EVALUATION OF BIT-ERROR-RATE PERFORMANCE FOR DCSK SYSTEM OVER LAND MOBILE SATELLITE CHANNEL

ĐÁNH GIÁ HIỆU NĂNG TỶ LỆ LỖI BIT CỦA HỆ THỐNG DCSK QUA KÊNH VỆ TINH DI ĐỘNG MẶT ĐẤT

Doan Thi Que, Nguyen Trong Thai, Nguyen Xuan Quyen, Hoang Manh Thang

School of Electronics and Telecommunications, Hanoi University of Science and Technology,
quedt@hnue.edu.vn, quyen.nguyenxuan@hust.edu.vn; thang.hoangmanh@hust.edu.vn

Abstract - In chaos-based digital communications, the differential chaos-shift keying (DCSK) system has been widely studied owing to its non-coherent demodulation without any synchronization. To date, BER performance of this system is investigated over various transmission channels such as noise, fading, multipath, and optical fiber. In this paper, for the first time, the BER performance of conventional DCSK system is evaluated over a land mobile satellite channel. The Lutz channel model with two-state, i.e., the best proper model, for describing satellite environments as well as the discrete-time model of DCSK transmitter and receiver are demonstrated and analyzed. In particular, the probability density functions (PDFs) of random processes in the channel model are defined and verified by comparing with the computed functions. The studied system with specific parameters is built up by means of a numerical simulation platform on PC. Evaluatation for the system performance in terms of BER values against Eb/N_0, channel states, spreading factor, and used chaotic maps.

Key words - chaos-based spread modulation; differential chaos shift keying; DCSK; land mobile satellite channel; Lutz channel model.

Tóm tắt - Trong truyền thông số sử dụng hỗn loạn, hiệu năng của hệ thống khóa dịch hỗn loạn vi sai (DCSK) đã được nghiên cứu nhiều. Cho tới nay, hiệu năng BER của hệ thống được khảo sát qua các kênh truyền dẫn khác nhau như kênh nhiễu, fading, đa đường, và cáp quang. Trong bài báo này, lần đầu tiên trình bày đánh giá BER của hệ thống DCSK qua kênh vệ tinh di động mặt đất được nghiên cứu. Mô hình kênh Lutz, mô hình thích hợp nhất để mô tả các môi trường vệ tinh, cũng như mô hình rời rạc của máy phát và máy thu DCSK được trình bày và phân tích. Cụ thể, các hàm mật độ xác suất của các quá trình ngẫu nhiên trong mô hình kênh được xác định và kiểm chứng thông qua so sánh với các kết quả tính toán số. Hệ thống đề xuất với các thông số cụ thể được xây dựng trên mô phỏng trên máy tính. Hiệu năng hệ thống sẽ được đánh giá theo mối quan hệ của BER theo Eb/N_0, trạng thái kênh, hệ số trải phổ, và các hàm hỗn loạn sử dụng.

Từ khóa - điều chế trải phổ dựa trên hỗn loạn; khóa dịch hỗn loạn vi sai; DCSK; kênh vệ tinh di động mặt đất; mô hình kênh Lutz.

1. Introduction

In the past two decades, spread-spectrum modulation schemes based on chaos have been received a great attention in wireless communication applications due to their good anti-fading, anti-jamming and transmission security capabilities [1]. These schemes are relied on the use of chaotic signal sequences generated by a nonlinear dynamical system with non-periodic, inherent wide-band characteristic, and sharp auto-correlation and low cross correlation values to carry data sequences. Among all the chaos-based modulation schemes, differential chaos shift keying (DCSK) [2] can achieve not only good performance in maltipath propagation environments [3] but also simple hardware implementation [4]. Therefore, beside the conventional CDMA technique, the DCSK-based schemes have been considered to be effective solutions for spread-spectrum communications.

So far, the theoretical performance of DCSK system have been investigated over various channel environments, such as Additive white Gaussian noise (AWGN), Rician and Rayleigh fading channels [5], [6], [7]. Lots of studies have focused on investigation of DCSK-based schemes accompaning with crucial wireless techniques as MIMO, OFDM, and UWB [8]. Currently, the DCSK-based systems are being considered as very good candidates for low power and low complexity for wireless communication applications, e.g. wireless personal area networks (WPANs) and wireless sensor networks (WSNs) [4]. Investigation of the DCSK-based systems over the land mobile satellite (LMS) channel has not been studied so far.

In this paper, we study the BER performance of the DCSK sytem over the land mobile satellite channel. Firstly, the land mobile satellite channel model, the Lutz model is presented. Then, the discrete-time model of the DCSK transmitter and receiver is given and analyzed. Finally, the BER performance of the system is obtained by the numerical simulation.

