National Aeronautics and
Space Administration

Enabling Communication and Navigation Technologies for Future Near Earth Science Missions

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David J. Israel, Gregory Heckler, Robert Menrad, John Hudiburg, Don Boroson, Bryan Robinson, and Donald Cornwell

Introduction

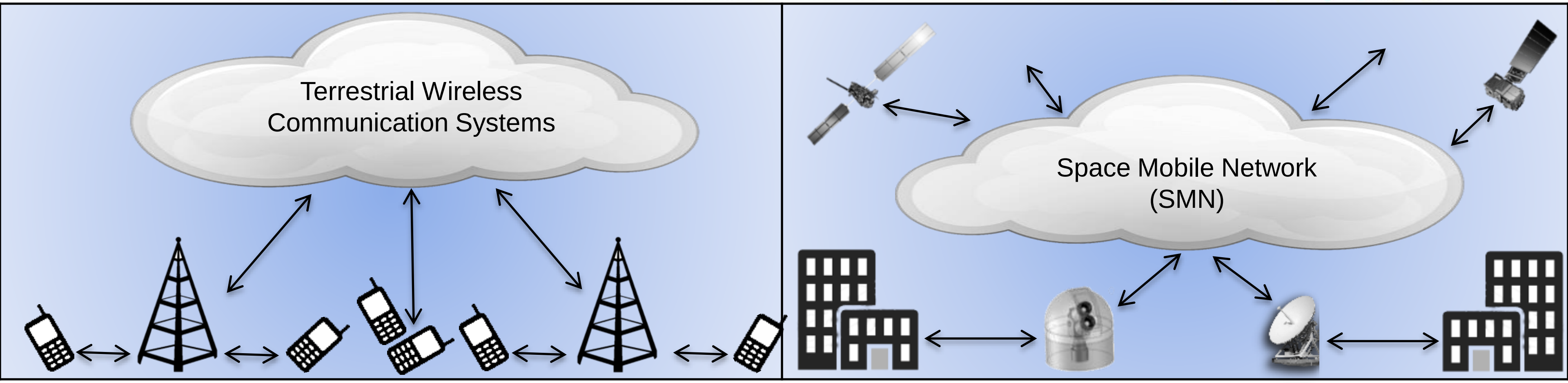
- Authors: David J. Israel, Greg Heckler, Robert J. Menrad, John J. Hudiburg, Don M. Boroson, Bryan S. Robinson, and Donald M. Cornwell

- NASA's Space Communications and Navigation (SCaN) Program chartered the Earth Regimes Network Evolution Study (ERNESt), which was completed in May 2015.

- NASA's Goddard Space Flight Center (GSFC) led study to create a next generation near-Earth space communications and navigation architecture for 2025 and beyond.

- Next Generation Architecture Goals:
  - Provide communication and navigation services to missions within 2M kilometers of the Earth (just beyond the Earth-Sun L2 point).
  - Customizable and scalable
  - Include industry and international partners
  - Advance new science and technologies
  - Reduce commoditized costs

