STUDY ON AN ANTI-JAMMING METHOD OF SPREAD-SPECTRUM COMMUNICATION BASED ON LT CODES

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Abstract

Lots of information is missing in poor communication environment and the data receiving terminal cannot recover source data, therefore, this paper proposed a new anti-jamming method of spread-spectrum communication based on LT codes. This method uses the characteristics of information scattered encoding and non-rate transmission of LT codes, through the spectrum of the signals which is the direct sequence spread spectrum broadening coding. In this way it has a good link with anti-flash and anti-jamming capability. Simulation results show that under the strong interference environment, adopting the method of spread spectrum communication based on LT codes can improve the anti-jamming capability of communication system.

1 Introduction

Fountain coding idea was proposed by Luby [1] [2] in 1998, it has simple coding and decoding methods, small decoding overhead and low decoding complexity. Fountain coding techniques are commonly used to solve the problems of communication feedback data retransmission and high dropout rate [3]. LT (Luby Transform) codes is a digital fountain codes that can be achieved, it puts the source packets to recode and generates any number of new packets, the receiver only needs to receive slightly more than the number of source packets successfully, and it can recover all of the source packets with a high probability. Information can be scattered in various coding information units by this way of coding [4] [5]. Once the communication interruption is caused by disturbance, it only needs to continue to receive subsequent code packages, which can return to the original information, without the retransmission [6] [7].

Because of the complexity of space environment and the external disturbance can easily cause the communication interrupt and the data loss. Literature [8] proposed the idea of adding on-off flags to monitor the data link, when the on-off flag was not detected, the system automatically starts the application to re-establish the link, but this method increases the encoding complexity, and it only can monitor whether the link is interrupted or not, after determining the loss of data, it should send the information again. Literature [9] proposed the idea of using backup link, when the communication link fails, the standby link quickly switch to prevent communication from interrupting, but this method increases the complexity of hardware implementation and link switching control precision. Literature [10] proposed the idea of finding out the damaged data points in the data transmission, and search the higher of damaged data to resend to repair the wrong data, but this method increases the complexity of the implementation of hardware and software, Under the environment of many interference sources, data loss rate will increase, and when there are multiple recipients, it will cause feedback explosion, which can lead to low handshake and retransmission efficiency.

This paper proposes a new anti-jamming method of spread spectrum communication based on LT codes [11] [12], this method has the characteristics of simple coding and decoding complexity and information scattered in various coding information unit etc., it can enhance the anti-interference performance of communication effectively, it can also avoid the problems of data of discontinuity and retransmission caused by corrupted data points. In addition, the implementations of the hardware and software are simple.

2 The of LT Codes

2.1 The Degree Distribution of LT Codes

The LT codes implements real-time transmission without code rate, which is a kind of practical digital fountain code and general delete code. It's not restricted the length of the input information unit, if the input data contains k information units, then in the process of encoding it generates each calibration unit which needs $O(\ln(k/\delta))$ times XOR operation. If the probability of the successful decoding is $1-\delta$ in the process of decoding, then the overhead of the decoding is $O(\ln^2(k/\delta)\sqrt{k})$ [13] [14].

The choice of the degree distribution of the LT code function largely determines the probability of the successful decoding. A good degree distribution function should let the encoder output contains a small portion of d d which the number of the data packets is k to ensure that all data sources involved in the final code, but also contains a large number of the smaller packets of d to ensure sustainable decoding code [15] [16]. The mature degree distribution has the "1" distribution, uniform distribution, the ideal soliton distribution, robust soliton distribution. The following describes the ideal soliton distribution and robust soliton distribution [17].

The ideal soliton distribution is shown in the Formula (1):

$$\rho(d)=\begin{cases}1/k & d=1\\ 1/[d(d-1)] & 2\le d\le k\end{cases} \tag{1}$$

where, the number of the source data is k, the degree of the code package is d.

