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IARIA

Communications and Networking Research Towards the Reliable and Efficient Interplanetary Internet

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Aim of the Talk

- To propose an overview of the Interplanetary Internet Challenges and Ideas for future research;

and, in particular

- Starting from the Challenges of the Interplanetary Internet to highlight the concept:

"Future Technologies from Space"

Aim of the Talk

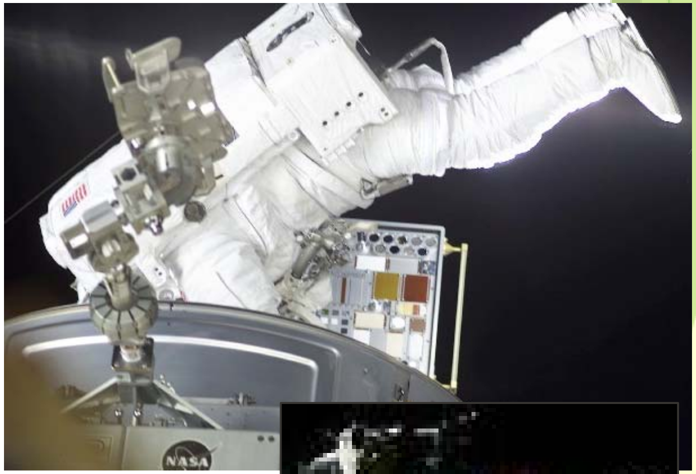
- A typical way to talk about the Future begins starting from the Past...

The Past of Space Missions

Main Reference: http://spaceodyssey.dmns.org/nrimages/

Importance of Space Missions

These factors give importance, urgency and inevitability to the advancement of space technology:



- Man's compelling urge to explore and to discover;
- Military defense objectives;
- National prestige;
- New opportunities for scientific observation and experiment.

Main Reference: http://www.fas.org/spp/guide/usa/intro1958.html

The ‘50s

- 1957 – R-7 Russian Sputnik. First successful orbital satellite;
- 1958 – US Explorer 1. First American spacecraft in orbit – discovery of Van Allen belts;
- 1959 – US Explorer 6 (Thor Able). First pix of Earth from space;
- 1959 – SS-6/R-7 Russian Luna 2. First spacecraft to reach the Moon – discovery of solar winds.

The ‘60s

- 1961 – Vostok 1. First manned spaceflight by Soviet Union (Cosmonaut Yuri Gagarin) –April 12, 1961;
- 1965 – Gemini 4. First American spacewalk – NASA June 3, 1965;
- 1965 – INTELSAT 1. First commercial communications satellite – Hughes Aircraft/USA;
- 1969 – Apollo 11. First manned lunar landing – NASA (Astronauts: Commander Neil Alden Armstrong, Command Module Pilot Michael Collins & Lunar Module Pilot Edwin Eugene ‘Buzz’ Aldrin, Jr.).

The ‘70s

- 1970 – Apollo 13. Furthest distance traveled by space crew - 401,056 km;
- 1971 – Mariner 9. First Martian orbiter – NASA;
- 1971 – Soyuz 11. First manned space station –RVSN;
- 1972 – Venera 8. Russian Atmospheric probe on Venerian Surface;
- 1972 – Pioneer 10. First spacecraft to travel through the asteroid belt and make direct observations of Jupiter –NASA;
- 1974 – Mariner 10. First flyby of Mercury – NASA;
- 1977 – Viking 1 e 2. Delivering of research equipment on Mars surface – NASA;

The ‘80s

- 1981 – Voyager 2. Flyby of Saturn – NASA;
- 1981 – Shuttle Program Starts – NASA;
- 1982 – Venera 13. Lands on Venus – Soviet;
- 1986 – Voyager 2. Closest approach to Uranus discovers 10 new moons – NASA;

The ‘90s

- 1996 – Sojourner. First Mars Rover – NASA;
- 1996 – NEAR. First robotic space probe to orbit & land on as asteroid (Eros) – NASA;
- 1997 – Cassini. First spacecraft to enter Saturian orbit via heliocentric orbit – NASA/ESA/ASI;
- 1997 – Huygens. First spacecraft to land on Titan (Saturn’s largest moon) – NASA/ESA/ASI.

The Nowadays Space Missions

Main Reference: http://spaceodyssey.dmns.org/nrimages/

The 2000s

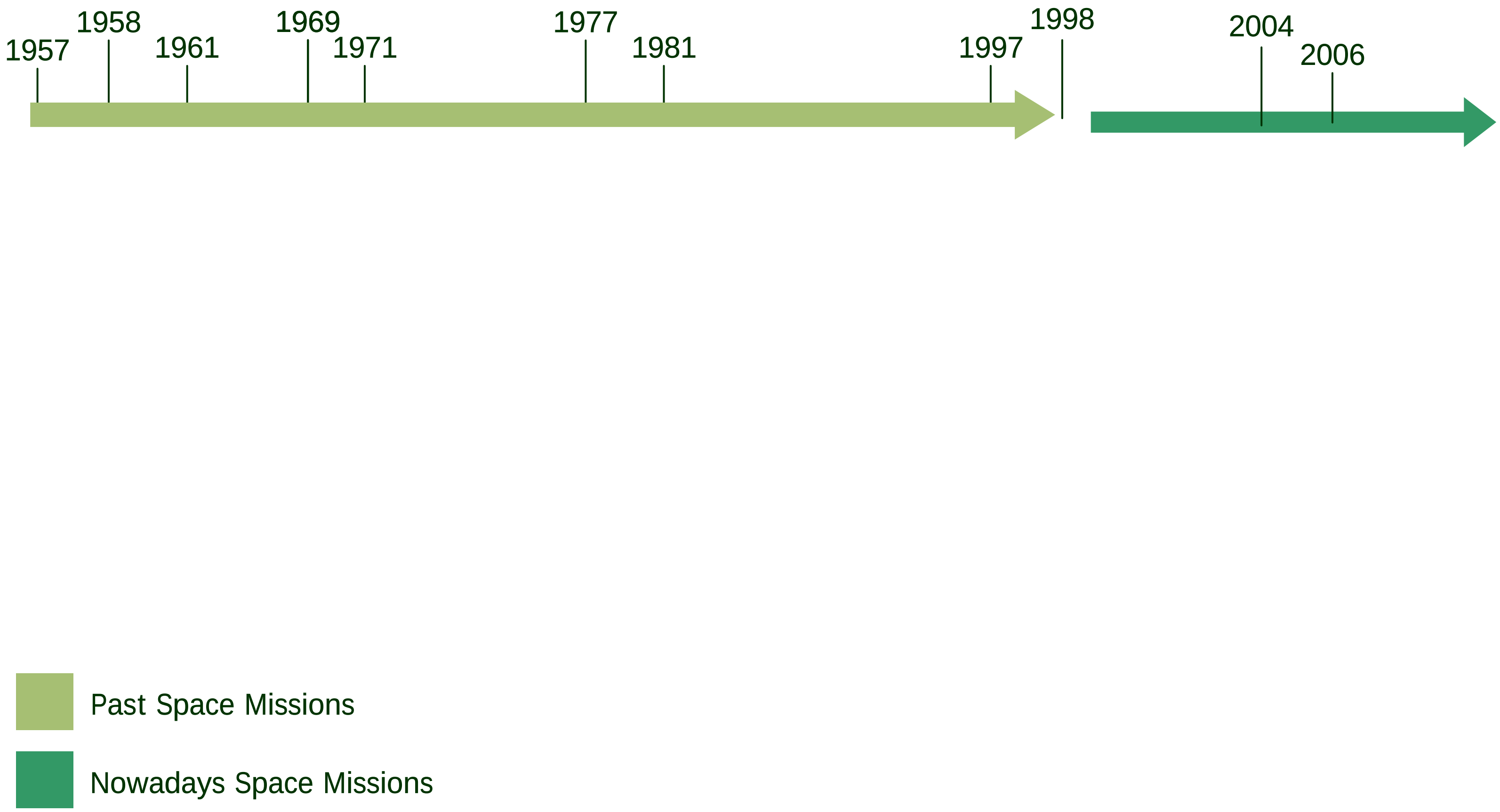
- 2000 – ISS. First resident crew on International Space Station – NASA/RKA/JAXA/CSA/ESA;
- 2000 – 100th flight of space shuttle program – NASA – Oct. 24th;
- 2004 – Messenger. Launch of first mission to orbit Mercury – NASA;
- 2004 – Spirit & Opportunity. Rovers landed on Mars – NASA.

