

Delay Tolerant Networking

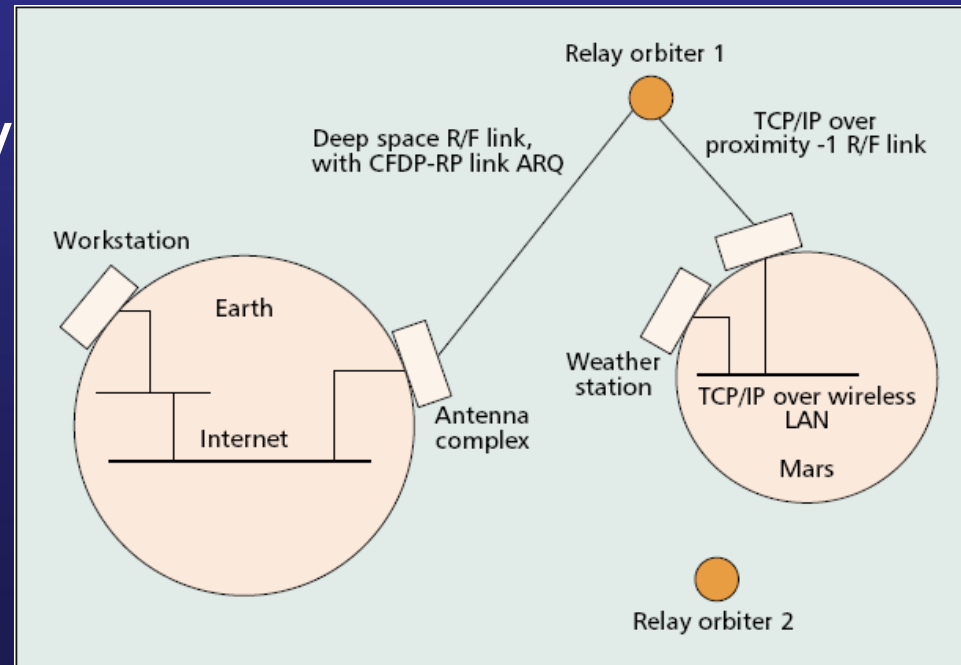
Steven Bingle
Eduardo Moreno



What is Delay Tolerant Networking? (DNT)

A DNT is a network that can handle delays in communication due to:

- Distance
- Periodic Connectivity



What About Current Protocols?

Why can't TCP/UDP, or other similar protocols, be adapted for DNT?

Why not just increase the timeout period?

Time

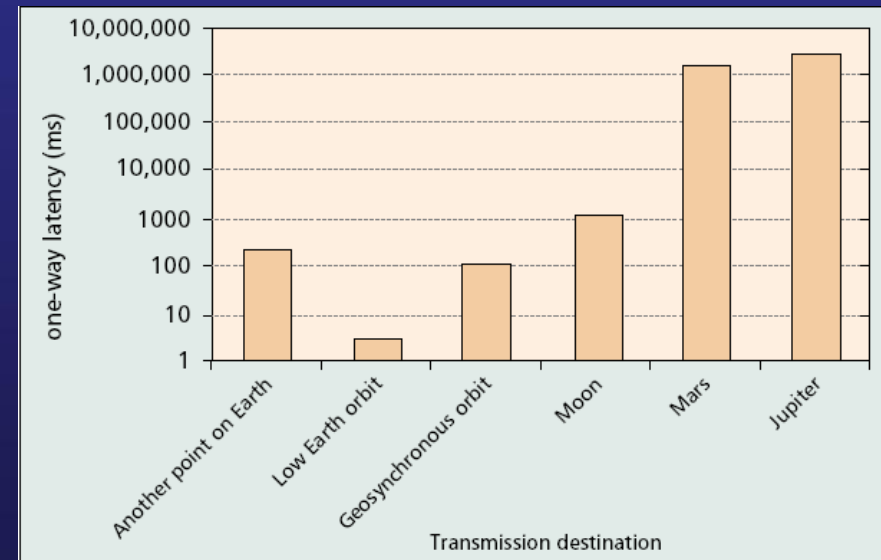
Round Trip latency could be very high
(On the order of minutes to hours or days)

TCP wants to

- Negotiate a connection
- ACKs for all data

Other reasons

- Reliability



What Are The Challenges?

A DNT would need to:

- Be reliable
- Handle loss of connection
- Handle poor connection
- Handle large round trip latencies

What Would a DTN Architecture Include?

