Virtual Research Presentation Conference

Development of a Cognitive Delay Tolerant Network Node

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Tutorial Introduction

Abstract

Delay Tolerant Network (DTN) is a set of networking protocols design to operate in networks where (a) links experience long delays or sporadic disconnections, and (b) there is exist a mismatch between a node's input and output data rate. As opposed to the Internet, where end-to-end transactions are typically established, DTN's uses bundles of data (akin to packets) to shepherd information through a set of hop-to-hop transactions. Additionally, persistent storage is provisioned on each hop, safeguarding bundles when the next hop is not available or operates at a reduced rate.

In this SURP, we are developing a Cognitive Delay Tolerant Network Node (CDTN) to autonomously manage an orbiter's memory buffers, as well as the data rates of its proximity and direct-to-Earth (DTE) radios. This CDTN is composed of two parts: a monitor, which continually polls the state of the memory buffers and radios; and a controller, which uses the information provided by the monitor to make autonomous decisions on which links to modify and which bundles to reject. Internally, this controller uses Reinforcement Learning (RL) to train a neural network over a discrete state space. As for the reward function, it generally tries to minimizes excess capacity in the network links. However, when the orbiter buffers near exhaustion, we instruct the RL agent to rapidly increase the data rates to avoid memory overflows.

To prototype the system, we are currently developing and testing the RL system in a simulated environment, using a lunar scenario in which Gateway plays the role of the orbiter and several human and robotic missions are on the lunar surface. In parallel, we are developing network management capabilities in the Interplanetary Overlay Network (ION), JPL's flight-software implementation of the DTN protocol stack. This will allow us to test the system in an emulated scenario using real data transfer across a network of nodes.

Problem Description

a) Context
- Several upcoming missions are planning to use DTN for routine operations (e.g., KPLO, PACE, Lunar IceCube).
- The lunar Gateway and the Human Landing System (HLS) are also expected to use DTN.
- DTN allows reliable data transfer over a network of non-persistent asymmetric links. To do so, it provisions a finite amount of persistent storage in each spacecraft that must be managed to prevent buffer overflowing and data loss.

b) State-of-the-art
- DTN's core protocols enabling reliable data transmission (e.g., Bundle Protocol) are standardized and well-tested.
- The Asynchronous Management Protocol (AMP) provides an extensible standardized "language" to manage DTN nodes. Therefore, we leverage AMP to implement the monitor and control functionality required by our CDTN.

c) Relevance to NASA and JPL
- DTN is a key enabling technology for novel autonomous spacecraft, and constellation/swarms of smallsats. While this research focuses on buffer management specifically, tools and lessons learned will extend to other aspect of DTN management (e.g., routing, adaptive data contact plans, etc.).
- While this work focuses on lunar scenarios, similar techniques could be used on the Mars Relay Network. Challenges inherent to maintaining state information with longer propagation delays would have to be addressed.

Methodology

a) RL agent definition:

- State Space: Node's memory utilization; data rate of all links transmitting bundles to the Gateway; data rate of the downlink with the DSN.
- Action Space: (1) Drop all incoming packets; (2,3) increase/decrease proximity (PRX) link data rate; (4,5) increase/decrease DTE link data rate and (6) do nothing.
- Reward Function:

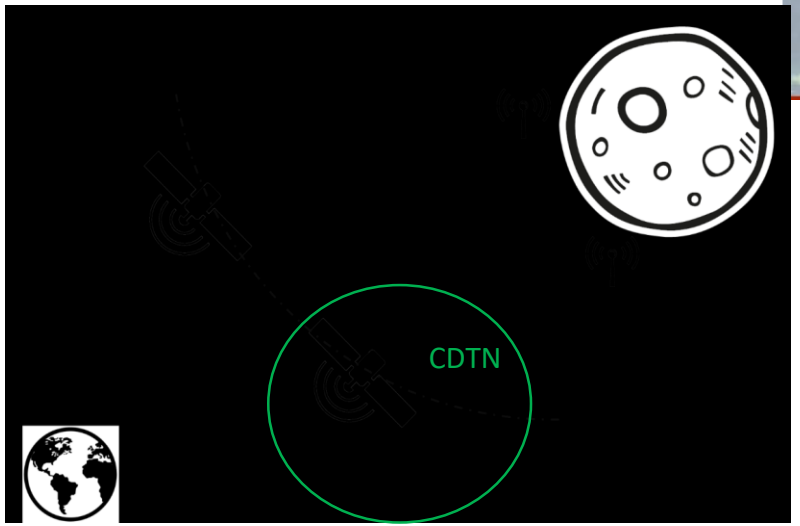
Memory state of Gateway and lunar surface nodes

