

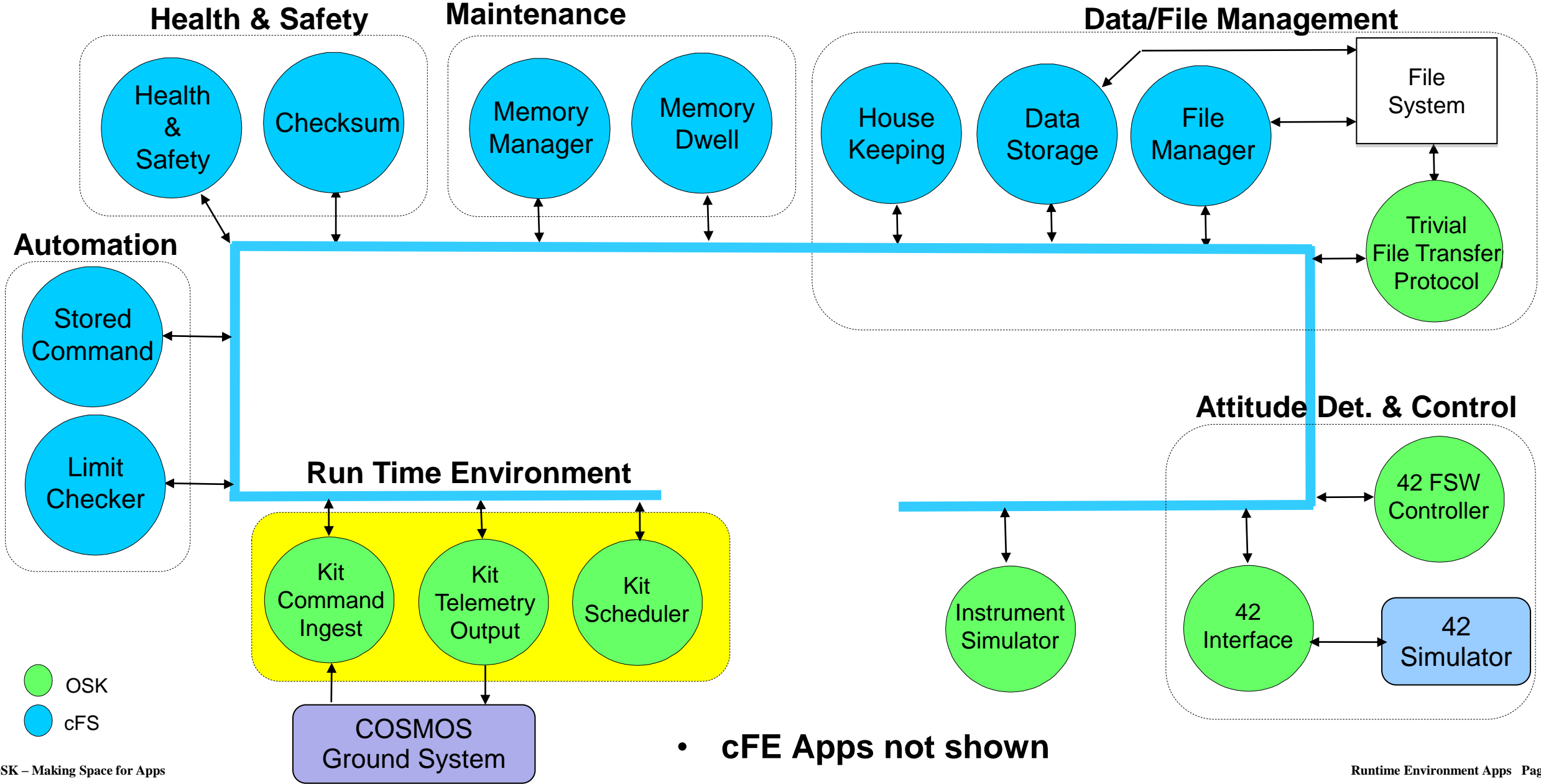


# Core Flight Executive (cFS) Training

Community Apps -  
Operational Runtime Environment

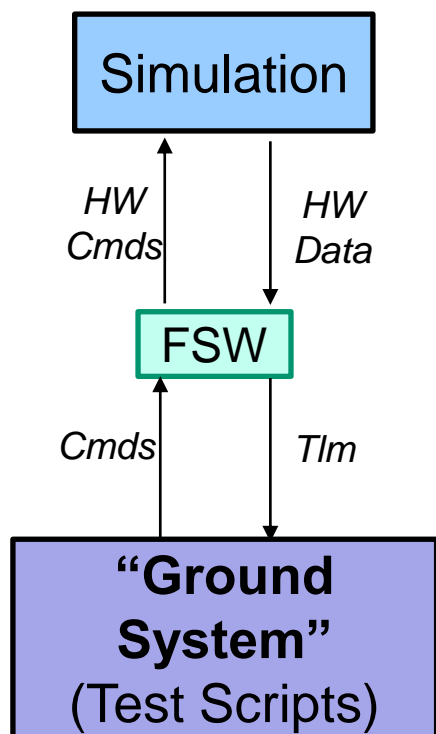


- **Runtime Environment Context**
- **Application Overview**
- **Command & Telemetry Apps**
- **Scheduler App**

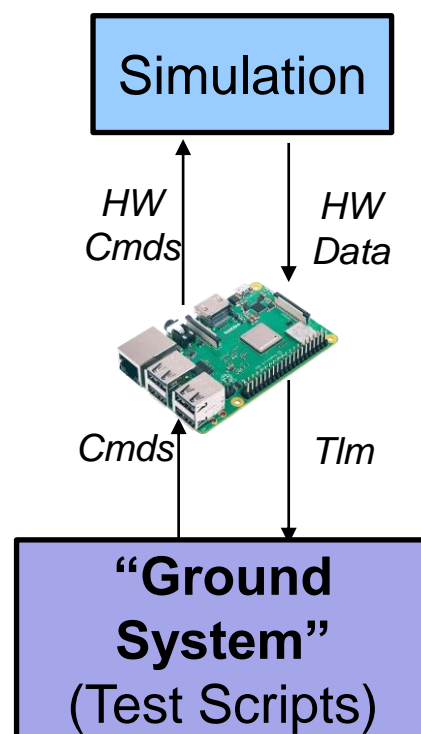




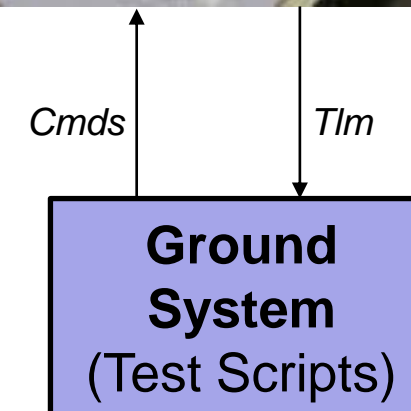
## Software in the Loop (SIL)



## Processor in the Loop (PIL)

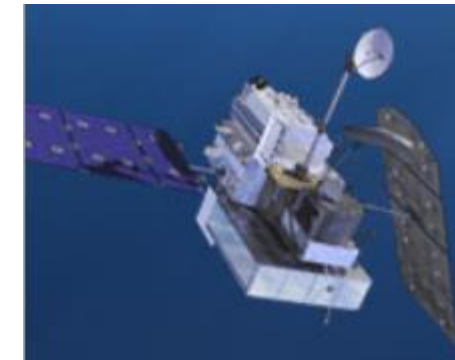
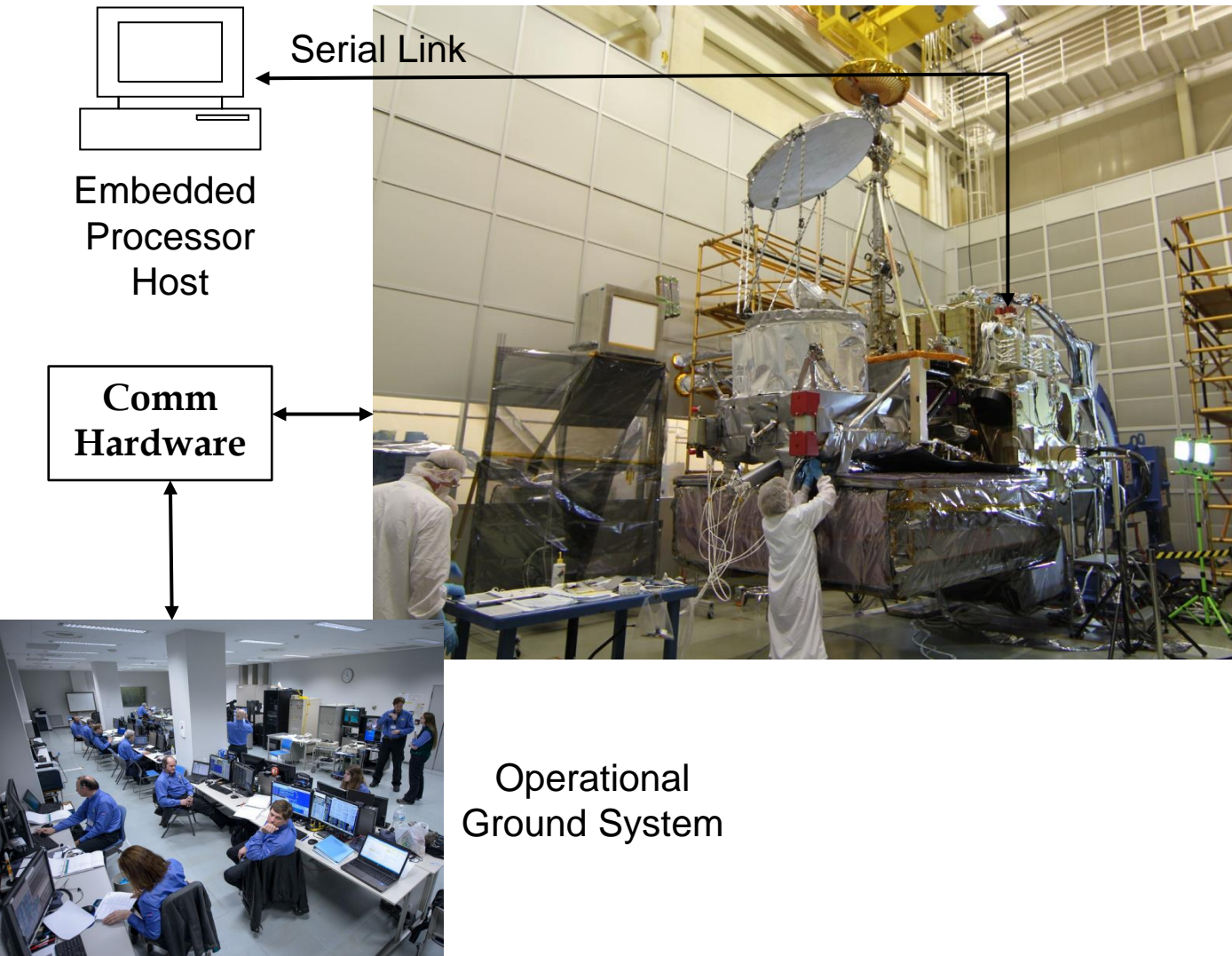


