VEHICLE NETWORK

TECHNOLOGY DEMONSTRATION

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ABSTRACT

iNET is a project tasked to foster advances in networking and telemetry technology to meet emerging needs. This paper describes one objective of the project, which is standardization and interoperability. It begins to explore issues for achieving a level of interoperability among differing vendor's hardware such as data acquisition units, data recorders, video systems, transceivers, and network encryption. Specifically, this paper addresses the expansion of the current demonstration system with the addition of multiple vendor data acquisition units. It will also attempt to address the level of standardization necessary for achieving interoperability while still enabling vendors to add their value added contributions into their products.

KEY WORDS

Ethernet, IEEE-1588, iNET, Interoperability, IP, Networking, vNET

PROGRAM BACKGROUND

The Central Test and Evaluation Investment Program (CTEIP) has launched the integrated Network Enhanced Telemetry (iNET) project to foster advances in networking and telemetry technology to meet emerging needs of major test programs as well as within the Major Range and Test Facility Base's. The iNET architecture has been developed to establish a framework that will enable standards development and allow the system to evolve as new technologies are introduced. The architecture defines a Telemetry Network System (TmNS) that would utilize traditional telemetry links in conjunction with a network-based telemetry link. The basic approach allows for the integration of network-based systems without significantly affecting traditional telemetry systems. The TmNS (Figure 1) architecture is divided into several levels and contains three key elemental areas: the Radio Frequency Network (rfNET) element, the test Vehicle Network (vNET) element, and the Ground Network Interface (gNET) element. In order to advance existing efforts and the need to gain insight into existing technologies relative to the

Telemetry Network System architecture, demonstrations utilizing Commercial Off The Self (COTS) equipment are being implemented. Demonstrations have been conducted to demonstrate a baseline of existing technologies to show potential users the validity and benefits of adding a two-way data connection to the test vehicle, which included a legacy serial streaming link. The current technology demonstrations are meant to expand on the previous concept demonstration to establish operational demonstrations to help develop operational procedures that will enable the deployment of the iNET system. Additionally, the technology demonstration will provide a test platform for architecture validation and standards development.

