a DSSS technique, the bandwidth of an information signal is widened by the use of modulation. Specifically, a data sequence is used to modulate a wide-band PN sequence by applying these two sequences to a product modulator or multiplier as shown in Figure 3. The PN sequence performs the role of a spreading code. By multiplying the information signal with the spreading code, each information bit is divided into a number of mall time increments. These small time increments are called as chips [2].

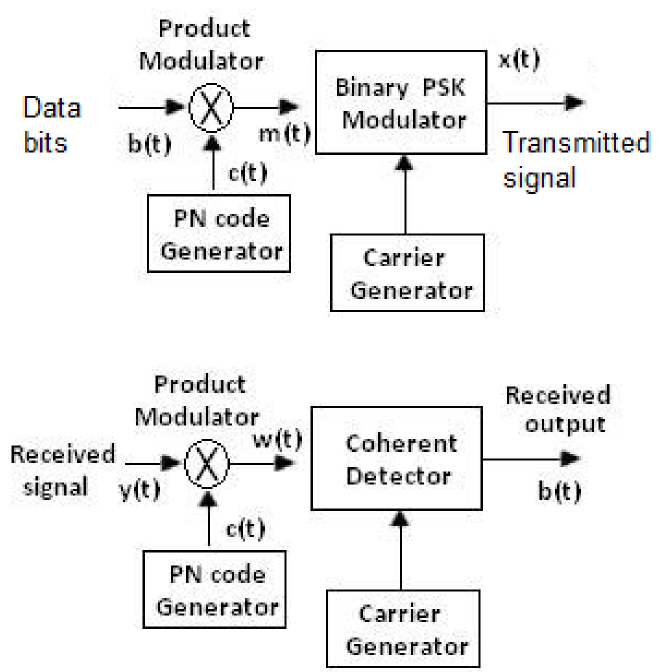

Figure 3: Model of DSSS binary PSK system

Mathematically, received signal can be expressed as-

$$y(t) = x(t) + j(t)$$
$$= c(t)s(t) + j(t)$$

where, $s(t)$ is the BPSK signal, and $c(t)$ is the PN sequence.

In the receiver, the input is given

$$u(t) = c(t)y(t)$$
$$= c^2(t)s(t) + c(t)j(t)$$
$$= s(t) + c(t)j(t)$$

For convenience, PN sequence is expressed as-

$$c^2(t) = 1 \; for \; all \; t$$
$$c(t) = \pm 1$$

Frequency-hopping spread spectrum (FHSS) is a method of transmitting signals by rapidly switching a carrier among many frequency channels, using a PN sequence known to both transmitter and receiver [2]. Figure 4 shows the block diagram of an FH/MFSK system. First the incoming binary data are applied to an M-ary FSK modulator. The resulting modulated wave and the output from a digital frequency synthesizer are then applied to a mixer. The frequency synthesizer is driven by the PN sequence, which enables the carrier frequency to hop. In the receiver side, the frequency hopping is first removed by mixing the received signal with output of frequency synthesizer. The resulting output is finally demodulated. The chip rate, R_c, for an FH/MFSK system is defined by-

$$R_c = \max(R_h, R_s)$$

where, R_h is the hope rate and R_s is the symbol rate.

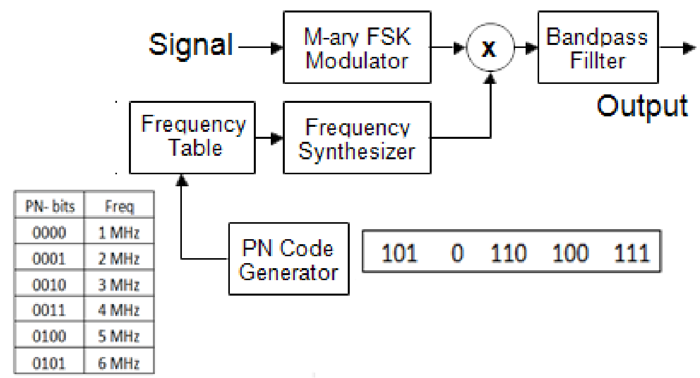

Figure 4: Model of FHSS M-ary FSK system

III. PROPOSED MODEL FOR ORTHOGONAL CHAOTIC SEQUENCE GENERATION FOR USE IN DSSS

Here, we briefly describe the design and working of the proposed orthogonal chaotic sequence generation approach for application is wireless channels.