## FlatSat



## Spacecraft Integration & Test

## Operations



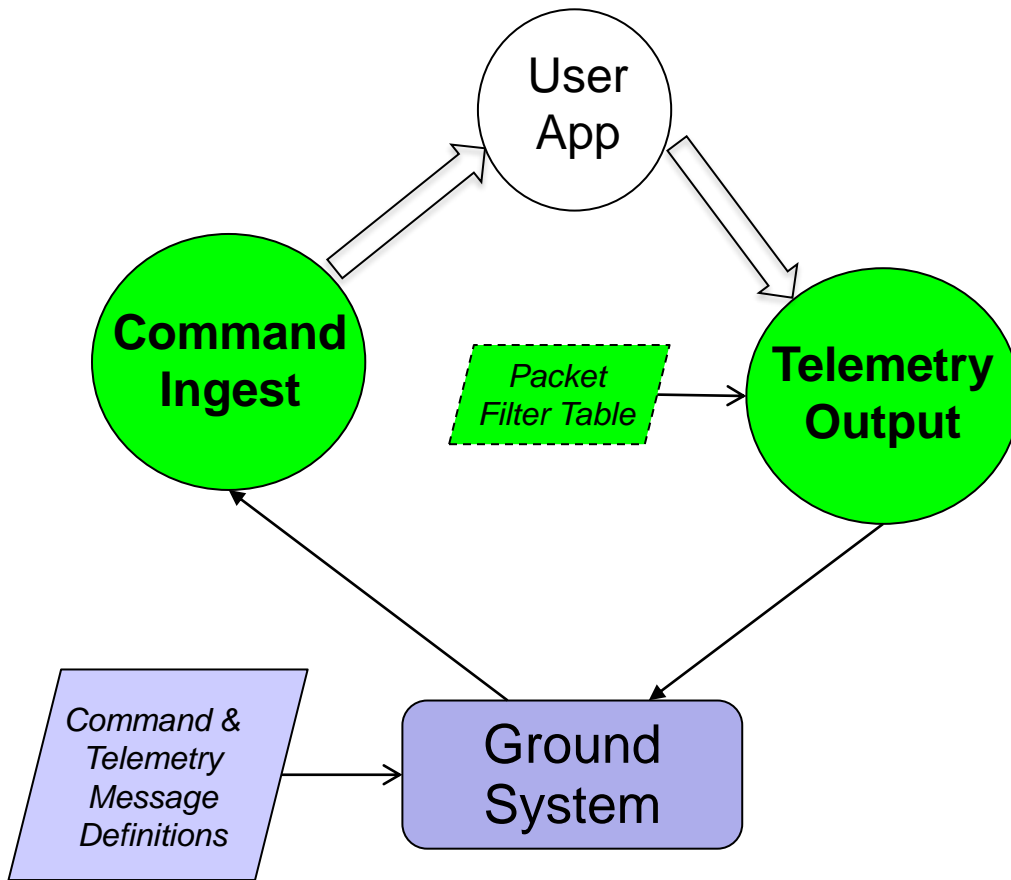
*Cmnds*

*Tlm*

**Ground System  
(Operational  
Scripts)**

## FSW Test Environment Considerations

- ➡ Objectives
- ➡ Fidelity
- ➡ Interfaces
- ➡ Test Reuse & Repeatability



- **Command Ingest (CI) App**

- Receives commands from an external source, typically the ground system, and sends them on the software bus

- **Telemetry Output (TO) App**

- Receives telemetry packets from a the software bus and sends them to an external source, typically the ground system
- Optional *Packet Filter Table* that provides parameters to algorithms that select which messages should be output on the external communications link

- **Different versions of CI and TO used on different platforms**

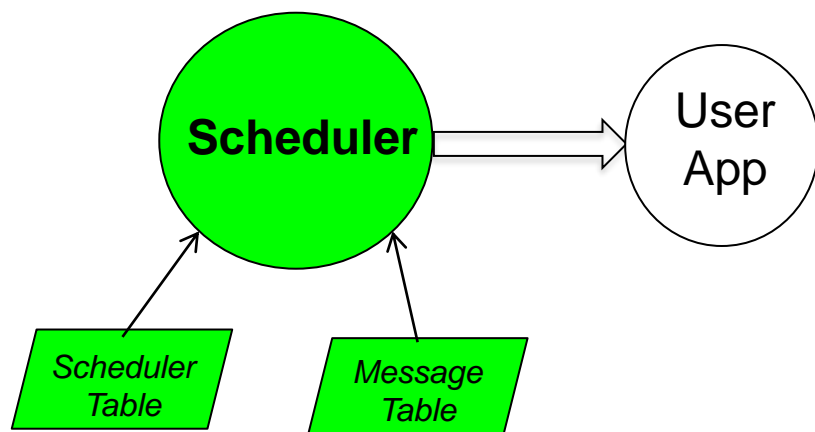
- cFS Bundle includes 'lab' versions that use UDP for the external comm
- JSC released versions that use a configurable I/O library for a different external comm links
- OSK versions use UDP and a JSON filter table
- ITAR-restricted flight versions typically used inflight



## KIT\_TO Packet Table Excerpt

```
"packet": {
  "name": "CFE_EVS_EVENT_MSG_MID",
  "stream-id": "\u0808",
  "dec-id": 2056,
  "priority": 0,
  "reliability": 0,
  "buf-limit": 40,
  "filter": { "type": 2, "X": 1, "N": 1, "O": 0 }
},
"packet": {
  "name": "CFE_EVS_HK_TLM_MID",
  "stream-id": "\u0801",
  "dec-id": 2049,
  "priority": 0,
  "reliability": 0,
  "buf-limit": 4,
  "filter": { "type": 2, "X": 1, "N": 1, "O": 0 }
},
"packet": {
  "name": "CFE_SB_HK_TLM_MID",
  "stream-id": "\u0803",
  "dec-id": 2051,
  "priority": 0,
  "reliability": 0,
  "buf-limit": 4,
  "filter": { "type": 2, "X": 1, "N": 1, "O": 0 }
},
```

- **Default file:** *cfs/osk\_defs/cpu1\_osk\_to\_pkt\_tbl.json*
- **Array of packet objects**
- **KIT\_TO subscribes to receive all packets defined in the table using id, priority, reliability, and buf-limit**
- **Filter allows “N of X” packets to be sent starting at offset 0**
  - 1 = Time based (rare)
  - 2 = Sequence count based
  - $((\text{sequence count} + O) \bmod X) < N$
- **If (X=0) then do not store packet**



- **Scheduler (SCH) App**
  - Synchronizes execution with clock's 1Hz signal
  - Sends software bus messages defined in the *Message Table* at time intervals defined in the *Scheduler Table*

- **Application Control Flow Options**

- Pend indefinitely on a *SB Pipe* with subscriptions to messages from the Scheduler
  - This is a common way to synchronize the execution of most of the apps on a single processor
  - Many apps send periodic “Housekeeping” status packets in response to a “Housekeeping Request message from Scheduler
- Pend indefinitely on a message from another app
  - Often used when an application is part of a data processing pipeline
- Pend with a timeout
  - Used in situation with loose timing requirements and system synchronization is not required
  - The SB timeout mechanism uses the local oscillator so the wakeup time may drift relative to the 1Hz



kit\_to\_func\_test.rb: test\_pkt\_tbl\_filters()

## KIT\_SCH: Scheduler Table (tst1\_to\_sch\_tbl.json)

Slot 0

- cFE ES HK Request
- cFE EVS HK Request

Slot 1

- cFE SB HK Request
- cFE TBL HK Request

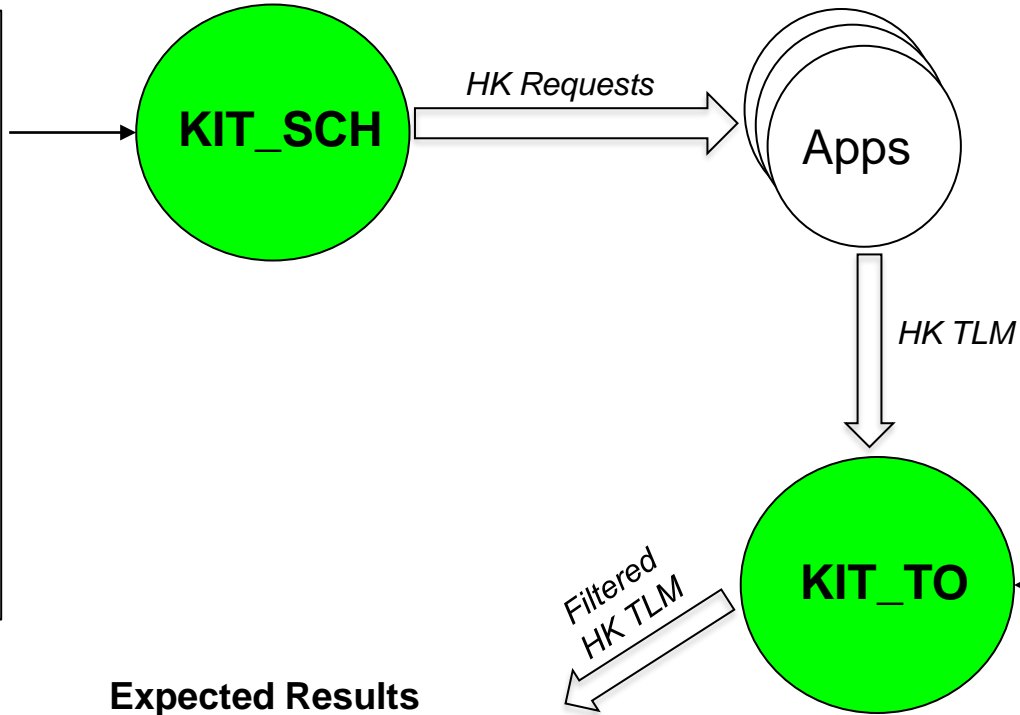
Slot 2

- cFE TIME HK Request
- cFE KIT\_CI HK Request

Slot 3

- cFE KIT\_SCH HK Request
- cFE KIT\_TO HK Request

All HK requests sent at 1Hz



## KIT\_TO: Packet Table (tst1\_to\_sch\_tbl.json, tst4\_to\_sch\_tbl.json)

Packet Array

- CFE\_ES\_HK\_TLM\_MID
- CFE\_EVS\_HK\_TLM\_MID
- CFE\_SB\_HK\_TLM\_MID
- CFE\_TBL\_HK\_TLM\_MID
- CFE\_TIME\_HK\_TLM\_MID
- CFE\_KIT\_CI\_HK\_TLM\_MID
- CFE\_KIT\_SCH\_TLM\_MID
- CFE\_KIT\_TO\_TLM\_MID

