

A SYSTEM APPROACH TO A NETWORK CENTRIC AIRBORNE DATA ACQUISITION SYSTEM

Albert Berdugo

VP of Advanced Product Development

John Hildin

Director of Network Systems

Teletronics Technology Corporation

Newtown, PA USA

ABSTRACT

Airborne data acquisition systems have changed very little over the years. Their growth has primarily been in the area of digital filtering and the acquisition of new avionic busses. Communication between data acquisition units operating as a system still employs Time Division Multiplexing scheme. These schemes utilize command and data busses like CAIS and PCM. Although this approach is highly efficient, it has many drawbacks. These drawbacks have resulted in rigid system architecture, system bandwidth limitations, highly specialized recorders to acquire unique avionic busses that would otherwise overwhelm the system bandwidth, and unidirectional flow of data and control.

This paper describes a network centric data acquisition system that is Ethernet based. Although Ethernet is known as an asynchronous bus, the paper will describe a deterministic time distribution over the bus per IEEE-1588 that allows the use of a packet network for airborne data acquisition. The acquisition unit within the network system is defined by its MIB (Management Information Base) and operates as a data source unit. Other network components may operate as a data sink unit, such as recorders, or as a data source and sink. The role of different units in the network system will be evaluated. The paper will also describe network gateways that allow the use of traditional PCM systems with a network-based system.

KEY WORDS

Network, Ethernet, SNMP, MIB, IEEE-1588, IP Recorder, Data Acquisition

INTRODUCTION

It is becoming apparent that the future of airborne distributed data acquisition system is moving fast toward a network centric architecture. iNET and specifically vNET is currently under architecture development study in order to standardize a vehicle network based acquisition system. It will take some time before a system architecture and more importantly a standard will be available to the flight test community. Aircraft manufacturers that have immediate needs to implements flight test systems to meet schedules are not waiting for any standards, and are pressing ahead with various approaches that may or may not include Ethernet base network as the flight test system backbone. Several applications of large commercial aircrafts have already been using network based acquisition system in the past few years [1] [2]. These applications made use of some COTS (Commercial Of The Shelf) equipment, newly developed equipment

that is rack mounted, and other small PCM equipment that was modified or adapted to interface to the flight test network. There are no known fighter aircraft that use Ethernet network for communicating and collecting flight test data at this time. However, this provides the opportunity to start defining and introducing the type of components that one needs to consider for an Ethernet based data acquisition system.

This paper will describe some basic terminology and definitions of some of the network components, and discuss the architecture of a network based data acquisition system. Additionally, we will identify and describe components of such a system including in bound time distribution per IEEE-1588 and elements that may be used to bridge legacy components to a network centric system. Software management of this system is beyond the scope of this paper.

DEFINITIONS AND TERMINOLOGY

Some terminology used throughout this paper is presented here. Many of these terms are widely used when describing a data network.

Node - Any device connected to the network. For example, networked data acquisition units, networked data recorders, a network management server, etc.

Source Node – Any network-attached device that generates data and sends it to a sink node (e.g., a sensor or multiplexer).

Sink Node – Any network-attached device that accepts data from a data source device (e.g., a flight recorder, a telemetry transmitter, etc.).

Segment - A section of a network that is bounded by a switch, gateway, router or bridge.

Bridge - A device that connects one network segment to another segment having the same network protocol.

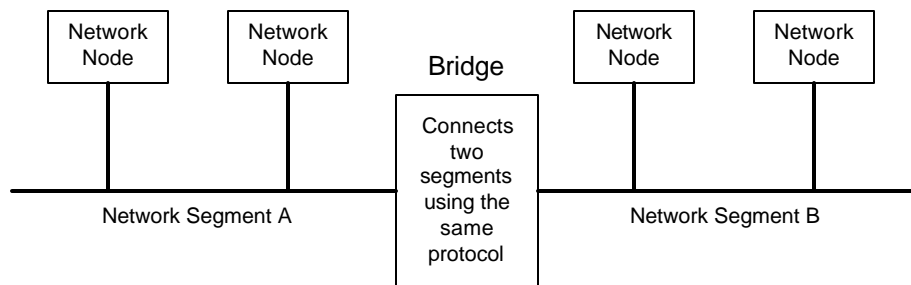


Figure 1 Network Bridge

Gateway - a device that converts one network protocol to another.

