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Interoperating Network Communications Architecture (INCA) – An Evolving Commercial Mission to demonstrate Delay Tolerant Network technologies combined with Quality of Service based routing for space communication systems

Gary P. Barnhard[a]

[a] *Xtraordinary Innovative Space Partnerships, Inc. 8012 MacArthur Boulevard, Cabin John, MD 20818, gary.barnhard@xisp-inc.com*

Abstract

This Mission seeks to advance the development and application of an Interoperating Network Communications Architecture (INCA). This effort will include four sub-mission components:

1. Testing Delay & Disruption Tolerant Networking (DTN) Technology with Real World Requirements
2. Pervasively Networked DTN Gateway for the International Space Station (ISS)
3. Earth Facing Applications
4. Space Facing Applications

Advancing and validating the application of DTN technologies has many commercial applications in space based communications systems as well as in terrestrial communication systems. Output from this mission includes: a) an ability to extend internet applications into Earth orbit and beyond, b) development of the Xlink Internet Services Protocol (XISP) and gateway, and c) ability to extend communications across multiple networks with interoperating nodes in the event an emergency requires it.

Keywords: Interoperating Network Communications Architecture Gateway Xlink

1. Introduction

In order to extend and maximize the effective availability and utility of NASA's Space Communications networks and the growing number of other communication systems (e.g., commercial, other U.S. agencies, international entities, and non-profit organizations), a transition from a manually scheduled, highly constrained and custom-crafted communications environment to a pervasively interoperable automated environment is required. Accomplishing such an open networked environment requires the capability of managing key challenges including quality of service (QoS) considerations (availability, performance, and security) across all potential users (government, international, and commercial). These challenges also include the inherent problems of accommodating both delay and disruption in the end-end path between all participating network nodes. However, these challenges are not unique to NASA space communication networks. A wide range of both space and terrestrial applications ranging from infrastructure assembly and management, remote operations/point-of-presence systems, as well as Cislunar, Mars and beyond space missions could benefit from using Delay / Disruption Tolerant Networking (DTN) technologies. The architectural threads that are key to understanding the necessary evolution of such communications system include:

- Transition from "scheduled" to "on demand" access of networks
- Quality of Service (QoS) based routing
  - Performance
    - Data rate
    - Data volume
    - Data latency
  - availability
  - security
- Spacecraft as Infrastructure
  - Space-to-space
  - Space-to-alternate surface
  - Space-to-Earth
- Pervasively Networked Environment
  - Ad Hoc Mesh Networks with QoS based Routing
- Interoperability
  - Define and control the criteria for what constitutes an interoperable node in networks
- Delay and Disturbance Networking Technology
- Plug-in/Plug-out technology
- Software Defined Radio & waveform libraries
- Commercial "Use"/"Value" Paradigm
  - All contracted work must have demonstrable value/work products for each increment of resources invested by government and/or industry
  - Government as a "customer"
  - "For-profit" customers

    - "Non-profit" customers
- Navigation Services
    - Timing Service
    - Positioning service
- Interferometry Services
- Signal sensing and characterization logic
- Mutable "locus of control"
    - Teleoperation ⇔ Autonomy
    - Ground Based ⇔ Spacecraft

Establishing the confluence of interests necessary to yield optimal support of Mission "Functions" is a requirement. Classically in architecture Form follows Function, and this work is not an exception.

NASA is faced with the challenge of creating a conceptual map between the states of their three existing networks: Space Network (SN), Deep Space Network (DSN), Near Earth Network (NEN) and the next generation network implementations currently under study. NASA's preliminary architectural concept envisions a voluntary international consortium of Space Communications Networks to serve the solar system as shown in Figure 1. Near Earth, Mars, and Lunar Network Concept, Figure 2. Planetary Networks Concept, Figure 3. Planetary Network Concept, and Figure 4. Near Earth C&N Architecture. [1-2]

NASA is asking for industry help to define a next generation network architecture in a manner which allows the confluence of interests to be developed between the stakeholders to a level that results in full funding and implementation.

- Next Generation Network Architecture
    - High Level Functional Taxonomy
        - Space-to-Space
            - Earth Orbit
            - Cislunar
            - Deep Space
        - Space-to-Alternate Surface
            - Moon
            - Mars
            - Other Near Earth Objects / Asteroids
        - Space-to-Earth
        - Earth-to-Space
        - Earth-to-Moon
        - Earth-to-Mars
        - Earth-to-Earth
        - Moon-to-Moon
        - Mars-to-Mars

Each higher level "Function" has a set of:

- "Features" which yield functional requirements,
- "Physical Elements" which yield system / subsystem requirements, and
- "Interfaces" which include hardware, software, specifications / standards, and operational guidelines / rules
- Hosting / participating "nodes" which are inter-operating devices that use and/or support functions at some level be it as "end" nodes, "repeater / relay" nodes, and/or "router / gateway" nodes.

