Research on Data Transmission Protocol Performance of DTN Relay Channel Based on CFDP

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Abstract. In this paper, we explore the transmission linking delay technology brings which improvement to DTN network based on CFDP in both theory and simulation. In past research, there are mainly focused on the performance of TCP and UDP as the transmission protocol in DTN network while they paid little attention to CFDP protocol as a transmission layer protocol which is below bundle layer. By a new data automatic retransmission mechanism, the performance of transmission link is strengthened in situation of high error reliable transmission rate. In the simulation, we compared the difference of file transferring delay, proportion of data which successfully reached, the effective data rate and date rate between normal mode and forwarding mode based on CFDP in DTN relay link.

Keywords: DTN · CFDP · Automatic retransmission · High error rate · High transmission delay · Bundle layer

1 Introduction

In deep space exploration, the traditional point to point communication technology has developed to a bottleneck. There is a trend to use the transmission linking relay technology in the future deep-space communication systems. In recent years, with the development of network technology and the increasing demand for people to use, emerges a class of new network. In such networks, the capacity of nodes is low, and the networks are often disconnected and the delay of data round-trip is long. In this context, tolerate network delays (Delay/Disrupted Tolerant Networks, DTN) came into being. Studying this kind of restricted network and data link systems thinking are important.

The propagation delay of the ground and space DTN rises from tens to hundreds of milliseconds to tens of milliseconds to tens of seconds or even longer. In terms of routing, buffer, congestion avoidance and control problems, the TCP protocol for the IP network on the ground is not suitable for the asymmetric DTN network and the uplink/downlink. Due to the congestion of the reverse response link, such as slow start, TCP is widely verified not suitable for the link whose asymmetric rates over 50:1. DTN network hopes the transmission protocol can transmit data with different network

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coverage. Overlay may be the most beneficial to the intermittent and short time of the network connection, so that the DTN nodes can transfer a large number of data as much as possible.

This paper is based on the relevant ideas of the following protocols, the interstellar transmission protocol (TP-Planet) is one of the early ideas for the reliable data transmission of deep space links. The main function of Planet - TP is the control way of congestion detection and processing. In addition, Planet - TP is used to deal with power outage, delay of SACK policy and the bandwidth asymmetry. Based on the rate of the increase in the product type (AIMD algorithm) congestion control, its operation depends on the congestion detection mechanism. However, at least in the current, deep space communications in the prearranged management procedures in the static operation, congestion control is not really needed, covering deep space connection of the flow multiplexing technology does not exist.

Space communication protocol standard transport protocol (TP-SCPS) is proposed by the Spatial Data System Advisory Committee (CCSDS) for the development of space communications. TP - SCPS is based on the widely used transmission control protocol (TCP) and a number of modifications and extensions to the deep space communication link constraints set.

Interstellar reliable communication protocol (RCP – Planet). RCP – Planet's detection rate control and data packet forward error correction resolve link congestion and error rate together. RCP – Planet also deployed a blackout status program and ACK for FEC, to detect the asymmetry of the link. RCP – Planet's main target is to transport the real-time application of data to ground, satellite or spacecraft and other nodes.

Deep space transmission protocol (DS-TP) is a transport layer protocol, this protocol is based on rate, hybrid quick response strategy and double automatic retransmission, the transmission efficiency is 2 times faster than the traditional protocol. DS – TP transmits data in the case of predictable and scheduled line speeds, using the principle of one hop, store and forward mail to control the current space communications and ease congestion avoidance and control requirements.

LTP protocol is a point to point protocol for the application of DTN overlay. LTP can send anonymous data blocks, and introduced through each data block is divided into two parts of the local reliability point of view, the "red" section is reliable and the "green" is unreliable. Besides, while the receiving terminal receives explicit request of the red section of data, it sends concise receive reply Report.

2 Simulation Scenarios

As the Fig. 1 showed, the deep space communication simulation scene can be simplified to the communication between the three nodes, the transmitting node, relay node and receiving node. Traffic in the network is transmitted to the receiving node by the sending node, and it is not a hop. By the experiment platform based on C language in Linux, we design node model and process model to achieve different forward behaviors. On the basis of this, two kinds of transmission performance are compared.

