Research on LT code coding scheme for deep-space optical communications

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Abstract: Deep-space optical communications have the characteristics of high code error rate, long delay and easily broken link etc. Channel coding, as a key technology, can solve the problems of the deep-space optical communication system. Compared with the traditional channel coding, LT code is more suitable for the system, in which the degree distribution design of LT code is also importance. In the paper, the double switch degree distribution scheme is proposed to improve degree distribution. Simulation results show that the bit-error rate (BER) performance of LT code with Robust Soliton Distribution (RSD) for the system is about 1.5 dB better than that of RS code for the system at BER of 10-6, and is also about 0.8 dB better than that of LDPC code for the system at BER of 10-6. LT code with RSD is about 0.45 dB worse than LT code with the double switch degree distribution at BER of 10-5.

1. Introduction

Deep-space optical communications have the characteristics of high code error rate, long delay and easily broken link etc.Channel coding is the key technology to ensure the reliability of the deep-space optical communication system, and it is of great significance to solve the above problems. So far, from the block codes, convolution codes, RS codes, concatenated codes to Turbo codes, LDPC codes , channel coding method is widely discussed or applied to the deep-space optical communication. It is also more and more approached for performance to reach the theoretical limit of the Shannon channel coding theorem [1]-[3].However, the traditional coding methods adopted in deep-space optical communication, because of its fixed code rate, need the ARQ mechanism to eliminate the error message occurred in the transmission process, this greatly increases the communication delay.

In 2002, Luby raised the first practicable fountain codes, LT code [4]-[5]. LT code is a rateless code, and is a good solution to the problems that cannot be solved very well by the traditional channel coding methods. LT code uses forward erasure correction (FEC) method without feedback channel in the process of information transmission. Therefore, LT code for deep-space optical communication can avoid the re-transmission and acknowledge of channel information, reduce the transmission delay and improve the transmission efficiency. Performance of LT code is closely related with how to construct the degree distribution. In [4], the author presented two kinds of degree distributions scheme, namely Ideal Soliton Distribution (ISD) and Robust Soliton Distribution (RSD). ISD theoretically ensures that each encoded packet has the same release probability [4] after each iterative decoding step. And when one encoded packet is recovered, new degree-one packet will appear again. But in fact, because of the randomness of the relationship between source packets and encoded packets, the degree-one packets will disappear easily in the process of decoding. Considering the disadvantage of ISD, RSD including double parameters is designed to guarantee the expected number of the degree-one packets [5], and also increases the probability of encoded packets with big-degree. At the same time, because of the higher coverage rate of encoded source packets, the redundancy is increased to reduce the efficiency of decoding. In [6-7], Binary Exponential Distribution (BED) is proposed to highly increase the probability of degree-one encoded packets, and reduce the probability of source encoded packets. In this paper, newly double switch degree distribution combined with BED, ISD and RSD is applied to design LT code with two

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switch points [8]. The simulation results demonstrate that the double switch degree distribution can improve the BER performance of the deep-space optical communication system.

The rest of the paper is organized as follow. In section II, we introduce the system model. Section III presents LT code and different degree distributions. Section IV shows the result of simulation experiments. In Section V, we conclude the whole paper.

2. System Description

The structure of this proposed system is shown in Fig.1. Consider the transmission of LT signals over a Poisson channel.

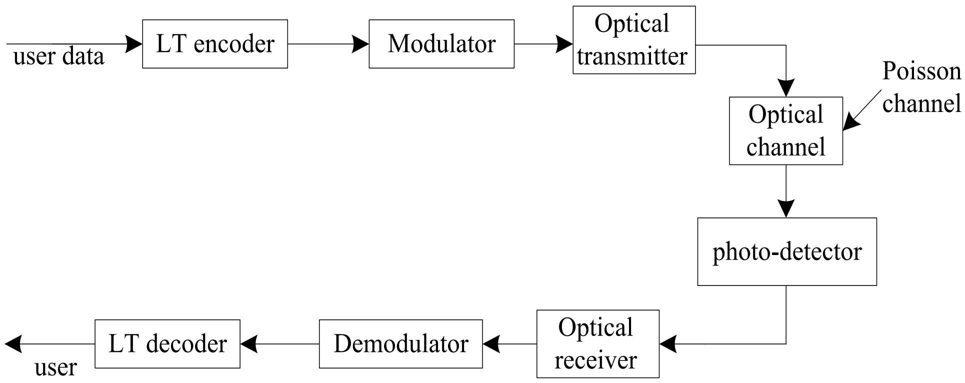

Fig.1. System model.

