La suite du protocole Internet dans l'espace

draft-many-deepspace-ip-assessment

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To infinity and beyond!

Agenda

- Considérations sur les communications dans l’espace
- La suite IP dans l’espace
  - L2
  - IP
  - Transport
  - QUIC
  - HTTP
  - Services réseaux

Qui suis-je?

- Ingénieur en réseau Internet depuis 30+ ans
- Développé plusieurs protocoles (17 RFC, co-président de plusieurs groupes de travail de l'IETF)
- Consultant pour fournisseurs Internet, grandes entreprises, manufacturiers, agences spatiales
- A commencé à être impliqué dans la réseautique de l'espace depuis le début des années 2000.
  - Co-président du groupe de travail IETF delay tolerant networking(dtn) pendant ~10 years.
- Membre du Interplanetary Network SIG(IPNSIG) Architecture WG and Projects WG
- Lead du groupe de travail sur la governance de la réseautique pour la Lune de l'IOAG (Interagency Operations Advisory Group)
- Investigateur de l'initiative 'Deepspace IP'

This Talk is

- Not about Internet users/applications
    - Specialized space applications, not typical Internet applications
- Not about Near Earth (LEO, MEO, GEO)

- It is about space applications using the Internet Protocol suite.

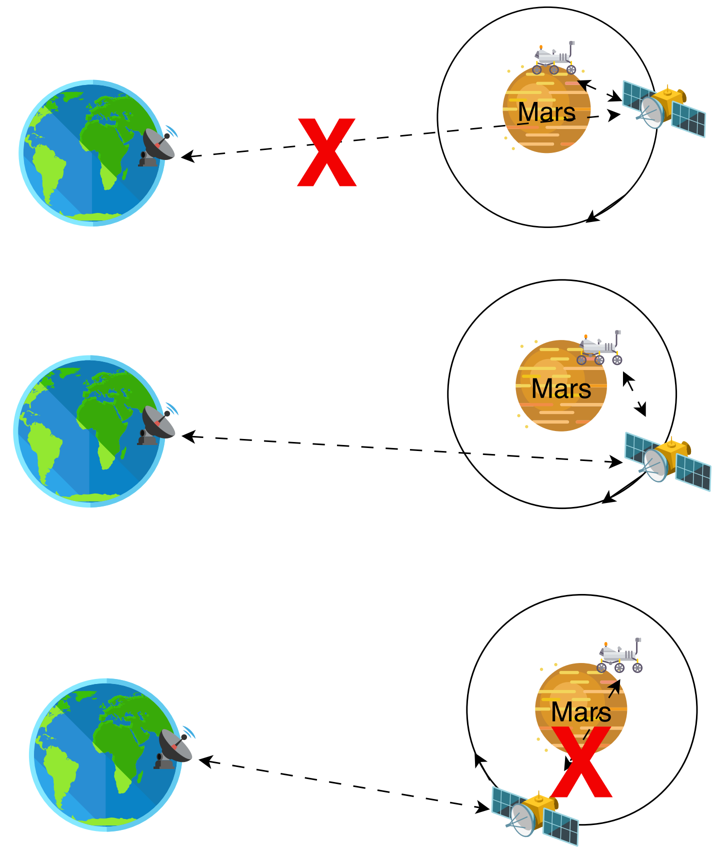
Deep Space Communications

- Delays:
    - Earth-Mars:
        - one-way delay: 5-20 minutes
        - Round trip time(RTT): 10-45 minutes
- Links:
    - One-way
    - Asymmetric
    - Variable

- Using Mars as benchmark, but will be first implemented on Moon

Deep Space Communications Are Interrupted

- Planets, Moons are orbiting
- Orbiters are orbiting ;-)
- Consequence:
  - No continuous communications: planned windows of communication between peers for each link
    - Earth-Mars relay
    - Mars relay - Mars rover/habitat/…
  - Relays/forwarders/routers need to store frames/packets until next hop becomes reachable.
    - Can be done at L2 (example: MRO for Mars) or L3 or ..



Can We Use our Internet Protocol Suite for Deep Space?

