IITMSAT: Innovative Packet Protocol and Concept of Operations

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Vanilla packet protocol — a new standard?

Motivation

1. **AX.25** link layer protocol is a successful standard but it was **not designed for Space to Earth links** (or vice-versa). Being widely used by radio amateurs, it was easily adopted by the small satellite community.
2. **Challenges with AX.25:**
   - Not designed for communication bandwidth constrained satellites. **Long headers** (>120 bits) make it sub-optimal for transmission of multiple short frames. Most telecommands designed for small satellite missions can fit within 80 bits (unless TC is used to send files/ upload new code).
   - Most COTS radios designed for small satellite missions adhere to AX.25 format only**. Implementation of AX.25 on these COTS radios imposes additional constraints** on the user (such as frame size, type of CRC).
   - There is a need for COTS radios that adhere to a basic packet protocol and gives users ability to customize on top of it.

Solution

1. A fresh approach was carried out to develop optimized TC TM structure.
2. Fields are customizable for mission specific designs. Easy to implement in H/W using SDR (software defined radio).
3. In a session, a train of frames is sent. A preamble frame first followed by information frames.
4. Instead of address/control fields being present in each frame, the preamble frame contains these fields. This frame cannot be standardized as it may be required to add synchronization bytes for phase modulations schemes.
5. Information frames have custom fields. Data in these frames is bit-stuffed and frames are separated by flags (0x7E).
6. Based on mission requirements, multiple lengths of frames can be designed.

IITMSAT has implemented this protocol in the GS and onboard system without any constraints.

Abstract: IITMSAT is a student-built nanosatellite mission of Indian IIT-M, Chennai, India. The science objective of the project is to understand the nature of precipitation of charged particles (high energy electrons and protons) from the Van-Allen Belts in Low Earth Orbit (600-900 km). The poster focusses on two aspects of IITMSAT design where innovative ideas have been implemented: Packet protocol and ConOps.

Envelope	**316 x 326 x 270 mm^3**
Mass	12 kg
Power system	7 W (consumption) with body mounted solar cells on 4 satellite faces, 4 LiPo batteries
Attitude scheme	Magnetic field pointing using 3 axis Mag-Gyro and 3 magnetorquer rods
Payload: SPEED (Space based Proton and Electron Energy Detector)	Plastic scintillators, PMTs, WLS fibres, High Voltage (1200V) Range and resolution: Protons: 17 - 100 MeV, 5 MeV Electrons: 1 – 15 MeV,1 MeV Detector Area: 506 cm^2
Antenna	Inverted F antenna
Downlink (Main) Beacon Uplink	19.2 kbps GMSK 435 MHz 40 bps CW 435 MHz 1 kbps FSK 145 MHz
Ground Station	IIT-M Campus
Mission	1 year
Launch	Oct / Nov 2016

IITMSAT TC TM protocol design (Non — AX.25)

PSC: Packet Sequence Count	APID: Application Process ID	Last TC field	TC size field	Abort on TC execution NACK field	TC Source field	SID: Service Type ID	SSID: Service Subtype ID	Application Data	PCS Packet Check sequence
• This is a unique ID given to a TC in each session. This is used for TM and ACK referencing	• As per ECSS PUS • In IITMSAT each uC is an application process	• Indicates whether the current packet is the last in the series of TCs transmitted	• Specifies the data size of the TC. • IITMSAT has 2 lengths of TC • Short: (11 Bytes) and Long (125 Bytes)	• In case a TC execution fails, depending on the value of this field, remaining TCs will initiated for execution or not	• Indicates the source of the TC. • Source of a TC can be earth station or internally generated by CDMS	• As per ECSS PUS • Services implemented in IITMSAT: FMS, MMS, OBSRS, OBOSC & PMS (custom)	• Most are as per ECSS PUS • Tailoring for some Service types	• All the details of the TC are specified in this field	• 16 bit CRC

IITMSAT TC packet protocol

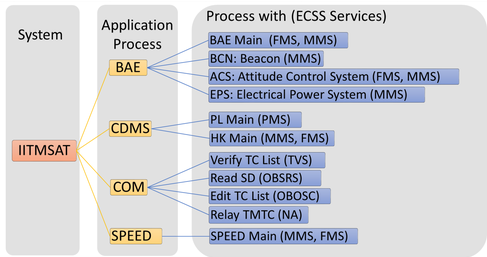
	Packet Header							Packet Data Field			PCS	Total
Field	TC PSC	APID	LAST TC	TC SIZE	ABORT ON EXEC. FAIL.	SPARE	TC SOURCE	SID	SSID	APP. DATA	CRC	
Bits	8	2	1	1	1	2	1	4	4	48	16	88

TC Packets design overview

- One TC packet in one frame.
- Two TC lengths (Long/ Short).
- Packet structure based on ECSS Packet Utilization standard (PUS).
  - Application process: There are three microcontrollers (uC) in the satellite. Each uC is an application process.
  - Application processes are further divided into processes.
  - A process is a sink for a TC and a source of TM.
- ECSS services (TC type) implemented in IITMSAT:
  - FMS (Function Management Service).
  - MMS (Memory Management Service).
  - OBSRS (Onboard storage and retrieval service)
  - OBOSC (Onboard operations scheduling service).
  - *PMS (Payload Management Service):* Time tagged TCs to change science mode
  - TVS (Telecommand Verification Service).
  - Preamble TC packet: Contains source and destination amateur radio call signs.

