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

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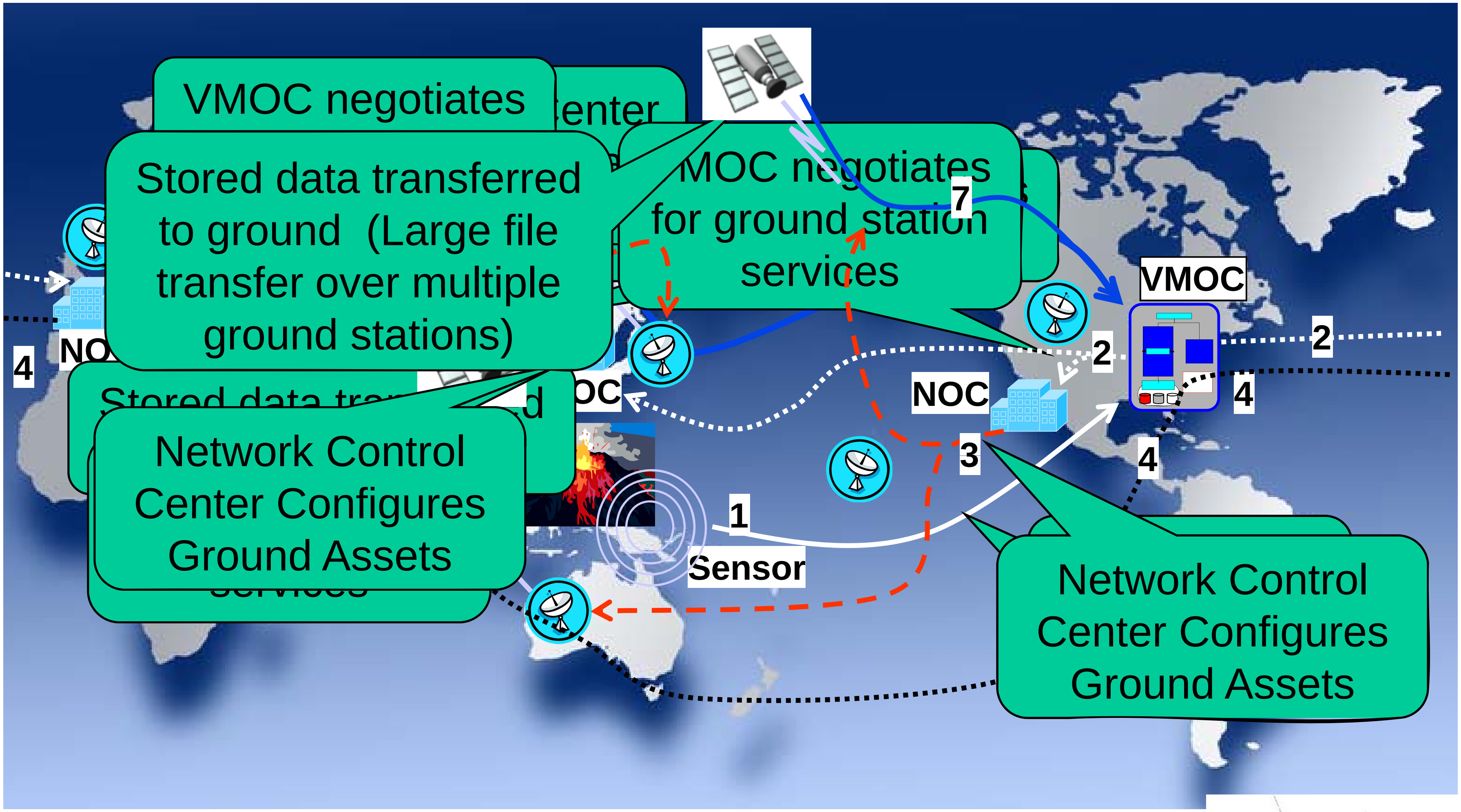
Outline

- Motivation – The Big Picture
- Problem to be Solved by DTN
- System Description
- Code Implementation
- Tests and Demonstration

