POST-DISASTER DATA EVACUATION FROM ISOLATED DATA CENTERS THROUGH LEO SATELLITE NETWORKS

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Overview: Satellite Numbers

i. Operating Satellites by Country

USA	Russia	China	Other	Total
549	131	142	483	1305

ii. American Satellites by Owner/Operator

Civil	Commercial	Government	Military
21	250	126	152

iii. Satellites by Type of Orbit

LEO (160-2000 km)	MEO (2000-35000 km)	HEO (Highly Elliptical)	GEO (35786 km)
696	87	41	481

Union of Concerned Scientists (2015)

Satellites and Aerial Platforms in the Media

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SPACEX LANDS $1 BILLION FROM GOOGLE AND FIDELITY

Airbus and OneWeb form joint venture to build 900 satellites

by **Peter B. de Selding** — January 27, 2016

SpaceX To Build 4,000 Broadband Satellites in Seattle

by **Peter B. de Selding** — January 19, 2015

Google's Project SkyBender aims to beam 5G internet from solar-powered drones

By Nick Statt on January 29, 2016 07:18 pm Email @nickstatt

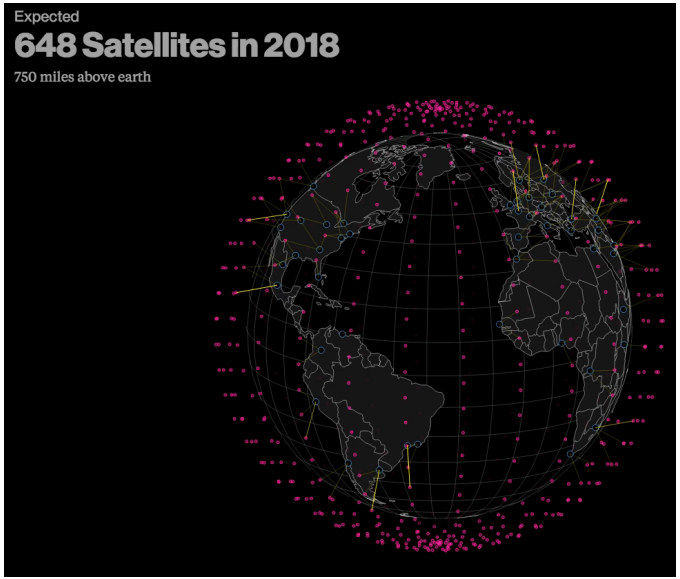
Inside Project Loon: Google's internet in the sky is almost open for business

By Ben Popper on March 2, 2015 11:34 am

Facebook's solar-powered internet plane looks like a stealth bomber

Meet the flying ISP

By Ariha Setalvad on July 30, 2015 03:10 pm Email @ArihaSetalvad



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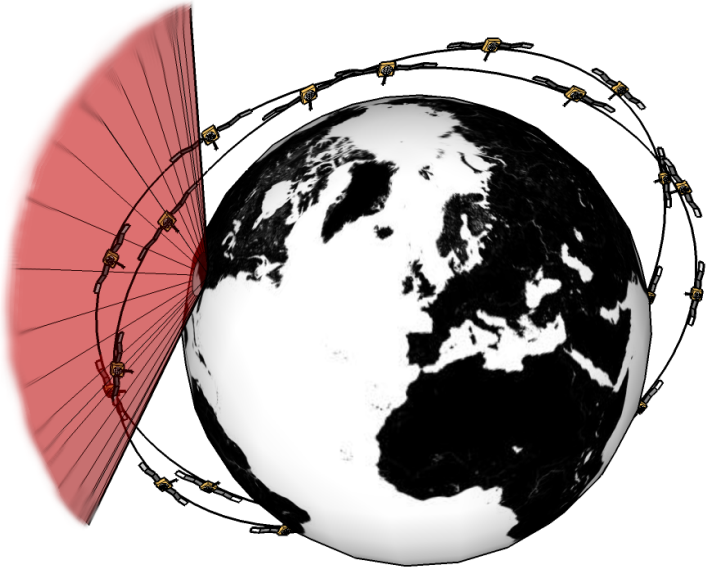
HEMP's Impact on Satellites



Problem Statement

Given

- Terrestrial network topology: post-disaster nodes and links, including geolocation of Ground Stations;
- Node and Link information: node buffering and switching capacity, and link data rates and delays;
- Satellite network topology: remaining LEO satellites and respective Inter-Satellite Links, including orbit descriptors.

