IMPLEMENTATION OF CCSDS RECOMMENDATIONS TO THE NPOESS SYSTEM

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ABSTRACT

The United States Government, through the Integrated Program Office (IPO), currently operates a converged polar orbiting constellation of POES and DMSP satellites to acquire, process and disseminate meteorological and environmental data on a global scale. Because of the increasing need for more precise and timely meteorological data, the IPO is developing the follow on system known as the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The NPOESS system is expected to use a modernized, CCSDS compatible data acquisition and distribution network, and will provide more timely data than for the current POES/DMSP satellites. The NPOESS satellite system will also continue the collection of long-term environmental data as a follow on to NASA's Earth Observation System (EOS). The continuation of NASA's EOS system will begin with a risk reduction effort in support of NPOESS, known as the NPOESS Preparatory Project (NPP). This paper will describe the CCSDS implementation that both the NPP and NPOESS satellites are expected to use beginning with the launch of the NPP spacecraft in 2006. The launch of the first NPOESS satellite is anticipated in 2009.

KEYWORDS

NPOESS, Telemetry, Telecommand, CCSDS Implementation, Earth Observation

INTRODUCTION

The overall system architecture for the NPOESS system will ultimately consist of a three-satellite constellation of sun synchronous satellites in different orbit planes. The first satellite in the constellation will, in fact, be the NPP spacecraft, although it will not have the full complement of instruments that will fly on the NPOESS spacecraft. A simplified diagram of the final NPOESS system architecture is illustrated in Figure 1, with the NPP spacecraft shown as a residual.

The NPP spacecraft and each of the NPOESS spacecraft will carry a suit of advanced instruments for gathering environmental data to enable the production of significant environmental data records for both short term weather forecasting and long term climate modeling. Key new instruments on the NPP spacecraft and each NPOESS spacecraft include the Visible Infrared Imager Radiometric Suite (VIIRS), the Cross track Infrared Sounder (CrIS), the Advanced Technology Microwave Sounder (ATMS) and the Ozone Mapper/Profiler Suite (OMPS). The NPOESS spacecraft will also carry a Conical Microwave Imager Sounder (CMIS), a GPS Occultation Sensor (GPSOS), a Space Environmental Suite (SESS), and a number of heritage instruments. Because of the complexity and advanced performance characteristics of these instruments, the volume of data produced by the three operational spacecraft, as well as, the NPP spacecraft will be more than an order of magnitude greater that that produced by the current POES and DMSP satellites. Additionally, the NPOESS system will be capable of delivering weather data products with a much shorter latency, compared to the current system.