Secure Autonomous Integrated Controller for Distributed Sensor Webs



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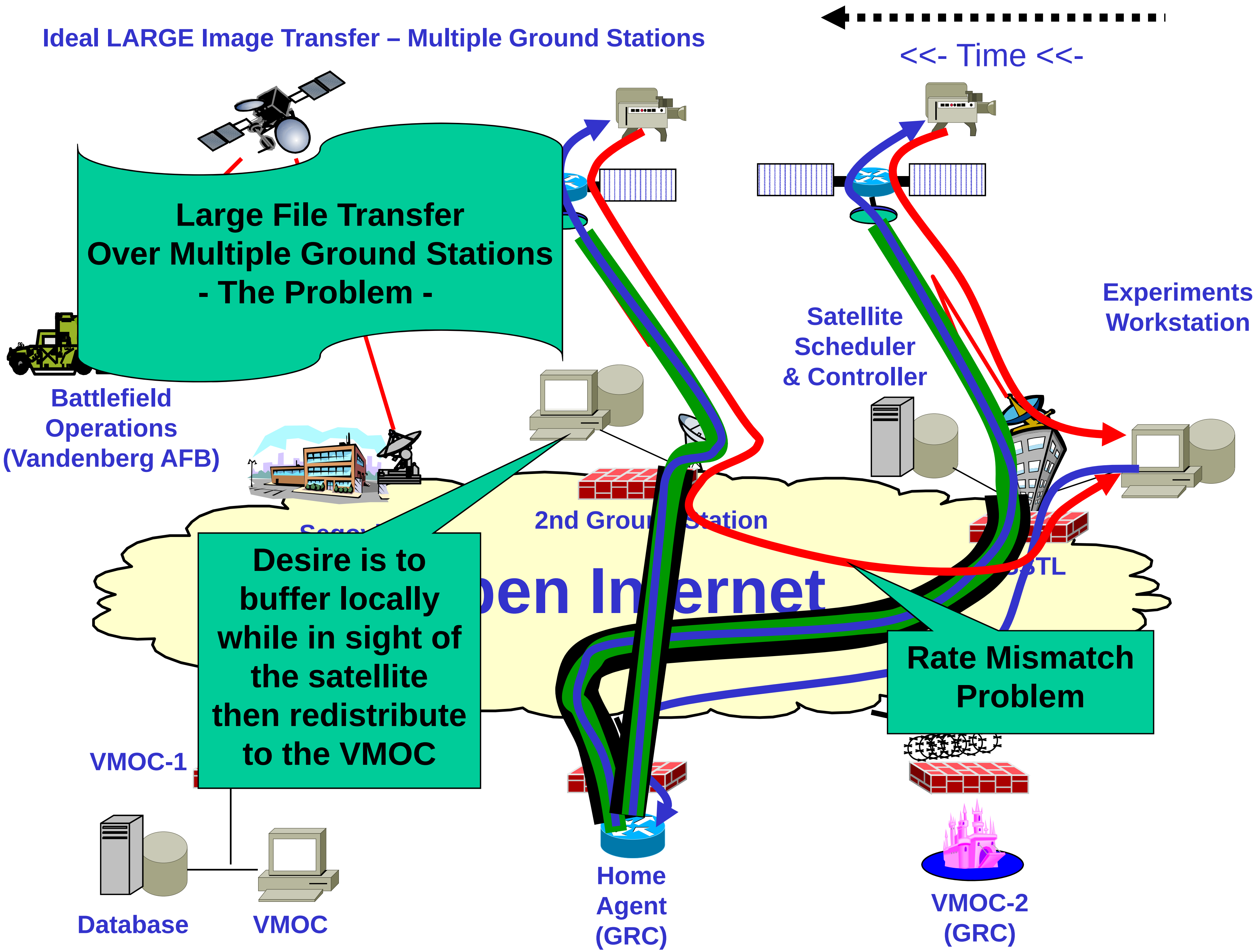
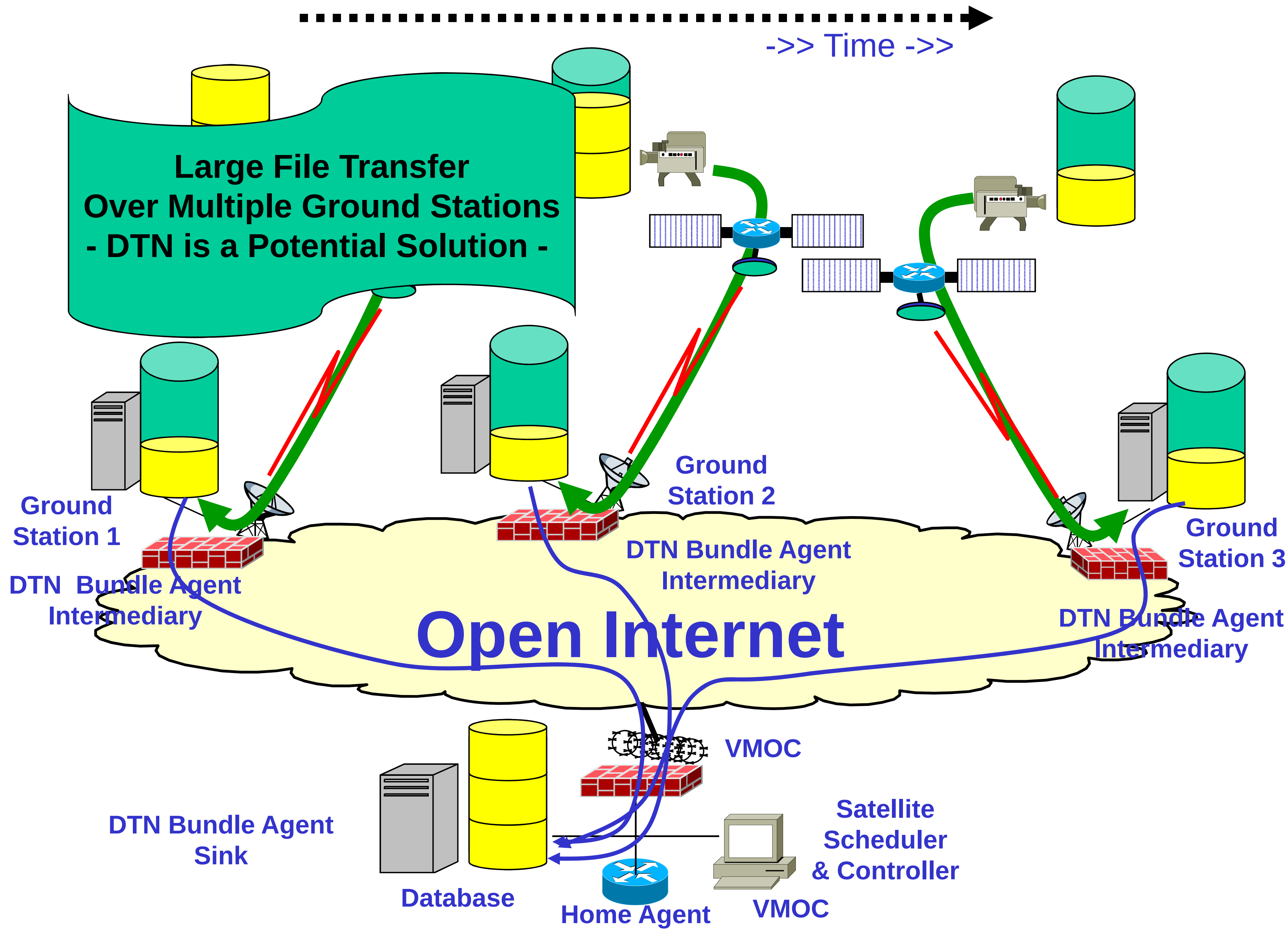
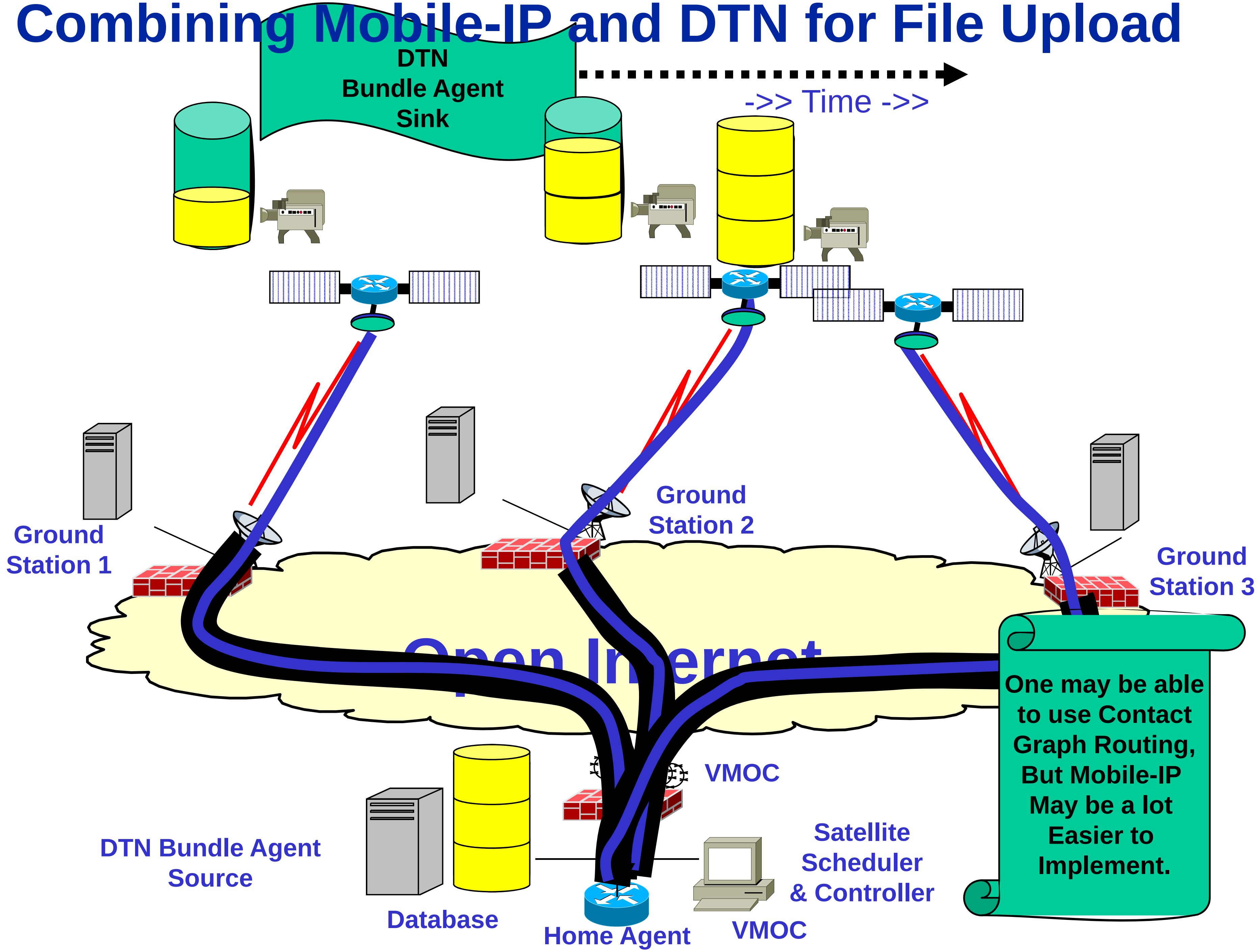
Large File Transfers Using Delay/Disruption Tolerant Networking (DTN) Store and Forward Protocol


