Enhancing Contact Graph Routing for Delay Tolerant Space Networking

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Presented at

IEEE GLOBECOM Conference

Houston, Texas

8 December 2011

Overview

JPL

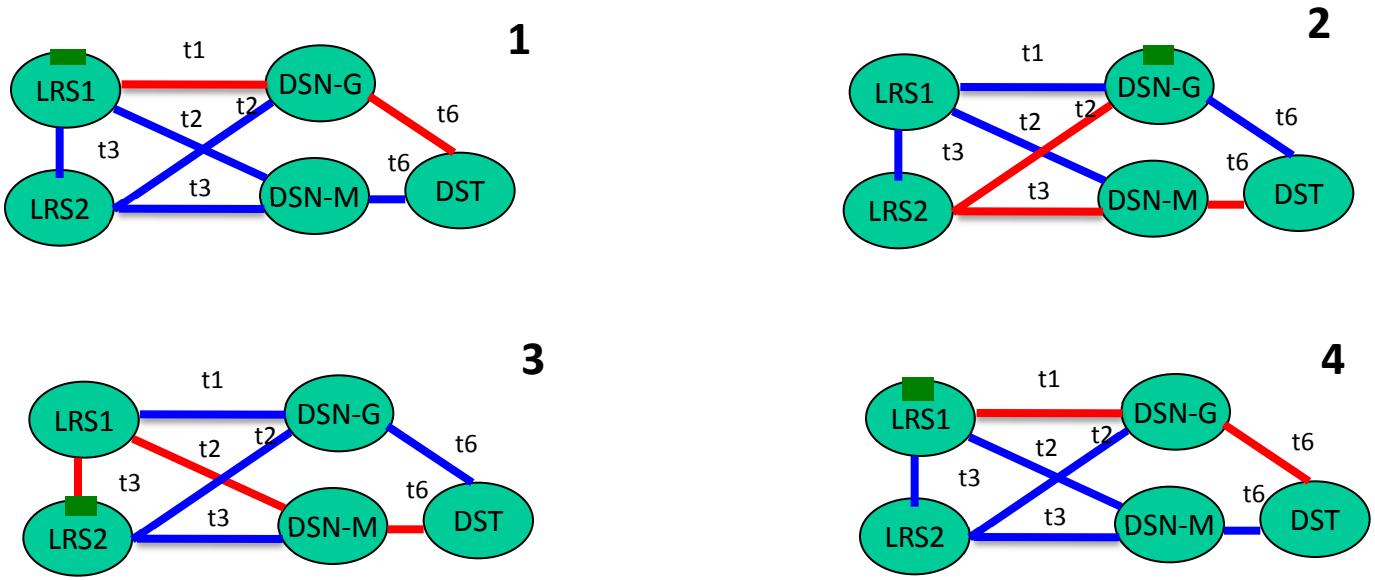
- DTN
- CGR
- Observations / Solutions
  - Routing Loop
  - Latency
  - Computational Requirements

DTN and CGR

- Delay/Disruption Tolerant Networking
  - www.dtnrg.org
  - Operates on ISS payloads
  - Tested on JPL deep space craft
- Interplanetary Overlay Network (ION)
  - NASA implementation of DTN (+ Network software)
- Contact Graph Routing
  - Future contacts for route selection
  - Earliest-Forfeit-Time vs. Earliest-Arrival-Time
  - Tested on JPL deep space craft

Observation: Routing Loop

Identified cause of routing-loop failure in current DTN Routing Algorithm



Bundle Sent from LRS1->DST

1) LRS1 Finds route through DSN-G
2) DSN-G finds route with earlier forfeit time through LRS2
3) LRS2 finds route with earlier forfeit time through LRS1. GOTO 1…

Note: link names specify contact forfeit time

Loop Cause/Solution

Identified Solution for DTN Routing-Loop Failure

- Published research [1] identifies monotonicity and isotonicity as sufficient criteria for convergence of path vector protocols such as CGR
  - Isotonicity: relationship between the weights of any two paths with the same origin is preserved when both are extended with the same edge
  - Monotonicity: weight of a path does not decrease for path extension
- Current CGR draft weighs path by earliest-forfeit-time
  - Relationships between paths are preserved when extended with the same edge
  - As the path is extended (contacts added) earliest-forfeit-time may decrease
- Identified non-monotonicity of path extension as cause of observed routing loop during CGR simulations
  - Same situation occurs in certain BGP policies resulting in route oscillation [2]
- **Solution: change to earliest-arrival-time path selection**
  - Delay is a strictly monotonic cost for path extension
  - Previous slide's loop resolved

[1] Sobrinho, J. L. 2003. Network routing with path vector protocols: theory and applications. In Proceedings of the 2003 Conference on Applications, Technologies, Architectures, and Protocols For Computer Communications (Karlsruhe, Germany, August 25 - 29, 2003). SIGCOMM '03. ACM, New York, NY, 49-60.

[2] Kannan Varadhan, Ramesh Godvindan, Deborah Estrin, "Persistent route oscillation in inter-domain routing", Computer Networks 32 (2000) 1—16.

