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Variable-Sequence-Length Transmitter for Noncoherent Chaos Shift Keying

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Abstract

In this paper we propose a new transmitter for noncoherent chaos shift keying. In this scheme, the new transmitter can use a different chaotic sequence length determined by an initial value. The performance of the communication system using the new transmitter is studied by computer simulation.

1. Introduction

Recently, the use of a noncoherent receiver for digital communications systems using chaos has been studied actively [1]-[4]. In particular, a suboptimal noncoherent receiver having a similar performance to the optimal noncoherent receiver has been developed.

In our previous research, we proposed a suboptimal receiver using a very simple algorithm. Our method detects symbols from the calculated values of the shortest distance between received signals and a 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, which was equal to the length of the chaotic sequence N. In addition, we confirmed that the performance of this suboptimal receiver improved as N increased.

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

2. System Overview

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

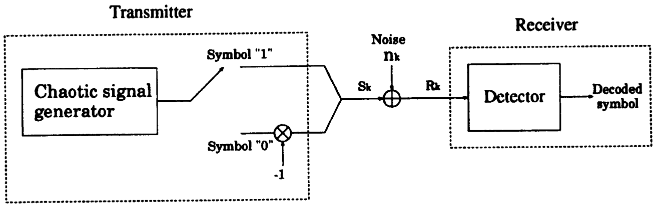


Figure 1: Block diagram of discrete-time binary CSK communication system

2.1 Transmitter

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

2.1.1 Skew tent map

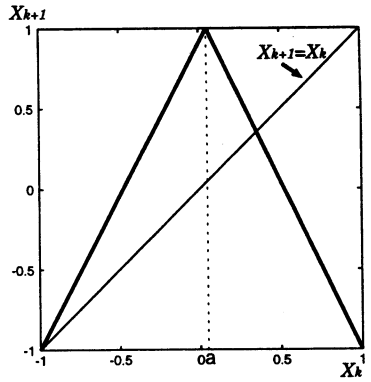


Figure 2: Skew tent map

The skew tent map is shown in Fig. 2. This map is a simple chaotic map and is described by

$$x_{k+1} = \begin{cases} \dfrac{2x_k + 1 - a}{1 + a} & (-1 \le x_k \le a) \\[2ex] \dfrac{-2x_k + 1 + a}{1 - a} & (a < x_k \le 1) \end{cases} \tag{1}$$

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

2.1.2 Chaos shift keying

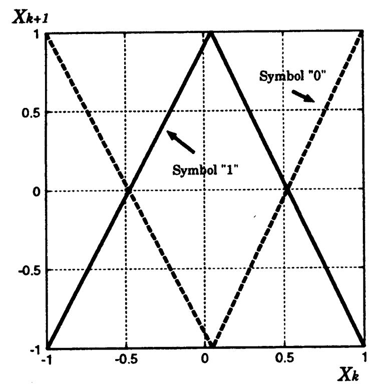


Figure 3: Chaos shift keying

CSK is a digital modulation system using chaos. When the transmitter generates signals, we use the chaotic sequences generated by different chaotic maps depending on the value of the 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. To transmit 1-bit information, N chaotic signals are generated, where N is the 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, a 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 and our suboptimal receiver

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

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

As an example, we explain the case of $N_d = 3$. Figure 4 shows the 3-dimensional space using the skew tent map whose coordinates correspond to the three successive received signals (R_k, R_{k+1}, R_{k+2}). To decide which map is closest to the point (R_k, R_{k+1}, R_{k+2}) in the 3-dimensional space in Fig. 4, the shortest distance between the point and

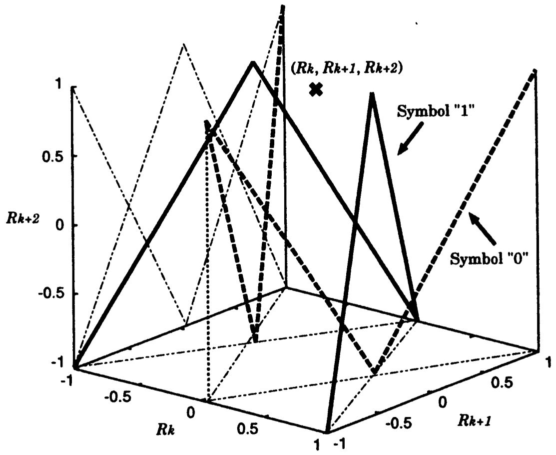


Figure 4: Detection method

the map has to be calculated. Therefore, we calculate the shortest distance using the scalar product of the vector.

