Internet Society
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IPNSIG

## IPNSIG STRATEGY WORKING GROUP REPORT

# STRATEGY TOWARD A SOLAR SYSTEM INTERNET FOR HUMANITY


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Strategy Working Group (SWG)
**Interplanetary Networking Special Interest Group** (**IPNSIG**)

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The views expressed herein are those of the authors and do not necessarily reflect the views of the **Internet Society** (**ISOC**).

# PREFACE

From Earth to the Moon, Mars and even beyond…

As humans push their boundaries further into space, a communication network that expands across the solar system could significantly serve multiple purposes, to explore and discover new knowledge, facilitate commercial business to arise, and inspire our young generations.

Since 1999, when the Interplanetary Networking Special Interest Group (IPNSIG) was organized, it has been our long-lasting vision to extend Internet to space.

This vision has been shared for more than 20 years amongst many of the stakeholders, including IPNSIG members who have worked to expand networking into space through the development and advancement of the Delay and Disruption Tolerant Networking (DTN) concept and to implement the technology needed to realize a Solar System Internet (SSI).

**A communication network that expands across the solar system to inspire our younger generations**


Work began with a small group at the Jet Propulsion Laboratory and MITRE in 1998. By 2004, the landing of the Spirit and Opportunity rovers on Mars led to the necessity to upgrade the supporting communication system to use a semi-automatic store-and-forward relay system including the rovers and orbiting mapping satellites that were repurposed as relays. By 2009, support from NASA and the US Defense Advanced Research Projects Agency (DARPA) allowed further laboratory and terrestrial testing of a new suite of DTN-based protocols: The Bundle Protocol Suite.

Subsequently, tests were undertaken with the EPOXI spacecraft and the protocols uploaded into the International Space Station (ISS) for crew support.

Collaborative activities with the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA) and the Korean Aerospace Research Institute (KARI) have been undertaken and are continuing. In one ESA experiment, METERON, a small robot vehicle in Germany was controlled in real-time by an astronaut on board the ISS. Other tests (e.g. NASA LLCD) demonstrated high speed optical communication possibilities for future missions.

More recently, the Bundle Protocol Suite has been implemented on three major Internet Cloud provider platforms in support of further application, capacity and resiliency testing. As of this writing, most of the NASA laboratories and JAXA, ESA and KARI are engaged in further development and test of the system.

In this context, the Strategy Working Group (SWG) was formulated under the IPNSIG, to discuss in depth how a Solar System Internet might be realized and inform the discussion by reviewing the history and lessons from the Internet to find possible parallels with SSI. The SWG has also analyzed the current issues that confront us today.

**The SWG has unveiled a “Roadmap”, that could potentially bring light to the development and evolution of the SSI in the decades ahead.**

As IPNSIG is a neutral body, we humbly believe that it is well positioned to lay out narratives, scenarios and principles for an SSI. The IPNSIG Strategy Working Group has outlined several paths into the future, which we call the “Roadmap”, that could potentially bring light to the development and evolution of the SSI in the decades ahead.

It is our hope that many of the stakeholders interested in space will engage and come on board to help to shape the journey on the “Roadmap” towards the realization of a truly sustainable SSI.

As history tells us, collaboration enables anything.

**YOSUKE KANEKO**

Chairman

# CONTENT INDEX

# EXECUTIVE SUMMARY

As humans extend their boundaries further into deep space, a robust Solar System Internet (SSI) architecture will become necessary and even inevitable. It is the IPNSIG's vision to extend networking to space, from the historical point-to-point and "bent pipe" communication architecture to a store-and-forward (packet switched) design, interconnecting multiple nodes and networks within the coming century.

This report, "**Strategy toward a Solar System Internet for Humanity**", describes the IPNSIG's assessment of strategic approaches to help us realize an SSI architecture. One that provides rich communication connectivity at interplanetary distances within our Solar System.

In this Report, after a brief "**Introduction**" the IPNSIG Strategy Working Group lays out its "**Vision**" and its approaches to assess a strategy to deliver a Solar System Internet in "**The Strategy Working Group (SWG) approach**".

To carry out such an endeavour, we must take into account **two dimensions**:

First, the **architectural foundations**: no connectivity infrastructure should be left ungoverned without ethical principles that safeguard its neutrality, openness and decentralization, as we have learned from the creation, development and expansion of the Internet, explained by Dr. Vinton Cerf in **Appendix A**, "**Lessons from the Internet**". Taking this past experience into account, we identify important challenges and issues that confront, from a strategic point of view, the realization of a Solar System Internet (SSI) in "**Issues of SSI today**". Only after doing so, we venture in to propose short, mid and long-term scenarios for the "**Evolution of the Solar System Internet (SSI)**", and articulate the "**Key Properties of an SSI**" needed for this connectivity architecture to be sustainable, democratic, open, decentralized and neutral.

**Second, the assembly of stakeholders** involved to make it happen. A mission to carry out such an endeavour will require the engagement of many stakeholders: governments, academia, private sector and the public. Thus**,** we lay out some **"Strategic Principles for public-private deployment of an SSI"**, to guide the public-private efforts that are needed to deliver this collective mission.

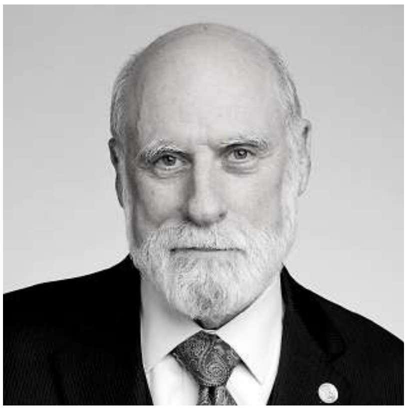
We enjoyed conducting an "**Open Discussion**" on the myriad of topics that remain to be worked out for the SSI: questions regarding governance, geopolitical stances and incentives for the deployment of the technology are highlighted in this section.

Then, we have outlined what we call the roadmap: a set of "**Activities Supporting the Evolution of the SSI"** that could potentially bring light to the development and evolution of an SSI in the long-term.

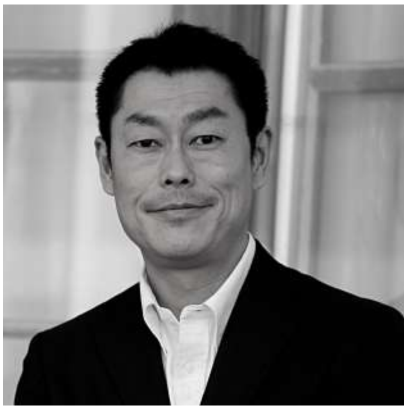
The IPNSIG is a community of like-minded professionals who share a common vision for delivering interplanetary connectivity. Our intent is to set the path for generations to come. In line with these activities, we describe how the IPNSIG can contribute to help stakeholders develop a Solar System Internet, by outlining in "**IPNSIG Roles**" our current efforts and next steps to realize a sustainable SSI in the nearest future.

Lastly, we further summarize our intent to articulate the IPNSIG's goals and vision for an SSI within the **"Summary"**.

Thoughts on the development of the Internet, 40 years in, can be found in **Appendix A**.



**Vinton Cerf**



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## SECTION 1
# INTRODUCTION

# Introduction

From Earth to the Moon, Mars and even beyond, a Solar System Internet (SSI) could become a resource for all humankind, enabling space exploration, science, and commercial activities, and could even deepen our cyber-physical interconnections and foster global citizenship.

SSI is a multi-faceted collective good intended as a tool to help us break the glass ceiling of using space as a venue for human activity and aspirations. But a grand endeavor such as the SSI may need decades to scale, achieving ever higher grades of operability and functionality, as well as reach, with time. Its scope requires a commitment of investment and deployment that can only be achieved by the many - governments, academia, and private companies together.

IPNSIG, the Interplanetary Networking Special Interest Group of the Internet Society (ISOC), has chosen as its mission to facilitate, foster and expedite the construction of the SSI and extend serious networking into space.

The Strategy Working Group (SWG) of the IPNSIG was formulated in this context, to assess how the SSI could be constructed from a strategic point of view through analysis of the present state, reviewing the lessons from the Internet and projecting possible future initiatives.

