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Two-Bit Modulation and Demodulation Schemes for Chaos-Based Noncohernet Communications Using Chaotic Dynamics

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Abstract

This paper proposes new modulation and demodulation schemes using a characteristics of chaos for chaos-based noncoherent communication systems. Successive chaotic signal samples are generated according to the specific rule, i.e., the chaotic dynamics. Based on the chaotic dynamics, the proposed scheme modulates 2-bit information data by the chaotic sequence and demodulates the data by using the chaotic dynamics which the incoming signal has. As results of computer simulations, we confirm that BERs of the proposed scheme show gain over a conventional noncoherent system.

1. Introduction

Chaos-based communication systems are an interesting topic in the field of engineering chaos [1]– [8]. Especially, many researchers focused on the development of noncoherent detection systems that do not need to recover basis signals (unmodulated carriers) at the receiver. Differential chaos shift keying (DCSK) [1] and the optimal receiver [2] are well-known typical noncoherent systems. Moreover, it is also important to develop a suboptimal receiver with performance equivalent to or similar to the optimal receiver using more efficient algorithms [3].

Analyzing chaotic sequence as well as its behavior is essential for improving the the performance of chaos-based communications. A Chaotic sequence is a series of non-periodic signals generated from nonlinear dynamical systems, i.e., a chaotic dynamics. These signals are sensitive to initial conditions and difficult to predict the behavior of the future from the past observational signal. Also the chaotic sequence can be generated from a simple model, such as a one-dimensional chaotic map. These characteristics are advantages of using the chaotic sequence for communication systems. Thus, we consider that the utilization of characteristics of chaos is important to improve the performance of chaos-based communication systems. In our previous research, we focused on the chaotic dynamics and proposed the error-correcting method using the chaotic dynamics. As results, we observed the better performance of the proposed error-correcting method [10]. Namely, using the chaotic dynamics is very effective for chaos-based communication systems.

In this study, we propose new modulation and demodulation schemes using the chaotic dynamics. Previously, the transmitter modulates the 1-bit information by Chaos Shift Keying (CSK) [4]. The proposed scheme modulates 2-bit information by the chaotic sequence in the transmitting side. Since successive chaotic signal samples are generated according to the chaotic dynamics, the receiver can demodulate the data by using the chaotic dynamics which the incoming signal has. We carry out computer simulations and evaluate the performance of the proposed method.

2. System Overview

Figure 1 shows the chaos-based communication system with new modulation and demodulation schemes. This system consists of a transmitter, a channel and a receiver. Each block is described in detail below.

2.1. Transmitter

In the transmitter, a chaotic sequence is generated by a chaotic map. In this study, the transmitter uses a skew tent map, a simple chaotic map, which is described by Eq. (1),

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

where a denotes the position of the peak of the skew tent map, k denotes the number of iterations. The input data is modulated by means of the chaotic sequence. To transmit each input data, N chaotic signal samples are generated,

2.2. Channel and Noise

We assume an additive white Gaussian noise (AWGN) channel with a mean of zero and a variance of $N_0 = \sigma^2$.

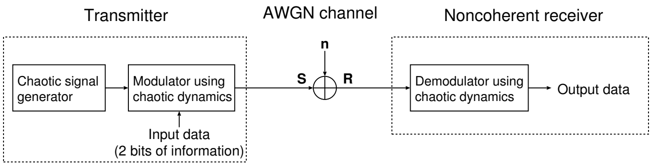


Figure 1: Block diagram of chaos-based communication system for transmitting 2-bit information.

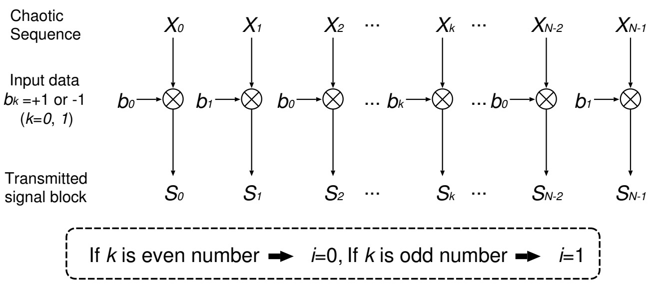


Figure 2: Operation of new modulation scheme.

