Overview of Current Space DTN Activities in China

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Background

- Some work has been done to study DTN in space communications in China, under a joint program by
  - Harbin Institute of Technology (HIT) (China)
  - Soochow University (China)
  - Lamar University (USA): a state university of Texas, USA
- The projects are led by
  - Dr. Ruhai Wang (Chair Professor at Soochow University and HIT, and associate professor at Lamar University)
  - Dr. Qinyu Zhang (HIT, China)

Overview

- The team is currently working on DTN for space as part of the research work needed for the China's ambitious Moon probing/landing and Mars probing projects in the next 10~20 years
- Current work focuses on **experimental** and **theoretical** investigation of DTN for space
  - Experimental: DTN implementations and experiments over testbeds (Extensive work already done)
  - Theoretical: Deep-space channel modeling and DTN modeling (Going on)

Experimental Activities

- The following projects have been done using two testbeds to investigate the performance of DTN implementations (including JPL's ION and DTN-2) and CFDP in cislunar and deep-space communication environments:
  - Licklider Transmission Protocol (LTP)-based DTN for cislunar and cismartian communications
  - Hybrid DTN protocols in interplanetary Internet
  - Effectiveness of DTN with asymmetric space channel rates
  - Relay path selection for higher goodput of DTN in cislunar and cis-Martian communication architecture
  - Performance of LTP with variation of window size
  - LTP over cis-Martion channels with in presence of long disruption

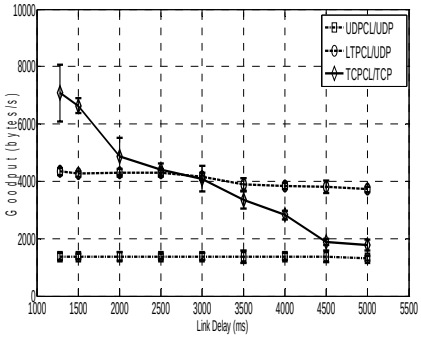
Results of Project One

- Licklider Transmission Protocol (LTP)-based DTN for Cislunar and Cis-Martian communications
  - In this work, an experimental performance of the BP running over various "convergence layer" protocols in a simulated cislunar and cis-Martian communications environments is conducted with focus on the LTP convergence layer adapter running on top of UDP/IP.
  - According to the studies, using any single convergence-layer stack under BP on all segments of a heterogeneous end-to-end path is shown to be invariably less efficient than individually selecting the most appropriate convergence-layer stack for each path segment.

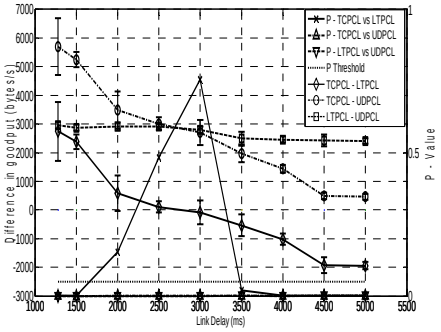
Results of Project One

- Licklider Transmission Protocol (LTP)-based DTN for Cislunar and Cis-Martian communications
  - For file transfer over a very lossy channel with a BER of around 10^{-5}, LTPCL has a significant goodput advantage over TCPCL at all the cislunar delay levels.
  - With Scott C. Burleigh at JPL also involved
  - The results willl be appeared in IEEE/ACM Transactions on Networking, in Feb. issue of 2011.

