Telemetry Storage Systems: A Comparison of Mission Approaches

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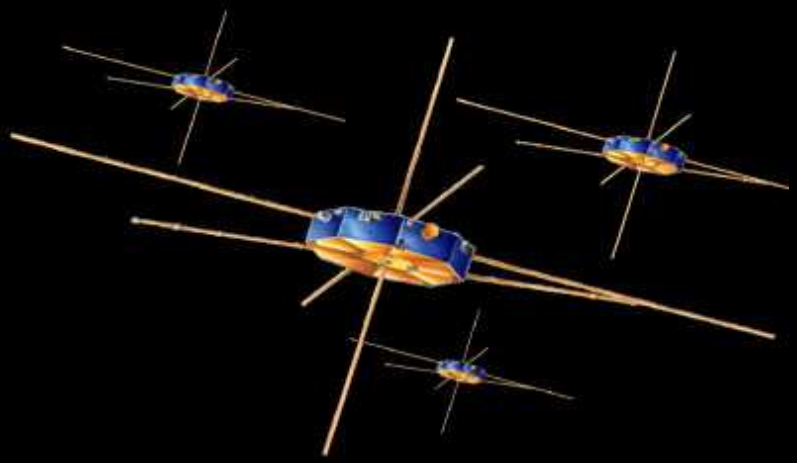
Overview

- Magnetospheric Multiscale (MMS)
  - Overview and Storage Approach
- Cyclone Global Navigation Satellite System (CYGNSS)
  - Overview and Storage Approach

MMS Mission

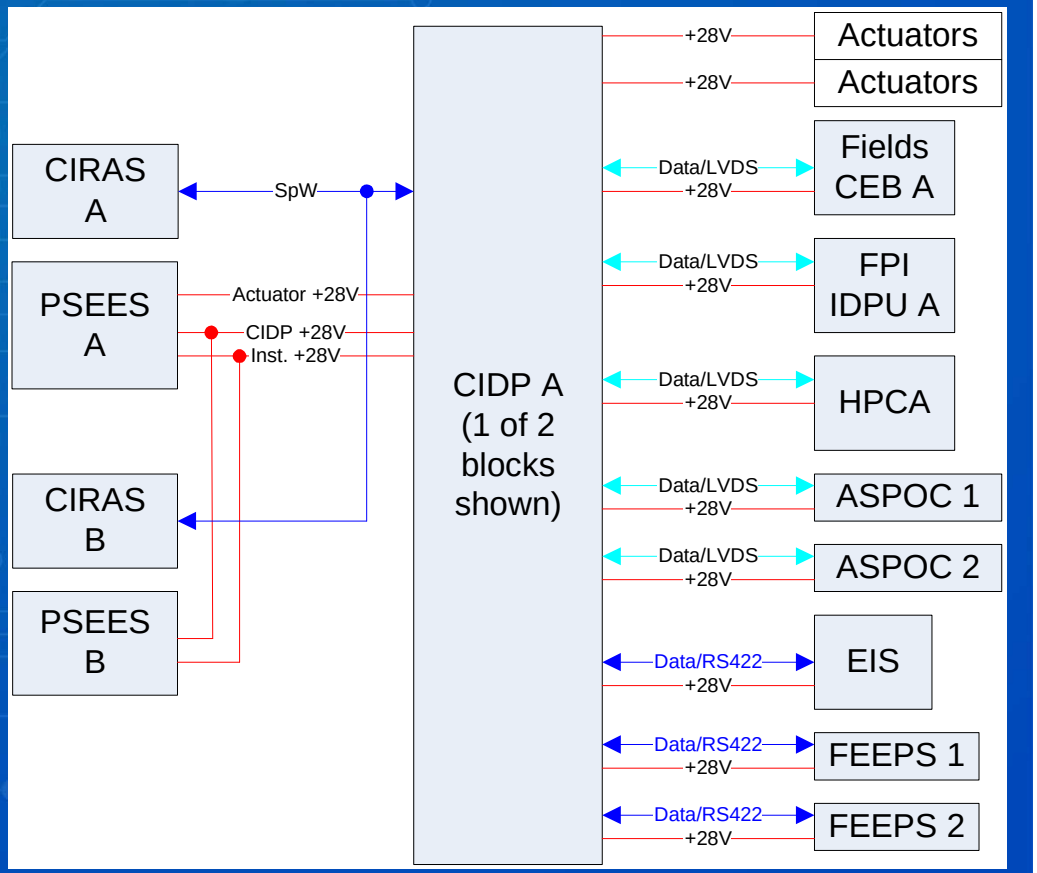
- Magnetospheric Multiscale (MMS)
  - Constellation of 4 identically spacecraft in variably spaced tetrahedron (7 km to several 100 km)
    - Ground contacts must be multiplexed in time in order to retrieve data from all 4 spacecraft each day
- Objective: To discover the detailed physics of the reconnection process including its controlling factors, its spatial distribution, and its temporal behavior.



