PERFORMANCE COMPARISON OF COMMUNICATION SYSTEMS USING CHAOS SYNCHRONIZATION

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ABSTRACT

In this article, the performance of some communication systems using chaos synchronization is evaluated and compared. The evaluation of bit error rate is done for not ideal communication channel but lossy and noisy one. It is confirmed that a chaos-based communication system has a good performance which may be almost the same compared with conventional analog modulation schemes.

1. INTRODUCTION

Recently chaos and its possible application to communications have received a great deal of attention. At the beginning vigorous efforts for communication schemes utilizing chaos synchronization [1]–[5] have been paid, while in the most recently studies on multiple access digital communications employing the property of wide-band and uncorrelated chaotic signals [6]–[9] have attracted attention. For realization of chaos-based communication systems, in either case, it is of significance to find or develop communication systems with a practically usable performance. In this sense performance evaluation of chaos-based communication systems and those comparison are very important. However performance comparison of chaos-based communication systems have been reported only in [6],[9]. Further it has been pointed out that chaos synchronization can not be used for communications because of the effect of a noisy and band-limited channel [6],[7]. However this has not been confirmed for all communication systems using chaos synchronization.

Therefore in this study we evaluate the performance of some communication systems using chaos synchronization and compare them in order to confirm whether the assertion is true or not and which system has best performance. As examples of communication systems using chaos synchronization, the chaotic masking [1], chaotic coding [2] and chaotic modulation [3],[4] systems are taken in this article, which are shown in Figs. 1–3. In order to consider the attenuation, impedance mismatch and noise of real communication channels, we use a channel model shown in Fig. 4. In this model, a transmission line is matched with its matching impedance, where an additive white Gaussian noise is added to the transmission signal similarly to [7],[9]. An amplifier is to compensate the effect of attenuation as in [10].

For the performance evaluation the bit error rate (BER) is simulated for not lossy and noisy communication channel but ideal one, because the BER of chaos-based communication systems is not always zero even for noise-free case. The BER evaluation of three systems is done and it seems that the performance of chaotic coding and modulation systems are as good as that of conventional analog communication schemes.

2. CHAOTIC COMMUNICATION SYSTEMS

The circuit configurations of the chaos-based communication systems investigated in this article are shown in Figs. 1–3.

In the chaotic masking system [1] shown in Fig. 1, an information signal $s(t)$ is masked by chaotic signal v_{C1} generated by the transmitter and then transmitted. Subtracting the signal v'_{C1} reproduced by the receiver from the received signal, the information $s'(t)$ can be recovered if the transmitter and receiver synchronize.

In the chaotic communication system [2], an information signal $s(t)$ is coded by the chaotic signal v_{C1}. The system using a coding function $c = v_{C1} + s(t)$ is shown in Fig. 2. The modulated signal $v_R(t)$ is transmitted to the receiver. The information signal can be recovered as the potential $s'(t)$ when the transmitter and receiver synchronize. We call the system chaotic coding system to discriminate from chaotic modulation system [3],[4].

In the chaotic modulation system [4] shown in Fig. 3, a current signal $i_i(t)$ which depends on an information signal $s(t)$ is injected into the transmitter and modulates the chaotic signal v_{C1}. The modulated signal v_{C1} is then transmitted to the receiver and the recovery of information can be achieved by detecting the current $i_d(t)$ flowing into the receiver.

The transmitter and receiver in all systems are constructed by Chua's circuit and connected with a communication channel. In the systems we can expect that if the channel is lossless, perfectly matched and noiseless then the transmitters and receivers will synchronize. But real communication channels are lossy, noisy, and often imperfectly matched, the performance of the systems must be evaluated under such conditions. For the purpose proper channel models are required. In [7],[9] AWGN (additive white Gaussian noise) channel models have been used. We will use a model as shown in Fig. 4. This model contains a transmission line and its matching impedance. The transmission line is further modeled by convenient models [11],[12] shown in Fig. 5 which are widely used for the transient simulation of transmission lines. An additive white Gaussian noise is added to the transmission signal similarly to [7],[9]. An amplifier is to compensate the effect of attenuation as in [10].