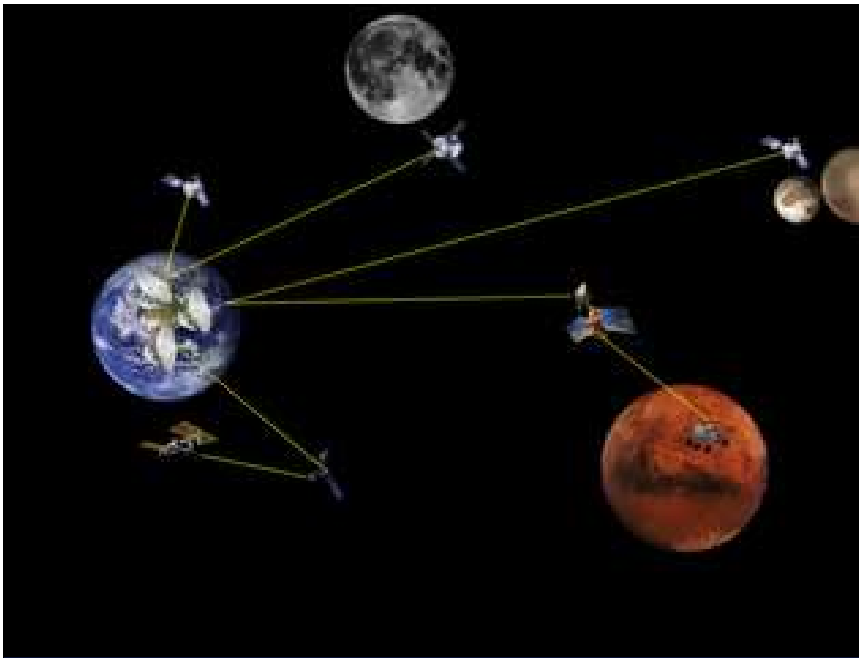
This report describes the IPNSIG's vision for an SSI and its possible evolution, first, and later delves into the sets of key properties (architectural foundations) and strategic principles (rules of the road for stakeholders) that could be used to support the development, operation and utilization of a communication network that extends across our solar system to connect us all.

# SECTION 2
# VISION

# Vision

As humans extend their boundaries further into deep space, the need for a robust SSI architecture will become inevitable. It is IPNSIG's vision over the 100 years ahead to extend networking to space evolving from a point-to-point-based and "bent pipe" communication architecture to a system in which many of the nodes and networks interconnect.

Figure 1 SSI in the longer term future



Today

100 years ahead

Figure I credit: NASA

## SECTION 3

# THE STRATEGY WORKING GROUP APPROACH

# The Strategy Working Group (SWG) approach

The SWG took the following stepwise approach to assess the strategy to realize the 100+ years vision for an SSI.

**Step 1** Analyze the current state and its issues

**Step 2** Present a possible scenario (model) of the SSI evolution

**Step 3** Identify the key properties and strategic approaches to realize an SSI

**Step 4** Identify open issues to be resolved

**Step 5** Present a "Roadmap" enabling the evolution of the SSI and how the IPNSIG will contribute

SECTION 4

# ANALYZING THE CURRENT STATE

# Lessons from the Internet

In **Appendix A** of this report, a summary of parallels is suggested between the history of the Internet and the SSI lessons that may be derived. Indeed, the following items have potential and real parallels in the SSI environment: long term government support from space agencies, private and public sector engagement and sharing of communication assets, the eventual commercialization of the network and its services, international cooperation for the assignment of unique identifiers, collaborative and mutually supportive funding, for example.

Institutions not unlike those encountered in the Internet ecosystem may be needed, and the facilitators of the SSI should anticipate their creation at need. It is vital to preserve flexibility, freedom to invent and expand SSI functionality and adoption of multistakeholder practices. The goal: to allow the SSI the same adaptability as has been demonstrated in the long history of the Internet's evolution.

# Issues of SSI today

Amongst the various issues facing the realization of a sustainable Solar System Internet, and aside from the purely technical ones, the SWG has identified the following challenges and issues that confront, from a strategic point of view toward the realization of a Solar System Internet (SSI).

## Incentives towards an SSI

- ### Vision-sharing

The overall vision of the SSI, mediated by its driving technology, different market opportunities, and how it will benefit humanity should be shared amongst all stakeholders, including space agencies and the private sectors. Sharing a common vision is the very first step to realize an SSI, creating common understandings of what it can deliver. Currently, the space agencies do not think that communication systems turn into missions by themselves because they do not understand the benefits of having an SSI per se.

But a communication mission may stand up, once we have a shared vision and the understanding of the benefits it provides. Likewise that could be the same for the private sector as well.

## From a Space Agency's perspective

- ### Mission by Mission approach

Generally, a space mission is designed to serve its own flight project only. In a typical mission, ground systems, spacecraft and as necessary a relay satellite are utilized to convey data to "solely" fulfill the mission objectives. Hence, there is little incentive for the space agency or the government to secure funds and resources to build SSI elements that would serve multiple purposes.

- ### Classic style communication systems employed

Most flight projects design their missions using "classic style" communication systems. This is driven by a "Failure is not an option" paradigm, where legacy technology is frequently employed for communication systems in view of reliability. Also, the communication system is considered as a bus system that operates within limited spacecraft resources. Therefore, there are limited opportunities to demonstrate advanced communication technologies in space.

## Private sector involvement

Today, there is a lack of incentive within the private sector to take part in the development, operation, and servicing of the Solar System Internet. It is evident that the private sector's expertise and efforts are critical to realizing a scalable, expandable, affordable SSI infrastructure. It could be extremely difficult for humanity to deliver an SSI until commercial network operators decide to commit to it. The SWG believes that Delay Tolerant Networking (DTN) on a relatively large scale is one path forward.

The Challenges to cultivate interest and leverage incentives for the private sector's involvement can be summed up under:

- **Hardware cost-benefit challenge**

Space systems hardware (ie. Communication systems) are typically expensive, as they need to accommodate very specific features, such as radiation tolerance, limitation to power allocations, reduced mass requirements, etc that are not applicable in our terrestrial environment.

In addition, transportation costs to bring such hardware to space remain very high. Thus, a significant decrease in a) transportation and b) development costs of the hardware are critical enablers of a scenario where the private sector finds sustainability in business cases for an SSI.

- **Pragmatic Proof of Concept (POC)**

Proof-of-concept missions to validate a business case could be costly due to the hardware cost-benefit challenge described above.

Therefore, key stakeholders, such as Governments and space agencies, should support technically, and in some cases fund, the private sector to help them develop these business opportunities. In the long run, proven concepts could turn into commercial services for which Governments, space agencies, etc. might be eager customers.

- **Pooled-resources partnerships**

A mission-oriented approach is needed to tackle this endeavour. Risk-taking and risk-sharing initiatives among governments, space agencies, and the private sector are needed to develop an SSI over time. It will require “working outside of the usual silos, coordinating across fields and finding the synergies that turn the components of co-operation into a whole that is larger than the sum of its parts”*. To this end, pooling resources, in the form of investment, equity, material supplies, intellectual property and ownership, may be needed in the first stages of development.

*Mission Economy, Marianna Mazzucato (2021).

## SECTION 5

# EVOLUTION OF THE SOLAR SYSTEM INTERNET (SSI)

# Evolution of the Solar System Internet (SSI)

Based on the present state, and reviewing how the Internet has evolved, the SWG proposes that the SSI might evolve as follows. Refer to figure 2.

## Today: A Government funded network

- Governments / Space Agencies sustain the space communication backbone.
- End users (nodes) are mostly Government or space agencies themselves who conduct narrowly targeted space missions. Inter-agency support or bartering amongst the space agencies is frequently applied to effectively accomplish a given mission.
- Some commercial entities are starting to enter the SSI arena, but this is still limited to those with sufficient capital today (e.g., Starlink from SpaceX, Google Cloud and AWS ground stations from Amazon, etc).