Ideal LARGE Image Transfer – Multiple Ground Stations
<<- Time <<-
Large File Transfer
Over Multiple Ground Stations
- The Problem -
Battlefield
Operations
(Vandenberg AFB)
Satellite
Scheduler
& Controller
Experiments
Workstation
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

Combining Mobile-IP and DTN for File Upload



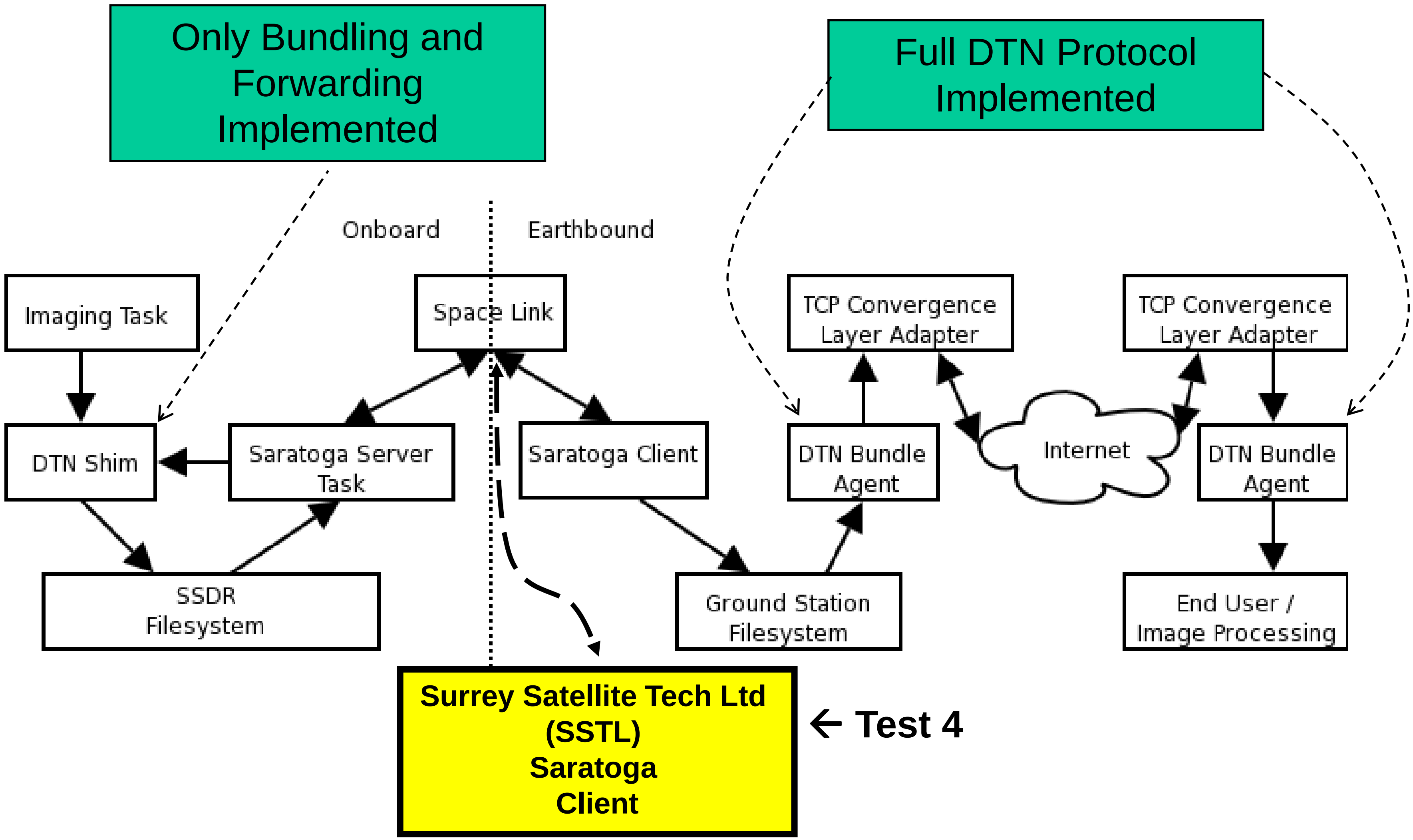
United Kingdom – Disaster Monitoring Satellite

- The United Kingdom -Disaster Monitoring Constellation (UK-DMC) satellite is an imaging 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

- 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 1 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

UK-DMC Implementation



Motivation for Implementation Choice

- Complexity
  - Code base must fit in 0.5 Mbyte footprint for bootable system image on SSDR including RTEMS OS and user applications
- Compatibility with existing code = COST!
  - UKDMC is an operational, money making satellite.
  - If DTN code upload DOES NOT disrupt SSTL normal operations cost savings of tens of thousands per test.
    - Cost is per pass
    - Therefore operational ground testing was extremely important
  - Else, UKDMC is out of commission for NASA testing and NASA must compensate for missed revenue.
    - Cost is per day rather than per pass
  - Code changes had to be reviewable by SSTL with minimal effort (diff files)

Interplanetary Network Overlay (ION)

- Investigated use of ION for onboard implementation.
  - The mission at hand only required bundle forwarding, not the entire protocol stack
  - ION implements the entire bundling protocol and includes Contract Graph Routing (CGR) and Compressed Bundle Header Encoding (CBHE) for “ipn” naming.
  - Implemented DTN naming as we used DTN2 on the ground and DTN2 does not currently understand “ipn” naming
  - Did not need functionality
  - Would be difficult to implement within the constraints of limited changes to SSTL code.
  - Code footprint would not fit into 0.5 Mbytes
  - Needed to develop a new convergence layer to run over Saratoga

Via the Deep Impact spacecraft, JPL successfully demonstrated ION in deep space including use of Contract Graph Routing and CBHE.

