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An Investigation Effects over Jammer Signal Excision of Different Spreading Sequences Employed in Spread Spectrum Communication

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Abstract – The performances of different spreading sequences employed in spread spectrum communication systems have been investigated over removing from the spectrum of non-stationary jamming signals involved in the system in this paper. The performances of the PN, Barker and CCK spreading sequences, located in the IEEE standards, are analyzed comparatively in this work, inspired by the proposed method in [1], for the excision of jamming signals included in the system. Computer simulations have been performed for the different values of noise power and the jamming signal power, involved in the system. The obtained simulation results have demonstrated that the best performances are achieved with CCK spreading sequence in even high jammer to signal ratio (JSR) values.

Keywords - *Signal jamming, DSSS-CDMA, Short time Fourier transform, Spreading codes.*

1 Introduction

Despite the significant advantages of direct sequence spread spectrum communications, whenever the number of user increases or the received signal is corrupted by an intentional jammer signal, it is necessary to model and estimate the channel effects in order to equalize the received signal, as well as to excise the jamming signals from it. Noise and jamming signals in the transmission medium at wireless communication system reduce the quality of transmission and can prevent as correct reception of the desired data to be sent in the receiver. This is a big problem for wireless communication systems. Although the different

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communication systems communicate in different frequency bands, each signal can show disruptive effect for the other. Such distorting effects that occur unintentionally, sometimes it also can be made intentionally by mixing jamming signals to the system. Especially, in military communications, intentional jammer interference is an important problem due to the corruption of the transmitted signals. To overcome this problem, spread spectrum techniques are used in wireless communications. Spread spectrum systems spread the transmitted energy over a wide band and therefore, signal to noise ratio is very low at the input receiver. However, the receiver has the ability, can use the transmitted signal separating successfully from the noise, despite the low signal to noise ratio. The aim of spreading spectrum; reducing the interference effects, simultaneously provide a plurality of users to communicate using the same channel, using multiple paths to communicate and the possibility of getting low is to provide a signal feature. Spread spectrum systems use two important spreading techniques. One spreading scheme is the direct-sequence spread-spectrum (DSSS), which is achieved by phase modulation [2]. Another spreading scheme is known as frequency-hopping spread-spectrum (FHSS) achieved by rapid changes in the carrier frequency [3, 4]. In DSSS systems, transmitted signal is spread over a bandwidth that is much wider than the minimum bandwidth necessary to transmit the information [5]. In particular, in order to least to be affected from this situation encountered in military communications applications, the employed method, made with DSSS techniques, is code division multiple access (CDMA) communication [1]. In DSSS-CDMA generally, after modulation the signal, multiplied by the spreading sequence, has spread in frequency domain and it is transmitted by a fairly large bandwidth of its band width [1]. The increased bandwidth makes the system resistant to noise and jamming signal. However, in the increasing jammer signal strengths DSSS fails and is needed an additional system, for removed of the jammer signal from the system [6].

Although DSSS systems have an intrinsic anti-jamming capability to some extend, both unintentional and intentional jamming interference mitigation is still an important problem in communications, including military applications. There are various techniques of jamming signal excision in the literature [7-9]. These techniques have been first developed for military applications as a means to combat hostile narrowband jamming of the DSSS signal, but they can also be used to mitigate the effects of unintentional narrowband interference caused by co-existence with conventional communications as well. The use of these techniques allows the CDMA users to communicate reliably with much less power than would otherwise be required in the presence of the narrowband users, and therefore increases the value for the maximum number of CDMA users that can be tolerated, with an acceptable level of degradation for the narrowband users.

So far, all the proposed jamming interference rejection techniques [10] for spread spectrum communications are interference excision techniques, which rely on applying an excision filter prior to the despreading. Excision filters act on suppressing the interference and thus increase the signal-to noise ratio at the correlator output of the receiver. These filters can be block or adaptive and may be realized in time [11], frequency [12], or time frequency domain. Many of them employ time-frequency distributions in the analysis of interference, including wavelet transform, Wigner distribution (WD), short-time Fourier transform (STFT) and their variants. Since time-frequency distributions are designed to characterize the frequency content of signals as a function of time and are usually applied to analyze process and synthesize signals with time-varying spectral content. The later includes the wavelet [13] and Gabor transforms [14] as well as bilinear time frequency distributions [15].

Time-frequency distributions have been used as powerful analysis tools for illustrating the jammer power on time-frequency plane [7, 8]. In [7], WD is used in the excision of interference signals. WD generates sharp and well-localized time-frequency representations of single-component signals; however it becomes ineffective for multi-component signals introducing cross-terms on the time-frequency plane [16].

