800 Mbps TELEMETRY PROCESSING SYSTEM

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ABSTRACT

Satellites are becoming more capable and complex, as such their downlink requirements are increasing. In addition, future satellite systems will be operating at Ka-band that provides ample bandwidth to support the increase in downlink rates up to 800 Mbps. This paper describes a new generation commercial solution that can support 800 Mbps telemetry processing for data reception, frame synchronization, time tagging, Reed-Solomon forward error correction, data routing, data storage, data playback for testing, networking, and Bit Error Rate (BER) Testing.

KEYWORDS

Telemetry Processing, CCSDS, Ground System Architecture

INTRODUCTION

Ground stations and ground station developments are moving fast out of government installations that have held them in the past. Satellite operators are turning to third parties for commercial equipment and in many cases turn key services. This has increased the pressure on the telemetry industry to provide more and more in the form of commercial-off-the-shelf equipment at a low cost. In addition to that, as more and more remote sensing applications are launched, the data rates required for each platform are increasing and now can be seen to be approaching 800 Mbps. Systems to support this level of performance used to be one of a kind, highly specialized, and very expensive. Now a new generation system solution is being developed by TSI TelSys, Inc. so that this level of performance can be offered as a commercial product at affordable cost with all the flexibility and reconfigurability for multi-mission support.

This paper will describe the system architecture, processing functions, key implementation issues, and how it fits into the overall ground station architecture.

SYSTEM ARCHITECTURE

The Telemetry Processing System (TPS), shown in Figure 1, is based on a CompactPCI system chassis. It consists of a CPU running management software (Gem), two High Speed Front End Processor (HSFEP) cards, a Fibre Channel interface and a RAID, a high performance network option for data output, and expansion capability. Each HSFEP card is capable of receiving and processing 800 Mbps, so for a single channel input of 800 Mbps, only a single card is used. For dual channel input, the inputs are de-rated to 400 Mbps to accommodate the performance of the system bus and RAID subsystem. More details on the HSFEP card are provided in the Implementation Section of this paper. The design of HSFEP also incorporates look back simulation functions and output channels to support pre-pass testing.

The RAID can be configured as a single unit with a single host adapter, or it can be configured into multiple volumes with two hosts for maximum performance. The high performance network interface can be Fibre Channel, Gigabit Ethernet, ATM, or HiPPI. The Fibre Channel could be used in conjunction with a Storage Area Network (SAN), and the others can support a simpler architecture with downstream post-processing, delivery and archive workstations (or some subset thereof). In addition, Level Zero processing software can be added to support specialized data delivery capabilities.

Data Capture is performed by receiving the data, performing frame synchronization, decoding the data, and storing it to the RAID. In addition, low rate data is simultaneously extracted (CLCW, Insert, Housekeeping, or time critical image data) for direct forwarding to the user. Post-processing is then performed using Gem to create frame and packet sets (as desired) from the data previously stored. This creates the data files that then become the basis for delivering data and performing archiving. To support archiving, the system can have a SCSI based tape library (or single drive) added to either the existing SCSI interface on the CPU, or an add-in higher performance interface.

