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Investigation of Noncoherent Detection using Chaotic Sequence with Biased Values

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Abstract

We investigate the chaotic sequence with biased values in chaos-based communication systems. In our previous research, we investigated the the performance of chaos communications using the sequence with biased values purposely. As results, we concluded that the chaotic dynamics affect the performance of chaos communications greatly. However, our previous study only performed the computer simulation the DCSK system using the chaotic sequence with biased values. In this study, we focus on the suboptimal receiver as one of chaos communication systems and observe its performance with the chaotic sequence with biased values.

1. Introduction

Research on digital communications systems using chaos becomes a hot topic [1]− [6]. Especially, it is attracted to develop noncoherent detection systems which do not need to recover basis signals (unmodulated carries) at the receiver. The differential chaos shift keying (DCSK) [1] and the optimal receiver [2] are well known as typical noncoherent systems. In addition, the correlation delay shift keying (CDSK) [3] similar to the DCSK scheme is also a noncoherent system.

Analyzing chaotic sequence as well as its behavior is essential for improving the the performance of chaos communications. A Chaotic sequence is a series of nonperiodic signals generated from nonlinear dynamical systems. These signals are sensitive to initial conditions and difficult to predict the behavior of the future from the past observational signals. Also a chaotic sequence can be generated from a simple model, such as a one-dimensional chaotic map. In our previous research, we investigated the the performance of chaos communications using the sequence with biased values purposely [8] [9]. As results, it could be observed that its performance was better than that of the conventional transmitter. From these results, we concluded that the chaotic dynamics affect the performance of chaos communications greatly. However, our previous study only performed the computer simulation the DCSK system using the chaotic sequence with biased values. Namely, we need to investigate the chaotic sequence with biased values in other chaos communication systems.

In this study, we focus on the suboptimal receiver as one of chaos communication systems. The suboptimal receiver is a detecting system that approximates the working of the optimal receiver using a different algorithm. We apply the chaotic sequence with biased values to the suboptimal receiver and investigate its performance.

2. System Overview

We consider the discrete-time binary CSK communication system, as shown in Fig. 1. This system consists of a transmitter, a channel and a receiver. Detail of each block is described below.

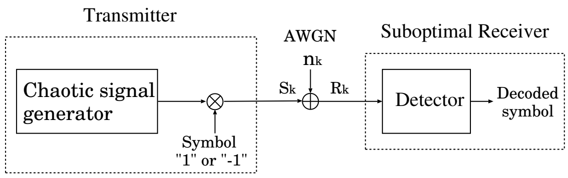


Figure 1: Block diagram of discrete-time binary CSK communication system.

2.1. Transmitter

In the transmitter, a chaotic sequence is generated by a chaotic map. Since we consider the chaotic sequence with biased values, the chaotic maps of this study has some slopes as shown in Fig. 2. This map is made from the skew tent map well known as a typical 1-dimensional map. Also, this map is described by

$$x_{k+1} = \begin{cases} \frac{(r_1+1)x_k - q_1 + r_1}{q_1+1} & (-1 \le x_k \le q_1) \\ \frac{(1-r_1)x_k - q_1 + ar_1}{a-q_1} & (q_1 < x_k \le a) \\ \frac{(r_2-1)x_k + q_2 - ar_2}{q_2-a} & (a < x_k \le q_2) \\ \frac{-(r_2+1)x_k + q_2 + r_2}{1-q_2} & (q_2 < x_k \le 1) \end{cases}, \quad (1)$$

where a denotes a position of the top of the skew tent map, q_1, r_1, q_2 and r_2 are the parameters deciding the slopes { $(-1.0 < q_1 < 0.0)$, $(-1.0 < r_1 < 1.0)$, $(0.0 < q_2 < 1.0)$, $(-1.0 < r_2 < 1.0)$ } . We can change the slopes of the map to change these parameters. An analysis of this map is taken up in Sec. 3.The transmitter can generate different chaotic sequences for every symbol by changing the initial value. The information symbol is modulated by CSK.

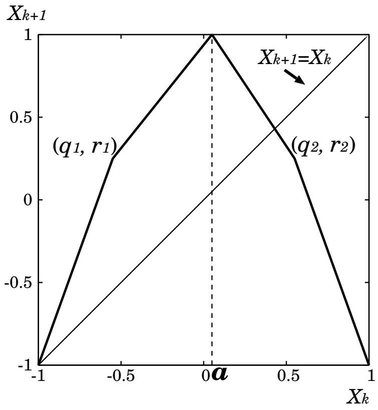


Figure 2: Chaotic map with 4 slopes.