2. Land mobile satellite channel model

In this section, we consider a land mobile satellite channel model with a fading factor s. Several satellite channel models have been proposed such as Loo, Corazza, Lutz, Nakagami, and Norton models [9]. Based on the investigation in [9], the Lutz model is the most proper to describe all mobile environments. It is noted that Lutz et al. [10] introduced the two-state model, i.e., good and bad state, whose block diagram is shown in Fig. 1.

In the good state, the received signal is affected by the clear line of sight (LOS) and multipath components. In this case, the channel characteristics can be described as the Rician process and the probability density function (PDF) of the envelope s of the received signal can be expressed by

$$p_{Rice}(s) = \frac{s}{\sigma^2}.exp\left[-\frac{(s^2+C^2)}{2\sigma^2}\right].I_0(\frac{sC}{\sigma^2}), \quad (1)$$

where σ^2 is the average power of the multipath components; $I_0(.)$ is the modified zero-order Bessel function; and C is the amplitude of the LOS path. In literature, the Rician distribution is usually specified by the parameter K, i.e., the Rician factor, which is given by

$$K = 10\,log\left(\frac{c^2}{2\sigma^2}\right)[dB]. \quad (2)$$

In the bad state, the LOS path is shadowed by obstacles and the multipath components are affected by the shadowing effect. The channel characteristics in the case can be presented by the Suzuki model combined by the Rayleigh and Lognormal processes. The PDF of the envelope s of the received signal is determined by

$$p_{Suzuki}(s) = \frac{s}{\sigma_M\sigma^2\sqrt{2\pi}}\int_0^{\infty}\frac{1}{y^3}exp\left(-\frac{s^2}{2y^2\sigma^2}\right).exp\left(-\frac{\left(ln(y)-m_\mu\right)^2}{2\sigma_\mu^2}\right)dy, \quad (3)$$

where σ_μ and m_μ are respectively the standard deviation and mean of the shadowed component ($ln(s)$); σ^2 is the average power of multipath components related to the Rayleigh process. The Rayleigh process is usually specified by the Rayleigh parameter $\bar{K}$, which is presented by

$$\bar{K} = 10\,log\left(\frac{1}{2\sigma^2}\right)[dB]. \quad (4)$$

In a two-state model, the PDF of the overall received signal envelope is defined as

$$p_{Lutz}(s) = (1-A).p_{Rice}(s) + A.p_{Suzuki}(s) \quad (5)$$

where A is the probability of bad-state.

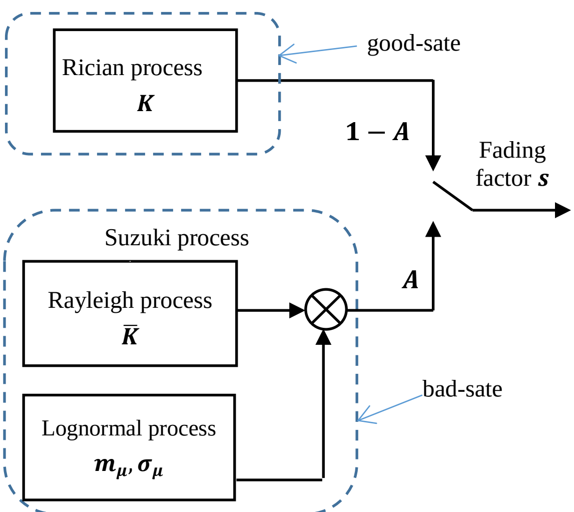

***Figure 1.** The block diagram of Lutz channel model.*

3. Discrete-time Modeling of the DCSK communication System

Figure 2 shows the block diagram of the studied communication system which consists of DCSK transmitter, two-state channel, and DCSK receiver.

3.1. Model of DCSK transmitter

The chaotic sequence $\{x_k\}$ at the output of the chaotic generator is produced by a chaotic map $F(.)$, $x_k = F(x_{k-1})$, where x_k is the value of the chaotic sequence at the k^{th} step.

In the DCSK transmitter as depicted in Figure 2(a),, each bit duration is divided into two equal time slots. In the first slot, chaotic reference sequences are transmitted. Depending on the transmitted data bit as $\{+1\}$ or $\{-1\}$, the copied version or the converted version of reference sequences are transmitted in the second slot. The output signal of the DCSK modulator is the sum of the reference and data-bearing sequences. Let 2β be the spreading factor in the DCSK system, defining the number of chaotic samples sent for each bit; β is an integer. During the i^{th} bit duration, the output signal of the transmitter e_k is

$$e_k = \begin{cases} x_k, 1 \le k \le \beta, \\ b_i.x_{k-\beta}, \beta < k \le 2\beta, \end{cases} \quad (6)$$

where $x_{k-\beta}$ is the delayed version of the reference sequence x_k, $b_i = \{\pm 1\}$ is binary value of the i^{th} bit.

