



# From Sputnik to Interplanetary Networking:

a concise overview of Space Communications in the last 60 years with a tribute to the city of Berlin

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# Outline

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- Slides presented to a seminar for Ph.D. students during ASMS 2018, Berlin
  - First part: from Sputnik to Internet
    - A historical retrospective
  - Second part: from Internet to InterPlanetary networking
    - Solar System Internet & DTN
- 2022 updates



# From Sputnik to Internet

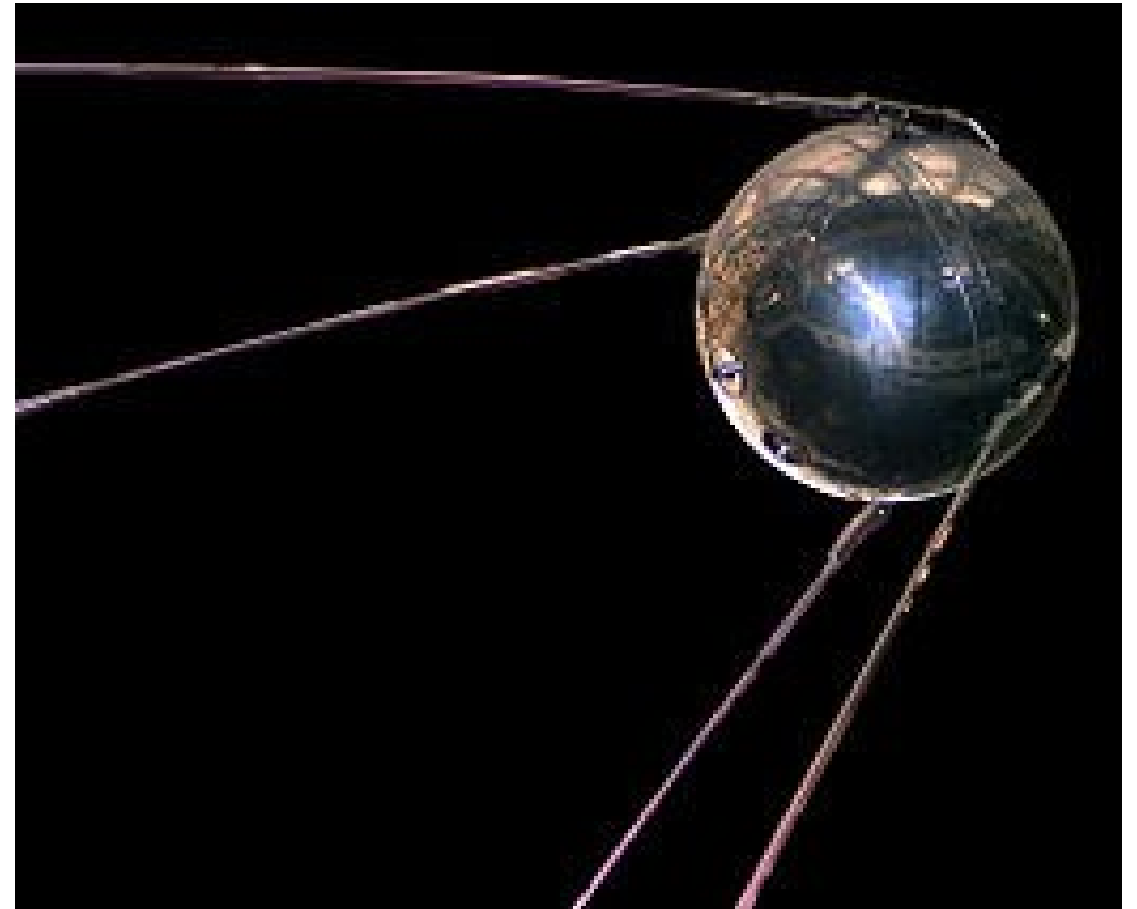
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A historical retrospective

# 1957: Sputnik

On 4th October 1957 Sputnik, the first artificial satellite, is launched by Russians

- It is not a geostationary satellite and in fact it is NOT a telecommunication satellite.
- However, it has a radio on board, which emits “bips”, intended for world wide radio amateurs.
- It is glossy to facilitate its vision by astrophiles.
- It is a product of the cold war, and in particular of the research on Inter Continental Ballistic Missiles (ICMB)
- The propagandistic impact is enormous. The US public opinion is shocked.
- The space race starts.

