VEHICLE NETWORK

CONCEPT DEMONSTRATION

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ABSTRACT

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. This paper describes the objective of the vNET concept demonstration to provide a test vehicle instrumentation network architecture that can support additional capabilities for data access to the test vehicle. Three specific iNET system needs have been identified as being desirable as the basis for evaluating a Concept of Operation through this demonstration project. These three key areas are Data Mining, Gapless Telemetry, and Error Free Data delivery.

KEY WORDS

Data Mining, iNET, vNET, Networking, IP, Multiplexer, Recorder

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. However, before a decision was made to start the iNET execution program, an iNET study was performed to determine the feasibly and maturity of implementing network-based technologies in a test environment. This iNET study has defined a Telemetry Network System (TmNS) that would utilize traditional telemetry links in conjunction with a network-based telemetry link. This basic approach allows for the integration of network-based systems without significantly impacting traditional telemetry systems. The Telemetry Network System (Figure 1) is divided into three focus areas; the Radio Frequency Network (rfNET), the test Vehicle Network (vNET), and the Ground Network Interface (gNET). In order to expound on existing efforts plus respond to the need to gain insight into existing technologies relative to the Telemetry Network System, a concept demonstration utilizing Commercial Off The Self (COTS) equipment is being implemented. The iNET project plans 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. A legacy serial streaming link will be implemented along with a burst-type multi-access network link for system control and data transmission. The project objectives are to show the test community that a hybrid, networked/streaming telemetry system can provide a level of increased performance and decreased spectral utilization.

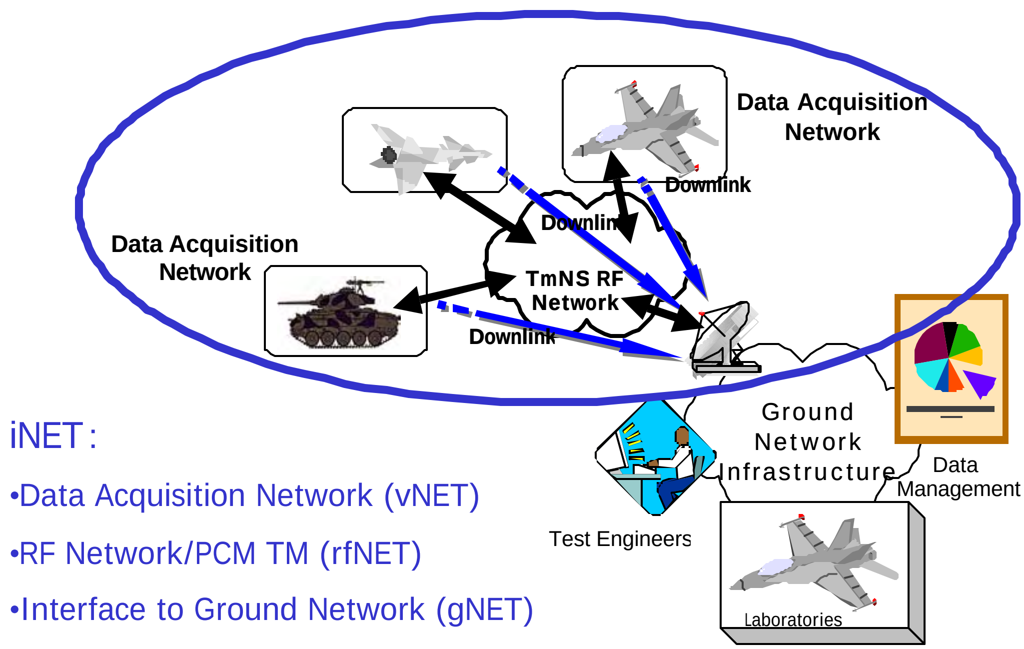

Figure 1: Telemetry Network System

INTRODUCTION

The objective of the vNET concept demonstration is to provide a test vehicle instrumentation network architecture that can support additional functionality for ground-based test users of the test vehicle. Three specific iNET system needs have been identified as being sufficient for evaluating the architecture proposed here: 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 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 will be accomplished by modifying one of the elements of the JSF high-speed instrumentation components; the AIM-2004. This multiplexer/recorder [1][2] will be enhanced to provide an external 100Base-T Ethernet interface and its software will be 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 has been extended to support an exploratory communications protocol to facilitate real-time communication with airborne flight test instrumentation from mission support stations. This paper describes these changes made to the existing AIM-2004 architecture along with the software infrastructure (both on-board and on the ground) that allow for interactive real-time data extraction from a vehicle under test.

