SUBOPTIMAL DETECTION OF MODIFIED LOGISTIC MAP-BASED CHAOS SHIFT KEYING MODULATION

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In this paper, a noncoherent chaotic shift keying with suboptimal recovery scheme is designed. The scheme uses a nonlinear chaotic map and its inverse for generating the chaotic sequence. The selection between two maps depends on the value of the input data bit. The suboptimal receiver decodes the received sequence for bit "1" or "0" by calculating the shortest distance between the sequence and the trajectory of the chaotic maps. The standard logistic map is first used for generating the chaotic sequence of length N samples per data bit. Then a modified logistic map is proposed to increase the reliability of signal in noisy channels. The results show that the suboptimal detection based on modified logistic map over perform the one based on classical logistic map. The results also show that the detection performance is improved as N increased.

Keywords: chaotic map, suboptimal receiver, non coherent detection, channel coding

1. Introduction

The principle objective of any digital communication system is to ensure that the data are transmitted without errors. Detection and correction are methods of detecting and correcting errors to guarantee that the information's are transmitted intact from its source to final destination successfully across noisy channel [1]. All Error Correcting Codes (ECC) are based on one fundamental idea: extra bits (redundancy bits) are added to the messages, in order to detect and correct any errors that may occur on the data transmitted, in the process of transmission or storage [2]. A lot of consideration has been paid to chaos in the previous years from various researchers, including mathematicians, physicists, and engineers [3]. In recent years, the research has been exchanging from finding the confirmation of chaos presence into applications and significant hypothetical study [4]. Chaotic sequences can be generated from a particular class of different maps, and they all have the same properties: nonperiodic, susceptible to initial conditions, and it is difficult to predict their future behavior from past observations [5].

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Chaos based communication systems are one of essential topics in the field of engineering chaos. Chaos based communication system can be classified into two classes as coherent and noncoherent based detection. In coherent, synchronization is required at receiver while noncoherent doesn’t require synchronization between the transmitter and chaotic receiver sequences [6]. Many researchers have concentrated on the improvement of noncoherent detection, which does not need to use basis signals (unmodulated carriers) for demodulation at a receiver since the chaotic sequences must have a unique feature itself. Therefore, the noncoherent detection considered as a special detection method using chaos. Differential chaos shift keying (DCSK) and the optimal receiver are renowned exemplary noncoherent systems [7]. Schimming and Hasler [8] proposed an optimal detection, and it is renowned as a noncoherent receiver. However, if the chaotic sequence length becomes very long, the calculation at receiver for signal detection becomes very complicated [9]. Suboptimal detection methods are proposed by Arai *et al*. [10]. It is based on calculating the distance between receiving signals and chaotic tent map for detecting symbols instead of the probability density function (PDF). The performance of suboptimal detection is further improved later through the use of nonlinear logistic chaotic map [11].

In this work, a suboptimal receiver with a new algorithm is designed to achieve chaos based non-coherent modulation. A non-linear equation is used to generate the chaos signal while its tangent is calculated for detection purpose. The detection decision is based on calculating the distance from the received point to the shortest tangent point. Bit detection based on the modified logistic map is used to improve system performance in noisy channels.

2. The system structure

The block diagram of the chaotic shift keying with the suboptimal receiver system is shown in Fig. 1. The transmitter side uses one out of two possible chaotic maps for modulating the input data. The map used to modulate the input data is selected depending on the value of input bit "1" or "0". The modulated data are encoded during the modulation process simultaneously by creating a statistical relation between each two sequential chaotic signals corresponds to the two sequential data bits. This process gives the receiver an additional feature to recover data and determine the initial value of each sequence.

