# 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

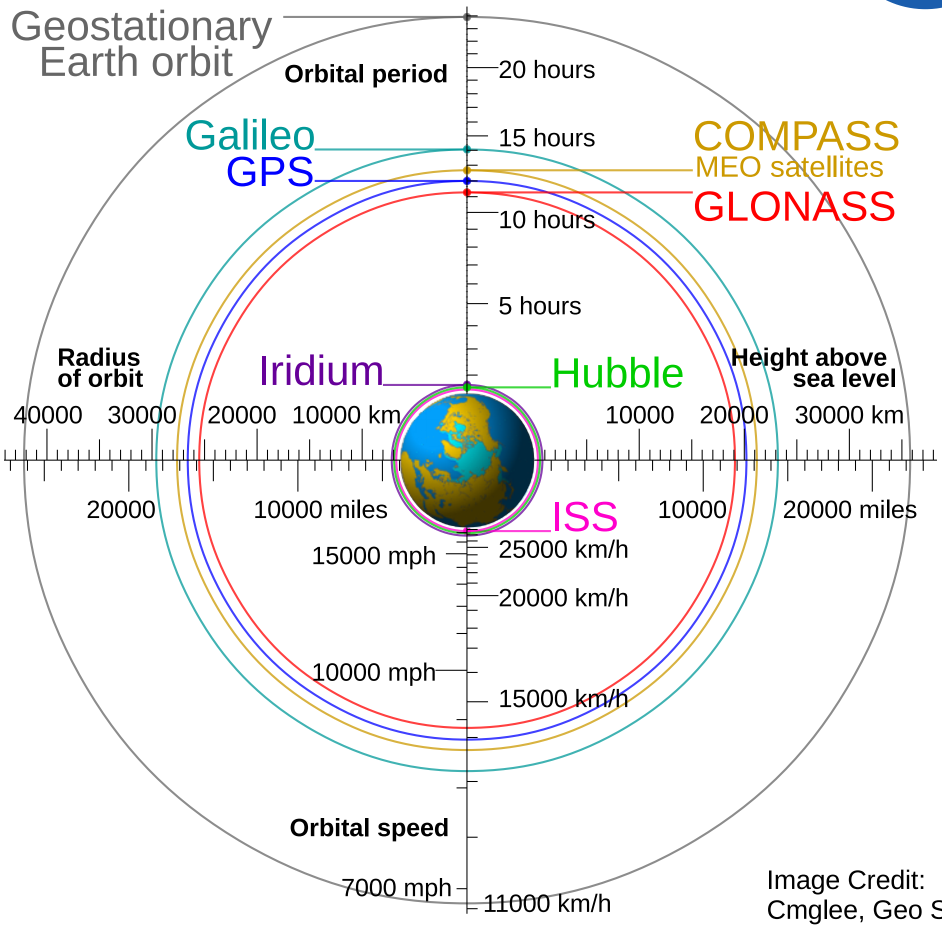
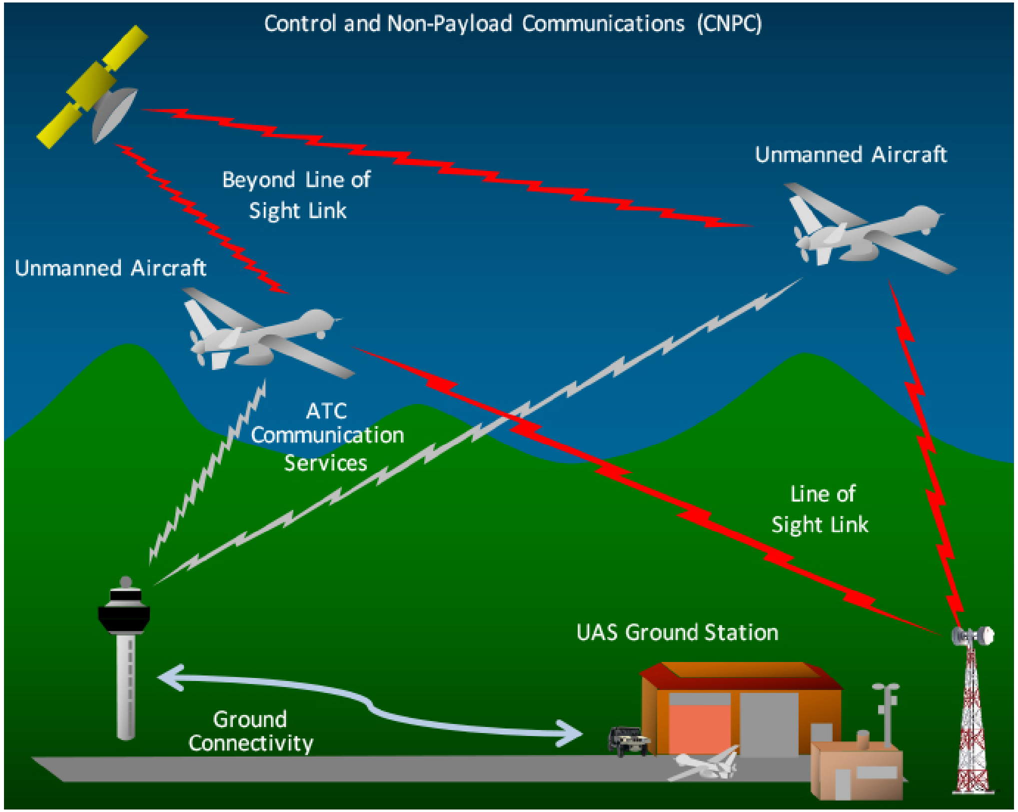