CSK is a digital modulation system using chaos. When the transmitter generates the signal, it is used that choice of chaotic map depends on the transmitted symbol. If the information symbol “1” is sent, Eq. (1) is used, and if “0” is sent, the reversed function of Eq. (1) is used. To transmit a 1-bit information, N chaotic signal samples are generated, where N is chaotic sequence length. Therefore the transmitted signal is denoted by a vector $\mathbf{S} = (S_1\ S_2\ \cdots\ S_N)$.

2.2. Channel and Noise

We assume the additive white Gaussian noise (AWGN) channel with a mean of zero and variance of $N_0 = \sigma^2$. AWGN channel is well known as the most popular and basic channel model. Here, the noise signal is denoted by the noise vector $\mathbf{n} = (n_1\ n_2\ \cdots\ n_N)$. Thus, the received signal block is given by $\mathbf{R} = (R_1\ R_2\ \cdots\ R_N) = \mathbf{S} + \mathbf{n}$.

2.3. Suboptimal Receiver

The suboptimal receiver is a detecting system that approximates the working of the optimal receiver using a different algorithm. The receiver has the chaotic map used for the modulation at the transmitter memorized. In this study, we use the suboptimal receiver proposed by the authors [7]. Our suboptimal receiver calculate shortest distances between the received signal and the chaotic maps and performs detection of the symbol. Our suboptimal receiver calculates shortest distances between the received signal and the chaotic maps and performs detection of the symbol.

Here, we introduce the operation of our suboptimal receiver. The receiver calculates the shortest distance between received signal and the map in the N_d-dimensional space using N_d successive received signal samples (N_d : $2, 3, \cdots$). As an example, we explain the case of $N_d = 2$. Figure 3 shows the 3-dimensional space of the skew

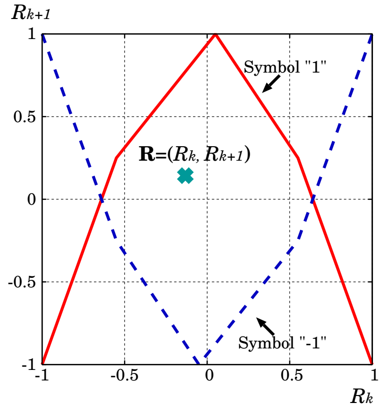


Figure 3: Detection method of our suboptimal receiver

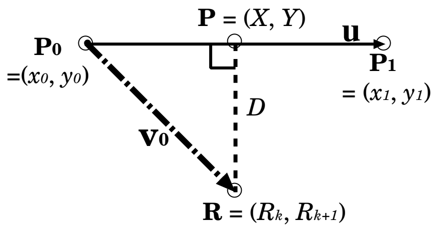


Figure 4: Calculation of the shortest distance

tent map whose coordinates correspond to the three successive received signal samples $\mathbf{R} = (R_k, R_{k+1})$ where $k = 1, 2, \cdots, N-1$. To decide which map is closer to the point $\mathbf{R}$ in the 3-dimensional space in Fig. 3, the shortest distance between the point and the map has to be calculated. Therefore, the receiver can calculate the shortest distance using the scalar product of the vector.

Any two points $\mathbf{P_0} = (x_0, y_0)$ and $\mathbf{P_1} = (x_1, y_1)$ are chosen from each straight line in the space of Fig. 3, as shown in Fig. 4.

Using Fig. 4, we can calculate the point $\mathbf{P} = (X, Y)$ closest to $\mathbf{R}$ and the shortest distance D using the following equations.

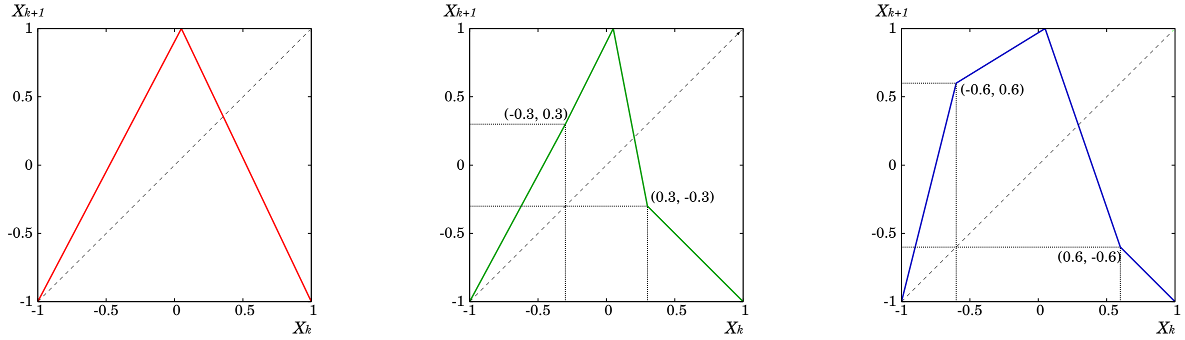
$$\mathbf{P} = (X, Y) = (\mathbf{u} \cdot \mathbf{v_0})\,\mathbf{u} + \mathbf{P_0} \tag{2}$$

