Licklider Transmission Protocol for GEO-Relayed Space Networks

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Abstract. As one of the most important convergence layer (CL) protocol for delay/disruption-tolerant networking (DTN), Licklider transmission protocol (LTP) has recently been proposed for deep space communications, but it has rarely been considered for near earth applications. In this paper, LTP is adopted instead of TCP as CL with Bundle protocol (BP) for future application in GEO-relayed space networks (GRSN). Experiments are conducted on our computer based testbed in emulation of the basic scenarios during data transmission from LEO satellite to a ground station in GRSN. The results show that in transmission efficiency BP with LTPCL outperforms other protocols, such as BP with TCPCL, direct terrestrial TCP (TCP Cubic) and TCP variants (TCP Hybla) for space segments in most scenarios. It could be envisioned that DTN with LTPCL for space segment is currently the best choice for future GEO-relayed space internetworking.

Keywords: Space networking · GEO relays · DTN · LTP · TCP

1 Introduction

Space internetworking through geostationary (GEO) relaying satellites has been envisioned as a promising technology for global tracking, control and data transmission for near earth space data systems [1]. Currently, there are several GEO relaying systems which have been deployed or are under development by different authorities, such as NASA's Tracking and Data Relay Satellite System (TDRSS), China National Space Administration (CNSA)'s Tianlian system, European Data Relay Satellite (EDRS) System, and Japan Aerospace Exploration Agency (JAXA)'s Data Relay Test Satellite (DRTS).

Although the onboard computational capability has grew fast in the past 20 years, most of these GEO relaying systems are still bent-pipe relays without

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networking functions. But GEO relayed space networks (GRSN) is getting into reality [2]. NASA's space network IP services (SNIS) has already been deployed over TDRSS to provide end-to-end IP communications between space vehicles and ground stations since around a decade ago [3]. Because of the huge success of the TCP/IP architecture in terrestrial Internet, commercial off-the-shelf (COTS) protocol stacks and networking equipments are extremely cost-attractive for space internetworking. Meanwhile, it is also well-known that the original TCP transmission control will experience severe performance degradation over satellite links which have longer round-trip times (RTTs) and higher bit error rates (BERs) compared to the terrestrial links [4]. TCP variants, such as TCP Hybla [5], have been proposed for better performance on the challenging satellite or wireless communications links.

Besides TCP/IP, a different network architecture, DTN has been adopted for communications to International Space Station (ISS) scientific payloads since May, 2010. And recently, DTN was officially announced as a communications service on board ISS by NASA. DTN is originally designed for interplanetary networking (IPN) [6]. Although DTN has been proposed as a possible network architecture instead of the terrestrial TCP/IP architecture for GEO relayed internetworking like in [7], most of the previous works have been involved in performance evaluation of DTN with TCP as convergence layer (CL) [7,8]. In the framework of DTN, Licklider transmission protocol (LTP) [9] is proposed targeted for challenging links with very long RTTs and/or interruptions characterizing deep-space communications. As one of the most important CL in the DTN architecture, LTP has been standardized with the essential bundle protocol (BP) by CCSDS. LTP is well investigated and evaluated for deep space scenarios [10,11] in the past few years. But to the best of the authors' knowledge, LTP has rarely been considered as a possible DTN CL for GRSN, in which near earth space information systems, such as low earth orbit (LEO) or mediate earth orbit (MEO) remote sensing satellites, can communicate with home ground stations through GEO relay satellites.

In this paper, we focus on the transmission efficiency of DTN with LTPCL in an emulated GRSN system characterized by various asymmetric channel rates, link delays and bit error rates. The main contributions of our work are as follows:

(1) Analytical models are built to characterize the file delivery delay in all the three basic scenarios in GRSN, which varies from 1 ms to nearly 500 ms. It is important to have a fair performance evaluation of all the possible protocols, such as BP with LTPCL, BP with TCPCL and direct TCP transmissions in all these scenarios for future applications in GRSN;
(2) Although much work has been done on performance evaluation of DTN and TCP/IP for space internetworking, the transmission efficiency of the deep-space originated LTPCL in GRSN has rarely been evaluated through network emulation.

The remainder of this paper is organized as follows, in Sect. 2, data transmissions in GRSN are categorized into three basic scenarios for fair performance comparison. And LTPCL and the DTN architecture for space internetworking are introduced as well. The setup and configuration of the testbed, the results of the emulations and the discussions are presented in Sect. 3. And finally, the conclusions and the possible future works are drawn in Sect. 4.