In order to evaluate the performance fairly we fix the parameters of Chua's circuit in all systems as follows:

$$\begin{array}{l} R = 1/G = 1700[\Omega],\ C_1 = 10[\text{nF}],\ C_2 = 100[\text{nF}], \\ L = 18[\text{mH}],\ m_0 = -0.75[\text{mS}],\ m_1 = -0.41[\text{mS}], \\ B_p = 1[\text{V}] \end{array} \quad (1)$$

and the line parameters:

$$\begin{array}{l} R_d = 20[\Omega/\text{km}],\ L_d = 0.25[\text{mH/km}], \\ C_d = 100[\text{nF/km}],\ G_d = 0[\text{S/km}] \end{array}$$

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The value of matching impedance is calculated by the following equation.

$$Z_m = |Z_0(j\omega)| = \left| \sqrt{\frac{R_d + j\omega L_d}{G_d + j\omega C_d}} \right|$$

3. PERFORMANCE COMPARISON

In this section we investigate the bit error rate (BER) for the performance evaluation of the systems. The performance is evaluated for not only lossy and noisy communication channel but also ideal one, because the BER of chaos-based communication systems is not always zero even for noise-free case. In all of evaluations we simulate the systems using fourth order Runge-Kutta method where a bit sequence with 10^4 bits is transmitted as information signal.

First the ideal BER performance of the communication systems is evaluated for ideal channel (i.e. the channel is lossless, perfectly matched and noiseless). The channel parameters are $Z_0 = Z_m = 50[\Omega]$, τ =0.5[msec] and $K = 1$, where K is the gain of the amplifier. The ideal performance is shown in Fig. 6 The chaotic masking system can cause undesirable transients at bit switching of information digital signal, which often result in desynchronization (bit error). So a low-pass filter (LPF) is introduced in order to reduce the transients and its output is used for the BER evaluation. Note that it is not shown in Fig. 1. In the chaotic coding system the BER for smaller amplitude is only shown because the system became unstable for larger one. In contrast to the chaotic coding system, only larger amplitude is used for the chaotic modulation system. In the system the quantity $C_1 dv'_{C1}/dt$ in the receiver must be estimated to detect the current i_d in the simulation. We can evaluate it only by applying difference approximation, but this caused "spike-like" error in the recovered signal when $|dv'_{C1}/dt|$ becomes larger. Smaller amplitude is affected fairly by this error, thus relatively larger amplitude is used.

In the chaotic masking system the BER becomes better if bit rate is lower. On the other hand, in the chaotic coding and modulation systems, the BERs are less than 10^{-4} and remain unchanged for the change of amplitude and bit rate. They have a good performance for ideal conditions.

Next noise performance for the carrier-to-noise ratio (CNR) is evaluated regarding the chaotic signal generated in the transmitters with no input signal as the carrier signal. In general the signal-to-noise ratio (SNR) is used for performance evaluation, but the average power of information signal in the three systems is different because of the above mentioned reason. Consequently the performance comparison using SNR is not fair, thus we prefer to use CNR than SNR. For the parameters of transmitter (1) the average power of the carrier in all systems is about 3.586. Also it can be expected that the recovered signals are affected by noise and so on, thus a LPF is introduced in order to reduce such effects. The LPF with the time constant 0.2[msec] is used for the following BER estimation, which is not shown in Figs. 1–3.

In the estimation of noise performance, 1[km] lossy transmission line is used, where the number of cells N is 25 and the gain K is 1.06. Fig. 7 shows the BER obtained. Further the performance for small parameter mismatch on linear resistor R is also investigated and illustrated, because it is difficult to match perfectly the component values of the transmitter and receiver in real circuits. For larger noise level the chaotic masking system has a best performance, while the performance of the chaotic coding and modulation systems become better as noise decreases. In particular the BERs of the chaotic coding and modulation systems are less than 10^{-4} for CNR 40[dB] and over, similarly to ideal case. Moreover this is also applied to the case that there is a small parameter mismatch between the transmitter and receiver. It is generally said that the SNR required to get BER 10^{-6} in analog communication is about 60[dB]. Therefore the chaotic coding and modulation systems may have almost the same performance as analog communication schemes, but this must be confirmed with increasing transmission bits at least by 10^6. In the point of implementation the chaotic modulation system has advantages, because the chaotic coding system has the current-controlled dependent source and it is difficult to realize ideal one.

4. CONCLUSIONS

In this article we have evaluated the performance of some communication systems using chaos synchronization and compared them. The chaotic coding and modulation system have a good performance even if their parameters have a small mismatch. The chaotic modulation system has advantages in the sense of good quality and facility for realization.

We intend to evaluate the performance of other chaos-based communication systems, e.g., chaotic inverse system.

