Post-Disaster Data Evacuation through Aerial Platforms

Prepared by: Rafael Lourenço

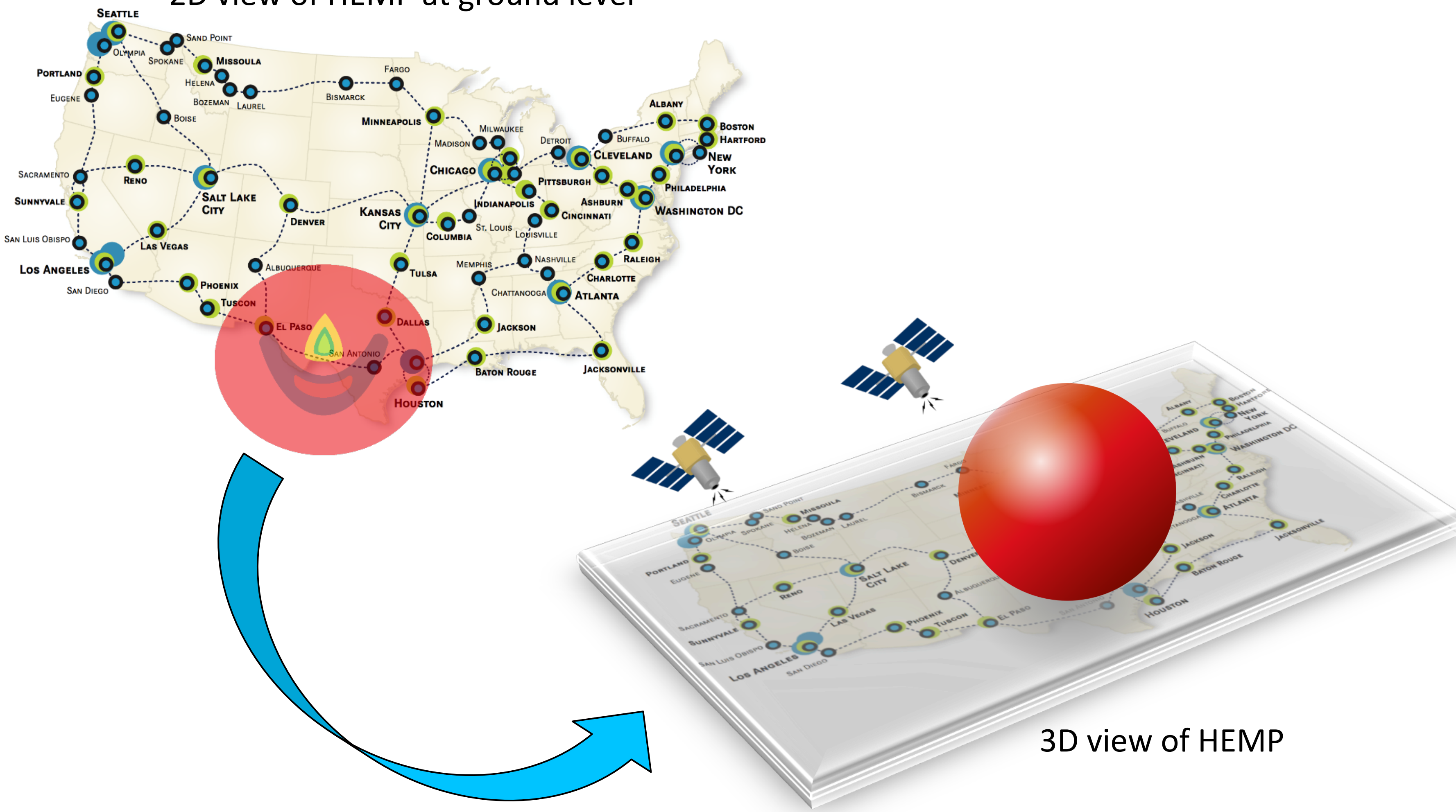
PhD Student

Department of Computer Science
University of California, Davis

March 11th, 2016

HEMP's Impact on Satellites

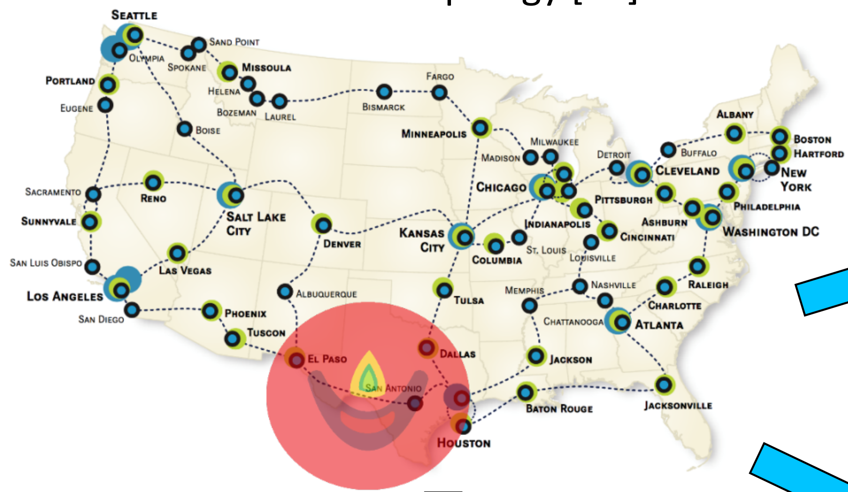
2D view of HEMP at ground level



3D view of HEMP

Possible HEMP Effect on Connectivity

Internet2 Topology [10].



(A) Texas is fully compromised.

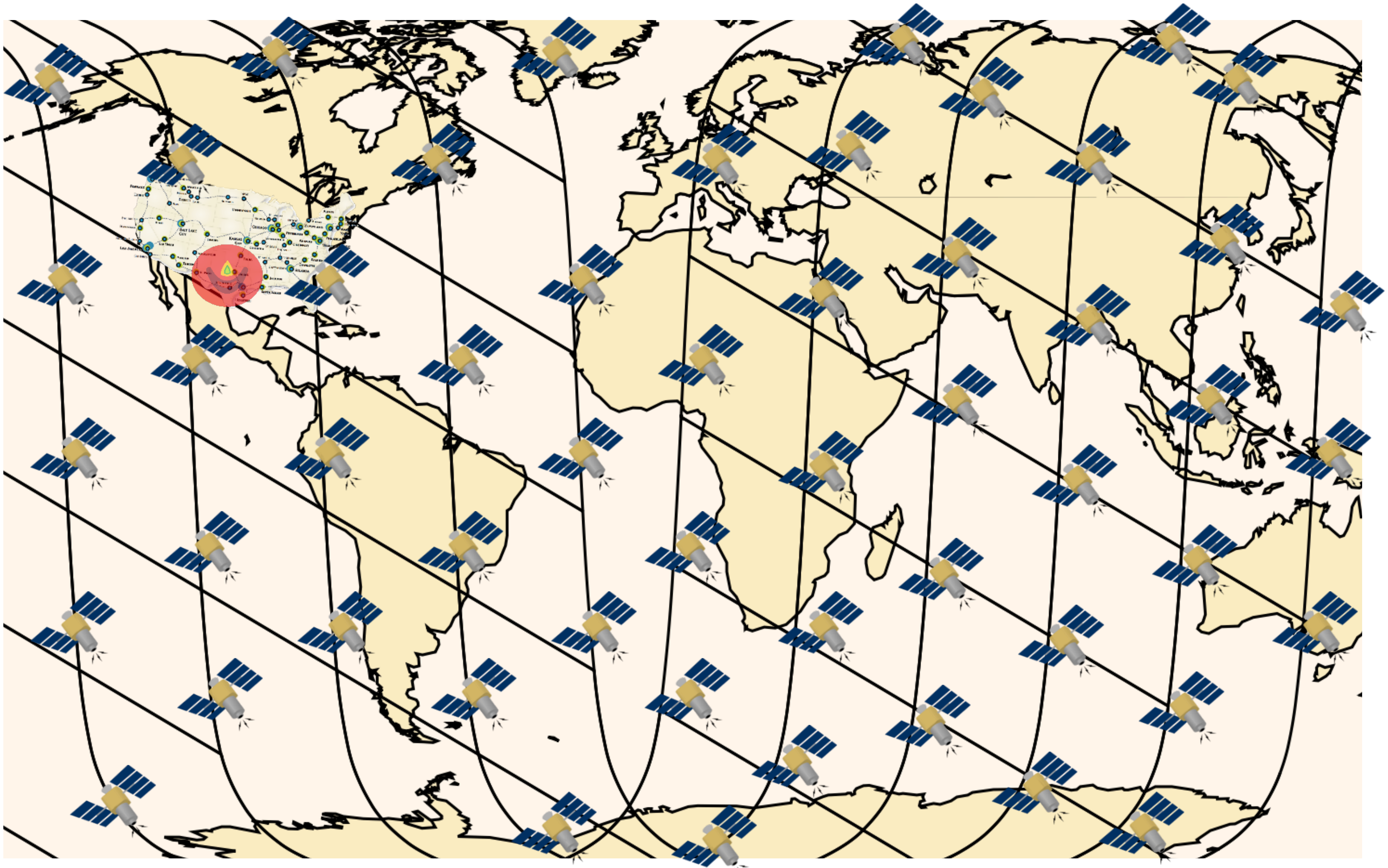
(C) Still some connectivity in Texas.

(B) Texas is partially compromised.

