NEXT GENERATION BROADCAST SERVICE (NGBS)
Objectives

- Current: space communications achieved through the Near Earth Network (NEN) ground terminals and the Space Network (SN)
  - The SN is composed of the Tracking and Data Relay Satellites (TDRS)
  - Requires service scheduling by Mission Operations Centers (MOCs) days in advance
  - Few spacecraft perform autonomous, on-board navigation

- Improved, future network
  - Enables user-hailed services that are autonomously scheduled by the network
  - Provides spacecraft with radiometrics and data to support autonomous, on-board navigation
  - Expands service volume
Service Description

• NGBS provides unique signals and data to *enhance user operations and enable autonomous onboard navigation*

• NGBS service consists of:
  – Global coverage via TDRSS S-band multiple access forward (MAF) service
  – Unscheduled, on-demand user commanding
  – Space environment/weather: ionosphere, Kp index for drag, alerts, effects of Solar Flares/CMEs
  – Earth orientation parameters
  – TDRS ephemerides and maneuver windows
  – PN ranging code synchronized with GPS time for time transfer, one-way forward Doppler and ranging
  – Global differential GPS corrections
  – GPS integrity

**NGBS has direct benefits in the following areas:**
• Science/payload missions
• SCaN/Network operations
• TDRSS performance
• GPS and TDRSS onboard navigation users
• Conjunction Assessment Risk Analysis
• Capabilities consistent with the modern GNSS architecture
Proposed Space Mobile Network (SMN)

- Similar to the architectural concepts that enable today’s terrestrial wireless networks
- Provides automated delivery of communication services and always available positioning and navigation capability
- User-hailing paradigm:
  - Spacecraft (“users”) autonomously request a communications link from the network
  - Network autonomously schedules comm. link, considering relative locations of user and network nodes

NGBS support of user-hailing

- Beacon concept allows access to any spacecraft within the service volume
- Signal structure allows radiometrics (range and Doppler measurements)
- TDRS Ephemerides and Maneuver Windows provide relay location and integrity

Additional benefits of NGBS

- Data to supplement and improve on-board navigation (e.g., EOPs, TEC, Kp index, DGPS)
- Forward commanding
- Space weather
**Signal Structure**

**Inphase Channel (Data)**
- PN_S 1023 chips; PN_L 16368 chips
- 2048 PN_S sequences/second, 128 PN_L sequences/second
- 2.095104 Mcps (1023x2048) spreading rate
- Rational timebase, 2105.579520 MHz (1023x2048x1005) carrier frequency

**Quadrature Channel (Pilot)**
- 10:1 power ratio on I and Q channels (Q is a dataless pilot)
- 1024 bps, CCSDS LDPC (2048, 1024) rate ½ encoded
- Designed for acquisition with zero a-priori information (lost in space)
- Designed for weak signal tracking
**Data Message**

