SYZYGY Engineering

Key Technologies Regarding Distributed and/or Collaborating Satellite Systems - Protocols

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Protocols

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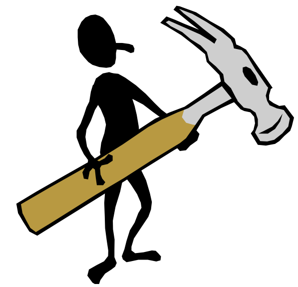
Protocols are tools
for communication

Some should not be used.



Some work OK

Some are designed
for the job at hand

One size does not fit all.

Beware on inappropriate comparisons (Marketing)

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Good Performance ☺

Poor Performance ☹

An Example of TCP Steady State Performance

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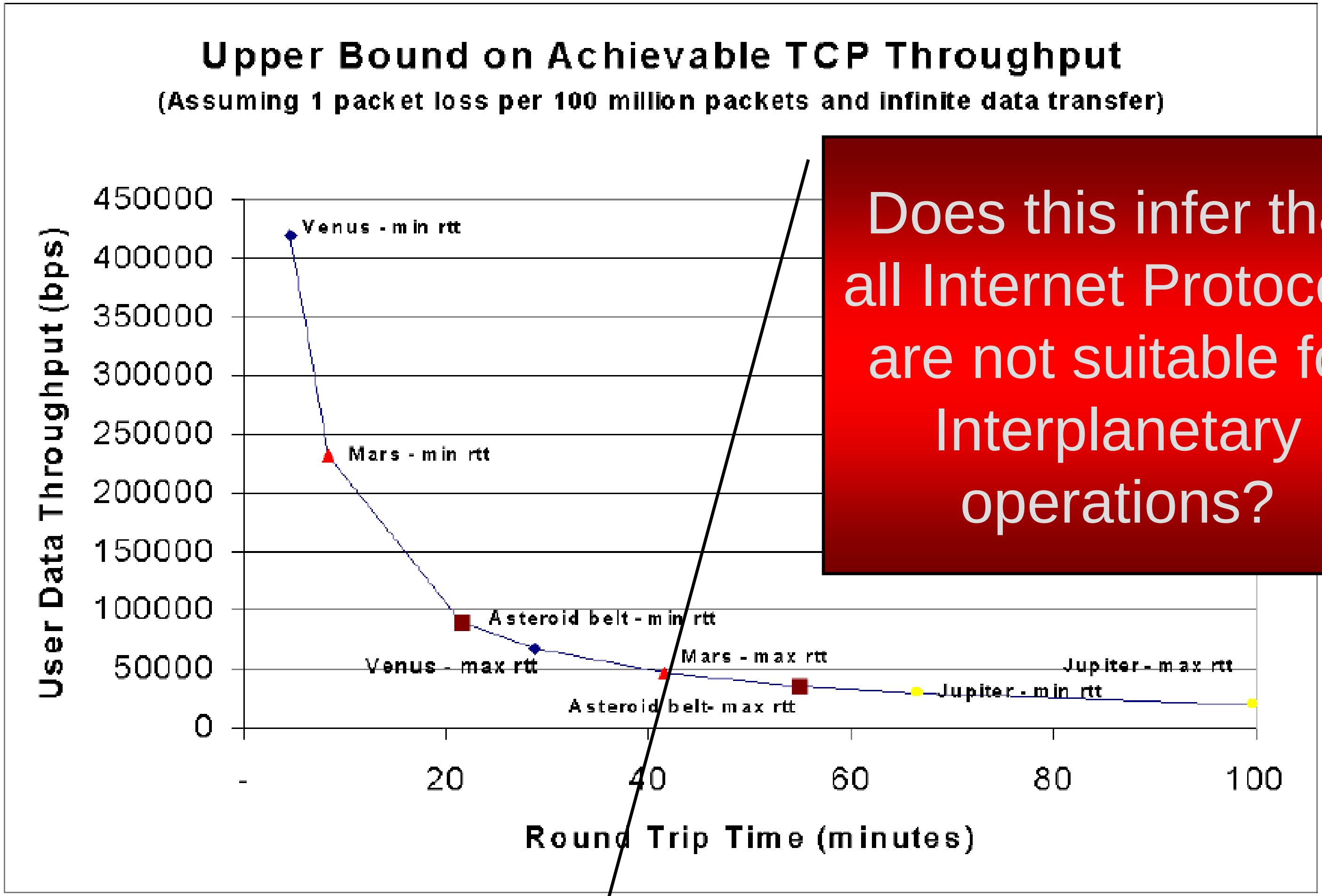

Does this infer that all Internet Protocols are not suitable for Interplanetary operations?

Figure 1. Upper Bound On TCP Throughput for Various Interplanetary Round Trip Times Assuming 1e-8 Packet Loss Rate

Chart is from "Why not use the Standard Internet Suite for the Interplanetary Internet?"
By Robert C. Durst, Patrick D. Feighery, Keith L. Scott

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Reliable, High-Rate Transport Protocols for Highly Asymmetric Private Links

Theoretical Steady State Throughput

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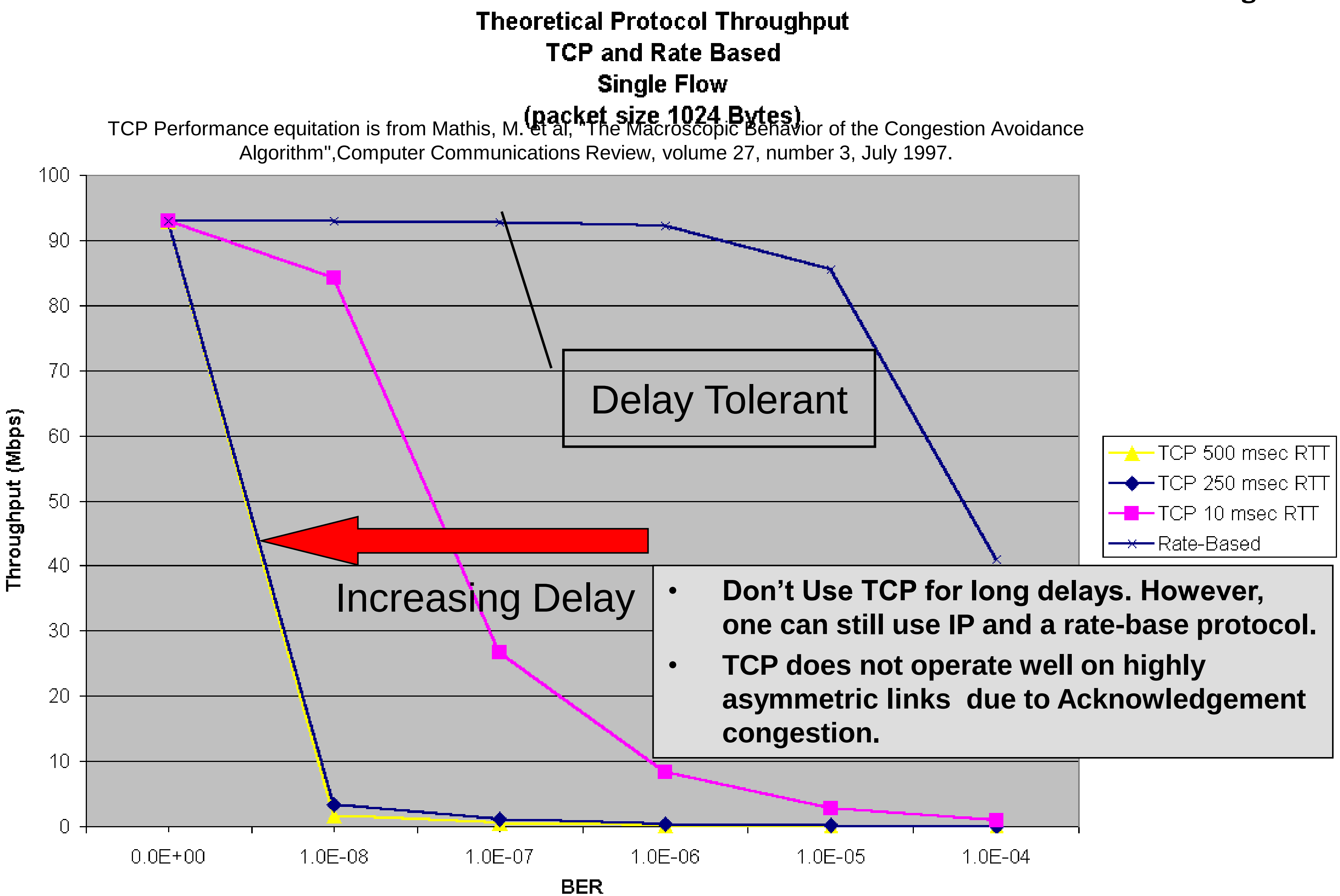

- **Don’t Use TCP for long delays. However, one can still use IP and a rate-base protocol.**
- **TCP does not operate well on highly asymmetric links due to Acknowledgement congestion.**

DTN Layering (RFC 5050)

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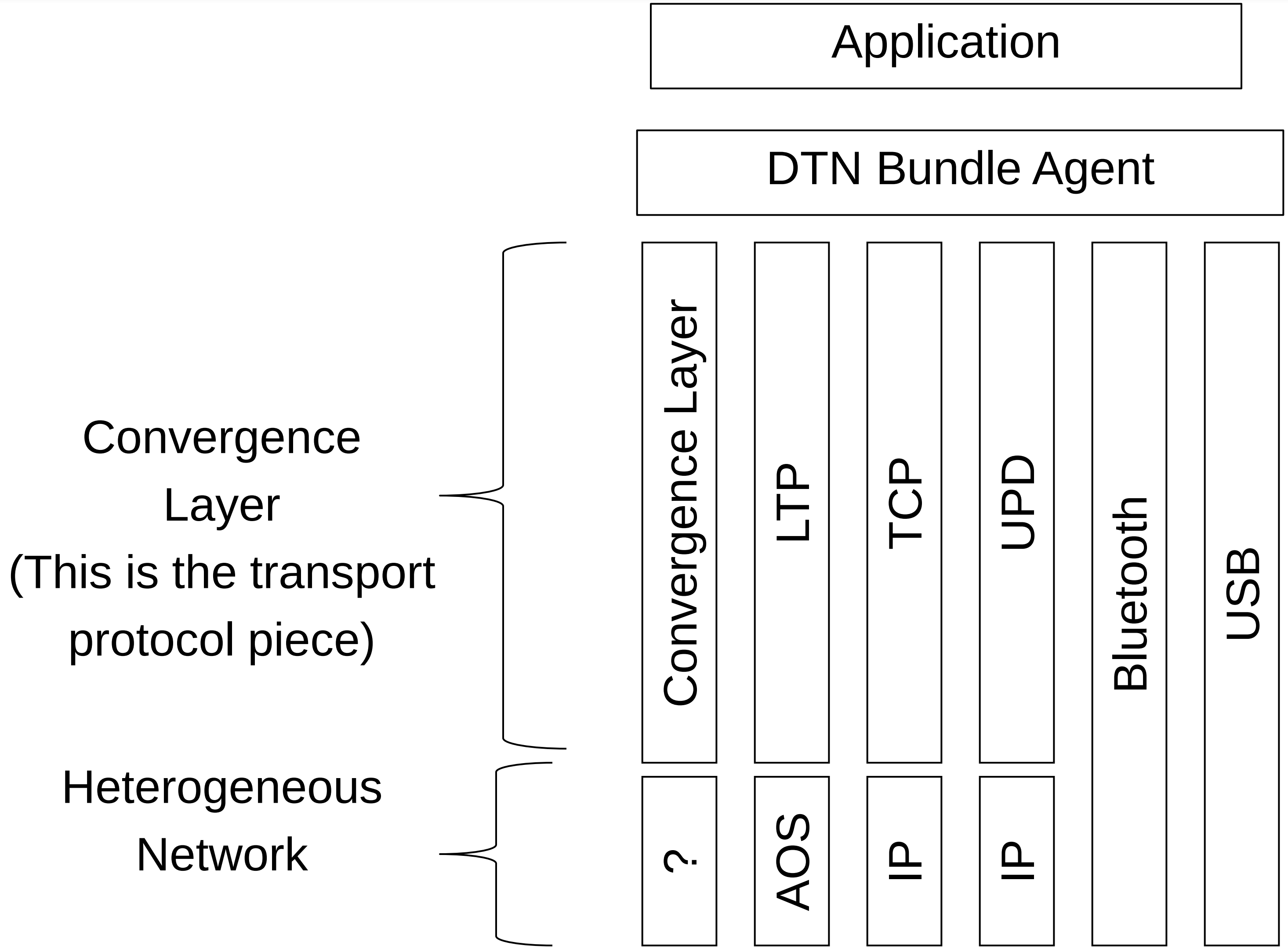

"PROTOCOLS FOR STORE-AND-FORWARD MESSAGE SWITCHING VIA MICROSATELLITES"

