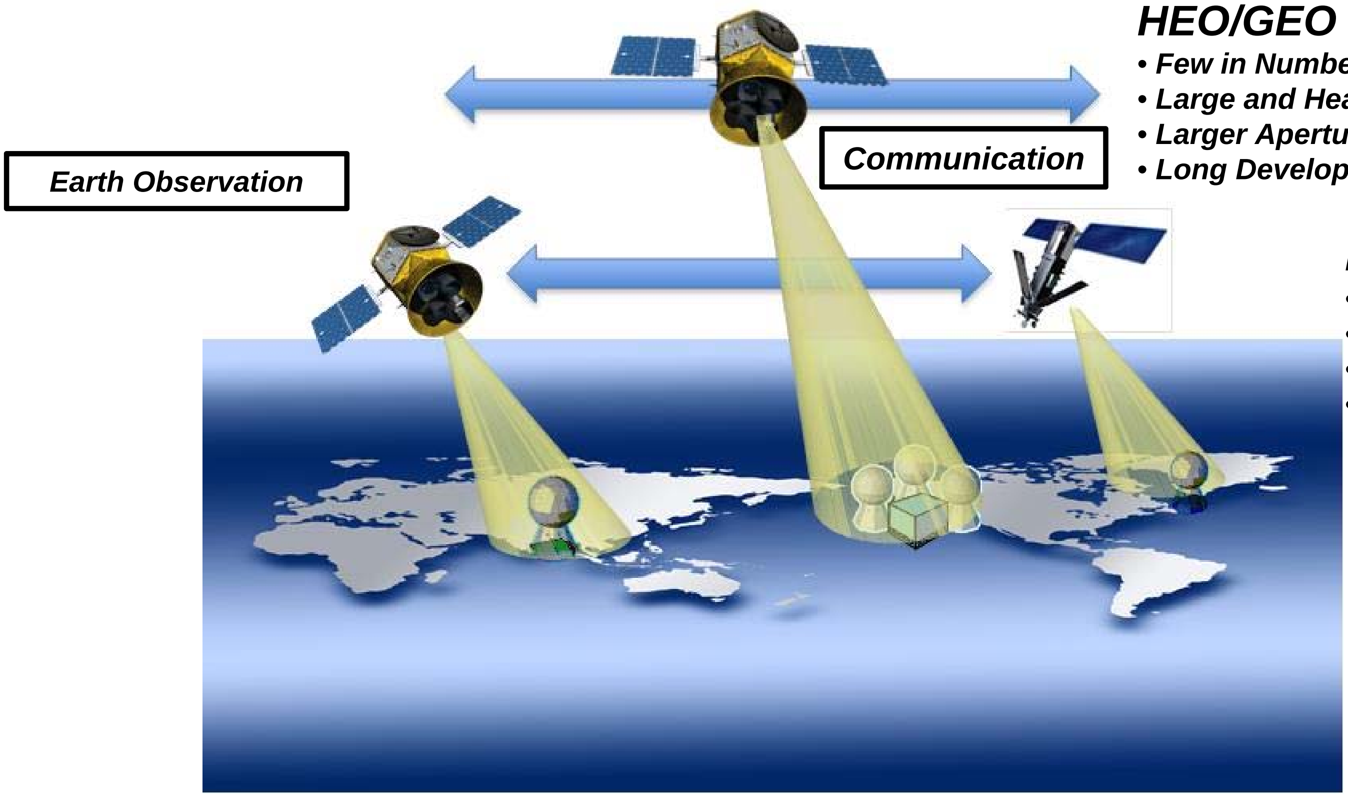
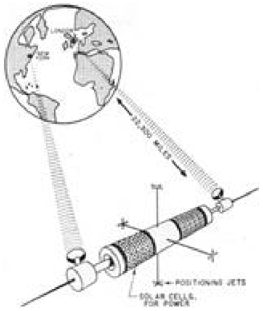
GENERAL DYNAMICS
Mission Systems

Smallsat/Cubesat – Ground Communication Methods and Limitations

Jim Startup

Satellite Missions





HEO/GEO
- ***Few in Numbers***
- ***Large and Heavy***
- ***Larger Apertures***
- ***Long Development Time***

LEO
- ***Many for Global Coverage***
- ***Smaller and Lighter***
- ***Smaller Apertures***
- ***Long Development Time***

Virtually All Missions Require Ability for Ground Systems To Communicate With On-Orbit Satellites