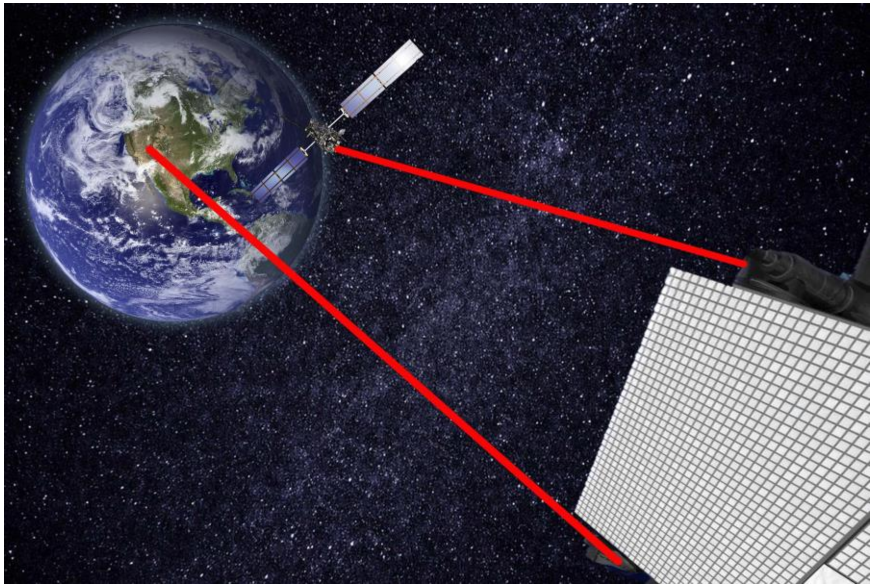
The Space Mobile Network



- The resulting architectural framework was named the “**Space Mobile Network (SMN)**” to accentuate the focus on the user experience with analogies to the terrestrial mobile wireless smartphone user experience
  - Increased availability and accessibility of services
  - Once connected to “the cloud,” services, sources, and destinations are available
  - Minimize user burden including the Size, Weight, and Power (SWaP) required for the flight systems.
- Key Enabling Technologies
  - Optical Communications
  - Delay/Disruption Tolerant Networking
  - User Initiated Services
  - Position, Navigation, and Timing Technologies

Optical Communications

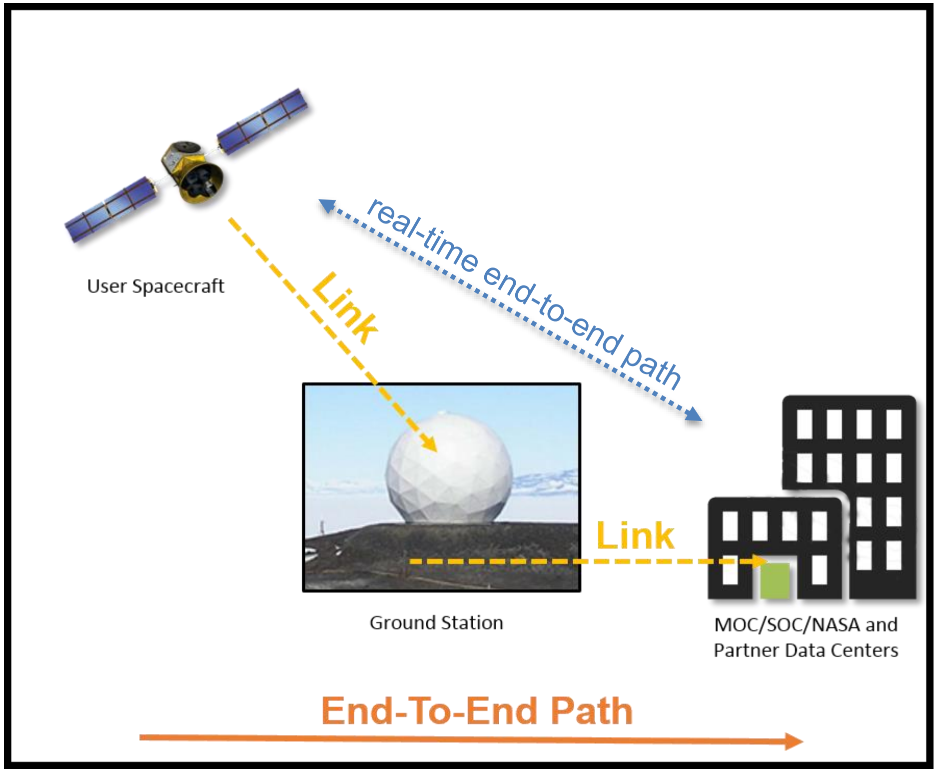
- Optical Communications enable the SMN through
  - Increasing maximum data rates by orders of magnitude
  - Reducing the Size, Weight, and Power of user and provider systems
- Relay Applications
  - Single Access links: Higher data rates available via relay with smaller user and relay systems
  - Multiple Access
    - Array of 3.2-cm telescopes could provide 10 Mbps duplex service to 100 simultaneous users with a square array less than about 40-50 cm on a side
    - A more robust and faster system, though, could be based on a wide field-of-view telescope (viewing the entire globe) with its image mapped onto a focal plane array of detectors, such as a camera
    - Greatly reduced user burden, when compared to an RF-based multiple access system, may allow for ubiquitous use of MA system
- Direct-to-Earth (DTE) Applications
  - Potential for extremely high data rates (10's to 100's of Gbps)
  - Low-cost and small ground terminals may allow for data delivery direct to science centers or other user locations



Delay Tolerant Users – Two Types of Latency Requirements

- ***"Get this data to its destination"***
  A mission with science data delivery timeliness requirements, possibly real-time (two-way voice /video, commands & telemetry, science alerts, telerobotics, etc.) will be concerned about the effective data rate between the user platform and data destination (i.e. an end-to-end path).