UK-DMC Flight Code

- 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 if from Onboard Computer 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

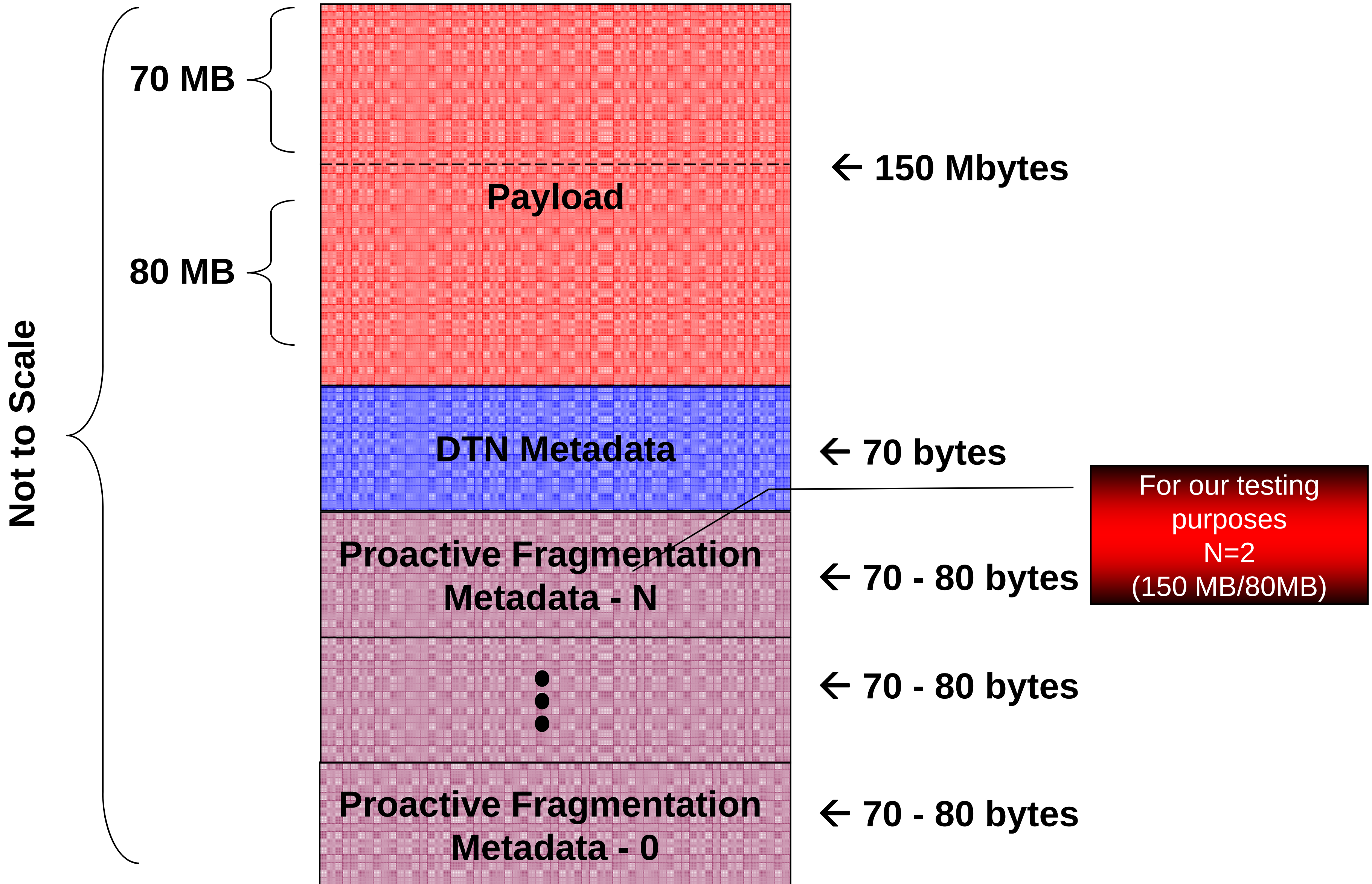
- File Transfer (Saratoga on Ground)
  - GRC independent PERL implementation that passes DTN bundles to DTN2 bundle agent
- DTN2
  - Modified to accept bundles from Saratoga
    - Named pipe-based convergence layer adapter
  - Modified (fixed) early version of DTN2 to operated with very large bundles
    - 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.