### Frame Structure

- 1024 bits
- 1 second
- Direction of data flow from beacon, MSB first

### Data Message Allocations

<table>
<thead>
<tr>
<th>Message</th>
<th>Label</th>
<th>Size (bits)</th>
<th>Quantity</th>
<th>Refresh Interval (s)</th>
<th>Data Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASM</td>
<td>ASM</td>
<td>64</td>
<td>1</td>
<td>1</td>
<td>640</td>
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<tr>
<td>Week</td>
<td>WK</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td>160</td>
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<tr>
<td>Second of Week</td>
<td>SOW</td>
<td>24</td>
<td>1</td>
<td>1</td>
<td>240</td>
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<tr>
<td>Frame ID</td>
<td>FID</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>80</td>
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<tr>
<td>GPS Integrity</td>
<td>A</td>
<td>184</td>
<td>10</td>
<td>10</td>
<td>1840</td>
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<tr>
<td>GPS Differential Corrections</td>
<td>B</td>
<td>72</td>
<td>32</td>
<td>10</td>
<td>2304</td>
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<tr>
<td>TDRS Ephemerides</td>
<td>C</td>
<td>200</td>
<td>10</td>
<td>10</td>
<td>2000</td>
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<tr>
<td>User Commands</td>
<td>D</td>
<td>200</td>
<td>4</td>
<td>10</td>
<td>800</td>
</tr>
<tr>
<td>Spares</td>
<td>E</td>
<td>200</td>
<td>4</td>
<td>10</td>
<td>800</td>
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<tr>
<td>Space Environment</td>
<td>F</td>
<td>152</td>
<td>3</td>
<td>10</td>
<td>456</td>
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<tr>
<td>Ionsphere</td>
<td>G</td>
<td>200</td>
<td>1</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>Solar flux</td>
<td>H</td>
<td>128</td>
<td>1</td>
<td>10</td>
<td>128</td>
</tr>
<tr>
<td>Earth Orientation</td>
<td>I</td>
<td>48</td>
<td>1</td>
<td>10</td>
<td>48</td>
</tr>
<tr>
<td>TDRS Health &amp; Safety</td>
<td>J</td>
<td>200</td>
<td>1</td>
<td>10</td>
<td>184</td>
</tr>
<tr>
<td>Unused</td>
<td>U</td>
<td>200</td>
<td>1</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>CRC</td>
<td>CRC</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td>160</td>
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<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>10240</strong></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

- Data message in a framed structure, 10 seconds to broadcast entire message.
- ~80 bps on average allocated to user command. With spares & unused, 180 bps.
- Goal to achieve 2048 bps data rate. If achieved, 1024 bps will be allocated for user commands.
SYSTEM ARCHITECTURE
• 2\textsuperscript{nd}/3\textsuperscript{rd} gen TDRS used to broadcast NGBS beacon
• MA forward (MAF) array can be split to provide two simultaneous MAF services
  – Current Space Network ground system does not support this capability
• MA return (MAR) array supports Demand Access Service (DAS)
• In concert with DAS, NGBS will provide a unique anytime/anywhere two-way communications channel
• **Data Integrator (DI)** located at WSC
• **Message Formatters (MF)** located in each NGBS enabled ground system
**User Element**

**Signal Processing (FPGA)**
- TDRSS/NGBS
  - TDRSS spread-spectrum
  - NGBS spread-spectrum
  - Unaided weak signal acquisition
  - Weak signal tracking
  - Coherent tracking
  - LDPC rate ½ decoder
  - Multichannel capability

**GPS**
- Navigator L2/L2 GPS receiver
- Unaided weak signal acquisition
- Weak signal tracking
- 24 channel capability

**Navigation (Host Processor)**
- GPS/Transponder housekeeping
- GEONS Extended Kalman Filter
- Monitor & Control
- Time Output (1PPS/10 MHz)

**G/T ≥ -28.2 dB/K**

**S-band Dual Omni/Hemi**
- L-band Hemi(s)

**FPGA/Processor Slice**
- S-Band RF Slice
- SSA/MA
- L-Band RF Slice
- GPS L1/L2

**GPS/TDRSS/TASS Transponder**
CURRENT STATUS
Coverage Analysis

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Orbit</td>
<td>Low inc LEO, SSO LEO</td>
</tr>
<tr>
<td>User Antenna</td>
<td>-3 dB ISO, GPS, MMS, LADEE</td>
</tr>
<tr>
<td>MAF Configuration</td>
<td>4 Element</td>
</tr>
<tr>
<td>NGBS Constellation</td>
<td>3 nodes, 5 nodes</td>
</tr>
</tbody>
</table>

- Static link parameters combined with dynamic STK/MATLAB analysis
  - NGBS & user antenna models
  - Slant range
- Analyzed all combinations of NGBS constellation, user orbit, and user antenna models
Coverage Analysis