Recently there has been a great deal of interest in the application of time-frequency signal analysis to problems in communications, particularly to spread spectrum communications [17]. The DSSS technique to some degree reduces interference power. Therefore, the interference immunity of a DSSS system can be reduced if the power of the interferences during transmission is very strong. Additional preprocessing techniques before despreading such as transform domain excision can enhance the interference immunity of the system. In many of these situations the type of jammer is known and the methods are adapted accordingly. Different methods have been proposed to mitigate broad-band jammers; many of the available excision techniques assume characteristics of the interference (e.g., sinusoidal or chirp interference), and then project the received signal either onto the signal-plus-noise space, or use time-varying filtering to excise the interference [18]. The Wigner-Hough transform method characterizes the jammer by a parametric model of its instantaneous frequency. Time-varying filtering and masking methods based on bilinear time-frequency distributions can excise jammers characterized by their instantaneous frequency, bandwidth, and support in the time-frequency plane [19]. The method of the projection excision technique improves the time-varying notch filtering [20].

In this paper, spread spectrum communications system, using pseudo-random (PN) sequence, Barker sequence and Complementary Code Switching (CCK) sequences located in the IEEE 802.11 Standard for different spreading codes, has been employed. Additionally, the effects on the performance of jammer signal excision of the different spreading codes has been analyzed in this study.

The remainder of this paper is organized as follows: spread spectrum communications and system model has been investigated in Section 2. Jammer signal estimation and excision has been introduced in Section 3. The simulation results are discussed by presenting both SNR and JSR vs. BER values in Section 4. Finally, conclusions are drawn in Section 5.

2 Spread Spectrum Communications and System Model

Spread-spectrum techniques for digital communications were originally developed and used for military communications either to provide resistance to jamming, or to hide the signal by transmitting it at low power, thus making it difficult for an unintended listener to detect its presence in noise [21]. Therefore, spread-spectrum communications have advantages in the areas of security, resistance to jamming, resistance to multipath fading, and supporting multiple-access techniques such as the CDMA [22].

Spread spectrum communication, by spreading signals in frequency spectrum so as to cover more than the required minimum bandwidth for transmission, is transmitted technique over the channel [23]. Although seen as a major disadvantage at first glance, extensive use of the bandwidth, a very important criterion for communication systems, spread spectrum communications, which makes data-resistant against the negative effects of the channel with the CDMA technique is quite efficient a communication technique [1].

If a system, composed of a transmitter and a receiver antenna, is considered, the data signal is multiplied by the spreading sequence in the transmitter side. In this study, a system, mixing of jammer signals for the purpose of disrupt intentionally the communications spectrum to DSSS system, has been modeled. If the sent to be desired data

$x(t)$ is a rectangular pulse, which is {-1, +1} amplitude values, when it is modulated with BPSK, the transmitted signal from the transmitter antenna are as follows:

$$m(t) = A_c x(t)\cos(2\pi f_c t) \tag{1}$$

where, A_c and f_c are carrier amplitude and frequency of BPSK modulation, respectively. In order to pass spread spectrum the modulated signal is multiplied by a PN code. Although PN code is the form of a rectangular pulse having {-1, +1} amplitude values like the information signal, the bandwidth of the PN code is selected a quite large compared to the bandwidth of $x(t)$. In this case, the spread signal will be sent from the transmitter, $y(t)$,

$$y(t) = A_c x(t) PN(t)\cos(2\pi f_c t) \tag{2}$$

in form is obtained. Consequently, in its most general form,

$$y(t) = A_c \cos(2\pi f_c t + \theta(t)) \tag{3}$$

with is expressed. Here, $\theta(t)$ indicates the phase of modulated signal.

In order to obtain a realistic simulation of designed communication systems, Rayleigh channel model is selected as commonly used channel in the city center and in the cases there is not line of sight between the receiver and the transmitter [24]. It was assumed that the transmitted signal coming from 100 and 1000 different ways to the receiver due to reflections and diffractions in simulation studies. The block diagram of the performed simulation system is shown in Figure 1 [25, 26].

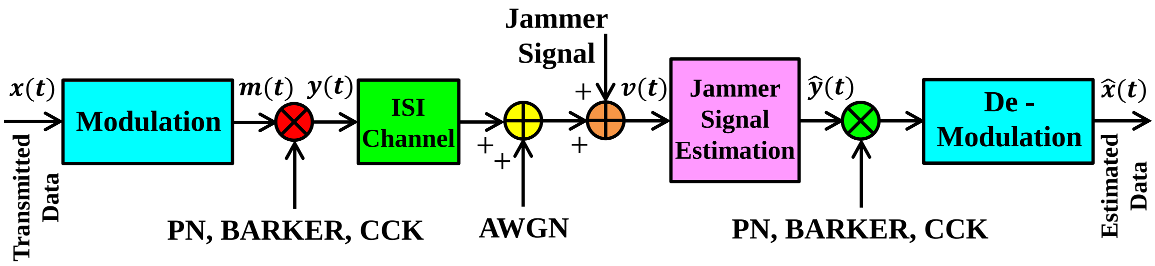

Figure 1. The block diagram of the designed communication system [25, 26].