The 2000s

- 2005 – Huygens. Separated from Cassini & landed on Saturn’s moon, Titan – NASA/ESA;
- 2006 – New Horizons. Launch of mission to Pluto (target arrival 2015) – NASA;
- 2007 – EPOXI. Deep Impact Flyby of Earth – NASA.

Towards the Future...

Space Missions



The Past of Internet

Main Reference: http://people.clarkson.edu/~jmatthew/networks/

The Origin

- 1958 – After USSR launches Sputnik, US forms the Advanced Research Projects Agency (ARPA), within the Department of Defense (DoD) to establish US lead in science and technology applicable to the military;

- 1961 – First published work on packet switching (“Information Flow in Large Communication Nets”, Leonard Kleinrock, MIT, graduate student);

- 1964 – other independent work in packet switching at RAND Institute and National Physics Laboratory in England.

Towards the First Connection

- 1966 – Lawrence Roberts (colleague of Kleinrock from MIT) publishes overall plan for an ARPAnet, a proposed packet switched network;

- 1968 – ARPA awards contracts for four nodes in ARPANET to UCLA (Network Measurement), Stanford Research Institute (Network Information Center), UCSB (Interactive Mathematics) and U Utah (Graphics); BBN gets contract to build the IMP switches.

The First Connections: 1969

- April 1969 – First RFC ("Host Software" by Steve Crocker) basis for the Network Control Protocol(NCP);

- September 1969 – Leonard Kleinrock's computer at UCLA becomes first node on the ARPANET;

- October 1969 – First packets sent; Charlie Kline attempts use of remote login from UCLA to SRI; system crashes as "G" in entered.

First Applications

- 1967-1972 – Vint Cerf, graduate student in Kleinrock’s lab, works on application level protocols for the ARPANET (File Transfer and Telnet protocols);

- 1971 – Ray Tomlinson of BBN writes email application; derived from two existing: an intra-machine email program (SENDMSG) and an experimental file transfer program (CPYNET).

Networks Growing

- 1970 – First cross-country link installed by AT&T between UCLA and BBN at 56kb/s;
- Other networks: ALOHAnet (microwave network in Hawaii), Telenet (commercial, BBN), Transpac (France);
- 1973 – Ethernet was designed in 1973 by Bob Metcalfe at Xerox Palo Alto Research Center (PARC)
- How do we connect these networks together?

Protocol Development

- 1972-1974 – Robert Kahn and Vint Cerf develop protocols to connect networks without any knowledge of the topology or specific characteristics of the underlying networks;

- 1972 – Robert Kahn gives first public demonstration of ARPAnet (now 15 nodes) at International Conference on Computer Communication.

TCP/IP

- 1974 – First full draft of TCP produced;
- 1977 – First three-network TCP/IP based interconnection demonstrated;
- 1978 – TCP split into TCP and IP.

Finally Internet

- 1981 – Term “Internet” coined to mean collection of interconnected networks;

- 1982 – ISO releases OSI seven layer model; actual protocols die but model is influential;

- 1983 – Original ARPANET NCP was banned from the ARPANET and TCP/IP was required;

- 1984 – Cisco Systems founded.

World Wide Web

- 1990 – Tim Berners-Lee develops hypertext system with initial versions of HTML and HTTP and first GUI web browser called “WorldWideWeb”;

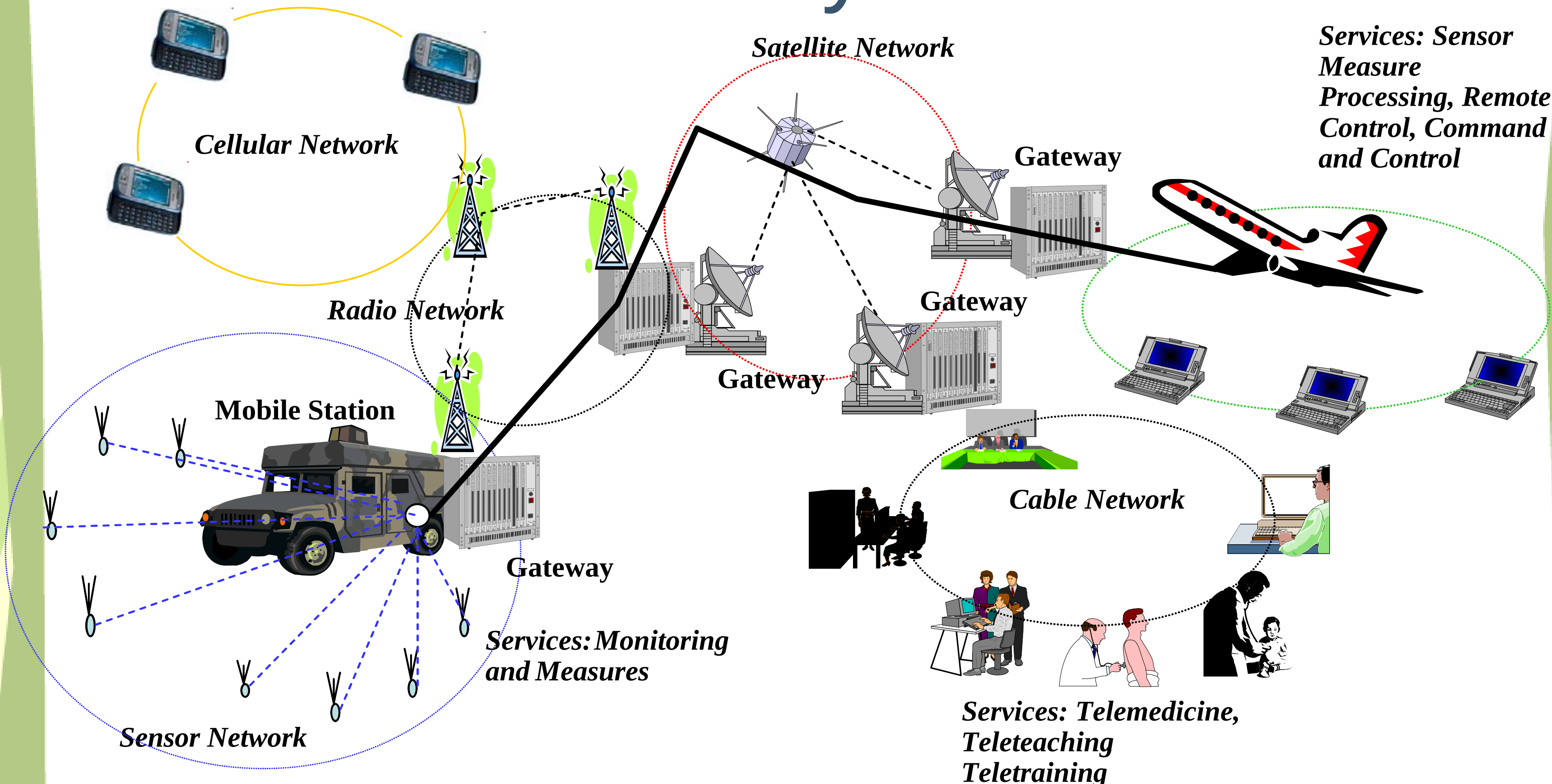
- 1993 – Mosaic, a GUI web browser, written by Marc Andreessen and Eric Bina at NCSA takes world by storm (showed in-line images and was easy to install);

- WWW proliferates at a 341,634% annual growth rate of service traffic.

The Nowadays Internet

Main Reference: M. Marchese, “Quality of Service over Heterogeneous Networks,” Wiley & Sons, Chichester, UK, 2007.