Figure 5 shows the block diagram of the orthogonal chaotic sequence based BPSK modulation system in a Rayleigh fading channel. At transmitter side, first the data is generated from a random source. A random source can produce a series of ones and zeros. Modulation scheme used to map the bits to symbols in this work is BPSK or QPSK. The modulated data is spreaded by a chaotic code in the transmitter side. Chaotic code is generated using logistic map and the code is made is made orthogonal as described in Section 2. Thus a new chaotic sample is generated. Next, the signal is passed through a channel which has Rayleigh fading characteristics. AWGN noise is added to the signal. The final step of the communication system is the received signal. The received signal is first de-spreaded using a replica of the chaotic signal used at the transmitter side of the system. The received signal is demodulated using BPSK or QPSK demodulator. Finally, BER is calculated between the transmitted and received bits. Performance measures are expressed in terms of BER, SER, mutual information, computational time and autocorrelation function. The simulation parameters are given in Table 1. A key aspect observed in this work is the use of logistic map based chaotic sequence generator which is a simple and efficient approach for obtaining spreading streams.

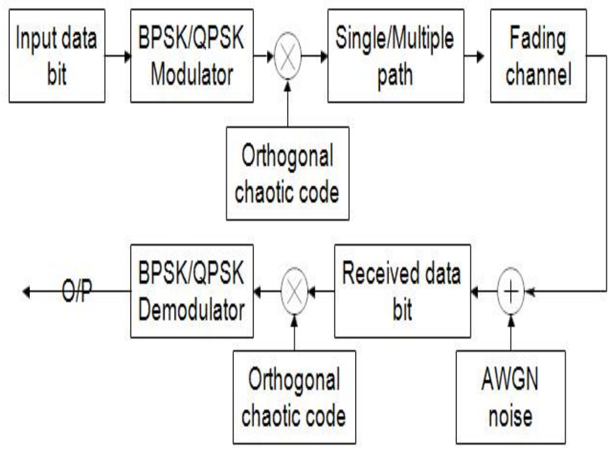

Figure 5: System model for orthogonal chaotic sequence based DSSS modulation

Table 1: Simulation Parameters

Sl.No.	Ietm	Description
1	Data Block	1000 to 10000 bits
2	Modulation Types	BPSK, QPSK
3	Access Type	DSSS
4	Chaotic Sequence length	1000 to 10000
5	Channel Type	Rayleigh, AWGN
6	Diversity Configurations	MISO, MIMO
7	Antenna Configurations	2x1, 2x2

The sequence is made orthogonal for improving the performance. The process logic of generating the logistic sequence is shown in Figure 6. Initially, we take r=3.56995, which is the value that generates chaotic behavior. We specify certain initial conditions and use the logistic map eq. (1) to generate chaotic sequences. The sequence length depends upon the number of iterations completed by the generation process as shown in Figure 6. The generated sequence is converted to binary sequence and 1's complement of the binary sequence is calculated. Finally, both these sequences are merged and a final sequence is obtained. We have generated sequence lengths between 1000 to 10000 for application in different fading situations (Figures 7 and 8). Suppose, we take a random code as 10110. Distinctly, this code is not orthogonal. We take the 1's complement of the code and it is given as 01001. Now, if we make a code merging these two codes, it will be 1011001001 and this code can be said to be an orthogonal code. In the same way the chaotic sequence is also made orthogonal. The chaotic sequence generated using equation (1) is converted to binary sequence. The complement of the binary chaotic sequence is calculated and with the help of the complement, the chaotic sequence is made orthogonal.

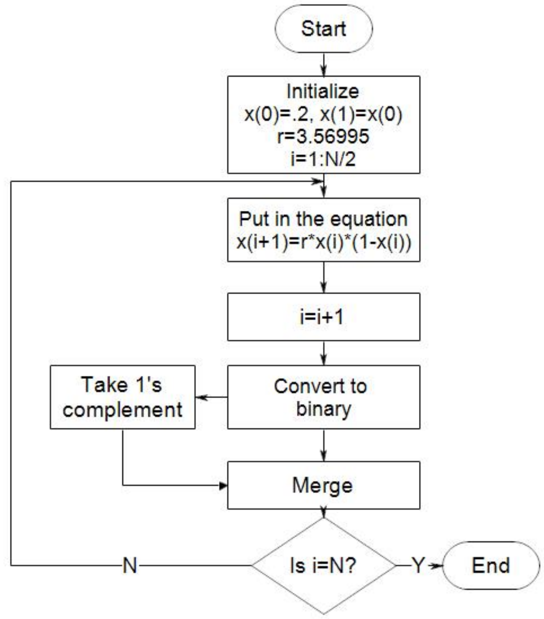

Figure 6: Flowchart for generation of orthogonal chaotic sequence

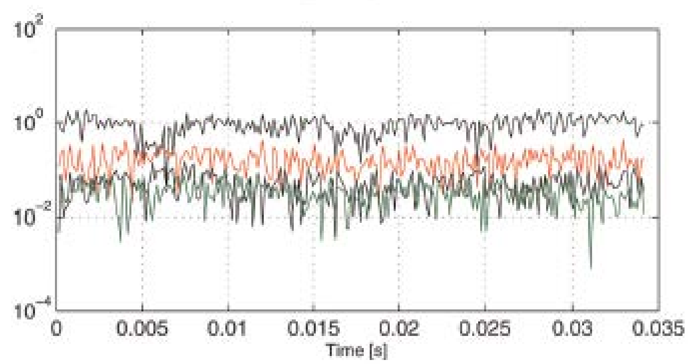

Figure 7: ITU pedestrian channel state considered with Rayleigh fading in a city area

