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Research on Suboptimal Receivers for Chaos Shift Keying

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1. Introduction

Recently, digital communication systems using chaos are studied actively [1]-[5]. In particular, a noncoherent receiver is hard to design while information could be recovered even if the sequence is unknown at the receiver. Therefore, it is important to study the noncoherent receiver. The optimal detection proposed by Schimming and Hasler is well known as a noncoherent receiver [1][2]. However, if a chaotic sequence length N becomes long, calculation becomes very complicated and the signal detection becomes difficult.

We have proposed a method of detecting symbols from the calculation value of the shortest distance between received signals and chaotic map [6]. In this study, we propose a method improving this noncoherent receiver. At first, we show the method of deciding the symbol by using 3 received signals. We also show the method of deciding the symbol by using 4 received signals. Computer simulations are performed for these two methods, and the bit error rates (BER) are evaluated.

2. System overview

We consider a discrete-time binary CSK communication system, as shown in Fig. 1. This system consists of a transmitter, channel and a receiver. We explain about each block.

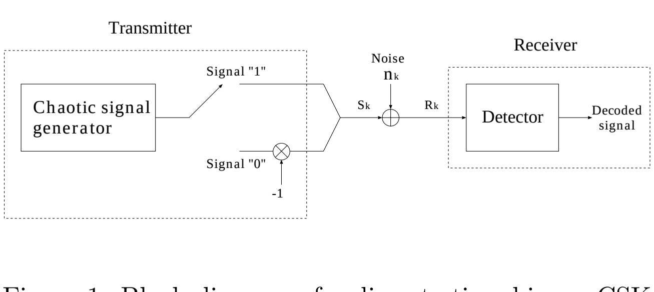


Figure 1: Block diagram of a discrete-time binary CSK communication system.

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

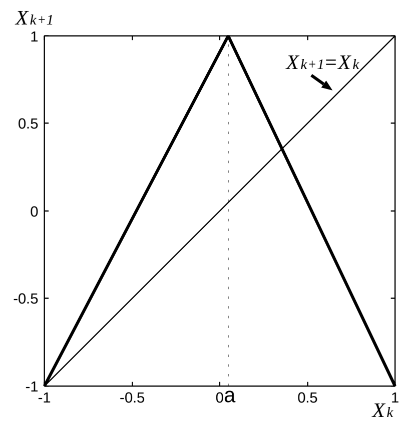


Figure 2: Skew Tent Map.

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

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

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

2.1.2. Chaos Shift Keying

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"

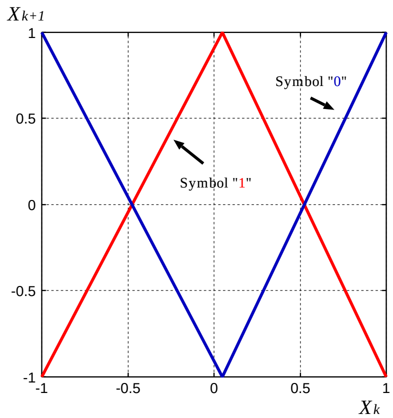


Figure 3: Chaos Shift Keying.

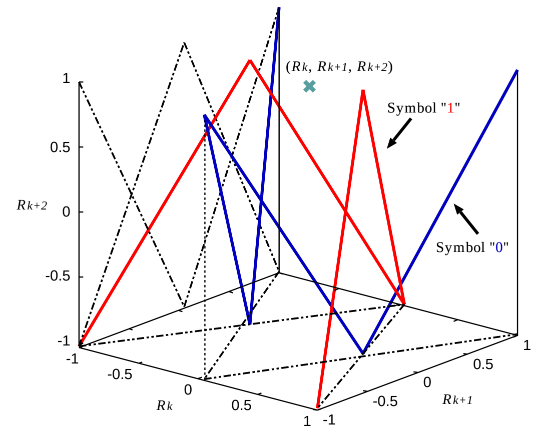


Figure 4: Three-dimensional space of $(R_k,\ R_{k+1},\ R_{k+2})$.

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 propose a noncoherent receiver.

3. Noncoherent Receiver

We have proposed a method of detecting symbols from the calculation value of the shortest distance between a point $(R_k,\ R_{k+1})$, which is given by the two successive received signals, and the skew tent map on the 2-dimension plane [6].

In this study, we extend this concept to the distance in 3-dimensional space using three successive received signals. Figure 4 shows the 3-dimensional space whose coordinates correspond to the three successive received signals $(R_k,\ R_{k+1},\ R_{k+2})$. In the figure, the relationships of the received signals made by using the skew tent map and its reversal map are also drawn.

3.1. Calculation of the shortest distance

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.

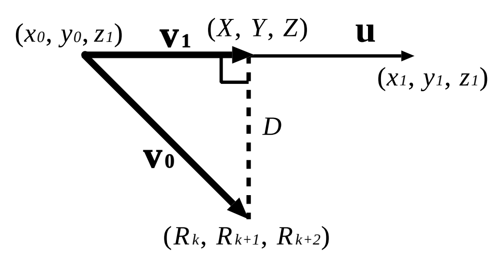


Figure 5: Calculation of shortest distance.

Calculating the shortest distance in 3-dimensional space is more difficult than the case of 2-dimensional plane. So, we calculate the shortest distance using the scalar product of the vector.

At first, 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,

$$\mathbf{u} = (l, m, n) = \left(\frac{x_1 - x_0}{A}, \frac{y_1 - y_0}{A}, \frac{z_1 - z_0}{A} \right) \quad (2)$$

where A is $\sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2}$. In addition, 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.

$$\mathbf{v_0} = (R_k - x_0, R_{k+1} - y_0, R_{k+1} - z_0) \quad (3)$$

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

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

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.