Accordingly, this architectural effort is necessarily both iterative and recursive. This paper is the latest report on the status of the ongoing INCA mission development effort.[3-8] The evolution of DTN technology and its relevance to interoperable networking has been addressed by multiple authors [9-23]. The implications of the same are also being address by the Internet Engineering Task Force. [25-26]. Furthermore, the Consultative Committee for Space Data Standards is actively engaged. [27]

2. The Problem Addressed

A "Pervasively Networked" system as defined in this context means a system that allows all sensible internal and external networks, infrastructure and nodes to be identified and interacted with consistent with their prevailing operational rules. A critical component of this network is the development and/or use of a pervasively networked gateway which implements the Xlink Internet Services Protocol (XISP) to provide QoS based routing and allow the virtualization of functions. Of particular importance is the ability to structure and order the knowledge associated with defining the link contexts. This must include the next hops/nodes, operational rules, and the time-to-live of any characterized links. Developing the XISP protocol is a major challenge and necessarily includes:

(1) XISP Definition and Articulation. The definition, mapping and extension/application of the XISP into the prevailing layer/process models (i.e., Open Systems Interconnect - OSI 7 layer, DOD4) as shown in Figure 5. Xlink Internet Services Protocol (XISP), must be made explicit, implementable, and understandable to the communities of interest.

(2) Interface Characterization. The characterization of the necessary interfaces, inclusive of all required data input and output across those interfaces, necessary to support the required functions of Pervasively Networked DTN Gateway system must be taken to a level which is both satisfactory and sufficient, as well as measurable / modelable in near real time.

(3) Interface Implementation. Each necessary interface must be implemented in one or more testable prototypes first on a standalone and then on an integrated basis.

2. The Proposed Solution

This mission seeks to bridge Technology Development, Technology Demonstration, and Technology Deployment (TD^3). Each TD^3 project proposed for the International Space Station (ISS) has the following characteristics:

- leverages the available resources to serve as a testbed,
- has an integral evolutionary path from experiment to infrastructure, and
- helps to mitigate perceived cost, schedule, and technical risk associated with the accommodation and use of new communications technologies.

The INCA mission elements, as shown in Figure 6. INCA Experiment Elements, are intended to be inherently iterative and recursive, yielding demonstrable value to supported missions for each increment of resources invested.

2.1 Technology Development

The technology development process starts with the knowledge base which includes the definition of the intellectual commons, patents and patents pending, identified trade secrets, and known unknowns. These elements serve as the foundation for building end-to-end state models. From there XISP-Inc has moved forward with the development of the Xlink Internet Services Protocol (XISP), a framework for accommodating DTN and modelling QoS requirements in a highly scalable computationally practical manner. Initially a single DTN enabled communications link QoS problem, hence to DTN enabled Gateway QoS routing for multiple links, and finally to prototyping dynamic scheduling. A block diagram of the proposed pervasively networked gateway is shown in Figure 7. INCA Pervasively Networked Gateway w/QoS Based Routing.

Creating a node in an inter-operating network requires some combination of hardware, software, interface specifications, and operational guidelines. The XISP framework will capture all of the above in a simple, readily extensible, and verifiable manner.

2.2. Technology Demonstration

The technology demonstration work starts with the virtualization of an individual function and the corresponding near realtime QoS. This sub-mission is entitled: Testing Delay Tolerant Networking (DTN) Technology with Real World Requirements. Testing Delay Tolerant Networking Technology with Real World Requirements approaches the problem of maturation of Delay/Disturbance (DTN) technology and facilitating its use from an end-user requirements perspective. The goal of this sub-mission is to demonstrate that real world requirements can be accommodated by an operational implementation of DTN technology that allows it to be used as a tool that meets customer requirements (performance, availability, and security) in a satisfactory and sufficient manner.

This sub-mission has selected the function of Internet Banking, which necessarily contends with some of the most stringent commercial requirements for performance, availability, and security. This sub-mission proposed for the ISS seeks to demonstrate that, through the use of DTN technology and thoughtful extensions of existing hypertext/web services, even some of the most challenging internet applications can be successfully extended into Earth orbit and beyond.

This sub-mission will be performed initially using a live boot solid state hard drive attached to one of the standard payload network laptops. It is anticipated that the available computational resources will be augmented by a space testable Intel® Core™ i5/i7 equipped Next Unit of Computing (NUC) thermally managed device with integrated Solid State Drive, high-performance graphics, 32 GB main memory, wired 10/100/1000 Mbps Ethernet, dual band AC 8260 wireless, running Debian Linux. Once on-orbit performance has been well characterized (using the NASA Open Mission Control Technologies (MCT) Web suite with the XISP-Inc near realtime state model extensions), and tuned for both thermal management and radiation tolerance, it is intended that that a clustered micro-rack with at least six NUC compute modules will be flown. This next generation modular server will serve as the Intra Vehicular Activity (IVA) function virtualization platform for subsequent INCA ISS experiments.

The next step in technology demonstration work is the virtualization of multiple functions and the corresponding QoS routing implementation. This sub-mission is entitled: Pervasively Networked DTN Gateway for the International Space Station. A Pervasively Networked DTN Gateway approaches the problem of maturation of DTN technology and facilitating its use from an infrastructure perspective.

The goal of this sub-mission is to create a pervasively networked point-of-presence gateway supporting quality of service based routing (performance, availability, and security) on all available internal and external networks accessible on the International Space Station for payload use consistent with operational guidelines. Such a gateway is effectively an automated telecommunications central office prototype.

Extending a pervasively networked environment around the Earth and into space requires an evolving ability to accommodate Delay/Disturbance Tolerant Networking. Achieving the Quality of Service (QoS) requirements for such networks requires an exquisite dynamic balancing of the driving requirements of Performance, Availability, and Security.