J. W. Ward and H. E. Price

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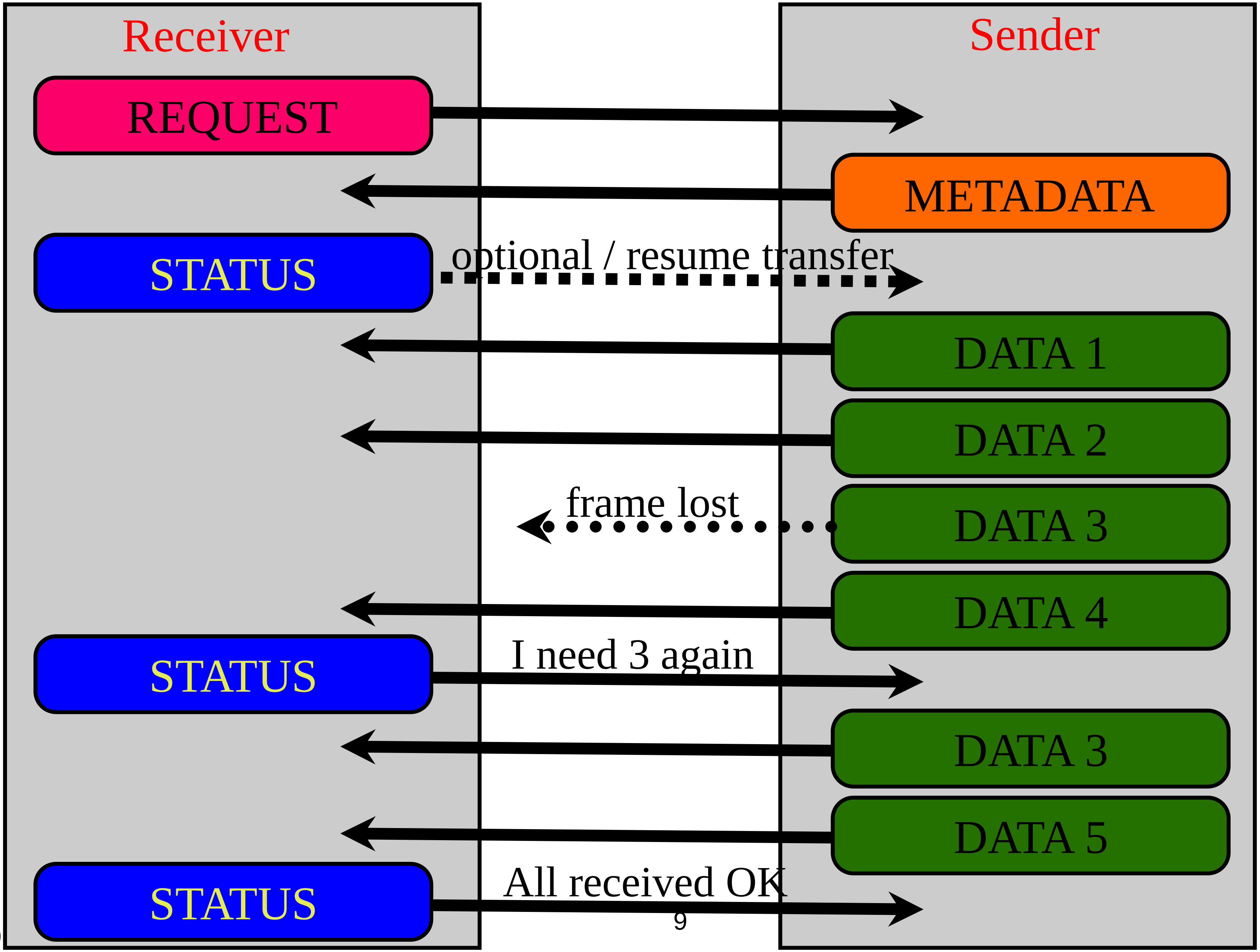
- A suite of protocols specifically optimized for use on store-and-forward microsatellite communications missions.
- Design the spacecraft software so that there was one generic data entity that it knew how to deal with and deal with well
- Leave all routing decisions to the ground segment.
- A client identifies a message which it requires and sends a broadcast request to the server.
- The client will receive some or all of the datagrams from its request. Upon receiving these (or other) datagrams, the client places them at the indicated byte offset in the appropriate file.
- When a client wishes to have the server retransmit missing datagrams, the client composes and transmits a repeat request datagram. If some of the desired datagrams are not received, then the clent sends the request again.
- The client repeats this process until the message is complete.

Generic SNACK GET Concept



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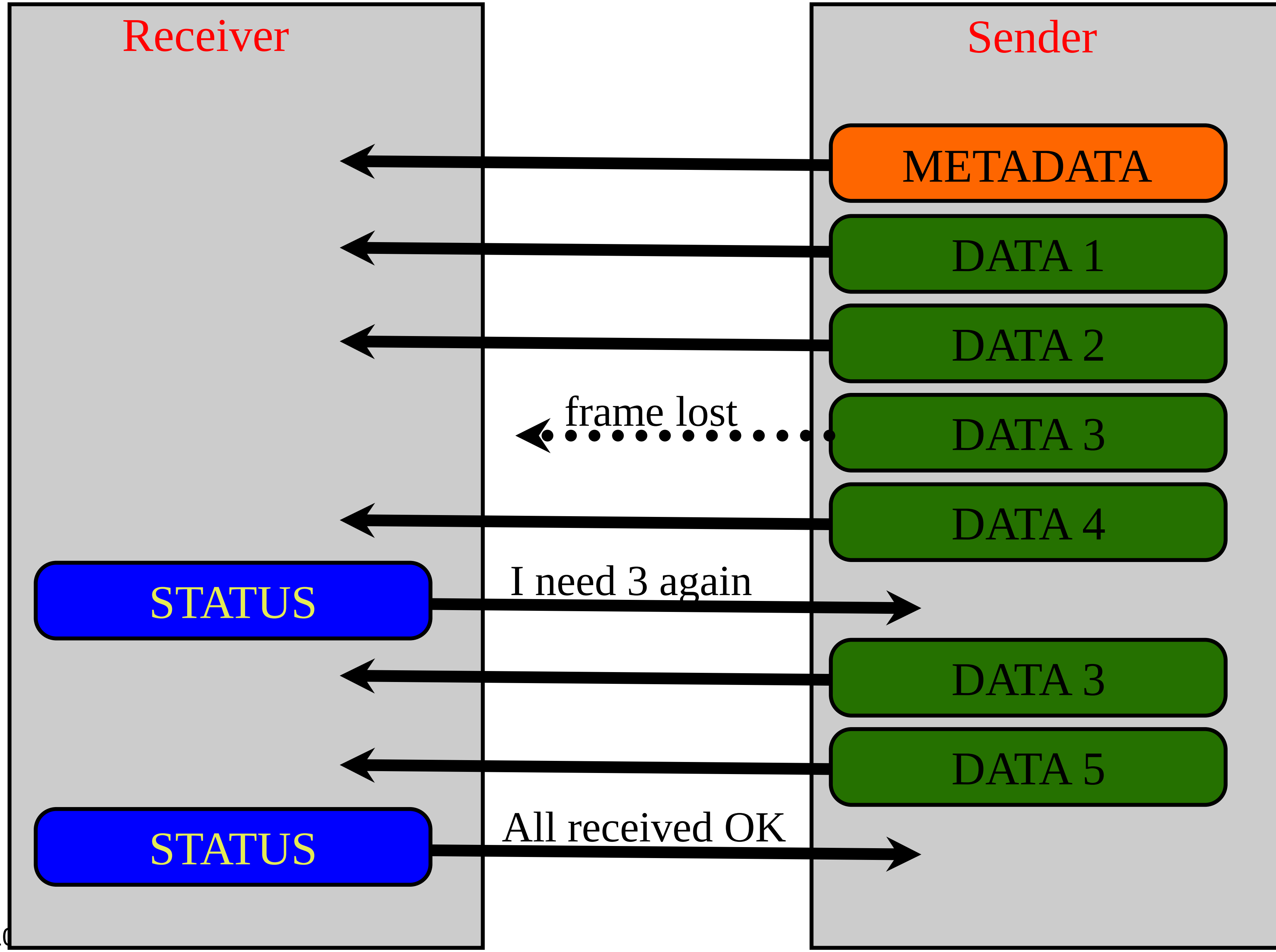
Generic SNACK PUT Concept



Selective, Negative Acknowledgment (SNACK) Protocols – not all inclusive

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Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP) - CCSDS 727.0-B-2:

- Selective Negative Acknowledgement
- Designed for Space Applications (Highly Asymmetric Links, Suspend/Resume timers during known outages)
- Private Links (No Congestion Control)
- Designed for File Transfers (really and application and transport protocol)
- Reliable or Unreliable file transfer
- Routing Capabilities (Preconfigured Next Hop – Static Routing)

Licklider Transport Protocol (LTP)

- Based on CFDP
- Distinguishes between important and unimportant data
- Timers work together with communication schedules and can be suspended whenever a scheduled link outage occurs
- Needs to be informed about link layer availability, round-trip time and communication schedule, basically requiring a management information base, Thus**, Highly stateful**

Saratoga (used buy SSTL daily)

- Based on "Protocols For Store-and-forward Message Switching Via Microsatellites"
- CFDP proved overly complex
- High-speed, UDP-based, peer-to-peer protocol, providing error-free guaranteed delivery of files, or streaming of data.
- No specified timers means no timeouts, so Saratoga is ideal for very long propagation delay networks (such as deep space)
- Able to cope with high forward/back network asymmetry (>850:1)

Store, Carry and Forward (SCF)
(DTN or Others)

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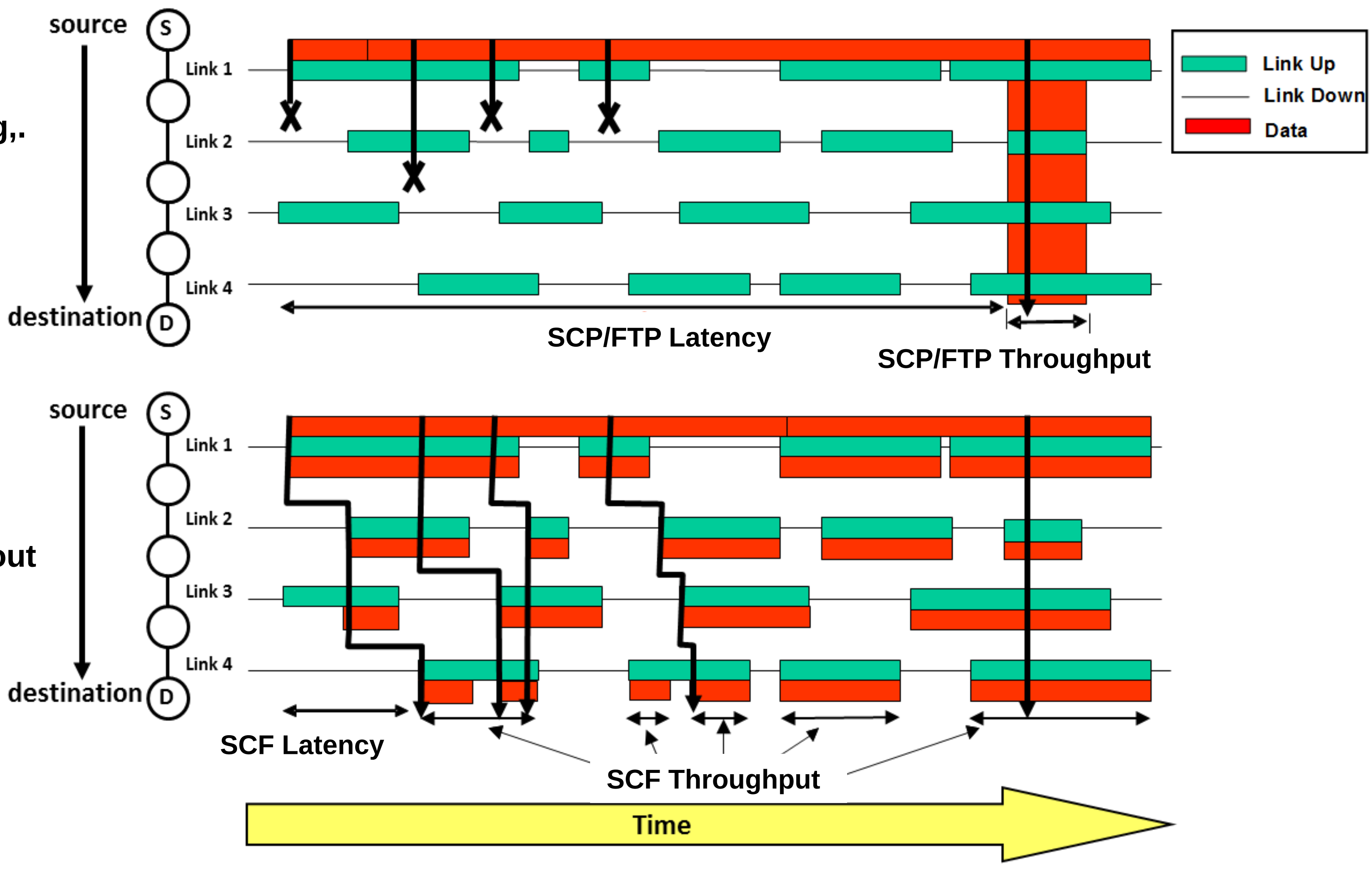
End-to-end (e.g,. SCP, FTP):
Must wait for complete path

SCF:
Incremental progress without end-to-end path



DTN
(Implies TCP cannot be used for convergence layer)

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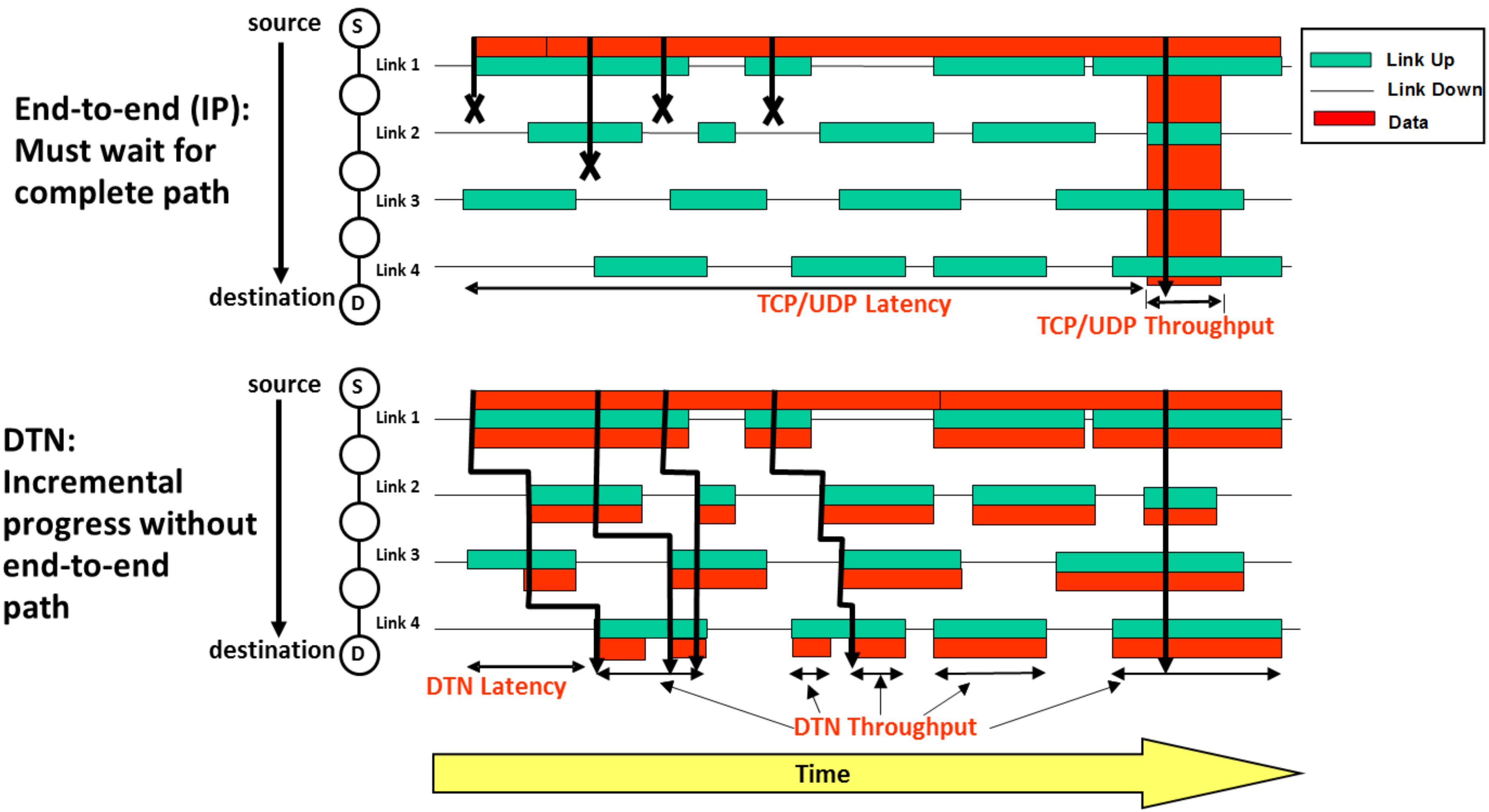


