Federated Ground Station Network Capacity Assessment

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Motivation

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Existing communication systems designed for single missions and highly constrained.

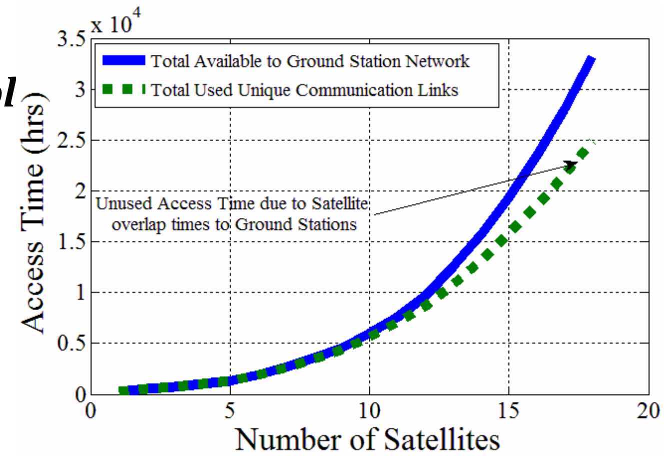
- Many small satellites communicate only to one or a handful of dedicated ground stations.
- Existing ground stations are monolithic in design and largely underutilized.

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

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

Potential Sol

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

Spangelo *et al.*

[1]J. Cutler, P. Linder, and A. Fox, "A Federated Ground Station Network," in SpaceOps Conference Proceedings, October 2002.

Federated Ground Station Networks (FGSNs)

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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)

Image Credit: NSF Government News Website

[1]H. Spence and T. Moore. A retrospective look forward on constellation-class geospace missions. FallAGU Meeting, December 2009.
[2]T. Jorgensen. The nsf cubesat program: The promise of scientic projects. Fall AGU Meeting,December 2009.

Contributions

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Motivation
Introduction
FGSN
Contributions
Network Model
Capacity Assessment
Conclusion
Future Work

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

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Capacity of Network:

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

m = # *Ground Stations*

n = # *Satellites*

Capacity of Ground Station j:

$$C_j = \sum_{i=1}^{n} \int_0^T \underbrace{a_{ij}(t) r_{ij}(t) l_{ij}(t) \eta_{ij}(t)}_{\text{Rate of data exchange}} dt$$

Rate of data exchange

a: Availability

r: Data rate

l: Link feasibility

η: Efficiency

T : Period

Network Capacity Model

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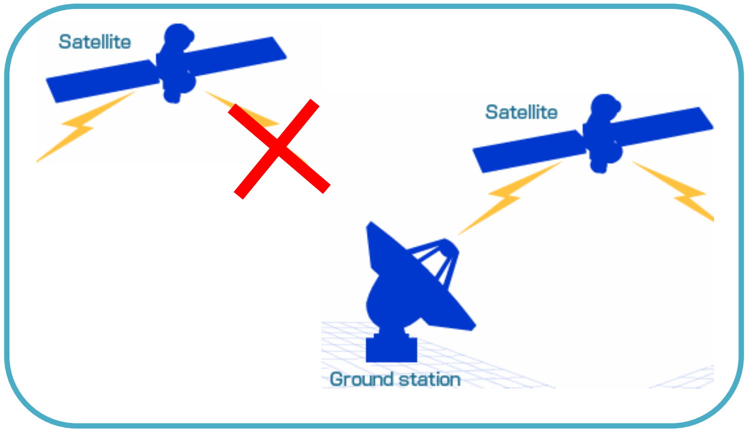
Ground Station Constraints:

Antenna size

Scheduling conflicts

Pointing/ slewing capabilities



Pow

storage

Satellite Constraints:

Antenna Size

Transmit/ Receive

On-board energy

Pointing Capabilities

Network Image Credit: NEC Microwave Tube, Ltd.
Satellite Image Credit: Falling Pixel Website

