Approaches to Difficult Aerospace Telecommunications Links

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What qualifies as a “Difficult Link”

- Straightforward issues
  - Low Capacity
  - High Latency
  - High Losses
  - Low Reliability
- More complex situations
  - Multiple links between endpoints
  - Reordering
  - Asymmetric links

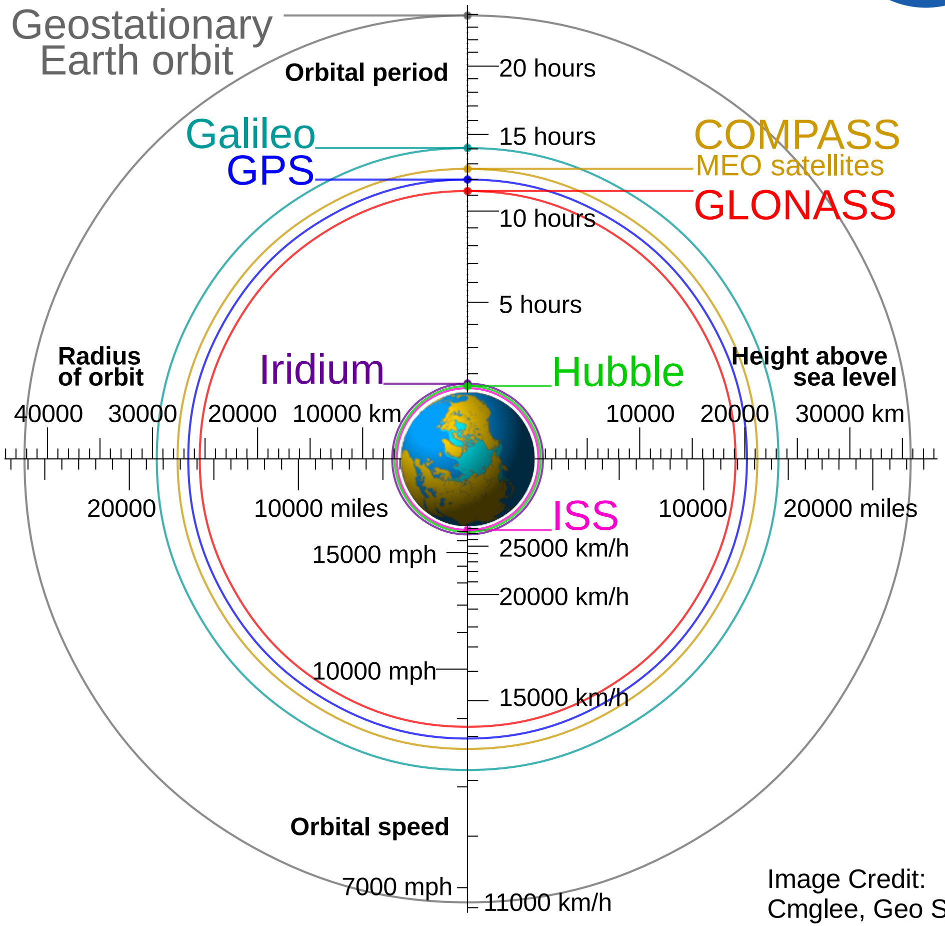
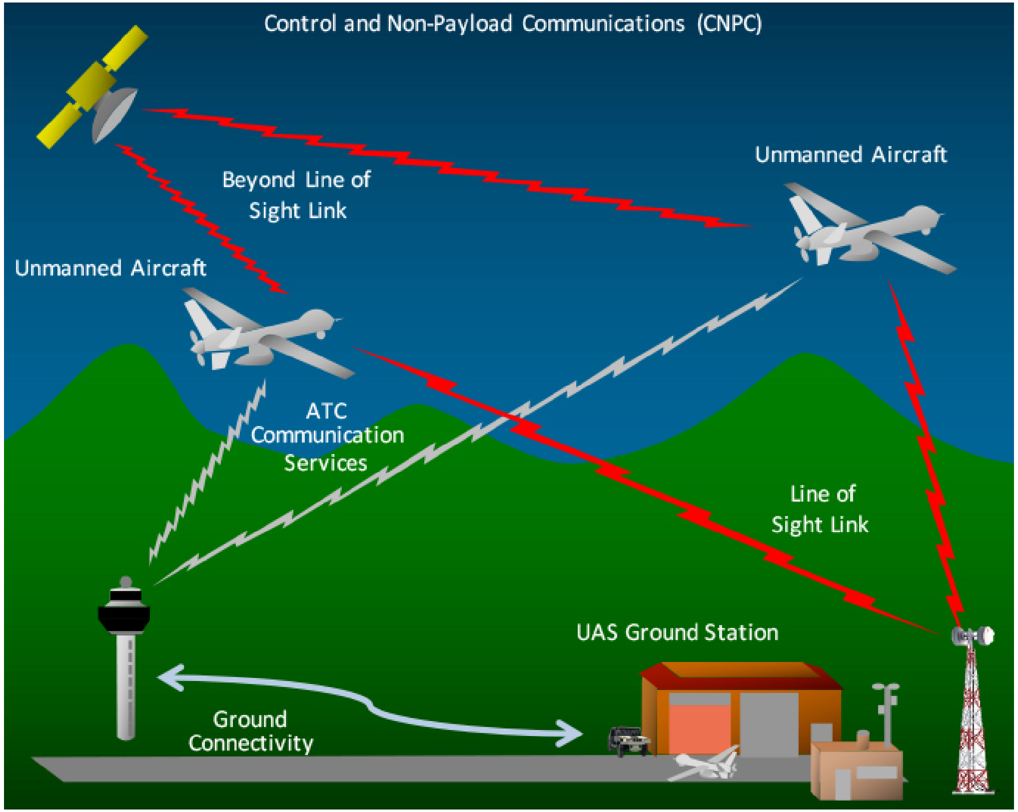