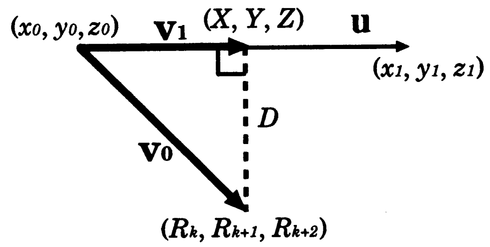


Figure 5: Calculation of shortest distance

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

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

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

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

The scalar product T of $\mathbf{u}$ and $\mathbf{v_0}$ is calculated using

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

Hence, $\mathbf{v_1}$ can be calculated from the scalar product of T and $\mathbf{u}$. Therefore, we can calculate the point with the shortest distance (X, Y, Z) and the shortest distance D using

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

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

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

For the 3-dimensional case, there are four straight lines in the space. Therefore, the minimum value of the four distances is chosen as the shortest distance D_1 for symbol "1". In the same way, the D of symbol "0" is chosen as D_0. We calculate both D_1 and D_0 for all k and find their summations $\sum D_1$ and $\sum D_0$. Finally, we determine 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 $N_d \geq 4$.

3. Proposed Method

3.1 Basis of proposed transmitter

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

On the transmitting side, the interval of the skew tent map $[-1,\ 1]$ is divided into 128 sections. We choose one section and selected 10^4 initial points from this section at random. Using the chaotic sequences starting from these initial points, we transmit 10^4 bits of information. The chaotic sequence length is fixed as $N = 4$ or $N = 8$. On the receiving side, the suboptimal receiver proposed by the authors is used to recover the information. To calculate the shortest distance, the number of dimensions is fixed as $N_d = 4$.

Figure 6 shows an example of the simulation results of the BER versus the section for $N = 4$ and $N = 8$ when E_b/N_0 is fixed as 13[dB], where E_b is the average energy per bit. From this figure, we can find that the BER strongly depends on the section selected. Furthermore, the BER for $N = 4$ is better than that for $N = 8$ for some sections, whereas $N = 8$ is better than that for $N = 4$ for others. For example, we can see that the BER of $N = 4$ is better than that for $N = 8$ for the 60th section. However, the BER of $N = 8$ is better than that for $N = 4$ for the 120th section. This means that the performance of the CSK communication system is changed depending on the initial value of the chaotic sequence.

From this result, we devise a new transmitter in which the chaotic sequence length N is changed by the initial value of the chaotic sequence. Namely, we propose a variable-sequence-length transmitter. We explain this transmitter in the next subsection.

3.2 Variable-sequence-length transmitter

Figure 7 shows the block diagram of the proposed transmitter. This system consists of three blocks.

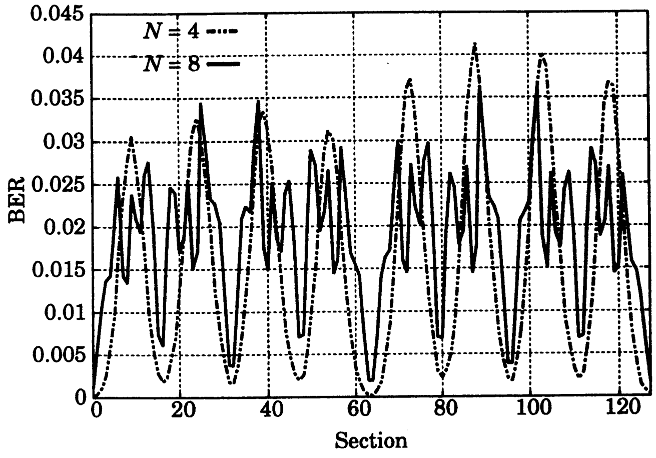


Figure 6: Basis of proposed transmitter (E_b/N_0 = 13[dB])

First, one section is determined by the initial value of the chaotic sequence in the 1st block. Next, a better sequence length is decided using the results shown in Fig. 6 in the 2nd block. Finally, the chaotic sequence with the better sequence length is generated in the 3rd block and used for the CSK modulation. Moreover, the next initial value is decided from the last value of the chaotic sequence.