The AWGN channel is the most commonly used basic channel model.

2.3. Receiver

The receiver recovers the transmitted signal from the received signal and demodulates the information data. Since we consider a noncoherent receiver, the receiver has the chaotic map used for the modulation at the transmitter in its memory. However, the initial value is not known on the receiving side.

3. New digital modulation and demodulation schemes for transmitting 2-bit information

3.1. Modulation scheme

Figure 2 shows an operation of new modulation scheme. Previously, to transmit 1-bit information, the transmitter generated N chaotic signal samples and outputted the chaotic sequence modulated by CSK. In the new modulation scheme of this study, to transmit 2-bit information ($b_i = \pm 1$ ($i = 0$ and 1)). the transmitter generates N chaotic signal samples and multiplies the even and odd samples of the its signal by b_0 and b_1, respectively, as follows Eq. 2.

$$b_i x_k = \begin{cases} b_0 x_k & \text{(If } k \text{ is even number)} \\ b_1 x_k & \text{(If } k \text{ is odd number)}\ , \end{cases} \tag{2}$$

Thus, the transmitted signal block $\mathbf{S}$ is expressed by Eq. 3.

$$\begin{aligned} \mathbf{S} &= (S_0,\ S_1,\ S_2,\ \cdots,\ S_k,\ \cdots,\ S_{N-1}) \\ &= (b_0 x_0,\ b_1 x_1,\ b_0 x_2,\ \cdots\ b_i x_k,\ \cdots,\ b_1 x_{N-1}) \end{aligned} \tag{3}$$

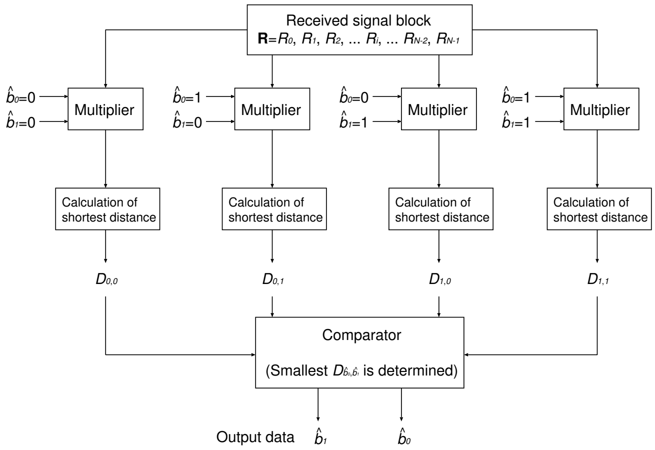


Figure 3: Block diagram of new demodulation scheme.

The transmitted signal arrives at the receiver through AWGN channel. Here, the noise signal is denoted by the noise vector $\mathbf{n} = (n_0\ n_1\ \cdots\ n_{N-1})$. Thus, the received signal block is given by $\mathbf{R} = (R_0\ R_1\ \cdots\ R_{N-1}) = \mathbf{S} + \mathbf{n}$.

3.2. Demodulation scheme

Figure 3 shows a block diagram of new demodulation scheme. First, the receiver feeds the incoming signal into four-multipliers and multiplies its signal by the projected information bits ($\hat{b}_i = \pm 1$ ($i = 0$ and 1)) which are prepared with each multiplier. Thus the received signal block is expressed by Eq. 4–5.

$$\begin{aligned} \mathbf{R} &= (R_0,\ R_1,\ R_2,\ \cdots,\ R_k,\ \cdots,\ R_{N-1}) \\ &= (\hat{b}_0 R_0,\ \hat{b}_1 R_1,\ \hat{b}_0 R_2,\ \cdots\ \hat{b}_i R_k,\ \cdots,\ \hat{b}_1 R_{N-1}) \end{aligned} \tag{4}$$

$$\hat{b}_i R_k = \begin{cases} \hat{b}_0 R_k & \text{(If } k \text{ is even number)} \\ \hat{b}_1 R_k & \text{(If } k \text{ is odd number)}\ , \end{cases} \tag{5}$$

Based each multiplied signal, the receiver measures the chaotic dynamics. In this study, we calculate shortest distances between each multiplied signal and the chaotic map for the measurement of the chaotic dynamics. The calculation method is based on our suboptimal receiver in our previous study [9].

