NETWORK CONNECTIONS BEYOND IEEE 802.11

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ABSTRACT

More and more aircraft system designs are incorporating a local-area-network (LAN) using either Fibre Channel (FC) or Ethernet. To date there hasn't been a means for creating a FC node connection between an airborne network and a ground based FC network or for creating a reliable high-speed Ethernet connection between air and ground. Ethernet connections have had some success by using the IEEE 802.11 wireless LAN for these types of connections; however, these connections suffer from many inherent problems using this standard. Problems include the lack of telemetry spectrum control, security validation, high-speed data transfer efficiency, and channel acquisition time.

This paper will describe a methodology that utilizes the IRIG-106 PCM standard for communicating between aircraft and ground-based networks. PCM can solve the aforementioned problems and it enables the user to take advantage of the many ARTM advances in PCM telemetry technology [1]. One such advance in technology has been the use of SOQPSK (Tier 1) or Multi-h CPM (Tier 2) to enable the user to effectively double or more their bandwidth efficiency compared to PCM/FM (or CPFSK) (Tier 0).

KEYWORDS

Keywords: Fibre Channel, Ethernet, PCM, airborne telemetry, network bridge, iNET, ARTM.

INTRODUCTION

In the year 2000, Boeing IDS Flight Test in Saint Louis began development of the Fibre Channel Interface Unit (FCIU) [2] to monitor and record data from an aircraft Fibre Channel Network (FCN). As a result of this effort, an encoding scheme was developed to convert the FC data into an IRIG-106 PCM stream so that standard COTS (commercial-off-the-shelf) recorders could be used. As a further byproduct of the encoding scheme, this FC data could now be telemetered to the ground in real-time.

FIBRE CHANNEL BASICS

Table 1 shows some of the attributes of the Fibre Channel (FC) and Table 2 shows the basic frame structure. The serial rate is much higher than that which is typically possible for telemetry transmissions; however, the actual average data rate can be much lower than this. One of the reasons Fibre Channel was chosen for the Boeing aircraft network was for low latency and not necessarily high speed, although video applications have taken advantage of the available speed. The frame size is small compared to some protocols, which helps to lower the probability that a given frame would need to be retransmitted when a communication error occurs. The FC protocol supports guaranteed delivery of frames with acknowledgment of the frames by the receiver node or it can be left up to the receiver node to only ask for certain critical frames to be resent. This gives the capability for flight critical parameters to be fully acknowledged while allowing for most of the data to be taken "as is". This feature can significantly reduce system traffic and complexity.

Characteristic	Fibre Channel
Serial Transmission Rate	1.0625 (Typ.) or 2.125 GBaud
Data Word Size	32 Bits per Word
Payload Words per Frame	0 to 528
Max. Number of Addresses	256 Domains, 256 Areas, 256 Ports (2^24 = 16,777,216)
Transmit/Receive Protocol	Full Duplex
Frame Timing	Random, Non-Consecutive, Multi-Tasking, Event Driven, Data-On-Demand
Frame Definition	Payload or Upper-Level-Protocol (ULP or FC-4) varies from general data to audio/video information (FC-AV, FCP, FC-AE, etc. [3])

Table 1 – Fibre Channel Attributes

Fibre Channel Frame
Start of Frame (SOF)
Destination Address (D_ID)
Source Address (S_ID)
Frame Control (F_CTL)
Sequence ID / Frame Count
Exchange ID (OX_ID/RX_ID)
Parameter Field (PARM)
(Optional Headers)
Payload Word #1
. . .
Payload Word #M
Cyclic Redundancy Check (CRC)
End of Frame (EOF)

Table 2 – Fibre Channel Frame Structure

CURRENT WIRELESS LAN TECHNOLOGY

Many are familiar with the widespread use of the wireless LAN technology at home and at work. The hardware is widely available because of its significant number of commercial users and applications. One such specification for this wireless technology is the IEEE 802.11 standard. In most applications where the transceiver is stationary and the transmission link is short, it's just a matter of plug-n-play. However, as a link between a ground node and a moving platform many problems start to arise. For maximum flexibility and ease of connection setup, the transmission frequency spectrum is uncontrolled with respect to when an arbitrary LAN device might start transmitting. Therefore, standard COTS equipment has limited power in order to cut down the possibility of interference with neighboring wireless LANs. This limits its usefulness over great distances. The data transmission bandwidth is limited to around 2 Mbps and the basic link is not secure. The data packets can be software secured using standard Internet protocols, but security of the data is not guaranteed, as it would be using PCM and a hardware security device.

