MULTIPLEXER / DEMULTIPLEXER IMPLEMENTATION USING A CCSDS FORMAT

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ABSTRACT

A multiplexer / demultiplexer design suitable to a wide range of input data types and link formats is presented. Based on the Consultative Committee on Space Data Systems (CCSDS) recommendations for Packet Telemetry, the design translates the prescribed layered architecture into a modular, layered hardware implementation. The design approach minimizes hardware yielding increased reliability and decreased product cost while retaining a high degree of flexibility. This implementation can be applied to flight data acquisition (direct transmission to the ground or recorded), ground data collection (including multi-stream record systems) and inter-range communications.

The use of an internationally recognized standard promotes inter-service interoperability and facilitates data handling/routing throughout a wide community.

KEYWORDS

Multiplexer, Demultiplexer, CCSDS Packet Telemetry

INTRODUCTION

The MUX/DEMUX design proceeded from the following design goals:

Input Signal: The basic architecture must not prohibit data types of the following, and ideally should decouple the input data acquisition from the MUX process as much as possible.

PCM, Data & Clock

Time Code Signals

1553 Data

Asynchronous Command & Status Data

Packetized Data

Communication links ('T carriers')

FM and FM multiplex data

Multiplexed (trunk) I/O: To cover the range of anticipated applications, the MUX/DEMUX multiplexed link should be able to accommodate:

Serial Data and Clock (for Helical Scan Tape recorders, RF Links, direct & optic links)

Parallel Formats (proprietary tape recorders & direct computer ingest)

SCSI (permits lower cost tape backup systems to be used as high speed recorder)

'T carrier' for communications links.

Operational Considerations:

The unit should require an absolute minimum of operator premission setup. For example: PCM data: NO knowledge of the input format should be required except for the maximum bit rate in order to calculate the multiplexed link rate required.

The unit's data buffering should not incur excessive throughput delays

The demultiplexed output must be a faithful reproduction of the input, not gated high speed bursts or other anomalous characteristics.

The ability to incorporate special techniques at the channel level should be retained, such as format conversion or data compression.

As will be seen, all of these goals were met within the recommendations of the referenced CCSDS documents.

WHAT PARTS OF CCSDS RECOMMENDATIONS APPLY?

Examination of the CCSDS Recommendation identified Packetized Telemetry as the basis for a MUX/DEMUX design. Within the Packet Telemetry Services, a layered approach is presented in Figure 1. [1] Each layer's implementation is independent of the next within the restriction that the input and output Data Units must conform to the Recommendations. The Data Sources can be generalized to include not only a particular sensor but also an entire PCM stream for example. Thus the recommendation does not restrict and in fact is independent of input format types. Along with the layers a variety of services are defined that make use of various capabilities of the Data Units available at each layer. [2] Within the bounds of the anticipated applications, many of these services are not required and their non-use substantially reduces the hardware implementation complexity.

SPACE TRANSFER LAYER - The Packet Transfer Service transfers a sequence of variable length SOURCE PACKETS from a source application to a sink / destination. Each input channel must therefore be converted into a SOURCE PACKET at the MUX site, and depacketized into its original format at the demux. The SOURCE PACKET may actually be **dynamically** variable in length, which also greatly facilitates the task at hand. This 'Packetizing' consists simply of converting the input data to a stream of 8 bit 'octets' with a 6 byte header attached.

VIRTUAL CHANNEL ACCESS LAYER - At the Virtual Channel Frame Service TRANSFER FRAMES are moved over a MASTER CHANNEL from source to destination. These TRANSFER FRAMES can implement VIRTUAL CHANNELS which are sets of SOURCE PACKETS grouped together typically by data rates. However, due to the Buffer Service being selected, this is not required and only one VIRTUAL CHANNEL is implemented.

CHANNEL ACCESS LAYER - Physical Access Service: A constant rate stream of fixed length TRANSFER FRAMES is implemented. This synchronous data transfer allows the widest possible use of the MUX/DEMUX equipment.