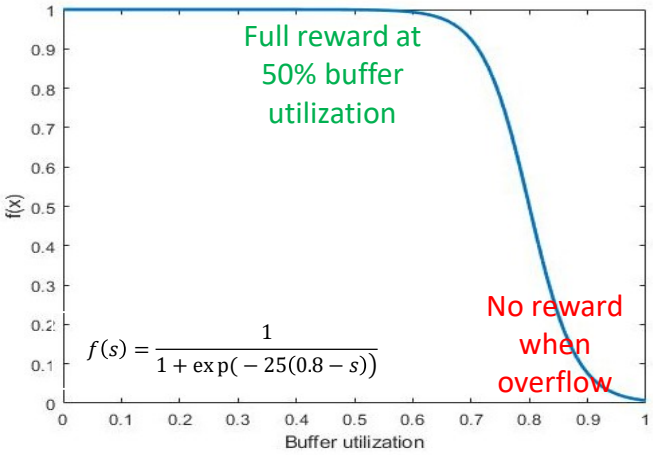
Level of over-capacity provisioned in the network

$$R(s,a) = f(s) \cdot f(\max_{i=1,\dots,N} s_i) \cdot \frac{bits\ arrive\ to\ DSN}{Capacity\ allocated\ to\ DTE\ and\ PRX\ link}$$

b) Innovation

- First attempt to use Artificial Intelligence, namely Reinforcement Learning, to develop autonomous cognitive DTN nodes.
- Development of network management capabilities in ION that can be reused in ground systems like the DSN, or the MOC.





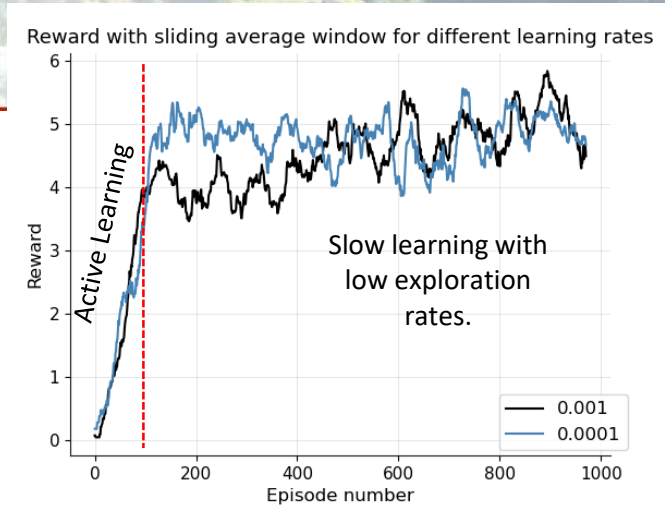
Results

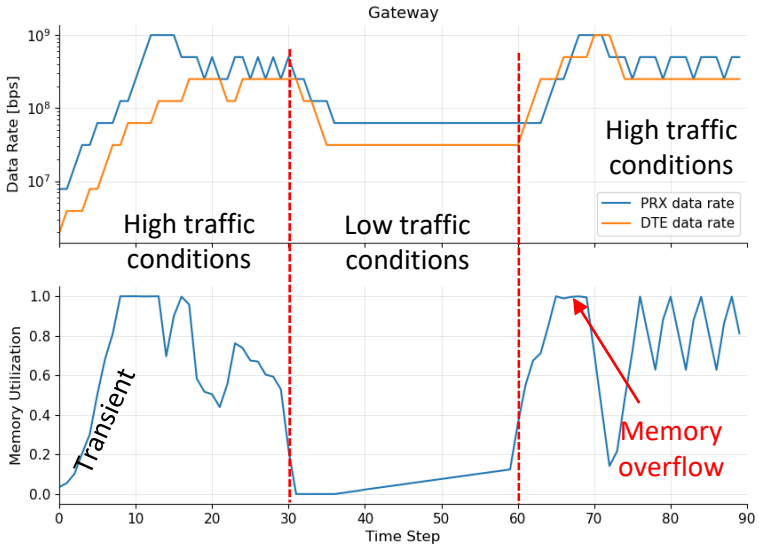
a) We demonstrated that we can train an RL agent to manage the Gateway buffers even in the presence of large transients triggered by changes in traffic conditions.
   - However, we need to do fine parameter tuning of the reword function and RL episode duration to ensure robustness to transients.

b) Our problem formulation has been shown to outperform a rule-based system based on heuristic actions.
   - However, we are also considering how it would perform against an agent build using control-theory (e.g., PID controller).

c) Our system requires the orbiter to aggregate information on the state of all nodes in the network except for the DSN (so propagation delay is not an issue).
   - However, a protocol to disseminate control information using DTN bundles needs to be developed.

d) We have demonstrated the ability to query the memory state of ION and the data rate commanded by the contact plan.
   - However, a full interface between the RL agent and AMP is still under development.





Publications and References

[1] Garcia Buzzi, P., Selva, D., and Sanchez-Net, M., “Autonomous Delay Tolerant Network Management Using Reinforcement Learning,” 2020 AIAA ASCEND, AIAA, 2020

[2] *Cerf, V. “RFC4838: Delay-Tolerant Networking Architecture”. IRTF DTN Research Group (2007)*

[3] *Birrane, E. “Asynchronous Management Protocol." IRTF DTN Research Group (2018).*