https://mms.gsfc.nasa.gov

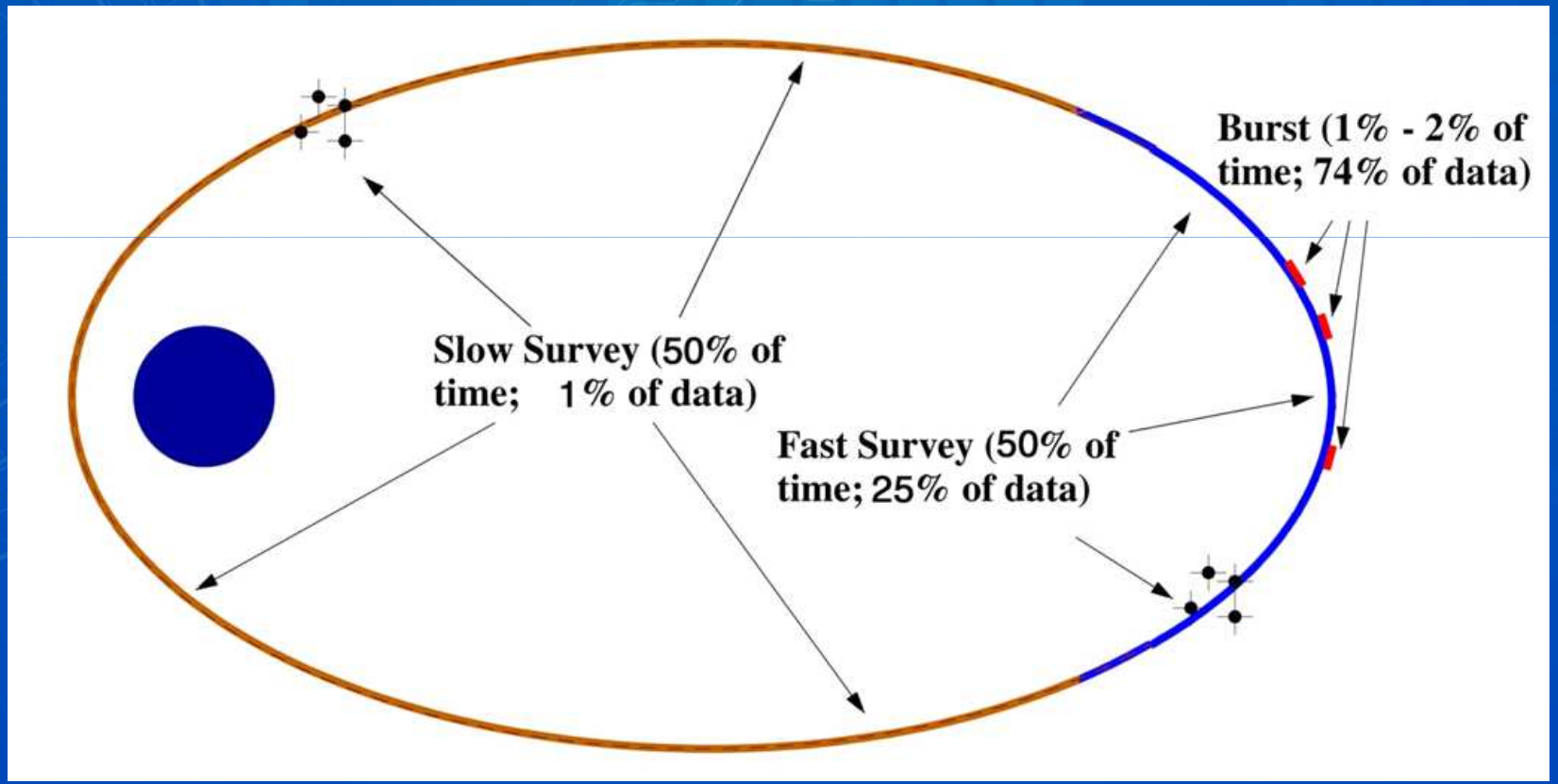
MMS Mission

- Solving Magnetospheric Acceleration, Reconnection, and Turbulence (SMART) Instrument Suite
  - Central Instrument Data Processor (CIDP)
    - SPARC Processor
    - Stores science data for the Instrument Suite
    - Instruments can collect far more data than can be sent via downlink



MMS Mission

- Highest resolution data is voluminous
  - Collect best quality data for region of interest



MMS Storage Approach - CFDP

- CCSDS File Delivery Protocol
  - CFDP is a protocol for transferring files to and from a spacecraft memory
    - Files can be transferred reliably, where it is guaranteed that all data will be delivered without error, or unreliably, where a best effort delivery capability is provided.
    - Files can be transmitted through at various speeds through different link types and through intermediate relay spacecraft.
      - Class 1 - Unreliable transfer
      - Class 2 - Reliable transfer
      - Class 3 - Unreliable transfer via one or more waypoints in series
      - Class 4 - Reliable transfer via one or more waypoints in series
    - File transfer can be initiated automatically by the onboard entity or manually by ground control.