The robust soliton distribution is shown in the Formula (2):

$$\mu(d)=(\rho(d)+\tau(d))/\beta \quad d=1,2,\cdots,k \tag{2}$$

where $\rho(d)$ is the ideal soliton distribution.

$$\beta=\sum_{d=1}^{k}(\rho(d)+\tau(d)) \tag{3}$$

$$\tau(d)=\begin{cases}s/(k\cdot d) & d=1,2,\cdots,(k/s-1)\\ s\lg(s/\delta)/k & d=k/s\\ 0 & d>k/s\end{cases} \tag{4}$$

where $s=c\ln(k/\delta)\cdot\sqrt{k}$, c is the appropriate constant in $[\frac{1}{k-1}\cdot\frac{\sqrt{k}}{\ln(k/\delta)},\frac{1}{2}\cdot\frac{\sqrt{k}}{\ln(k/\delta)}]$, δ is the probability limit of the unable decoding after receiving N confirmation packet, which $N=k+0(\sqrt{k}\ln^2(k/\delta))$.

2.2 The Encoding Process of LT Codes

Assuming that the source data contains $k(s_i,i=1,\cdots,k)$ packets with the same size, then each generated LT coding packets can use the following steps to complete:

(1) Through the selected degree distribution function $\rho(d)$ determines the degree of each code packet;

(2) Through the predetermined degree, randomly selected d packets from the k source packets;

(3) Each of the d packets one by one takes the XOR operation to get a new code;

(4) Repeat the above steps.

The encoding process of the LT code is shown in **Figure 1**.

2.3 The Decoding Process of the LT Codes

Assuming the decoder receives *M* encoded data packets, and we know that the degree of each coded data packet is *d*. Since in the whole coding process, only the degree of 1 coded packet is not involved in the XOR operation, which the new code and the old data packets of the same data packet, so it is important to find out the coded packet whose degree is 1 in the processing of decoding. The decoding process is as follows:

(1) To find an encoding data packets whose degree is 1, namely the coded packet is associated with a source data packets, only this can restore the original data. If the degree of 1 case was found, the decoding process will be terminated, or only by receiving more packets to make degree is 1, and then began to decoding process.

(2) Let $S_i=S'_j$, let all the coded packets associated with S_i and S_i do the XOR operation, the remove all the edges associated with S_i.

(3) Repeat the above steps until all of the source data is restored.

The decoding process is shown in **Figure 2**.

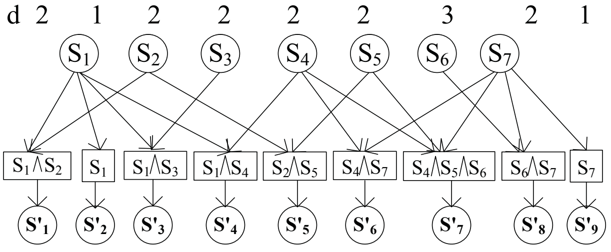

Figure 1. Encoding process of LT codes.

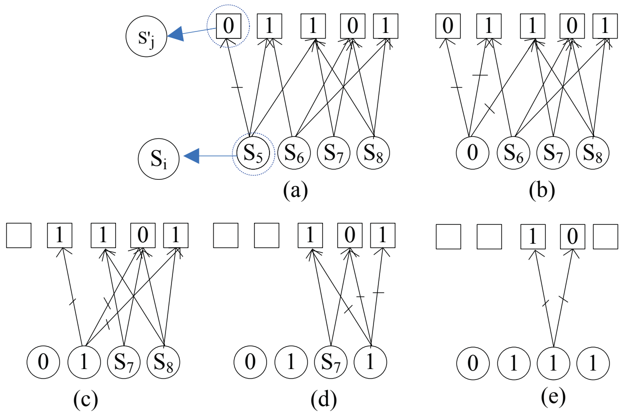

Figure 2. Decoding process of LT codes.

3 Anti-Jamming Method of Spread Spectrum Communication Based on LT Codes

3.1 Affiliations Direct Sequence Spread Spectrum (DSSS)

Direct sequence spread spectrum is a wireless transmission mode of sequence types with high safety and high noise immunity, it utilizes high code rate of spreading codes sequences to extend signal frequency spectra. In the receiving end, using the same spreading codes sequences to despread the signal to restore the original information. DSSS signal has a wide frequency band and very low power spectral density, therefore, it has strong concealment and anti-interception.

