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Distributed LT codes for mars exploration

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Abstract. This paper focuses on the investigation of distributed LT codes for Mars Exploration. A scenario comprising two sources and one relay node, referred as Y-network model, is considered. When traditional Soliton-like Rateless Code is used for this model, its performance can be degraded. Consequently, a distributed LT code scheme, named Chopped Soliton-like Rateless Codes (CSLRC), is proposed to solve the problems of high decoding complexity and large relay buffer demand. At the source nodes, weak robust Soliton distribution (WRSD) is adopted as check-node degree distribution. And the packets with the smallest variable-node degree are selected for encoding. At the relay node, a shift-based relay buffer is used. Simulation results show the proposed distributed LT code scheme can reduce decoding complexity and save decoding overhead.

Key words. Distributed lt codes, mars exploration, encoding scheme, shift-based relay buffer
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1. Introduction

Mars exploration is an important part of human outer space activities. The communication between Mars and the earth is confronted with the problems of long transmission distance, large propagation delay, lower signal-to-noise ratio (SNR) of the received signal, and so on. The reliable transmission of precious Mars data has become a major challenge. In order to guarantee the reliable transmission of Mars data, fountain codes can be adopted. The first efficient and practical realization of rateless codes was proposed by Michael Luby, termed LT code [1,2]. LT codes

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are rateless in the sense that a possibly limitless number of output symbols can be generated in the encoding of a finite number of message symbols. Each receiver can successfully decode when it receives a given number of output symbols. The distributed LT (DLT) codes were first proposed by Puducheri S [3,4]. A drawback of DLT codes is that it is not resilient to nodes churn rates. The scheme is not suitable for the case of arbitrary number of sources in the network. At present, DLT has been studied in different application environments, and suitable improvement schemes have been putted forward [5,6]. However, the performance of these schemes is affected by the intermittent link between the source and the relay in the Mars communications. Lian Andrew putted forward SLRC scheme by combined fountain codes with network codes [7]. We studied the performance of SLRC scheme over AWGN channel and found that the decoding complexity of SLRC is higher when the RSD is used for SLRC encoding. Moreover, the performance of SLRC scheme can be influenced by the limited relay buffer capacity and need to be improved. Consequently, we propose an improved SLRC scheme to suit Mar exploration environment.

2. Network model

For Mars missions, the distance between Mars and the earth is very long. Long transmission distance can cause large delay. A total communication link can be segmented into several links by relay method. The distance between each segment link becomes shorten. Thus the signal loss can be reduced and the SNR can be improved. Moreover, the shielding problem caused by the revolution of planets can be effectively solved. Consequently, a relay link model consisting of the earth orbit satellite, the Lagrange relay node and the Mars detector is established. According to this model, a "Y" model consisting of double sources, single relay and single sink can be abstracted, as shown in Fig.1. In Fig. 1, the detection data is transmitted through free space. The free space channel is similar to the additive white Gaussian noise (AWGN) channel. Therefore, the channel model of the Y-type topology can be modeled as an AWGN channel with packet loss.

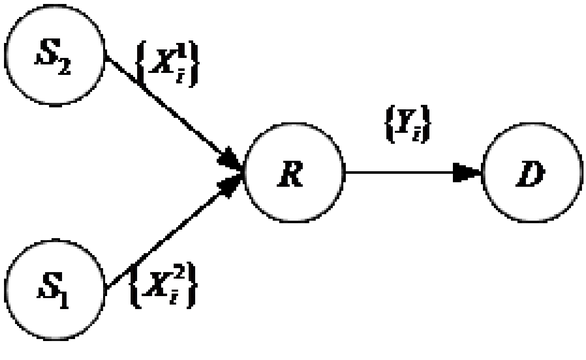

Fig. 1. Network model

3. WRSD-based Encoding Algorithm at Source Nodes

The traditional SLRC scheme uses RSD for encoding, and the aggregate distribution at the relay node R is Soliton-like distribution. Its decoding complexity increases rapidly with the code length k. For deep space communications, there are some high demands such as the higher communication reliability, lower decoding overhead and complexity, higher decoding success rate, and so on. Therefore, WRSD is used as the degree distribution to reduce the decoding complexity [8]. In order to reduce the error floor caused by WRSD, we propose an encoding strategy at source nodes. For ease of algorithm description, the set *min_ set* is used to represent the information symbol set with the minimum degree $d_{\min}$, and the set *temp_ set* represents the symbol set with degree$d_{\min}+1$. Num indicates the number of elements in the *min_ set*. The modified encoding scheme is outlined in Algorithm 1