Two test tables:  
Tst1\_ - Sends all packets  
Tst4 - - Sends 1 of 4 packets

Expected Results

Test Case	Packets Per Sec	Bytes Per Sec
1Hz	8	842
0.25Hz	2	210

# App Main Loop Control

Application	Main Loop Control	Control Notes
CF – CFDP	Pend Forever	Scheduler wakeup and HK request
CS – Checksum	Pend Forever	Scheduler wakeup and HK request
DS - Data Storage	Pend Forever	Subscribed message wakeup and HK request
F42 - 42 FSW Controller	Pend with timeout	Pends for sensor data packet from I42
FM – File Manager	Pend Forever	Ground Command, Scheduler HK request
HK - Housekeeping	Pend Forever	Scheduler combo pkt request and HK request
HS – Health & Safety	Pend with timeout	Scheduler HK request
I42 – 42 Simulator I/F	Synched with 42	Flight equivalent depends upon H/W interfaces
KIT_CI – Command Ingest	Task Delay, Socket	
KIT_SCH – Scheduler	Synched with CFE_TIME	
KIT_TO – Telemetry Output	Pend with timeout	Subscribed message wakeup and HK request
LC – Limit Checker	Pend Forever	Scheduler wakeup and HK request
MD – Memory Dwell	Pend Forever	Scheduler wakeup and HK request
MM – Memory Manager	Pend Forever	Ground Command, Scheduler HK request
SC – Stored Command	Pend Forever	Scheduler wakeup and HK request
TFTP	Task Delay, Socket	Simulation environment, CF is flight-like

# SimSat Scheduler Table

Activities <sup>2</sup>	Slot 0	Slot 1	Slot 2	Slot 3
	Collect Sensor Data <sup>1</sup>	Run Limit Checker	Collect Sensor Data <sup>1</sup>	Run Limit Checker
	Run Stored Command	Send HK Combo Pkt	Run Health & Safety	Send HK Combo Pkt
	Run Memory Dwell		Run Memory Dwell	
	Checksum		Collect Payload Data	
		Run File Transfer App		Run File Transfer App
	Send App HK Requests <sup>3</sup>	Send App HK Requests	Send App HK Requests	Send App HK Requests

1. Simplified assumption that sensor data initiates a 'pipeline' of app executions to perform attitude determination & control and guidance navigation & control
  - a. Sensor and actuator interfaces drive the
2. All activities in a slot are executed immediately without delays
  - a. Slots are used to control delays
3. Offsets can be used to help load balance a particular slot for activities with a period longer than 1 Hz
  - a. HK requests are often on the order of 3-5 seconds

## KIT\_SCH Scheduler Table

(Slot 1 Excerpt)

Schedule Table

Slot 0
Slot 1
Slot 2
Slot M-3
Slot M-2
Slot M-1

One Schedule Table slot processed every  $(T / M)$  microseconds  
[default:  $T/M = 10000\mu s = 10ms$ ]

Entire schedule processed once per Major Frame ( $T$  microseconds)  
[default:  $T = 1000000\mu s = 1s$ ]

Activity 0
Activity 1
Activity N-2
Activity N-1

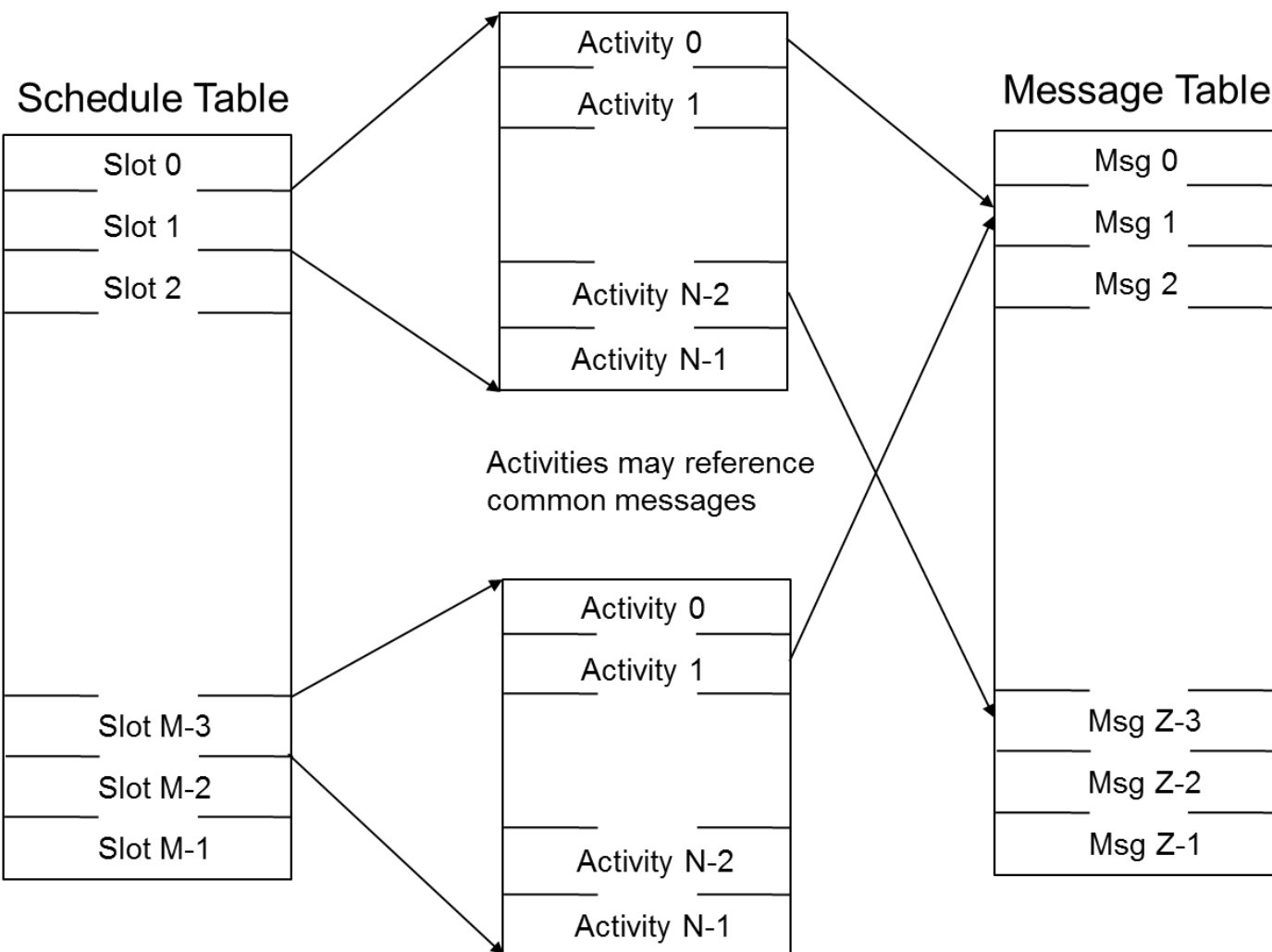
Each Schedule Table Slot contains  $N$  Activities

```
{ "slot": {
  "index": 1,
  "activity-array" : [
    { "activity": {
      "name": "LC Execution(Sample AP)",
      "descr": "",
      "index": 0,
      "enabled": "false",
      "period": 1,
      "offset": 0,
      "msg-idx": 17
    }},
    { "activity": {
      "name": "HK Combined Pkt 1",
      "descr": "Period can be shortened",
      "index": 1,
      "enabled": "true",
      "period": 4,
      "offset": 2,
      "msg-idx": 24
    }}
  ]
}
```

- SCH maintains a count of number of times entire table is processed and reports it in housekeeping telemetry



## KIT\_SCH Message Table



```

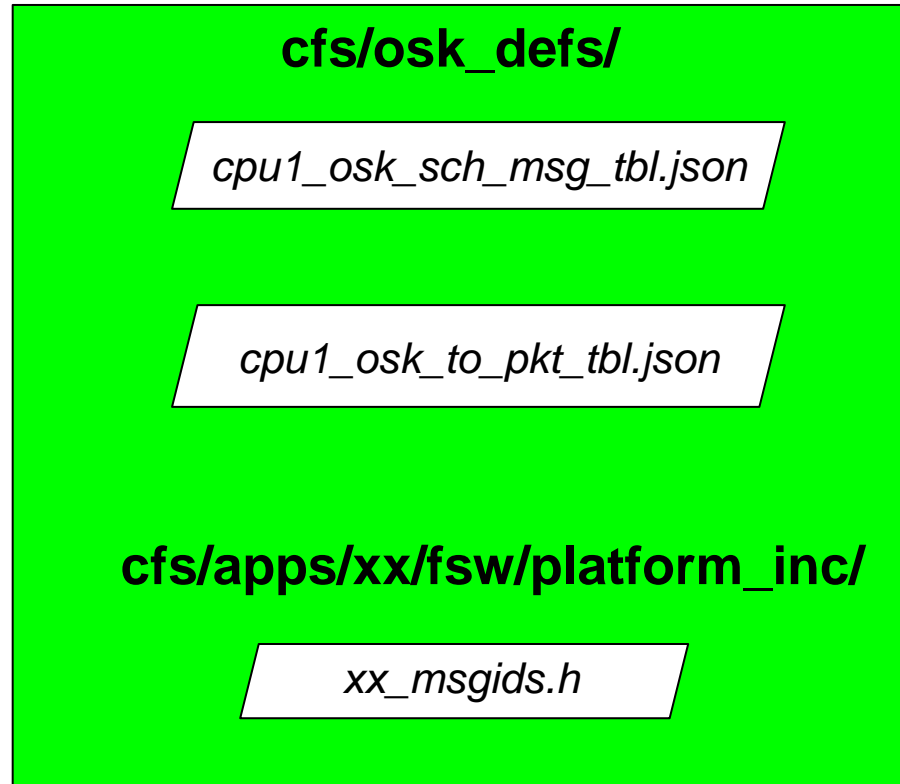
{"message": {
  "name": "LC_SEND_HK_MID",
  "descr": "0x18A5(6309), 0xC000(49152), 0x0001",
  "id": 16,
  "stream-id": 6309,
  "seq-seg": 49152,
  "length": 1
}},

{"message": {
  "name": "LC_SAMPLE_AP_MID",
  "descr": "0x18A6(6310), 0xC000(49152), 0x0001",
  "id": 17,
  "stream-id": 6310,
  "seq-seg": 49152,
  "length": 1
}},

{"message": {
  "name": "MD_SEND_HK_MID",
  "descr": "0x1891(6289), 0xC000(49152), 0x0001",
  "id": 18,
  "stream-id": 6289,
  "seq-seg": 49152,
  "length": 1
}},

