Convergence Layers

ICTP Trieste

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Convergence Layers

Adaptability

- Convergence layers allow the Bundle Protocol to function efficiently across paths that may contain a wide range of environments
- A single reliability mechanism might struggle

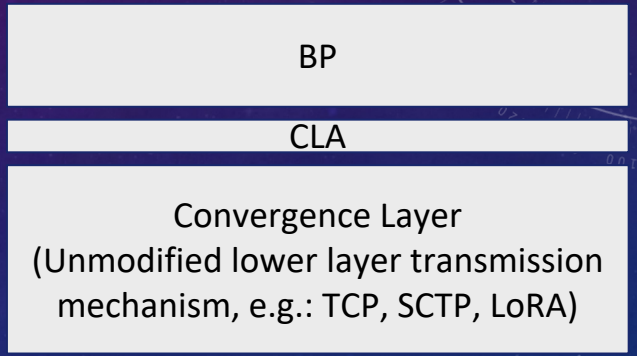
Reliability: In the Bundle Protocol v7, the main reliability mechanism is via convergence layers

- Reliable convergence layers ensure that bundles make it hop-to-hop correctly and intact

Convergence Layers vs. Convergence Layer Adaptors

Convergence Layer Adaptor: Mechanism for adapting BP to use the convergence layer

- How to encapsulate / multiplex bundles into the convergence layer, e.g.:
  - UDP
    - One bundle per datagram
    - Restricts max bundle size
  - Tcpclv4
    - Allows for large bundles
    - Complex multiplexing



Convergence Layer: The underlying transport mechanism, e.g. TCP, UDP, LoRA, QR code

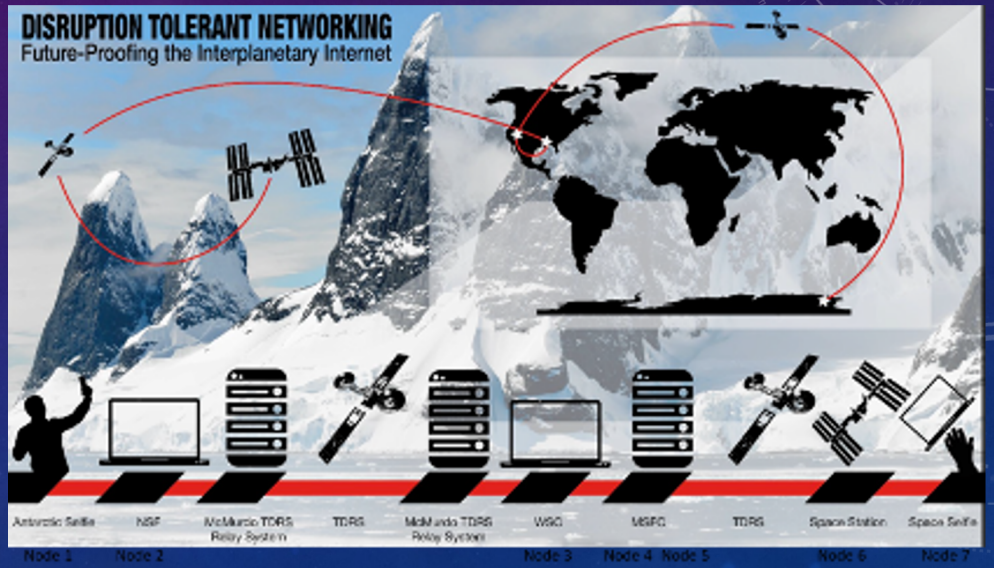
Use for the File-Based Convergence Layer