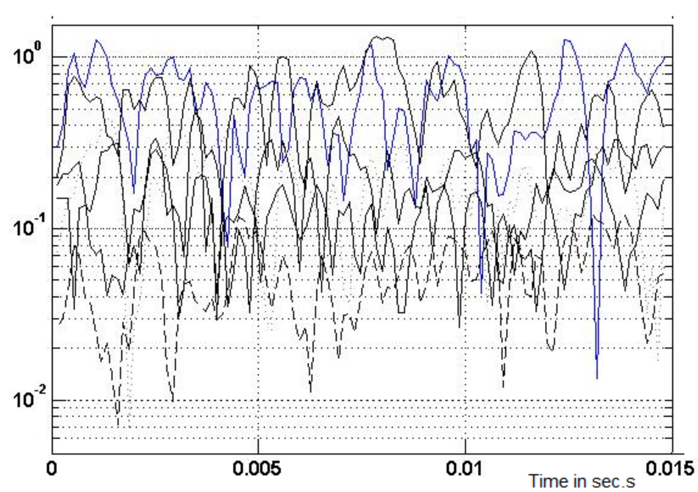

Figure 8: ITU vehicular channel with Rayleigh fading in a city area (40-60kmph)

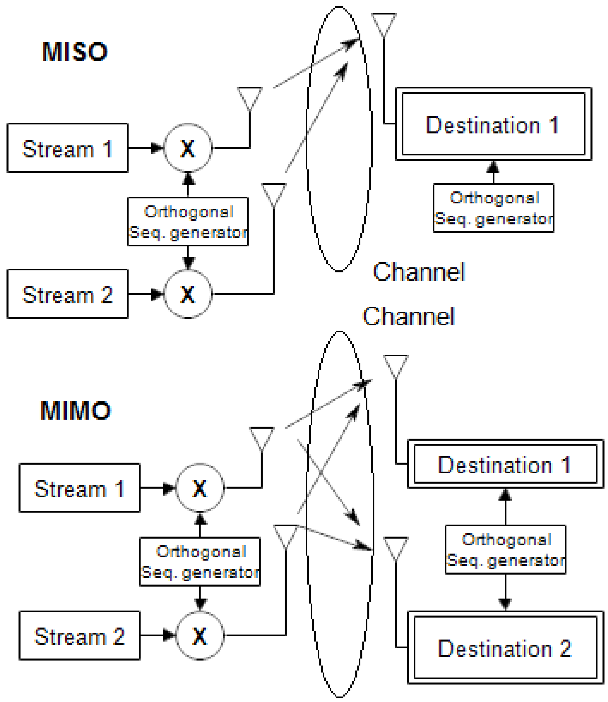

Figure 9: Experimental Set-up

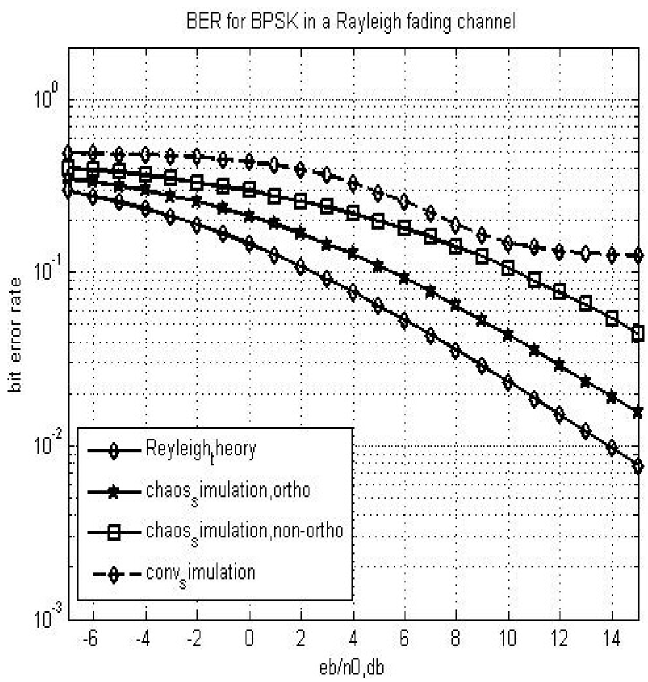

Figure 10: BER comparison curve for orthogonal and non-orthogonal chaotic codes with convolutional codes in a Rayleigh fading channel

