LTP Asynchronous Accelerated Retransmission Strategy for Deep Space Communications

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***Abstract*—To describe the transmission performance of LTP protocol more intuitively and accurately, it is an original work to model the transfer procedure of a single LTP session, and analyze the expected file delivery time of a data block theoretically. In order to improve the data transmission efficiency in extreme long and error-prone deep space links, an asynchronous accelerated retransmission strategy triggered by the receiver during the course of the red-part original transmission is proposed for recovering the missing data segments sooner. The asynchronous accelerated retransmission process in deep space environment is modeled, and the theoretical expression of the expected file delivery time based on the proposed strategy is derived. The performance of strategy is analyzed by numerical simulations under the Mars to Earth scenario. The strategy is verified to accelerate the retransmission process, effectively shorten the file delivery time and improve the efficiency of file transmission.**

Keywords-Deep space communications；Licklider transmission protocol；Asynchronous accelerated retransmission；File delivery time

I. Introduction

With the concepts of IPN and DTN have been proposed, the space communication protocols are also in constant development. In May 2015, CCSDS officially launched the LTP blue book [1]. The LTP protocol is based on the CFDP protocol, specifically designed for single hop deep space link characterized by extremely long distance and frequent interruptions. It is a convergence layer protocol in DTN protocol stack, which can provide reliable services based on retransmission. In order to overcome the problem that huge round-trip transmission delay leads to underutilization of the links, although the session concept is introduced in the design of LTP protocol, but in a single session until the receiver successfully received the end of red-part (EORP) segment, the retransmission process starts, this deferred transmission mechanism still restricts the efficiency of data transmission.

The direct idea is to start the data segment retransmission during the course of the red-part original transmission. This approach would not only recover the lost data sooner and improve the deep space link utilization; but also reduce the dependence on EORP to start retransmission and decrease the influence of the retransmission mechanism on data transmission efficiency.

This paper aims for better understanding of the transmission performance and operation of LTP protocol in deep space long-haul communications, LTP transmission mechanism is modeled and a detailed theoretical analysis is made. In extreme long and error-prone deep space links, LTP's deferred transmission model will affect the data transmission efficiency. By optimizing the retransmission mechanism, an asynchronous accelerated retransmission strategy is put forward, the asynchronous accelerated retransmission process is modeled and the theoretical analysis of expected file delivery time of a data block is done. Under Mars to Earth scenario, the simulation analysis of the performance and gains of asynchronous accelerated retransmission strategy is implemented, and the effectiveness of the transmission strategy is verified.

The remainder of this paper is organized as follows. Section II presents the related work. Section III models and analyzes the LTP transfer mechanism. Section IV proposes an asynchronous accelerated retransmission strategy, and analyzes the accelerated procedure theoretically. Section V makes a comparison between standard LTP and our strategy based on simulations. Finally, conclusions are drawn.

II. Related Work

Some work have been done to analyze and compare the performance of LTP with correlative transmission protocols. The performance of several convergence layer protocols, including LTPCL, TCPCL and UDPCL, was compared in channel asymmetric cislunar communications[2-6]. The effect of flow control window size on throughput was analyzed in lossy cislunar communications[7]. The transfer performance of BP over LTP was evaluated combined with UDP protocol in cislunar link[8]. The effect of custody transfer was assessed, and a conclusion that DTN custody transfer would decrease the transmission performance in deep space communications was drawn[9]. The file delivery time and throughput performance of multiple LTP sessions was roughly evaluated under the deep space channel with one-way propagation delay of 10min[10]. The effect of bundle and data block size on transmission efficiency was analyzed in [11], an improved packet sending algorithm based on LTP was proposed. A DTN transmission protocol integrated rateless coding with LTP was proposed, and the performance of file delivery time, throughput and node storage capacity was analyzed in cismartian

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communications[12]. The data transfer performance of DTN BP/LTP was analyzed on a testbed in Mars to Earth communications through orbiters[13,14]. The dynamic variation of memory for LTP protocol in data transfer was modeled and analyzed in a typical relay-based deep space environment[15].

From the above literature research, we found that almost work were executed in experimental means based on testbeds. Although these studies yielded significant experimental results or conclusions, those work commonly lacked of theoretical analysis and optimization design of transmission strategy. Furthermore, a majority of work were implemented in cislunar communications scenarios, some results or conclusions may not be applicable for farther deep space scenarios. It is necessary to build an analytical model to visualize the operation of a LTP session in a theoretical manner. Moreover, the effective strategy for enhancing the transmission efficiency should be investigated for farther deep space communications.