3.2. Decision of symbol

The shortest distance is calculated for both the skew tent map and its reversal map. For the 3-dimensional case, there are four straight lines in the space for symbol "1". 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 $\sum D_1 > \sum D_0$).

3.3. Four-dimensional case

This method based on the shortest distance can be extended to 4-dimensional space. In this case, the four successive received signals (R_k, R_{k+1}, R_{k+2}, R_{k+3}) are used for the calculation. The calculation method using the vector is similar to the case of the 3-dimensional space.

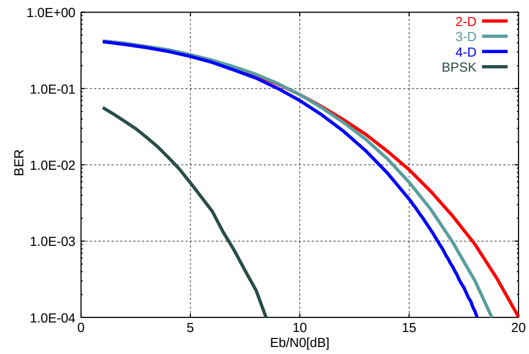
4. Simulation result

The simulation conditions are as follows.

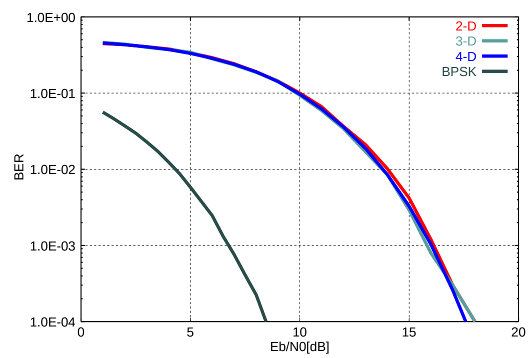
- 10^4 symbols are transmitted.
- Chaotic sequence length N are 4, 8 and 16.
- In the channel, noise is assumed only AWGN. Noise at transmitters and receivers is not considered.

In the simulation, we recorded the BER when E_b/N_0 was changed from 1 into 20, where E_b denotes the average energy per bit. For comparison, the result using the distance on 2-dimensional plane is also shown.

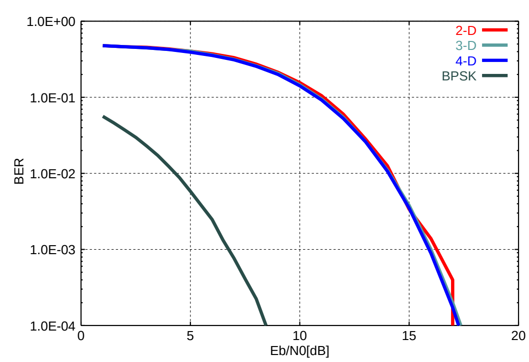
Figures 6(a), (b) and (c) show the BERs versus E_b/N_0 for N are 4, 8 and 16, respectively. It can be observed that the BER performance improves as the dimension increases, as shown in Fig. 6(a). However, when N becomes large, the BER performance is similar for all of the three different dimensions, as shown in Figs. 6(b) and (c).



(a) $N = 4$.



(b) $N = 8$.

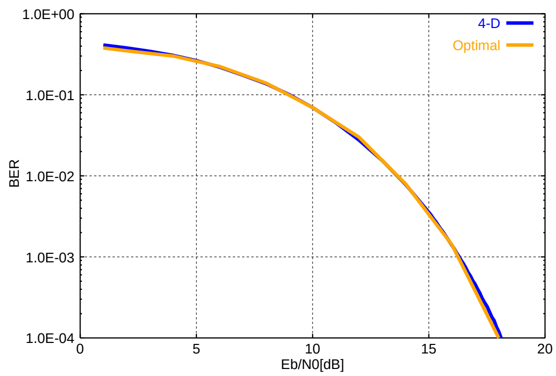


(c) $N = 16$.

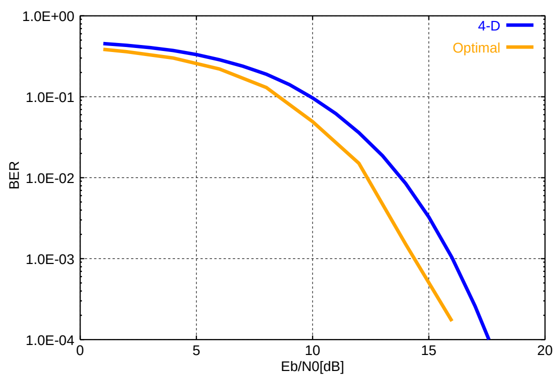
Figure 6: BER performance.

Figures 7(a) and (b) show the BERs for the 4-dimensional method and the optimal detection for N are 4 and 8. When N is 4, the two curves are almost the same. However, when N is 8, the BER performance of the optimal detection is better than the proposed method.

From this result, we consider that our method using the shortest distance in N_d-dimensional space becomes almost identical with the optimal detection for the case that the dimension N_d is equal to the length of the chaotic sequence N. We believe that our method can be extended for larger dimensions such as $N_d = 16$ or $N_d = 64$. However, it is difficult to compare those results with the optimal detection, because it is too difficult to perform the optical detection for larger N. Investigating the relationship between the two detection methods is our important future research.



(a) $N = 4$.



(b) $N = 8$.

Figure 7: Comparison between the optimal detection and the proposed method.

5. Conclusions

In this study, we proposed the method of detecting symbol from the calculation value of the shortest distance between successive received signals and 3 or 4 dimensional space.

On the basis of the result obtained in this study, when chaotic sequence length is N_d, detecting the shortest distance of N_d-dimensional space is our future work.

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