$$\begin{aligned} D &= ||\mathbf{P} - \mathbf{R}|| \\ &= \sqrt{(X - R_k)^2 + (Y - R_{k+1})^2} \end{aligned} \tag{3}$$

where

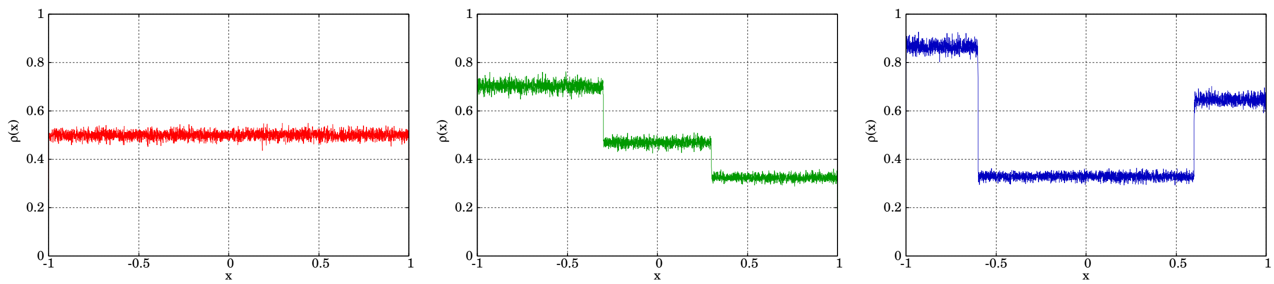
$$\begin{aligned} \text{Unit vector } \mathbf{u} &= \frac{\mathbf{P_1} - \mathbf{P_0}}{||\mathbf{P_1} - \mathbf{P_0}||} && (4) \\ \mathbf{v_0} &= \mathbf{R} - \mathbf{P_0}\ . && (5) \end{aligned}$$

Note that if the point is outside of the cube, we calculate the distance between the point and the nearest edges of the maps.



(a) (b) (c)

Figure 5: Chaotic Maps: (a) Skew Tent Map, (b) Type 1 $(q_1, r_1) = (-0.3, 0.3)$, $(q_2, r_2) = (0.3, -0.3)$, (c) Type 2 $(q_1, r_1) = (-0.6, 0.6)$, $(q_2, r_2) = (0.6, -0.6)$.



(a) (b) (c)

Figure 6: Invariant Measures: (a) Skew Tent Map, (b) Type 1, (c) Type 2.

In this case, there are eight straight lines in the space. Therefore, the minimum value from four distances is chosen as the shortest distance D_1 for symbol "1". In the same way, D of symbol "0" is chosen as D_0. the receiver calculates both D_1 and D_0 for all k and find their summations $\sum D_1$ and $\sum D_0$. Finally, we decide the decoded symbol as 1 (or 0) for $\sum D_1 < \sum D_0$ (or $\sum D_1 > \sum D_0$).

The calculation of the shortest distance can be extended to N_d-dimensional space for $N_d \geq 3$.

3. Analysis of Chaotic Map with Some slopes

In this section, we analyze chaotic maps for the chaotic sequence with biased values. Here, we apply the invariant measure to analyze the chaotic map. The invariant measure is the function deciding the iteration density of a map, namely we can observe the distribution of the value of the chaotic sequence. The invariant measure $\rho(x)$ is described by

$$\rho(x) \equiv \lim_{N\to\infty} \frac{1}{N} \sum_{i=0}^{N} \delta(x - f^i(x_0)) \ , \qquad (6)$$

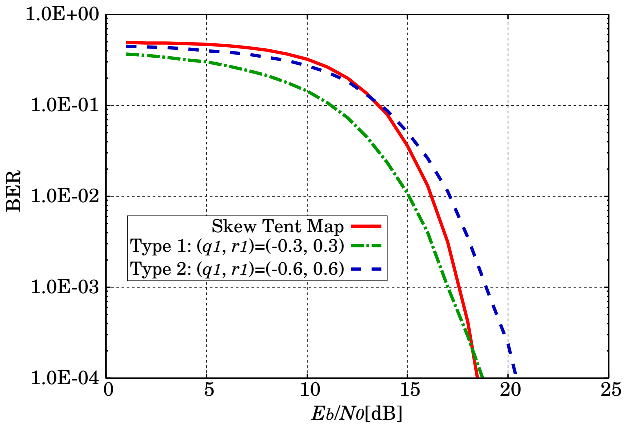
where $x_{n+1} = f(x_n)$, $n = 0,\ 1,\ 2,\ \cdots$, x_0 is an initial value, δ is the delta function. If $\rho(x)$ is the system that is not dependent on an initial value, it is called ergodic. In this study, to calculate using the computer, N is assumed to 10^6.

