Architecture Issues for Integrated Space and Terrestrial Networks

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Robust Dynamic Tactical Networks
support 10-500k communicating devices in theater

- Beyond traditional "tactical" which is voice/human user oriented
- High reliability delivery
- Beyond traditional ad-hoc networks
Network topology

Space backbone (Lasercom)

Terrestrial backbone (fiber)

Airborne

Ground radio

Access network

Space user
Network properties

- Ultra-long propagation delays
- Software delays
- Large delay-bandwidth product
  - Many packets in flight
- Time-varying channel
  - Capacity
    - Symbol-size
    - Code-rates
  - Fading
    - Outage
    - Block erasures
- Dynamic connectivity (unpredictable)
  - Multiple connectivity
  - Changing channel quality
- Pol., linear and nonlinear distortions
Dynamic 4-D Network

- **Dynamic rate allocation**
- **Agile beams**
- **MAC**

- **Dynamic routing**: deterministic & stochastic
- **Heterogeneous network**: Satcom, fiber, wireless
- **Differentiated services**: cost-based, time-deadline, ...

- **Joint application-network coding**
- **Policy networking**
Critical architecture issues

1. **Physical topology**

2. **Modulation and coding**
   a. Lasercom
   b. RF trunk
   c. RF AJ access
   d. RF ground radio

3. **Media access control protocol (MAC)**
   RF, Lasercom

4. **Network routing hardware and protocol**

5. **Transport Layer protocol**

6. **Network management and control**

7. **Source coding** (*interactions with others*)

8. **Internetworking**

9. **Security** (*not just crypto*)
**S/C node:** Processing + MAC + switching + routing
$	extbf{Constellation connection topology}$

- Uniform & hub traffic
- % pass-thru traffic increases with $N$
- Degree 3, 4 seems best
- Mesh is better: asymmetric traffic will have more dramatic effects

**Ring (U)**

**Circulant (U)**

**Circulant (H+u)**

- One architecture does not fit both traffic patterns
Media Access Control (MAC) Protocol

- Efficient use of satellite resources (e.g. receivers, xmitters)
- MAC protocol critical for efficient performance
  - Random access?
  - Scheduling for larger transactions
  - Access delay of several roundtrips will have significant interactions with TCP
  - Open air interface security
RF space-ground links

- Highly variable channel
  - Rain attenuation
  - Turbulence scintillation

- Adaptive modulation and coding
  - Adaptive signal constellation
  - Variable coding rate
  - Interleaving
  - Diversity combining (rake-like)
  - Trellis coding at lower code rates
  - Fiber optics codes not appropriate

- May use ARQ to get better reliability performance

- Variable capacity, long delays, large bandwidth-delay product not previously encountered in terrestrial networks – will have significant interactions with upper layers, severe performance degradation possible
Atmospheric optical communication channel

- Boundary layer turbulence
- Atmospheric turbulence

- 0.1-10 ms fades – outages
- Interarrival time 1-100 ms
- FEC alone will require large interleaver
- Possibly combine with ARQ (delay)
- Diversity via multiple receiver or AO must be used
TCP Window Flow Control & Throughput

- Outage creates window closing, slow start, ...
- Window scale option only takes care of max window problem
- With almost an outage within each RTT, window will not build up – low throughput or assure no outage which is costly in link power
- Other fairness problems when mixed with terrestrial traffic

For $\sigma_x = 0.5$, 1Gb/s link

1 user

For $\sigma_x = 0.5$, 1Gb/s link

many users
Network routing at Layer 3

- Dynamic adaptation based on channel states - variable link capacities and qualities; fast adaptations may lead to oscillations

- Maximizes downlink capacity and/or delay via optimum routing/scheduling

- End-to-end routing including terrestrial subnet

- Time deadline QoS

- Routing algorithm - OSPF ?, ..., Internetworking - BGP?, ...

- Security of Layer 3 network management and control
Transport Layer Protocol – TCP, …?

• TCP is an end-to-end reliable delivery protocol

• If a long delay link does not make any errors, then window options can allocate unfair amount of resources

• If the long delay links have outages, then window flow control may prevent full rate transmissions, leading to very inefficient use of channel

• Proxy service decouples Layer 3 communication – hard to provide QoS such as time deadlines

• UDP plus add on protocol? Others?
Interoperable distributed spacecom

- Interoperable spacecom, EHF, SHF, UHF, ..., commercial
- Data networking with packet switching and QoS (e.g. priority) in space
- Serious internetworking issues
- Security
Network security

Security is crypto + denial of service + interception + location
Involves: crypto + NM&C + all layers + interactions among layers

• Crypto
• Proxy vulnerabilities

• TCP/IP vulnerabilities in open air
• Traffic analysis

• Compromised routers - IP vulnerabilities,
• Hardware vulnerabilities
• Internetworking (BGPs)
• Traffic analysis

• Interference with MAC, ARQ, FEC

• Jamming
• Interception, location, ...
• Intrusion entry point
Window closing due to Physical-layer attack:

TCP reacts poorly to jamming, closes window
Reduces rate to < 1%

- Nulling
- Rerouting
- Change TCP
Some observations

1. **Mesh/circulant constellation** connection topology

2. Space-terrestrial links will have **time-varying capacities, outages, ...**

3. Non-stationary and large delay-rate-product channel properties impact **Transport Layer protocol** performance - TCP or not TCP for space, XCP?, UDP+?

4. **Node switching hardware** architecture important to be a right mix

5. **Routing algorithm** to optimize resources and adapt to channels with **stability**

6. **Network management and control** is a big issue, especially internetworking and **security**

7. **Network architecture must last over 25 years**, therefore
   
   a. *Not forever tied to a specific today standard*
   
   b. *Upgradable protocols*
   
   c. *Good for multiple generations of technologies*
   
   d. *Pick an architecture trend that evolves*