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Variable Sequence Length Transmitter for Noncoherent Chaos Shift Keying

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Abstract

This paper proposes a new transmitter for Noncoherent Chaos Shift Keying (CSK). In this scheme, the new transmitter can use a different chaotic sequence length N determined by an initial value. The performance of the communication system using the new transmitter is studied by computer simulation. In addition, we compare its and an exiting CSK communication system.

1. Introduction

Recently, a noncoherent receiver for digital communications systems using chaos is studied actively [1]-[4]. Especially, it is attracted to develop suboptimal noncoherent receiver having the performance similar to the optimal noncoherent receiver.

In the previous research, we have proposed the suboptimal receiver using a very simple algorithm. Our method detects symbols from the calculated values of the shortest distance between received signals and chaotic map [5]. Furthermore, we extended this concept to the distance in N_d-dimensional space using N_d successive received signals $(N_d : 3, 4, \cdots)$ [6]. As a result, we obtained the best performance for the dimension N_d is equal to the length of the chaotic sequence N. In addition, the performance of this suboptimal receiver becomes better as N increases. Also, the average energy per bit becomes large.

In this study, in order to use the average energy per bit effectively and improve the bit error performance, we propose a Chaos Shift Keying (CSK) transmitter using variable sequence length. We carry out computer simulations and investigate the performance of the proposed method.

2. System Overview

First, we explain a discrete-time binary CSK communication system with an existing transmitter, as shown in Fig. 1. This system consists of a transmitter, channel and a receiver. Detail of each block is described below.

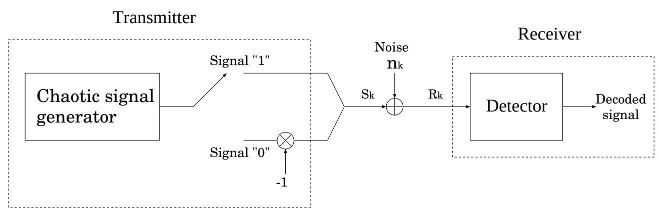


Figure 1: Block diagram of a discrete-time binary CSK communication system.

2.1. Transmitter

In the transmitter, a chaotic sequence is generated by a chaotic map. In this study, we use a skew tent map to generate the chaotic sequence.

2.1.1. Skew Tent Map

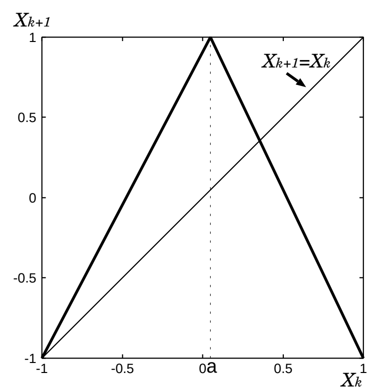


Figure 2: Skew Tent Map.

The skew tent map is shown in Fig. 2. This map is one of simple chaotic maps, and it is described by Eq. (1)

$$x_{k+1} = \begin{cases} \dfrac{2x_k + 1 - a}{1 + a} & (-1 \leq x_k \leq a) \\ \dfrac{-2x_k + 1 + a}{1 - a} & (a < x_k \leq 1) \end{cases} \quad (1)$$

where a denotes a position of a top of the skew tent map.

2.1.2. Chaos Shift Keying

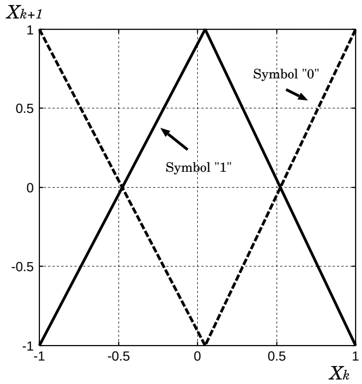


Figure 3: Chaos Shift Keying.

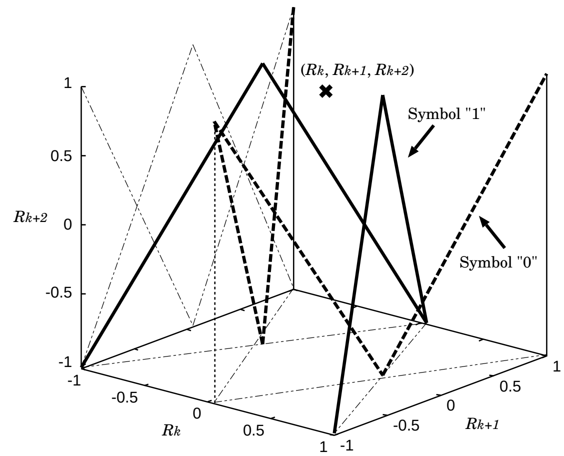


Figure 4: Detection method.