3.2. Model of communication channel

The channel model is composed of the Lutz channel model and additive white Gaussian noise (AWGN) depicted in Figure 2 (b). The output signal of the channel corresponding to the k^{th} transmitted symbol can be expressed by

$$r_k = s.e_k + n_k, \quad (7)$$

where e_k is the transmitted signal corresponding to the k^{th} information symbol, n_k is additive Gaussian noise with a single-side power spectral density $N_0/2$ and the fading factor s is a random variable with its PDF given by Eq. (5).

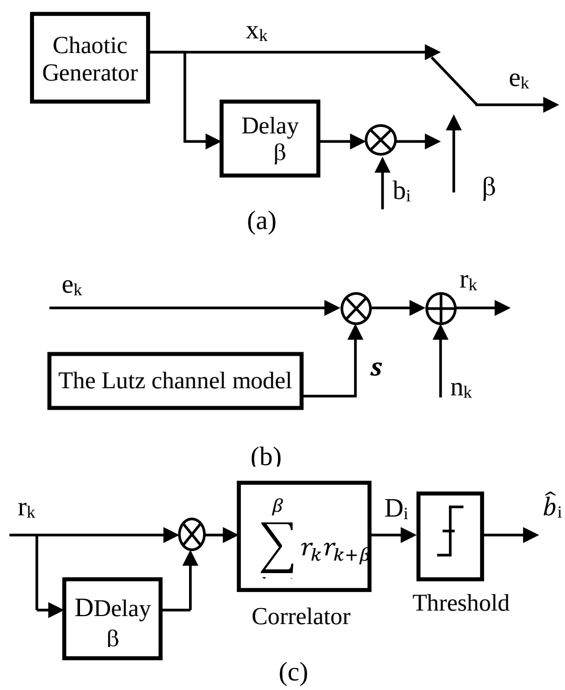

***Figure 2.** The block diagram of the DCSK system:*
(a) the DCSK transmitter; (b) Communication channel;
(c) the DCSK Receiver

3.3. Model of DCSK receiver

As depicted in Figure 2(c), the received signal r_k is correlated to a delayed version of the received signal $r_{k+\beta}$ and summed over a half bit duration T_b (where $T_b = 2\beta T_c$ and T_c is the chip duration) as follows:

$$D_i = \sum_{k=1}^{\beta} r_k.r_{k+\beta}. \quad (8)$$

Based on Eqs. (6), (7) and (8), we have

$$D_i = \sum_{k=1}^{\beta}(s.x_k + n_k).(s.b_i.x_k + n_{k+\beta}) \quad (9)$$

The observation signal at the output of the correlator, D_i, is used to recover the i$^{\text{th}}$ received data bit according to the following rule:

$$\hat{b}_i = \begin{cases} +1, if\ D_i > 0, \\ -1, if\ D_i < 0. \end{cases} \quad (10)$$

4. Simulation of Lutz channel model

As mentioned in Section 2, the Lutz channel model is mixed by Rician, Rayleigh and Lognormal processes. For wireless channel characteristics, these processes can be achieved by Gaussian random processes which are presented in detail in [11].

Simulink block diagrams of Rician, Rayleigh and Lognormal processes are shown in Figure 3, Figure 4 and Figure 5, respectively, where Gaussian random process is generated by the Random Number Generator.

