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CSCI 5273
Final Project - Checkpoint #1

Delay-Tolerant Networking for the Interplanetary Internet

16th April 2020

OVERVIEW

I intend to do some research in the area of space-based networking (specifically interplanetary) and the challenges of crafting efficient and robust protocols for store and forward relays in the presence of high latencies and disjoint links. Deep space communication poses several unique challenges for network design, including, but not limited to:

1. Extremely long and variable propagation delays
2. High link error rates for radio-frequency (RF) communication channels
3. Intermittent link connectivity (i.e. blackouts)
4. Asymmetrical forward and reverse link capacities
5. Lack of fixed communication infrastructure

   [1, 2]

My research will revolve around the design and implementation of Delay-Tolerant Networking [1] in the quest for realizing the Interplanetary Internet [2]. In particular, I will focus on the transport layer and the necessary improvements and modifications to existing reliable transport protocols like TCP and techniques like ARQ for efficient operations in deep space. There exist some publications and proposals for solutions to some of the problems faced in this environment, such as TP-Planet [3], as well as techniques for end-to-end acknowledgements and custody-transfer from the DTN architecture [4]. There are also existing models that leverage TCP with some modifications and extensions to meet the needs of deep space systems. One such standard is the Space Communications Protocol Standards-Transport Protocol (SCPS-TP) [5, 6] a set of TCP extensions for space communications developed by the Consultative Committee for Space Data Systems (CCSDS). A more recent variation for file transfer is the CCSDS File Delivery Protocol (CFDP). Some aspects of this protocol have been shown to be independently valuable and potentially modularizable for use in other transport layer protocols, as is suggested with “CFDP-RP” in [1].

GOALS

1. Gain a firm understanding of the challenges to networking across interplanetary distances.
2. Identify the shortcomings of standard Internet protocols in addressing these challenges and operating amidst these constraints.
3. Survey the current research, implementations, and standards that seek to overcome these challenges.
4. Simulate an interplanetary network using Google Cloud Platform to observe the various behaviors of networks in the presence of these obstacles.
5. Identify an area needing improvement and make a research contribution in that area.

STATUS

I have begun researching the field of space-based networking and am starting to stitch together the history of the research and contributions others have made to date. I am starting to see trends across some of these papers and am trying to identify which of those threads to pull on further. To that end, I am still in the early stages of my survey and have yet to decide where exactly I want to focus my efforts. I do believe it will be roughly focused in the transport layer, perhaps in reliable transport protocol implementations, such as TP-Planet. My next step is to do a thorough re-reading of all my current sources, and then expand out from each of those by looking at the references they each cite. I will probably start a spreadsheet of sorts to track the trends and problem spaces across each paper to help me select my focus.