Network Capacity Model Levels

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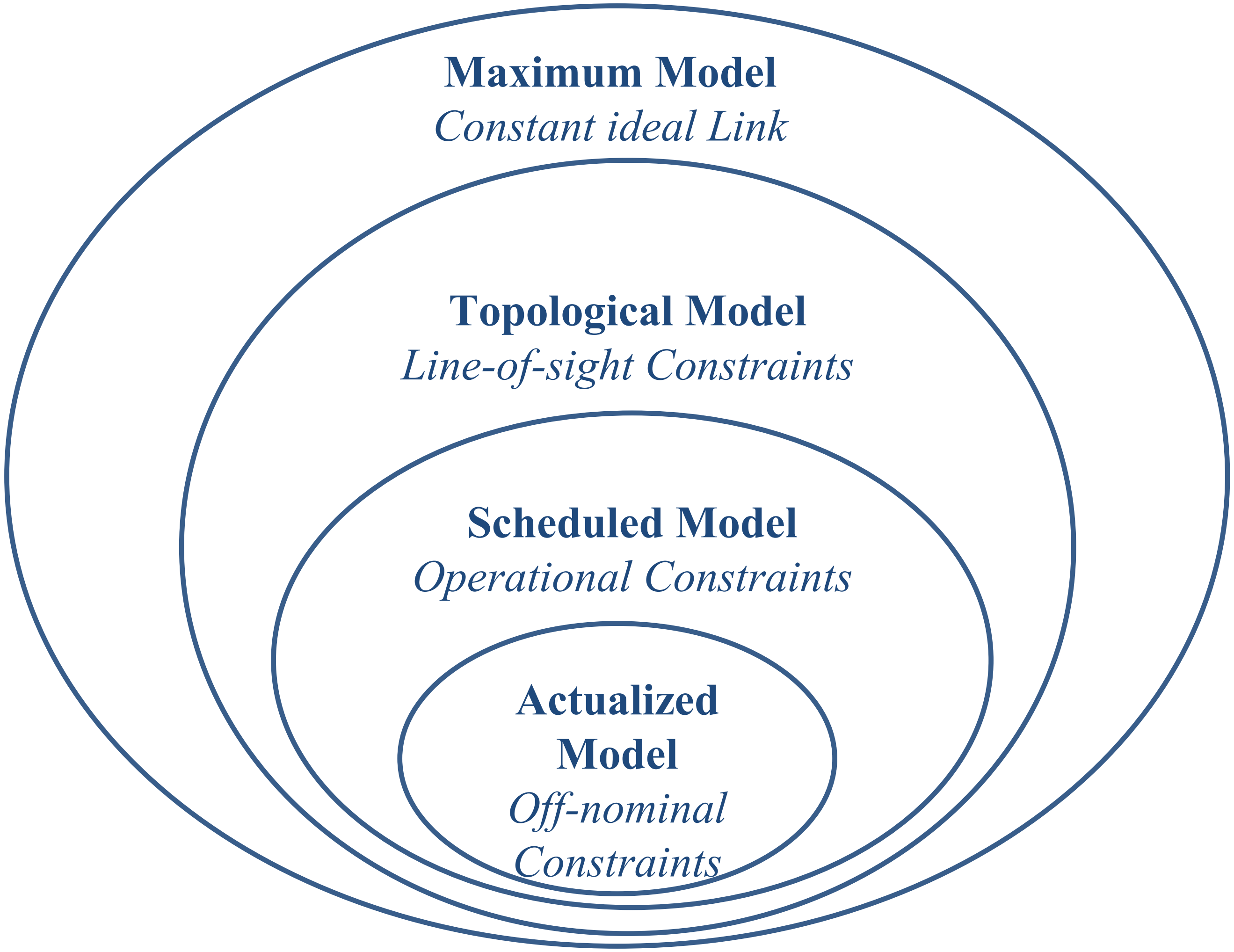
Ellipse Area: Network Capacity, decreases with increasing model fidelity



Capacity Assessment: Tools

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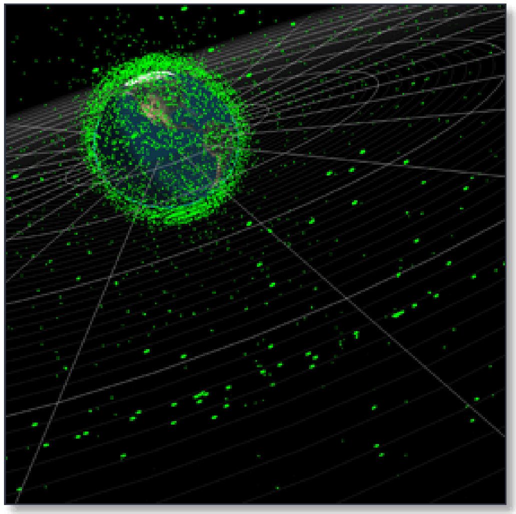
Tools



- 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

Image Credit: STK Website

Capacity Assessment: Example Satellites and Ground Stations

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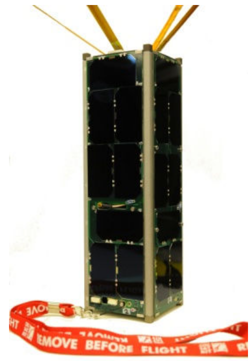
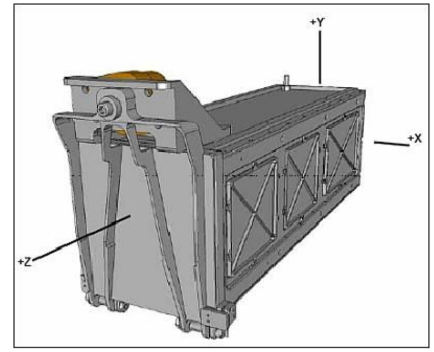
CubeSats



Radio Aurora Explorer (RAX)