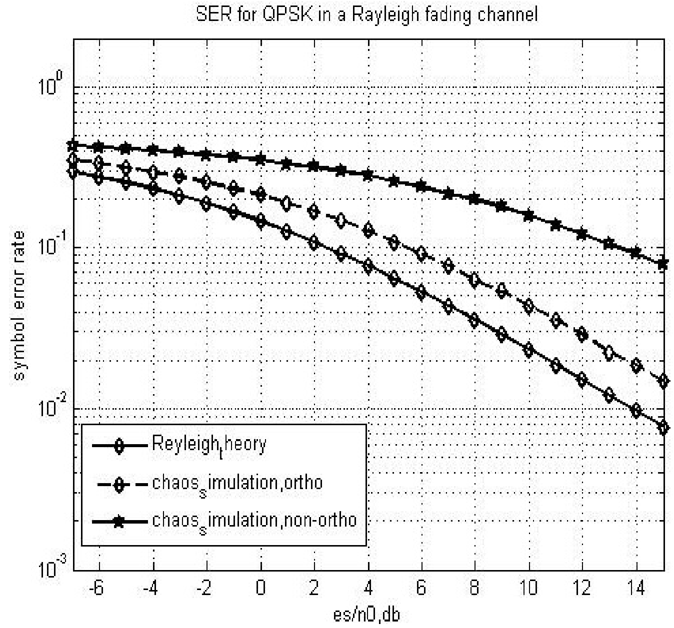

Figure 11: SER comparison curve for orthogonal and non-orthogonal chaotic codes in a Rayleigh fading channel

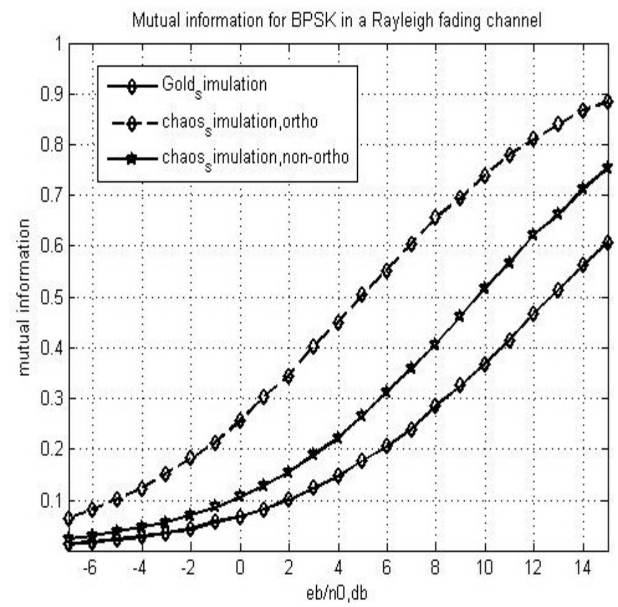

Figure 12: Mutual information comparison curve for orthogonal and non-orthogonal chaotic code in a Rayleigh fading channel

IV. EXPERIEMNTAL DETAILS AND RESULTS

A set-up as shown in Figure 9 is used to perform the experiments. The considerations include use of the proposed orthogonal chaotic codes of different lengths, used with BPSK and QPSK signal in Gaussian and Rayleigh faded channels. The fading conditions further includes specific conditions as outlined by ITU pedestrian (Figure 7) and ITU vehicular channels (Figure 8). Signal to noise ratio (SNR) variations -10 to 20 dB are considered with channel noise variations confined to -3dB to +3dB included in the work. Further, the results are compared with that obtain using traditional coding approaches. In most cases, bit error rate (BER) has been taken as the primary metric to ascertain the performance of the system. The BER performance of the system using chaotic code generated using logistic map is presented in Figure 10 and is compared to that obtained from theoretical considerations for BPSK. The simulated results obtained using orthogonal chaotic code is compared with a non-

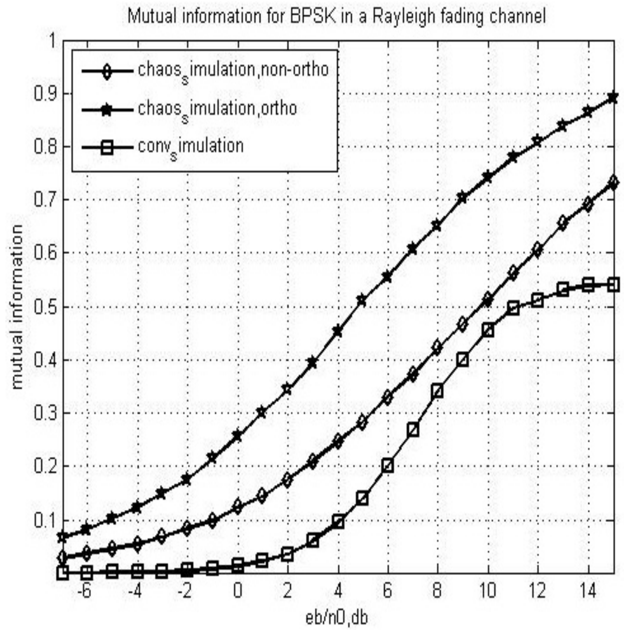

Figure 13: Mutual information comparison curve for orthogonal chaotic codes, non-orthogonal chaotic codes and convolutional codes in a Rayleigh fading channel