- Analysis incorporates 36 dBW peak EIRP, conservative user terminal G/T
- 3 TDRS constellation can provide global coverage with a 1024 bps data rate
- 1024 bps link is robust, 2048 has positive (slight) margin

<table>
<thead>
<tr>
<th>Orbit</th>
<th>User Antenna Model</th>
<th>% Availability</th>
<th>Outage Duration (Minutes) 90% Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS</td>
<td>GPM</td>
<td>98.46</td>
<td>0.45</td>
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<tr>
<td>ISS</td>
<td>-3 dB ISO</td>
<td>100.00</td>
<td>0.00</td>
</tr>
<tr>
<td>ISS</td>
<td>MMS</td>
<td>99.97</td>
<td>0.00</td>
</tr>
<tr>
<td>ISS</td>
<td>LADEE</td>
<td>100.00</td>
<td>0.00</td>
</tr>
<tr>
<td>SSO LEO</td>
<td>GPM</td>
<td>92.16</td>
<td>0.67</td>
</tr>
<tr>
<td>SSO LEO</td>
<td>-3 dB ISO</td>
<td>100.00</td>
<td>0.00</td>
</tr>
<tr>
<td>SSO LEO</td>
<td>MMS</td>
<td>100.00</td>
<td>0.00</td>
</tr>
<tr>
<td>SSO LEO</td>
<td>LADEE</td>
<td>100.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
- Objective 1: validate 4 element array beam pattern and peak EIRP
- Objective 2: quantify 2nd gen TDRS MAF EIRP margin

SCaN TestBed used to validate EIRP contours

Ground measurements taken at WSC & GRC
Ground Element

Legacy SN Ground System

SGSS Architecture

• SN Ground Sustainment System (SGSS) architecture will:
  – Enable dual MAF capability built into 2nd and 3rd generation TDRS
  – Allow for low cost insertion of NGBS ground system hardware
  – Reduce one-way forward ranging errors

• Data Integrator (DI) and Message Formatter (MF) software under development
  – User commands transmitted through the system
  – TDRS ephemeris and space weather data sources were streamed from recorded data
  – Data ingest of real time GDGPS data from JPL
  – Data was modulated on a S-band carrier, demodulated, and decoded

Real time data connection from JPL
User Element

• NGBS terminal combines following mature technologies:
  – Navigator GPS
  – TDRSS transponder waveform
  – NGBS receiver waveform
  – Goddard Enhanced Onboard Navigation System (GEONS) flight software
  – SpaceCube 2.0 hardware

• STP-H6 provides a low-cost opportunity to flight qualify NGBS terminal
  – Launches in Dec 2018

• NBGS terminal intellectual property:
  – Deployable on lower SWAP hardware platform
  – Opportunity for smallsat/cubesat community

ML605 breadboard development platform

NavCube Engineering Test Unit with GPS + SpaceCube flight components
Potential for Initial Operational Capability

- Strategic opportunity exists:
  - Launch of TDRS-M in Oct 2017 will provide 6 NGBS capable spacecraft
  - SGSS necessary for NGBS ground implementation
  - STP-H6 provides a low cost opportunity to fly NGBS user element and demonstrate NGBS on orbit
  - NGBS user element is built on mature Navigator GPS receiver technology

- NGBS is a first step in advancing the next generation network paradigm as laid out in Space Mobile Network
  - Lessons learned from NGBS will inform beacon service on 4th gen TDRS
Closing Thoughts...

• **NGBS:**
  – With DAS, enables user-hailed services that are autonomously scheduled by the network
  – Provides spacecraft with radiometrics and data to support autonomous, on-board navigation and operations
  – Provides capabilities fundamental to the Space Mobile Network concept

• A fully operational beacon service will go beyond current implementation of NGBS:
  – Specifically designed service on “4th gen” TDRS could provide increased data rate and also a greater service volume
  – Earth based beacons could offer much higher EIRP for users in HEO or cis-Lunar space

• **Engagement from the user community is key**