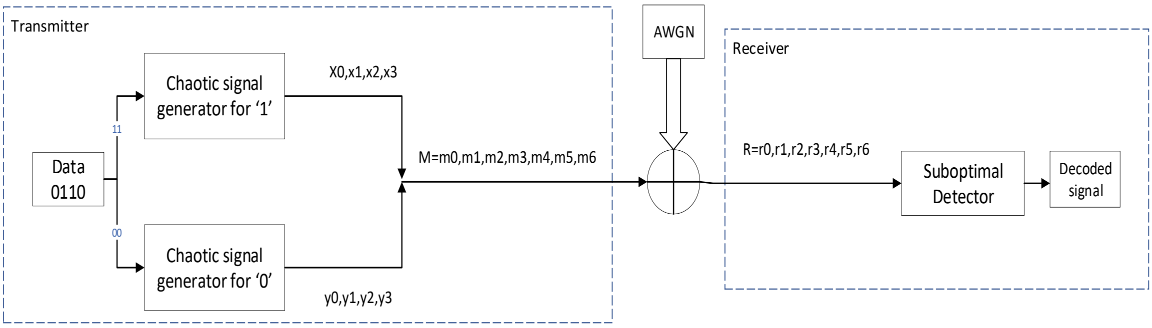


Fig. 1. The chaotic shift keying with the suboptimal receiver system

The suboptimal detector at the receiver side is used to calculate the distance from the received signal to the two chaotic maps used by the transmitter in light of the dynamics of statistically related chaotic signals. The decoder will decide the received signal is "0" or "1" depending on the distance calculated by the suboptimal detector and identify the minimum value of distance. It analyzes the measurable relations between each of the two successive sequences for incoming data.

3. The Mathematical Model of the System

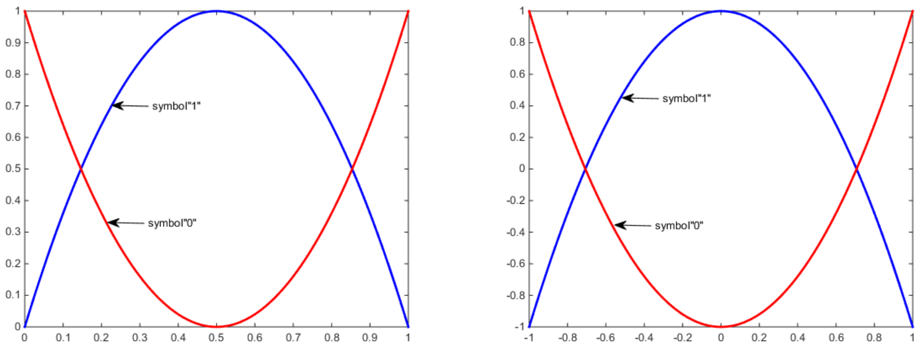
A Traditional Logistic Map (TLM) given in equation (1) is used to generate the chaotic sequence with a view to encode the input binary data.

$$X_{n+1} = a\,X_n\,(1 - X_n) \qquad 0 \leq X \leq 1 \tag{1}$$

Where $0 < a \leq 4$ is called control parameter of the system, and x_n is between 0 and 1. TLM has an extensive variety of behaviors, from stationary when a is near to 0, to chaotic when a is near to 4. If a between 3.57 and 4, then the TLM will be in chaos state, which means it has all the properties of a chaotic map. Otherwise, (for instant when $a = 3.55$), it will show non-chaotic behavior. The modified logistic map is proposed as given in equation (2) to increase the effectiveness of the system in the noisy channel. The trajectory of the modified logistic map is between (1,-1) while the TLM is between (0, 1), therefore; the trajectory of the modified logistic map is better than the TLM, and this gives a new feature for the detection system.

$$X_{n+1} = -a\left(\frac{x_n^2}{2} - 0.25\right) \qquad -1 \leq X \leq 1 \tag{2}$$

where a is also the control parameter of this map. It is a positive real constant which has the same bounds of the original logistic map. The modulation is achieved using two sequences, each with a different map. The transmitter selects between the two maps depending on the value of data symbols. When symbol "1" is sent, the chaotic sequence is generated using equation (1) in case of using TLM, and equation (2) if the modified logistic map is used. When symbol "0" is sent, the sequence is generated by the reverse of equations (1) and (2) as shown in fig.2.