Communication ConOps philosophy

- Designed for Half-Duplex communication.
- A TC list approach (multiple TCs) for each session. Possible to have multiple sessions in a pass.
- TC execution begins when all TCs in the TC list are received correctly by satellite.
- All TM packets are tagged by TC PSC (except OBSRS TM, tagged by SD block no).
- OBSRS TCs are designed to access each block in SD directly and retrieve science and archived housekeeping data.
- Not possible to request for retransmission of TM. Need to resend TC in case of incorrect TM.
- Status of all TCs and TC List sent after execution of each TC.
- All TCs executed in order of PSC (except OBOSC).
- OBOSC TCs are TCs to designed to edit TC list (Retry TC execution, disable TC and reset session).



TM Packets design overview

- TM type:
  - FMS
  - MMS: RAM(L/S), FLASH (L/S)
  - OBSRS: Archived Science and archived HK
  - OBOSC: TC LIST STATUS, ACK.
  - Preamble TM packet

TM Type	TM Size	TM PSC	ACK Code	Application Data
• TM types are categorized into different types of HK and Science data for GS sorting and display	• TM data can be of different data sizes • In IITMSAT, there are two TM data sizes	• This is a unique ID for each TM packet of a TC • Used to keep track of number of TM packets	• Acknowledgement status of the TC • As per ECSS PUS	• Detailed TM is in this field

IITMSAT TM packet protocol

	Packet Header				Packet Data Field		PCS	Total
Field	TM TYPE	TM SIZE	TC PSC	TM PSC	ACK. CODE	APP. DATA	CRC	
Bits	4	4	8	8	8	1024	16	1072

Concept of Operations:

How can these requirements be made easier to use?

Motivation

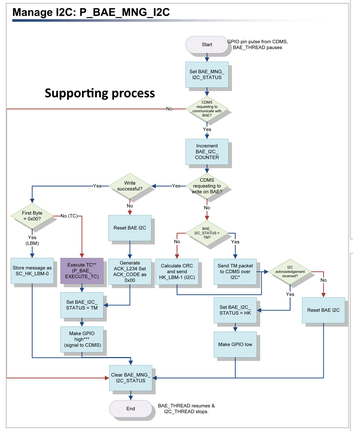
1. A need to **specify operational requirements** in a clear comprehensible manner.
2. Essentially the question was how they should be defined so that they can be easily verified. Initially the approach taken was to classify all **operation scenarios as possible 'states'** of the system. However this scheme ended up with the system having **so many 'states'** that did not convey any intuitive understanding of the system.

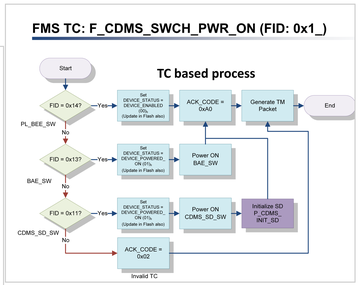
Solution

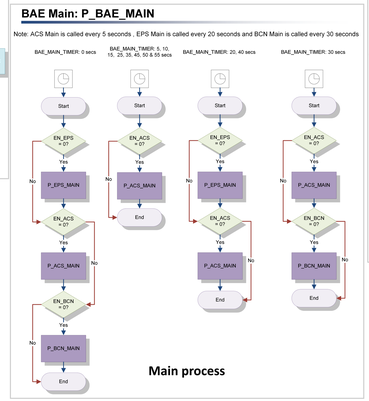
1. ECSS defines 'application process' as a source of TM and a sink for TC. Taking this idea forward, the system is now divided into **four application processes**. Further each application process was divided into **2-3 'processes'** wherein each process can have 2-4 'operational states'.
2. Each process has **a well-defined flow chart** that contain clear indicators **(flags/ software variables)** whenever a state is changed. This approach has been helpful in describing operational requirements to newcomers, explaining concepts to reviewers, act as a starting point for software developers and aid in generating test scenarios to verify software.
3. There are four types of processes. **Main, TC based, timer based and supporting processes**.
4. Processes can be called by each other. During implementation, each step of the process corresponds to a piece of software. However style of implementation can be different from the flowchart.
5. A blue step is a simple step but a purple step is another process (that has another flowchart).
6. IITMSAT ConOps team has developed more than hundred detailed flowcharts and is being used effectively.

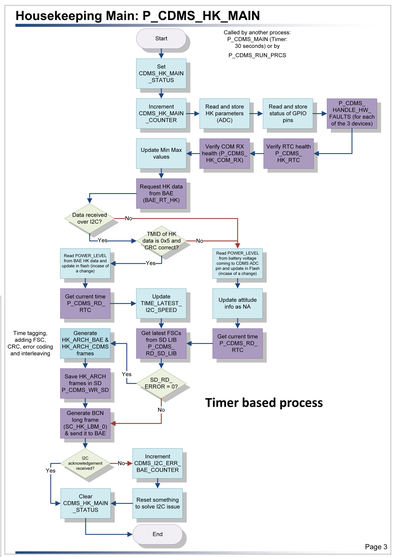
Software and ConOps requirements have been merged into a set of flowchart documents to make it simple and verifiable -> Leads to mission success

IITMSAT ConOps flowcharts









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