The system model is shown in Fig.1. It consists of LT encoder, modulator, optical transmitter, optical channel, photo-detector, optical receiver, demodulator and LT decoder. As shown in the block diagram, user data is first encoded by LT encoder, modulated, then passed into the entire channel, demodulated, and then decoded by LT decoder before finally being put onto the user.

The entire channel (optical transmitter, optical channel, photo-detector, and optical receiver) is modeled as Poisson processes in the same way as in [9] and [10]. The information is encoded, modulated and transmitted over an optical channel that is modeled as a Poisson point process. And the optical channel is regarded as the Poisson channel. Letting nb be the mean noise photons in a slot and ns the mean signal photons in a pulsed slot, the channel then reduces to a binary-input, discrete-output Poisson channel, with signal and noise slot mass functions

$$p(k|1) = \frac{(n_s + n_b)^k \exp[-(n_s + n_b)]}{k!} \tag{1}$$

$$p(k|0) = \frac{n_b^k \exp[-n_b]}{k!} \tag{2}$$

The LT decoder is using the belief propagation (BP) algorithm[11].

3. LT Code Theory

3.1. Different degree distribution schemes for LT code

LT code is an erasure code applied in the deep-space optical communication system. The LT encoding is done by randomly selecting d packets from k source packets and doing XOR of these packets to form one encoded packet. By repeating doing this process, we can get an infinite long encoded packets flow. The variable d is chosen according to the degree distribution. Therefore, it is essential for LT code to design the better degree distribution scheme.

3.1.1. Robust Soliton Distribution

The function of Ideal Soliton Distribution (ISD) is:

$$\rho(d) = \begin{cases} 1/d & d = 1 \\ 1/d(d-1) & d = 2,3 \cdots k \end{cases} \tag{3}$$

Robust Soliton Distribution (RSD) makes an improvement of ISD, it introduces two parameters, c and δ to ensure the expected number of degree-one packets S which is:

$$s = c \ln\left(\frac{k}{\delta}\right)\sqrt{k} \tag{4}$$

The function of this distribution is:

$$\mu(d) = \frac{\rho(d) + \tau(d)}{Z} \tag{5}$$

Where,

$$\tau(d) = \begin{cases} \frac{s}{k}\frac{1}{d} & d = 1,2,\cdots(k/s)-1 \\ \frac{s}{k}\log(s/\delta) & d = k/s \\ 0 & d > k/s \end{cases} \tag{6}$$

$$Z = \sum_d (\rho(d) + \tau(d)) \tag{7}$$

Where, ρ(d) is the probability of an encoded packet with degree d when adopting the ISD to encode, μ(d) is the probability of an encoded packet with degree d when the RSD is used to encode. k is the number of source packets, δ is a bound on the probability that the decoding fails to run to completion after a certain number k ' of packets have been received. c is a constant between 0 and 1.

3.1.2. Double Switch Degree Distribution

In [6],author presented Binary Exponential Distribution (BED),

$$b(d) = \begin{cases} 1/2^d & d = 1,2,3 \cdots k-1 \\ 1/2^{d-1} & d = k \end{cases} \tag{8}$$

The double switch degree distribution is combining 3 degree distributions using two switch point. There are BED, ISD and RSD. At first we use BED to encode, after receiving a certain number of encoded packets, switching to ISD, and at last changing into RSD. The function of double switch degree distribution is:

$$n(d) = \begin{cases} b(d) & i \le \alpha k \\ \rho(d) & \alpha k < i \le (\alpha+\beta)k \\ \mu(d) & i > (\alpha+\beta)k \end{cases} \tag{9}$$

Where, n(d) is the probability of an encoded packet with degree d when adopting the double switch degree distribution to encode. b(d) is BED, ρ(d) is ISD, μ(d) is RSD, k is the number of source packets, i is ith encoded packet, α and β are the switch points. The optimal value of α and β by fig.2 are 0.06 and 0.25 .