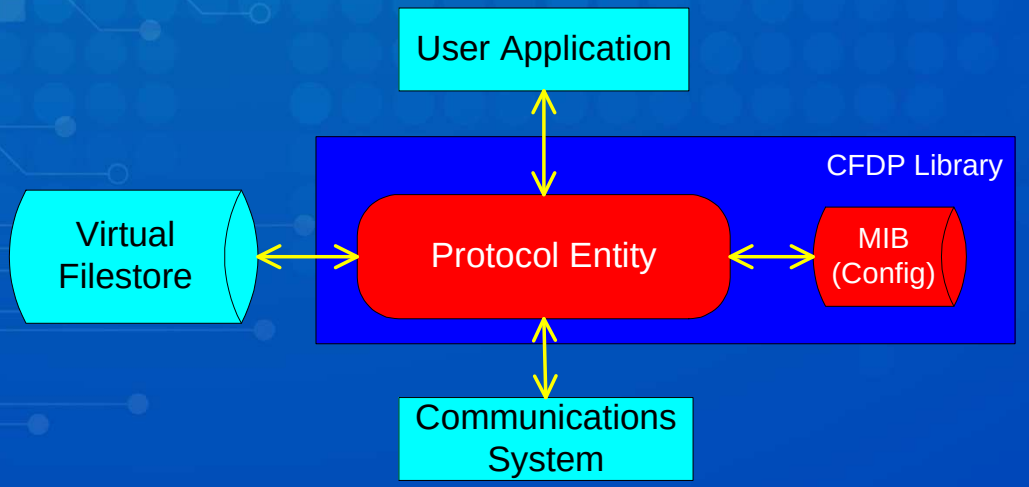
Since we do not relay through intermediate waypoints, only Class 1 and Class 2 service are implemented on the MMS CIDP entity. In order to maximize the science data return, file transfer is initiated by the entity onboard.

Why use CFDP?

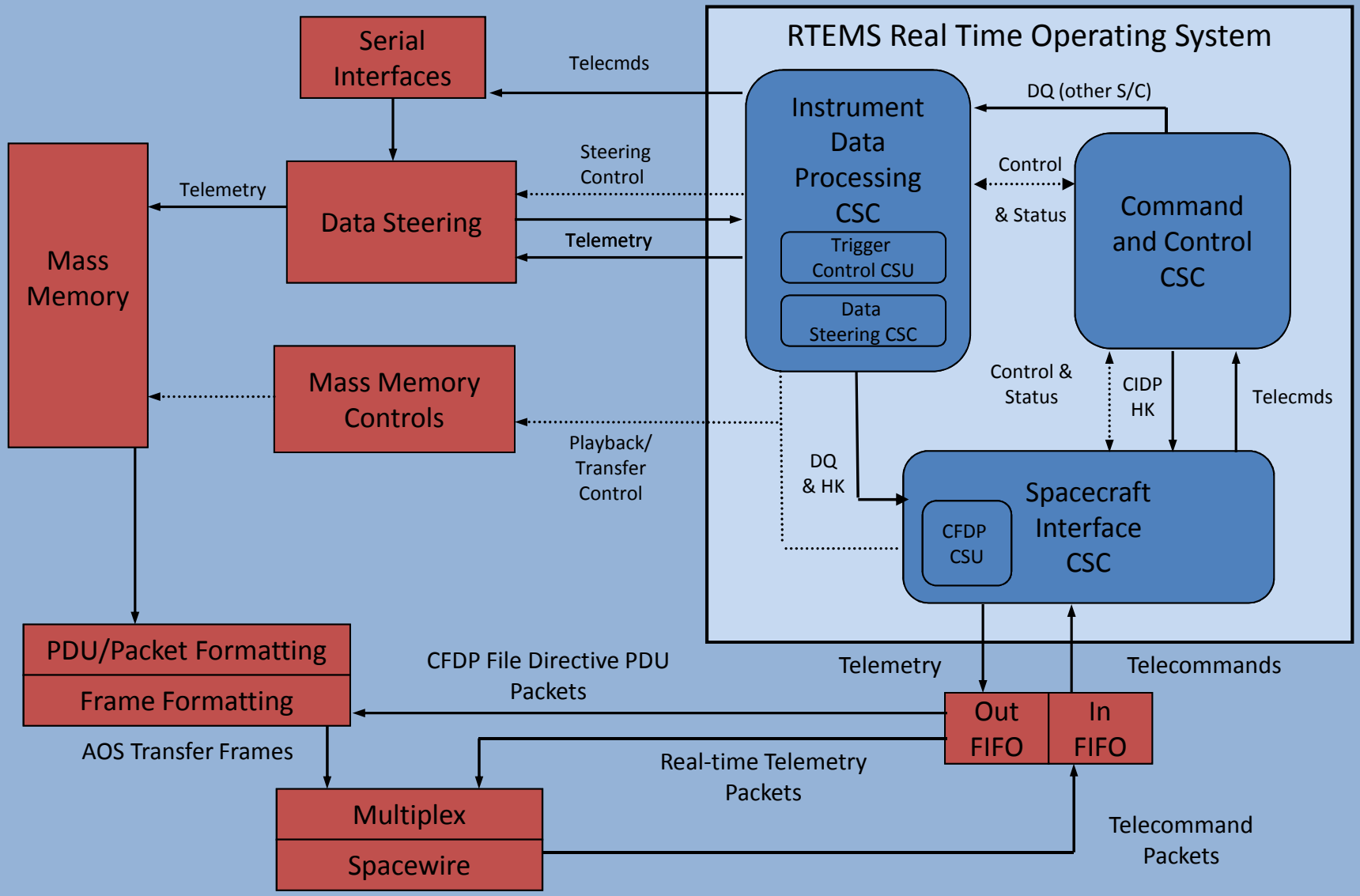
- Downlink is a precious resource
  - Ground contacts are limited - make the most of them
  - Lost data can mean lost opportunities for science
- Operations costs are a significant part of the mission budget
  - CFDP helps to automate routine data delivery operations to simplify operations, thereby providing some promise for reducing these costs
- Standard protocol encourages interoperability
  - Benefit realized as CFDP is adopted on more missions

