Ad Hoc CubeSat Constellations: Secondary Launch Coverage and Distribution

Anne Marinan
Austin Nicholas, Kerri Cahoy
Massachusetts Institute of Technology

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Outline

• Motivation
• Approach
  – Launch opportunities
  – Case Studies
• Coverage analysis and observations
  – On-board propulsion
• Conclusions
Motivation

• CubeSat Constellations
  – Higher spatial and temporal resolution
  – Smaller, cheaper satellites

• Launch challenges
  – Secondary payload – cheaper, but variable
  – Primary payload – more expensive, but guaranteed orbits of choice
Questions

- Would an ad hoc constellation give comparable science to a planned configuration?
- What would be required to make it a reality?
  - Propulsion: distribution, overcoming drag
  - Launch opportunities
CubeSat Launches

http://space.skyrocket.de/doc_sat/cubesat.htm
Broad Agency Announcement: Edison Small Satellite Flight Demonstration Missions
Case Studies

- **Case 1**
  - 2010-2011 CubeSat launch opportunities

- **Case 2**
  - 2012-2013 CubeSat launch opportunities
  - A: No on-board propulsion
  - B: On-board propulsion to distribute satellites and negate drag

- **Case 3 (Reference)**
  - 6 evenly distributed orbital planes,
  - 781 km, 86° (based on Iridium)
## Case Studies

<table>
<thead>
<tr>
<th>Case</th>
<th>Date</th>
<th>Altitude (km)</th>
<th>Inclination (°)</th>
<th>Launch Facility</th>
</tr>
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<tbody>
<tr>
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<td>5/20/2010</td>
<td>300</td>
<td>51</td>
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<tr>
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<td>98</td>
<td>Dombarovsky/Yasniy</td>
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<tr>
<td></td>
<td>10/2012</td>
<td>750</td>
<td>98</td>
<td>Sriharikota</td>
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<td></td>
<td>10/2012</td>
<td>275</td>
<td>51</td>
<td>Wallops</td>
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<td>Tyuram/Baikonur</td>
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</table>
Case 1 Launch Profile

- **July 2010**: 300 km, 51 degrees
- **August 2010**: 630 km, 98 degrees
- **September 2010**: 650 km, 72 degrees
- **October 2010**: 300 km, 35 degrees
- **November 2010**: 690 km, 98 degrees
Case 2A Launch Profile

Analysis
Coverage Analysis Assumptions

- **Focus: revisit time**
  - Average time between satellite coverage for each spot on the Earth
  - Analysis performed over 24-hour period
- **Identical 3U, 4 kg CubeSats**
  - 0.01 m² drag profile
- **Sensor footprint** – 45° cone
- **One year (or time to deorbit) satellite lifetime**
Coverage: 1 Satellite per Plane

Case 2 (Ad Hoc) vs Reference Case

- Reference case shows more frequent coverage
- 3-5 hours max revisit time for either
Creating a Constellation

• Use on-board propulsion to distribute multiple satellites across orbital planes
  – Could also use to counter orbital decay due to atmospheric drag (extend mission lifetime)

• Disadvantages:
  – Adds mass and complexity to system

• Constellation size limited by:
  – Number of satellites on each launch vehicle
  – Initial orbital altitude (duration)
On-Board Propulsion

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Inclination (°)</th>
<th>Maneuver Time [days]</th>
<th>Maneuver ΔV* [m/s]</th>
<th>Mission Life with no Drag Compensation** [days]</th>
<th>Extra ΔV for 1 Year Mission Life** [m/s]</th>
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<td>10.7</td>
<td>&gt; 405</td>
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</table>

* Assumes Isp of 1000 s

** After proper distribution has been achieved

- About a month required to distribute 6 satellites over one orbital plane
- Baseline electrospray thrusters (Isp 1000 s)
Amount of Propellant Needed

Fuel Cost of Maneuvering

- \( I_{sp} = 450s \)
- \( I_{sp} = 1000s \)
- \( I_{sp} = 2000s \)
- \( I_{sp} = 3000s \)
Orbital Positioning – 400 km

State History - 3 Satellites, 400 km Circular Orbit

Control History - 3 Satellites, 400 km Circular Orbit
Orbital Positioning – 300 km

Control History - 6 Satellites, 280 km Circular Orbit

Tangential Thrust [µN]

Time [days]
Average Revisit Time: 3 Satellites per Plane

Case 2B

Reference Case

- Case 2 maximum around 1.4 hours
- Reference case maximum around 1 hour
Average Revisit Time: 
6 Satellites per Plane

- Case 2 maximum around 1 hour
- Reference case maximum around 30 minutes
Future Considerations

• Goal – achieve revisit time comparable to reference constellation
• Higher altitudes generally better
  – Less deltaV to maneuver and distribute
  – Less fuel required to counter drag
  – Larger swath for given sensor FOV
  – But, fewer launch opportunities
• Sensitivity analysis:
  – Launch schedule
  – Available orbits
  – Sensor FOV
• Extend analysis to include all possible LEO launch options
Secondary launch opportunities are a cost-effective option for CubeSat constellations.

Without propulsion, worst-case revisit time is 5 hours.

With propulsion, worst-case revisit time is 1 hour.

On-board propulsion enables more satellites per plane (better science coverage):
- One month to distribute properly
- Combat atmospheric drag to extend mission life