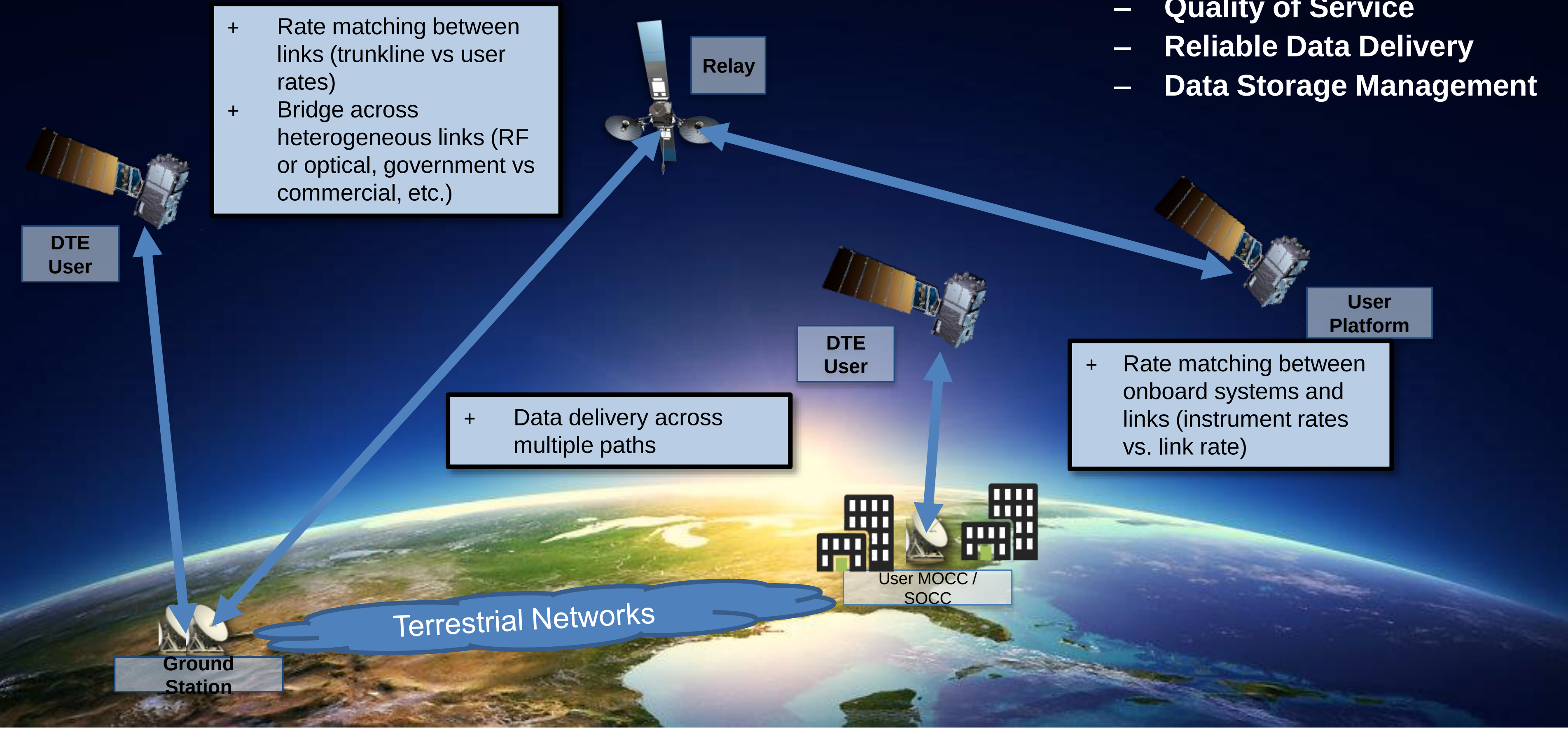
- ***"Get this data off my platform"***
  A mission that needs to offload data in order to free up onboard storage or meet some other operational constraint is only really concerned with the speed of the space link from their spacecraft to the communications asset. The latency requirement through the rest of the end-to-end path is driven by science needs.