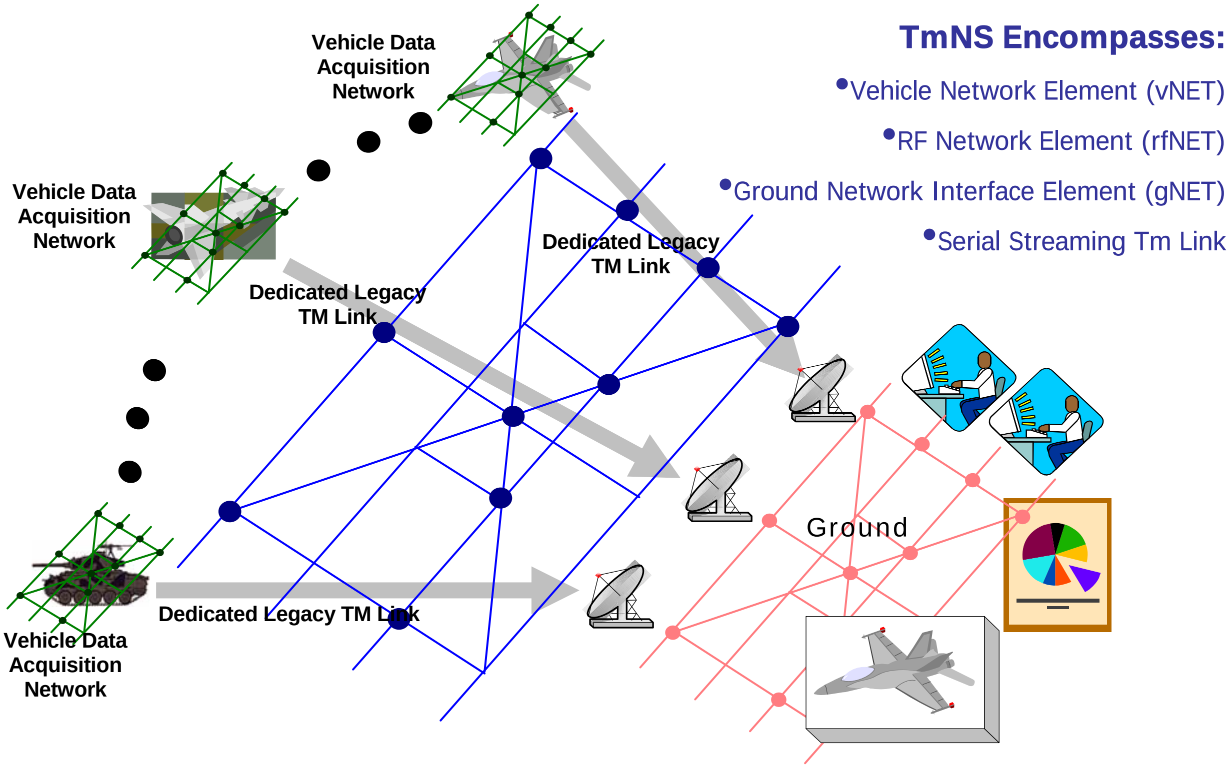

Figure 1: Telemetry Network System

INTRODUCTION

The objective of the vehicle network technology demonstration is to provide a test vehicle instrumentation network test bed that can support operational demonstrations and provide a platform for architecture validation and standards development. The technology demonstration system is an expansion of the concept demonstration system in order to retain the functionality established previously. The concept demonstration system was not bounded by the iNET architecture but where feasible the technology demonstration test bed will conform functionality wise to the TmNS architecture. The technology demonstration is expected to build off the functionality of the concept demonstration that demonstrated three specific iNET system needs: Data Mining, Gapless Telemetry, and Error Free Data Delivery. Data Mining is the real-time ability to recall and transmit data parameters present in the on-board recorder that may not be contained in the telemetry stream. Gapless Telemetry is a real-time technique to recover lost telemetry frames at the ground station by transmitting commands to the test vehicle to locate the missing frames in the on-board instrumentation recorder and retransmit them over the networked data link. Error-Free Data Delivery provides for reliable delivery of error sensitive data, such as high-resolution video images.

The concept demonstration [1] was based on modifying one of the modules of a high-speed instrumentation multiplexer: the AIM-2004. This multiplexer/recorder was enhanced to provide an external 100Base-T Ethernet interface and its software was augmented to provide real-time external control of the recording media and real-time data extraction independent of its normal recording process. Additionally, the AIM-2004 was extended to support an exploratory communications protocol to facilitate real-time communication with airborne flight test instrumentation from mission support stations, which included a web-based interface.

IRIG time was utilized as an external time source but as we evolved the demonstration system into a real network, an IEEE-1588 Network Time Grandmaster was added to distribute time via the network utilizing IEEE-1588 while still maintaining the traditional IRIG B that is a direct-wired connection to each IRIG time receiver. The network time grandmaster being utilized provides timing that synchronizes the IRIG B signal with the IEEE-1588 time source.

This part of the technology demonstration will incorporate multiple vendors hardware communicating via Ethernet with time synchronization being accomplished between the IEEE-1588 and traditional IRIG B. This paper will address standardization, interoperability, time synchronization, and message transports in a network data acquisition system.

OSI REFERENCE MODEL

Before the domination of the internet, many networks were built in isolation for specific purposes utilizing different hardware and software implementations. In the fullness of time, people eventually wanted these systems to communicate with each other. These systems were typically incompatible because the networks were using different specifications to communicate with each other. The International Organization for Standardization (ISO) began researching various network schemes to address this problem of networks being incompatible and unable to communicate with each other. The ISO recognized there was a need to create a network model that would help vendors create interoperable network implementations. In 1984, ISO approved the Open Systems Interconnection (OSI) reference model standard for communications architecture. It is now considered the primary architectural model for inter-computer communications. We believe one of the primary reasons why this model has been widely adopted is because the model aided network interconnection without necessarily requiring complete redesign of existing networks. The descriptive network scheme of the model ensures greater compatibility and interoperability between various types of network technologies. The model describes how information or data makes its way from application programs through a network medium to another application program located on another network. The reference model further divides the problem of moving information between computers over a network medium into seven layers. Breaking networking into small manageable layers reduces complexity. Each layer provides a service to the layer above it in the protocol specification. Each layer communicates with the same layer’s software or hardware on other computers. The lower 4 layers (1, 2, 3, & 4) are concerned with the flow of data from end to end through the network. The upper three layers (5, 6, & 7) are orientated more toward services to the applications. Data is encapsulated with the necessary protocol information as it moves down the layers before network transmission as illustrated in Figure 2.