Here, we introduce the calculation of the shortest distance. The receiver calculates the shortest distance between the received signal and the maps 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 $N_d = 2$. In this

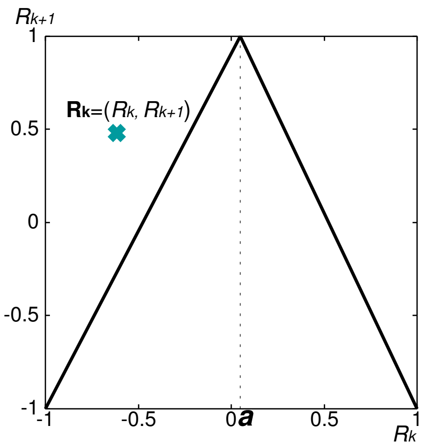


Figure 4: 2-dimensional space of skew tent map whose coordinates correspond to two successive received signal samples.

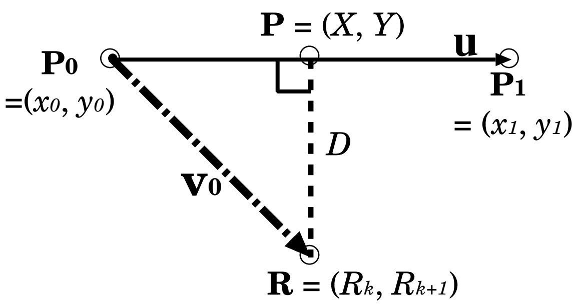


Figure 5: Calculation of shortest distance.

case, we consider two successive received signal samples $\mathbf{R} = (R_k, R_{k+1})$ as coordinate of chaotic map (Fig 4)/ To decide which map is closer to the point $\mathbf{R}$ in Fig. 4, 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. 4, as shown in Fig. 5. Using Fig. 5, the receiver can calculate the point $\mathbf{P} = (X, Y)$ closest to $\mathbf{R}$ and the shortest distance D using the following equations.

$$\mathbf{P} = (X, Y) = (\mathbf{u} \cdot \mathbf{v_0})\, \mathbf{u} + \mathbf{P_0} \tag{6}$$

$$\begin{aligned} D &= ||\mathbf{P} - \mathbf{R}|| \\ &= \sqrt{(X - R_k)^2 + (Y - R_{k+1})^2} \end{aligned} \tag{7}$$

where

$$\text{unit vector } \mathbf{u} = \frac{\mathbf{P_1} - \mathbf{P_0}}{||\mathbf{P_1} - \mathbf{P_0}||} \tag{8}$$

$$\mathbf{v_0} = \mathbf{R} - \mathbf{P_0}\ . \tag{9}$$

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

In the case of using Fig 4, there are two straight lines in the space. Therefore, the minimum value from two distances is chosen as the shortest distance D. The receiver performs these operations until the last sample (i.e., R_{N-1}) is included, and calculates the summation $\sum D$. Since we prepare four-multipliers for the receiver in this study, each multiplier outputs each different distance $D_{\hat{b_0},\hat{b_1}}$. Namely, total four-types of $D_{\hat{b_0},\hat{b_1}}$ ($D_{0,0}$, $D_{0,1}$, $D_{1,0}$ and $D_{1,1}$) are outputted.

