Application Layer Channel Coding for Space DTN

Dongxu Hou, Kanglian Zhao(✉), and Wenfeng Li(✉)

School of Electronic Science and Engineering, Nanjing University,
22 Hankou Rd, Nanjing 210093, Jiangsu, People's Republic of China
kaldon@163.com, zhaokanglian@nju.edu.cn, leewf_cn@hotmail.com

Abstract. Space communications have the characteristics of long link delays, frequent link disruptions and high error rates. With reliable Licklider Transmission Protocol (LTP) or Transmission Control Protocol (TCP), automatic repeat request (ARQ) is applied to enable reliable data delivery in delay/disruption tolerant networking (DTN). However, ARQ is inefficient for space communications especially in links with long round trip time (RTT). In this paper, an application layer Reed-Solomon (ALRS) channel coding scheme is proposed, which is further combined with ARQ to guarantee reliable transmission in DTN architecture. The proposed ALRS coding scheme is implemented in open source ION-DTN software and its performance is evaluated on a dedicated testbed. The results of the experiments show that this scheme in DTN can be speed up in most scenarios compared with ARQ-only scheme. With coding in application layer, the scheme is also more compatible with the overlay characteristic of DTN.

Keywords: Delay/disruption tolerant networking · Application layer Reed-Solomon channel coding

1 Introduction

Along with the development of space technology and the progress in the exploration of MARS, efficient and reliable data transmission in space is becoming more and more important. Delay/disruption tolerant networking (DTN), a new network architecture, has been proposed for deep space internetworking. To enable reliable data transmission between the sender and the receiver, ARQ is provided by Licklider Transmission Protocol (LTP) [1] or the classical Transmission Control Protocol (TCP) in space DTN. However, due to challenging link conditions in space communications, retransmissions of lost data based on ARQ is the principal reason that sharply decreases network performance.

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How can we reduce the number of retransmissions to acquire higher delivery speed in space communications? Forward error correction (FEC) with erasure codes in different layers might be a good option to the ARQ solution [2]. Some studies that incorporate erasure codes within space DTN have been proposed previously. First, erasure codes can be combined with link layer to rectify bit-level faults, which is known as the classical physical layer channel coding. However, space communications channels are characterized with long fading or even link disruptions. In such cases, typical link layer recovery fails, resulting in bursty frame-losses in the order of tens to thousands of frames. Link layer failures are reflected in the upper layers as packet losses that need to be retransmitted in reliable transmission. Hence, the network performance in this manner can be limited especially in links with long round trip time (RTT).

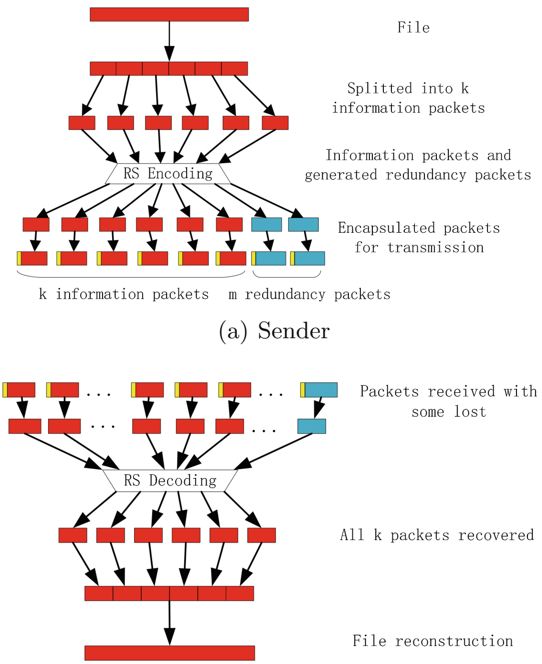
Second, erasure codes applied at packet level [3] is proposed to be promising to guarantee higher robustness against consistent link errors and information loss [4]. Erasure codes incorporates with Licklider Transmission Protocol is one option. When LTP is used as transport protocol, data is splitted into LTP data blocks and each block is fragmented into LTP segments. These segments are encoded by erasure codes and they can generate redundancy segments. Then the segments are encapsulated for transmission [5]. A reverse decoding process will be implemented at the receiver. As the design philosophy of DTN is an overlay network, it should work across different network domains, which might employ potocols, such as LTP, User Datagram Protocol (UDP), Transmission Control Protocol (TCP) or other new protocols in one transmission. Although erasure codes incorporating with LTP can improve network performance obviously [6], the method is LTP dedicated and can not guarantee the performance end-to-end.