3 Jammer Signal Estimation and Excision

In the designed communication system inspired by reference [1], FFT based jammer signal estimation has been performed and subtracted from signal at the receiver. In order to eliminate the effect of jammer signal at the receiver, signal estimation has been performed using short time Fourier transform (STFT) at jammer signal estimation and excision block, in Figure 2. STFT, giving together time and frequency information for time-varying signals of frequency content, is a linear transformation. The main idea of STFT is to Fourier analyze time varying signals during appropriate short time intervals and obtain the entire time frequency behavior of the signal by concatenating consecutive analyses [1]. A STFT image has been described to the distribution of the signal energy in the time and frequency domains [1]. In this technique, the signal is divided into parts that can be accepted stationary by means of a window and STFT has been obtained by calculating Fourier transform of each piece [1, 8]. STFT,

$$STFT_v(t,f) = \int_{-\infty}^{\infty} v(\tau)g(\tau - t)\, e^{-j2\pi f t} dt \tag{4}$$

in form can be expressed. Here, $g(\tau)$, t and f indicate the window function, time and frequency variable, respectively. $v(\tau)$ is the corrupted signal by AWGN, ISI channel and jammer signal.

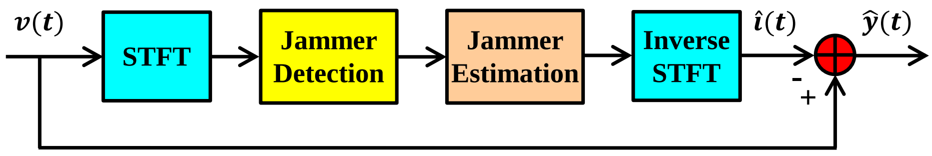

Figure 2. The block diagram of jammer estimation and excision [1, 8].

In the simulations, the jammer estimation and excision technique is employed at the receiver as shown in Figure 2. At first, STFT of a block of received signal $v(t)$ is computed. Then, the STFT is used in the estimation of the mixed interference. To estimate the localization of jamming signal on the time frequency plane, the support is constituted by thresholding the STFT image. The pixel values of the support image are assigned as either '0' or '1' and corresponding to the coordinates determined by the support, the original values of STFT are taken into account. Thus, an estimation of the STFT of the jammer signal is obtained. By computing the inverse-STFT, estimated jammer signal, $\hat{\imath}(t)$, is computed in time-domain. Finally, the estimated jammer signal is subtracted from the received signal, $v(t)$, in time domain as in Equation (5).

$$\hat{y}(t) = v(t) - \hat{\imath}(t) \tag{5}$$

The processing is finalized by correlation of PN, Barker and CCK code and demodulation as in Figure 1. Interference and jammer excision procedure based on the STFT computations is explained in detail in [1, 8].

4 Computer Simulation Results

In this section, the obtained simulation results have been demonstrated that in Rayleigh fading channels, using Jakes channel model [27], for the investigation of the effects over jammer signals excision of 11-bit PN, 11-bit Barker and 8-bit CCK spreading sequences. In computer simulation studies, in an environment where the carrier frequency is of 1900 MHz, the mobile vehicle speed is of 50 km/h, the scenarios were tested that the signal is coming from to the receiver 100 and 1000 different ways due to the reflections and refractions. In the STFT computations, estimated of jammer signal, a 129 point Hanning window was employed. The simulation studies were obtained for the BPSK modulation signals of the sampling rate is of 2 over 1000 independent loops. The single component chirp signal that has a duty cycle of 33% was used as a jammer signal as in [1]. In the performed simulation studies, the performances were compared in scenarios that the power of jammer signal to the power of the CDMA signal ratio (JSR) is of 10, 20, 30, 40, 50 and 60 dB [25, 26].

When JSR value is of 10 dB, the comparison of bit error rate (BER) versus signal to noise ratio (SNR) performances for the excision of jammer signal of CCK, PN and Barker spreading sequences have been illustrated for multi path number (MPN) is of 100 in Figure 3 and MPN is of 1000 in Figure 4.