MMS Storage Approach - CFDP

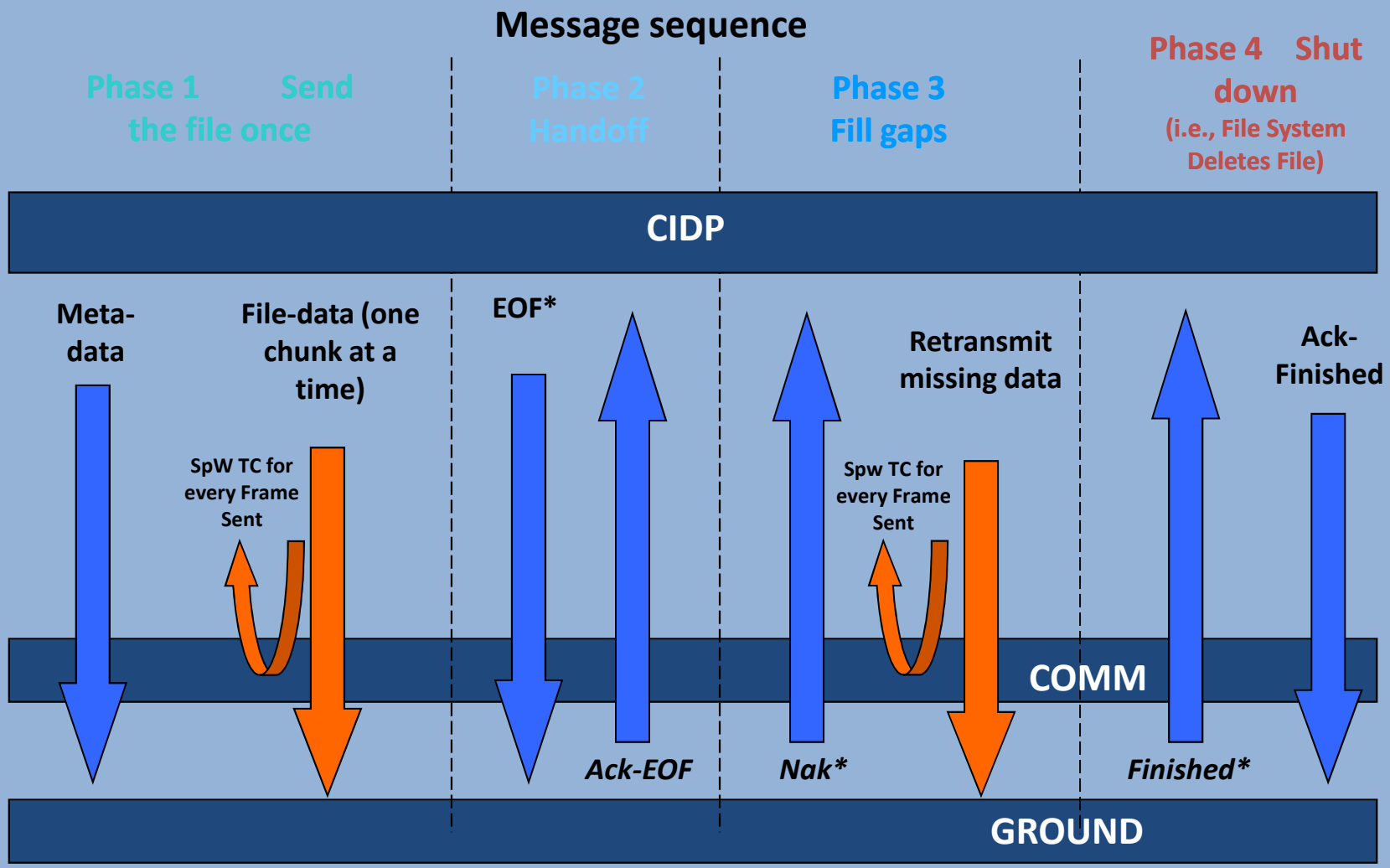
- Highlights
  - CCSDS Space Packet Protocol is underlying protocol
  - Class 2 (Reliable) with Deferred NAK
  - Class 1 (Unreliable) is backup
- Use NASA GSFC CFDP Library
  - Implements State Machines
  - Interfaces to User Application, Virtual Filestore and Communications System
- CIDP Mass Memory is Virtual Filestore
  - No File System
  - Partitioned into 4 MB fixed-size files
  - Flash buffers managed in pools
    - In-use
    - Free
    - Held
      - Available for downlink
      - Downlink may occur while in region of interest



MMS Storage Approach - CFDP



MMS Storage Approach - CFDP



** Timers are used to ensure retransmission of the EOF, Nak, and Finished messages as required. The Nak message reports all missing data (including Metadata).*

MMS Storage Approach - CFDP

- Application Interface
  - Calls to CFDP Library
    - Set Configuration (i.e. MIB) Dynamically
    - Give Request to Library
    - Give PDU to Library
    - Control delivery rate for PDUs

      Function invoked to send next data PDU
    - Register callbacks for Indication
  - Callbacks from Library
    - CFDP Indications
- Virtual Filestore Interface
  - Callbacks from library
    - File I/O primitives

      fopen(), fseek(), fread(), fwrite(), feof(), fclose()
    - Other Posix primitives

      rename(), remove(), tmpnam()
- Communication System Interface
  - Callbacks from Library
    - Open PDU channel
    - Channel Ready?
    - Send PDU on channel

