Post-HEMP Data Evacuation through Satellite Networks

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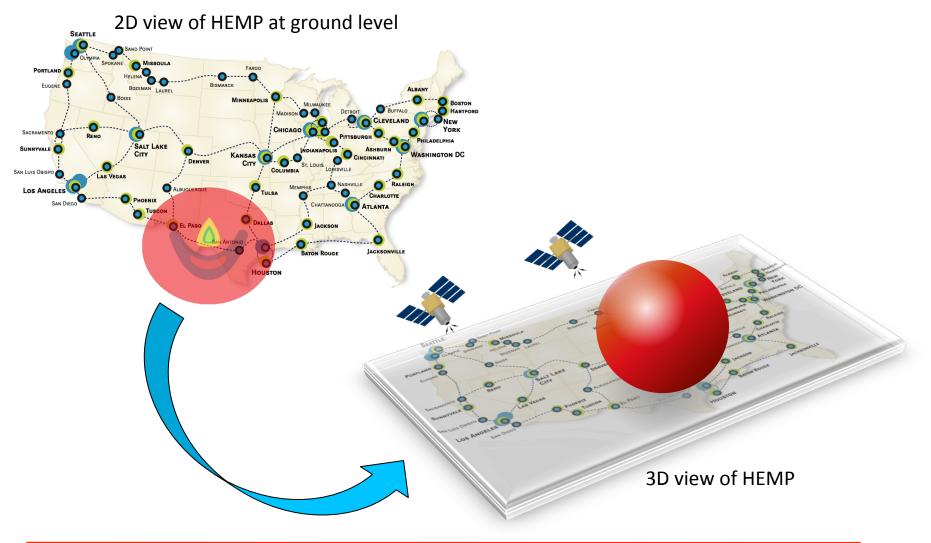*PhD Student*

Department of Computer Science
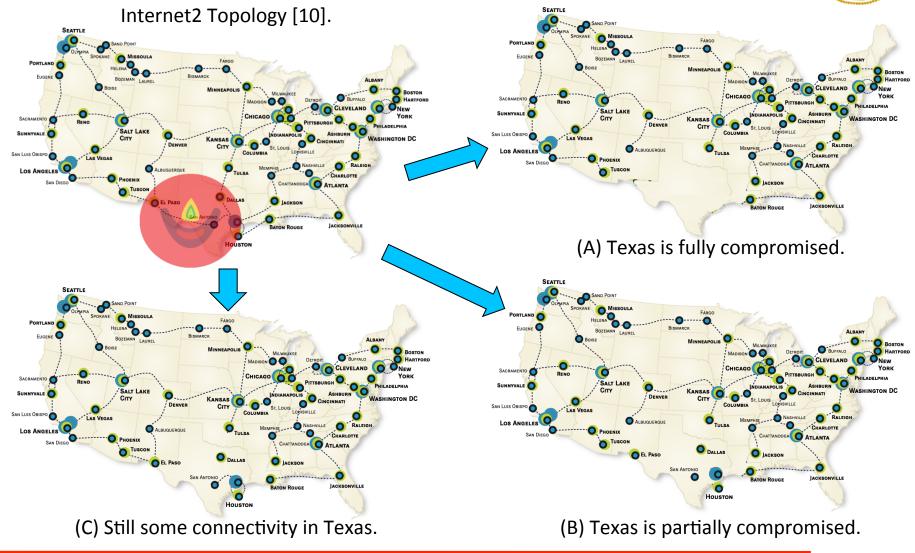*University of California, Davis*