(a) (b)

Fig. 2. (a) Traditional logistic map (b) Modified logistic map

4. The transmission algorithm with noisy channel

Fig.3 shows the encoding structure of CSK. When K bits are transmitted through a noisy channel, the transmitter generates N chaotic sequence for each bit from the same chaotic map. Therefore, the length of the overall sequence becomes equal to $K\times N$. The initial value is selected randomly at the beginning for the first symbol "1" (x_0) and "0" (y_0) in the stream of data bits. Afterward, the initial value of sequence for the next symbol "1" and "0" will be taken from the end value of the previous sequence. For example, assuming $N = 2$ and $K = 4$, at first the initial value for symbol "1" (x_0) and (y_0) for symbol "0" are randomly chosen and the data bits are 0110. Fig.3 shows the modulated signal vector M which is given as follows:

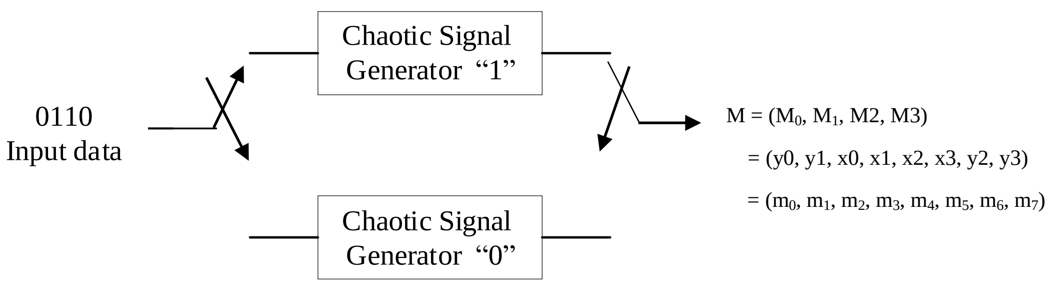


Fig. 3 Encoder based on CSK

$M= (M_0, M_1, M_2, M_3)$

$= (y_0, y_1, x_0, x_1, x_2, x_3, y_2, y_3)$

$= (m_0, m_1, m_2, m_3, m_4, m_5, m_6, m_7)$

where y_2 has the same value of y_1 and also x_2 has the same value of x_1

The signal is transmitted through additive white Gaussian (AWGN) channel with a mean of zero and a variance σ^2. The received signal is signal plus noise. Thus, the received signal block is $R = [r_0, r_1, r_2, r_3, r_4, r_5, r_6, r_7]$.

5- The Proposed Detection Algorithm

The detection of symbols is done by calculating the shortest distance between the received signal and the chaotic maps. In this work, Euclidian distances are used to determine which map is closest to the received point R. These distances are calculated by deriving the tangent equations of the nonlinear maps and then calculating the minimum distance from received point $R=(r_i,r_{i+1})$ where $i = 1, 2, 3, 4…, N–1$ to the point of the tangent. Fig.4 shows the received point and the distance to the tangent of modified logistic map function.

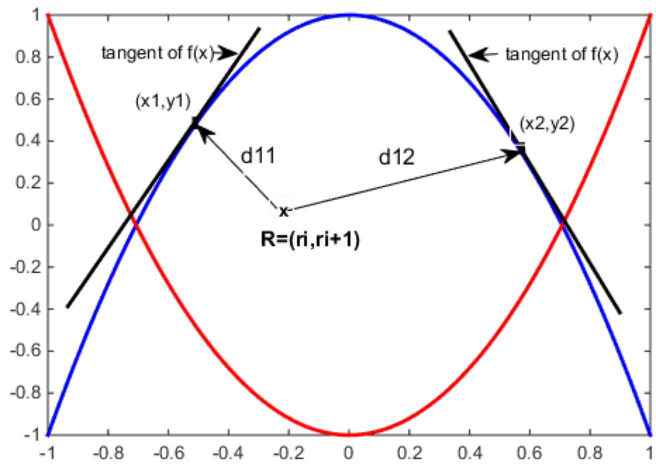


Fig. 4 The calculation of minimum distance using the tangent of the nonlinear map