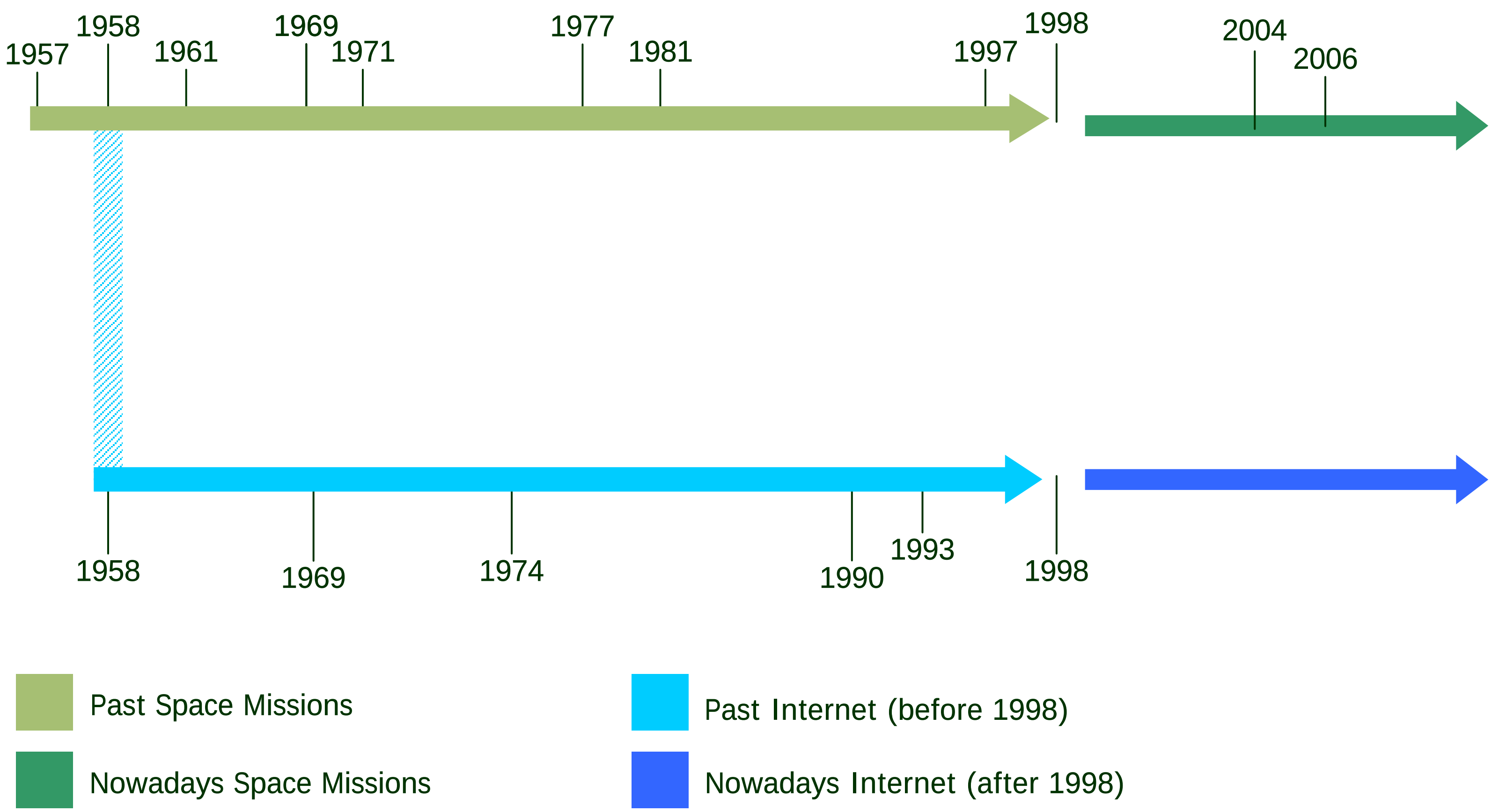
The Nowadays Internet



Any Time and Any Where Internet

Towards the Future...

Space Missions and Internet



Interplanetary Internet: the Beginning and the Approaches

Main Reference: L. Wood, “Implementing the Interplanetary Internet – differing approches,” Surrey Space Centre guest Lecture, February 2009.

The Beginning

- Vint Cerf announces start of effort over ten years ago, in July 1998;
- He collaborates with Adrian Hooke of NASA Jet Propulsion Lab (JPL) – who leads CCSDS (Consultative Committee for Space Data Systems), an ISO subgroup that sets standards for space since 1982;
- Space probes predate computing; tape recorder bitstream mindset;
- Want to move them towards packets and networking;

The Beginning

- Vint Cerf set up an Internet Society: IPN Special Interest Group (IPNSIG);
- Then a short-lived IRTF “Interplanetary Internet” group (IPNRG) and a couple of internet-drafts, 2000/2001;
- Problem scope widens to “Delay Tolerant Networking” (Kevin Fall) and bundles are created, 2002/2003;
- IRTF DTN research group set up, 2003;
- DARPA Disruption-Tolerant Networking proposers’ day, January 2004.

The Approaches

Scott Burleigh

- Careful consideration of legacy CCSDS base and slow migration;
- Gave us CFDP, Licklider LTP, and Bundle Protocol;
- CCSDS File Delivery Protocol (CFDP) a bit like Bundle Protocol – layers over everything: TCP, UDP...;
- CFDP (lite) in use by Messenger Mercury probe and Deep Impact mission.

The Approaches

Keith Hogie

- Proposed basic standards use – IP in standard Frame Relay over ISO standard HDLC;

- Showed that this worked on final Columbia mission;

- HDLC can also be carried as bitstream over CCSDS, as CCSDS supports “tape recorder bitstream” – easier than CCSDS ways to carry IPv4 (and other ways to carry IPv6).

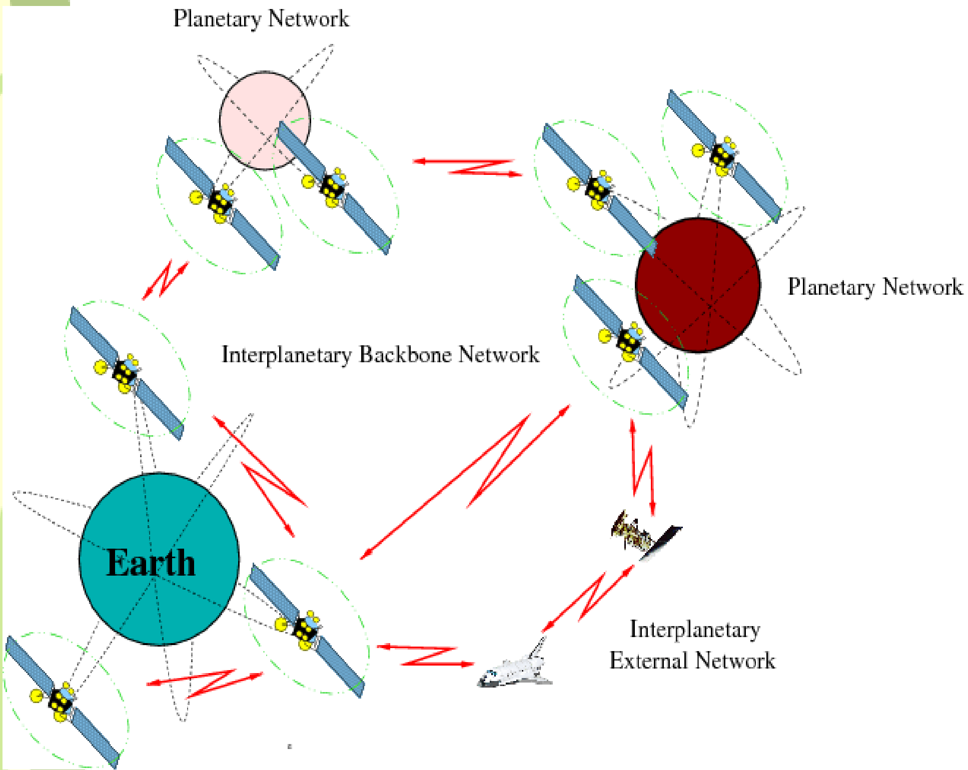
Interplanetary Networks: Architectural Analysis, Technical Challenges and Solutions Overview