In this paper, we propose an application layer channel coding scheme for DTN. Reed-Solomon code is added over Bundle Protocol (BP) [7] to provide FEC at the application layer. In this way, erasure coding is only conducted at BP, which is separated from the protocol employed in the transmission layer. Thus for variable implementation of network protocol stacks [8], this scheme inherits the good portability of the overlay DTN architecture.

The remainder of this paper is organized as follows: In Sect. 2 we briefly introduce the proposed application layer erasure coding scheme. In Sect. 3 the configuration of the experiments are given and the results of the experiments are also presented and analyzed. Finally, in Sect. 4, we conclude the paper and provide some directions for future research.

2 Application Layer Erasure Coding Scheme

We briefly describe the proposed application layer (ALRS) erasure coding scheme in this section. Erasure codes, Reed-Solomon (RS) code in this paper, is incorporated with space DTN at the application layer. Files that need to be transferred will be split into k data packets firstly, where $k = fileSize/maximumPacketSize$. Then, a set of k data packets are encoded into n packets with m redundancy packets, where $m = n - k$. The corresponding



(a) Sender

(b) Receiver

Fig. 1. The hybrid ALRS encoding/decoding process for space DTN. (a) Sender, (b) Receiver.

code rate is k/n. Currently, $maximumPacketSize$ is set in accordance with the size of maximum transmission unit (MTU) in IP layer. Since RS are systematic codes, the first k encoded packets are data packets and the last m encoded packets are redundancy packets [9]. The architecture of RS encoding/decoding processes are shown in Fig. 1.

The problem of this scheme, or the problem of FEC, is that when the channel is out of the capability of the coding scheme, some errors can not be corrected and the reliable transmission can not be finished. So, we further propose a hybrid ALRS and ARQ scheme for the automatic reliable transmission in DTN. The process of this hybrid scheme is shown in Fig. 2. All the packets are first passed to BP in order. Each packet is encapsulated into a single bundle and encoded with ALRS scheme described earlier. Then the coded bundles are sent to the receiver. An additional FIN packet will be sent at the end of these encoded bundles to indicate the end of the transmission. According to the theory of RS code, random k bundles of n encoded bundles must be received at the receiver for the correct recovery of the original file. When the number of the received bundles is greater than or equal to k and the file is recovered, an END bundle will be sent to inform the sender that the file has been received successfully.

While when the number of the received bundles is less than k, the receiver will check the first four bytes of each received bundle, which indicates the sequence number of the bundle in all the n encoded bundles, to record the lost bundles. These sequence numbers will be written into a REQ bundle which will be sent to the sender and inform the sender of the lost bundles for retransmission.

As the FIN bundle, the REQ bundle and the END bundle are unique control bundles for the hybrid transmission scheme, different timers are set at the sender or the receiver for these bundles. Upon the arrival of these bundles, the timer is canceled, otherwise, upon expiration of the timer, the control bundle will be retransmitted immediately. In this way, the hybrid scheme can guarantee reliable delivery of the original file to the upper application without support of ARQ based reliable transmission protocols. Unreliable LTP (Green) convergence layer or UDP convergence layer can be adopted in this scheme.

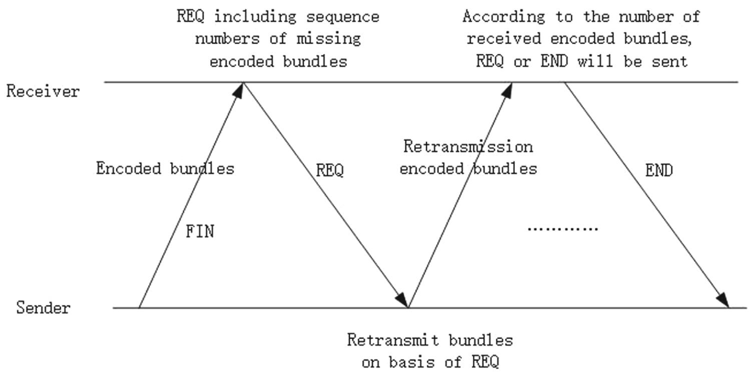


Fig. 2. Transmission of the hybrid ALRS.