```

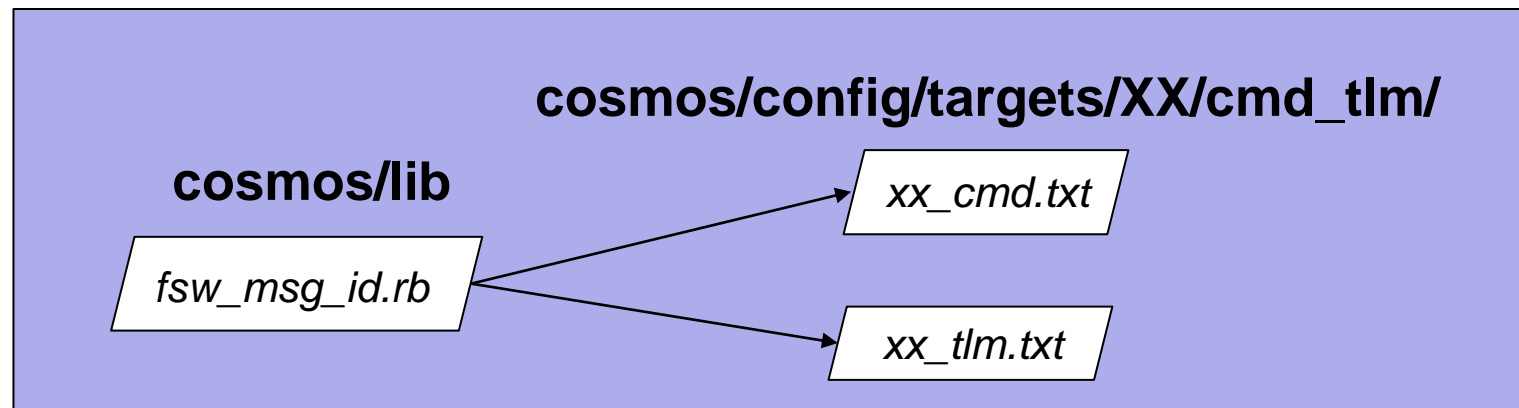
**Core  
Flight  
System**



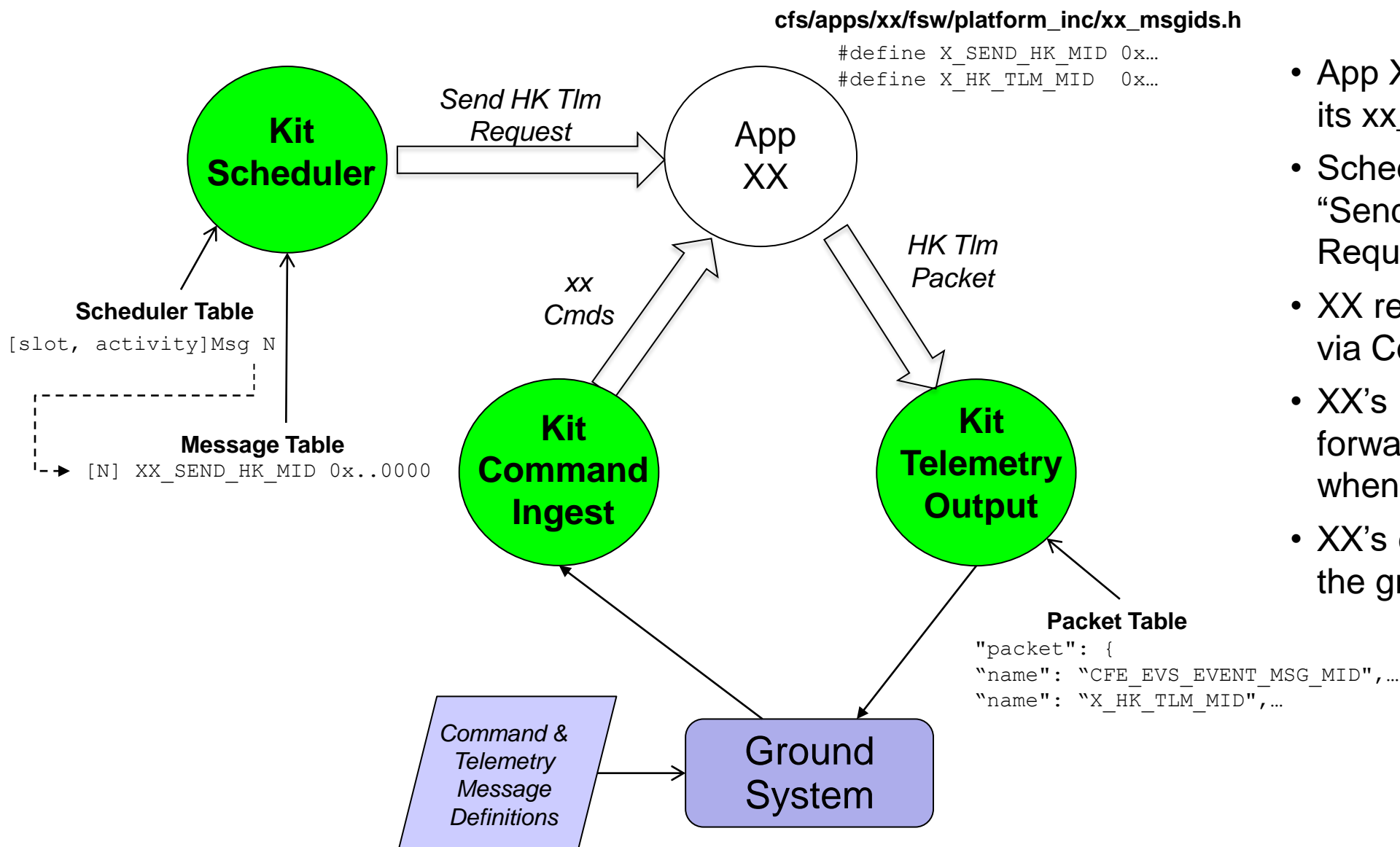
Manual  
process to keep  
files in synch

Long term  
goal is for a single  
message definition  
location and automatic  
file generation for all  
dependencies

