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Study of Anti-Jamming Capabilities of Chaotic Digital Communication Systems

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Abstract

Chaos-based communication systems are known to offer advantages that are shared by spread-spectrum communications. One important aspect of performance of any spread-spectrum communication system is the ability to resist jamming. This area of study, however, is not available in the literature. In this paper, the anti-jamming performance of the coherent CSK system is presented. Two common types of jammers are studied, namely single-tone jammers and pulsed-noise jammers. Analytical bit error rates are derived and verified by computer simulations.

Index Terms — Chaos communication, chaos-shift-keying, anti-jamming.

1. Introduction

A decade ago, chaos-based communication systems began to receive attention from both the system theory and communication research communities [1]–[3]. Much of the work has focused on the basic modulation processes and the noise performance assuming ideal channel conditions. The ability to resist jamming, though is an important aspect of performance, has not been thoroughly studied. Jamming signals come in various different forms, e.g., single-tone jammer, multiple-tone jammer, partial-band jammer, pulsed-noise jammer, etc.

In this paper, we investigate the performance of chaos-based digital communication system when the channel is subject to a jamming signal as well as additive white Gaussian noise. Fig. 1 shows a block diagram of the system under study. Instead of studying the bandpass system shown in Fig. 1 directly, we transform the bandpass system to an equivalent baseband model and analyse the system using discrete time analysis. Specifically, the coherent chaos-shift-keying (CSK) system will be studied and two common types of jamming signals, namely single-tone jammer and pulsed-noise jammer, will be considered.

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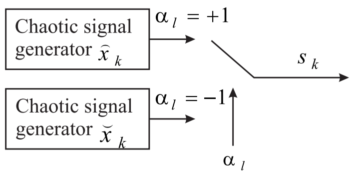
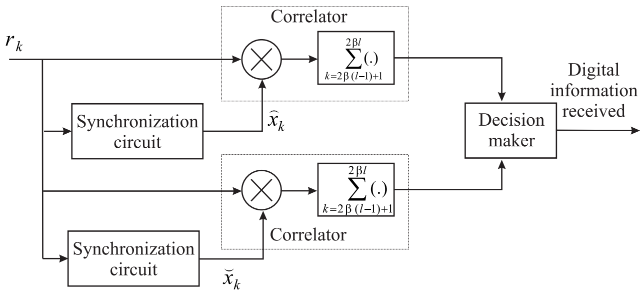


(a)



(b)

Fig. 2: Block diagram of a coherent CSK system: (a) transmitter; (b) receiver.

2. Coherent Chaos-Shift-Keying System

In a coherent CSK system, the receiver has the information of the chaotic signal that carries the information [4]. This is often achieved through a so-called chaos synchronization process. Thus, the detection method for a coherent system involves a correlation process operated upon the received signal and the known (reproduced) chaotic signal at the receiver.

We consider a discrete time binary CSK communication system, as shown in Fig. 2. For simplicity, we consider a CSK system in which one chaos generator is used to produce chaotic signal samples $\{x_k\}$. The two possible transmitted sequences are $\{\hat{x}_k = x_k\}$ and $\{\check{x}_k = -x_k\}$. Suppose $\alpha_l \in \{-1, +1\}$ is the symbol to be sent during the lth bit period and assume that "-1" and "$+1$" occur with equal probabilities. Define the spreading factor, 2β, as the number of chaotic samples used to transmit one binary symbol. During the lth bit duration, i.e., for time $k = 2(l-1)\beta + 1, 2(l-$

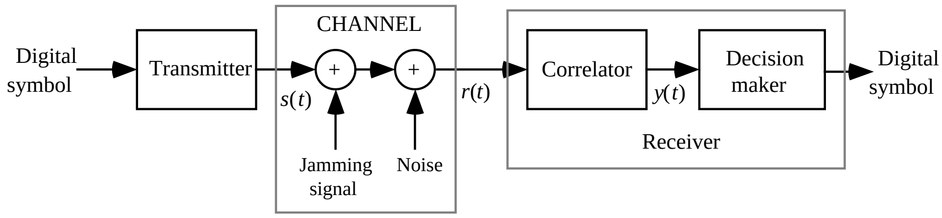


Fig. 1: Block diagram of a chaotic communication system with jamming and noise added.

$1)\beta + 2, \ldots, 2l\beta$, the output of the transmitter is $s_k = \alpha_l x_k$. The received signal is given by $r_k = s_k + u_k + \eta_k$ where u_k represents the jamming signal and η_k is a Gaussian noise sample of zero mean and variance (power spectral density) $\frac{N_0}{2}$.