FIBRE CHANNEL SWITCH CONNECTIONS

Figure 1 shows two examples of FC networks. The FC is a point-to-point connection. To expand a system, a network switch is used to interconnect multiple End Nodes such as Node A and Node B. In some cases where the number of ports that are available on a switch is exceeded, multiple switches are connected together. In this arrangement, they may act as a "bridge" to another remote area, as is the case when connecting two distant buildings together, in order to minimize the number of lengthy cables or fibers. A transmit port of a switch that is connected to an end port will only pass information related to the end port. It acts like a filter and does not present all of the available switch traffic to this port. On the other hand, a switch port connected to another switch will pass information associated with many ports.

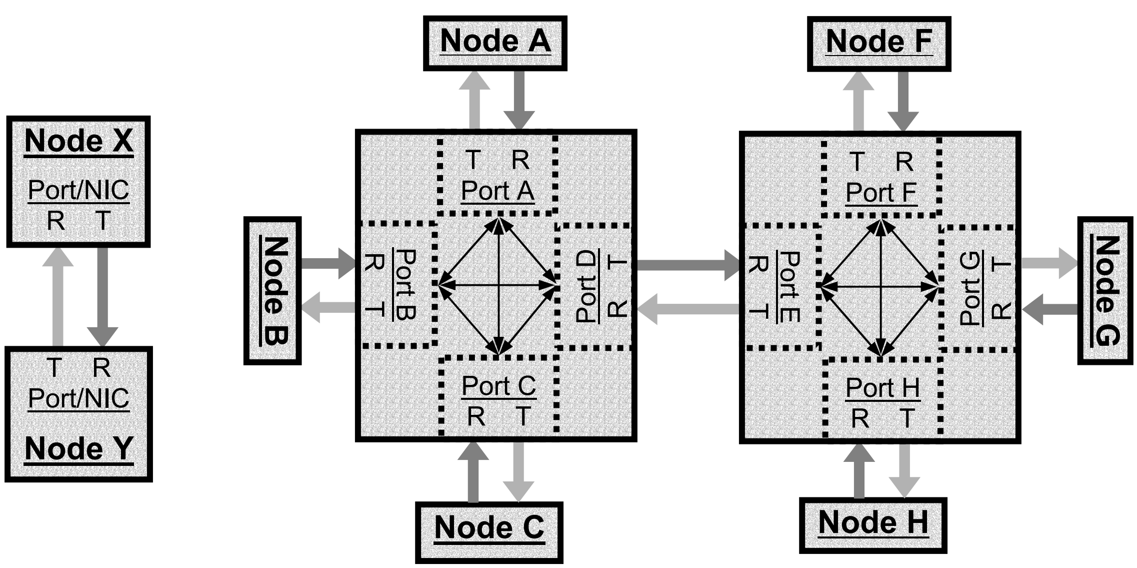

Figure 1 – Fibre Channel Network Configurations

FIBRE CHANNEL – PCM TELEMETRY BRIDGE

A Fibre Channel (FC) to PCM Telemetry Bridge is a device that can receive FC packets / frames and then reformat them into an IRIG-106 like Chapter 8 PCM stream. An example of a bridge is shown in **Figure 2**. This bridge contains two similar sets of functional blocks, one for the FC transmit path and one for the FC receive path. Each contains a NIC interface to the FC network with a corresponding buffer. These buffers are sized to achieve maximum performance based upon the needs of the application. Requirements for more bandwidth and more range will increase the size of these buffers in order to sustain traffic because of the increased time needed for frame acknowledgements to return back to the Node or Switch Port. For maximum flexibility, the bridge should be designed to function as either an End Node or a Switch Port. A bridge used in an aircraft could be identical to the one on the ground because they are functionally equivalent. In fighter aircraft applications, communication bus redundancy is usually a requirement and should be accounted for in the bridge design. One way of accounting for redundancy is to design the PCM Frame Generator to accept multiple inputs and add bus identifiers to the encoded data.

