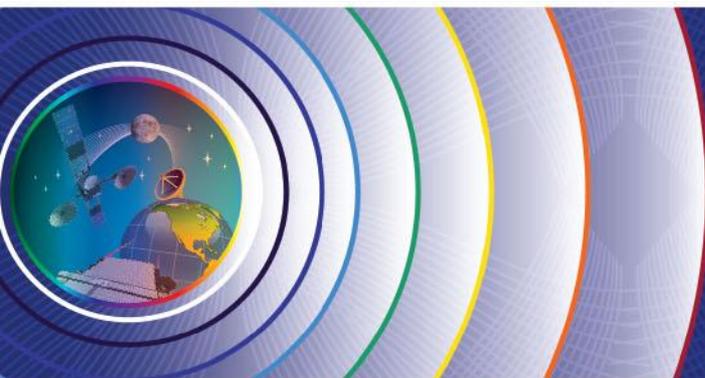




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Earth Regime Network Evolution Study (ERNESt)

- Introducing the Space Mobile Network -

April 5, 2016



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Introduction



- NASA's Space Communications and Navigations (SCaN) Program is responsible for all NASA space communication and navigation activities through 3 networks...
 - Deep Space Network (DSN)
 - Near Earth Network (NEN)
 - Space Network (SN)
- SCaN chartered the *Earth Regimes Network Evolution Study* (ERNESt), and the team completed the study in May 2015
 - NASA's Goddard Space Flight Center (GSFC) led the study to create a next generation near-Earth space communications and navigation architecture for 2025 and beyond
 - Included participation by: NASA/Glenn Research Center, Lincoln Laboratory, Jet Propulsion Lab, SCaN, TASC, and key Subject Matter Experts from industry
 - Study focused upon the SN and NEN services to the Near-Earth Regime User community
 - Goals:
 - Provide communication and navigation services to missions within 2M kilometers of the Earth
 - Agile: Customizable, Scalable
 - Include industry and international partners
 - Advance new science concepts and provide future on-ramps for today's nascent technologies
 - Leverage cost efficiencies resulted from commoditized services

Introduction...*continued*



- SCaN challenged us to be visionary – *the ERNESt Team rose to that challenge*
- The team determined that NASA, through SCaN, is uniquely capable of positioning the U.S. as the leader in the emerging space-based global network with the ability to adapt, guide and leverage the communication and navigation services of the future through recommendations that...
 - Provided a game-changing leap-forward in communications and navigation capability while ensuring all Near Earth Regime NASA missions continue to be served
 - Leveraged terrestrial mobile networking capability by creating a “Space Mobile Network” with all of its associated benefits to the users
 - Established a management paradigm that is flexible and adaptable to an evolving implementation responsive to needs and incorporating maturing technologies
 - Developed an architecture that exploits opportunities for commercialization, private investment, and insertion of new technology arising from the commercial sector
 - Advanced our national capability in space-based optical communications and Advanced Networking technologies

***Resulting ERNESt architectural framework was named: “Space Mobile Network (SMN).”
Vision is to accentuate the focus on user experiences with analogies to
the terrestrial mobile wireless smartphone environment.***

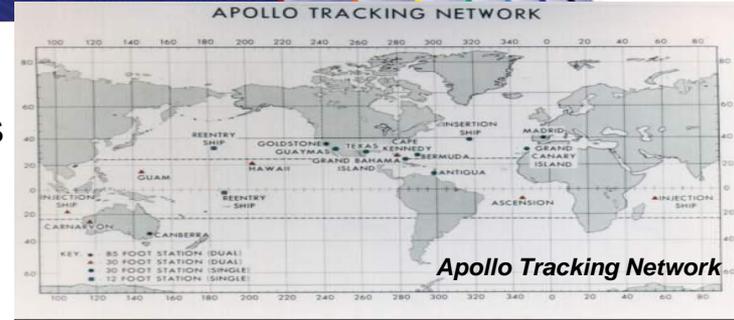
Evolution of Space Communications and Navigation Networks at NASA



PAST...