- Postal model of communication
 - Can't rely on query/response systems
 - Data should be atomic units of work
 - Messages should be asynchronous
 - Data packed into bundles
- Tiered Functionality
 - Different environments require different protocols
 - Use these local protocols to take advantage of the region
- Terseness
 - Bandwidth likely will not be cheap



Tiered Forwarding

Different regions within a DTN use different protocols

- Each region forwards the data its own way
 - A region is a set of nodes which use a common local protocol
- Gateways forward between regions
- Forwarding nodes may need to store bundles
 - Storage for mins/hours/days
 - Connectivity can not be assumed



Tiered Naming and Addressing

In order to reach their destination, bundles need to be tagged with a destination identifier

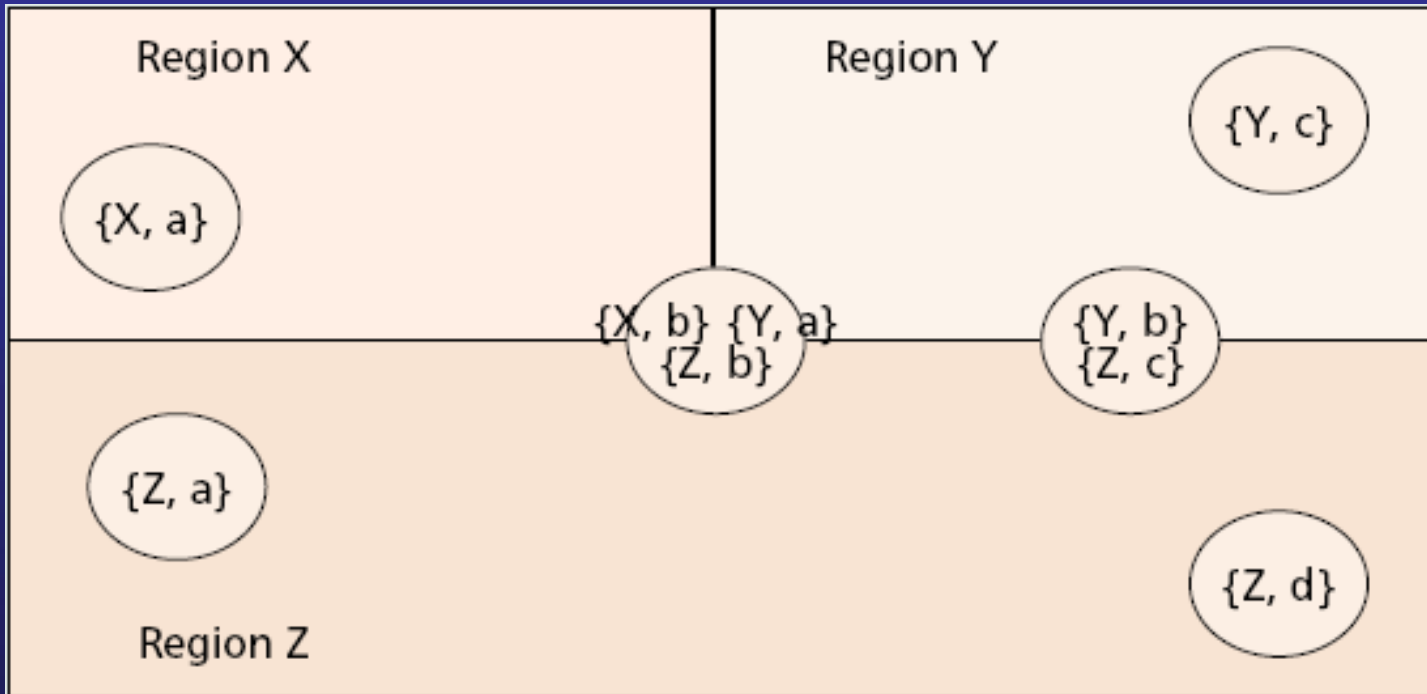
- Destination region
- Node within region

Names are late bound

- Mapped to regional addresses after arriving in region
- Nodes do not need to understand all possible naming schemes



Regions Within a DTN



Tiered Routing

The forwarding performed by bundling needs to be sensitive to future link opportunities.

These opportunities may come about because

- Networking management
- Prediction of node movement (orbital)
- Real time discovery



Tiered ARQ

Need to be careful with ARQ usage

- Too soon - wasted bandwidth
- Too late - degraded throughput

Each region should handle internal ARQs

What about lost data?

- Nodes take custody of bundles
- If custodial node does not receive custody request - retransmit



Tiered Security

- Limited bandwidth necessitates minimal usage.
- Keep unauthorized data from congesting network
- Nodes may be mutually suspicious of each other
- Need to be careful - shared key and key servers are not efficient
- Embed certificates? May violate terseness



Tiered Congestion Avoidance

- Regions of low latency can use TCP which controls congestion
- Regions of high latency use reservation for bandwidth usage



Resilient Delivery

Long transmission times may mean the receiver has stopped being ready for the data

- Node should hold onto data until receiver is ready again
- Nodes may also signal the receiver to become ready



