Transmission Performance of Licklider Transmission Protocol (LTP) and Bundle Protocol (BP) in DTN Architecture

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Abstract. From Near-Earth orbit (NEO) to Earth-Sun Lagrangian points will continue to be a majority of future space exploration quests. A few works have been done with long distance delay/disruption tolerant networking (DTN) technology for Near-Earth orbit (NEO) transmission and provided feasibility for its adoption in NEO and long distance exploration quests. [1] However, no much work has been done to fully evaluate the performance of DTN architecture in such an environment, especially in the presence of long link disruption, data corruption and loss, and link asymmetry. [2] In this research, we present an experimental performance evaluation of DTN architecture and protocol stack, with Licklider transmission protocol (LTP) serving as a convergence layer adapter (CLA) underneath bundle protocol (BP), in typical NEO and long distance transmission infrastructures accompanied by a very long link outage, various packet corruption and loss rates, and channel rate symmetry and asymmetry. [3] In addition, we present an experimental investigation of the performance of DTN custody transfer with long link break. The experiment was conducted by performing realistic file transfers over a virtual server test-bed.

Introduction

Jet Propulsion Laboratory developed the DTN architecture and Ohio University partially maintained this new infrastructure. The insertion of DTN functionality in to the space transmission research is very impractical. So this new architecture is designed and used in deep space research systems in order to reduce the risks and payment in transmission by simplifying the construction and operation of automated long distance transmission network.

Implementation of The DTN architecture is intended to work successfully in an interplanetary network environment characterized by two major constraints namely the link constraints and processor constraints. The link constraints are mainly characterized by slow and asymmetric bandwidth. Signals are also very weak since the antennas in the spacecraft are relatively small and this also limits the speed at which the data can be transmitted from spacecraft to earth. The processor constraints are characterized by the limited availability of the electric power to operate space computer and they are constantly slower. This leads to the increase in cost for processing data and processors are heavily loaded. Therefore, the processing performed by spacecraft computer should be highly predictable and highly reliable. The core principles of DTN that are intended to overcome the above mentioned constrains is shared memory, zero-copy procedures, highly distributed processing and portability.

Related Work on Convergence Layer Protocols for DTN Architecture

Operating at the application layer of the Internet architecture, BP protocol forms a store-and-forward overlay network to provide custody-based, message-oriented transmission in DTN. BP is designed to cope with connectivity interruption and to take advantage of scheduled, predicted, and opportunistic connectivity. It conducts message transmission and reception using the services of an underlying CLA stack. Currently, the TCP-based CLA (i.e., TCPCL), user datagram protocol (UDP)-based CLA, and LTP-based CLA are supported under BP.

The TCPCL works jointly with underneath TCP to provide reliable transmission services between DTN nodes. A UDP-based CLA is intended for use over dedicated private links where congestion control is not required, and it assumed that a bundle will always fit into a single UDP
datagram of around 64 Kbytes. This means that a UDP CLA is not able to support segmentation of large DTN bundles across multiple UDP packets. Different from the basic UDP-based CLA implementation, LTP-based CLA supports segmentation of large DTN bundles across multiple UDP packets. It provides selectable reliable and unreliable services according to mission requirements and transmission capability. Therefore, it is considered that LTP provides both TCP-like and UDP-like transmission service. Due to thesis length limitation, the design and operation of LTP are not discussed in details here. Readers can refer to for its details and for a summarized side-by-side comparison between TCP and LTP for their design differences.

**Experimental Setup and Configuration**

This work focuses on performance evaluation of DTN architecture in a NEO transmission environment. NEO-satellite transmission architectures have been well described in literature. For a simple point-to-point NEO-satellite transmission architecture, refer to. [4] A virtual server-based Space Transmission and Networking Testbed (SCNT) was built to emulate a relay-type of NEO-satellite transmissions infrastructure for the proposed experimental evaluation of DTN. See [5] for a block diagram of the SCNT and a detailed discussion of its operation. Previous research [3, 4] shows that the evaluation results obtained from the SCNT have generality and the test-bed can effectively evaluate the realistic performance of a protocol. A network emulation package of Ubuntu server, netem [6], was adopted to simulate the satellite channel conditions such as link outage, propagation delay, packet corruption, and packet loss.

