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Correlation Receiver to Mitigate Sweep Jammer in Differential Chaos Shift Keying Communication System

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Abstract

In this paper, a frequency-hopping orthogonal frequency-division multiplexing (FH-OFDM)- based differential chaos shift keying (FH-OFDM-DCSK) system under the effect of a sweep jammer is proposed. The wavelet packet jammer estimation algorithm (WPJE) is employed to enhance system performance by estimating jamming signals and mitigating them. Different wavelet filters and different filter lengths are considered. The threshold value was estimated using the threshold equation to produce an educated estimate of the jammer signal. As a result, we made an estimate as accurate as possible. The simulation results show that the proposed receiver substantially outperforms the standard receiver in system performance. In contrast, the BER performance difference between the presented system and the system without a jammer was 3 dB. The proposed receiver 5 end superscript with the parameters Eb/N0 = 20 dB, JSR = 5 dB, and beta = 100. The best outcomes were achieved by employing Daubechies of length 24 (db12).

Keywords: Differential chaos shift keying, Frequency hopping, Orthogonal frequency division multiplexing, Sweep jammer, Wavelet packet jammer estimation.

1. Introduction

Chaotic communication (CC) is introduced as a traditional spread-spectrum system that uses pseudo-random noise (PN) sequences with low cross-correlation and low security. There are two types of chaotic systems: coherent and non-coherent. Due to their apparent ease of study, non-coherent chaotic systems have received much attention [1]. The differential chaotic shift keying (DCSK) system is the best researched and basic example of non-coherent chaotic systems.

The DCSK system has been studied extensively, but it has several limitations, including a low data rate, high power consumption, and high complexity. These limitations have prompted the proposal of various cutting-edge solutions. Several systems have been proposed to lessen these issues. Several variants of the DCSK scheme are proposed to increase its data rate and spectrum efficiency, including high-efficiency DCSK (HE-DCSK) [2], improved DCSK (I-DCSK) [3], and short reference DCSK (SR-DCSK) [4]. A reference-modulated DCSK (RM-DCSK) system is also introduced by Yang and Jiang [5] to enhance transmission reliability and simplify the DCSK scheme. In addition, Kaddoum and Soujeri [6]presented a noise-reduction DCSK (NR-DCSK) technique to reduce the noise variance of the received signal and, by extension, improve the system's performance. To solve the problem of RF delay in DCSK systems, Xu et al. [7] introduced a technique known as code-shifted differential chaos shift keying (CS-DCSK). A multicarrier DCSK (MC-DCSK) method for enabling multi-carrier transmission was proposed by Kaddoum et al. [8].To reduce system complexity in multi-carrier DCSK systems, Zhao and Wu [9] proposed an OFDM-DCSK system. Compared with [8], this approach reduces complexity and increases bandwidth efficiency by using IFFT and FFT at both the transmitter and the receiver. Hussien and Abdullah [10], and Hasan and Valenzuela [11] combined OFDM with sort reference quadrature chaos shift keying (SR-QCSK) and orthogonal chaotic vector shift keying (OCVSK), respectively. However, the security of the OFDM system is compromised because the chaotic carrier is transmitted on a fixed subcarrier. It's possible that an eavesdropper could utilize this vulnerability to read the transmitted data. A frequency hopping sequence can be used to increase the safety of an OFDM system by randomly assigning chaotic reference chips to different subcarriers. This is an FH-OFDM-DCSK [12] system.

The ability to withstand jamming is crucial for general communication systems, particularly chaotic systems. These tests were performed to determine the robustness of chaos-based communication systems against signal interference. Lau et al. [13] measured the efficiency of chaotic shift keying CSK

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and differential code shift keying (DCSK while a single-tone jammer was present. CSK and DCSK were studied for their susceptibility to interference from a part-time jammer [14], [15]. Van Nguyen et al. [16] examined the performance of NR-DCSK in the presence of multiple jammers. Blanking nonlinearity in the receiver has been discussed by Vuong et al. [17] and Juwono et al. [18] to mitigate the impact of pulse jamming on DCSK systems and power line communications, respectively.

In this research, the FH-OFDM-DCSK system under the effect of a sweep jammer is investigated, and its reduction is achieved using wavelet packet jammer estimation (WPJE). The WPJE technique provides a precise time-frequency representation of a signal, enabling better analysis and mitigation of jamming signals.

The remainder of this research is divided into the following sections. FH-OFDM-DCSK for transmitter and receiver in section 2 and FH-OFDM-DCSK with WPJE in section 3. The simulation results and discussion are presented in Section 4. Section 5 will contain the conclusion.