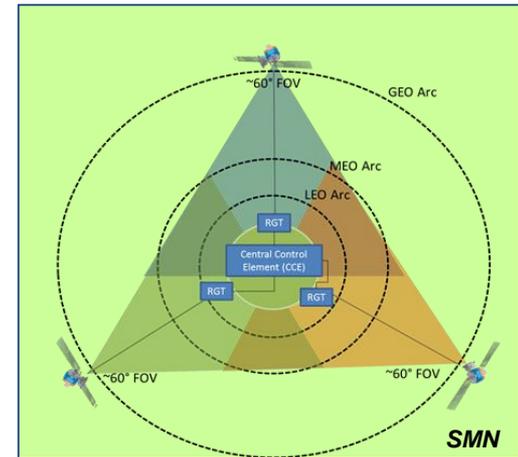
- Space Comm began with Worldwide Ground Terminals
 - Supported “heavily scripted” Scientific and Human Space Flight Missions
 - Required sophisticated, user-intensive pre-planning and scheduling
 - Experienced blackout periods due to lack in coverage

- Established “Switch-board” in the Sky with TDRSS
 - Missions continued to be preplanned and “scripted”
 - Bent-pipe in space provided continuous equatorial coverage
 - Service scheduling typically required weeks before events



FUTURE...

- *Space Mobile Network (SMN)*
 - Maintains continuous coverage...with growth where the users go
 - Autonomous service management eliminates the need for manual scheduling contributing to reduced infrastructure costs / burdens
 - S/C designers free to define new ways to accomplish mission goals



TDRSS Solved Coverage Challenges...SMN Enables Mission Automation

Why a Space Mobile Network?



The effect of mobile smartphone technology on modern society has been profound. Wireless mobility enables “seemingly” instant communication anywhere, anytime, mobilizing the rapid transfer of information and services over immense distances, unbound by geographic barriers – all done automatically without humans in the loop

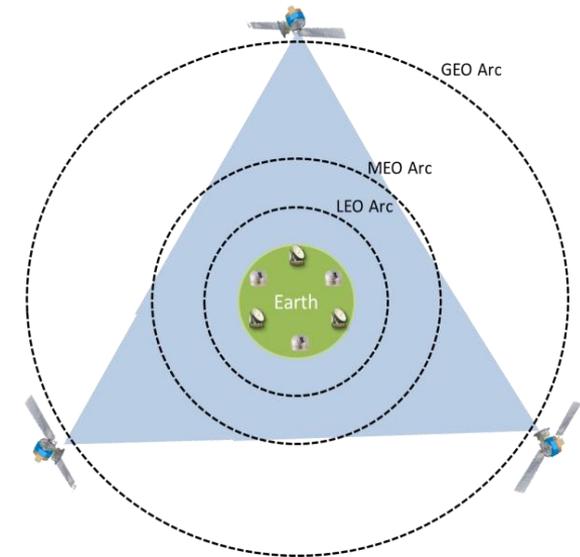
- New ways to connect, share, and innovate using mobile network technology are invented every day around the world, and are enabling innovative applications, many of them unimagined in the past
- Applying this paradigm, NASA would:
 - enable innovation in science and exploration missions;
 - streamline space operations; and
 - create an environment where an enterprise approach to space communication and navigation becomes possible through the implementation of the Space Mobile Network (SMN) Architecture.

The Space Mobile Network would provide a 21st Century communication and navigation solution that meets a growing demand for data and enables innovation through anytime/anywhere connectivity.

Salient Features of the... Space Mobile Network



- 24x7 near-Earth Global Coverage for **User Initiated Services**
 - Autonomy of scheduling services (e.g., user flexible scheduling)
 - Maximize use of existing infrastructure (WSC, NOCC, etc.)
 - Enables innovation in conducting and collecting science data
- Advanced Networking with **increased automation**
 - Responsive Service Management function in the background
 - Interoperable with open standards and security
 - Re-configurable for flexibility
 - Scalable to increase robustness
- **Advanced Comm through Optical terminals**
 - Lower SWaP/High Data Rate for relay and user
 - New operations concepts (e.g., reduced contact times)
 - RF where applicable to meet mission need
- **Advanced Position, Navigation, and Timing**
 - Lower SWaP/Increased precision for relay and user
 - New operations concepts using navigation augmentation data services
 - Use of optometrics from optical communication links



