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Anti-jamming Performance Simulation and Analysis of Tactical Data Link Communication System

Hao Xie[1,2], Jun Hu[1], and Wen-Yan Yin[1]

[1] Centre for Optical and Electromagnetic Research (COER), Zhejiang University
Hangzhou 310058, China

[2] State Key Lab of Complex Electromagnetic Environment Effects on
Electronic and Information System (CEMEE)
xiehao@coer-zju.org

Abstract— **A Tactical Data Link Communication System (TDLCS) simulation model is proposed with the help of the software of Simulink/Matlab, based on direct-sequence spread spectrum (DSSS), frequency-hopping spread spectrum (FHSS) and channel coding technologies. Further, such simulation model is adopted for evaluating anti-interference performance of the TDLCS for various electromagnetic interference (EMI) signals.**

Key words: TDLCS, DSSS, FHSS, EMI, Bit error rate (BER)

I. INTRODUCTION

It is well known that the objective of a communication system is to transmit the information from transmitter to receiver correctly, and Tactical Data Link Communication System (TDLCS) [1] is often used for defence purpose, which can achieve information superiority. However, such TDLCS always faces with a severe transmission electromagnetic (EM) environment, where non-intentional as well as intentional electromagnetic interferences (IEMIs) do exist [2], [3], which may degrade the transmission data quality seriously. So, the TDLCS should have good ability to suppress the EMI or IEMI effect, and it is important for us to explore some effective techniques to enhance the TDLCS capability.

In this paper, a TDLCS simulation model is proposed based on the Simulink platform of Matlab software, where the technologies of direct-sequence spread-spectrum (DSSS) [4], [5] and frequency hopping spread-spectrum (FHSS) are used for our simulation [6]. In addition, channel coding techniques consisting of cyclic redundancy check (CRC) [7], Reed-Solomon (RS) codes and interleaving are also adopted so as to improve the communication system performance [8], [9], [10], with different EMI signals considered. The simulator is successfully used for evaluating the anti-interference performance of the TDLCS to various EMI signals [11], [12], with some figures of frequency spectrogram changing processes and bit error rate (BER) plotted according to the Simulink Simulations.

II. KEY TECHNOLOGIES OF TDLCS

Figure 1 shows the schematic of the TDLCS. It can perform 10 time DSSS and hops among 32 frequencies points, where the frequency separation of every two neighbouring frequency points is 10 MHz.

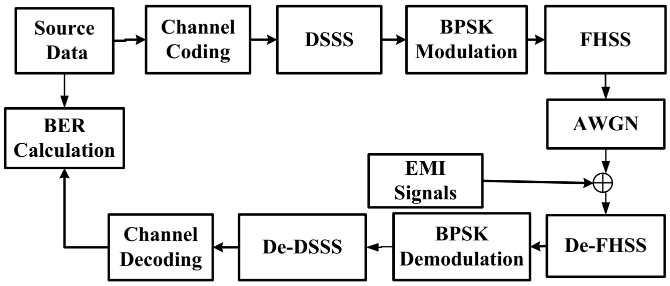


Fig. 1. Schematic of the TDLCS.

In order to improve the TDLCS performance of resisting EMI signals in the complex EM environment, some key techniques of channel coding and spread spectrum are applied [13], [14], such as CRC, RS, interleaving, DSSS, and FHSS, *etc*.

A. Channel Coding

As we know, some errors often exist during the information transmission because of non-ideal channel and additive white Gaussian noise (AWGN). The system BER can be reduced as some suitable channel coding techniques are used. The channel coding techniques considered here are CRC, RS codes and interleaving.

The coding technique CRC is an error-detecting code, which can only detect whether any error caused during the information transmission. As the CRC has no error correction ability, it requires the transmitter to retransmit the information while errors are detected. The CRC code used in Tactical Data Link Communication System is CRC (237, 225) here.

The coding technique RS has very good error correction performance. It can correct both random and burst errors and it is often expressed as RS (n, k). The code length is n, and the input data dimension is k, while the minimum Hamming distance is $n-k+1$. If the RS codes do not know positions of errors in advance, it can correct up to $(n-k)/2$ errors. Otherwise, it judges up to $n-k$ bits data [9]. The RS code used in the TDLCS is RS (31, 15) correction coding.