Algorithm 1: Modified DLT (MDLT)Encoding Algorithm

Step 1. Randomly choose degree$d_i$from the given load of degree distribution$\Omega\left(x\right)$. If $d_i < num$, turn to Step 2, otherwise skip to Step 3;

Step 2. Chose d_i neighbors of the encoding symbols from *min_ set* as distinct information uniformly at random. Move these symbols from *min_ set* to *temp_ set*, and update Num, then skip to Step 4;

Step 3. Select all the symbols from *min_ set* and $d_i - Num$ symbols from *temp_ set*. Move unselected symbols from *temp_ set* to *min_ set*. Then update Num and turn to Step 4;

Step 4. Perform XOR operation for the d_i chosen information symbols for encoding. Go back to Step 1.

4. Relay processing scheme at relay node

The capacity of relay buffer in the traditional SLRC scheme is k. Spacecraft equipment storage capacity is limited. Therefore, a relay buffer scheme based on the literature [10] is proposed.

4.1. Shift-based Relay Buffer

Two buffers ($Buff1$and$Buff2$) are given to store the encoding packets (x_t^1andx_t^2) of two sources (S_1andS_2) separately at time t. And the capacity of each buffer is set. The proposed relay buffer strategy is described in Algorithm 2.

Algorithm 2: Relay Buffer Strategy

Step 1. If the buffer is not full, it stores the current packet. Otherwise, execute Step 2;

Step 2. First packet of the buffer is dropped. The remaining packets are sequentially shifted to the right, and the current packet is stored to the left end of the buffer.

Based on the improved relay buffer strategy, the relay processing scheme is proposed and described in Algorithm 3. Define parameter $\lambda (0 \le \lambda \le 1)$, and corresponding degrees d_t^1, $d_t^2$of the encoding packets x_t^1, x_t^2.

Algorithm 3: Relay Processing Scheme

Step 1. Determine whether the relay node receives the encoding packets x_t^1 and x_t^2 from the two sources at time t. If the relay node receives these two packets, turn to Step 2, otherwise skip to Step 5;

Step 2. Generate a random number γ with value (0,1). If $\gamma < \lambda$, execute Step 3, otherwise skip to Step 4;

Step 3. If $\left(d_t^1 = 1 \vee 2\right) \wedge \left(d_t^2 = 1 \vee 2\right)$, then randomly retransmit any of the encoding packet x_t^1 or x_t^2 with equal probability. And put another encoding packet into the corresponding buffer according to Algorithm 2. If $\left(d_t^1 = 1 \vee 2\right) \wedge \left(d_t^2 \neq 1 \vee 2\right)$, then retransmit x_t^1, and put x_t^2 into the $Buff2$. If$\left(d_t^1 \neq 1 \vee 2\right) \wedge \left(d_t^2 = 1 \vee 2\right)$, then buffer x_t^1 to the $Buff1$, and retransmit x_t^2. Otherwise execute Step 4;

Step 4. Perform XOR operation for x_t^1 and x_t^2, then go back to Step 1;

Step 5. Put the received packets into the corresponding buffer. Choose one packet from each of the two buffers, $Buff1$ and $Buff2$, and perform XOR operation. Then, go back to Step 1.

In Algorithm 3, $\wedge$ and $\vee$ represents the AND and OR operators respectively.

The maximum degree is less than the number of input symbols, which is called chopped degree distribution [11]. The degree distribution generated at the relay node is called chopped Soliton-like Distribution (CSLD). It is defined as follows.