The Space Mobile Network concept leverages the combination of high availability, low latency, low data rate links with delay tolerant users and shared high rate links

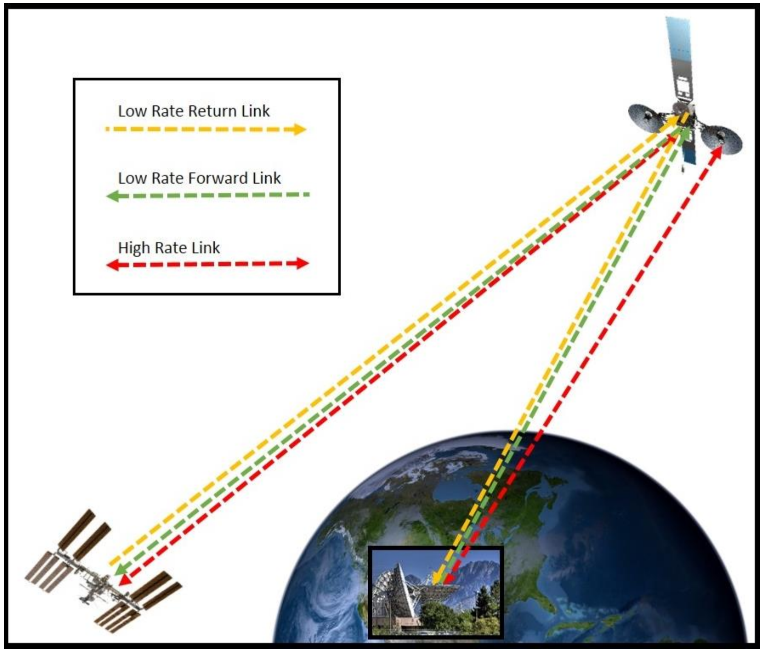
DTN Enables SMN

- **All nodes benefit from DTN**
  - **Routing**
  - **Multiplexing**
  - **Quality of Service**
  - **Reliable Data Delivery**
  - **Data Storage Management**



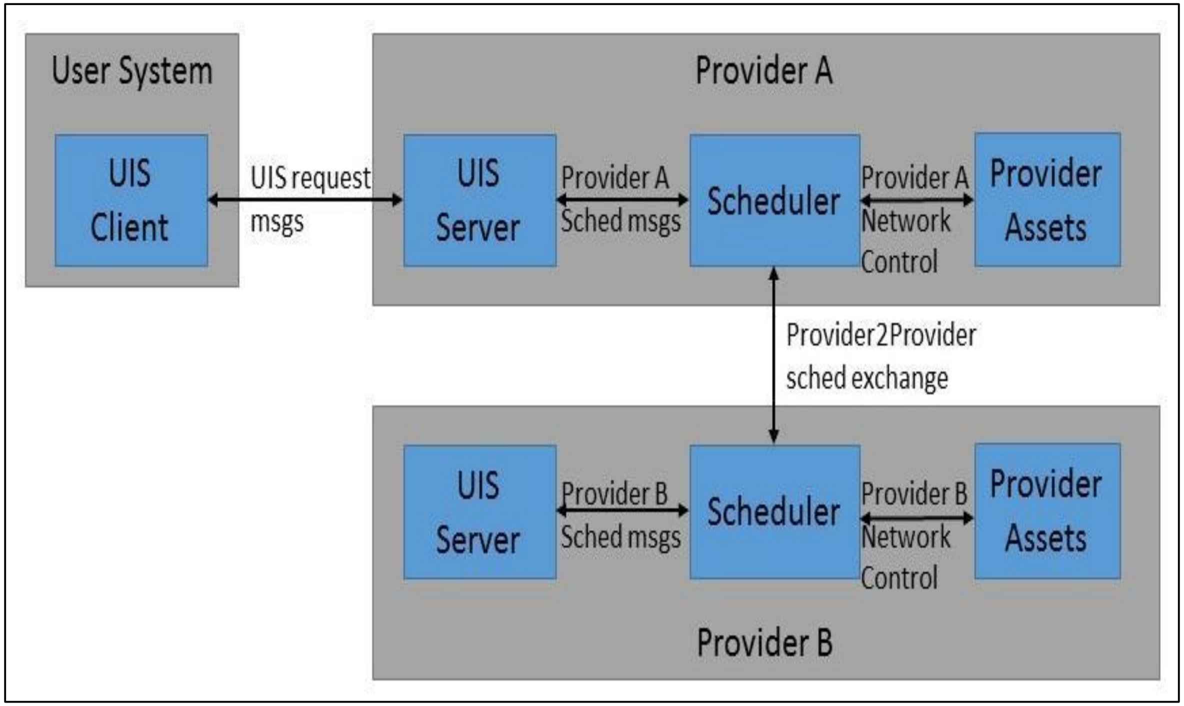
User Initiated Services (UIS)