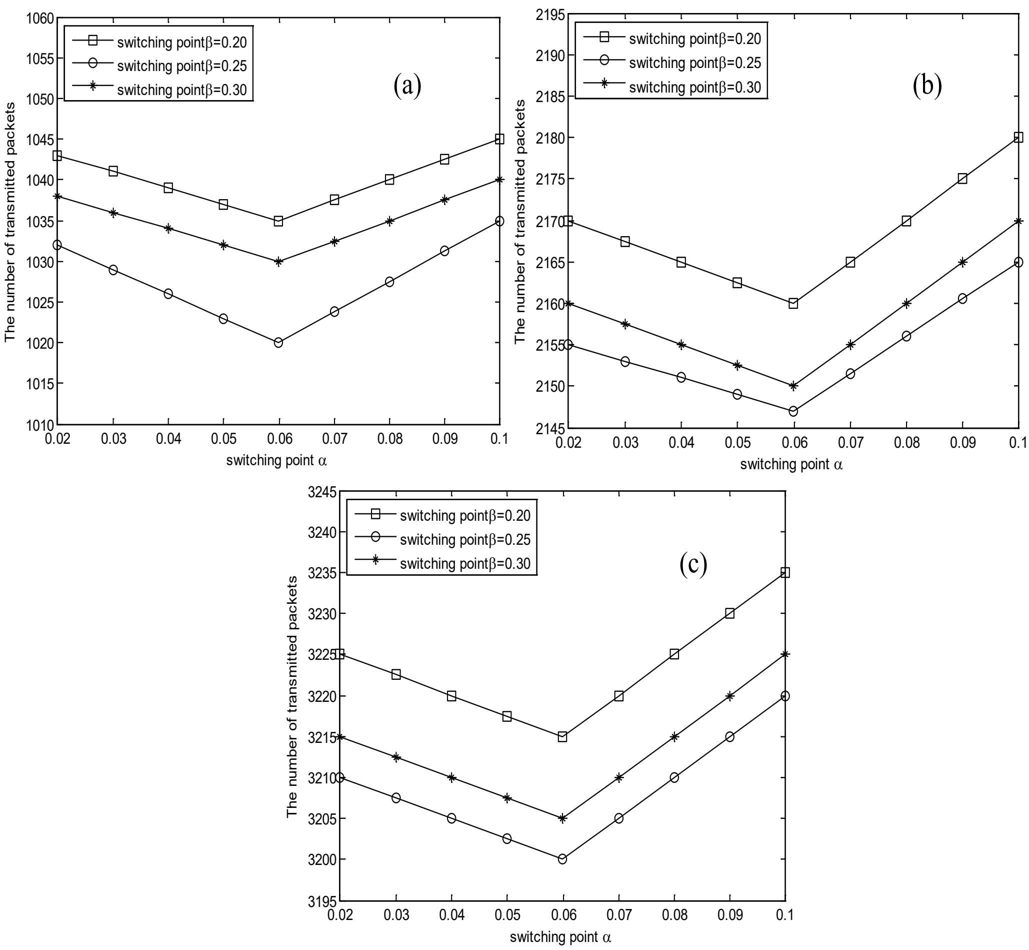

Fig.2. Relationship between switching points and the number of transmitted packets.

3.2. Decoding of LT code

The decoding process of LT code is triggered as soon as the destination receives enough encoded packets to be decoded. We adopt a bipartite graph with encoded packets connecting to source packets and randomly choose one degree-one packet to start decoding, because the degree-one packet is just the copy of source packet, we can easily recover the source packet by doing XOR with its neighbors, the degree of each connected neighbor is decreased by one. We should keep this process looping until all the source packets are recovered. And the process is the BP decoding algorithm.

4. Simulation Results

We show the results of our computer simulation. In all simulations, we assume: 1) The channel is the Poisson channel given by (1) and (2) with nb=0.2 and slot duration Ts=32ns.2) The LT codes are employed. Below a brief comparison of LT code, RS code and LDPC code will be given.

Fig.3 shows the BER performance of LT code, LDPC code and RS code. The degree distribution of LT code is RSD. LDPC code uses the (3,6)-regular LDPC code with the code length N = 4608 at rate 1/2. And RS code adopts the (255,223) RS code. As can be seen, the performance curve of LT code is steeper than that of LDPC code and RS code. Three things can be immediately seen from the plots: 1) LT code shows more significant performance improvement than LDPC code and RS code. The performance of LDPC code is also better than that of RS code. 2) The performance of LDPC code is about 0.8 dB worse than that of LT code at BER of 10-6. 3)The performance of LT code is about 1.5 dB better than that of RS code at BER of 10-6.

Fig.4 plots the BER performance of LT code with different degree distributions. As can be seen, the better the degree distribution, the steeper the performance curve, which clearly depicts the gain of the degree distribution. Obviously, the BER performance of LT code with double switch degree distribution is better than that of LT code with RSD, and is about 0.45 dB at BER of 10-5. So, compared to RSD, the LT code with double switch degree distribution is suitable for the deep-space optical communication system, and the performance of the system is better.