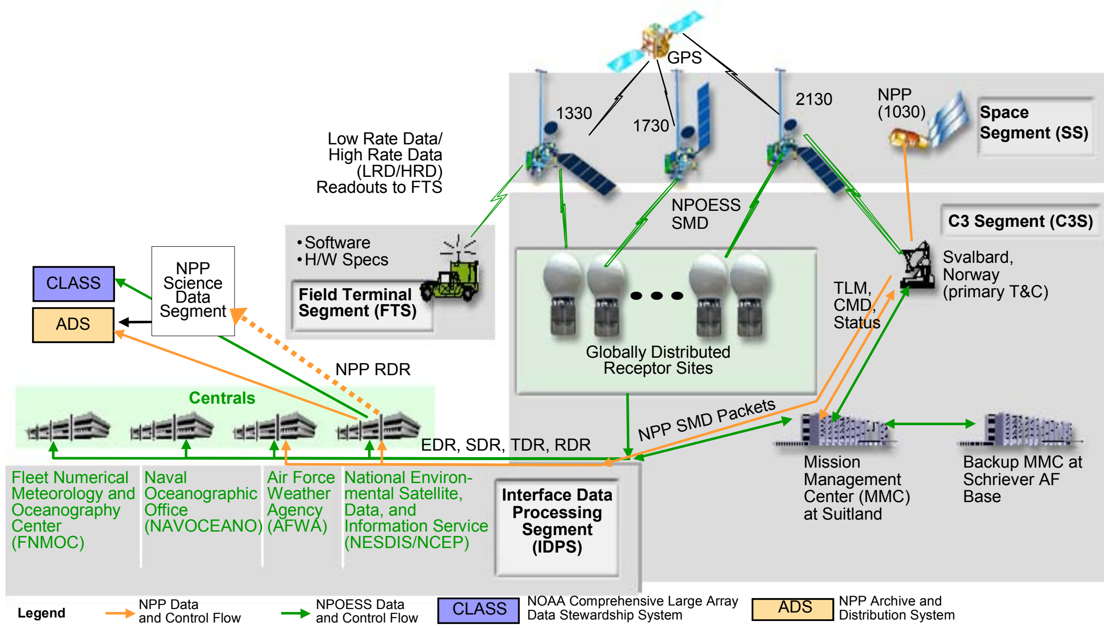

Figure 1. NPOESS System Architecture

Stored Mission Data (SMD) from an NPOESS Satellite will be downlinked to individual, globally distributed receptors whenever the receptor is in view. This SMD will be sent to four processing centrals in the United States via a Data Routing and Retrieval (DRR) wide area network. The processing centers include the NESDIS facility at Suitland, MD, FNMOC in Monterey, CA, NAVOCEANO in Stennis, MS and AFWA in Omaha, NE. The Interface Data Processing Segments (IDPS) at each of the centrals will process the raw SMD data records into the environmental data records and data products and distribute them to the users. Because of this distributed, automated system architecture, the latency time between the time of observation and the availability of the data products is expected to be less than thirty minutes. For the NPP spacecraft only, the SMD will be downlinked to a polar Mission Ground Station (MGS) to be located at Svalbard, Norway.

Direct broadcasts of High Rate Data (HRD) and Low Rate Data (LRD), NPOESS only, will be provided to appropriately equipped field terminals. The HRD data stream will contain all of the data records collected by the satellite, on a real time basis, while the LRD data stream will contain selected data records intended for a more limited user. All NPOESS and NPP mission data, including SMD, HRD and LRD, will use CCSDS type 1 packetization and Grade 2 service. [1]

Command and control of the NPP and NPOESS missions will reside in a Mission Management Centers (MMC's) located in Suitland, Maryland. During the NPOESS era, a second MMC will reside in Schreiver AFB, Colorado. Normal operations are expected to be based in the Suitland MMC, with the Schreiver MMC providing redundancy. Communications for command and telemetry to each of the spacecraft (both NPP and NPOESS) will be accomplished via the MGS at

Svalbard, Norway. Back up communications capability for LEO & A will be provided via NASA's Space Network (SN).

ON-BOARD DATA FLOW

A simplified diagram of the on-board data flow data flow for the NPOESS spacecraft is shown in Figure 2. (The data flow will be similar for the NPP spacecraft, except for the number of instruments.) Each of the instruments will form the raw data from the sensors into CCSDS Application Packets (AP's), using the application ID field (See Figure 3) to identify the content of the data field, according to the individual data channel within the sensor, such as wavelength band, or other distinguishing characteristic. Virtual Channels (VC's) will be used to identify the originating instrument and the intended downlink pathways. For example, the VIIRS instrument collects data in twenty-two frequency bands on a continuous basis. The data from each of these bands is formed into an application packet whose APID's, together with VIIRS unique VCID's identify the particular band. A subset of these bands with unique APIDs are also image compressed on NPOESS and sent down the LRD path. This allows the data to be routed directly to the appropriate algorithm within the IDPS. Similarly, each of the other instruments will have unique combinations of APID's and VCID's to identify the data content. Telemetry from the instruments and commands from the ground will also identified according to their respective APID's and VCID's.

