layer_transformations_v1

October 21, 2025

OSI Mapping (One-Page Summary)

L7 (Application)

- cFS app cmds/tlm → serialize fields (big-endian), assign MsgIDs/APIDs, seq cnt.
- Wrap in CCSDS Space Packets (primary + optional secondary header/time).
- Optional L7 services: CFDP (file delivery), compression, encryption, MIC/CRC.
- Below the SP body everything is payload-agnostic.

L4/L3 (Transport/Network)

- UDP/IP for bench/LAN legs only (COSMOS↔cFS, sims); does not cross RF unless explicitly designed to tunnel IP.

L2 (Data Link)

- TM/TC or AOS framing (VCID/SCID, FHP/segmentation, VC/MC as needed).
- Insert ASM; randomize; FEC (RS+Conv or LDPC/Turbo) with interleave/puncture.
- Optional OCF (CLTU/BC/AC) and frame CRC; AOS MAP mux of multiple APIDs.
- Idle frames/idle fill when no payload.

L1 (Physical)

- Bit→symbol mapping (QPSK/OQPSK, offset on Q), RRC shaping, resampling/DUC.
- TX gating/TDMA windows; RF front-end.
- RX mirror: AGC/DC/IQ fix, CFO/phase/timing recovery, RRC, soft LLRs, decisions.

1 Purpose and Scope

This document explains how cFS application messages traverse the OSI stack on a CCSDS-compliant link. The key idea: *meaning* (commands/telemetry semantics) is confined to Layer 7; Layers 2 and 1 simply move opaque bytes with reliability and timing guarantees.

2 Layer 7: Application (cFS → CCSDS Space Packets)

2.1 Message Formation

a) **Serialization:** Pack each command/telemetry field into a byte-accurate layout using big-endian ordering for multi-octet integers and IEEE-754 for floats. Avoid compiler padding by using explicit field sizes.

b) **Identification:** Assign a cFS/cFE MsgID that maps to a CCSDS APID. Maintain a per-APID sequence counter for duplicate detection.

c) **Space Packetization:** Create the CCSDS primary header (version, type, sec hdr flag, APID, sequence flags/count, packet length). Optionally prepend a secondary header (e.g., COARSE/FINE time).

2.2 Optional L7 Services

- **CFDP:** Adds file-delivery PDUs on top of Space Packets for reliable/acknowledged file transfer.
- **Compression/Encryption/MIC:** If used at L7, apply to the Space-Packet *user data* so L2 remains agnostic.

2.3 Interfaces

On benches and in simulation, the same L7 bytes may be carried over UDP sockets (e.g., COSMOS $\leftrightarrow$ cFS). Across the RF link, the L7 payload is carried only as Space Packets inside L2 frames.

3 Layers 4/3: Transport/Network (Bench Use Only)

- Use UDP/IP solely for lab legs (telemetry display, automation, or hardware-in-the-loop). Do not assume IP exists across the space link unless you explicitly design and test an IP-over-CCSDS tunnel.

4 Layer 2: Data Link (TM/TC/AOS)

4.1 Core Functions

a) **Framing/Segmentation:** Pack Space Packets into TM/TC or AOS frames. Use First Header Pointer (FHP) to indicate where a new packet begins; segment long packets as needed.

b) **Synchronization:** Prepend the Attached Sync Marker (e.g., 0x1ACFFC1D) to form a CADU.

c) **Randomization:** Apply the CCSDS polynomial scrambler to decorrelate long bit runs.

d) **FEC:** Choose RS+Convolutional (with interleaver, optional puncturing) or modern LDPC/Turbo per link budget and latency goals.

e) **OCF/CRC:** Optionally include Operational Control Field for return channel control and a frame-level CRC when the standard calls for it.

f) **MAP Mux:** With AOS, multiplex multiple APIDs via Virtual Channels and MAPs; idle frames when no payload is ready.

4.2 Design Notes

Keep L2 throughput fixed and deterministic: frame size, code rate, and interleave depth define the service rate available to L7. L2 does not inspect or alter L7 semantics.

5 Layer 1: Physical (Waveform and RF)

5.1 Transmit Path

a) **Bit Mapping:** Map coded bits to QPSK or OQPSK symbols (OQPSK uses a half-symbol offset on Q).

b) **Pulse Shaping:** Apply an RRC filter (roll-off α and span chosen per spectral mask and latency).

c) **Rate Conversion:** Resample and digitally upconvert (DUC) to the DAC/RF chain; gate TX for TDMA windows as required.

5.2 Receive Path (Mirror)

a) **Front-End Corrections:** AGC, DC/IQ imbalance mitigation, coarse/fine frequency and phase recovery, timing recovery.

b) **Matched Filtering & Decisions:** RRC matched filter, soft LLR generation for FEC, then de-randomize and deframe at L2 to yield original Space Packets for L7.

6 End-to-End Invariance

No matter which cFS command (HS, FM, CF, LC, etc.) you send, nothing in L2/L1 changes. Only L7 cares about message meaning; L2/L1 provide synchronization, protection, and spectrum efficiency.