Assuming that a correlator-type receiver is employed, the correlator output for the lth bit, y_l, is given by

$$\begin{aligned} y_l &= \sum_{k=2\beta(l-1)+1}^{2\beta l} r_k x_k \\ &= \underbrace{\alpha_l \sum_{k=2\beta(l-1)+1}^{2\beta l} x_k^2}_{\text{required signal}} + \underbrace{\sum_{k=2\beta(l-1)+1}^{2\beta l} x_k u_k}_{\text{jamming signal}} \\ &\quad + \underbrace{\sum_{k=2\beta(l-1)+1}^{2\beta l} \eta_k x_k}_{\text{noise}} . \end{aligned} \tag{1}$$

Depending upon y_l is larger than or less than zero, a "$+1$" or "-1" is decoded, respectively.

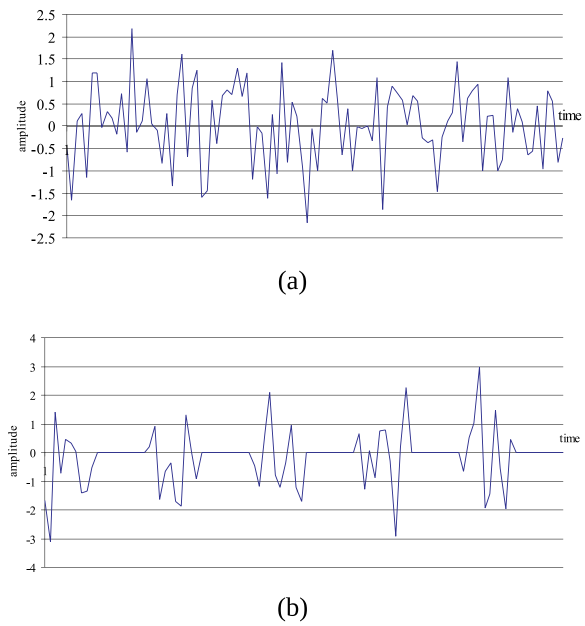


Fig. 3: Pulsed-noise jamming signal. (a) $\rho = 1.0$; (b) $\rho = 0.5$.

3. Types of Jammers

Two types of jammers, namely single-tone jammers and pulsed-noise jammers are studied. The characteristics and modelling of the jammers are briefly described below.

3.1. Single-Tone Jammer

A single-tone jammer, easily generated by an oscillator, is a sinusoidal wave whose frequency lies within the bandwidth of the signal being jammed (chaotic signal in our case). The objective of the single-tone jammer is to disrupt any narrow-band communication.

In the baseband model, the sinusoidal jammer is modelled by a sine wave of power P_{jam} and frequency f. At discrete time mode, it is further represented by $u_k = \sqrt{2P_{\text{jam}}} \sin\left(2\pi k \frac{F}{2\beta}\right)$ where F is the normalized jamming frequency defined as $F = fT_b$, T_b represents the bit duration, and θ is the initial phase angle of the jamming signal and is assumed to be an arbitrary constant angle selected from $[-\pi, \pi]$.

3.2. Pulsed-Noise Jammer

A pulsed-noise jammer is a wideband jamming source which turns on and off periodically. The philosophy of the pulsed-noise jammer is to concentrate the jamming power during the "on" time to severely disrupt a spread-spectrum communication system. The duty factor, ρ, is the fraction of time during which the jammer turns on.

We assume that the pulsed-noise jammer transmits pulses of bandlimited white Gaussian noise having total average power P_j. Also, the jamming signal occupies the same bandwidth as the chaotic signal. As mentioned before, the pulsed-noise jammer concentrates its power during the "on" time to disrupt the spread-spectrum communication system. Since the jammer turns on for a fraction ρ of the time and the average jamming power is P_j, as defined earlier, the jamming power equals $\breve{P}_j = P_j/\rho$ when the jammer is turned on. Figs. 3 (a) and (b) compare the transmitted waveforms when $\rho = 1.0$ and $\rho = 0.5$. Two types of pulsed-noise jammers are considered, namely slowly switching and fast switching jammers.

3.2.1. *Slowly Switching Jammer*

For a slowly switching jammer, the frequency at which the jamming signal switches between "on" and "off" is much lower than the bit frequency of the information signal. That is to say, the period in which the jamming signal stays on or off is much longer than the bit duration. In this case, if a particular transmitted symbol is jammed, it is jammed for the whole symbol duration. The probability of a particular symbol being jammed is thus equal to ρ.

The jammed noisy signal arriving at the receiver is thus modelled by $r_k = s_k + v_k + \eta_k$, where v_k represents the jamming signal, which is Gaussian with zero mean. The variance of v_k is $\breve{P}_j = P_j/\rho$ when the jammer is turned on, and is zero when the jammer is off.