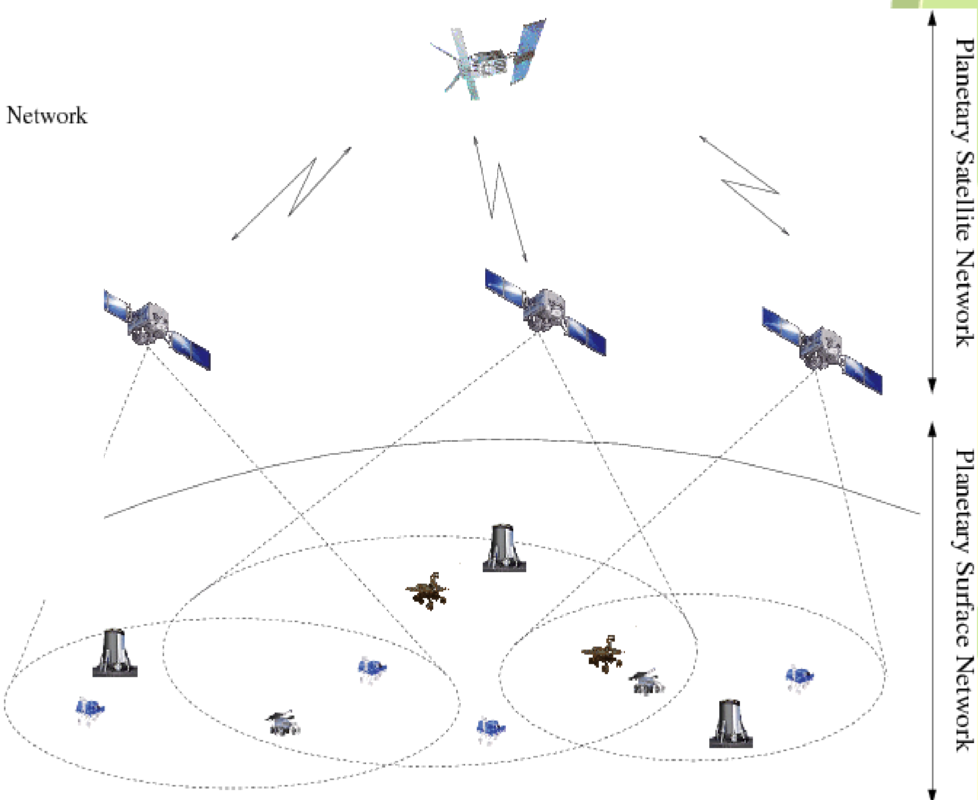
Main Reference: G. Araniti, I. Bisio, M. De Sanctis, "Interplanetary Networks: Architectural Analysis, Technical Challenges and Solutions Overview," In Proc. IEEE International Communications Conference 2010 (IEEE ICC'10), 23 – 28 May 2010, Cape Town, South Africa, and references therein.

Interplanetary Internet Necessities

- Nowadays and Future space exploration missions will need a robust, efficient and flexible communication infrastructure.
- This implies new communications and networking challenges, which are the ones of the so called InterPlaNetary (IPN) Internet.
- In that framework, it is important:
  - To provide a description of the challenging scenario,
  - To survey its technical problems,
  - To envisage possible advanced communications and networking solutions starting from the analysis of a specific IPN architecture.

IPN General Scenario





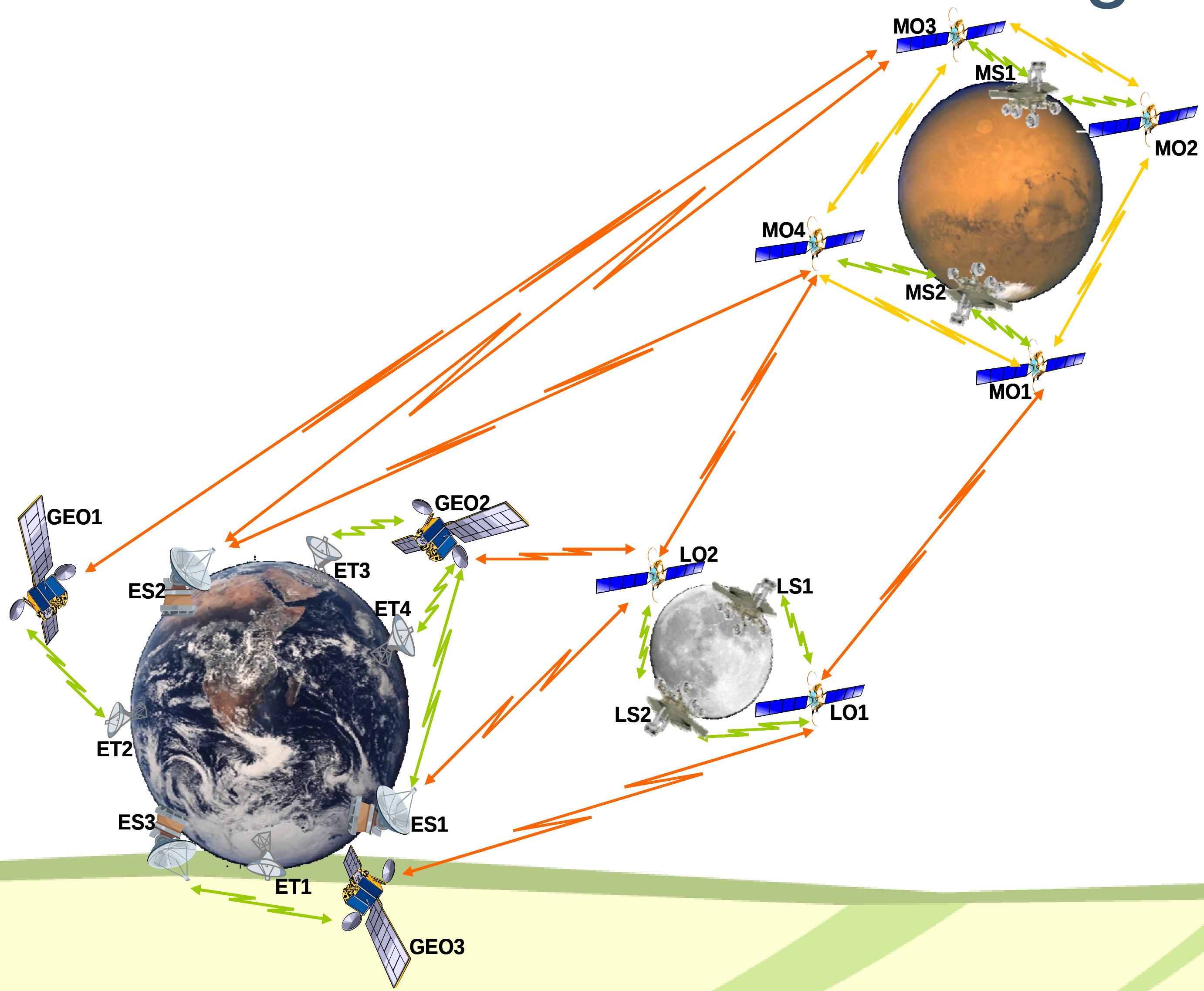
Applications

- The early exploration missions are giving way to a new data-intensive era of long duration observational outposts, landed vehicles, sample returns, and multi-spacecraft fleets and constellations.
- These changes require the ability to connect:
  - earth mission centers with space elements (Mission Applications);
  - scientists with remote instruments (Scientific Applications);
  - engage the public by giving them traditional Internet visibility into the space missions (Public Applications).

Challenges

- From the communications viewpoint, the main problems of the IPN scenario concern:
  - extremely long and variable propagation delays (e.g., 3-20 minutes for Mars to Earth);
  - asymmetrical forward and reverse link capacities;
  - variable error probability;
  - intermittent link connectivity (due to satellites, spacecraft and space probes eclipses and common link failures due to disturbances);
  - absence of fixed communication infrastructure;
  - high transmission power required due to distances;
  - power, mass and size of communications hardware and costs, of both in terms of hardware and protocols' complexity;
  - backward compatibility requirement due to high cost involved in deployment and launching procedures.