End-to-end networking between McMurdo Base and the ISS

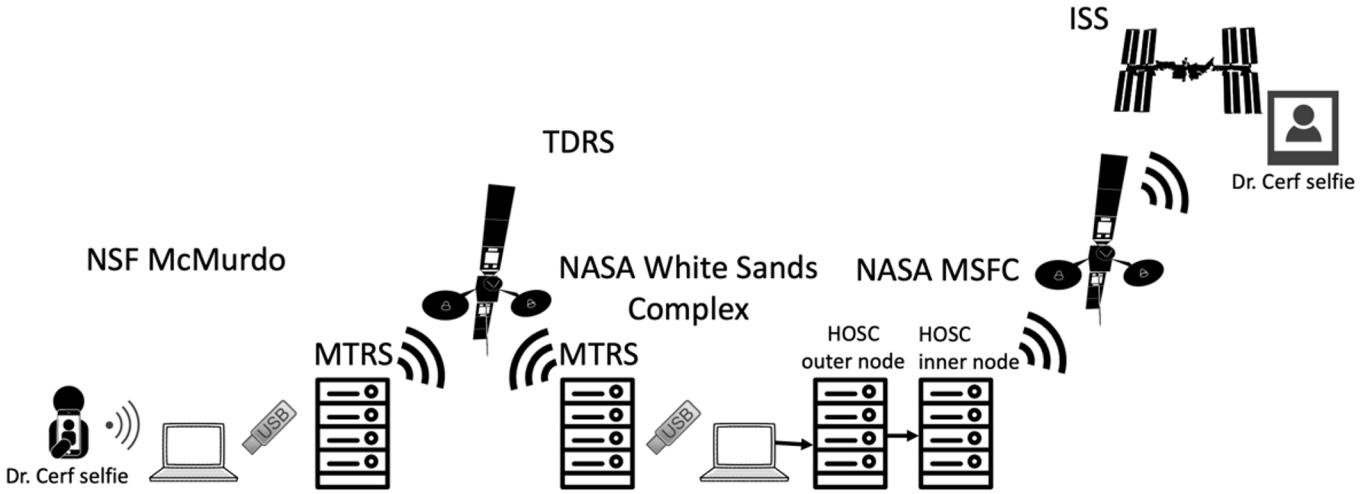
Multiple DTN implementations (ibr-dtn, ion, dtn2/dtnME)

Older TDRS ‘drifted’ far enough South for a few hrs per cycle to support relay comms from Antarctica

No direct external network connectivity to the TDRS relay system



DTN DEMO 2017



MTRS team (POC Salem) coordinates with NSF (POC Pat) to take photo with DTN cell phone.

MTRS team takes cell phone to JSOC and connects to WiFi. Connects DTN Laptop to WiFi. DTN Bundles are transferred from cell phone to Laptop

DTN Bundles are transferred to USB stick

DTN Bundles are manually pulled from USB stick by MTRS team and placed on MTRS and queued for transfer

Bundles are transferred via TDRS and Stored on MTRS@WSC

Bundles are manually transferred from MTRS@WSC (POC Ron Biel) to USB stick. USB stick Bundles are transferred to WSC DTN Node

WSC DTN Node transfers to HOSC outer node

HOSC outer node transfers to HOSC inner node in prep for transfer to ISS

HOSC outer node transfers to ISS via TDRS

ISS receives bundles and reassembles picture

Picture reception is recorded via HD Camera

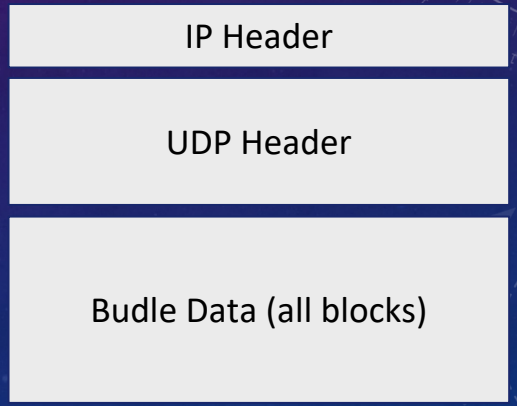
(Many) Convergence Layers

Need a table listing the CLAs supported by different implementations AND the BP versions those implementations support.