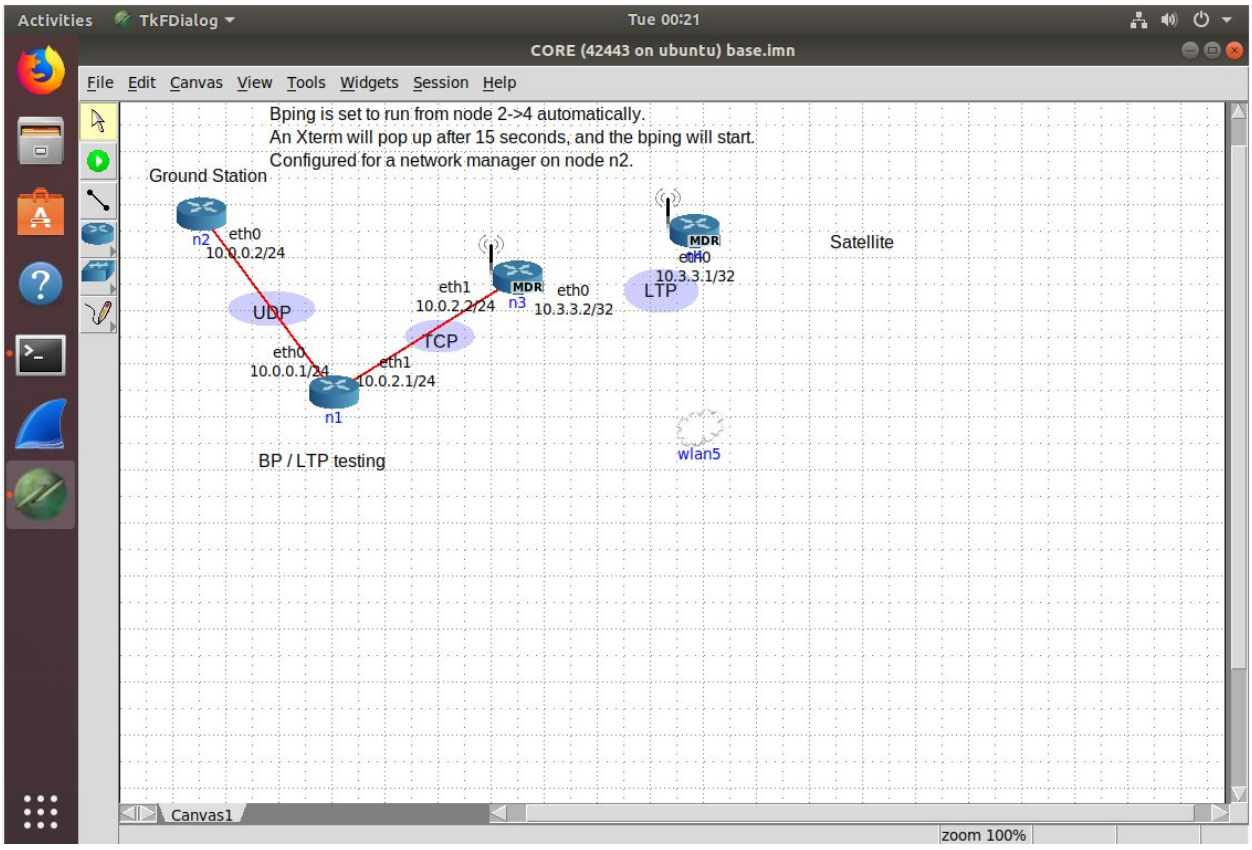
Checkpoint #1

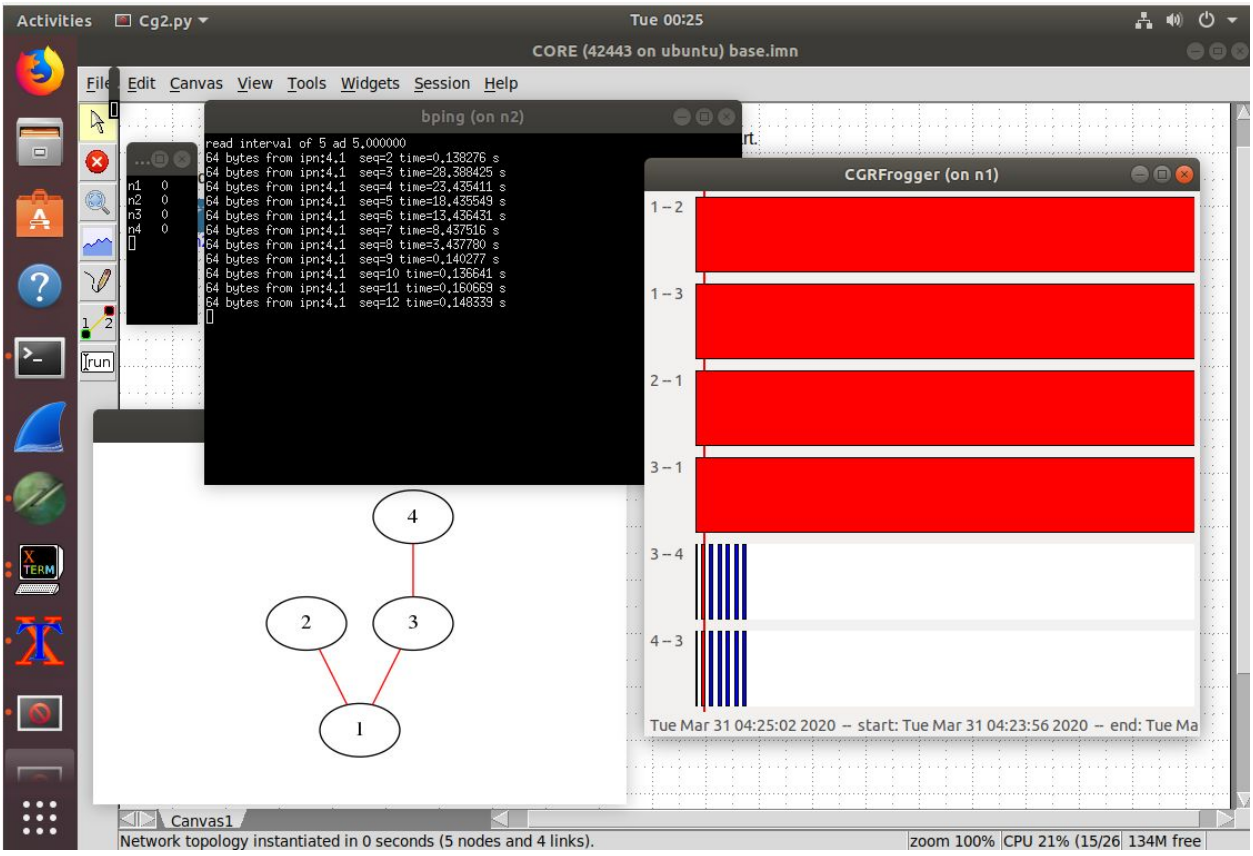
CHANGES

Since submitting the proposal, I have narrowed in on the exact area of research I will be working on in this space. I am investigating the data retransmission procedures outlined by the CCSDS File Delivery Protocol (CFDP) for reliable file delivery. I am working to isolate the retransmission protocol in CFDP, “CFDP-RP” for short, as outlined in CCSDS 727.0-B-4 Blue Book section 4.1.6.4 [8] and evaluate the performance of various heuristics across a high-loss link with varied propagation delays. I am doing my investigation of CFDP running within a Delay/Disruption Tolerant Networking implementation.

PROGRESS

- Continued reading of CCSDS standards [8, 9, 10]
- Continued reading of Delay Tolerant Networking challenges and architecture [4, 11]
- Investigation into publicly available implementations of Delay Tolerant Networking and CFDP. The software library for the latter appears only to be available to federal employees and contractors working on NASA missions. The former has an open-source implementation provided by NASA, called Interplanetary Overlay Network (ION). As part of this project, NASA also provides a “DTN Development Kit” packaged as an Ubuntu virtual machine. This VM is meant to help in experimenting with and understanding the ION implementation of DTN. I have spent some time getting this VM spun up and playing around with some of the pre-built network topologies. The screenshots below are from one of those topologies, where a simulation is run across four nodes, one of which (n4) is a satellite progressing through its orbit. At its furthest point, node 4 loses connection with the rest of the network and node 3 maintains custody of queued up bundles until node 4 regains connection. The ping response times can be seen varying from sub-second to ~28sec as a result.


Activities
TkFDialog
Tue 00:21
CORE (42443 on ubuntu) base.imn
File Edit Canvas View Tools Widgets Session Help
Bping is set to run from node 2->4 automatically.
An Xterm will pop up after 15 seconds, and the bping will start.
Configured for a network manager on node n2.
Ground Station
n2
eth0
10.0.0.2/24
UDP
eth0
10.0.0.1/24
n1
eth1
10.0.2.1/24
TCP
eth1
10.0.2.2/24
MDR
n3
eth0
10.3.3.2/32
MDR
eth0
10.3.3.1/32
LTP
Satellite
wlan5
BP / LTP testing
Canvas1
zoom 100%