Definition 2 (CSLD): The codes length is k, and $p\left(d\right)$ is the probability of degree-d. The following properties are satisfied.

(1) $p\left(1\right) > 0$; (2) $p(\textbf{??}) << p(2)$; (3) $\lim_{k\to\infty} p(2) \geq 0.5$; (4) $d = 2$is peak point; (5) $\max\left(d\right) = 2\left(D+1\right)$; (6) There is an integer, set A: $\forall x, y \in A$, $3 \leq |A| \leq k$, if $x \leq y$, $p_K(x) \geq p_K(y)$.

According to Algorithm 3, encoding packets of degree-1 or degree-2 are retransmitted directly in Step 3. $q\left(l\right)$ is the probability of a retransmitted packet with degree-l :

$$\tau = \tau_0\left(1/2 - \xi\right) \ , \tag{1}$$

where $\lambda {\sim} Uniform[0,1]$, and $\Omega\left(j\right)$ is probability of degree j from WRSD. So in the CSLD scheme, the degree distribution of the retransmitted packets is as follows:

$$\phi\left(l\right) = \begin{cases} \frac{q(l)}{\sum_{j=1}^{2} q(j)} & l = 1, 2 \\ 0 & \text{others} \end{cases} \tag{2}$$

4.2. The Effect of Buffer Capacity on Decoding Performance

The correct decoding rate is an important index to measure the decoding performance. For the different source-relay erasure probability P_{sr}, the impact of buffer capacity on the decoding performance is studied. In the scheme that only the relay algorithm is modified (for short MSLRC), the source nodes still use RSD as degree distribution.

Fig.2 shows that the packet erasure probability increases, but the decoding rate remains basically unchanged when the buffer capacity is greater than 40. Next, the buffer capacity is set to 50. The decoding performance comparisons of the MSLRC and the traditional SLRC are shown in Fig.3. From Fig.3, it can be seen that the MSLRC's decoding rate fluctuates around the decoding rate of conventional SLRC. And when the decoding overhead is greater than 0.35, both the MSLRC and the traditional SLRC can be completely decoded.

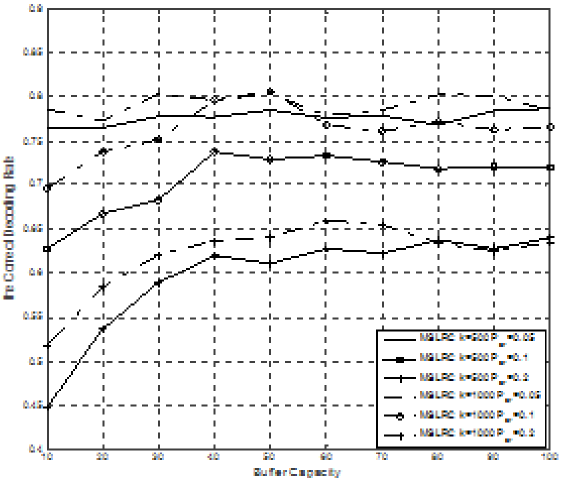

Fig. 2. Decoding performance under different buffer capacity (overhead=0.2)

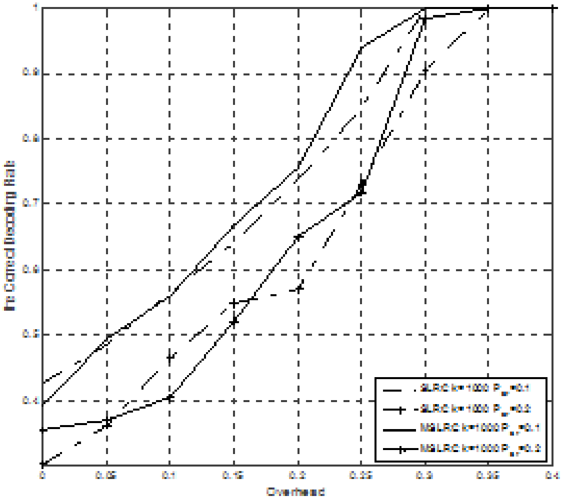

Fig. 3. Decoding performance under different overhead (buffer capacity=50)