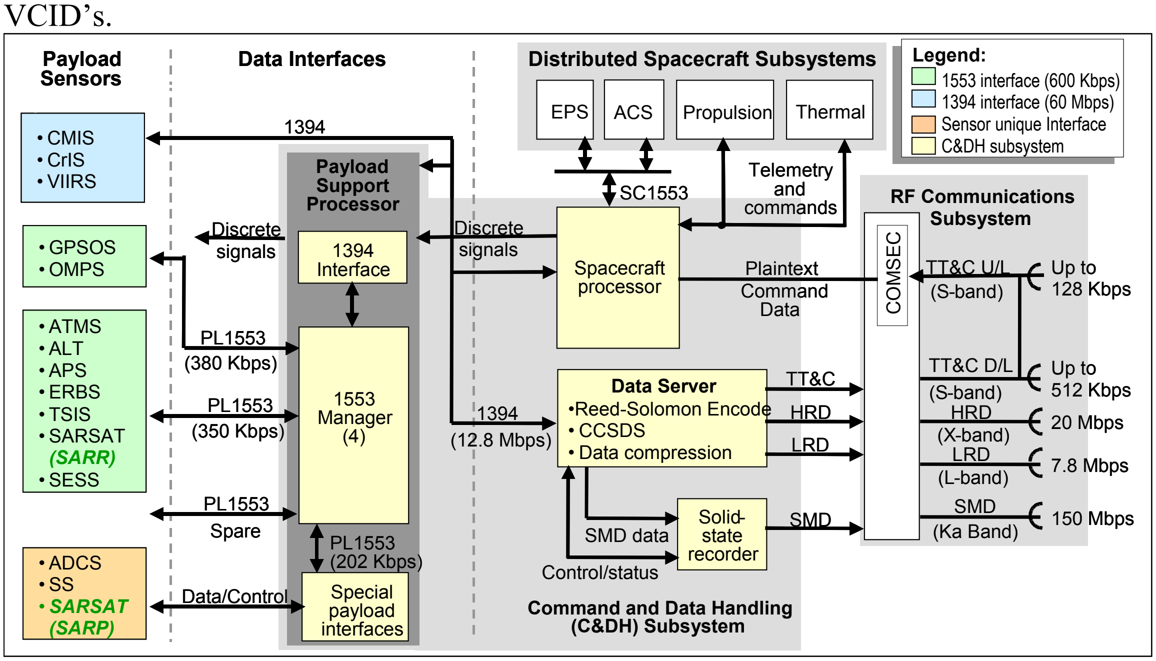

Figure 1 On-Board Data Flow:

Because of the high data rate associated with VIIRS, CrIS and CMIS, the NPOESS and NPP spacecraft will use a space qualified IEEE 1994 data bus to route their respective AP's to the Command and Data Handling (C&DH) subsystem. At the time this paper was written, the peak data rate for the VIIRS instrument alone is about 26.5 Mbps(including LRD data), with about 2.5 Mbps needed for CrIS, and about 500 kbps for CMIS. The aggregate data rate of the other sensors is significantly less, allowing the proven 1553 data bus to be used for these sensors. The AP's will be segmented by the bus protocol at this layer of the on-board processing to fit the data into the correct block sizes. At the time of the writing of this paper, CCSDS recommendations concerning on board interfaces were still under development, and hence, for NPOESS and NPP, theses interfaces were developed independently.

Within the C&DH processor, the AP's are formed into the Virtual Channel Data Units (VCDU's) , and Coded Virtual Channel Data Units (CVCDU's) with the Reed-Solomon code applied are formed and passed to the Solid State Recorder (SSR) for delayed broadcast to the SMD. Finally, Channel Access Data Units (CADU's), directly or delayed by the SSR, are formed and broadcast by the SMD and HRD down links. The C&DH also selects the desired VC's for delivery to the LRD subsystem for this downlink. The details of the packet structure for the mission data are shown in Figure 3. [2] (NOTE: The NPOESS specific insert zone is not shown.) Each of the instruments and the C&DH also receives a time code packet and a one pulse per second signal from an on-board GPS receiver. This information is used to time tag all collected data through the CCSDS time code format recommendation. [3]