Activities
Cg2.py
Tue 00:25
CORE (42443 on ubuntu) base.imn
File Edit Canvas View Tools Widgets Session Help
bping (on n2)
read interval of 5 ad 5.000000
64 bytes from ipn:4.1 seq=2 time=0.138276 s
64 bytes from ipn:4.1 seq=3 time=28.388425 s
64 bytes from ipn:4.1 seq=4 time=23.435411 s
64 bytes from ipn:4.1 seq=5 time=18.435549 s
64 bytes from ipn:4.1 seq=6 time=13.436431 s
64 bytes from ipn:4.1 seq=7 time=8.437516 s
64 bytes from ipn:4.1 seq=8 time=3.437780 s
64 bytes from ipn:4.1 seq=9 time=0.140277 s
64 bytes from ipn:4.1 seq=10 time=0.136641 s
64 bytes from ipn:4.1 seq=11 time=0.160669 s
64 bytes from ipn:4.1 seq=12 time=0.148339 s
n1 0
n2 0
n3 0
n4 0
CGRFrogger (on n1)
1 – 2
1 – 3
2 – 1
3 – 1
3 – 4
4 – 3
Tue Mar 31 04:25:02 2020 -- start: Tue Mar 31 04:23:56 2020 -- end: Tue Ma
4
2
3
1
Canvas1
Network topology instantiated in 0 seconds (5 nodes and 4 links).
zoom 100%
CPU 21% (15/26
134M free

TIMELINE

Completion Date	Item	Description
02.18.2020	Brainstorming	Initial brainstorming around potential project interests
03.03.2020	Project Proposal	Submission of project proposal
~~03.20.2020~~ 03.27.2020	Contribution Selection	While my proposal has the general space I want to research, I still need to narrow that down into an attainable area to contribute to.
03.31.2020	Checkpoint #1	Submission of checkpoint #1
04.07.2020	ION DevKit Experiments	Continue experimenting with the ION DevKit pre-built scenarios to solidify my understanding of Delay Tolerant Networking.
04.14.2020	ION DevKit Customization	Implement a custom network topology to simulate a high-loss link and observe the reliable retransmission behaviors of DTN's bundling/custody model.
04.16.2020	Checkpoint #2	Submission of checkpoint #2
04.21.2020	Retransmission Experiments	Begin to experiment with the various retransmission schemes outlined by CFDP and gather performance metrics.
04.28.2020	Custom Retransmission Scheme and Final Eval	Implement a custom retransmission scheme (stretch goal) and perform final evaluations of all schemes across varied network topologies and scenarios.
04.30.2020	Final Report	Submission of final report

EVALUATION

For evaluation of retransmission schemes, I will be looking at total throughput, average/max/tail latency, total data retransmitted, and overhead of retransmission protocol messages. These metrics will be captured across several different network topologies with varied simulations to introduce delay and disruption into the network. I will perform all of this evaluation using NASA's Interplanetary Overlay Network implementation on the DTN Development Kit VM.

In a more general sense, my biggest hope and my own personal "evaluation" will be to walk away with a firm understanding of the concepts of Delay Tolerant Networking and how these technologies come together to overcome the many challenging use cases of interplanetary communication. In addition, I hope to realize where there are still shortcomings to these protocols and implementations and highlight those as areas for further independent study.

Checkpoint #2

CHANGES

No major changes to my research goals. Only addition was from feedback from Jose suggesting I look into additional variables to control during my simulation and applications to connect to the nodes for varied traffic patterns. I have added two line items (in blue) to my timeline to capture that work.

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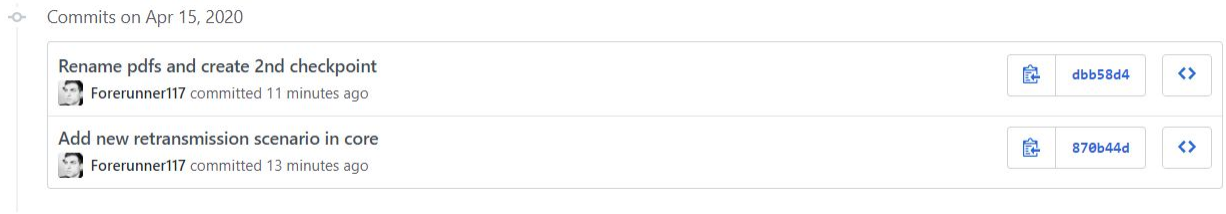
04.16.2020	Checkpoint #2	Submission of checkpoint #2
04.21.2020	Retransmission Experiments	Begin to experiment with the various retransmission schemes outlined by CFDP and gather performance metrics.
04.24.2020	Introduce Perturbations	Determine ways to introduce perturbations to the simulations, such as lossy links.