- RFC4838 (published in 2007) concludes “no”. Very short summary:
  - Transport (TCP), protocols and applications are too chatty for delays and disruptions in space.
  - Consequence was the invention of a new Networking Stack: Bundle Protocol (RFC5050, RFC9171), based on a store and forward design, with its own new: transport, routing, naming, security, neighbor discovery, application API, network management, …
  - DTN: Delay (and Disruption)-tolerant Networking. Typically, DTN means Bundle Protocol.
    - This presentation is about DTN using IP.
- Internet and Internet Engineering has evolved since then:
  - IoT, disruptions of communications
  - new transport protocols (QUIC)
- Reassessment of the use of the Internet Protocol Suite for Deep space. Short answer: “yes”!
  - https://deepspaceip.github.io
  - Documented in draft-many-deepspace-ip-assessment
  - Subject of this presentation

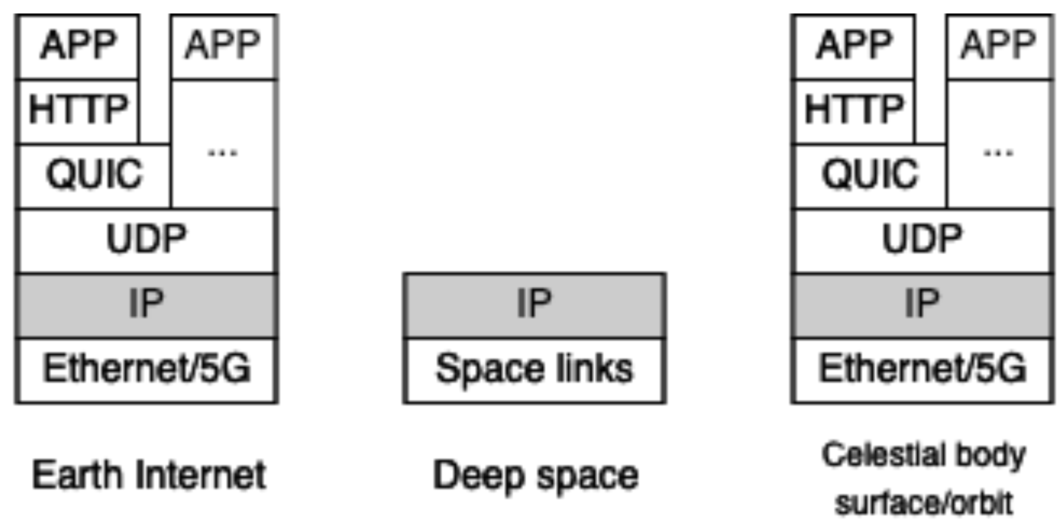
- N.B., The InterAgency Operations Advisory Group(IOAG) already define the use of IP on surface and orbit of Moon and Mars

Key Design Points

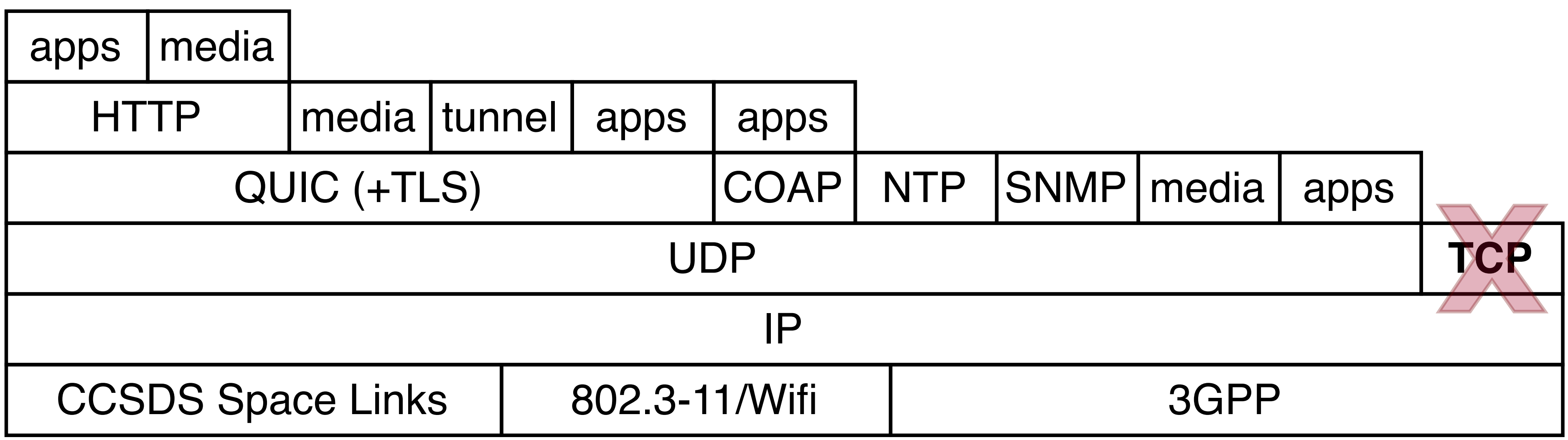
- Use IP on surface and orbits of celestial bodies (Moon, Mars). Same as today on Earth.
- Use IP on deepspace CCSDS links
- Buffer/Store and Forward IP packets when links are temporarily down (and no alternative route) in relays
- Properly configure Transport and Application timers for these RTT