Postal Service Levels

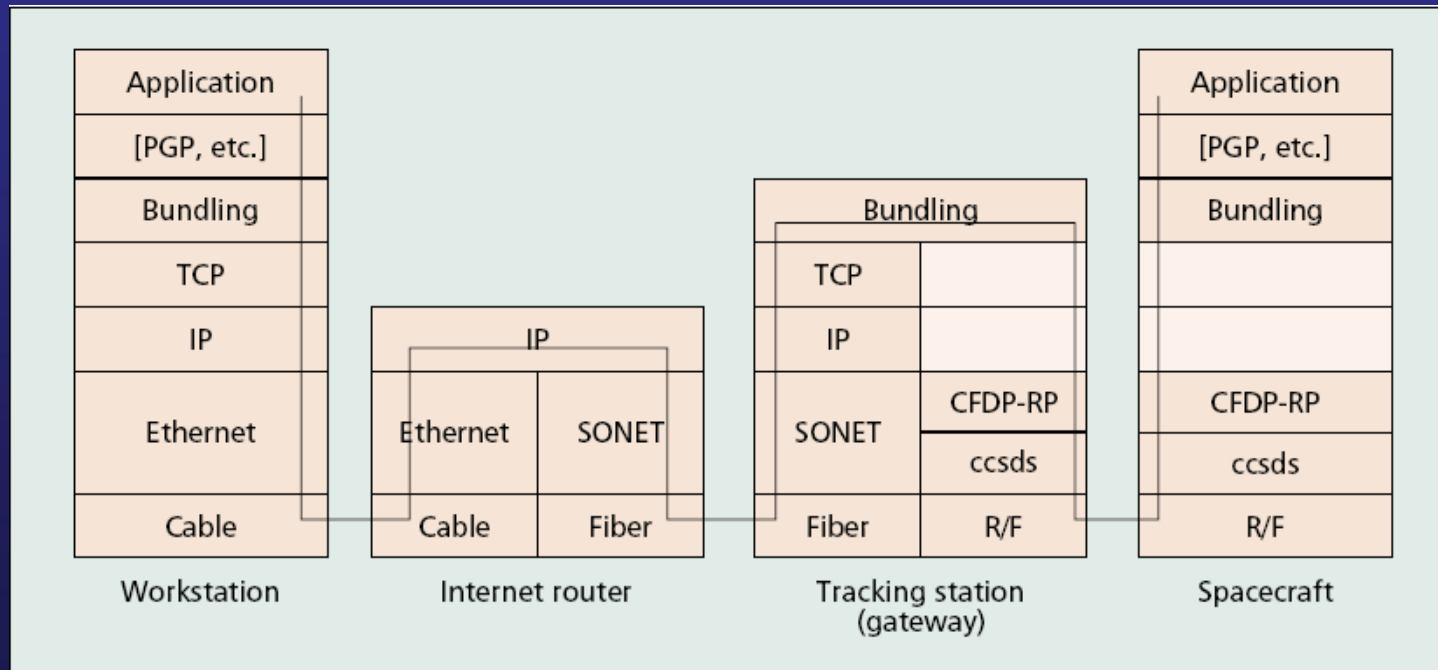
Being based on a postal model, some additional attributes may be useful

- Priority levels
 - Low, Standard, High
- Notices
 - Of transmission
 - Of delivery
 - Of route taken



DTN Architecture

A network that can integrate these elements is very adaptable, extensible, and simple



Reliability Options for Data Communications in the Future Deep-Space Missions

De Cola, T.; Paolini, E.; Liva, G.; Calzolari, G.P.