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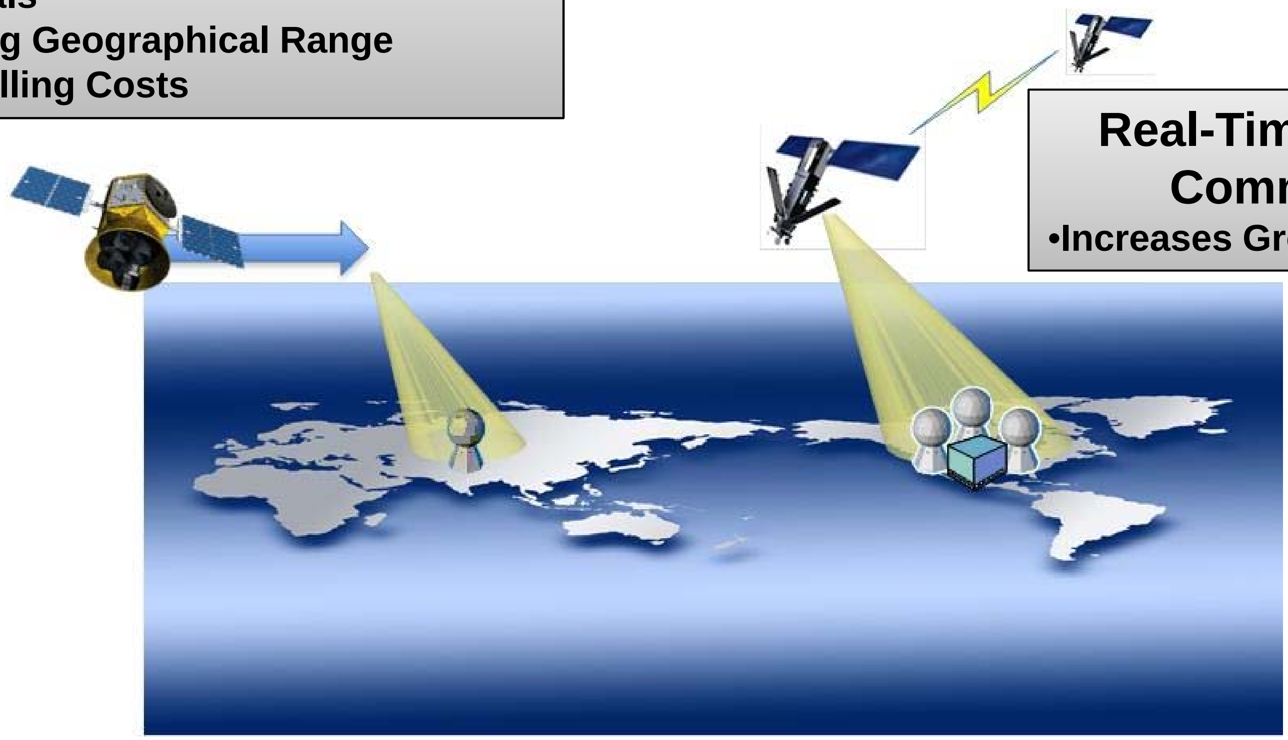
Satellite Missions

Store and Forward Systems
- **Reducing the Number of Ground Terminals**
- **Limiting Geographical Range**
- **Controlling Costs**



Real-Time/Low Latency Communications
- **Increases Ground System Costs**

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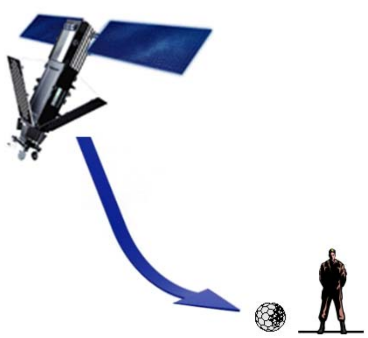
Communication Systems

Satellite System	Description	Development Time	Cost	Satellite Weight	Satellites in Constellation	Total Throw
MUOS	• GEO • Large and Heavy • Large Aperture (46 ft) • High Cost • Failure Immediately and Significantly Impacts Coverage	10 yrs	$7B	6800 lbs	4	27,200 lbs (to GEO)
Iridium	• LEO • Smaller/Lighter • Smaller Aperture (188 x 66 cm) • Lower Cost • Failure Less Catastrophic	7 yrs	$5B	1513 lbs	66	99,858 lbs (to LEO)