IPN Architecture under Investigation



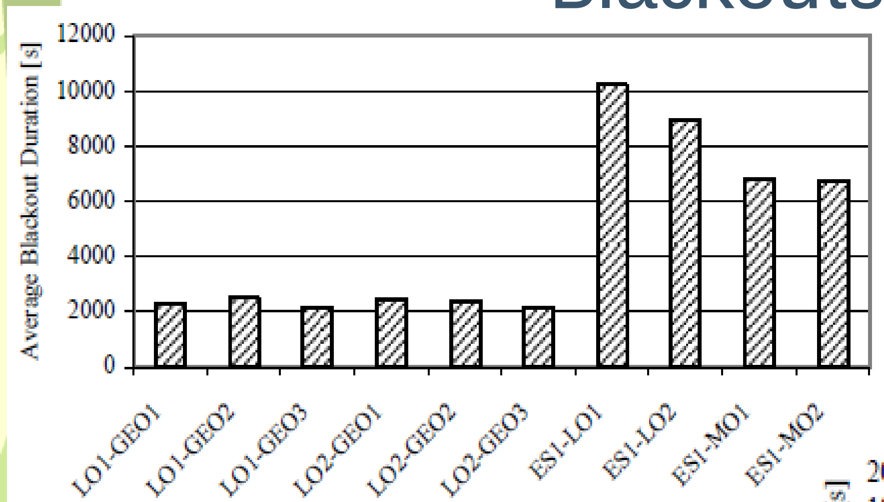
IPN Network Architecture Analysis

Blackouts and Delay

- The analysis has been carried out for a sample period of 24 hours by using the Satellite Tool Kit;
- During such 24 hours of orbital propagation of the spacecraft orbital motion and Planetary motion, only link obscuration due to Planets has occurred;
- The lunar lander LS1 is positioned on the dark side of the Moon, and hence, it could not communicate directly with the Earth without using a Lunar relay orbiter;
- Lunar orbiters has the further task to relay the communications between Mars and Earth when direct communication is not possible.
- The average blackout duration and the mean value of the propagation delay for a selected set of IPN links between external nodes is summarized in the following figures.

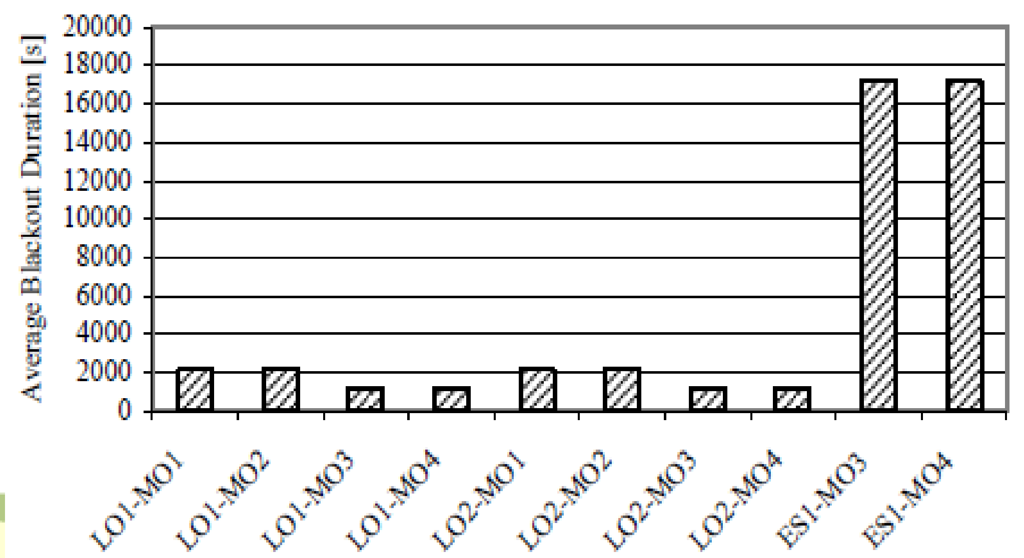
IPN Network Architecture Analysis

Blackouts and Delay



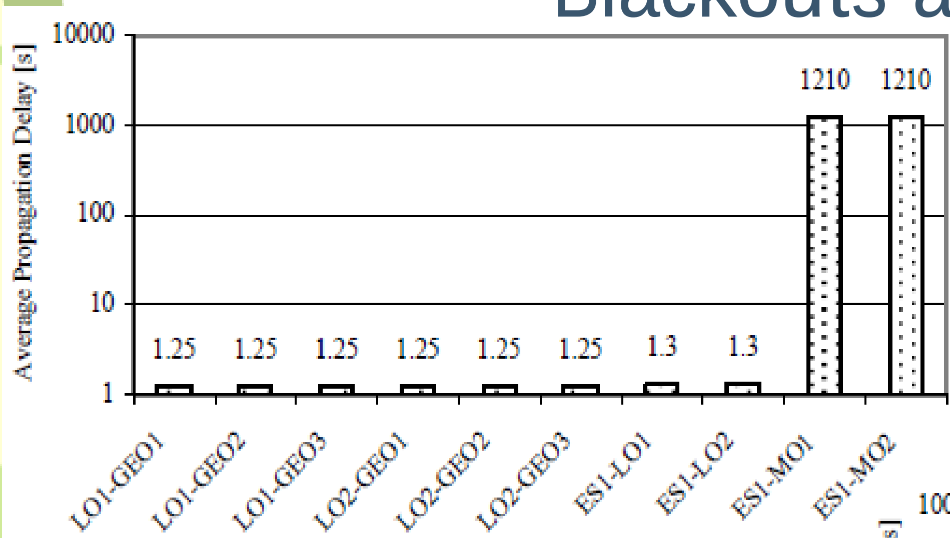
- Blackouts have durations from half an hour to five hours.

- ES1 (Canberra), ES2 (Goldstone) and ES3 (Madrid), show long blackout durations of the links to the Lunar or Martian orbiters.



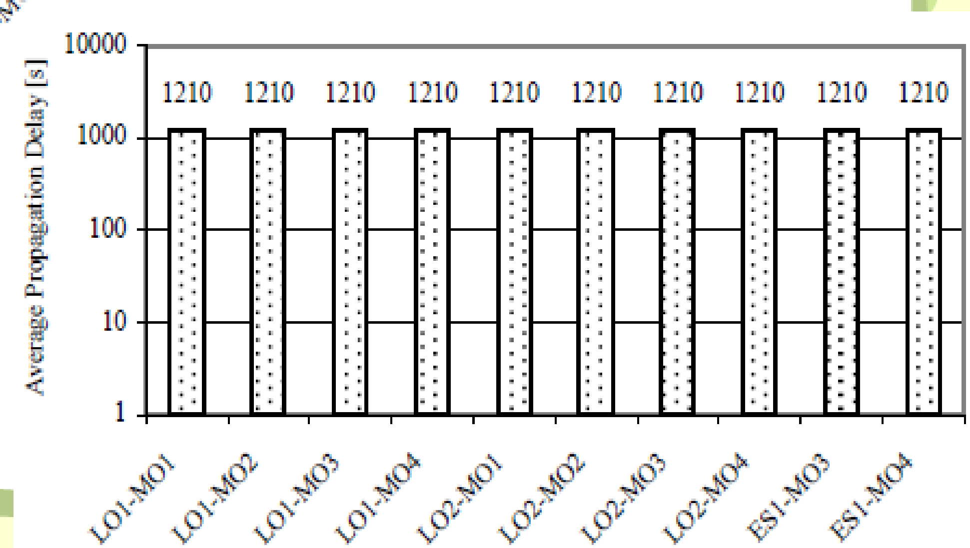
IPN Network Architecture Analysis

Blackouts and Delay



- Average Delay are mainly due to the relative distances. It can be as long as 20 minutes in the case of Mars-Earth connection.

- Since the shortest path from Mars to Earth is not always available, in many cases the total end-to-end delay can be much higher.

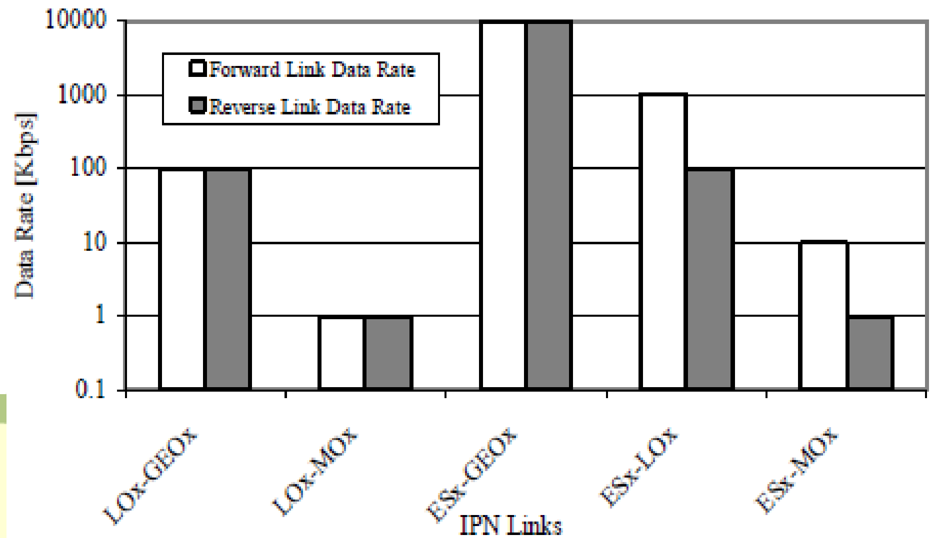


IPN Network Architecture Analysis

Data Rate

- The data rates for both Forward Links and Reverse Links of the proposed IPN network infrastructure have been computed on the basis of the DVB-S2 standard and with realistic values of transmission power and antenna size (ETSI EN 302 307, v1.1.2, 2006);

- The data rate has been computed in each link for the maximum distance (worst case) by using the lowest modulation index and code rate (i.e. QPSK 1/4) with a packet length of 64800 bits.