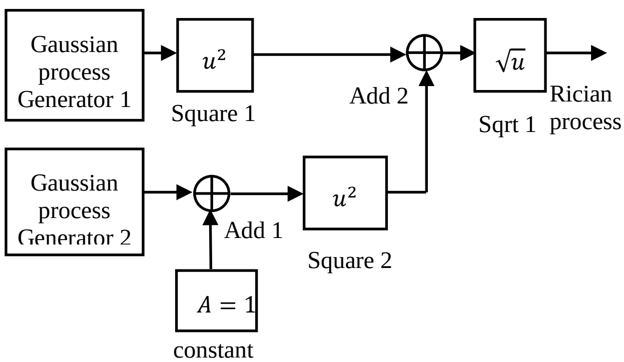

Figure 3. *Simulink of Rician process*

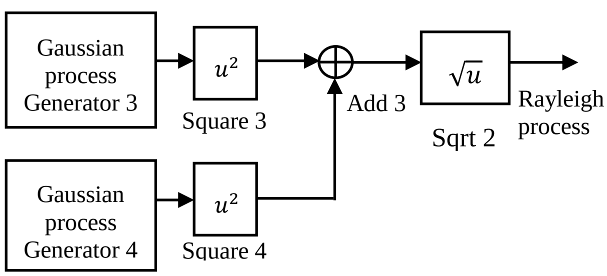

Figure 4. *Simulink of Rayleigh process*

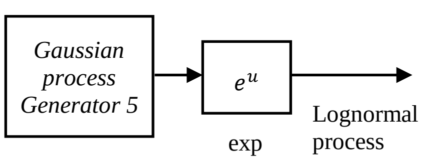

Figure 5. *Simulink of Lognormal process*

To verify the simulation channel model, we make a comparison between the PDFs of the random processes in the simulation and analytical models. Figures 6, 7 and 8 respectively illustrate the PDFs of the Rician, Suzuki and Lutz process. These results point out that the PDFs of random processes computed by Simulink totally agree with those in the analytical model.

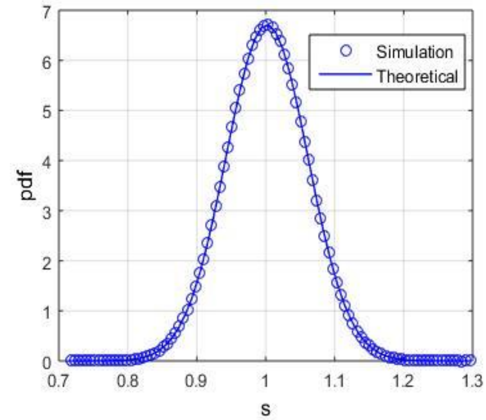

Figure 6. *PDFs of Rician processes*

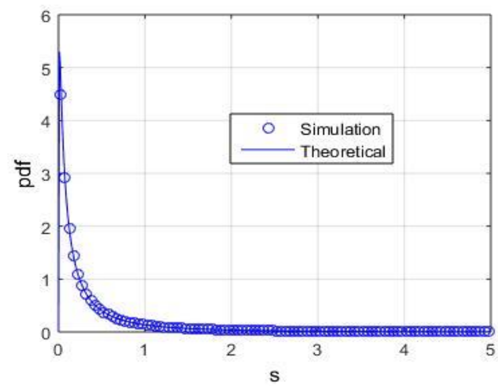

Figure 7. *PDFs of Suzuki processes*

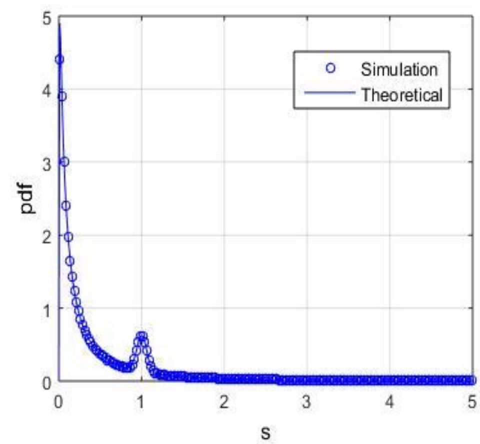

Figure 8. *PDFs of Lutz processes*

5. Simulation results

In this section, the BER performance of the studied system is evaluated by the numerical simulation. The dependence of BERs upon the system parameters such as the probability of bad state, the different chaotic maps, and the different spreading factors are carried out. Two different chaotic maps are chosen, i.e., the second-order Chebyshev polynomial function (CPF) and the Cubic map [12], [13], respectively given by

$$x_k = 2x_{k-1}^2 - 1, \quad (11)$$

$$x_k = 4x_{k-1}^3 - 3x_k, \quad 12)$$

In all simulations, we assume that the input parameters of the Lutz channel model are chosen with $K = 21.5\ dB$, $\overline{K} = 15.9\ dB$, $m_\mu = -4.8\ dB$, $\sigma_M = 1.7\ dB$. These values are within the value range of model parameters for a typical land mobile satellite system propagation [14].