3.2.2. *Fast Switching Jammer*

For a fast switching jammer, within each symbol period, the jammer is turned on for a fraction ρ of the symbol period and is off for the remaining symbol period. In this case, all transmitted CSK symbols are affected by the jamming signal for a fraction ρ of the symbol period. Assume that $\lambda = \rho\beta$ where λ is an integer. Consider the lth symbol duration. The jamming signal u_k is now given by

$$u_k = \begin{cases} w_k & \text{for } k = (l-1)\beta + 1, \ldots, (l-1)\beta + \lambda \\ 0 & \text{for } k = (l-1)\beta + \lambda + 1, \ldots, l\beta \end{cases} \qquad (2)$$

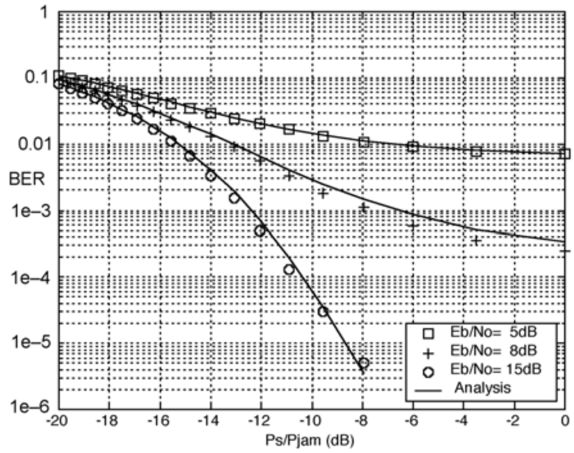
where w_k is a Gaussian random variable with zero mean and variance $\breve{P}_j = P_j/\rho$.

4. Simulation Results and Discussions

Chebychev maps [5] have been used to generate the chaotic sequences. Assuming normal distribution on the conditional correlator output y_l, the analytical expressions for the bit error rates (BERs) can be derived. Due to the limitation of space, they are not presented here but will be plotted and compared with the simulation results.

4.1. Single-Tone Jammer

The relevant simulated BERs for the coherent CSK system are shown in Fig. 4. As expected, the BER generally decreases (improves) as the jamming power decreases. Further, it can be observed that the jamming frequency has little effect on the BER, and in general, a larger spreading factor improves the anti-jamming performance of the coherent CSK system.



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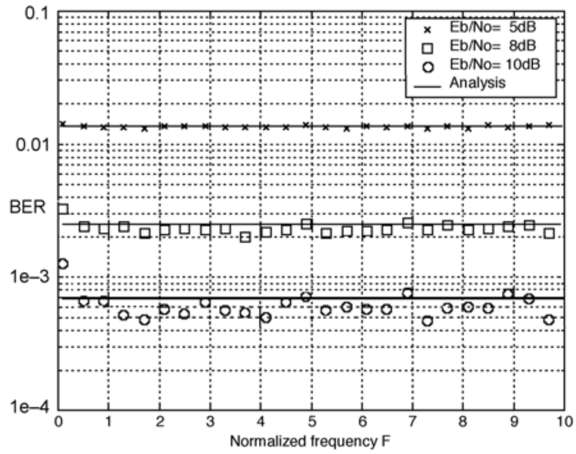

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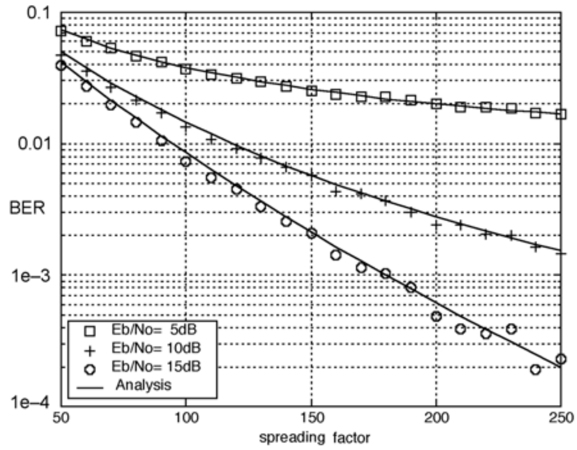

(c)

Fig. 4: BER of the coherent CSK system under a single-tone jammer. Simulated BER's are plotted as points and analytical BER's plotted as lines. (a) BER versus P_s/P_{jam}. Average E_b/N_0 is 5, 8 and 15 dB. Spreading factor is 200. Normalized jamming frequency is 3.12735. (b) BER versus the jamming frequency. Average E_b/N_0 is 5, 8 and 10 dB. Jamming level P_s/P_{jam} is –9.54 dB. Spreading factor is 200. (c) BER versus the spreading factor. Average E_b/N_0 is 5, 10 and 15 dB. Jamming level P_s/P_{jam} is –12.04 dB.