Output

A note-to-node time schedule listing all transmissions and respective data quantities to be sent at each instant.

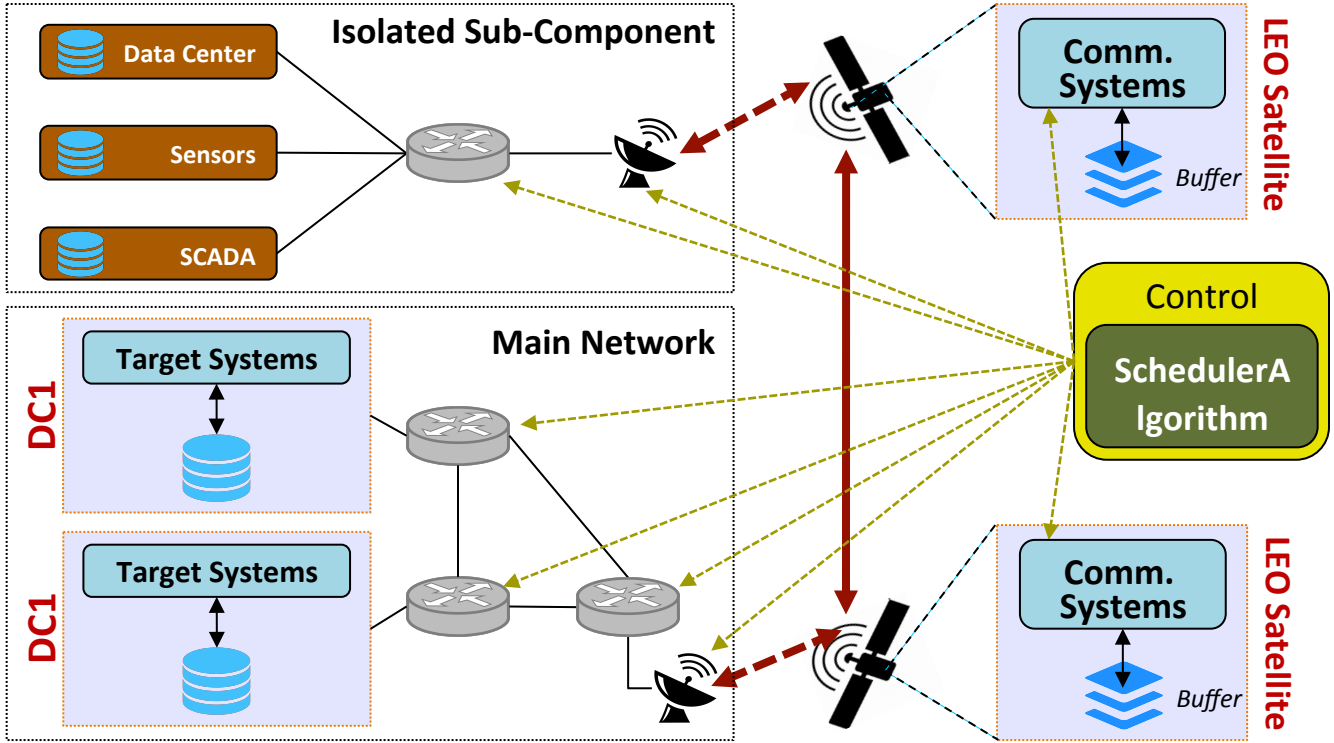
Goal

An evacuation plan that maximizes the data evacuated from from isolated components in a given time period.

Constraints

Link data rates, contact durations, and buffer sizes.