Image Credit: Cmglee, Geo Swan

Formidable Links and Where to Find Them

- Yes, they do exist!
- Two frequent sources
  - As a result of physical environment
  - As a result of sharing spectrum
    - Highly contentious, sparse resource
    - Number of expected users
    - Licensed vs Unlicensed
- Examples
  - Satellite links, Deep Space Links
  - Command and Control Links



What makes these links so difficult for the network and users?

- Network protocols are designed to provide certain features/functions
  - TCP: Reliable, In-Order Data Stream (and other features)
- These protocols employ different methods to work
  - TCP: Connections, relies on feedback for control
- A protocol can suffer issues with certain link conditions
  - TCP: Does not do well with very high losses or high delay…
- Solutions introduce trade-offs, attempts to re-insert functionality
  - TCP not viable: Use UDP?

Network Layers

- TCP example shows impacts to the transport layer
- Switching from TCP to UDP impacts the application layer
  - Rewriting code
  - Need to pay attention to best practices – RFC 8085
- Protocols at all layers are impacted by these links

Application
Transport
Internet
Data Link
Physical

- Layer abstraction?
- How do we keep our links fully utilized and efficient?

Another Issue: Too many solutions

- Smart folks have thought up a lot of different solutions
  - Alphabet Soup of Solutions: DTN, MPTCP, DCCP, SCTP, ROHC, …
  - Solutions at every layer...
- Some users re-invent functionality
  - Check out my new custom Protocol Z over UDP for …
- So there are a lot of solutions – and that is a problem
  - Usually not a single solution that solves all the users problems
  - May not stack cleanly: Are at odds with each other in some way
  - Actually introduce other issues or complications
  - Almost always end up with security implications