VEHICULAR NETWORK

The Vehicular Network (vNET) is the network internal to the test article that interconnects the Data Acquisition, Archive, Sensors, and Onboard Processing systems. The elements of vNET are shown enclosed in dotted lines in Figure 2.

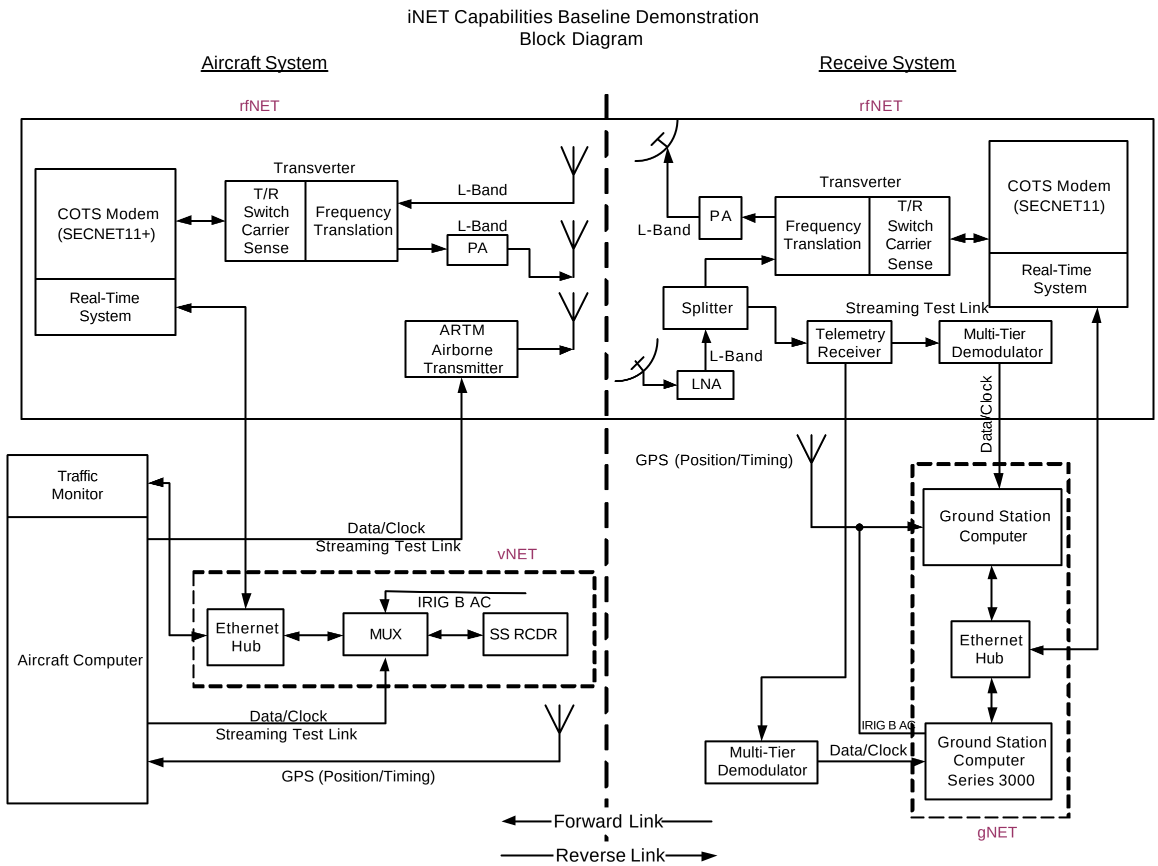

Figure 2: iNET Baseline Demonstration

In the aircraft segment of the concept demonstration, one key element of the vNET is the AIM-2004 with its associated solid-state drive. The AIM-2004 is an airborne instrumentation multiplexer and recorder used in a variety of flight test programs including JSF. This unit is designed to accept up to four data I/O cards that support a variety of high-speed interfaces including IEEE 1394b, Fibre Channel, PCM, 1553, Video, and 10/100Base-T Ethernet. In addition to providing data multiplexing and recording services at data rates up to 1 Gbps, the unit can operate as a CAIS remote data acquisition node that provides both selected data from the I/O cards in addition to card/unit/recorder status for transmission of flight safety data. For purposes of the vNET demonstration, the software on the AIM-2004 has been modified to allow the Ethernet card to function as a two-way communication channel to the system rather than a data acquisition interface. In order to service IP packets sent to/from this interface, a HTTP web server has been added to the AIM-2004 system software firmware. This server provides a back-end interface to the standard data acquisition and switch software that manages the multiplexer.