Proceedings of the IEEE , vol.99, no.11, pp.2056-2074, Nov. 2011

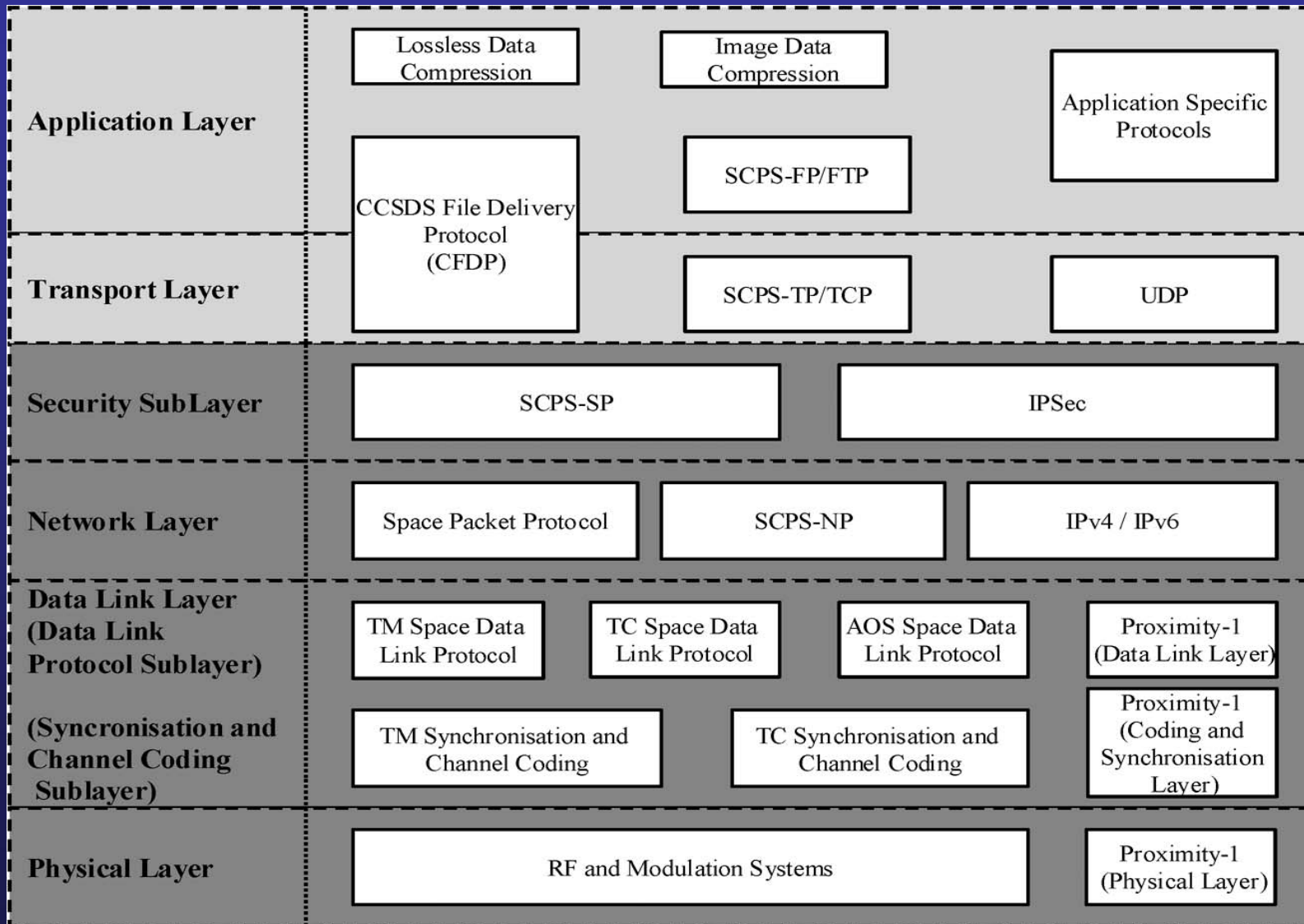


Consultative Committee for Space Data Systems (CCSDS)

- Formed in 1982 to solve common problems in the operation of space data systems.
- 11 members, 22 observers agencies, 100+ industrial associates.
- Standardization and interoperability of different space agencies.
- Protocol recommendations.
- Reduce risk, development time and project costs



CCSD



Channel Coding

- TM - Packet Telemetry
 - stream of fixed length transfer frames (space to ground)
- TC - Packet Telecommand
 - stream of sporadic, variable length transfer frames (ground to space)
- AOS - advanced orbiting systems
 - back and forth "online" data (developed for the ISS)
 - video and data
 - few hundred bps uplink

Channel Coding

- Dominated by Proximity-1
 - two way communication (used in Mars Rover)
 - Physical Layer
 - Pulse code modulation bi-phase-encoded
 - Datalink
 - frame delimiting, frame synchronization, bit transition generation and removal, and error control coding (TM)
 - segmentation/blocking and transmission control (TC)



Other Layers



- Network

- Space Packet Protocol (SPP)
 - routing operations by means of path
- (SCPS -NP)
 - no longer standard CCSDS
- IPv4 and IPv6 (IETF)

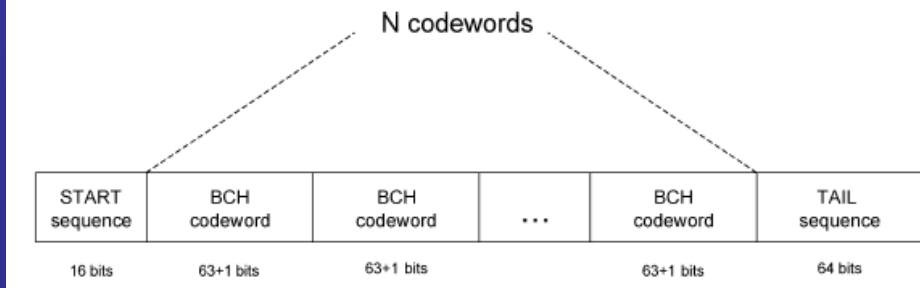
- Transport

- use is not mandatory in CCSDS
- SCPS transport protocol based on TCP but improved for deep-space environment

- Application

- FTP like system
- Asynchronous message service (AMS)
 - housekeeping data

Reliability



Undetected error probability $< 10^{(-9)}$

Rejection probability - entire communication link transmission unit (CLTU) rejected if only one BHC (Bose, Chaudhuri, Hocquenhem) $< 10^{(-3)}$

$$g(X) = X^7 + X^6 + X + 1 = (X^6 + X + 1)(X + 1). \quad (1)$$

Hamming code (63,57)

becomes (63,56) with padded '0' resulting in:

$10^{(-22)}$ TED

$10^{(-17)}$ SEC



Reliability

Proximity - 1

CCSDS convolutional code (7,1/2).

$$\begin{aligned}g(X) &= X^{32} + X^{23} + X^{21} + X^{11} + X^2 + 1 \\ &= (X^{21} + 1) \cdot (X^{11} + X^2 + 1)\end{aligned}\quad (4)$$

32 bit CRC can detect single, double, triple, odd multiplicity, single error bursts < 32 bits in length and two error bursts whose sum < 22 bits.

