Optimizing Data Transmission for Deep Space A Comprehensive Overview and Research Trends of Licklider Transmission Protocol

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***Abstract*—**Since the advent of the space exploration era, not only simple satellite communication but also communication distances such as Earth-Mars are getting longer and longer, and more space exploration technologies are being developed, so the technical requirements for deep space communication networks are increasing. Existing deep space communication networks have used DTN (Delay/Disruption Tolerant Network), a delay/disruption tolerant network for stable data transmission, as a core internetworking technology due to long link delay and link asymmetry. In this paper, we introduce the concept of LTP (Licklider Transmission Protocol), a core data transmission protocol as one of the convergence layer protocols of DTN and investigate recent research trends.

Keywords—LTP, DTN, Bundle Protocol, Deep Space, Licklider Transmission Protocol;

I. Introduction

Space communication networks have become indispensable for supporting diverse applications, ranging from Earth observation to interplanetary exploration and scientific research. These networks encounter unique challenges, including long signal propagation delays, high data loss rates, asymmetric channel bandwidths, and frequent link disruptions caused by planetary rotations, space weather phenomena, and other environmental factors. Such challenges necessitate the development of robust and reliable data transmission protocols to ensure mission success. [1]

To address these challenges, Delay/Disruption Tolerant Networking (DTN) has emerged as a pivotal architecture for space communication systems. [2] DTN introduces a store-and-forward mechanism that enables reliable data delivery despite intermittent connectivity. Through the implementation of the Bundle Layer and the Bundle Protocol (BP), DTN segments end-to-end paths into multiple DTN hops, each adaptable to its unique channel conditions. This approach ensures that packet losses in lower layers are resolved locally, enhancing the overall transmission efficiency of the network. [3]

At the core of DTN lies the Licklider Transmission Protocol (LTP), a convergence layer protocol designed specifically for deep-space communication environments. LTP overcomes the limitations of traditional protocols like TCP by employing block-based data transmission without requiring connection establishment. It incorporates selective retransmission mechanisms to recover lost data efficiently, making it particularly suitable for long-delay, high-latency, and highly asymmetric environments. Furthermore, LTP supports dual transmission modes: reliable (Red) and unreliable (Green). This flexibility allows it to adapt to mission-specific requirements, prioritizing either reliability or transmission speed as needed. [4]

As space exploration continues to advance, ranging from cislunar missions to interplanetary probes, the role of LTP in ensuring reliable data transmission becomes increasingly significant. Its ability to address the unique demands of deep-space environments positions it as a cornerstone of modern space communication architectures.

This paper provides a comprehensive overview of the Licklider Transmission Protocol, detailing its operational principles, key features, and recent research trends. Through this analysis, it underscores LTP's critical role in enabling reliable and efficient deep-space communication networks

II. Body

The Licklider Transmission Protocol (LTP) is a protocol specifically designed to ensure reliability in environments with long delays and frequent disconnections. [4] Unlike the TCP/IP protocol suite, LTP operates within the DTN architecture, delivering exceptional performance in specialized environments such as deep-space communication.

A. TCP vs LTP

Unlike TCP, LTP differs in data transmission and retransmission mechanisms. LTP transmits data without a connection establishment procedure, manages data on a session basis, and operates on block-level data transmission. By selectively retransmitting only lost data, it enhances transmission efficiency over long-delay links. Additionally, it transmits data at a consistent rate, making it more suitable for high-latency links. [5]

Conversely, TCP dynamically adjusts its transmission window size based on the Round-Trip Time (RTT) and uses congestion control algorithms to resolve network congestion. This approach can lead to a significant drop in transmission rates in environments with high RTT, as TCP interprets packet loss as a sign of congestion. Furthermore, the process of retransmitting lost data reduces overall transmission efficiency. Since TCP ensures data order, packet loss can delay the entire data flow.

In terms of connection maintenance, LTP exhibits notable differences. LTP can process data blocks by separating reliability and unreliability even in intermittently disconnected environments. In contrast, TCP halts data transmission when the connection is disrupted, necessitating connection recovery. As a result, TCP is better suited for stable network environments, while LTP operates flexibly in environments with unreliable or high-latency connections. [4]

B. *Structure of LTP*

Based on transmission reliability, LTP categorizes data segments into Red and Green segments, representing reliable and unreliable transmissions, respectively. This segmentation enables LTP to handle data flexibly based on network conditions. Red segments guarantee reliable data transmission, similar to TCP, by minimizing data loss and retransmitting lost data.

Red segments use a selective Negative Acknowledgment (NAK) mechanism to retransmit only the lost data. By processing data in blocks, they provide information about lost portions to the sender, who then retransmits only the missing parts, enhancing efficiency. During the transmission of Red segments, checkpoints (CP) and report segments (RS) are added to confirm successful receipt. Upon receiving a CP, the receiver sends an RS to report its reception status, facilitating segment loss detection and retransmission.