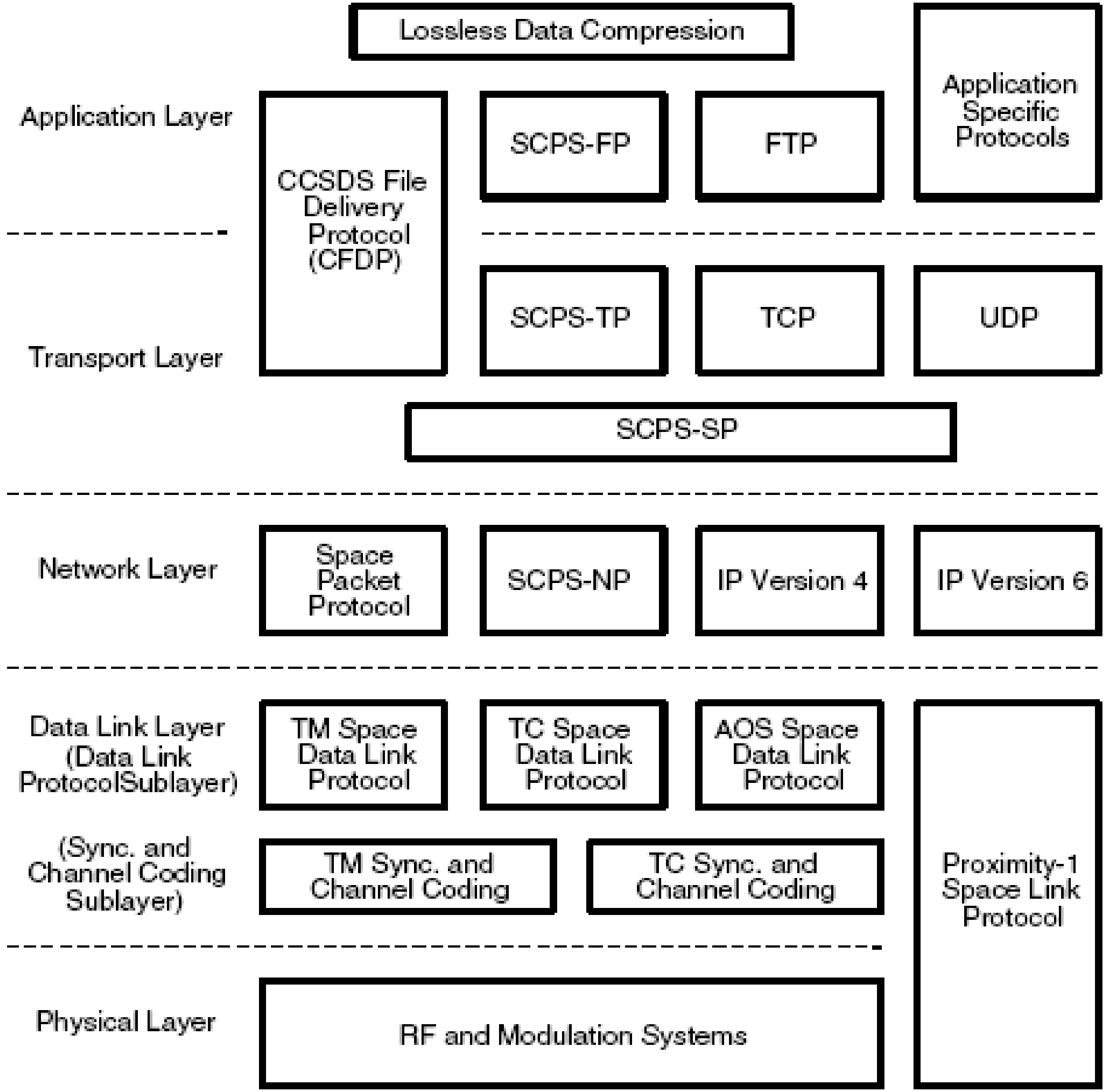


Figure 2-1: Space Link Protocols

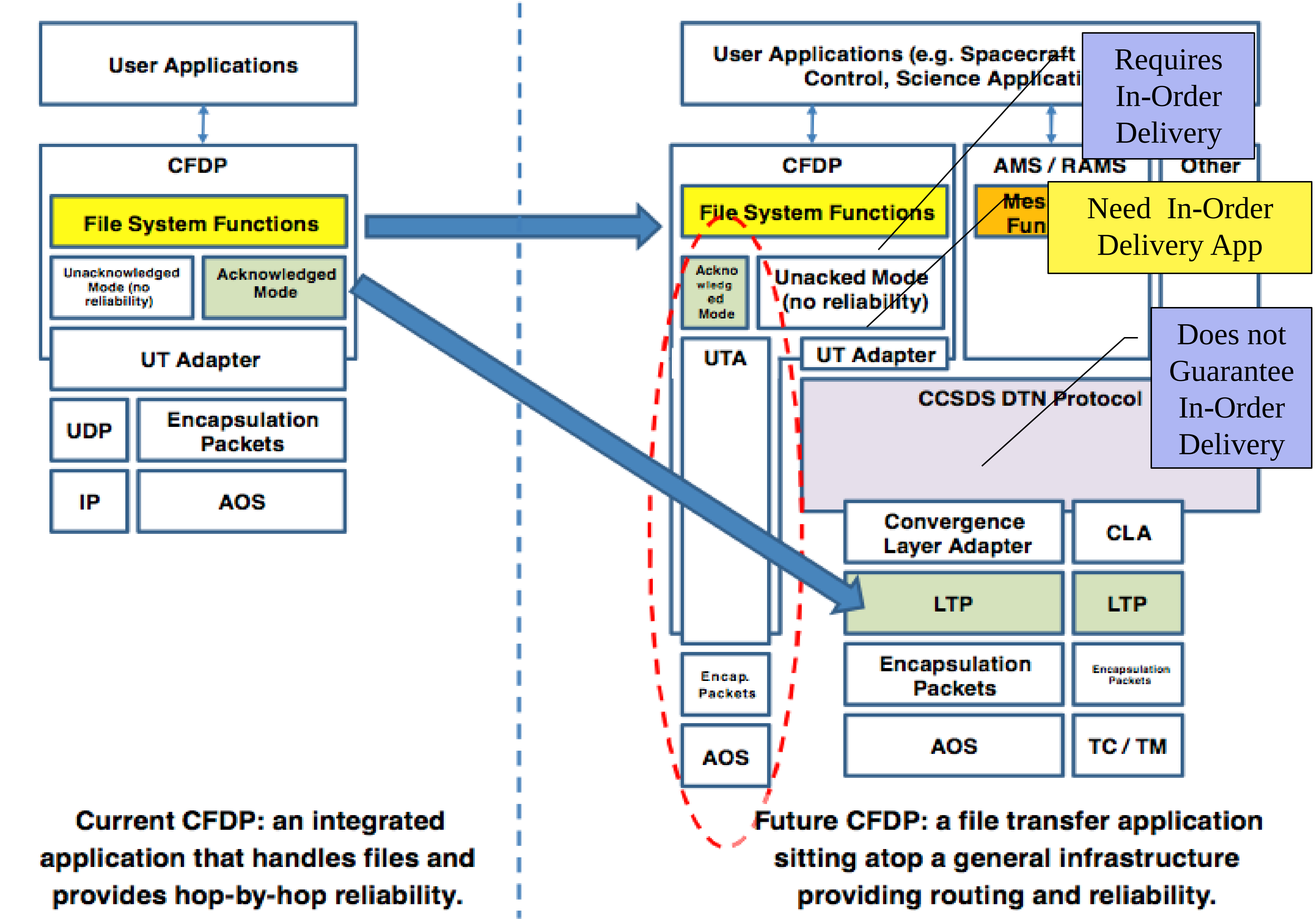
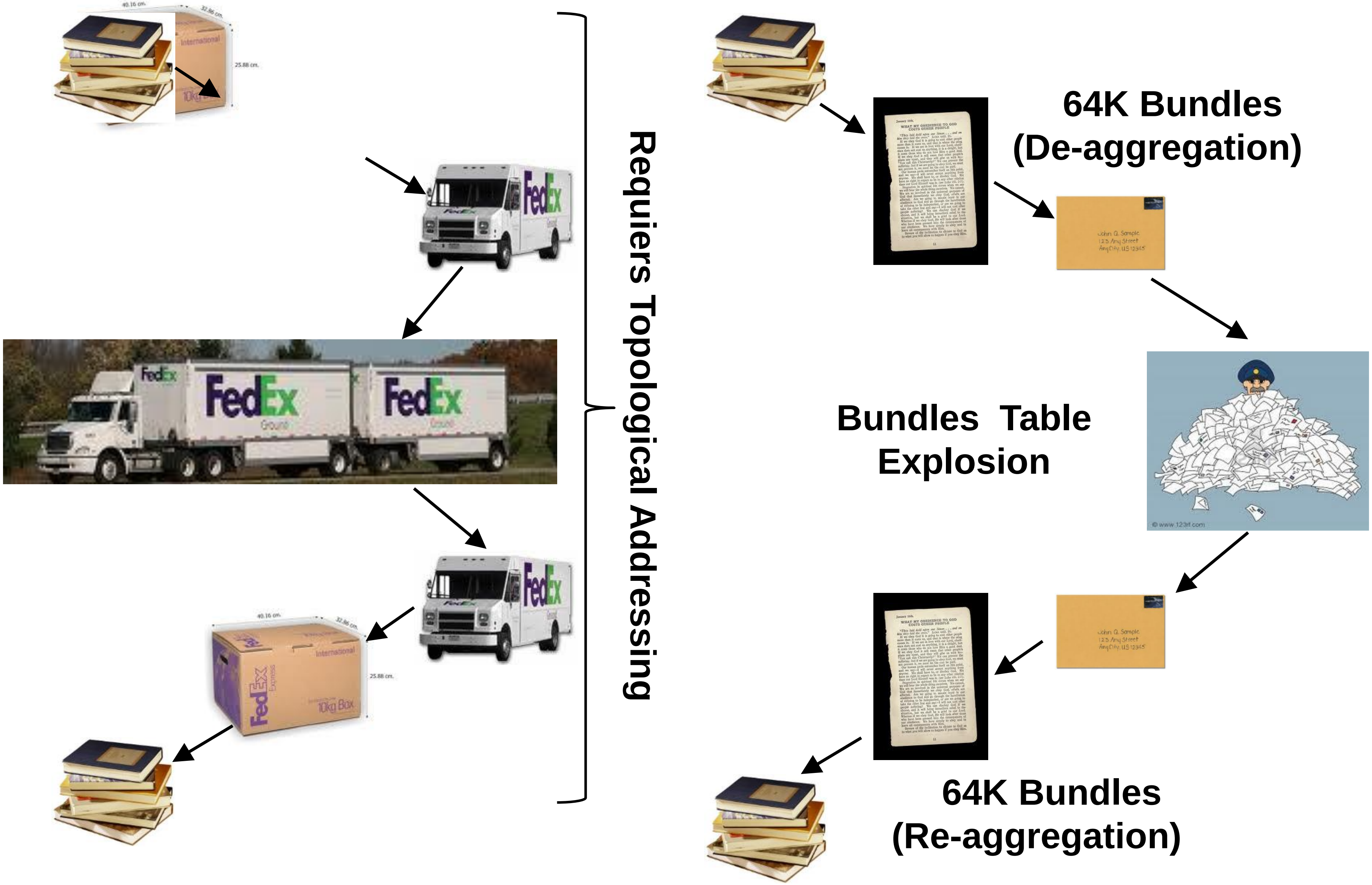


Figure 4-4: A CFDP Evolution Path to Use DTN as the CFDP Unitdata Transfer Service

Aggregation (or Not?)



DTN in a Nutshell

DTN Source

Can you take this letter to my brother at Fort Pitt?

Where are you headed?

Dave Smith
@ Ft. Pitt

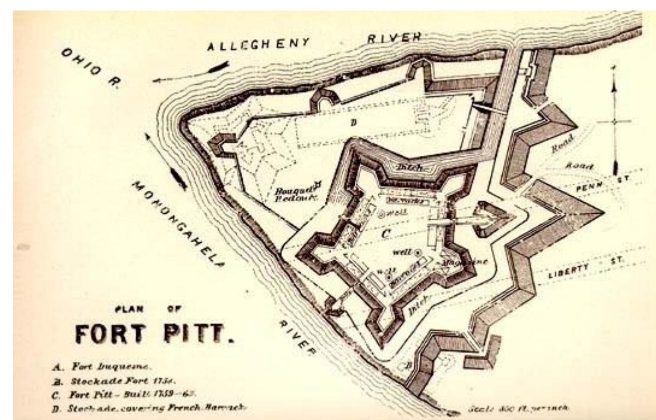
DTN Bundle Forwarding Agent

Yes Mam, I sure can.

Knoxville, Wheeling, then Fort Pitt.

Dave Smith
@ Ft. Pitt

DTN Destination



This is bundling.

This is “opportunistic” bundle-agent Discovery

DTN in a Nutshell

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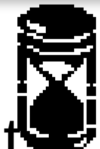
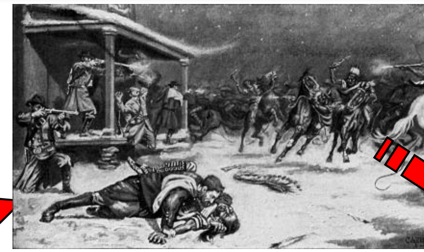
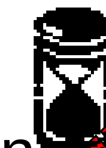
DTN Bundle
Forwarding Agent





DTN Bundle
Forwarding Agent



DTN Destination

Why DTN?