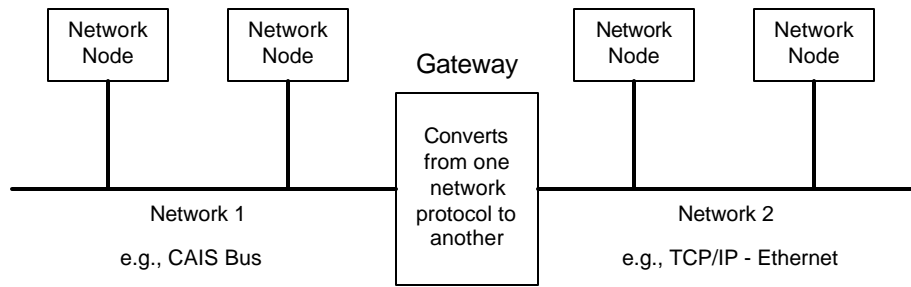


Figure 2 Network Gateway

Switch - a device that filters and forwards data between different network segments. Often, the switch performs the functions of a router, which involve routing traffic to various segments connected to the switch.

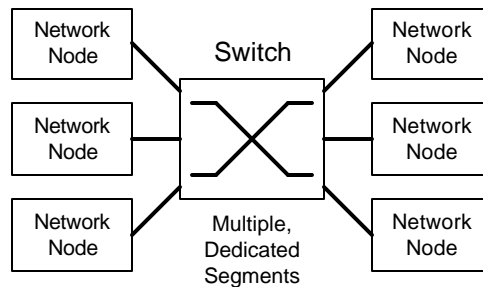


Figure 3 Network Switch

Hub - a device that allows connection of multiple nodes to a common shared network segment.

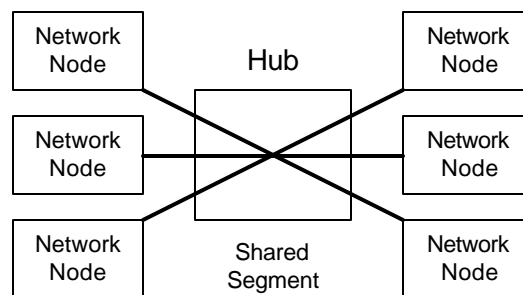


Figure 4 Network Hub

NETWORK-BASED DATA ACQUISITION SYSTEM

The concept of network-based data acquisition and recording systems is not new. Its efficiency and cost-effectiveness has been proven by the telecommunications industry. However, its application within the commercial aviation, military, and aerospace sectors is relatively recent.

TTC is progressively migrating its data acquisition and recording products to support an IP-based networked airborne environment. Hardware and software is currently being developed to allow users to program, transport data, and query network nodes using the Internet Protocol (IP). This supports enhanced flexibility to allow two-way communication between various sensors, DAUs, recorders, switches, transmitters, etc. The network-based system thus furnishes a “gateway” to legacy (non-network aware) systems, allowing users to operate existing equipment in its current environment. There is no need to “forklift” commissioned equipment for the sake of innovation. The key to the network communication is the network switch, which directs data to and from network nodes. The advantage of high-speed bi-directional communication permits flexibility in instrumenting the test vehicle. An important function of the switch is the delivery of network time packets to all the nodes requiring time synchronization. A ruggedized Gigabit Airborne Network Switch [3] with support of the IEEE-1588 protocol for handling and distributing network time on all its ports is already available. The support of Simple Network Management Protocol (SNMP) to manage the network nodes to allow configuration, statistics gathering, and health monitoring is an added benefit to such a system. The network system and its components may look like the one shown in Figure 5.