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 on the aircraft. The application provides the link between the ODE server that manages the incoming telemetry data and the aircraft portion of vNET. The application translates requests for missing PCM frames from the ODE server into the communications protocol for transmission over the rfNET to the aircraft.

CONCEPT DEMONSTRATION

The data being transmitted over the serial telemetry link will be known data with each PCM major frame time tagged with IRIG time prior to transmission. The format of the serial streaming link will be classical IRIG PCM with an embedded major frame number and a 16 or 32-bit cyclic redundancy check (CRC) for each major frame. A frame synchronization pattern will be used to maintain frame sync and to determine the individual frame boundaries. A running log of frames will be kept at the receive node along with the IRIG time for each start of a frame transmission. The ground station receiving this serial link will utilize the CRC to determine if there was an error within the major frame. If a missing or corrupt frame is detected, the networked link will request the vNET subsystem (through the rfNET subsystem) for frame retransmission based upon the start and stop times of the dropout interval. Consecutive dropped or corrupt frames will be collapsed into a single interval to reduce the number of requests that need to be sent to the on-board recorder. The requested frame(s) contained within that time slice will be accessed on the vNET solid-state recorder and sent to the rfNET data link for transmission to the ground. The rfNET link will handle error detection and retransmissions will occur until the data is received. Once the ground station receives the error free retransmitted frame(s), this information is saved and merged near real-time back into the recorded data and presented as gapless or error-free data.

Thus, the concept demonstration provides for the implementation of the three iNET specific needs desired: Loss of PCM frames over the telemetry link triggers a request for data to the on-board media (Data Mining) which results in transmission of frames over rfNET (Error Free Data Delivery) and the replacement of missing frames at the ground station (Gapless Telemetry).

COMMUNICATION PROTOCOL

The Communications Protocol is an application-level protocol designed to facilitate real-time communication with airborne flight test instrumentation from mission support stations. Amongst other things, facilities empowered by the exploratory communications protocol will be capable of ground based recorder control and data mining procedures.

This Communications Protocol leverages years of proven technology offered by the Internet Engineering Task Force (IETF) and the World Wide Web Consortium (W3C). As such, the protocol can be viewed as an application specific layer riding on top of standard Internet protocols. Details on Internet protocols are beyond the scope of this document, but are readily available at the IETF web site, www.ietf.org, and the W3C web site, www.w3.org. Specifically, this protocol relies on RFC 2396 Uniform Resource Identifiers (URI) [3], RFC 2616 Hypertext Transfer Protocol (HTTP) [4], RFC 2045 Multipurpose Internet Mail Extensions (MIME) Part One [5], and Hyper Text Markup Language (HTML) 4.01 [6]. Familiarity with those standards will greatly assist the readers understanding of this communications protocol.

As a facilitator of data downloads, the protocol is dependent on the underlying data packet format used by the airborne instrumentation. It leverages packet format standards published by the Range

Commanders Council for seamless integration with a broad range of mission support stations. Specifically, this protocol adopts the IRIG 106, Chapter 10, "SOLID STATE ON BOARD RECORDER STANDARD" (Chapter 10) [5]. Details on Chapter 10 are beyond the scope of this document, but are readily available at the RCC web site, http://jcs.mil/rcc/.

Terminology

The following terms define specific entities within the iNET system and the communication between these entities.

1. *Message* - The basic unit of the communication protocol, consisting of a structured sequence of octets matching the syntax defined within this specification.

2. *Request* - A request message is as defined in Section 4.

3. *Response* - A response message is as defined in Section 5.

4. *Client* - An application program that establishes connections for the purpose of sending requests.

5. *Server* - An application program that accepts connections in order to service requests by sending back responses.

6. *Recording session* - An interval as defined by Chapter 10 Section 10.2.

7. *Packet* - A unit of data as defined by Chapter 10 Section 10.2.

8. *Data set* - A distinct selection of packets.

Operational Overview

The protocol is based on the request/response paradigm defined by HTTP. Communications are established and standard HTTP message traffic is carried over TCP connections. A client initiates all communication, which trigger responses from a server.