[10] Internet2 Network Infrastructure Topology (2015)

Post-HEMP Restoration with Satellite Assistance

Possible HEMP effect on Iridium constellation [12] include impairment/destruction of satellites:

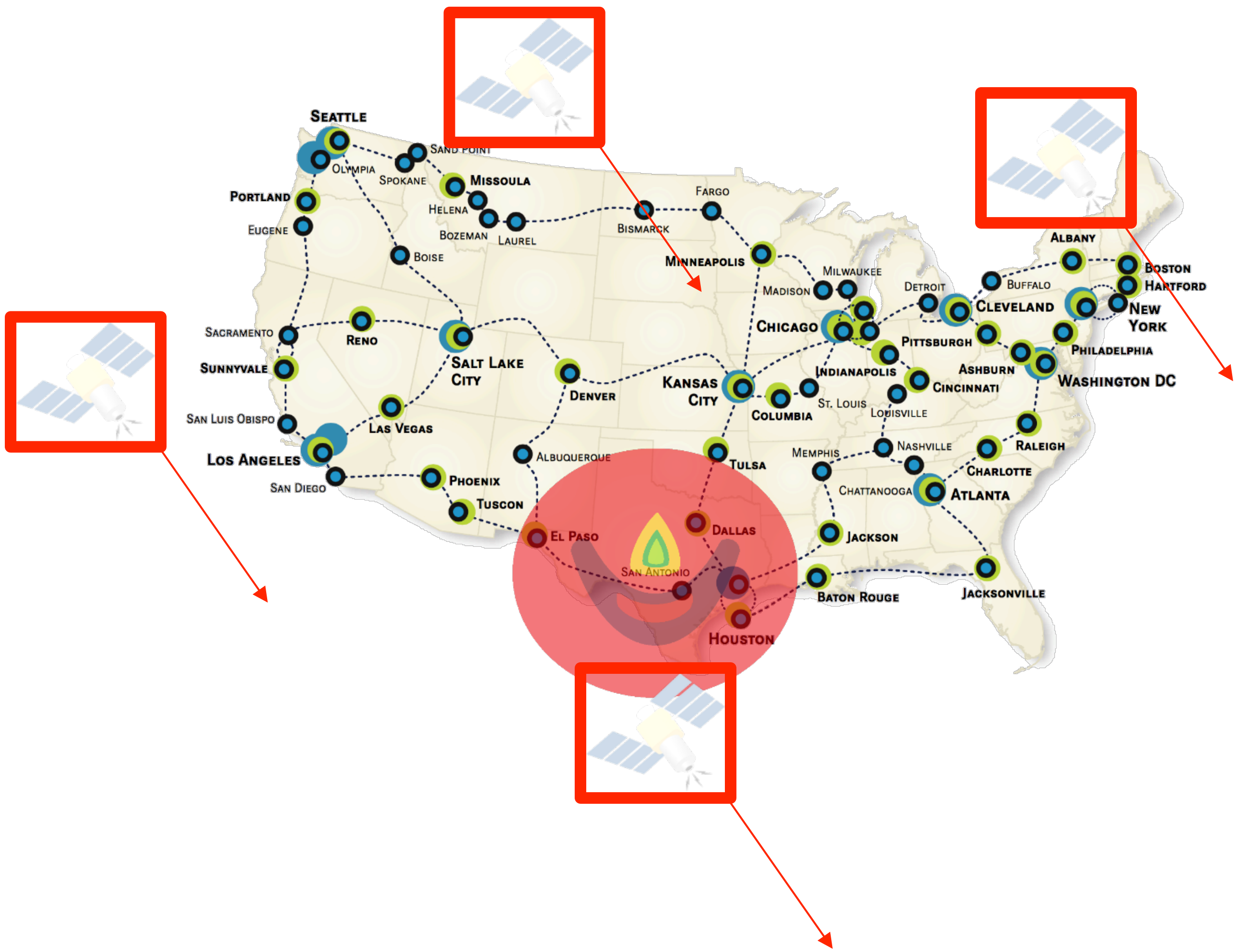


[12] Pratt, Stephen R., et al. "An operational and performance overview of the IRIDIUM low earth orbit satellite system." (1999)

Post-HEMP Restoration with Satellite Assistance

Initially, LEO satellite coverage would be lost:

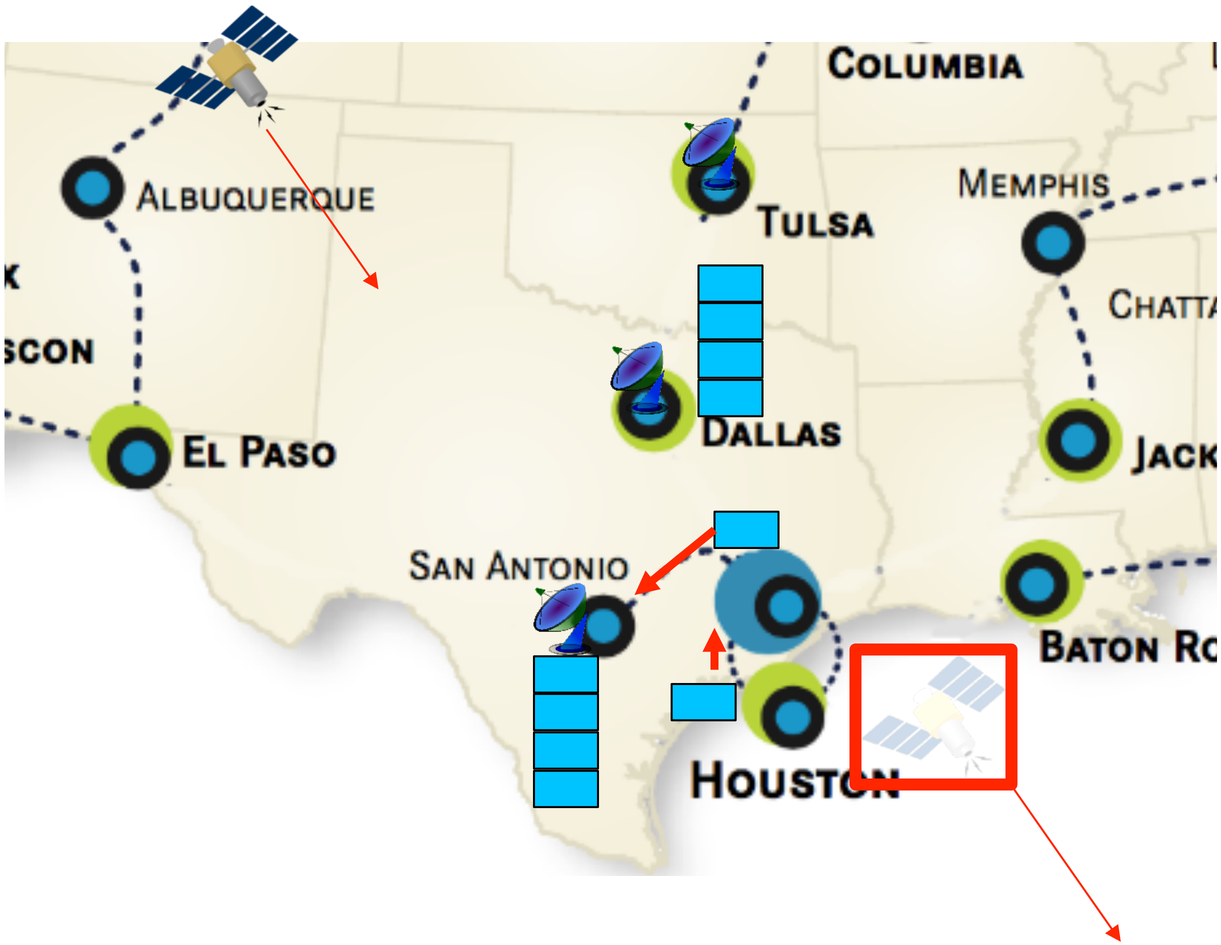
t = 0 min



Proposed Solution:
Post-HEMP Restoration with Satellite Assistance

Survived nodes buffer the traffic to be sent outside of the damaged area once there is LEO satellite connection:

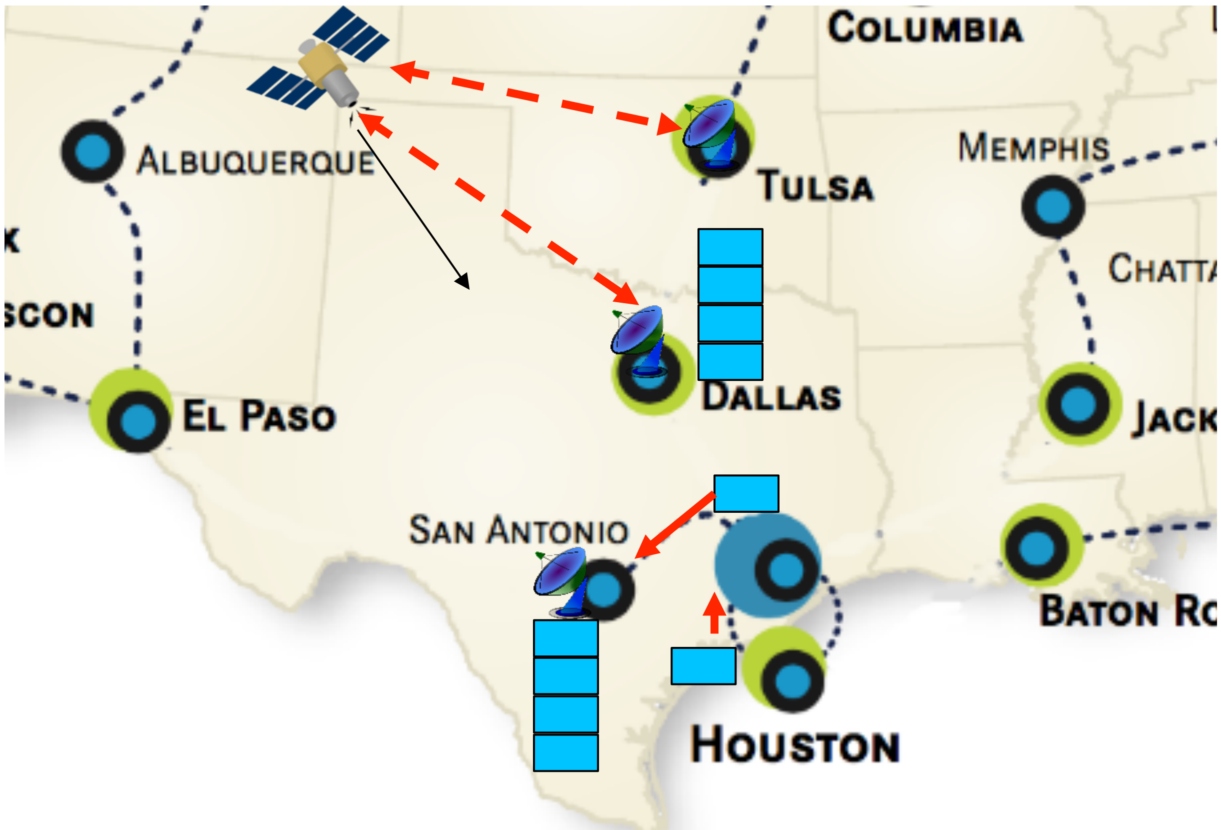
t = 15 min



Proposed Solution: Post-HEMP Restoration with Satellite Assistance

As coverage is slowly regained, buffer nodes begin evacuating queues to nearest (minimum delay) LEO satellite land station of main network:

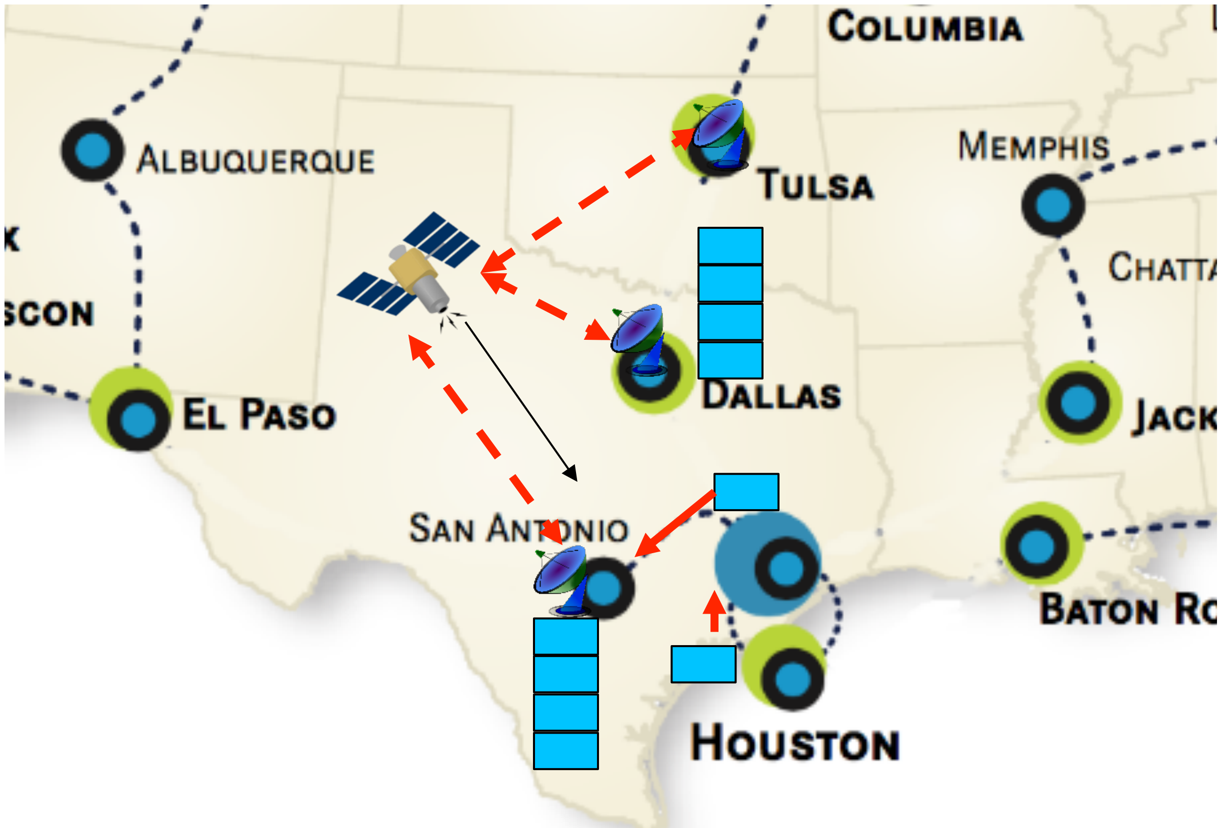
t = 30 min



Proposed Solution: Post-HEMP Restoration with Satellite Assistance

While having LEO satellite connection, queues are evacuated based on the priority of emergency communication:

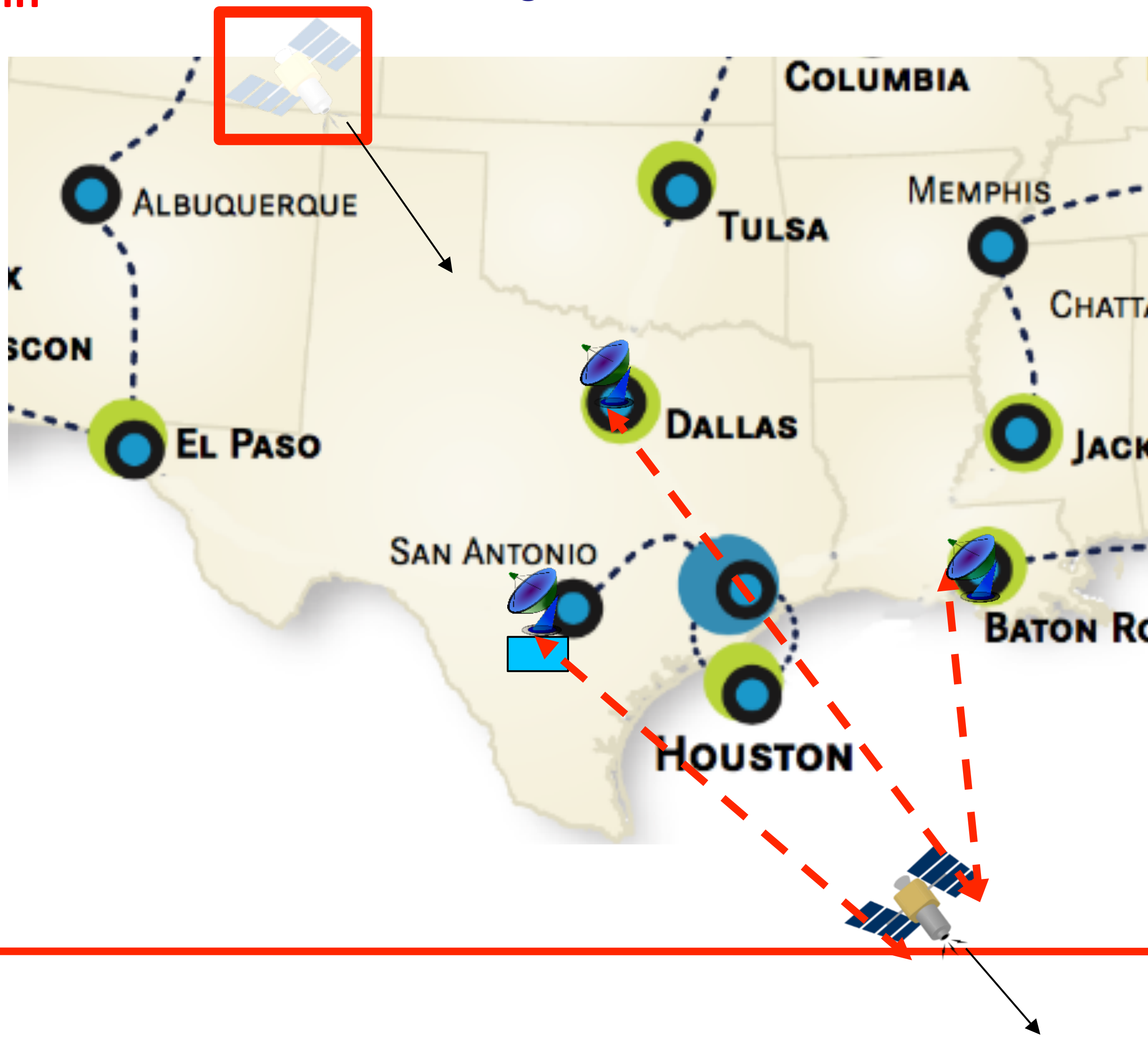
t = 35 min



Proposed Solution: Post-HEMP Restoration with Satellite Assistance

As LEO constellation "hole" approaches, main network is informed and scheduling starts again:

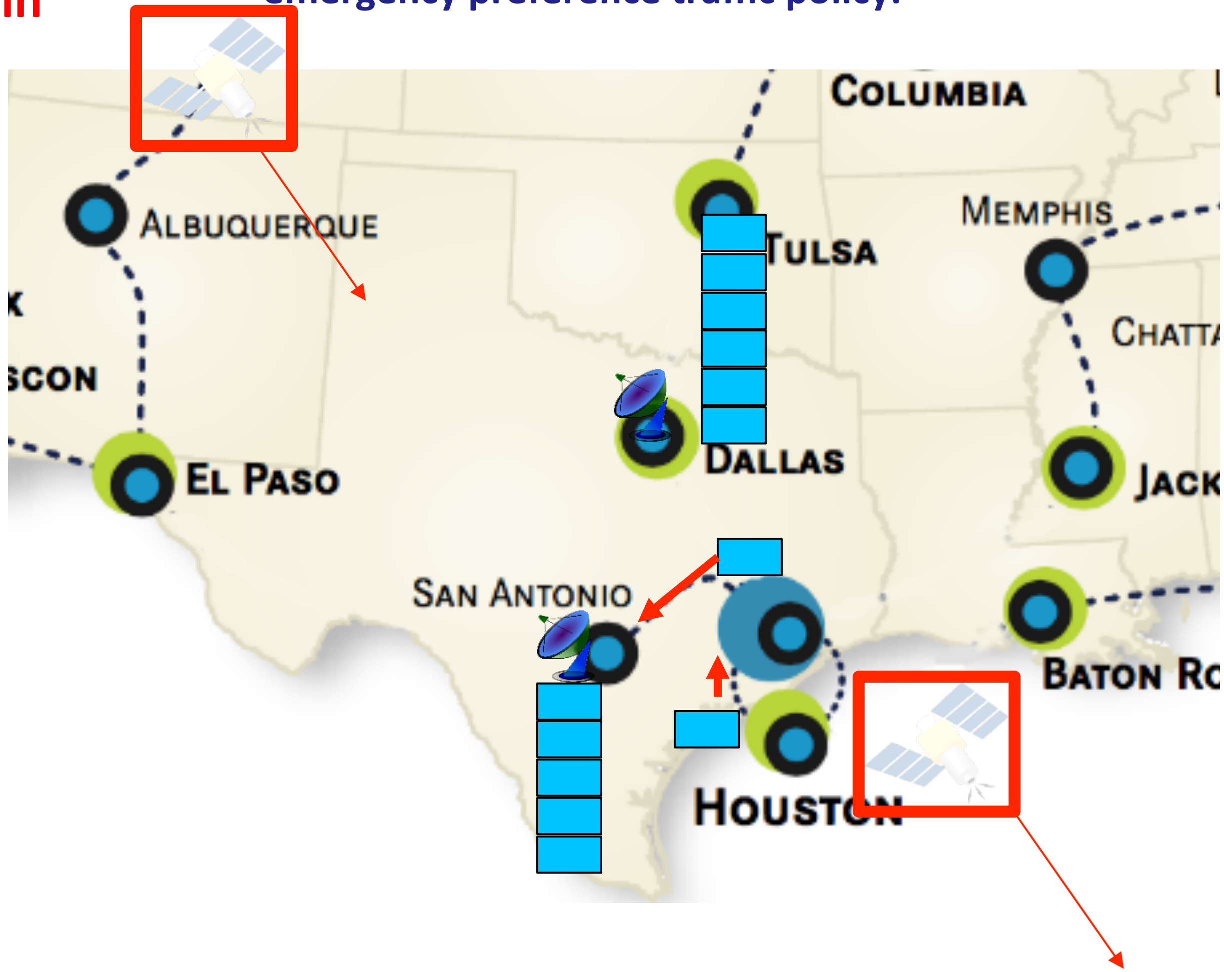
t = 1 h 10 min



Proposed Solution: Post-HEMP Restoration with Satellite Assistance

During lack of LEO coverage period, flows are buffered according to an pre-determined emergency preference traffic policy:

t = 1 h 25 min



Satellites and Aerial Platforms in the Media

http://www.theverge.com/2016/1/29/10873676/google-project-skybender-drones-5g-internet