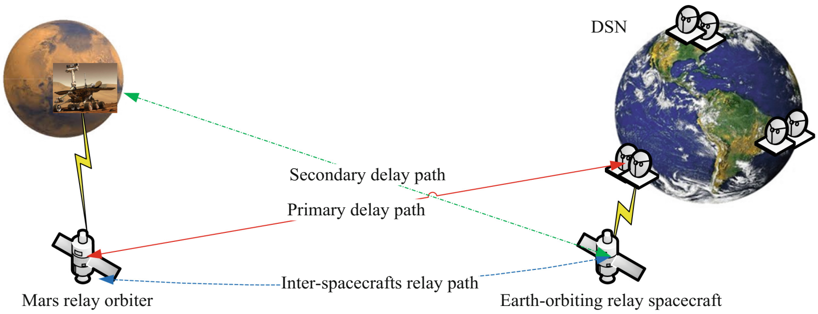

Fig. 1. Simulation scenarios.

3 The Transmission Model Based on CFDP

The transport mechanism for storage and automatic forwarding of redundant data with the new automatic retransmission mechanism is based on CFDP. The source node of the file to be transmitted is divided into several sections, each section forming a protocol data unit. First send metadata package, containing the file name, file size, source and destination ID and other information. But it and most of the data unit, there is no confirmation, that the sender does not need to wait for the receiver to return confirmation information, whether metadata packet is successfully received or not, the sender will be issued after the metadata packet data continues to transfer files unit. That is the sender and the recipient does not need a handshake can start transferring files, which will save a lot of time in deep space. Each data unit header are marked active ID. If the recipient receives a file labeled with the new ID data unit represents a new file transfer begins. Each data unit also contains a special field, which indicated the data unit carried by the contents of the file start and stop bits, the data unit sequence by checking the recipient has received it can determine which data units sent failed. Simultaneous retransmission ensure the reliability of the information (Fig. 2).

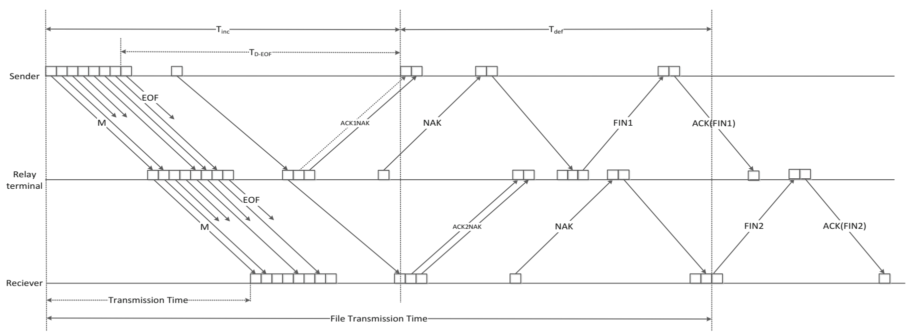

Fig. 2. Schematic view of the transport mechanism

The forwarding node could storage data elements at first by the transmission of data elements from the sender to the relay terminal. Feedback EOF and the corresponding lost package NAK which marked the sequence information of retransmission data elements by the specific domain will be transmitted when the relay terminal received the sender file confirmation EOF, but when there is no data elements missing data, it is empty. Then the interaction between the sender and the relay terminal will begin to work for the purpose of data retransmission from the sender to relay terminal. Relay terminal keep sending after receiving data elements. When relay terminal accept EOF ACK sent to the receiver, relay terminal begin with the data elements interaction, start the second phase of data retransmission work. Application of automatic retransmission mechanism, when transmitting data error will send negative confirmation. Each NAK information indicates the start bit file area should the end bit of the other area that before NAK information indicates.

First, it needs some instructions on variables to estimate two rounds of interaction time of this model. Assumptions for file transfer in the of data elements (PDU) number (including the MPDU) is N, L_{PDU} is the length of each PDU, P_e is link error rate, L_{EOF} is the length of the EOF PDU, T_{tran} represents a single link transmission delay, T_{PDU} represents the time needed for transmitting PDU, T_{ACK} represents the time needed for transmitting NAK, T_{EOF} represents the time needed for single link transmitting EOF, $T_{ACK-EOF}$ represents the time needed for single link transmitting ACK-EOF, T_{D-EOF} is the transmission time of EOF, P_{ePDU} represents the two links PDU error probability, P_{eEOF} represents the probability of transmission error of EOF, P_{eNAK} represents the probability of transmission error of NAK. The length and the BER of all PDU are same. Also the length and the BER of all NAK are same. So the probability of errors that single link PDU occurs P_{ePDU} and the relationship between P_{eEOF} and bit error rate P_e is

$$P_{ePDU} = 1 - (1 - P_e)^{L_{PDU}},\ P_{eEOF} = 1 - (1 - P_e)^{L_{EOF}} \tag{3-1}$$