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



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

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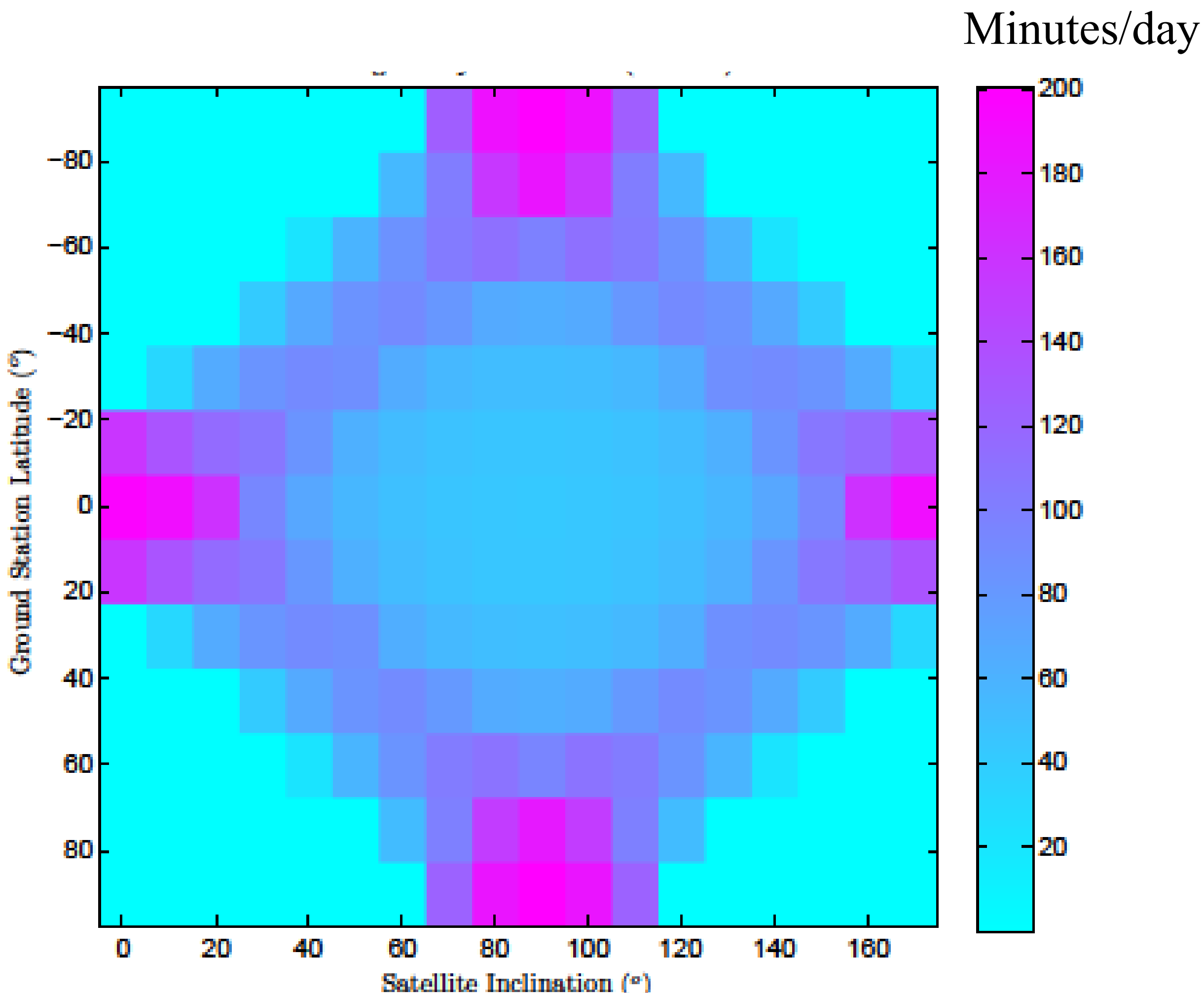
Average Daily Access Time