From Fig. 4, the minimum distance from the received point R to the two functions of symbol "1" is calculated using the following equation:

$$d_1 = \sqrt{(x - r_1)^2 + (f(x) - r_2)^2} \quad (3)$$

where $f(x)$ is the function of the nonlinear map which is given by

$$f(x) = -a\left(\frac{x^2}{2} - 0.25\right) \tag{4}$$

where $a=4$. Removing the square root of equation (3) gives

$$d_1^2 = (x - r_1)^2 + (f(x) - r_2)^2 \tag{5}$$

Deriving the distance yields:

$$\frac{\partial (d_1)^2}{\partial x} = 16x^3 + (8r_2 - 6)x - 2r_1 \tag{6}$$

To find the roots of the equation (6), we equate it to zero

$$16x^3 + (8r_2 - 6)x - 2r_1 = 0 \tag{7}$$

Now substituting $x= (x_1, x_2, x_3)$ in equation (1) to find (y_1, y_2, y_3) and then find the minimum distance for "1". The same steps are used to find the minimum distance for "0". The suboptimal receiver calculates the cumulative distance for "1" $(\sum d_1)$ and "0" $(\sum d_0)$ For all the bits sequence. The detector decides which bit is "0" or "1" depending on the shortest distance calculated, if $\sum d_0 > \sum d_1$ the signal is decoded as "1" otherwise it is decoded as "0".

6. Simulation Results

In this work, the modified logistic map is proposed to generate the chaotic signal and suboptimal receiver for nonlinear equation is used instead of the optimal receiver. The performance of CSK modulator that uses the modified and traditional logistic maps in noisy channels is evaluated with computer simulations. The simulation conditions used at the transmitter are: $K = 32$, the control parameter $a = 4$ for both maps, and the length of the chaotic sequence per 1 bit is chosen for three cases as N=2, 3 and 4. Fig. (5) shows the bit error rate (BER) versus energy per bit over noise (E_b/N_0) for a traditional logistic map for different values of N (2, 3, and 4). It can be seen from this figure that the performance is improved when N is increased. For instance, at BER=10^{-3}, 1.2 dB gain in E_b/N_0 is obtained when N = 4 over than N=3. This improved performance is referred to the increase in the spreading factor of the chaotic signal.

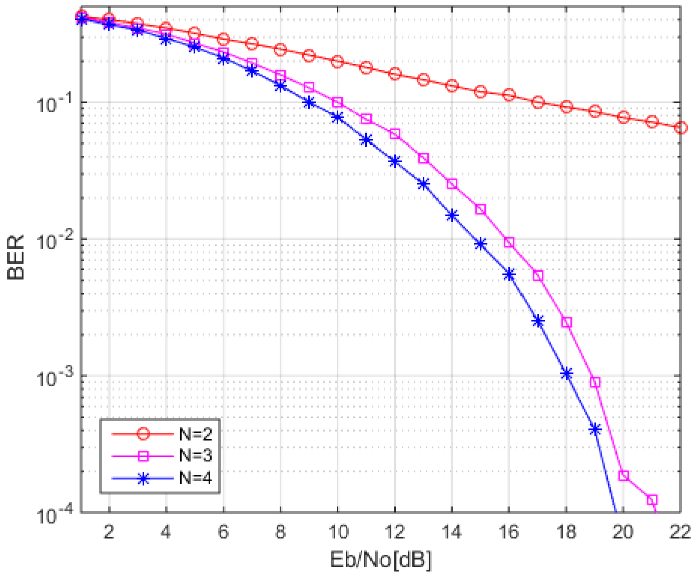


Fig. 5. BER performance for N=2,3,4 using traditional logistic map

Fig. (6) shows BER performance for TLM versus modified logistic map for N=2. At this value, although the performance of modified logistic map is better than that TLM, it falls in the poor performance range (BER>10^{-2}). So, when N=2, it is not recommended for the use in CSK modulation. Fig. (7) shows BER performance of TLM versus modified logistic map for N=3. In this case, a recognizable improvement in the performance can be seen. For instance, at BER = 10^{-3}, the modified logistic map has a gain in E_b/N_0 of 4 dB over the traditional logistic map.

