Federated Ground Station Network Capacity Assessment

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Motivation

Existing communication systems designed for single missions and highly constrained.

- Many small satellites communicate only to one or a handful of dedicated ground stations.
- Existing ground stations are monolithic in design and largely underutilized.

Growing number of satellite developers planning science missions face ground station infrastructure limitations

- Satellites are unable to maintain 24/7 coverage with current ground stations.
- Systems are complex, non-standardized, and have reliability issues.

Potential Solution:

Federated Ground Station Network (FGSN)
Federated Ground Station Networks (FGSNs)

FGSN: Synergy of autonomous, globally distributed ground stations\(^1\)

*Internet-enabled communication system where ground stations are independently owned + loosely cooperative*

Federated Ground Station Networks (FGSNs)

FGSN Advantages:

- Communication opportunity, dynamic, flexible framework
- Science Missions: constellations capture data to avoid space and time aliasing (more than just glimpses of micro- and macro-physics)\(^1\)
- Studying the sun, heliosphere, magnetosphere, ionosphere, mesosphere, atmosphere, and climate change.\(^2\)

Potential beneficiaries:

- QB50, NPSCuL, MMC Projects
- NASA, Industry, DoD, Air Force Networks
- National Science Foundation (NSF)
- International CubeSat Community (Michigan, CalPoly, etc)

\(^1\) H. Spence and T. Moore. A retrospective look forward on constellation-class geospace missions. Fall AGU Meeting, December 2009.
1. Analytical model as a function of ground station and satellite constraints and mission requirements

2. Assess network capacity and identify trends of existing and future networks by numeric simulation

Larger Goal:

Develop robust, real-time optimization algorithms for multi-satellite missions and FGSNs
Network Capacity Model

**Capacity:** Amount of information exchanged across the network

**Capacity of Network:**

\[ C_N = \sum_{j=1}^{m} C_j(t) \]

- \( m = \# \text{Ground Stations} \)
- \( n = \# \text{Satellites} \)

**Capacity of Ground Station \( j \):**

\[ C_j = \sum_{i=1}^{n} \int_{0}^{T} a_{ij}(t) r_{ij}(t) l_{ij}(t) \eta_{ij}(t) dt \]

- \( a: \text{Availability} \)
- \( r: \text{Data rate} \)
- \( l: \text{Link feasibility} \)
- \( \eta: \text{Efficiency} \)
- \( T: \text{Period} \)

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**Ground Station Constraints:**

- Antenna size
- Scheduling conflicts
- Pointing/ slewing capabilities

**Satellite Constraints:**

- Antenna size
- Transmit/ Receive
- Power
- On-board energy
Network Capacity Model Levels

Ellipse Area: Network Capacity, decreases with increasing model fidelity

- **Maximum Model**
  - Constant ideal Link

- **Topological Model**
  - Line-of-sight Constraints

- **Scheduled Model**
  - Operational Constraints

- **Actualized Model**
  - Off-nominal Constraints
Tools

- Satellite Tool Kit (STK)® and Matlab®
- Two line elements (TLEs) for CubeSats from www.spacetrack.org
- STK/SGP4 Propagator for orbit maneuver and trajectory analysis
- Models ideal P-POD deployment (ΔV, plunger)
- Computes separation, contact times
Capacity Assessment: Example Satellites and Ground Stations

CubeSats

- Low cost, standardized access to space
- Miniaturized satellite (nanosatellite)
- Each Cube (1U): 10cm cube, 1 kg

Radio Aurora Explorer (RAX)

Example launcher: Poly Picosatellite Orbital Deployer (P-POD) standard interface between CubeSat and Launch Vehicle

Ground Stations

CubeSat Ground Station Community

Air Force Satellite Control Network (AFSCN)

Images Credit: CalPoly Website, University of Michigan CubeSat Survey, US Air Force Portal Website
Capacity Assessment

Average Daily Access Time

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Minutes/day
Percentage of satellite orbits the satellite will be in view of a ground station with minimum elevation $0^\circ$. 
Effect of Ground Station Latitude

- 3 Ground Stations in Air Force Satellite Control Network (AFSCN) to a AeroCube-2 satellite in P-POD TacSat3 launch

AeroCube-2 Satellite from Dnepr-2 Launch
Orbital Parameters

- $i = 98.04^\circ$-$98.08^\circ$
- $e_{avg} = 0.0086$
- $a = 7.085 \cdot 10^3 \text{km}$

Figure: Total Daily Access Time (sec) vs. Days from Epoch 17 Apr 2007

- GTS $\lambda = 13.6^\circ$
- NHS $\lambda = 42.9^\circ$
- TTS $\lambda = 76.5^\circ$

- $\lambda$: Ground station latitude

Legend:
- High latitude
- Mid latitude
- Low latitude
Effect of Ground Station Latitude

Simulation of Satellite at 40° Inclination using STK SPG4 Propagator
## Capacity Assessment

### Ground Station | Latitude Category
---|---
AFSCN | Multiple

**AeroCube3, CP6, Hawksat Satellites (TacSat3 Launch)**

- $i = 40.5^\circ$
- $e_{avg} = 0.003$
- $n = 15.4 \text{ rev/day}$
- $a = 6.83 \text{ km}$

**Time after Epoch**

- 43 days

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Earth Inertial Axes
1 Jul 2004 00:00:00.000  Time Step: 30.00 sec

Educational Use Only
Clustered Satellite P-POD Launch

Individual and Total Network Capacity

3 satellites from P-POD TacSat3 launch vehicle from Minotaur I
Ann Arbor Ground Station (Latitude: 42.27 N, Longitude: 83.74 W)

AeroCube3, CP6, HawkAat
Orbital Parameters

- \(i = 40.5^\circ\)
- \(e_{avg} = 0.003\)
- \(a = 6.83 \cdot 10^3 \text{km}\)
Ground Station Network to 3 CubeSats

AeroCube3, CP6, HawkAat
Orbital Parameters

$i = 40.5^\circ$
$e_{\text{avg}} = 0.003$
$a = 6.83 \cdot 10^3 \text{km}$

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Full Air Force Satellite Control Network to 3 Satellites in P-POD from TacSat3 launch vehicle from Minotaur I
Future Work & Applications

**Future Work:**

- CubeSat Survey to identify spacecraft needs
- Increase satellite and network model fidelity
- Develop real-time scheduling tools
- Dynamic optimization techniques for mission design & tactical scheduling

**Future Applications:**

- CubeSat Developers (104 users, 98 GSs, 291 antenna systems)
- Naval Postgraduate School (NPS) NPSCuL to deploy 50 1U CubeSats
- QB50 Project : 50 CubeSats science mission (*in-situ* and re-entry research)

Image Credit: USGS NASA Website
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Questions?

NASA’s First Deep-Space Internet

Photo Credit: NASA JPL Website