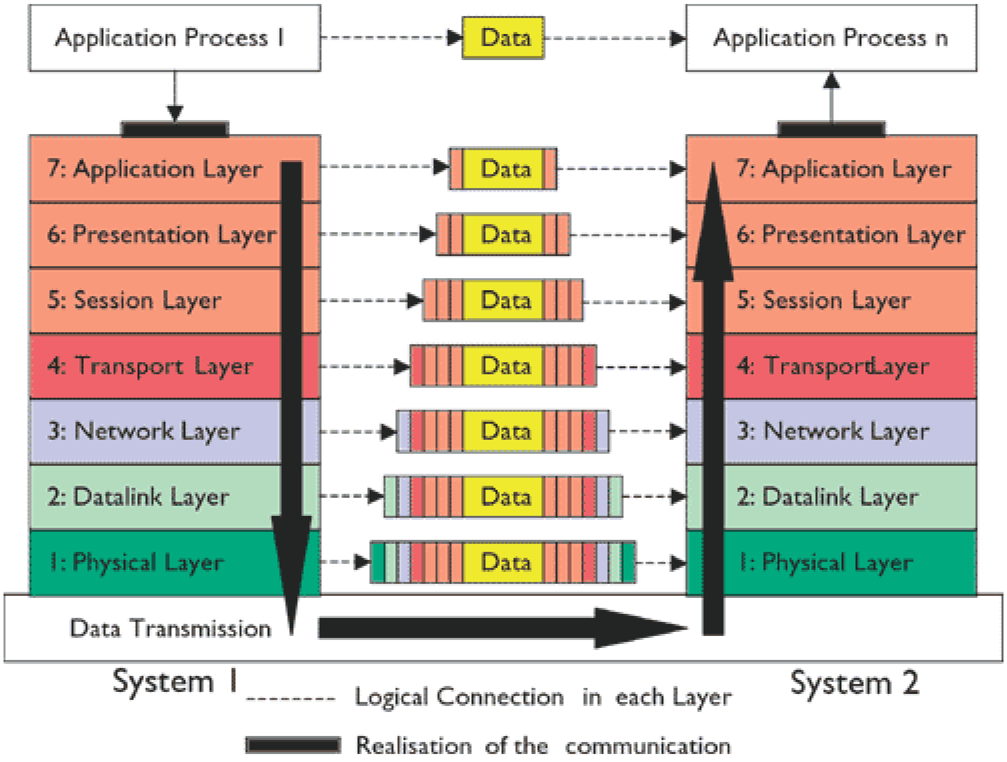

Figure 2: Data exchange in the OSI Reference Model [7]

These model elements may be grouped into architectural levels that represent major functional capabilities, such as switching and routing, data transfer, and the performance of applications. So architecturally, one can look at communications in three levels: (1) Data Transmission (below the physical layer) that provides all of the capabilities (physical and electrical) to establish a transmission path between functional system elements (wires, wireless, interconnecting network infrastructure, etc…), next (2) Network Switching (layers 1 through 3) establishes connectivity through the network elements to support the routing and control of traffic (switches, controllers, network software, etc…), then (3) the Data Exchange (layers 4 through 7) that accomplishes the transfer of information after the network has been established (end-to-end, user-to-user transfer) involving more capable processing elements (hosts, workstations, servers, etc…).

The model aims at establishing open systems operation and implies a standards-based implementation. It strives to permit different systems to accomplish complete interoperability and quality of operation throughout the network. The OSI reference model has supporting standards, which ensure vendors greater compatibility and interoperability between various types of network technologies. The seven layers of the OSI model are structured to facilitate independent development within each layer and provide for changes independent of other layers. However, in typical implementations many of these layers are lumped together especially at the lower and upper layers which has fostered the Internet Protocol (IP) as seen in the Internet

Architecture hourglass design. Protocols standards in conformance with the reference model layer have been published by various standards organizations; the IP protocol suite is a good example.