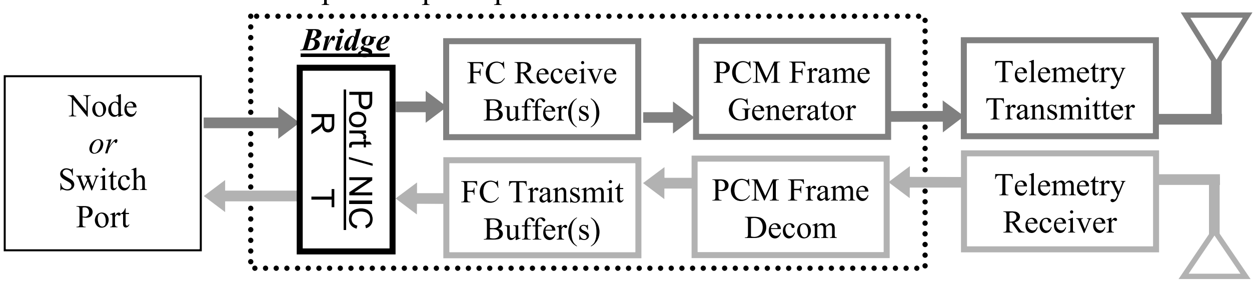

Figure 2 – Fibre Channel - PCM Telemetry Bridge

In some cases, multiple aircraft may need to be involved and communicate with each other. One example of a system is shown in **Figure 3**. In this example the Ground station is used as a node and as a router for connecting the two aircraft together. If the PCM encoding scheme includes some type of identifier, the individual aircraft could use it to know when to ignore the Ground station. Freq. G is typically low bandwidth since it is only used for command and control. This link could be used to control the transmitter's off and on state of aircraft A and B such that A and B could share the same transmitter frequency. However, this will decrease the efficiency slightly do to the time needed for PCM frame resynchronization.