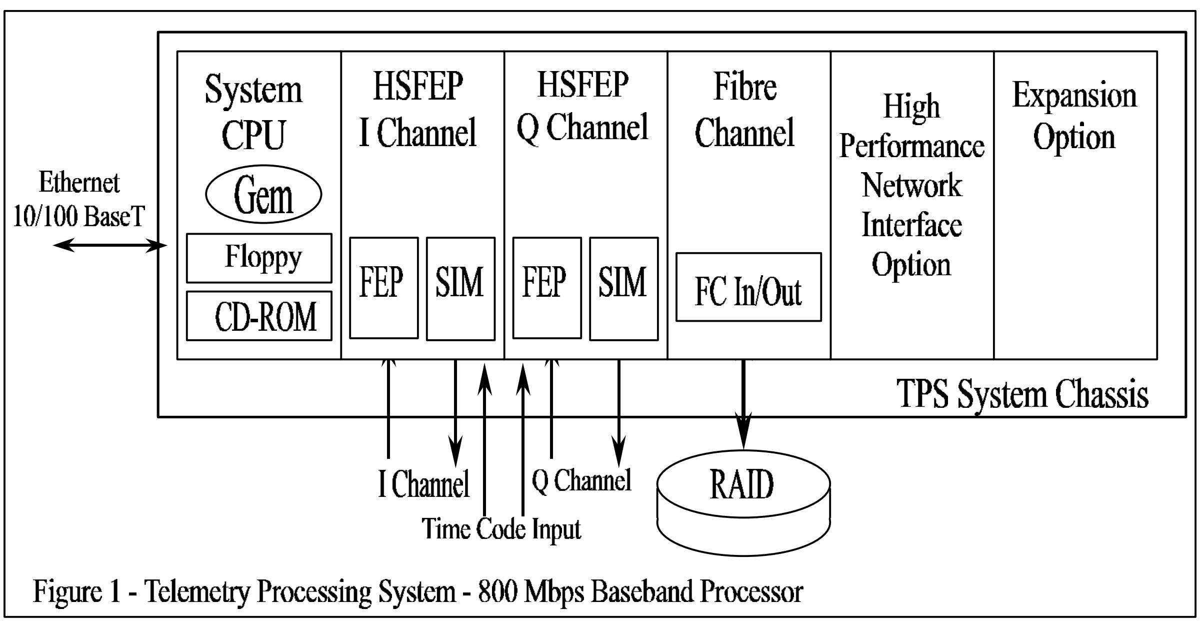

Figure 1. Telemetry Processing System – 800 Mpbs Baseband Processor

SYSTEM PROCESSING FUNCTIONS

Unlike some other products that only perform data reception and recording at high data rate, the TPS provides a full set of processing functions at data rates up to 800 Mbps. This includes data reception, frame synchronization, time tagging, Reed-Solomon forward error correction, data routing, data storage, data playback for testing, networking, and BER Testing. A part of data can be extracted for CCSDS service processing in real-time.

Front-End Processing

Each TPS platform can be configured with one or two HSFEP subsystems capable of sustained 800 Mbps telemetry data acquisition and processing. The HSFEP processes digital, bit-synchronized telemetry data at rates from <100 bps to 800 Mbps. The TPS is also capable of an upgrade to support multiple downlink channels simultaneously to provide the ability to merge two bit streams in a fashion not supported by available demodulator and bit synchronizers. The HSFEP provides three data input interfaces: differential ECL, RS-422, or TTL. An IRIG-B time code input is also available directly on the card. The input is user-selectable from setup parameters, allowing for pass-by-pass selection of the input source. The HSFEP is fully-compliant with the CCSDS telemetry processing and has the following features:

- User-programmable frame synchronization parameters, including frame sync word size to 64 bits, sync word value, sync word length, and the ability to mask individual bits anywhere in the sync word
- Programmable frame synchronization in a search, check, lock, flywheel strategy, with programmable synchronization and state transition tolerances, positive and negative bit slips to +/- 4 bits, and various error tolerances
- User-selectable CCSDS de-randomization (pseudo-random noise decoding)
- Virtual Channel Data Unit (VCDU) CRC decoding and error detection (for Grade 3 service support)
- Reed-Solomon Virtual Channel Data Unit (VCDU) header decoding, error detection and correction, or full Coded Virtual Channel Data Unit (CVCDU) decoding, error detection, and error correction up to interleave level 8 (for Grade 2 and 3 support)
- Optional, user-selectable VCDU time stamping in the CCSDS Day-Segmented (CDS) time format, with a resolution of 1 microsecond
- Frame data quality annotation, indicating the synchronization state of each frame received and identification of detected and corrected frame synchronization and RS/CRC errors

Virtually every function of the HSFEP subsystem is programmable and can be enabled or disabled under user control. This control is on a pass-by-pass basis. That is, a completely different set of control parameters can be used for each spacecraft pass (or post-pass) activity. In addition, many of the parameters can be modified in real-time, for example to adjust the frame sync pattern or lock strategy. TSI TelSys Inc.’s FEP has built-in support for CCSDS Version 1 and Version 2 telemetry, as well as support for Grades 2 and 3 of CCSDS AOS front end processing, and various TDM telemetry data formats. In addition, the HSFEP can be programmed to receive and correlate PN codes for BER measurements.