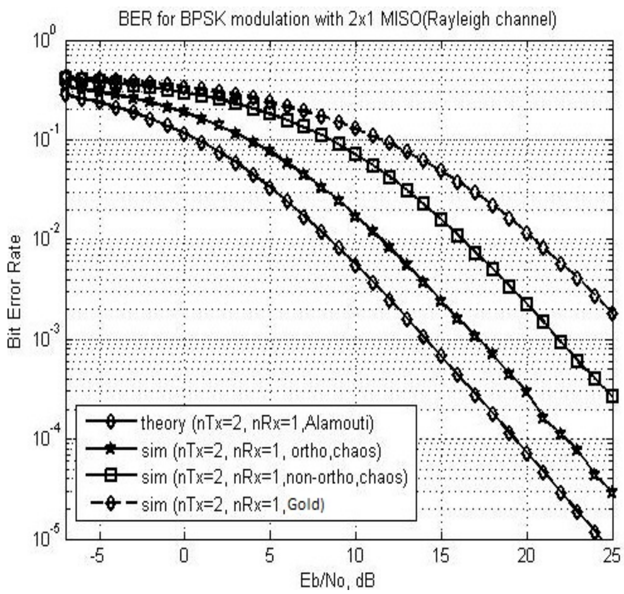

Figure 14: BER comparison for orthogonal and non-orthogonal chaotic codes in a MISO channel

orthogonal chaotic code based system. Figure 10 also shows the BER curves obtained using orthogonal chaotic and convolutional code in a Rayleigh fading channel. Figure 11 shows the symbol error rate (SER) performance to compare orthogonal chaotic code and non-orthogonal chaotic code. It is obtained from average calculations over fading conditions observed in pedestrian and vehicular channels.

The simulated results (Figures 10 and 11) show that the orthogonal chaotic code can provide better performance compared to non-orthogonal codes. At BER value of 0.02, the chaotic code provides around 10 dB gain for a sequence of

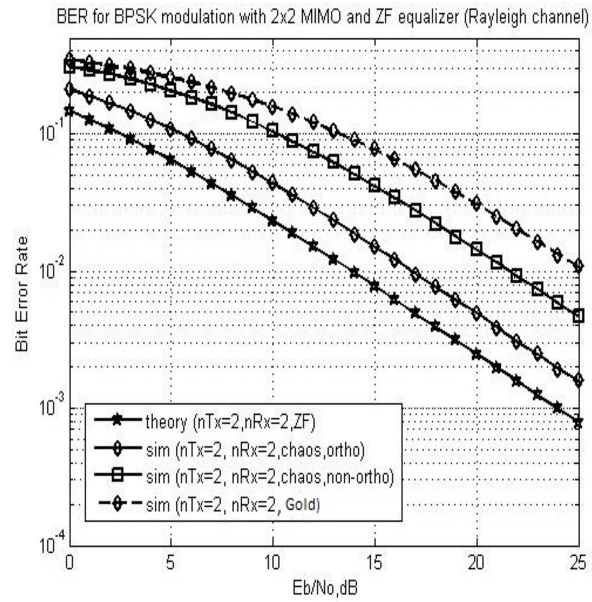

Figure 15: BER comparison for orthogonal and non-orthogonal chaotic codes in a MIMO channel

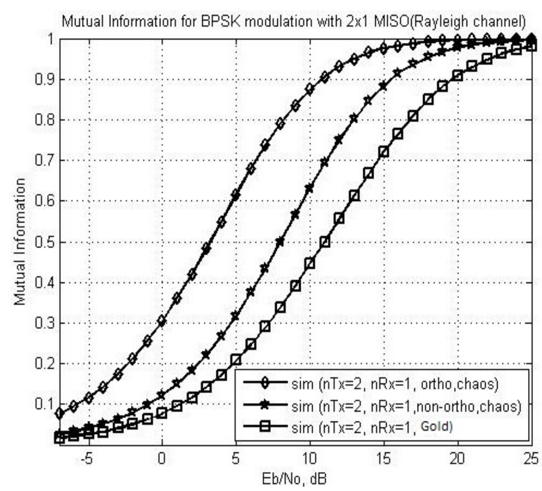

Figure 16: Mutual information comparison for orthogonal and non-orthogonal chaotic codes in a MISO channel

