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Detection of Information Symbols and Sequence Lengths Using Suboptimal Receiver for Chaos Shift Keying

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Abstract—This paper proposes a new detection method of a receiver for Noncoherent Chaos Shift Keying. In this scheme, the receiver detects not only an information symbol but also a chaotic sequence length which used for Chaos Shift Keying. The detection of the chaotic sequence length is performed by the method adapting the suboptimal receiver proposed in our previous research, and it is the very simple method using the feature of chaos. In order to investigate its detection, we carry out computer simulations and observe the performance.

1. Introduction

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

In the previous research, we have proposed a suboptimal receiver using 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 is equal to the length of the chaotic sequence N. In addition, we confirmed that the performance of this suboptimal receiver became better as N increased. Moreover, in order to use the average energy per bit effectively and to improve the bit error performance, we proposed a Chaos Shift Keying (CSK) transmitter which the chaotic sequence length changes efficiently and obtained a better BER performance than the existing CSK communication system [7]. However, this simulation was carried out by the case which assumed that the chaotic sequence length was known at the the receiving side. Hence, the receiver has to detect the chaotic sequence length, i.e., a point where the chaotic sequence length is changed.

In this study, based on the detection method of the information symbol in the suboptimal receiver proposed in our previous research, we experiment with a detection of the point where the chaotic sequence length is changed. We carry out computer simulations and investigate the performance.

2. System Overview

We consider the discrete-time binary CSK communication system, as shown in Fig. 1.

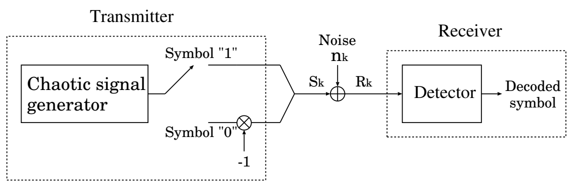


Figure 1: Block diagram of discrete-time binary CSK communication system.

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

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

where a denotes a position of the top of the skew tent map. The information symbol is modulated by CSK using the skew tent map and its reversal map. In other words, 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 1-bit information, N chaotic signals are generated, where N is the chaotic sequence length. Therefore, the transmitted signal is denoted by a vector $\mathbf{S} = (S_1\ S_2\ \cdots\ S_N)$.

In the case of the existing CSK transmitter, the chaotic sequence length is fixed value. In this study, in order to detect the point where the chaotic sequence length is changed, the transmitter changes the chaotic sequence length at random. Here, we consider a very simple model which switches 2 different chaotic sequence lengths, $N = 8$ or $N = 12$. Also, the initial value is changed for every information symbol.

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

The receiver recovers the transmitted signals from the received signals and demodulates the information symbol. In this study, we use the suboptimal receiver proposed in our previous research [6]. Based on the detection method of the information symbol in the suboptimal receiver, we experiment with the detection of the point where the chaotic sequence length is switched.

2.4. Detection Method of Information Symbol [6]

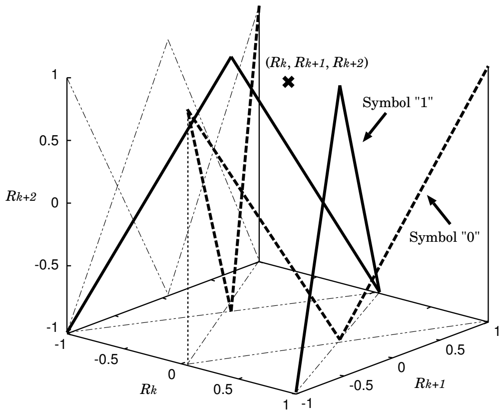


Figure 2: Detection method.

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 ($N_d : 3, 4, \cdots$).

As an example, we explain the case of $N_d = 3$. Figure 2 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}) where $k = 1, 2, \cdots, N-2$. In order to decide which map is closer to the point (R_k, R_{k+1}, R_{k+2}) in the 3-dimensional space in Fig. 2, the shortest distance between the point and the map has to be calculated. Therefore, we calculate the shortest distance using the scalar product of the vector.