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- **Pros**
  - Flexibility
  - Reliability
  - Robustness
  - Automates routing for multi-hop, multi-path network topologies
- **Cons**
  - Added complexity
  - Not needed for single hop systems
  - Adds Overhead
    - Can be significant overhead depending on the bundle size

Delay/Disruption Tolerant Networking (DTN)

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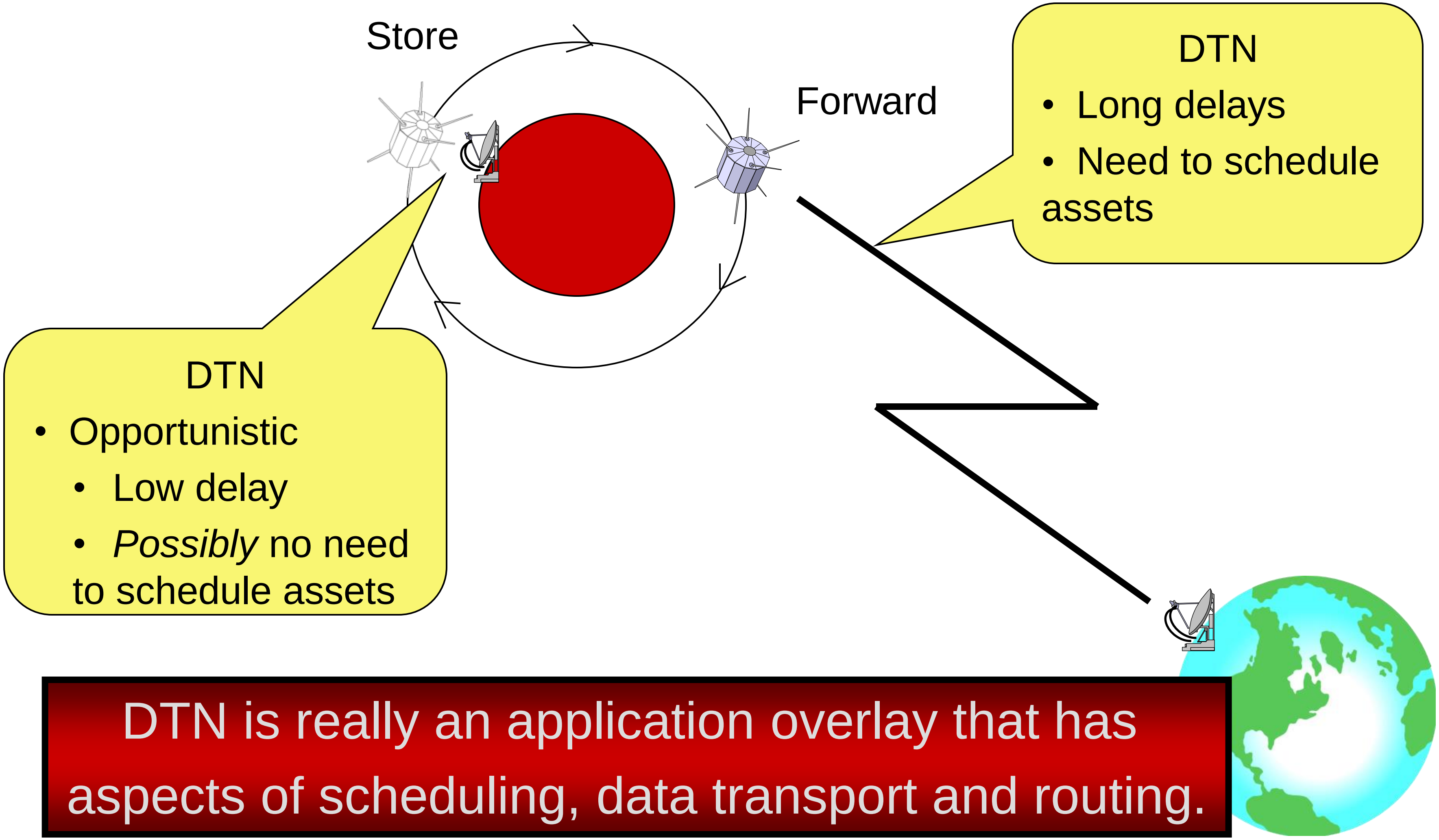
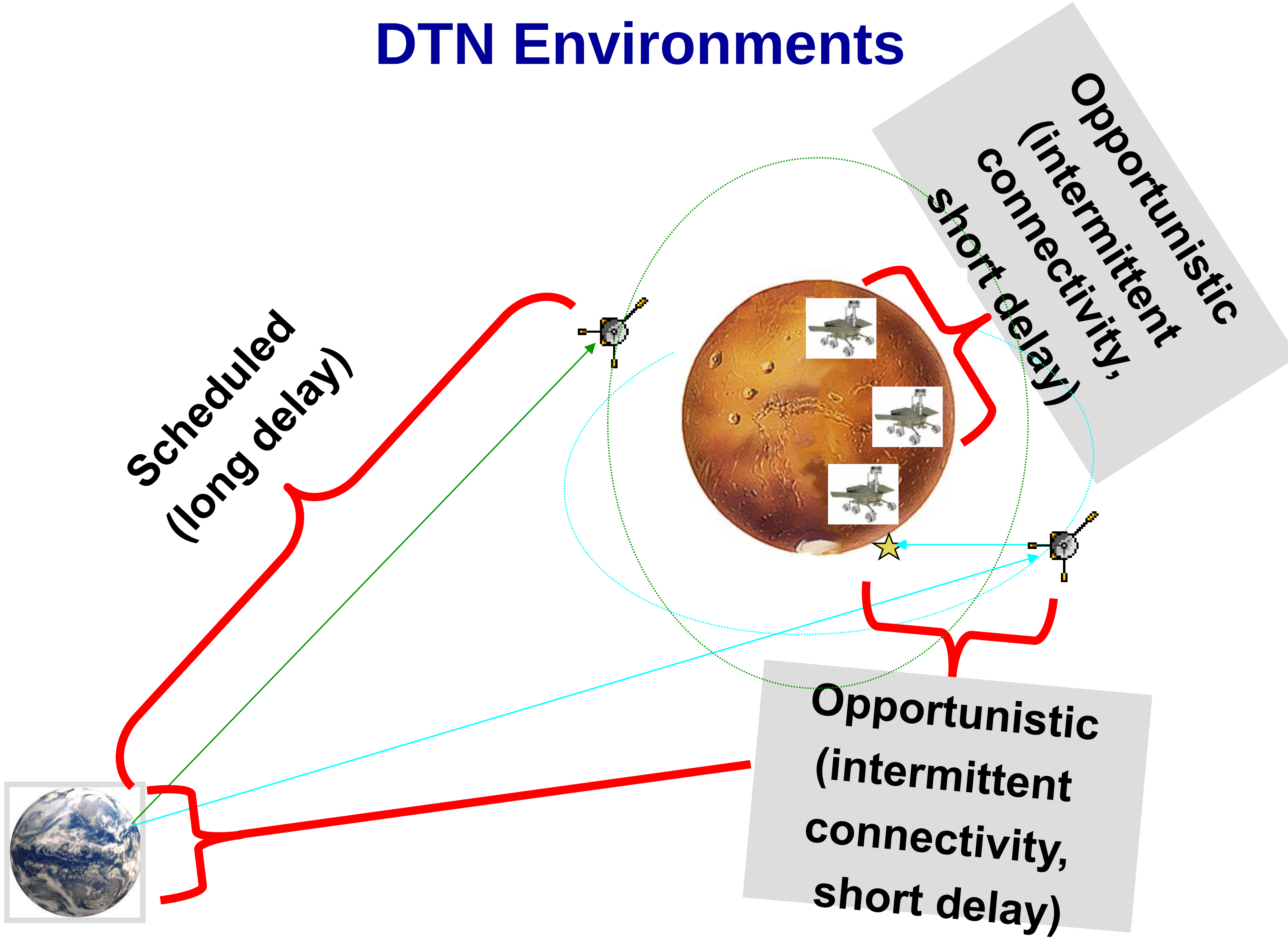


DTN is really an application overlay that has aspects of scheduling, data transport and routing.

DTN Environments



Single-Hop Architecture

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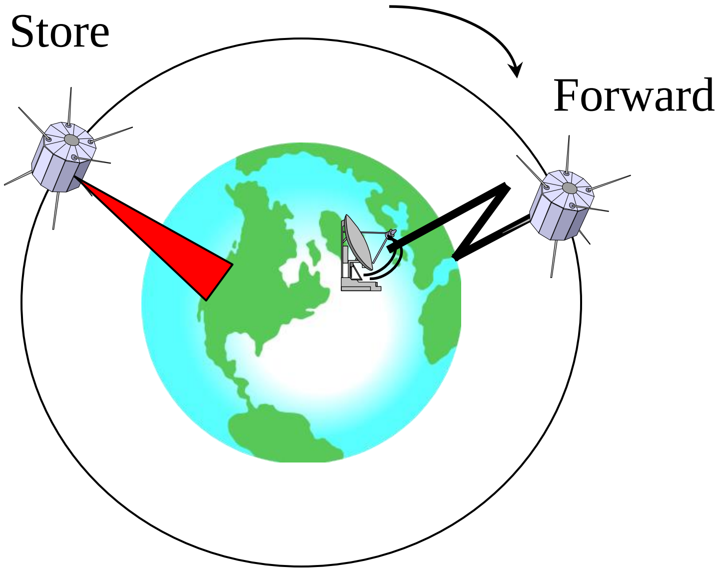
- CFDP
- LTP
- Saratoga
- Others
- No Need for DTN Complexity
  - DTN is most useful for multi-hop networks



Delay/Disruption Tolerant Network (DTN)

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- Goal: A standardized store and forward protocol and routing protocol
- Designed for extreme environments
  - Large transmission link delays
  - Extended periods of network partitioning
  - High per-link error rates making end-to-end reliability difficult
  - Routing capable of operating efficiently in the following environments
    - Frequently disconnected
    - Pre-scheduled or Opportunistic link availability
    - Heterogeneous underlying network technologies (including non-IP-based internets)
- The architecture operates as an overlay network

DTN Layering (RFC 5050)

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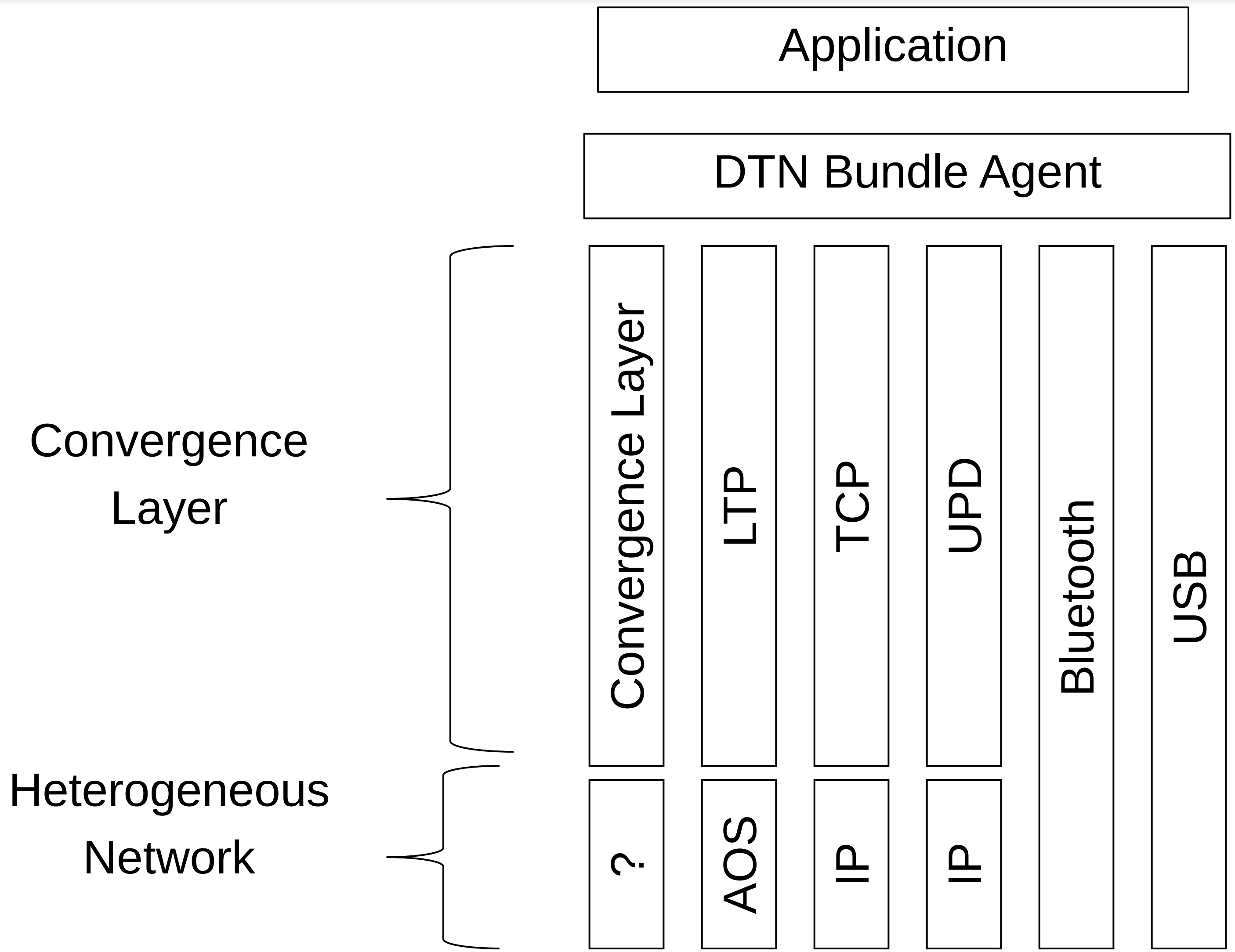

Known Issues with Current Bundling Specifications

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- No IRTF generated Request For Comments (RFCs) are standards.
  - RFC5050 is an Experimental Specification not a Standard
- Requires loose time synchronization
- No reliability checks on the header
- No way to terminate routing loops
- Naming is addressing
  - Flat name space makes scalability hard if not impossible
  - No identified way to aggregate routes
- Dynamic Routing is incomplete
- Discovery is incomplete
- Bundle Security Protocol
  - Specification is overly complex
  - Cases have been identified were it is broken
  - Security does not work with reactive fragmentation
  - Key exchange and key management is an open issue

DTN ON THE INTERNATIONAL SPACE STATION

ISS History

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- Design dates back to 80s and early 90s
  - pre-Internet era
- Phase 0
  - Commanding via low rate S-Band uplink
    - Uplink bandwidth is limited resource that must be managed.
  - Payload data downlink via Ku-Band at 50 Mbps
  - Highly asymmetric links and both may not be on simultaneously
- Phase I
  - KuBand uplink at 3 Mbps
  - Orbital communication adapter (introduced Internet
    - 3 Mbps Up, 6.5 Mbps down IP in CCSDS packets
- KuBand Upgrade
  - 30 Mbps Up, 300 Mbps Down Ku-Band
  - IP onboard with IP encapsulated in CCSDS up/down