Capacity Assessment

Percentage coverage of Ground Stations

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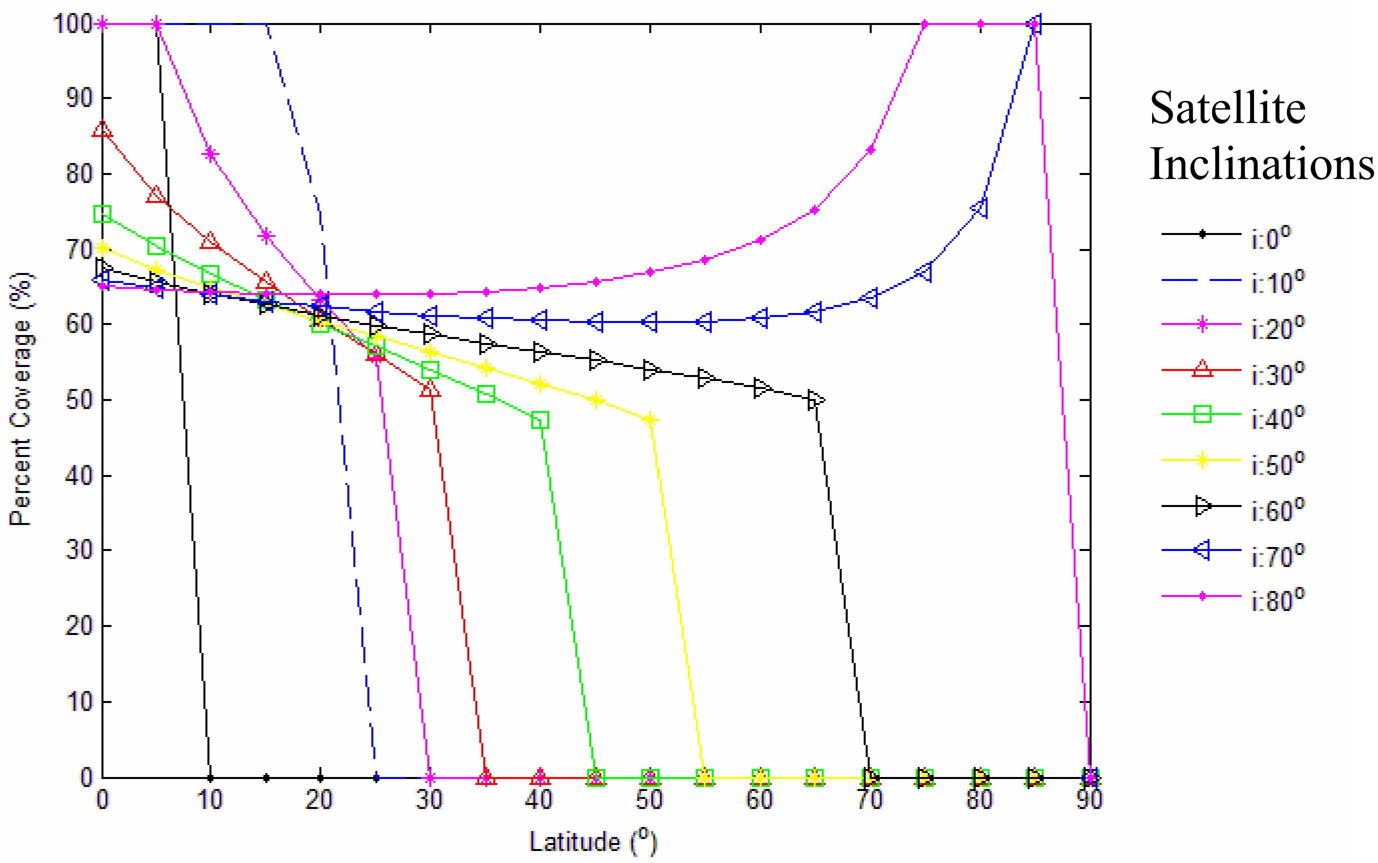

Percentage of satellite orbits the satellite will be in view of a ground station with minimum elevation 0°.

Capacity Assessment

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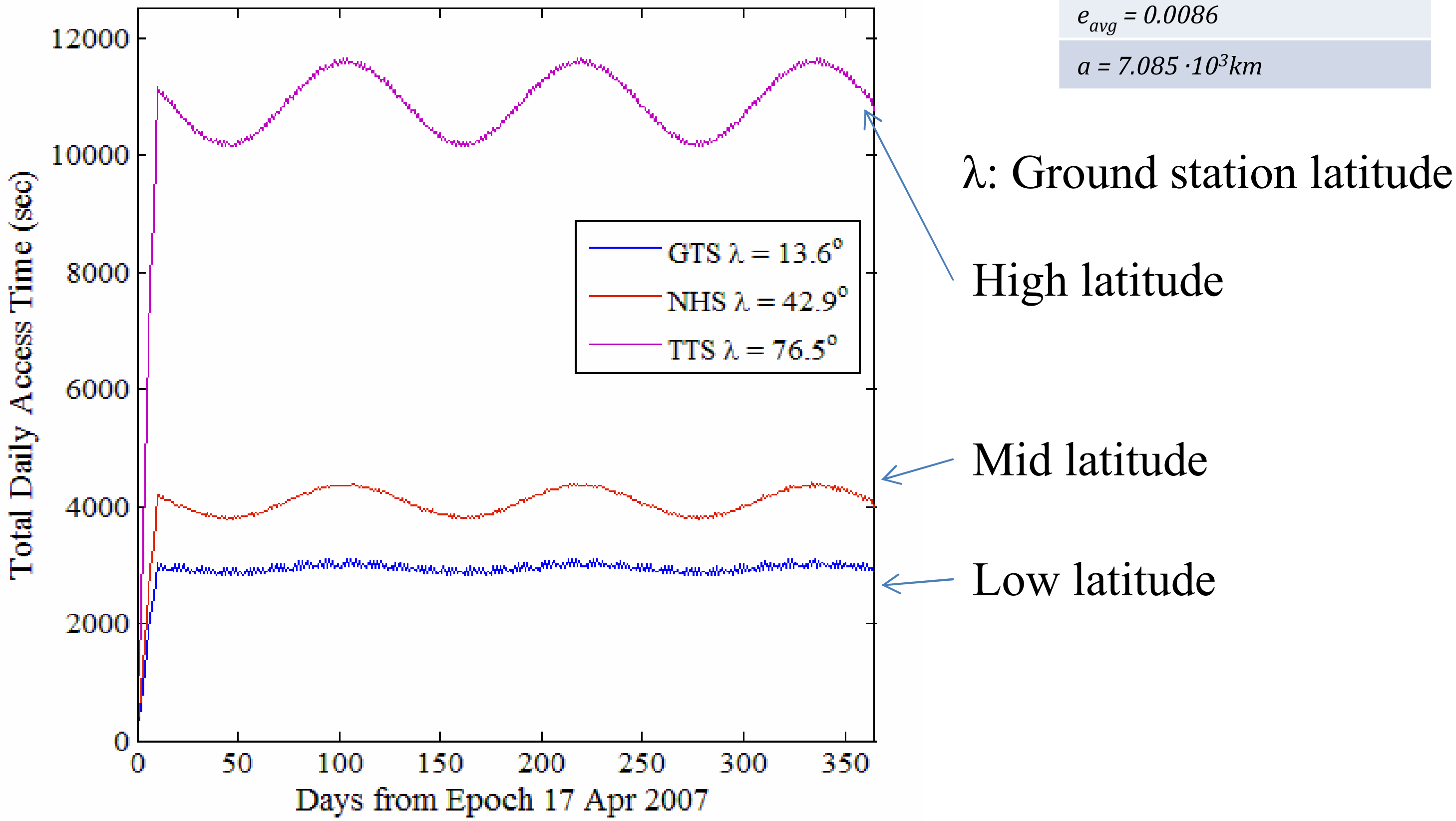
Effect of Ground Station Latitude