2. Methodology

The system under investigation comprises a sweep jammer, a source, and a destination. This study investigated an additive white Gaussian noise (AWGN) channel model and a sweep jamming(SJ) signal.

2.1. FH-OFDM-DCSK Transmitter system

The block diagram of the FH-OFDM-DCSK transmitter system is shown in Fig. 1. This system employs binary data storage and chaotic sample manipulation. To express the k^{th} sample of the i^{th} subcarrier DCSK modulated signal $t_{i,k}$ can express as [19]:

$$t_{i,k} = \begin{cases} x_k & \text{for } i = 0 \\ d_i x_k & \text{for } i = 1, \dots, M' \end{cases} \quad k = 1, \dots, \beta \qquad (1)$$

x_k denotes chaotic samples produced from the 2nd Chebyshev Polynomial Function (CPF) and is expressed [20]:

$$x_{k+1} = 1 - 2x_k^2 \qquad (2)$$

The mean value of x_k is $\mathrm{E}[x_k] = 0$, the mean squared value is $\mathrm{E}[x_k^2] = 1$, and that's due to the normalization of the chaotic sequences, $x_k \in (-1, 1)$ [19]. The matrix form of $t_{i,k}$ signal is:

$$t_{i,k} = \begin{bmatrix} t_{0,1} & t_{0,2} & \cdots & t_{0,\beta} \\ t_{1,1} & t_{1,2} & \cdots & t_{1,\beta} \\ t_{2,1} & t_{2,2} & \cdots & t_{2,\beta} \\ \vdots & \vdots & \ddots & \vdots \\ t_{M,1} & t_{M,2} & \cdots & t_{M,\beta} \end{bmatrix} \qquad (3)$$

Reference and information-carrying chips are spread across all occupied subcarriers by applying the 1D frequency-hopping function to each column of matrix t. These are the respective expressions for the function's output and its matrix form:

$$u_{i,\mathrm{k}} = t_{f(i),\mathrm{k}} \quad , \mathrm{k} = 1, \dots, \beta \qquad (4)$$

$$u_{i,\mathrm{k}} = \begin{bmatrix} u_{0,1} & u_{0,2} & \cdots & u_{0,\beta} \\ u_{1,1} & u_{1,2} & \cdots & u_{1,\beta} \\ u_{2,1} & u_{2,2} & \cdots & u_{2,\beta} \\ \vdots & \vdots & \ddots & \vdots \\ u_{M,1} & u_{M,2} & \cdots & u_{M,\beta} \end{bmatrix} \qquad (5)$$

The i^{th} subcarrier's frequency hopping operation is denoted by $f(i)$, and the resulting sample is denoted by $u_{i,\mathrm{k}}$. The output of the FH procedure is fed into the IFFT algorithm to produce the n_{th}OFDM modulated sequence, which looks like this:

$$U_{n,\mathrm{k}} = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} u_{i,\mathrm{k}} e^{\frac{j2\pi n i}{N}}, \; \begin{matrix} n \in [0, M] \\ k \in [1, \beta] \end{matrix} \qquad (6)$$

Using N as the number of subcarriers and M as the number of data bits, we get $N = M + 1$. A chip time slot contains k IFFT-modulated symbols and n subcarriers, where k is the index of the symbols and n is the index of the subcarriers. After a P/S conversion and the addition of a cyclic prefix to decrease inter-symbol interference (ISI) [20], the symbols are sent across the channel:

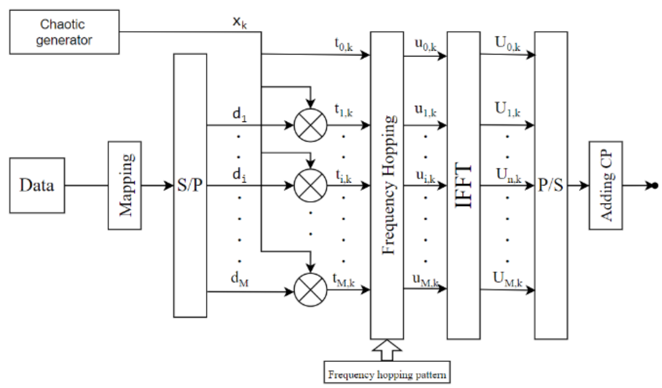

Figure 1. FH-OFDM-DCSK transmitter.