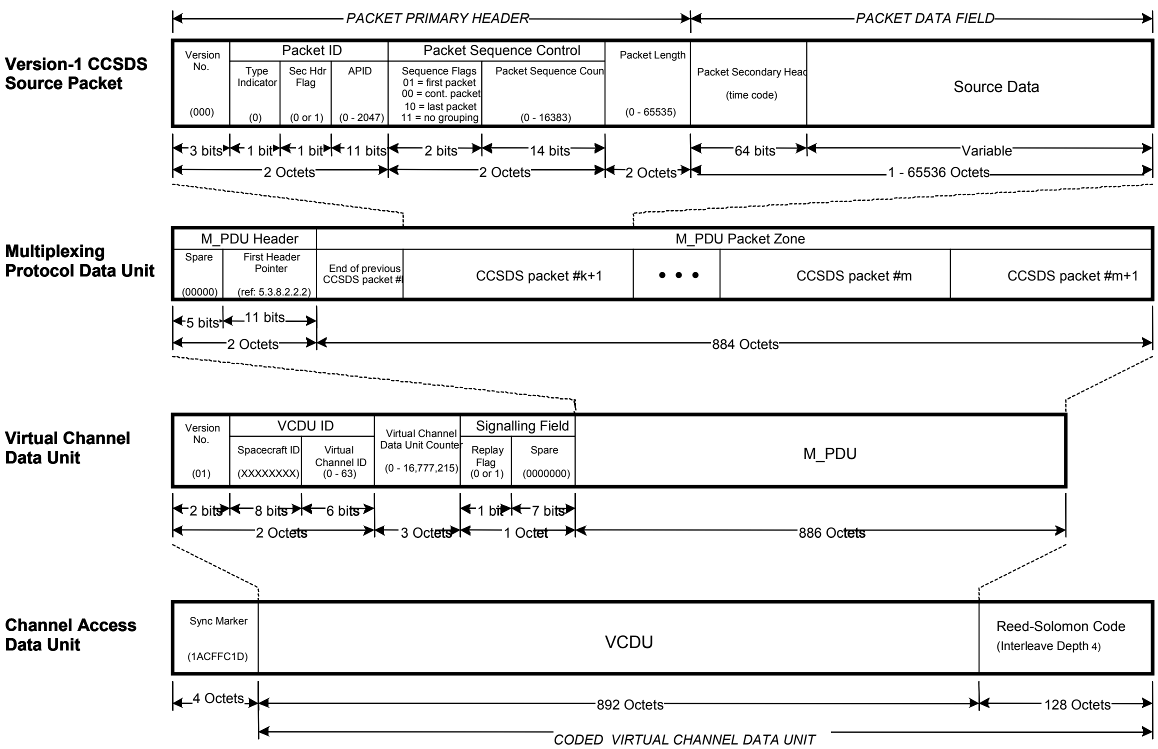

Figure 2 Mission Data Packet Structure

ON-BOARD TELEMETRY PROCESSING:

The C&DH handles the on-board processing of instrument and spacecraft telemetry in essentially the same way as mission data, especially for instrument telemetry, which is delivered to the C&DH as CCSDS AP's. Other on-board telemetry for the spacecraft bus is delivered directly to the C&DH and must be packetized within the C&DH. Sensor telemetry (house keeping, health and status, etc.)

is sorted according to APID and VCID. All NPOESS telemetry is encrypted at the multiplexer service level forming an encrypted data field for insertion into VCDU data fields. Telemetry and mission data are multiplexed into the mission data stream in the form of CADU's that, in turn, are provided to the SSR for SMD. Real time telemetry is also provided via a separate communications subsystem, which will be transmitted directly to the MGS at the data rates summarized in Table 1.

Table 1 NPOESS and NPP Telemetry Data Rates

Parameter	NPOESS Value	NPP Value
Normal Operations	I-Channel: 32.768 kbps Q-Channel: 524.288 kbps stored	16.384 kbps real-time 32.768 kbps real-time 524.288 kbps playback
LEO&A	I-Channel: 1.024 Or 4.096 kbps Q-Channel: N/A	1.024 kbps or 4.096 kbps
SN SSA Data Rates	1.024 or 4.096 kbps	1.024, 4.096, or 16.384 kbps
For all telemetry links:	(*Does not include convolutional encoding overhead in accordance with SNUG convention*)	(*Does not include convolutional encoding overhead in accordance with SNUG convention*)

The format for telemetry is essentially the same as for mission data, except for the size of the data fields in the VCDU's and CVCDU's, as shown in Figure 4. All spacecraft telemetry is multiplexed with the mission data in the SSR and is downlinked to the receptor sites. The MGS also provides real time reception of the HRD and LRD RF communications links for the purposes of monitoring the quality and content of the HRD and LRD data streams, i.e., including frequency, signal strength, data rate and APID content from the AP Primary headers. The instrument data will not be processed by this monitoring function.

For both spacecraft, routing of telemetry data back to the United States from the MGS will be accomplished via commercial satellite links, or under sea fiber optic links, if available in the appropriate time frame. Telemetry (and Commanding) contact between the MMC and the NPP/NPOESS spacecraft is expected to occur as often as once per day.