NASA ISS DTN Project

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- ISS Disruption Tolerant Networking (DTN) Architecture for flight, ground, and test/simulation
- Increased reliability of payload data transfers between ISS and remote payload control centers during Acquisition of Signal (AOS) / Loss of Signal (LOS) transitions
- Increased automation of Payload Developer (PD) requests for data transfers
- Mechanism to alleviate extensive support to plan payload transfers around AOS/LOS and operator required transfers
- Mechanism to use standard, publicly available protocols, avoiding the use of costly custom protocol implementations
- Opportunity to gain valuable experience using DTN, which is the expected communication protocol of choice for future space exploration

Current Payload Operations

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- Uplink/Downlink request
- Entire files have to be re-transmitted when transfer errors occur
- Manual transfer by operations required for file transfers across AOS/LOS
- 24x7 continuous support operations to ensure access to science data
- Data recorded to Outage Mass Memory unit requires operators to playback
- Custom file transfer protocols utilized. Currently each payload, tool, support equipment uses a custom method or protocol to transfer data reliably between on-orbit and ground
  - Ex. Alpha Magnetic Spectrometer (AMS) and custom AMS Crew Operations Post (ACOP) system to store and buffer data in a proprietary implementation

DTN Benefits to Payload Communications

- Provides capability to automate operations and ensure science delivery with little regard for link or facility outages
  - MSFC, MCC-H, and ISS DTN nodes will store user file uplinks/downlinks and forward bundles as Kuband becomes available
- Reduce real-time support to access and downlink science data
- DTN stores data during LOS and automatically initiates transfer upon AOS
- A download transfer can span Ku-Band AOS periods without any special scheduling or scripting
- Reduces need for duplicate storage and extra retrieval actions

DTN Benefits to Payload Communications

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- Reliable data transfer for ISS during LOS/AOS cycles
  - Automatic verification of bundle receipts, retransmissions reduced
  - When transmission errors occur only the bundles that have errors are retransmitted
  - Maximizes use of bandwidth by reducing the amount of data that has to be retransmitted
- Allows Payload Developers to use DTN protocols for their own applications
- Efficient use of downlink stream through DTN Quality of Service (QoS)
- Tolerance for high network latency (600 ms Round Trip Time (RTT) delay is typical on Ku link)

Current/Future ISS DTN Use Cases

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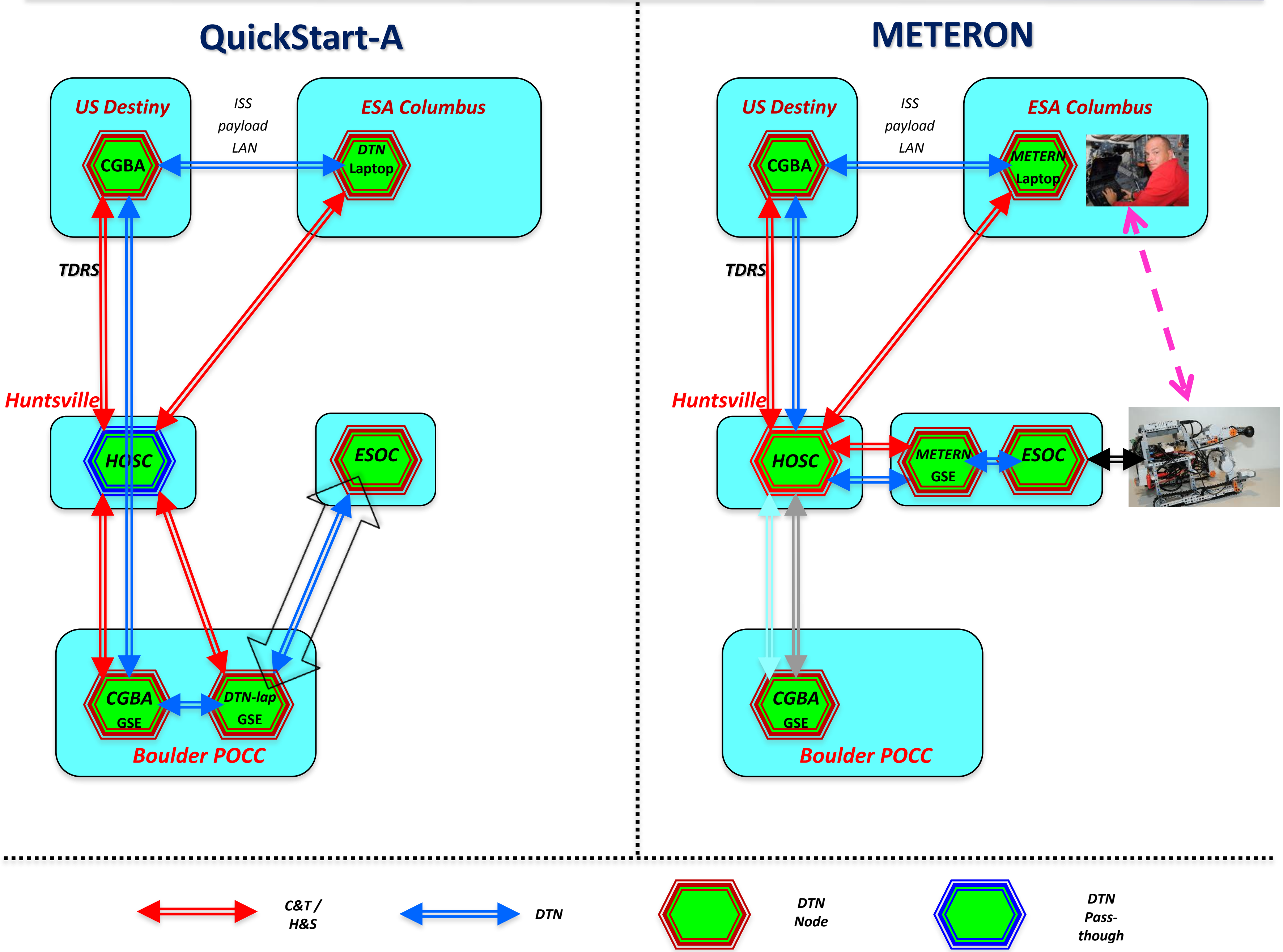
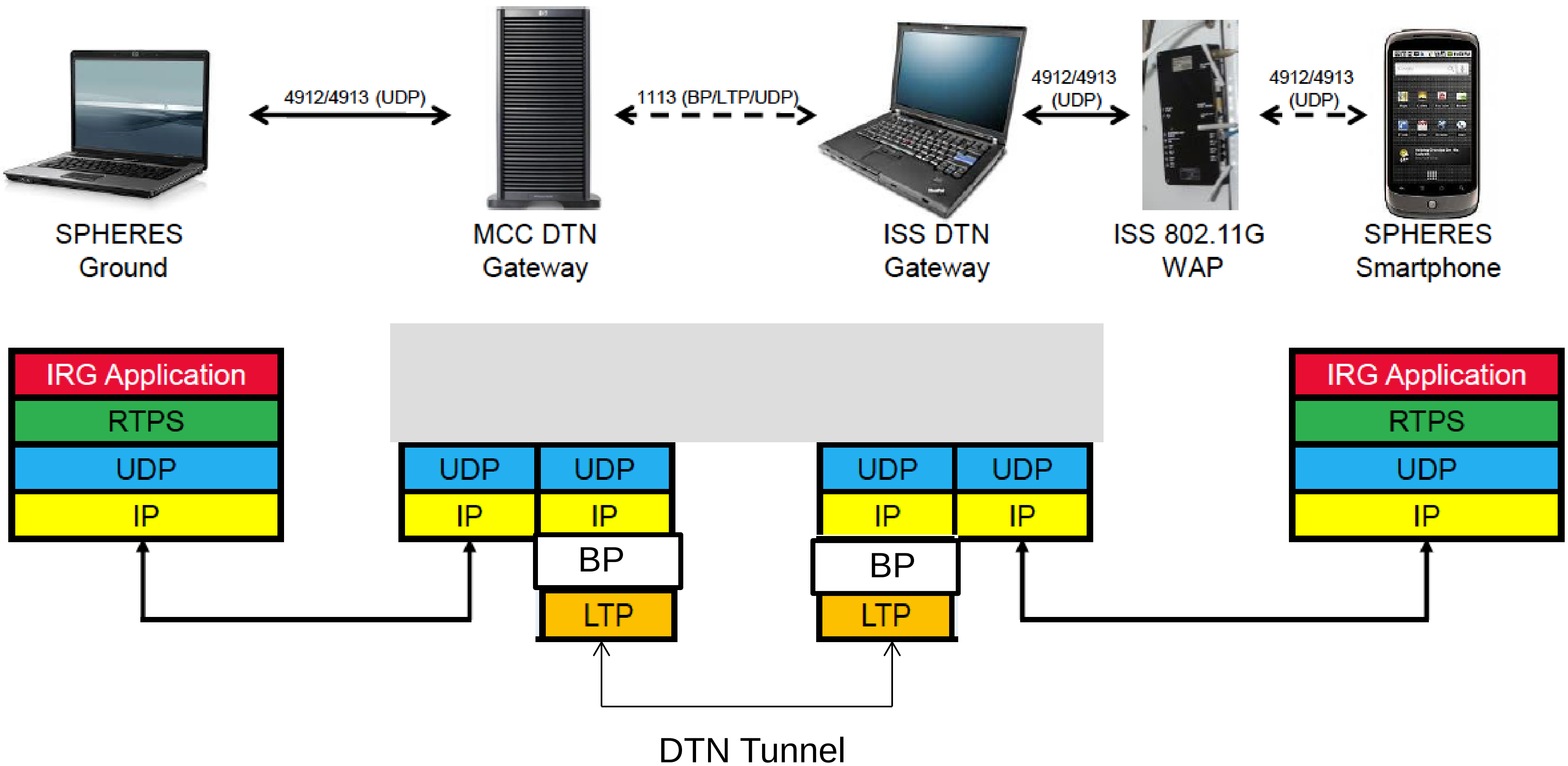
- Current Users of DTN on ISS:
  - Various “developmental” DTN configurations have been in use on ISS in support of payload activities for several years
  - DTN is or has been used in support of the following Payloads
  - BioServe Commercial-Grade Bioprocessing Apparatus (CGBA)
  - DARPA Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES) Smartphone
  - ESA Quickstart and OPSCOM I
- Additional Payloads discussing use of DTN include:
  - Multiple User System for Earth Sensing (MUSES)
  - ESA’s METERON (Multi-Purpose End-To-End Robotic Operation Network)
  - Human Exploration Telerobotics (HET) Surface Telerobotics
  - JAXA Kibo KaBand Rain fade mitigation
  - Other payloads are becoming interested

ESA QuickStart-A and METERON topologies



Spheres



4912/4913 (UDP)
1113 (BP/LTP/UDP)
4912/4913 (UDP)
4912/4913 (UDP)
SPHERES Ground
MCC DTN Gateway
ISS DTN Gateway
ISS 802.11G WAP
SPHERES Smartphone
IRG Application
RTPS
UDP
IP
UDP
UDP
IP
IP
BP
LTP
UDP
UDP
IP
IP
BP
LTP
IRG Application
RTPS
UDP
IP
DTN Tunnel

Summary

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- The implementation of DTN on ISS will provide a standard method of communication for payloads that is reliable, autonomous and more efficient than current techniques, resulting in better utilization and more science return from ISS
- The use of DTN by payloads will significantly ease Payload Development of both onboard and ground communication systems and could reduce payload operator costs

Implementation of DTN for Large File Transfers from Low Earth Orbiting Satellite

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Secure Autonomous Integrated Controller for Distributed Sensor Webs