Sample Results of Project One

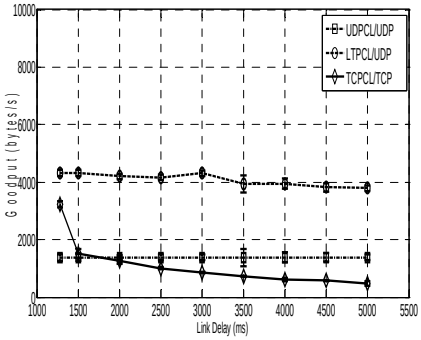


BER=10E-6

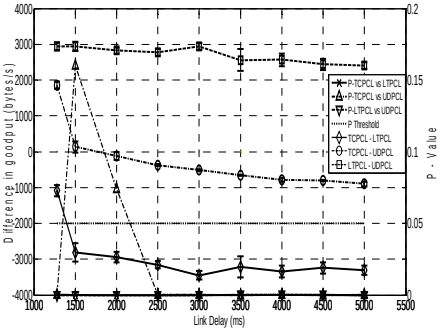


Corresponding Analysis Results at BER=10E-6 using Statistical t-test

Sample Results of Project One

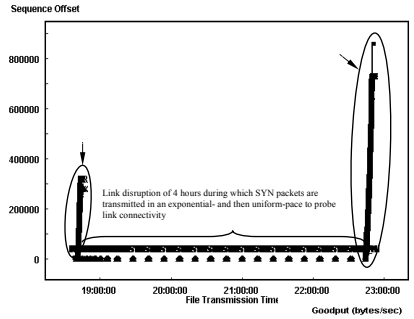


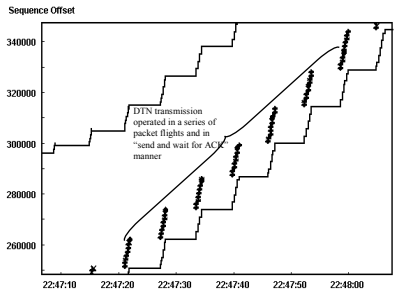
BER=10E-5



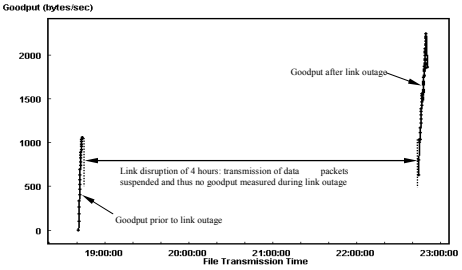
Corresponding Analysis Results at BER=10E-5 using Statistical t-test

Sample Results of Project One





Transmission patterns of TCPCL over cislunar channels with link delay of 3000 ms and link disruption of 4 hours at BER=10E-6 (TSGs and Goodput)



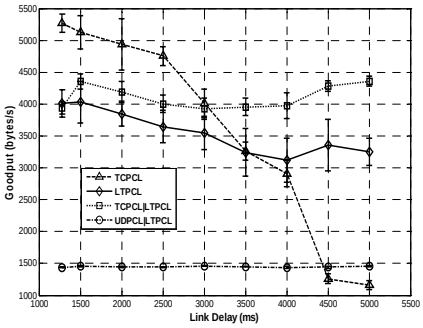
Results of Project Two

- Hybrid DTN protocols in interplanetary Internet
  - Using any single convergence-layer stack under BP may be inefficient over a heterogeneous end-to-end interplanetary communication infrastructure.
  - In this work, a hybrid of DTN CLPs is investigated to run over different hops of a typical three-node, relay-type of interplanetary communication infrastructure for efficient file transmission, i.e. using one CLP for one hop of the end-to-end path and a different CLP for another hop of the path.

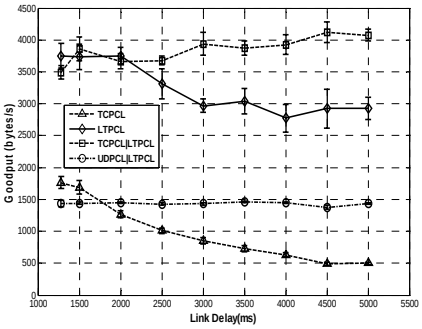
Results of Project Two

- Hybrid DTN protocols in interplanetary Internet
  - The experiment proves that using any single convergence-layer stack under BP on all segments of a heterogeneous end-to-end space path is shown to be invariably less efficient than individually selecting the most appropriate convergence-layer stack for each path segment.
  - A hybrid of TCP-based CLP (i.e., TCPCL) and Licklider transmission protocol CLP (i.e., LTPCL) has significant goodput advantage over all the protocols at long link delays, especially with a high BER.

Sample Results of Project Two



BER=10E-6

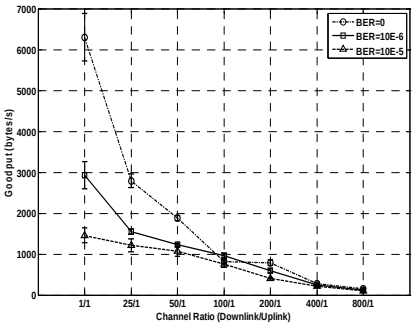


BER=10E-5

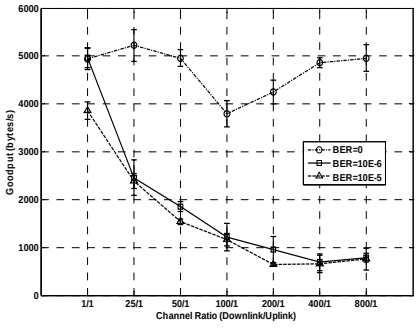
Results of Project Three

- Effectiveness of DTN with asymmetric space channel rates
  - This work focuses on investigation of the effectiveness of the DTN CLP adapters for long-delay interplanetary Internet in the presence of highly asymmetric channel rates and varying data loss rate.
  - One major conclusion is that the hybrid of TCP and LTP convergence layer protocols has significant goodput advantage over other protocol options over all the experimented asymmetric channel ratios (varying between 25/1~800/1) and channel BERs (0~10-5).