Both interleaving and deinterleaving are commonly used in some communication systems [10], which can improve the error correction ability of RS codes. The data always transmits over the channel with a burst error. As mentioned above, if the number of errors exceeds the correcting ability of RS codes, they will lose all error correcting capability. The interleaving shuffles the transmitted data, which also disperses the burst errors and creates a balanced error distribution [10]. Therefore, Both interleaving and RS codes can be used together for reducing the BER.

B. Direct-sequence Spread Spectrum (DSSS)

It is one popular spread spectrum technique. A DSSS communication system spreads the transmitted signal to a wide frequency band by a pseudonoise (PN) code [4], [5]. The spread signal takes up more bandwidth than the original signal. At the receiver, the signal is restored to the original one using the same PN code as at the transmitter.

The process of DSSS can also be described by some mathematical formulas. The source sequence $a(t)$ with data rate R_a and date period T_a are expressed as (1), where $T_a = 1/R_a$, and

$$a(t) = \sum_{n=0}^{\infty} a_n w_a (t - nT_a) \tag{1}$$

where a_n is the source data and w_a is the source window function.

The PN sequence $c(t)$ can be expressed as (2), with data rate R_c and data period T_c, where $T_c = 1/R_c$, and

$$c(t) = \sum_{n=0}^{\infty} c_n w_c (t - nT_c) \tag{2}$$

where c_n is PN data and w_c is the pseudonoise window function.

The essence of DSSS is mode-2 addition of source sequence $a(t)$ and PN sequence $c(t)$, which can also be seen as multiplication of them. The rate of PN sequence R_c is much higher than the rate of source one R_a, and the value of R_c/R_a is an integer. So, the rate of the spreading sequence is R_c, and it is the same as the PN sequence rate. The expression of the spreading sequence is

$$d(t) = a(t)c(t) = \sum_{n=0}^{\infty} d_n w_c (t - nT_c) \tag{3}$$

where $d_n = \begin{cases} +1 & c_n = a_n \\ -1 & c_n \neq a_n \end{cases}$, and $(n-1)T_c \leq t \leq nT_c$.

The DSSS spreads the transmitted signal to a very wide frequency band, and decreases the power spectral density (PSD). The lower PSD signal is transmitted over the channel among the noise, and it is very difficult to be detected.

The demodulated signal at receiver is

$$d'(t) = a(t)c(t) + n(t) + J(t) \tag{4}$$

where $n(t)$ is noise and $J(t)$ is the interference signal. Then, the de-spread process is

$$\begin{aligned} d'(t)c(t) &= (a(t)c(t) + n(t) + J(t))c(t) \\ &= a(t)c^2(t) + (n(t) + J(t))c(t) \\ &= a(t) + n(t)c(t) + J(t)c(t) \end{aligned} \tag{5}$$

Because the values of spread sequence $c(t)$ are +1 and -1, $c^2(t) = 1$. It is uncorrelated between the spread sequence $c(t)$, noise $n(t)$, and interference signal $J(t)$. The signal $a(t)$ is a narrow band one, and the signals $n(t)c(t)$ and $J(t)c(t)$ are wide band ones. Then, the transmitted data are recovered even when the noise and interference signal exist. The DSSS communication system has good performance for anti-interference.

C. Frequency-hopping Spread Spectrum (FHSS)

In the FHSS technology, the carrier frequency of the communication system is changed rapidly and randomly with a PN sequence [6]. The PN sequence is only known by the transmitter and the receiver. The PN sequence is not transmitted from the transmitter to the receiver directly, but only used for selecting the working frequency with the PN sequence known in advance by the transmitter and receiver.

At the receiver, the frequency of received signal is recovered using the same PN sequence as that at the transmitter. The frequency changing rule cannot be known by the opponent. So, this frequency-hopping system cannot be disturbed seriously, and it has high capability for anti-interferences.