CSK is a digital modulation system using chaos. When the transmitter generates the signals, we use chaotic sequences generated by different chaotic maps depending on the value of an information symbol. In this study, we use the skew tent map and its reversal map, as shown in Fig. 3. If the information symbol "1" is sent, Eq. (1) is used, and if "0" is sent, the reversed function of Eq. (1) is used. In order to transmit a 1-bit information, N chaotic signals 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

In the channel, noise is assumed to be additive white Gaussian noise (AWGN) and 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. Receiver

The receiver detects the transmitted signals from received signals and demodulates the information symbol. In the detection methods, there are coherent detection methods that record the initial value of chaotic sequence at the receiver and noncoherent detection methods that do not record one. In this study, we use the suboptimal receiver proposed in previous research [6].

2.3.1. Our Suboptimal Receiver

The suboptimal receiver proposed by the authors calculates the shortest distance between received signals and the map in the N_d-dimensional space using N_d successive received signals $(N_d : 3, 4, \cdots)$.

For example, we explain the case of $N_d = 3$. Figure 4 shows the 3-dimensional space of the skew tent map whose coordinates correspond to the three successive received signals (R_k, R_{k+1}, R_{k+2}). In order to decide which map is closer to the point (R_k, R_{k+1}, R_{k+2}) of three successive received signal in the 3-dimensional space in Fig. 4, the shortest distance between the point and the map has to be calculated. In this method, we calculate the shortest distance using the scalar product of the vector.

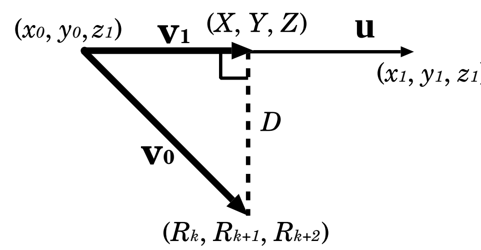


Figure 5: Calculation of the shortest distance.

Any two points of (x_0, y_0, z_0) and (x_1, y_1, z_1) are chosen from the straight line in the space of Fig. 4, as shown in Fig. 5. In Fig. 5, a unit vector $\mathbf{u}$ is calculated from (x_0, y_0, z_0) and (x_1, y_1, z_1) by the following equation,

$$\mathbf{u} = (l, m, n) = \left(\frac{x_1 - x_o}{A}, \frac{y_1 - y_o}{A}, \frac{z_1 - z_o}{A} \right) \tag{2}$$

where A is $\sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2}$. In addition, vector $\mathbf{v_0}$ is calculated by (R_k, R_{k+1}, R_{k+2}) and (x_0, y_0, z_0) from the following equation.

$$\mathbf{v_0} = (R_k - x_o, R_{k+1} - y_o, R_{k+1} - z_o) \tag{3}$$

Product T in $\mathbf{u}$ and $\mathbf{v_0}$ is calculated from the following equation.

$$T = l\,(R_k - x_0) + m\,(R_{k+1} - y_0) + n\,(R_{k+2} - z_0) \tag{4}$$

So, $\mathbf{v_1}$ can be calculated from the product of T and $\mathbf{u}$. Therefore, we can calculate coordinates of the shortest distance (X, Y, Z) and the shortest distance D from the following equation.

$$(X, Y, Z) = (Tl + x_0, Tm + y_0, Tn + z_0) \quad (5)$$

$$D = \sqrt{(X - R_k)^2 + (Y - R_{k+1})^2 + (Z - R_{k+2})^2} \quad (6)$$

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

For the 3-dimensional case, there are four straight lines in the space. So, the minimum value in four distances is decided as the shortest distance D_1 for symbol "1". In the same way, D of symbol "0" is decided as D_0. We calculate both of 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 $\sum D_1 > \sum D_0$).

In this system, calculation of the shortest distance above 4-dimension also possible by using this method. However, we can not draw a high-dimensional space like 3-dimension.

3. Proposed Transmitter

3.1. Basis on Proposed Transmitter

As described above, the successive received signals are required in order to calculate the shortest distance. the bit error rate (BER) increases for some successive received signals. In order to expound on this cause, we carried out the following computer simulation.

On the transmitting side, -1 to 1 is divided into 128. In addition, a chaotic sequence is generated by an initial value determined at random from one section divided into 128. Here, one section is fixed until transmitting 10^4 bits is finished. On the receiving side, the number of dimensions (N_d) using the suboptimal receiver uses the chaotic sequence length N in the transmitter. For example, when N is 4, the receiver uses $N_d = 4$.

Based on the above conditions, the BER is recorded for various the average-bit-energy-to-noise-spectral-density ratio (E_b/N_0) when N is 4 or 8. Moreover, this simulation is carried out for all sections (0 $\sim$ 127).

Figure 6 plots the BERs versus sections for $N(N_d) = 4, 8$ (an average of results for E_b/N_0 = [10, 20][dB]). From this figure, we can find that BERs of N=4 and 8 different by each section. In other words, when the initial value is determined, the optimal calculation method of the shortest distance is decided by each section.

For example, we can find that the BER performance of N=4 is better than N=8 in the 1st section. However, it can be also observed that the BER performance of N=8 is better than N=4 in the 10th section. Therefore, it can be said that the performance of the CSK communication system is changed by any initial value of the chaotic sequence.

From this result, we devised new transmitter that the chaotic sequence length N is changed by the initial value. Namely, we propose a Variable Sequence Length Transmitter. We explain about this transmitter in next subsection.