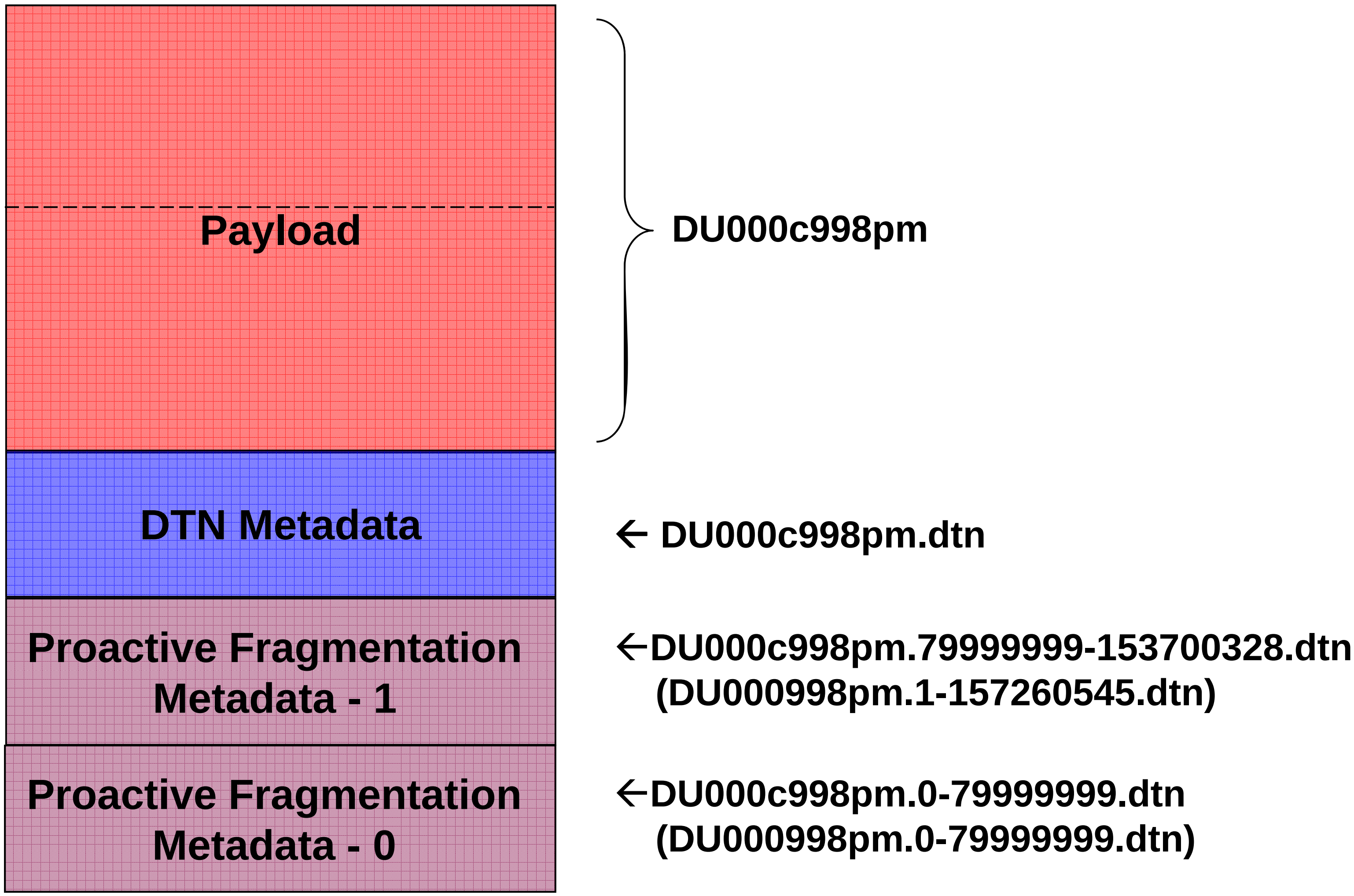
Saratoga

- 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.

Bundles on UK-DMC



File Names


Payload
DU000c998pm
DTN Metadata
← DU000c998pm.dtn
Proactive Fragmentation Metadata - 1
←DU000c998pm.79999999-153700328.dtn
(DU000998pm.1-157260545.dtn)
Proactive Fragmentation Metadata - 0
←DU000c998pm.0-79999999.dtn
(DU000998pm.0-79999999.dtn)

Checksums were very useful

- We implemented manual MD5 checksums over the payload
  - Greatly aided in debugging
    - Identified errors in our Saratoga transport protocol implementation
    - Allowed us to prove data was transmitted correctly received without errors
      - Used for full bundle and reconstituted bundle fragments checking
      - 150 Mbytes is a bit to much to manually check
  - Checksums can take significant time relative to a satellite pass, thus, we made it a command option
    - Apparently sometimes SSTL dumps an image and takes another during the same pass (8 – 12 minutes).

DTN Test Plan

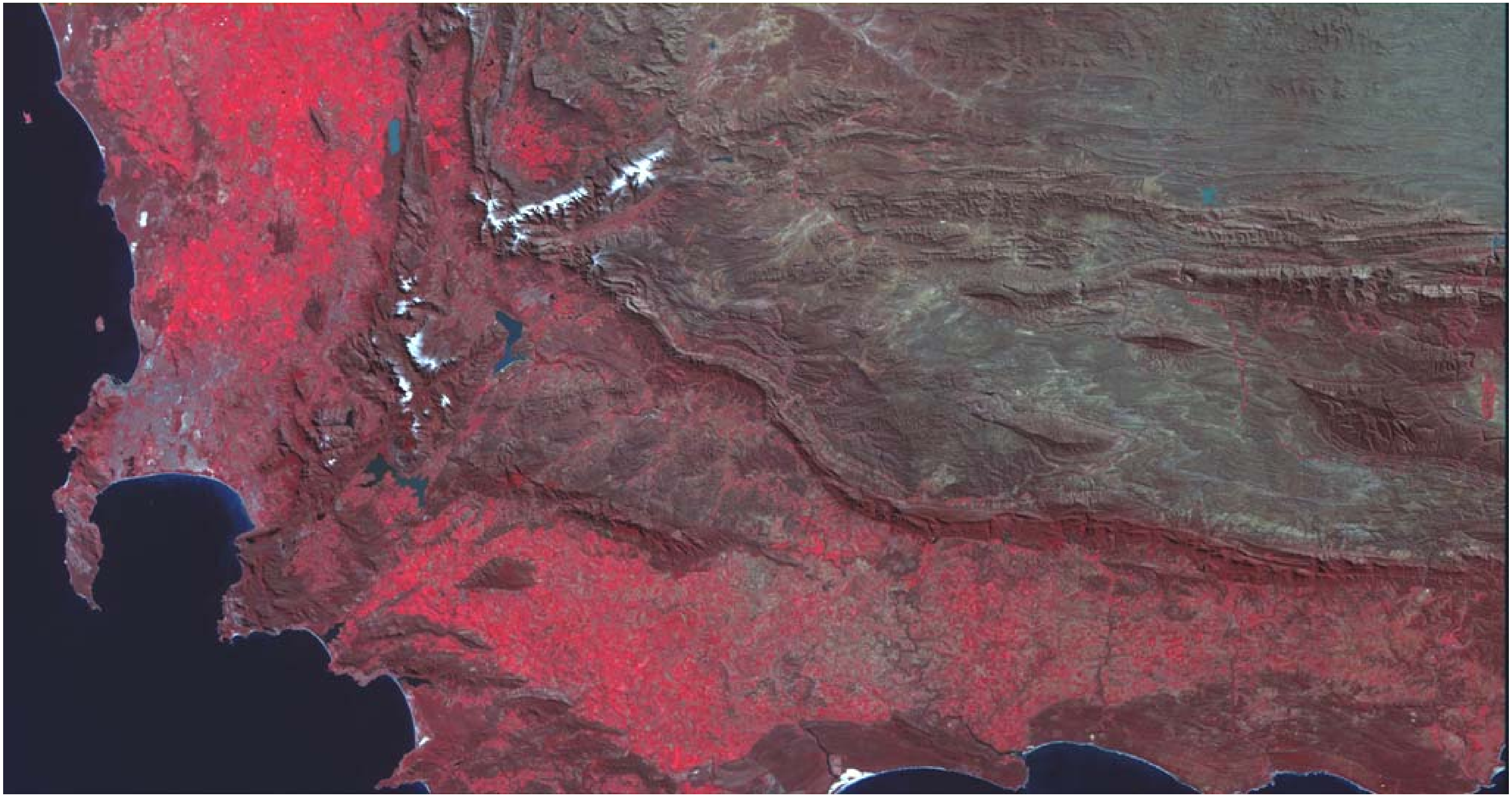
- Goal
  - Demonstrate DTN Bundle Transfer from UK-DMC to SSTL Ground Station
  - Demonstrate that DTN code and general SSTL code can coexist without affecting normal SSTL Operations
- Configuration
  - UK-DMC acquired a150 Mbyte image Cape of Good Hope, South Africa using the DTN SSDR code. DTN bundling code default set to 80 Mbytes for proactive fragmentation
- Tests
  1. Basic file download using existing technique (GRC implementation of Saratoga version 0)
  2. Same file downloaded but treated as single bundle (DTN)
  3. Same file download but using DTN proactive fragmentation with 80 Mbytes preconfigured fragments.
  4. SSTL used their Workstation and SSTL implementation of Saratoga version 0