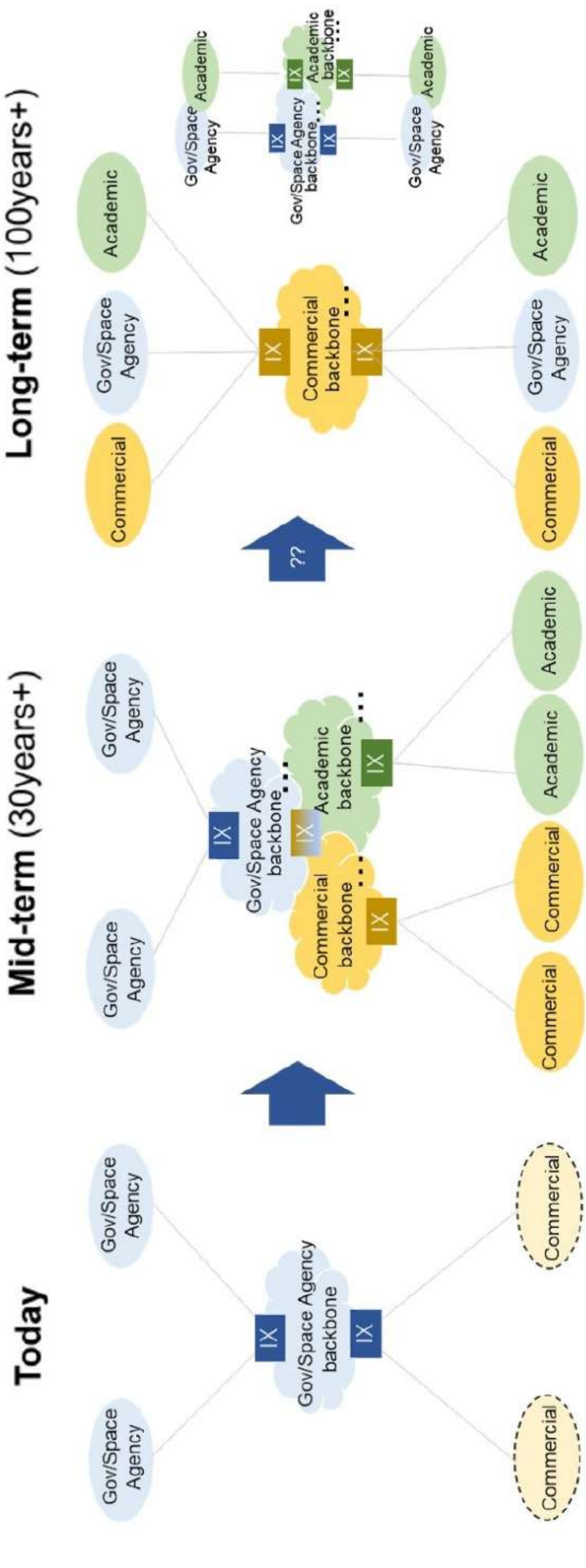
## 30 years+: Government - Commercial - Academic network Coexist

- Governments/Space Agencies, commercial, academic entities sustain their own backbones.
- End users (nodes) could be Government / space agencies and also commercial and academic entities. Expect commercial entities to start providing networking services for their end users.
- All backbones will have the capability to interconnect, similar to the peering concept (via internet exchange points) in our Internet environment.

## 100 years+: Commercial network (autonomy)

- Commercial entities are the main providers of SSI backbone service.
- Many users will make use of the commercially provided backbone and its networking services to fulfill their own needs (science, academic, business purposes etc).
- However, it is expected that there are still demands for dedicated private space networks, serving for classified government missions or for academic purposes. Therefore, some backbones could still be sustained by the Government, Space agencies or academia.

## FIGURE 2 - SSI EVOLUTION



## SECTION 6

# KEY PROPERTIES OF AN SSI

# Key Properties of an SSI

A grand endeavor such as the Solar System Internet may need decades to realize, achieving ever higher grades of operability and functionality, as well as reach, with time.

The SWG has assessed the key properties that must characterize such a truly sustainable SSI. Broad strategic principles to enable the collaboration between public and the private sectors are described in more detail in section 7.

## Collaboration

IPNSIG envisions the SSI as a common structure serving all humankind. Therefore, it seems absolutely natural to enlist the efforts and expertise of many stakeholders and differing initiatives, regardless of nation state, in building it, as it is still very costly today to build or launch assets to space that will compose a part of the SSI.

Therefore, the SSI should be constructed as a collaborative effort, leveraging the expertise and resources across the globe from various countries and entities, understanding that investments made today will be mutually beneficial in the long term.

This formula was applied successfully with the International Space Station and is planned for the Gateway project.

## Global Standards

The SSI can learn from the success of the Internet. The Internet is operated in conformance to technical standards such as TCP/IP, DNS and BGP, and such standards have presented a single way of interconnecting the nodes and networks in our terrestrial Internet environment.

In the case of the SSI, DTN protocol standardization is crucial to allow for deep space communications under delayed and disrupted environments. These standards will enable nodes and networks provided by different entities to interconnect.

This is why defining a single body of global technical standards that are open for everyone is the key to realizing the SSI as a common infrastructure that is to be built, operated and used by many of these initiatives.

Having global technical standards will also encourage innovation in SSI development, cultivating an industry ecosystem revolving around the SSI, as interoperability enables new business use cases to be ideated and developed.

## Stability

The stability of a technical standard is important. It is suggested that these standards should not rapidly change nor become backwardly incompatible. The overall goal of technical standard stability is to sustain the robustness of the SSI infrastructure. We should avoid repeating IPv4/v6 incompatibility problems that occurred on the Internet.

## Democracy

A democratic approach must be acknowledged in the SSI. This means that any entity who wishes to build, join, operate, or use the SSI must have the freedom to do that. It is also important to note that no single actor should dictate configurations for the SSI. The SSI should naturally evolve while accepting minimum governance to preserve the coherence of the overall infrastructure.

For example: formal mechanisms for avoiding collisions in the assignment of node identifiers are necessary to preserve coherence of the SSI architecture when using DTN protocols.

## Affordability

Deploying and utilizing the SSI must be and remain affordable to its stakeholders. This does not necessarily mean that cost-effectiveness is paramount, but rather that the costs incurred must be covered by some agreed means. Such costs may be evaluated differently by the various SSI stakeholders.

For the case of a commercial entity that would wish to deploy a networking service for SSI, the investments made to bring assets to space and operate them must be recovered, e.g., through service provided to end users.

For the case of an academic entity, the cost incurred to use the network service must be justified by the potential academic or science benefit.

## Expandability

The SSI should have the ability to scale up and add new functionality as it evolves over time. It is important for its architecture to be flexible enough to adopt new technology, and this feature must be acknowledged from the early phase of the SSI construction.

## Security

While supporting a democratic approach for the SSI, it is crucial that the architecture be capable of securing the information that it conveys. When multiple networks serving various purposes emerge, it is important that classified (or sensitive) information can be isolated from information that is not. The architecture or its supporting technical standards must accommodate the potential requirements for network isolation as the SSI evolves and expands.

SECTION 7

# STRATEGIC PRINCIPLES FOR PUBLIC-PRIVATE DEPLOYMENT OF AN SSI

# Strategic Principles for public-private deployment of an SSI

The SWG has identified the following broad strategic principles to enable collaboration between public and the private sectors given that:

- Governments need private stakeholders for their agility, ideas, knowledge sharing and prototype iterations.
- Private stakeholders need support for the success of commercial activities.

See Table-1, which summarizes incentives for - and challenges in - cooperation from Government and Private sectors' perspectives.

## 1. Vision-sharing

The SSI is an infrastructure to be built as a common structure leveraging expertise from both the Government and the private sector. This is crucial and is the very first step toward making an SSI a reality: sharing a common vision for the SSI amongst stakeholders.

## 2. Co-creation

Co-creating and co-developing are indispensable. Amongst the incentives: support in funding, tech and human capital support, idea and techniques iteration and feedback, consensus to enable through policies and regulation, and the possibility of the government being a client for the resulting service.

## 3. Risk-sharing

Sharing cost, risk, and responsibilities. In their long-term strategies, missions, and strategic investments - such as those made in Quantum Information Sciences - governments and national agencies know that they must encourage industrial cooperation, working towards a shared vision and sharing the risks with private companies.

Governments & national agencies have strong incentives for risk-sharing nowadays. If governments perceive the need to engage in the SSI endeavor, they might seek to share the risk with private companies from the very beginning.

Possible paths include:

- Co-ownership of patents, SSI backbone infrastructure.
- Open standards and royalty-free licensing.
- Anchor tenancy. Government commits to procurement of sufficient quantities of a commercial space product or service that is needed to meet Government mission requirements.

## 4. Pooling & sharing

Pooling & sharing industrial schemes are partnerships established between stakeholders (public-public, public-private, or private-private) who seek to share the costs of creating and maintaining a prototype or final product.

The difference between co-creation and risk-sharing on the one hand, and pooling & sharing on the other, is that the latter is a specific scheme whereby a sensitive / strategic asset is created and owned by one party and others (public/private) share in the service provided by that asset in exchange for helping with maintenance. It is cooperation with regard to an asset that the owner cannot afford to maintain – and the collaborator cannot afford to own.