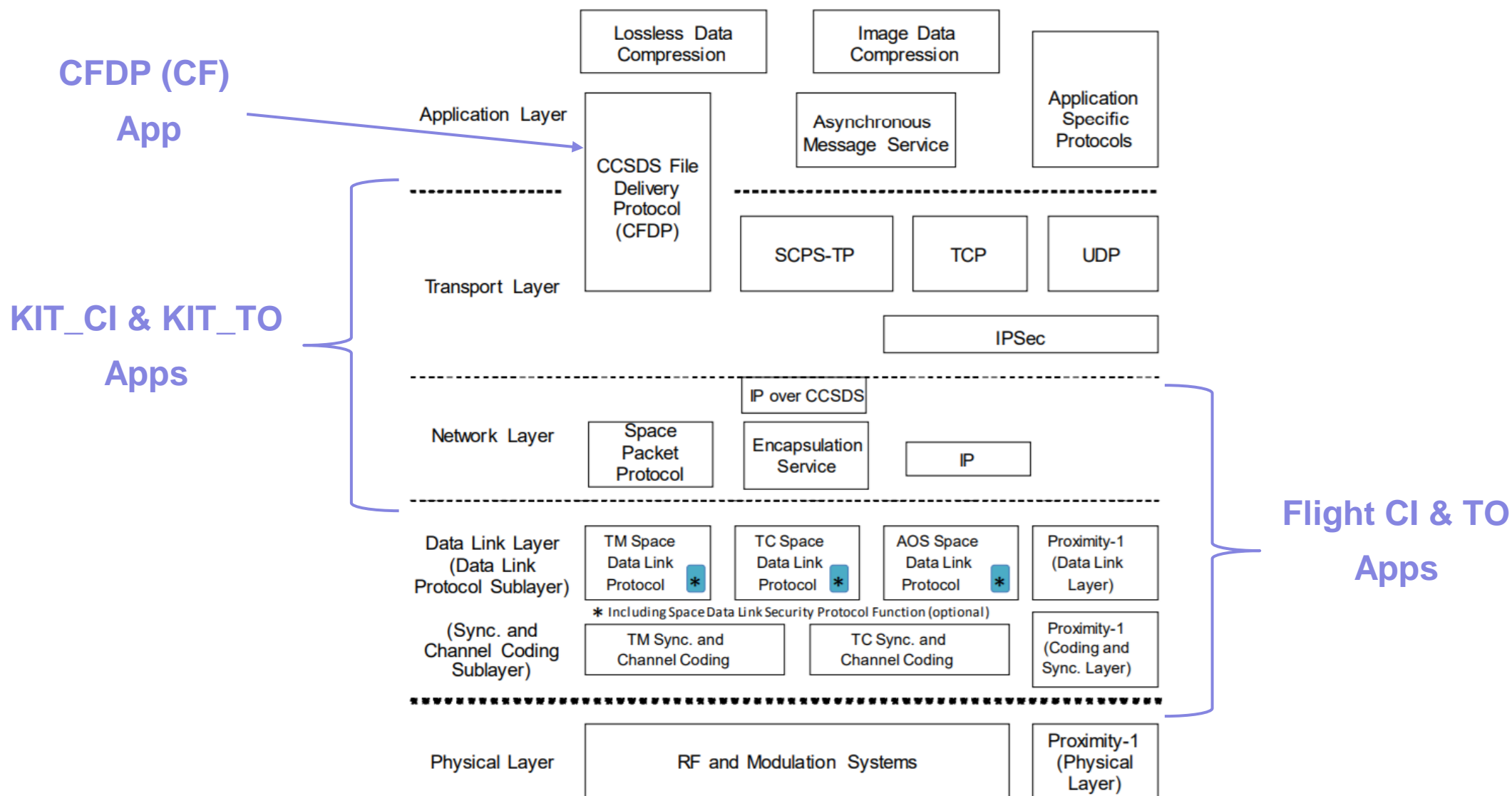
**COSMOS**



# App Runtime Environment Conclusion

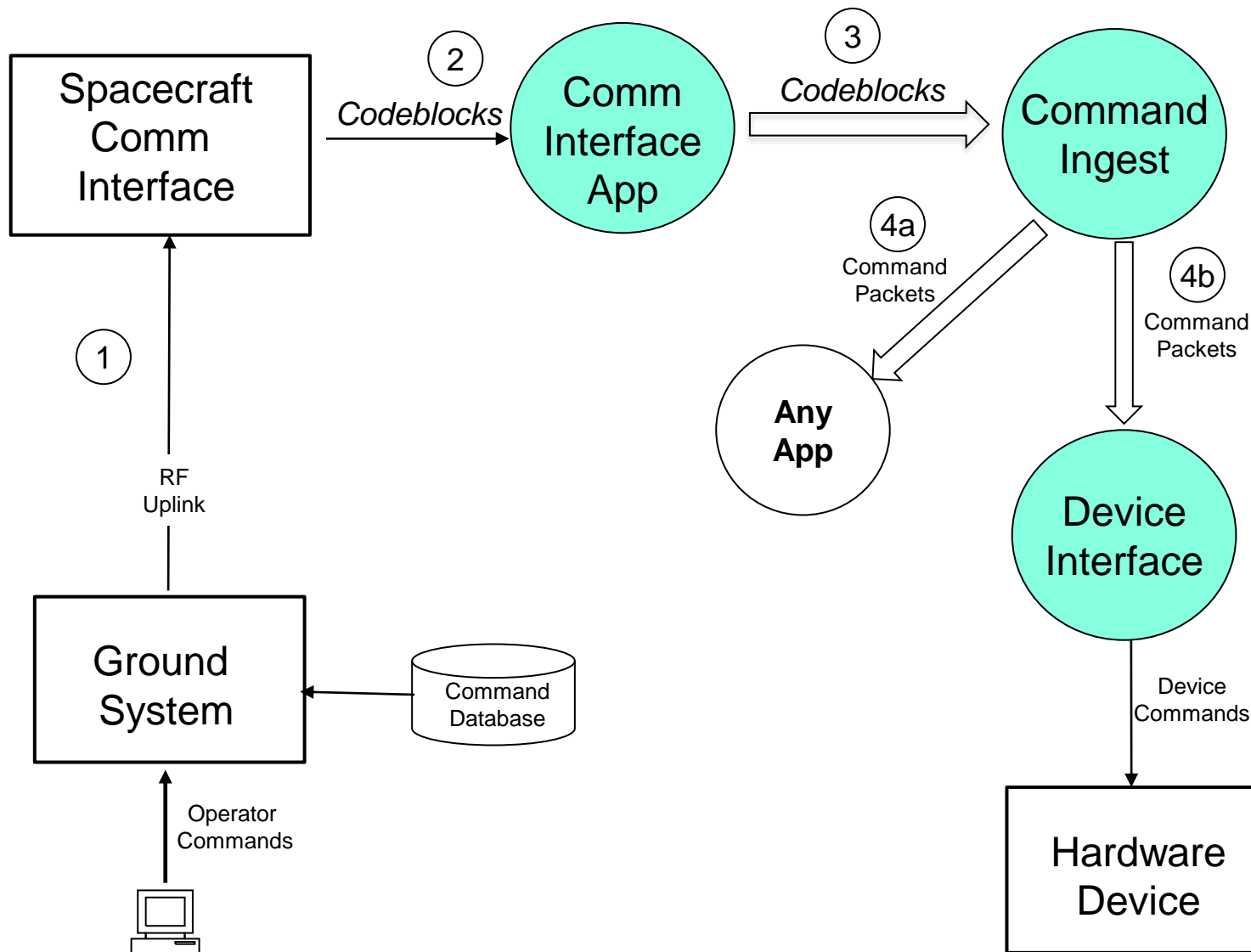


- App XX defines message ID's in its xx\_msgids.h file
- Scheduler periodically send XX's "Send Housekeeping Telemetry Request"
- XX receives ground commands via Command Ingest
- XX's HK telemetry packet is forwarded by Telemetry Output when its not filtered
- XX's event messages are sent to the ground





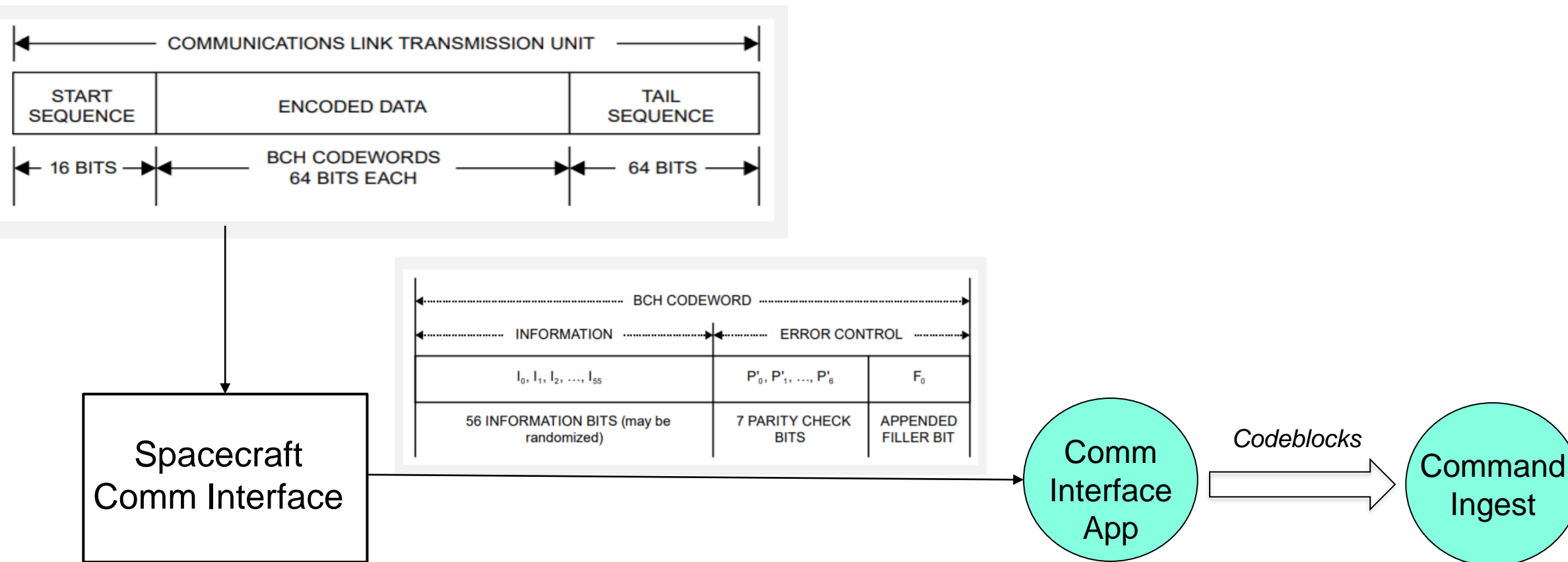
- 1) Commands sent from ground system are received by Comm Interface
- 2) Comm Interface processes Communications Link Transmission Units and sends Code Blocks to Comm Interface App
- 3) Comm Interface App extracts, validates and forwards Code Blocks to CI
- 4) CI constructs, validates and processes transfer frames, then extracts, validates and sends Command Packets on the software bus
  - a) Command packets processed by apps
  - b) Command packets processed by hardware devices. A device interface routes the commands to the device and performs any necessary reformatting if the device does not interpret CCSDS command packets



- These slides describe a 4 step process that a flight CI app would perform to implement a minimal implementation of the CCSDS telecommand standards
- The CCSDS standards provide several implementation variations that trade quality attributes such as scalability, efficiency, security and complexity
- There are many heritage ground and flight systems that can be used as starting points
- Each step should provide buffers that retain all intermediate data for troubleshooting & diagnostics

## 1. Receive and validate code blocks

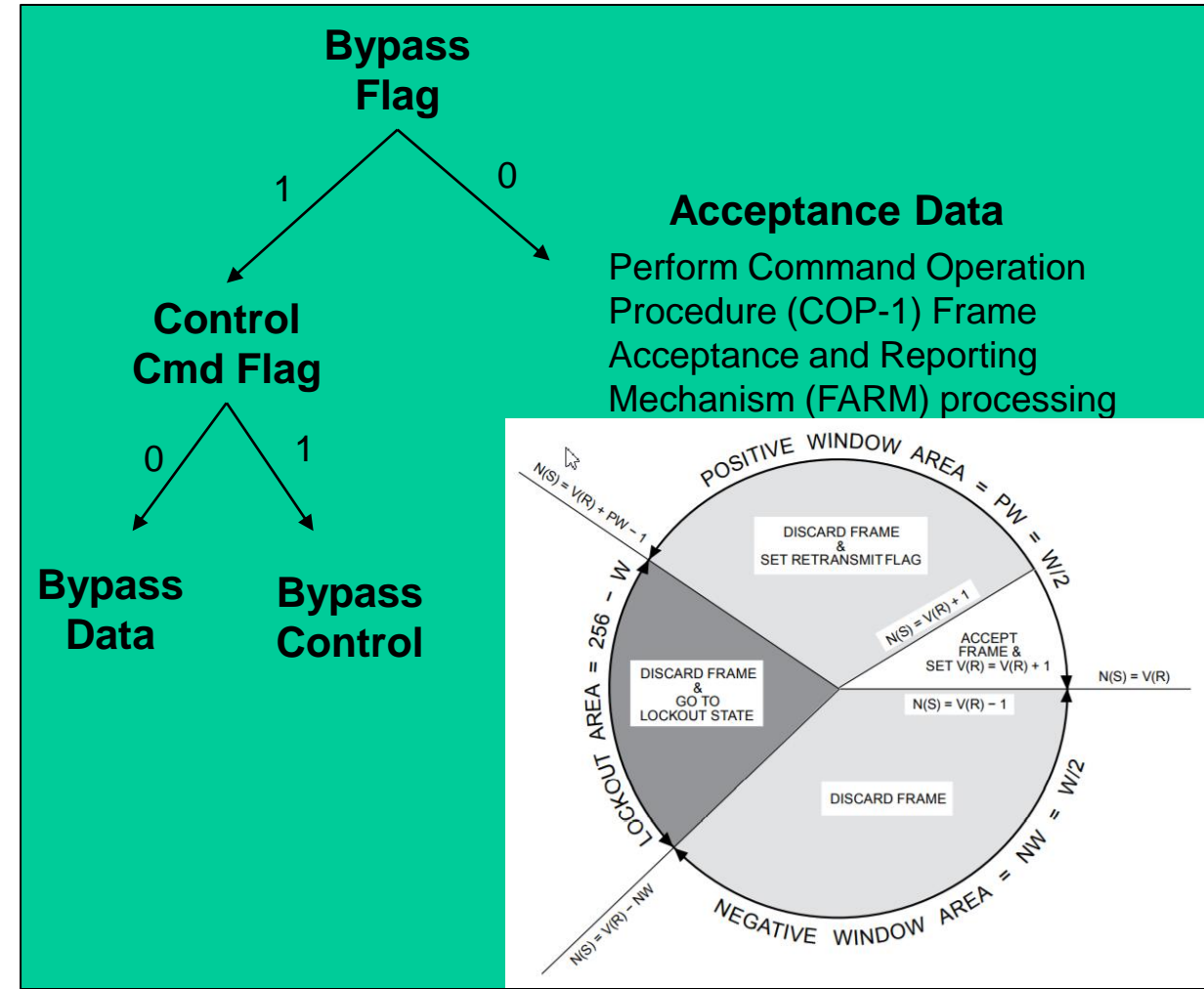
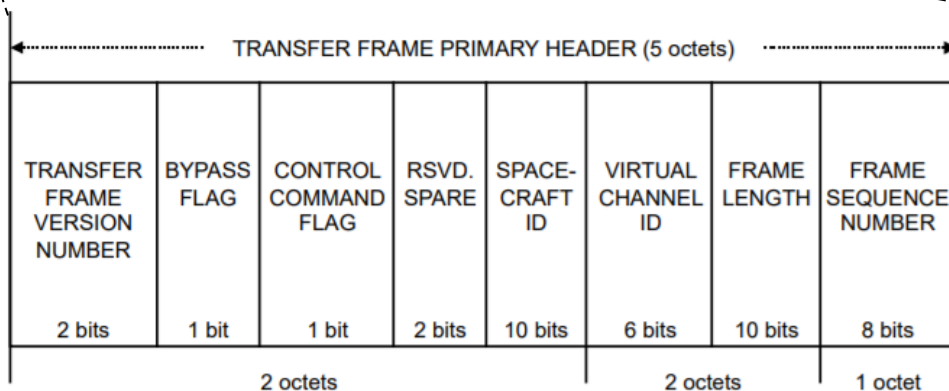
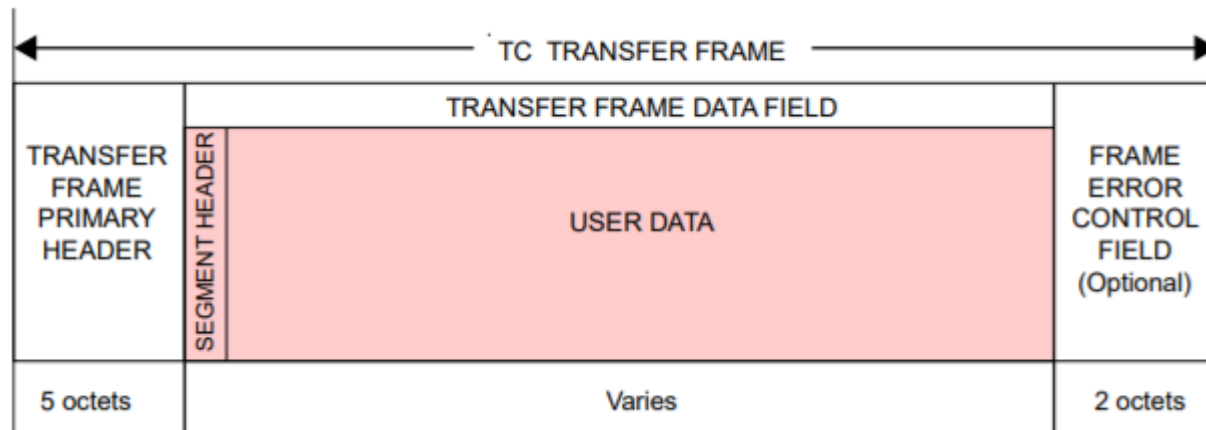
- Defined in CCSDS 231.0-B-3, Telecommand Synchronization and Channel Coding
- A separate comm interface app is typically required that sends “BCH Codewords” aka Codeblocks to CI