MMS Storage Approach - CFDP

- Virtual Filestore Interface
  - Callbacks from library
    - File I/O primitives
      - fopen() - transfer file to Output Buffer and optionally perform compression
        - Set start offset to 0
        - Return corresponding buffer index
      - fread()
        - If first call after fopen() or fseek(), then initiate HW playback
        - Simply advance read count
      - fseek()
        - Set HW start offset for retries
      - fwrite()
        - Not allowed

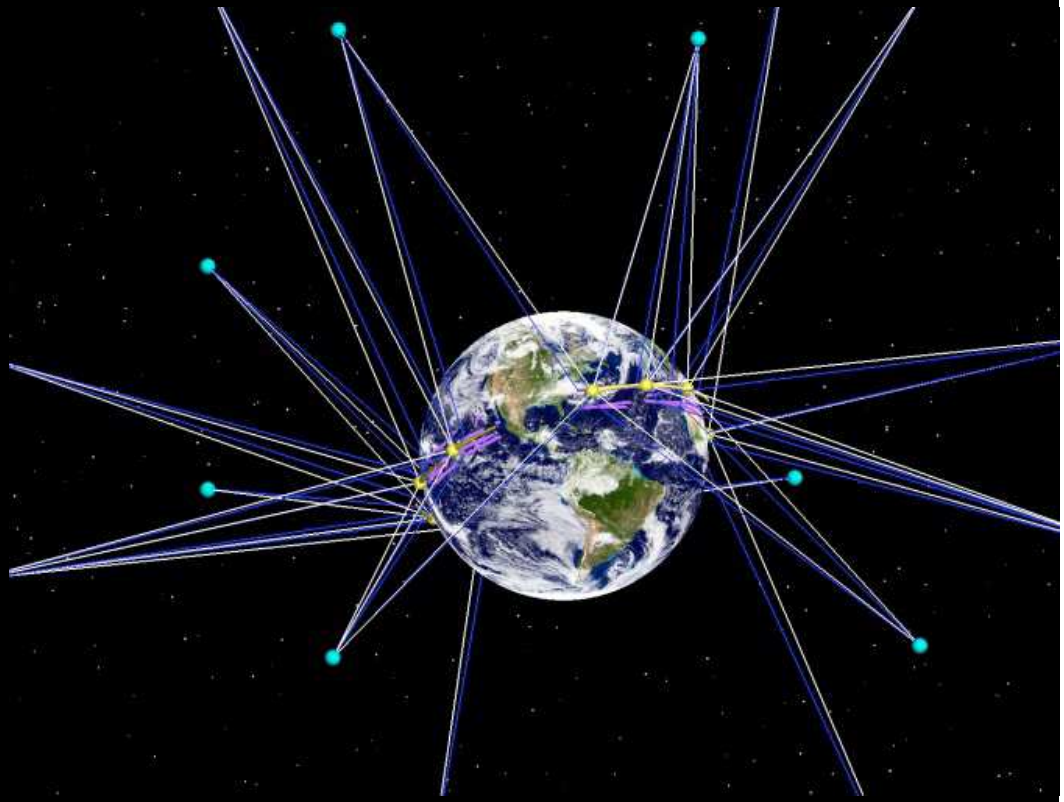
- Communication System Interface
  - Callbacks from Library
    - Open PDU channel
      - Initiate HW handshaking
    - Channel Ready?
      - HW ready if SpW link is up
    - Send PDU on channel
      - Send File Directive PDUs to Data Formatter to include in VC stream
      - Ignore File Data PDUs – these are being generated by the

MMS Storage Approach - CFDP

- Use Virtual Filenames
  - Mass Memory Buffer Index + Timestamp
- Hardware forms File Data PDUs
- Software forms and responds to File Directive PDUs
- Hardware/Software Synchronization
  - Hardware provides for configuration of start and end offsets in Mass Memory Buffer
    - Aligned on segment boundaries (i.e. ~ 1 KB)
  - Once playback is initiated, HW transfers File Data PDUs until completed
    - Interrupt wakes up SW task when a number of segments have been transferred
    - SW task calls CFDP Library rate control function in a loop to match up file read pointer with those segments sent by HW

CYGNSS Mission

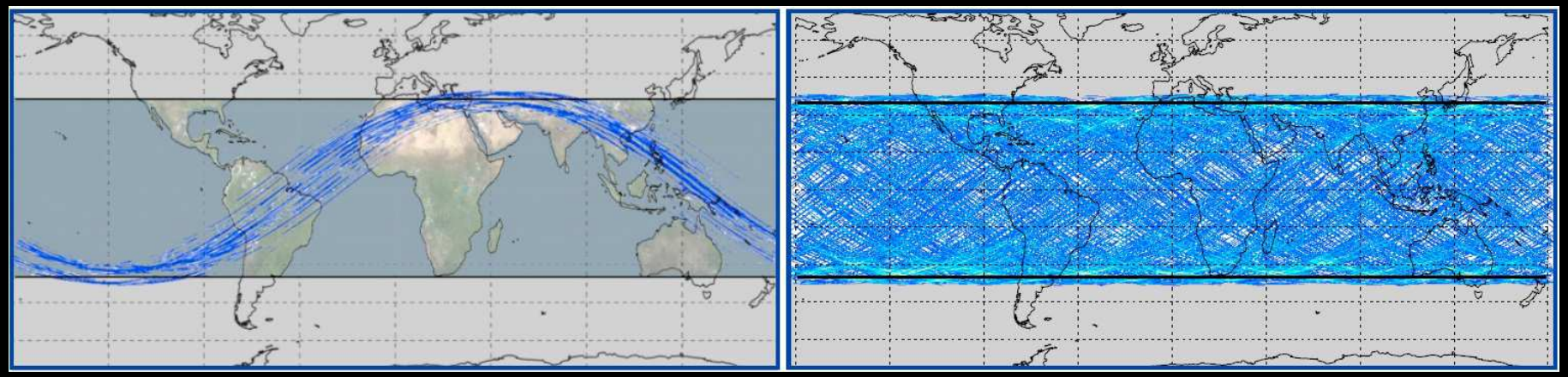
- Cyclone Global Navigation Satellite System (CYGNSS)
  - Constellation of 8 low-earth orbiting microsatellites that receive both direct and reflected signals from the Global Positioning System (GPS) satellites
  - Direct signals pinpoint satellite positions, while the reflected signals respond to the ocean surface roughness, which can be used to derive wind speed