Image Credit:
Cmglee, Geo Swan

# 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 <u>single</u> 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

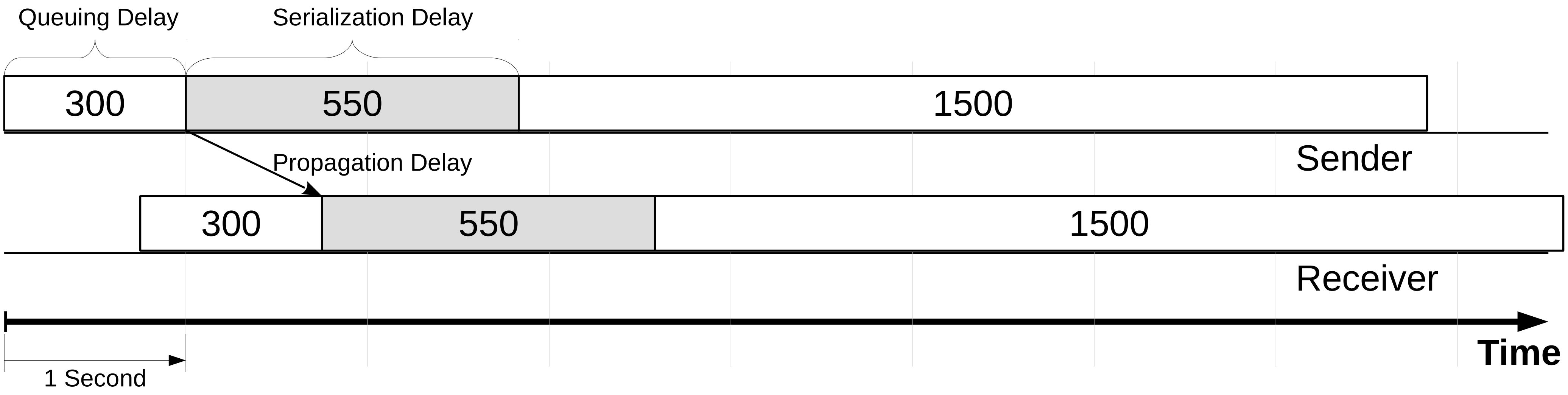
- Header Compression [ROHC]
  - Can significantly shrink headers.  For example, 80 bytes to just 2
  - Impacted by how and when encryption is done
  - Risk of increased loss depending on what you compress
- Shrink TCP Initial Congestion Window
  - RFC 3390 (4K) and RFC 6928 (10 segments) are over sized
  - 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