Green segments signify unreliable data transmission and do not involve any retransmission in case of loss. They prioritize rapid transmission and omit CP and RS, making the transmission process simpler than for Red segments. Consequently, senders can transmit subsequent data without confirmation, ensuring faster processing. [7]

C. *Related research trends*

[8] analyzed the impact of link disruptions on LTP's reliable data transmission in deep-space communication environments. The authors developed a model to evaluate the influence of multiple random link disruptions on LTP data transmission and validated it experimentally. By setting thresholds to determine whether two consecutive disruptions interact or are considered a single disruption, the study identified conditions under which consecutive link disruptions could be treated as single events. Experimentally, data transmission based on LTP was tested by varying the start time and duration of link disruptions, confirming the model’s accuracy. Early disruption start times necessitate more transmission attempts, increasing transmission time and reducing network goodput.

[9] proposed replacing TCP with LTP in networks utilizing GEO (Geostationary Earth Orbit) satellites. The study developed a mathematical model combining LTP and the Bundle Protocol for predicting file delivery times in satellite-to-ground station communications under varying network conditions. Parameters such as transmission error probability, block size, and segment size were mathematically defined, and the data segment transmission procedure was modeled using geometric probability distributions based on loss probabilities. The study concluded that LTP outperforms TCP in environments with high bit error rates and channel asymmetry, particularly in multi-hop scenarios.

[10] proposed extending LTP with Multicolor LTP, adding an Orange segment to the existing Red and Green segments to introduce a notification feature. Multicolor LTP maps each session to a single color, providing QoS differentiation. Orange segments notify upper layers of transmission failures, offering a lightweight reliability mechanism compared to traditional ARQ protocols. The proposed protocol was evaluated in terms of data transfer time, session delay, and transmission loss under high RTT and high Bandwidth-Delay Product (BDP) environments, demonstrating superior reliability and efficiency over traditional LTP.

III. Summary

This paper introduces the Licklider Transmission Protocol and reviews research trends surrounding it. LTP is a data transmission protocol designed to address long delays and link disruptions in deep-space communication. Its selective retransmission mechanism enhances reliability, enabling efficient block-level transmission without connection establishment.

Compared to TCP, LTP delivers superior performance in environments with high bit error rates and channel asymmetry, excelling in multi-hop network scenarios. Its NAK-based retransmission mechanism contributes to efficient resource usage and improved transmission speeds.

The first study analyzed the impact of random link disruptions on LTP performance in deep space communications. By developing and validating a model considering disruption start times and durations, it demonstrated that link disruptions lead to increased transmission attempts, delays, and reduced goodput, accurately predicting LTP performance.

The second study proposed using LTP instead of TCP in GEO satellite networks, combining it with the bundle protocol to model file transfer times. Experimental results showed that LTP outperforms TCP under high bit error rates and channel asymmetry, making it a suitable choice for GEO-relayed space networks.

Lastly, the third study introduced Multicolor LTP, extending LTP with orange segments to enhance QoS and provide lightweight reliability mechanisms. Experiments confirmed its superior efficiency and reliability in high RTT and BDP environments, highlighting LTP’s adaptability and scalability.

As deep-space communication networks advance, the application of LTP is expected to expand. With its potential for optimizing data speed, reliability, and latency, LTP offers promising contributions to interplanetary communication and beyond.

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References

[1] S. Burleigh et al., "Delay-tolerant networking: An approach to interplanetary internet", IEEE Commun. Mag., vol. 41, no. 6, pp. 128-136, Jun. 2003

[2] K. Fall, "A delay-tolerant network architecture for challenged Internet", Proc. SIGCOMM, pp. 27-34.

[3] S. Burleigh, M. Ramadas and S. Farrell, "Licklider transmission protocol - motivation", Internet Requests for Comments RFC Editor RFC 5325, September 2008

[4] R. Wang, S. C. Burleigh, P. Parikh, C. -J. Lin and B. Sun, "Licklider Transmission Protocol (LTP)-Based DTN for Cislunar Communications," in IEEE/ACM Transactions on Networking, vol. 19, no. 2, pp. 359-368, April 2011,

[5] Licklider Transmission Protocol-Specification. Retrieved September, 2008 from https://tools.ietf.org/html/rfc5326

[6] A. Bisacchi, C. Caini and T. de Cola, "Multicolor Licklider Transmission Protocol: An LTP Version for Future Interplanetary Links," in IEEE Transactions on Aerospace and Electronic Systems, vol. 58, no. 5, pp. 3859-3869, Oct. 2022

[7] CCSDS 734.1-B-1, "Licklider Transmission Protocol for CCSDS," 2015

[8] L. Yang et al., "A Study of Licklider Transmission Protocol in Deep-Space Communications in Presence of Link Disruptions," in IEEE Transactions on Aerospace and Electronic Systems, vol. 59, no. 5, pp. 6179-6191, Oct. 2023

[9] Zhang, W., Yang, G., Jiang, F. et al. Licklider Transmission Protocol for GEO-Relayed Space Internetworking. Wireless Netw 25, 3747–3757, 2019

[10] A. Bisacchi, C. Caini and T. de Cola, "Multicolor Licklider Transmission Protocol: An LTP Version for Future Interplanetary Links," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 58, no. 5, pp. 3859-3869, Oct. 2022,