The process of FHSS can also be expressed by some mathematical formulas. The transmitted signal after frequency-hopping $s(t)$ can be expressed as

$$s(t) = b(t)\cos[(\omega_0 + n\Delta\omega)t + \varphi_0] \tag{6}$$

where $b(t)$ is the transmitted signal after modulation, $\cos[(\omega_0 + n\Delta\omega)t + \varphi_0]$ is the frequency-hopping signal, which is the output one of frequency synthesizer, $n = 0, 1, 2, \cdots, N-1$, $\Delta\omega$ is frequency separation of frequency synthesizer, $\Delta\omega = 2\pi/T$, T is every frequency-hop period, and φ_0 is the initial phase.

The receiver receives the signal $y(t)$ which can be expressed as

$$y(t) = s(t) + n(t) + J(t) \tag{7}$$

where $s(t)$ is the transmitted signal, $n(t)$ is noise, and $J(t)$ is interference one.

The received signal $y(t)$ multiplies the frequency-hopping one with $\cos[(\omega_0 + n\Delta\omega)t + \varphi_0]$, we can get the signal $b'(t)$ before demodulation, and

$$\begin{aligned} b'(t) &= y(t)\cos[(\omega_0 + n\Delta\omega)t + \varphi_0] \\ &= [s(t) + n(t) + J(t)]\cos[(\omega_0 + n\Delta\omega)t + \varphi_0] \\ &= \frac{1}{2}b(t) + \frac{1}{2}b(t)\cos[2(\omega_0 + n\Delta\omega)t + 2\varphi_0] \\ &\quad + [n(t) + J(t)]\cos[(\omega_0 + n\Delta\omega)t + \varphi_0] \end{aligned} \tag{8}$$

Therefore, we can get one useful component $b(t)$ after signal $b'(t)$ passing through a filter, and the transmitted data $a(t)$ can be got after demodulation.

The period of PN sequence is very large and its complexity is very high. So, it is very difficult to detect the PN sequence changing rule by an intentional interferer. Thus, the FHSS communication system has good characteristics of high resistance ability for anti-interference.

III. Anti-jamming performance of DSSS and FHSS system

The TDLCS simulation model is proposed in Fig. 2, which consists of DSSS, FHSS, channel coding modules and BPSK modulation modules [14]. Based on this simulator, we can find the good parameters of this communication system after a lot of simulations. In order to investigate the EMI resistance performance of the TDLCS, some common EMI signals are added after the AWGN channel module [15], such as the PN code MSK modulation, noise amplitude modulation, and multiple tones jamming.

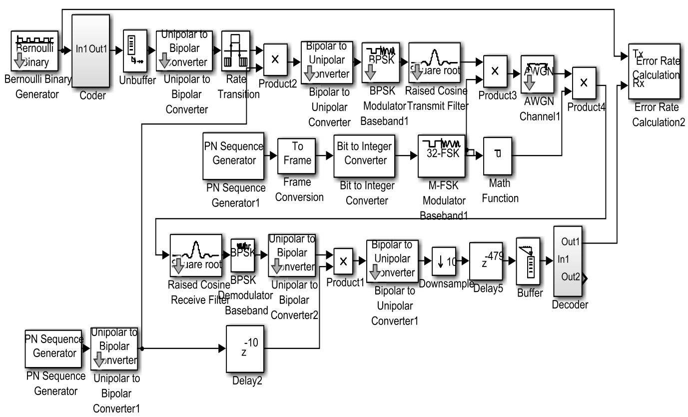


Fig. 2. The simulation model of BPSK modulation DSSS and FHSS (TDLCS).

The parameters of the above simulation model are set as follows:

1) The sample time of the transmitted data, PN sequence of FHSS module, and PN sequence of DSSS module are chosen to be 1e-6, (3e-6)/64/5, and (3e-6)/64s, respectively.

2) The sample time of the transmitted data is changed from 1e-6 to (3e-6)/64s after channel coding module as the redundancy is added.