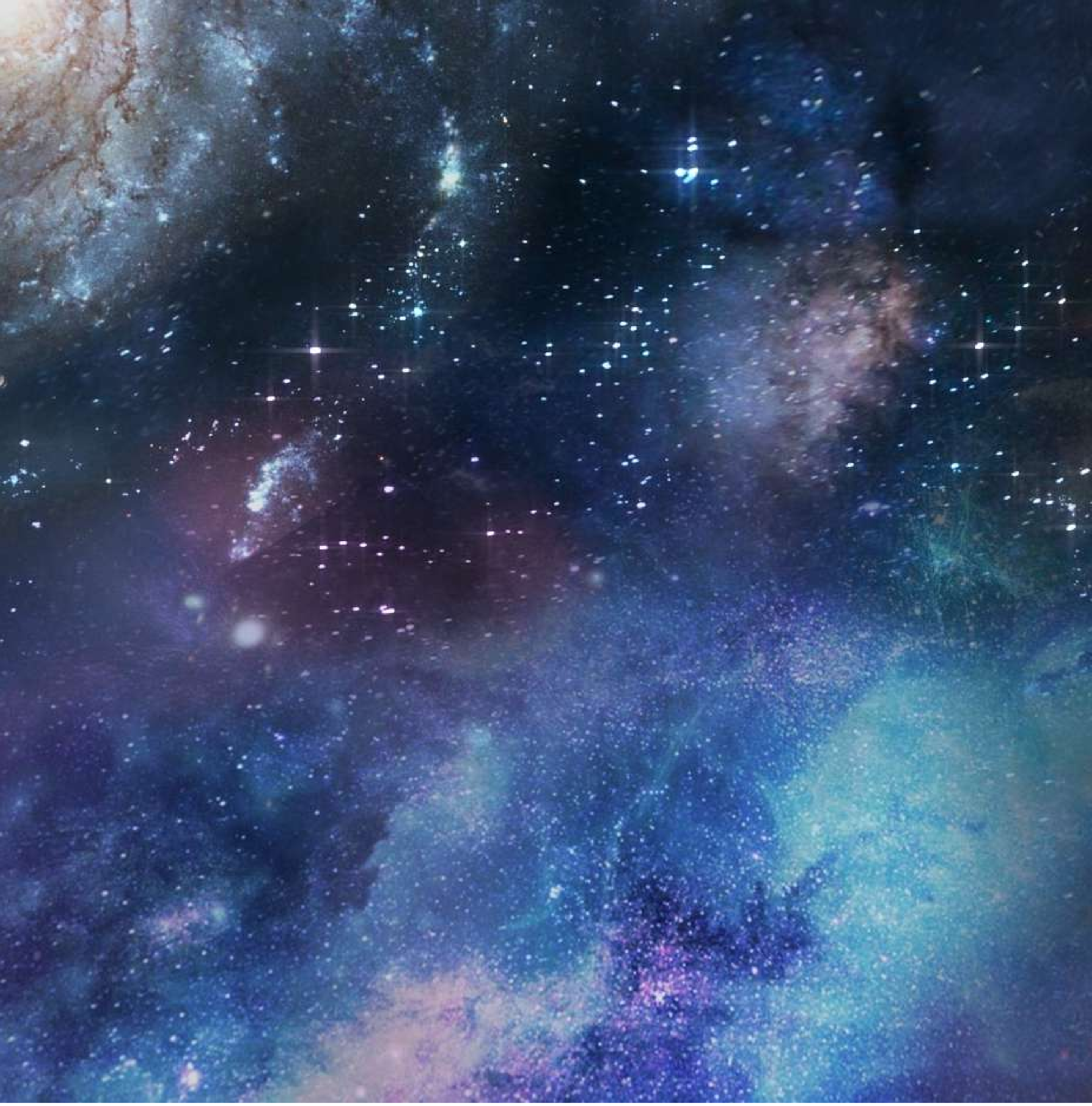
**Examples of Pooling & Sharing**:

- European Air Transport Command (EATC) pooled & shared assets: Airbus military aircraft, where Germany owns / keeps the property, and other countries enjoy the use of the asset (up to X %) and share the costs of maintaining the fleet.
- In our specific case: historically, inter-space agency resource sharing is termed “cross support”. This is a “Barter” (equivalent exchange) system such as “exchanging ground station resources” or “providing a communication resource in exchange of receiving scientific data”.
- Most of today’s Internet involves settlement-free peering in which each party carries the other’s traffic without further compensation.

## Table-1 Incentives and challenges for cooperation

| Incentives for cooperation (co-creation, risk-sharing, pooling & sharing) | |
|---|---|
| **Governments** | **Private actors** |
| Ensure access to technologies and services | Access to know-how, resources, and financial support |
| Support a sustainable model for space exploration | Gain credibility, validate their capabilities |
| Foster domestic industry growth and cooperation | Create potential revenue streams |

| Challenges to cooperation (co-creation, risk-sharing, pooling & sharing) | |
|---|---|
| **Governments** | **Private actors** |
| Mutual understanding of expectations and goals | |
| Establishment of appropiate cost and risk-sharing schemes | |
| Change in government priorities and funding | |
| Commercial viability and profitability | |



# SECTION 8
# OPEN ISSUES

# Open Issues

## 1. Management authority of Standards

There is an open question regarding the management authority of the standards: which standards organization is the proper authority for developing and publishing standards and ensuring that implementations conform to them? One strong candidate would be the Consultative Committee for Space Data Systems (CCSDS), which is affiliated with the International Organization for Standardization (ISO). Another possibility, though, would be the Internet Engineering Task Force (IETF), which is affiliated with the Internet Society. Both are currently involved in cooperatively developing DTN standards.

### Open Discussion

Which is the more salient element of the nature of SSI, its deployment in space or its close ties to the Internet? Or should some other option be considered, such as an industry group (e.g., the Object Management Group), a broader standards organization (e.g., the International Telecommunications Union), or an entirely new organization that focuses solely on SSI/IPN? At present, CCSDS and IETF cooperate to keep their respective work technically synchronized. As a practical matter, as with the Internet, many Standards Development Organizations contribute standards that are used in various combinations to realize interoperability and functionality of the Internet Protocol Suite and might do so for the SSI as well.

## 2. Governance of the Solar System Internet (SSI)

A further question of authority and purview would be the governance of the deployed networks themselves. Efficient operation of the Solar System Internet will rest on the uniqueness of data labels, node identifiers, service identifiers, multicast group identifiers, and region identifiers, as well as on the authenticity of cryptographic keys, contact plans, clock synchronizations, and network management directives in general.

## Open Discussion

How will these administrative responsibilities be discharged fairly and reliably? Should we have an organization comparable to ICANN in SSI? There exists already an organization overseen by CCSDS called the Space Assigned Numbers Authority (SANA) mirroring the Internet Assigned Numbers Authority of the Internet Corporation for Assigned Names and Numbers. It is useful to keep in mind that the SSI, like its terrestrial Internet counterpart, may be made up of multiple, independent but interconnected networks requiring collaboration and coordination to function. Governance practices that can support this level of multi-party complexity will be needed.

## Various challenges could be foreseen on SSI governance:

### Perks and challenges for governments

- A strong basic group of countries and their respective private sector contractors, space agencies, and other entities should be aligned to discuss the topic of the SSI.
- Geographical, territorial, continental diversity is strongly recommended - to maintain equilibrium of power and avoid digital sovereignty of states.
- These countries should collectively adopt the concept, narrative, function, and utilization of the SSI. Important to note that if there is no governance viability, there will be no commercial engagement.

### Perks and challenges for International Agencies, Standards Bodies

- Leading roles of a few countries in the development of standards may constitute a problem.
- A single private sector entity that provides substantial funding could practice control over the standard itself.

### United Nations (UN) and related agencies challenge

- The United Nations may be the authority to oversee governance issues within the SSI. UN could own the role of placing “stamps of legitimacy” on standards and deployment choices at some stage of the development of SSI.