RF COMMUNICATIONS

The RF communications subsystem consists of four transmit modules (see Figure 2) for each of the SMD, HRD and LRD data downlinks, and the real time telemetry, except there is no LRD on NPP. The modulation format for the three mission data links on NPOESS satellites will be QPSK, with rate one half convolutional encoding with Viterbi decoding, per CCSDS recommendations, [4] for SMD, HRD and LRD. The NPP satellite will use only the Reed Solomon encoding for SMD, and SQPSK for HRD. The real time telemetry will use a combination of BPSK and Spread spectrum, to maintain compatibility with the existing Space Network conventions. For the NPP spacecraft, transmission of SMD will be in X-Band, (8212.5 MHz) at a channel data rate of 300 Mbps, with HRD at 7800 MHz, at 30 Mbps. For the NPOESS spacecraft, SMD transmission will be in Ka Band, at a convolutionally encoded channel data rate of 300 Mbps, while HRD will be in X-Band (7800 MHz) at an encoded channel data rate of 40 MBps. For NPOESS only, LRD will in L-Band

(1706 MHz), at an encoded channel data rate of 7.8 Mbps. Real time telemetry will be transmitted in S-Band, at the data rates shown in Table 1.

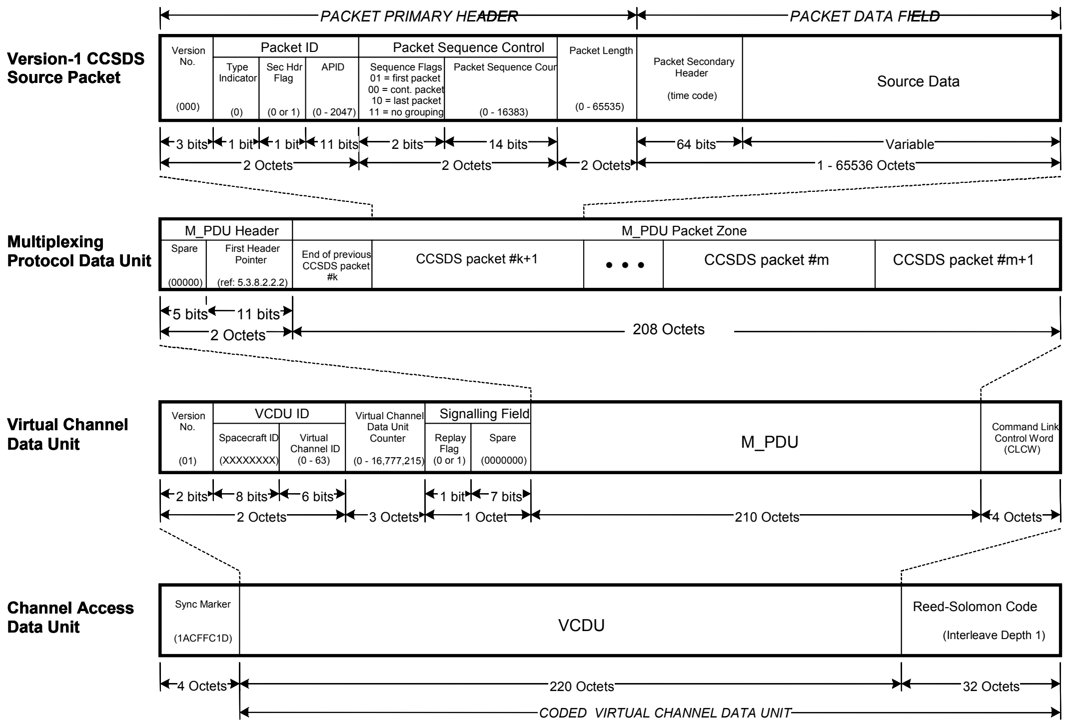

Figure 4: Telemetry Data Format

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STORED MISSION DATA PROCESSING

The specified goal for NPOESS is to process 95% of the data into environmental data products in less than thirty minutes. To accomplish this, the globally distributed network of receptors will receive the SMD data multiple times per orbit, and deliver, via a Virtual Private Network with Multicast capabilities, the data to each of the centrals via the DRR subsystem. Since this is an automated process, and the receptors will not have the capability to transmit, each spacecraft will downlink all SMD data twice.