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

(Google Titan)

Share on Facebook (5,845) Tweet Share (622) Pin (4)

Google is working in secret at a spaceport in New Mexico to build and test solar-powered internet drones in a new initiative codenamed Project SkyBender, according to a report from *The Guardian* today. The company is reportedly renting 15,000 square feet of hangar space from Virgin Galactic — the commercial spaceflight outfit of business mogul Richard Branson — at the privately owned Spaceport America located near a town called Truth or Consequences. The lynchpin of Project SkyBender appears to be cutting-edge millimeter wave technology, which can transmit gigabits of data every second at speeds up to 40 times faster than modern 4G LTE.

http://www.theverge.com/2015/3/2/8129543/google-x-internet-balloon-project-loon-interview

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

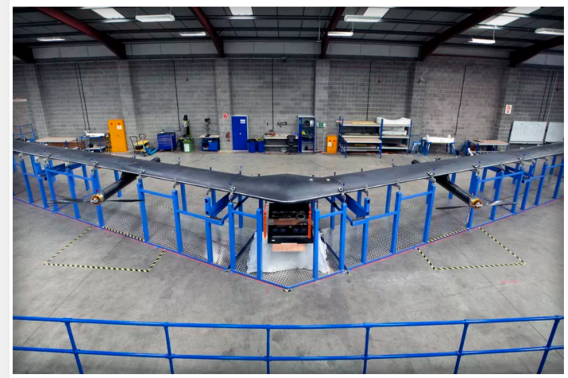
By Ben Popper on March 2, 2015 11:34 am

(Watch on

Share on Facebook (3,321) Tweet Share (817) Pin (45)

"Good news," says Katelin Jabbari, Google X's communications chief. "It's about to explode."

http://www.theverge.com/2015/7/30/9074925/facebook-aquila-solar-internet-plane



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

Share on Facebook Tweet Share Pin

Facebook's plans to become a flying internet service provider for the developing world are coming to fruition. The company today introduced Aquila, a high-flying, long-endurance plane that will bring basic internet access to the developing world. A working model of the plane is now ready for testing, Facebook said.

Satellites and Aerial Platforms in the Media

http://spacenews.com/spacex-opening-seattle-plant-to-build-4000-broadband-satellites/

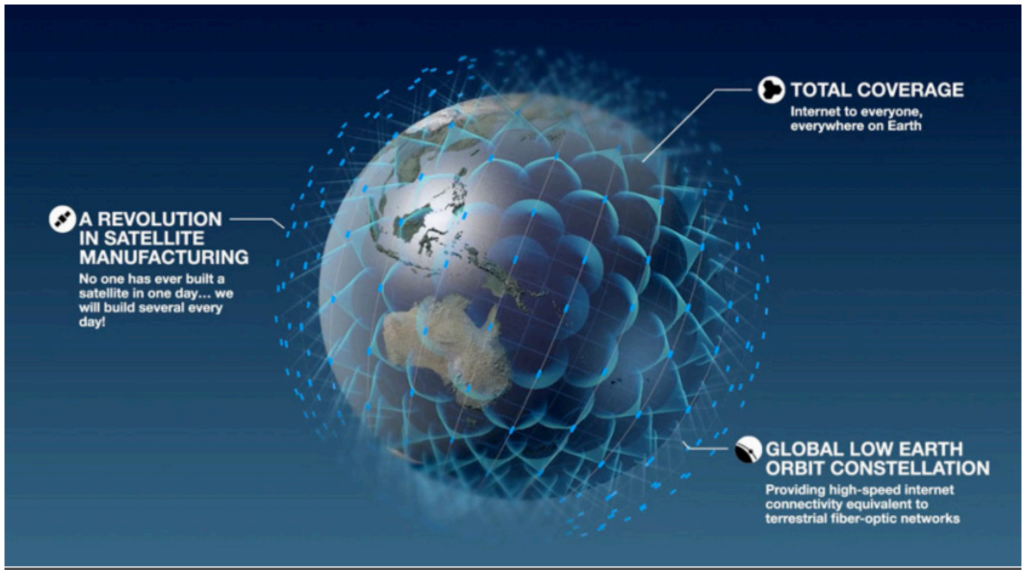
SpaceX To Build 4,000 Broadband Satellites in Seattle

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

http://spacenews.com/airbus-and-oneweb-form-joint-venture-to-build-900-satellites/

Airbus and OneWeb form joint venture to build 900 satellites

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



OneWeb's constellation will consist of 648 low-Earth orbit satellites plus spares. Credit: Airbus/OneWeb

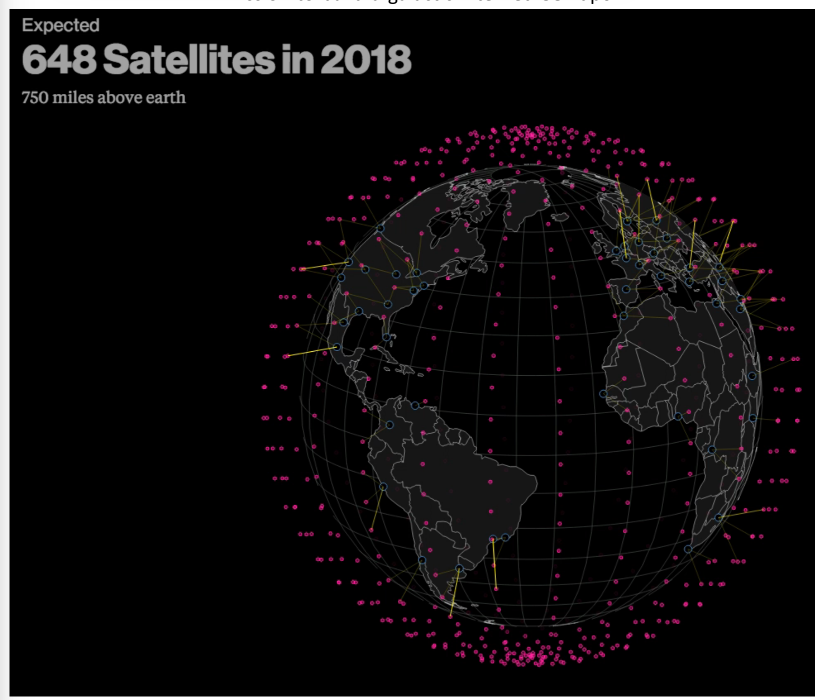
Airbus and OneWeb on Jan. 26 announced they had formed the company OneWeb Satellites, which will build the OneWeb constellation – 648 satellites plus spares, for a total of about 900.

http://www.wired.com/2015/01/google-spacex-investment/

ISSIE LAPOWSKY BUSINESS 01.20.15 11:19 AM

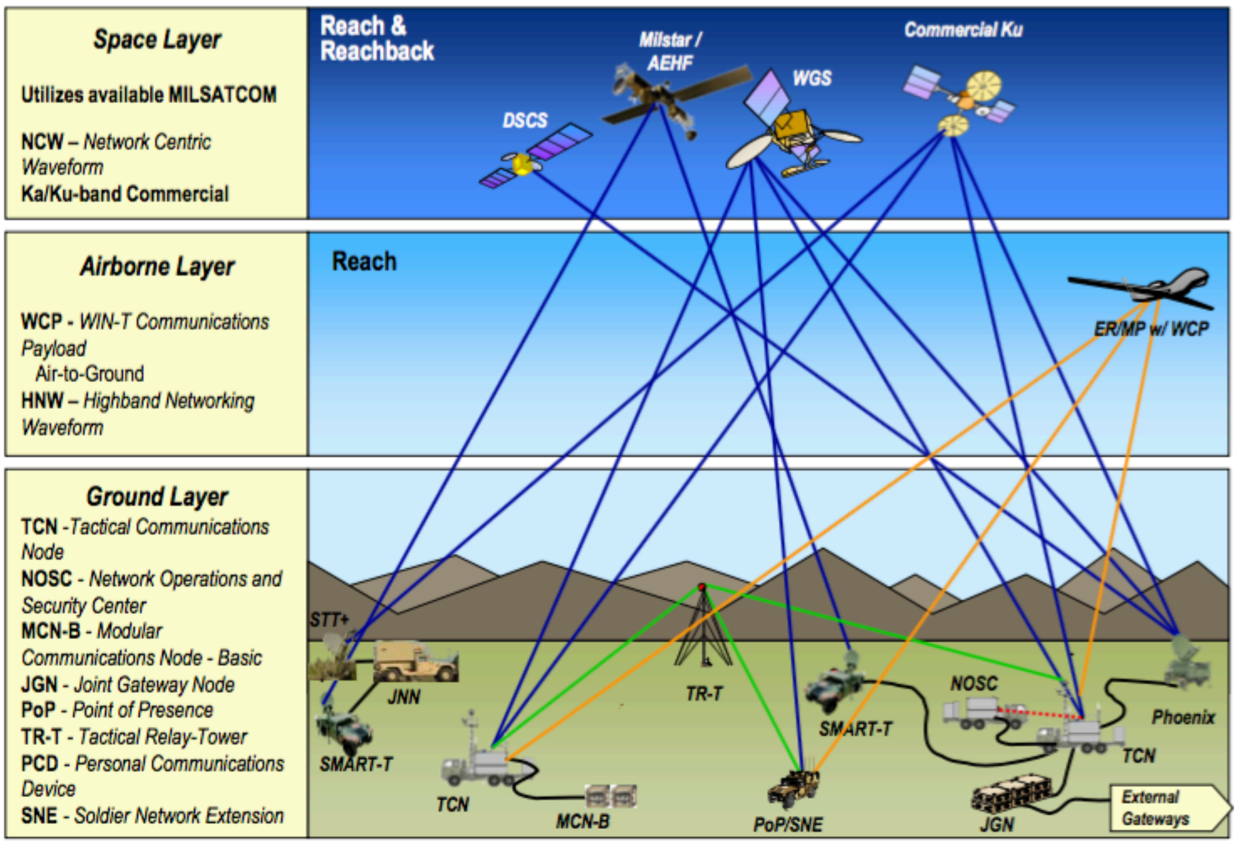
SPACEX LANDS $1 BILLION FROM GOOGLE AND FIDELITY

http://www.bloomberg.com/news/features/2015-01-22/the-new-space-race-one-man-s-mission-to-build-a-galactic-internet-i58i2dp6



Military Tactical and Regional Hubs

- Project Manager Warfighter Information Network- Tactical (PM WIN-T):
  - Design, acquire, field and support fully integrated, easy to operate and cost effective Tactical Networks and Services that meet Warfighter capability needs while sustaining a world class work force.