CCSDS Service Processing

The TPS uses its Service Processing software (SP) to extract and provide streamed output of the CCSDS service data units. The SP extracts Service Data Units (SDU) from CCSDS frames over the internal high rate data bus. The input can be either CCSDS Version 1 Transfer Frames or CCSDS Version 2 (AOS) CADUs and the output is either a CCSDS Packet or an AOS SDU (Path, Insert, Multiplexing, VCA, VCDU, Encapsulation, Bitstream, and CLCW). The SP performs error checking, quality annotation, and generates statistics for the units processed.

The SP accepts frame data as input from the frame data source defined in the SP setup, which can be the Front End Processor, the Frame Demultiplexer, or the File Input Subsystem, performs basic quality assessment of each frame based on the FEP Subsystem trailers. (Reed Solomon and Frame Sync) and sends the frames to the appropriate Source Processor, based on Spacecraft ID (SCID) and Virtual Channel ID (VCID). The Source Processor’s performs the service data unit extraction. If no Virtual Channel Processor exists for a particular SCID/VCID pair, the frame is dropped. In addition, frames are sent to the Quicklook Processor, provided that the Quicklook service is turned on in the SP setup. The Quicklook Processor allows a snapshot of the data to be stored based on a user command or a configurable data event.

Frame Demultiplexing

The TPS provides a mechanism to split input frame structures based on programmable value select, mask and match values. The user defines a one to four byte zone to evaluate that starts at a specified offset from the start of the input frame structure. The user then specifies a mask to apply to that zone and identifies values of interest to match to the resulting masked data zone. If a value is matched, it is identified with a tag that the HRDR understands so the data unit can be routed to storage or to the network. This function also allows unknown data types to be stored separately, and specified data to be removed from the stream.

Telemetry Data Storage

The TPS manages data product output to a disk or network source through its High Rate Data Router (HRDR) software. The HRDR maps input streams to output streams through the use of fully qualified data tags. The data tag identifies the system and subsystem source of the data, and also specifies the data product. For example, the FEP subsystem’s primary data product output is raw frame synchronized, optionally error corrected frame data. The Service Processor, however can output any of thousands of fully qualified data types as defined by the set of the spacecraft ID, Virtual Channel ID, and packet ID (or other service data unit ID). As outputs, the HRDR can route data to the network through the TCP or UDP protocol and any available underlying physical layer NIC, to a HiPPI interface as raw HiPPI, or to the file system. Any standard file system device is supported by the HRDR. Selection of the specific file system device is driven by performance and reliability.

A Fibre Channel RAID is used to satisfy the telemetry storage requirements for the TPS at 800 Mbps. For the highest performance, dual controller options are used with the multiple RAID devices configured in a striped configuration. After processing the data can be moved from the local RAID to a location on the network associated with data delivery and archival. For lower performance users an Ultra SCSI RAID is able to sustain only 33 Mbytes/second of data transfer in an ideal case (single linear transfer with large bursts). A single Fibre Channel interface and a RAID approach 90 Mbytes/sec, and the dual controller option provides the extra performance needed to meet the 100 MBytes/sec requirement to support the 800 Mbps data capture (or playback).

Frame Playback

To support frame data post-processing, the TPS uses a File Input Subsystem (FIS) in place of the HSFEP to feed the SP and HRDR. Assuming raw data has been stored to disk (with or without annotation headers), the FIS can be programmed to read the data from the disk and send it to the data processing subsystems for service data unit extraction and output through the HRDR to either the network or a file.

