Orbital Communication Analysis for Small Satellite Missions using the Iridium Constellation

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I. Objectives:

- Model orbital contact geometry between the Iridium constellation and CubeSat in LEO
- Analyze geometric and timing factors affecting successful message completion rate
- Compare predictions to experimental data

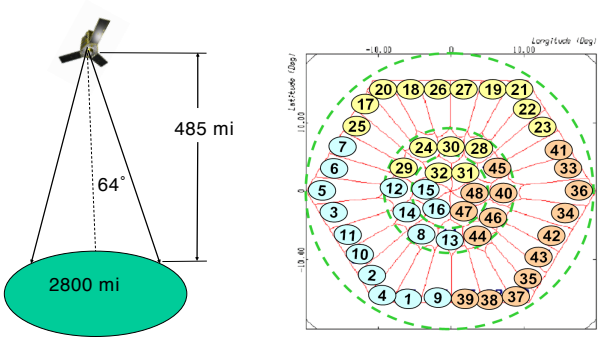

Figure 1. Iridium Spot Beam Geometry

II. AGI Systems Toolkit (STK) Modeling

- Use Iridium constellation from STK catalog
- Model Iridium satellite spot beam array geometrically
- Half cone angle of 64˚, 700 Km altitude
- Range limit of 100 to 8000 miles
- TES5 CubeSat ephemeris for modeling Satellite1
- ISS orbit @ 51˚ inclination and 350 Km altitude
- Nadir and Zenith antenna pointing cases
- Determine Line of Sight (LOS) access intervals for one day period to only one belt of Iridium constellation (6 Iridium satellites)

III. Orbital Simulation and Rate Predictions

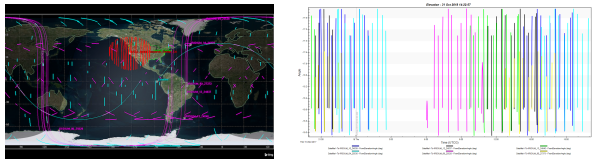

Figure 2. Nadir Case: STK Orbital Contacts

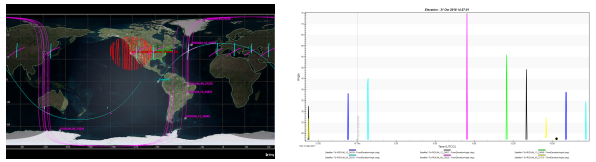

Figure 3. Zenith Case: STK Orbital Contacts

- Nadir Case shows all Iridium contacts are at limb of constellation
- Zenith Case shows all Iridium contacts are overhead
- Other attitudes are a blend of these two cases
- Contacts to Ames ground terminal are shown in red

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IV. Iridium Short Burst Data® (SBD®) Protocol Timing Analysis

- SBD® Timing: 30-50 seconds required for successful SBD transaction from cold start
- Entire SBD® transaction has to be completed while within a SINGLE spot beam
- Total pass duration > 200 seconds to meet transfer timing for outer spot beam contact
- Total pass duration > 400 seconds to meet transfer timing for inner spot beam contact
- Nadir can only make outer spot beam contacts; Zenith can make both inner and outer contacts
- Forward attitude case is blend of nadir and zenith and can make both inner and outer contacts
- Estimated TES cycle time is 35 seconds minimum: 2468 contact attempts per day
- STK was used to generate contact schedules using full constellation for an entire day
- Python script was used to statistically analyze STK pass duration for all contacts to full Iridium constellation over an entire day to generate generate figures of merit specific to a given mission scenario and analysis.

V. TechEdSat (TES) Experimental Data

TES pioneered by Marcus Murbach and TechEdSat team over multiple missions for telemetry downlink and meeting requirement of at least one command uplink per orbit

Spectrum Management: Use of Iridium for CubeSats is covered under an Experimental Short Term Authorization and additionally requires approval from Iridium Satellite LLC