Expectations for the T_{inc} is

$$E(T_{inc}) = 2N \times T_{PDU} + E(T_{D-EOF}) \tag{3-2}$$

Set $E(\eta_{EOF})$ is the number of the sender sends a total EOF when receiver successfully received EOF, so that we can know the expectation for $E(\eta_{EOF})$ is

$$E(\eta_{EOF}) = 2\sum_{i=1}^{\infty}(1 - P_{eE0F})iP_{eEOF}^{i-1} = 2(1 - P_{eEOF})\sum_{i=1}^{\infty}iP_{eEOF}^{i-1} = \frac{2}{1 - P_{eEOF}} \tag{3-3}$$

Suppose $T_{timeout-EOF}$ is a retransmission time for EOD PDU, so

$$T_{timeout-EOF} = 2T_{tran} + T_{ACK-EOF} \tag{3-4}$$

So the expectation for the transmission time of EOF can represented as

$$E(T_{inc}) = \frac{(2 + 2P_{eEOF})T_{tran} + 2T_{EOF} + 2T_{ACK-EOF}}{1 - 2P_{eEOF}} \quad (3-5)$$

The expectation of T_{inc} can be obtained to get (3-5) into the Eq. (3-2)

$$E(T_{inc}) = 2N \times T_{PDU} + \frac{(2 + 2P_{eEOF})T_{tran} + 2T_{EOF} + 2T_{ACK-EOF}}{1 - 2P_{eEOF}} \quad (3-6)$$

Suppose the transmission number of entire T_{def} period in two links are $M1$ and $M2$. Then, after N PDUs data packets through the T_{inc} stage, the expectation for $2N'$ which is the number of PDU that still need transmission interaction is

$$\begin{aligned} E\left(2N'\right) &= \sum_{i=0}^{\infty} C_N^i (1 - P_{ePDU})^{N-i} P_{ePDU}{}^2 i + \sum_{i=0}^{\infty} C_{NP_{ePDU}}^i (1 - P_{ePDU})^{NP_{ePDU}-i} P_{ePDU}{}^2 i \\ &= N \times P_{ePDU} + N \times P_{ePDU} + N \times P_{ePDU}^2 = N1' + N2' \end{aligned} \quad (3-7)$$

After entering T_{def} stage, we had to consider the probability of error of NAK P_{eNAK}, therefore, the single link failure PDU interaction probability at T_{def} stage is

$$P_{ef} = 1 - (1 - P_{ePDU})(1 - P_{eNAK}) \quad (3-8)$$

The total number of packets required for the interaction at T_{def} stage is $2N'$, From the above formula, we need to know the expectation for retransmission number of interactions when $N1' + N2'$ packets interaction is complete.

Suppose N_i' is the expectation for the number of packets after i times retransmission interaction still remaining retransmission, there is

$$N1_i' = N1' \times P_{ef}^i \qquad N2_i' = N2' \times P_{ef}^i \quad (3-9)$$

Suppose after $M1_1$ times transmission interaction, $N1''$ is the expectation for the number of remaining packets after times retransmission interaction. $M1_1$ satisfies the following two relationship

$$N1'' = N1' \times P_{ef}^{M1_1} \leq 1 \qquad N1' \times P_{ef}^{(M1_1-1)} \geq 1 \quad (3-10)$$

Then, the expectation for the remaining packet number of transmission finished $M1_2$ is

$$M1_2 = N1'' \times \frac{1}{1 - P_{ef}} \quad (3-11)$$

So you can find the expectation for the number of retransmission interaction that $N1'$ packets retransmit for the entire T_{def} period.

Known the number of retransmission interactions in the first phase of the link T_{def} period M. In every single link exchange process, the interaction phase delay of the first link i times interaction is

$$T_{spurt}(i) = T_{NAK} + N_i \times T_{PDU} + 2T_{tran} \quad (3-12)$$

The delay of entire retransmission stage consist of M times interaction delay and $T_{ACK-EOF}$, there is

$$T_{def} = T_{ACK-EOF} + \sum_{i=1}^{M} T_{spurt}(i) = T_{ACK-EOF} + M(T_{NAK} + 2T_{tran}) + (\sum_{i=1}^{\infty} N_i)T_{PDU}$$

The number of packets which need to retransmit at T_{def} stage is $N^{'}$, the $N^{'}$ PDUs come from the packets which resent in the interactive stage and passed the channel which error rate is P_{ePDU}, there is

$$E(\sum_{i=1}^{M} N_i)(1 - P_{ePDU}) = N^{'} \quad (3-13)$$

Therefore the expectation for the time of retransmission stage is

$$E(T_{def}) = T_{ACK-EOF} + E(M)(T_{NAK} + 2T_{tran}) + E(\sum_{i=1}^{M} N_i)T_{PDU} \quad (3-14)$$