***Benefits to the User: Increased service performance, reduced user burden,
and reduced operations complexity.***

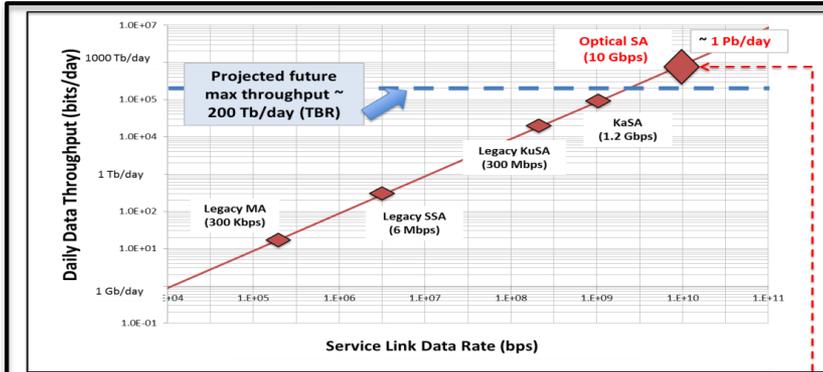
How Would New Missions Operate?



- Launch & Early Orbit
 - Unless technology advances faster than currently envisioned, all users will continue to rely on S-band coverage for early critical events and emergency operations (i.e. omni coverage)
- Mission Ops (Routine and Special)
 - Employing a protocol analogous to terrestrial cell-phones, user's will know the location of SMN "cells", find the best signal...or find the "right" signal
 - GEO slots still remain the best location for stable "coverage maps"
 - Next Generation Broadcast Service (formerly: TASS) was studied to show how a "waking" S/C would determine its position and locate cell towers
 - International "inter-operability" has strengths and weaknesses
 - Users would have access to matured optical flight terminals that exploit the low-SWaP inherent with optical communication
 - *User Initiated Service* allows users to request service "when needed", "where needed", "as often as needed" over low SWaP Optical Multiple Access links...enabling a new era in S/C automation

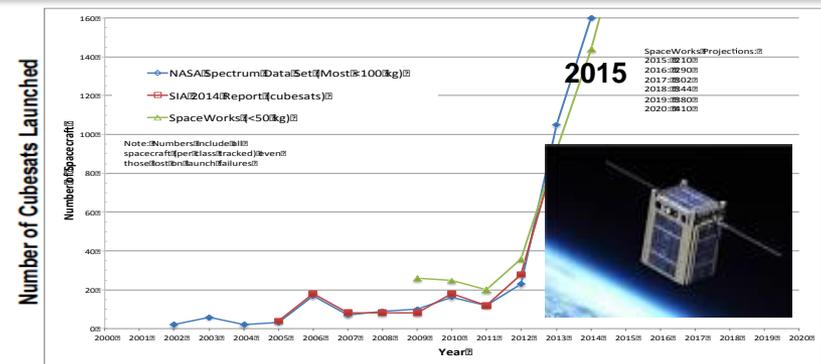
Optical Communications...

Making the SMN Possible



1 Optical SA @ 3 GEO nodes supports 200 Tb/day at ~ 7 % network loading factor

Optical Comm offers an ultra-large capacity vs. Legacy SN Links



Cubesats Launched by Year (as of Feb 2015)

- Demonstrating Operational Readiness:
 - NASA LLCSD Successfully demonstrated in 2013 (622 Mbps /1550 nm)
 - ESA's EDRS in 2015 (1.8 Gbps Space-to-Space Link/1064 nm/BPSK modulation)
 - NASA LCRD in 2019 (1.24 Gbps Space-to-Space and Space-to-Ground Links/1550 nm/DPSK modulation)
- Order of magnitude higher data rate than comparable RF
- Architectures with optical comm displayed benefits to cost and user needs satisfaction (ITACA Analysis)
- Lower SWaP than comparable RF systems (applicable to SmallSat/CubeSat)
- Existing RF spectrum allocations are increasingly under encroachment (Optical is unregulated)
- Low susceptibility to interference due to narrow laser beam as well as inherently more secure
- Most components now available from industrial suppliers
- 1550 nm wavelength allows leveraging of terrestrial fiber components