BACKGROUND

Implementations of instrumentation systems have long challenged instrumentation engineers with establishing systems that allow the integration of new technologies while being standardized and interoperable. Traditionally, interoperability was limited to a particular developer of instrumentation. This typically locked a program into a single supplier that resulted in limiting innovation and technology to the budget of the customer. The CAIS (Common Airborne Instrumentation System) program attempted to provide a level of commonality and interoperability that it achieved through the development of the CAIS Bus standard. The standard enabled multiple vendors' hardware to interoperate even though the underlying architectures were different but not necessarily radically different; however, it failed to establish a common tool for configuring hybrid vendor systems [2]. These systems were PCM-based data acquisition systems that utilized a Time Division Multiplexing (TDM) scheme. The TDM scheme is highly desirable by instrumentation engineers because these systems are highly deterministic in nature. The systems are relatively small and use a simple design to execute and generate a PCM data stream. The system may include a single unit or a group of units that form a distributed data acquisition system. In most cases, a distributed system is synchronous by way of hardwired synchronization signals or with a bus such as CAIS. The format that controls the parameter acquisition sequence is generally located in the PCM/acquisition controller, and sometimes (based on the system manufacturer) a copy of that format or subset of that format may also reside in the remote acquisition units. The format is executed in a time-correlated way by simple state machines.

The format consists of fixed instruction commands operating at a highly precise PCM word rate. Each command instruction within the format is transmitted in the system to the appropriate channel for data sampling. Data is sampled synchronously to the overall PCM word rate and format sequence. Data arrival at the PCM output is pipelined with a fixed delay for all channels in order to provide a PCM output channel sequence identical to the user input format sequence.

Inherently, while packet networks offer many advantages over a traditional PCM architecture, they suffer from at least one significant shortcoming: timing accuracy. Accurate time distribution within a packet network has been difficult to accomplish to date. IEEE 1588 seems to hold the most promise in the near term [3].

NETWORK TIMING

IEEE 1588 [4] addresses the clock synchronization requirements of measurement and control systems. The objective of IEEE 1588 standard is to define a protocol enabling precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing, and distributed objects. The protocol will be applicable to systems communicating by local area networks supporting multicast messaging including but not limited to Ethernet. The protocol will enable heterogeneous systems that include clocks of various inherent precision, resolution, and stability to synchronize. The protocol will support system-wide synchronization accuracy in the sub-microsecond range with minimal network and local clock computing resources. The default behavior of the protocol will allow simple systems to be installed and operated without requiring the administrative attention of users.

This implementation has been demonstrated to be able to achieve accuracies in the range of 100-300 nanoseconds across real-world local area networks. It works on the simple principle of clock adjustment. A master node on the network whose clock has been determined to be the most accurate (see the 1588 standard [5] for a discussion of how this is done) sends its time to a slave node. If the transfer of time were simultaneous, then the two clocks on the network would be synchronized. However, this is false as there are many sources of delay in sending an IP message from one network node to another. If we knew the delay caused by the transmission of the message, we could add that to the received clock time and easily synchronize the clock in the slave to that in the master. There are two sources to the delay in transfer; that caused by the software IP stack and operating system and that caused by the network itself.