Extend Size/Weight/Power/Cost Benefits of Iridium™ to SmallSat Class of Satellites



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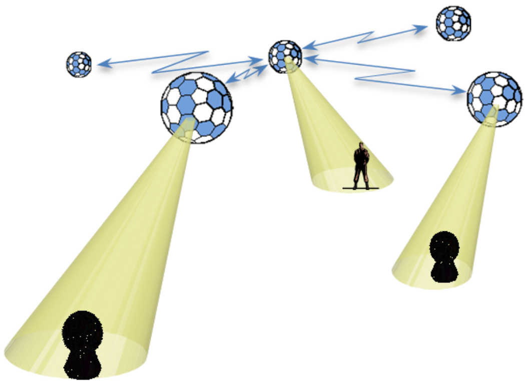
SmallSat Approach

- Proposed Approach
  - System Composed of Three Nodes (Satellite, Ground Station and User Terminal)
    - Loosely Organized LEO Fleet With Less Rigid Geometry and Needing Very Little Active Control
  - Interconnected Via Inter-Node Links to Form an Ad Hoc Mesh Network
    - Act Autonomously as Cooperative Agents to Manage Network and Efficiently Move Data From Node-to-Node
    - Requires Minimal Central Control
      - Cost Effective
      - Maintains Network Connectivity
    - All Nodes Use Autonomous Scanning/Discovery/Ad Hoc Networking Methods to Locate Peers, Negotiate Layer-1 Links and Update/Repair Network
    - All Nodes Use Software Defined Radio Technology
    - Enables Diversity Techniques



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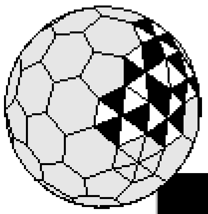
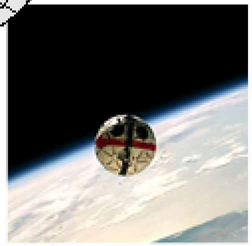
SmallSat Approach

- Satellites
  - Spherical
    - Half of the surface covered by solar arrays/half covered by multi-band antennas
    - Communication links can be formed in any direction
    - Solar pointing is not an issue
    - Performance analysis is simplified
  - Autonomously Seek and Connect With Peer Nodes
  - New Nodes Automatically Assimilated Without Disruption
  - Failing Nodes are Eliminated but Mesh Remains Viable
  - Antenna Elements Combined to Form Beams in the Direction of a Partner Node
  - Satellites Provide Ground Coverage Such That Any Point on the Ground is Covered by More Than 3 Satellites at Any Time
    - Enables Diversity
    - Failure of any satellite is automatically accommodated by nearby satellites with no disruption of service





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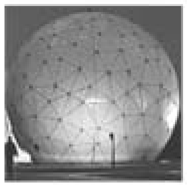
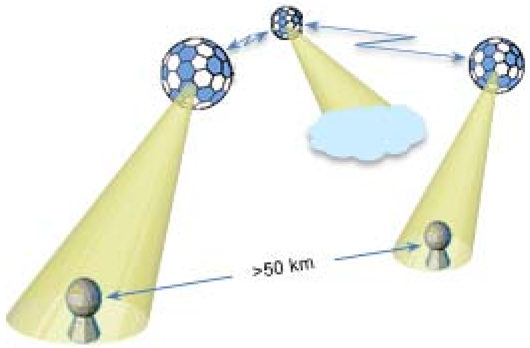
SmallSat Approach

- Proposed Approach
  - Ground Station Nodes
    - Semispherical Phased Arrays Configured to Form Beams in Any Direction
    - Act as Routing/Switching Points in the Greater Mesh
    - Architecture Accommodates multiple Ground Station Nodes With Direct Space-Ground Links to the On-Orbit Mesh
    - Can Maintain Links With Multiple Satellites
      - Potentially Supports Multiple Missions
    - Separated by at Least 50 km to Maximize Diversity Gains
      - Employs Diversity Techniques (Large Scale Site Diversity for Instance)
      - Significantly Smaller Than Dish Antennas, Which Cannot Employ Diversity
      - Mitigates Rain and Scintillation Fades
    - Placed Strategically to Provide Coverage, Capacity and Availability