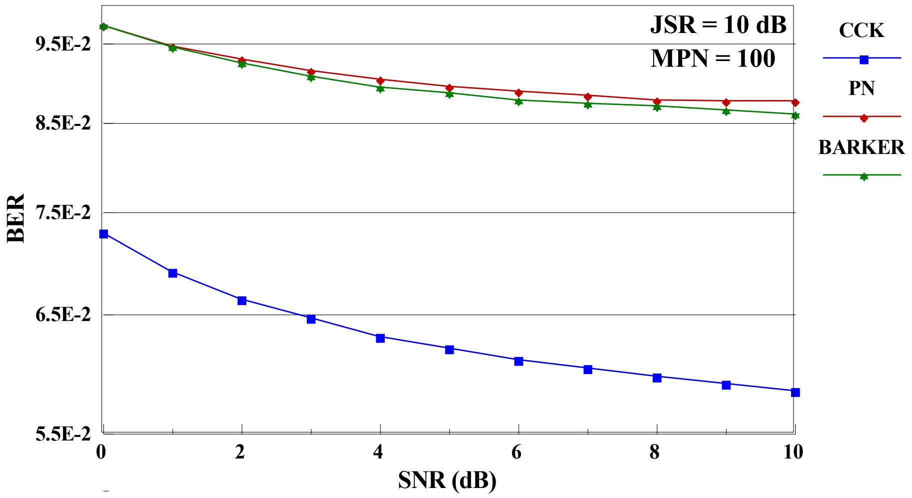

Figure 3. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 10 dB and MPN is of 100.

When the performances of BER-SNR are analyzed for JSR is of 10 dB and MPN is of 100 in Figure 3, while it is obtained approximately the same performance with 11-bit PN and 11-bit Barker spreading sequences in all SNR regions, it can be easily seen that the best performance has been obtained with 8-bit CCK spreading sequence. As a result, it is understood that the communication system, using CCK spreading sequence, can better distinguish the jammer signal.

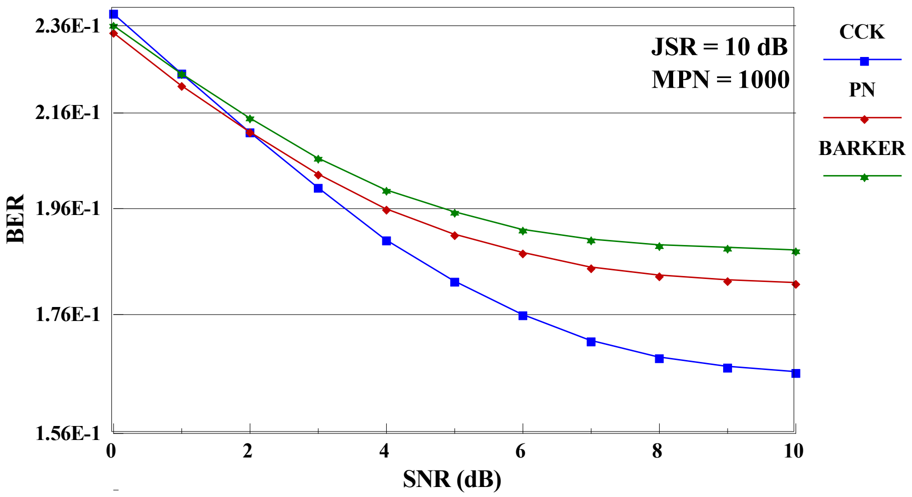

Figure 4. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 10 dB and MPN is of 1000.

When the performances of BER-SNR are analyzed for JSR is of 10 dB and MPN is of 1000 in Figure 4, it is observed that the obtained performance of 11-bit PN performs better than the obtained performance of 11-bit Barker. However, it can be easily understood that 8-bit CCK spreading sequence outperforms the performance of another spreading sequences and can better distinguish the jammer signal.

When JSR value is of 20 dB, the comparison of BER versus SNR performances for the excision of jammer signal of CCK, PN and Barker spreading sequences have been demonstrated for MPN is of 100 in Figure 5 and MPN is of 1000 in Figure 6.

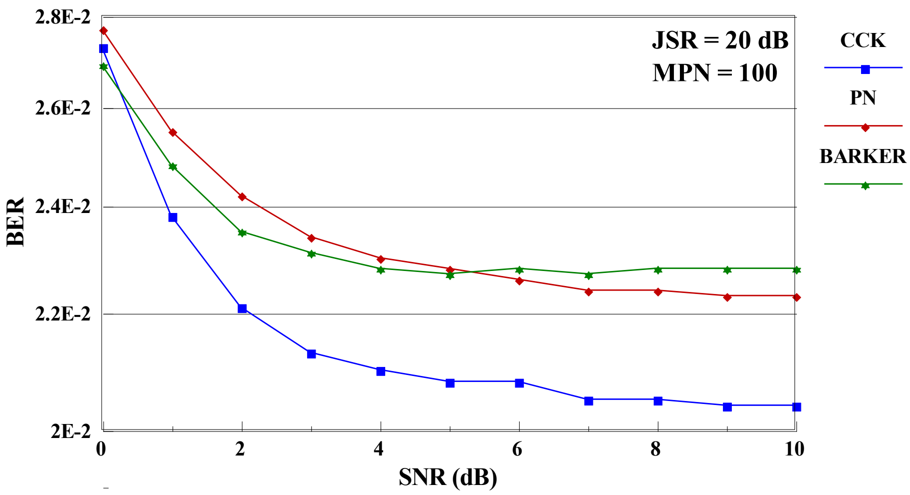

Figure 5. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 20 dB and MPN is of 100.