Convergence Layer	Typical Environment	Reliability	Overhead / Complexity	Strengths	Weaknesses
STCP, TCPCLv4	Terrestrial networks, connected environments (e.g., Internet)	Built-in reliable, in-order delivery	Moderate (TCP headers, connection state)	Leverages existing Internet infra, easy to deploy, supports TLS for security, bidirectional connections allow for return traffic through firewalls	Performs poorly in very long delay or disrupted links (timeouts, retransmission overhead)
UDP (v1)	Lightweight, mobile or ad-hoc networks, local comms	None (unreliable, connectionless)	Low (minimal headers, stateless)	Very simple, low resource use, good for short links	No hop-by-hop reliability; burden shifts to Bundle Protocol or higher layers
UDP (v2)	Lightweight, mobile or ad-hoc networks, local comms	None (unreliable, connectionless)	Low to moderate	Provides additional services w.r.t. 'Plain UDP': bundles larger than a single UDP datagram via segmentation/reassembly, datagram TLS	More complex than 'plain UDP'
LTP (Licklider Transmission Protocol)	Space links, deep space missions, high-delay / disrupted environments	Designed for reliability over long RTT links (selective retransmission)	Higher (specialized protocol)	Tolerant to long/lightly scheduled disruptions, optimized for asymmetric links	Complex, not widely deployed outside space/military contexts Variable-length headers makes hardware implementations more difficult
High-Rate LTP				Above + designed to make hardware implementations easier; proof-of-concept runs at O(10Gbps)	
CCSDS Encapsulation Service	Space agency networks (NASA, ESA), standardized missions	Depends on service (can support reliability)	Low	Interoperable with CCSDS-defined space link services	Specialized; limited use outside space comms
Bluetooth / LoRa, Other Radio CLs	Tactical or mobile scenarios	Depends on link	Low to moderate	Useful for opportunistic contacts, DTN over radios	Link stability can be highly variable
File	Highly disconnected environments where network connectivity is minimal or not allowed	Generally good	Low	Works when network connectivity is minimal or not allowed	Slow
Email	Terrestrial connected	Strong, email server decouples sender and receiver	Moderate (SMTP/TCP)	Gets through firewalls	Requires environment supporting SMTP/IMAP
QR Codes	Demo / snail-mail	As good as your country's snail-mail service	Low	Gets through firewalls; doesn't require network connectivity	Slow

Simple CLA: UDPCL v1
(And Direct Encapsulation of UDPCL v2)

One bundle per UDP datagram; no explicit length (aside from what's in the IP header); no padding; no extra signaling



Pros:

- Easy to understand / debug
- Not a lot of extraneous / spurious traffic (e.g. keepalives)
- Can be used over unidirectional links

Cons:

- Constrains bundle size
- Unreliable transport

TCPCLv4

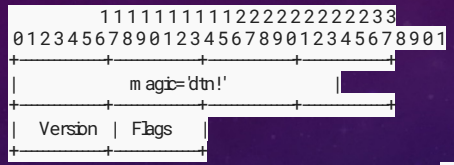


Figure 16: Contact Header Format

Pros:

- Reliable
- Supports larger bundles
- Can be used for (1-way) firewall penetration

Cons:

- Harder to understand with tcpdump
- Keepalives provide spurious traffic

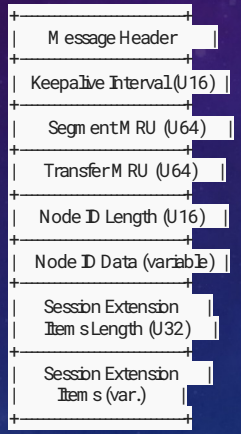


Figure 19: SESS_INIT Format

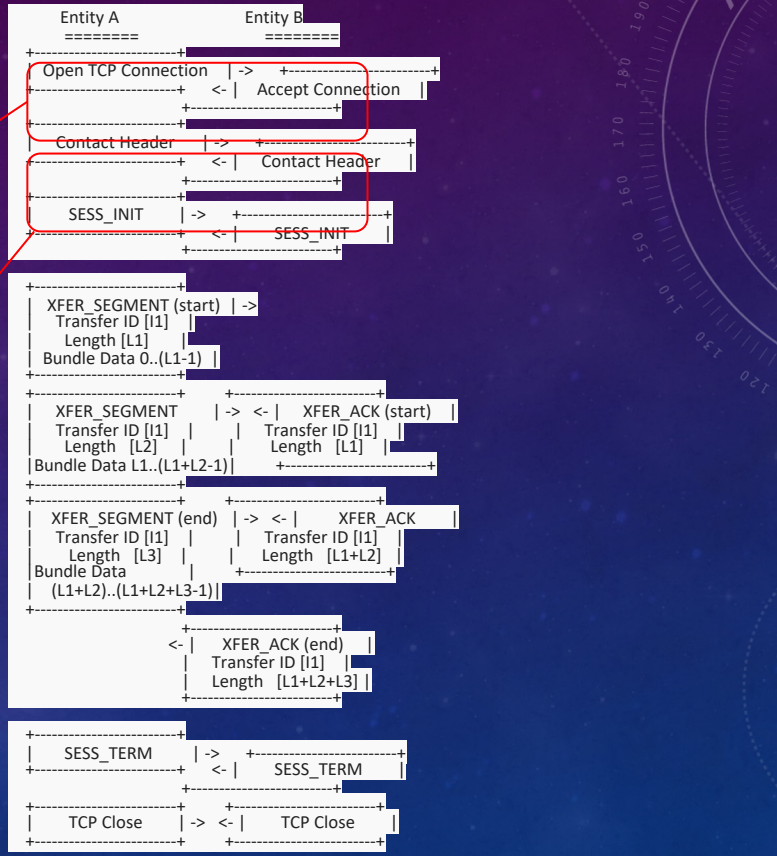


Figure 15: An Example of the Flow of Protocol Messages on a Single TCP Session between Two Entities

TCPCLv4

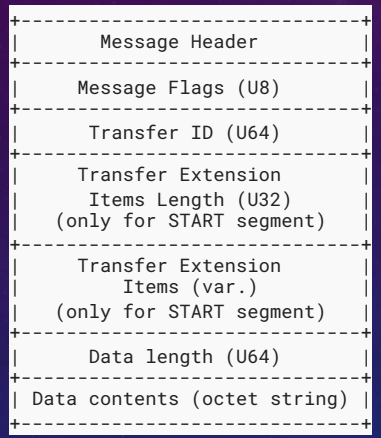


Figure 22: Format of XFER_SEGMENT Messages

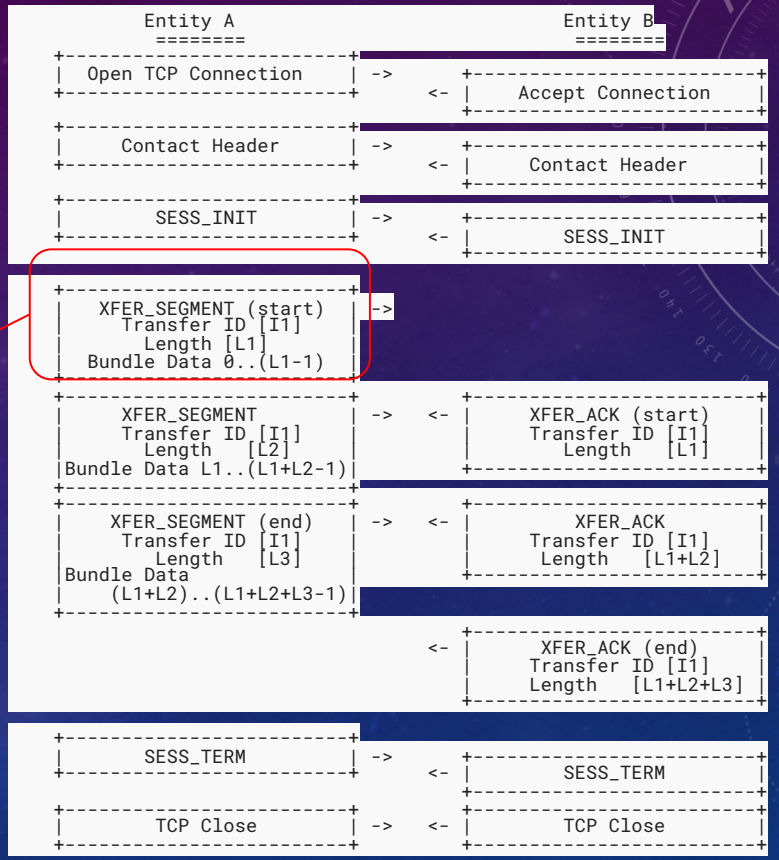


Figure 15: An Example of the Flow of Protocol Messages on a Single TCP Session between Two Entities