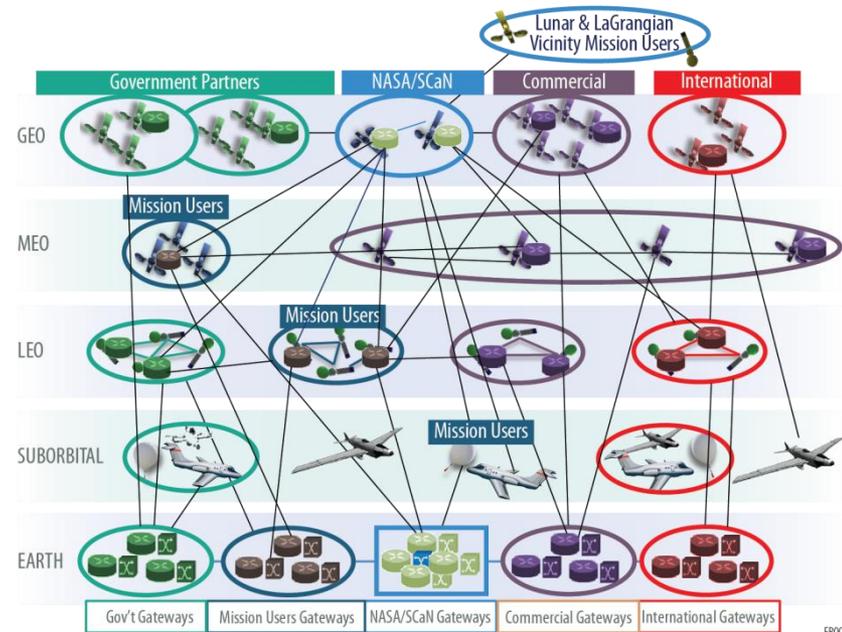
“Optical Multiple Access” leverages throughput capacity in ways previously considered impractical.

Bridging Past and Future...

Networking is the Evolutionary Step



- Automated end-to-end data delivery service
 - Enables new types of missions and operations (e.g. Inter-satellite cooperation)
 - Reduces operational complexity for users
 - Optimizes communications with links of differing data rates and different data delivery priorities
- Provides scalability
 - Provides for potential growth in number of users without changing the fundamental architecture
- Synergistic with Optical Communications
 - Maximizes utilization of deployed Optical assets
 - Leverages Optical Comm inherent on-board processing
 - Enhanced Quality of Service
- Allows data to move through heterogeneous links and multiple provider networks
- Seamless delivery of data through terrestrial and space networks direct to user



Networking enables advanced communications capabilities

Space Mobile Network - like the terrestrial smartphone - has the potential to stimulate innovation in support of spaceflight missions and commercial applications.

Space Mobile Network...

Technology Maturation Areas



- Technology Maturation Areas apply across the architecture
 - User Platforms
 - Relay Platforms
 - Ground Stations
 - Network Operations Centers
 - User Mission Operations Centers
 - Science Operations Centers
- Technologies work together to achieve full architecture, but can be separated into five main areas
 - Multiple Access Link (Optical MA, Advanced and Enhanced RF MA)
 - Single Access Link (High rate/low SWaP optical and RF systems)
 - User Initiated Services (UIS Protocols and UIS Agents)
 - Data Services (DTN, IP)
 - Position, Navigation, and Timing

Initial Technology Focus Areas



Networking/PNT Technology

- Conduct proof of concept for SMN architecture
- Validate signaling/beaconing functions using TDRSS
- Develop new network navigation algorithms
- Test network navigation techniques in network environment
- Integrated GNSS Receiver and User TDRS transponder

Optical Technology

Optical MA

- Develop OMA architecture and signaling details
- Survey commercially available components
- Conduct OMA laboratory Proof-of-Concept Demo

High Rate Optical Terminals

- Continue Heliostat Development
- Explore implementation and use of integrated photonics