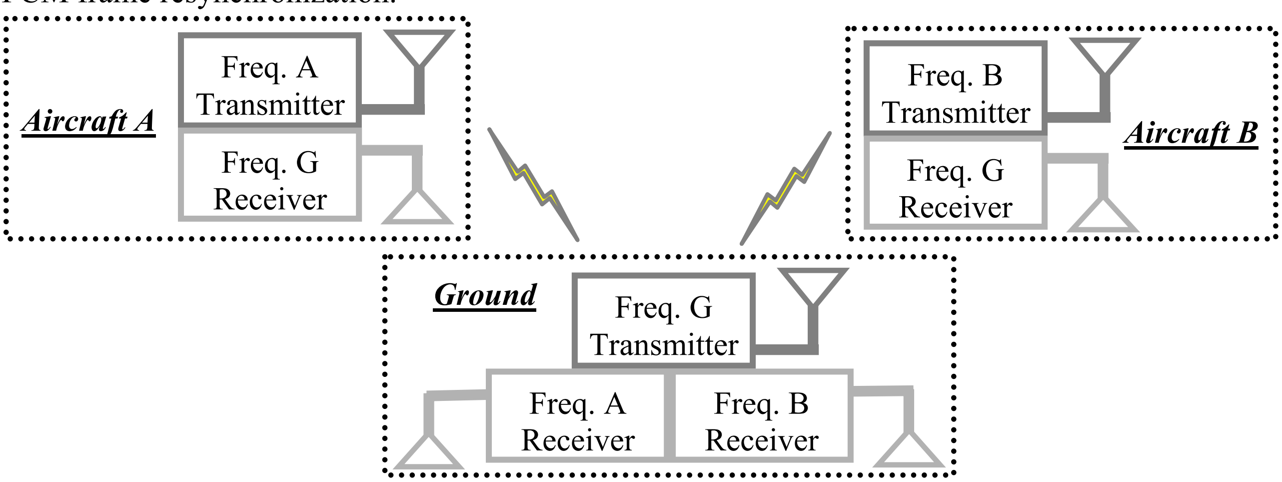

Figure 3 – Fibre Channel – PCM Bridge Network

PCM TELEMETRY PERFORMANCE

Telemetry performance is continually being advanced in order to keep up with the ever-increasing demands of the aircraft systems and to monitor these systems in real-time. It is becoming more and more common for data from an aircraft to be at rates above 10 Mbs. This has been achieved by changing from the traditional FM transmission methods for PCM to enhanced methods such as SOQPSK which effectively doubles the bit-rate within the same occupied telemetry bandwidth. In many cases, Onboard Processors [4] can help to reduce the required bandwidth. Combining these processing systems with the telemetry uplink controls (such as described in iNET [5]) may further reduce the telemetry spectrum requirements by only asking the aircraft to send the information that is required during any moment in time. These methods should work well for the more typical Flight Test sensor data, however, with the abundance of data in the aircraft communication networks, aircraft systems engineers will always be asking for more. And in many cases, they will not tolerate Flight Test affecting their network timing and performance. If Flight Test remains an inactive participant by being a non-intrusive monitor of the network, it will guarantee that the production aircraft will perform the same as the Flight Test aircraft. Another practicality of using PCM for transmission is the simple matter of adding an approved hardware device to guarantee the security of the data. This eliminates any headaches involved with trying to certify that unwanted users cannot decipher the data. A further important advantage of PCM over the typical wireless LAN is bandwidth efficiency. PCM is a continuous signal while the wireless LAN works like Ethernet in that it frequently starts and stops transmissions and must account for multiple nodes colliding with each other trying to gain access to the network. This inefficiency can account for a typical loss of about 50-60% from the actual transmission rate. However, this technique can benefit from the fact that the frequency spectrum can be shared among several users. On the other hand, since it is a shared spectrum and not controlled as it is with PCM transmissions, it may not be possible to get a clear channel for all of the required data and this won't be known until the test flight is being conducted. **Figure 3** showed an example with only two aircraft and one ground station. If many more aircraft need to be connected together, the aircraft transmitters could use alternative transmission techniques such as spread spectrum. The ground station, which would have multiple receivers and correlators, could then be responsible for adding the appropriate identifier to the PCM before retransmitting the data to the aircraft.

FCIU IMPLEMENTATION

As shown in **Figure 4**, the Fibre Channel Interface Unit (FCIU) supports up to 8 FC ports. It can combine the received FC information from these ports into two PCM outputs. One can be used to collect all of this FC traffic and send it to a recorder while the other can be used to selectively send only a portion of this traffic to a telemetry system. IRIG-106, Chapter 8 describes merging up to eight MIL-STD-1553 streams. It adds an 8-bit byte tag to each of the original MIL-STD-1553 16-bit words in order to identify items such as the bus number and the type of word (i.e. command, status, data, time, etc.). The FCIU's PCM output is a pseudo Chapter 8. The FCIU adds either a 4-bit nibble or a byte to each of the FC 32-bit words. Similarly, these bits are used to identify items such as start and end of frames, time, payload, etc. The 36-bit word format can be used to identify up to 4 merged FC streams while the 40-bit format can identify up to 64 FC streams. This method of merging the streams replicates the functionality of the most general type of port, the Switch Port.

For its current application, the FCIU is acting as a monitor only and therefore not using its transmit buffer for acknowledgments or data transfers. The FCIU's recorder and telemetry interface throughput were sized to capture all of the required information without the need to slow down the FC traffic and therefore not affect the system being monitored. Since the output stream of the FCIU is PCM, the FC information is being recovered using COTS decoms.