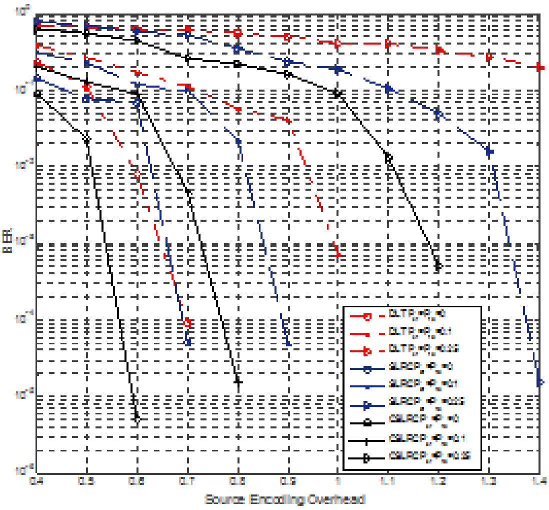

Fig. 4. Decoding performance under different encoding overhead (k=1000, SNR=0.9dB, $\varepsilon = 0.05$)

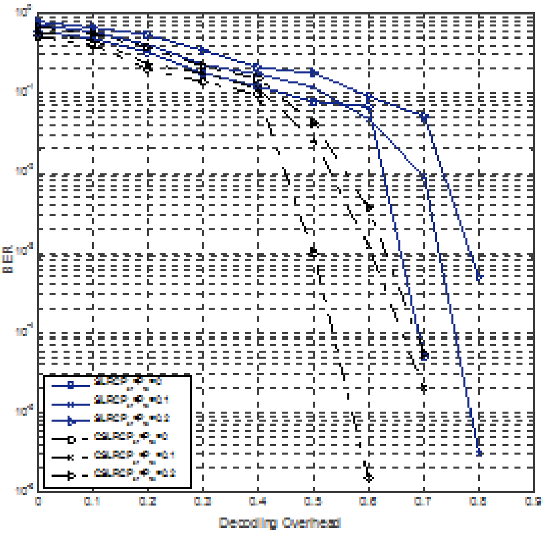

Fig. 5. Decoding performance under different decoding overhead (k=1000, SNR=0.9dB,$\varepsilon = 0.05$)

5. Decoding Performance Evaluation of CSLRC

It can be found that SLRC is unsuited for the deep space communication environments through analyses. Therefore a distributed LT code scheme, called Chopped Soliton-like Rateless Codes (CSLRC) is proposed. Although the distributed LT code is rateless, it still needs to set the maximum number of codes in the application to the deep space environment. Fig. 4 shows that in the case of the presence of the channel erasure probability, the decoding performance of DLT codes is significantly lower than that of the CSLRC or the SLRC. In the case of no packet loss, DLT encoding overhead requires at least 0.7 to be successfully decoded, while the CSLRC only needs 0.6. In the case of the erasure probability $P_{sr} = p_{rd} = 0.25$, the BER of DLT codes is still about 20% when the encoding overhead is 1.4. At the relay node, the CSRC and the SLRC can take full advantage of the received encoding packets to improve the number of transmitted packets. Under the same encoding overhead, the sink node can receive more encoding packets for decoding. Fig. 5 show that the CSLRC scheme can improve the decoding performance under the condition of same decoding overhead. Simulation results show that the CSLRC scheme reduces the decoding overhead by 10% compared with SLRC.

6. Conclusions

In our work, a DLT code scheme, referred to as CSLRC, utilizing the benefits of SLRC and WRSD with two sources is proposed. The CSLRC scheme is implemented base on WRSD and the limited buffer capacity. It selects the packets which variable-node degree is smallest for encoding. Research shows that the CSLRC scheme can reduce the decoding complexity and improve the decoding performance.

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