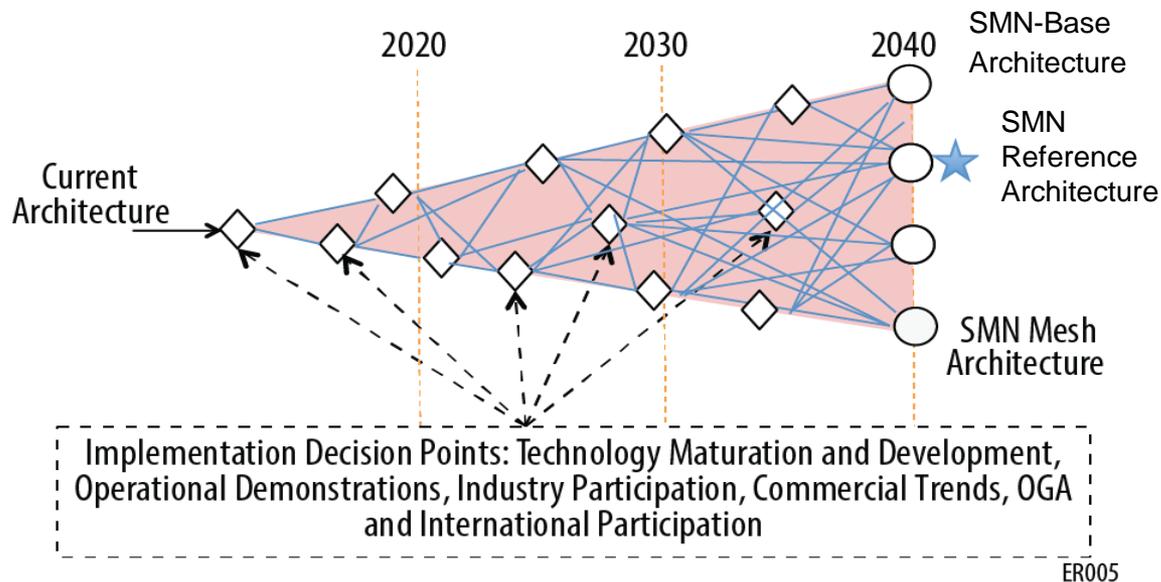
RF Technology

- Develop EMA design
- Build enhanced GBBF
- Select coding techniques for EMA and prototype demo
- Build TDRSS antenna arraying software prototype
- SCan Testbed demonstrations