Research Ideas

Topological Solutions

- The goal is the design of a set of space systems such that the durations of the link unavailability and the propagation delay (i.e., the path length) can be minimized.

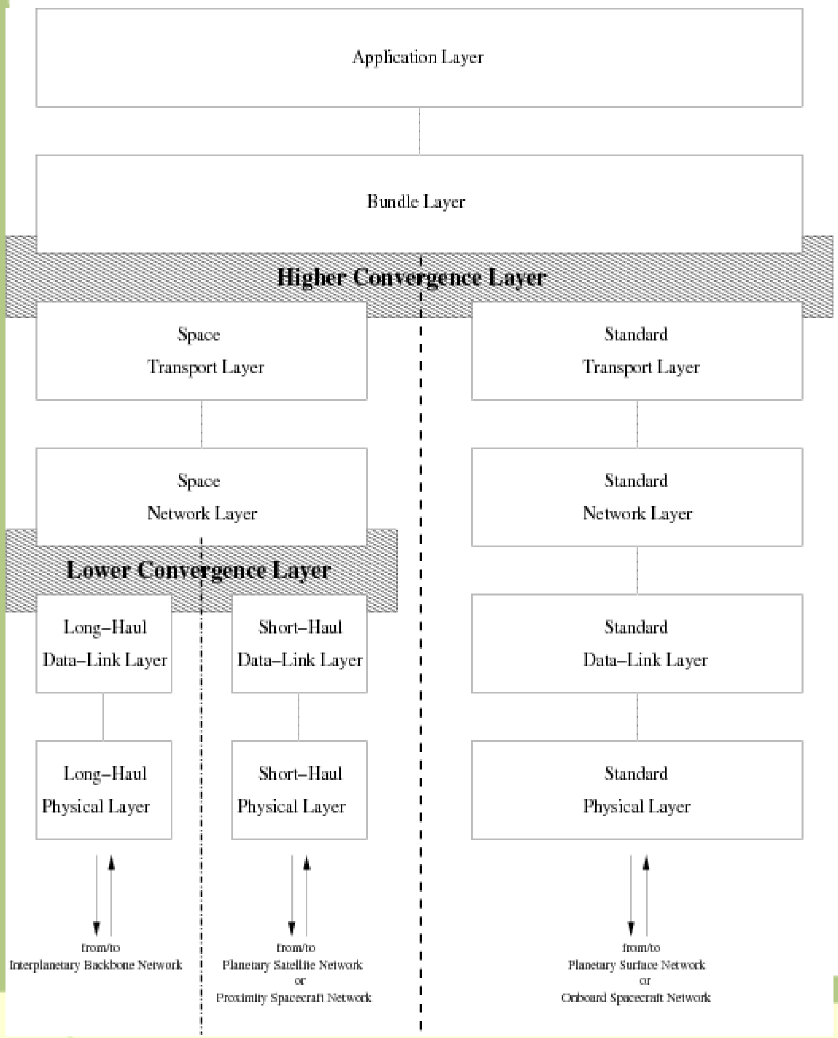
- The envisaged optimization will consider a combination of the average duration of the link unavailability and the average propagation delay and it will deal with the orbital parameters of each satellite included in the IPN architecture.

- In general it is possible to design a planetary satellite constellation network and a set of ground stations such that the availability of communication links is ensured, but this implies very high costs.
  - The maximum number of satellites must be fixed;
  - Flower Constellations, currently under investigation, could represent a solution.

Communications and Networking Solutions

- A second goal is the design of an “ad hoc” IPN Node, which will include advanced physical layers, networking layers and control procedures suited for application in the IPN environment.
- The IPN Node will not be based on traditional Internet Protocols, but on innovative optimized protocols, though compatible with the former ones.
- The IPN Node will include adaptive functions that will allow employing it in each part of the considered network whatever channel conditions are experienced.
- This analysis leads to propose a network architecture based on an independent middleware, the Bundle Layer, which is the key element of the Delay/Disrupt Tolerant Network (DTN) paradigm.
- However, it is not sufficient to offer reliable and efficient transmission over the IPN Internet because of the dynamics of the considered environment.
  - A more insightful approach is needed for the join optimization of the bundle overlay layer and the other layers.

The InterPlaNetary Node General Scheme – (1/2)



- It includes the Bundle Layer and a Higher Convergence Layer that act as bridge between two different portions: a standard stack (e.g., the TCP/IP one) used to connect common network devices to the IPN Node and the space protocol stack suited to be employed in the IPN environment.
- The Higher Convergence Layer will allow managing traffic flows both sent by standard hosts and DTN-compatible hosts. It acts as adaptation layer and realizes the backward compatibility with common protocol stacks.
- After the adaptation phase all packets become bundles, the transmission unit of DTNs, and they are sent though specific transport and network layers designed for the space portion of the IPN network.

The InterPlaNetary Node General Scheme – (2/2)

- The IPN Node transport and network protocols parameters will be adaptively optimized starting from the employed channel conditions.
- Data Link and Physical Layers have been again differentiated into two families: Long and Short-haul:
  - In the former case, the lower layers solutions will be specialized for very long distance channels (e.g., between satellites of the IPN backbone).
  - In the latter case, solutions are suited to be used in short distance channels (e.g., between spacecrafts and proximity satellites of the IPN network or between PN satellites and planet surfaces).
- The Lower Convergence Layer acts as selector between the Long or Short-haul layers in dependence on the position of the IPN network elements.

Bundle, Transport and Network Layers

Open Issues

- To match the IPN environment requirements, the Bundle Layer needs to be extended. Its current specification does not include error detection mechanisms of bundles. It opens the doors to the employment of application layer coding, both in terms of source coding and error detection and recovery approaches.

- Other important open issues related to the Bundle Layer will be taken into account:

  - the bundle size optimization and the related problem of fragmentation;

  - the study and the design of common bundle layer routing approaches for the IPN environment;

  - the Quality of Service (QoS) concept, whose meaning in the IPN network differs from the common one, together with new QoS mechanisms;

- In terms of recovery procedures and congestion control schemes, new transport protocol should be employed.

Data Link and Physical Layers – Open Issues

- Data Link Layers protocols of the IPN Node will be developed by considering their link typology (short- or long-haul), in particular concerning the medium access control (MAC) and error control functions.

- In addition, physical layer solutions that exploit Extremely High Frequency (EHF) bands will be considered. EHF employment, in particular the W-band, represents an answer to the needs of IPN links: the saturation of lower frequency bands, the growth of data-rate request and the reduction of mass and size of equipment.

  – Considering that the main disadvantage of the use of W-band frequencies is the atmospheric attenuation, the benefits of its employment could be fully exploited in deep space channels where the atmosphere is absent. The reduced antenna size due to the use of higher frequencies represents a further advantage of this choice.

Convergence Layers – Open Issues

- Convergence Layers, both Higher and Lower, and IPN Network Control approaches is another group of innovative solutions envisaged.
- The action of the Higher Convergence Layer is to offer a common interface to the transport layers (space and standard).
- The Lower Convergence Layer will offer a common interface towards data link and physical layers and vice versa and it will offer innovative control functions in terms of selection of the opportune lower layer stack (vertical handover) by considering the situation in which the IPN Node operates (long- or short-haul network segment).