Proposed Architecture



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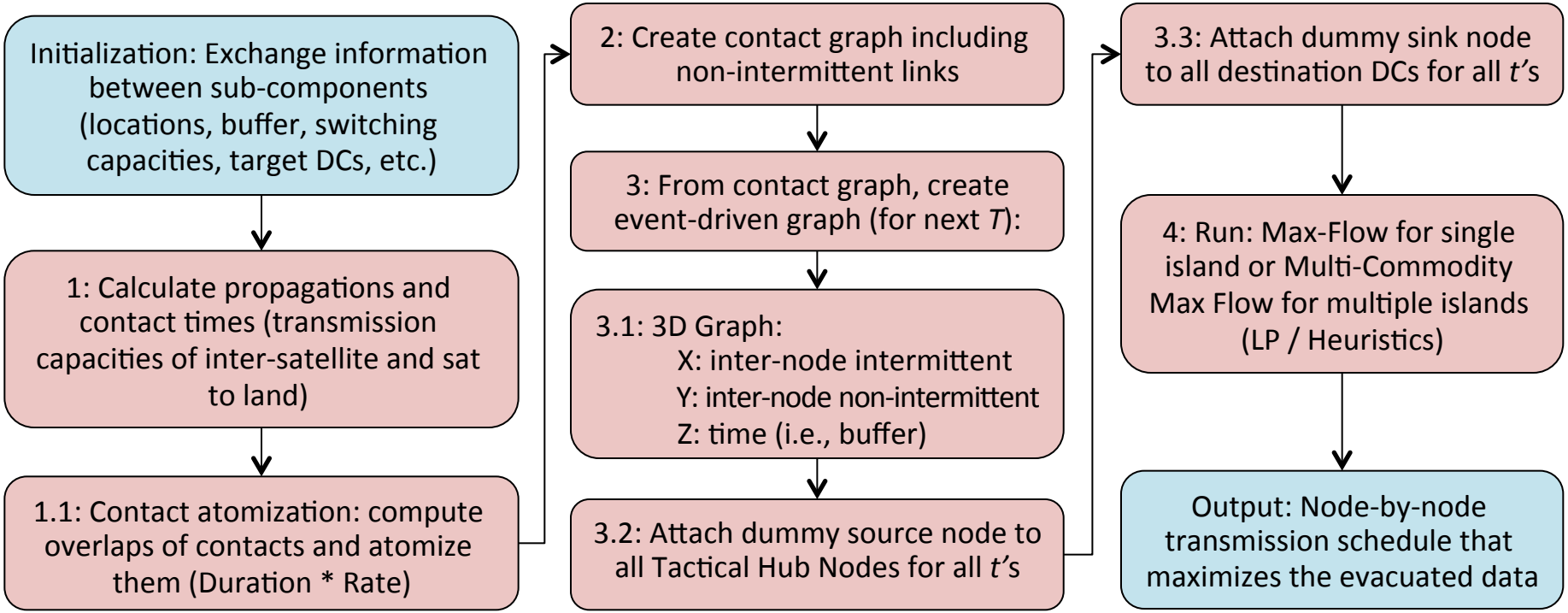
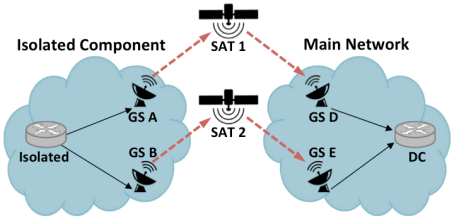
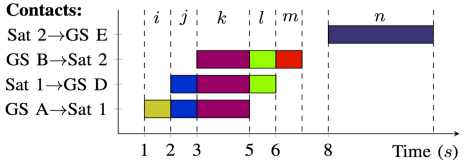
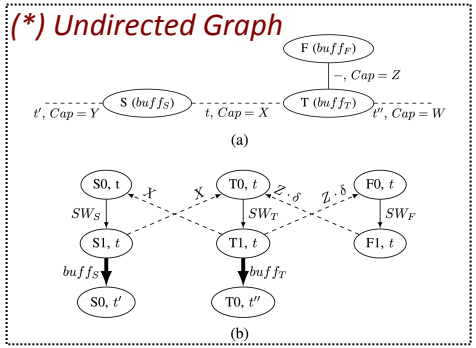
Proposed Solution