When the performances of BER-SNR are analyzed for JSR is of 20 dB and MPN is of 100 in Figure 5, it is seen that the obtained performance of 11-bit PN performs better than the obtained performance of 11-bit Barker after 5 dB of SNR value. However, it can be easily understood that the best performance has been obtained with 8-bit CCK spreading sequence and can be better distinguished the jammer signal.

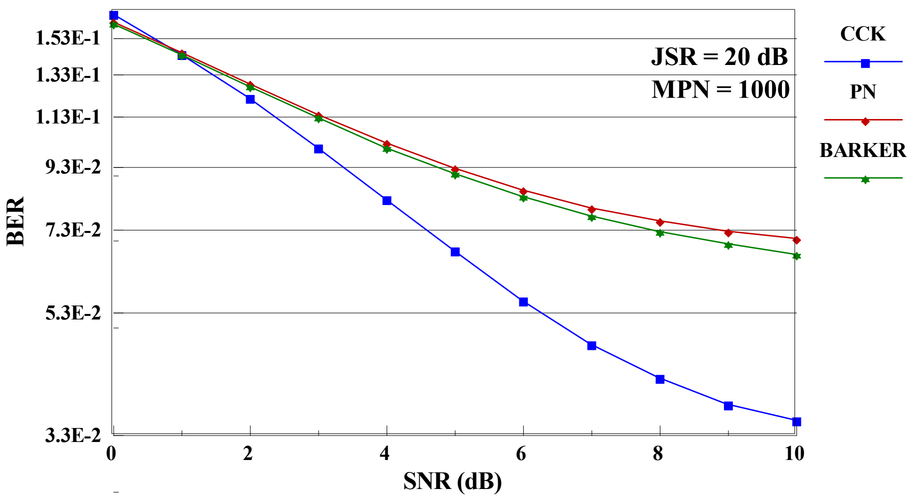

Figure 6. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 20 dB and MPN is of 1000.

When the performances of BER-SNR are analyzed for JSR is of 20 dB and MPN is of 1000 in Figure 6, it has been seen that the obtained performance of Barker sequence is exceeding the obtained performance of PN sequence in high SNR region (SNR > 3 dB).

However, it can be easily understood that the performance of CCK spreading sequence better than another spreading sequences in all SNR region and it can be better distinguished the jammer signal with CCK.

When JSR value is of 30 dB, the comparison of BER versus SNR performances for the excision of jammer signal of CCK, PN and Barker spreading sequences have been illustrated for MPN is of 100 in Figure 7 and MPN is of 1000 in Figure 8.

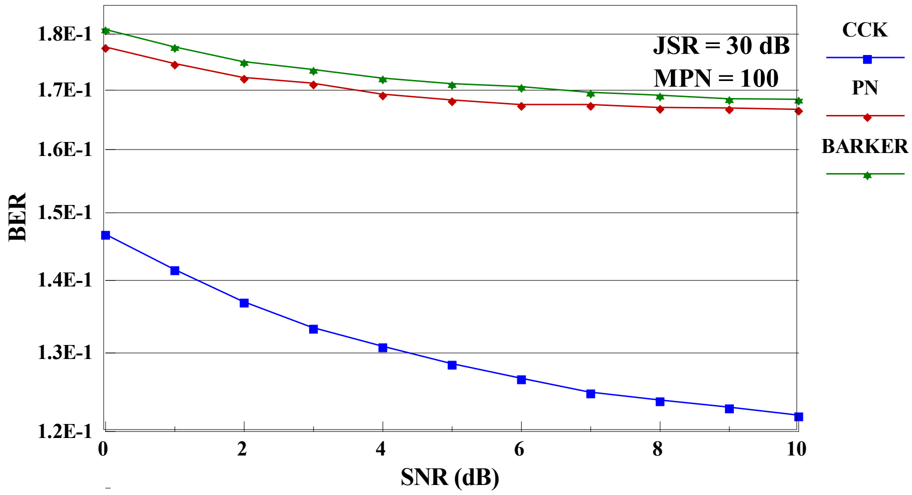

Figure 7. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 30 dB and MPN is of 100.