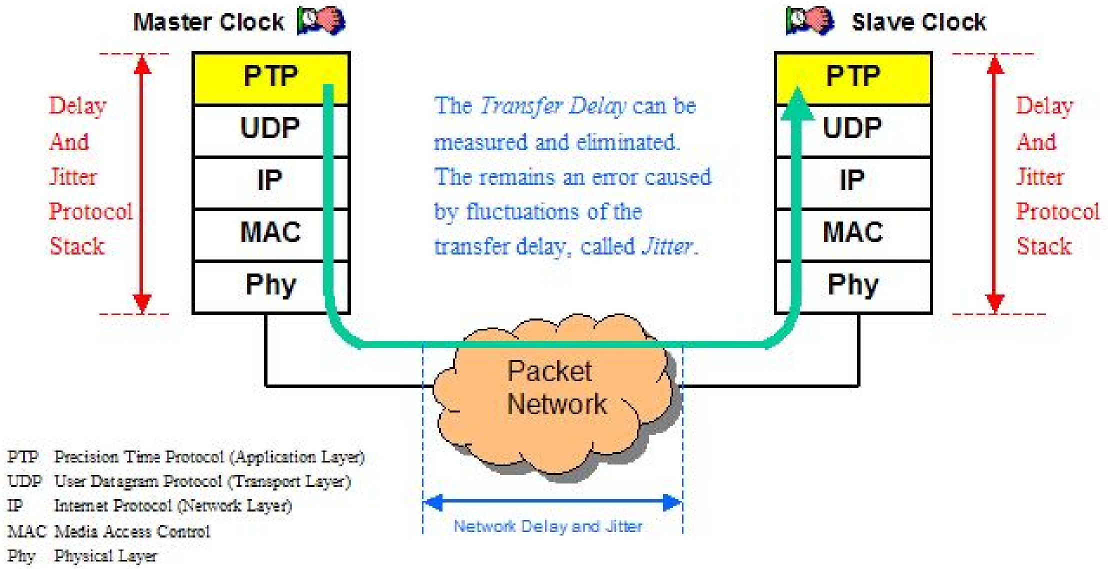

Figure 3: IEEE 1588 Jitter and Delay

Messages sent and received by the software are affected by a constant process (number of lines of code needing to be executed, distance between nodes on the network) and by a varying process (task switching, memory management, caching, interrupt latency, bus arbitration, packet queuing, switching, etc…) which result in a constant latency (delay) and a varying latency (delay variation or jitter). IEEE 1588 achieves its high accuracy by inserting hardware time stamping units in the network physical transport layer to order to eliminate the impact of these processes (delay and jitter) on the time synchronization of clocks between two nodes in the network. The time stamps (Figure 3) are inserted between the Ethernet PHY and MAC devices on the MII bus and monitor all packets being sent and received between the node and any other device on the network. Packets being sent by the Precision Time Protocol (PTP) (a component of the IEEE 1588 standard) are recognized and time stamped as they are sent and received and those times are made available to both the master and slave nodes for use in computing the delay and jitter found in the system.

Once multiple data acquisition nodes have synchronized their local clocks to the global master clock, simultaneous sampling of distributed parameters becomes possible. However, the principle on which this process operates is very different from an IRIG synchronized system. A PCM-based data acquisition system triggers simultaneous sampling via reception of a global signal transmitted either in-band or out-of-band of the timing reference source. The accuracy of this operation depends upon the timing skew introduced by the transmission of the signal over the wiring between the individual units. In a 1588-based data acquisition system, the sampling is triggered by all units reaching a previously agreed upon timing marker. The accuracy of this operation depends upon the overall system time determinism. The timing skew is dependent upon the overall accuracy of the unit's local clock, whereas the skew is independent of any signal path propagation delays within the network during operation.

VEHICLE NETWORK TECHNOLOGY DEMONSTRATION

This portion of the Technology Demonstration will demonstrate interoperability between multiple vendors' hardware over a network. The test Vehicle Network (vNET) is the network internal to the test article that interconnects the Data Acquisition, Data Archive, Sensors, and Onboard Processing systems. In the aircraft segment of the technology demonstration, the key element of the vNET portion is a specially developed airborne 10/100/1000 Ethernet switch with built-in support for IEEE 1588. Its primary function is to switch IP packets between nodes within the network and distribute 1588 or IRIG time from its built-in GPS receiver.

The acquisition system (see Figure 4) has six nodes connected through the airborne switch. The first node is the TTC AIM-2004 with its associated solid-state drive. This airborne multiplexer is designed to accept inputs from various high-speed data sources, including PCM and Ethernet data. In addition to providing data multiplexing and recording services, this unit can operate as a CAIS remote data acquisition node that provides selected data from the I/O cards and unit status information for transmission. The other nodes that are part of the network are the Acra KAM-500 data acquisition unit, the In-Snec UMA-2000 data acquisition unit, the L-3 Telemetry East NetDAS network data acquisition system, the TTC MnVid-2000 video acquisition unit, and the TTC MnPCM-2000 PCM gateway unit. All the data acquisition units' package data into IP packets per the message structure define in the next section. Three of the units via the Ethernet interface accept the IEEE 1588 timing protocol and will synchronize the unit to that timing reference while other units will be feed time from the IRIG B time source. Both of these time sources are synchronized to the GPS time source that is inside the airborne switch. The data acquisition units are like traditional data acquisition systems and acquire typical varying data types. In this setup, they are configured to acquire analog measurements.