Issue #1: Low Capacity

Media	Capacity	Time to process a single 1500 byte packet
Gigabit Ethernet	1,000,000,000 bits/s	0.000012 s
Average Cellular 4G LTE	30,000,000 bits/s	0.000400 s
Dial-Up 56K Modem	56,000 bits/s	0.214286 s
UAS Mode D Control	34,400 bits/s	0.348837 s
UAS Mode A Control	4,680 bits/s	2.564103 s
Iridium® Modem	2,400 bits/s	5.000000 s

Network Overhead vs. Capacity

- Brief summary of Unmanned Systems in the National Airspace Goals
  - Design future proof network [IPv6]
  - Ground operators can reach a mobile platform [Mobile IPv6]
  - Communications are secured [IPsec, ESP, AH]
  - Small unidirectional data messages [UDP]

Mobile IPv6 Header	Original IPv6 Header	IPsec	UDP	Data	ESP
40	40	16	8	21	13

- Network Headers alone total 117 bytes!

Low Capacity Potential Solutions

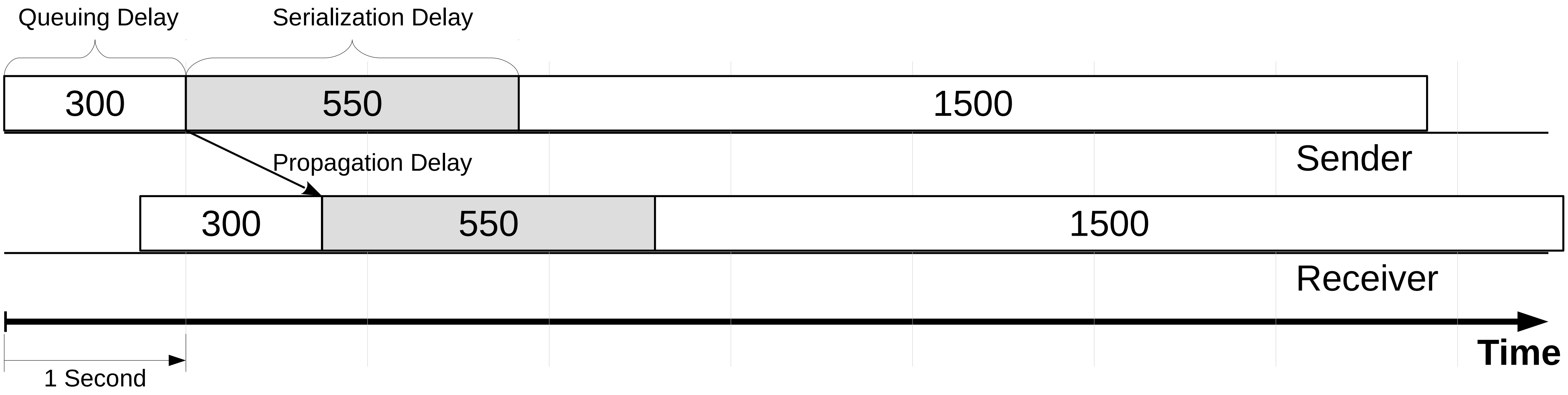
- Header Compression [ROHC]
  - Can significantly shrink headers. For example, 80 bytes to just 2
  - Impacted by how and when encryption is done
  - Risk of increased loss depending on what you compress
- Shrink TCP Initial Congestion Window
  - RFC 3390 (4K) and RFC 6928 (10 segments) are over sized
  - Troublesome if links have a large range of performance
- Waiting for faster links is not a solution [Moore's Law]
  - Iridium® first available in November 1998 (20 years later!)
  - UAS CNPC links being designed now for 2020 and beyond.