DTN Test Results – January 2008

- Test 1 - Image file DU00076pm was received using GRC Saratoga version 0 implementation
- Test 2 - DTN file and associated metadata for the full bundle was received by Bundling-SSTL and then forwarded as a full bundle to Bundinging-GRC1
- Test 3 – Proactive Fragmentation:
  - The 1st proactive fragmented bundle from the UK-DMC and it was automatically transferred using DTN-2 between Bundling-SSTL to Bundling-GRC1.
  - The 2nd proactive fragmentation bundle was not retrieved
    - The directory and the syslog file showed creation of the 1st fragmentation metadata file, but not the second.
    - Analysis showed SSTL operating system limits file names to 32 characters.
- Test 4 – SSTL downloaded 150 Mbyte image cleanly
- Post Test analysis
  - Reconstructed DTN bundle payload and image file (tests 1 and 2) did not match
    - Bug found in GRC Saratoga Implementation of “Holes to fill” (we did not request retransmissions properly)
    - Decided to implement MD5 checksum on Spacecraft

DTN Test Results – August 2008

- Test 1 - Image file was received using GRC Saratoga version 0 implementation
- Test 2 - DTN file and associated metadata for the full bundle was received by Bundling-SSTL and then forwarded as a full bundle to Bundinging-GRC1
- Test 3 – Proactive Fragmentation:
  - The 1st proactive fragmented bundle from the UK-DMC and it was automatically transferred using DTN-2 between Bundling-SSTL to Bundling-GRC1.
  - The 2nd proactive fragmented bundle from the UK-DMC and it was automatically transferred using DTN-2 between Bundling-SSTL to Bundling-GRC1.
- Test 4 – SSTL downloaded 150 Mbyte image cleanly
- Post Test analysis
  - Reconstructed DTN bundle payload and image file (tests 1 and 2) matched



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.

Downloaded using bundling over *Saratoga*, with proactive fragmentation. Fragments assembled at NASA Glenn, then postprocessed at SSTL.

First sensor imagery delivered by bundles from space.

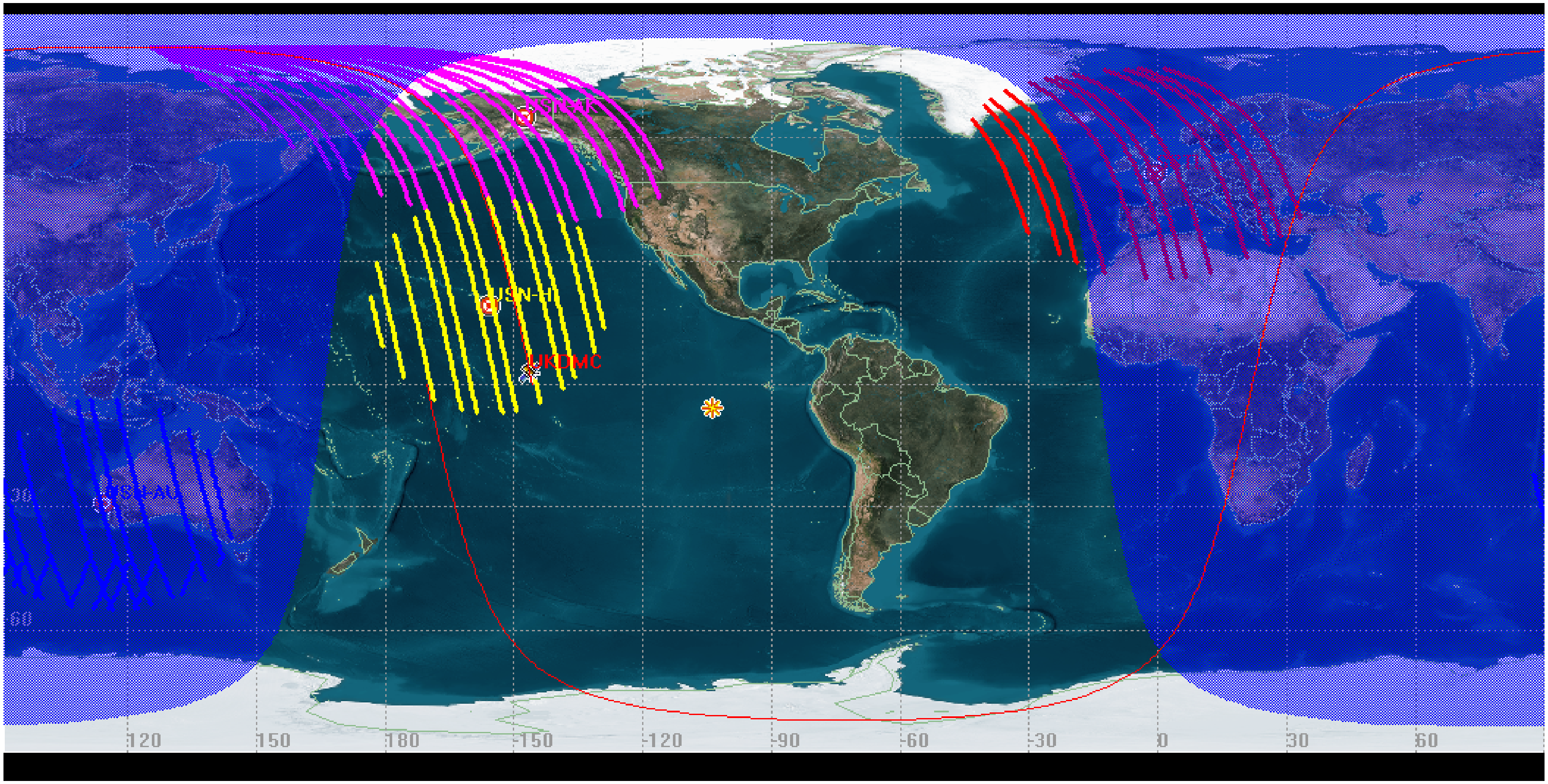
Large File Transfers using DTN

- First successful test August 27 and 28, 2008
  - Demonstrate DTN Bundle Transfer from UK-DMC to SSTL Ground Station.
  - Demonstrate that DTN code and general SSTL code can coexist without effecting normal SSTL Operations.
- Configuration
  - UK-DMC acquired a 150 Mbyte image.
  - DTN bundling code default set to 80 Mbytes for proactive fragmentation.
- Tests (All Successful)
  - Basic file download using existing technique (GRC Saratoga).
  - Same file downloaded but treated as single bundle (DTN).
  - Same file download but using DTN proactive fragmentation with 80 Mbytes preconfigured fragments. (Somewhere in the downloads we want to make sure we download the sysconfig that has the MD5 payload checksum).
  - Basic file download using SSTL Saratoga