February 12th, 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.
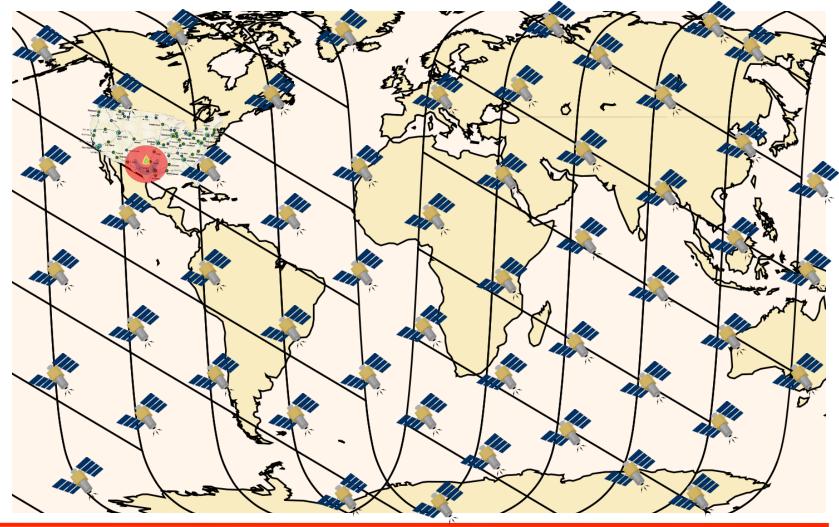
(B) Texas is partially compromised.

[10] Internet2 Network Infrastructure Topology (2015)

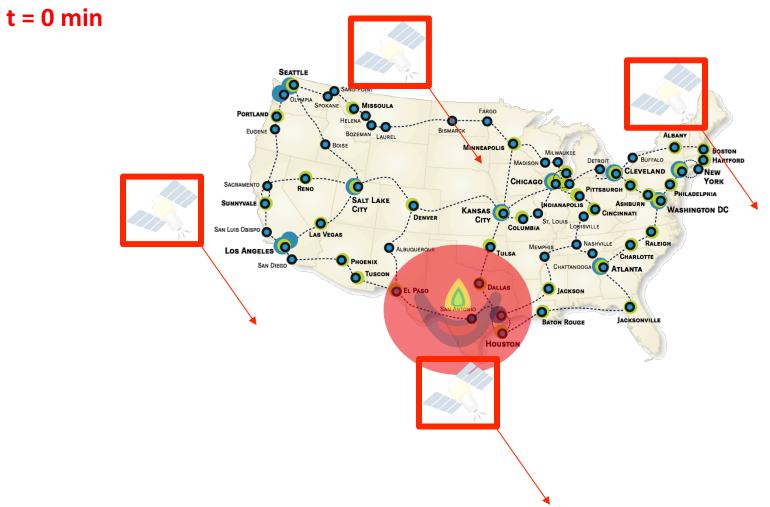# Post-HEMP Restoration with Satellite Assistance

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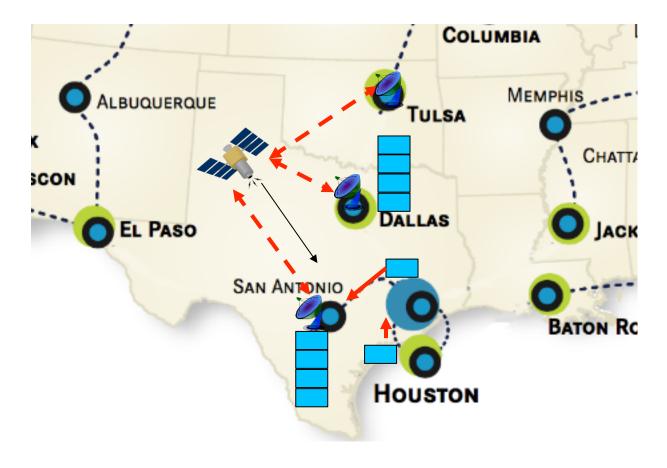
As coverage is slowly regained, buffer nodes begin evacuating queues to nearest (minimum delay) LEO satellite land station of main network:

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

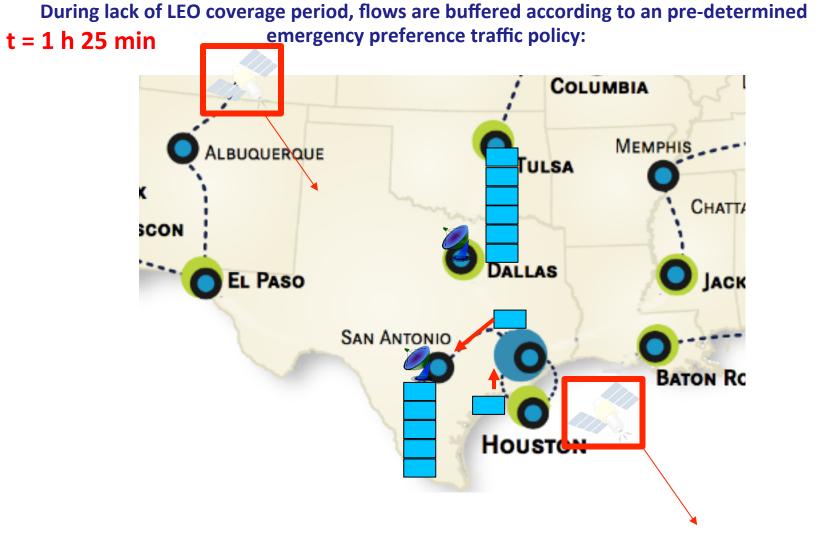**During lack of LEO coverage period, flows are buffered according to an pre-determined emergency preference traffic policy:**

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)

f Share on Facebook (5,845) Tweet in 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

f Share on Facebook (3,321) Tweet in 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

f Share on Facebook Tweet in 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

- TOTAL COVERAGE
  Internet to everyone, everywhere on Earth

- A REVOLUTION IN SATELLITE MANUFACTURING
  No one has ever built a satellite in one day... we will build several every day!

- GLOBAL LOW EARTH ORBIT CONSTELLATION
  Providing high-speed internet connectivity equivalent to terrestrial fiber-optic networks

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
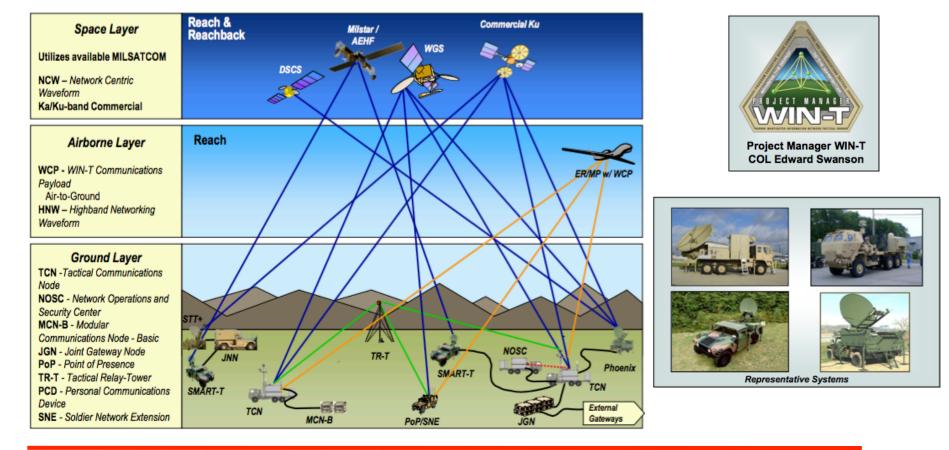
SPACEX LANDS $1 BILLION FROM GOOGLE AND FIDELITY

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

Expected
648 Satellites in 2018
750 miles above earth

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.

Space Layer

Utilizes available MILSATCOM

NCW – *Network Centric Waveform*
Ka/Ku-band Commercial

Reach & Reachback — DSCS, Milstar / AEHF, WGS, Commercial Ku

Airborne Layer

WCP - *WIN-T Communications Payload* Air-to-Ground
HNW – *Highband Networking Waveform*

Reach — ER/MP w/ WCP

Ground Layer

TCN -*Tactical Communications Node*
NOSC - *Network Operations and Security Center*
MCN-B - *Modular Communications Node - Basic*
JGN - *Joint Gateway Node*
PoP - *Point of Presence*
TR-T - *Tactical Relay-Tower*
PCD - *Personal Communications Device*
SNE - *Soldier Network Extension*