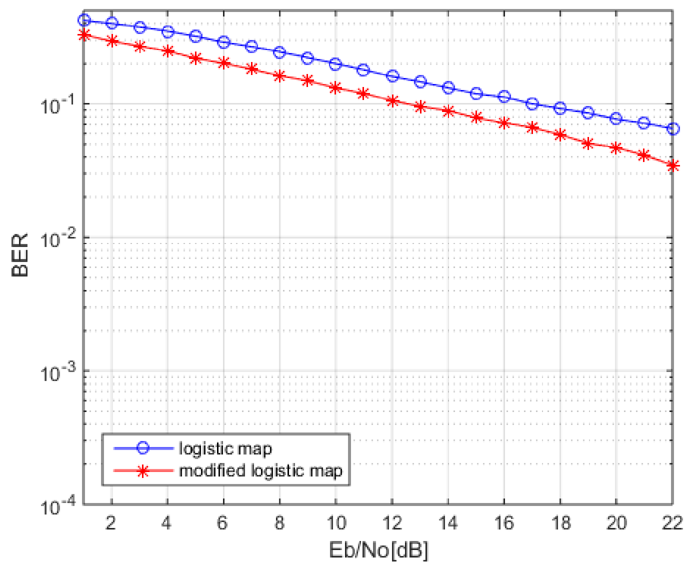


Fig. 6. BER performance for traditional and modified logistic map when N=2

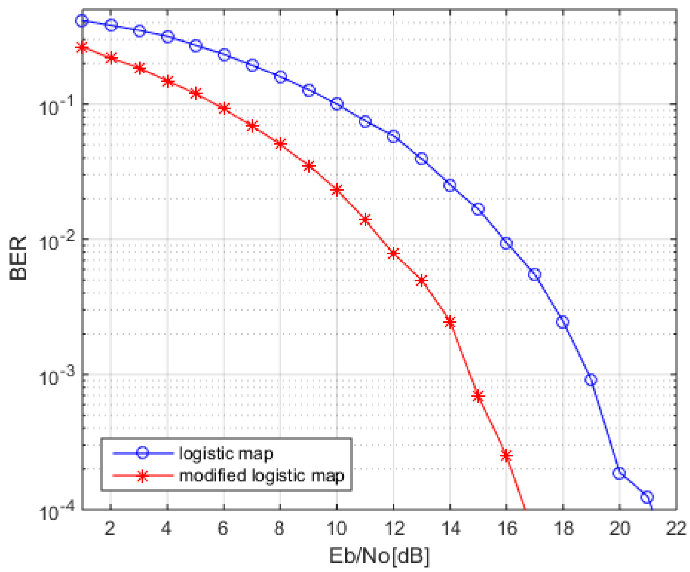


Fig. 7. BER performance for traditional and modified logistic map when N=3

Fig. (8) shows BER performance of TLM versus modified logistic map when *N*=4. Here the performance is further improved. For an instance, at BER = 10^{-3}, the gain in E_b/N_0 is 5.5 Db, using modified logistic map.

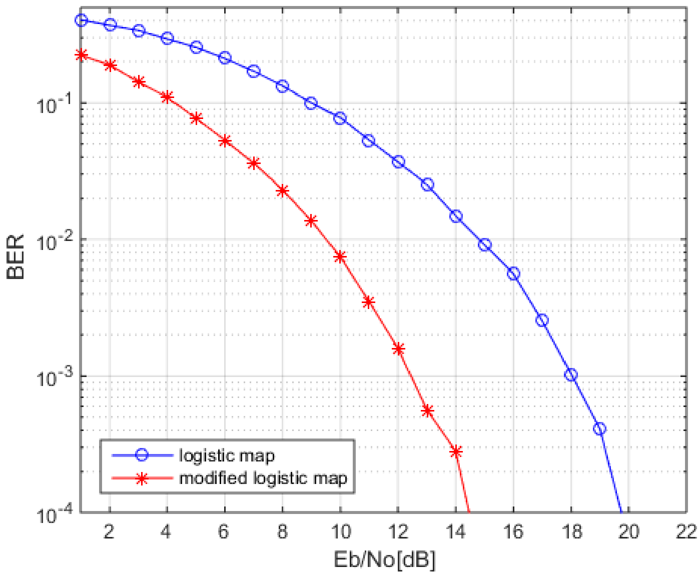


Fig. 8. BER performance for traditional and modified logistic map when N=4

7. Conclusions

Chaotic dynamics can be applied as extra information to recover the sent data correctly. The proposed suboptimal receiver with nonlinear map reduces the complexity of calculations due to the use of tangents. It also improves bit error rate of the system in noisy transmission channels. The performance of the system is better than the conventional CSK method when using the same length of sequence *N*. The complexity of CSK modulation and the reduction in bit error rate increase as the length of chaotic sequence increases, therefore; a tradeoff between complexity and length of the sequence must be considered according to performance requirements.

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