Sample Results of Project Three



BP/TCPCL/TCP



Hybrid of LTPCL and TCPCL

Results of Project Four

- Relay Path Selection for Higher Goodput of DTN in Cislunar and Cis-Martian Communication Architecture
  - This work focuses on an experimental study of the DTN architecture and protocol implementation over typical primary and secondary space relay architecture to see which network relay path and DTN protocol configuration brings a higher goodput in cislunar and cismartian communications.

Results of Project Five

- Performance of LTP with variation of window size
  - Throughput performance of LTPCL/UDP is investigated with variation of the number of sessions and nominal block size under various transmission conditions to find a window size for maximum throughput performance.
  - It was found that for the transmissions with various nominal block sizes, a large number of sessions generally give performance advantages.

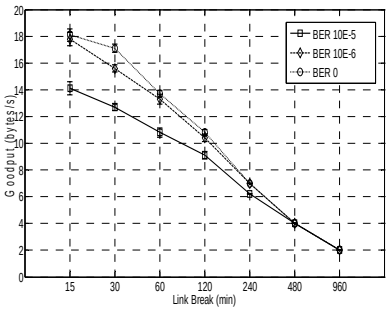
Results of Project Five

- Performance of LTP with variation of window size
  - For the transmissions with a fixed window size (Number of Sessions × Nominal Block Size), the greater the number of sessions and lower the nominal block size, the higher the throughput performance, regardless of the channel BER.

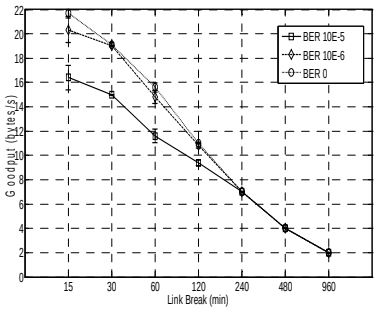
Results of Project Six

(LTP over Cis-Martion Channels with in Presence of Long Disruption)

- Preliminary results on performance of LTP with long disruption over symmetric and asymmetric channel rates of 50/1



Symmetric Channel



Asymmetric Channel

Latest Research Results

- Scott Burleigh at JPL, Caltech, discussed part of these projects at panel of discussion—"The state of DTN evaluation" of *ACM MobiCom Workshop on Challenged Networks* (*CHANTS'2010*), Chicago, IL, USA, September 2010.
- Latest Selected Publications (published or under review)
  - R. Wang, B. Shrestha, X. Wu, T. Wang, A. Ayyagari, E. Tade, S. Horan, and J. Hou, "Unreliable CCSDS File Delivery Protocol (CFDP) over cislunar communication links," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 46, No. 1, January 2010, pp. 147-169.
  - R. Wang, X. Wu, T. Wang, X. Liu, and L. Zhou, "TCP Convergence Layer-based operation of DTN for long-delay cislunar communications," *IEEE Systems Journal*, vol. 4, No. 3, September 2010, pp. 385-395.
  - R. Wang, X. Wu, Q. Zhang, T. Taleb, Z. Zhang, and J. Hou, "Experimental evaluation of TCP-based DTN for cislunar communications in presence of long link disruption," special issue on opportunistic and delay tolerant networks of *EURASIP Journal on Wireless Communications and Networking*, November 2010.

Selected Latest Research Results

- Latest Selected Publications (continued)
  - R. Wang, X. Wu, L. Zhou, and J. Hou, "TCP convergence layer (TCPCL)-based DTN over Cislunar Channels in Presence of long link disruption," In *Proc. of IEEE GLOBECOM 2010*, Nov.-Dec., 2010.
  - R. Wang, P. Parikh, R. Bhavanthula, J. Hou, L. Zhou, and T. Taleb, "Licklider Transmission Protocol (LTP)-based DTN for long-delay cislunar communications," In *Proc. of IEEE GLOBECOM 2010*, Nov.-Dec., 2010.
  - R. Wang, S. Burleigh, P. Parik, C-J Lin, and B. Sun, "Licklider Transmission Protocol (LTP)-based DTN for cislunar communications," *IEEE/ACM Transactions on Networking*, vol. 19, No. 1, February 2011 (to appear).
  - R. Wang, S. Burleigh, B. Modi, Q. Zhang, L. Zhou, and A. Vasilakos, "Hybrid Delay-Tolerant Networking (DTN) Protocols for Interplanetary Internet," *IEEE/ACM Transactions on Networking* (under review).
  - R. Wang, H. Jain, Q. Zhang, and L. Zhou, "Relay Path Selection for Higher Goodput of DTN in Cislunar Communication Architecture," *IEEE Transactions on Aerospace and Electronic Systems* (under review).

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- Hans Kruse and his group, Ohio University

Thank you!

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