Telemetry Simulation

To perform self-test, the TPS is equipped with a 800 Mbps Loop back Simulator (LSIM) to be used in conjunction with TSI TelSys Inc.'s powerful and user-friendly SimGen™ test data generator software product. SimGen™ Plus is used for the creation of high-fidelity CCSDS and TDM telemetry data sets. This product provides a user-friendly GUI for:

- Definition of mission-specific CCSDS or TDM protocol data structures
- Specification of protocol field values within these data structures
- User-controlled specification and injection of deterministic and random bit and protocol field errors
- Generation of telemetry data for simulations
- Generation of quality and accounting parameter counts that should be expected when the generated telemetry data is processed

The Loop-back Simulator functions in one of two modes. In the first mode, the data to be output is stored entirely within the memory of the HSFEP card (~64MB). The file can be output a selectable number of times or continuously. This mode eliminates bus traffic and CPU loading for the data output and is useful for testing. In the second mode, the data file is read directly from the RAID and output through the HSFEP. In both cases, the output clock can be generated internally or provided from an external source. The LSIM outputs data as differential ECL, RS-422, or TTL. The LSIM can also be programmed to output a PN code for use in BER testing.

System Management

The Telemetry Processing System is managed through the TPS management software (Gem). This product employs Java based graphical user interface (GUI) to provide a user-friendly environment for control and monitoring of system operations. It can be run locally or remotely to control the TPS, and can simultaneously control multiple Telemetry Processing Systems. In addition, the TPS management software provides a unique Pass Automation capability, allowing for complete automation of system operations according to a spacecraft pass schedule.

Operation of the TPS is controlled using system setup files called Configuration Sets. These files contain parameters that control individual Telemetry Processing System subsystems and they are typically created a priori and stored for later use. A user-friendly GUI tool set is provided to create these Configuration Sets.

The primary TPS GUI supports activating pre-defined configuration sets, issuing setup changes, reporting subsystem status, managing the API, operating the scheduler, and preparing the Quality and Accounting Reports of the system. The TPS GUI provides a number of displays of real-time system status and telemetry quality and accounting parameters. These displays are updated in real-time at a user specified (1 second default) rate, at the same time telemetry processing is being performed, to present the current state of the telemetry processing.

The TPS management software also provides a C language API for remote control and monitoring of system operations. This API provides capabilities for remote control of telemetry data acquisition activities, and also makes all system status and telemetry data quality information available to local or remote user programs. Any system status or telemetry data quality or accounting parameter that is available via the user interface is also available via the API. In addition, the controlling application can add events to and delete events from the schedule, thereby controlling the pass automation capabilities. This means that system can be run in a completely remote mode, with a remote application program controlling system operation via direct commands or scheduled passes, and monitoring system operation in real-time, all via the API.

IMPLEMENTATION FEATURES

This section will highlight some of the key technical features that enable the system performance to increase from 300 Mbps to 800 Mbps. These features include increased I/O, frame synchronization, Reed Solomon decoding, hardware assisted service processing, and system bus design. Data capture will be considered first, followed by data output. Although they will be considered separately, physically the new HSFEP is supporting both input and output simultaneously on the same card.

Data Capture

A simple data flow for data capture is shown in Figure 2. Two HSFEP cards are shown receiving clock and data as input streams. In this case consider one stream an I channel stream and the other a Q channel stream, each operating independently at 400 Mbps. A single 800 Mbps stream is processed in the same manner as the two independent streams. The input to the HSFEP is nominally differential ECL serial clock and data. The form factor for the HSFEP is 6U CompactPCI and that provides the ability to support both front panel I/O and rear panel I/O with optional transition modules. This enables the HSFEP to simultaneously provide support for parallel input, RS-422 input, and TTL input.