Deepspace Path Stack

- Single Network Layer
- End 2 end
- Network tools and protocols as we know today
- Application Interface as we know today



Deep Space IP Stack



* The Interagency Operations Advisory Group(IOAG) identifies that 3GPP and IEEE 802.11 Link layers will be used on and around celestial body surface and orbits, while CCSDS Space Links will be used in deep space (and to/from surface).

IP and TCP-UDP in Deep Space

- IP ✅
  - has no notion of time, no reliability
  - can be encapsulated into CCSDS space links
  - since IP over space links are point to point, header compression can be used. (Makes a whole IP-UDP headers into a single byte)
  - Forwarders with interrupted links have to temporarily store packets. Our Linux prototype is 200 lines of C code.
- TCP: does not work in space because chattiness and timers TCP
- UDP has no notion of time, no reliability ✅

QUIC in one slide

- Over UDP, Reliable transport, e2e, single handshake, 0RTT, user-space
- Mandatory security (TLS)
- Single connection is a pipe of streams, bidirectional, may be long-lived
- Carry HTTP and other application protocols, including tunnelling
- While it was not designed with deep space in mind, it is well suited for. ✅

QUIC for Deep Space

- But QUIC by default assumes short delays, interactive communications and does congestion control
- By setting various QUIC parameters to appropriate values (typically large) and by simplifying the congestion control, QUIC works just fine in space.
- A QUIC connection to/from a spacecraft can be:
    - Long-lived (hours, days, weeks, months)
    - Pre-established while spacecraft has not left Earth
- QUIC may use proxies, which could be used at space edges, where access policies, buffering, QoS, … is applied.
- With appropriate setting of the QUIC stack by the application, and no modification of protocol or the QUIC stack itself, we were able to …

Send An HTTP Request to Voyager!

- 18 hours (64800 seconds) delay each way; 36 hours RTT

	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.65.33	192.168.65.25	QUIC	1242	Initial, DCID=d61b8e047f
2	64800.438656	192.168.65.25	192.168.65.33	QUIC	1380	Handshake, DCID=2f26ef8a
3	129600.8077…	192.168.65.33	192.168.65.25	QUIC	1242	Handshake, DCID=bf92a7a2
4	129600.8086…	192.168.65.33	192.168.65.25	QUIC	200	Protected Payload (KP0),
5	194401.1215…	192.168.65.25	192.168.65.33	QUIC	691	Protected Payload (KP0)
6	259201.4231…	192.168.65.33	192.168.65.25	QUIC	79	Protected Payload (KP0),
7	259201.4236…	192.168.65.33	192.168.65.25	QUIC	96	Protected Payload (KP0),
8	259201.4245…	192.168.65.33	192.168.65.25	QUIC	86	Protected Payload (KP0),

- 1-2: client-server initial connection handshake. Crypto set.
- 3. NCIDs. Most likely not needed. haven’t yet worked on it.
- 4. GET HTTP REQUEST
- 5. HTTP RESPONSE
- 6. NCIDs. Most likely not needed. Haven’t yet worked on it.
- 7-8. Client connection close

- HTTP in deep space: ✅

10 days RTT!!!