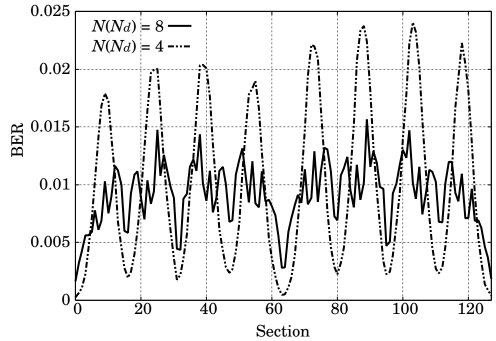


Figure 6: Basis on proposed transmitter (average of results for E_b/N_0 = [10, 20][dB]).

3.2. Variable Sequence Length Transmitter

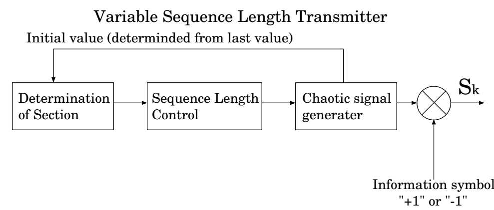


Figure 7: Proposed transmitter.

Figure 7 shows the block diagram of Variable Sequence Length Transmitter. This system consists of three blocks.

First, any section is determined from the initial value by 1st block. Next, the optimal sequence length is decided by any section in 2nd block. Finally, chaotic sequence with optimal sequence length is generated from 3rd block and modulated by CSK. Moreover, next initial value is decided from Last value of chaotic sequence.

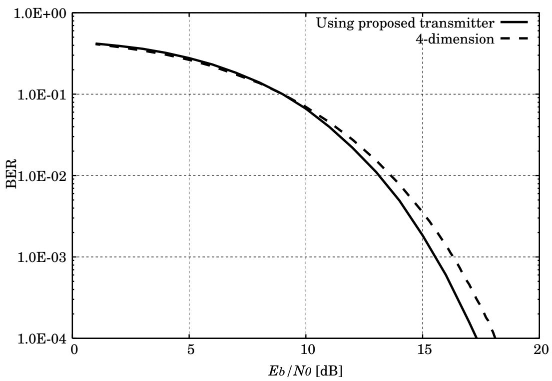
One merit of this system is to improve the BER performance as described above. Additionally, this system has other merit. This system can use the average energy per bit effectively by changing the chaotic sequence length. So, the transmitting efficiency improves compared with the existing CSK communications system.

4. Simulation Result

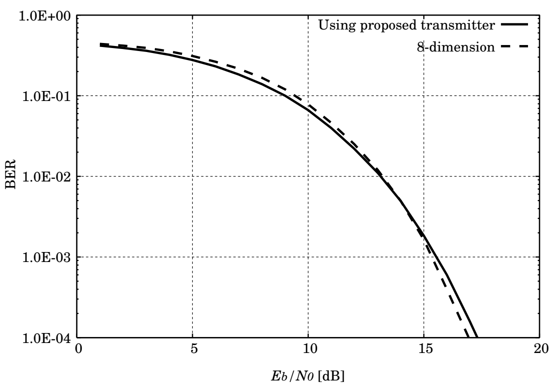
In this section, we study the performance of the CSK communication system using the proposed transmitter by computer simulations. The simulation conditions are as follows.

In the proposed transmitter, chaotic sequence length N uses 4 or 8 and changes by any section. In the channel, noise is assumed only AWGN. So, noise at transmitter and receiver is not considered. In the receiving side, the suboptimal receiver proposed by the authors is used. And in order to calculating the shortest distance, 4 or 8 dimensional space is changed by the chaotic sequence length N of received signals. In this study, the chaotic sequence length N of the received signal assumes that it can determine by the receiving side.

Based on the above conditions, the system performance is shown by plotting the BER against E_b/N_0 when 10^4 symbols are transmitted.



(a) Comparison of 4-dimension with the proposed transmitter.



(b) Comparison of 8-dimension with the proposed transmitter.

Figure 8: Simulation results.

Figures 8(a) and 8(b) show the simulation results for the proposed transmitter. For comparison, the results of 4-dimension (Fig. 8(a)) and 8-dimension (Fig. 8(b)) are also shown.

As expected, the performance of the proposed transmitter is better than that of 4-dimension. Moreover, it can be observed that the curves of the proposed transmitter and 8-dimension are almost the same, as shown in Fig. 8(b).

Therefore, we can find that changing the chaotic sequence length N by the initial value is effective in CSK communication system. However, in this study, we assumed that the chaotic sequence length N of the received signal can determine with the receiving side. In fact, changed sequence length on the transmitting side is unknown with the receiving side. Hence, it can be said that developing the receiver that can detect the chaotic sequence length N is very important.

5. Conclusions

In this study, in order to use the average energy per bit effectively and improve the bit error performance, we proposed the CSK transmitter using variable sequence length. As a results, a better BER performance is achieved compared with that obtained from the existing CSK transmitter.

On the basis of the result obtained in this study, developing the receiver that can detect the chaotic sequence length decided the transmitting side is our future work.

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