PHYSICAL ACCESS LAYER - Physical Access Service: This service provides the MUX to DEMUX lowest level, bit transport. Again, it's the ability to move TRANSFER FRAMES across RF, hardwire, optic, recorders and communications links which provide the required flexibility.

Within this overall approach, the BUFFERED SERVICE provides another key ingredient to the MUX/DEMUX design. "The distinctive feature of buffered service, which is essentially time-division multiplexing, is that the timing of data transfer is driven **by the service provider, not the user**" [highlight added]. [3] In the APOGEE LABS Multiplexer, the TRANSFER FRAME GENERATOR transfers the data from the SOURCE PACKET generators at a fixed Sample Interval and in a fixed sequence. The Sample Interval (SI) is precisely eight transfer frames in duration. At the beginning o each SI, the SOURCE PACKET generators are sequentially emptied of the data accumulated during the previous SI.Therefore, in the case of PCM data inputs, the SOURCE PACKET lengths will vary in direct proportion to the data bit rate: higher data rates providing more data per SI. It can now be seen that at the DEMUX, clock reconstruction has been simplified: by knowing how many octets were received in the fixed interval of time (the SI), the output bit rate can be easily calculated. An important operating feature has been implemented: no operator input of the nominal channel rate is required. The output will simply follow the input over the ENTIRE operating range of each channel. The user need only insure sufficient link bandwidth to account for the combined source data and packet headers.

Definition of the SOURCE PACKETS and TRANSFER FRAME structures and their use to implement the various services is contained in reference [4]. The TELEMETRY CHANNEL CODING [5] is used only to the extent of adding an ATTACHED SYNC MARKER. This facilitates the CHANNEL ACCESS and PHYSICAL ACCESS layer operations. Other provisions such as convolutional coding, Reed-Solomon coding, and randomizing are not implemented as these are typically found in the tape recorders and communications circuits.

HOW TO KEEP IT SIMPLE

Figure 2 illustrates the FUNCTION / DATA UNIT layers resulting from the forgoing discussion as applied to the Multiplex function. All inputs are now converted to SOURCE PACKETS and placed into one VIRTUAL CHANNEL.The result is that the MASTER CHANNEL and VIRTUAL CHANNEL Multiplex layers are effectively merged as denoted by the dashed outline. Since the master channel is transferring Source Packets on a regular basis, it has essentially established a sample interval which aids in the Source Packet generation and subsequent data reconstruction.

Figure 3 illustrates the implementation of the multiplex process, ignoring the unit's front panel control processor and other auxiliary formats. Each input feeds on FPGA device and RAM which implements the channel data buffer and Source Packet generator. These are connected by a Data Collector Bus (DC Bus) to the packetizer chip which establishes the sample interval, generates the synchronous stream of transfer frames and fills those frames with Source Packets or fill data if insufficient channel data is available to fill out the 8 transfer frames.

The demultiplex function is implemented as a mirror, with the addition of a Direct Digital Synthesizer (DDS) for each PCM output Channel as Figure 4 shows. As the demultiplexed source packets are routed to the output channels, a microprocessor examines the packet length and buffer status for each channel and accordingly controls the DDS Bit clock frequencies. Because the DDS makes phase continuous frequency changes, variations over the entire usable channel rate are accommodated with high resolution and without "holes" or band edges to contend with.

The ability to implement Source Packet generation and subsequent data reconstruction with such a small amount of hardware derives from the resulting simplicity of the sources selected. As shown in Figure 3-1 located on page 3-1 of the CCSDS 102-B-4 Blue Book November 1995, only three of the seven header fields contain data which is changed. Version number, type indicators and the flag bits are all hard coded.

In a similar fashion, Figure 5-1 located on page 5-2 of the CCSDS 102.0-B-4 November 1995 Book shows that only three of the eleven fields are variable in the transfer frame and the two frame counts can actually use the same counter since only a single virtual channel is placed within the master channel).