- 5 days delay one way (432000s), 10 days RTT (864000s)
- Packets:
  - 1-2 connection establishment
  - 4-5 HTTP GET and RESPONSE
  - 7-8 connection close
- If connection is already established and is not closed, then only one RTT for request and response

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	10.132.239.239	10.132.239.121	QUIC	1242	Initial, DCID=31e20cceeacc6ddb3903704db5c9be687df54441, SCID=05e7e0f8a63866b8, PK…
2	432000.0…	10.132.239.121	10.132.239.239	QUIC	1380	Handshake, DCID=05e7e0f8a63866b8, SCID=c2d1484de334b668, PKN: 0, CRYPTO
3	864000.0…	10.132.239.239	10.132.239.121	QUIC	1242	Handshake, DCID=c2d1484de334b668, SCID=05e7e0f8a63866b8, PKN: 0, ACK_ECN, CRYPTO
4	864000.0…	10.132.239.239	10.132.239.121	QUIC	200	Protected Payload (KP0), DCID=c2d1484de334b668, PKN: 1, NCI, NCI, NCI, NCI, STREA…
5	1296000.…	10.132.239.121	10.132.239.239	QUIC	689	Protected Payload (KP0), DCID=9e463c45aa076440
6	1728000.…	10.132.239.239	10.132.239.121	QUIC	77	Protected Payload (KP0), DCID=c2d1484de334b668, PKN: 2, ACK_ECN
7	1728000.…	10.132.239.239	10.132.239.121	QUIC	84	Protected Payload (KP0), DCID=c2d1484de334b668, PKN: 3, ACK_ECN, CC
8	2160000.…	10.132.239.121	10.132.239.239	QUIC	81	Protected Payload (KP0), DCID=9e463c45aa076440, PKN: 4, ACK_ECN, CC

HTTP and Applications for Deep Space

- HTTP does not have any notion of time, by itself.
  - If some time-related HTTP headers are used, such as Cache-Control and Expires, then proper value must be set.
  - The server and client typically have timeouts. Set value properly
    - Examples: curl -m; nginx *_timeout config
- Typical web browsers with GUI should work, but may not be the best tool for looong delays
  - Disable timeout or set timeout value to large value
  - Make sure the browser app and window stays there for the whole time.
- HTTPS when used over QUIC: TLS is done at the QUIC layer
- One can design a space application using HTTP, REST API, Javascript, …
    - Have the right design:
      - Asynchronous
      - Local references with local (pre-)caching/preloading of assets
      - Timers set properly
    - Consider various Web optimizations:
      - WASM
      - HPACK

Media

- « one-way »: aka streaming a camera from space to Earth
- Two-way: audio/video conferencing
  - Possible but not typical for deep space because of inherent delays
- Media transport:
  - Directly over UDP: Streaming using RTSP; SIP/RTP
  - Over QUIC: see IETF Media Over QUIC (MOQ) wg
  - Over HTTP-QUIC: as done today on Internet