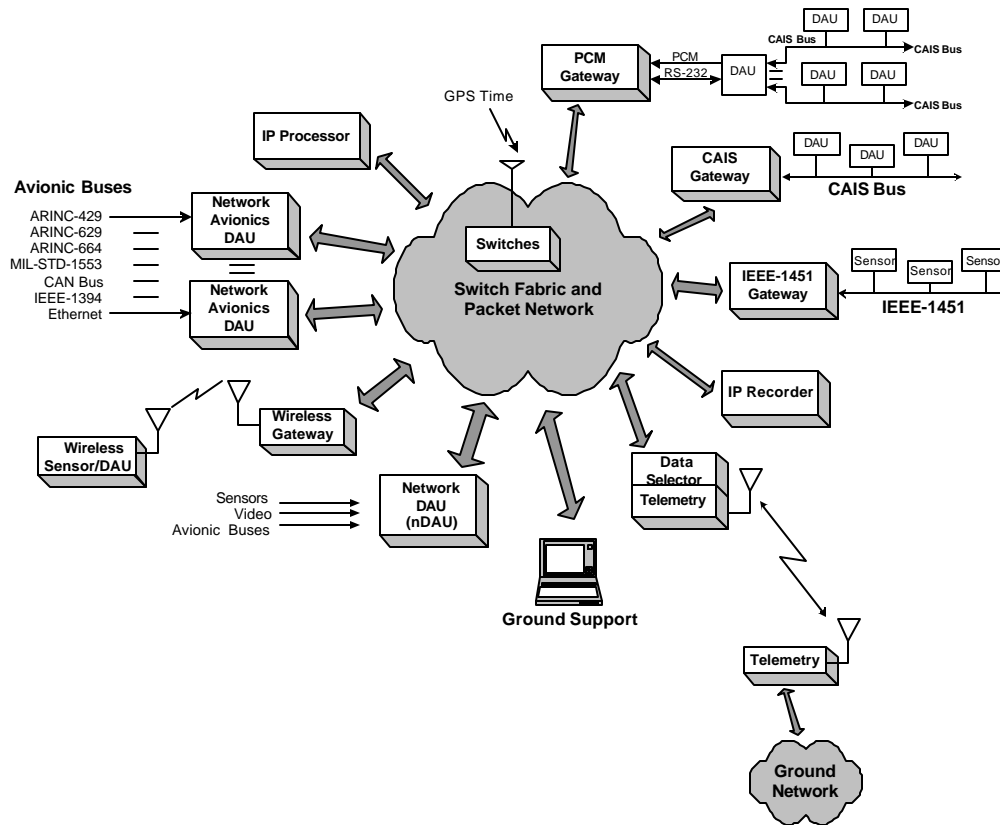


Figure 5 Network-Based Data Acquisition System

The system includes components that are well understood in flight instrumentation with new components that are either new due the network nature of the system, or adapted to the network system. These components may include:

- Network Switches (switch fabric)
- Network acquisition units
- Network gateways
- Data (IP) Recorder(s)
- Network Management Server
- Network Processor / Data Selector
- Network Telemetry Transceiver
- Connection for on-board data analysis system and on-board flight test clients
- Connection for ground support system

Role of the Network Switch

The switch is the core of the network. In addition to its primary function of forwarding packets, the switch can be used to support the growth of the network. If more nodes are required, switches (switch ports) can be added to accommodate their connection to the overall network. Since all the data in the network traverses at least one switch (or switch –like device), the switch must have low latency and provide non-blocking service. In other words, the switch fabric must be able to support the movement of the maximum data rate without congestion. Congestion in the switch can lead to high latency or dropped (lost) packets.

Another key function of a switch in a network-based data acquisition system is the ability to distribute time information. There are several well-known techniques used today to support time distribution within a data network (e.g., Network Time Protocol). One technique that has been gaining in acceptance is IEEE-1588 Precision Time Protocol (PTP). PTP is a protocol standard that can offer time coherency to within several hundred nanoseconds on a distributed network. To enable this level of accuracy, the switch must provide support for the protocol. Otherwise, latency introduced by the switch cannot be accounted for. PTP defines a grand master time source. The timing grand master is the timing reference within the network, not unlike a stratum clock in a terrestrial-based telecommunications network. The timing grand master can exist as a separate device attached to the network or as an integral part of the switch. For example, the switch could contain a GPS receiver from which it derives the grand master clock.