After reception, the data is converted to parallel, buffered, and provided to the frame synchronizer. TSI TelSys, Inc.’s existing FEP mezzanine uses the Parallel Integrated Frame Sync (PIFS) Application Specific Integrated Circuit (ASIC) that was developed by our engineers while still at NASA. The PIFS however is limited to under 500 Mbps operation and would not support the 800 Mbps requirement. The code from the PIFS has been ported to an Field Programmable Gate Array (FPGA) implementation that has significantly higher performance to support 800 Mbps. The data frame is time tagged as it is received. The IRIG-B time code is received and processed directly within the Frame Sync FPGA to afford an extremely accurate and deterministic time tag. Reed Solomon decoding is then performed on the frames. This function also uses the ASIC our engineers developed while still at NASA. As with the PIFS, the Reed Solomon decoder operates to about 500 Mbps. To meet the 800 Mbps requirement, two Reed Solomon ASICs are used in parallel.

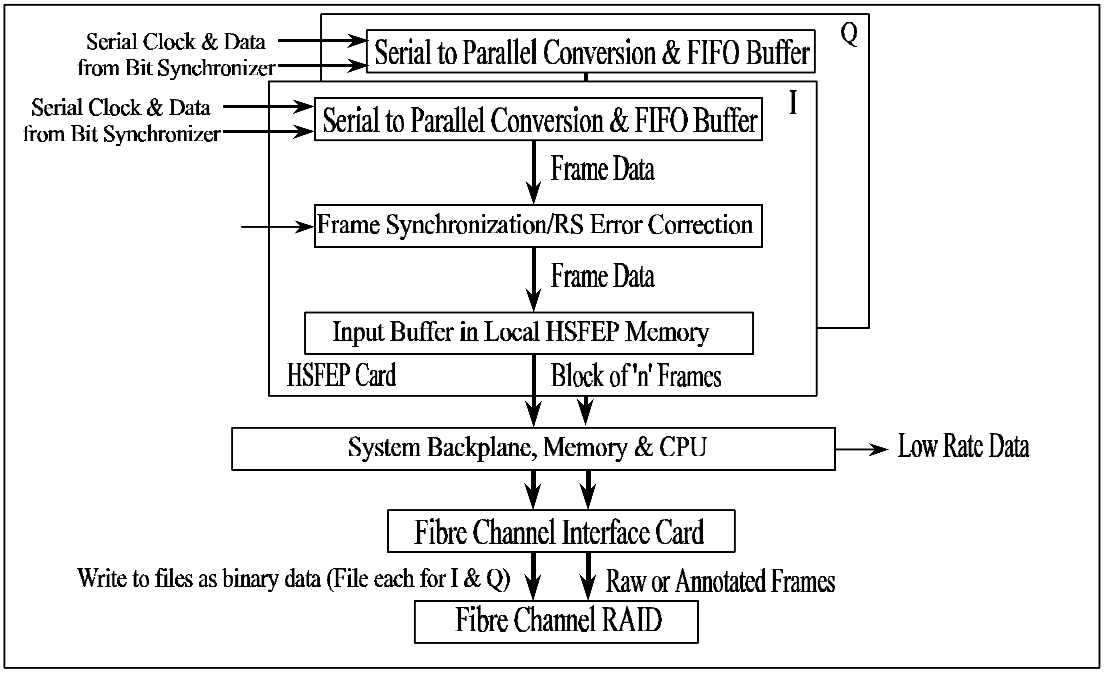

Figure 2. Data Flow for Data Capture

After the data has been corrected, it is provided to a buffer where it can be shuttled to either the software for processing (or delivery to a user), or to the Fibre Channel interface card for logging to disk. One of the key features of this process is the ability to perform some of the CCSDS Service Processing functions directly on the HSFEP. This includes VCA and VCDU Services. Virtual Channels can be removed from the stream so as not to be logged, and they can also be repeated to be buffered separately for real-time processing. This allows low rate housekeeping data, or time critical image data to be extracted from the stream for real-time processing while simultaneously being logged. In addition, the HSFEP extracts the Insert and CLCW Service Data Units directly for output.

Data is moved from the buffer to the RAID for logging. The HSFEP system bus is 64 bit/66 MHz PCI that provides ample margin for supporting 800 Mbps. The single Fibre Channel RAID is capable of supporting 90MB/sec. However two Fibre Channel RAID units can be configured in a striped configuration to meet the 800 Mbps requirement.