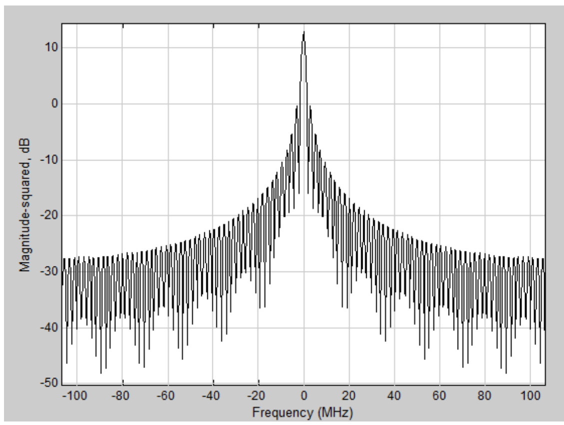
3) Every five bits of the PN sequence of FHSS module are converted into an integer as the input of M-FSK modulation baseband module.

4) The rates of system transmission and the hopping signal are the same, and it is an equal speed frequency-hopping system.

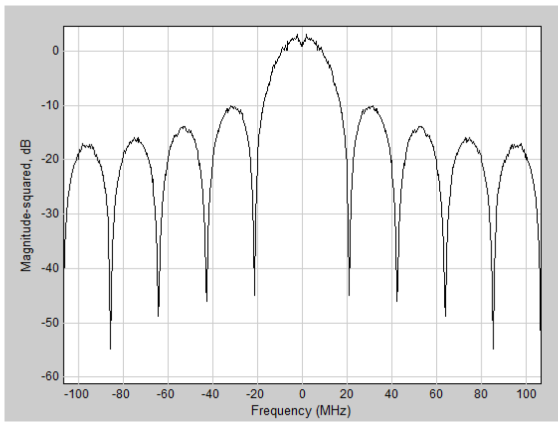
5) The frequency separation of the M-FSK modulation baseband module is 10 MHz, and M-ary number is 32.

Based on these chosen parameters, this system can achieve 10 times DSSS. Its operating frequency can hop among 32 frequency points, and the frequency separation of every two neighbouring frequency points is 10 MHz. The frequency spectrogram changing processes are shown from Figs. 3 to 6, respectively.

Comparing Figs. 3(a) with 3(b), it is found that the bandwidth after DSSS is 10 times of the original bandwidth before DSSS. The DSSS simulation model designed realizes 10 times spread spectrum, which meets the system design requirement.

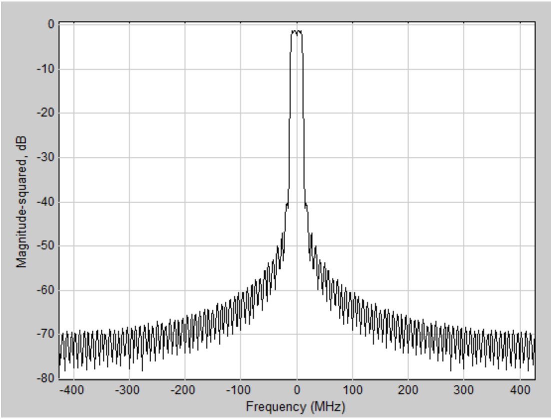


(a)

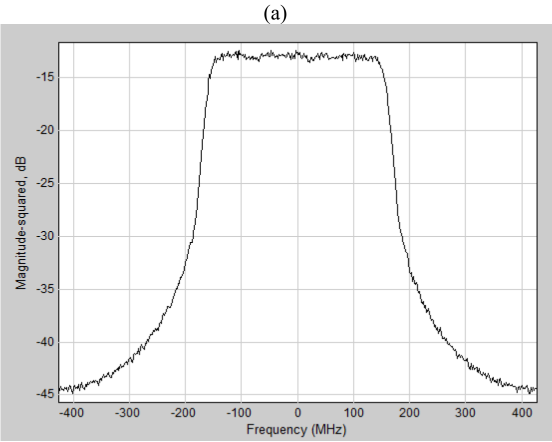


(b)

Fig. 3. The frequency spectrogram: (a) after channel coding and (b) after DSSS.