SMN 2040 Reference Architecture achieved through “Incremental” Implementation



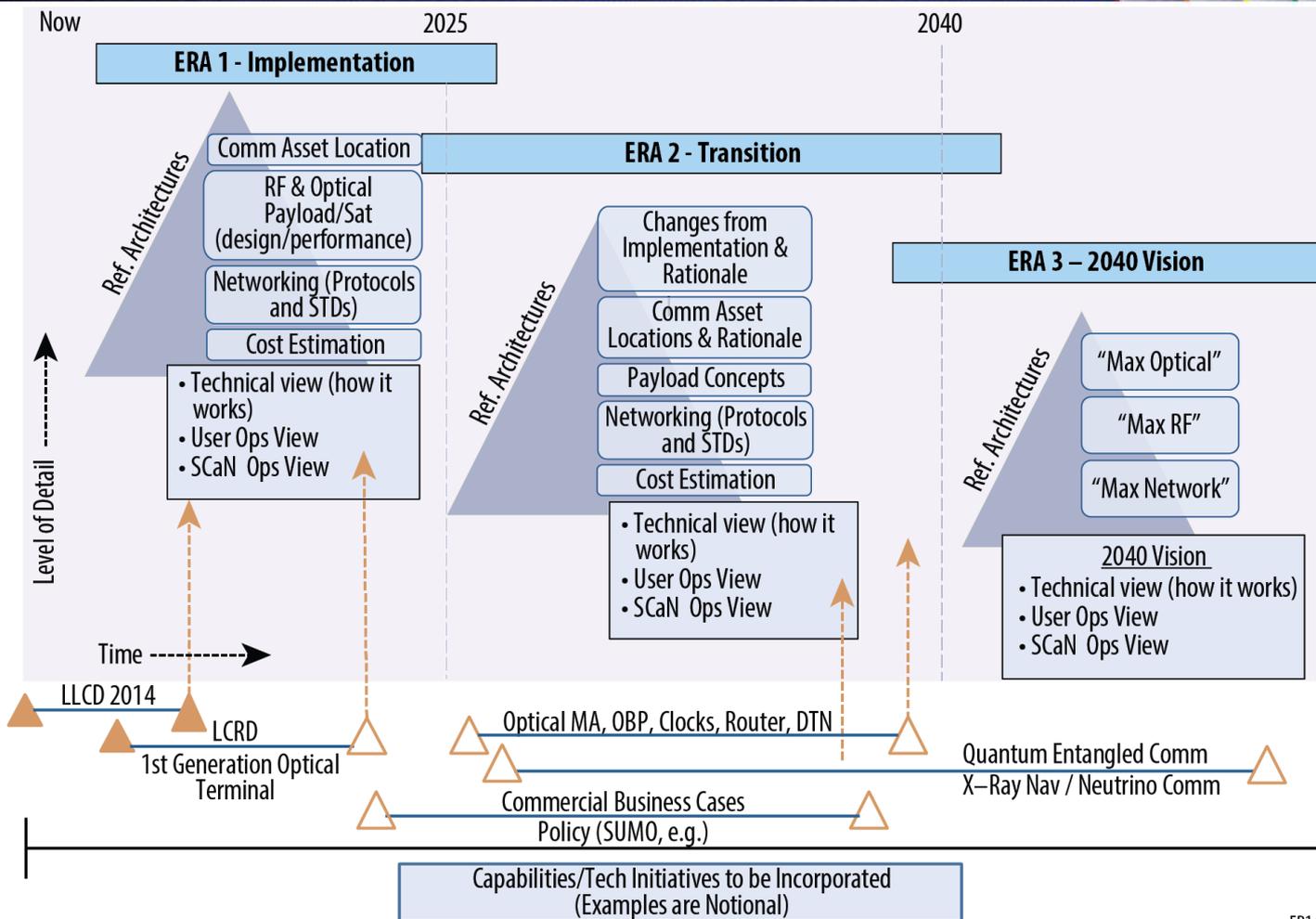
- The Team sought out a framework that maintained agility for responding to changing user needs and business landscapes versus defining a singular path to reach its vision...
- As an example, the ERNESt Team considered a range of architectures:
 - *SMN-Base*: A minimum instantiation of a 3-network node NASA constellation
 - *SMN-Mesh*: A maximum instantiation that is approaching a mesh network
 - *SMN Reference Architecture*: A hybrid instantiation that is a mixture of NASA, commercial, and partner network nodes



SMN defines a 2040 Reference Architecture in “functional” terms now, while spreading “implementation” decision points over time.

Strategic Framework...

"Repeatable" ERA's Inform Decisions



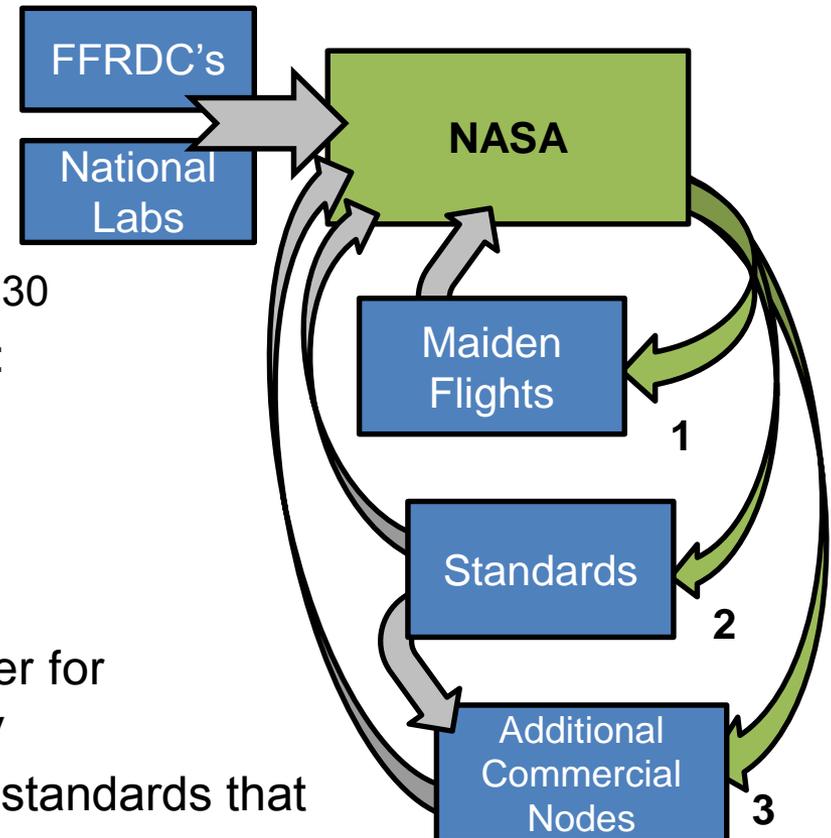
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A strategic framework for architecting allows SCA to continually evolve its communications and navigations networks in a structured yet responsive manner by exercising repeatable processes over an absolute timeline