The expectation for the entire time T_{file} is

$$E(T_{file}) = E(T_{inc}) + E(T_{def}) \quad (3-15)$$

4 Simulation and Analysis

4.1 The Relationship Between File Transmission Delay and Packet Loss Rate

Form the Fig. 3 we can see that the network communications situation of two models is similar when the packet loss rate is low. And in this case the file transfer delay of store and forward mode and non-store and forward mode is basically same. When loss rate of channel a and channel b increases, that is when the communication conditions getting closer to of deep space communication, the gap of two modes delay in increasing. So the store and forward mechanism has a strong research value when the packet loss rate as high as deep space is.

Next, we will do a comprehensive analysis of total transfer delay from the theoretical and practical measured data (Tables 1 and 2).

The situation of the relay node to receiving node is same to sending node to relay node. Therefore, the total delay of store-and-forward mode is

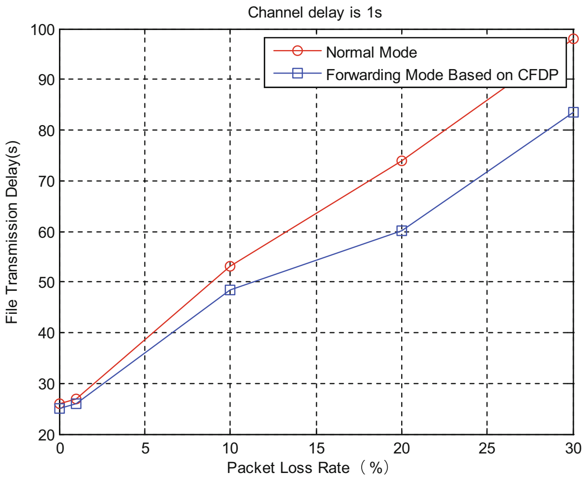

Fig. 3. The file transfer delay of two models in different packet loss rate

Table 1. Retransmission times (n) and the arrival probability (p)

n	0	1	2
p	0.64	$0.36 \times 0.64 = 0.2034$	$0.36^2 \times 0.64 = 0.0829$
n	3	4	5
p	$0.36^3 \times 0.64 = 0.0299$	$0.36^4 \times 0.64 = 0.0107$	$0.36^5 \times 0.64 = 0.0037$

Table 2. The probability of retransmission from sending node to relay node

n	1	2	3	4
p	0.16	0.032	0.0064	0.00128

$$T_{file} - T_{file0} = 36.4675s$$

In theory, $T_{file} - T_{file0}$ is 35.8457 s. The output of simulation is equal to theoretical analysis. The total delay of Store-and-forward mode is shorter than the delay of non-store-and-forward mode.

4.2 The Relationship Between File Transmission Delay and Channel Delay

When the channel delay of link a and link b is different, we measured the total delay of sending data packets of the platform. Each data was measured ten times and then we get the average of these data. The Fig. 4 is the result of the measurement.

When the channel delay is 0 s, two modes are same. When the channel delay reaches 1 $\sim$ 2 s, the differences between the two models become clear. With the delay further increasing, the total delay of forwarding mode is better than normal mode.

We set the channel delay is 10 s and do a theoretical analysis.
Non-store and forward

$$T'_{file} - T'_{file0} = 50.3582s$$

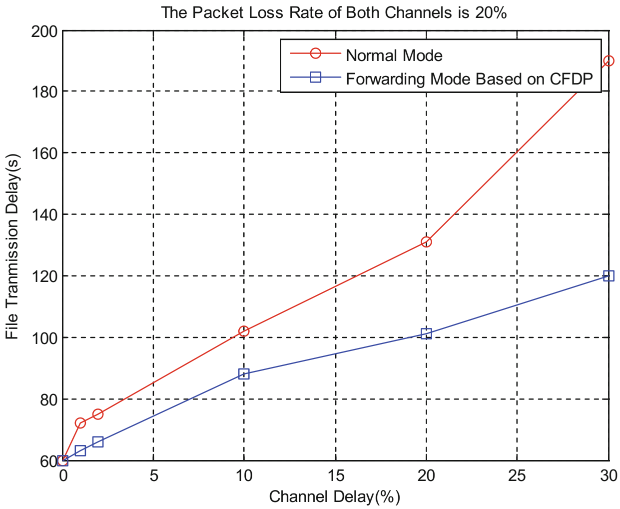

Fig. 4. The total delay of two models

Store and forward

$$T_{file} - T_{file0} = 29.4839s$$

The output of simulation is equal to the result of theoretical analysis.
In the Table 3, the packet loss rate is 20%.