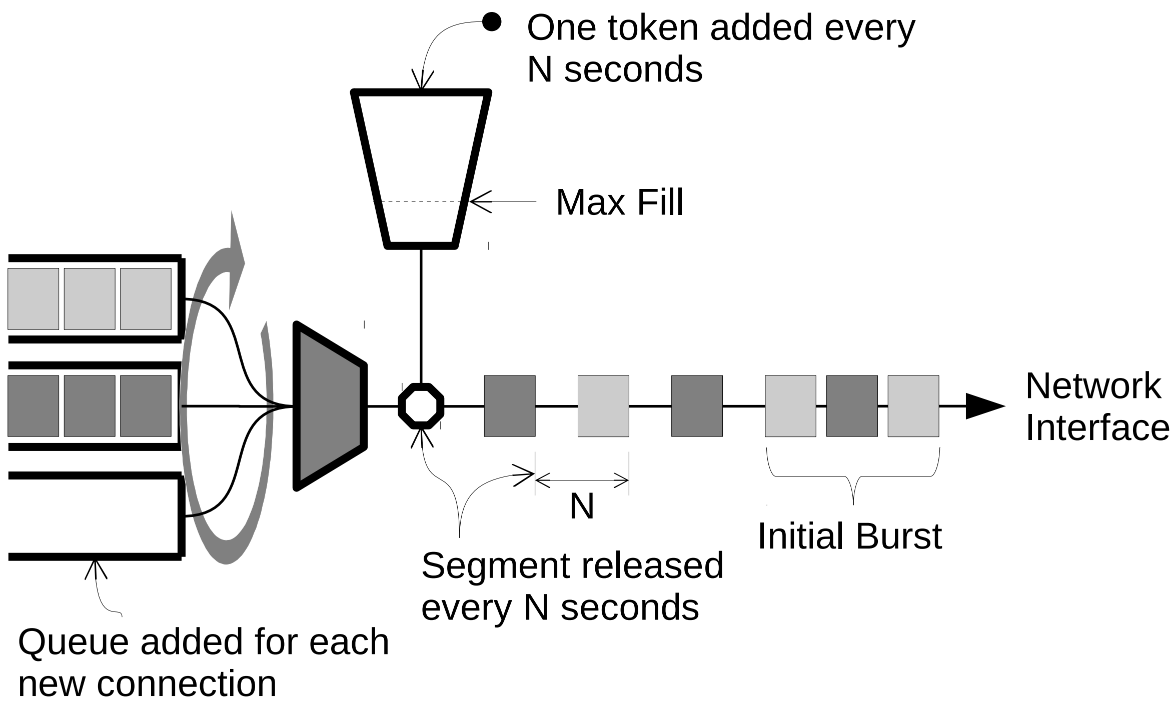
- Iridium® One-Way Delay is about 750 ms or larger (not 3 ms)
  - Delay impacted by more than just range or line-of-sight
  - Processing, encoding, satellite-satellite routing, ground station location

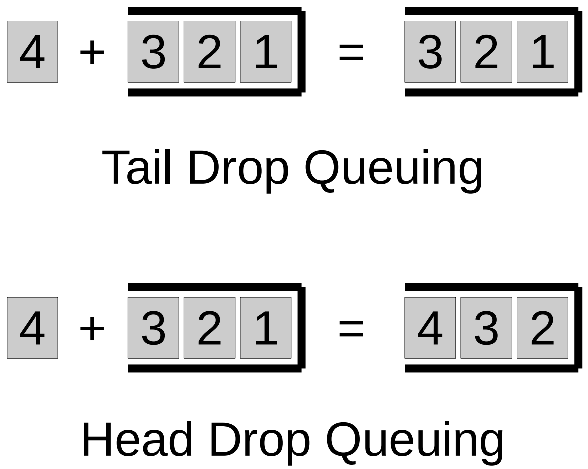


# Latency Potential Solutions

- 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

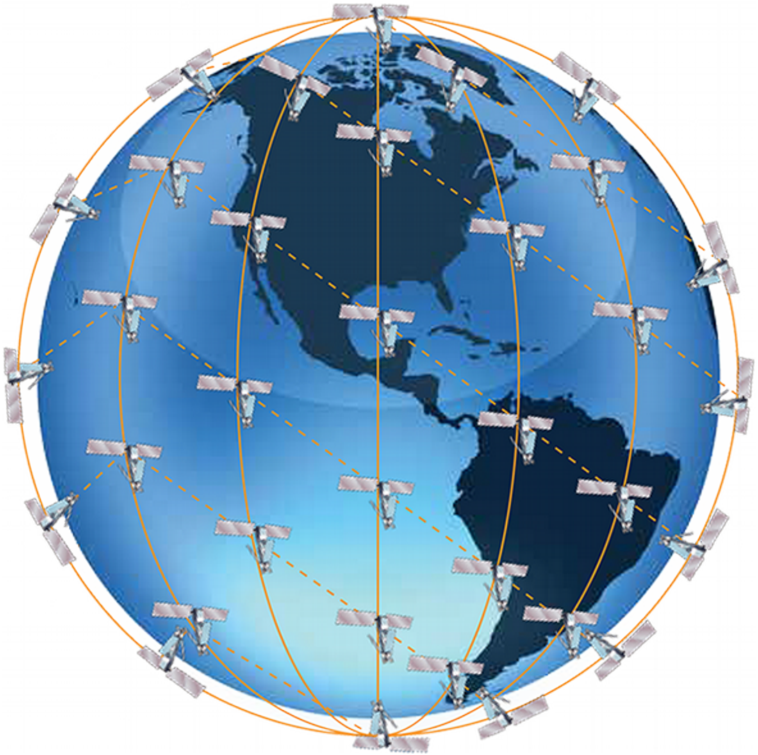
- Wireless data transmission is prone to errors
  - Bit flips, bit insertion, bit loss…
  - Quality can vary depending on conditions (ie: weather) and distance
  - Erred data packets are usually discarded on reception
- Mistaking delays for loss
  - Iridium® one way minimum delay of roughly 750 ms (1.5 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