Next Generation Uplink (NGU)

data rates > 1 Mbps



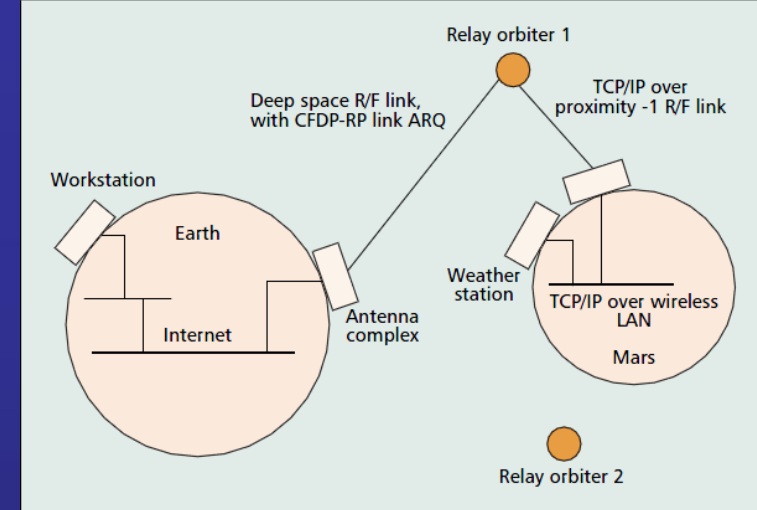
Erasure Codes

- Turn message of k symbols into message of n symbols such that original message can be recovered from a subset of n symbols (n,k)
 - Low Density Parity Check (LDPC)
- Frame Erasure Code - generation and transmission of information and redundancy
- Type I hybrid ARQ - retransmission of symbols that could not be recovered
- ~~● Type II hybrid ARQ - sending additional redundancy symbols when erasure decoding fails~~
- ~~● weather genie - exploits return channel to acquire channel state and adapt the coding accordingly.~~



Bundle Protocol (BP)

- Store-carry-forward
 - great for link disruption and service unavailability
 - Requires high memory.
- Message carrying service - Application data encapsulated in BPDUs
- Mailman principle
 - Each node is responsible for the integrity and transmission of each bundle
- Works with different protocols
 - TCP, UDP and LTP.