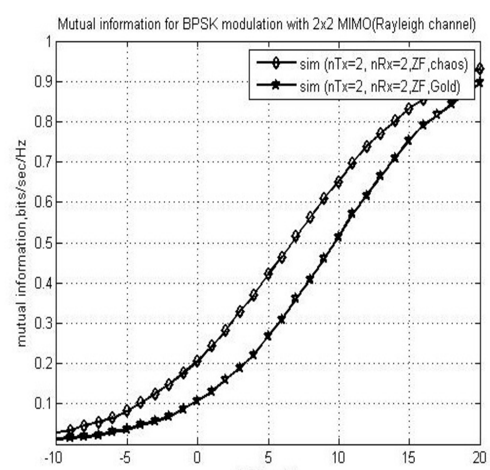

Figure 17: Mutual information comparison for MIMO

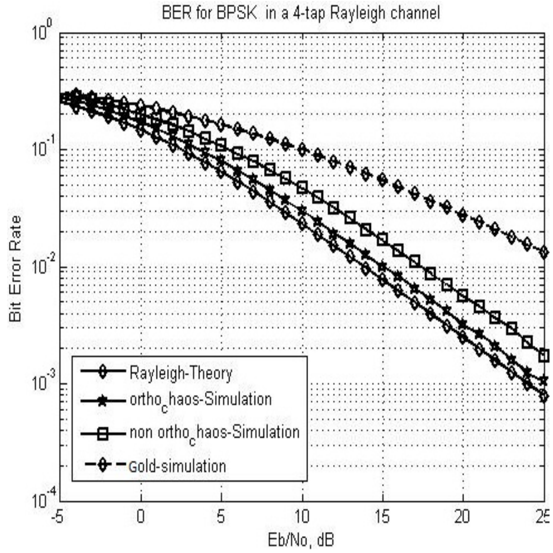

Figure 18: BER comparison for orthogonal and non-orthogonal chaotic codes in multipath channel

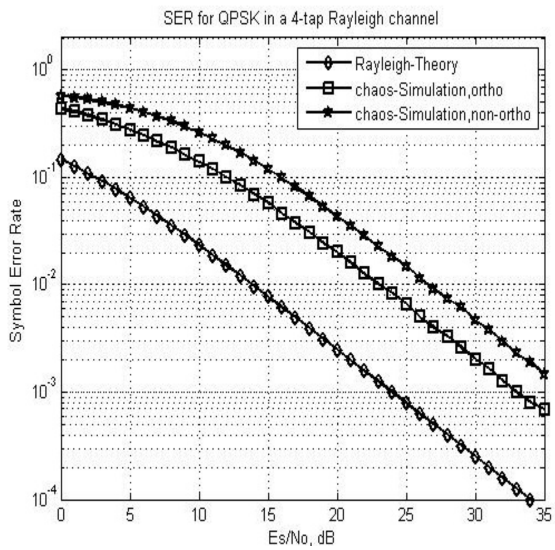

Figure 19: SER comparison for orthogonal and non-orthogonal chaotic codes in multipath channel

bits transmissions. Hence, it can be advantageous while using in wireless channels. The effectiveness of the chaotic coding is further analyzed using transmitted and recovered data sequences. The mutual information plot between these two sequences is shown in Figures 12 and 13. It reflects the channel capacity attributes related to the system. .

Next, the channel type is changed to MISO and MIMO and BER is presented in Figures 14 and 15 using MISO and MIMO channel. The simulation results show that at BER value of 0.03, the orthogonal chaotic code provides around 10dB gain for a sequence of bits transmissions in MIMO channel. Hence, in these type of channels also, orthogonal chaotic codes can perform better compared to non-orthogonal chaotic codes and Gold codes. To measure the closeness between transmitted and received data sequences the mutual information for the systems is also plotted in Figures 16 and 17.

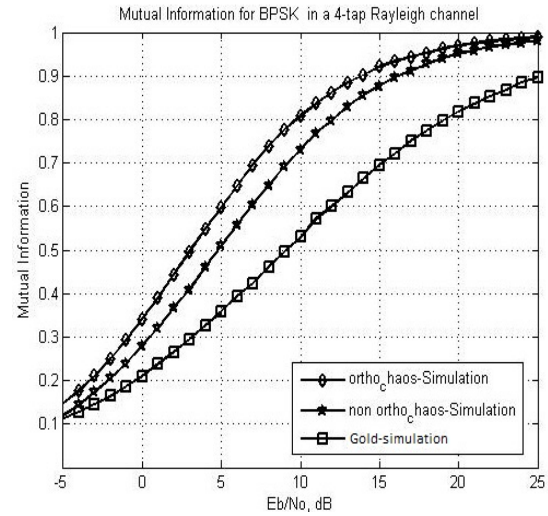

Figure 20: Mutual information comparison for orthogonal and non-orthogonal chaotic codes in multipath channel

Next, performance measures are analyzed in a multipath environment, which has Rayleigh fading characteristics. BER comparison between orthogonal chaotic code, non-orthogonal chaotic code and Gold code is presented in Figure 18. Figure 19 shows the SER performance to compare orthogonal chaotic code and non-orthogonal chaotic code in a multipath channel. The simulated results clearly indicate that orthogonal chaotic codes outperform non-orthogonal chaotic codes and Gold codes in any wireless channel. To verify the effectiveness of chaotic sequence, mutual information is plotted in Figure 20.