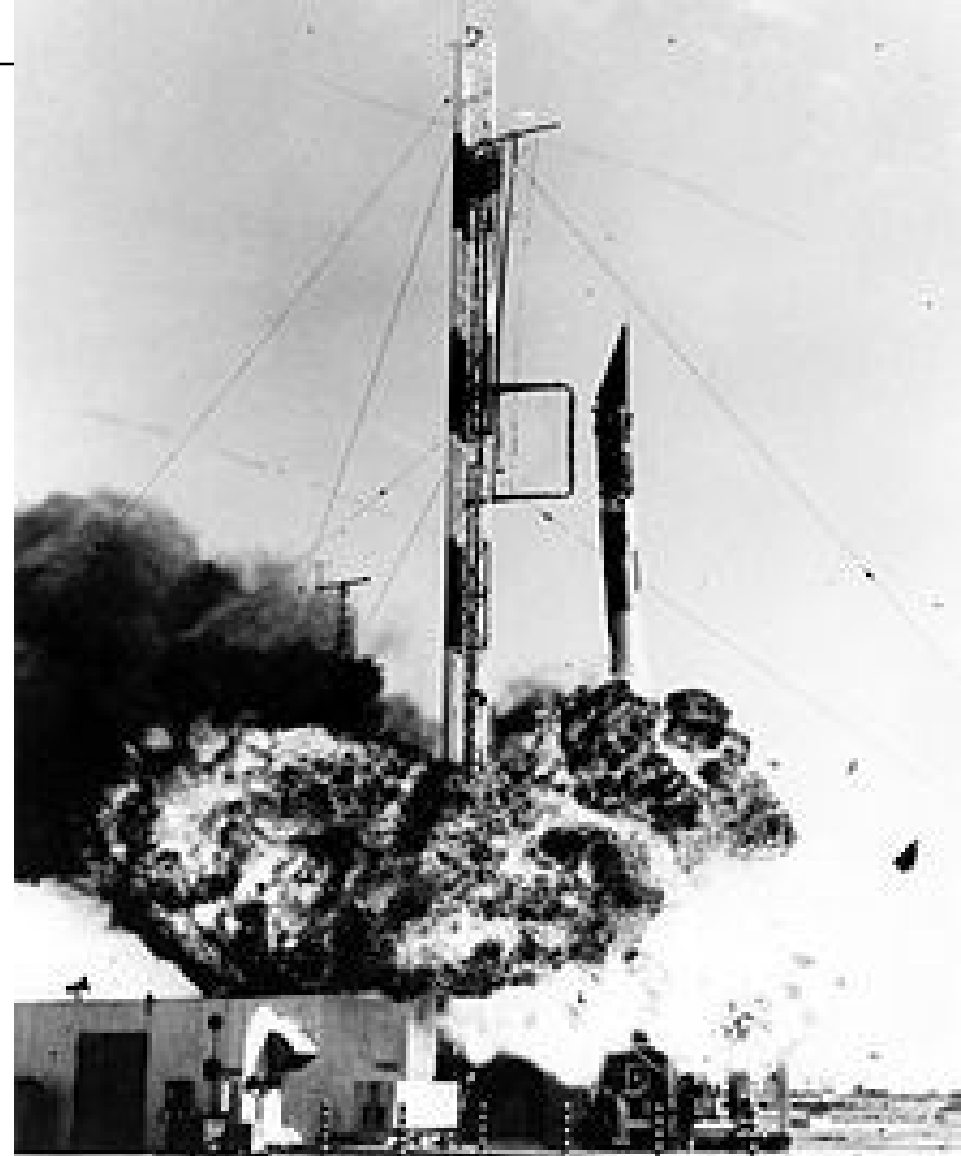


## 1957: Kaputnik (Vanguard)

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Two months later, on 6th December 1957, the US Vanguard (US NAVY) missile, with the satellite VT3 on board, explodes on the launching pad, live on TV.

- Humiliation for the failure is added to the loss of technical supremacy.
- US press becomes furious against the administration.
- The ABMA (US ARMY) center, where the German scientist Werner Von Braun (the designer of V1 and V2) works, previously blocked for political reasons, is asked to put a remedy as soon as possible.



# 1958: Explorer

- After other two months, on 31st January 1958, the US satellite Explorer 1, built in only 84 days by JPL Caltech, is put into orbit by a Jupiter-C missile (designed by Von Braun)
- In February 1958 ARPA (Advanced Research Projects Agency, then DARPA) is founded. The aim is to assure the technological supremacy of the United States.
- On 29th July 1958 NASA (National Aeronautics and Space Administration) is founded.



# 1961: Cold war & Berlin wall

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# 1961: Cold war & Berlin wall

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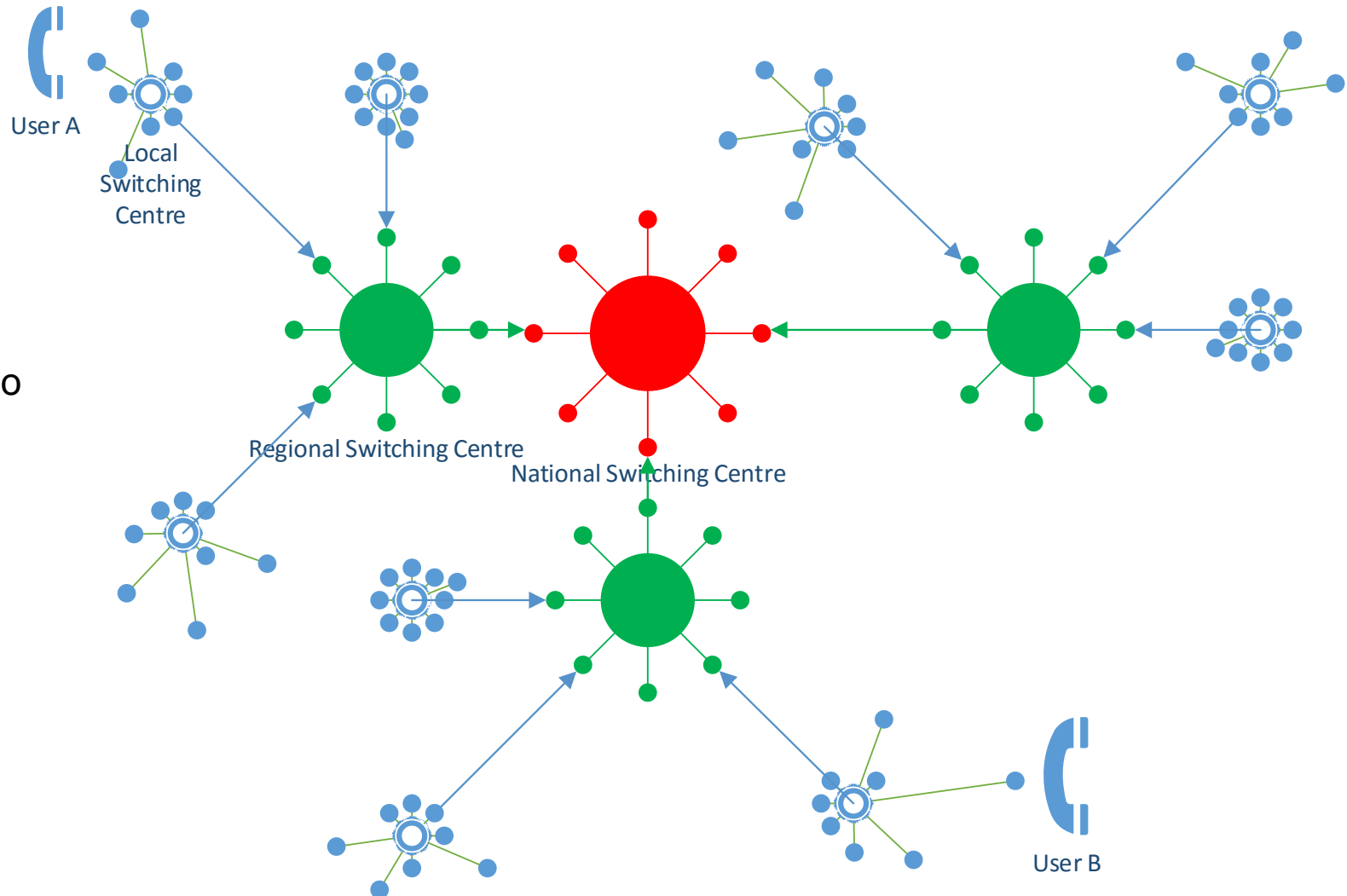


# Early 60': Internet origin

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- Was Internet conceived for WWW, iTunes, Facebook, WhatsApp, Google...?
- In facts, it was work shaped by the Cold War
- Paul Baran became interested in the survivability of communication networks in the event of a nuclear attack (early 60's):
  - "Both the US and USSR were building hair-trigger nuclear ballistic missile systems. If the strategic weapons command and control systems could be more survivable, then the country's retaliatory capability could better allow it to withstand an attack and still function; a more stable position.
  - But this was not a wholly feasible concept, because long-distance communication networks at that time were extremely vulnerable and not able to survive attack. That was the issue. Here a most dangerous situation was created by the lack of a survivable communication system."
- These ideas greatly contributed to the design of ARPANET