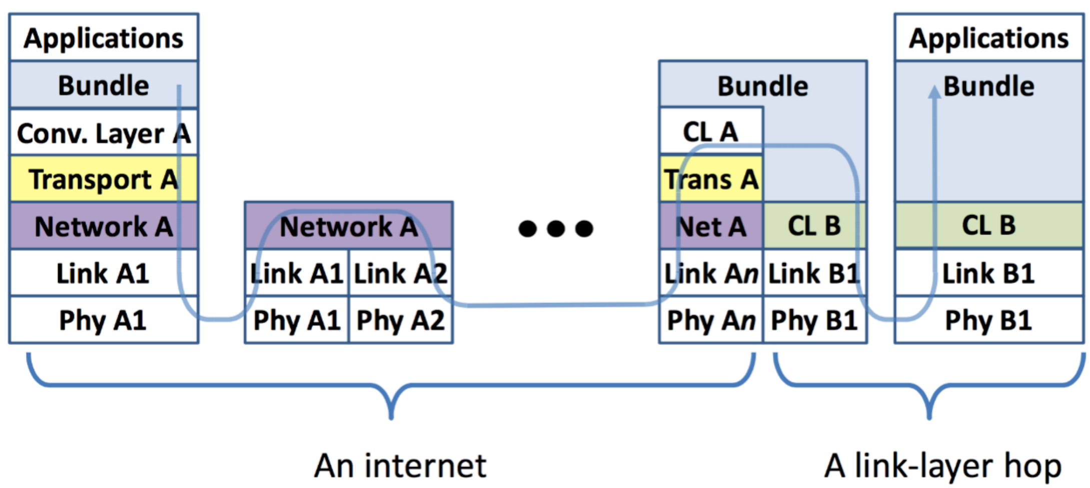
Project Manager WIN-T
COL Edward Swanson

Representative Systems

[1] Satellite Communications within the Army's WIN-T Architecture (presentation, 2014)

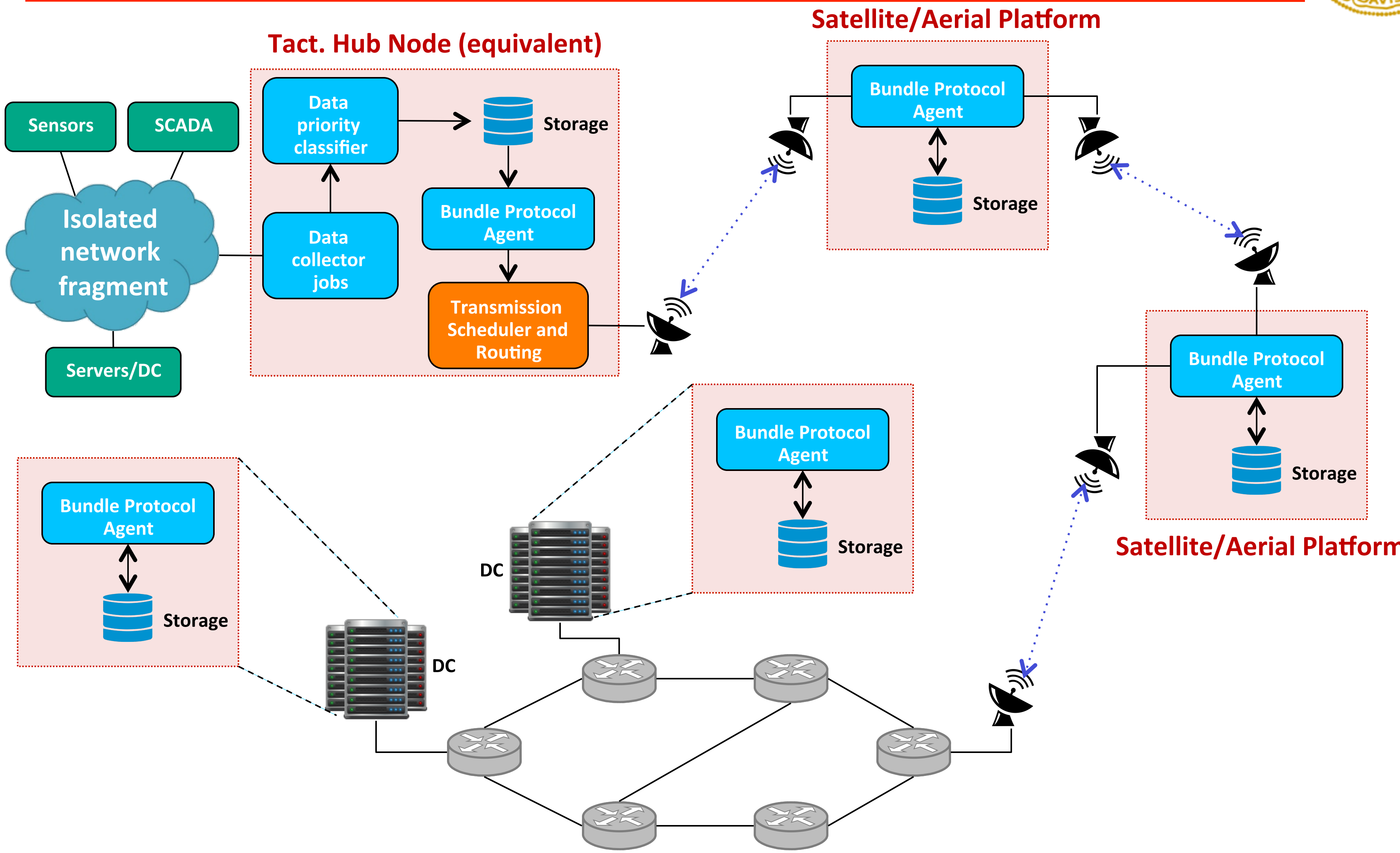
DTN Bundle Protocol (RFC5050)

- Delay Tolerant Networking is an end-to-end architecture providing communications in and/or through highly stressed environments. Stressed networking environments include those with intermittent connectivity, large and/or variable delays, and high bit error rates. To provide its services, <u>BP sits at the application layer of some number of constituent internets, forming a store-and-forward overlay network</u>. Key capabilities of BP include:
  - Custody-based retransmission
  - Ability to cope with intermittent connectivity
  - Ability to take advantage of scheduled, predicted, and opportunistic connectivity (in addition to continuous connectivity)
  - Late binding of overlay network endpoint identifiers to constituent internet addresses



[2] Scott, Keith L., and Scott Burleigh. "Bundle protocol specification." (2007).
[3] Araniti, Giuseppe, et al. "Contact graph routing in DTN space networks: overview, enhancements and performance." Communications Magazine, IEEE 53.3 (2015): 38-46.

Proposed Architecture



Problem Statement

Objective

Maximize the amount of gathered data sent from the isolated sub-components of the network to destination data centers in the main network;

Given

- Network topologies (original and post-HEMP sub-network);
- Buffering capabilities of network nodes and satellites;
- Knowledge of unaffected satellites and their orbits (TLEs), available capacity, and throughput characteristic;
- Ability to exchange necessary initial information before performing any computation;
- Free capacity and degraded-service tolerance of connections in the main network;

- **Constraints**
  - Throughput, delays, buffer capacities, and contact times of satellite network;
  - Degraded-service tolerance and latency sensitivity of data being sent through bundles;

Expected Output

Traffic scheduling and routing strategy to minimize the total unused capacity of the aerial links.

Current Solution

Initialization: Exchange information between sub-components to gain knowledge of other buffers and locations

1: Calculate contact* times and transmission capacity of each (inter-satellite and sat to land)
***atomic contacts**

2: Create contact graph and set non-intermittent links ***t*** to -1

3: From contact graph, create event-driven (for next ***T***) graph where contacts with ***t*** = -1 are present for all instants

3.1: Attach dummy source node to all Tactical Hub Nodes for all ***t***'s

3.2: Attach dummy sink node to all destination DCs for all ***t***'s

4: Run Max-Flow

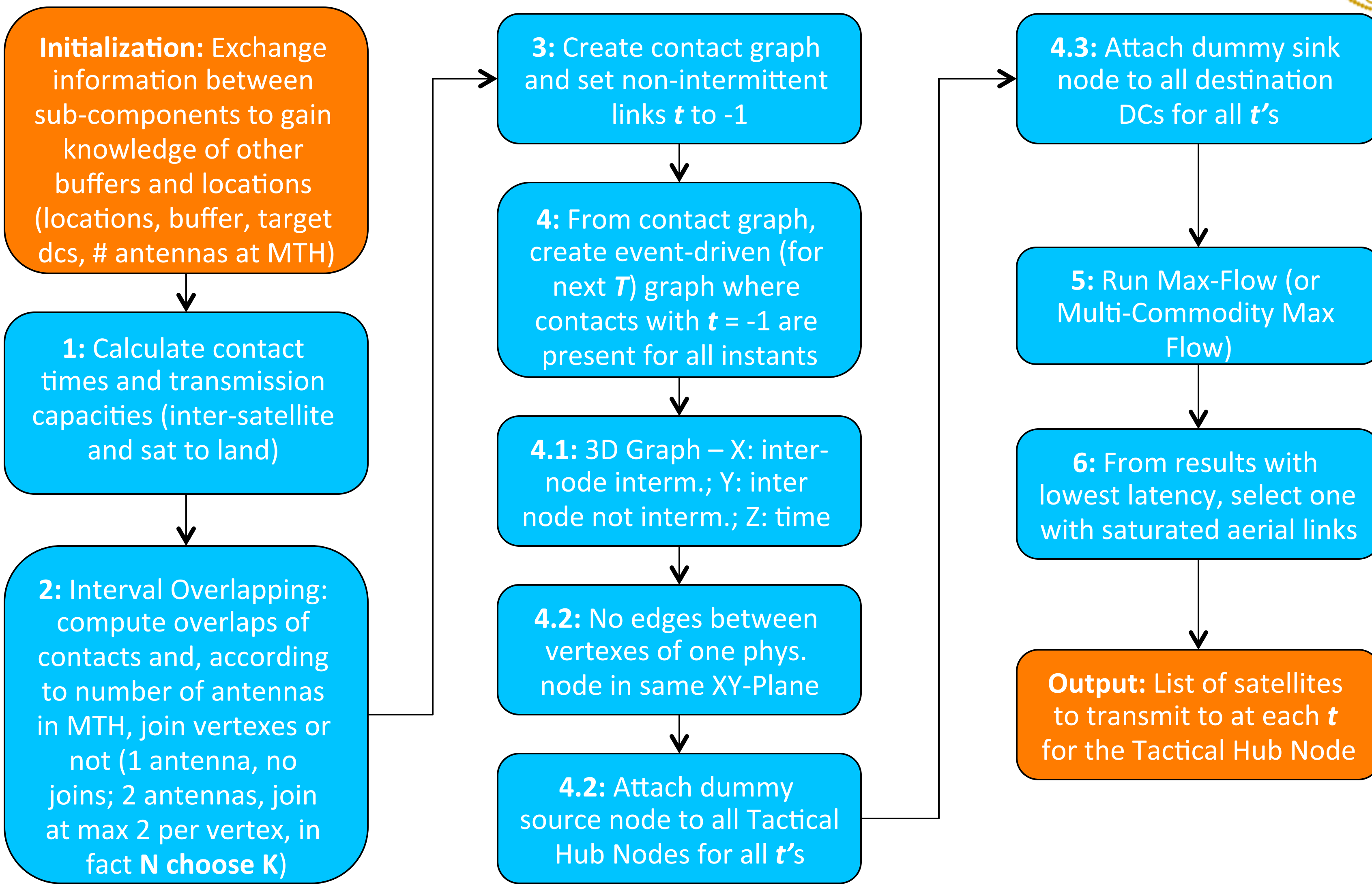
5: From results with lowest latency, select one with saturated aerial links