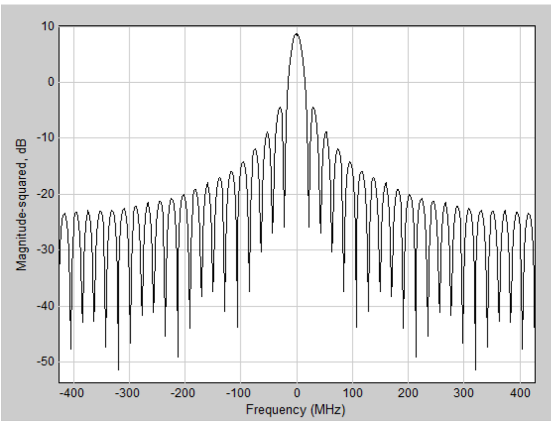
(a)



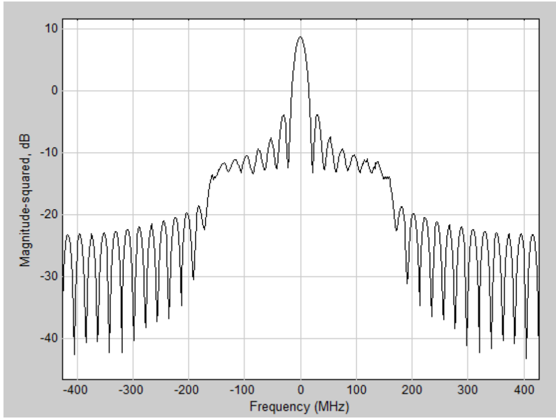
(b)

Fig. 4. The frequency spectrogram: (a) after modulation and (b) after FHSS.

Comparing Figs. 4(a) with 4(b), it is seen that the spectrum bandwidth is broadened obviously. There are 32 frequency points and the frequency separation is 10 MHz. The bandwidth of the signal in Fig. 4(b) is 320 MHz because 32*10MHz=320 MHz. So, the frequency spectrogram result meets the system design requirement.



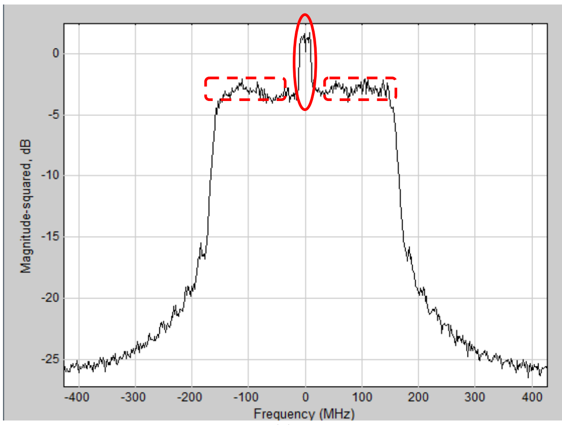
(a)



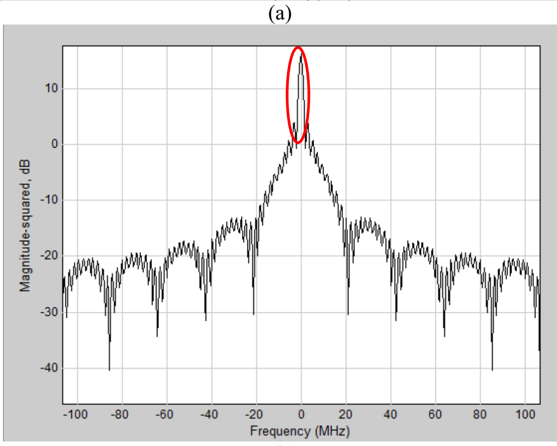
(b)

Fig. 5. The frequency spectrogram: (a) jamming signal and (b) after channel.

Figure 5(a) shows the frequency spectrogram of jamming signal, and Fig. 5(b) shows the frequency spectrogram after channel, with the jamming signal added. It is seen that the signal is distorted in comparison Fig. 4(b) with 5(b).



(a)



(b)

Fig. 6. The frequency spectrogram: (a) after De-FHSS and (b) after De-DSSS.