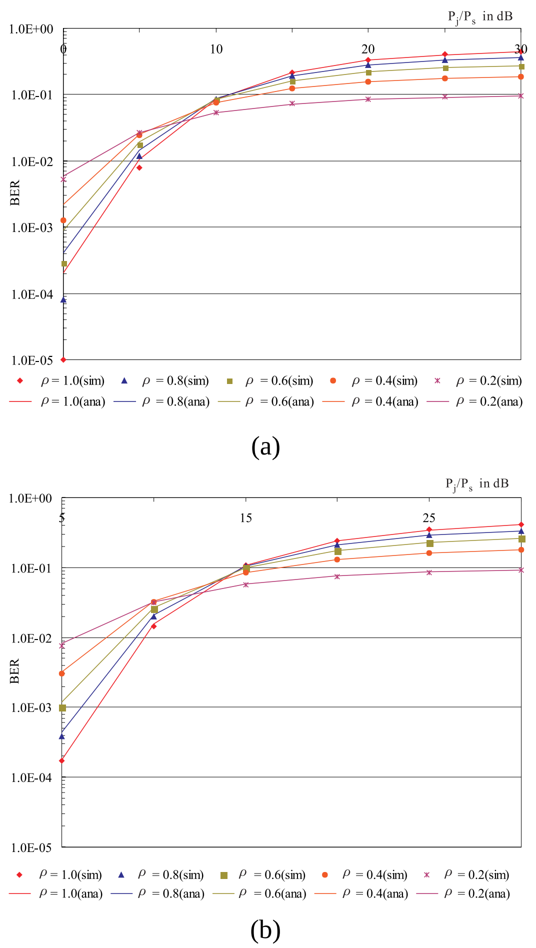

Fig. 5: BERs versus P_j/P_s of the coherent CSK system with a slowly switching pulsed-noise jammer. Simulated BERs are plotted as points and analytical BERs plotted as lines. E_b/N_0 = 20 dB and ρ = 0.2, 0.4, 0.6, 0.8 and 1.0. (a) Spreading factor is 20; and (b) spreading factor is 50.

4.2. Slowly Switching Jammer

Fig. 5 shows the BERs versus P_j/P_s for different duty factors ρ. Here, we fix E_b/N_0 at 20 dB. From Fig. 5, we observe that the BERs generally increase as P_j/P_s increases (higher jamming power). Also, the BERs improve (decrease) when the spreading factor increases. Note the user of different scales in the x-axis. Furthermore, the analytical BERs agree very well with the simulation results. This is because the validity of the assumption of normal distribution of the conditional correlator output holds better for higher spreading factors.

4.3. Fast Switching Jammer

In Fig. 6, the simulated BERs versus P_j/P_s for different ρ are plotted. From the figure, we observe that the simulated

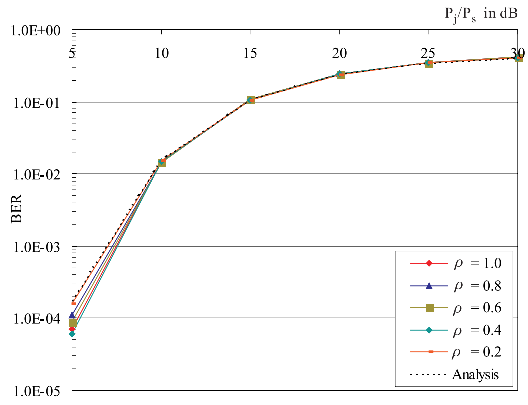

Fig. 6: BERs versus P_j/P_s of the coherent CSK system with a fast switching pulsed-noise jammer. E_b/N_0 = 20 dB and ρ = 0.2, 0.4, 0.6, 0.8 and 1.0. Analytical BER is independent of ρ. Spreading factor is 50.

BERs are independent of the duty factor ρ. Further, the simulated and analytical BERs agree.

5. Conclusion

Chaos-based communication has aroused considerable interest in the past few years both in physics and engineering research communities. Noise performance has been studied for many different types of systems. Rarely studied but certainly of interest is the anti-jamming capability of these systems. This paper attempts to fill this gap by presenting the results of the anti-jamming performance of a chaos-based digital communication system. The specific system studied is the coherent chaos-shift-keying system. From these results, useful design data for chaos-based digital communication systems can be obtained.

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