When the performances of BER-SNR are analyzed for JSR is of 30 dB and MPN is of 100 in Figure 7, it has been seen that the performance of 11-bit PN is exceeding the performance of Barker in all SNR region. However, it can be easily understood that the best performance has been obtained with CCK spreading sequence and can be better distinguished the jammer signal.

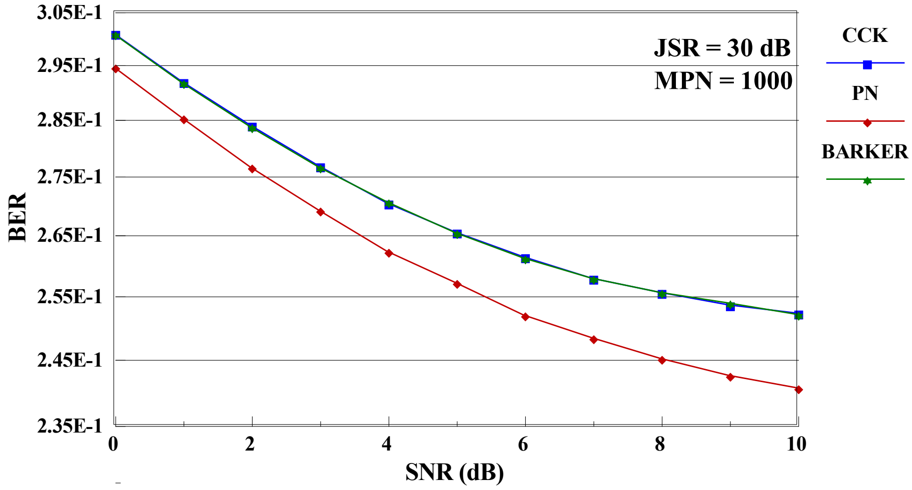

Figure 8. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 30 dB and MPN is of 1000.

When the performances of BER-SNR are analyzed for JSR is of 30 dB and MPN is of 1000 in Figure 8, it has been seen that it is obtained approximately the same performances with 11-bit Barker and 8-bit CCK spreading sequences in all SNR region. However, it can be easily understood that the best performance has been obtained with 11-bit PN spreading sequence and can be better distinguished the jammer signal.

When JSR value is of 40 dB, the comparison of BER versus SNR performances for the excision of jammer signal of CCK, PN and Barker spreading sequences have been demonstrated for MPN is of 100 in Figure 9 and MPN is of 1000 in Figure 10.

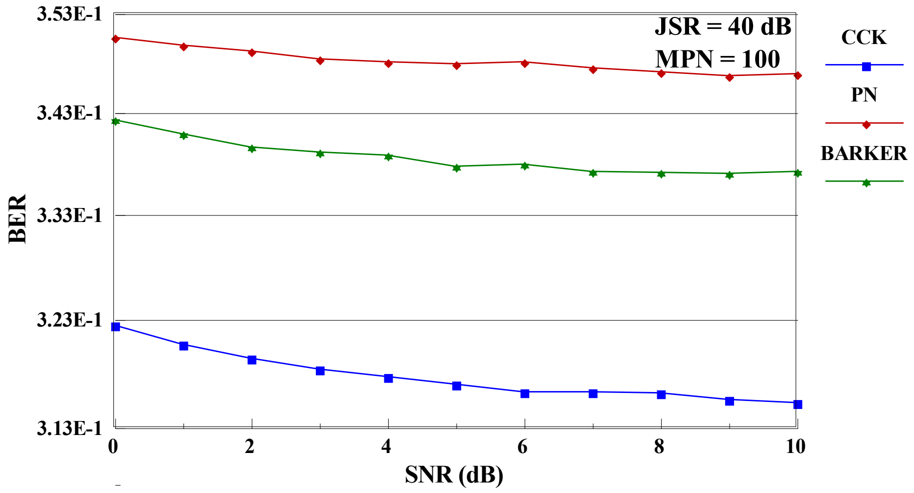

Figure 9. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 40 dB and MPN is of 100.

When the performances of BER-SNR are analyzed for JSR is of 40 dB and MPN is of 100 in Figure 9, it has been seen that the performance of 11-bit Barker is exceeding the performance of PN in all SNR region. However, it can be easily seen that the best performance is obtained with CCK spreading sequence.