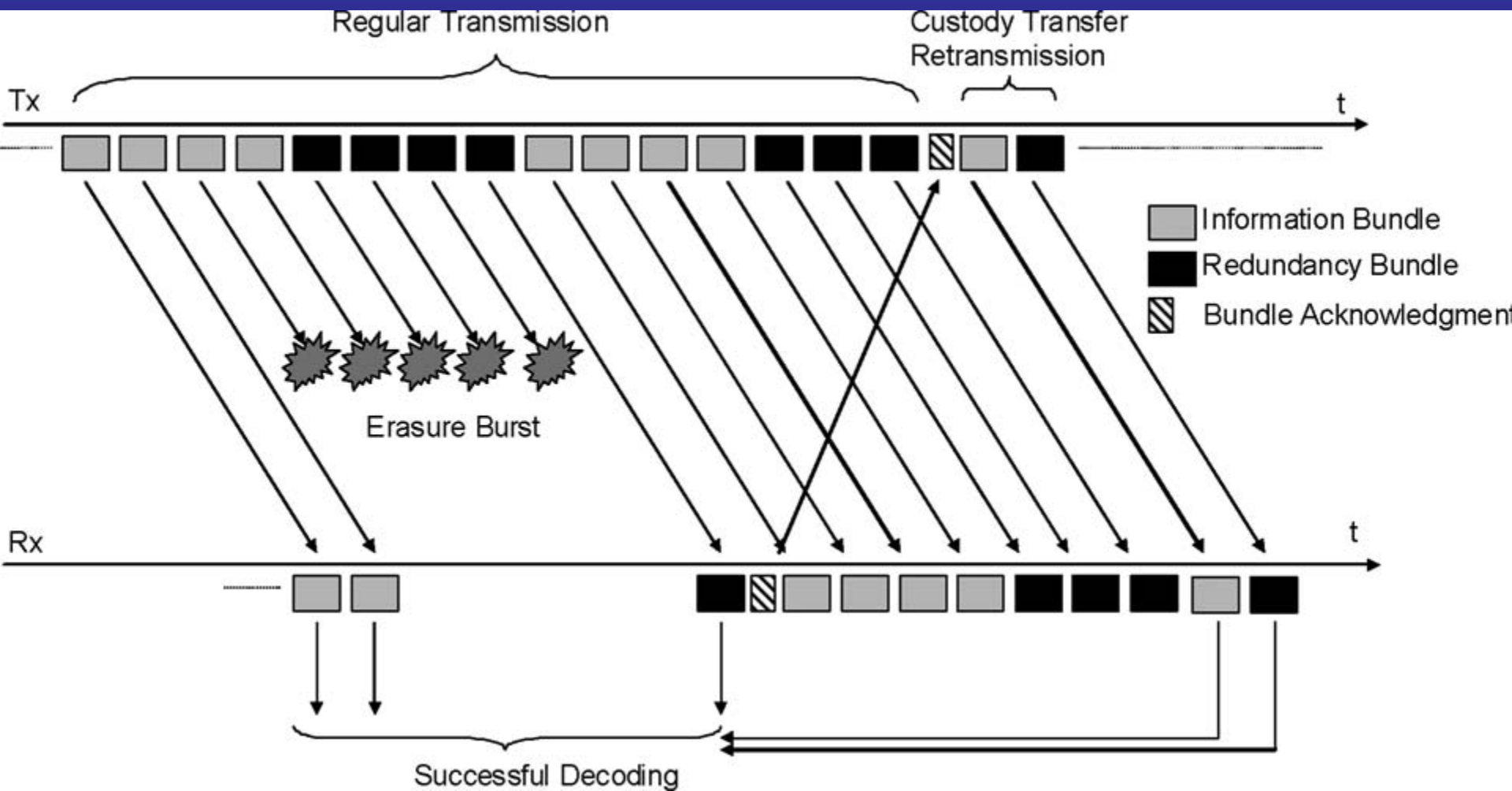


Licklider Transmission Protocol (LTP)

- Point to point
 - replaces TCP
 - better at handling long delays and large error ratios
- Check if available transmission link.
- Determines QoS demanded by each block
 - Red - reliable delivery
 - has to be acknowledged by receiver
 - held available until ACK
 - Green - delivery immediacy
 - no ACK



Erasure codes + Bundle Protocol



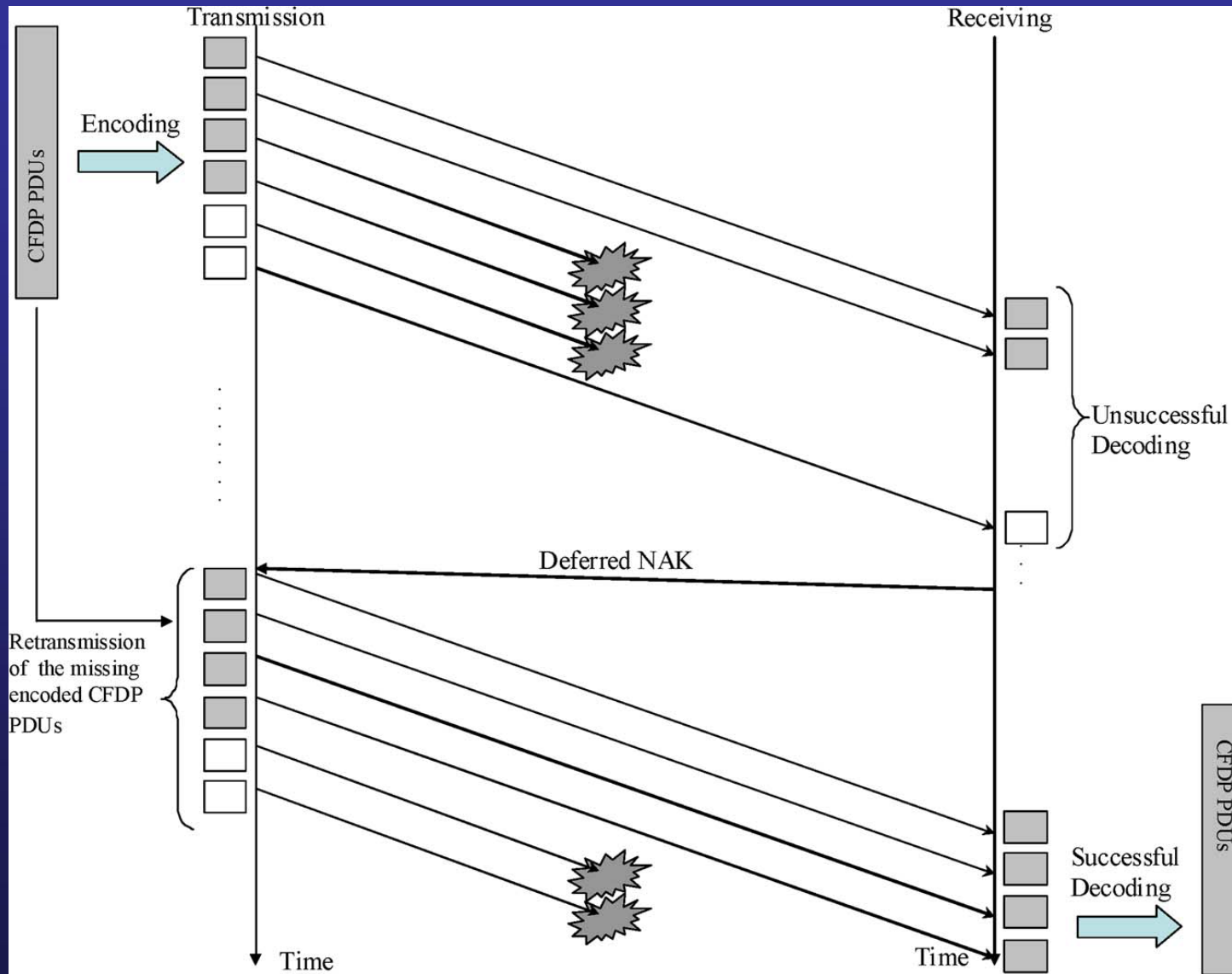
CCSD File Delivery Protocol (CFDP)