Integral to this work is the demonstration and leveraging of:

- In situ Space Qualification of Computational Resources
- ISS as Near Earth Preparedness and Response Network Node
- ISS as an Ad Hoc Communications & Navigation Mesh Network
- ISS and co-orbiting elements serving as a Platform Infrastructure Technology Testbed
- Leveraging the deployment of Low Earth Orbit and Beyond Earth Orbit technology development cubesats (such as Alpha CubeSat, which uses novel trajectory calculations and insert methods, multi-band software defined radio, and reflectarray solar array/rectenna.
- Parallel development and testing of interface kits for all potential inter-operating nodes including terrestrial, on-orbit, and beyond Earth orbit systems.

3. Possible Applications

The INCA functions proposed for implementation are shown in Figure 9. INCA Proposed Function Implementation.

3.1 Earth Facing Applications

3.1.1 Near Earth Emergency Preparedness and Response Network

This sub-mission approaches the problem of maturation of DTN technology and facilitating its use from a cooperating / interoperating network interface perspective with an emphasis on terrestrial applications.
The ISS provides an unparalleled platform to serve as a focal point as one of the operating relay nodes for the development of a new international near Earth emergency preparedness and response communication network. Recent environmental emergencies/natural disasters and electromagnetic pulse (EMP) events have drawn out the need for assured first responder communications capabilities. In particular, ones that are not necessarily reliant on the availability of traditional ground infrastructure. The technology to accomplish this sub-mission can be extended to allow cooperative communications across multiple networks with interoperating nodes in the event an emergency requires it. ISS has a number of very useful characteristics as an inter-operating node. Its location is approximately 419 km in altitude on a known orbital track which passes over 98% of the habitable world, it has extensive communications capabilities/potential, and is readily visible at night. It also has an extraordinary limiting characteristic namely that the accessible time from a given location on Earth ranges from 2 to 10 minutes per applicable orbital pass. However, if the ISS can be made an effective node in an inter-operating network, any other potential node in space, in flight, fixed, mobile, portable, or hand held is just a simpler instance of the same problem. The goal of this sub-mission is to support the development and implementation of an international Near Earth Emergency Preparedness and Response Network by prototyping and testing readily deployable pervasively networked highly mobile point-of-presence systems including dynamically schedulable space assets.

3.1.2 Near Earth Pervasively Networked Communications

There are multiple applications where near Earth pervasively networked communications would be helpful on a full time basis. One application is linking space and ground systems to support interferometric analysis and the collaboration channels required for effective research. Another application is border security management. As we progress from being able to at best understand what is present across the electromagnetic spectrum, to understanding what is changing, the combination of both secure and freely accessible pervasively networked communications will become instrumental in keeping the peace, managing the environment, and establishing literal ground truth.

3.2 Space Facing Applications

Cislunar Pervasively Networked Communications Technology Development approaches the problem of maturation of DTN technology and facilitating its use from a cooperating/interoperating network interface perspective with an emphasis on Cislunar applications.
That emphasis will support the development and implementation of a Cislunar Communications Network by prototyping and testing readily integratable interface kits. These will allow new - and where possible - existing space systems to be become cooperating / interoperating nodes interacting with pervasively networked point-of-presence systems.

3.2.1 Cislunar Pervasively Networked Communications

Creating a Cislunar pervasively networked communications environment will support interoperable communications links between the Earth, orbital communications assets, and deployed assets beyond Earth orbit including both the surface of the moon and other near Earth objects.

4. Next Steps in Mission Development

The INCA mission is an XISP-Inc commercial mission moving forward as a supported mission under an existing Space Act Agreement with NASA ARC and a Space Act Umbrella Agreement under negotiation with NASA Headquarters.

INCA is intended to build on the foundational technology for defining and building near realtime state models being developed to support the evolving XISP-Inc mission set. That work includes:

- Flight test articles based on the NASA CubeQuest Challenge Team Alpha CubeSat preliminary design (see Figure 9. INCA 6U Flight Test Article Derived from Team Alpha CubeSat Design) in cooperation with Tethers Unlimited, Deep Space Industries, and other interested parties are being defined.
- Public/Private implementation team forming up CASIS integration support, Commercial Cargo, and ISS resource allocation requests in development.
- Near realtime characterization of the Quality of Service (Performance, Availability, and Security) for a single defined function.
- Additional partners/participants are being sought in the commercial, academic, non-profit, and government sectors.
- Use of ISS helps ensure that this is an international cooperative/collaborative research effort.

5. Conclusion

This paper has described the evolution of this mission set from the draft mission narratives, to a formal mission set proposal, to what is now a XISP-Inc NASA recognized commercial mission. A process that has greatly benefited from enumerable conversations, presentations/papers by the author [3-8] as well as important papers by others that provide key support for the particulars of the proposed experiments. [1-2, 9-27]

The path forward now entails translating the narrative into actually building real systems that provide services of demonstrable value and validating the same through peer review in the communities of interest. It is through this cyclic process that maximum value can be derived from each increment of resources committed to this mission as well as its anticipated extensions and follow-ons.