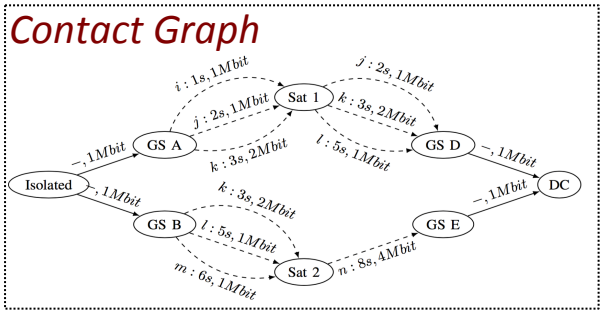


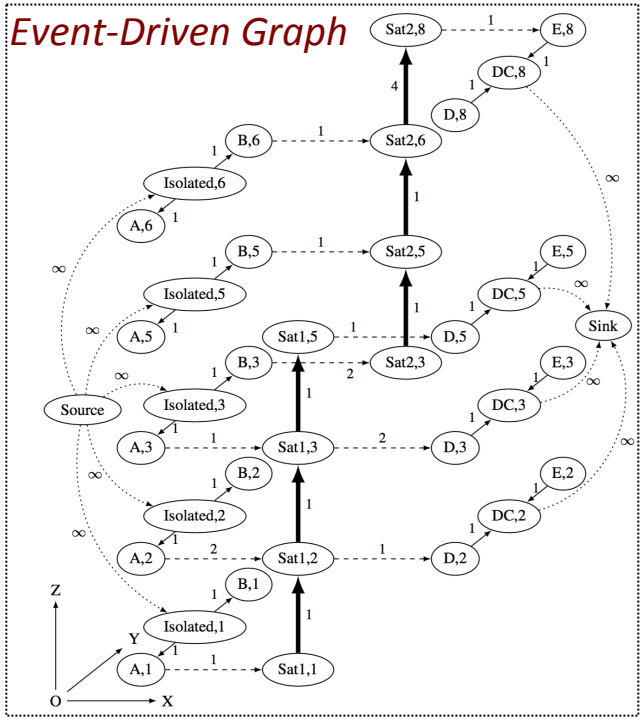
Graph Creation











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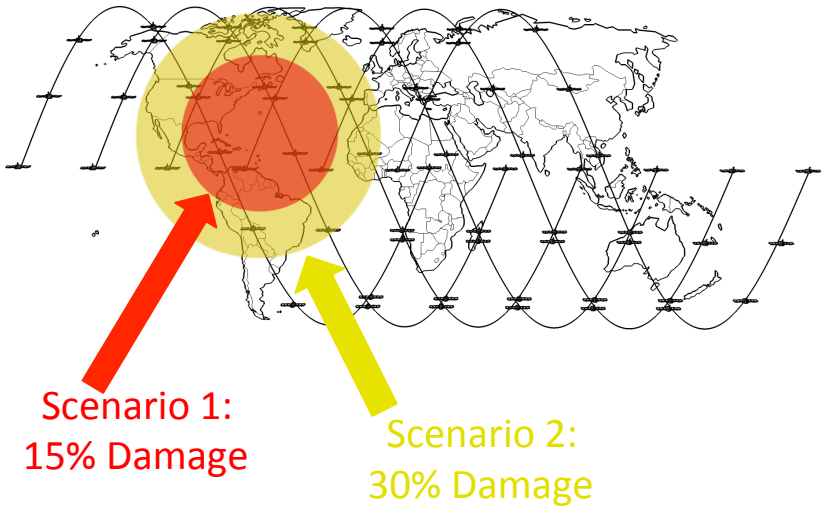
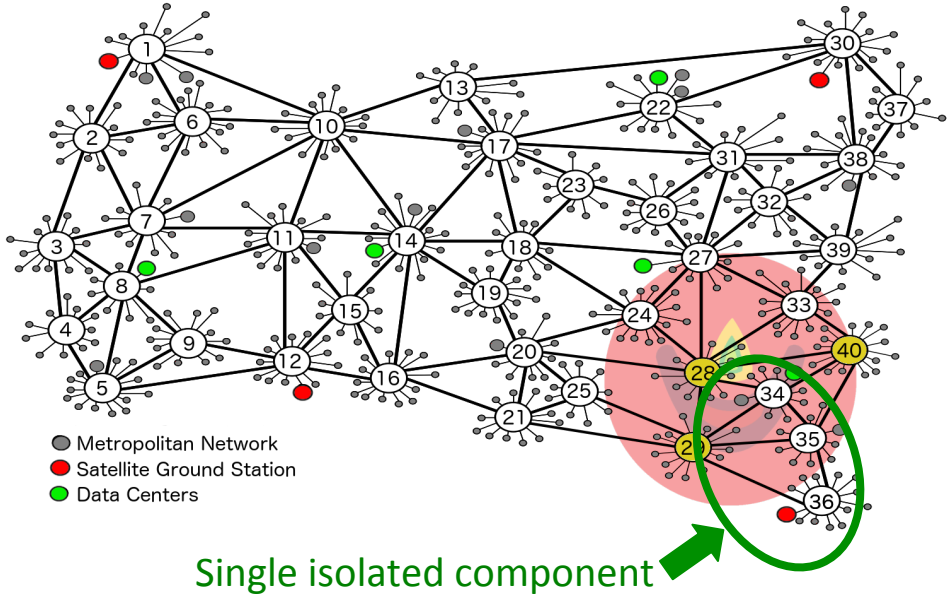
Results