## 2. Construct, validate and process transfer frame

- Transfer frame defined in CCSDS 232.0-B-3, Telecommand Space Data Link Protocol
- Data acceptance algorithms defined CCSDS 232.1-B-2, Communication Operation

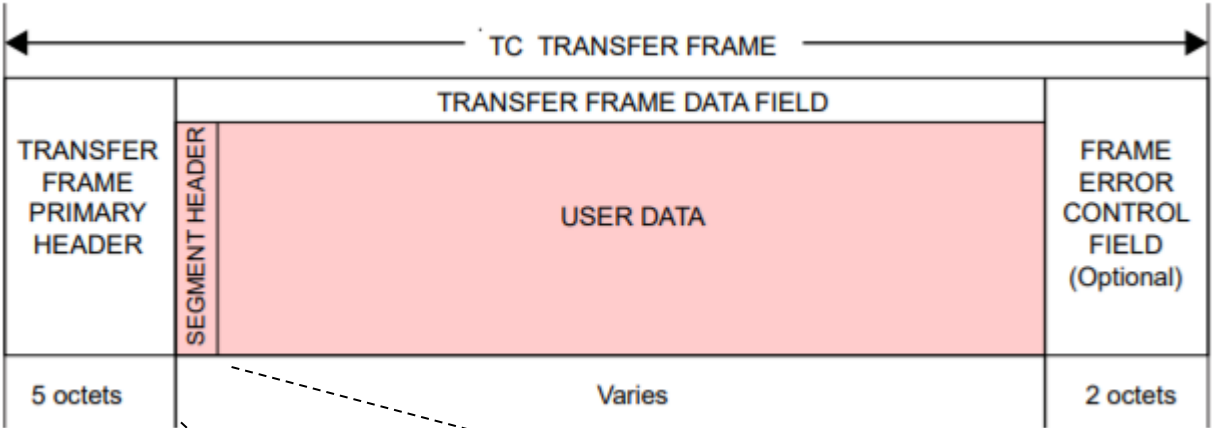
### Procedure-1





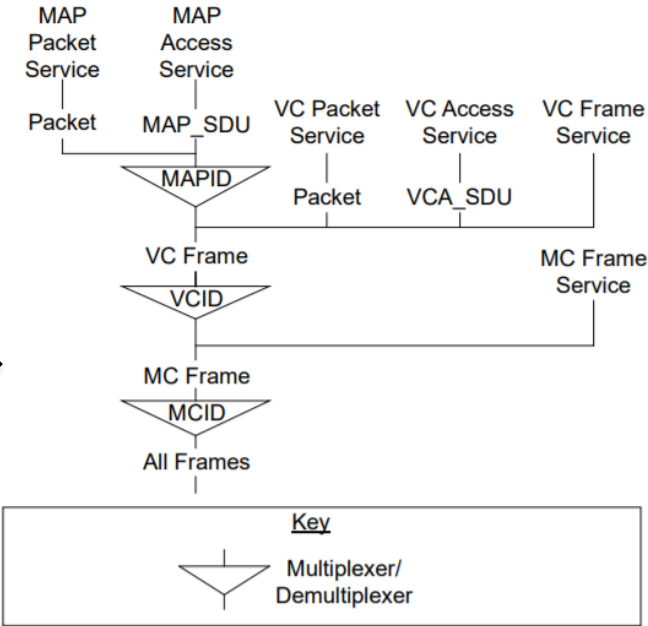
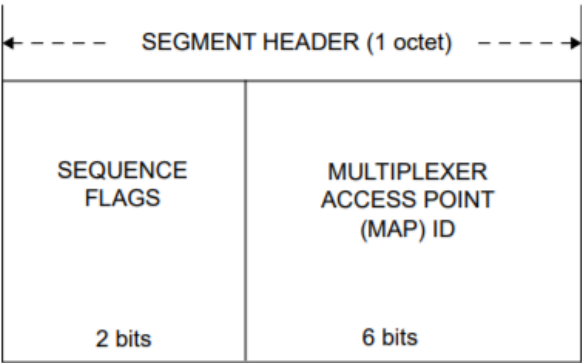
3. **Validate and process segmentation header**
  - a. Defined in CCSDS 232.0-B-3, Telecommand Space Data Link Protocol

Simplest approach is no segmentation, single MAP ID and Virtual Channel



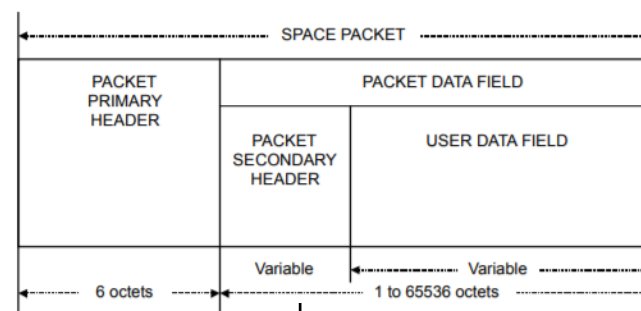
Sequence Flags

Bit 0	Bit 1	Interpretation
0	1	First portion of service data unit on one MAP
0	0	Continuing portion of service data unit on one MAP
1	0	Last portion of service data unit on one MAP
1	1	No segmentation (one complete service data unit or multiple Packets)

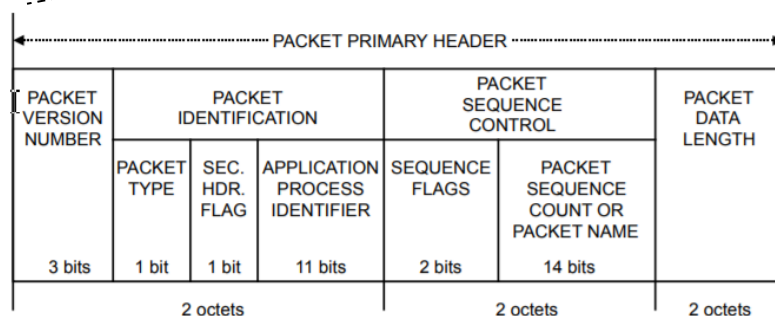


## 4. Command packet validation

- Defined in CCSDS 133.0-B-2, Space Packet Protocol
- Validate packet length
- Validate checksum defined in cFS command secondary header
- Send command packet on the software bus