- Core - data transfer between two consecutive file stores
- Extended - data transfer through intermediate CFDP nodes, allows suspend resume
- Acknowledge - NAK based ARQ
 - immediate, deferred, prompted and asynchronous
- Unacknowledged - no reliability

Core + Acknowledge immediate is the recommended by CCSDS



Erasure code + CFDP



Future Work

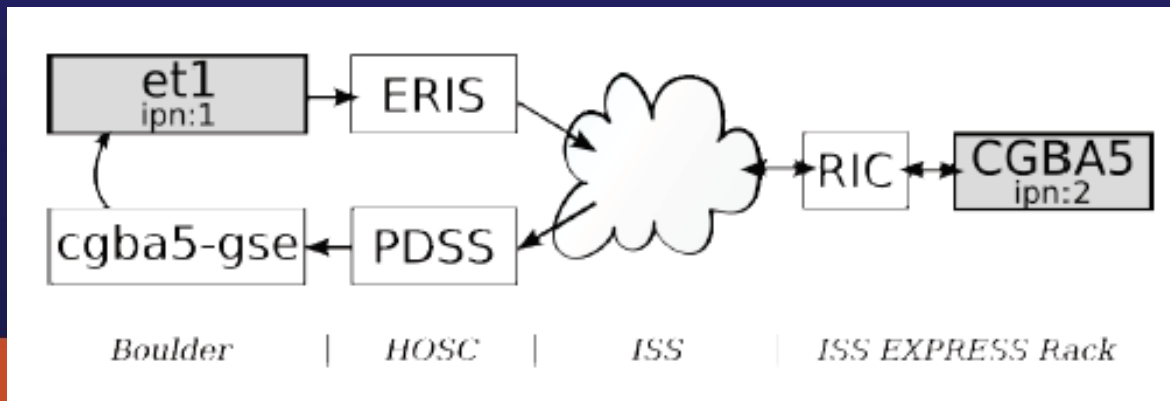
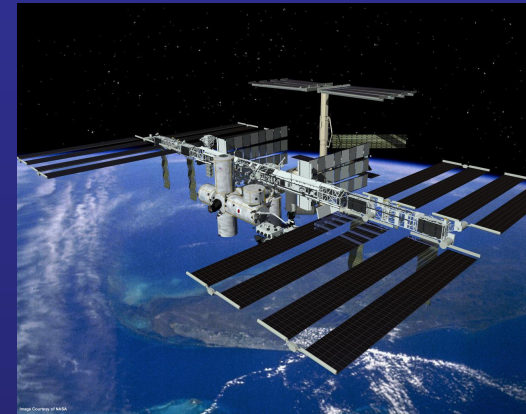
- Erasure code + ARQ implemented by CCSDS
- CFDP that stores only redundancy packets to recreate signal
- Improve Erasure code
 - BCH (63,56) changed to BCH(128,64)
 - (128,64) binary photograph LDPC

Delay/Disruption-Tolerant Networking: Flight Test Results from the International Space Station

Jenkins, A.; Kuzminsky, S.; Gifford, K.K.; Pitts, R.L.; Nichols, K.
Aerospace Conference, 2010 IEEE , vol., no., pp.1-8, 6-13 March 2010

Implementation on ISS

- Bundle Protocol Agent installed on Commercial Grade Bioprocessing Aparatus 5 (CGBA5)
 - 1Ghz Intel Celeron (32 bit)
 - 1GB RAM, 4GB SSD
 - Debian Etch OS Linux 2.6.21
- Payload Data Service System
 - TM to Control Center in Boulder, CO
 - IP address and UDP port
 - EHS Remote Interface System (ERIS) sends messages to Rack Interface Computer (RIC)



Non-DTN

	Packet Size (bytes)		Bandwidth (bits/s)
	RIC	Channel	
Uplink	96	2048	150
Downlink	1248	2048	400,000