A simplified block diagram of the processing architecture from receptor through DRR to the IDPS is shown in Figure 5. The first portion of any pass will downlink the most recently collected data (‘first copy’), followed immediately by the data transmitted that was ‘first copy’, at the previous receptor site (‘second copy’). If necessary, additional older data can be transmitted, as requested by the MMC during the most recent contact via MGS. Within the receptor, a receiver will demodulate the downlink signal and perform the Viterbi decoding. A pre-processor within the receptor will perform the CCSDS Reed-Solomon decoding of the CADU blocks to provide error detection, as part of the monitoring of link quality. The fully formatted CCSDS data stream, for ‘first copy’ data only, will be encapsulated into the VPN protocol for delivery to each of the centrals. (‘Second copy’ data will be held at the receptor, pending possible retransmission requests from the MMC.)

Final processing of the data into CCSDS AP's is accomplished at each central in the Front End Processor (FEP), which appends an extended data field that is used to increase the effective size of the packet counter. This permits the unique identification of the data in the onboard SSR. The data flow is monitored by a Data Monitoring & Recovery subsystem, which insures that 99.9% or more of the data collected is delivered; the packets are in order, and duplicates eliminated.

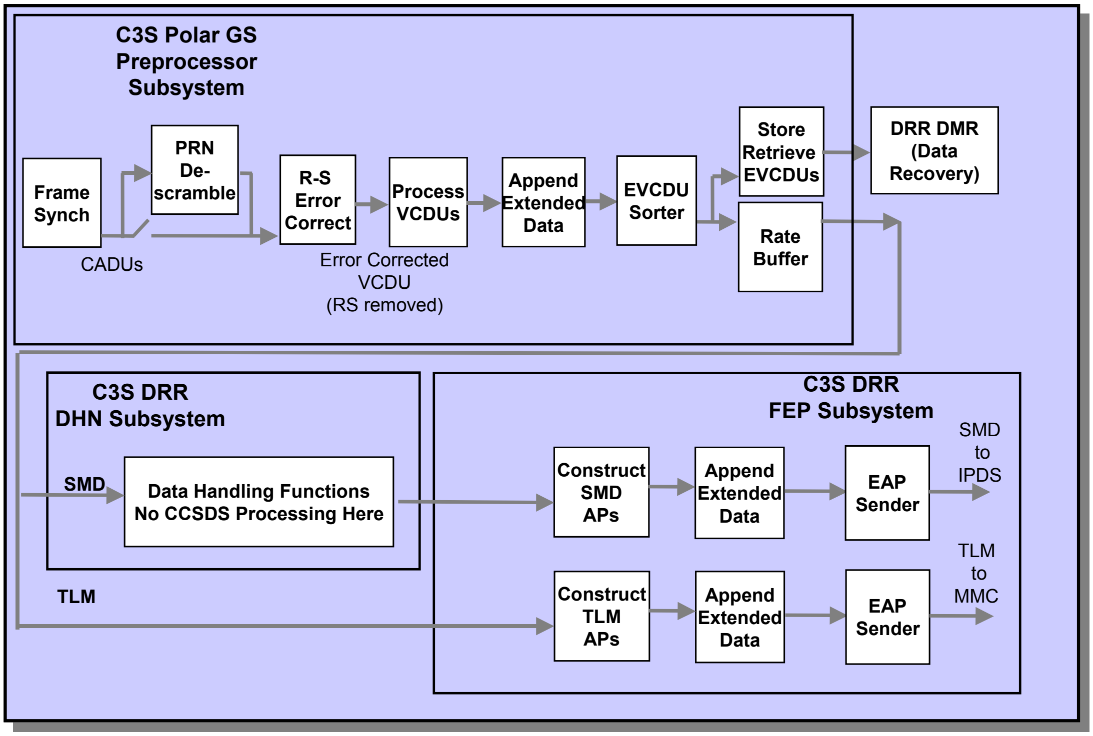

Figure 5 Ground System Data Routing Flow

Retransmission of missing data may be requested from the receptors, or possibly from the spacecraft, by the MMC. The FEP provides the AP's to the IDPS for processing.