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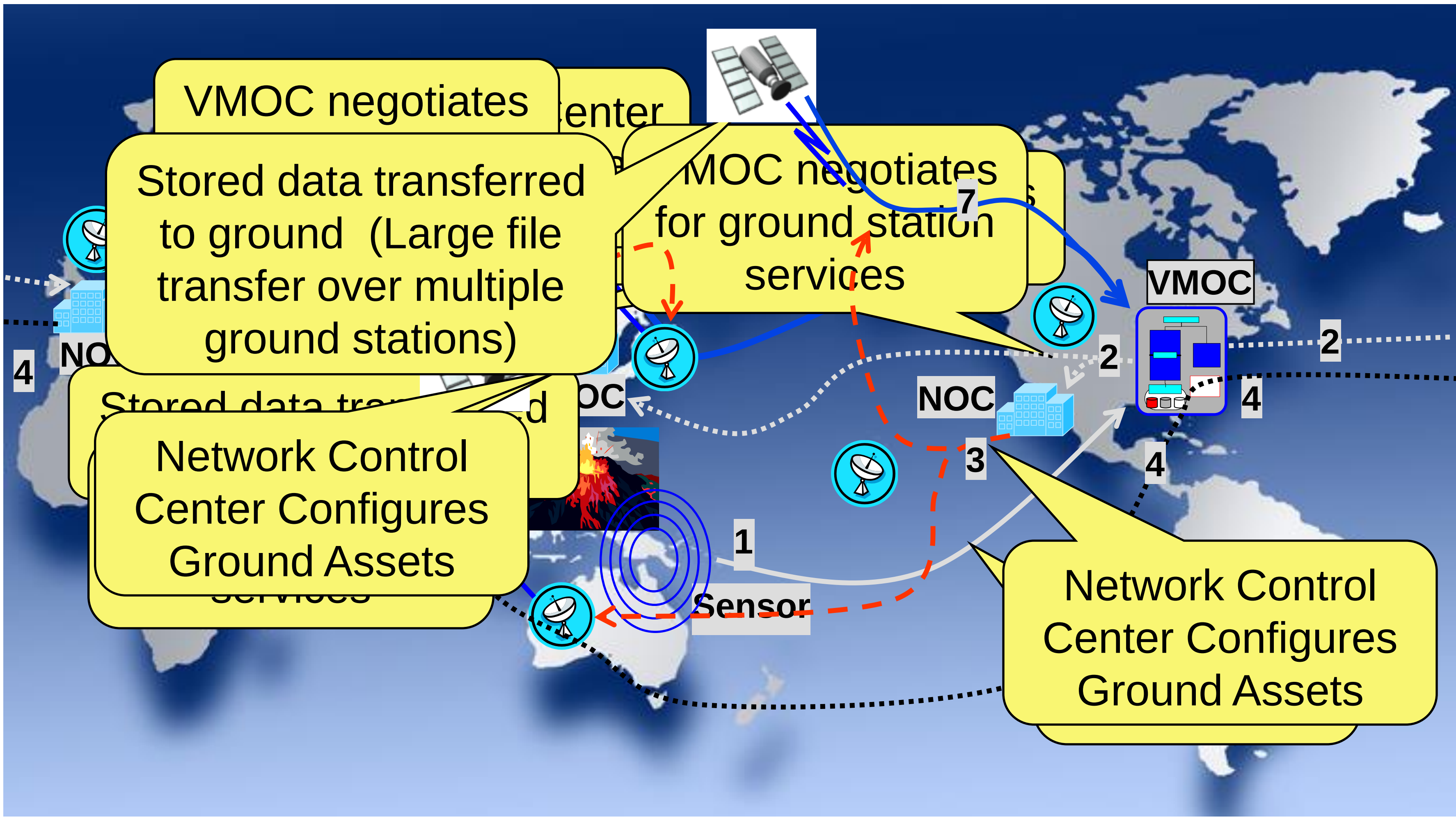
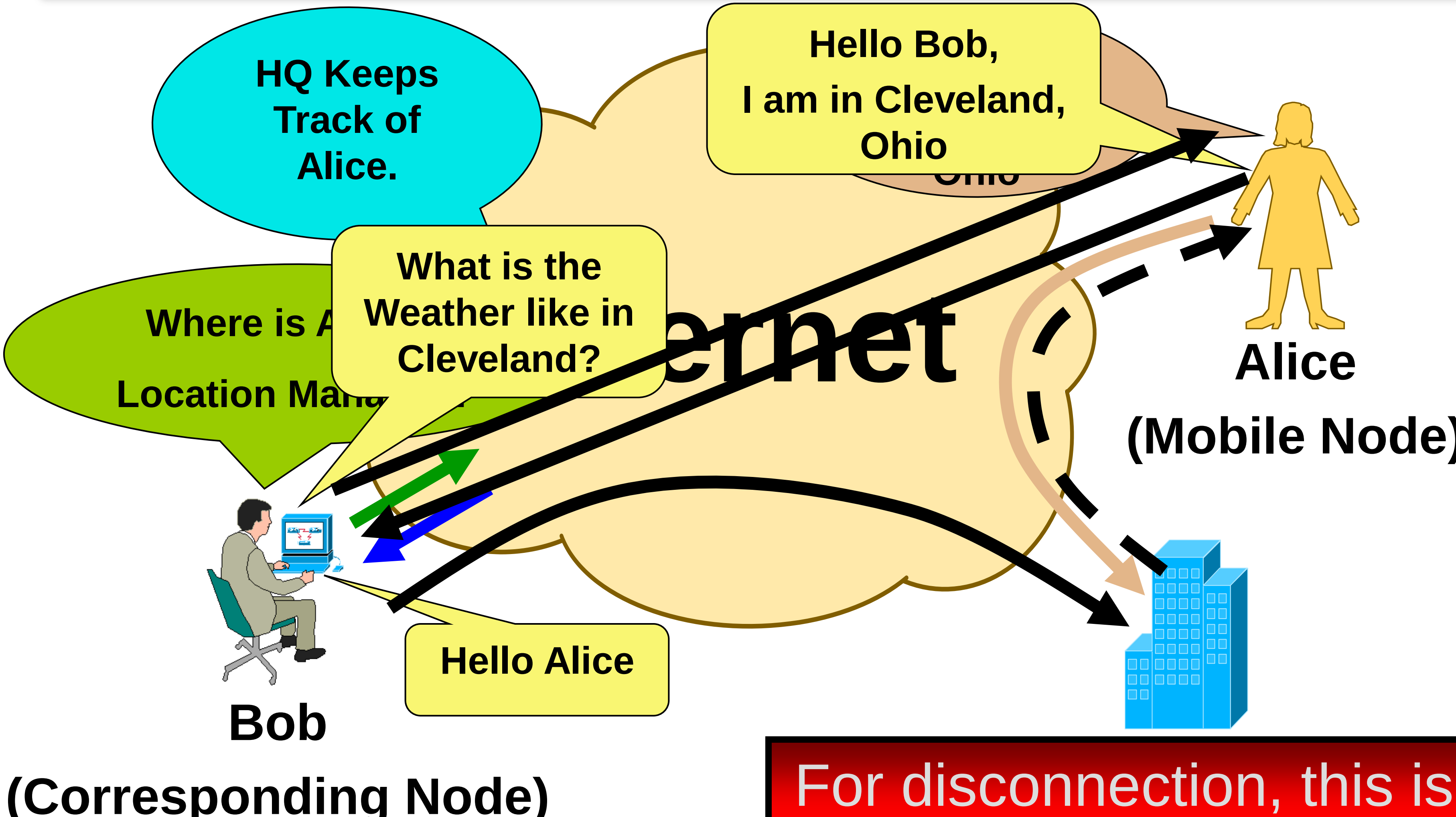
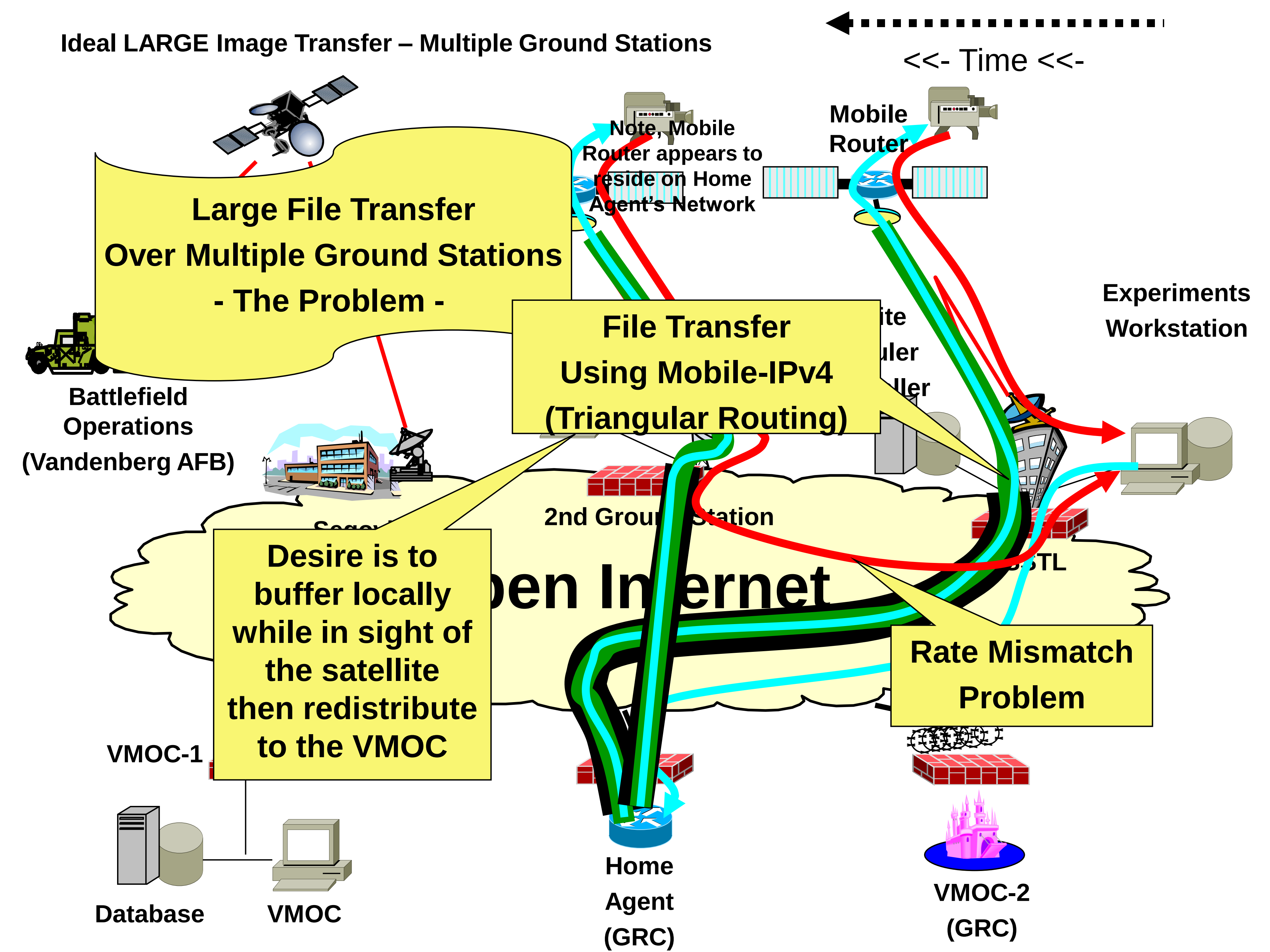


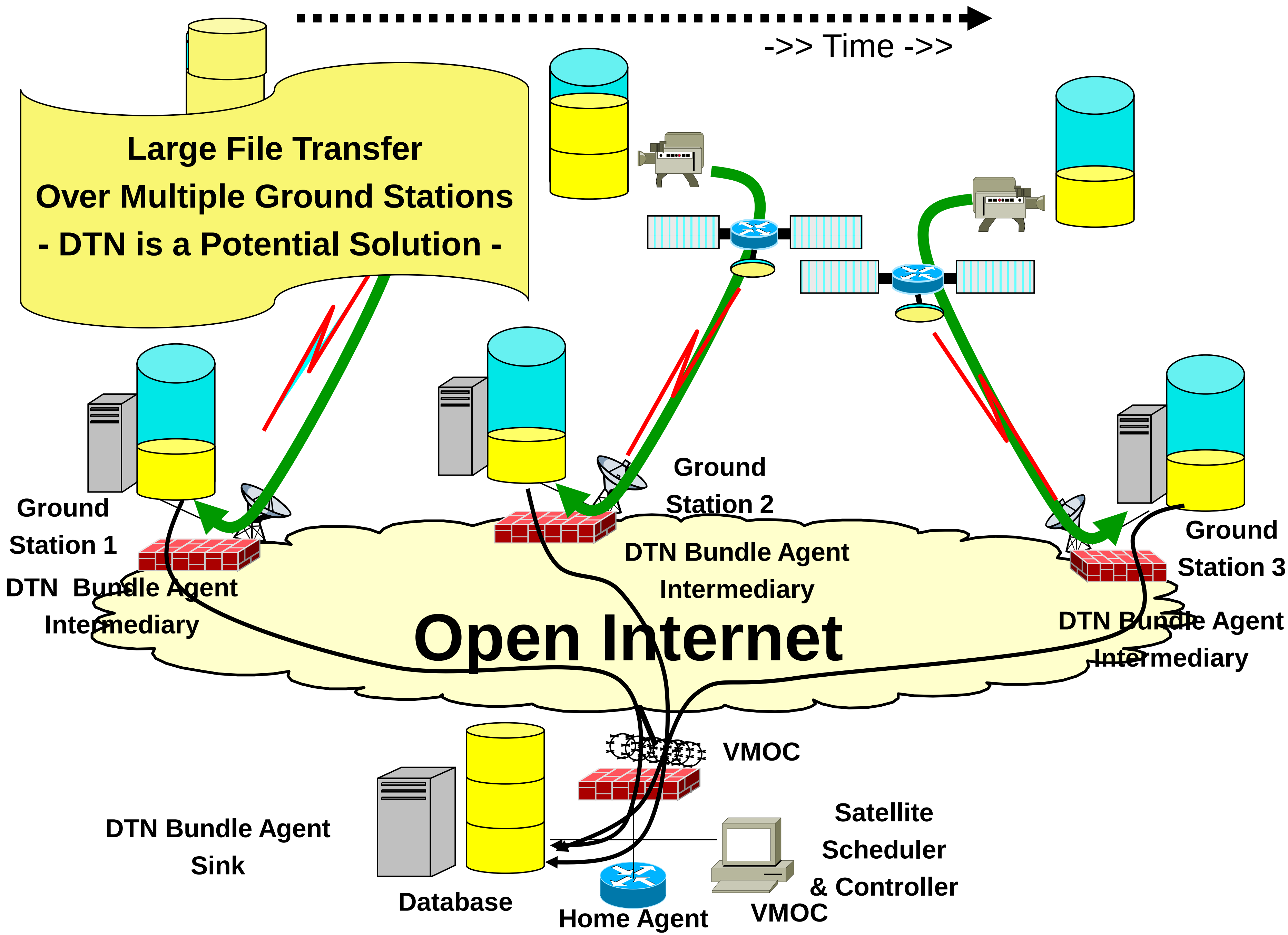
General Mobility

Registration and Discovery



For disconnection, this is a hard problem


Ideal LARGE Image Transfer – Multiple Ground Stations
<<- Time <<-
Large File Transfer
Over Multiple Ground Stations
- The Problem -
Note, Mobile Router appears to reside on Home Agent's Network
Mobile Router
File Transfer
Using Mobile-IPv4
(Triangular Routing)
Experiments Workstation
Battlefield Operations (Vandenberg AFB)
2nd Ground Station
Open Internet
Desire is to buffer locally while in sight of the satellite then redistribute to the VMOC
Rate Mismatch Problem
VMOC-1
Database
VMOC
Home Agent (GRC)
VMOC-2 (GRC)



->> Time ->>
Large File Transfer
Over Multiple Ground Stations
- DTN is a Potential Solution -
Ground
Station 1
DTN Bundle Agent
Intermediary
Ground
Station 2
DTN Bundle Agent
Intermediary
Ground
Station 3
DTN Bundle Agent
Intermediary
Open Internet
VMOC
DTN Bundle Agent
Sink
Database
Home Agent
Satellite
Scheduler
& Controller
VMOC

United Kingdom – Disaster Monitoring Satellite

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- The United Kingdom -Disaster Monitoring Constellation (UK-DMC) satellite is an ima satellite
  - One of 5 (or 6 or 7 as constellation grows)
  - Commercial Money Making Operation
    - *You* can request an image (and pay)
- Polar Orbit approximately once every 100 minutes
- Satellite is in view of any one ground station for 8 to 14 minutes – hence disruption.
- Round Trip Time Delay is ~ 100 msec, thus delay is not the issue here (unlike for deep space).

UK-DMC Characteristic

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- Onboard experimental Payload, Cisco router in Low Earth Orbit (CLEO)
  - Not Used for DTN Testing
- Three Solid State Data Recorders
  - 1 with a StrongARM Processor
  - 2 with Motorola MPC8260 PowerPC (We use one of these)
    - RTEMS operating system (POSIX API, BSD sockets)
    - Storage Capacity 1 GByte RAM
    - Operating System Image limit is 0.5 Mbyte
- Uplink is 9600 bits per second
- Downlink is 8.134 Mbps
- Datalink – Frame Relay/HDLC
- Network Protocol – IPv4 (could easily run IPv6)
- Transport Protocol (Saratoga version 0 over UDP)
  - Saratoga version 0 is existing SSTL transport
  - Saratoga version 1 is what is in the Internet Drafts
    - Enhances version 0 to make it more widely usable

Saratoga

SYZYGY Engineering

- Simple High Speed File Transfer Protocol
  - Replaces CFDP
    - Most of the features of CFDP not needed
    - CFDP implementation was to slow to fully fill SSTL downlinks
  - Implemented for highly asymmetric links
    - Asymmetry up to 850:1 for S-Band transmitters
    - Asymmetry up to 8333:1 for X-Band transmitters
  - Negative acknowledge rate-based protocol
  - Uses UDP at the network layer
  - Sends Beacon to allow ground station that the space/ground link is up.