Table I lists the major configuration parameters of protocol in our experiment. The experiment was conducted by transferring a text file of 5 Mbyte from the simulated NEO-node in space to the ground station node on the space center, with the experimental parameters configured over the channel. Each file transfer was performed twenty (20) times in each configuration. This sample size was chosen according to Fisher’s Least Significant Difference comparison procedure. [7]

| Experimental Factors                   | Settings/Values                                                                 |
|----------------------------------------|--------------------------------------------------------------------------------|
| DTN Protocol implementations           | Interplanetary Overlay Network (ION) v2.2.1 from JPL, California Institute of Technology, CA |
| DTN protocol layering                  | BP/LTPCL/UDP/IP/Ethernet                                                        |
| BP custody transfer option             | Enabled                                                                         |
| LTP red/green settings                 | Bundles are set 100% red data                                                 |
| MTU size                               | 5000 bytes                                                                     |
| Operating system                       | Ubuntu server 19.10 (Eoan-Ermine)                                             |
| Packet corruption rate                 | 0%, 15%, and 30%                                                              |
| Packet loss rate                       | 0% and 10%                                                                     |
| Channel ratio (Data rate : ACK rate)   | 1/1 (6.4 Mbit/s : 6.4 Mbit/s, Symmetric channel)                               |
|                                        | 500/1 (6.4 Mbit/s : 8 Kbit/s, Asymmetric channel)                              |
| One-way link delay                     | 5 ms (A typical NEO-satellite link delay)                                      |
| Experimental file size                 | 5,000,000 bytes                                                                |
| Sample size                            | 16 repetitive runs for each configuration                                     |

The experiments for long distance transmissions are done in a similar method as for LEO-satellite transmissions. In Figure 1, shows a block diagram of the virtual server-based testbed space transmission networking testbed and the details of transfer channel.
Table 2 shows a block diagram of virtual server-based testbed. The test-bed contains a Linux-based file source virtual server (fs.dingwang.com), file relay virtual server (relay.dingwang.com), file destination virtual server (fd.dingwang.com), and the SLS, which connects three file virtual servers.

Table 2. Experimental Factors and Configuration for Long Distance.

| Protocol Layering | ION BP/LTPCL/UDP |
|-------------------|------------------|
| Custody transfer  | Have custody transfer | Have not custody transfer |
| Delay             | 400 second        |
| Link Breaks       | 15 min 30 min 60 min 1 hour 4 hour 8 hour 16 hour |
| Ratio of Channel Rate | 1:1          |
| BER               | 0 10^{-6} 10^{-5} |
| File Size         | 100k 400k 4M 40M |

Experimental Results and Discussions

We start with a rough comparison of the goodput performance with and without a link outage involved. Following this point, we discuss the performance of the protocol without a link outage. We then discuss the performance when a long link outage is involved.

Comparison of Performance with and without Link Outage Involved

In Figure 2, a comparison of goodput performance for the LTP-based DTN protocol to transmit a 5 Mbyte file over NEO-satellite channels is presented among three link corruption rates with respect to no link outage and long link outages of 1 hour, 4 hours, 8 hours and 16 hours involved. A direct observation is that for all the experimented channel-rate configurations (i.e., symmetric and asymmetric) and packet loss rates (0% and 5%), the transmissions without a link outage involved show significantly higher goodput than those with a link outage involved. While the goodput without a link outage involved ranges from 20,000 bytes/s to 100,000 bytes/s, the goodput with a link outage involved merges and approaches zero. This is reasonable because a long link outage dominates the short file transmission time, resulting in very poor goodput performance, provided that a high-speed data channel rate of 6.4 Mbps was configured for transmission of a 5 Mbyte file during the experiment.

It is also observed that the performance is significantly different among three packet corruption rates of 0%, 10% and 20% for all the configurations when no link outage is involved. In
comparison, their performance merges and shows no statistically significant differences for all link outage durations varying from 1 hour to 8 hours.

As another observation, for all three corruption rates, the goodput performance without a link outage decreases when either a packet loss rate of 5% and/or asymmetric channel are introduced. This can also be easily explained. Data loss causes retransmission of data packets (although in a deferred mode), creating additional file transmission time thus degradation of goodput. When channel-rate asymmetry is involved, the forward channel rate (from the Earth to a NEO-satellite) may be too near to handle the transmission of returning ACKs effectively, resulting in late arrival or frequent losses of ACKs and consequentially performance degradation of the protocol.

Figure 2. Goodput comparisons for the LTP-based DTN protocol to transmit a 5 Mbyte file over NEO-satellite channels with respect to no link outage and long link outages involved. (a) SYM with Loss Rate=0%. (b) SYM with Loss Rate=5%. (c) ASYM with Loss Rate=0%. (d) ASYM with Loss Rate=5%.

BP/LTPCL with Custody Transfer vs BP/LTPCL without Custody Transfer with 1MB File Size

In Figure 3, a comparison of goodput performance for the BP/LTPCL with custody transfer vs BP/LTPCL without custody transfer to transmit a 1 Mbyte file over long distance channels is presented at three BERs with respect to no link outage and long link outages ranging from 10 minutes to 8 hours.