IMPLEMENTATION RESULTS

SIMPLICITY OF CONTROL: Control of the MUX section requires only the composite (link or trunk) rate to be selected. This should be set to account for the overhead bits and combined data rates.

Control of the DEMUX section requires only the composite rate to be specified and the active input to be selected (local loopback or the appropriate line input).

In the case where Source Packet generation includes more complex operations such as an Analog to

Digital converter, these of course will require their own unique setup. It is important to note, however, that only the resulting data rate need be taken into account when controlling the basic MUX function. For example, there are no commutation tables. The data is simply moved from input to output. This decoupling of data source from data transport and MUX link format is one of the great advantages of a packetized approach.

SIMPLICITY OF IMPLEMENTATION: As illustrated, the layered services are readily translated into a modular, layered hardware implementation. A wide variety of input types and link formats are thus possible by changing these respective modules. New modules are cost effectively added due to the well defined environment developed. Future flexibility is certainly retained. By designing a modular hardware MUX/DEMUX, it can be packaged into a variety of configurations and applied to airborne, spaceborne, laboratory, communications and recording systems.

By using the CCSDS recommended Packet Telemetry Format, data generated by an APOGEE LABS Multiplexer can be Demultiplexed and processed using any vendor's CCSDS compatible equipment. Multiplexer tape recordings, for example, can be ingested by a CCSDS data stripper function for data collection and processing. Multiple mission formats are therefore transparent to the record, communication and ingest functions.

OVERHEAD EXAMPLE

In the APOGEE LABS MUX/DEMUX unit, a sample interval is established as:

8 Transfer Frames = 1 Sample Interval

In a typical application where 5 data streams are multiplexed into a single output stream, the overhead bits required would be:

8 Attached Sync Markers (32 bits each)	256 bits
8 Transfer Frame Primary Headers (48 bits each)	384 bits
8 Transfer Frame Error Control Fields (16 bits each)	128 bits
5 Source Packet Headers (48 bits each)	240 bits
1 Fill/IDLE Source packet (7 bytes minimum)	56 bits
TOTAL OVERHEAD Bits:	1064 bits (1.62%)
Total Transmitted Bits:	65536 bits

Thus for a composite output rate of 32.0 Mbps, approximately 31.3 Mbps is available. This is consistent with empirical performance measurements of the unit.

LINK DELAY: End-to-end delay is comprised of two components:

1. Time to accumulate the input sample octed and subsequently output a byte of data:

   Input Shift Register (1-8 bits)
   Output Shift Register (1-8 bits)
   4-5 bits of “pipelining”

   TOTAL: 6-20 bits

2. Time to transmit a source packet from MUX to DEMUX:

Input Packet Transmit:	65536 bits / Sample Interval
Receive Packet:	65536 bits / Sample Interval
½ Buffer Delay:	32768 bits

   TOTAL: 163,840 bits

3. For Example; @ 32 Mbs link and with 1 Mbs Channel data; the average 10 bits of data will require 10 microseconds and the 163,840 bits will require 5.12 milliseconds.

CONCLUSIONS

It has been shown that the hardware realization of a high performance MUX/DEMUX system using the CCSDS recommendations can be made very cost effective, while retaining the distinctive features of a layered approach. Decoupling applications data collection from the data transport mechanisms provides the ability to accommodate a wide range of data input types as well as the MUX to DEMUX link.

REFERENCES

[1] Packet Telemetry Services, CCSDS 103.0-B-1 Blue Book, May 1996, Figure 2-2: CCSDS Packet Telemetry Layers, page 2-4

[2] Packet Telemetry Services, CCSDS 103.0-B-1 Blue Book, May 1996, Buffered service, page 2-5

[3] Packet Telemetry Services, CCSDS 103.0-B-1 Blue Book, May 1996, Table 2-1: Summary of Packet Telemetry Services, page 2-3

[4] Packet Telemetry, CCSDS 102.0-B-4 Blue Book, November 1995

[5] Telemetry Channel Coding, CCSDS 101.0-B-3 Blue Book, May 1992