Network-Based Acquisition Units

Historically, IRIG-106 Chapter 4 was developed and published to provide a common standard of formatting PCM frames of parametric sensor data. In the early 90's Chapter 8 was added to format 100% of MIL-STD-1553 data. In 2004/5 Chapter 8 was modified to add 100% of ARINC-429 data. In 2003/4 IRIG 106 added Chapter 10 for standardizing the recording of PCM, MIL-STD-1553, Video, ARINC-429, IEEE-1394, and other data.

Integrating parametric data such as sensor data with avionics data within a single network fabric provides many challenges and advantages as compared with the current IRIG-106 standard. A basic comparison of PCM vs. Network was discussed in [4] called “Migrating from PCM to Network Data Acquisition System”. A network-based data acquisition system is considered a Data Source Interface (DSI) node. It collects data from sensors or avionic data buses, encapsulates the acquired data with time and source ID for transmission over the network fabric. The possible types of acquisition units are:

- Network Based Data Acquisition Units (nDAU)
 - For Sensor Data (Parametric data)
 - For Video (MPEG-2 and MPEG-4)
 - For Avionic buses (100% of data into the network fabric)
 - ARINC-429
 - ARINC-629
 - ARINC-664
 - MIL-STD-1553
 - CAN-Bus
 - Ethernet Bus
 - IEEE-1394
 - Other propriety Buses

Network-Based Data Acquisition Unit for Sensor Data

A network acquisition unit is an element that conditions and acquires multiple input sensor channels with similar or dissimilar data types, and combines them into data packets for transmission over the network fabric. The network port also provides the unit with the gateway for setup and configuration, SNMP status and control, and time synchronization using IEEE-1588 time. The unit acquires data from accelerometers, strain gages, various temperature sensors, pressure sensors, synchro/resolver sensors, LVDT, discrete signals, video, and an entire host of avionic buses. Acquired IEEE-1588 time is distributed within the acquisition unit for time tagging sensor data, and selected avionic bus data. Time can also be used to trigger time dependent events within the acquisition unit such as simultaneous sample, and across multiple acquisition units in the network. This unit is similar to a PCM data acquisition unit, with all the added capabilities of a network hookup. Since this unit is processor based, it can be used to provide engineering unit calculation on selected parameters, and possibly format the data on the network in various ways. The unit can host a web browser, is XML programmable, and can change channel parameters (such as gain, offset, etc.) from the network as described in [5].

Network-Based Data Acquisition Unit for Video Data

Although this function can be combined with the sensor acquisition unit, it provides greater flexibility when it is realized as a dedicated video node. Compressed video in a network fabric required very little processing to be monitored by on-board instrumentation engineers, or post processing from a flight recorder. Video time inversion, and packet time tagging are available from IEEE-1588 time. All video and audio parameters are XML programmable via the network fabric for data rate, resolution, data source (Composite, RGB, etc.), time insertion ON/OFF, location of time in the picture frame, and video format.

Network-Based Data Acquisition Unit for Avionic Data Buses

Network-based avionic bus acquisition units monitor and collect 100% of the avionic data, and format that data for transport over the network fabric. While some units may acquire data from a single bus, others collect data from multiple buses of the same type. Network time is based on IEEE-1588 and is used for time tagging data after the PHY layer in all cases. Each bus type includes rules for multicasting data packets. These rules are design to simplify the tasks for telemetry, on-board data analysis, and optional data processing. The acquisition unit for ARINC-

429 is capable of acquiring up to 32 buses per node, and the MIL-STD-1553 unit will be capable of acquiring up to 8 or 16 buses per node. ARINC-629, and ARINC-664 (Dual redundant Ethernet like bus) acquisition units have been designed for a single bus each.

Network Gateways

Network-based data acquisition is a new paradigm relative to traditional PCM-based systems. The majority of systems deployed today are PCM based. As such, bridging the gap between the network-based system and a legacy system is an important consideration. It allows customers to protect their investment in existing systems while leveraging the advantages of a network-based system. This desire drives the need for a network gateway. Below are four examples of relevant network gateways. Figure 5 shows how various gateways could be implemented in a data acquisition network.