3 Results and Analysis of the Experiments

3.1 Testbed Configuration

To evaluate the potential of the proposed ALRS scheme in deep-space and near-earth environments, we set up a dedicated DTN testbed, which is shown in Fig. 3. Network Emulator (Netem) is employed on a computer as a channel emulator to simulate long delays, high error rates, and link asymmetry in space communications. To realize ALRS, we modify the ION-DTN [10] software which has been installed on the computers emulating the sender and the receiver in the testbed.

For deep space communication scenario, communications between Mars orbiter and Earth is considered. For near earth communication scenario, transmission from satellites in geostationary (GEO) orbit towards Earth ground station is considered. Considering the packet loss ratio, the number of packets and

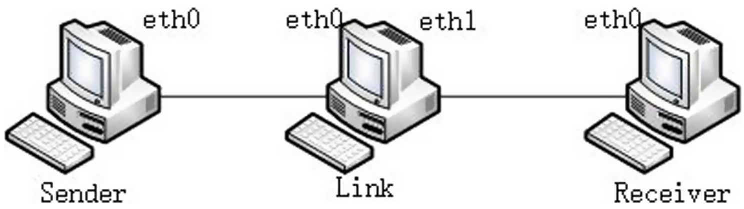


Fig. 3. Network topology for research.

Table 1. Experimental factors and values (Deep-Space)

Experimental factors	Settings/Values
Data packet size (bytes)	1460
File size (Kbytes)	250
DTN protocol layering and configuration	ALRS/BP/UDPCL/IPBP/LTPCL/IP
Downlink rate (kbps)	1500
Uplink rate (kbps)	15
One-way link delay (s)	40
PER (%)	0, 5, 10, 15, 20, 25, 30
Code rate	0.9

Table 2. Experimental factors and values (Near-Earth)

Experimental factors	Settings/Values
Data packet size (bytes)	1460
File size (Kbytes)	250
DTN protocol layering and configuration	ALRS/BP/UDPCL/IPBP/LTPCL/IP
Downlink rate (kbps)	150
Uplink rate (kbps)	1.5
One-way link delay (ms)	100
PER (%)	0, 5, 10, 15, 20, 25, 30
Code rate	0.9

the purpose of testing the transmission of the Hybrid ALRS, we set the code rate equal to 0.9. A summary of the parameters configuration is given in Tables 1 and 2.

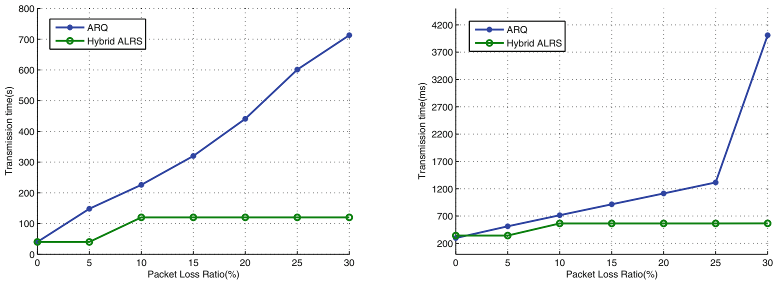
We evaluate the performance of hybrid ALRS and ARQ scheme with various metrics. We record (1) the file transmission time, (2) total transmission data including data bundles, redundancy bundles and retransmission bundles, and (3) goodput defined as a ratio of the unique number of delivered data bytes to the total data delivery time as a measure of transmission efficiency and link utilization.

3.2 Results: Transmission Time

Figure 4(a) and (b) provides a comparison of the data transmission time between ARQ and the proposed hybrid scheme with various packet loss ratio (0%, 5%, 10%, 15%, 20%, 25%, 30%) in different communication environments. In deep space, long propagation delay time and dedicated high transmission rate are considered, the additional delivery time of redundancy bundles can be neglected. As shown in Fig. 4(a), when there is no packet loss, the transmission time of ARQ and the proposed hybrid scheme is very similar. When the packet loss ratio increases, the transmission time of ARQ increases sharply. When the packet loss ratio reaches 30%, ARQ's transmission time is nearly 6 times more than the proposed hybrid scheme.