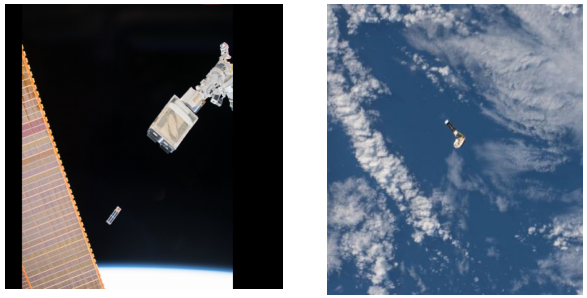

Figure 4. TES6 Deployment from ISS

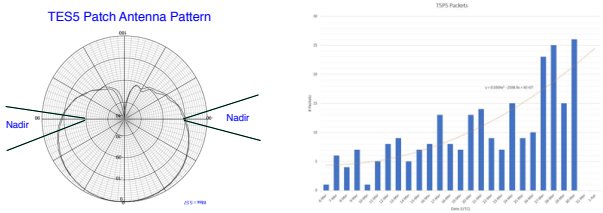

Figure 5. TES5 Antenna Pattern and SBD® Statistics

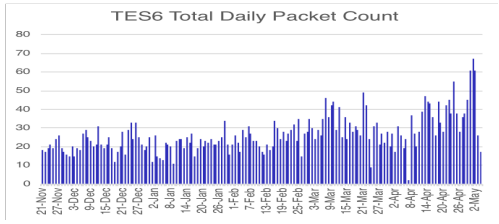

Figure 6. TES6 SBD® Statistics

VI. TES Data from Iridium Satellite Viewpoint

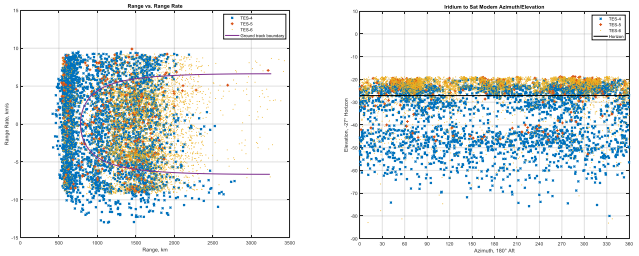

Figure 7. TES Data from Multiple Iridium Satellites
This material provided by Iridium Satellite LLC

Range/Rate and Az/EL Data for TES Missions

- Doppler shift is compensated within range of 7.5km/s (40KHz) up to 13km/s (70KHz) range rate
- Solid curve represents range/range rate boundary for normal contacts from a ground based unit
- Negative range rates are closing geometries
- Most likely the contacts occur near the limb where dwell time in a spot beam is longer
- A surprising number of contacts occur above the Earth horizon at -27°
- Iridium Sat local coordinates: 0° or 360° AZ is forward, 0° EL is local horizontal, -90° is nadir
- Max elevation of TES to Iridium is -18.5°

MISSION	High Altitude	Low Altitude
Average Message Rate	Messages/Day	Messages/Day
TES4	15	35
TES5	10	25
TES6	25	50

Figure 8. TES4 – TES6 Message Statistics

- High altitude is over 350 Km and low altitude is under 350 Km
- Probability of contact goes up with lower altitude

VII. Observations

- Ground-based terminal has good contact geometry, many contact opportunities and reasonable spot-beam intervals, allowing most SBD® transfers to complete
- Zenith pointing satellite has far fewer contact opportunities than ground terminal due to orbital and spot-beam dwell interval is half that of ground-based terminals
- Nadir pointing produces more contact opportunities, yet shorter spot beam dwell time than zenith pointing or ground terminal
- Doppler shift is within tolerance and should not constrain transfers
- Contact opportunities and spot beam timing are highly dependent upon CubeSat altitude and Iridium satellite coverage cone angle
- CubeSat modem software timing is a key variable for determining message rate

VIII. Conclusions

- Ample contact opportunities exist for all orbital attitudes, but at reduced message completion rates compared to ground terminals
- Primary constraints are the change in contact opportunities due to orbital altitude reducing contact opportunities and duration spent within the spot beams for a given contact geometry
- The Iridium link met mission objectives for the TechEdSat series, producing experimental data sets consistent with orbital analysis
- The use of Iridium for LEO CubeSat communications can provide "opportunistic" SBD® messaging over entire orbit without requiring dedicated ground stations, reducing cost and providing flexibility
- Iridium SBD® message transfer can provide low-data-rate asynchronous control and telemetry capability for Small Satellite missions tolerant to variable latency