A direct observation is that for all the experimented transfer configurations (i.e., with custody transfer and without custody transfer) and bit error rate (0, 10−5, and10−6), the transmissions without a link outage involved show significantly higher goodput than those with a link outage involved. While the goodput without a link break involved ranges from 3,000 bytes/s to 1,000 bytes/s, the goodput with a link break of 1 hour involved merges and approaches the same value. This is reasonable because a long link break dominates the short file transmission time, resulting in very poor goodput performance, provided that a high-speed data channel rate was configured for transmission of a 1 M byte file during the experiment.
Figure 3. Goodput comparisons for the LTP-based DTN protocol to transmit a 1Mbyte files over long distance channels with different links disruption and BER. (a) BER=0 (b) BER=10^{-6} (c) BER=10^{-5}.

It is also observed that the performance is significantly different among two different transmission modes with custody transfer and without custody transfer for all the configurations when no link break is involved. In comparison, their performance merges and shows no significant differences for all link break durations varying from 2 hours to 8 hours. As another observation, for all two transmission modes, the goodput performance without a link break decreases when either a packet bit error rate of 10^{-5} and/or 10^{-6} are introduced. This can also be easily explained. Data loss causes retransmission of data packets (although in a deferred mode), creating additional file transmission time thus degradation of goodput. When bit error rate is involved, the forward channel rate may be too Near to handle the transmission of returning ACKs effectively, resulting in late arrival or frequent losses of ACKs and consequentially performance degradation of the protocol.

The key reason for performance degradation when custody transfer is added to bundle transmission over LTP is that it doubles the number of bundles that must be sent: for each original data bundle that is sent—via LTP reliability—in the forward direction, a small custody acceptance signal bundle is sent—again via LTP reliability—in the reverse direction. The total number of bytes is not doubled, because custody signals are much smaller than most original data bundles, but transmission of a custody signal causes an additional report segment and report ACK segment to be transmitted, so the LTP overhead is doubled.

Custody transfer does hop-by-hop reliable transmission while TCP does end-to-end reliable transmission. A single custody transfer hop may span multiple bundle forwarding hops, because not all nodes are required to take custody; the next custodian might not be an immediate neighbor in the network. A node that has taken custody of a bundle will typically re-forward the bundle if no custody acceptance signal has been received (for that bundle) from any other node prior to expiration of a “countdown timer” for that bundle.

The custody transfer system does not do any integrity checking (such as a checksum) on received bundles, but convergence-layer protocols will typically discard any received protocol data unit that is determined to be corrupt. A node would typically never receive the bundle transmitted by another node, because the convergence layer would have discarded it. If the convergence layer adapter did pass the corrupt bundle up to BP at the node, the bundle protocol agent could check its integrity and detect the corruption. In that event it might theoretically send back a custody refusal signal, but there really isn’t any custody transfer signal reason code that signifies to retransmit; reasons for custody refusal tend to be shortages of storage or forwarding resources.

From the above discussions, custody transfer really isn’t designed to be a NACK-based retransmission system. In fact, the only mission that causes retransmission by a bundle custodian is expiration of a countdown timer. In general, custody transfer isn’t designed to be a full-featured reliability system at all. The specification imposes very few solid requirements on the implementer. Even the parameters of DTN architecture has modified, the result is not satisfactory.\[8\]

**Conclusion**

For transmissions over NEO-satellite channels without a link outage experienced, the impact of channel-rate asymmetry (with a channel ratio around 500/1) on the goodput performance of LTP-based DTN decreases along with the increase in packet corruption rate (from 0% to 20%).
impact decreases more significantly when packet losses (around 5%) are occurred over the channel. The impact of packet corruption (around 10%~20%) on the goodput performance of the protocol increases when the channel rate becomes asymmetric, and it increases more significantly over a loss channel.

For long distance transmissions, BP/LTPCL protocol is very effective in data transmission in presence of an extremely long link delay of 5 minutes of delay. The comparison results are different depending on the transmission condition. BP/LTP without custody transfer has performance advantage over with custody transfer when no break or over short break is involved for transmission of a big file. The comparisons with custody transfer and without custody transfer shows very similar performance for a long link break channel and/or small file sizes. BP/LTPCL without custody transfer to transmit big size file with long break is very effective. According to this study, custody transfer really isn’t designed to be a NACK-based retransmission system. And it does not show performance advantage in long distance transmission.

Future Work

DTN architecture has been used successfully for experimental file transfer in space transmissions. However, DTN has yet to be used operationally in long-running space flight missions. While evaluation of BP and supporting routing protocols is recognized as critical for DTN development, extensive evaluation and optimization of LTP is likewise critical before DTN is deployed in space flight. In addition, the impact of the LTP flow control “window size” on the performance of DTN should also be investigated in order to achieve the maximum throughput of LTP.

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