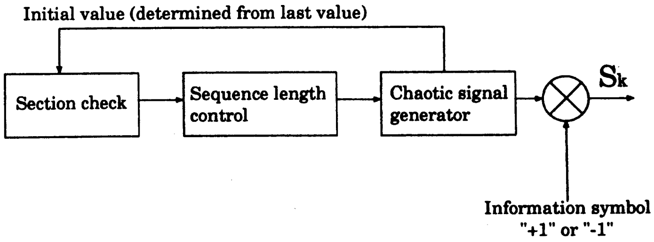
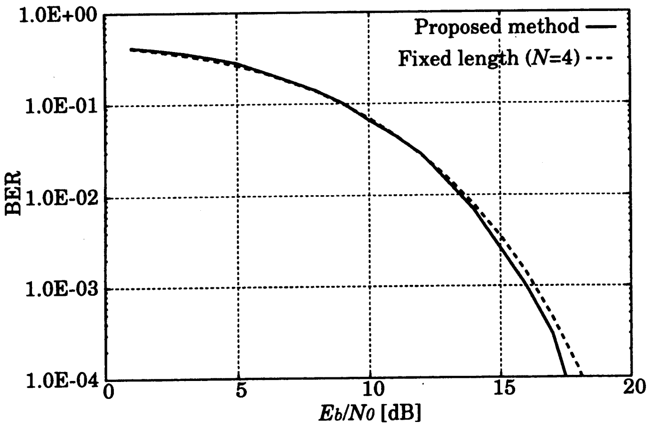


Figure 7: Proposed transmitter

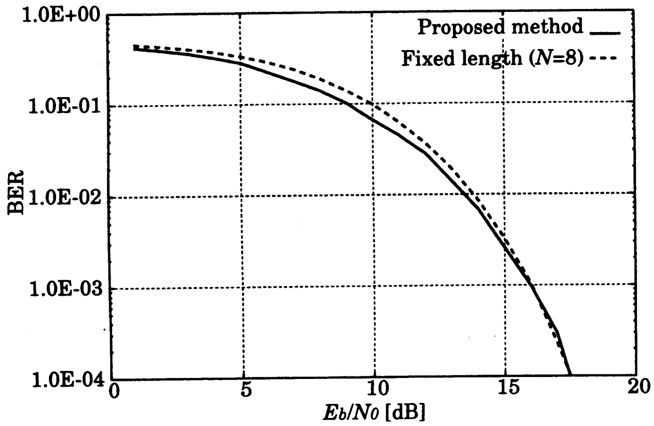
4. Simulation Result

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

In the proposed transmitter, the chaotic sequence length N is 4 or 8. In the channel, noise is assumed to be only AWGN. Hence, the noises at the transmitter and receiver are not considered. On the receiving side, the suboptimal receiver proposed by the authors is used. To calculate the shortest distance, we use 4-dimensional space. In this study, we assume that the chaotic sequence length N is known on the receiving side. On the basis of these conditions, the system performance is evaluated by plotting BER against E_b/N_0 when 10^4 bits of information are transmitted.



(a) Comparison with $N = 4$



(b) Comparison with $N = 8$

Figure 8: Simulation results

Figures 8(a) and 8(b) show the simulation results of the proposed method. To compare the performance of the proposed system with the fixed-length transmitter, the performances of $N = 4$ and $N = 8$ are shown together in Figs. 8(a) and 8(b), respectively. From the results, we find that the performance of the proposed transmitter is similar to or better than that of the fixed-length transmitter for both $N = 4$ and $N = 8$ for any E_b/N_0. In other words, the proposed transmitter has a good performance for $N = 4$ for small E_b/N_0 and a good performance for $N = 8$ for large E_b/N_0. Hence, we can conclude that the proposed method uses the average energy per bit effectively depending on noise level.

5. Conclusions

In this study, to use the average energy per bit effectively and improve bit error performance, we have proposed a CSK transmitter using variable sequence length. As a result, a better BER performance has been achieved. However, we assumed that the chaotic sequence length is known on the receiving side. Hence, we have to develop a receiver that can detect the chaotic sequence length in our future research.

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