## SECTION 9
# A ROADMAP IN SUPPORT OF THE EVOLUTION OF THE SSI

# Roadmap in support of the Evolution of the SSI

While a detailed roadmap for a 100 year program might be an exercise in hubris, the SWG has some preliminary ideas for making progress in the nearer term. The IPNSIG can be a catalyst and an active participant in forging ahead with the experimental and operational deployment of an SSI. The Bundle Protocol Suite, while maturing, still needs to be further tested at scale and in situ (i.e. space). Moreover, as there are multiple implementations, their interoperability needs to be demonstrated. If the vision of an operational SSI is to be fulfilled, commercial interests must be attracted and suitable business models developed for sustainability. Given the history of space exploration, government involvement is also essential. In the course of preparing this document, several courses of action have been identified, as outlined below.

## 1. Testing at scale

The basic idea is to implement the Bundle Protocol Suite on currently available cloud services (Azure, Google Cloud, Amazon Web Services) with suitable APIs allowing Bundle Protocol Suite implementations on laptops, desktops and mobiles to interact with cloud-based resources. IPNSIG would sponsor implementations of the ION version of BP7 (and LTP) on all three cloud services and port ION implementations on IOS, MACOS, LINUX and ANDROID operating systems. These would support applications such as AI image recognition, streaming audio and video, real-time conferencing among others. Once the basic BP software and APIs are in place, others may design and build applications for testing.

The basic purpose of this exercise is to generate significant traffic in a terrestrial setting to verify that the network management, security framework, installation, registration and addition of new nodes all works at scale. As much as possible, this work would be highly automated. Performance reporting would be automated. Operations and maintenance would need to be supported, possible with volunteers or even paid operators. Documentation to onboard new users would be needed. The basic idea is similar to the famous “SETI@home” effort that allowed the public to participate in the analysis of received radio signals from the SETI array to search for anomalous signal regularities.

For simplicity of support, operations and maintenance, it is proposed to use the most current version of ION to power this effort and to avoid interoperability problems while exercising the network and performance management systems at scale. As this effort proceeds in phases, we would expect to evolve to a multiple-region implementation (as analog of the Internet's Autonomous Systems), with the concomitant need to articulate operational processes and security enhancements among multiple network jurisdictions.

## 2. Interoperability

To support further testing of interoperability among distinct implementations of the Bundle Protocol Suite, the DTNbone (NASA labs et al) could be extended to include cloud access and used for that purpose. There remain many questions about configuration, registration, network management, security and application interworking across different implementations of the Bundle Protocol Suite and this effort would be focused on exposing and fixing interoperability issues.

## 3. Promotion

One of the success stories of the Internet's evolution was the founding of the INTEROP conference and exhibition. This rapidly growing phenomenon drew commercial and government attention to the promise of the Internet. It is possible that a similar enterprise would be instrumental in attracting support for and investment in operational implementations of the Bundle Protocol Suite and associated applications and services.

## 4. Experimental and Active Mission Deployment

In support of ongoing space exploration, IPNSIG recommends operational deployment of implementations of the Bundle Protocol Suite among the national space agencies including the National Aeronautics and Space Administration (NASA), the Japan Aerospace Exploration Agency (JAXA), the European Space Agency (ESA), the Korean Aerospace Research Institute (KARI), among others. Lessons learned from the other activities noted previously would inform operational use of the Bundle Protocol Suite. Such an effort would require cooperation and liaison among the space agencies and, eventually, with commercial software, hardware and service providers.

This plan highlights the paramount importance of network operations, concepts of autonomous systems and contact graph management, registration into contact graph visibility, ground station and relay satellite operation (e.g. Deep Space Network, TDRSS, etc.). In the Internet, the reliability and security of the Border Gateway Protocol (BGP) routing system is being increased with Resource Public Key Infrastructure (RPKI) and similar considerations for the SSI will motivate both test and operational deployments.

## 5. Advocacy

Finally, IPNSIG can become a vigorous advocate for the Bundle Protocol Suite and the prospective SSI. It would seek to develop a shared vision of the SSI, its importance, the value it creates, and what it would take to build it. IPNSIG would seek engagement among key stakeholders in academia, government, private sector and the general public.

Through such efforts, IPNSIG hopes to develop a shared vision of the importance of the SSI among various stakeholders, and build a collective understanding of the need to construct an SSI as a common infrastructure. These various efforts would raise awareness among private sector entities of viable SSI business cases, leverage the capabilities of DTN as demonstrated by the deployment and use of the Bundle Protocol Suite by the public, cloud computing providers, academic participants and the space agencies. Successful accomplishment of these goals could establish the plausibility of private sector proof-of-concept missions. In addition, success would generate momentum towards commoditizing DTN nodes (hardware). If commercial use of DTN networks becomes more widespread in terrestrial applications (mobile, laptop pad, Internet of Things), volume pricing of DTN hardware and software would further reduce the SSI development cost.

# SECTION 10
# IPNSIG ROLES

# IPNSIG Roles

The IPNSIG can contribute to the SSI endeavor by presenting a narrative and roadmap and communicating it to relevant stakeholders, including Government, Space Agencies, CCSDS, IOAG, IETF/IRTF, Private companies etc. The IPNSIG can also contribute to a range of goals by means of the activities referenced in **Section 9** including proof of concept demonstrations of the Bundle Protocol Suite, stimulation of public interest in the SSI and DTN concepts in general, hardening and scaling of implementations of the Bundle Protocol Suite and stimulating IPNSIG membership engagement in the general effort.

In aid of these objectives, IPNSIG has formed a set of **Working Groups** made up of IPNSIG members and volunteers:

- **SWG (Strategy Working Group)**: Developing a shared vision, key principles and a possible roadmap for an SSI and communicating it with various stakeholders.
- **PWG (Pilot Projects Working Group)**: Conducting Pilot Projects to demonstrate the capability of DTN to enlighten and cultivate public/private sector interest.
- **TDWG (Technical Documentation Working Group)**: Enabling easy, quick access to information on IPN and DTN by maintaining an annotated library of documentation.
- **OWG (Outreach Working Group)**: Improving and broadening IPNSIG outreach activities and projects to support the strategy and roadmap of the SSI.
- **BWG (Business Working Group)**: To be launched in the future, intended to brainstorm and foster new businesses and business models using DTN in terrestrial applications and in the SSI.

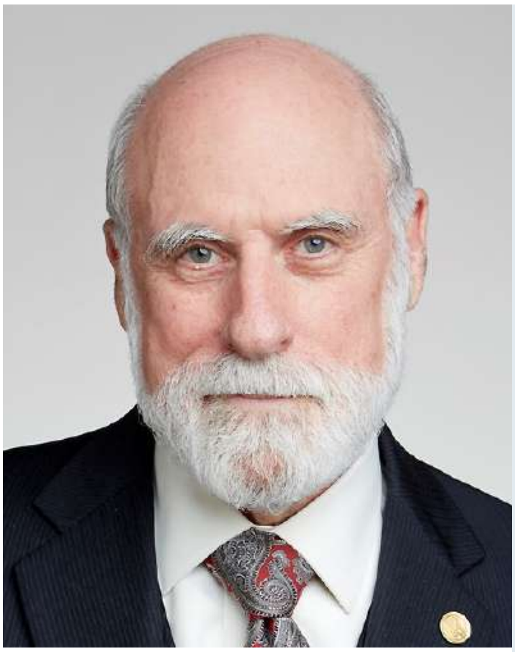
# Summary

The IPNSIG will articulate our vision and overarching goals for an SSI, and it is our will to progressively engage the membership in the pursuit of these goals and vision.

Through joint efforts by the different Working Groups that compose our organizational structure, the SWG will advocate to communicate this roadmap with various stakeholders, with the goal of progressively generating public engagement, and inspire action.

The means to accomplish these advocacy efforts will be webinars, workshops and international conferences and forums, which will also serve to further refine the concept presented in this Report, and to expand the community of stakeholders who may wish to take this journey together: to make a Solar System Internet a reality in the long term future.

# MEET THE STRATEGY TEAM



## VINTON CERF

At Google, Vint Cerf contributes to global ity.policy and business development and continued spread of the Internet. Widely known as one of the “Fathers of the Internet,” Cerf is the co-designer of the TCP/IP protocols and the architecture of the Internet. He has served in executive positions at the Internet Society, the Internet Corporation for Assigned Names and Numbers, the American Registry for Internet Numbers, MCI, the Corporation for National Research Initiatives and the Defense Advanced Research Projects Agency and on the faculty of Stanford University. Vint Cerf sat on the US National Science Board and is a Visiting Scientist at the Jet Propulsion Laboratory. Cerf is a Foreign Member of the Royal Society and Swedish Academy of Engineering, Fellow of the IEEE, ACM, American Association for the advancement of Science, American Academy of Arts and Sciences, British Computer Society, Worshipful Companies of Information Technologists and Stationers and is a member of the National Academies of Engineering and Science. Cerf is a recipient of numerous awards and commendations in connection with his work on the Internet, including the US Presidential Medal of Freedom, US National Medal of Technology, the Queen Elizabeth Prize for Engineering, the Prince of Asturias Award, the Japan Prize, the Charles Stark Draper award, the ACM Turing Award, the Legion d’Honneur and 29 honorary degrees.