Any two points of (x_0, y_0, z_0) and (x_1, y_1, z_1) are chosen from each straight line in the space of Fig. 2, as shown in Fig. 3. In Fig. 3, 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,

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

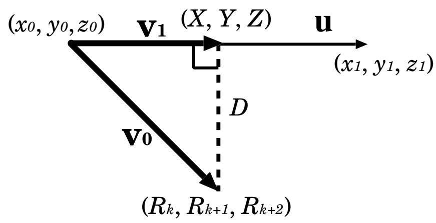


Figure 3: Calculation of the shortest distance.

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 from (R_k, R_{k+1}, R_{k+2}) and (x_0, y_0, z_0) by the following equation.

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

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

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

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

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

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

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

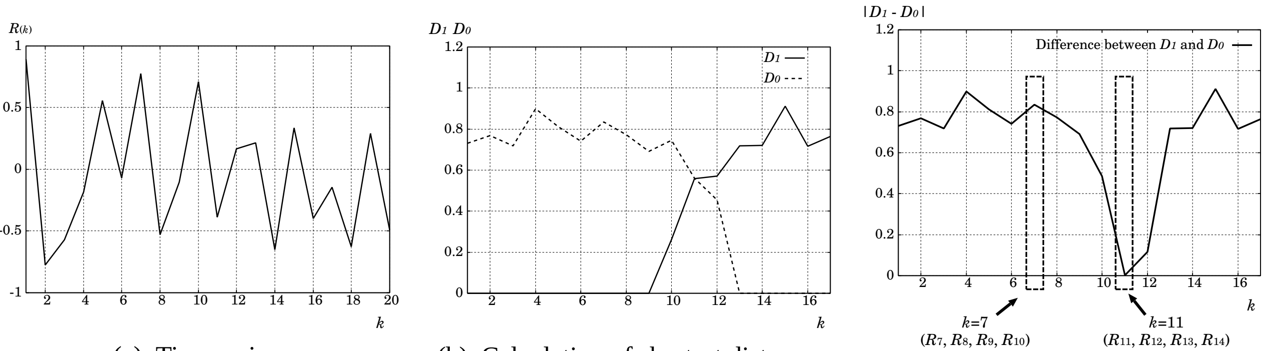
For the 3-dimensional case, there are four straight lines in the space. Therefore, the minimum value in four distances is chosen as the shortest distance D_1 for symbol "1". In the same way, D of symbol "0" is chosen as D_0. We calculate both of D_1 and D_0 for all k and find their summations $\sum D_1$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

The calculation of the shortest distance can be extended to N_d-dimensional space for $N_d \geq 4$.

3. Detection Method of Chaotic Sequence Length (Proposed Method)

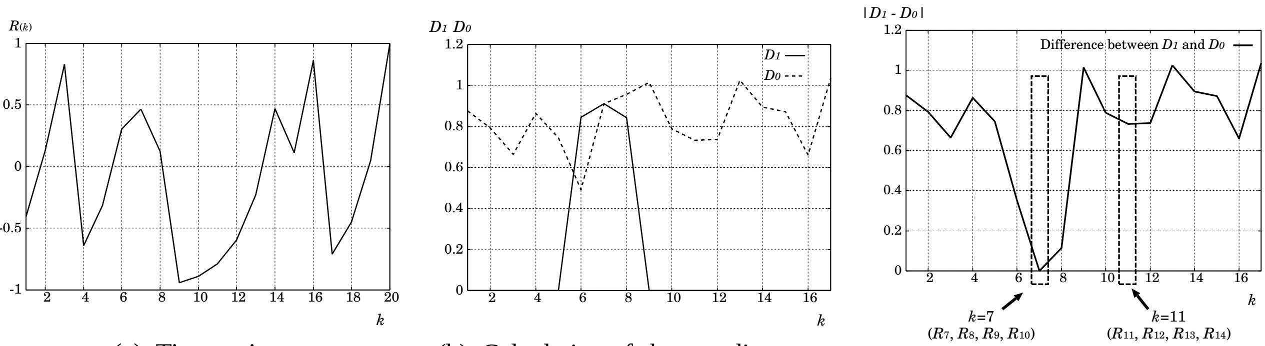
Based on the detection method of the information symbol in the suboptimal receiver, we explain the detection method of the point where the chaotic sequence length is switched.