# Old Telephone Network Layout (simplified)



- Due to the hierarchical structure, from User A to User B only one path is possible

# Internet basis

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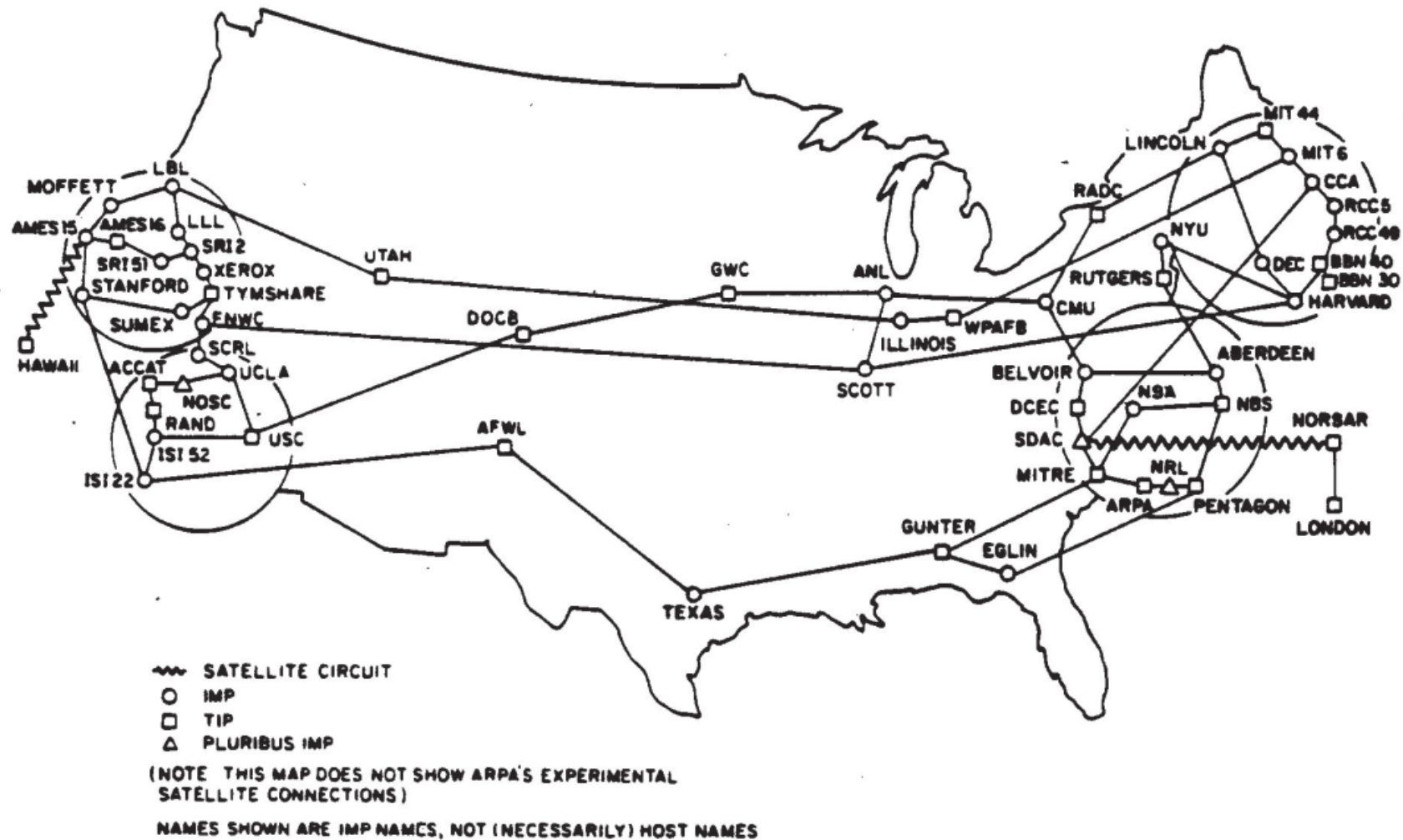
- Design pillars

- Packet switching (connectionless) instead of circuit switching
  - Packet switching divides messages into arbitrary packets; if connectionless routing decisions are made per-packet.
- Distributed & redundant architecture

- Aim

- Provided that there is a continuous path between A (source) and B (destination), communication must be possible.
  - The path through intermediate nodes is found in an automatic way
- We will see that DTN goes further and releases even this continuous path constraint!

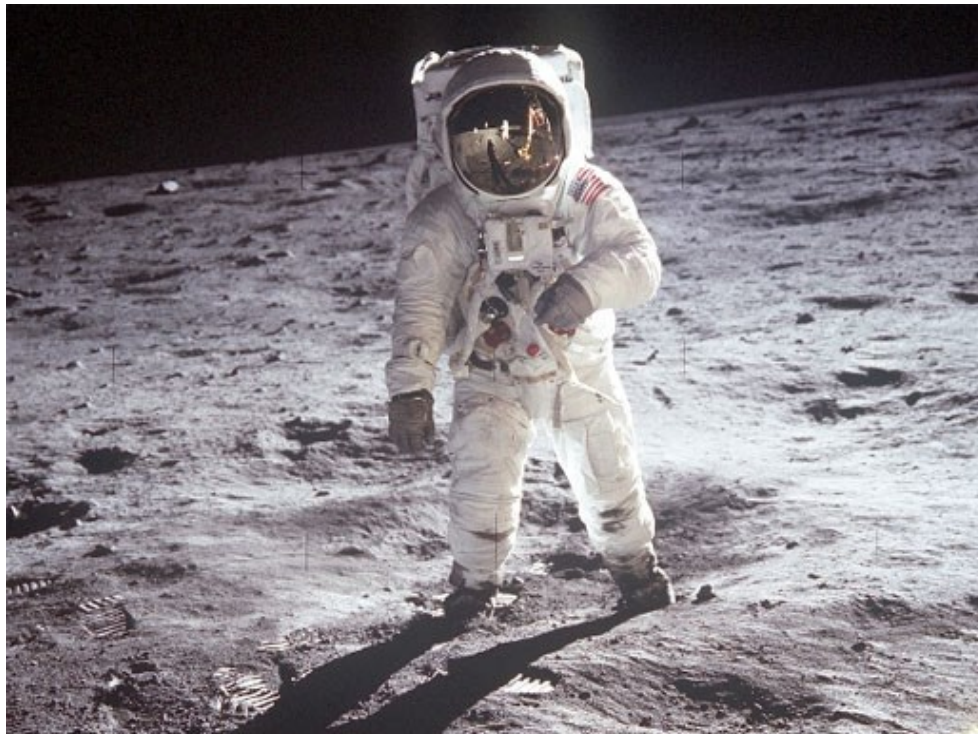
# ARPANET



# Internet (&space) evolution



- **1963: Memorandum for Members and Affiliates of the Intergalactic Computer Network, from J. C. R. Licklider (ARPA)**
  - A joke by a visionary man (visionary=having or showing clear ideas about what should happen or be done in the future)
- **1969: First man on the Moon on July 21 th**
- **1969: First message on the ARPANET on October 29th**
  - <http://www.internetsociety.org/internet/what-internet/history-internet/brief-history-internet>



29 OCT 69	2100	LOADED OP. PROGRAM	CSK
		EDIC BEN BARKER	
		BBV	
	22:30	Talked to SRS	CSK
		Host to Host	
		Left op. program	CSK
		running after sending	
		a host dead message	
		to imp.	