2 Architecture for GRSN

2.1 Transmission Scenarios in GRSN

Figure 1 presents three typical transmission scenarios classified by number of hops between the source node and the sink node. The typical end-to-end link delay in each scenario can be calculated by

$$T_{delay} = \frac{D_{linkpath}}{c} \tag{1}$$

where $D_{linkpath}$ represents the end-to-end distance between the source node and the destination node, and c is the speed of light. In different scenarios, $D_{linkpath}$ can be split into one or several hops, for example in Scenario III: $D_{linkpath} = D_{EC} + D_{CA} + D_{AF}$. D_{CA} and D_{AF} are constant values, while D_{EC} varies from D_{P1C} to D_{P3C}. As a result, the link delay varies in transmitting distance. Based on the basic geometry and the orbital information, the link delay of three scenarios can be calculated. The results are listed in Table 1. GS represents ground station in both Table 1 and Fig. 1.

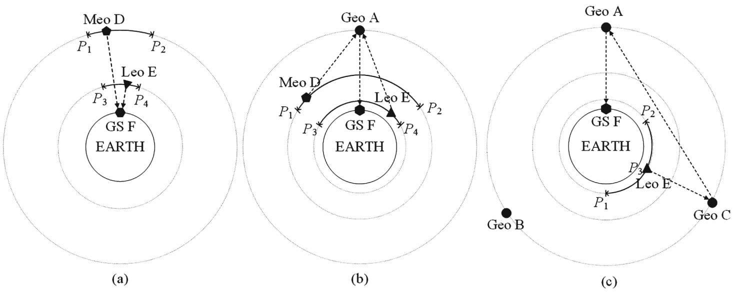


Fig. 1. Typical scenaios in GRSN. (a) Scenario I. (b) Scenario II. (c) Scenario III.

Table 1. Link delay in different scenarios

Scenarios	Hop count	Link delay	Data transfer path
I	1	1–80 ms	LEO E/MEO D → GS F
II	2	200–250 ms	LEO E/MEO D → GEO A → GS F
III	3	480–500 ms	LEO E → GEO C → GEO A → GS F

2.2 Network Architectures

TCP/IP protocol is widely used in satellite network service currently. Various enhanced versions of TCP have been proposed for performance improvement in satellite network scenarios, such as Hybla. As a matter of fact, long link delay will result in reduced performance of TCP severely. Besides, channel asymmetry is also typical in GRSN. Coverage issue at high altitude is another problem. The GRSN cannot provide global coverage. Continuous end-to-end connectivity is usually unavailable in GRSN.

DTN introduces an overlay protocol, called Bundle Protocol (BP), which interfaces either the transport layer protocols (LTP, TCP, UDP, etc.) or lower layer protocols. The essential point is that in such an overlay, delays and disruptions can be handled at each DTN node between the source and sink. Two main features of BP are the store-and-forward transmission mechanism and the custody transfer option. Nodes on the path can provide necessary storage before forwarding to the next hop.

BP has been designed as an implementation of the DTN architecture and is by far the most broadly used DTN protocol. The basic unit of data in the BP is a bundle which is a message that carries application layer protocol data units, sender/receiver names, and any additional data required for end-to-end delivery. Two reliable convergence layer (CL) protocols, TCPCL and LTPCL, are investigated in this paper. With specialized features of BP [12], DTN is particularly suited to cope with the challenges presented in satellite networks, including GRSN.

2.3 Overiew of the Licklider Transmission Protocol

LTP is designed to provide retransmission-based reliability over links characterized by extremely long RTTs and/or frequent interruptions in connectivity. LTP is intended to serve as a convergence layer protocol, underlying the BP, in deployment environment with long RTTs. Different from TCP, LTP performs selective negative acknowledgment (NAK). And LTP can provide both reliable and unreliable services. Datas are transmitted in "red" parts in a reliable service, and "green" parts in an unreliable one. We only consider the former for reliable transmission in this paper. Data encapsulation and transmission are shown as Fig. 2. Two main differences between TCP and LTP are summarized as follows:

(1) LTP data transmission is organized in sessions. A session is defined as the process of LTP segment exchanges undertaken to transmit a single data block successfully. TCP data transmission is based on connection.
(2) LTP performs selective NAKs on bytes in block, while TCP performs ACKs on bytes in windows and SACK is optional.