Issue #2: Latency

Media	Approximate Distance	One Way Delay
Local Network	100 m	< 0.001 s
Coast-to-Coast	4,000 km	0.030 s
Trans-Atlantic	4,600 km	0.035 s
Low Earth Orbit	781 km	0.003 s
Geosynchronous Orbit	35,786 km	0.120 s
Moon	384,402 km	1.282 s
Mars (Near) [2018-07-27]	57,774,698 km	(> 3 min) 192.716 s
Mars (Far)	401,000,000 km	(> 22 min) 1337.592 s

Latency Factors

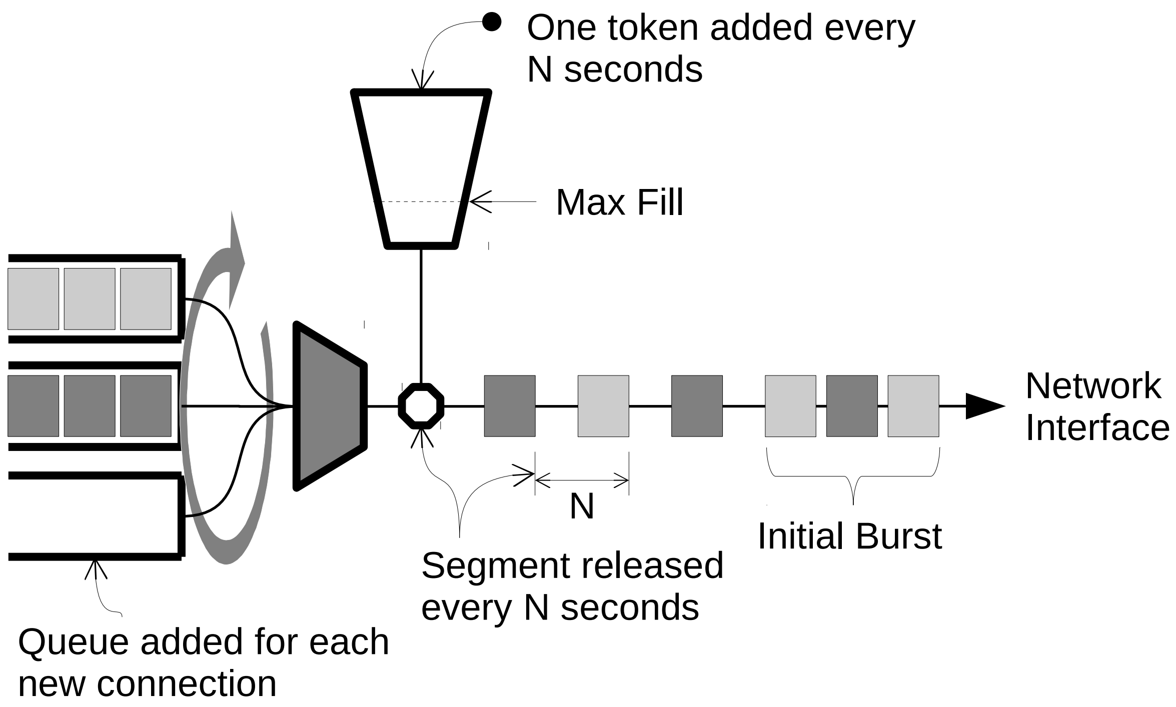
- Iridium® One-Way Delay is about 750 ms or larger (not 3 ms)
  - Delay impacted by more than just range or line-of-sight
  - Processing, encoding, satellite-satellite routing, ground station location

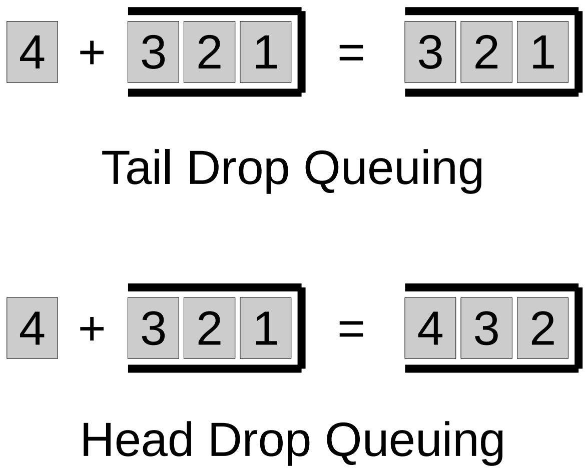


Latency Potential Solutions

- Can change the propagation speed to a point
  - Different mediums propagate faster… doesn't help for space
- Smarter queue management [SFQ, RED, AQM]
  - Gives feedback on congestion to all flows
  - Keep queuing delays to a minimum
- Shrink MTU
  - Increases responsiveness and fairness between flows
    - Oh yeah, it’s not just us out there.
  - Risk of fragmentation [PMTUD]
- Rate Limiting