# MEET THE STRATEGY TEAM

## YOSUKE KANEKO

Chairperson Yosuke Kaneko is a member of JAXA (Japan Aerospace Exploration Agency). He is passionate about the future of IPN and is thrilled to lead the IPNSIG. From 2002 to 2016, he worked at the ISS/JEM (Japanese Experiment Module) Project, Communication and Avionics engineer, Flight Director for JEM (Japanese Experimental Module, Kibo) on the ISS. Currently, a wide variety of scientific, medical, and educational experiments are conducted on JEM. Indeed, as a part of the ISS, JEM provides extensive opportunities for space environment utilization. From 2017 to 2019, he worked within the ISS Program, Exploration Programs (Gateway, Moon, Mars), Japanese Representative for ICSIS (International Communication System Interoperability Standards). Since 2020, he works at the JAXA Headquarters, in the Strategic Planning Division. Kaneko has been heavily engaged in Space Agency business up to date, but recently came to realize the importance of bringing many of disparate initiatives including Government, Space Agencies, CCSDS, IETF/IRTF, Commercial Space Sector and Private Service Providers and more, in a single venue, to discuss their needs, requirements, and the driving technology to be developed that constitute a sustainable IPN architecture. He believes IPNSIG can play a key role in moving in that direction.

# MEET THE STRATEGY TEAM

## SCOTT BURLEIGH

Scott Burleigh is a Principal Engineer at the Jet Propulsion Laboratory, California Institute of Technology, where he has been developing flight mission software since 1986. A founding member of the Delay-Tolerant Networking (DTN) Research Group of the Internet Research Task Force, Mr. Burleigh was a co-author of the DTN Architecture definition (Internet RFC 4838). He also co-authored the specification for version 6 of the DTN Bundle Protocol (BP, Internet RFC 5050) supporting automated data forwarding through a network of intermittently connected nodes, and is now lead author for the specification for BP version 7. Mr. Burleigh leads the development and maintenance of implementations of BP and related protocols that are designed for integration into deep space mission flight software, with the long-term goal of enabling deployment of a delay-tolerant Solar System Internet. Mr. Burleigh has received the NASA Exceptional Engineering Achievement Medal and four NASA Space Act Board Awards for his work on the design and implementation of these communication protocols.

# MEET THE STRATEGY TEAM

## KIYOHISA SUZUKI

Kiyohisa Suzuki is currently an associate senior engineer at JAXA (Japan Aerospace Exploration Agency). He is working at JAXA since 2002.

He had mainly worked ICT (Information and Communication Technology) field in space, such as communication satellite missions, mission interface design for ground assets.

He is currently working to research spacecraft networking and interoperability issues, and also working a development of implementation of DTN protocol suites and researching its application.

And Kiyohisa is serving as deputy chairperson of Delay Tolerant Networking Working Group in the Consultative Committee for Space Data Systems (CCSDS) for standardizing DTN protocol suite. He is also a member of several International Working Group such as the Interagency Operations Advisory Group (IOAG)'s Space Internetworking Strategy Group, Internet Engineering Task Force's Delay Tolerant Networking working group.

# MEET THE STRATEGY TEAM

## MARÍA LUQUE

María Luque is a strategist and a public affairs consultant. Her purpose is to align the interests of the public and private sectors over ideas, policies, projects and ventures that create value.

María delivers unorthodox non-market strategies for the technology sector as Managing Director for the consultancy boutique Mission-Oriented. Over the years, she has provided intelligence on intangible assets and political risks to project development, strategy to achieve market and social impact, and communications and public affairs actions to engage stakeholders in understanding the value of products and ideas.

María has mainly worked within Spain and the United Kingdom, and has partnered with the likes of the United Nations, the OCDE, and several government Cabinets, along with private industry stakeholders.

María is excited about the development of DTN-enabled Interplanetary Networking, as well as the overall terrestrial applications of DTN technologies. She believes that strategizing the creation of the connectivity infrastructures of the future is of utmost importance: they constitute the backbone for our connectedness, and its development will likely face uncounted challenges of sensitive public and private nature.

# GLOSSARY OF TERMS

**BGP:** *Border Gateway Protocol*, a protocol designed to exchange routing and reachability information among autonomous systems (AS) on the Internet.

**BP:** *Bundle Protocol*, a key element of Delay-Tolerant Networking technology. BP serves essentially the same function in a DTN-based network that the Internet Protocol (IP) serves in the Internet: it is a network protocol that enables data to flow among network nodes despite frequent, lengthy lapses in connectivity and/or very high signal propagation latencies.

**CCSDS:** *Consultative Committee for Space Data Systems*, a multi-national forum for the development of communications & data systems standards for spaceflight.

**DNS**: *Domain Name System*, a hierarchical and decentralized naming system for computers, services, or other resources connected to the Internet or a private network.

**DSN:** *Deep Space Network*, a worldwide network of U.S. spacecraft communication facilities, located in the United States (California), Spain (Madrid), and Australia (Canberra), that supports deep space spacecraft missions.

**DTN:** *Delay-Tolerant (and/or Disruption-Tolerant) Networking*, an architecture for automated digital communications that can provide Internet-like communication service in environments where the assumptions on which the Internet is built - in particular, the expectation of very brief query/response cycles between network nodes at all times - do not hold. DTN principles are especially well suited to interplanetary networking.

**DTN Protocol Suite:** the collection of protocols developed by the space communication research community to implement a delay and disruption tolerant network.

**EATC:** *European Air Transport Command*, a command center that exercises the operational control of the majority of the aerial refueling capabilities and military transport fleets of a consortium of seven European Union (EU) member states.

**ESA:** *European Space Agency,* an intergovernmental organization of 22 member states where the Agency provides and promotes, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications.

**ICANN:** *Internet Corporation for Assigned Names and Numbers*, a multistakeholder group and nonprofit organization responsible for coordinating the maintenance and procedures of several databases related to the namespaces and numerical spaces of the Internet, ensuring the network's stable and secure operation.

**IETF:** *Internet Engineering Task Force*, an open standards organization which develops and promotes voluntary Internet standards, in particular the standards that comprise the Internet protocol suite.

**IOAG**: *Interagency Operations Advisory Group*, a forum for identifying common needs across multiple agencies related to mission operations, space communications, and navigation interoperability.

**IPN:** *Interplanetary networking*, the research and development initiative aimed at conceiving, establishing, and operating the Solar System Internet.

**IRTF**: *Internet Research Task Force*, an organization focusing on longer-term research issues related to the Internet while the parallel organization, the Internet Engineering Task Force (IETF), focuses on the shorter term issues of engineering and standards making.

**ISO**: *International Organization for Standardization*, an international standard-setting body composed of representatives from various national standards organizations.

**JAXA**: *Japan Aerospace Exploration Agency*, a space agency of Japan responsible for research, technology development and launch of satellites into orbit, as well as pursuing many advanced missions.

**KARI**: *Korea Aerospace Research Institute*, an aeronautics and space agency of South Korea, conducting technological advancements, development, and dissemination in the field of aerospace science and technology.

**LTP:** *Licklider Transmission Protocol,* a key link layer protocol designed to support BP operation on a point-to-point basis incorporating error detection, coping with one-way links and scheduled disconnection due to orbital mechanics. Can operate over UDP.

**NASA:** *National Aeronautics and Space Administration*, a space agency of the U.S. federal government responsible for the civilian space program, as well as aeronautics and space research.

**RPKI:** *Resource Public Key Infrastructure (RPKI),* is a specialized public key infrastructure (PKI) framework to support improved security for the Internet's BGP routing infrastructure.

**SANA:** *Space Assigned Numbers Authority*, the registrar function for the protocol registries created under the Consultative Committee for Space Data Systems (CCSDS).

**SSI:** *Solar System Internet*, the aggregate interplanetary network infrastructure that will comprise growing numbers of spacecraft, relay satellites, space stations, and habitats and vehicles on planetary surfaces, together with ground stations on Earth and the terrestrial Internet itself.