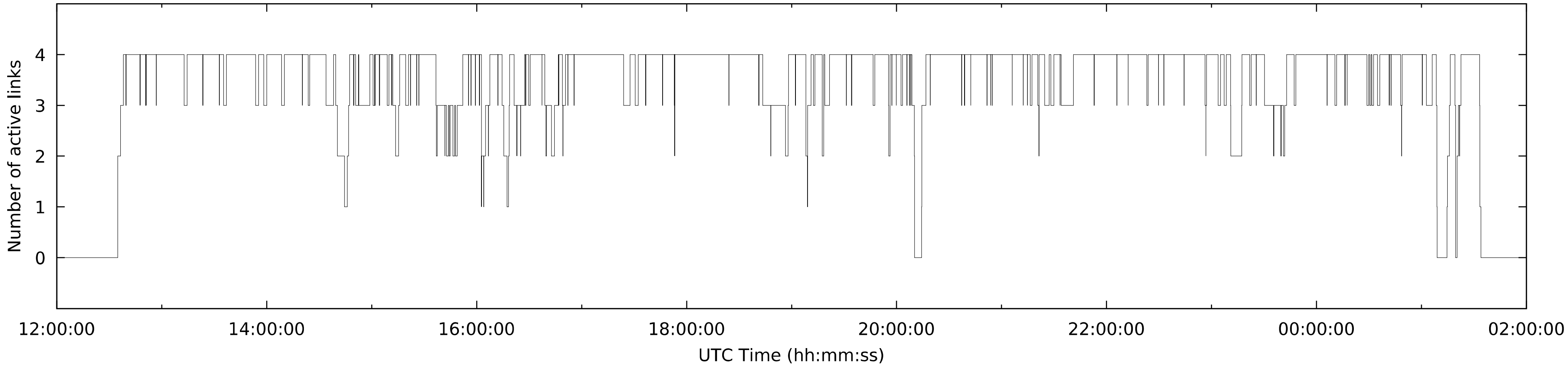
- Use of Forward Error Correction (FEC) [Reed-Solomon, LDPC]
  - Usually applied to the link – Corrects errors “in-flight”
  - Stronger encoding/decoding usually takes longer
  - Adds latency
- Accurate or longer timers
  - Hard problem to balance responsiveness and accuracy
  - Sometimes changing system 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% |

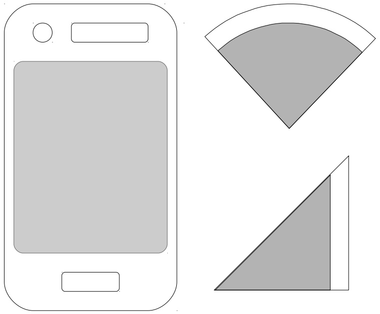
# Low Reliability Potential Solutions

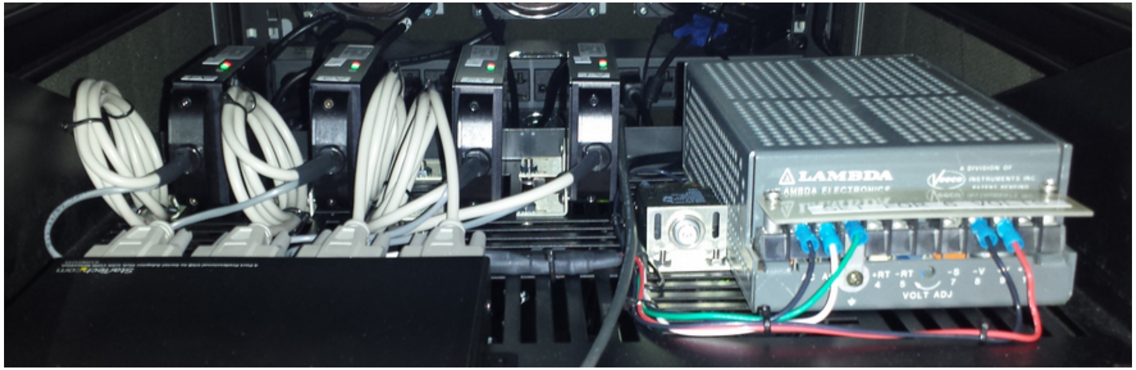
- Adaptive modulation to increase range
  - Capacity decreases
- Use multiple or alternate connections
- Typical Iridium® usage will deploy 4 or more modems
  - Currently 4 channels are used to provide a total of 9.6 Kbit/s
  - Decreases probability of having no links available
    - In the flight example, 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
- <u>Hard</u> 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