FIELD TERMINAL PROCESSING:

The processing of the broadcast data in a field terminal is similar to that performed in the receptors. The receiver will demodulate the downlink signal and perform the Viterbi decoding while a pre-processor will perform the Reed-Solomon decoding of the CADU's. Since the field terminal processing software is an integral part of the field terminal architecture, the pre-processor can fully process the remainder of the data to provide CCSDS AP's directly to the algorithm processing software, within the field terminal. Actual design and development of field terminals is not currently part of the NPOESS program, hence a precise description of a field terminal architecture is not yet available.

COMMAND PROCESSING, AND TRANSMISSION:

While the functioning of the NPP and NPOESS spacecraft and data retrieval system will be largely automated, it will still be necessary to provide regular command and control of spacecraft systems for such functions as the uploading of calibration tables for each of the instruments, instrument or spacecraft flight software uploads, as well as, the normal requirements for control of the spacecraft systems, such as attitude maneuvers. The NPOESS system will use an S-band uplink from the MGS as the primary path for spacecraft commanding and uploads. For LEO&A , the MMC will also have the means to communicate with any spacecraft via the NASA Space Network. The functional flow for this command uplink is shown in Figure 6.

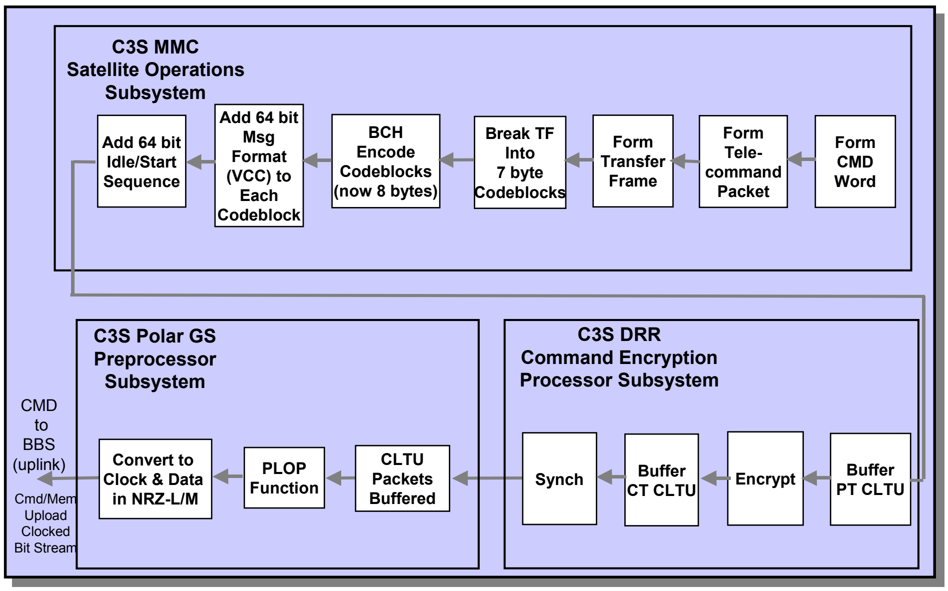

Figure 6. Command Generation and Data Flow

Spacecraft command and control begins in the MMC, where the command words are generated according to the particular operational scenario in progress. The MMC Satellite Operations subsystem will form the command packets and TeleCommand (TC) transfer frames which will be encoded with the CCSDS BCH code. [4] The idle and start sequence are then added to form the Command Link Transmission Unit (CLTU) (See Figure 7) for routing by the DRR, which also handles the command uplink encryption. The DRR subsystem delivers encrypted CLTU's to the Preprocessor subsystem at the MGS, where they are passed to the PLOP function and Baseband hardware for uplinking to the satellite.

The commands are received by the spacecraft command receiver and provided to the C&DH which extracts the TC Codeblocks from the CLTU's, performs the error control decoding (detection only for NPP), de-randomizes the transfer frame and recovers the command packets. The C&DH subsystem also implements the COP-1 protocol [5] to validate the CLCW's, which are delivered to the appropriate destination for execution. The process for uploading calibration tables, sensor memory upgrades, flight software upgrades are similar to the command-processing path. The transmission data rates will also be higher that the normal command data rate. Table 2 lists the uplink data rates for NPP and NPOESS.