AeroCube-2 Satellite from Dneprt2 Launch Orbital Parameters
i- 98.04°-98.08°
e_{avg} = 0.0086
a = 7.085 ·10³km



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

Capacity Assessment

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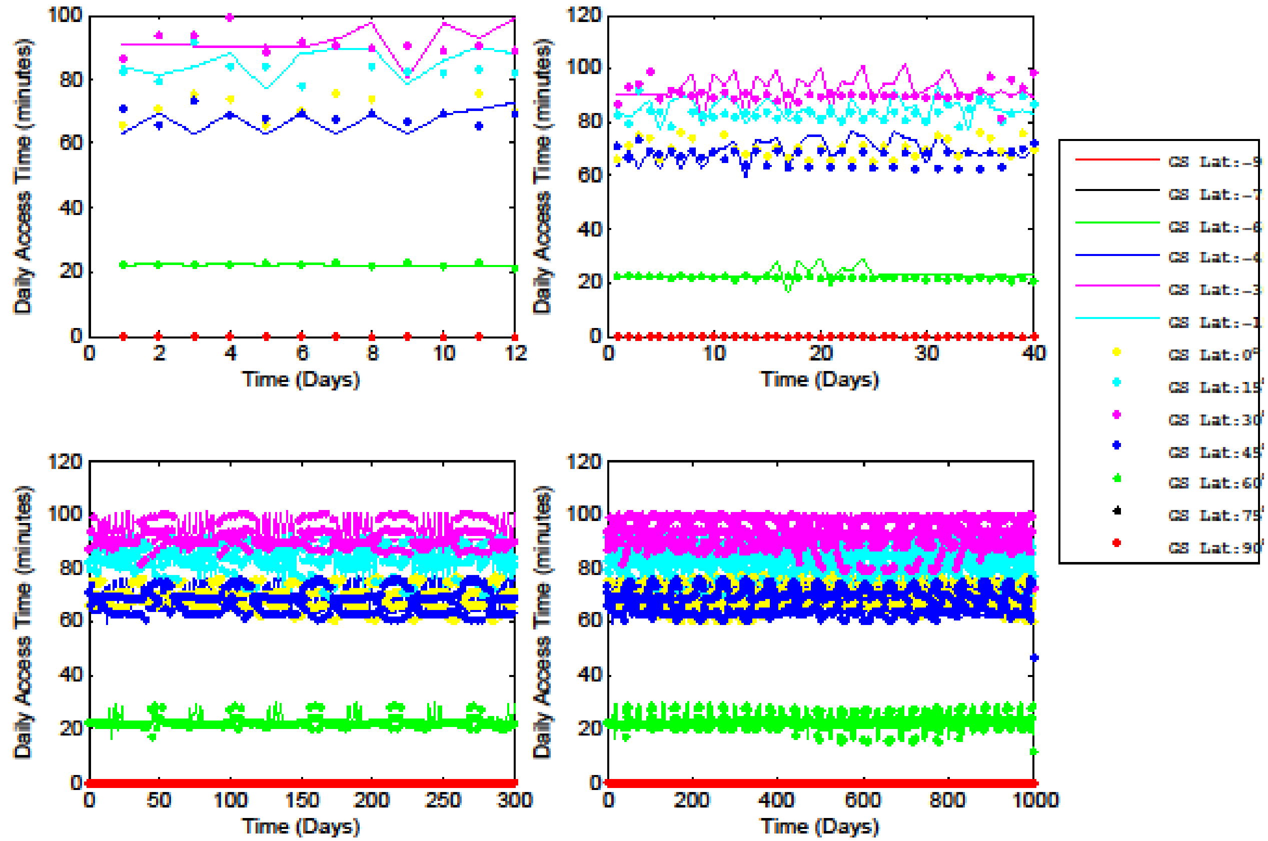
Effect of Ground Station Latitude