Output: List of satellites to transmit to at each ***t*** for the Tactical Hub Node

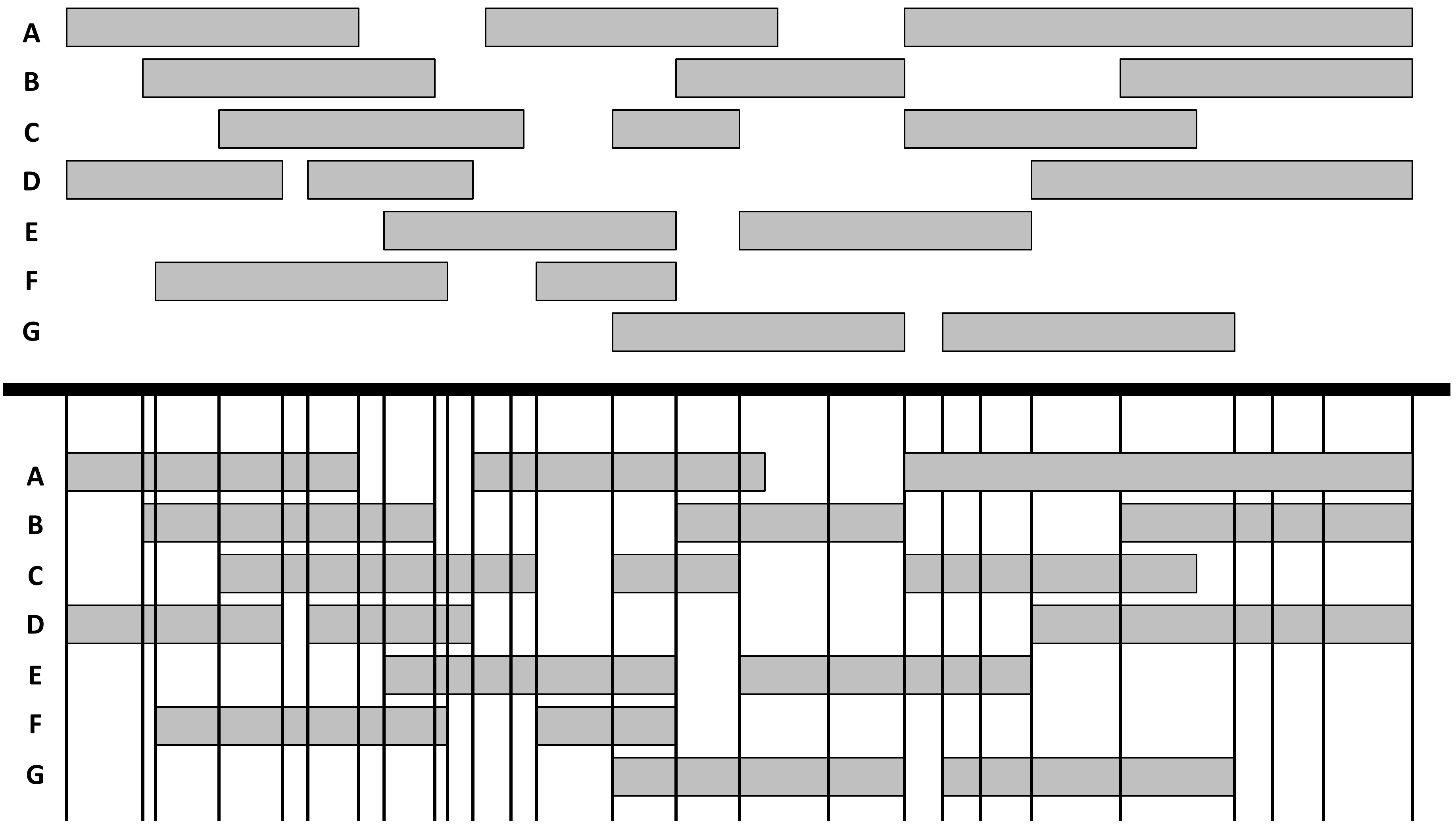
Questions:

1. **Initialization** always possible (GEO)? Or Game Theory approach?
2. (Step 1) Atomic contacts: not optimal when contacts overlap
3. (Step 3) Next ***T***: event-driven graph is DAG, should introduce cycles to avoid ***T***?
4. (Step 4) If bundles must end-up at same place: Maximum Multi Commodity Flow
5. (Step 5) Saturated aerial links: no routing intelligence in satellites
6. How to present results?