**TCP**: *Transmission Control Protocol*, a protocol that provides reliable, ordered, and error-checked delivery of a stream of octets (bytes) between applications running on hosts communicating via an IP network.

**TCP/IP**: *Transmission Control Protocol/Internet Protocol*, a suite of communication protocols used to interconnect network devices on the internet. The entire IP suite, a set of rules and procedures, is commonly referred to as TCP/IP.

**TDRSS:** *Tracking and Data Relay Satellite System*, a network of U.S. communications satellites (each called a tracking and data relay satellite, TDRS) and ground stations used for space communications purposes.

**UDP:** *User Datagram Protocol*, a simple Internet protocol for packet transmission without guarantee of delivery, ordering, or avoidance of duplication owing to end/end retransmission being external to the protocol itself.

# APPENDIX A

## Lessons from the Internet

### History

The Internet began as a project in 1968 to experiment with packet switching as a means of connecting disparate computers, called “hosts” to each other. Apart from building and programming the homogeneous packet switches, called Interface Message Processors (IMPs), the most significant challenge was to design computer communication protocols that could be implemented in hosts of widely varying brands based on hardware and operating systems that were unalike except that they all had the property that they implemented time-sharing services. The purpose of the network was to allow research teams at universities and other institutions to share their computing capacity and application software in the pursuit of artificial intelligence and other computing research objectives.

This so-called Arpanet project was fully funded by the US Defense Advanced Research Project Agency (DARPA) and involved about a dozen groups in the US, Norway and the UK. Coherence of the project arose from leadership at DARPA and at UCLA, the where the first node of the Arpanet was installed. Stephen Crocker, a graduate student at the time, led an informal Network Working Group (NWG) made up of graduate students and researchers at the cooperating institutions. The NWG tackled the design of protocols organized in a layered fashion to be used by the time-sharing computers of the Arpanet. The primary host-host protocol was implemented in the Network Control Program (NCP) which was sometimes referred to as the Network Control Protocol. Layered on top of the NCP were protocols for remote terminal access to time-shared systems (TELNET) and file transfer (FTP) and eventually electronic mail (Simple Message Transfer Protocol or SMTP).

The success of the Arpanet project led to the development of the Internet, again sponsored by DARPA. Its objective was to explore the use of computers in support of command and control. That goal meant that computers would find their way into ships at sea, aircraft and mobile vehicles. The Arpanet had been built using dedicated telephone circuits connecting the IMPs.

Such circuits could not connect the ships, planes and mobile vehicles, so DARPA concurrently began developing a mobile Packet Radio Network (PRNET) and a Satellite Network (SATNET) to support these applications. The Internet concept, invented by Robert Kahn, then at DARPA and Vinton Cerf, then at Stanford University in 1973 was aimed at interconnecting disparate packet switched networks that, in turn, connected diverse computers. The goal was to make the ensemble of different computers and networks appear to be uniform. To achieve this goal, Cerf and Kahn developed the Transmission Control Protocol (TCP) that eventually evolved into a pair of protocols: TCP and the lower layer Internet Protocol (IP). Known as TCP/IP, this pair of protocols formed the foundation of the Internet and the so-called Internet Protocol Suite.

Over a ten year period from 1973-1983, DARPA funded research and development of the TCP/IP protocols to interconnect the Arpanet, PRNET and SATNET using “gateways” that were “Internet aware” and could forward Internet Protocol packets between gateways by encapsulating the Internet Packets as payloads in the native packets of each network. TCP differed from NCP because it dealt directly with packet loss, retransmission, duplicate detection, packet fragmentation and more sophisticated end-to-end flow control. On January 1, 1983, all the computers on the three networks were transitioned to run the TCP/IP protocol and on that date, the Internet became operational. The research Arpanet was split into a continuing research network and the operational military MILNET, joined by gateways.

## Commercialization

During the course of Internet development, the research laboratories of IBM, Hewlett-Packard and Digital Equipment Corporation all voluntarily programmed TCP/IP for their operating systems. DARPA also funded Bill Joy at the University of California, Berkeley, to implement TCP/IP for AT&T’s UNIX operating system. Coincidently, Robert Metcalfe and David Boggs at XEROX Palo Alto Research Center (PARC) invented the Ethernet packet switching technology around 1973 and by 1979, the technology spun out of PARC to become 3Com led by Robert Metcalfe. Another company that made token rings, called Proteon, spun out of MIT in 1981 with the help of David D. Clark and especially Noel Chiappa.

[2]The developers of the original concept called it the Interplanetary Internet or the Interplanetary Network (IPN).

Among their early products was a version of TCP/IP for Unix but this was eventually supplanted by the UC Berkeley version. In 1982, SUN Microsystems was founded by Scott McNealy, Vinod Khosla, Andy Bechtolsheim, Stanford graduate students and the aforementioned Bill Joy. They adopted TCP/IP and Unix (re-cast as Solaris) as the software engine of their workstation product.

These early steps towards commercialization were significantly enhanced by the development of commercial gateways, called “routers” by Cisco Systems, a spinoff from Stanford University, led by Leonard Bosack and Sandy Lerner in 1984.

## Expansion

Noting the success of the Internet, the US National Science Foundation funded the Computer Science Network (CSNET) project in 1982, which was instigated by Lawrence Landweber and David Farber among others including David H. Crocker who developed the key application: electronic mail in the form of his Multimedia Memorandum Distribution Facility (MMDF). The success of the CSNET led NSF to underwrite the development of a much more ambitious project, the NSFNET that was intended to interconnect some 3000 research universities in the US.

The initial incarnation of NSFNET in 1986 was based on “Fuzzball” routers programmed by David Mills at the University of Delaware. An initial 56 kilobit/second six node network was instantly overloaded. NSF invited new proposals for a 1.5 Mb/s system which was built by a consortium of MCI, IBM and MERIT at the University of Michigan. The idea was to build a backbone network (NSFNET) and a dozen or so intermediate level networks that would, in turn, support a number of regional universities.

This design took advantage of the basic Internet concept: multiple interconnected networks.

[3] https://www.internetsociety.org/internet/history-internet/brief-history-internet/ (accessed 4/11/2021)

The NSFNET and the intermediate level networks grew rapidly and the backbone speeds were increased to meet traffic loads until by 1995, the backbone was running at 155 Mb/s (OC-3). At this point, the NSFNET was actually decommissioned because a number of commercial networks had grown up in the US, starting in 1989 with UUNET, PSINET and CERFNET which were interconnected with the NSFNET as well as each other through the Commercial Internet Exchange (CIX) - forerunner of the Internet eXchange Point (IXP) and emulator of the Federal Internet Exchanges that connected the backbone networks of the US research agencies: the Energy Sciences Network (ESNET) of the Department of Energy, the NASA Science Internet (NSINET), NSFNET and, until 1990, the Arpanet.

Interestingly, by 1995, the original three networks of the Internet: Arpanet, PRNET and SATNET had all been decommissioned but the Internet was thriving. Non-profit groups such as the Network Startup Resource Center (NSRC) at the University of Oregon, with the support of NSF and others, were instrumental in bringing the Internet to academic communities around the world. In the US, this role was played by a collaboration of academic research institutions forming the “Internet2” organization after the NSFNET backbone was retired.

In the same timeframe as NSFNET was gestating, five countries in northern Europe, Norway, Denmark, Iceland, Sweden and Finland were developing national research and education networks out of motivations similar to the NSFNET. They formed a collaborative NORDUNET backbone interconnecting their respective academic research networks. The NORDUNET continues to operate to the present. In the UK, the Joint Academic Network (JANET) was initiated in 1984 but based on the 1976 X.25 communication protocol standards with a suite of host level protocols called the “Coloured Book Protocols.” It was not until March 1991 that JANET supported TCP/IP which quickly grew to be the primary source of traffic on the network.

In Europe, a collaborative GEANT backbone linked many of the continental academic networks. In Japan, in 1985, Prof. Jun Murai at Keio University started the WIDE project which formed the Japanese University Network (JUNET) that introduced the Internet to Japan. It is worth noting that the NSF International Connections program that began at about the same time as the NSFNET project, helped to pave and pay the way for international academic network interconnections to the NSFNET backbone, another enabling step by a US Government research funding agency.

Around the world, similar stories can be found in which academic networking formed the vanguard of Internet introduction and eventual commercialization.