Simulations

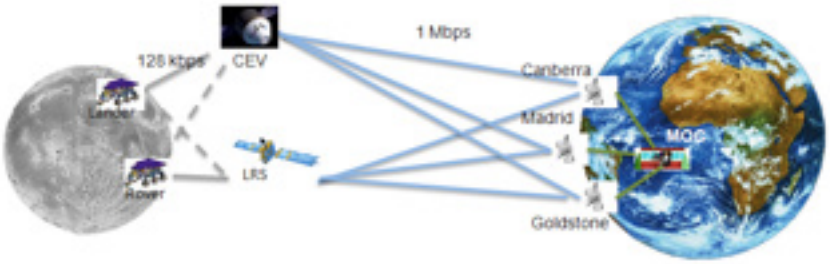


Figure 1 - Lunar Simulated Topology

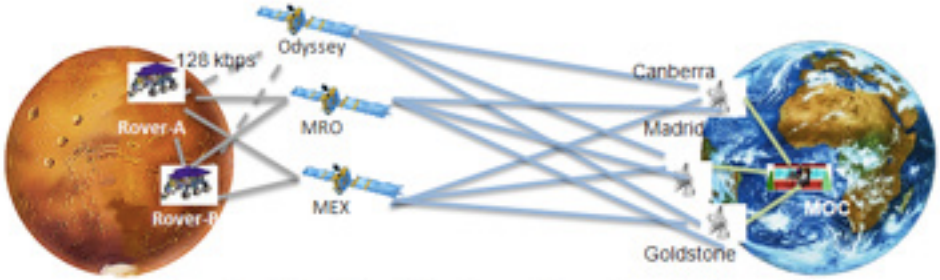


Figure 2 - Martian Simulated Topology (Historic)

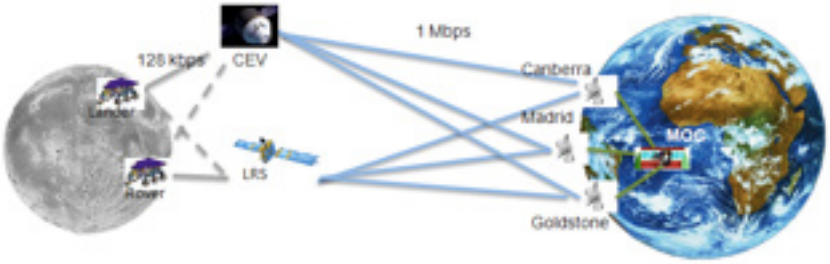


Figure 1 - Lunar Simulated Topology

Figure 3 - Martian Simulated Topology (2018)

- Simulated 4 Solar System Scenarios
  - Lunar, Lunar Polar, Martian Historic, Martian Future

Latency and Computational Improvements

Developed MACHETE model of earliest-arrival-time Dijkstra CGR

- Earliest-Arrival-Time weight function allows use of Dijkstra traversal algorithm
  - Known upper-bound *approx*= O(#contacts + #nodes)
    - Significant computational improvement
- Developed MACHETE simulation model of CGR using earliest-arrival-time Dijkstra
  - Compared earliest-forfeit-time and earliest-arrival-time CGR data performance
    - Analyzed latency, buffer and computational performance for representative Martian and Lunar scenarios
  - Useful for investigating more advanced path weighting functions that offer potential for better network performance

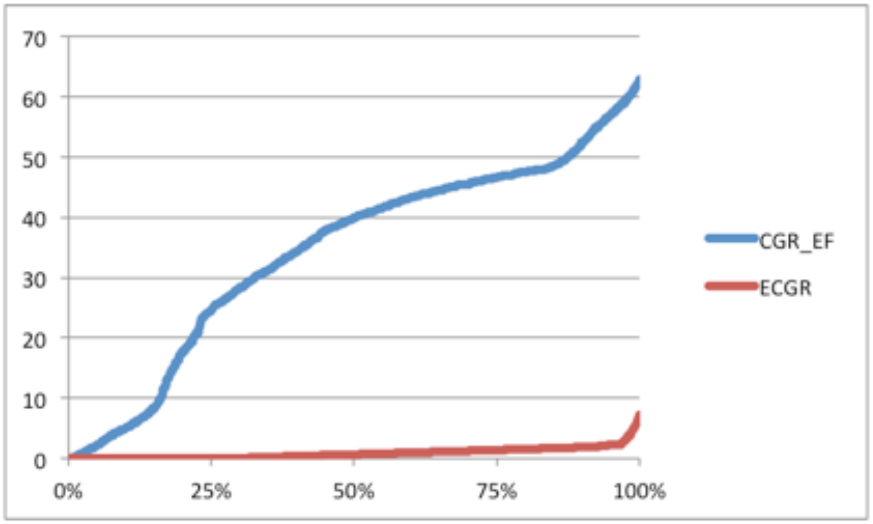
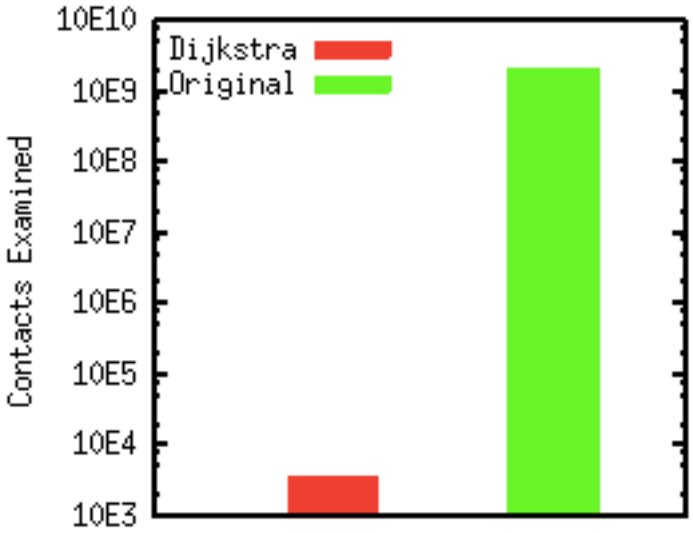