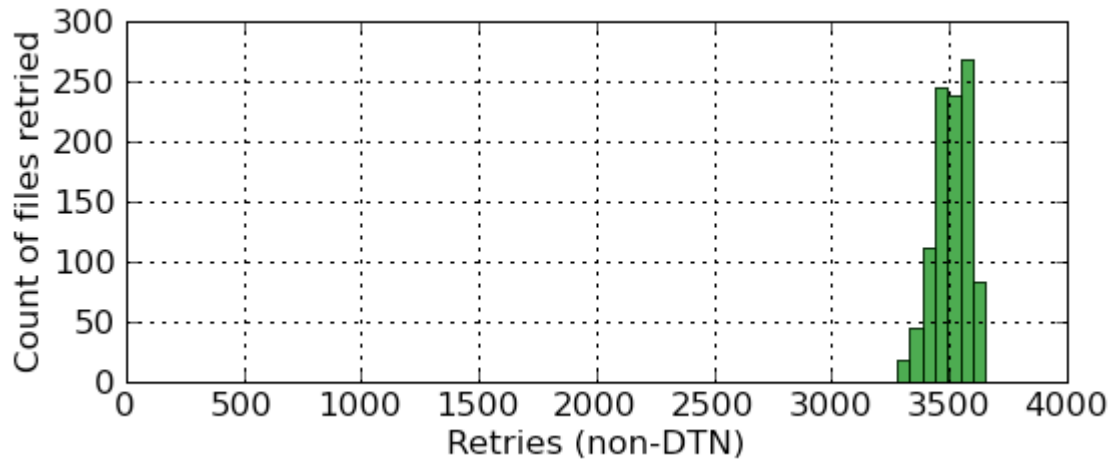
- 88 byte packets (440 bytes a week) commands
- commands from CGBA5 were sent via "transmit-in-the-blind"
- To compensate for losses without feedback files replayed thousands of times

DTN

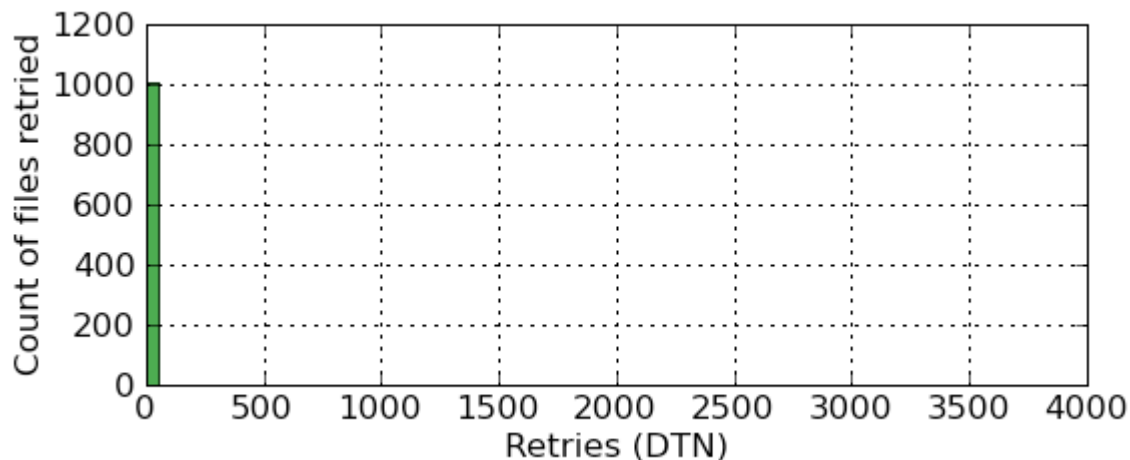
- Feedback Acknowledgements that can be enabled or disabled
- Bundle Protocol



Results



3 days worth
of
transmissions
(14 files/hour)
N= 1008



NDTN
3276-3651

DTN
< 4



Custodial Signal Compression

- Downlink 2800 > Uplink
- Maximize bandwidth
- Suggest modifying Bundle Protocol to support a different type of custody signal

$$\overbrace{(24 \text{ CBHE BPB} + 3 \text{ Admin Block Hdr} + 22 \text{ Custody Sig})} \cdot 2800 = 140\text{KB}$$

$$1 \frac{\text{file}}{\text{bundle}} * 1 \frac{\text{KiloByte}}{\text{file}} * 8 \frac{\text{bits}}{\text{Byte}} = 8 \frac{\text{kilobits}}{\text{bundle}}$$

$$400 \frac{\text{kilobits}}{\text{sec}} / 8 \frac{\text{kilobits}}{\text{bundle}} = 50 \frac{\text{bundles}}{\text{sec}}$$

$$50 \frac{\text{CT Signals}}{\text{sec}} \cdot 49 \frac{\text{bytes}}{\text{CT Signal}} = 2500 \frac{\text{Bytes}}{\text{sec}} \gg \frac{\text{Uplink Req}}{18 \frac{\text{Bytes}}{\text{sec}}} \ll \frac{\text{Uplink Avail}}$$

$$2800 \cdot \frac{1 \text{ CT Sig Bundle}}{250 \text{ Bundles}} = 0.80\text{KB}$$



Future Work

- Expand to include another payload (CGBA4) expanding the network to 2 space nodes and 2 ground nodes
- Install a DTN node in JAXA so they can communicate with "Kibo"
- Mars End-To-End Robotic Operations Network (METERON)

Issues with research

- Use the TC to send ACKs and short messages, TM for larger data files.
- Take into account time delay.