The video acquisition unit accepts single analog video and audio inputs that are compressed using the MPEG-2 standard and transmitted as IP packets using the IRIG 106 Chapter 10 standard. The PCM-to-Network Gateway unit facilitates the connection of legacy PCM-based systems to a networked system. The gateway accepts PCM clock and data and provides a major/minor frame correlator; timestamps minor frames using the network IEEE-1588 time, and packetizes data into a message structure for transmission on the network. The source of data for the PCM gateway is the TTC MCDAU, the same PCM source being used for input to the AIM-2004. Using the same PCM stream for both the AIM-2004 and the PCM gateway allows us to compare the relationship and accuracy of using a mixed IRIG and 1588 based data acquisition system by comparing and analyzing the timestamps recorded in each synchronous data stream.

This demonstration system will show four vendors data acquisition units working together in a single network system.

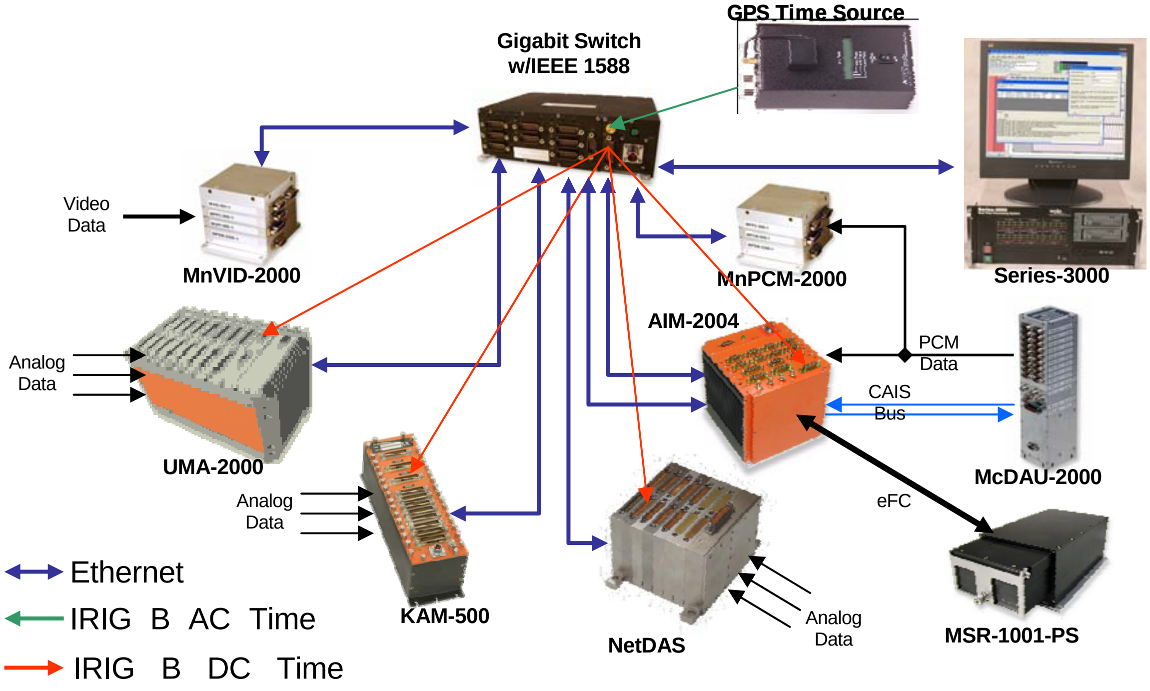

Figure 4: vNET Technology Demonstration

On the ground, the gNET portion of the network consists of a general-purpose computer that contains a user application that communicates over TCP/IP with the HTTP server in the AIM. The application provides the link between the Omega Data Processing station [6] that manages the incoming telemetry data and the aircraft portion of vNET. This application monitors the incoming PCM stream and looks for predescribed conditions that cause the system to query the airborne recorder for data. Specifically, the system through several applications/processes is filling in PCM dropouts and displaying a complete clean picture of the data.

Message Structure

For the purposes of this demonstration, a modified version of the Chapter 10 data structure was used. The data packet structures defined by Chapter 10 was chosen because it provided a neutral starting point and enabled a common message structure in which to communicate. However, in the near future this message structure will change as more is learned about data acquisition over networks.