The signal received at the destination is:

$$r_{n,k} = s_{n,k} + j_{n,k} + N_{n,k} \qquad (7)$$

The sweep jamming (SJ) signal is denoted by $j_{n,k}$, where $N_{n,k}$ is a complex (AWGN) with variance $N_0/2$ and $s_{n,k}$ is denoted the desired signal.

An SJ transmits a narrowband signal with a fluctuating frequency. More specifically, the sweep signal is characterized by a sweep rate $\Delta f$and a sweep time T_{sw}, oscillating between the frequencies $f_{start}$and f_{stop}. The common sweep jamming variant is based on a sinusoidal signal and a linear sweep method. However, other variants depend on alternative narrowband signals and different sweep techniques. [16].

$$j_{n,k}(t) = \sqrt{2P_j} \sin\left(2\pi f_{start} t + \pi \Delta f t^2 + \theta_{sw}\right) \quad (8)$$

The sweep rate and the initial phase of the sweep jamming signal are denoted by $\Delta f$and θ_{sw}, We expressed the SJ signal as a discrete baseband model, which can be written as:

$$j_{n,k} = \sqrt{2P_j} \sin\left(\pi \frac{kF_{\text{start}}}{\beta} + \pi \frac{k^2 \Delta F}{4\beta^2} + \theta_{\text{sw}}\right) \quad (9)$$

Where $\Delta f = \frac{f_{stop} - f_{start}}{T_{sw}}$, $F_{\text{start}} = f_{\text{start}} T_b$, $\Delta F = \Delta f T_b^2$ T_b is the bit duration.

2.2. FH-OFDM-DCSK Receiver system

The conventional FH-OFDM-DCSK receiver system is depicted in Fig. 2. The received signal first undergoes a serial-to-parallel conversion and CP removal. Then the signal is fed into the FFT algorithm for OFDM demodulation, resulting in the following sequence:

$$R_{i,k} = \frac{1}{\sqrt{N}} \sum_{n=0}^{M} r_{n,k} e^{\frac{-j2\pi ni}{N}}, \quad \begin{matrix} k \in [1,\beta] \\ i \in [0,M] \end{matrix} \qquad (10)$$

Subsequently, the frequency-dehopping algorithm is applied to the input symbols. The chaotic modulated signals can be normalized by recreating the identical FH pattern used by the transmitter, using the same initial values, and reversing the procedure performed by the transmitter. A correlator is applied to the reference chips to decode the M information signals. The data D_i, Where i ranges from 1 to M, was input into a threshold detector. The bit to be transmitted will be set to 1 if $D_i \geq 0$ is less than zero; otherwise, set to 0. An example expression for the decision variable D_i is as follows:

$$D_i = \sum_{k=1}^{\beta} T_{i,k}(T_{0,k})^* = \sum_{k=1}^{\beta} \left(d_i x_k + j_{i,k} + n_{i,k}\right)\left(x_k + j_{0,k} + n_{0,k}\right)^* \qquad (11)$$

3. FH-OFDM-DCSK System with WPJE

This section will discuss the FH-OFDM-DCSK receiver with WPJE when a sweep jammer is present. Fig. 3 depicts the receiver as a combination of a conventional receiver and a WPJE block, and Fig. 4 shows the algorithm of WPJE [21].

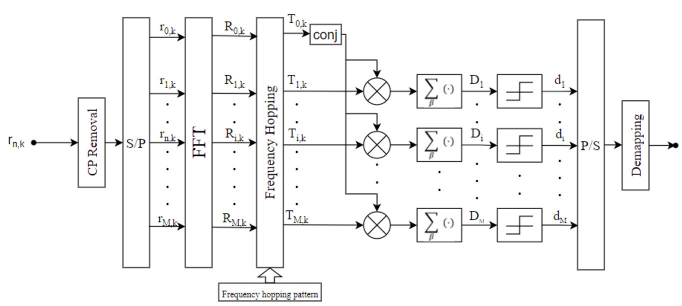

Figure 2. FH-OFDM-DCSK receiver.

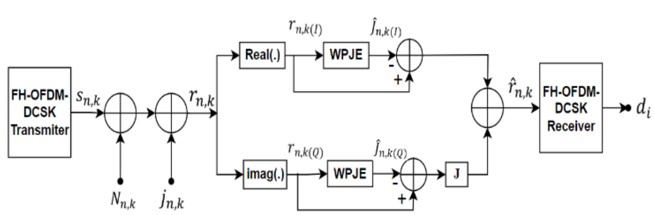

Figure 3. FH-OFDM-DCSK receiver with WPJE

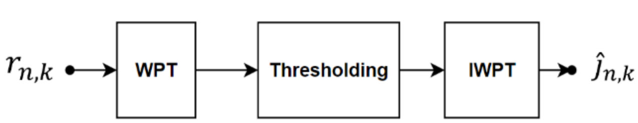

Figure 4. WPJE algorithm.