LEO Constellation with 66 Satellites (ISL 5 Gbps; UL/DL 1 Gbps)



Terrestrial Network Topology (100 Gbps links)



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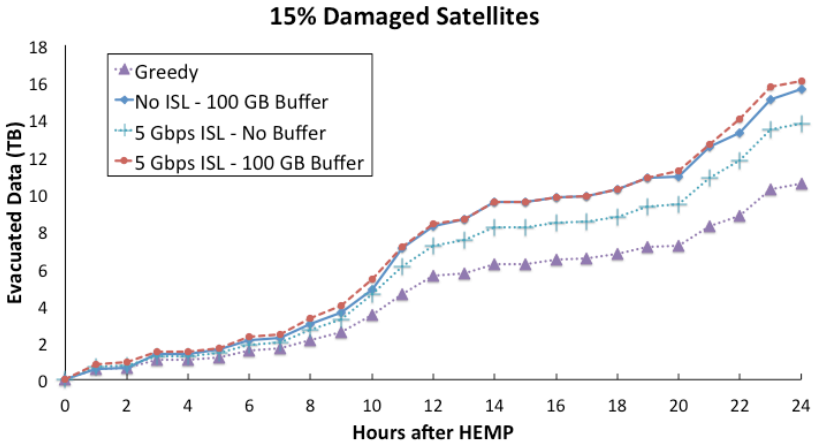
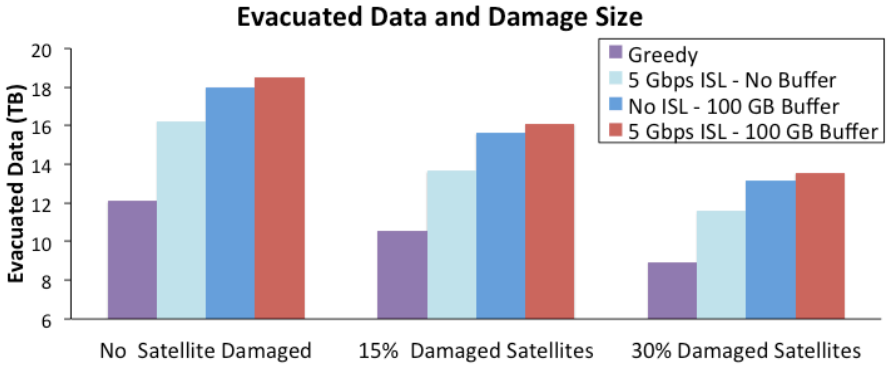
Results


15% Damaged Satellites
Greedy
No ISL - 100 GB Buffer
5 Gbps ISL - No Buffer
5 Gbps ISL - 100 GB Buffer
Evacuated Data (TB)
Hours after HEMP
0
2
4
6
8
10
12
14
16
18
20
22
24


Evacuated Data and Damage Size
Greedy
5 Gbps ISL - No Buffer
No ISL - 100 GB Buffer
5 Gbps ISL - 100 GB Buffer
Evacuated Data (TB)
No Satellite Damaged
15% Damaged Satellites
30% Damaged Satellites

Subsequent Work

Extension:

- Delay-constrained data;
- LEO and non-LEO integration (transmission delays);
- Mega constellations.

Future work:

- Multiple isolated components (“Maximum Multi-commodity Flow”): ILP or Heuristics [1], that allow fairness between components;
- Consider routing limitations in the terrestrial network;
- Use of other (aerial) platforms with higher mobility to help reduce bottlenecks.