In ARQ scheme, only when all k data bundles are received, can file be recovered at the receiver. Once there is missing data bundles, the sender simply retransmits the lost data bundles in response to a request from the receiver. Hence, the number of the transmission rounds required for successful file delivery increases greatly as the packet loss ratio increases. For the proposed hybrid scheme, as long as the receiver get k random data bundles from the all n coded bundles, the transmitted file can be reconstructed. The number of the transmission rounds for successful delivery of an entire file is decreased by applying appropriate ALRS encoding/decoding. So as shown in Fig. 4, the packet loss ratio has significant effect on ARQ, but little impact on the proposed hybrid scheme.

When near earth scenario is considered, the propagation delay time is short and the transmission rate is considered low for shared multiple access systems, the transmission time of redundancy bundles can't be neglected. Figure 4(b) shows that ARQ has a shorter transmission time than the hybrid scheme when packet loss ratio is low. As packet loss ratio increases, the transmission time of ARQ surpasses the hybrid scheme gradually.



(a) Deep-Space (b) Near-Earth

Fig. 4. Comparison of the transmission time between hybrid ALRS and ARQ.

3.3 Results: Total Transmission Data

Figure 5 gives a detailed insight about the total transmission data between ARQ and the hybrid scheme with different packet loss ratio. When packet loss ratio is no more than 10%, ARQ has a less total transmission data. With the increase of packet loss ratio, the advantage of the hybrid scheme is shown. It is obvious that the proposed hybrid scheme has a better energy efficiency in high packet loss ratio scenarios.

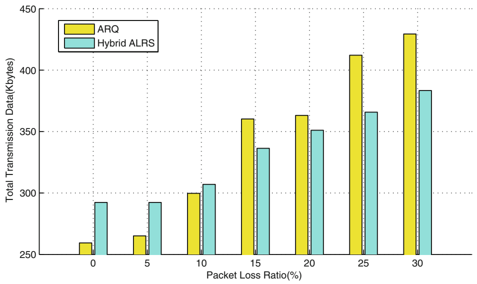
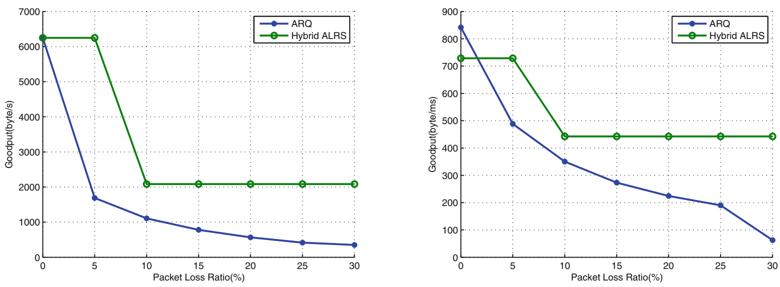


Fig. 5. Total transmission data for different packet loss ratio

3.4 Results: Goodput Performance

The comparison of goodput performance is presented in Fig. 6(a) and (b). Figure 6(a) presents the goodput in deep space, we neglect the delivery time of redundancy bundles as mentioned above. The transmission efficiency of ARQ degrades obviously with the increase of packet loss ratio. Due to the effect of ALRS encoding/decoding which decreases the number of retransmission, the proposed hybrid scheme degrades only slightly and reach a steady level when packet loss ratio equals to 10% and more.



(a) Deep-Space (b) Near-Earth

Fig. 6. Comparison of the goodput performance between hybrid ALRS and ARQ.

In near earth scenario, as shown in Fig. 6(b), the effect of the delivery time of redundancy bundles is considered for transmission efficiency. Therefore, ARQ has a better goodput when packet loss ratio is low.

4 Conclusions and Future Work

An application layer channel coding scheme that builds on top of BP in DTN is introduced in this paper. The theory behind the use of erasure codes stems from the necessity of limiting data retransmissions due to high error rate links in space. Experiment results and our analysis confirm the potential of this approach.

In the future work, on the one hand, we will investigate the performance trade-offs in multi-hop scenarios, where adaptive application layer erasure codes may be examined, in which code rate is adjusted based on the observations of the channel status at each hop. On the other hand, high code rate requires longer codec time, which may lead to lower performance. We will study the effect of different code rates.

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