Figure 4(a) shows a time series where the chaotic sequence is switched at $k = 12$. This sequence contains two chaotic sequences of the information symbols "1" and "0". We assume that the noise is not added to this sequence. Figure 4(b) shows the calculation results of the shortest distances for every k. Here, we use 4-dimensional space for



(a) Time series. (b) Calculation of shortest distance. (c) Difference between D_1 and D_0.

Figure 4: Connected two chaotic sequences of the information symbols “1” and “0” (switched when N is 12) .



(a) Time series. (b) Calculation of shortest distance. (c) Difference between D_1 and D_0.

Figure 6: Connected two chaotic sequences of the information symbols “1” and “1” (switched when N is 8) .

the calculation of the shortest distances. In Fig. 4(b), the solid line and the dotted line show D_1 and D_0, respectively.

Since the noise is not added, the difference between the two lines is very large for $k = 1 \sim 9$. However, the difference between the two lines becomes small for $k = 10 \sim 12$. In order to observe the difference in detail, we show the absolute value of the difference between D_1 and D_0, as Fig. 4(c). We can see that the differences around the switching point ($k = 12$) are much smaller than other differences. In order to expound on this cause, we use Fig. 5.

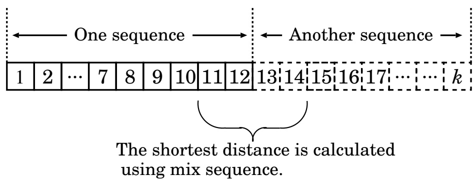


Figure 5: Cause of small difference between two lines around switching point.

Figure 5 shows the switching of two chaotic sequences. We can observe that the two chaotic sequences are mixed for the calculation around the switching point ($k = 12$). Therefore, the shortest distance around the switching point is calculated as if the noise was added. This is the key point of the proposed method. Namely, if the difference between D_1 and D_0 around the switching point becomes very small, it becomes easy to find the point where the chaotic sequence length is switched. In this study, we consider a very simple model which switches 2 values ($N = 8$ and $N = 12$). Hence, the receiver calculates 2 differences between D_1 and D_0 around 8 and 12, and these two values are compared. Finally, the receiver can decide the chaotic sequence length by which is smaller between $N = 8$ and $N = 12$. In the case of Fig. 4(c), the difference around $N = 12$ is smaller than that around $N = 8$. Therefore, the chaotic sequence length is decided as $N = 12$. Moreover, since D_1 is smaller than D_0, the information symbol is detected as “1”.

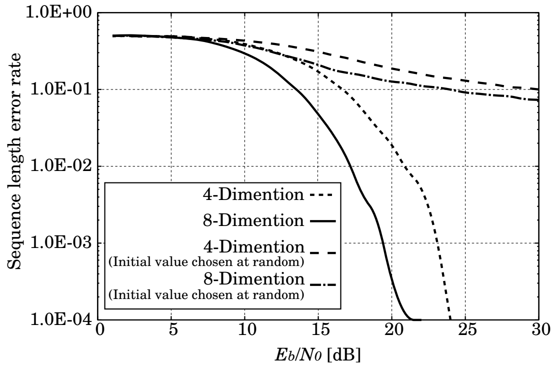
In the same way, the proposed method can detect the chaotic sequence length and the information symbol even when the same information symbol continues like “1” and “1”, as Fig. 6. From Figs. 6(b) and (c), we can find that the chaotic sequence length and the information symbol is detected as $N = 8$ and “1”, respectively.

This detection method improves the performance when D_1 and D_0 around the switching point is very small. Namely, the initial value should be chosen such that the distances in the N_d-dimensional space between the signal point and the two maps, which correspond to the symbols “1” and “0”, is very small. Therefore, when choosing the initial value of the next transmitted signal, the transmitter calculates D_1 and D_0 using two values, the last value of the previous transmitted signal and the random value. This operation is performed repeatedly. Finally, the random value which is the closest to D_1 and D_0 is chosen as the initial value of the next transmitted signal.