We use three types of chaotic maps for calculating the invariant measure; The first is the skew tent map as the chaotic map without biased values (Fig. 5(a)); The second is the chaotic map with $(q_1, r_1) = (-0.3, 0.3)$, $(q_2, r_2) = (0.3, -0.3)$ (Fig. 5(b)); The third is the chaotic map with $(q_1, r_1) = (-0.6, 0.6)$, $(q_2, r_2) = (0.6, -0.6)$ (Fig. 5(c)) In this study, we label the second and the third as Type 1 and Type 2, respectively. To calculate using the computer, N of each result is assumed to 10^6.

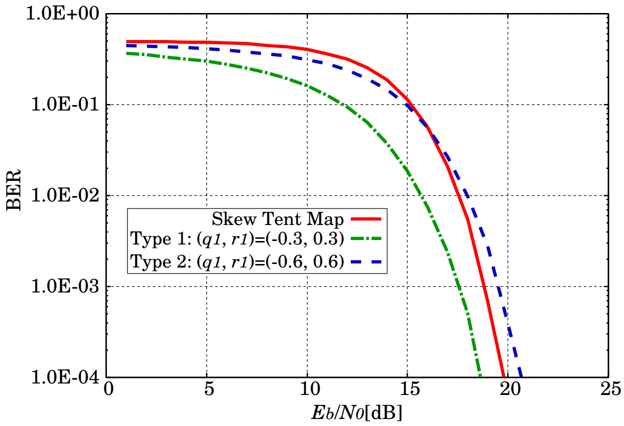
Figures 6(a), (b) and (c) show the invariant measures of Fig 5. Now, let us observe each invariant measure.

First of all, we observe the skew tent map. From Fig 6(a), $\rho(x)$ is constant, namely, In other words, the distribution of the chaotic sequence generated from the skew tent map is not dependent on an initial value, namely, we can confirm that the skew tent map is ergodic. Second, we focus on Type 1 (Fig 6(b)). As one can see, $\rho(x)$ increases as x approaches -1. Thus, we can say that the chaotic sequence with the biased value is distributed to the left side. Finally, we observe Type 2 (Fig 6(c)). This distribution is divided into right and left with center on $x = 0$ according to (q_1, r_1). Especially, $\rho(x)$ increases as x approaches -1 or 1. Namely, we can say that the chaotic sequence generated from Fig 6(c) has many values of surrounding 1 and -1.

From these analysis, by changing the slope of the chaotic map, we become available the chaotic sequence with the



(a)



(b)

Figure 7: BER: (a) $N = 64$, (b) $N = 128$.

desired biased values.

4. Computer Simulation

In this section, we carry out the computer simulation of our suboptimal receiver using Figs 5. The simulation conditions are as follows. On the transmitting side, 10,000 symbols are transmitted using chaotic sequences with different initial values. Here, the parameter of the skew tent map is fixed as $a = 0.05$, As the chaotic sequence length, we set $N = 64 and 128$. On the receiving side, BER is recorded for various E_b/N_0. Also, to calculate the shortest distance, the receiver applies 2-dimensional space (2-D).

Figures 6(a) and (b) plot the BER versus E_b/N_0 for each type parameter. To compare the performance, we perform the simulation of the skew tent map without biased values, i.e., as the conventional method. We can observe that the performance of Type 1 from Figs 6(a) and (b). From these results, it can be said that the chaotic sequence which changed the distribution of biased values is effective for the suboptimal receiver. Therefore, we can sat that the chaotic sequence with biased values is effective not only DCSK but also the suboptimal receiver.

5. Conclusions

In this study, we have investigated the suboptimal receiver by changing the some slopes. As results, we have obtained the better BER performance by controlling the distribution of the chaotic sequence with biased values, Moreover, we have confirmed that the chaotic sequence with biased values is effective not only DCSK but also the suboptimal receiver. Since the simulation with $N_d = 2$-dimensional space has been performed for calculating the shortest distance, investigating of the chaotic sequence with biased values is our future work in the case of our suboptimal receiver with $N_d \geq 3$.

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