Where $\hat{j}_{n,k}$ is a guess for the strength of the jamming signal, using the jammer signal as the primary one and the random one as noise. The WPJE method's de-noise capabilities may be used to calculate $\hat{j}_{n,k}$. The WPJE technique works by first splitting the input signal into approximation and detail components, then splitting those components into further approximation and detail components, and so on. This operation is performed using the Wavelet Packet Transform (WPT). The WPJE technique can also be seen as a form of multi-resolution analysis, where the input signal is decomposed into a set of scaling and wavelet functions, expressed as:

$$\phi(t) = \sqrt{2} \sum_k h[k]\phi(t-k) \qquad (12)$$

$$\psi(t) = \sqrt{2} \sum_k g[k]\psi(t-k) \qquad (13)$$

As a result, we can reconstruct the original input signal as:

$$r_{n,k} = \sum_{m=1}^{L} \sum_{n\in\mathbb{Z}} c_{m,n}\phi_{m,n} + \sum_{m=1}^{L} \sum_{n\in\mathbb{Z}} d_{m,n}\psi_{m,n} \qquad (14)$$

Where $c_{m,n}$and $d_{m,n}$Regarding the wavelet coefficients,$c_{m,n} = \langle r, \phi_{m,n}\rangle, d_{m,n} = \langle r, \psi_{m,n}\rangle$, $\phi_{m,n} = 2^{-m/2}\phi(2^{-m}t-n)$, $\psi_{m,n} = 2^{-m/2}\psi(2^{-m}t-n)$. $\langle X_1, X_2\rangle$ is the inner product between X_1 and X_2.

After taking a WPT, the decomposed signal is thresholded using an appropriate threshold. The most widely used cutoff is as follows, although many other possibilities exist. [21], [22]:

$$\bar{\gamma} = \delta\sqrt{2\ln\left(N \ln(N)\right)/\ln(2)} \qquad (15)$$

Where:

$$\delta = \frac{MAD}{0.676} \qquad (16)$$

MAD refers to the wavelet coefficients' median absolute deviation, and N denotes the signal's length. Then we apply a threshold to reduce any wavelet coefficient above $\bar{\gamma}$To zero. The inverse Wavelet Packet Transform (IWPT) is carried out on the revised wavelet coefficients to obtain a jamming signal estimation. To complete the process, by removing the estimated jamming component from the received signal, a conventional correlation-based receiver can recover the transmitted data. [23].

4. Result and Discussion

In this section, Simulation results illustrating the advantages of the proposed receiver are presented. The simulations are conducted based on the system model described in this paper with $\beta = 100$. In the simulation, the jammer frequency is swept from 0 Hz to 50 kHz, with a sweep time of total transmission time/5, and Daubechies wavelet filters with length 24 (db12) are used.

In Fig. 5, we show the BER performance of the FH-OFDM-DCSK system under the effect of a sweep jammer with and without WPJE versus Eb/N0. We consider jamming-to-signal ratio (JSR) values of 5 dB and 15 dB and observe improved system performance with the addition of WPJE; however, BER increases with increasing JSR. Without WPJE, the BER performance is about 0.5.

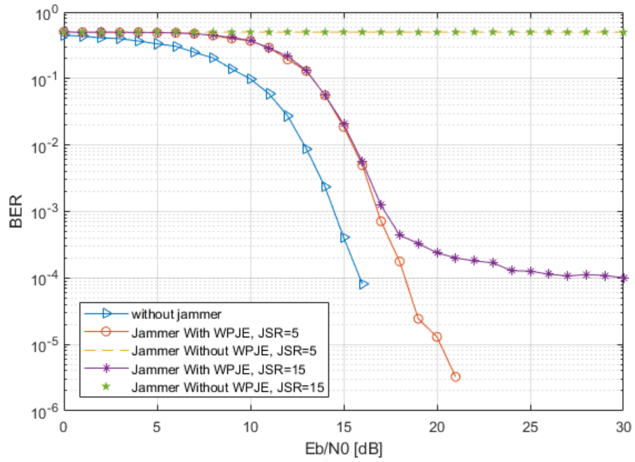

Figure 5. BER performance of the FH-OFDM-DCSK system

Fig. 6 depicts the BER performance for wavelet filters of equal length (24), namely Daubechies (db12), Coiflets (coif4), and Symlets (sym12), with JSR=5. We observe the best BER performance with Daubechies (db12). Fig. 7 depicts the BER performance using Daubechies wavelet filters with different lengths and JSR=5. We observe the best BER performance with (db12). As a result, the BER will improve more as the filter length increases.