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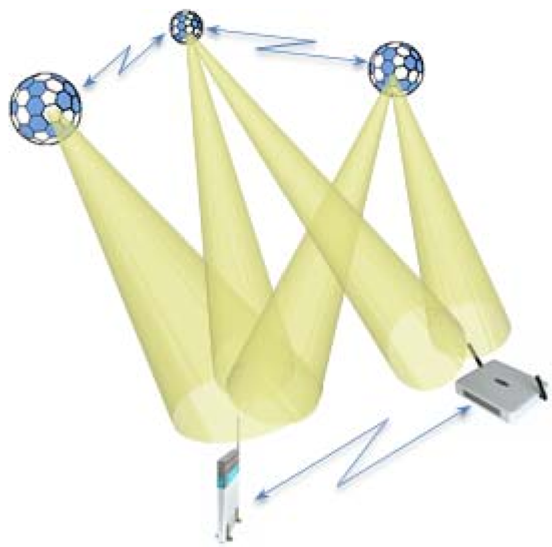
SmallSat Approach

- User Terminals
  - Small, Battery Operated
  - Fixed, Nomadic or Mobile
  - Links Established By User Terminals, Which Scan For Satellites
    - Beacon Channels From the Satellite Provide User Terminals With Access Method Information
  - Multi-Antenna Techniques Employed
  - Dynamic Frequency Re-Use Patterns
    - Satellites Distribute Re-Use Patterns Depending on User Distribution
  - Employs Cooperative Communication
    - Non-Collocated Terminals Employ Other Available “Team” Nodes to Cooperatively Transmit Information Messages Using MIMO and Space-Time Encoding Techniques



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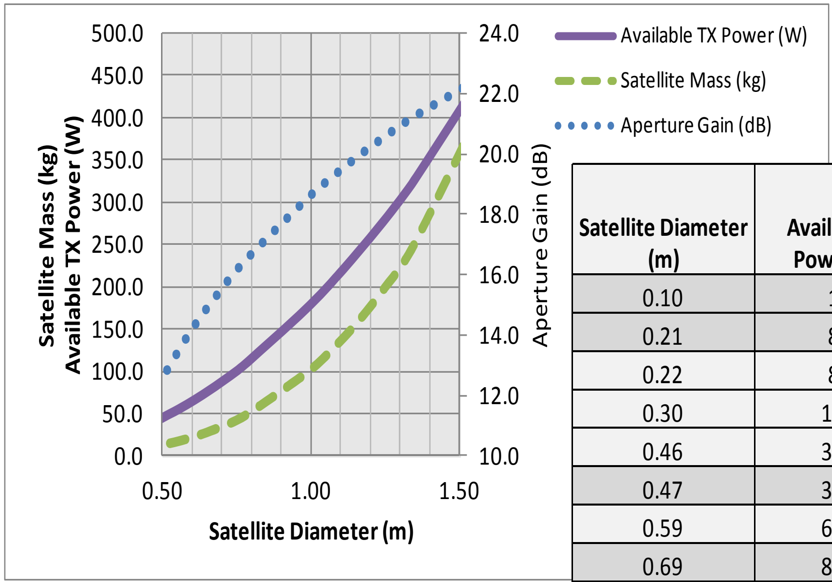
Performance

Link Performance vs. Satellite Size and Mass



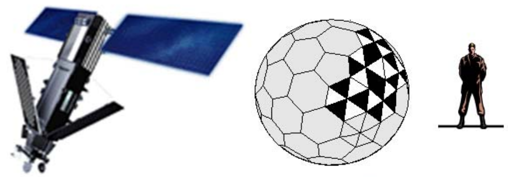
Satellite Diameter (m)	Available TX Power (W)	Satellite Mass (kg)	Satellite Weight (lb)	Aperture Gain (dB)	Satellite Type
0.10	1.8	0.1	0.2	-1.4	Picosatellite 0.1 to 1.0 kg
0.21	8.2	1.0	2.2	5.2	
0.22	8.6	1.1	2.4	5.5	Nanosatellite 1.0 to 10.0 kg
0.30	16.1	2.8	6.1	8.2	
0.46	38.0	10.0	22.0	11.9	
0.47	39.5	10.6	23.3	12.1	Microsatellite 10.0 to 100.0 kg
0.59	61.5	20.6	45.3	14.0	
0.69	84.2	33.0	72.6	15.4	
0.79	110.5	49.6	109.2	16.5	
0.99	176.4	100.0	220.0	18.6	
1.00	178.7	101.9	224.3	18.6	Minisatellite 100.0 to 500.0 kg
1.10	216.2	135.7	298.5	19.5	
1.25	279.2	199.1	438.0	20.6	
1.40	350.2	279.7	615.4	21.6	
1.70	515.7	500.0	1100.0	23.2	