Simulation of Satellite at 40° Inclination using STK SPG4 Propagator

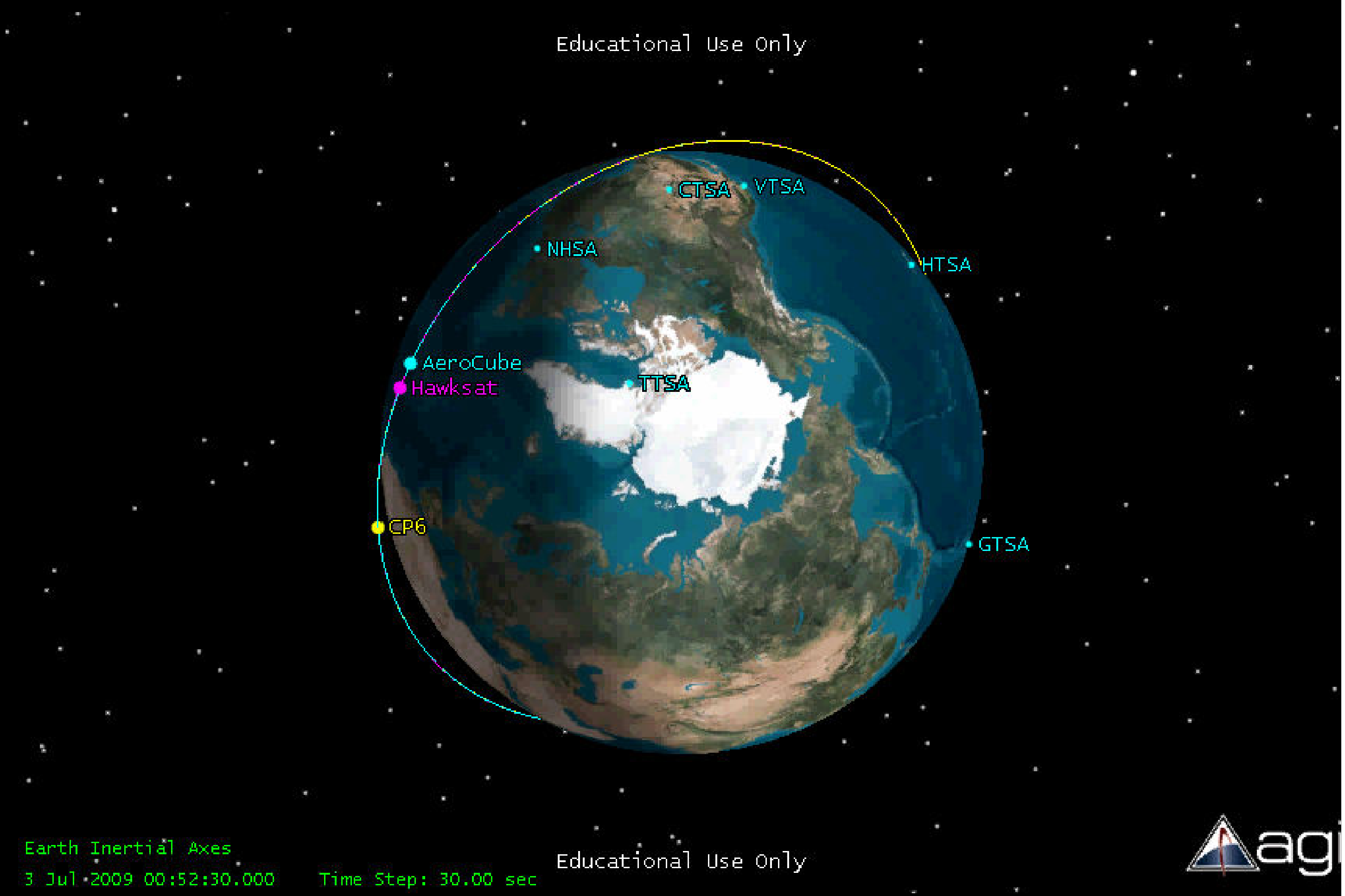
Capacity Assessment

6 Ground Stations
3 Satellites

Ground Station	Latitude Category
AFSCN	Multiple

AeroCube3, CP6, Hawksat Satellites (TacSat3 Launch)
i- 40.5º
$e_{avg} = 0.003$
n = 15.4 rev/day
a = 6.83km