Multi-Terminal Large File Transfers using DTN

- 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)

Ground Stations and UKDMC Contact Times



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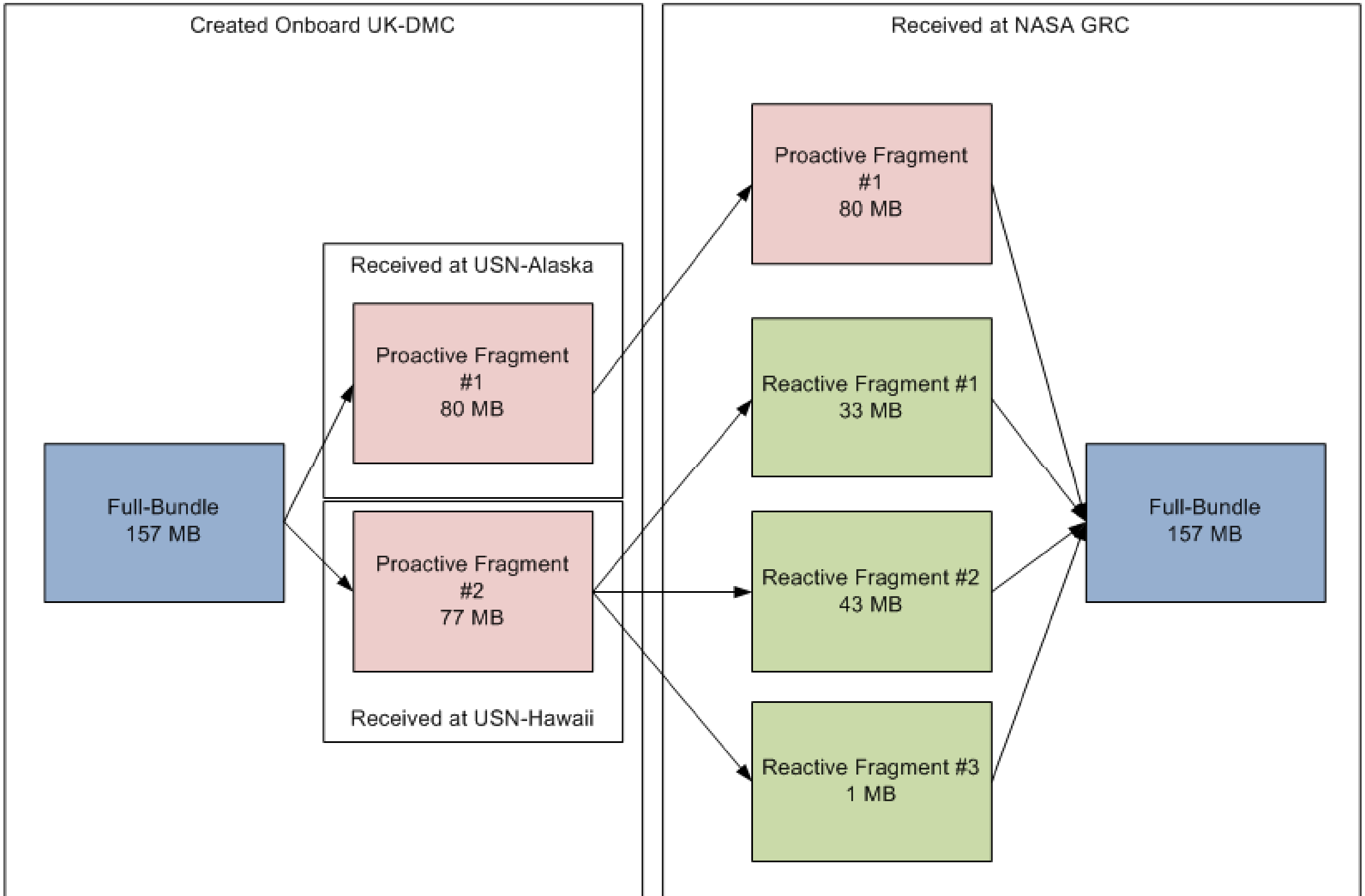
Multi-Terminal Large File Transfers using DTN

September 30 / October 1 Tests



Multi-Terminal Large File Transfers – Procedure

1. Use Satellite Tool Kit to determine UK-DMC contact times with Ground Stations
   - UKDMC high-rate passes require sunlight operations to conserve battery power
2. Check USN Operations Schedule for ground station availability
3. Reserve USN ground station time via email request
4. Request SSTL Operations via email
5. Check new USN operation schedule to confirm reservation and check SSTL confirmation. If steps 3 or 4 fail repeat with step 1 to determine new time.

Example Schedule Request for USN Operations

From: Ivancic, William D. (GRC-RHN0)
To: 'scheduler@uspacenet.com'
Cc: 'dstewart@grc.nasa.gov'
Subject: UKDMC Pass Requests for October 14

Message | Oct14_2009_ Request_Schedule.csv (4 KB)

```
UKDMC,AUWA01,Add,10/14/09,287,0:50:00,10/14/09,287,1:03:00,0:13:00,High Rate Pass access SSDR
UKDMC,USHI01,Add,10/14/09,287,19:08:00,10/14/09,287,19:18:00,0:10:00,High Rate Pass access SSDR
UKDMC,USAK01,Add,10/14/09,287,19:21:00,10/14/09,287,19:30:00,0:09:00,High Rate Pass access SSDR
```

Lessons Learned or Confirmed

- "Holes to fill" bug would have been caught with checksums (reliability check)
- Stringent ground-based testing with spacecraft engineering model or equivalent to identify and correct problems
- For DTN, Time Synchronization is critical
  - Test time synchronization of all DTN nodes prior to testing
  - DTN expiration timer was arbitrarily set to 3 days for UKDMC bundles
    - Requires image to be downloaded and delivered within 3 days of capture.
  - Perhaps current DTN requirement for time synchronization should be reconsidered.
    - Perhaps time synchronization optional?
    - Lots of discussion in the research community
    - Not all DTN nodes may be able to do time synchronization.
      - A definite problem in military networks
        - Maintain sync of a large radio network consisting of cheap radios (clock drift)
        - Bundle have short lifetime (Incoming!)
      - EVA currently may not have UTC time sync requirement
        - Bundles may have a short lifetime (Help!)

