Post-Disaster Data Evacuation through Aerial Platforms

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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.

(B) Texas is partially compromised.

(C) Still some connectivity in Texas.

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

Initially, LEO satellite coverage would be lost:

\[ t = 0 \text{ min} \]
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:

$t = 15 \text{ min}$
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:

$t = 30\text{ min}$
Proposed Solution: Post-HEMP Restoration with Satellite Assistance

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

$t = 35\ \text{min}$
Proposed Solution: Post-HEMP Restoration with Satellite Assistance

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

\[ t = 1 \text{ h } 10 \text{ min} \]
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:

\[ t = 1 \text{ h 25 min} \]
Satellites and Aerial Platforms in the Media

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

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

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

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

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

http://www.theverge.com/2015/7/30/9074925/facebook-aquila-solar-internet-plane
**Satellites and Aerial Platforms in the Media**

[Image of SpaceX To Build 4,000 Broadband Satellites in Seattle]

[Image of Airbus and OneWeb form joint venture to build 900 satellites]

[Image of SpaceX Lands $1 Billion From Google and Fidelity]

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**SpaceX To Build 4,000 Broadband Satellites in Seattle**

by Peter B. de Selding — January 18, 2015

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**Airbus and OneWeb form joint venture to build 900 satellites**

by Peter B. de Selding — January 27, 2016

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**SPACEX LANDS $1 BILLION FROM GOOGLE AND FIDELITY**

ISSIE LAPOWSKY, BUSINESS 01.20.15 11:19 AM

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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.
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.

[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, BP sits at the application layer of some number of constituent internets, forming a store-and-forward overlay network. 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

Proposed Architecture

Tact. Hub Node (equivalent)

- Sensors
- SCADA
- Isolated network fragment
- Servers/DC
- Bundle Protocol Agent
- Data priority classifier
- Data collector jobs
- Bundle Protocol Agent
- Transmission Scheduler and Routing
- Storage

Satellite/Aerial Platform

- Bundle Protocol Agent
- Storage
- Satellite/Aerial Platform
- Bundle Protocol Agent
- Storage
- Satellite/Aerial Platform
- Bundle Protocol Agent
- Storage
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

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**

**Initialization:** Exchange information between sub-components to gain knowledge of other buffers and locations (locations, buffer, target dcs, # antennas at MTH)

1: Calculate contact times and transmission capacities (inter-satellite and sat to land)

2: Interval Overlapping: compute overlaps of contacts and, according to number of antennas in MTH, join vertexes or not (1 antenna, no joins; 2 antennas, join at max 2 per vertex, in fact \( N \text{ choose } K \))

3: Create contact graph and set non-intermittent links \( t \) to -1

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

4.1: 3D Graph – X: inter-node interim.; Y: inter node not interim.; Z: time

4.2: No edges between vertexes of one phys. node in same XY-Plane

4.2: Attach dummy source node to all Tactical Hub Nodes for all \( t’ \)s

4.3: Attach dummy sink node to all destination DCs for all \( t’ \)s

5: Run Max-Flow (or Multi-Commodity Max Flow)

6: 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
Contacts Overlapping
Creating an event-driven graph from a directed contact graph

Dealing with undirected graph

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

3D Event Driven Graph

Intra-node edges (Buffer)

Ground Station that has a buffer

Coming from some earlier contacts

Inter-node intermittent edges

Bundle arrives at DC at t4

Node a,t3

Node b,t3

Node c,t3

Node d,t4

Node e,t4

Node f,t4

Node a,t2

Node b,t2

Node c,t2

Node d,t2

Node e,t2

Node f,t2

Node a,t1

Node b,t1

Node c,t1

Node Bundle arrives at DC at t4
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.
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.
At $t = 4$:

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

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

L1 sent 150 GB. L2 and L3 sent 0.
Simple Scenario

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

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<th>TIME TO SEND</th>
<th>DST</th>
<th>TIME RECEIVED</th>
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<td>a</td>
<td>4</td>
<td>50.0</td>
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<td>3</td>
<td>N6</td>
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</tbody>
</table>
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)
Thank you!