Fair, Rate-Limited, Head Drop Queues





Which is better for TCP?

Issue #3: High Losses

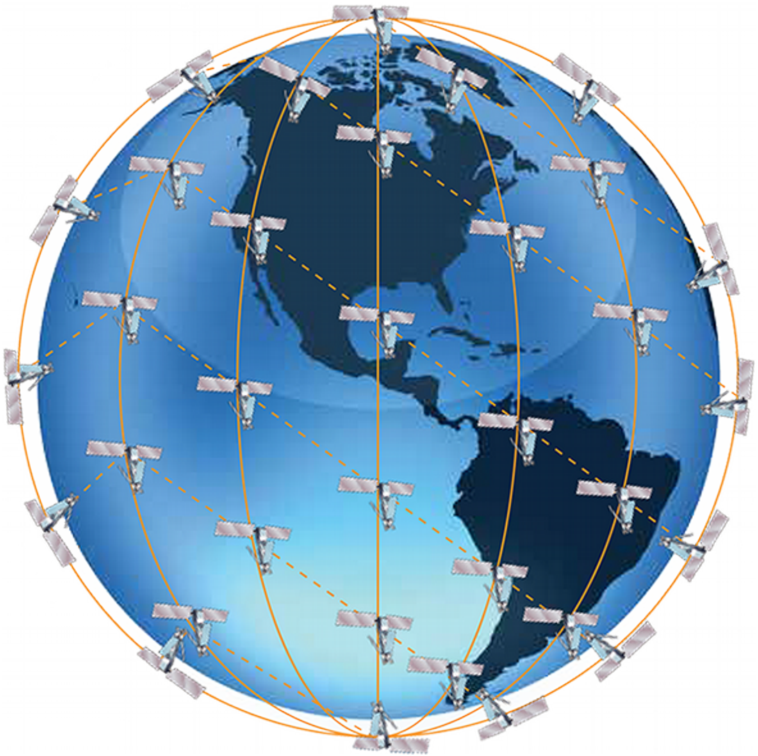
- Wireless data transmission is prone to errors
  - Bit flips, bit insertion, bit loss…
  - Quality can vary depending on conditions (ie: weather) and distance
  - Erred data packets are usually discarded on reception
- Mistaking delays for loss
  - Iridium® one way minimum delay of roughly 750 ms (1.5 s round trip)
  - RFC 6298 (TCP retransmit timer) reduces initial timeout to 1 seconds
  - Unnecessary retransmissions are costly (due to low capacity)
  - Protocols such as TCP suffer, mistaking loss for congestion