http://clasp-research.engin.umich.edu/missions/cygnss

Objective:
Study the relationship between ocean surface properties, moist atmospheric thermodynamics, radiation and convective dynamics, to determine how a tropical cyclone forms and strengthens.

CYGNSS Mission



http://clasp-research.engin.umich.edu/missions/cygnss

The 8 CYGNSS microsatellites are at an inclination of 35 degrees and are each capable of measuring 4 simultaneous reflections, resulting in 32 wind measurements per second across the globe. Ground tracks for 90 minutes (left) and a full day (right) of wind samples are shown above.

CYGNSS Storage Trade Study

- To CFDP or not to CFDP?
  - In contrast to MMS which had long contacts (1 hour / day), CYGNSS has much shorter contacts (10 minutes / two days).
  - USN does not have bandwidth to relay playback data in real-time
  - No substantial benefit to using CFDP in this case

Considerations	CFDP	Custom Packet Replay
Cost to Design	No Impact	Minimal Negative Impact
Cost to Implement in FSW	Moderate Negative Impact	Moderate Negative Impact
Cost to Implement in EGSE	Moderate Negative Impact	Minimal Negative Impact
Ground System and Operations Software	Major Negative Impact	Minimal Negative Impact
FSW Size	Moderate Negative Impact	Minimal Negative Impact
FSW Processor Load	Moderate Negative Impact	Minimal Negative Impact
Downlink Rate	Moderate Negative Impact	No Impact

CYGNSS Storage Approach

- Hybrid Hardware/Software Implementation
  - Use CCSDS Space Packet Protocol without CFDP
  - Simple Sequential Input/Output

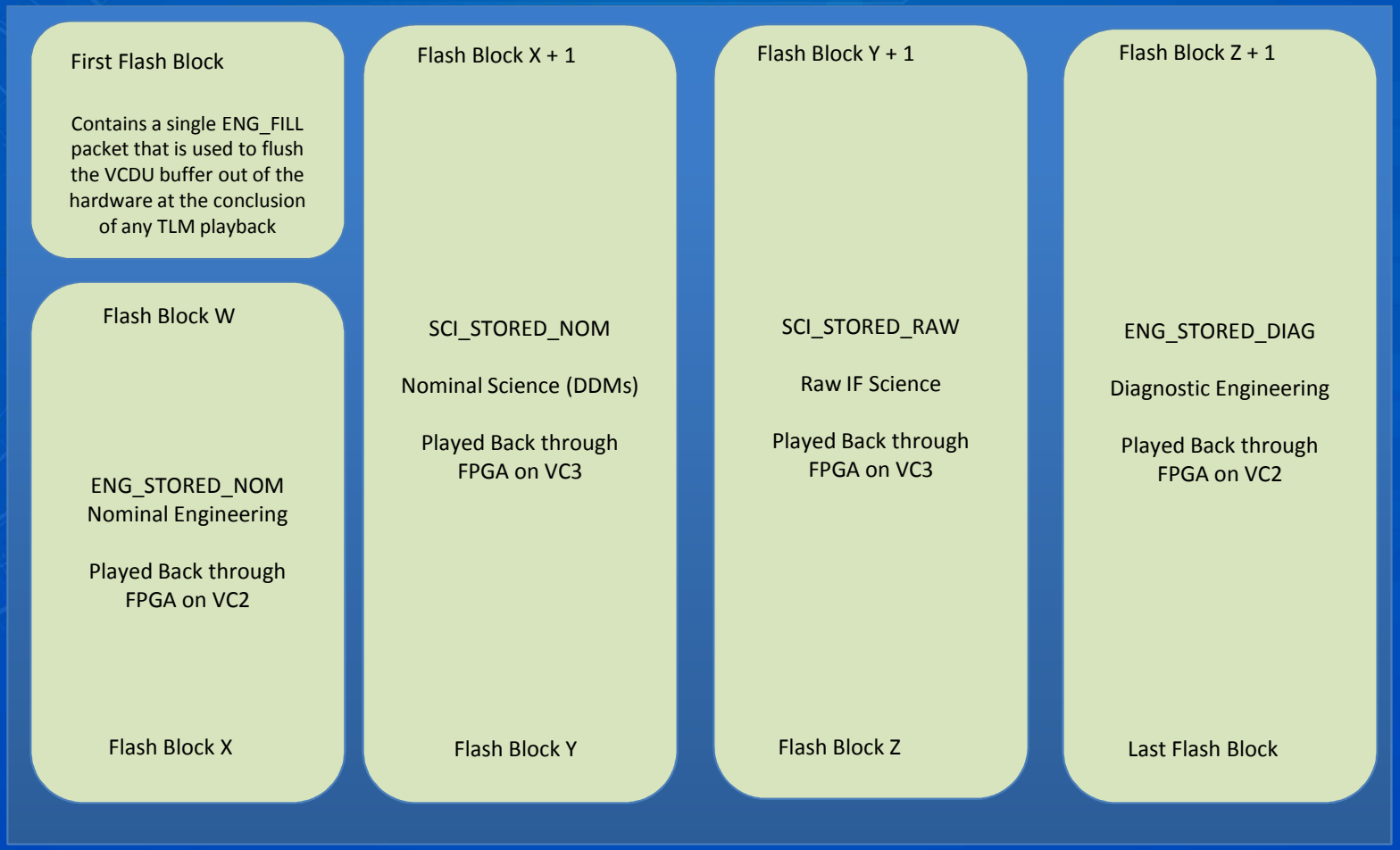
- Hardware
  - Does playback heavy lifting
    - Maximizes downlink*
    - Read back CCSDS Space Packets
    - Formats packets into frames and ultimately CADUs
    - One block at a time
      - Interrupt software when block playback complete