In DSSS communication system, the carrier modulation commonly uses the BPSK, the transmitted signal is as follows:

$$s(t)=\sqrt{2Pd_{(t)}}c(t)\cos(w_0t) \tag{5}$$

where, $d(t)$ is the information data, $c(t)$ is the spread spectrum code sequence. The ideal spread spectrum code is the binary random sequence; its autocorrelation function is as follows:

$$R_c(\tau) = \begin{cases} 1 - \dfrac{|\tau|}{T_c} & |\tau| \le T_c \\ 0 & |\tau| > T_c \end{cases} \tag{6}$$

Executing the Fourier transform, the power spectrum density is:

$$P_c(f) = T_c \sin c^2(fT_c) \tag{7}$$

In the formula, $\sin c(x) = \sin \pi x / \pi x$, the power spectrum is a continuous spectrum.

In the actual DSSS systems, the spread spectrum code sequence is generally the periodic pseudo-random sequence. The most typical pseudo-random sequence is m sequence; the autocorrelation function of m sequence is as follows:

$$R_{PN}(\tau) = \begin{cases} 1 - \dfrac{\tau}{T_c}(1 + \dfrac{1}{L}) & |\tau| \le T_c \\ -\dfrac{1}{L} & T_c < |\tau| < (L-1)T_c \end{cases} \tag{8}$$

Due to its autocorrelation function is cyclical, the corresponding spectrum is discrete. If the period of m sequence L is equal to N, *i.e.*, an information data bit contains a complete m-sequence cycle, the power spectral density is:

$$P_{PN}(f) = \frac{N+1}{N^2} \sum_{\substack{K=-\infty \\ K \ne 0}}^{+\infty} \sin c^2(\frac{k}{N}) \delta(f - kf_d) + \frac{1}{N^2}\delta(f) \tag{9}$$

Regardless of the system time delay, the received signal is:

$$r(t) = s(t) + j(t) + n(t) \tag{10}$$

where, $j(t)$ is a man-made interference signal, $n(t)$ is the thermal noise.

At the receiving end first dispreading the received signal processing, assuming the reception side spreading code and carrier synchronization has been achieved precisely, the bilateral power spectral density of the thermal noise is $N_0 / 2$.

Because $c(t) \times c(t) = 1$, the useful signals dispread into conventional narrowband signals, while other signals, the results of the different spread spectrum codes are not the same. When the selection of the spreading code is a long sequence, the power spectral density is approximated by Formula (7), when the selection of the spreading code is a long sequence, the power spectral density is represented by Formula (9).

3.2 m Spread Spectrum Sequence

The m sequence is short for the sequence of the longest linear feedback shift register. It is the longest sequence generated by linear feedback shift registers. The m sequence has the following attributes:

(1) m sequence is generated by the n-order shift register and its period is $2^n - 1$.

(2) In addition to the all "0" state, the other possible states of the n-order shift register appear but only once. Therefore, the probabilities of the appearance of "1" and "0" in m sequence is same approximately, the number of "1" is only one more than that of "0".

(3) In a sequence, the consecutive and same codes called a run. For m sequence, the run-length of 1 accounts for 1/2, the run-length of 2 accounts for 1/4, the run-length of 3 accounts for 1/8, and so on. We can deduce that the run-length of k accounts for 2^{-k} [$1 \le k \le (n-1)$]. In m sequence, the run-length of "1" and run-length of "0" accounts for 1/2 respectively.

m sequence has double value auto correlation characteristics: its auto correlation coefficient has only two different values. When its period is relatively large, the m sequence has a sharp auto correlation function, which is very similar to the white noise.

3.3 Process of the Communication System

First, to encode the source data with LT encoder, and extend the encoded signal with DSSS system, sending the signal into channel after BPSK modulator, the receiver will get signal, demodulate and despread it, and correct the offset signal before sending the sampling into LT decoder, thus the source signals are recovered. The process is represented in **Figure 3** below.

In this paper, we take source code length of 100, 250, 500, and 1000 for examples. The new data packages of LT encoder generates slightly more than the length of source data packages, the new data is sampled 800 times and do the XOR operation with equal length of PN codes. The process is represented in **Figure 4** below.