3 Experimental Setup and Results

To implement an emulated GRSN infrastructure for the evaluation of different protocols, we use three PCs equipped with DTN protocol stack and TCP suites

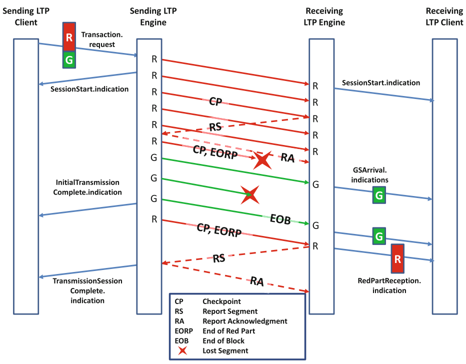


Fig. 2. Overview of LTP Interactions [13] (Color figure online)

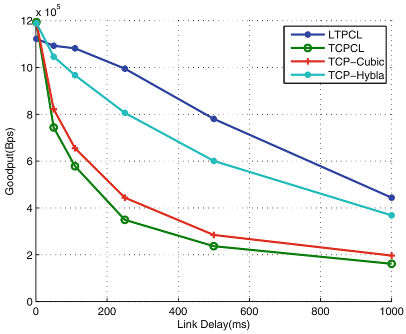


Fig. 3. Impacts of link delays

Table 2. Experimental factors and configuration

Experimental factors	Settings/values
BP custody transfer option	Disabled
LTP red/green setting	100% red
Data bundle size	40000 bytes
LTP block size	6 bundles/block
LTP segment size	1400 bytes
Channel rate	1:1 (10 Mbps:10 Mbps)
	10:1 (10 Mbps:1 Mbps)
	50:1 (10 Mbps:200 kbps)
BER	$10^{-7}, 10^{-6}, 10^{-5}$
One-way link delay (ms)	1.5, 50, 110, 250, 500, 1000
Experimental file size	10,000,000 bytes
Sample size	16 repetitive runs

to set up a testbed, representing source node, sink node and channel emulator. As GEO relaying satellites act as bent-pipe, they only affect the link characteristics, such as delay and bit error rate (BER). Link characteristics are emulated by NetEm [14], included in Ubuntu 14.04.3 LTS kernel. The DTN BP and LTP protocol implementations used for our experiments were provided by the Interplanetary Overlay Network(ION) v3.4.1. TCP-Cubic and TCP-Hybla were supported by Ubuntu kernel. Channel ratio is defined as the ratio of data channel rate over the ACK channel rate. Parameter settings are shown in Table 2. Datas are transmitted via BP with LTPCL, BP with TCPCL (running over TCP-Cubic), direct TCP-Cubic and TCP-Hybla in our testbed. Network throughput is measured as the major performance metrics in our test.

3.1 Impacts of Link Delays

BER of 10^{-7} and CR of 10:1 is set here. The performance should not suffer degradation because of BER and CR in such a condition. Then we focus on the effect of link delays. The goodput of BP/LTPCL, BP/TCPCL, TCP-Cubic, and TCP-Hybla are measured with link delays increased from 1.5 ms to 1000 ms. This covers all the three different transmission scenarios mentioned in Sect. 2. The results are shown in Fig. 3.

From Fig. 3 we can find that performance of LTPCL, TCPCL, TCP-Cubic, and TCP-Hybla are very close when link delays are short (about 1.5 ms), which is similar to terrestrial network environments. And LTPCL shows slightly worse performance than the other three. As the link delay increases, all four protocols suffer performance degradation. LTPCL shows the best performance with increasing link delay. Among the other three, TCP-Hybla shows the best performance because of its targeted improvement in congestion mechanism under long RTTs. Perfomance of TCPCL and TCP-Cubic are very similar. Because BP caused additional overhead, performance of TCPCL is the worst.

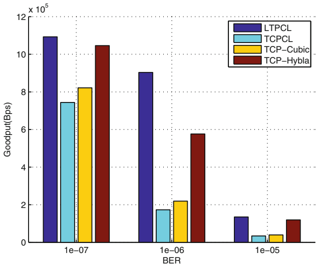
Discarding the influence of BER and CR, a conclusion can be drawn that when link delay is short, for example, a one-hop transmission in Scenario I, TCP-Cubic, TCP-Hybla and TCPCL will be better than LTPCL in performance. But when the transmission contains more than one hop and RTT increases, as shown in Scenario II and III, LTPCL would be the best choice. As we all know, covering time of LEO only accounts for about 10 percent of entire orbital period. In other words, transmission is GRSN contains two or several hops most of the time, and LTPCL would be the best choice.