# 1975: Apollo-Soyuz rendez vous; end of the space race

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<https://www.nasa.gov/topics/history/features/astp.html>





# 1975: Astronauts and Cosmonauts

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The training leading up to the mission exposed the two crews to each other's nations, helping to break down cultural and language barriers.

By the way, what is the difference between cosmonauts and astronauts?





# 1989: Berlin Wall's fall & end of Cold war

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# 1989: Berlin Wall fall's: begin of a new era of peace?

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# 1991: World Wide Web; a new era really begins (but of peace?)

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- 1969 Internet
  - Remote login, e-mail, file download, BBS (Bulletin Board Service), newsgroups, ...
- 1991 World Wide Web
  - ubiquitous network that allows document retrieval through hypertext links
  - HTML documents, HTTP protocol, WWW server & browsers
- 1996 Social web
  - Facebook, Tik Tok, Twitter, etc.
- Present threats
  - Cyber attacks
  - Cyber bullying
  - Addiction
  - Privacy violation
  - Political polarization
  - Fake news...

Reporters with various forms of "fake news" from an 1894 illustration by Frederick Burr Opper





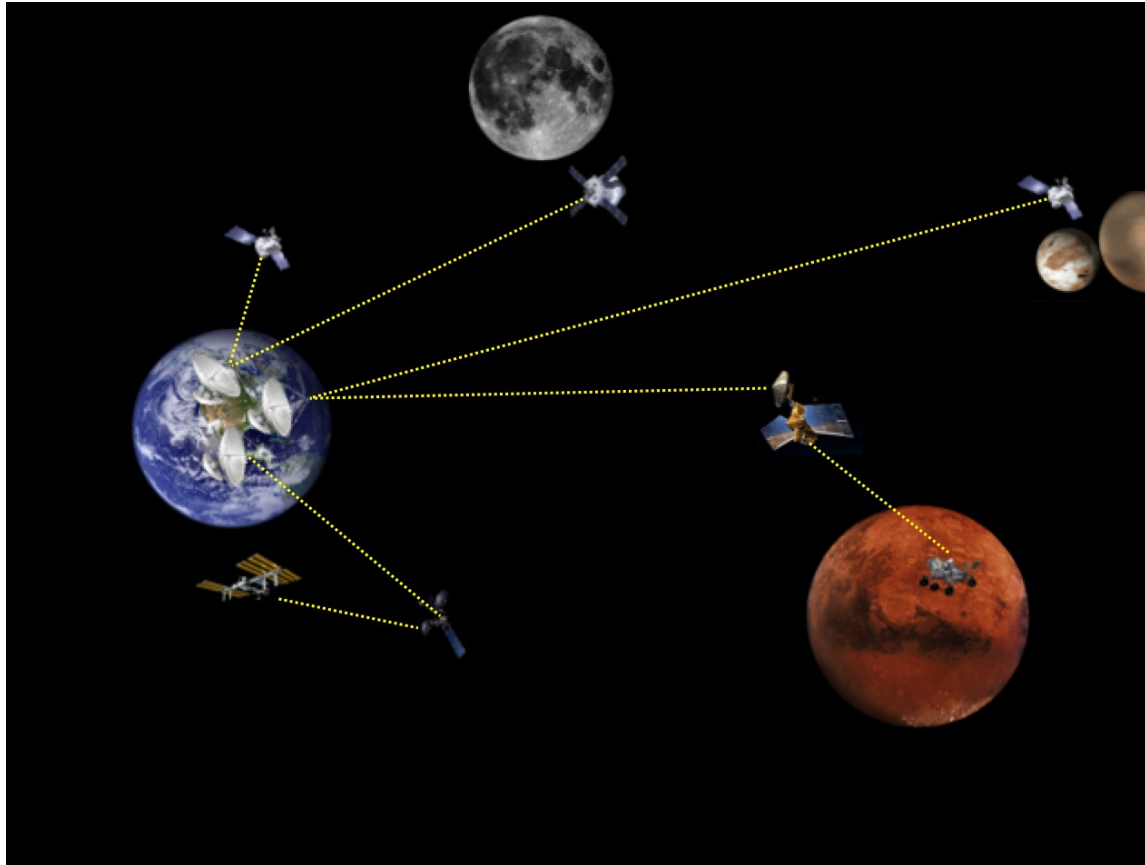
# From Internet to Interplanetary Networking

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Solar System Internet & DTN

# The past (and the present) of space communications

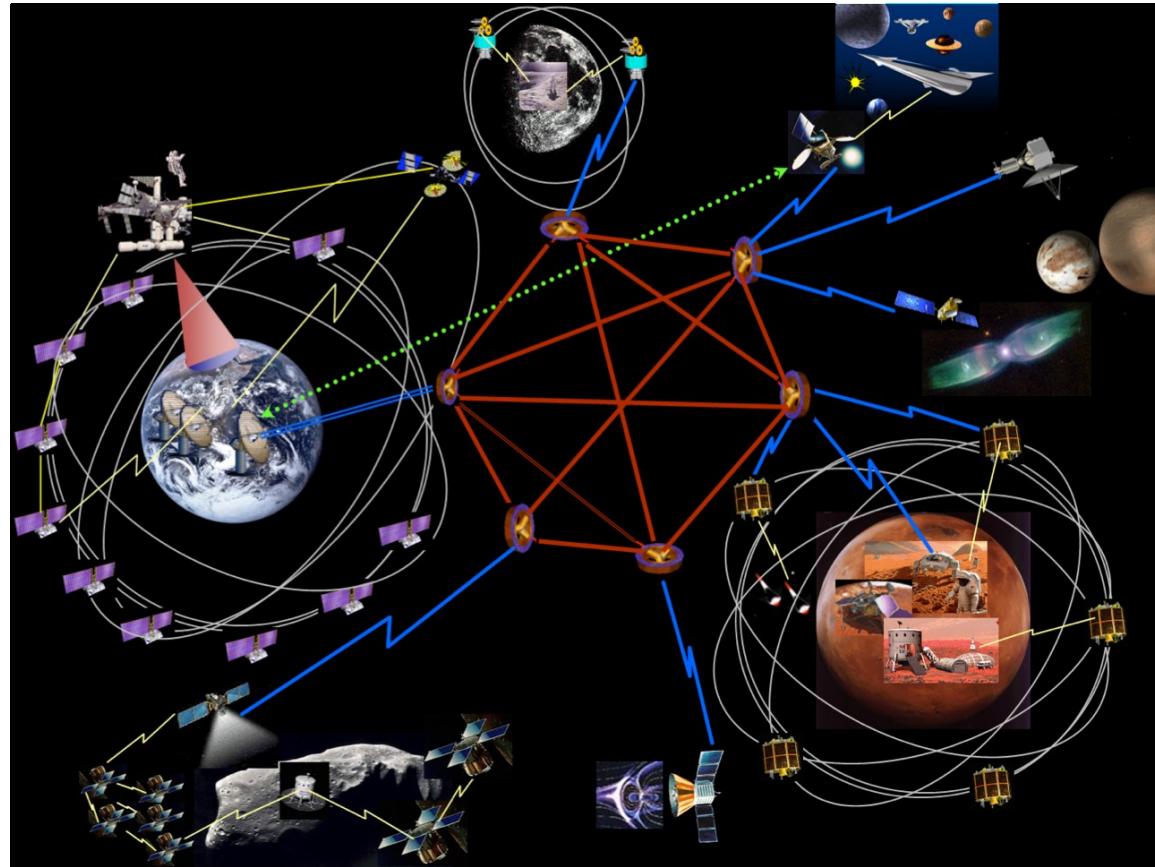
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- NASA missions have used
  - Direct
  - or single relay communication
- Future missions
  - Internet-like communication necessary