In 1986, Dan Lynch founded a conference/exhibition he called INTEROP, for “interoperability.” This effort began simply as lectures on the design of the Internet but quickly became an exhibition (“expo”) to allow vendors of Internet-related hardware, software and services to demonstrate their value and interoperability. in fact, one could not exhibit on the show floor without being connected to the “Shownet” (big yellow cable ethernet) and showing interoperability with others on the floor. An enormous amount of debugging took place in the weeks and hours leading up to the opening of the show! The INTEROP show promoted visibility and viability of the Internet to the public, government and private sectors. It is conceivable at some point that a similar kind of event might make sense for the Bundle Protocol Suite.

The point to take away from this brief and incomplete history is that government sponsorship over a period of many years (decades in some cases) proved vital to the evolution and refinement of the Internet technology. Steady recognition of commercial potential and enabling legislation allowed many of the experimental and research networks to migrate into commercial operation or to spawn commercial network creation so that support for the service could grow beyond the academic and research community.

## Standards Development and Institutional Evolution

In the Arpanet project, an informal working group was organized by Stephen D. Crocker, a graduate student at UCLA at the time, who was deeply invested in developing a protocol that could link disparate host computers to each other through the homogeneous packet-switched Arpanet. He called this group the Network Working Group (NWG) and established a document series he called Request for Comments (RFC) which has documented the details of the Arpanet and Internet protocols since 1969. Crocker eventually joined ARPA as a program manager for Artificial Intelligence. The ethos of the NWG was collaboration and egalitarian humility. Anyone could participate and ideas with merit were pursued and tested.

Crocker eventually gave to Jonathan B. Postel the responsibility for managing the RFC series and also for managing the assignment of Arpanet and Internet Protocol addresses and Domain Names when that system came into being in the early 1980s. At the Stanford Research Institute (later SRI International), a Network Information Center was formed to make operational all the production and distribution of documentation associated with the Arpanet project and its unique identifiers.

In this early time frame, the parallel Packet Radio and Packet Satellite programs continued to mature and involve non-US participants in the US, Norway, UK, Germany and Italy. An International Coordination Board (ICB) was formed to allow the national sponsors of Internet research in the US, UK, German and Italy to align their efforts.

Over time the NWG leadership morphed into the Internet Configuration Control Board (ICCB) created by Vint Cerf while an ARPA program manager, assigning chairmanship as Internet Architect to David D. Clark at MIT’s Laboratory for Computer Science. Postel became the Deputy Internet Architect. The ICCB became the Internet Activities Board (IAB) under the leadership of Barry Leiner who inherited the Internet project at ARPA after Cerf’s departure.

The IAB spawned ten task forces which eventually evolved and merged to become the Internet Engineering Task Force (IETF) and Internet Research Task Force (IRTF). At that point the IAB was re-named the Internet Architecture Board. The former were part of the standards-track effort to develop and confirm international standards recommendations for the Internet while the IRTF was organized around longer team research. The Bundle Protocol (BP) and Licklider Transmission Protocol (LTP) were lodged in the IRTF among its research groups and eventually moved into the IETF for formal standardization in coordination with the CCSDS.

In 1992, the Internet Society (ISOC) was formed to support the Internet Architecture Board and its components. The RFC series has continued to the present with ISOC, IAB and IETF support. Meanwhile, as the commercialization of the Internet continued apace, more formal mechanisms and institutions were established to deal with IP address allocation and assignment leading to the creation of the so-called

Regional Internet Registries (RIR): RIPE NCC (Reseau IP Europeene Network Coordination Centre), American Registry for Internet Numbers (ARIN), Asia/Pacific Network Information Center (APNIC), Latin and Central American Network Information Center (LACNIC) and the African Network Information Center (AFRNIC). Other informal Network Operation Groups such as NANOG (North American Network Operations Group) were formed to allow informal coordination among operators of the networks of the Internet.

With the introduction by Sir Tim Berners-Lee of the World Wide Web (WWW) in December 1991, a new burst of development on the Internet ensued. Web sites were voluntarily crafted. With the arrival of the MOSAIC browser created by Marc Andreessen and Eric Bina at the National Center for Supercomputer Applications (NCSA), and subsequent formation of Netscape Communications that offered its commercial Netscape Navigator browser and service software, interest in the Internet's content soared. So did interest in investing in Internet-related companies. The dot-boom was on!

In late 1994, the World Wide Web Consortium (W3C) was founded to manage further protocol development for the Hypertext Transport Protocol (HTTP) and Hypertext Markup Language (HTML). The surging interest in the Internet led to debate about how to manage the Domain Name and Internet address spaces which, until that time, were essentially supported under research contracts with various agencies of the US Government. After a heated two year debate that eventually involved the Clinton White House, the non-profit Internet Corporation for Assigned Names and Numbers (ICANN) was authorized in 1998 by the US Government under contract to the National Telecommunications and Information Administration to manage these critical and unique identifiers.

Of special importance is the multistakeholder model of policy development adopted by ICANN. Under this model, governance policies would be developed by an amalgam of government, technical sector, private sector and civil society representatives. Interest in the Internet continued to grow until in 2003, the United Nations launched a World Summit on the Information Society (WSIS) that began as an inter-governmental discussion about the concept of online society.

The Internet quickly became the focus of attention and its governance especially so. ICANN was highlighted as a primary example of governance and its multistakeholder model led to the creation of a Working Group on Internet Governance that was, itself, multistakeholder in character. At the close of the WSIS in 2005, the matter of Internet governance remained unresolved and that resulted in the creation of the Internet Governance Forum (IGF) which has persisted to the present with annual meetings.

In recent years, spontaneous regional and national Internet Governance Forums have been established to allow for inter-sessional work on the topic to continue between annual meetings of the IGF. Debate about Internet governance has grown with the Internet's continued expansion and use, now tackling very difficult topics including the spread of misinformation, disinformation and other harmful content via social media of all kinds. Fragmentation of the Internet owing to national efforts to control its use threaten to diminish its ability to support global collaboration and enterprise.

### Relevance to the SSI

The Interplanetary Internet story has parallels with the Internet, not surprisingly. First initiated at the Jet Propulsion Laboratory, a NASA FFRDC operated by the California Institute of Technology (Caltech), in 1998, the effort soon spread to almost all of the NASA laboratories. At the same time, the effort also spawned interest in and eventual direct engagement by the UN Consultative Committee on Space Data Systems and consequently the involvement of the members of CCSDS, most notably NASA, the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA) and the Korean Aerospace Research Institute (KARI).

Experimental implementations of the Bundle Protocol Suite were undertaken by these agencies and also by academic research institutions including the Luleå University of Technology and the Technische Universität Braunschweig. A considerable body of documentation is available concerning design, implementation and performance of the Bundle Protocol Suite. A number of live tests with various implementations have taken place in space (e.g. the EPOXI spacecraft and the International Space Station) and terrestrially (e.g. with the US military, Luleå University).

A multi-laboratory testing network has been operating under the leadership of the Jet Propulsion Laboratory for most of the history of the development of the Bundle Protocol Suite. At NASA, a focus on deployment and operational use has become a prominent part of the development program. IETF and CCSDS standardization efforts are reaching fruition. Commercial interest in the use of the Bundle Protocol Suite is evidenced by commercial spacecraft makers' participation in the IETF WG that is standardizing the protocol suite.

What is now of high importance is exposure of the capability to the aerospace industry in support of national space exploration and increased interest in space commercialization. There are credible avenues for the general public to become aware of and to assist in increasing the technology readiness level of the various implementations and demonstration of their interoperability. While the path to adoption of the Bundle Protocol Suite will not be identical to TCP/IP in the Internet, similar steps and potential institutional creations may be needed. For example, the equivalent of ICANN can be found within the CCSDS structure, called the Space Assigned Numbers Authority (SANA).

If and when commercial adoption becomes appropriate, distributed registration mechanisms may emerge to facilitate contact graph formation and the analog of the Border Gateway Protocol of the Internet will be needed. The equivalent of Certificate Authorities may be needed to facilitate strong authentication of the elements (nodes) of the SSI. As operational instances of Bundle Protocol applications and their underlying networks emerge, so will the need for jurisdictional entities arise, likely in some multistakeholder and distributed form. The multi-national Artemis/Gateway missions form at least one concrete opportunity to exercise the technology, administrative functions and operation practices that will inform further evolution of the SSI.

[4] Federally Funded Research and Development Center, a US legal construct.
[5] http://ipnsig.org/dtnrg-wiki-documents/

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