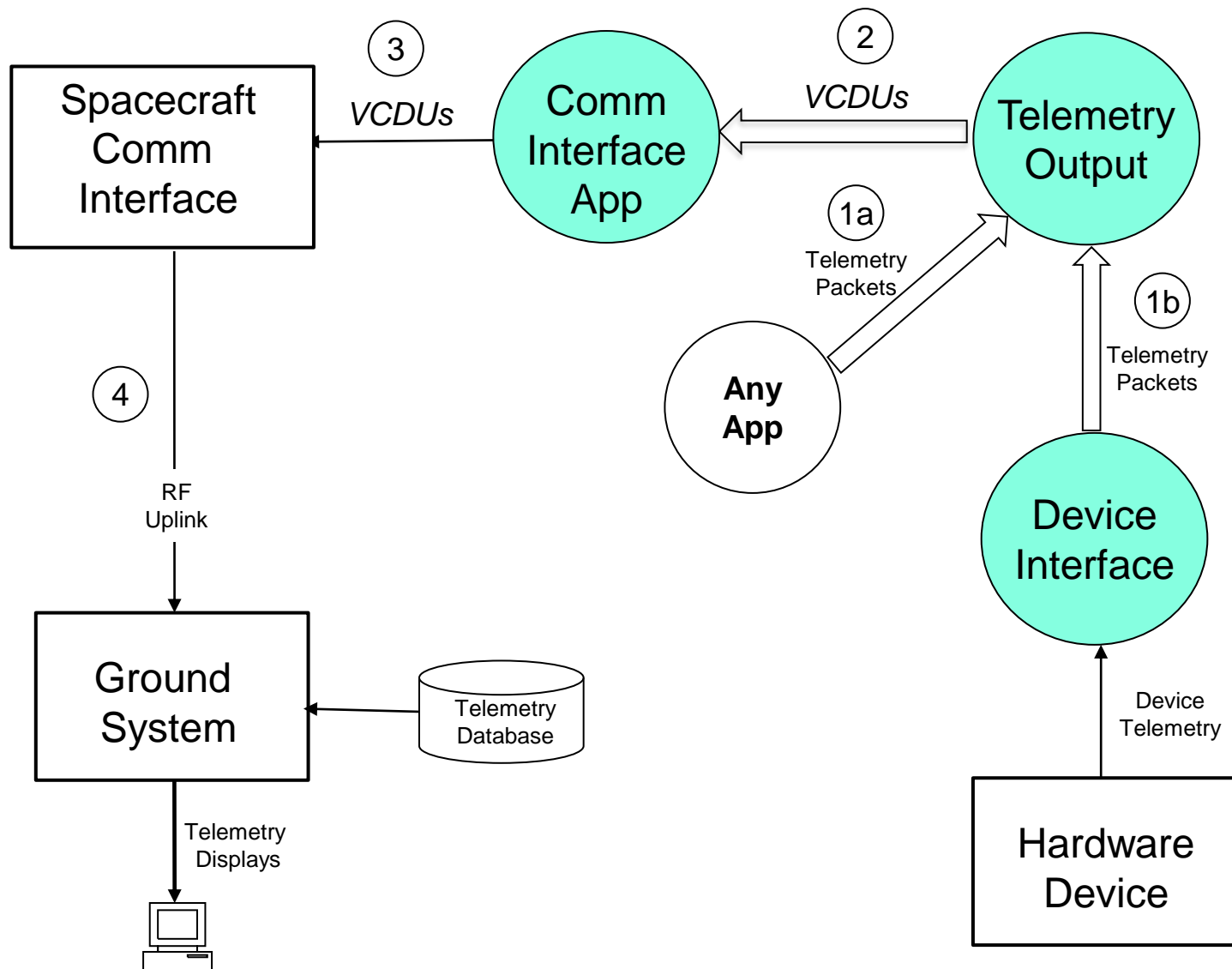


↓ cfs/cfe/fsw/cfe-core/src/inc/ccsds.h



```
/*----- CCSDS command secondary header. -----*/
typedef struct {
    uint16 Command; /* command secondary header */
    /* bits shift ----- description ----- */
    /* 0x00FF 0 : checksum, calculated by ground system */
    /* 0x7F00 8 : command function code */
    /* 0x8000 15 : reserved, set to 0 */
} CCSDS_CmdSecHdr_t;
```

- 1) Telemetry routed to TO on the software bus
  - a) Apps send telemetry packets
  - b) Device Interface apps collect hardware telemetry and package it into CCSDS telemetry packets if needed
- 2) TO collects, filters, builds and sends real-time AOS Transfer Frame on the software bus
- 3) Comm Interface App packages and sends AOS Transfer Frames to Comm Interface
- 4) Telemetry is received by the ground system from communication hardware bus



- Additional considerations
  - Virtual channel management
  - Security
  - Fill frames
  - Real-time vs playback data
- Data rate management between and between apps sending data to TO
- Defined in CCSDS 133.0-B-2, Space Packet Protocol
- Defined in CCSDS 732.0-B-3, Advance Orbiting System (AOS) Space Data Link Protocol
- Historical Documents
  - VCDU



- Telemetry Packet

Packet Identification				Packet Sequence Control		Packet Length	Secondary Header			Packet Data
Version (3)	Type (1)	Sec Hdr Flag (1)	Application ID (11)	Segmentation Flag (2)	Source Sequence Count (14)	Pkt Length (16)	Res. (1)	Seconds (31)	Sub Seconds (16)	Application Data (n*8)

....

- VCDU Data Field

X'0000' – Pkt Hdr at first byte

X'07FF' – No Pkt Hdr in frame

- X'07FE' – Fill Pkt only

M_PDU Header		M_PDU Packet Zone
Spare (5)	First Header Ptr (11)	Source Packet Data 1770 Octets (1770 x 8 = 14160 bits)

Real-Time VCDU (X'7FC000000000')

VCDU Primary Header							VCDU Data	VCDU Trailer	
Version AOS=1 (2)	VCDU ID		VCDU Counter (24)	Replay Flag RT=0 (1)	Time Corr Bit (1)	Spare (6)	1772 Octets (1772 x 8 = 14176 bits)	CLCW (32)	CRC (16)
	Space- craft ID (8)	VC ID (6)							

Message Sent to SW application

Packet Header	SpaceWire Cargo	
	Synchronization Marker	
	0x1ACFFC (4 Bytes)	Downlink Data (1784 Bytes)

# Telemetry Packet

Packet Identification				Packet Sequence Control		Packet Length	Secondary Header			Packet Data
Version (3)	Type (1)	Sec Hdr Flag (1)	Application ID (11)	Segmentation Flag (2)	Source Sequence Count (14)	Pkt Length (16)	Res. (1)	Seconds (31)	Sub Seconds (16)	Application Data (n*8)

TRANSFER FRAME PRIMARY HEADER								
MASTER CHANNEL ID		VIRTUAL CHANNEL ID	VIRTUAL CHANNEL FRAME COUNT	SIGNALING FIELD				FRAME HEADER ERROR CONTROL (Optional)
TRANSFER FRAME VERSION NUMBER	SPACECRAFT ID			REPLAY FLAG	VC FRAME COUNT USAGE FLAG	RSVD. SPARE	VC FRAME COUNT CYCLE	
2 bits	8 bits	6 bits		1 bit	1 bit	2 bits	4 bits	
2 octets			3 octets	1 octet				2 octets

M_PDU HEADER		M_PDU PACKET ZONE				
RSVD. SPARE	FIRST HEADER POINTER	END OF PREVIOUS CCSDS PACKET #k	CCSDS PACKET #k+1	.....	CCSDS PACKET #m	START OF CCSDS PACKET #m+1
5 bits	11 bits					

AOS TRANSFER FRAME				
TRANSFER FRAME PRIMARY HEADER	TRANSFER FRAME INSERT ZONE (Optional)	TRANSFER FRAME DATA FIELD	TRANSFER FRAME TRAILER (Optional)	
			OPERATIONAL CONTROL FIELD (Optional)	FRAME ERROR CONTROL FIELD (Optional)
6 or 8 octets	Varies	Varies	4 octets	2 octets

# Telemetry Packet

Packet Identification				Packet Sequence Control		Packet Length	Secondary Header			Packet Data
Version (3)	Type (1)	Sec Hdr Flag (1)	Application ID (11)	Segmentation Flag (2)	Source Sequence Count (14)	Pkt Length (16)	Res. (1)	Seconds (31)	Sub Seconds (16)	Application Data (n*8)

M_PDU HEADER		M_PDU PACKET ZONE				
RSVD. SPARE  5 bits	FIRST HEADER POINTER  11 bits	END OF PREVIOUS CCSDS PACKET #k  (32)	CCSDS PACKET #k+1  (16)	.....	CCSDS PACKET #m	START OF CCSDS PACKET #m+1

VCDU Primary Header					VCDU Data	
ID	VC ID (6)	VCDU Counter (24)	Replay Flag RT=0 (1)	Time Corr Bit (1)	Spare (6)	1772 Octets (1772 x 8 = 14176 bits)

TRANSFER FRAME PRIMARY HEADER							
TRANSFER FRAME ID	VIRTUAL CHANNEL ID	VIRTUAL CHANNEL FRAME COUNT	SIGNALING FIELD				FRAME HEADER ERROR CONTROL (Optional)
SPACECRAFT ID			REPLAY FLAG	VC FRAME COUNT USAGE FLAG	RSVD. SPARE	VC FRAME COUNT CYCLE	
8 bits	6 bits		1 bit	1 bit	2 bits	4 bits	
2 octets	3 octets		1 octet				2 octets

AOS TRANSFER FRAME				
TRANSFER FRAME PRIMARY HEADER	TRANSFER FRAME INSERT ZONE (Optional)	TRANSFER FRAME DATA FIELD	TRANSFER FRAME TRAILER (Optional)	
			OPERA- TIONAL CONTROL FIELD (Optional)	FRAME ERROR CONTROL FIELD (Optional)
6 or 8 octets	Varies	Varies	4 octets	2 octets