# Solar System Internet

- The Disruption Tolerant Networking protocols will enable the Solar System Internet
  - data stored in nodes until transmission is possible.
- From [NASA-DTN](#)



# Space communication challenges (why TCP/IP breaks)

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## ○ Challenges

- Intermittent connectivity (contacts), due to the orbital motion of planets and space assets (no continuous path)
- Very long propagation delays (the use of feedback based protocols, such as TCP is impossible)
- Possible high losses

## ○ Solution

- A new architecture that extends the TCP/IP one to cope with these challenges
  - IPN Interplanetary Networking
  - <http://www.ipnsig.org/>



# Distances from Earth



- A perfectly scaled diagram showing the orbital altitudes of several satellites (LEO, MEO, GEO).
  - [https://en.wikipedia.org/wiki/Low\\_Earth\\_orbit#/media/File:Orbitalaltitudes.jpg](https://en.wikipedia.org/wiki/Low_Earth_orbit#/media/File:Orbitalaltitudes.jpg)

# Challenged Networks and DTN

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- Challenges in space are however partially in common to a few terrestrial networks
  - Wireless sensor networks, Emergency networks, remote area networks, tactical networks, underwater networks...
- “Challenged networks” definition
  - Environments where at least one of TCP/IP assumptions does not hold
  - **Space networks a subset of challenged networks**
- DTN (Delay-/Disruption- Tolerant Networking)
  - A novel networking architecture to cope with ALL challenged networks
    - it broadens the original scope of IPN
    - One common solution better than many independent solutions
    - Space communications are, however, the most important driver of DTN research
  - [DTN-DINET w/ Vint Cerf You Tube](#)