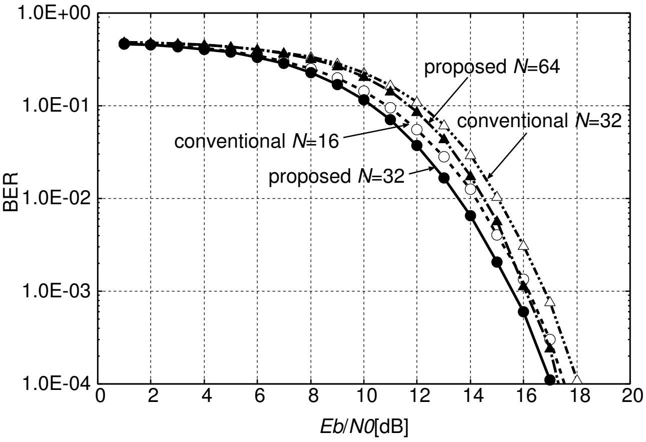
After calculating shortest distances, each $D_{\hat{b_0},\hat{b_1}}$ is fed into a comparator. The comparator selects the smallest $D_{\hat{b_0},\hat{b_1}}$ from four-distances. If the incoming signal is not influenced by the channel, the shortest distance between the chaotic map and its signal which multiplied the transmitted information bits becomes zero. The reason for this is that successive chaotic signal samples are generated according to the chaotic dynamics. Namely, when the projected information bits correspond to the transmitted information bits, the incoming signal becomes the successive chaotic signal according to the chaotic and the distance between its signal and the chaotic map becomes zero. On the contrary, since the incoming signal is not successive according to the chaotic dynamics if the projected information bits does not correspond to the transmitted information bits, the distance between its signal and the chaotic maps shows a significantly larger value than zero. Even if the incoming signal is influenced by the channel, the chaotic dynamics of its signal is kept partially although it depends on the noise level. Therefore, the comparator can output the projected information bits $\hat{b_0}$ and $\hat{b_1}$ as the decoded bits.

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

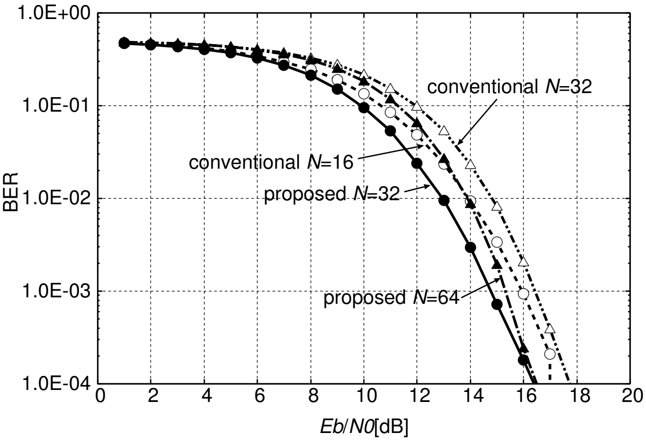
4. Simulation Results

To evaluate the proposed method, we carry out computer simulations under the following conditions. On the transmitting side, 100,000 bits are transmitted with different initial values. We assume $N = 32$ and 64, and the parameter of the skew tent map is fixed as $a = 0.05$. On the receiving side, to compare the performances for different numbers of dimensions used in the calculation of the shortest distance, we use 2-dimensional space and 4-dimensional space, i.e., $N_d = 2$ and 4. Based on these conditions, we calculate the average of BERs.

Figures 6(a) and (b) show the BER versus E_b/N_0 for the proposed method with $N_d = 2$ and 4, respectively. To observe the effectivity of the proposed method, Figs. 6(a) and (b) also show the performance of the suboptimal receiver as the conventional noncoherent scheme. Note that the BERs of the conventional scheme with half length of the sequence of the proposed method are plotted to compare the performance with the same E_b/N_0. Namely, it becomes the pair of the proposed method with $N = 32$ and the conventional



(a)



(b)

Figure 6: BER performances: (a) $N_d = 2$, (b) $N_d = 4$

scheme with $N = 16$, and the pair of the proposed method with $N = 64$ and the conventional scheme with $N = 32$.

From these results, we observe that the both BERs of the proposed method show gain over the conventional scheme. Especially, the BERs of $N_d = 4$ improves significantly. It would be said that the receiver calculates the shortest distance reflecting the chaotic dynamics due to the large successive chaotic signal. Moreover, even if we compare the performances of both methods with same E_b/N_0, the performance of the proposed method is better. Essentially, although E_b decrease if we transmit the signal with 2-bit information, the choice of data doubles as compared with the signal with 1-bit. In other words, both relationships are the trade-off. However, since the performance of the proposed method is better than that of the conventional method even if the choice of data increases, we consider that the chaotic dynamics of the incoming signal operates greatly for the demodulation. Therefore, it can be said that the proposed method is very effective as new modulation and demodulation schemes.

5. Conclusions

We have focused on the chaotic sequence according to the chaotic dynamics and have proposed new modulation and demodulation schemes using the chaotic dynamics. As results of computer simulations, it has been confirmed the effectivity of the proposed method for chaos-based noncoherent communication systems.

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