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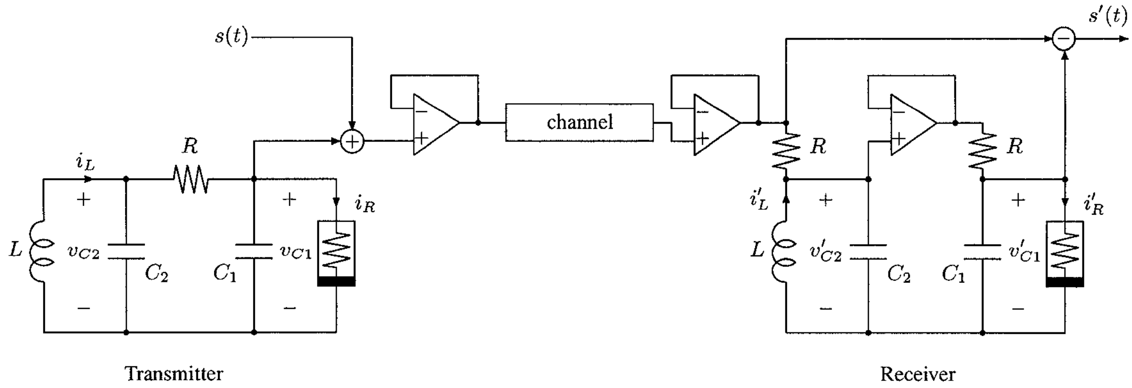

Figure 1: Chaotic masking system.

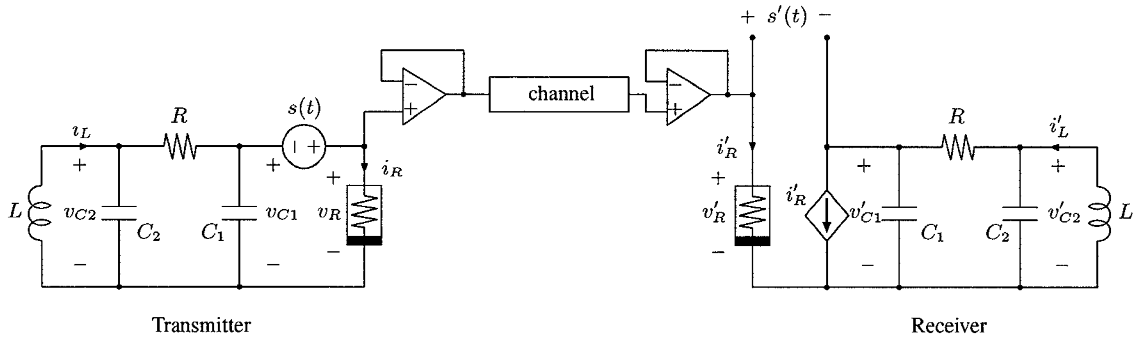

Figure 2: Chaotic coding system. The diamond shaped current source is a current-controlled dependent source.

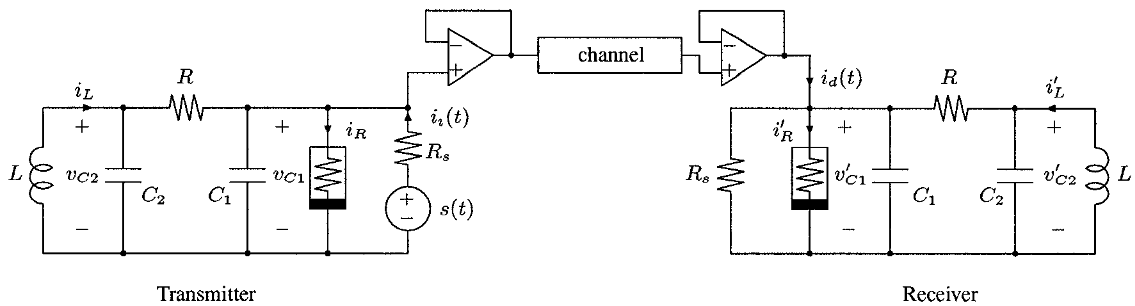

Figure 3: Chaotic modulation system.

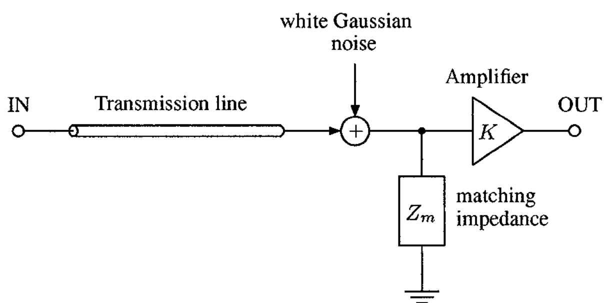

Figure 4: Channel model using transmission line.