Chapter 10 defines three common packet elements for all data types: a Packet Header, a Packet Body, and a Packet Trailer. The format of these elements is defined by the Chapter 10 standard. The modifications made to the packet structure for the Technology Demonstration are as follows. The maximum packet size is 65,536 bytes instead of 524,288 bytes. This restricts the PCM minor frame size to 65,504 bytes. The relative time counter is not used but instead a modified version of the IEEE-1588 Precision Time Protocol (PTP) is used as a time stamp. In order to fit the PTP time, which is 64 bits into the 48 bits used in the Chapter 10 relative counter, the two most significant bytes are truncated from PTP time. These items are not used: the intra-packet data word used, filler data, data checksum, and no packet trailers are sent across the network.

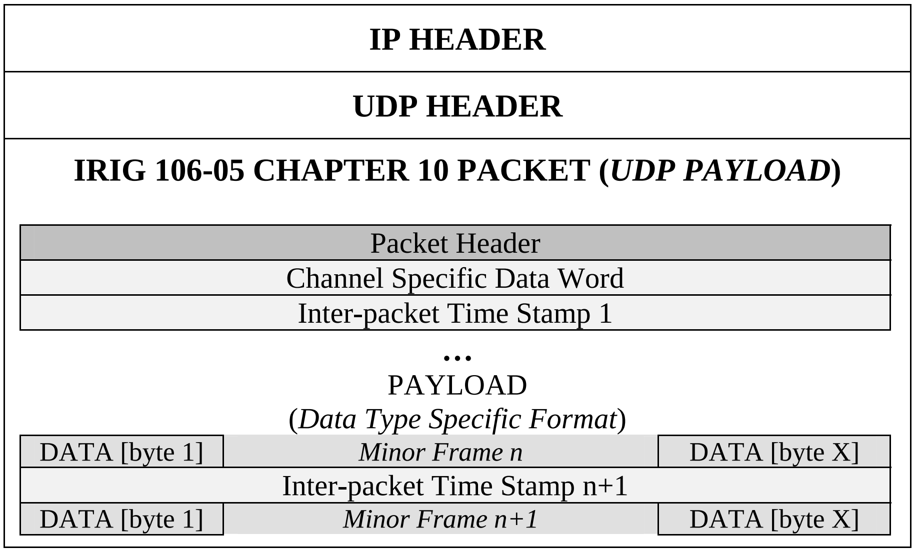

Figure 6: PCM Data Encapsulation

Chapter 10 packets are transported from the network nodes to the AIM as standard UDP datagram's. The entire Chapter 10 packet (header and body) is fully encapsulated within the UDP payload. Figure 6 depicts this encapsulation.

CONCLUSION

Network architecture is a set of high-level design principles that guides the technical design of the network that provides a sense of direction to help serve as a basis for individual technical decisions. The Technology Demonstration, in principle, is to help understand the choices and establish a more focused set of design principles that will ensure a solid set of standards that the community can utilize to establish future telemetry systems. In the area of network based data acquisition systems, it brings forward a new level of understanding within the community. Many times, we are forced to rethink how we do business or why we do the things we do and ask ourselves why are they important. The OSI reference model in conjunction with the iNET architecture provides a framework to help guide us in discussing how our communication systems work and how we can bridge those systems with new items incorporating newer technologies. The OSI model enables us to deal with the technical complexity of change and provides a path for standardization and interoperability. In this paper, we discussed some of the issues related to achieving interoperability as we migrate from traditional PCM systems to network based systems. The power and flexibility of network-centric data acquisition architectures make them attractive as a migration path for future avionics acquisition systems. However, in order for a network-centric architecture to succeed, communication of timing must be an intrinsic function of behavior as is communication of data. The development of the IEEE 1588 standard and its accuracy makes it an attractive solution for communication of timing in an IP network. Any proposed network data acquisition-based system implementation will need to follow an evolutionary approach rather than a revolutionary one, as the need to maintain some form of compatibility with existing test infrastructure is required. In addition, a level of interoperability needs to achieved when deploying standards therefore using a reference model can help provide a standardization path to enable interoperability but yet allow vendors to incorporate there value added items. The ability to interconnect and maintain a multiple vendor data acquisition system can be a challenge but through standardization and common tools, it is achievable. The implementation of this part of the Vehicle Network Technology Demonstration is expected to be completed the summer of 2007 with results being presented at ITC 2007.

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