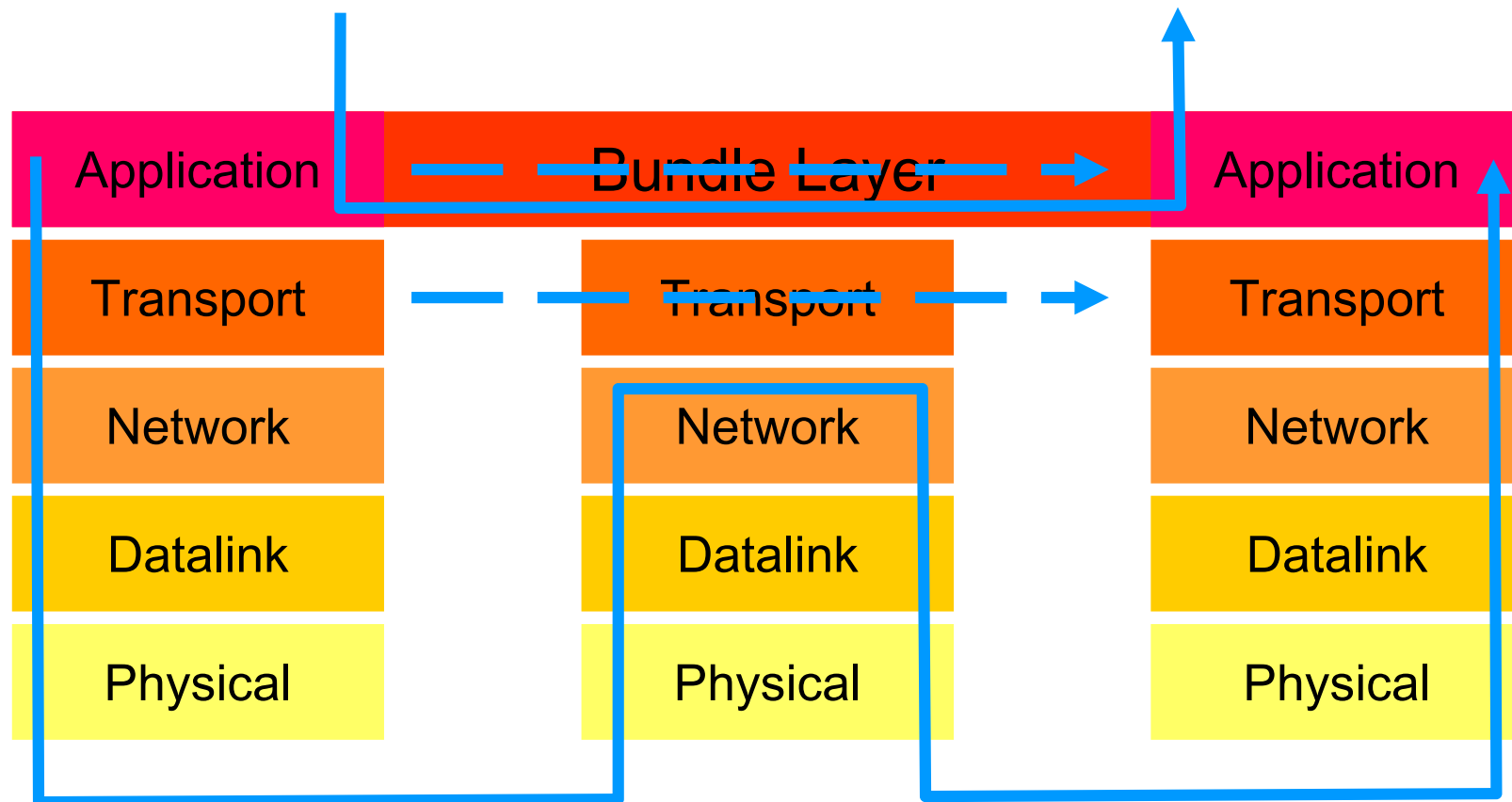
# DTN architecture & Bundle layer

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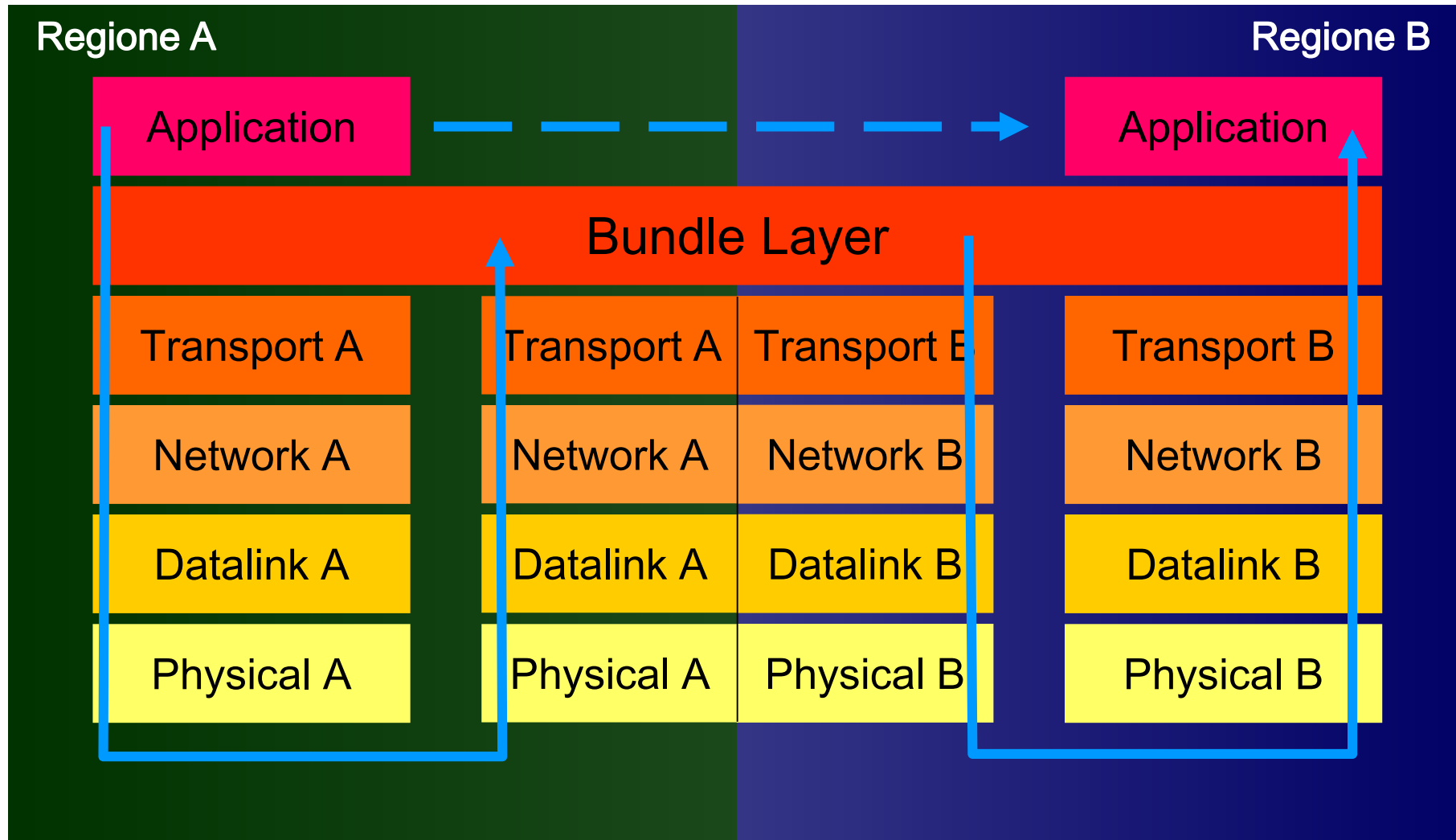
- It is based on the introduction of the Bundle layer between Application and lower layers (e.g. Transport)
  - “Bundles” are (possibly large) data packet at this layer
  - Store and forward
    - A bundle is first received, **stored** (even for long periods), and then transmitted (when possible)

# Bundle Layer

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# Bundle Layer



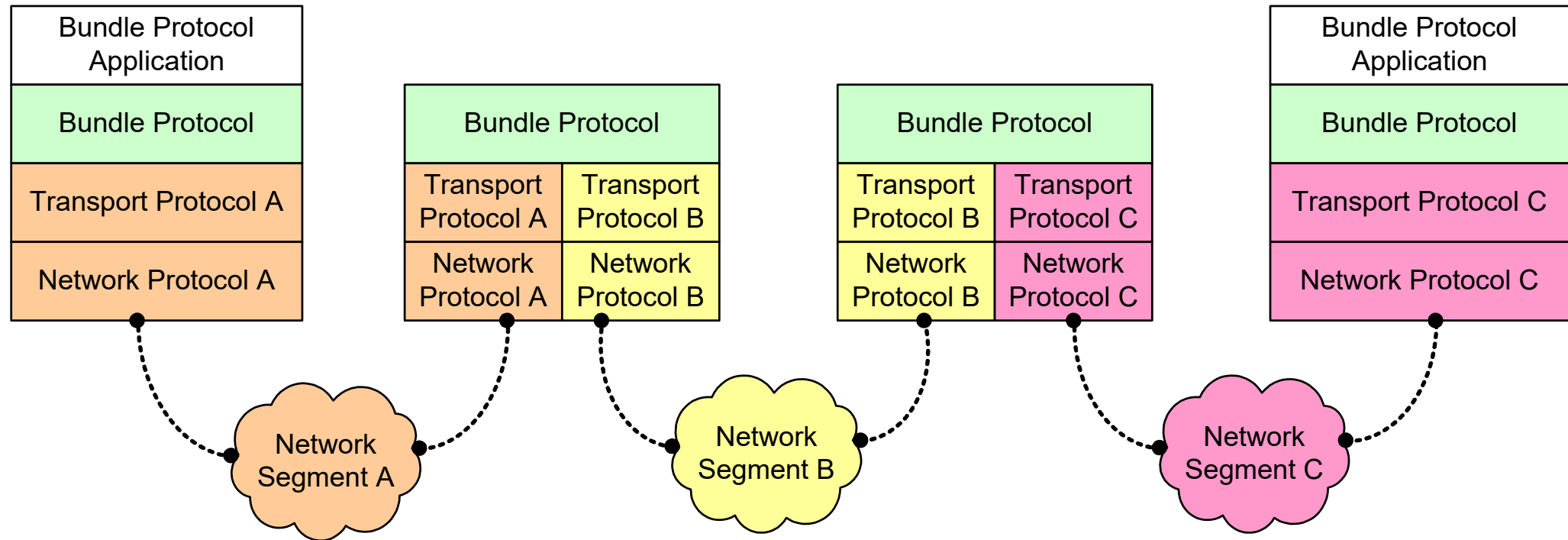
# DTN design pillars

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- Overlay network
  - End-to-end path divided into multiple DTN hops
  - Transport end-to-end semantics confined inside each DTN hop
  - Possible use of different transport protocols in different DTN hops
    - TCP on terrestrial hops
    - Licklider (called after J. Licklider) Transmission Protocol (LTP) on space links
- Information stored inside the network
  - To cope with the possible lack of a continuous end-to-end path
    - Link intermittency
    - “data mule” applications
  - More efficient loss recovery with long RTT