- Software
  - Does recording heavy-lifting
    - Command ERASE of Flash blocks
    - Write complete pages of Flash
    - Flash blocks only contain complete packets to facilitate hardware playback
  - Tracks bad blocks
  - Chains together consecutive blocks for playbacks

```
* - A hardware implementation of
the CFDP protocol would be much
more complex.
```

CYGNSS Storage Approach

- CCSDS Space Packets stored in partitions that consist of sequential blocks of Flash memory

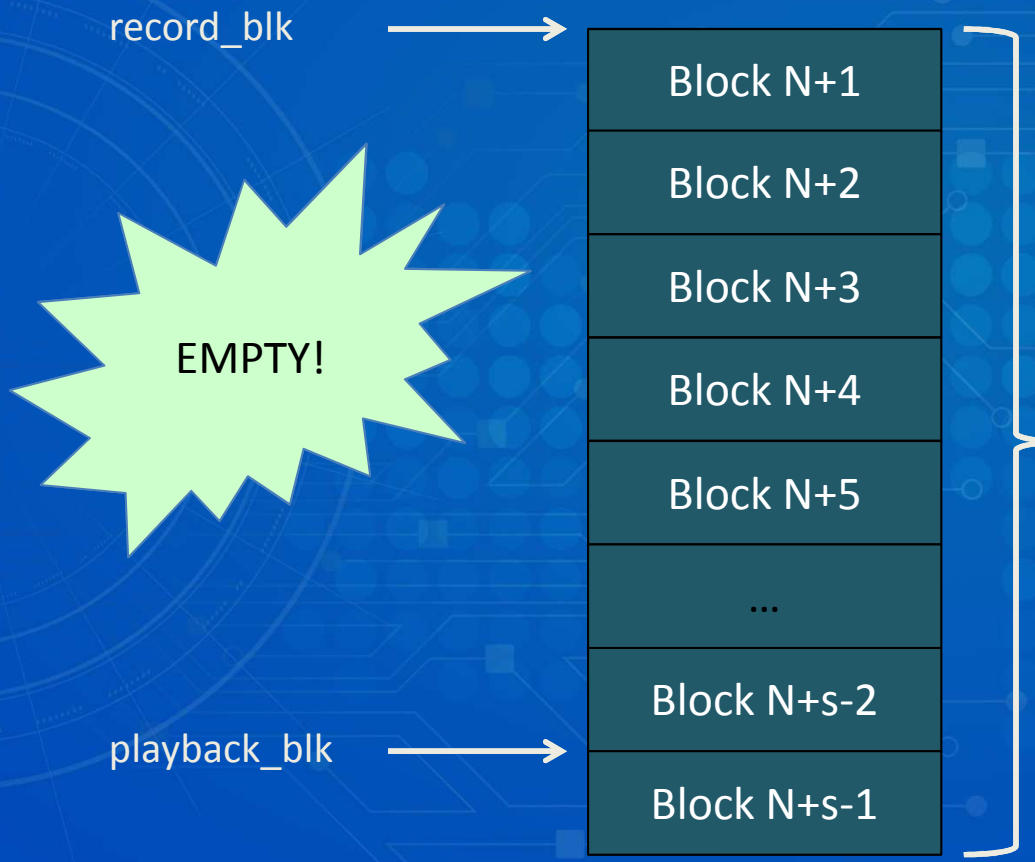


CYGNSS Storage Approach

- Data Structures - Flash Allocation Table (FAT)
  - Track playback and record pointers for circular buffers

	Next Block To Be Recorded `uint32_t`	Block just before Next Block to be Played Back `uint32_t`	Block Area Start Index `uint32_t`	Block Area Length `uint32_t`	Next Record Page uint32_t	Number of Bytes Buffered uint32_t	Overwrite Status uint32_t	Ticking Byte Counter uint32_t
Engineering Stored Nominal	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Page Number]*	*[Number of Bytes]*	*[Overwrites Allowed]*	*[Byte Counter]*
Engineering Stored Diagnostic	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Page Number]*	*[Number of Bytes]*	*[Overwrites Allowed]*	*[Byte Counter]*
Science Stored DDM	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Page Number]*	*[Number of Bytes]*	*[Overwrites Allowed]*	*[Byte Counter]*
Science Stored RAW	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Block Index]*	*[Page Number]*	*[Number of Bytes]*	*[Overwrites Allowed]*	*[Byte Counter]*