The centre narrow band part of the signal marked in Fig. 6(a) is highly identical with the modulated one in Fig. 4(a). It is means that the modulated signal is recovered even when the transmission one is distorted by the jamming signal seriously. The interference signal marked with red dashed rectangle is spread again, which is moved to both sides of the centre useful signal after the de-frequency-hopping.

The centre narrow band part signal marked in Fig. 6(b) is highly identical with the signal after channel coding in Fig. 3(a). It is indicated that the modulated signal is recovered even when the transmission signal is distorted by the jamming signal seriously.

We can get the BER curves by changing the jamming signal type and its power. To characterize the jamming influence, we set the parameter signal to noise ratio (SNR) of AWGN channel module to be 100 dB with the influence of AWGN ignored. By adjusting the jamming signal power, we can get the simulated results as shown below.

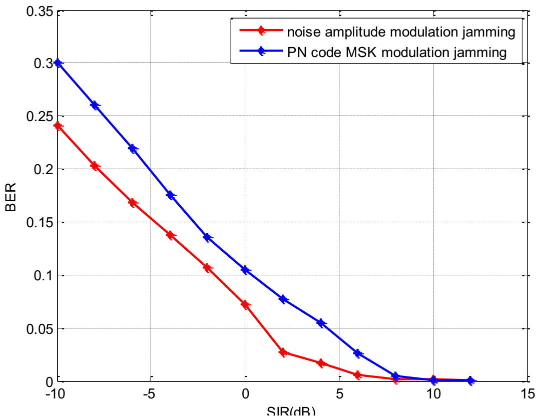


Fig. 7. The BERs of DSSS and FHSS for different interferences.

It is shown that the BER decreases as the signal to interference ratio (SIR) increases in Fig.7. The jamming effect of the PN code MSK modulation jamming is better than the noise amplitude modulation one.

Further, the EMI signals of the simulation model are changed to five and seven tones jamming signals so as to estimate the anti-jamming performance. The five tones are 10 and 70MHz, while the seven tones are 10， 40 , 70, 100 and 130MHz. Then, we can get the BER curves as shown below by changing the SIR.

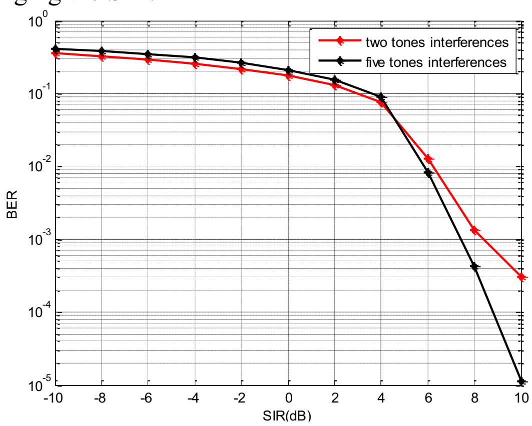


Fig. 8. The BERs of DSSS and FHSS resisting different tone interferences.

It is seen from Fig. 8 that the jamming effect of five tones is better than two ones when the SIR is lower than 5 dB. This is because five tones jamming signal disturbs more frequency points in the frequency domain. However, the jamming effect of five tones is worse than that of two ones, when the SIR is higher than 5 dB. The reason is that each tone power of five tones jamming is smaller than the two tones jamming, when the total jamming power is a constant. When the interference signal power is reduced to a certain extent, its power assigned to each frequency point is too small, and the interference to the system is relatively reduced.

IV. Conclusions

In this paper, we have combined the spread spectrum and channel coding techniques into an integrated communication system for building up the TDLCS simulation model, with some EMIs added. Based on this model, the anti-interference performance of the TDLCS to various EMI signals has been evaluated, respectively. The simulated results of frequency spectrogram show that the modulated signal can be recovered even when the transmission signal is distorted by the jamming one seriously. The BER figures have demonstrated the jamming effects on the TDLCS for different EMI signals. These simulation results we obtained will be useful for the practical design of TDLCS.

Acknowledgment

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