- UIS allows platform-triggered acquisition of services through the use of continuously available low rate links
- User can access a high rate or other scheduled service on short notice



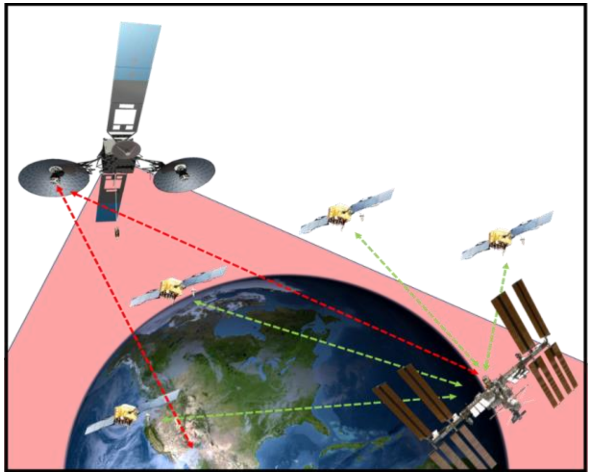
- Provides mission designers the potential to enable new science and reduce operations costs and complexity through fundamentally different concepts in operations execution.

User Initiated Services Functional Diagram



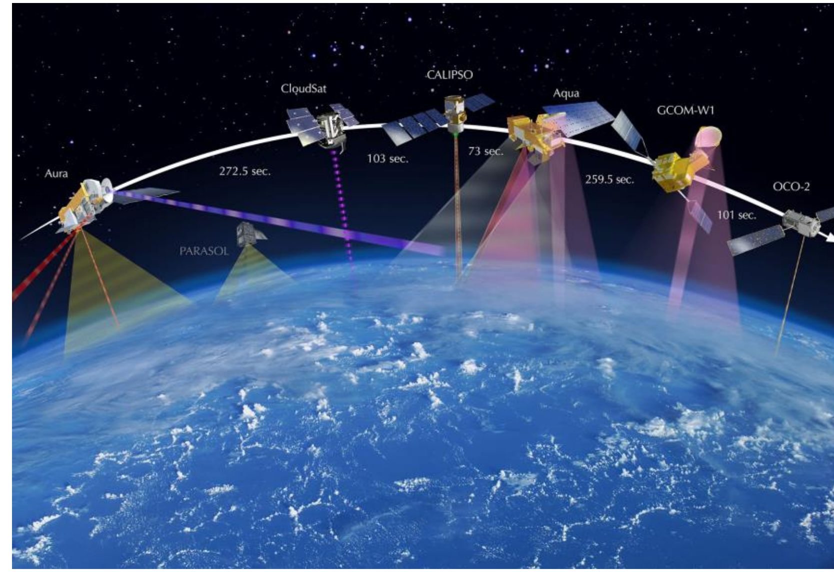
- The UIS will require a scheduling system capable of dynamically fielding the requests: comparing them against available resources, schedules, and priorities.
- The system must also provide a way to dispatch the now scheduled service details to the user systems and provider elements
- Services can be provided by a combination of providers and scheduling systems