Data Output

A simple data flow for data output is shown in Figure 3. Two HSFEP cards are shown providing clock and data as output streams. In this case consider one stream an I channel stream and the other a Q channel stream, each operating independently at 400 Mbps. The HSFEP has the option of receiving an external clock to drive the output data. The output from the HSFEP is nominally differential ECL serial clock and data. The form factor for the HSFEP is 6U CompactPCI and that provides the ability to support both front panel I/O and rear panel I/O with optional transition modules. This enables the HSFEP to simultaneously provide support for parallel input, RS-422 input, and TTL input.

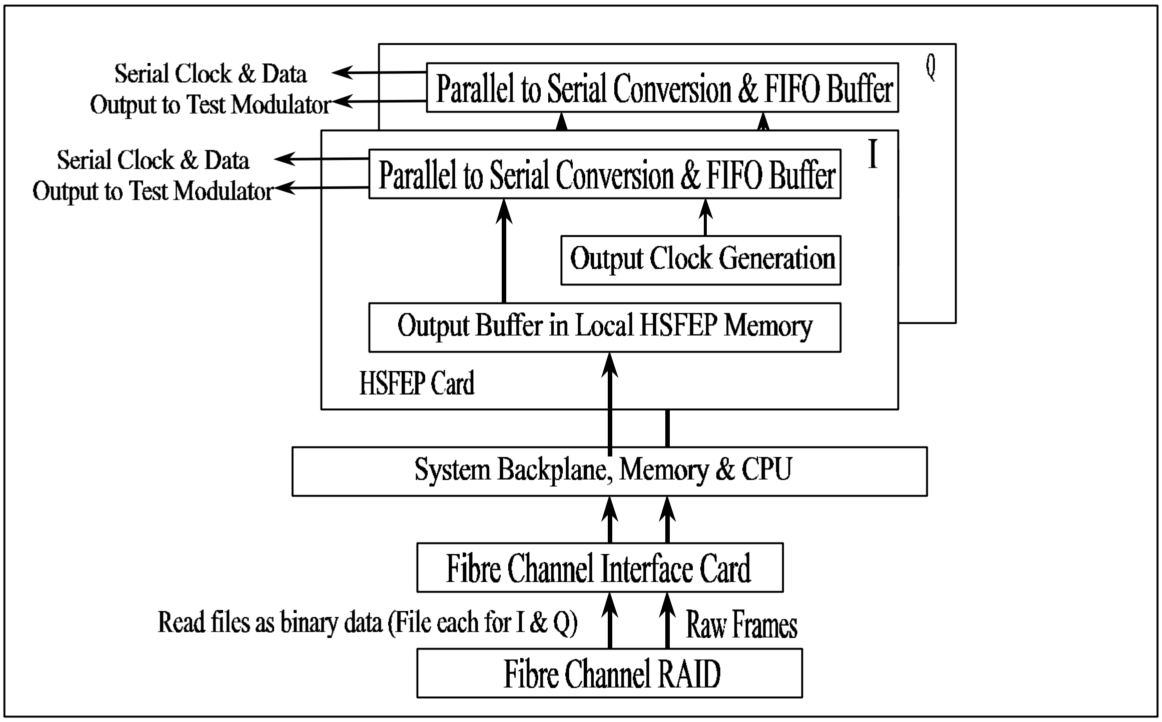

Figure 3. Data Flow for Data Output

A key feature for the HSFEP is the ability to simultaneously support input and output on the same card as it reduces system size and power. The data output functions have been defined in the Loop Back Simulator description earlier. Fundamentally, DMA data transfers are requested based on buffer availability, which is cleared by the output clock driving bits out the line. This ensures data is provided in sufficient time so that data is continuously output.