ERNESt Recommendation... Commercialization Strategy



- “Make before break” for backwards compatibility
- Synchronize transition with expected degradation of SN
 - Need to have first “Nodes” on station NLT 2030
- Use diverse models for access to space for:
 - Lower cost of low-TRL maiden flights
 - Provide flexibility in make-vs-buy decisions
 - Leave “stable” cell tower behind
 - Employ Class-D, technology risk category
- Use limited instances of operational free-flyer for Government requirements, when necessary
- Translate “maiden flight” results into “open” standards that can be competitively exploited by industry
 - Allow the community’s progress to determine **“where available / when available”**
 - “Enable” SMN roaming equivalent services nationally and internationally

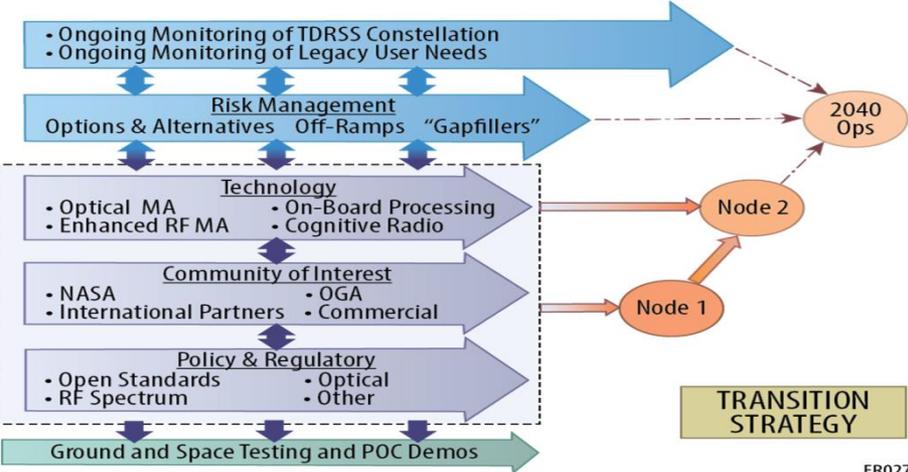
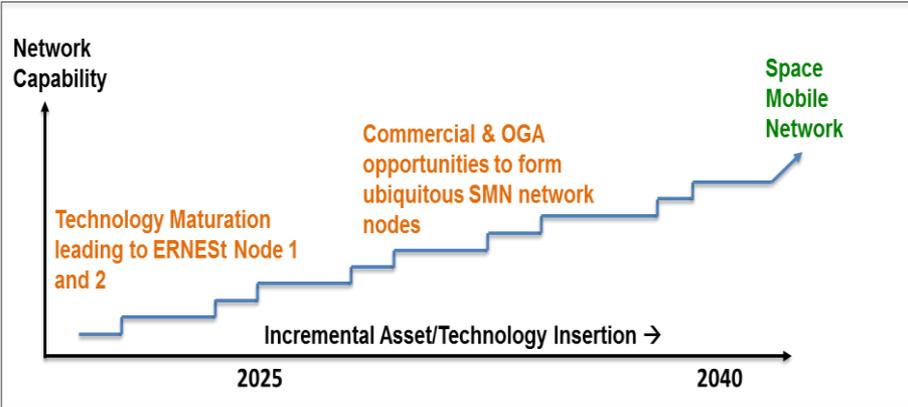