4 Simulation Results and Analysis

In order to study on the performance of the anti-jamming method of spread spectrum communication based on LT codes, in this paper, the spread spectrum code uses the m sequence and BPSK modulation, the carrier frequency is

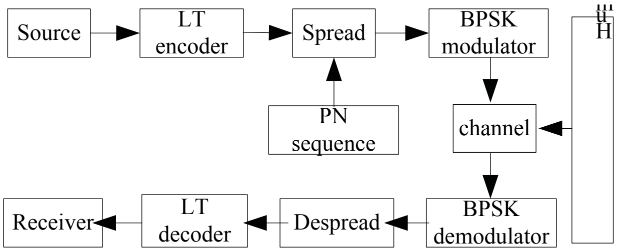

Figure 3. Process of anti-jamming method of DSSS system based on LT codes.

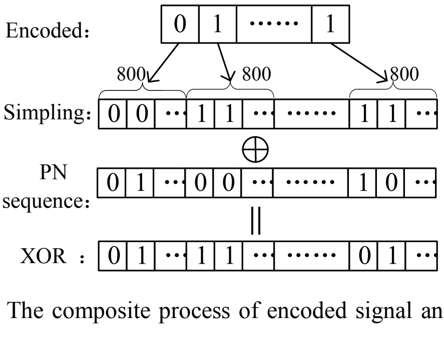

Figure 4. The composite process of encoded signal and PN sequences.

1000 Hz, *K* is the number of source packets, in simulation, N is the number of encoded data packets, and we prepare to analysis of the communication system through the study of multiple communication simulation tests. In the simulation, human disturbance is joined in the channel.

Figure 5 is shown that the comparison of bit error rates of spread-spectrum system without coding, spread-spectrum system with LDPC codes, and spread-spectrum system with LT codes. In simulation, the source length is 1000, LDPC code is a rate 2/3 of the regular codes, the redundancy of LT codes is 0.4 (The bit error rate of LT code is the average value of the repeated simulation). As can be seen from the graph, the bit error rate of spread-spectrum system is lower than other two kinds of spread-spectrum systems; this shows the anti-jamming method of spread-spectrum communication based on LT codes has a very stable performance of anti-jamming communication when SNR is above 0 dB.

Figure 6 is shown that the relationship between probability of decoding failure and redundancy overhead of encoding in different degree distribution of the anti-jamming method of spread-spectrum communication based on LT codes. In simulation, the source length is 1000, the increase of redundancy overhead of encoding reduces the probability of decoding failure, and the probability of decoding failure in robust soliton distribution is obviously lower than the probability of decoding failure in ideal soliton distribution, the probability of decoding failure is 10% when the cost of redundancy overhead of encoding reaches 0.3, and when the redundancy overhead of encoding reaches 0.5, the probability of decoding failure reaches close to 0.

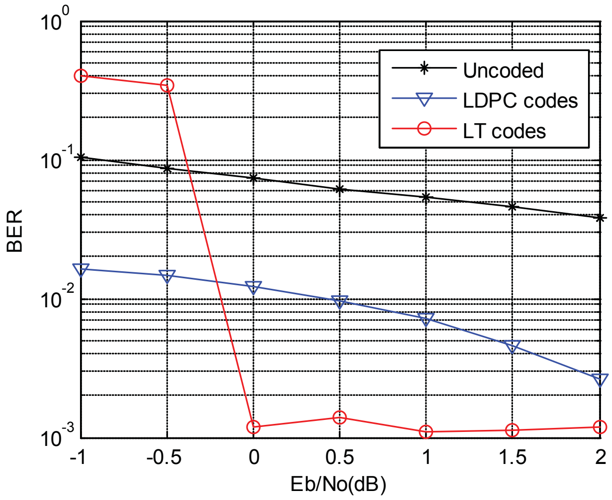

Figure 5. The BER comparison of three different spread-spectrum systems.