III. MODELING OF LTP TRANSMISSION PROCEDURE

The data block transferred in a LTP session logically comprises red-part and green-part, either of which may be of length zero. The red-part must be assured by acknowledgment and retransmission, followed by the green-part, but not assured. Thus, LTP can provide both TCP-like reliable service and UDP-like unreliable service. Moreover, in the transfer process of data block, LTP relies on retransmission timer and available link state cues to cope with link interruptions. During the periods of disconnection, retransmission timers maintained by LTP are suspended and restarted until the link resumes.

A. *LTP Transfer Procedure*

Taking a LTP session as an example, the transmission process of data block is described. Firstly, according to the actual maximum transmission unit size of the link layer, the whole data block is divided into red data segments and green data segments, whose ratio is determined by the actual needs of transmission. The last data segment of the red part is labeled for end of red-part(EORP), and as a checkpoint(CP) requires receiver upon receipt of EORP must reply a reception report segment (RS). After sending the EORP, the sender starts a timer to prepare the automatic retransmission of the EORP in case of timeout. The last data segment of the entire data block is marked as the end of block(EOB). On reception of the first data segment, the receiving session is started immediately. If no error or loss data in the receiving process, once receiving the EORP, the receiver issues a RS and start a timer, so that the RS automatic retransmission without response. Upon receiving RS, the sender immediately shuts down the EORP timer, and replies a report-acknowledgment segment (RA). Upon receiving RA, the receiver immediately closes the RS timer, the session of the red data segment is completed and the session is finished. If one or more red data segments other than EORP are lost in the transmission process, the data retransmission process is triggered. The receiver returns one (or more) RS, and starts a timer(for each RS). After receiving the RS, the sender immediately issues a RA and arranges the retransmitted data segments, and the last retransmitted data segment is marked as CP, which contains the RS sequence number. After receiving RA, the corresponding RS timer is closed. When received the CP, the receiver counts received red data segments and RA, if at this time all the response of RA and all red data segments have been successfully received, the transmission of entire data block is completed. If there is still missing data or RA, the process repeats until all red data segments are successfully received, the session can be closed.

Defining the file delivery time starts from the first bit of session data, and ends the instant until all red data segments have been successfully delivered to the receiver, as shown in Fig. 1. The file delivery time is chronologically split into two stages: the first sending stage and retransmission stage, does not contain the RS-RA at the end of the confirmation process. Herein, T_{prop} is one-way propagation delay, T_R and T_G respectively represent the transmission time of red and green data segment.

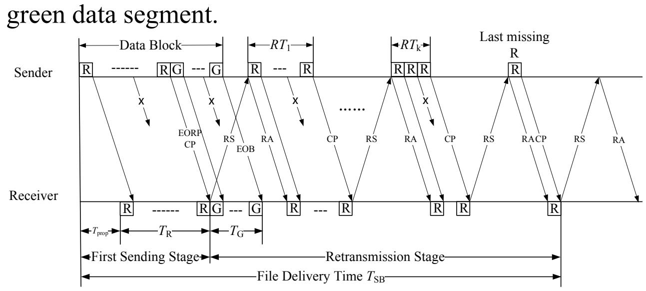


Figure 1. Transfer procedure of LTP data block.

Notations used in this paper are specified in Table I.

TABLE I. NOTATIONS.

Symbol	Definition
N	Total number of segments in a block
N_R	Number of red segments
N_G	Number of green segments
P_{ef}	Error probability of segment
T_{prop}	One-way propagation time
T_{seg}	Transmission time of a segment
T_R	Transmission time of red segments
T_G	Transmission time of green segments
RT	Transmission time of the segments in retransmission stage
S_i	A random variable, transmission number of i^{th} red segment in retransmission stage
T_{mar}	2s margin, considering factors such as processing, queuing
τ	Red segments ratio in a data block
γ	Location of asynchronous trigger point

For the convenience of theoretical analysis, the transmission channel is regarded as AWGN channel and following assumptions are made:

- Length of data segments is identical.
- Error probability of each segment is identical(except EORP/CP/EOB).
- Error events in uplink and downlink are statistically independent.
- Transmission times of RS and RA are negligible.
- EORP/CP/EOB, RS and RA is transmitted reliably.