Figure 7 - Cumulative Latency (hours) for Scenario 1

Delay for Lunar Scenario



Computational Improvement

Network Load

- ECGR decreased network load and increased delivery ratio (given finite horizon)

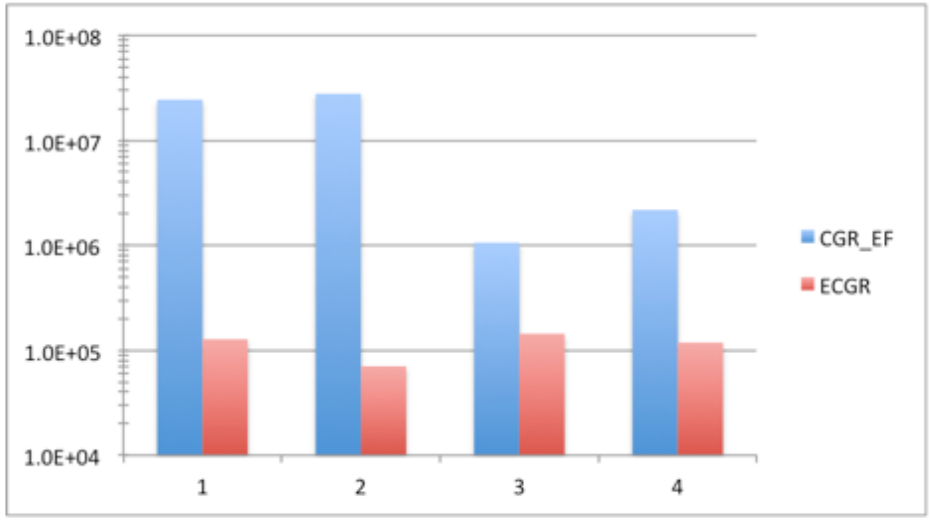


Figure 5 - Total Frames Transmitted (per scenario)

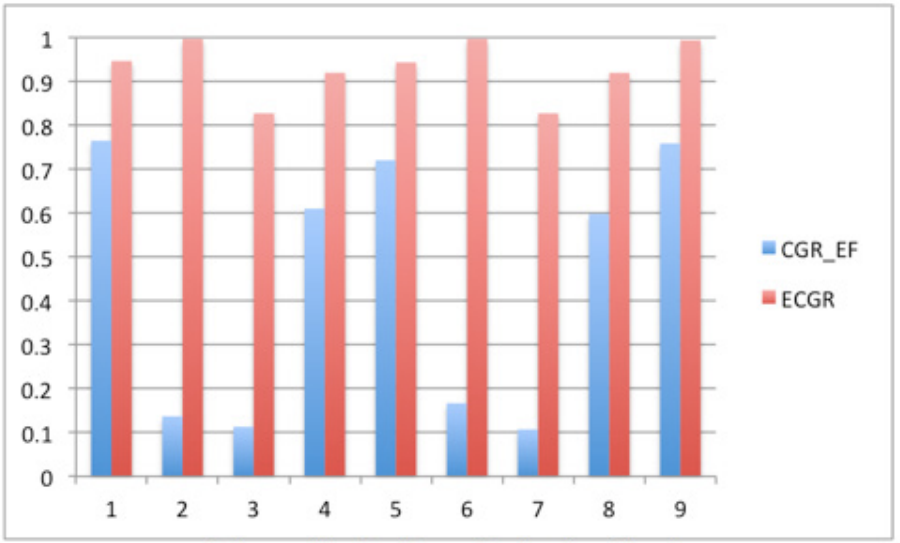


Figure 10 - Delivery Ratio (per flow)

Summary

- Enhanced CGR by moving to earliest-arrival-time cost and temporal Dijkstra algorithm
- Simulations showed ECGR improved network load, data latency and delivery ratio
- Code being pushed to ION Open Source
  - http://ion-dtn.sourceforge.net/

Questions?

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