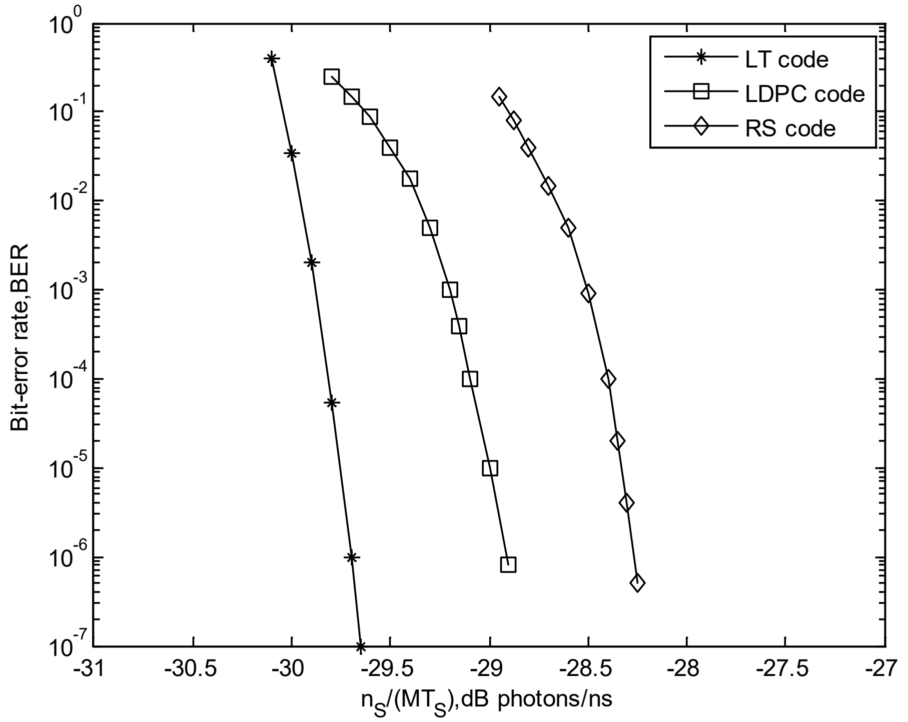

Fig.3. BER performance of different codes.

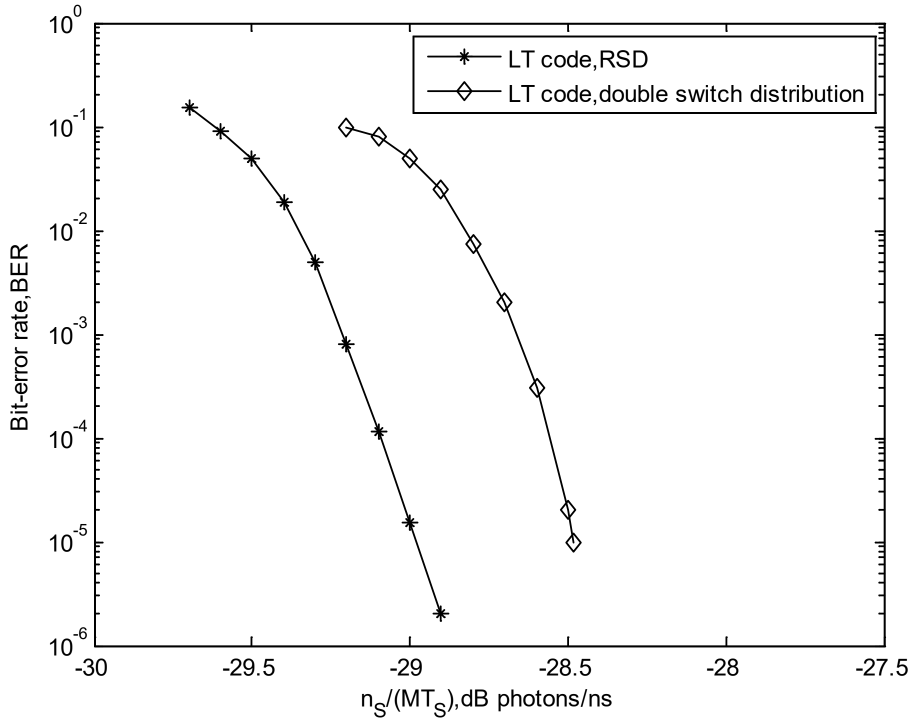

Fig.4. BER performance of LT code with different degree distributions.

5. Conclusion

In practical applications, due to the existence of signal attenuation, long delay and easily broken link, the deep-space optical communication system needs to choose the appropriate coding to make effective communication. Compared to the traditional channel coding, LT code can better solve the above problems. And LT code with a good degree distribution can also improve the performance of the system. Simulation results show that LT code is more suitable for the system, at the same time, the double switch degree distribution is better for the system performance.

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