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Figures

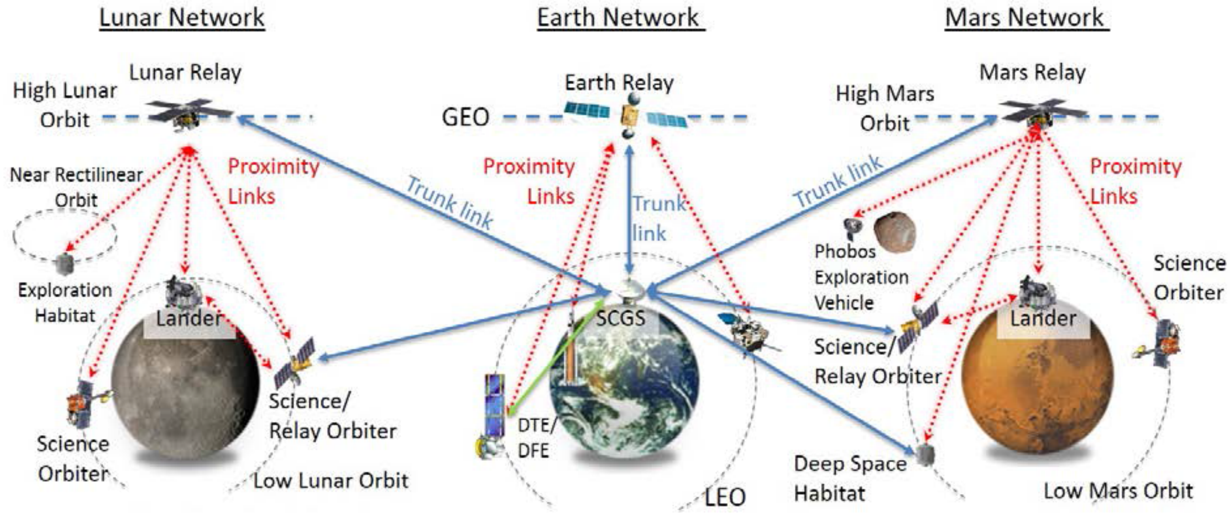

Figure 1. Near Earth, Mars, and Lunar Network Concept [1-2]

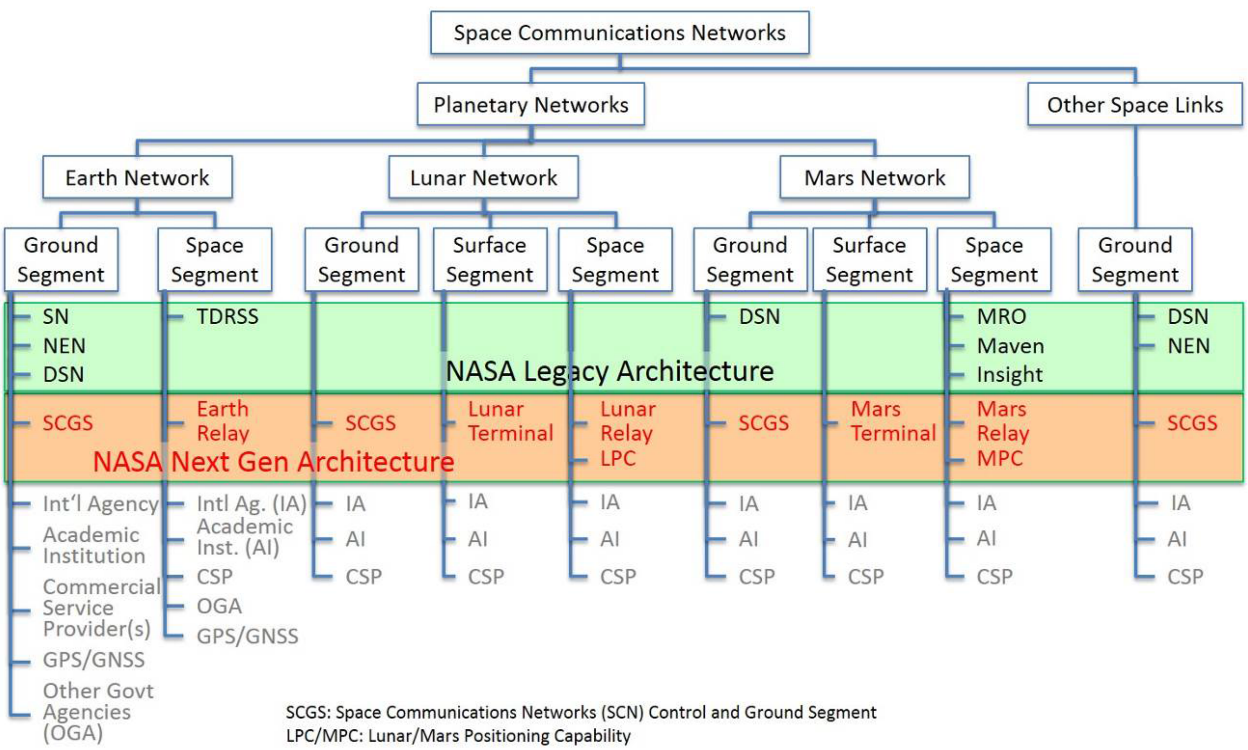

Figure 3. Planetary Networks Concept [1-2]