B. Theoretical Analysis

As shown in Fig. 1, the time spent in first sending stage is $T_{prop}+T_R+T_{mar}$, where T_{mar} is a margin to allow for small degrees of unaccounted processing and queuing delays at both ends, and 2 seconds seem to be a reasonable default value[16].

Now let us pay more attention to the analysis of retransmission stage, we denote random variable S_i the transmission number of i^{th} red segment up to and including its first successful transmission during the period of retransmission. Under the channel assumptions, S_i obeys geometric distribution, and S_i is nonnegative because some possible red segments have been successfully delivered to the receiver during the first sending stage. The retransmission spurts will reoccur until all segments are transferred to the receiver. Therefore, random variable $S_M=max(S_1,S_2,...,S_N)$ is defined as the number of retransmission spurts.

In the case depicted in Fig. 1, when the RS issued by the receiver arrives at the sender, transfer of all green segments is completed, the retransmitted red segments can be delivered immediately. So the total delivery time of a data block in a session is

$$T_{SB}=T_{prop}+T_R+T_{mar}+\sum_{k=1}^{S_M}(2T_{prop}+RT_k+2T_{mar}) \tag{1}$$

The expected time during the whole retransmission stage is given as

$$\begin{aligned}&E\left(\sum_{k=1}^{S_M}(2T_{prop}+RT_k+2T_{mar})\right)\\&=E(S_M)\cdot(2T_{prop}+2T_{mar})+E\left(\sum_{k=1}^{S_M}RT_k\right)\end{aligned} \tag{2}$$

The calculation of $E(S_M)$ can be derived as

$$\begin{aligned}E(S_M)&=\sum_{m=1}^{\infty}P(S_M\geq m)\\&=\sum_{m=1}^{\infty}\left[1-P(S_M<m)\right]\\&=\sum_{m=1}^{\infty}\left[1-\prod_{i=1}^{N_R}P(S_i<m)\right]\\&=\sum_{m=1}^{\infty}\left[1-\left(1-P_{ef}^{m}\right)^{N_R}\right]\end{aligned} \tag{3}$$

Note that the second term in (2) means the expected total time needed for transmission of the missing red segments until all of them have been successfully received. It can be written as

$$E\left(\sum_{k=1}^{S_M}RT_k\right)=\sum_{i=1}^{N_R}E(S_i)T_{seg}=N_R\cdot T_{seg}\cdot(\frac{P_{ef}}{1-P_{ef}}) \tag{4}$$

Therefore, the expected file delivery time of a session can be formulated as

$$\begin{aligned}E(T_{SB})&=T_{prop}+N_R\cdot T_{seg}+T_{mar}+\\&2E(S_M)\cdot(T_{prop}+T_{mar})+\frac{N_R\cdot P_{ef}\cdot T_{seg}}{1-P_{ef}}\end{aligned} \tag{5}$$

After further simplification, (5) can be rewritten as

$$E(T_{SB})=(T_{prop}+T_{mar})\cdot\left[2E(S_M)+1\right]+\frac{N_R\cdot T_{seg}}{1-P_{ef}} \tag{6}$$

Thus far, we have completed the modeling and analysis for transfer procedure of a LTP session. We will propose an asynchronous accelerated retransmission strategy and analyze it theoretically in Section IV.

IV. Asynchronous Accelerated Retransmission Strategy

This section elaborates the necessity of accelerated retransmission and chooses the desirable transmission strategy. The modeling and analysis of the asynchronous accelerated retransmission strategy is made theoretically.

A. Strategy Selection

During the actual transmission process, retransmission occurs only on receipt of a RS indicating incomplete reception. A RS is normally generated and transmitted at the end of original transmission of the red-part or at the end of a retransmission. No matter in which case, the last red data segment is a mandatory CP, which is fixed and unable to deal with the actual situations of link transmission. In addition, EORP and CP essentially are red data segments, also face the loss possibility in transmission. If any one of the two fails to reach the receiver, RS will not be produced, so the subsequent retransmission process is delayed. In spite of the fact that LTP has set a timer for automatic retransmission without response, it is still necessary to wait for at least one round trip time to initiate the subsequent retransmission process. This will seriously affect the efficiency of data transmission in deep space communications.