# NASA's Open Source Scheduler (SCH) App

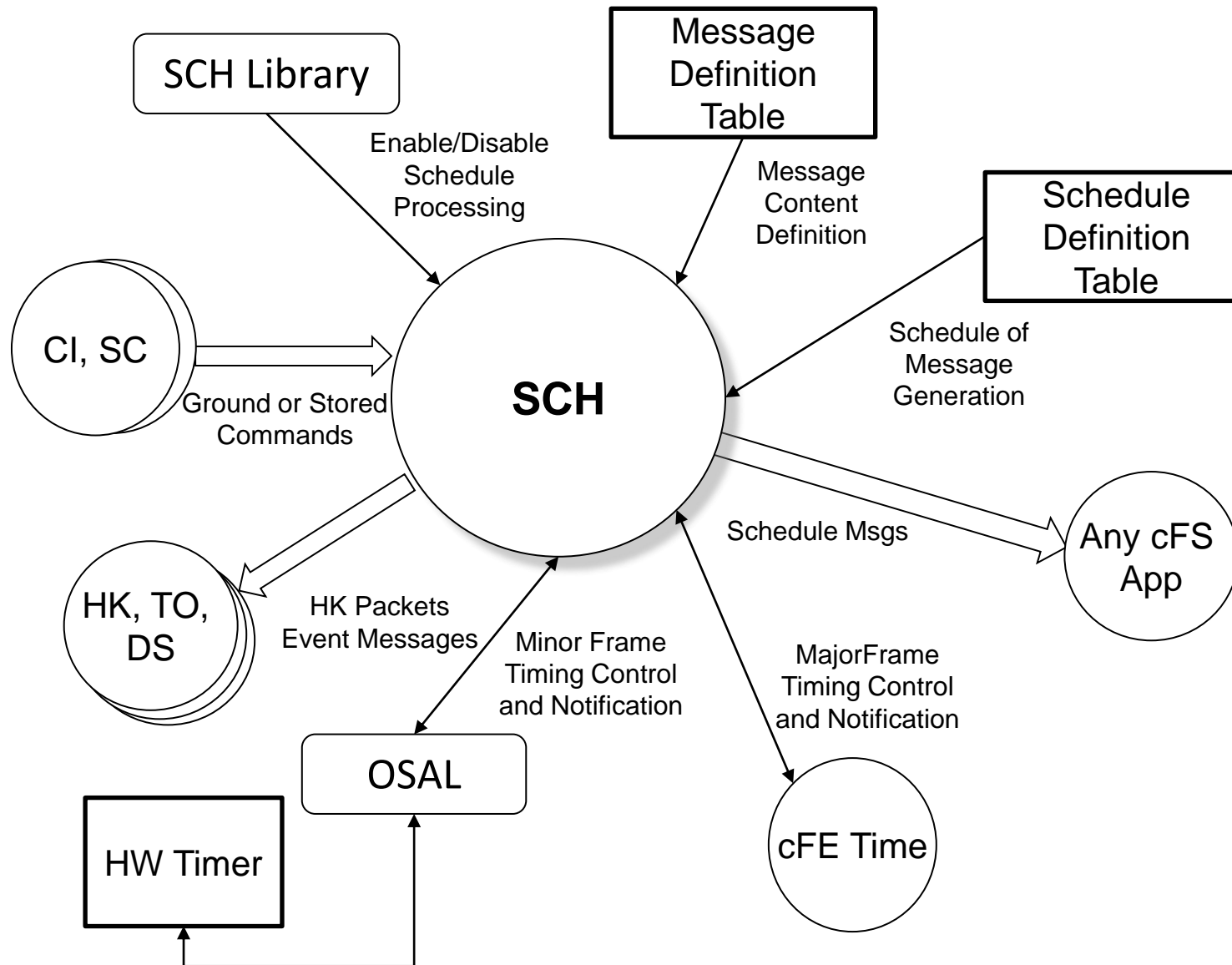
<https://github.com/nasa/SCH>

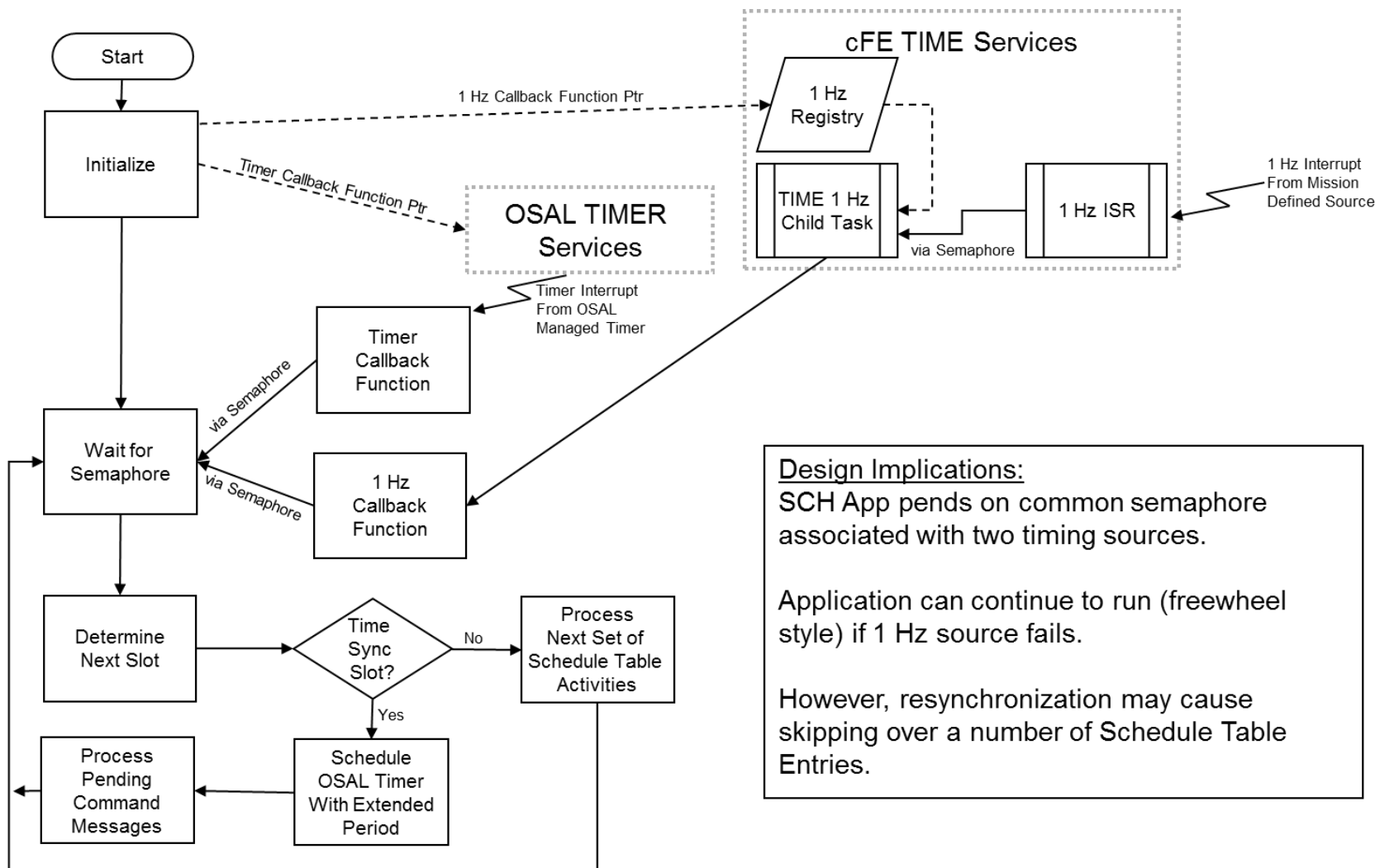
- **Provides method of generating messages at pre-determined timing intervals**
  - Operates in a Time Division Multiplexed (TDM) fashion with deterministic behavior
    - Synchronized to external Major Frame cFE TIME 1 Hz signal
    - Each Major Frame split into a platform configuration number of smaller slots (typically 100 slots of 10 milliseconds each)
      - o Each slot can contain a platform configuration number of software bus messages that can be issued within that slot

**Groups are good for redundancy management**



# SCH Context Diagram





# SCH Configuration Parameters - 1

Parameter	Description	Default Value
SCH_PIPE_DEPTH	Software bus command pipe depth	12
SCH_TOTAL_SLOTS	Minor Frame Frequency (in Hz)	100
SCH_ENTRIES_PER_SLOT	Maximum Activities per slot	5
SCH_MAX_MESSAGES	Maximum Number of Message Definitions in Message Table	128
SCH_MDT_MIN_MSG_ID	Minimum Message ID allowed in Message Definition Table	0
SCH_MDT_MAX_MSG_ID	Maximum Message ID allowed in Message Definition Table	CFE_SB_HIGHEST_VALID_MSGID
SCH_MAX_MSG_WORDS	Maximum Length, in Words, of a Message in the message table	64
SCH_MAX_LAG_COUNT	Maximum Number of slots allowed for catch-up before skipping	(SCH_TOTAL_SLOTS/2)
SCH_MAX_SLOTS_PER_WAKEUP	Maximum Number of Slots to be processed when in "Catch Up" mode	5
SCH_MICROS_PER_MAJOR_FRAME	Conversion factor for how many microseconds in a wake-up period	10000000

# SCH Configuration Parameters - 2

Parameter	Description	Default Value
SCH_SYNC_SLOT_DRIFT_WINDOW	Additional time allowed in Sync Slot to wait for Major Frame Sync	5000
SCH_STARTUP_SYNC_TIMEOUT	Timeout on waiting for all applications to start at initialization	50000
SCH_STARTUP_PERIOD	Number of microseconds to attempt major frame synchronization	(5*SCH_MICROS_PER_MAJOR_FRAME)
SCH_MAX_NOISY_MAJORF	Maximum noisy major frames prior to desynchronization	2
SCH_LIB_PRESENCE	Presence of SCH Library	1
SCH_LIB_DIS_CTR	Processing disabled counter at startup	0
SCH_SCHEDULE_FILENAME	Default schedule table filename to load at startup	"/cf/apps/sch_def_schtbl.tbl"
SCH_MESSAGE_FILENAME	Default message table filename to load at startup	"/cf/apps/sch_def_msgtbl.tbl"
SCH_MISSION_REV	Mission revision number	0

Command	Description
<b>No-op</b>	Increments the Command Accepted Counter and sends a debug event message
<b>Reset Counters</b>	Initializes housekeeping counters to zero
<b>Enable Entry</b>	Enables an entry in the Schedule Definition Table
<b>Disable Entry</b>	Disables an entry in the Schedule Definition Table
<b>Enable Group and/or Multi-Group(s)</b>	Enables a group and/or multi-group(s) of entries in the Schedule Definition Table
<b>Disable Group and/or Multi-Group(s)</b>	Disables a group and/or multi-group(s) of entries in the Schedule Definition Table
<b>Enable Sync</b>	Enables usage of Major Frame Signal if previously autonomously disabled for being "noisy"
<b>Send Diagnostic Tim</b>	Generates and sends the SCH Diagnostic Telemetry Packet that contains the current state of all activities defined in the Schedule Definition Table





# SCH Housekeeping Telemetry Message - 1



Telemetry Point	Description
CommandCounter	Number of accepted ground commands
CommandErrCounter	Number of rejected ground commands
ScheduleActivitySuccessCounter	Number of scheduled activities processed
ScheduleActivityFailureCounter	Number of scheduled activities failed due to error
SlotsProcessedCounter	Number of schedule slots processed
SlotsSkippedCounter	Number of instances when one or more slots were skipped
MultipleSlotsCounter	Number of instances when two or more slots were processed at once
SameSlotCounter	Number of instances when SCH woke up in the same time slot as previously
BadTableDataCount	Number of table entries with an error that have been encountered
TableVerifySuccessCount	Number of successful table verifications performed
TableVerifyFailureCount	Number of failed table verifications performed
TablePassCounter	Number of times Schedule Table was completely processed
ValidMajorFrameCount	Number of Valid Major Frame Signals received
MissedMajorFrameCount	Number of Major Frame Signals that did not occur when expected
UnexpectedMajorFrameCount	Number of Major Frame Signals that occurred when not expected to occur
MinorFramesSinceTone	Number of Minor Frames processed since last Major Frame



# SCH Housekeeping Telemetry Message - 2



Telemetry Point	Description
NextSlotNumber	The next slot to be processed in the Schedule Definition Table
LastSyncMETSlot	Slot Number when last Time Synchronization occurred
IgnoreMajorFrame	Major Frame Signals are ignored because they are deemed "noisy"
UnexpectedMajorFrame	Last Major Frame Signal occurred when not expected
SyncToMET	Minor Frames are synchronized to MET.
MajorFrameSource	Identifies the source of the Major Frame Signal (timer, MET, etc)