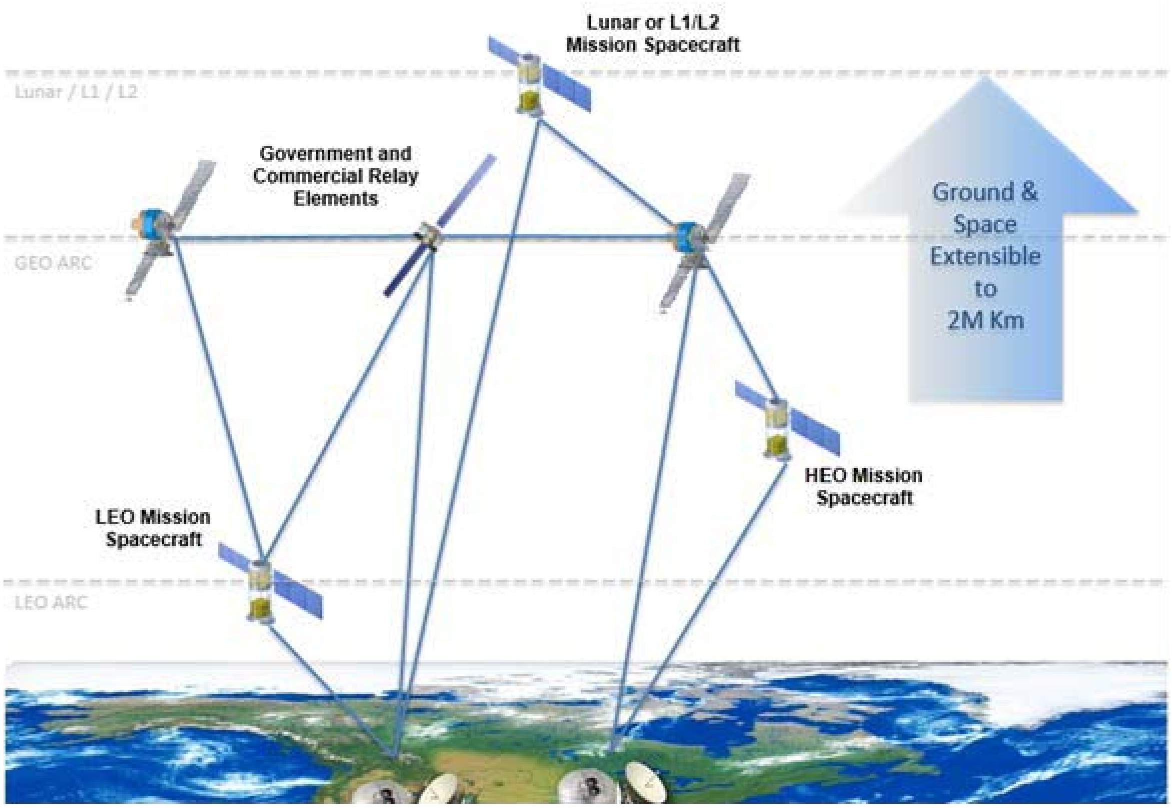

Figure 4. Near Earth Communications & Navigation Architecture [1-2]

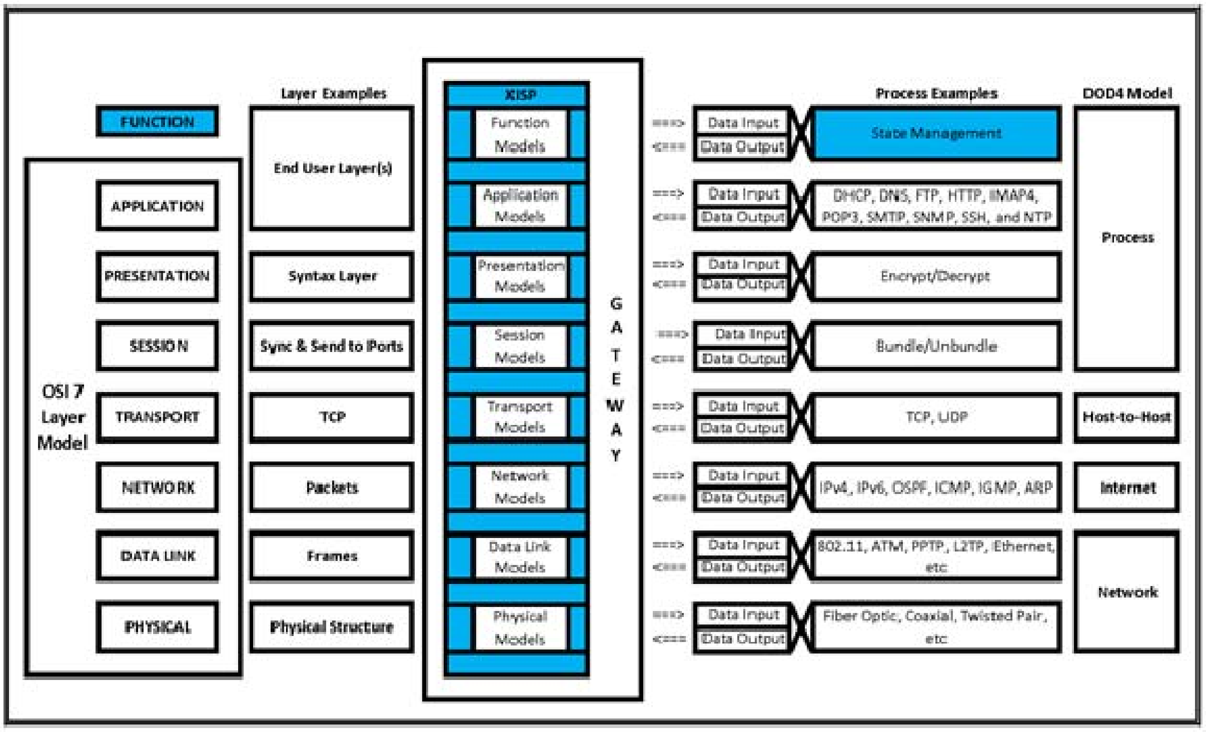

Figure 5. Xlink Internet Services Protocol (XISP) [4]