3.2 Impacts of Bit Error Rate

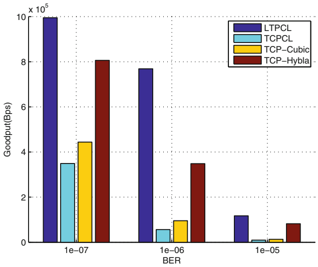
Channel ratio is still set as 10:1. Three BERs are investigated: $10^{-7}, 10^{-6}$ and 10^{-5}, representing low bit error rate, medium bit error rate and high bit error rate respectively. Figure 4 illustrates the goodput performance of four protocol options in three scenarios with consistent channel ratio and varying BERs.

When the BER is 10^{-7}, LTPCL and TCP-Hybla show better performance than the other two in all three scenarios. When BER increases to 10^{-6}, both TCP protocols decrease more than a half, while LTPCL decreases less than 25%. When BER further increases to 10^{-5}, which represents a high loss channel, all the four protocols show unsatisfactory performance.

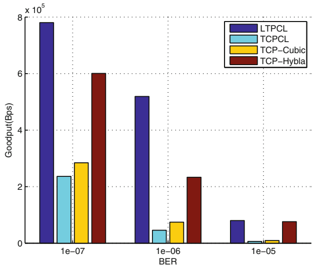
As BER increases, more packets transmission will be lost, and need to be retransmitted, which is an aggravation for both the data channel and the ACK channel. When lost data being retransmitted, TCP's strategy is to retransmit all the packets before the lost packet that are unacknowledged, that causes a lot of packets which have been transmitted correctly being retransmitted again. As contrast, LTP will only retransmit segments that are not transmitted correctly, saving considerable bandwidth resources.



(a) Scenario I. CR = 10:1

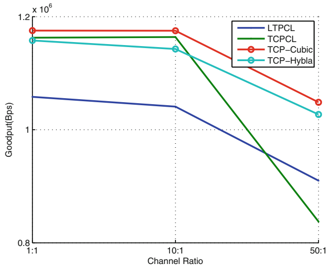


(b) Scenario II. CR = 10:1

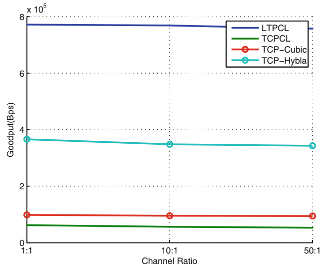


(c) Scenario III. CR = 10:1

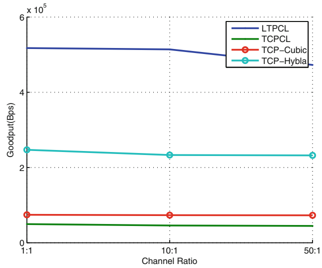
Fig. 4. Impacts of BER



(a) Scenario I. BER = 10^{-6}



(b) Scenario II. BER = 10^{-6}



(c) Scenario III. BER = 10^{-6}

Fig. 5. Impacts of CA

3.3 Impacts of Channel Asymmetry

To measure impacts of channel asymmetry (CA) on the performance in different scenarios, we choose a medium BER because it won't put too much influence on results. Considering real communication environments in GRSN, we investigate three channel ratios (1:1, 10:1, 50:1). The results are shown in Fig. 5.

In scenario I, as channel ratio increases, goodput of TCPCL decrease by about 25%. And the other three suffer less performance degradation. But LTPCL outperforms the other three in both scenario II and III. And in scenario II and III, channel ratio does not show much influence on performance of four protocols. There are two reasons. One is that the channel ratio is quite small. And the other is that link delay plays a major role in the influence as we explained in Sect. 3.1.

As expected, LTPCL shows the best tolerance of channel ratio among four protocols in the scenario II and scenario III. As mentioned above in Subsect. 2, when CR increases and the ACK channel becomes narrow, large amounts of ACKs won't be transmitted to the source node in time. According to LTP's ACK strategy, a ACK will be sent corresponding with a block. Previous researches has shown that multiple BP bundles should be aggregated into a single block to resist the effect of highly asymmetric data rates in space network [11]. Benefit from this strategy, LTP only need to sent small amount of ACKs and is capable of dealing with narrow ACK channel.

4 Conclusion

In this paper, we propose to apply LTP instead of TCP as CL protocol with BP for future application in GRSN. The performance of LTPCL is compared with that of TCPCL, direct TCP-Cubic and TCP-Hybla on the emulation testbed. We also build analytical models to characterize the file delivery delay in three basic scenarios in GRSN. The theoretical analysis and results of network emulation show that LTPCL outperforms the other protocols in most cases. LTP is proved to be more promising choice for the best transmission efficiency in GRSN. Furthermore, GEO relays investigated above are still bent-pipe, and relay satellites equipped with DTN protocol suites and networking functions, served as DTN route, would be studied in further research.

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