UDPCLv2

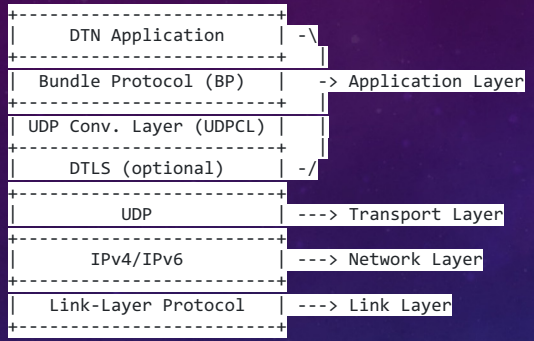


Figure 1: The Locations of the Bundle Protocol and the UDP Convergence-Layer Protocol above the Internet Protocol Stack

First octet determines type

Octet Value	Message Content	Message Extent
0x00	Padding	Remainder of packet
0x06	**BPv6 Bundle**	**Remainder of packet (to be decoded by BPA)**
0x14--0x1A or 0x20--0x3F	DTLS Record	Remainder of packet
0x80--0x9F	**BPv7 Bundle (CBOR array)**	**Remainder of packet (to be decoded by BPA)**
0xA0--0xBF	Extension Map (CBOR map)	End of map item, possibly followed by other map or padding
others	unused	

Pros:

- Backwards compatibility with simple UDP encoding
- Extensions that support:
  - segmentation / reassembly (supports large bundles)
  - sender identification and a UDPCLv2 port on which it is listening (firewall traversal)
  - DTLS and ECN

Cons:

- Unreliable

draft-ietf-dtn-udpcl-01

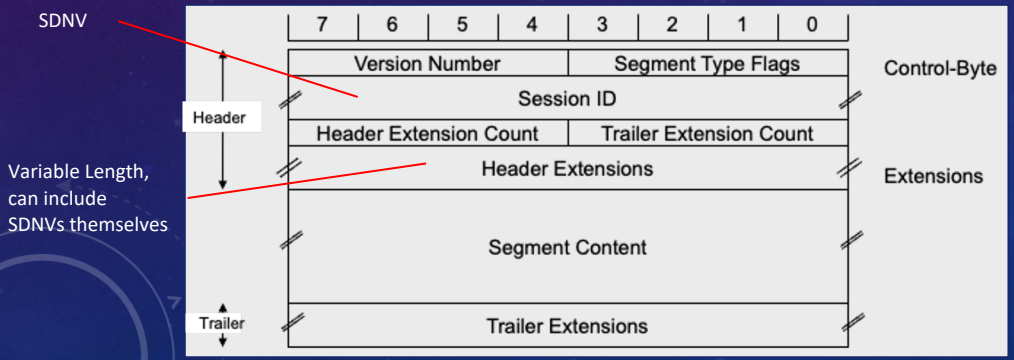
Licklider Transmission Protocol (LTP)

Pros: Designed for resource-constrained spacecraft / links

- Accommodates highly asymmetric channels (TCP, e.g. doesn't do well above about 75:1 asymmetry)
- Two services: reliable (red) and unreliable (green) (TCP-like and UDP-like)
- Compact headers using variable-sized self-delimiting numeric values (SDNVs)

Cons:

- Due to variable-length fields, LTP(v1) is difficult to decode with FPGAs and hence difficult to implement at high rates
- Allowing mixed-color blocks opens a resource leakage hold