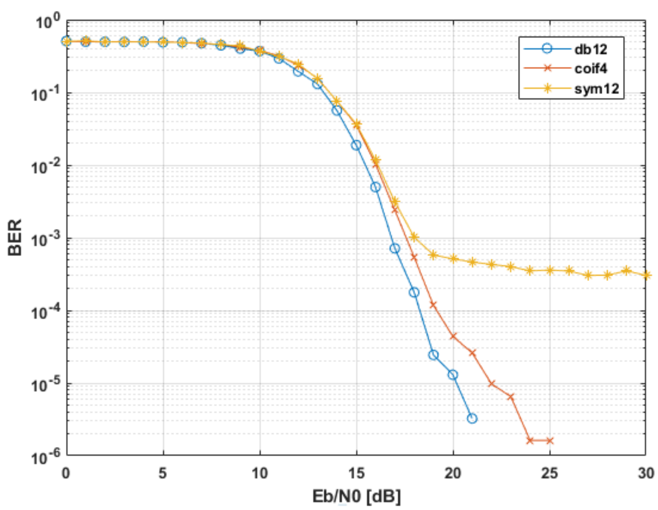

Figure 6. BER comparison of the FH-OFDM-DCSK system employing different wavelet filters at JSR = 5.

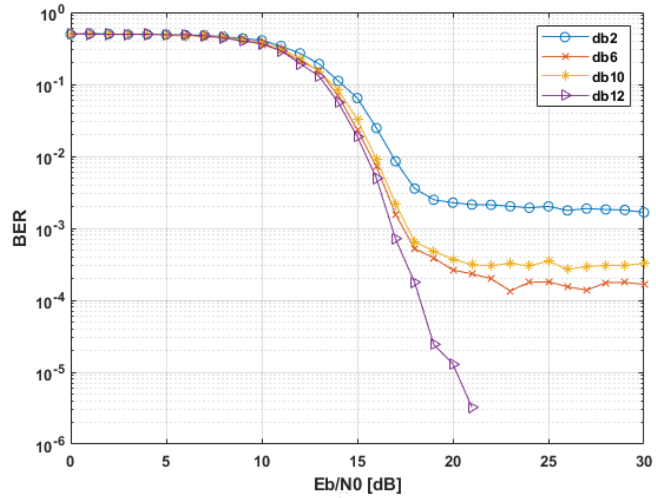

Figure 7. BER comparison of the FH-OFDM-DCSK system employing different Daubechies wavelet filter lengths at JSR = 5.4. Conclusions

In this study, a sweep-type jammer is proposed for FH-OFDM-DCSK. This system has a lower BER than DCSK, is non-coherent, and is energy- and bandwidth-efficient. To address the security issue with DCSK and introduce frequency and timing diversity, one-dimensional scrambling is achieved via frequency hopping. We propose a novel receiver that employs WPJE to estimate and mitigate jamming signals, thereby improving BER performance. We employ various wavelet filters and filter lengths. The threshold value was computed using the threshold equation to provide an informed estimate of the jammer signal. This enabled the estimation to be as accurate as possible. Simulation results show that the proposed receiver vastly outperforms the conventional receiver in system performance. When Eb/N0 = 20 dB, JSR = 5 dB, and beta = 100, the receiver without WPJE has a BER of 0.5. In contrast, the receiver with WPJE has a BER of 10^{-5}. Using Daubechies with a length of 24 (db12) yielded the best results.

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Abbreviations

$r_{n,k}$	Received signal
$s_{n,k}$	Desired signal
$j_{n,k}$	Jammer signal
$N_{n,k}$	AWGN signal
$\hat{j}_{n,k}$	Estimated jammer signal
$\bar{\gamma}$	Threshold constant

Conflict of interest

The authors affirm that this research was conducted free of conflicts that could compromise its integrity.

Author Contribution Statement

Taha Ali Nuhad and Fadhil Sahib Hasan proposed the research problem.

Fadhil Sahib Hasan verified the analytical methods and investigated and supervised the findings of this work.

Taha Ali Nuhad developed the theoretical framework and performed the computations. Both authors discussed the results and contributed to the final manuscript.

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