4.3 The Relationship Between Data Transferring Rate and Packer Loss Rate

When the packet loss rate of link a and b is different, we measured the total rate of sending data packets of the platform. Each data was measured five times and then we get the average of these data. The Fig. 10 and Fig. 11 is the result of the measurement.

From the Fig. 5 we can see that, when the channel delay time is 1 s and packet loss rate is 0%, the total data transfer rate of store and forward mode is slightly higher than the normal mode. With the packet loss rate gradually increasing, the data transfer rate of store and forward mode total declined slightly, but remained equal to the normal model. When the channel delay time is 1 s and packet loss rate is 0%, the effective transfer rate of store and forward mode is consistent with the normal model. With the

Table 3. Retransmission times and remaining packets

Retransmission times	Sent packets (normal mode, packet loss data is 20%)	Remaining packets (packet loss data is 20%)
0	384	200
1	138	40
2	50	8
3	18	2
4	6	0
5	3	0
6	0	0

packet loss rate gradually increasing, forwarding mode based on CFDP has a better performance than the normal mode (Table 4).

When the packet loss rate of link a and link b is 20%, the number of the data package which had been transferred in normal model is 1199, while in the store and forward mode is 850. In 4.1, the transfer delay is analyzed when the packet loss rate is 20%. So,

$$V_N = 15234\, byte/s$$
$$V_S = 14516\, byte/s$$

The actually measured data is basically same to theoretical analysis. The rate of data transmission of two model is the same.

In the same case, the number of valid data packet which had been transmitted of both in normal model and forwarding mode based on CFDP is 600. Then we can get

$$V_N = 10169\, byte/s$$
$$V_S = 8180\, byte/s$$

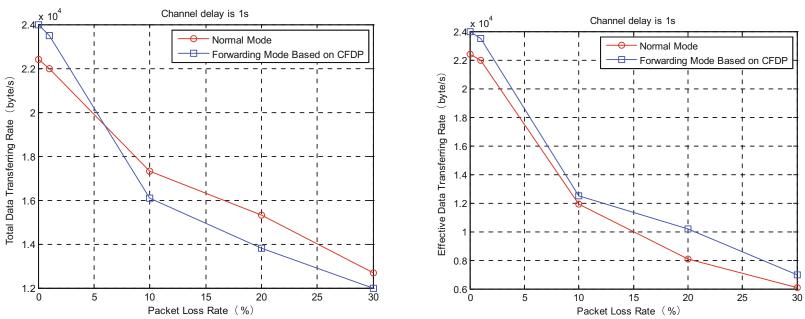

Fig. 5. The relationship between data transferring rate and packer loss rate

Table 4. Retransmission times and remaining packets

Retransmission times	Sent packets (normal mode, packet loss data is 20%)	Remaining packets (packet loss data is 20%)
0	600	600
1	984	800
2	1122	840
3	1172	848
4	1190	850
5	1196	850
6	1199	850

Table 5. The comparison between the two modes

	Transmission Delay (Same channel delay)	Transmission Delay (Same packet loss rate)	Data Arrival Proportion
Normal Mode	high	high	low
Forwarding Mode based on CFDP	low	low	high
	Total Data Transferring Rate	Effective Data Transmission Rate	
Normal Mode	slightly high	low	
Forwarding Mode based on CFDP	slightly low	high	

5 Conclusion

In this paper, we explore what improvement that link forwarding technology brings to transmission in DTN network based on CFDP. By using new redundant data automatic retransmission mechanism, the effectiveness of reliable transmission in links of high error rate has strengthened. The comparison between the two modes is as shown in Table 5.

In bundle layer, the forwarding node was changing toward destination node by reliable protocol of transmission layer and store and forward technology. The moving of forwarding node minimize the potential of forwarding hops, the additional load on the network caused by retransmission of information and the total time of a reliable transmission bundle to its destination. This improvement has enhanced the link which has a long delay or decay. In the links which have a large decay, forwarding node retransmission needed less retransmission than sending node retransmission (linear growth vs exponential growth associated with the number of hops). When the link is unreliable, store and auto-forwarding mode has better reliability and validity than normal. This advantage is mainly because that the responsibility of retransmission moves from the source node to the destination node. This model divides the long length of the propagation path into short length path and long delay path into short delay path by hops. And this model assigned the responsibility to whole forwarding nodes instead of source node and destination node. Above all, this kind of transmission node based on CFDP has a better transferring performance in DTN network.

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