[1] N. Garg and J. Koenemann, “Faster and simpler algorithms for multi- commodity flow and other fractional packing problems,” SIAM Journal on Computing, vol. 37, no. 2, pp. 630–652, 2007

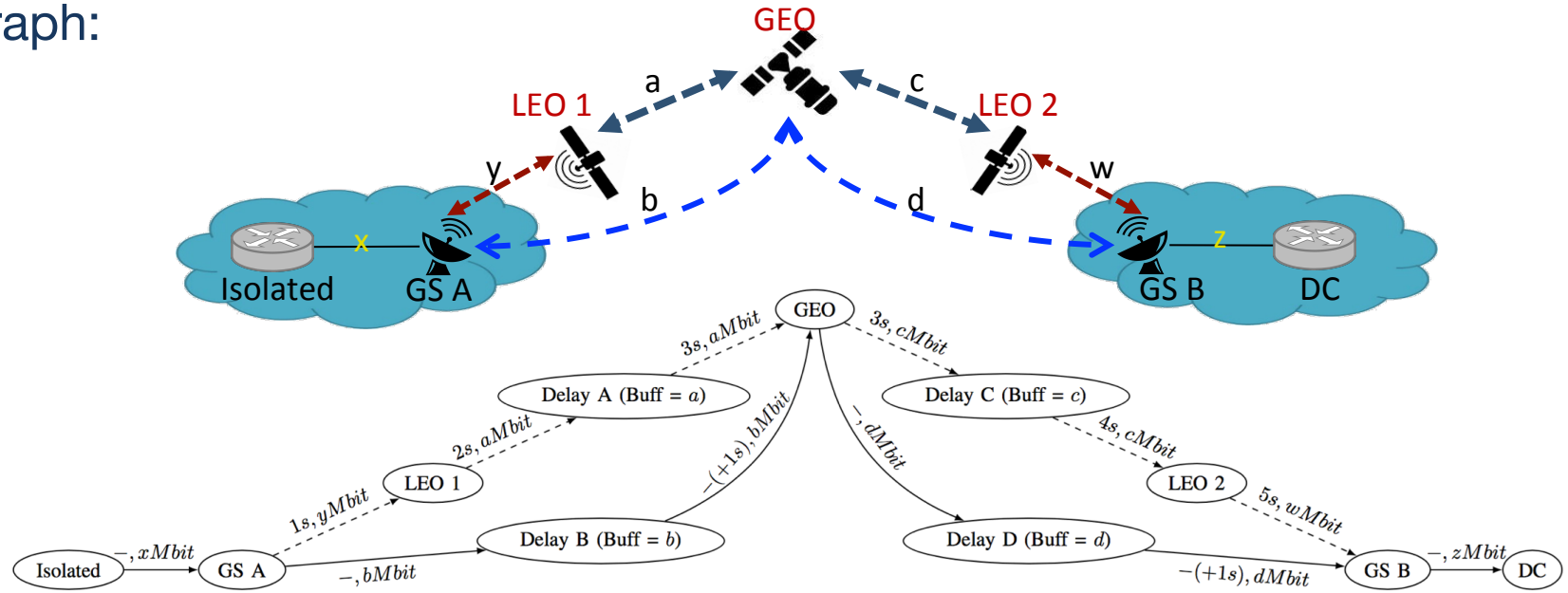
Subsequent Work: *Delay-constrained Data*

Node-to-node transmission schedule conveys time information:

- Iteratively calculate Max-flow and select solution that delivers the maximum amount of data while minimizing the amount of data whose delay-constraints are hurt.

Subsequent Work: *LEO and non-LEO integration*

Represent link propagation delays adding dummy nodes to contact graph:



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Subsequent Work: *Mega Constellations*

Prune Event-driven graph:

- Traverse Event-driven graph from isolated nodes and record all reached nodes. Traverse reversed Event-driven graph from DC and record all reached nodes. Remove all nodes (and resp. edges) that are not reached in both traversals;
- Investigate more sophisticated pruning approaches.

Use better performing Max-Flow algorithms than the current Edmonds Karp approach (such as Push-Relabel or the worst case O(nm) approach proposed in [1]).

[1] Orlin, James B. "Max flows in O(nm) time, or better." Proceedings of the forty-fifth annual ACM symposium on Theory of computing. ACM, 2013.

Subsequent Work: *Future Work*

Utilize graph pruning methods mentioned to enable an efficient ILP solution.

Investigate integration of post-disaster routing approaches in the terrestrial network.

Investigate multi-commodity Max-Flow heuristic solution implementations.

Investigate other aerial platforms mobility characteristics.