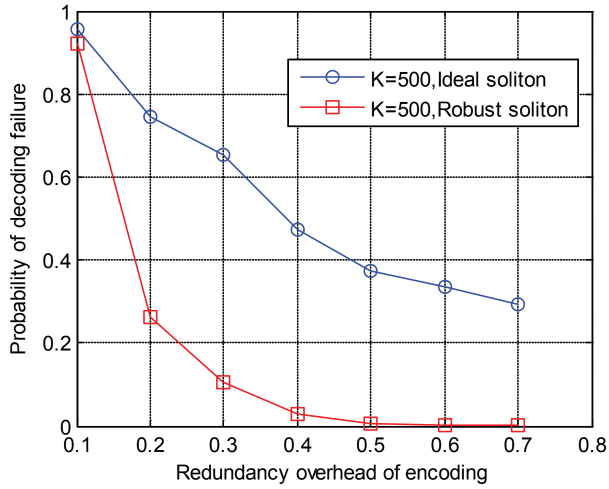

Figure 6. Probability of decoding failure in different degree distribution.

Figure 7 is shown that the relationship between the probability of successful decoding and the redundancy overhead of encoding when K = 100, 250, 500, 1000. The probability of successful decoding will rise with the increase of redundancy overhead of encoding, and when K = 1000, the probability of successful decoding is higher than the other situations as can be seen from the diagram. So we can get that when the redundancy overhead of encoding is fixed values, the value of K increasing, and the higher probability of successful decoding.

Figure 8 is shown that the relationship between the redundancy overhead of encoding and the failure rate of decoding in different rates of data loss. In simulation, the

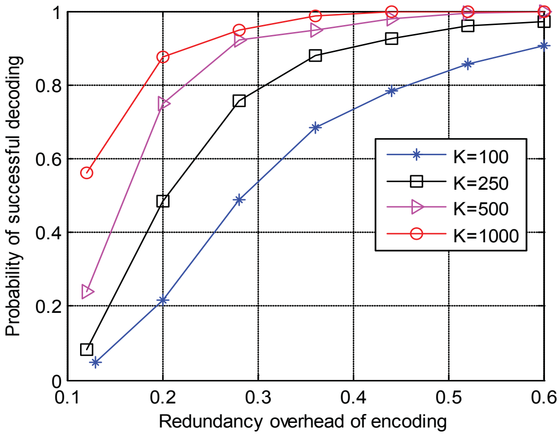

Figure 7. The BER comparison of three different spread-spectrum systems Effects of probability of successful decoding and redundancy overhead of encoding when K is different.

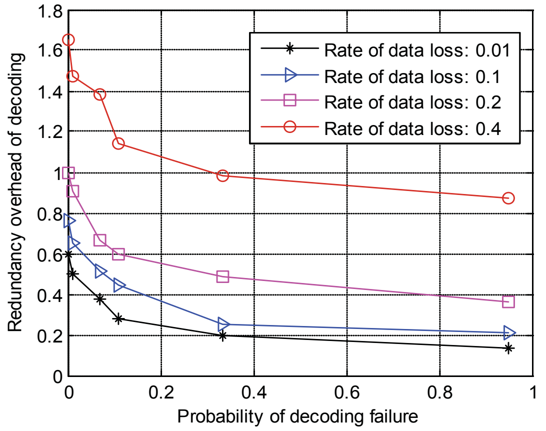

Figure 8. Effects of redundancy overhead of encoding and failure of decoding in different data loss rates.

source length is 500, and rate of data loss = 0.01, 0.1, 0.2, 0.4. As can be seen from the graph, in the same probability of decoding failure, the data loss rate is higher; the cost of redundancy overhead of encoding is greater. If the probability of decoding failure reaches 0, the cost of the redundancy overhead of encoding should be above 0.6 when the rate of data loss is 0.01, however, the cost of the redundancy overhead of encoding should be more than 1.6 when the rate of data loss is 0.4.

5 Conclusion

In view of the complicated and changeable communication environment and considering the loss of data caused by human disturbance, this paper proposed a new anti-jamming method of spread-spectrum communication based on LT codes. This method guarantees the system of high security and immunity; it uses LT codes, which make the communication have a high ability of anti-jamming and anti-flash capacity. As can be seen from the simulation results, the new anti-jamming method of spread-spectrum communication based on LT codes has very stable anti-jamming performance when SNR is 0 dB or above, and its decoding performance will increase with the increase of the source length.

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