STT+, JNN, SMART-T, TCN, MCN-B, TR-T, PoP/SNE, SMART-T, NOSC, JGN, TCN, Phoenix, External Gateways

Project Manager WIN-T
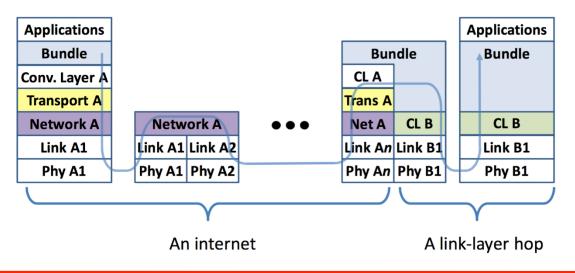COL Edward Swanson

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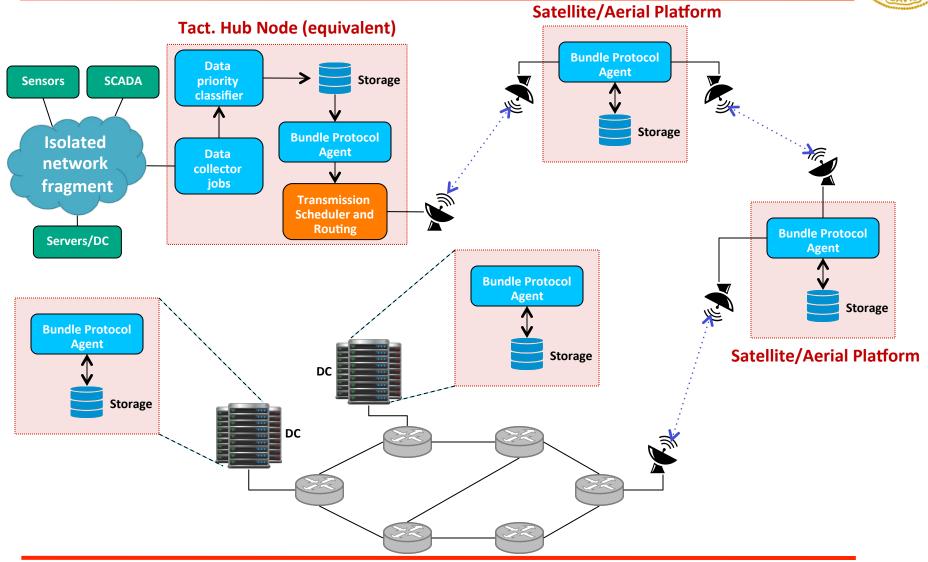
[2] Scott, Keith L., and Scott Burleigh. "Bundle protocol specification." (2007).
[3] Araniti, Giuseppe, et al. "Contact graph routing in DTN space networks: overview, enhancements and performance." Communications Magazine, IEEE 53.3 (2015): 38-46.

Proposed Architecture

Tact. Hub Node (equivalent)

Sensors

SCADA

Isolated network fragment

Servers/DC

Data priority classifier

Data collector jobs

Storage

Bundle Protocol Agent

Transmission Scheduler and Routing

Satellite/Aerial Platform

Bundle Protocol Agent

Storage

Bundle Protocol Agent

Storage

Satellite/Aerial Platform

Bundle Protocol Agent

Storage

Bundle Protocol Agent

Storage

DC

DC

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.