CAIS-to-Network Gateway

Many airborne data acquisition systems used today employ the Common Airborne Instrumentation System Bus (CAIS Bus). Using the CAIS Bus, an entire data acquisition system can be programmed and queried. A CAIS-to-Network gateway provides the capability to acquire data, program, verify and initiate calibration commands to CAIS Bus devices, via the network. The gateway becomes a source node in the network. From a CAIS Bus point of view, devices on the bus operate normally, without any specific knowledge of devices on the network.

PCM-to-Network Gateway

Data acquisition systems that use serial PCM data are common in many flight test programs. The PCM-to-Network Gateway 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 for transmission on the network. In addition, the gateway provides a serial RS-232/422 pass-through mode that allows the downstream PCM system to be configured.

IEEE-1451-to-Network Gateway

Another sensor network that has emerged over the last 5 years is based on the IEEE-1451 standard. An IEEE-1451-to-Network Gateway would essentially act as an NCAP (Network Capable Applications Processor). NCAP is the term used in the standard to describe a device that interfaces the digital network to one or more “smart transducers”. The gateway would implement the necessary protocols and interfaces (i.e., 1451.1 and 1451.2) to enable data acquisition network traffic to interact with 1451 traffic. As with all data collection devices, time coherency of data samples is an important consideration. Time maintained in the gateway is based on the IEEE-1588 time distributed over the network. Time distribution over 1451, however, is to be studied.

Wireless Network Gateway

There are a number of wireless standards being considered for use on airborne programs. These include variants of IEEE-802.11, Bluetooth®, and ZigBee™ to name a few. The wireless gateway provides the interface from the wired network (i.e., IEEE-802.3) to the radio. With the gateway in place, one or more wireless sensors/data acquisition units can act as source nodes to the overall data acquisition network. As different wireless communications standards implement

different protocols, the distribution of time over them can present unique challenges. For example, IEEE-1588 may or may not be adequate for accurate time distribution over IEEE-802.11g. This is an area for further study. It is conceivable that a wireless link might bridge together two disparate Ethernet networks on the same test article. The treatment of time on both networks and the wireless link in between, in this scenario, warrants additional research.

Network-Based IP Recorder

As with most, if not all, data acquisition systems, the recorder is one of the primary data sinks. A network-based system is no different. The IP Recorder appears to the network as another node [6]. Unlike most nodes, the recorder may have more than one network connection to support increased throughput. For example, the recorder may have two or more gigabit connections. In addition, the recorder can also play the role of a source node, retrieving and sending data to other network nodes (e.g., telemetry transceiver, network management server, instrumentation engineer's terminal, etc.).

Time synchronization may or may not be a concern at the recorder, depending on the customer's requirements. Acquired data bound for the recorder is already time stamped. However, there may be a need to timestamp the data as it arrives at the recorder. In the network presented here, IEEE-1588 PTP would be supported on the recorder to facilitate local timestamping.

Network-Based Management Server

The management server acts as the central resource for configuring, controlling, and monitoring the acquisition network. Typically, a management server would provide a GUI into the workings of the acquisition network, providing the user with a friendly and efficient way to verify the operation of the system. Statistics being gathered at different nodes within the network would be collected by the server and formatted for presentation to the user. Any error conditions or out-of-bounds situations would be detected by the server and presented to the user. Changes made to the operation of any of the elements in the network would be managed by the server to ensure consistency of the network and the server would guarantee that the appropriate procedures were being followed and that the operator had the required privileges needed to make the changes.

Network-Based Data Processor

Data processor may be used for processing some of the acquired data for use by on-board flight test engineers, pilot, and/or for transmission. When used stand-alone, this function is considered both a data sink and a data source. The Data Processor function can be combined with a data selector, IP recorder, or can be parsed out to each data acquisition unit to perform some data processing.

Network-Based Data Selector

The Data Selector is considered a data sink node. It monitors data in the network fabric intended for a specific operation (e.g., telemetry). Its job can be simple if data sources are performing some of the data selection, and multicast that data using programmable addressing that the data

selector identifies as the targeted sink node for that data. The data selector can further sift through the data down to the parameter level for TM. In a very large network application, this function can be a stand-alone function or an integrated function of the RF telemetry transceiver. In very small applications, this function can be built into the acquisition unit. In some applications, it is possible to delegate this function to an IP recorder. In all cases this function is required in a network application when TM of selected data is used.

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