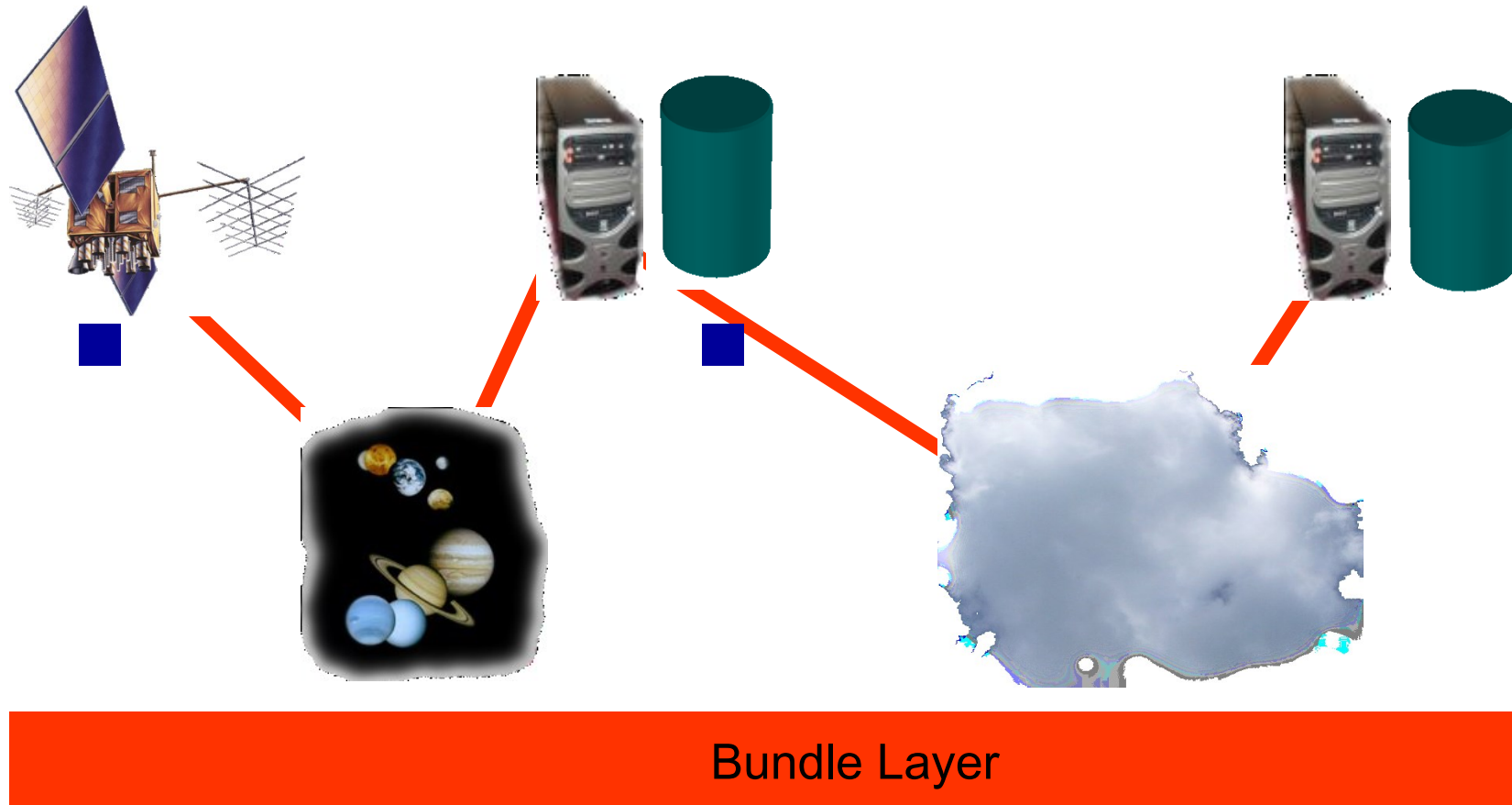
# DTN overlay over a heterogeneous network

End to End exists only between two DTN consecutive nodes, i might change protocol between nodes during the path.  
The reason is that you might not have a direct path between source and dest. active at all the time



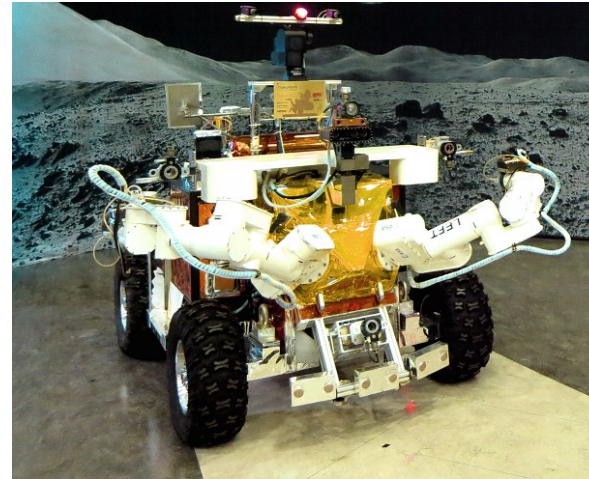
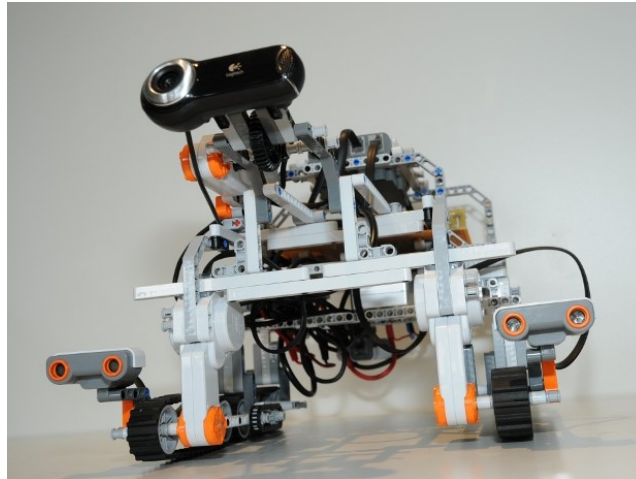