High Losses Potential Solutions

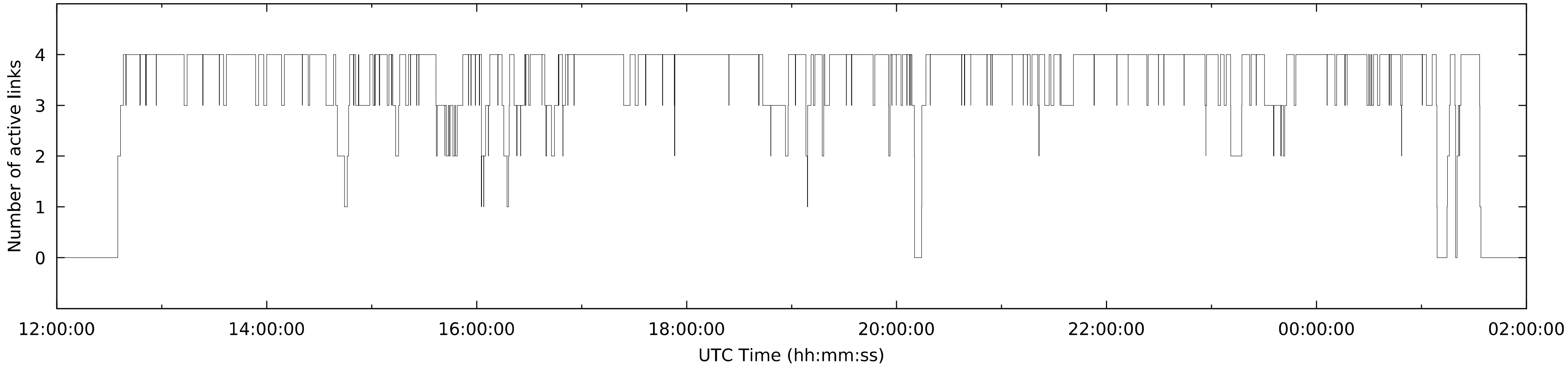
- Use of Forward Error Correction (FEC) [Reed-Solomon, LDPC]
  - Usually applied to the link – Corrects errors “in-flight”
  - Stronger encoding/decoding usually takes longer
  - Adds latency
- Accurate or longer timers
  - Hard problem to balance responsiveness and accuracy
  - Sometimes changing system defaults are hard
    - RFC 6298 timeout of 1 second is hard coded into the Linux kernel
      #define TCP_TIMEOUT_INIT ((unsigned)(1*HZ))

Issue #4: Low Reliability

- In addition to losses, links may fail completely
  - Out of range
  - Loss of coverage
  - Lack of resources
- Transitions may be frequent
- What does that mean for:
  - Protocols
  - Connections
  - State



Iridium® Link Transitions



- **Flight Date:** November 18, 2016
- **Flight Duration:** 13 Hours
- **Events that changed the number of active links:**
  - 325 (25 changes / hour)
- **Nearly one fourth of the flight is in a degraded state**

Number of Active Links	Seconds	Percent
4	35643	76.26%
3	8269	17.69%
2	1969	4.21%
1	235	0.50%
0	624	1.34%

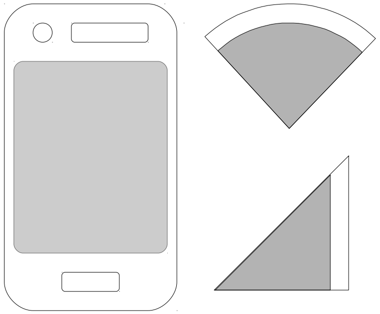
Low Reliability Potential Solutions

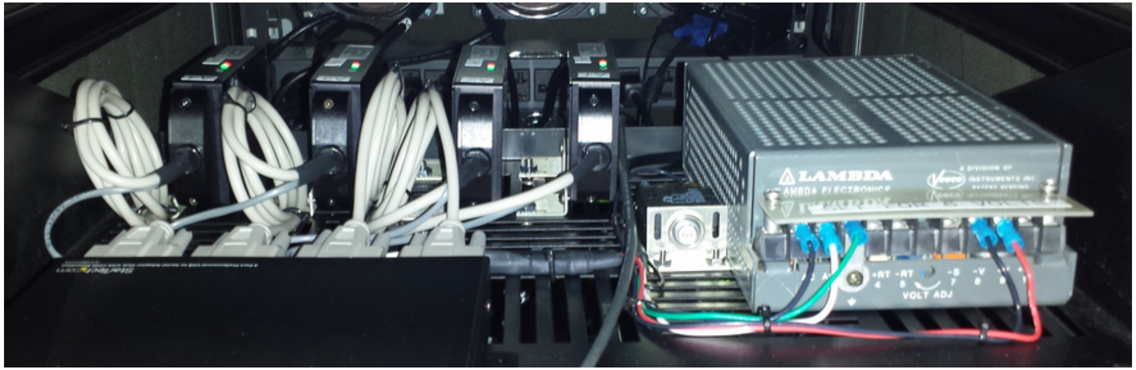
- Adaptive modulation to increase range
  - Capacity decreases
- Use multiple or alternate connections
- Typical Iridium® usage will deploy 4 or more modems
  - Currently 4 channels are used to provide a total of 9.6 Kbit/s
  - Decreases probability of having no links available
    - In the flight example, only 1.34% of the flight had no connection
- Unfortunately multiple links create their own set of issues