The client sends requests for specific resources (as defined by the protocol) to the server. Resources are described using the communication protocol syntax [7]. Requests are sent as standard HTTP Request messages where the URL indicates the desired resource. Resources are partitioned by services, and further qualified by function. Optionally, functions may take parameters. As such, an iNET URL can pinpoint anything from static configuration data, to dynamic data, to recorder control and status on a particular airborne instrument. For example, an iNET URL can request resources (or actions on resources) such as, recorder erasure, current time, TMATS, or a stream of data for a given channel on a given recorder over a specified time interval.

The server responds to requests with standard HTTP Response messages. Server responses may include standard HTTP status codes or extended status codes [7]. In addition, response message bodies may include standard HTML, and/or Chapter 10 packets.

Uniform Resource Identifiers – Overview

A Uniform Resource Identifier (URI) in iNET-CP complies with the syntax and semantics as defined by HTTP for an http URL. However, iNET-CP adopts "absoluteURI" only. Clients MUST present iNET URLs to iNET servers with a Request-URI in the absolute form. A Request-URI in the context of this protocol is defined to fully qualify a resource in the airborne instrumentation cluster by specifying the host, service, function and function parameters. For the purpose of describing iNET-CP URI syntax, the rules defined by "Appendix A. Collected BNF for URI", RFC 2396 URI Generic Syntax [6] are employed.

Sample iNET URLs

A few sample iNET URLs are presented below to give a flavor for iNET-CP. See the iNET Communication Protocol [7] for a more complete discussion and description.

- **Return the TMATS data for recorder 1**
    - http://aim.ttcdas.com/iNET/1.0/data?f=tmats&r=1
- **Start recording on recorder 1**
    - *http://aim.ttcdas.com/iNET/1.0/control?f=start&r=1*
- **Return the operational state of recorder 1**
    - *http://aim.ttcdas.com/iNET/1.0/status?f=state&r=1*
- **Return the last IRIG time packet, status, and current relative time counter**
    - *http://aim.ttcdas.com/iNET/1.0/data?f=time*
- **Identify all chapter 10 packets on recorder 1 from channel 0x0280 recorded at or after 023:14:30:45:000 and before or at 023:14:30:50:000**
    - http://aim.ttcdas.com/iNET/1.0/data?f=stream&r=1&cid=0x0280&start=023:14:20:45:000&stop=023:14:20:50:000
- **Return the chapter 10 packets previously identified by a stream request**
    - *http://aim.ttcdas.com/iNET/1.0/data?f=stream&stream-id=77eaf23.ch10*

CHALLENGES

One of the difficulties associated with data mining is the ability to read previously recorded acquisition data while not disturbing the ongoing recording process. While it is true that the recording and data mining procedures could be tightly controlled such that neither is attempted in parallel, the wide disparity between the onboard data rates and the downlink data rates makes it feasible to allow both to occur simultaneously while only affecting the onboard recording in an minimal or non-existent fashion. In addition, there are many scenarios that occur during flight test where it would be very desirable to maintain onboard recording while data mining. An alternate approach to making this happen would be to mirror the onboard data to a secondary recorder. Data mining would only occur within the secondary record, which could be controlled in any fashion desired without affecting the primary recorder. Unfortunately, the drawback to this approach would be the additional space for secondary media and the need for the multiplexer to reliably support twice the actual needed data recording bit rate.

During the development of the vNET concept demonstration, a test was done to measure the impact of reading while writing to the data acquisition media. Many flight test programs make use of both hard disk and solid-state media for data recording purposes. The AIM-2004 makes use of electrical fibre channel as the means to communicate with either external or internal recording media. This allows for the customer to supply their own media as desired and take advantage of the latest recording media technology as it becomes available. For the purposes of this experiment, a 147GB fibre channel hard disk and a 10GB fibre channel solid-state driver were used to measure the impact of reading data while writing at the maximum sustained data rate. Figure 3 shows the conceptual diagram of the experiment:

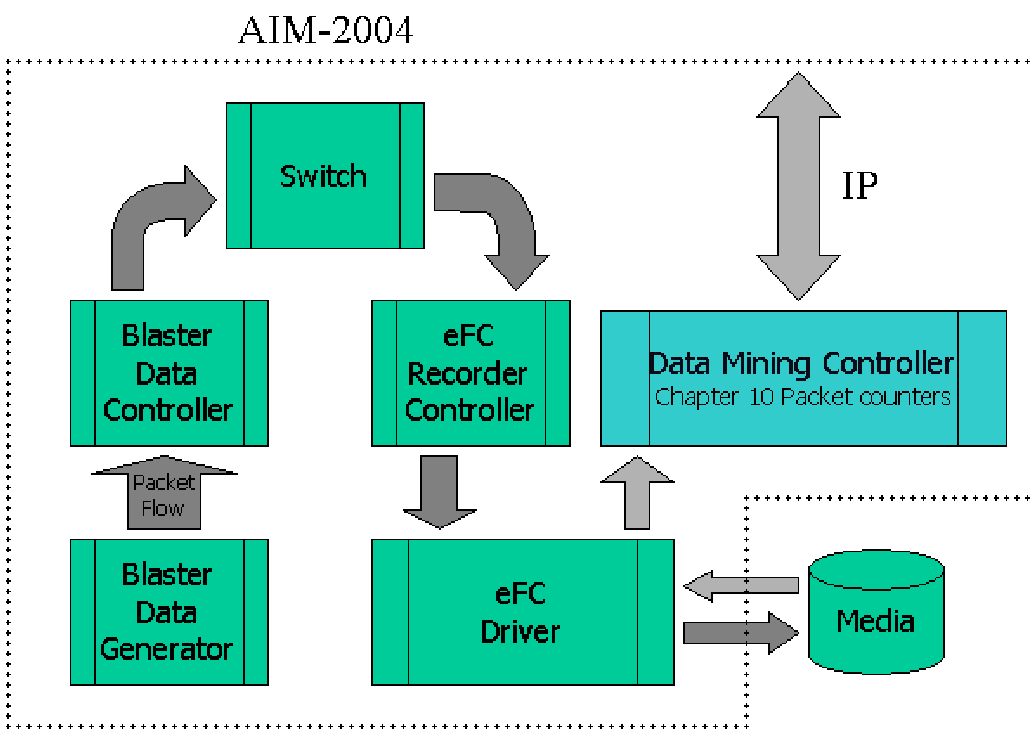

Figure 3: Media Performance Measurement

The AIM-2004 system software includes a packet generator called *Blaster* that can be used to test elements of the internal switch software. For the purposes of this experiment, Blaster was configured to generate 64K byte packets at 1000 packets per second. This data rate was sufficient to saturate the bandwidth of either media tested. A total of three measurements were done, the first was to measure the sustained write rate of the media without any data mining occurring, the second measurement repeated the first measurement while reading 12 Mbits/sec, and the last measurement repeated the first measurement while reading 60 Mbits/sec. The results are shown below:

Data Acquisition Rate	Data Mining Rate	Hard Disk Sustained Write Rate	Solid-State Sustained Write Rate
64 Mbytes/sec	0 Mbits/sec	37 Mbytes/sec	30 Mbytes/sec
64 Mbytes/sec	12 Mbits/sec	35 Mbytes/sec	29 Mbytes/sec
64 Mbytes/sec	60 Mbits/sec	29 Mbytes/sec	28 Mbytes/sec

The hard disk sustained write rates shown above reflect writing to an empty disk. As the disk fills, the sustainable write rate decreases as the heads move from the inner cylinders into the outer cylinders. Because of this effect, the actual sustained data acquisition rate for the media must be chosen to be the slowest rate supported by the hard disk. Because of this, the actual impact of data mining the hard disk during the recording process is negligible until the end of the media is reached. In the case of solid-state media, the effect described above is not present. However, because of the lack of the mechanical constraints present in the hard drive, the solid-state media is able to more efficiently overlay the read and write operations, resulting in a lower percentage loss in the write sustained data rate during data mining.

CONCLUSION

The purpose of this concept demonstration is to provide a system migration step between classical streaming PCM telemetry and a fully networked telemetry system. The intermediate step described within this paper maintains the serial streaming link enhanced by a network IP link that can provide recorded data on demand. The streaming link will carry the bulk of the data payload while the networked link provides industry-standard IP and protocol connectivity that allows for time-based PCM frame retrieval from aircraft recorded data in real-time. Our work has shown that it is possible to provide this functionality with minimal impact on the airborne instrumentation multiplexer in a flight test environment similar to that being using within the JSF program.

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