For some applications and occasions, one desirable solution is to trigger data segment retransmission during the original transmission course of red data segments so that the missing segments are recovered sooner. One alternative strategy can triggered by sender, any one of the red data segment before EORP can additionally be labeled as a CP. The other strategy can also triggered by the receiver, an asynchronous RS can be unilaterally issued at any time during the original transmission of red data segments. The former is similar to CFDP prompted NAK mode, and the latter is something like CFDP asynchronous NAK mode. In this paper, we mainly target the latter, which is named asynchronous accelerated retransmission strategy.

B. Modeling and Analysis

Ordinary, the one-way propagation time is so much larger than the time required for radiating the whole data block in deep space communications. One typical case of asynchronous accelerated retransmission in a single LTP session is illustrated in Fig. 2.

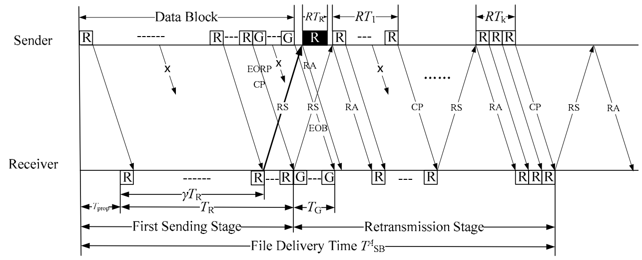


Figure 2. Asynchronous accelerated retransmission procedure.

In this case, during the initial transmission of red data segments, an asynchronous RS is generated and accelerated retransmission is triggered at $\gamma \cdot T_R$, $\gamma \in [0,1]$. In the light of the receiving conditions, the receiver issues the RS and sends it out. When RS arrives at the sender, the green data have already been sent out, the sender acknowledges a RA and retransmits the required red segments if necessary. It is clear that there are $(1-P_{ef})\cdot\gamma\cdot N_R$ red segments have been successfully delivered to the receiver before the arrival of EORP. When EORP is received successfully, the retransmitted red segments are still in flight, just the left $(1-\gamma)\cdot N_R$ original red segments and $P_{ef}\cdot\gamma\cdot N_R$ asynchronous retransmitted red segments need to be considered in the following retransmission stage. Based on the upon analysis, the delivery time of a data block can be formulated as

$$T^A{}_{SB} = (T_{prop} + T_R + T_{mar}) + (T_1 + RT_1 + 2T_{mar}) + \sum_{k=2}^{S_M}(2T_{prop} + RT_k + 2T_{mar}) \tag{7}$$

Where

$$T_1 = \begin{cases} 2T_{prop} & RT_R \le (1-\gamma)T_R \\ 2T_{prop} + [RT_R - (1-\gamma)T_R] & RT_R > (1-\gamma)T_R \end{cases} \tag{8}$$

As long as expected value of the third term in (7) can be obtained, the expected delivery time of a data block can be calculated. The expected value of the third term can be given by

$$\begin{aligned} &E^A\left(\sum_{k=1}^{S_M}(2T_{prop} + RT_k + 2T_{mar})\right) \\ &= E^A(S_M)\cdot(2T_{prop} + 2T_{mar}) + E^A\left(\sum_{k=1}^{S_M} RT_k\right) \end{aligned} \tag{9}$$

It should be noted that the number of red segments required to be considered during the retransmission stage is $[1-(1-P_{ef})\cdot\gamma]\cdot N_R$.

Similarly, the second term in (9) can be derived as

$$\begin{aligned} E^A\left(\sum_{k=1}^{S_M} RT_k\right) &= \sum_{i=1}^{[1-(1-P_{ef})\cdot\gamma]\cdot N_R} E(S_i)T_{seg} \\ &= [1-(1-P_{ef})\cdot\gamma]\cdot N_R\cdot T_{seg}\cdot(\frac{P_{ef}}{1-P_{ef}}) \end{aligned} \tag{10}$$

Where

$$\begin{aligned} E^A(S_M) &= \sum_{m=1}^{\infty} P(S_M \ge m) \\ &= \sum_{m=1}^{\infty}[1 - P(S_M < m)] \\ &= \sum_{m=1}^{\infty}\left[1 - \prod_{i=1}^{[1-(1-P_{ef})\cdot\gamma]\cdot N_R} P(S_i < m)\right] \\ &= \sum_{m=1}^{\infty}\left[1 - \left(1 - P_{ef}^m\right)^{[1-(1-P_{ef})\cdot\gamma]\cdot N_R}\right] \end{aligned} \tag{11}$$