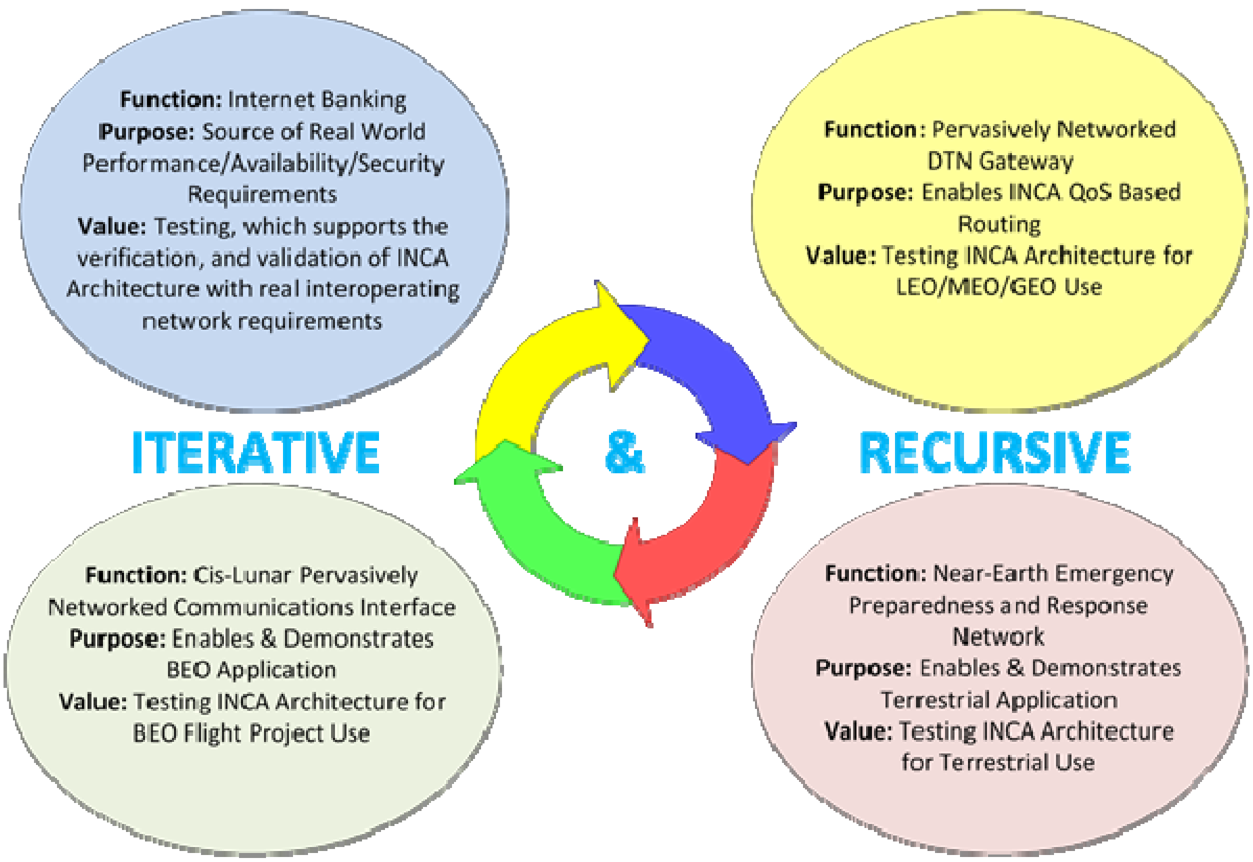

Figure 6. INCA Experiment Elements

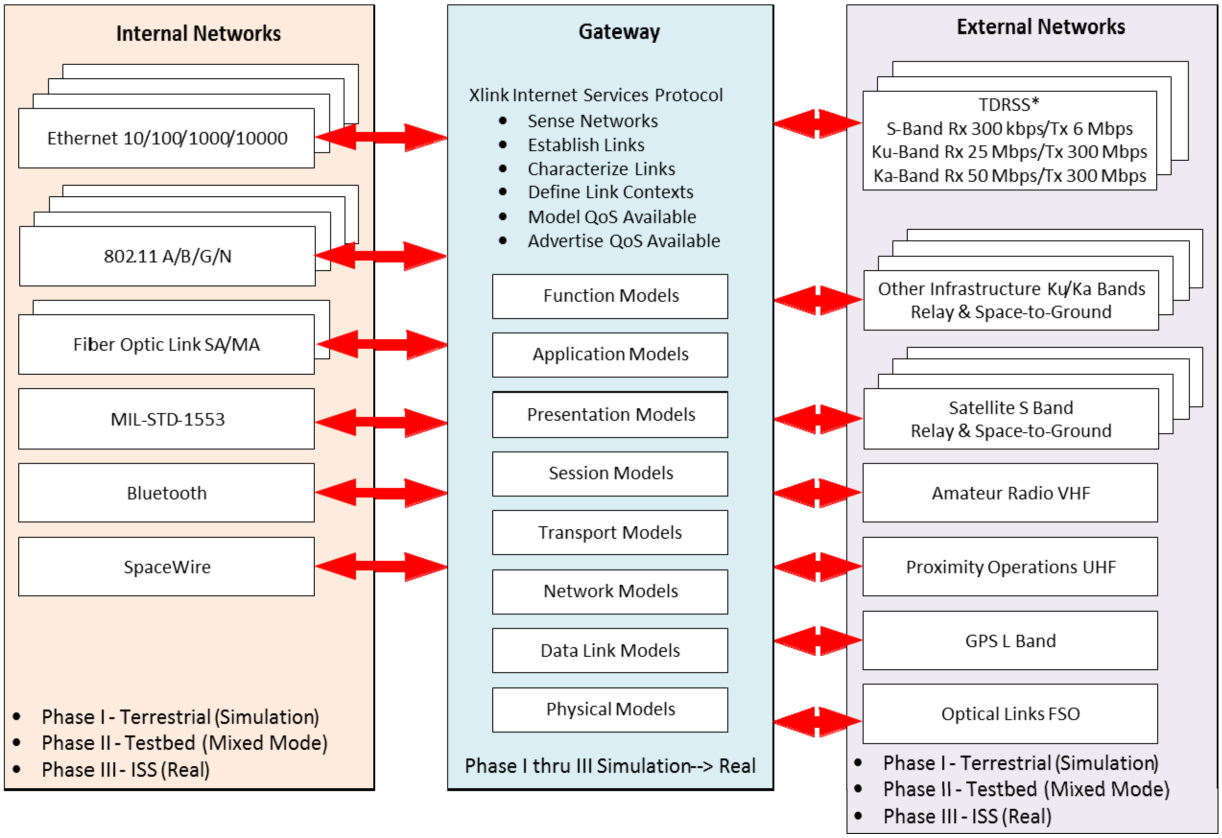

Figure 7. INCA Pervasively Networked Gateway w/QoS Based Routing

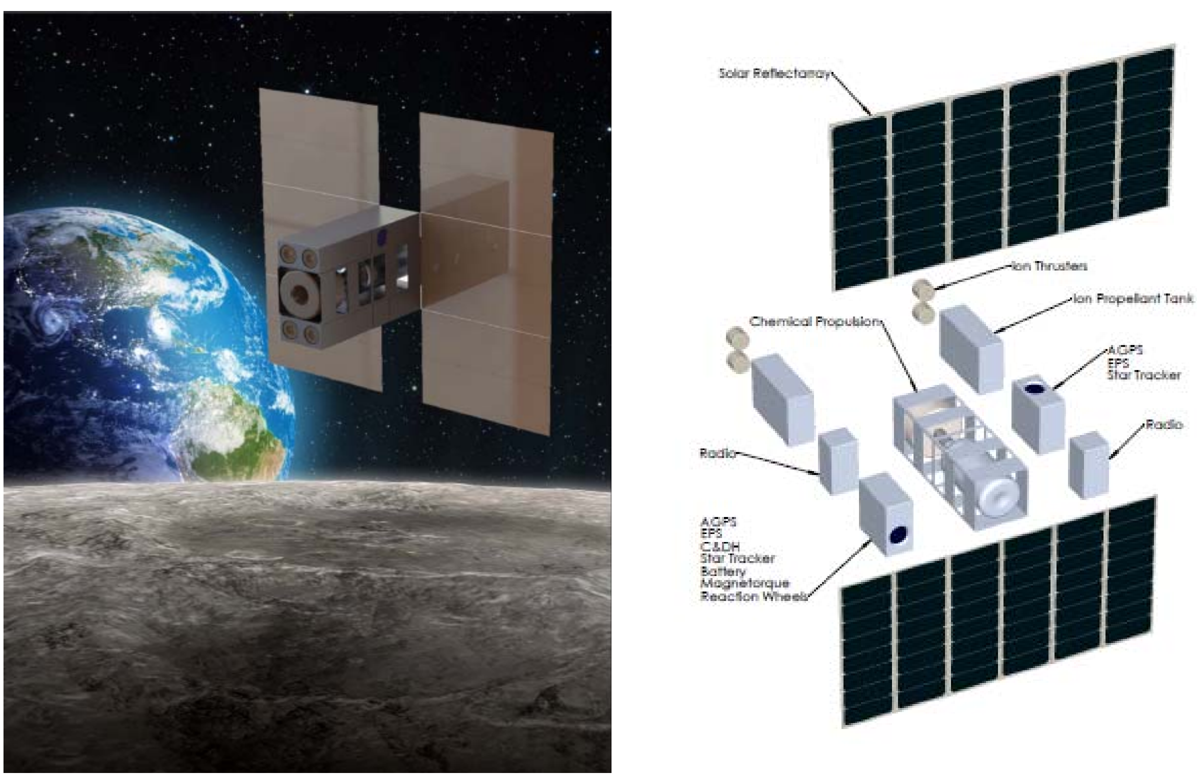

Figure 8. INCA 6U Flight Test Article Derived from Team Alpha CubeSat Design

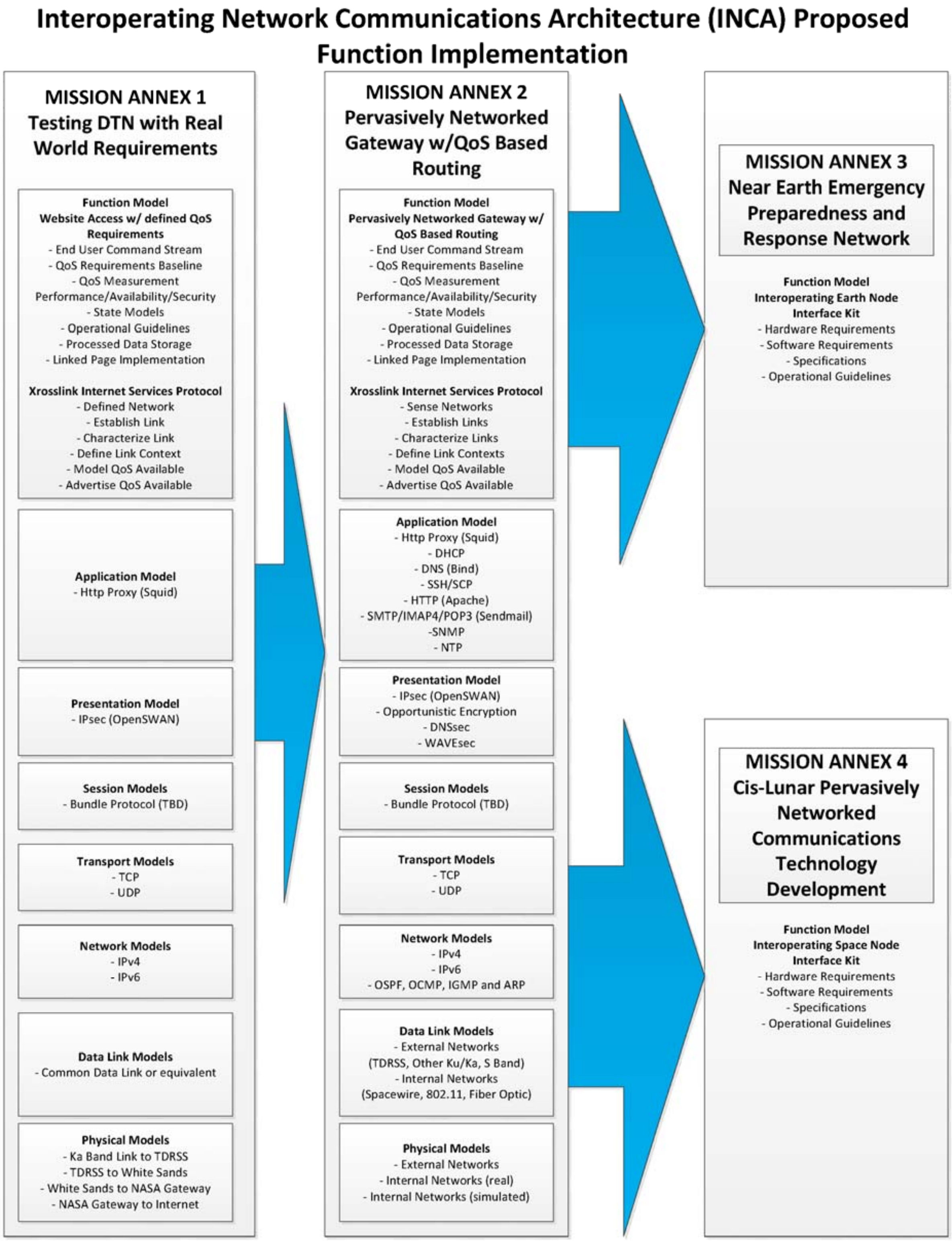

Figure 9. Interoperating Network Communication Architecture (INCA) Proposed Function Implementation
Note: Xrosslink is synonym for Xlink

Services – 2015 era	Services - 2025 era	Services – 2040 era
• Forward data delivery service o Communication Link Transmission Unit (CLTU) o file • Return data delivery service o frame o packet o file • Radiometric data service o on-line o off-line • Science data service o radar