Cross Layer Control – Open Issues

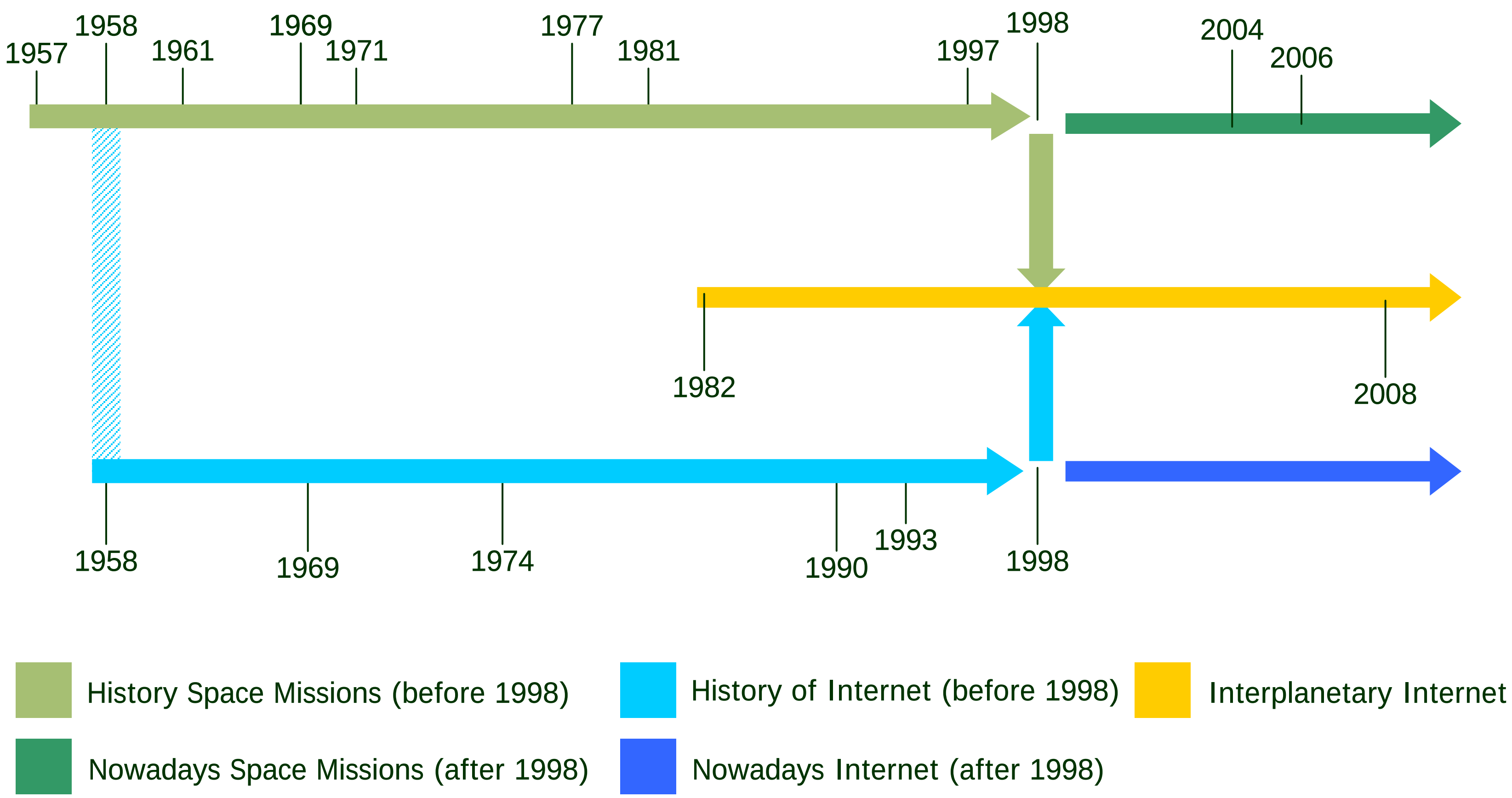
- In order to smooth the effect of the intrinsic heterogeneity of the IPN network, adaptive mechanisms, based on the cross-layer principle, are needed.

- It means that appropriate solutions are necessary to harmonize each single layer solution and jointly optimize the capabilities of IPN Node layers.

- For example, the transport and network protocol parameters need to be dynamically tuned in dependence on the channel status and also with respect to the position of the IPN Node.

Towards the Future...