04.26.2020	Various Applications	Experiment with various applications in the simulation, such as basic ping, file transfer, and image transfer.
04.28.2020	Custom Retransmission Scheme and Final Eval	Implement a custom retransmission scheme (stretch goal) and perform final evaluations of all schemes across varied network topologies and scenarios.
04.30.2020	Final Report	Submission of final report

PROGRESS

The main addition to date has been a new custom scenario in the DTN dev kit. The associated config files for that scenario were pushed as part of the “Add new retransmission scenario in core” commit. These changes build off of pre-existing scenarios and add modifications to the simulation and configurations of nodes in the environment.



COSTS

I do not expect to have any costs for this project since everything I am leveraging is open sources and virtualized on my own machine.

EVALUATION

Ultimately, my goal is to create a scenario with at least 3 nodes. One terrestrial ground station, one relay orbiter around Mars, and one rover on the Martian surface. The simulation will need to mimic the orbits and occultations of such a scenario. I may also include a 4th node acting as a terrestrial end-user connected over a wired link to the ground station. The dev kit provides three separate applications that I intend to try running through my simulation. I have so far tested basic ping messages (in DTN, these are sent as simple bundles with an echoed bundle from the

receiver). I intend to leverage wireshark during simulation runs to evaluate the ratio of retransmission traffic to content traffic.

CHALLENGES

I am struggling a bit to ramp up on all the features and functionality of the dev kit. There's a lot to it and the documentation is pretty light and scattered. Since there are several prebuilt examples, I am able to learn by trial and error of how things should be pieced together, but it's definitely just taking more time than I had hoped.

References:

[1] Burleigh, Scott, et al. "Delay-tolerant networking: an approach to interplanetary internet." *IEEE Communications Magazine* 41.6 (2003): 128-136.

[2] Akyildiz, Ian F., et al. "InterPlaNetary Internet: state-of-the-art and research challenges." *Computer Networks* 43.2 (2003): 75-112.

[3] Akan, Ozgur B., Jian Fang, and Ian F. Akyildiz. "TP-Planet: A reliable transport protocol for interplanetary internet." *IEEE Journal on Selected Areas in Communications* 22.2 (2004): 348-361.

[4] Cerf, Vinton, et al. "Delay-tolerant networking architecture." (2007).

[5] Durst, R., P. Feighery, and E. Travis. "Users manual for the SCPS Transport Protocol." *WN 97W0000018, McLean, Virginia* (1997).

[6] Lawas-Grodek, Frances J., et al. "SCPS-TP, TCP and rate-based protocol evaluation for high delay, error prone links." *SpaceOps 2002 Conference*. 2002.

[7] McMahon, Alex, and Stephen Farrell. "Delay-and disruption-tolerant networking." *IEEE Internet Computing* 13.6 (2009): 82-87.

[8] CCSDS. “CCSDS File Delivery Protocol (CFDP).” *Recommended Standard - 727.0-B-4*, Blue Book - Jan. 2007. public.ccsds.org/Pubs/727x0b4.pdf.

[9] CCSDS. “CCSDS File Delivery Protocol (CFDP) - Part 1: Introduction and Overview.” *Informational Report - 720.1-G-3*, Green Book - Apr. 2007. https://public.ccsds.org/Pubs/720x1g3.pdf.

[10] CCSDS. “CCSDS File Delivery Protocol (CFDP) - Part 2: Implementers Guide.” *Informational Report - 720.2-G-3*, Green Book - Apr. 2007. https://public.ccsds.org/Pubs/720x2g3ec1.pdf.

[11] Alhilal, Ahmad, Tristan Braud, and Pan Hui. "The Sky is NOT the Limit Anymore: Future Architecture of the Interplanetary Internet." *IEEE Aerospace and Electronic Systems Magazine* 34.8 (2019): 22-32.