Position, Navigation, and Timing Technologies

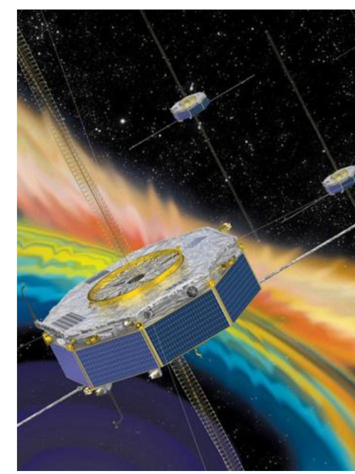


- Increased spacecraft autonomy implies a transition from ground based orbit determination processes to onboard processes
- **Flight GPS/GNSS systems**
  - Acquire and track GNSS signals anywhere between LEO and Lunar orbits with hemispherical (low gain) antenna
  - Receivers will continue to decrease in size and increase in capability in accordance with Moore's law
  - Increased signal availability within while also expanding the region of the space service volumes
- **Clock Stability**
  - Stability performance over time as normalized on a per dollar, per mass, or per volume basis also facilitates the autonomous navigation capability
  - More stable clocks will increase GNSS receiver accuracy and availability and also a transition from two-way to one-way radiometric techniques.
- **Optimetrics** and other new types of observations
- **Onboard navigation filters** allow user to self-ascertain and maintain their orbital state given intermittent observations processing GPS, network radiometrics, and celestial navigation observations simultaneously
- **Standards** that allow individual autonomous navigation components to be delivered by multiple vendors while easily integrating into a single onboard system will allow for per-mission customization.