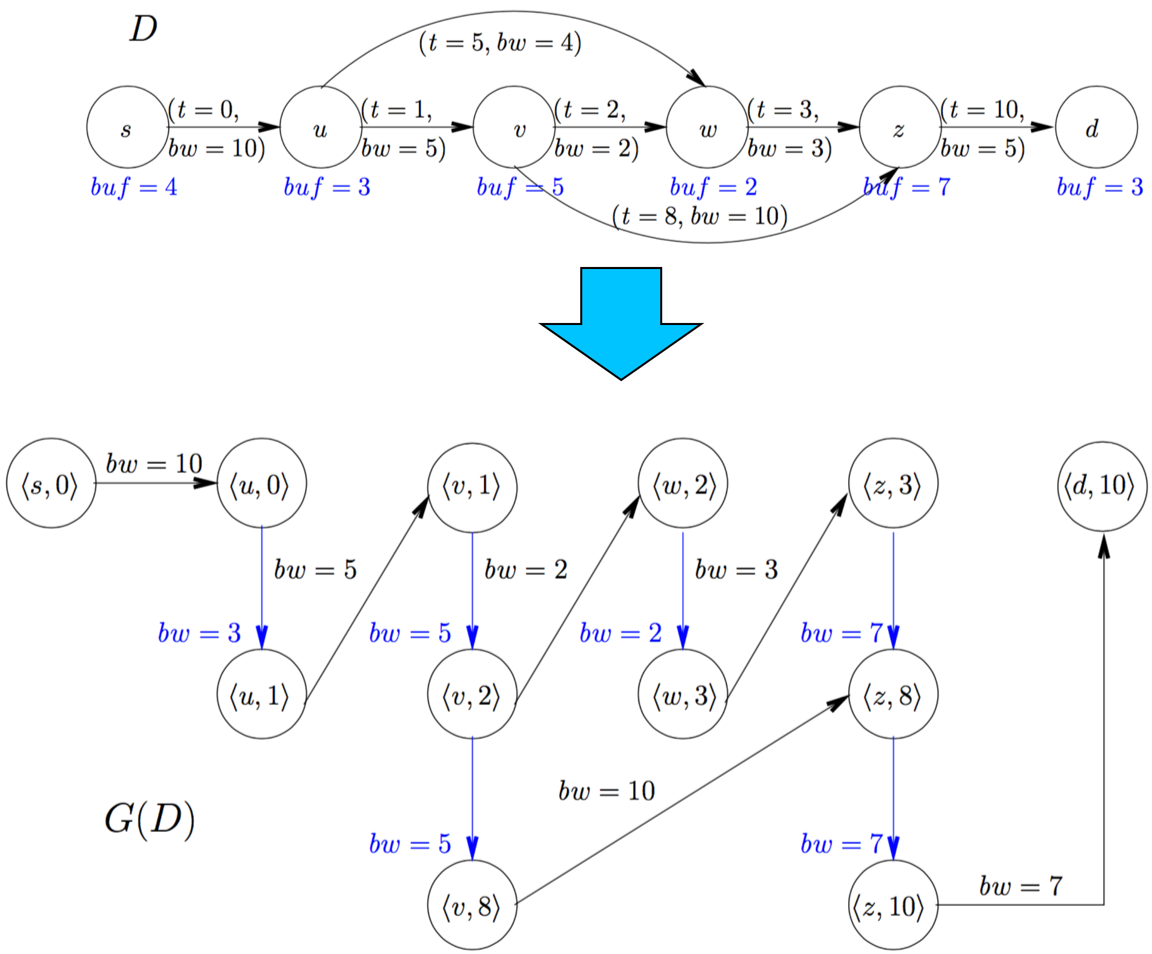
Current Solution



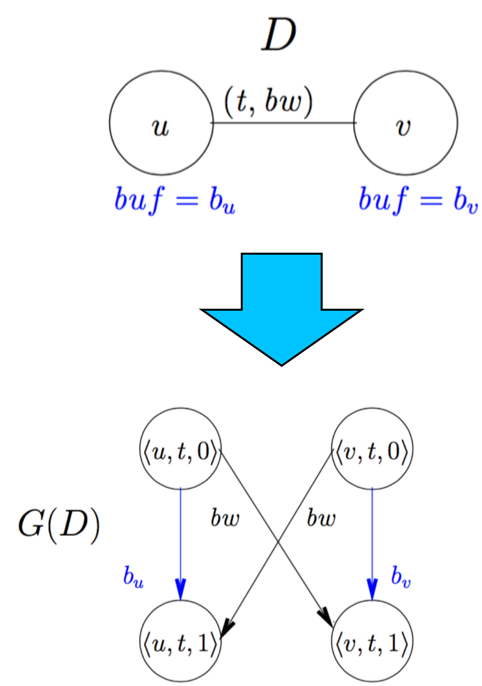
Contacts Overlapping



Optimal Routing and Scheduling for Deterministic Delay Tolerant Networks



Creating an event-driven graph from a directed contact graph

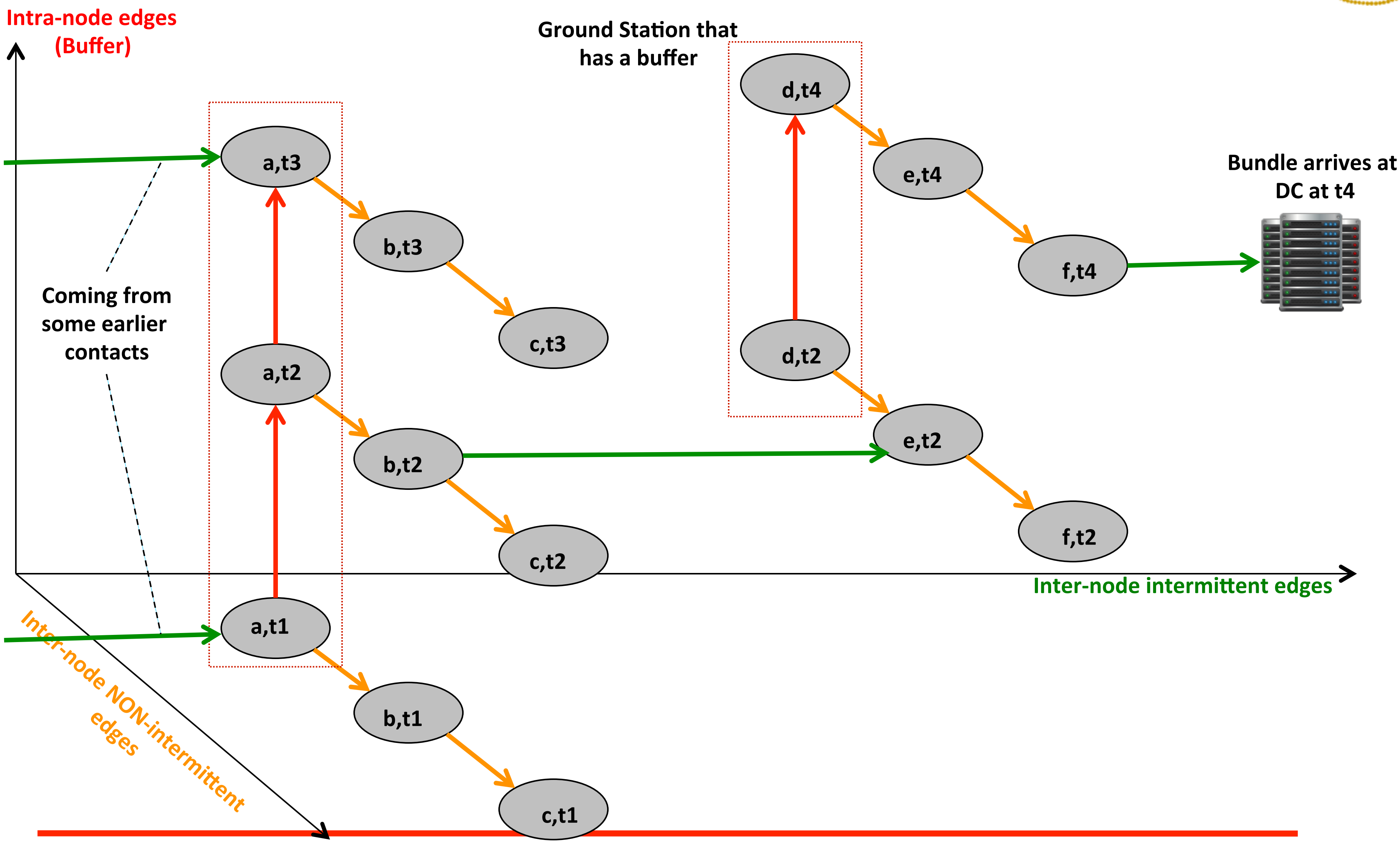


Dealing with undirected graph

(A little different when dealing with non-intermittent connections)

[4] Hay, David, and Paolo Giaccone. "Optimal routing and scheduling for deterministic delay tolerant networks." Wireless On-Demand Network Systems and Services, 2009. WONS 2009. Sixth International Conference on. IEEE, 2009.

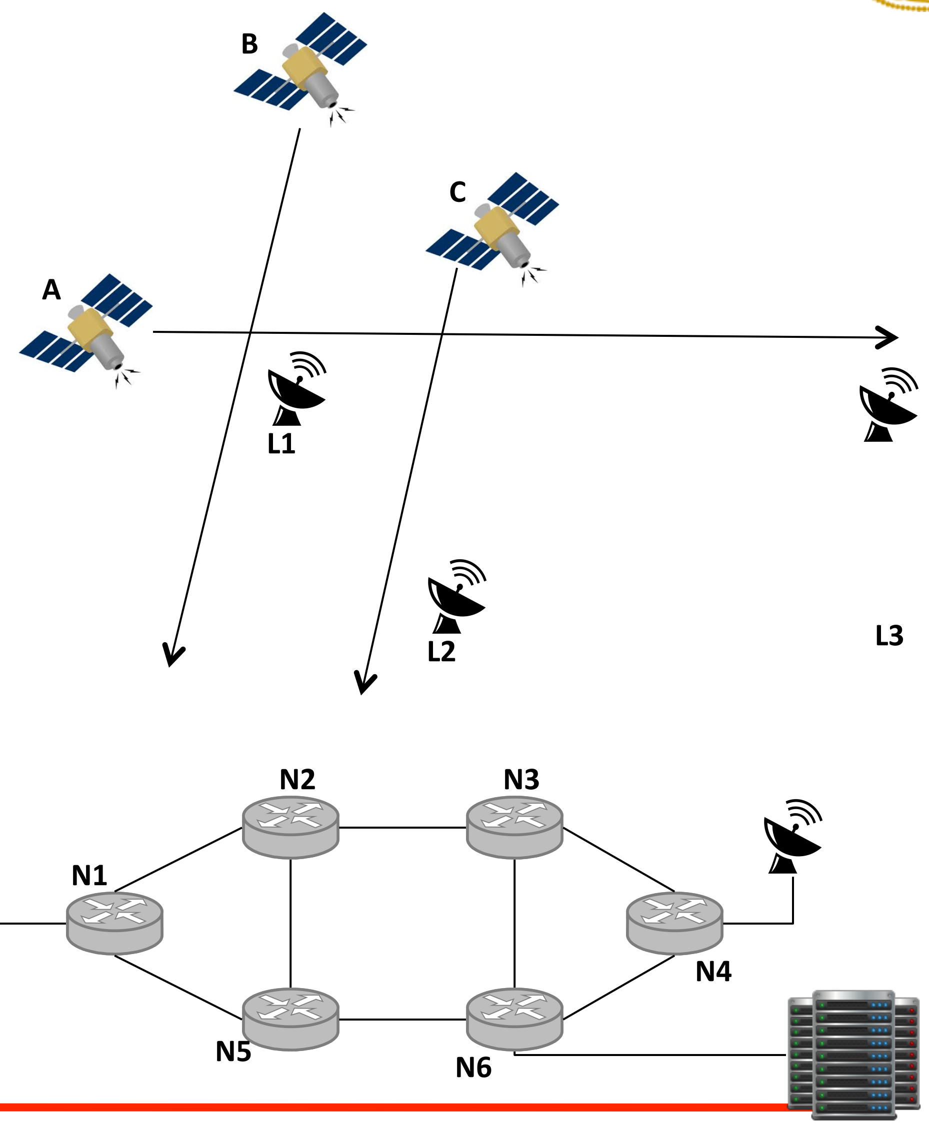
3D Event Driven Graph



Simple Scenario

At t = 1:

L1 sees and is able to transmit 50GB to satellite C (which has a buffer of 50GB)



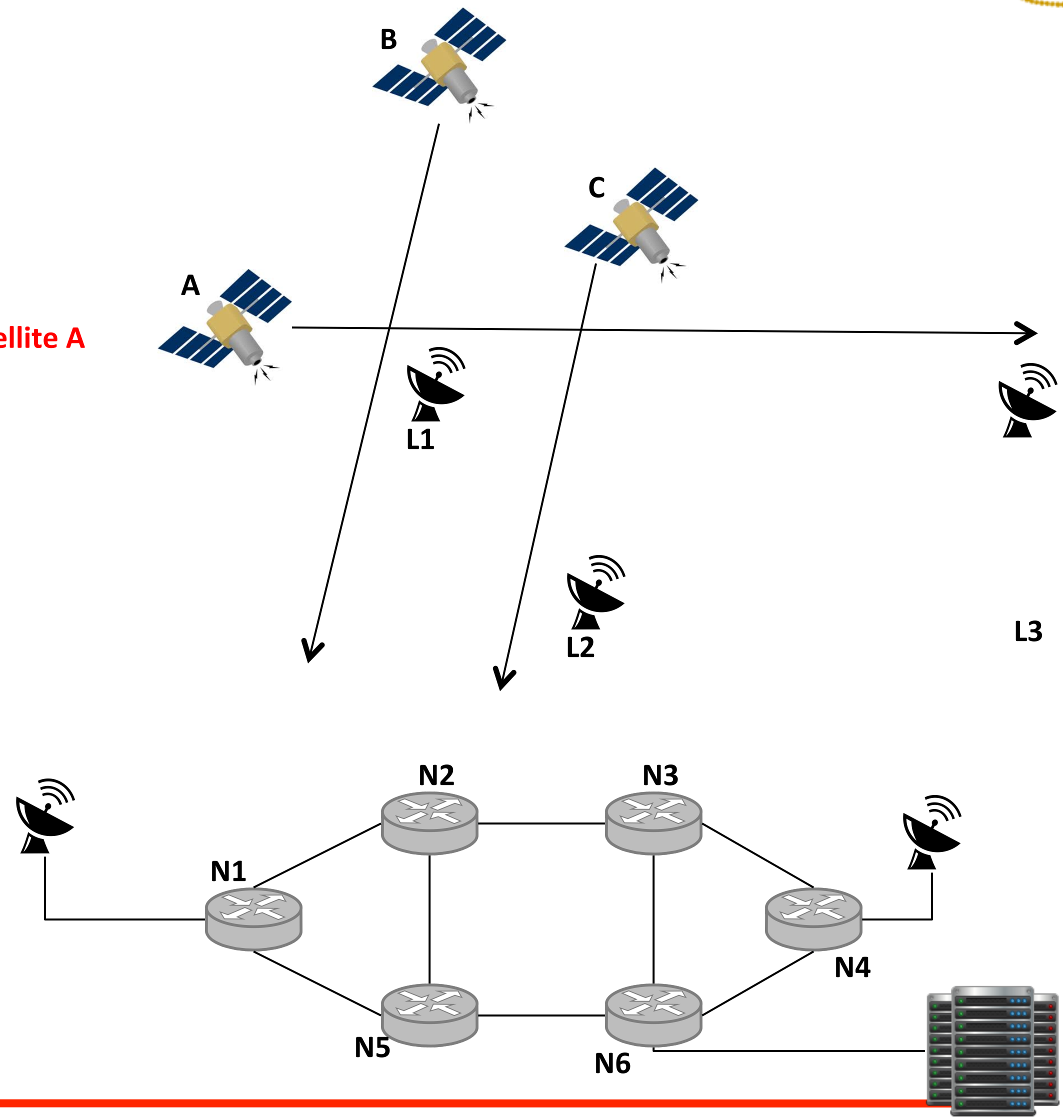
Simple Scenario

At t = 2:

L1 sees and is able to transmit 50GB to satellite A (which has a buffer of 50GB)

L3 sees and can't transmit to satellite A.