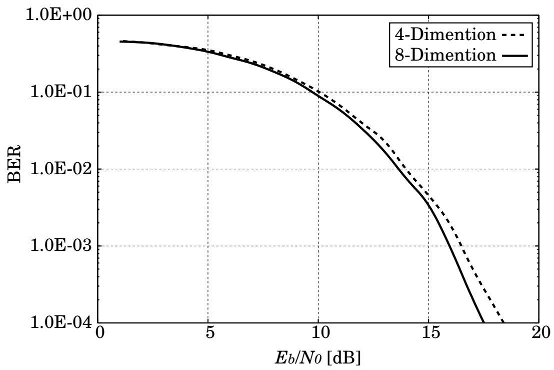
4. Simulation Result

In this section, we study the performance of the proposed method by computer simulations. The simulation conditions are as follows.

In the transmitting side, the chaotic sequence length N is switched as $N = 8$ or $N = 12$. In the channel, noise is assumed to be only AWGN. Hence, the noise at the transmitter and the receiver are not considered. In order to calculate the shortest distance, we use the 4-dimensional and 8-dimensional space on the receiving side. Based on these conditions, the system performance is evaluated by plotting the sequence length error rate and BER against E_b/N_0 when 10^4 bits of information are transmitted. Here, we assumed that the bit error rate (BER) is calculated in the case where the chaotic sequence length is detected correctly.



(a) Sequence length error rate.



(b) Bit error rate.

Figure 7: Simulation results.

Figures 7(a) and (b) show the sequence length error rate and BER. In order to compare the performance of choosing the initial value of the next transmitted signal, Fig. 7(a) shows the result of the simulation with the initial value of the chaotic sequence chosen at random together. From both results, we can find that the performance of 8-dimension is better than 4-dimension. This is because the sequences are generated from chaotic dynamics. In other words, chaotic sequences with 8 values have more appropriate to express the chaotic feature than 4 values. Therefore, it can be said that the detection of chaotic sequence length is effective by using higher-dimensional data. In addition, since the performance of the method choosing the initial value efficiently is better than that chosen at random, we can say that choosing the initial value of the method choosing is very important.

5. Conclusions

In this study, based on the detection method of the information symbol in the suboptimal receiver proposed in our previous research, we experimented with a detection of the chaotic sequence length, i.e., the point where the chaotic sequence length is changed. We have confirmed that the detection of the information from the chaotic sequence is possible even when the chaotic sequence length changed. Moreover, in the previous research, we proposed the CSK transmitter which the chaotic sequence length changes efficiently and obtained a better BER performance than the existing CSK communication system [7]. Therefore, investigating the performance of the chaos communication system which changes the chaotic sequence length efficiently using the proposed method in this study is our future work.

References

[1] M. Hasler and T. Schimming, “Chaos communication over noisy channels,” Int . Journal of Bifurcation and Chaos, vol. 10, no. 4, pp. 719-736, 2000.

[2] F. C. M. Lau and C. K. Tse, “Approximate-optimal detector for chaos communication systems,” Int. Journal of Bifurcation and Chaos, vol. 13, no. 5, pp. 1329-1335, 2003.

[3] F. C. M. Lau and C. K. Tse, “On optimal detection of noncoherent chaos-shift-keying signals in a noisy environment,” Int. Journal of Bifurcation and Chaos, vol. 13, no. 6, pp. 1587-1597, 2003.

[4] F. C. M. Lau and C. K. Tse, *Chaos-Based Digital Communication Systems*, Springer, 2003.

[5] S. Arai and Y. Nishio, “Research on noncoherent detection for chaos shift keying,” Proc. NCSP’04, pp. 265-268, Mar. 2004.

[6] S. Arai and Y. Nishio, “Research on suboptimal receivers for chaos shift keying,” Proc. NCSP’05, pp. 375-378, Mar. 2005.

[7] S. Arai and Y. Nishio, “Variable sequence length transmitter for noncoherent chaos shift keying,” Proc. NCSP’06, pp. 301-304, Mar. 2006.