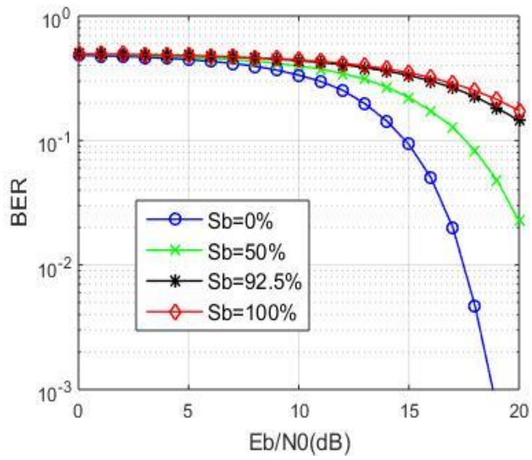

Figure 9. *The BER performance with different states of the channel,* $\beta = 500$

The BER performance of the studied system with different channel states is presented in Fig. 9. The BER curves are plotted with respective to $\frac{E_b}{N_0}$ for different cases of the channel states, i.e. the good-state channel (S_b=0%), the two-state channel (S_b=50%, S_b=92.5%), and the bad-state channel (S_b=100%), respectively. It clearly appears that BER values in the case of two-state channel are between those of the good-state and bad-state channels. For instance, at the same $\frac{E_b}{N_0} = 18$ dB, BER values with $S_b = 0\%$, $S_b = 50\%$, $S_b = 92.5\%$, $S_b = 100\%$ are corresponding to 0.0047, 0.0832, 0.2248, and 0.2519.

Table 1 shows the statistical properties of the normalized chaotic sequences. The BER results with different chaotic maps are shown in Figure 10. It can be observed that the BER of the system using CPF is equivalent to that of using the Cubic map. The main reason is that the values of $E[x_k]$, $E[x_k^2]$ and $var[x_k^2]$ for CPF and the Cubic map are the same.

Table 1. *Statistical properties of the normalized chaotic sequences*

	CPF	Cubic map
$E[x_k]$	0	0
$E[x_k^2]$	0.5	0.5
$var[x_k]$	0.5	0.5
$var[x_k^2]$	0.125	0.125

Finally, we consider the effect of the spreading factor on the system performance in case of using the second-order Chebyshev polynomial function. For a fixed value $\frac{E_b}{N_0} = 17\ dB$, the BER against the spreading factor 2β is shown in Figure 11. It can be seen that with different states of the channel, there exists an optimal value of the spreading factor so that the best value of BER ocan be found. Specifically, the optimal spreading factor for the cases of S_b=50%, S_b=75%, S_b=92.5% are around 50. For β is greater than the optimal value, increasing β leads to the increase of BER, while for β is less than the optimal value, the BER decreases when β increases.

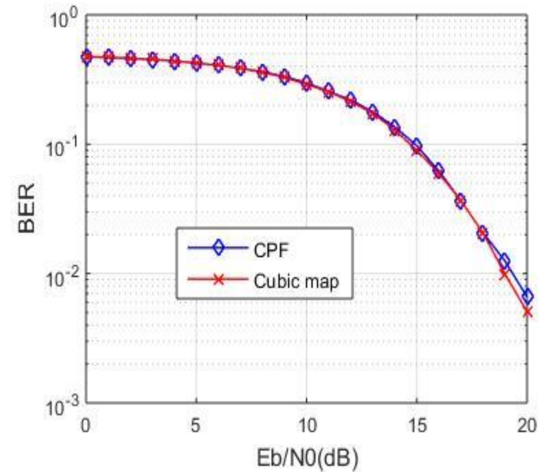

Figure 10. *The BER performance with different chaotic maps,* $\beta = 100, S_b = 50\%$.

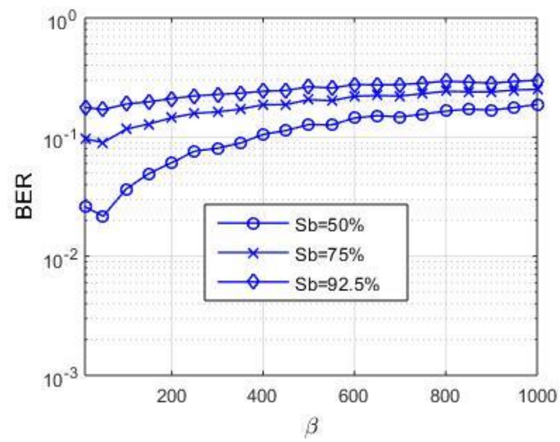

Figure 11. *The BER performance with different spreading factor in the case of* $\frac{E_b}{N_0} = 17\ dB$

6. Conclusion

In this paper, we have studied the BER performance for the DCSK system over the Lutz channel model. The theoretical analysis and simulation of the Lutz channel model as well as the discrete-time model of the transmitter and receiver are presented. The BER of the studied system is investigated by numerical simulation with different parameters. The simulation results have shown that the BER depends seriously upon the channel state. Our future works will focus on applying fading mitigation techniques to the performance improvement of DCSK system over the Lutz channel.

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