Use Case Examples

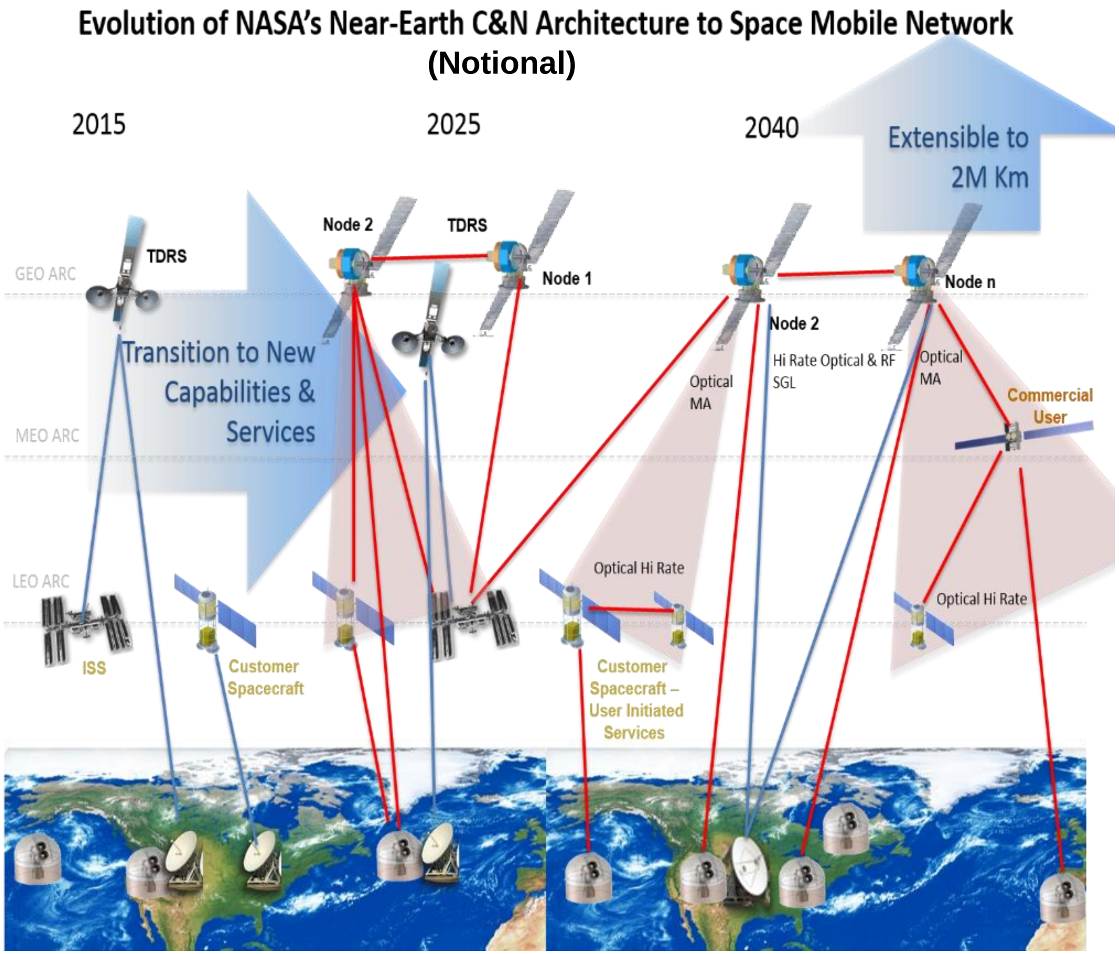


- Variable Science Data Collection
  - A mission has a lower rate of science data collection while in a nominal monitoring/baseline data collection mode
  - A science event triggers instruments to collect data at a higher rate by either turning on more instruments or increasing resolution
  - The mission is able to use UIS to acquire the necessary services to delivery all of the data even though the data volume and time of event were not predictable
- Collaborative science platforms.
  - One platform detects an event and transmits a notification to collaborating platforms, while also scheduling up the opportunity to transmit the full data collected
  - Other platforms receive the notifications, begin their appropriate response (repoint an instrument, increase resolution, etc.), and then transmit their data through the available channels
- Satellite Formation Flying
  - Small, micro, and nano satellite buses offer on opportunity to place large numbers of observation platforms into orbit
  - Small satellite maneuvering will be attained as actuator technology scales down to fit within the size, mass, and volume constraints of small satellite buses
  - Formation flying of small satellites will be achieved through the application of precision autonomous orbit determination, maneuver planning, and execution



Conclusions

- The SMN architecture provides a framework for the evolution of the near earth space communications and navigation architecture to enable and enhance the future spaceflight missions
- The technologies presented can begin to be implemented before any new space relay nodes or ground station antennas are deployed
  - Though the performance of initial demonstrations may be limited to lower data rates or longer latency than desired, the implementation will allow for the demonstration of the benefits, the requirements and the challenges of the future systems.



- Further work is already underway to validate and refine the architecture, to develop the associated technology, and to implement the first demonstrations and early operational capabilities.

Acronyms

C&N - Communication and Navigation
DTE – Direct to Earth
DSN - Deep Space Network
DTN - Disruption/Delay Tolerant Network
ERNESt - Earth Regimes Network Evolution Study
ESC - Exploration and Space Communications
GEO - Geosynchronous Orbit
GNSS - Global Navigation Satellite System
GSFC - Goddard Space Flight Center
LEO - Low Earth Obit
MA - Multiple Access
NASA - National Aeronautics and Space Administration
NEN - Near Earth Network
NGBS - Next Generation Broadcast Service
RF - Radio Frequency
SCaN - Space Communications and Navigations
SMN - Space Mobile Network
SN - Space Network
SWaP - Size, Weight, and Power
TASS - TDRSS Augmentation Service for Satellites Service
TDRSS - Tracking and Data Relay Satellite System
UIS - User Initiated Services

MISSION

As a national resource, the Exploration and Space Communications (ESC) Projects Division enables scientific discovery and space exploration by providing innovative and mission-effective space communications and navigation solutions to the largest community of diverse users.

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GSFC/ESC EXECUTIVE LEADERSHIP TEAM

Bob Menrad, Associate Director
Cathy Barclay, Deputy Program Manager/Execution
Mark Brumsfield, Deputy Program Manager/Implementation
Dave Israel, ESC Architect
Tracy Felton, Program Business Manager
Mike Weiss, Associate Program Manager

PRESENTER:

David Israel
david.j.israel@nasa.gov
301-286-5294

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