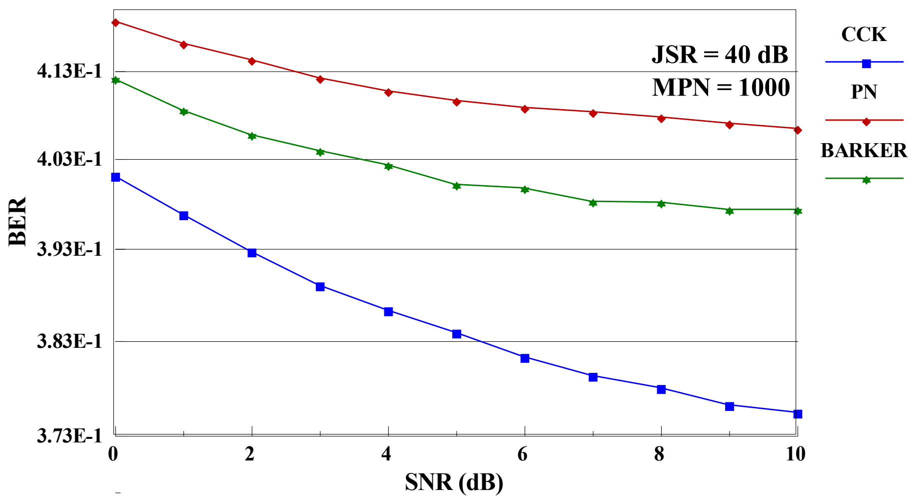

Figure 10. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 40 dB and MPN is of 1000.

When the performances of BER-SNR are analyzed for JSR is of 40 dB and MPN is of 1000 in Figure 10, as similar to previous result, it has been seen that the performance of 11-bit Barker is exceeding the performance of PN in all SNR region. However, it can be easily seen that the best performance is obtained with CCK spreading sequence.

When JSR value is of 50 dB, the comparison of BER versus SNR performances for the excision of jammer signal of CCK, PN and Barker spreading sequences have been illustrated for MPN is of 100 in Figure 11 and MPN is of 1000 in Figure 12.

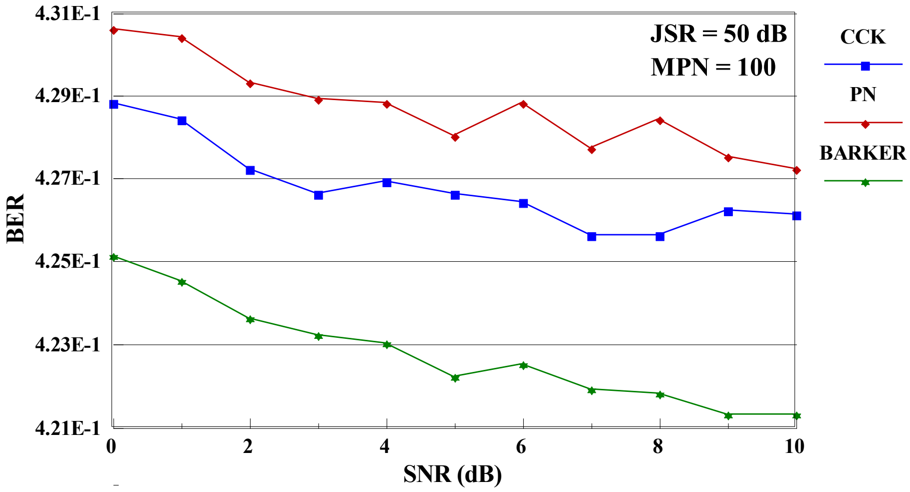

Figure 11. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 50 dB and MPN is of 100.

When the performances of BER-SNR are analyzed for JSR is of 50 dB and MPN is of 100 in Figure 11, it can be easily seen that the best performance is obtained with 11-bit Barker sequence in all SNR region. However, it has been seen that the worst performance is obtained with PN spreading sequence.

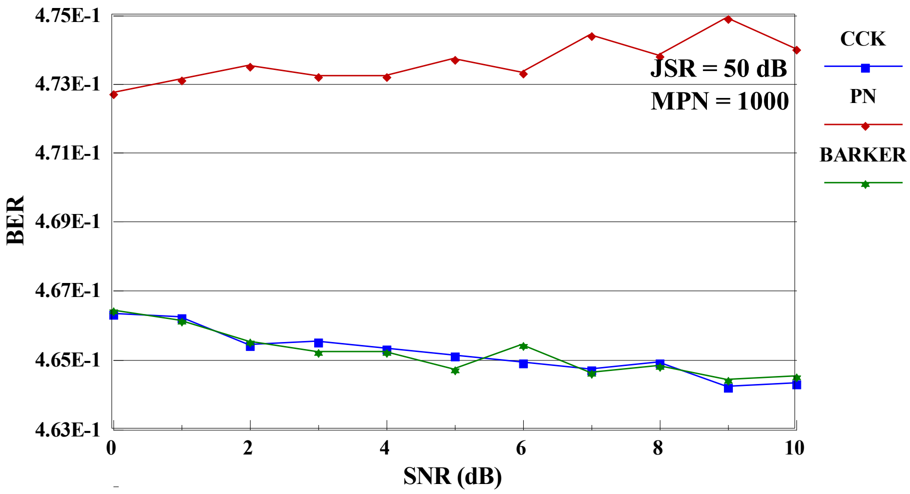

Figure 12. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 50 dB and MPN is of 1000.