Considering the length of transmission time between the asynchronous retransmitted data and the left original red segments, the expected delivery time of a data block can be represented as

If $RT_R \le (1-\gamma)T_R$

$$\begin{aligned} E(T^A{}_{SB}) = (T_{prop} + T_R + T_{mar}) + E^A(S_M)\cdot(2T_{prop} + 2T_{mar}) + \\ [1-(1-P_{ef})\cdot\gamma]\cdot N_R\cdot T_{seg}\cdot(\frac{P_{ef}}{1-P_{ef}}) \end{aligned} \tag{12}$$

If $RT_R > (1-\gamma)T_R$

$$\begin{aligned} E(T^A{}_{SB}) = (T_{prop} + T_R + T_{mar}) + [RT_R - (1-\gamma)T_R] + \\ E^A(S_M)\cdot(2T_{prop} + 2T_{mar}) + [1-(1-P_{ef})\cdot\gamma]\cdot N_R\cdot T_{seg}\cdot(\frac{P_{ef}}{1-P_{ef}}) \end{aligned} \tag{13}$$

V. COMPARISON MEASUREMENTS

Transmission performance of asynchronous accelerated retransmission strategy is compared with the standard LTP under Mars to Earth scenario in this section.

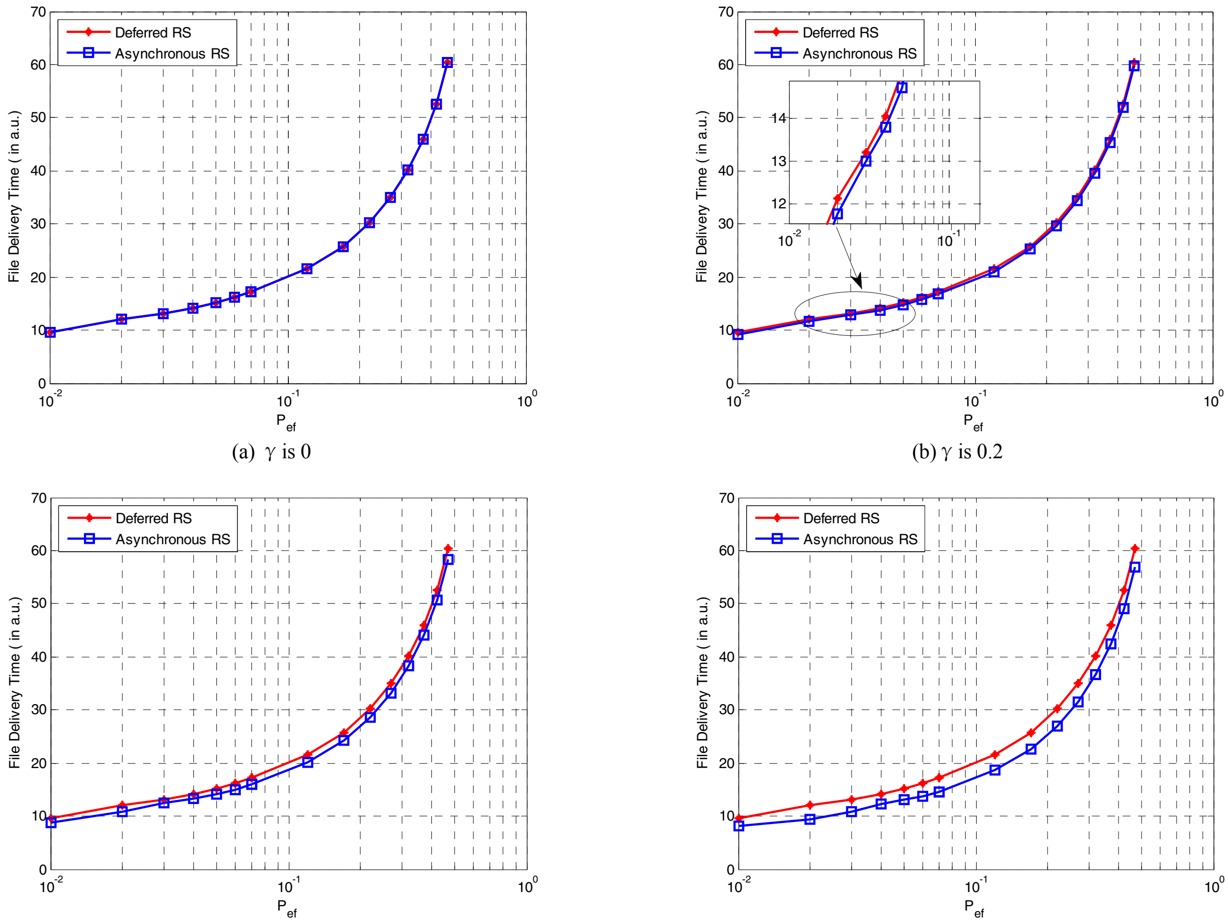
A. Expected delivery time

Under the simulation parameters listed in Table II, we implement several experiments to compare asynchronous accelerated retransmission strategy with standard transfer procedure in a LTP session. The comparisons between them under Mars to Earth scenario are shown in Fig. 3 and Fig. 4.

TABLE II. CONFIGURATION OF SIMULATION PARAMETERS.

Parameters	**Values**
Block size	20MB
N	10000
P_{ef}	0.01~ 0.5
T_{prop}	2.5 a.u. (1200 sec)
L_{seg}	2KB
τ	0.5
γ	0, 0.2, 0.5, 0.8

As shown in Fig. 3, the expected file delivery time of a data block based on the proposed strategy, relative to the recommended transfer of a LTP session, continuously decreases with the right shift of asynchronous trigger point. When the asynchronous trigger point locates at zero, the performance of asynchronous accelerated retransmission strategy is identical to that of the recommended LTP transfer process. It is mainly because the reception report is unable to be generated. However, with constant shift of the asynchronous trigger point, performance of asynchronous retransmission strategy is gradually accelerated. When the asynchronous trigger point is situated at 0.8, compared with the standard LTP transfer, asynchronous accelerated retransmission strategy approximately can reduce 3 a.u. in terms of the expected file delivery time for completing the transmission of a data block. Especially, when γ is 1, $P_{ef} \cdot N_R$ red segments will be retransmitted by asynchronous accelerated and EORP-RS process respectively.