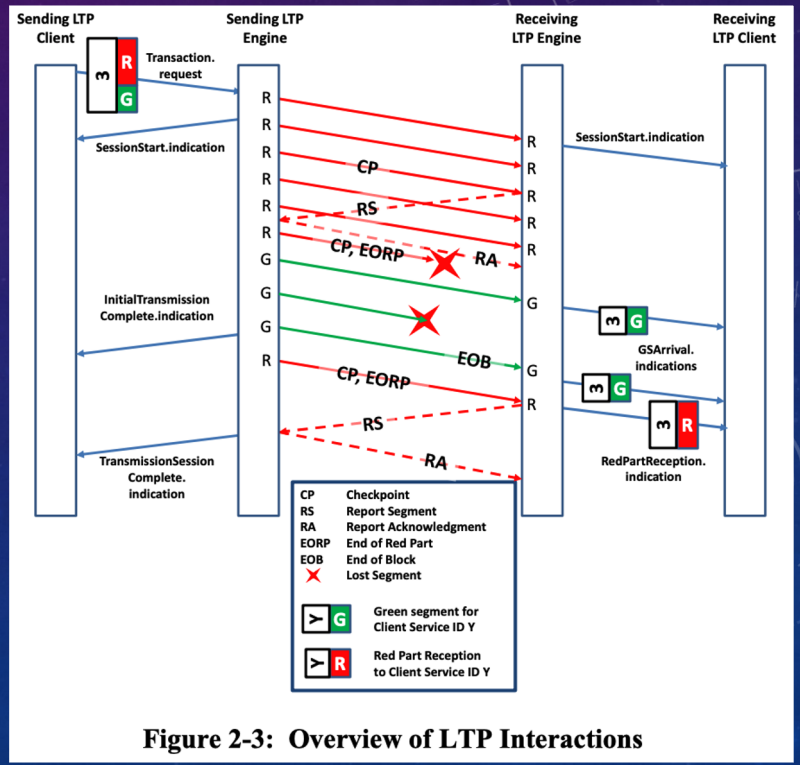


Figure 2-3: Overview of LTP Interactions

High-Rate LTP (HRLTP) (LTPv2)

Pros:

- Simplified header fields (designed to facilitate FPGA implementations)
- Keeps LTP's ability to operate in highly asymmetric channels
- Still allows variable-length headers but also carries a length field to aid FPGA implementations
- Throughput: O(10Gbps)

Cons:

- TBD

4.1 HPRP SEGMENT

Bit	0 1	2 3	4 5	6 7
0	Version Number	*Extension Control Flags*: Sys. extensions / User extensions	Segment Type ID	Unused
8	Session Originator Length		Session Number Length	
16	Session Originator			
VAR	Session Number			
VAR	Header Extensions Length (optional)			
VAR	Header Extensions (Optional, variable)			

QR-Codes

Print (the hex of?) a bundle directly onto a QR code.

Pros:

- Its cool
- You can send bundles by snail-mail, hand them out at parties, …

Cons:

- Limited bundle size

LoRA

- I don’t know much about LoRA CLAs
- Samo build one
- My understanding is that the CLA just dumps bundle bytes into a single LoRA transmission and that LoRa does some framing and maybe some security

Email

Pros:

- Firewall traversal
- Long-term stable CL endpoints (without paying for AWS elasticIP addresses or using something like tailscale)
- Supports large bundles

Cons:

- Slow
- Requires an email account

Conclusions / Takeaways

- Convergence Layers allow BP to adapt to changing / different conditions along the path
- Convergence Layer Adaptors MAY provide some additional protocol / functionality between bundle protocol and the underlying convergence layer
- Different BP implementations support different sets of convergence layers

Backup

TCPCLv3 Contact Header

```
0000   4e 99 15 fc 0c 41 8e dc f5 69 7c 7a 08 00 45 00   N....A...i|z..E.
0010   00 44 77 4e 40 00 40 06 a1 09 0a 2d 07 01 0a 2d   .DwN@.@....-...-
0020   07 02 a5 20 11 cc 85 52 5a e5 77 7e 26 5f 80 18   ... ...RZ.w~&_..
0030   01 f6 22 93 00 00 01 01 08 0a 24 d5 51 f0 85 8f   ..".......$.Q...
0040   7b 65 64 74 6e 21 03 01 00 0f 07 69 70 6e 3a 32   {edtn!.....ipn:2
0050   2e 30                                             .0
```

Magic

Version = 3