When the performances of BER-SNR are analyzed for JSR is of 50 dB and MPN is of 1000 in Figure 12, it has been seen that it is obtained approximately the same performances with 11-bit Barker and 8-bit CCK spreading sequences in all SNR region. However, it can be easily seen that the worst performance is obtained with PN spreading sequence.

When JSR value is of 60 dB, the comparison of BER versus SNR performances for the excision of jammer signal of CCK, PN and Barker spreading sequences have been illustrated for MPN is of 100 in Figure 13 and MPN is of 1000 in Figure 14.

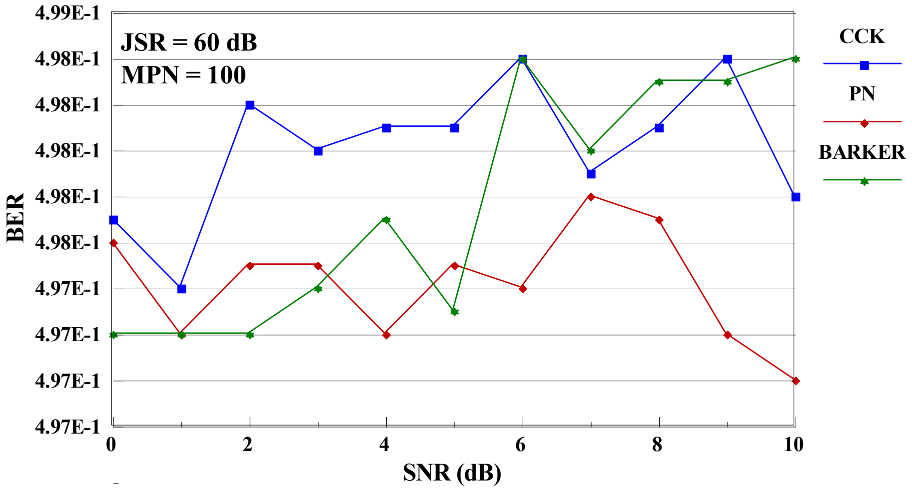

Figure 13. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 60 dB and MPN is of 100.

As shown in Figures 13 and 14, it can be easily seen that the obtained performances with all three spreading sequence are very close to one another. However, it has been seen that the obtained performances are not satisfactory due to the increased power of jammer signal.

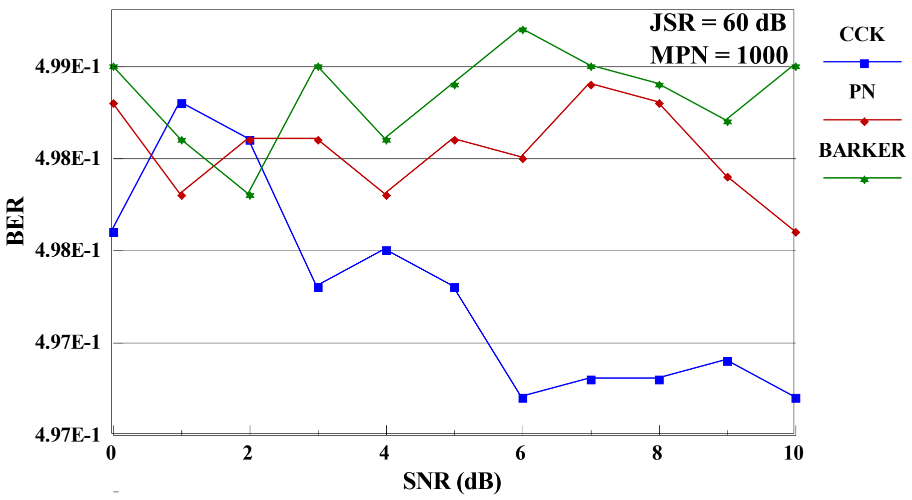

Figure 14. The comparison of BER-SNR performances of the performed communication system with CCK, PN and Barker spreading sequences while JSR is of 60 dB and MPN is of 1000.

5 Conclusions

Signal mixing / jamming has especially with a big importance in military communications systems. Jamming problems are important in DSSS-CDMA communications because both intentional and unintentional jamming can occur in several practical circumstances. In this paper, as an alternative to the studies in literature, computer simulations and analyses have been performed comparatively of the performances over estimation and excision of jammer signals of different spreading sequences such as PN, Barker and CCK. In general of the performed simulations, it has been seen that the obtained performances with CCK spreading sequence are better than the others. When the power of jammer signal is increased, it has been observed that the obtained performances by the three spreading sequences decrease gradually.

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