Table 2 NPP/NPOESS Uplink Data Rates

Parameter	NPOESS Value	NPP Value
Normal Operations	4.0 kbps	2.0 kbps
Memory Upload	256.0 kbps	128.0 kbps
SN SSA Data Rates	250 or 2000 bps	125 or 1000 bps
For all command links:	(*Includes all overhead, including encryption and authentication as appropriate*)	(*Includes all overhead, including encryption and authentication as appropriate*)

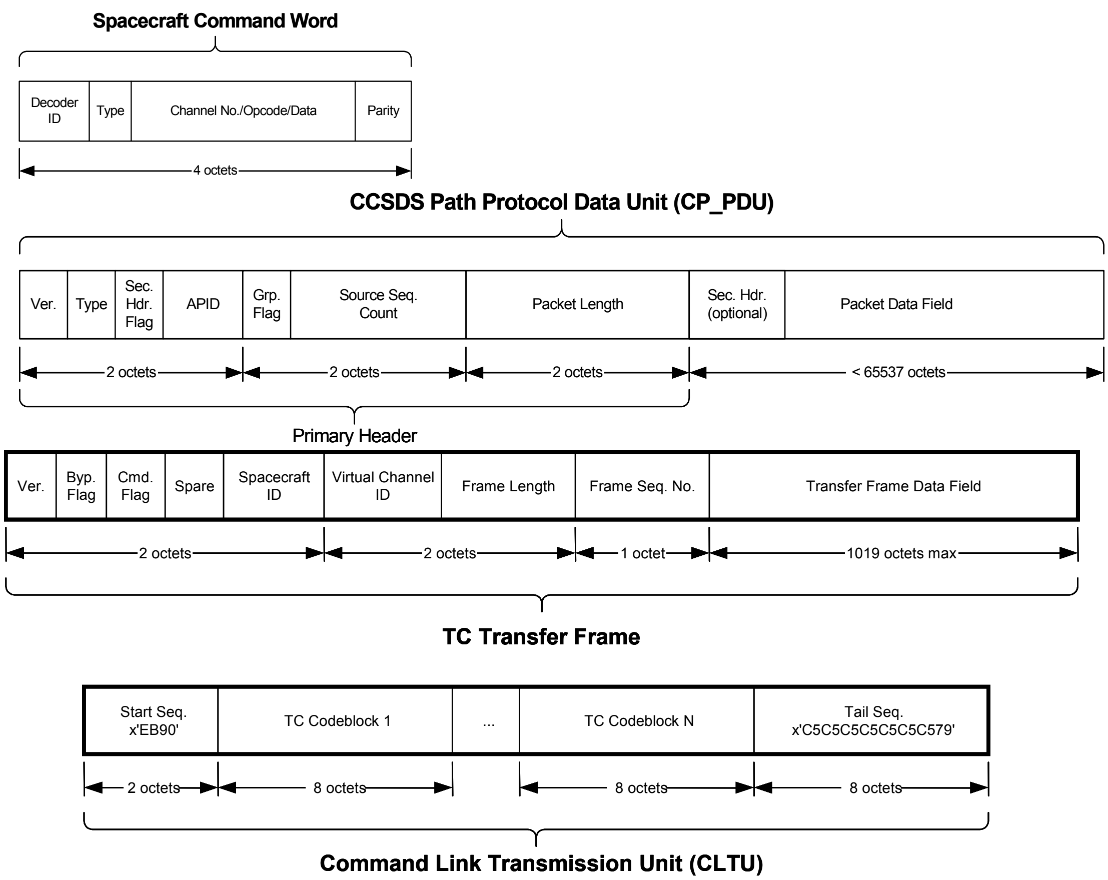

Figure 7. CCSDS Formatting for Command Uplink

SUMMARY AND CONCLUSION

The NPOESS system architecture, as described in this paper, will the CCSDS recommendations to provide a highly advanced, automated system for collecting, processing, and disseminating meteorological data on a world wide, operational basis. This system will provide this data with an optimized latency that can give the user the required environmental data products within thirty minutes of observation, 95 % of the time. The use of CCSDS APID's, VCID's and error control mechanisms will allow the NPOESS system to achieve significant data availability, with 99.9% of the data delivered on an overall basis. The system configuration will also permit ease of expandability and maintainability that will allow it to incorporate technology advances in the ground system architecture and continue to provide high quality environmental data produces over the lifetime of the program.

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