Cisco router in Low Earth Orbit

- Experimental payload onboard UKDMC
- Designed and integrated in 3 months!
- Full Commercial Cisco IOS, nothing special for flight
  - IOS (tm) 3200 Software (C3200-I11K9-M), Version 12.2(11)YQ, EARLY DEPLOYMENT RELEASE SOFTWARE (fc1) Synched to technology version 12.2(11.2u)T TAC Support: http://www.cisco.com/tac Copyright (c) 1986-2002 by cisco Systems, Inc. Compiled Thu 29-Aug-02 22:34 by ealyon Image text-base: 0x8002008C, data-base: 0x80BC4A00
- Demonstrated Capabilities
  - Mobile-IPv4
  - IPv4 IPsec
  - IPv6
  - Web Browsing
  - Security via SSH and HTTPS

Secure, Network-Centric Operations of a Space-Based Asset: Cisco Router in Low-Earth Orbit (CLEO) and Virtual Mission Operations Center (VMOC)

NASA/TM-2005-213556

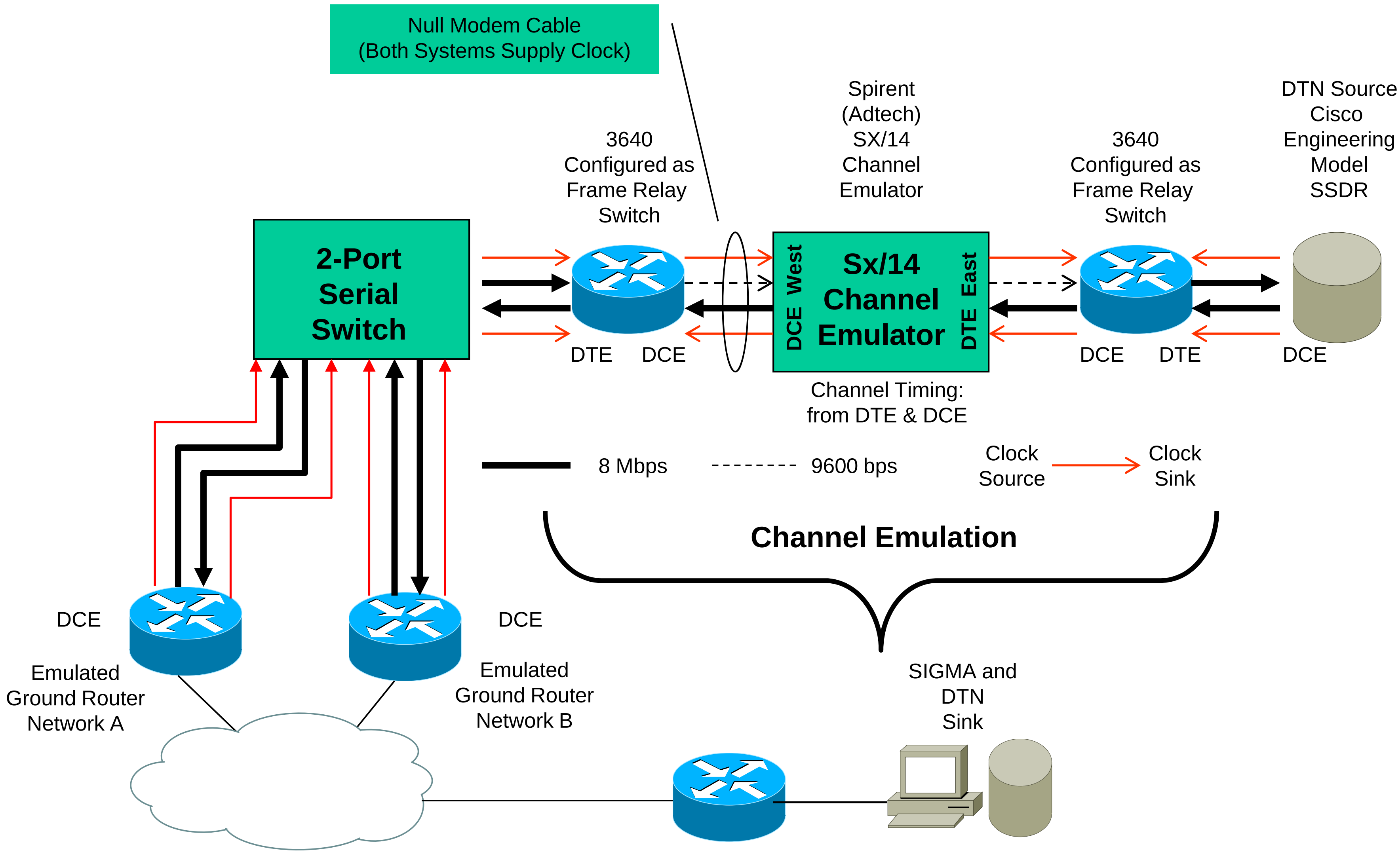
http://roland.grc.nasa.gov/~ivancic/papers_presentations/2005/cleovmoc.pdf

Backup

Number of Possible Tests per Pass

Description	Units					
Pass time	min	8	9	10	11	12
Pass time	seconds	480	540	600	660	720
Image Size (Mbytes)	Mbytes	160	160	160	160	160
Fragment Size (Mbytes)	Mbytes	80	80	80	80	80
Number of Fragments	GCI	2	2	2	2	2
Downlink Line Rate	Mbps	8	8	8	8	8
Test1: Saratoga full file Transfer Test	seconds	160	160	160	160	160
Test 2: DTN full Bundle Transfer	seconds	160	160	160	160	160
Test 3: Saratoga Proactive Fragmentation Transfer	seconds	160	160	160	160	160
Number of Tests Completed		3	3.375	3.75	4.125	4.5
Number of bundles that can be transferred in test 3		2	2.75	3.5	4.25	5

DTN Testbed


Null Modem Cable
(Both Systems Supply Clock)
3640
Configured as
Frame Relay
Switch
Spirent
(Adtech)
SX/14
Channel
Emulator
3640
Configured as
Frame Relay
Switch
DTN Source
Cisco
Engineering
Model
SSDR
2-Port
Serial
Switch
DTE
DCE
DCE West
Sx/14
Channel
Emulator
DTE East
DCE
DTE
DCE
Channel Timing:
from DTE & DCE
8 Mbps
9600 bps
Clock
Source
Clock
Sink
Channel Emulation
DCE
DCE
Emulated
Ground Router
Network A
Emulated
Ground Router
Network B
SIGMA and
DTN
Sink