(a) γ is 0
(b) γ is 0.2
(c) γ is 0.5
(d) γ is 0.8

Figure 3. Expected file delivery time under cismartian scenario.

B. Asynchronous accelerated gains

In order to measure performance of the proposed strategy under different link qualities, the gains in circumstances of different error probabilities under cismartian scenario are drawn in Fig. 4. Here the gain refers to the difference of the expected file delivery time spent on transmitting a data block in a session between the standard LTP and proposed strategy. It is clear that the gains brought by the asynchronous accelerated retransmission strategy, increase with the right shift of asynchronous trigger point, simultaneously rise with the increase of the error probability. In particular, when the segment error probability is 0.5, the change tends to be almost linear. Because the number of segments is fixed, the expected file delivery time is absolutely dominated by the product of retransmission spurts and long one-way propagation delay.

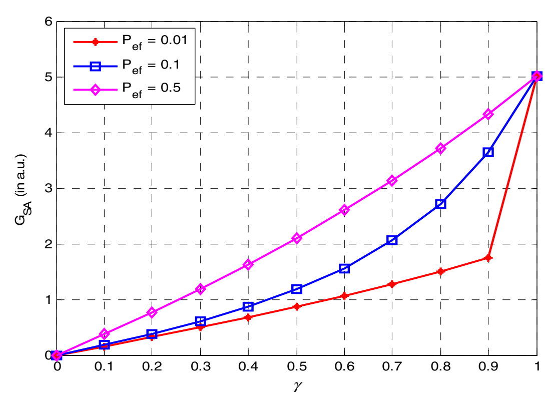


Figure 4. Asynchronous gains under different error probabilities.

VI. Conclusion and Future Work

In this paper, an mathematical model has been developed for the transfer procedure of a single LTP session in deep space long-haul communications. An asynchronous accelerated retransmission strategy aimed for accelerating the retransmission process has been proposed and analyzed under the cismartian scenario. The performance of the asynchronous accelerated retransmission strategy is compared with the recommended LTP-based transmission. Our theoretical evaluation and preliminary simulation results reveal that asynchronous accelerated retransmission strategy outperforms standard LTP transfer model in terms of file delivery time. This improved strategy favors the occasions with short contact, long propagation delay and high error probability greatly, which are frequently faced in deep space communications.

Future work will emphasize on the analysis of the dynamic variations of intermediate node storage capacity during the transfer process. Further performance analysis and optimization of data aggregation for multiple concurrent sessions will also be tackled in our future work.

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