To measure the closeness between transmitted and received data sequences autocorrelation function for the systems is also plotted in Figures 21, 22, 23, 24 and 25. The comparative results are summarized in Table 2.

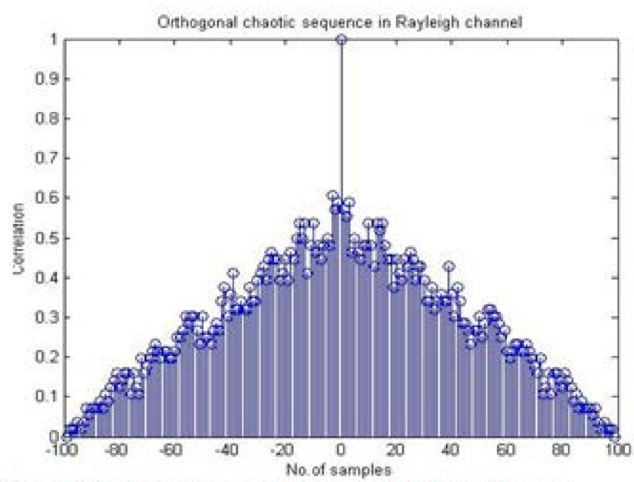

Figure 21: Autocorrelation function plot for orthogonal chaotic code

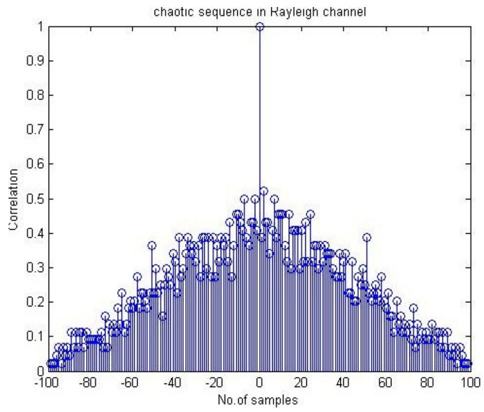

Figure 22: Autocorrelation function plot for chaotic code

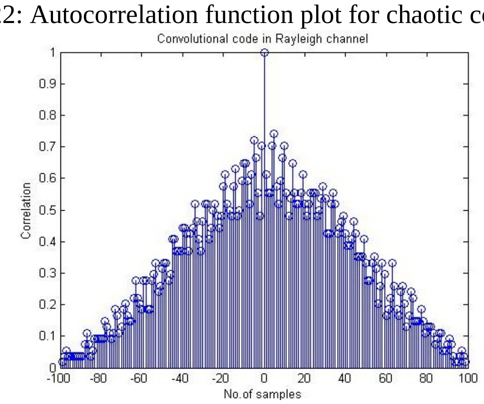

Figure 23: Autocorrelation function plot for convolutional code

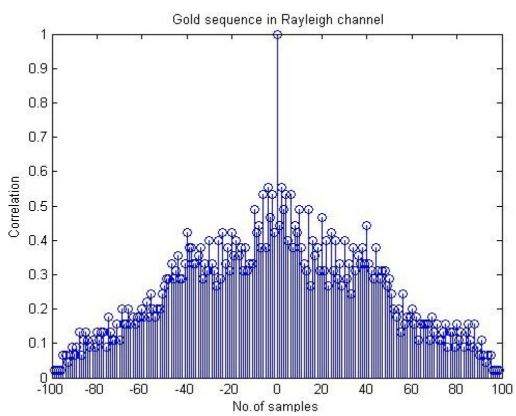

Figure 24: Autocorrelation function plot for Gold code

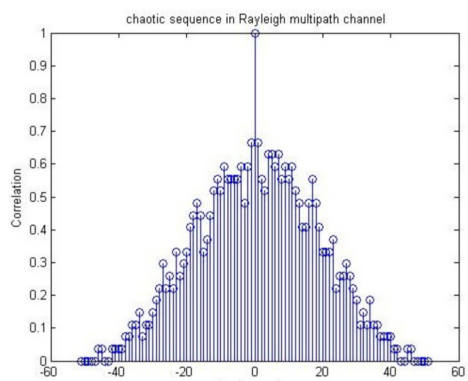

Figure 25: Autocorrelation function plot for chaotic code in Rayleigh multipath channel

Table 2: Comparative Results for Orthogonal Chaotic code and Non-Orthogonal Chaotic code