UK-DMC Implementation

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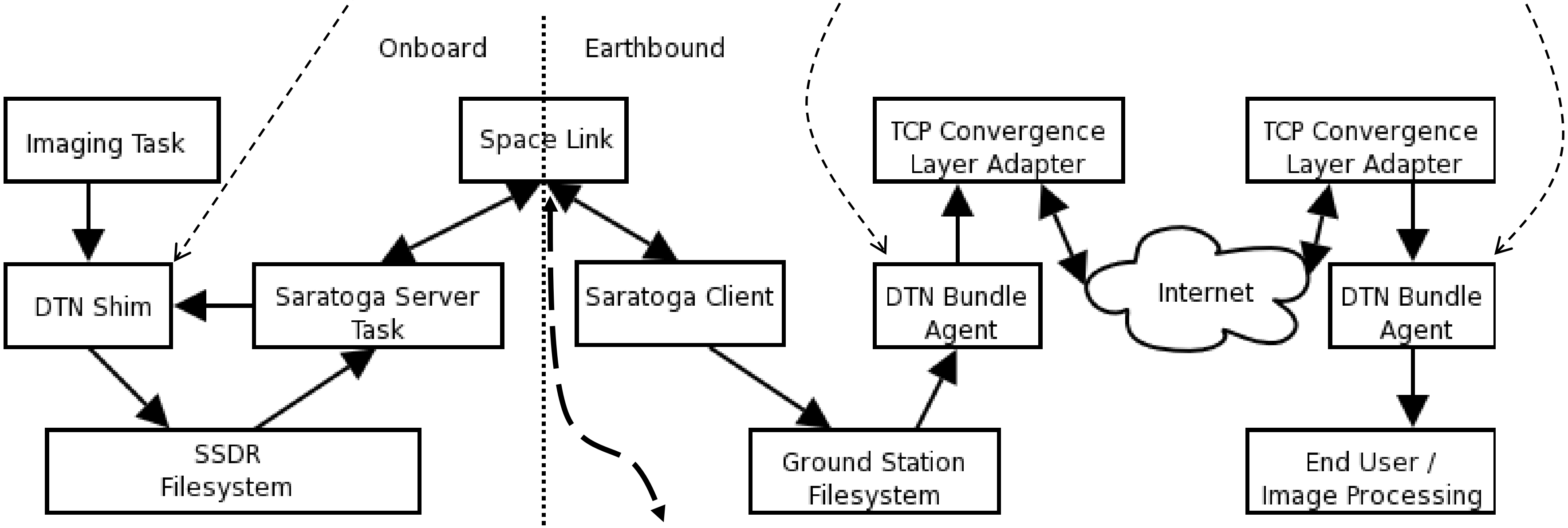
Only Bundling and Forwarding Implemented

Full DTN Protocol Implemented



Surrey Satellite Tech Ltd (SSTL) Saratoga Client

← Test 4

UK-DMC Flight Code

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- Main Satellite Control if via Onboard Computer
- Imaging has separate Flight Code residing in Solid State Data Recorder
  - RTEMS based
  - Major Functions
    - Control Area Network (CAN) bus interface
      - Commanding from the Onboard Computer is via CAN bus
      - Added command for MD5
    - Image Capture and Storage
      - Optional MD5 calculation (added by NASA – Wes Eddy)
    - Memory Wash
    - Bundling Shim (added by NASA – Wes Eddy)
    - File Transfer (Saratoga in Spacecraft)
      - Modified to handle Bundling Shim (Metadata plus offset)

Ground Station Code

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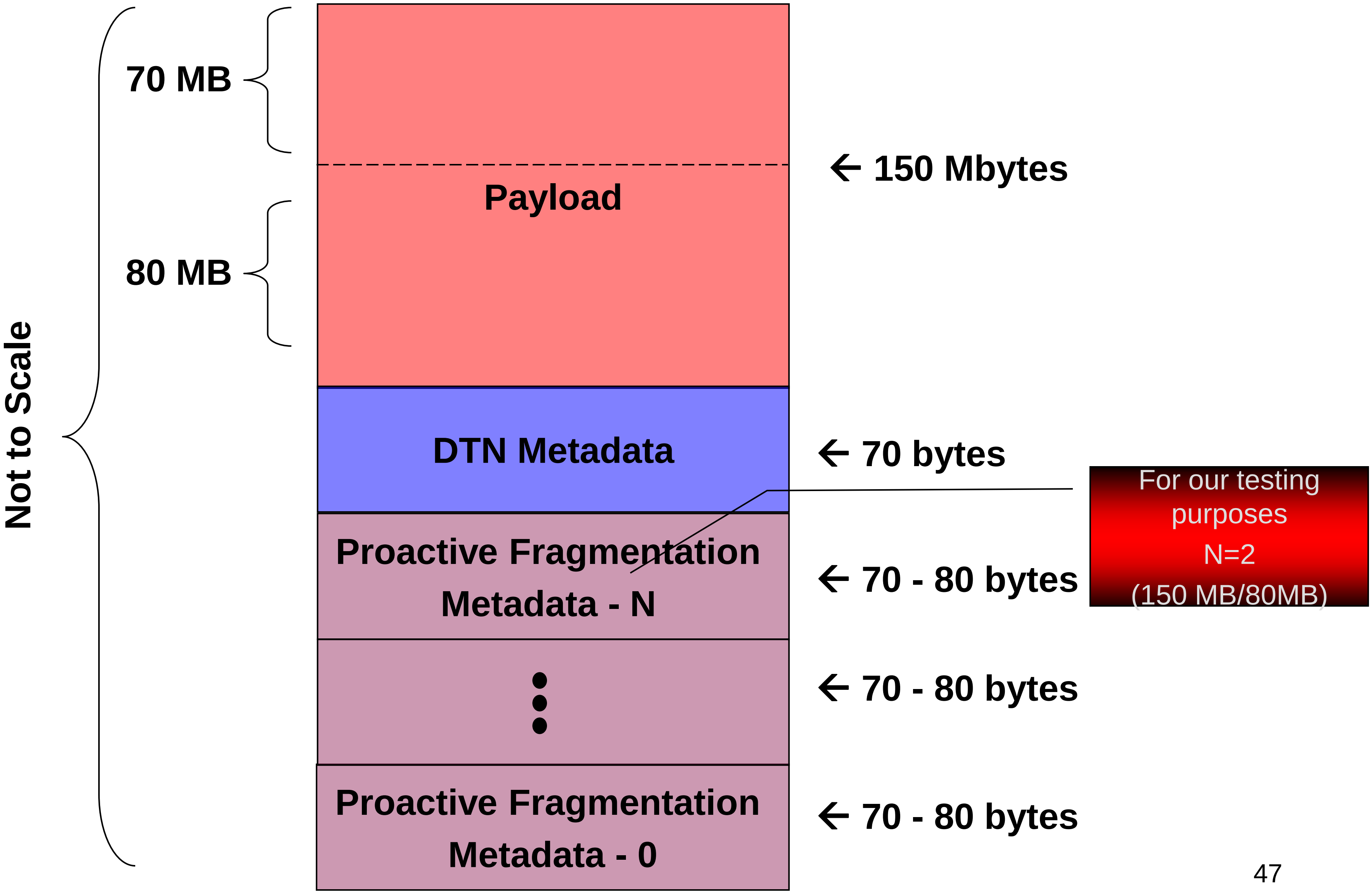
- File Transfer (Saratoga on Ground)
  - GRC independent PERL implementation that passes DTN bundles to DTN2 bundle agent
- DTN2
  - Modified to accept bundles from Saratoga
    - Named pipe-based convergence layer adapter
  - Modified (fixed) early version of DTN2 to operated with very large bundles
    - Patch is in current DTN2 implementation
- Bundle to File Application
  - Single Bundle
    - Removes Metadata and creates file
  - Multiple Fragments
    - Combines Multiple bundle fragments into a single file

Put the protocol intelligence and complexity on the ground.

Bundles on UK-DMC



Multi-Terminal Large File Transfers using DTN

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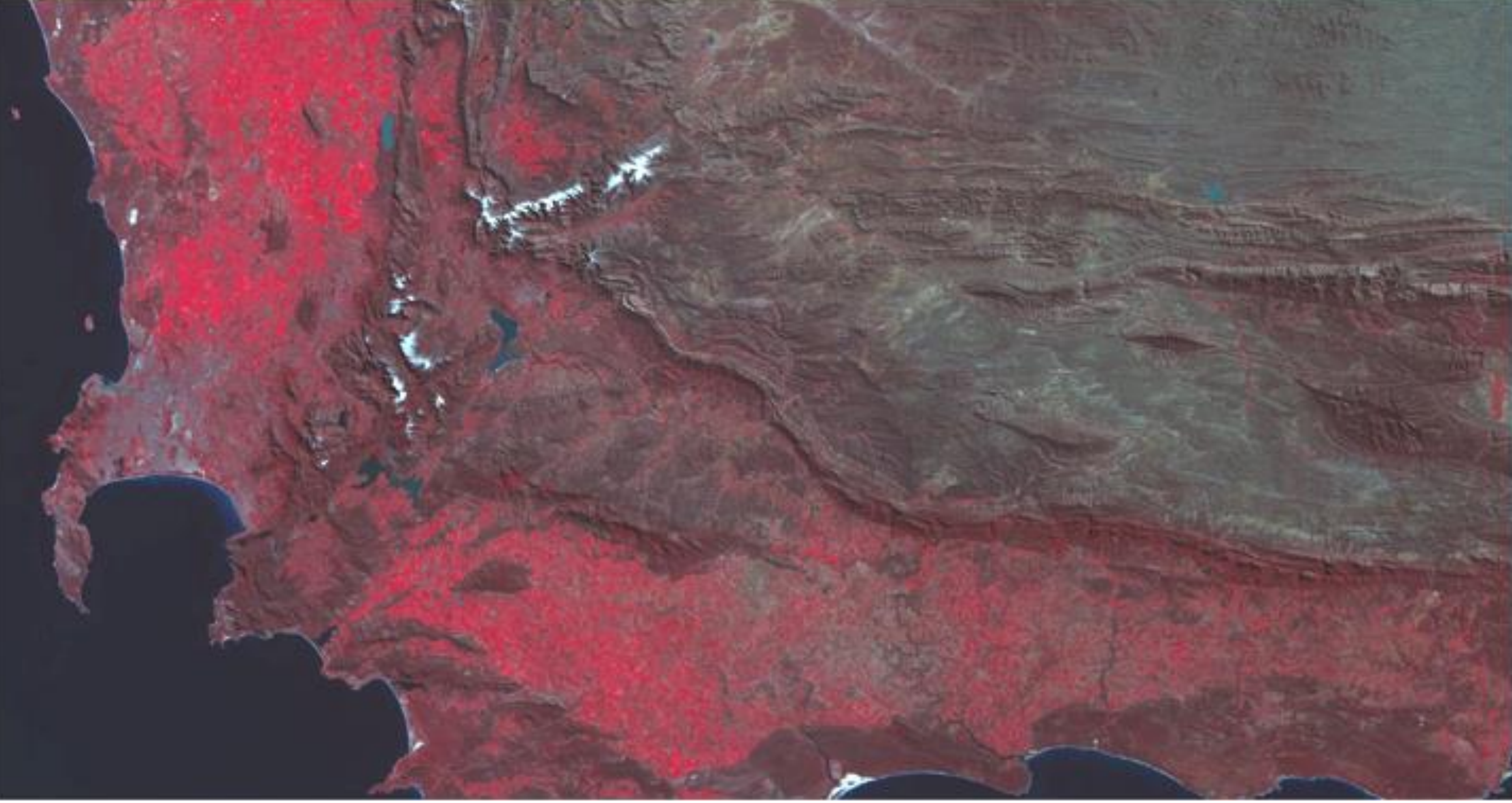
- September 30 and October 1, 2009 successfully demonstrated multi-terminal large file transfers using DTN and ground stations in Alaska followed by Hawaii (approximately 80 minute separation)
  - Demonstrated proactive fragmentation
  - Demonstrated Store and Forward of ground infrastructure
    - Ground station held bundles until routes were established
  - Demonstrated reactive fragmentation between Hawaii ground station bundle agent and GRC bundle agent.
  - Configuration
    - UK-DMC acquired a 150 Mbyte image.
    - DTN bundling code default set to 80 Mbytes for proactive fragmentation.
- September 30 and October 1, 2009 successfully demonstrated multi-terminal large file transfers using DTN and ground stations in Hawaii followed by Alaska (approximately 5 minutes between passes but effectively overlapping handover)



Sensor data example: The Cape of Good Hope and False Bay.

False colours – red is vegetation.

Taken by UK-DMC satellite on the morning of Wednesday, 27 August 2008.
(Downloading this image also demonstrated optional “DTN bundle” use.)