o VLBI/Radio astronomy	• Existing o Radiometric data service o Science data service o Radar o Radio science o VLBI/Radio astronomy • Internetworking o Network layer service o End-to-end file service • Navigation o Timing service o Positioning service • Space link layer service o Forward data delivery service o Return data delivery service	• Existing o Radiometric data service (by all relay networks and Earth based ground stations) o Science data service (by Earth based ground stations) ▪ Radar ▪ Radio science ▪ VLBI/Radio astronomy • Internetworking o Network layer service ▪ Extended to all relay networks and Earth based ground stations o End-to-end file service ▪ Extended to all relay networks and Earth based ground stations o End-to-end messaging service ▪ By all relay networks and Earth based ground stations o Service-Oriented Architecture (SOA) services (by Earth based ground stations) • Navigation o Timing service ▪ By all relay networks all relay networks and Earth based ground stations) o Positioning service ▪ By all relay networks • Space link layer service (by all relay networks and Earth based ground stations) o Forward data delivery service o Return data delivery service • Optometric data service (by all relay networks and Earth based ground stations) • Celeslocation service (by planetary networks with positioning capability)
LEGEND: Green Text indicates New Services Types in 2025 era, Blue Text indicates New Service Types in the 2040 era		

Table 1. Next Generation Architecture – Services [1-2]