Performance

Size and Mass Improvements

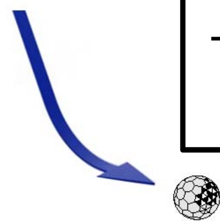
- Assume User Downlink Limited
- Start With a Spherical Satellite With Roughly the Same Performance as Iridium

Satellite System	Main Mission Antenna Gain	Weight	Transmit Power Available
Iridium	~ 24 dB	1513 lbs	~ 600 watts
SmallSat Equivalent	24 dB	1431 lbs	615 watts



Equivalent Performance

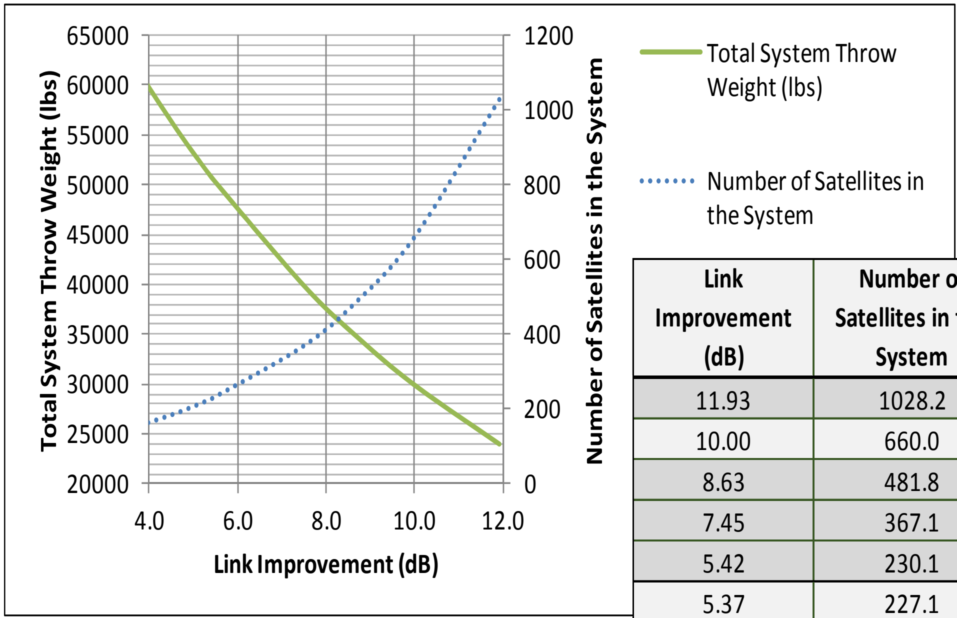
Employ Multi-Antenna Techniques To Improve Link Performance



Increase Number of Satellites to Achieve Capacity

Performance

Size and Mass Improvements



Link Improvement (dB)	Number of Satellites in the System	Satellite Mass (lbs)	Total System Throw Weight (lbs)	Satellite Type
11.93	1028.2	23.3	23941.9	Microsatellite 10.0 to 100.0 kg
10.00	660.0	45.3	29883.0	
8.63	481.8	72.6	34977.0	
7.45	367.1	109.2	40071.0	
5.42	230.1	220.0	50614.0	
5.37	227.1	224.3	50940.2	Minisatellite 100.0 to 500.0 kg
4.94	206.0	259.6	53487.2	
4.54	187.7	298.5	56034.2	
3.78	157.7	387.6	61128.2	

GENERAL DYNAMICS
Mission Systems

System Comparison

	Cost	Satellite Mass (wet)	Satellites in Constellation	Total Throw
MUOS	$7B	6800 lbs	4	27,200 lbs (to GEO)
Iridium	$5B	1513 lbs	66	99,858 lbs
SmallSat	Lower	45.3 lbs	660	29,883 lbs

- Proposed System
  - Ad Hoc, Mesh Network Employing Node Intelligence and Inter-Node Cross-Links
  - Employing Multi-Antenna Techniques
  - Less Costly
    - Launch Costs Significantly Reduced
    - Operational Costs Reduced
  - Ground Stations Can Be Shared Between Missions/Systems
    - Spreads Costs Among Many Different Systems
  - More Robust
    - Failures Gradually Degrade the System
    - Replacement Satellites are Easier and Cheaper to Launch
    - Redundancy Systems No Longer Needed (Further Reducing Mass)

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