A PROPOSED GROUND STATION ARCHITECTURE

Figure 4 shows the Telemetry Processing System as part of a high performance ground station's baseband processing flow (the antenna and RF equipment is not shown). The system consists of a multiple Telemetry Processing Systems available for data capture feeding multiple downstream systems for post-processing. The High Performance Network Hub/Switch could be a Gigabit Ethernet fabric or a Fibre Channel fabric.

The Storage Cluster is shown for the case in which the Fibre Channel fabric is used in conjunction with a storage area network. In this example, the second Telemetry Processor is shown acting as a line outage recorder. This is shown only recording data. If the primary string of equipment had a failure during the pass, the LOR would then be configured to play back the data into the primary string after repairs had been made. A network card could be added to the system to allow it to playback data directly to the post-processing machines over the network. Data is passed between the various processing systems using either simple utilities or commands from the Monitor and Control application. The archive system can accept the data products produced by any of the systems and as such can produce archive tapes of raw data, sorted frames, packets, or higher level data sets depending on user requirements and system capabilities. In addition, the baseline methodology for moving data between the tiers is ftp over a Gigabit Ethernet fabric or file copies over the SAN. It is, or course, possible at any time to ftp any of the data products to a user via the management network.

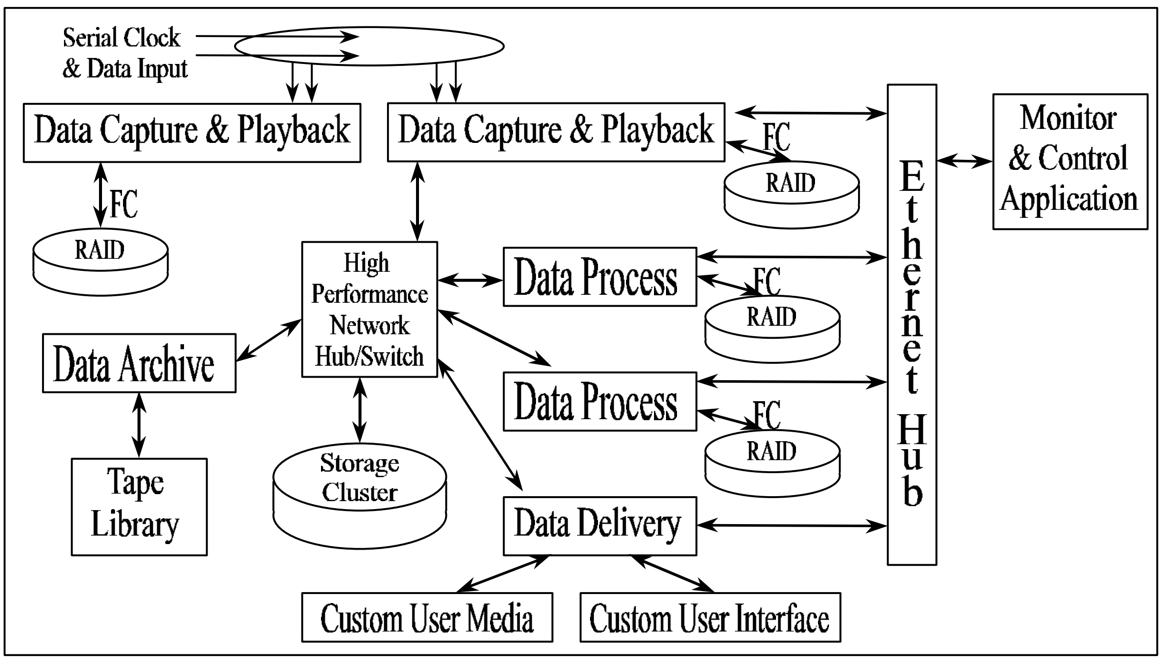

Figure 4. Telemetry Processing System Integrated into Ground Station Baseband Processing

SUMMARY

The 800 Mbps Telemetry Processing System is a new generation commercial product for data acquisition and processing. Built upon the state-of-the-art technology and many years of ground system development experience, the TPS provides a commercial solution for high rate telemetry capture, processing and distribution. At 800 Mbps, it sets a new benchmark in its class on system performance and capability.