Domain Name System (DNS) for Deep Space

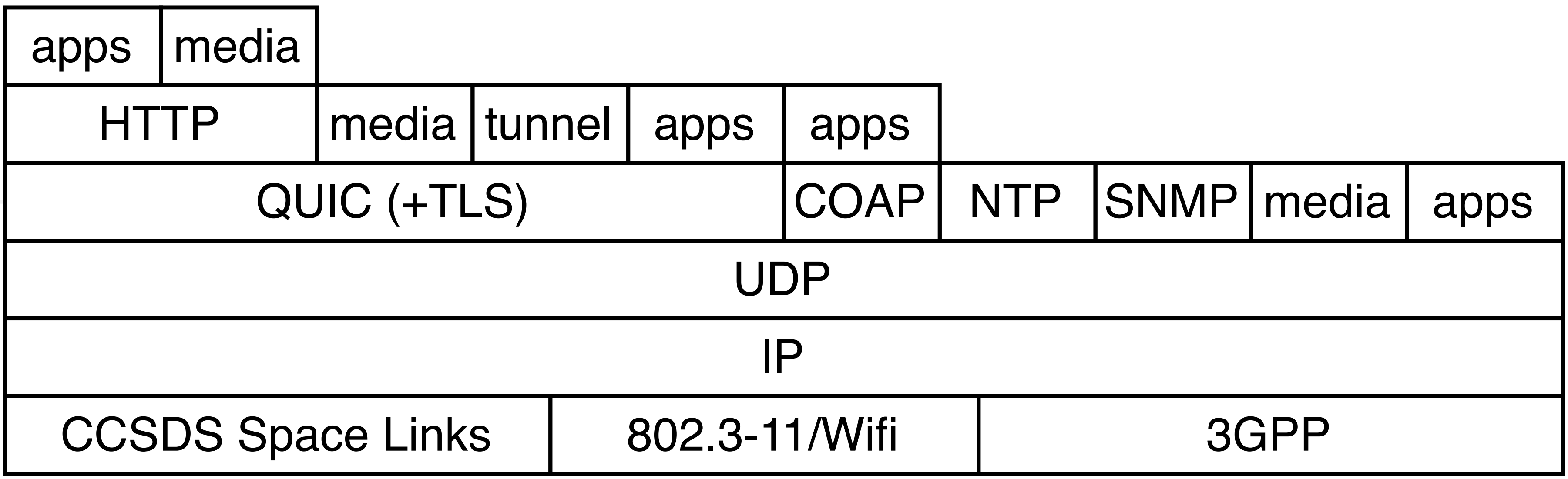
- DNS runs over UDP (also runs over other transports)
- Resolving a name through a deep space link such as Mars to Earth does not make a lot of sense.
- Appropriate pre-caching and proper deployment techniques are necessary so that name resolution and security(aka DNSSEC) is local to the planetary body network
- No need for protocol changes.
- DNSSEC key and RR lifetimes need to be carefully set for enough long values
- Naming hierarchy has an impact on how to deploy but any level is possible.
- See draft-many-dnsop-isolated-networks

Naming and DNS: ✅

(IP) Network Management

- SNMP (over UDP) with MIBs. ✅
- NETCONF over QUIC or RESTCONF with YANG. ✅
- SSH (does not work in space) ~~SSH~~

Deep Space IP Stack



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Why Deep Space IP?

- IP will be used anyway on surface and orbit around celestial bodies
- By using IP also on deep space links, it creates a seamless network using a single L3 protocol: IP end to end
- Reuse of IP protocols, applications, software, frameworks, tools, devops, network management, security, routing, QoS, …
  - Way cheaper
  - Multiple implementations
  - Multiple vendors
  - Way more scrutiny on security
  - Easier to find developers, network managers, …
  - Software has been tested and exercised in real environments, with hard metrics
  - Hardware already exists for X00Gbps
- Way more reliable
- Way easier to develop applications
- Significantly decrease mission/project risks

Next Steps and Future Work

- New IETF working group
    - To be discussed during a BOF in IETF Dublin, November 2024
- Best Current Practice/Profile documents
- More simulations
- Investigate additional protocols
    - Example: Netconf over QUIC

Summary

- By:
  - Temporarily storing IP packets in forwarding nodes until links are back up
    - Only for IP forwarders seeing intermittent links
  - Setting appropriate QUIC parameters
    - Or using UDP-based protocols and applications
  - Properly design applications to be asynchronous and have large timers
- The Internet Protocol Suite can be used end to end in deep space.
- Results from simulations in a testbed have confirmed that deep space IP is working.
- Obviously more work needed

Acknowledgements and Further Info

- Acknowledgements:
  - IP forwarding storage implementation: Jean-Philippe Dionne
  - QUIC: Christian Huitema(picoquic, IETF), Martin Thompson(neqo, IETF), Benjamin Saunders(quinn), François Michel(UCL), Maxime Piraud(UCL), Martin Duke(Google)
  - QUIC workbench: Adolfo Ochagavia
  - Routing: Dean Bogdanovic, Tony Li
  - COAP: Carlos GomezMontenegro
  - TAPS: Émile Stephan
  - DNS: Warren Kumary, Mark Andrews,
  - Discussions and argumentation: Vint Cerf, WIDE project, KDDI, James Schier(NASA), Felix Flentge(ESA), Juan Fraire(INRIA), …
  - Specifications reviews: too many to list.

- Further info:
  - IETF deepspace mailing list (mailto:deepspace@ietf.org)
  - https://deepspaceip.github.io
  - draft-many-deepspace-ip-assessment
  - Marc Blanchet, marc.blanchet@viagenie.ca