L2 sees but can't transmit to C.

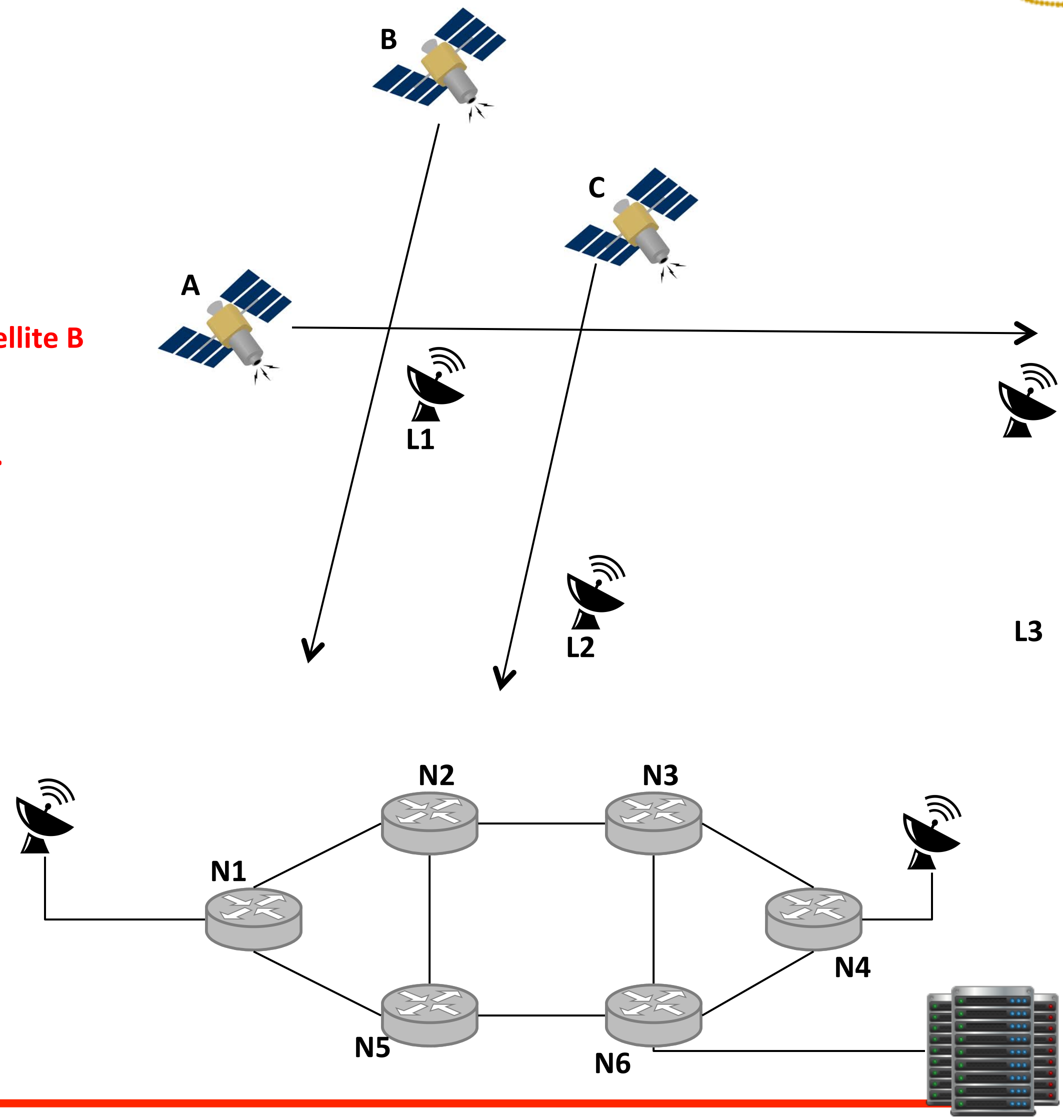


Simple Scenario

At t = 3:

L1 sees and is able to transmit 50GB to satellite B (which has a buffer of 50GB)

N1 sees and receives 50GB from satellite C.



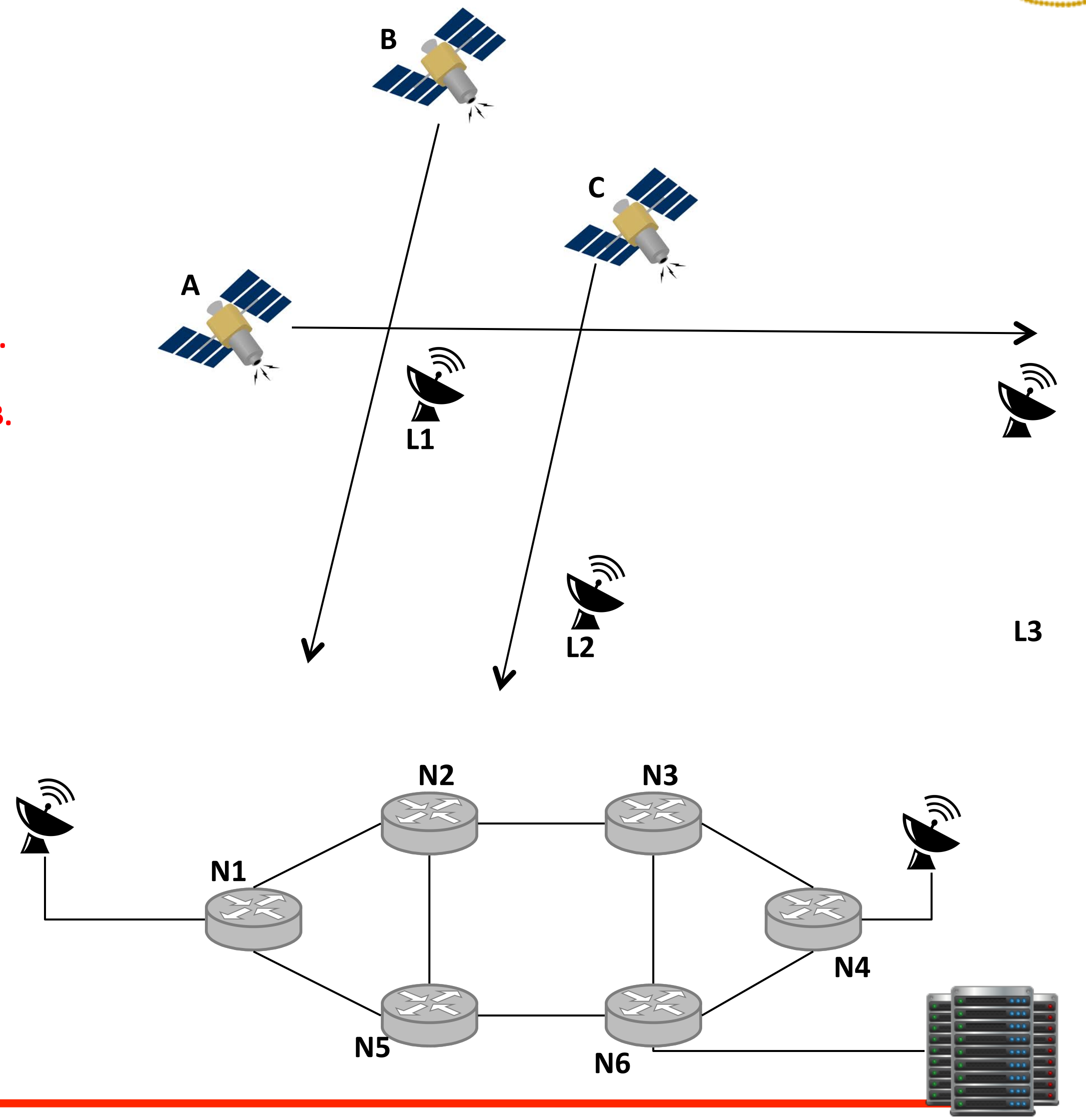
Simple Scenario

At t = 4:

N4 sees and is able to receive 50GB from A.

N2 sees and is able to receive 50 GB from B.

L1 sent 150GB. L2 and L3 sent 0.



Simple Scenario

Algorithm result for the simple scenario.
Max-Flow = 150GB

SRC	TIME TO SEND	DST	TIME RECEIVED	GB
N5	3	N5	3	50.0
a	2	a	4	50.0
L3	2	a	2	50.0
N5	3	N6	3	50.0
c	3	N1	3	50.0
N6	4	N6	4	100.0
source	-1	L1	3	50.0
N1	4	N5	4	50.0
source	-1	L1	1	50.0
c	2	c	2	50.0
N5	4	N5	4	50.0
N4	4	N6	4	50.0
L1	3	b	3	50.0
a	4	N1	4	50.0
b	3	b	4	50.0
c	1	c	2	50.0
N6	3	N6	3	50.0
N1	3	N5	3	50.0
b	4	N4	4	50.0
N6	4	DC	4	100.0
source	-1	L3	2	50.0
DC	4	sink	-1	100.0
N6	3	DC	3	50.0
DC	3	sink	-1	50.0
c	2	c	3	50.0
N5	4	N6	4	50.0
L1	1	c	1	50.0

Larger Scenario

- Initial setting
- US 24 nodes
- 4 disconnected subcomponents
- 4 ground stations
- 66 satellites

- Comparisons:
  - Number of antennas per satellite/ground-station (i.e., # of simultaneous transmissions)
  - How much data evacuated in the same amount of time as the greedy approach
  - How many times transmissions were made VS buffering (which one is more impactful)
  - Increase number of disconnected subcomponents and satellites

- Progress: implementing the Max-Flow result selection.

References

[1] Satellite Communications within the Army's WIN-T Architecture (presentation, 2014)
[2] Scott, Keith L., and Scott Burleigh. "Bundle protocol specification." (2007).
[3] Araniti, Giuseppe, et al. "Contact graph routing in DTN space networks: overview, enhancements and performance." Communications Magazine, IEEE 53.3 (2015): 38-46.
[3] Min, Gyung Chan, Yeong Kwan Jung, and Jeong-Jin Kang. "Development of the HEMP Propagation Analysis and Optimal Shelter Design, Simulation Tool" KTI HEMP CORD"." (2013).
[4] Hay, David, and Paolo Giaccone. "Optimal routing and scheduling for deterministic delay tolerant networks." Wireless On-Demand Network Systems and Services, 2009. WONS 2009. Sixth International Conference on. IEEE, 2009.

Thank you!