Optimal Routing and Scheduling for Deterministic Delay Tolerant Networks

David Hay and Paolo Giaccone, Politecnico di Torino, 2009
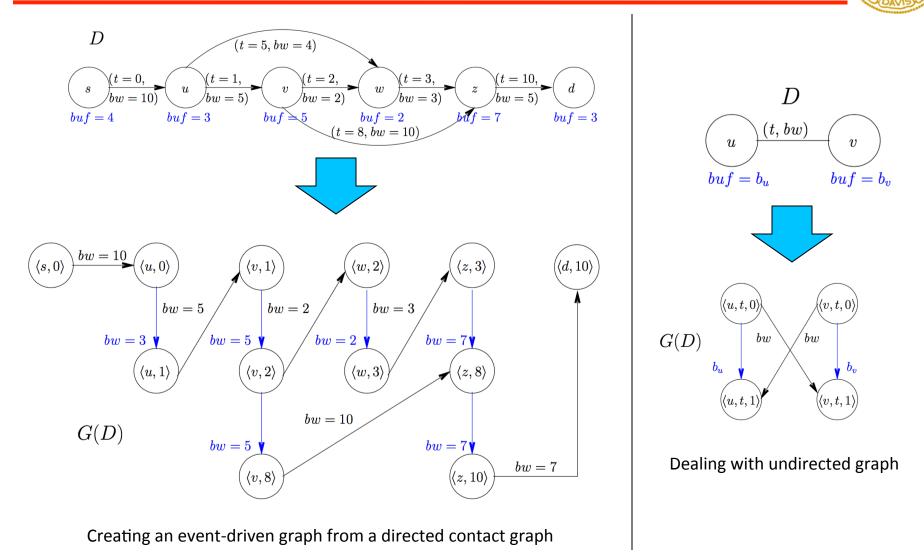
Construct a <u>time-independent</u> graph expressing the chronological order between contacts

- *Atomic contacts*: contact durations are negligible with respect to the inter-contact times

- *Contact graph*: graph where each edge is present at some specified time **t**

- *Events*: node **v** is associated with *sending event* at time **t** if there is an outgoing contact from **v** at time **t**; Node **u** is associated with *receiving event* at time **t** if there is an incoming contact to **u** at time **t**

<u>Time-independent graph</u>: each *event* is a node. Event-nodes are connected if either they are the sending and receiving event of the same contact or if both events occur on the same node and no event in that node occurs between them.

[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.

Optimal Routing and Scheduling for Deterministic Delay Tolerant Networks

Creating an event-driven graph from a directed contact graph
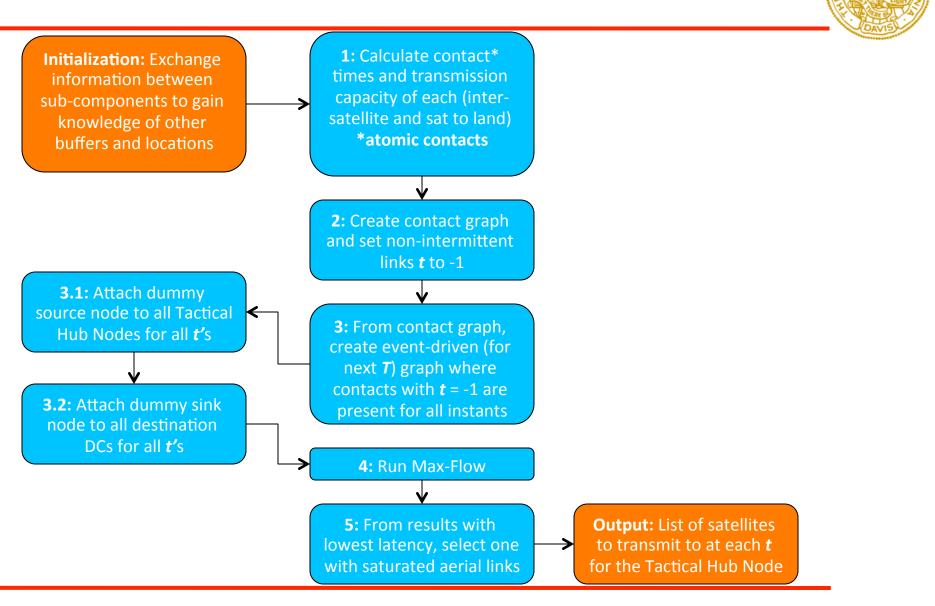
Dealing with undirected graph

[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.

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

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

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

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

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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?

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!