Interplanetary Internet

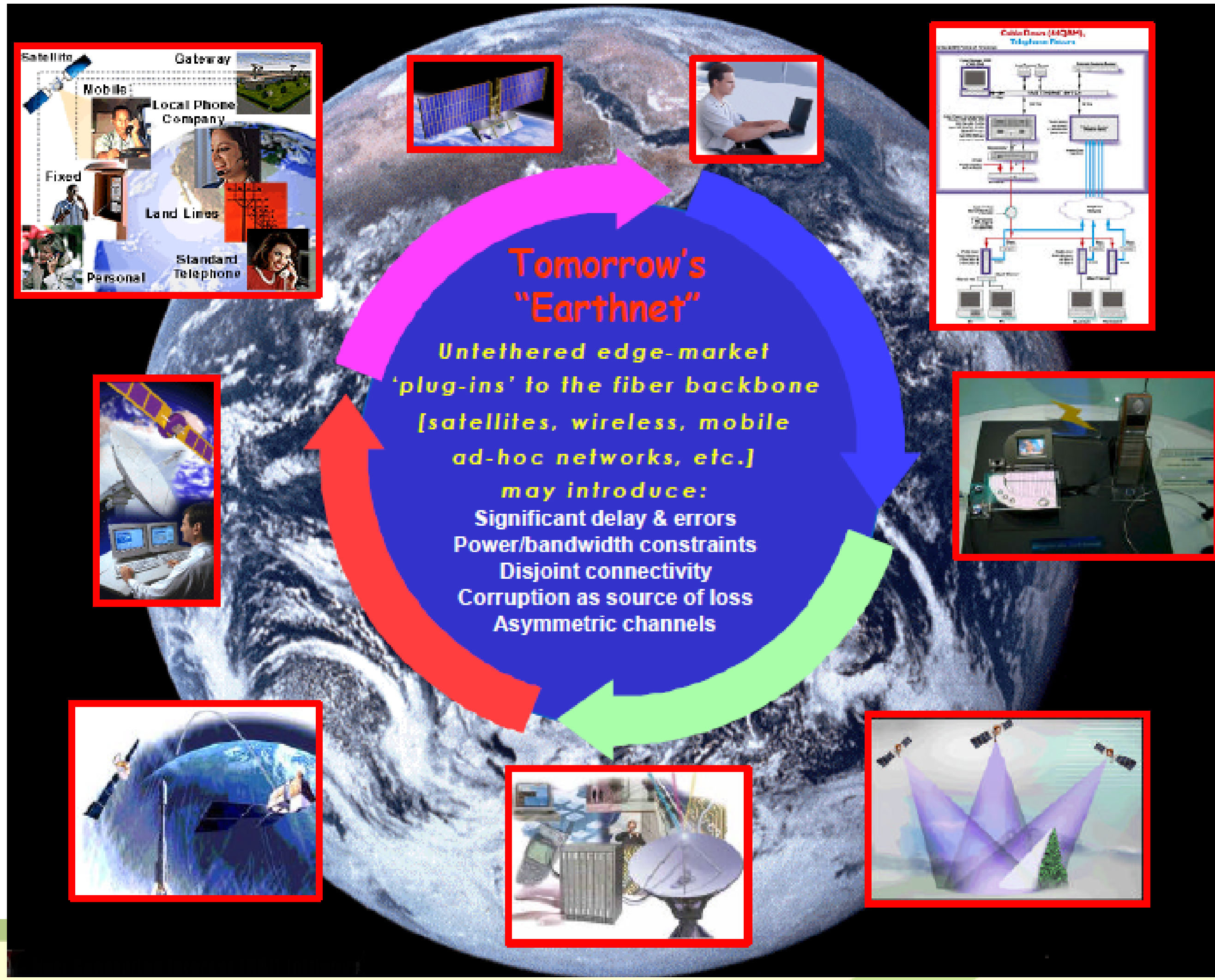


Final Considerations

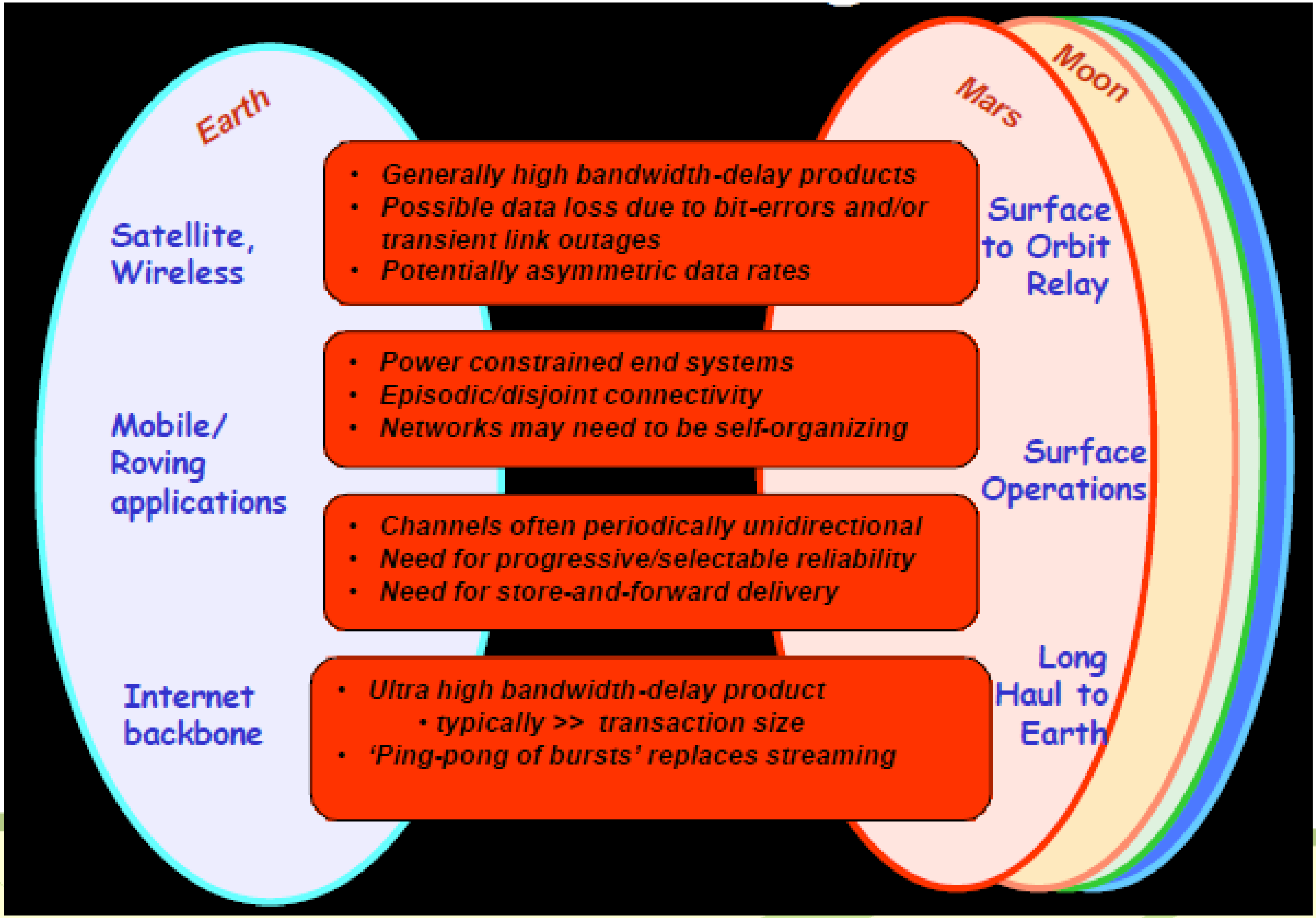
Main Reference: A. J. Hooke, “Interplanetary Internet,” In Proc. Third Annual International Symposium on Advanced Radio Technologies, Boulder, CO, September 2000.

Internet in 2000s

The Nowadays *Any Time Any Where* Internet

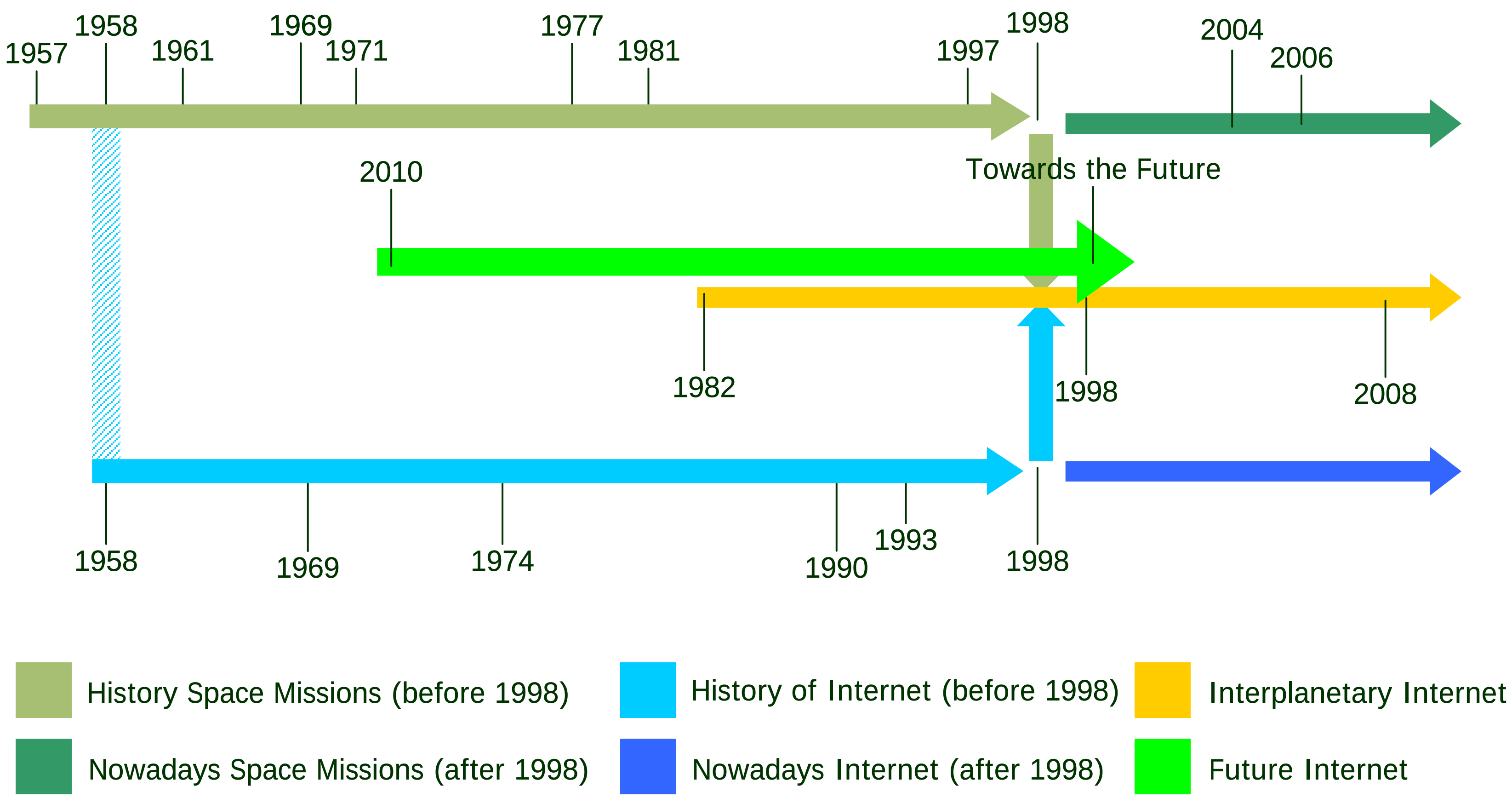


Sharing of Issues and Technologies



Towards the Future...

Future Internet Technologies from Space



Conclusions

- Interplanetary Internet Solutions support Space Missions and their specific aims that are very important for the humanity;
- Interplanetary Internet Solutions are also valid for the Nowadays Internet;
- The fusion of the Interplanetary Internet and the Nowadays Internet will be the common concept of Internet;
- To win the challenges of the Interplanetary Internet means to provide the future communications and networking technologies.

Thank You!