Channel Type	Parameter at 10 dB	Proposed code	Chaotic Code
AWGN	BER	.009	.02
	Mutual information (bits/sec/Hz)	.9	.7
	Computational time (sec)	1.10	1.22
Rayleigh	BER	.02	.04
	Mutual information (bits/sec/Hz)	.7	.6
	Computational time (sec)	1.22	2.23
MISO	BER	.04	.08
	Mutual information (bits/sec/Hz)	.9	.8
	Computational time (sec)	1.63	2.19
MIMO	BER	.02	.05
	Mutual information (bits/sec/Hz)	.9	.7
	Computational time (sec)	1.54	2.24

Table 3: Percentage variation in performance parameters

Channel Type	Parameter	% variation
AWGN	BER	Fall of 122%
	Mutual information	Rise in 22%
	Computational time	Fall of 83%
Rayleigh	BER	Fall of 100%
	Mutual information	Rise in 14.2%
	Computational time	Fall of 51.6%
Channel Type	Parameter	% variation
MISO	BER	Fall of 100%
	Mutual information	Rise in 11.1%
	Computational time	Fall of 34.3%
MIMO	BER	Fall of 150%
	Mutual information	Rise in 22%
	Computational time	Fall of 45.5%

Compared to conventional chaotic code, the proposed code provides a decrease of BER by 100 to 150% for AWGN, Rayleigh, MISO and MIMO cases. Computational time falls by atleast 34.3% and mutual information improves by minimum of 11.1%. This establishes the usefulness of the proposed approach.

V. CONCLUSION

This paper has presented the design of an orthogonal chaotic sequence based secure DSSS communication system, where an orthogonal chaotic sequence is used as a spreading sequence instead of conventional PN sequences. The performance measures of the proposed system are described and investigated by means of the theoretical analysis and numerical simulation. It can be seen from the obtained results, that the proposed system has significant improvement in performance measures compared to Gold codes and convolutional codes. The performances are investigated for several channel conditions such as Rayleigh, AWGN, MISO and MIMO. Simulated results show that the proposed can can perform better in any channel condition. In multipath channel also, it can outperform the conventional spreading codes. Hence, it can fulfill the requirements of appropriate spreading sequences in DSSS communication systems.

REFERENCES

[1] A. Sarma, K. K. Sarma, N. Matorakis, Dynamic Chaotic Approach to Sequence Generation for Use in Stochastic Wireless Channels, 5th International Conference on Circuits, Systems, Control, Signals, pp. 281-285, Salerno, Italy, 2014.

[2] K. Kashyap, K. K. Sarma, M. P. Sarma, N. Mastorakis, Generation of Orthogonal Logistic Map Sequences for Application in Wireless Channel and Implementation using Multiplierless Technique, 5th International Conference on Circuits, Systems, Control, Signals, pp. 292-296, Salerno, Italy, 2014.

[3] M. I. Youssef, M. Zahara, A. E. Emam, and M. Abd ElGhany, Chaotic Sequences Implementations on Residue Number Spread Spectrum System, International Journal of Communications, Vol.2, Issue.2, pp. 143-153, 2008.

[4] A. P. Kurian, S. Puthusserypady, and S. M. Htut, Performance Enhancement of DS/CDMA System Using Chaotic Complex Spreading Sequence, IEEE Transactions On Wireless Communications, vol. 4, no. 3, pp. 984-989, 2005.

[5] M. P. Kennedy, R. Rovatti, and G. Setti, Chaotic Electronics in Telecommunications, pp. 1495-1499, 2002.

[6] A. Abel and W. Schwarz, Chaos communications principles, schemes, and system analysis, Proc. IEEE, vol. 90, no. 5, pp. 691-710, 2002.

[7] C.K. Chen and C.L. Lin, Text Encryption using ECG Signals with Chaotic Logistic Map, 5th IEEE Conference Industrial Electronics and Applications (ICIEA), pp. 1741 -1746, Taichung, 2010.

[8] J. Ravindrababu, E. V. Krishna Rao, Performance Analysis and Comparison of Spreading Codes in Linear Multi-User Detectors for DS-CDMA System, WSEAS Transactions on Communications, Vol.11, Issue.11, pp.427-436, 2012.

[9] T. Li, D. Zhao, Z. Huang S. Su, C. Liu and Z. Zuo, Breaking Chaotic Direct Sequence Spreading Spectrum Signals Under the Multipath Fading Channel, Circuits System Signal Process, Newyork, pp. 973-986, 2013.

[10] A. Sarma, K. K. Sarma, N. Matorakis, Orthogonal Chaotic Sequence Generation for a Class of Stochastic Wireless Channels, International Conference on Applied Mathematics, Computational Science and Engineering, pp. 369-379, Varna, Bulgaria, 2014.

[11] D. Swami, K. K. Sarma, Logistic Map based Spreading Sequence for Direct Sequence Spread Spectrum Modulation in Multipath Channels, Recent Advances in Circuits, Systems, Telecommunications and Control, 4th European Conference on Recent advances in circuits, systems, telecommunications and control, pp. 260-265, 2013.

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