Issue #5: Multiple links between endpoints

- N-times the same type of link or

  Multiple types of links
  - Often used to increase capacity or used as a fail over
  - Appears at N interfaces
  - Example: Wi-Fi + Cell
  - Example: Iridium®
    - Image shows 4 modems
- Hard managing data over multiple streams





Multiple Links Potential Solutions

- Link Level Bonding
  - Appears as one physical interface
  - Hides issues from other layers
    - TCP reacting to losses isolated on only a single bad link
- Bonding at Upper Layers
  - Identify and isolate link issues
  - More complex state
  - Solution not as universal
    - MPTCP good for TCP only

Application	Web Requests, Internet Relay Chat, etc.			
Transport	TCP			
Network	IP			
Data Link	MLPPP			
	PPP	PPP	PPP	PPP

Web Requests, Internet Relay Chat, etc.			
MPTCP			
TCP	TCP	TCP	TCP
IP	IP	IP	IP
PPP	PPP	PPP	PPP

Issue #7: Asymmetric links

- Links are not always the same capacity in each direction
  - Similar to how home internet has different upload and download speeds
- Satellite links can have large down-link to up-link ratios
  - Further exaggerated by long delays
- Really impacts protocols such as TCP
  - May limit the TCP ACK stream and overall rate
  - Feedback constrained on return channel
- Possible Solutions
  - Different types of feedback algorithms or mechanics [NACKs]
  - Unidirectional communication

Issue #6: Reordering

- Reordering does happen
  - Multiple links (Dumping a queue on a failed link)
  - Multiple paths
  - Changing delays
  - Even a single link is not immune
- Possible Solutions
  - Use protocols that have a mechanism to deal with reordering (like TCP)
  - Handle ordering in the application
  - Is order even important? May not be to some applications
  - Request: Please do not assume in-order delivery (even in slides)

Thank you

Questions?

Backup Slides

Glossary of Terms and References (In order of appearance)

- Iridium® - https://www.iridium.com/
- GPS – Global Positioning System
- ISS – International Space Station
- UAS – Unmanned Aircraft Systems
- ATC – Air Traffic Control
- TCP – Transmission Control Protocol
- UDP – User Datagram Protocol
- RFC 8085 - UDP Usage Guidelines
- DTN – Delay/Disruption Tolerant Networking
- MPTCP – MultiPath Transmission Control Protocol
- DCCP – Datagram Congestion Control Protocol
- SCTP – Stream Control Transmission Protocol
- ROHC – Robust Header Compression
- IPv6 – Internet Protocol Version 6
- IPsec – Internet Protocol security
- ESP – Encapsulating Security Payload
- AH – Authentication Header
- RFC 3390 – Increasing TCP's Initial Window
- RFC 6928 – Increasing TCP's Initial Window
- SFQ – Stochastic Fairness Queuing
- RED – Random early detection
- AQM – Active Queue Management
- MTU – Maximum Transmission Unit
- PMTUD – Path MTU Discovery
- RFC 6298 – Computing TCP's Retransmission Timer
- FEC – Forward Error Correction
- Reed-Solomon
- LDPC – Low Density Parity Checks
- NACK – Negative Acknowledgments