Signature of Success = Robust mixture of government and industry “cell towers”

Bringing it all together... Enabling SMN through a New Paradigm



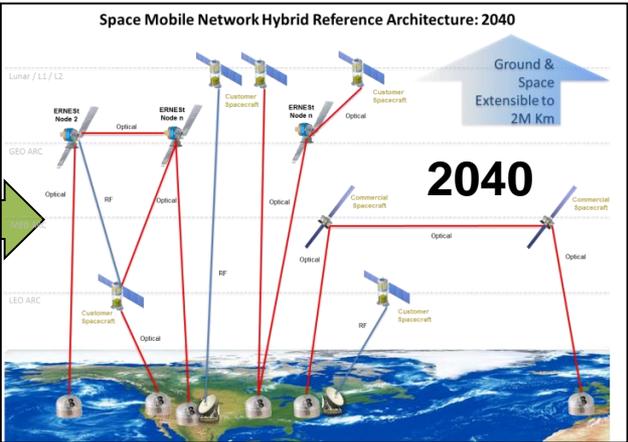
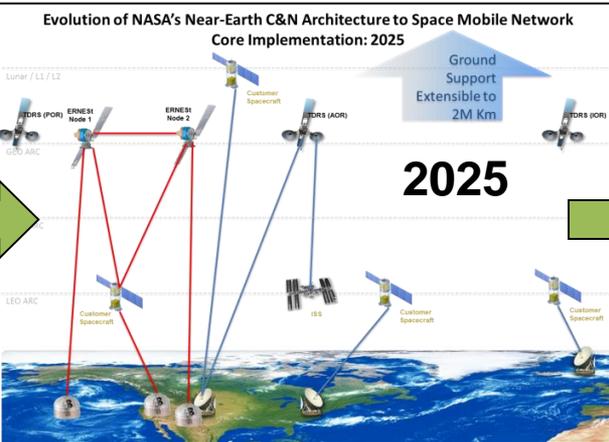
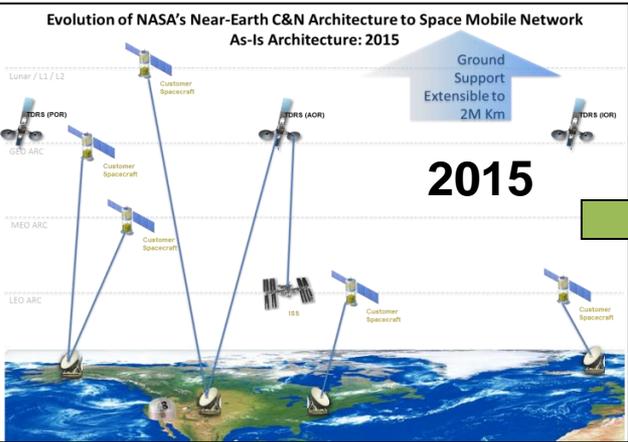
SMN Incremental Capability Approach



ERA 1: As-Is & Tech Dev

ERA 2: Core Implementation

ERA 3: Hybrid Ref. Architecture



The ERNESt Proposed new management paradigm enables an incremental capability approach, which allows for efficient transition from current state to 2040 Hybrid Reference Architecture

Summary



- The completed ERNESt Study has defined and recommended a new Space Mobile Network architecture, including:
 - Operations concepts
 - Technology maturation areas
 - Incremental capability build-up approach
- Team determined that the Space Mobile Network will benefit users by providing:
 - Increased service performance
 - Reduced user burden
 - Reduced operations complexity with increased flexibility
 - New business models for private industry to exploit, thereby reducing government infrastructure costs
- Strategic benefits accrued in striving to create a Space Mobile Network extend well beyond NASA to include Government- and Civil-Space by...
 - Expanding the trade-space spaceflight users exploit
 - Enabling continued US preeminence in space communication and navigation by leveraging existing and maturing technologies through innovative means
 - Incremental flight demonstrations that prove new product lines
 - Opportunities for collaboration with OGAs at the enterprise planning, portfolio definition or specific mission level thereby fostering flexibility in meeting national needs



MISSION

As a national resource, the ESC 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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