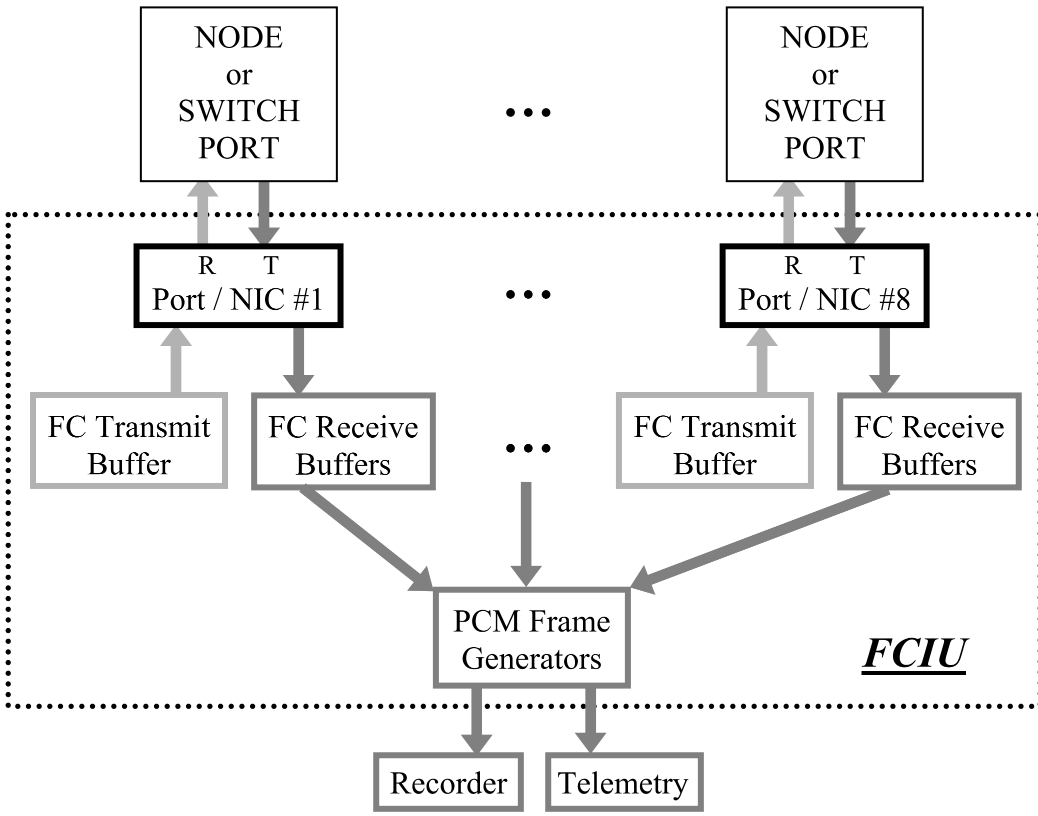

Figure 4 – FCIU Bridge Configuration

CONCLUSION

This paper described a Fibre Channel to PCM Telemetry Bridge. A similar bridge could be constructed for other types of networks such as Ethernet. IEEE 802.11 may still be the choice for some applications when absolute security, range, and guaranteed bandwidth (i.e. data transfer rate) are not an issue. Simple IEEE 802.11 networks are easier to construct and less expensive than PCM network connections. However, for the raw power user, the FC to PCM T/M Bridge is much superior in efficiently transferring large amounts of data over significantly greater distances and will continue to outpace IEEE 802.11 in this area. When creating a wireless network connection, both the IEEE 802.11 and the FC-to-PCM Bridge should be considered and their advantages and disadvantages compared. Lastly, the Fibre Channel Interface Unit has proven the possibility of a high performance wireless node connection between a flying platform and the ground. It has implemented the key features required to build this bridge.

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NOMENCLATURE

ARTM	Advanced Range Telemetry (An U.S. Air Force Program)
COTS	Commercial-Off-The-Shelf
CPFSK	Continuous Phase Frequency Shift Keying (Another name for PCM/FM)
CPM	Continuous Phase Modulation (Multi-h CPM)
FC-4	Application or Upper Level Protocol – Examples: SCSI, IP, A/V, Proprietary, etc.
FM	Frequency Modulation
IRIG	Inter-Range Instrumentation Group
LAN	Local Area Network
Mbps	Mega-Bits-Per-Second
NIC	Network Interface Connection
Node	A node is the source or destination of information. (i.e. computer, disk array, etc.)
Payload	Frame location where information is contained (i.e. commands, data, status, etc.)
PCM	Pulse-Code-Modulation
Port	Physical connection to/from a node.
SOQPSK	Shaped Offset Quadrature Phase Shift Keying
T/M	Telemetry