Time after Epoch
43 days



Capacity Assessment

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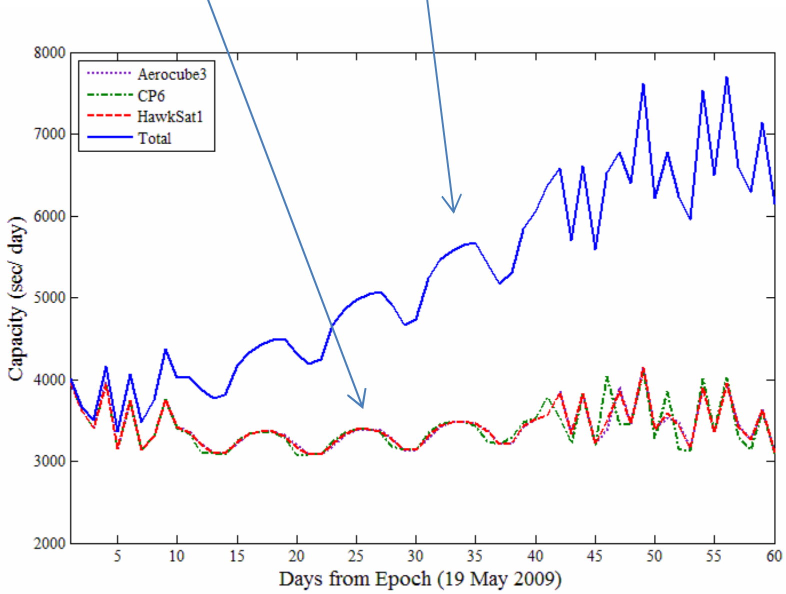
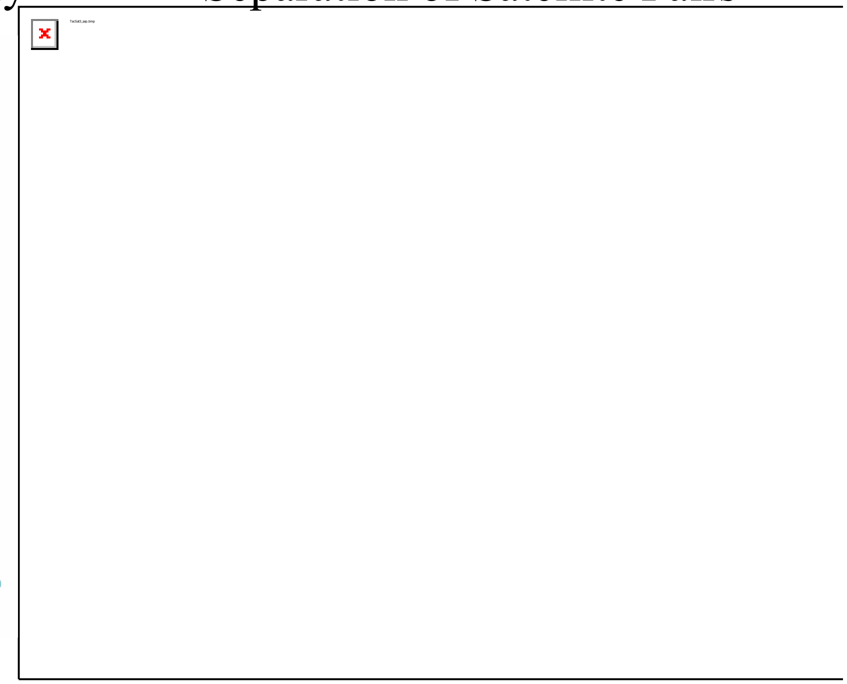
Clustered Satellite P-POD Launch

AeroCube3, CP6, HawkAat Orbital Parameters
i- 40.5º
e_{avg} = 0. 003
a = 6.83 ·10³km

Individual and Total Network Capacity



Separation of Satellite Pairs



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

Capacity Assessment

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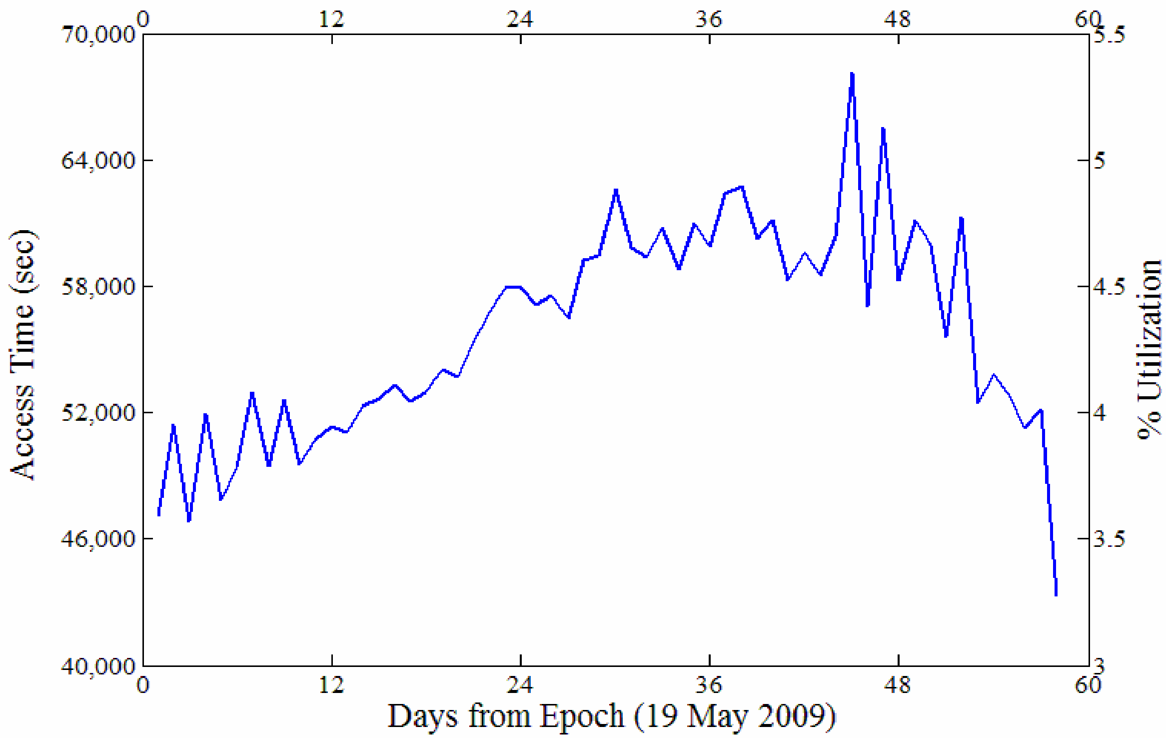
Ground Station Network to 3 CubeSats