# Bundle storage at intermediate nodes



# DTN & LEGO & on (ESA Meteron)

- Lego robot controlled by ISS via DTN (2013 ESA experiment)
  - “The experimental DTN we’ve tested from the space station may one day be used by humans on a spacecraft in orbit around Mars to operate robots on the surface, or from Earth using orbiting satellites as relay stations.”
- Other experiments with larger robots (Eurobots) are going on from ISS via DTN
  - <http://blogs.esa.int/meteron/>
  - <http://esamultimedia.esa.int/multimedia/virtual-tour-iss/>



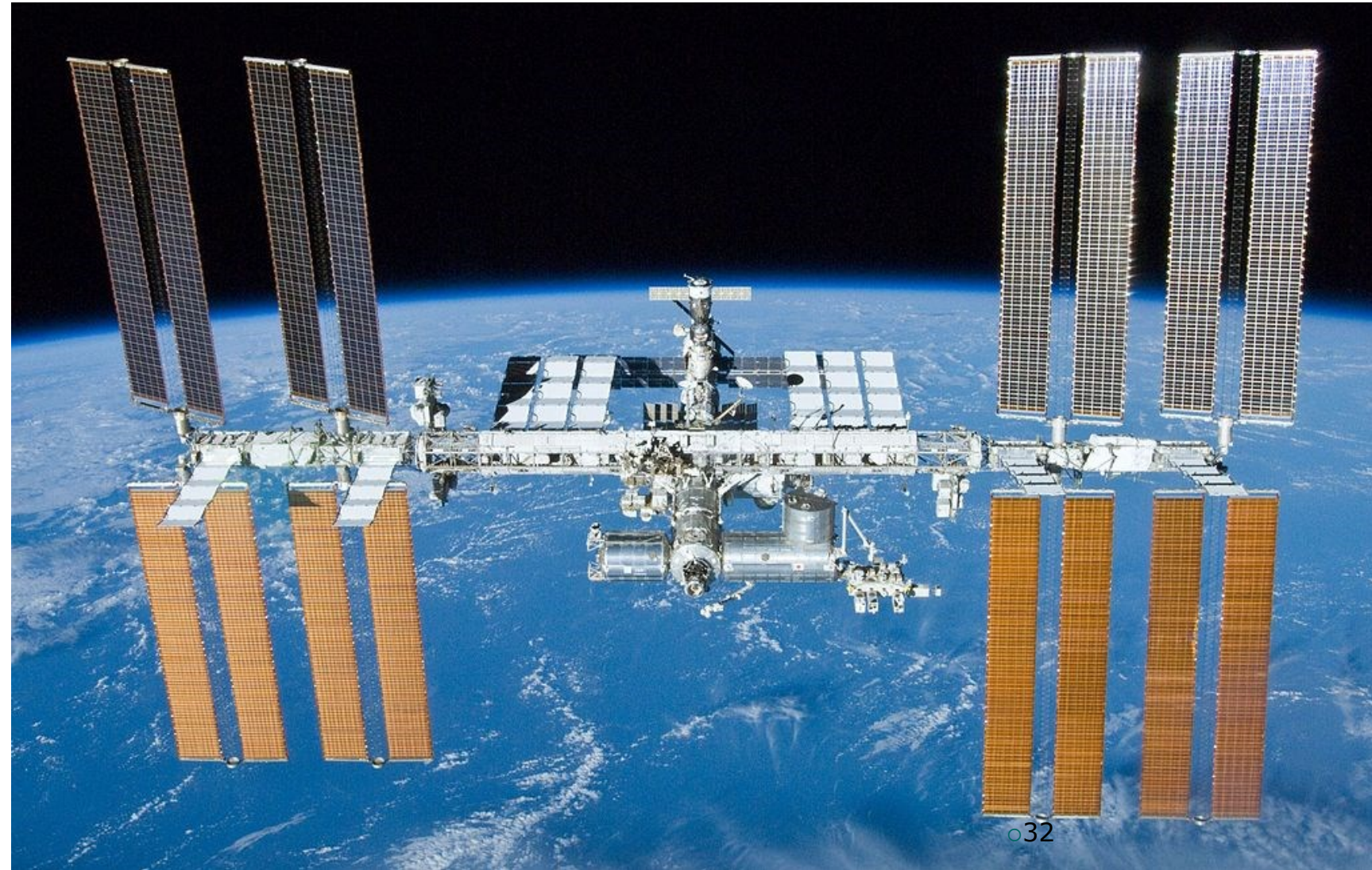


# 1998-present: cooperation in space, the International Space Station

The ISS is the result of a wide international cooperation

NASA, Roscosmos,  
JAXA, ESA, CSA

- After the American Space Shuttle program ended in 2011, Russian Soyuz rockets were the only means of transport to ISS for all astronauts, until May 2020 (SpaceX Falcon9).
- **DTN nodes are on board!**
- <https://www.youtube.com/watch?v=SGP6Y0Pnhe4>



# 1982-present: cooperation in space, CCSDS

## The Consultative Committee for Space Data Systems

Founded in 1982 by the major space agencies of the world, the CCSDS is a multi-national forum for the development of communications and data systems standards for spaceflight.

- **Including DTN!**
- 15-19 October 2018, CCSDS fall meeting in Berlin, hosted by DLR



# References

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  - <http://tools.ietf.org/html/rfc4838>.
- RFC5050: Bundle Protocol Specification, K. Scott and S. Burleigh, Nov. 2007
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  - DOI: [10.1109/JPROC.2011.2158378](https://doi.org/10.1109/JPROC.2011.2158378)



# 2022 Updates: the cold war is not over...



- “I don’t agree that the Cold War is back. It never ended.”
  - quote by an ex KGB member, reported on NYT 5-6 March 2022

# 2022: Impact on space collaboration

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- OneWeb (UK) LEO sat mega constellation (global Internet)
  - The launch of 36 satellites scheduled on 4/3/2021 with a Soyuz rocket has been cancelled by Roscomos (Russia space agency)
- ISS
  - [Russia's space agency warns US sanctions could 'destroy' cooperation on the International Space Station](#)
  - NASA “continues working with all our international partners, including the State Space Corporation Roscosmos, for the ongoing safe operations of the International Space Station.”
    - at present there are both cosmonauts and astronauts on board, and they MUST cooperate
- Future missions
  - Moon and Mars missions
    - already planned in competition; new space race (China-US)?
  - Building an Interplanetary internet run by all space agencies?
    - I would say there is no hope, but... never say never.
- Space collaboration seems an impossible dream now, but it was the same in late 60s. We need a new miracle.