CYGNSS Storage Approach



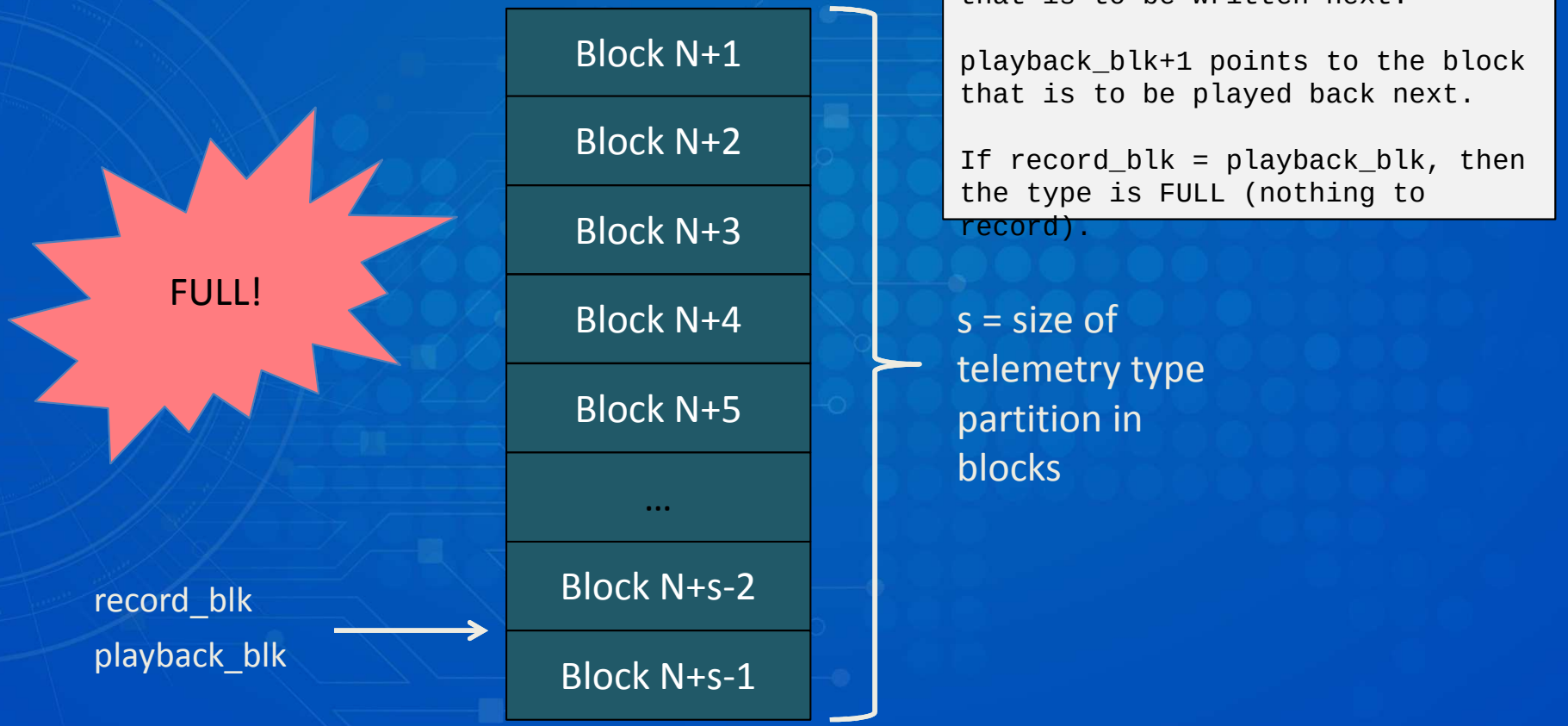

```
record_blk points to the block
that is to be written next.

playback_blk+1 points to the block
that is to be played back next.

If playback_blk+1 = record_blk,
then the type is EMPTY (nothing to
playback).
```

s = size of telemetry type partition in blocks

CYGNSS Storage Approach



CYGNSS Storage Approach

- Data Structures - Flash Block Table (FBT)
  - Track number of ERASE cycles and bad blocks

	Erase Counts `uint32_t`	Block Status `uint32_t`
Block #1	*[Erase Count 1]*	*[NOT-BAD / BAD]*
Block #2	*[Erase Count 2]*	*[NOT-BAD / BAD]*
Block #3	*[Erase Count 3]*	*[NOT-BAD / BAD]*
Block #4	*[Erase Count 4]*	*[NOT-BAD / BAD]*
Block #5	*[Erase Count 5]*	*[NOT-BAD / BAD]*
Block #6	*[Erase Count 6]*	*[NOT-BAD / BAD]*
….continued….		

Size = 128 kB MRAM

Summary

- Magnetospheric Multiscale (MMS)
  - Used CFDP as a front-end for a primitive file system
  - Reliable file transfer provided in the protocol
  - Worked well for daily contacts of about 1 hour
- Cyclone Global Navigation Satellite System (CYGNSS)
  - Used a simple sequential record/playback approach
  - Reliable file transfer not provided by the protocol but loss is tolerable
  - Expect to work well for short contacts where playback data is buffered by USN and not relayed in real-time to mission operations

Questions?