Ground Stations and UKDMC Contact Times

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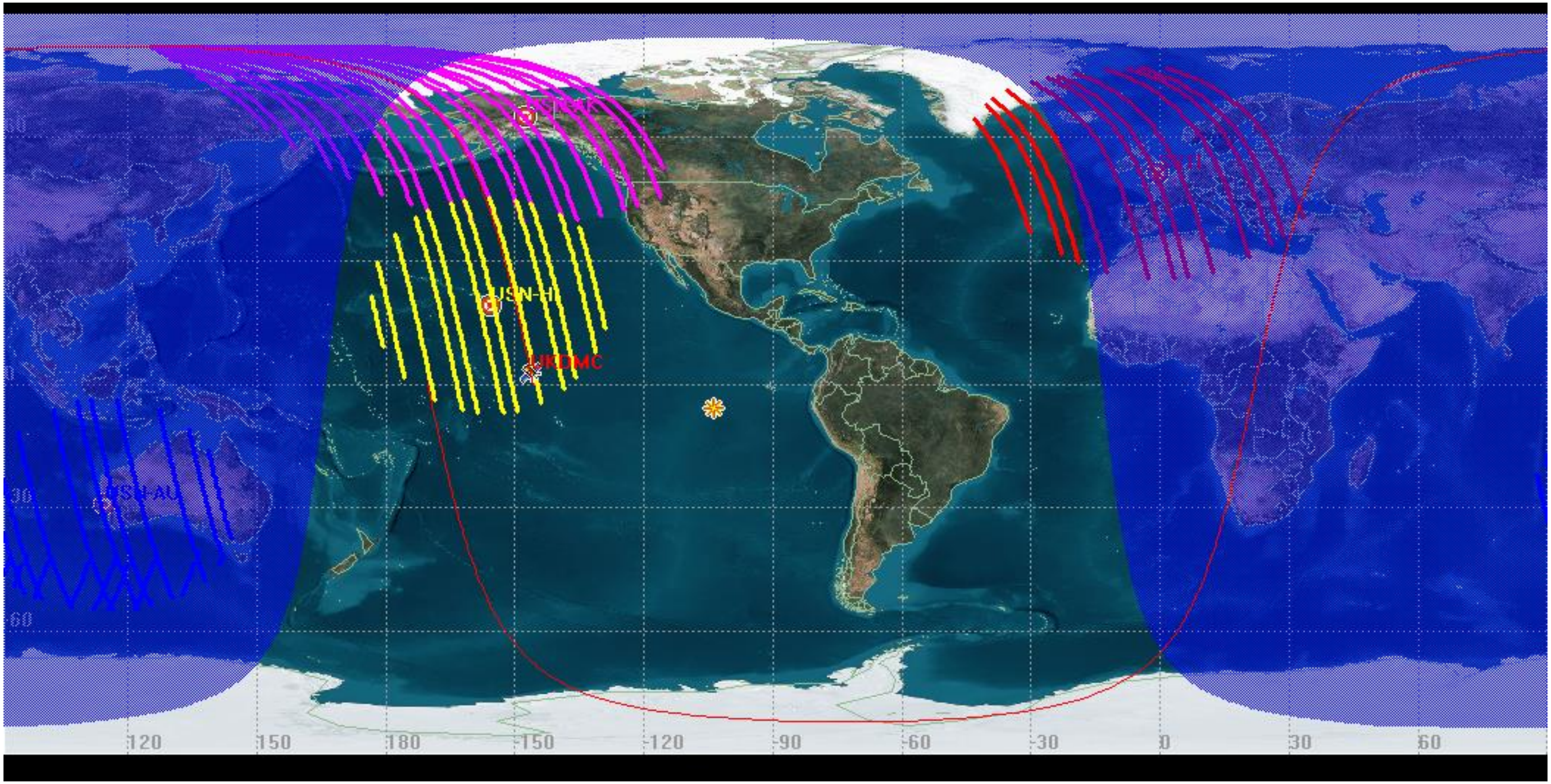
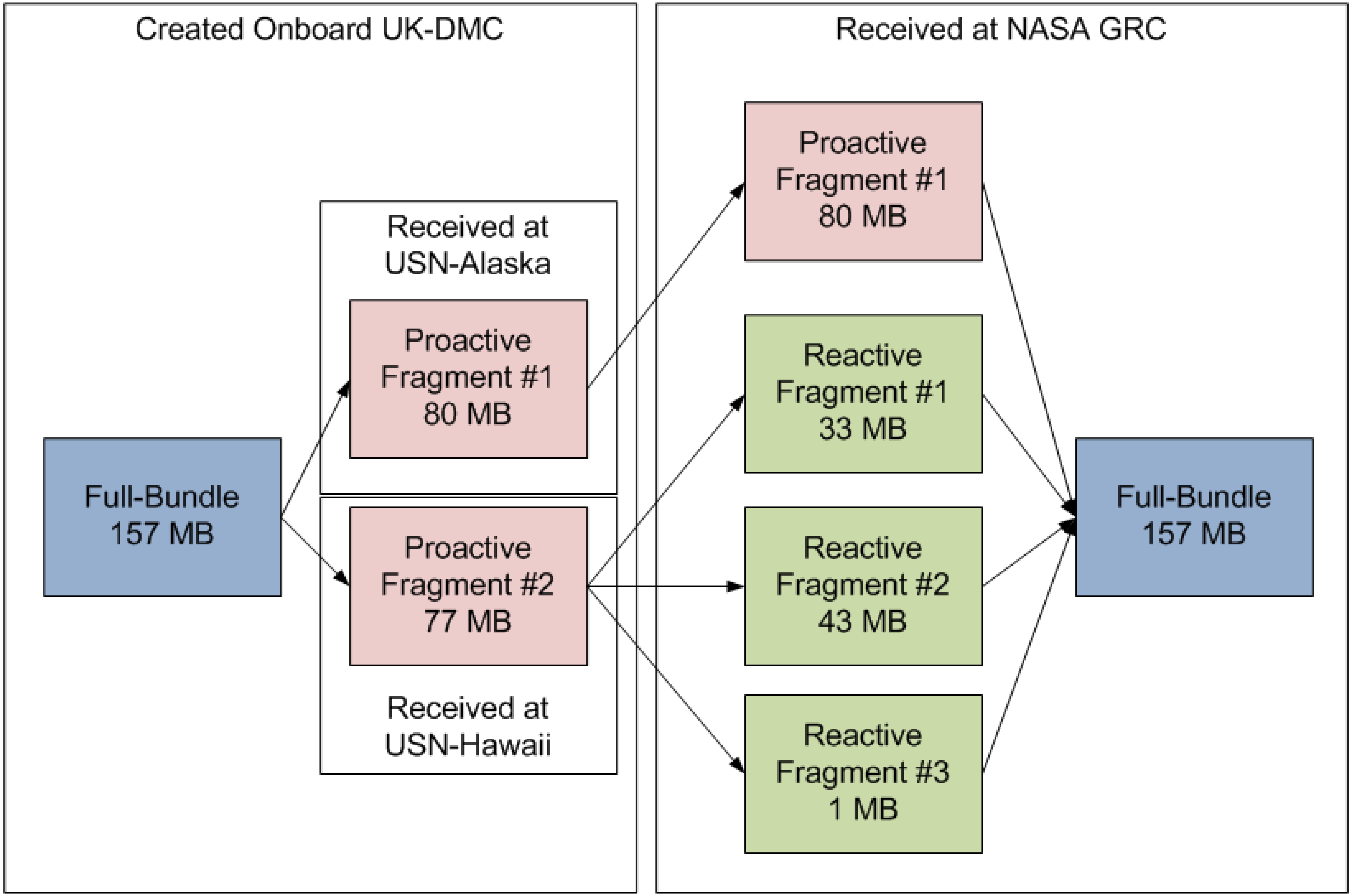


Multi-Terminal Large File Transfers using DTN

September 30 / October 1 Tests



Observations

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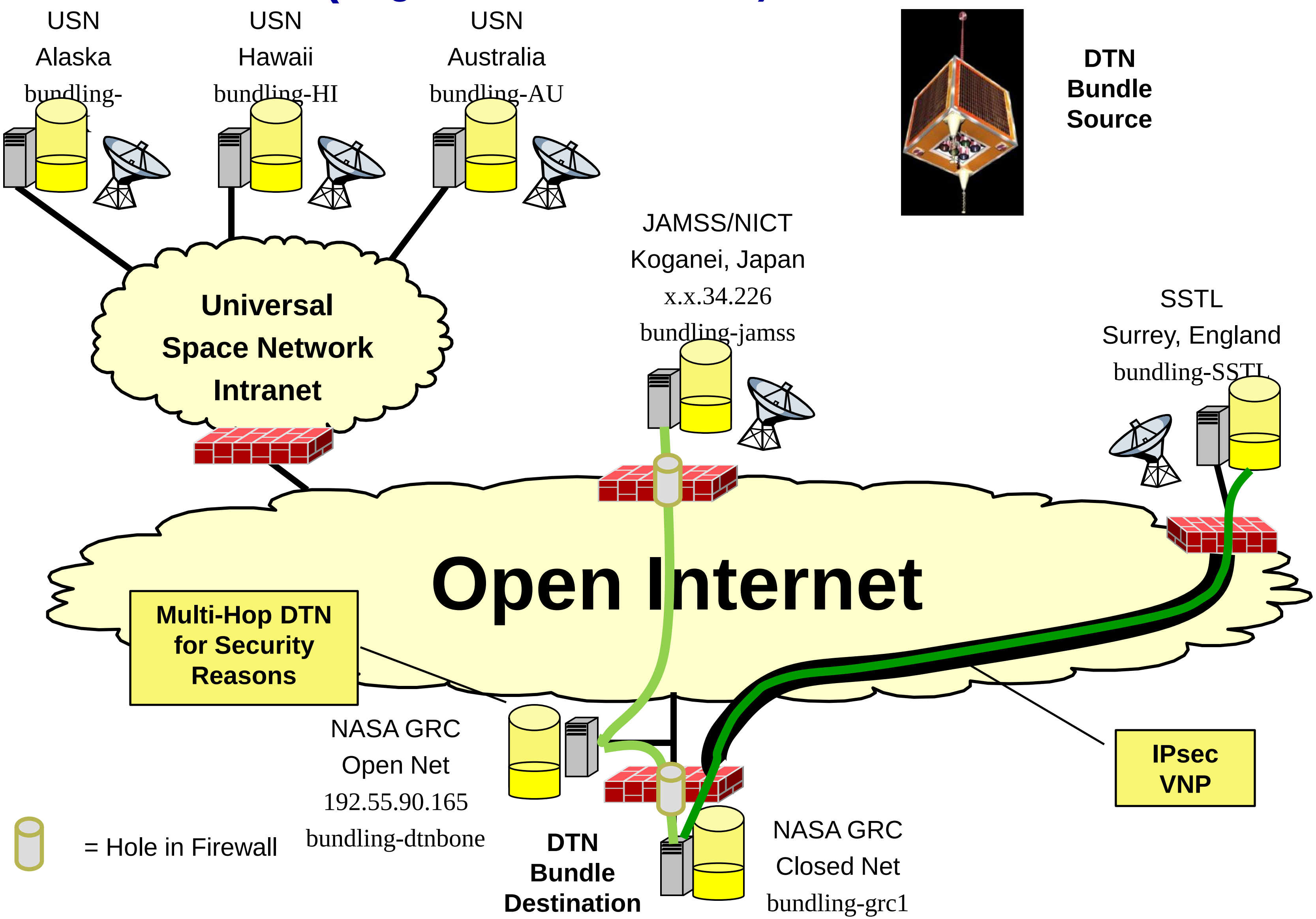
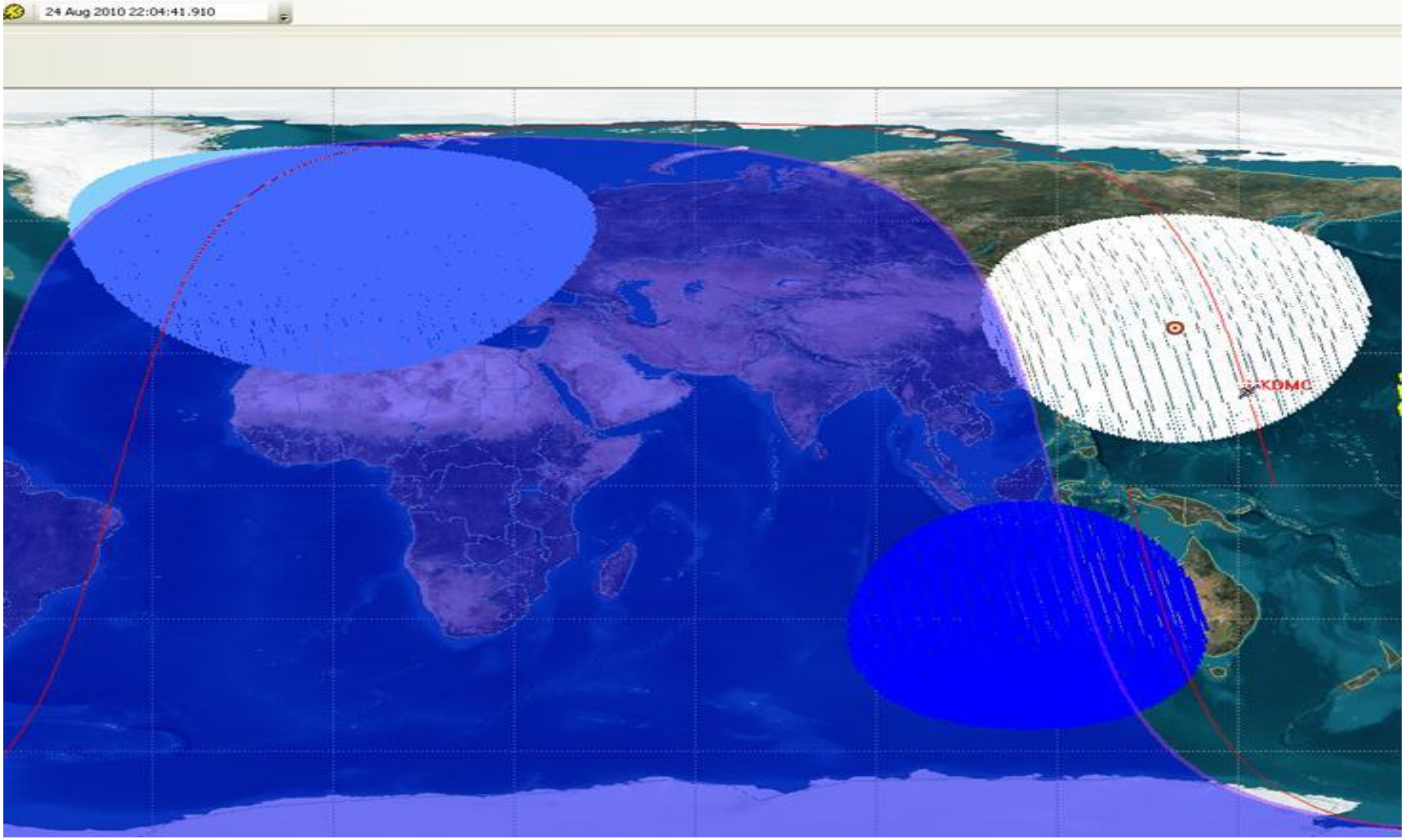
- TCP convergence layer transmission between Hawaii ground station and Cleveland destination was problematic.
  - Cause has yet to be determined.
- Without reactive fragmentation, these tests would have failed.
  - If bundle security protocol (BSP) bundle authentication block (BAB) was used, reactive fragmentation would have failed.
  - If per-hop reliability checks via the BSP payload confidentiality block (PCB), or even some other per-hop reliability check, were used, reactive fragmentation would have failed.
- Conclusion: It is desirable to be able to perform reactive fragmentation and still be able to utilize some form of hop-by-hop reliability as well as bundle security.

DTN Network
(August 17 and 24, 2010)



August 24, 2010 Passes

SYZYGY Engineering



Multi-Terminal Testing with NICT/JAMSS

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- Passes over Koganei and SSTL occurred on August 24, 2010 from 22:02 to 22:38.
  - Both proactive bundle fragments were downloaded to the Koganei ground station and automatically transferred to NASA Glenn.
  - A bundle fragment and the last Syslog file were also downloaded at the SSTL ground terminal.
    - A duplicate bundle fragment was received at GRC. DTN2 noted the duplicate and only stored one copy.

Successfully showed use of multiple terminals for large image transfer and international interoperability between USA (NASA) UK (SSTL) and Japan (JAMSS/NICT).