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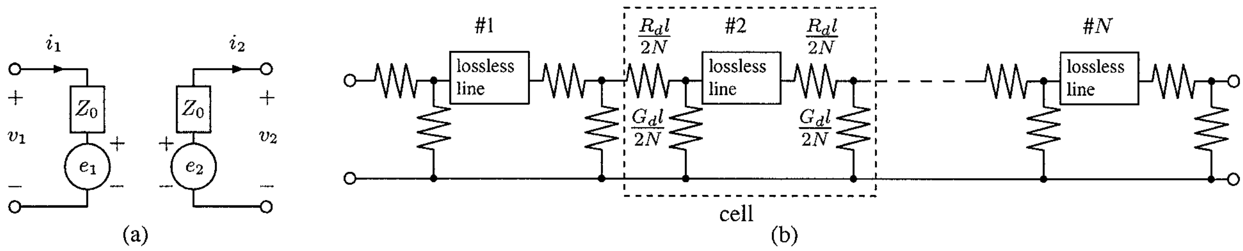

Figure 5: (a) Characteristic model of lossless transmission line and (b) modeling of lossy transmission line.

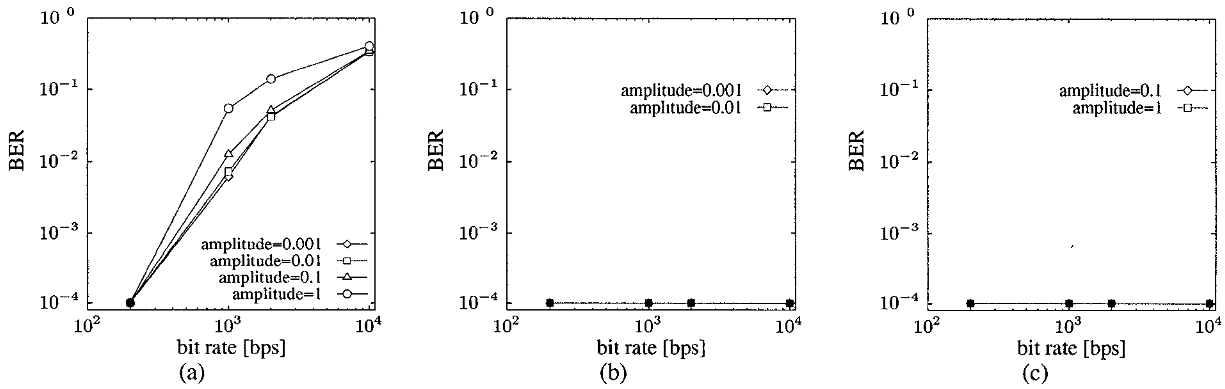

Figure 6: Ideal performance in the chaotic communication systems. (a) chaotic masking system, (b) chaotic coding system, (c) chaotic modulation system. For only chaotic masking system a LPF with the time constant 0.2[msec] is used. The dark shaded mark denotes a BER *less than* 10^{-4}.

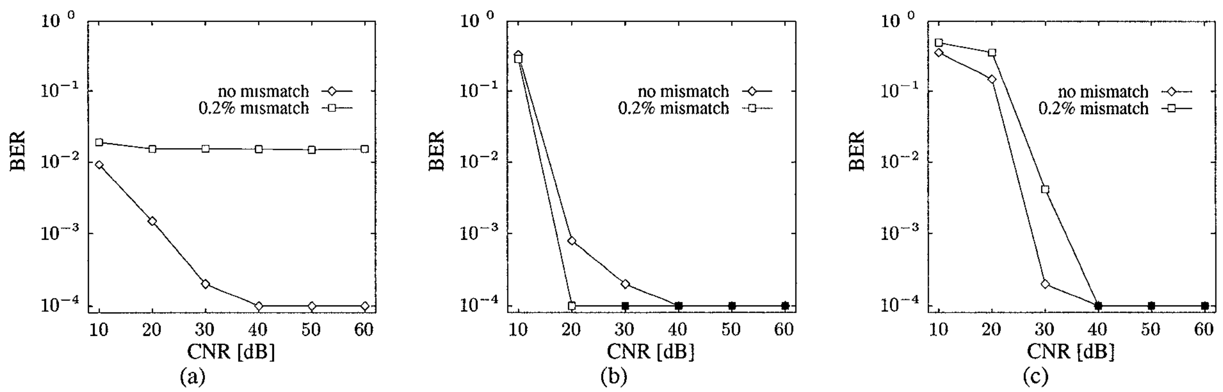

Figure 7: Noise performance in the chaotic communication systems. (a) chaotic masking system (amplitude=0.1[V], bit rate=200[bps]), (b) chaotic coding system (amplitude=0.01[V], bit rate=2000[bps]), (c) chaotic modulation system (amplitude=0.5[V], bit rate=2000[bps]). For all systems a LPF with the time constant 0.2[msec] is used. The dark shaded mark denotes a BER *less than* 10^{-4}.