AeroCube3, CP6, HawkAat Orbital Parameters
i- 40.5º
e_{avg} = 0. 003
$a = 6.83 \cdot 10^3$km



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

Future Work & Applications

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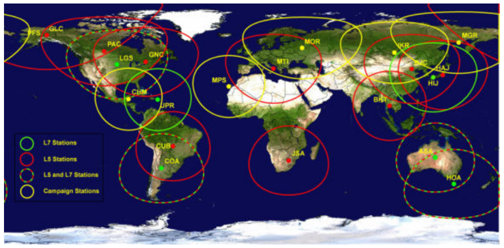
Future Work:

CubeSat Survey to identify spacecraft needs

Increase satellite and network model fidelity

Develop real-time scheduling tools



International Ground Station Network

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

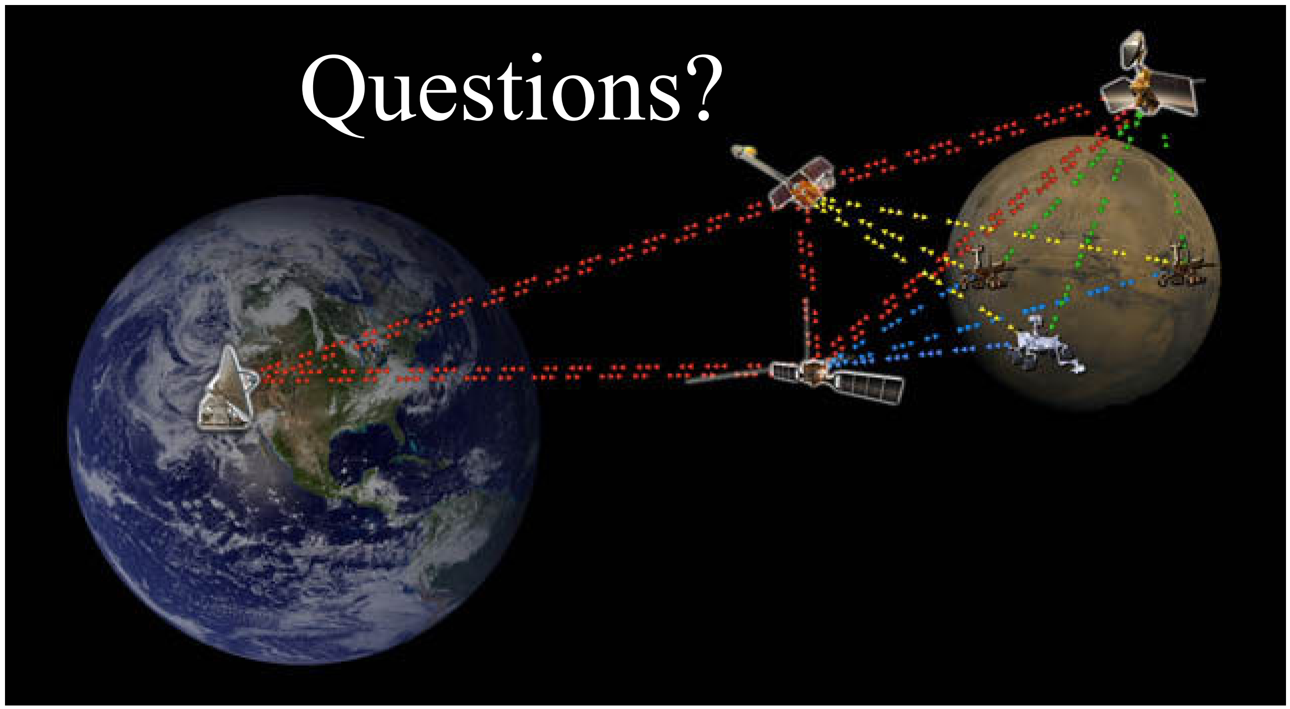
QB50 Project : 50 CubeSats science mission (*in-situ* and re-entry research)

Image Credit: USGS NASA Website

Acknowledgments

Spangelo *et al.*

- ✓ Small Satellite Research Group
- ✓ Radio Aurora eXplorer (RAX) Team
- ✓ Professor McKague & CubeSat Community
- ✓ National Science and Engineering Research Council of Canada (NSERC)
- ✓ University of Michigan Aerospace Engineering Department



NASA's First Deep-Space Internet

Photo Credit: NASA JPL Website