BRIDGING LEGACY AVIONICS DATA BUSSES TO ETHERNET BASED NETWORKS

Troy Troshynski

Avionics Interface Technologies

ABSTRACT

Ethernet is becoming more widely used as the network backbone in Integrated Modular Avionics (IMA) architectures. The advantages provided by Ethernet solutions include higher data throughput rates, ubiquitous use, lower costs, and high availability of components. Because of these advantages, new aircraft system designs and technology updates to existing system designs are considering Ethernet to replace legacy data bus technologies including MIL-STD-1553, ARINC-429, and CANbus based networks. Despite the advantages of Ethernet over these legacy technologies, latencies in standard IEEE 802.3 Ethernet networks is unpredictable. Defining when a data packet leaves a node and is received by another in absolute terms, and guaranteeing that the data will be received at its intended destination cannot be accurately predicted or guaranteed. Enhancements to IEEE 802.3 such as ARINC-664, and AS6802 enable determinism and guaranteed quality of service that the legacy data bus technologies provided.

This paper provides an overview of deterministic Ethernet technologies such as ARINC-664 and AS6802 (TTEthernet) that define deterministic, guaranteed quality of service networks. It also considers the advantages, disadvantages, and possible applications utilizing bridges between MIL-STD-1553 data busses and these Ethernet protocols and considers other related protocols such as IRIG 106 Chapter 10.

INTRODUCTION

Airborne systems are becoming increasingly complex. As a result, Integrated Modular Avionics (IMA) architectures are becoming standard in new system designs. IMA architectures help system designers more easily ensure reliability, maintainability, and certifiability. IMA architectures use real-time, distributed computing resources to host avionics applications of differing criticality levels. These architectures enhance overall system reliability by providing common, distributed computing resources which allow for portable software applications which may be re-hosted to available, healthy network nodes in the event of failures. Strict partitioning of system computing and communications resources is employed to allow a single integrated system to support application of differing criticality levels.

IEEE 802.3 Ethernet based protocols can provide ideal networking solutions for use as the communications backbone of IMA systems. These protocols support high speeds, up to 1 Gigabit per second, and are flexible enough to allow use of both electrical and optical signaling. Ethernet also allows for the use of a simple star network topology which simplifies aircraft design reducing overall system weight and complexity.

While Ethernet based protocols are becoming more and more common in new avionics system architectures, these new systems also will continue to use legacy data bus technologies such as ARINC-429 and MIL-STD-1553. As a result, system designers must consider issues related to bridging between Ethernet networks and these legacy data buses. Specifically, the differing levels of service provided by the various Ethernet based protocols must be evaluated against the overall system requirements.

IEEE 802.3 ETHERNET OVERVIEW

IEEE 802.3 Ethernet is the most widely used local area network (LAN) technology in the world. Initially the 10 Mbit/sec version was widely used. More recently, adaptations for 100 Mbit/sec and 1000 Mbit/sec have become dominant and widely used. 802.3 Ethernet is a physical and data link layer protocol. At the physical layer, multiple options are provided to allow use of a variety of physical signaling media.

100BASE-TX Ethernet, also known as Fast Ethernet, is currently the most widely used physical layer option. This physical layer uses a star topology with full duplex connections between each end system and switch. The duplex connections are implemented using differential voltage signaling over two conductor pairs and allow 100 Mbit/sec data rates in both directions simultaneously.

Prior to Fast Ethernet, 10BASE-TX was widely used. 10BASE-TX also uses a star topology and the same wiring scheme as 100BASE-TX to provide 10Mbit/sec throughput simultaneously in both directions. Most off the shelf end system interfaces and Ethernet switches provide support for both 10BASE-TX and 100BASE-TX and utilize an auto negotiation mechanism to automatically detect the determine the link speed that shall be used on all connections. 100BASE-TX uses multi-level transmit signaling and a 4b/5b encoding scheme. 10BASE-TX uses Manchester signaling.

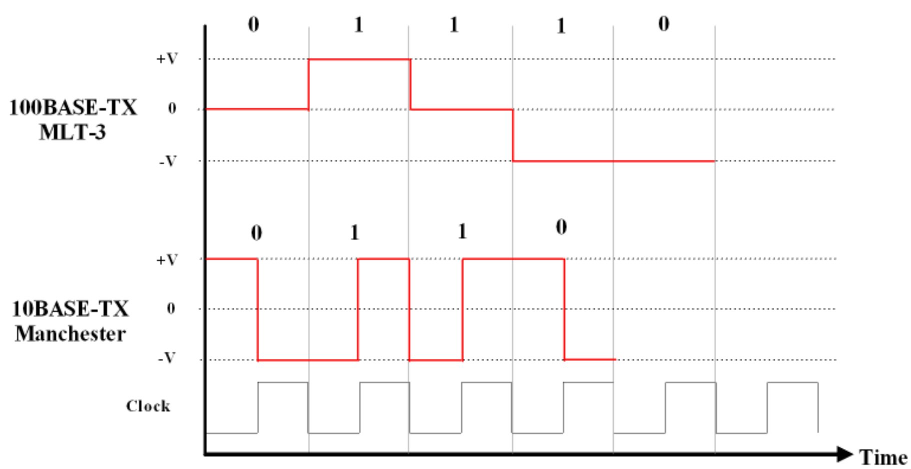

Figure 1: 10/100BASE-T Ethernet Signaling of Data 0x6

As data throughput needs continue to increase, Gigabit Ethernet is becoming more widely used. Typical Gigabit Ethernet applications utilize 1000BASE-T as the physical layer. 1000BASE-T uses the same standard cabling, CAT-5, typically used in the 10/100BASE-T networks. While 10/100BASE-T connections use two differential pairs, 1000BASE-T utilizes all four pairs available in a CAT-5 cable. 1000BASE-SX is the popular choice for Gigabit Ethernet applications utilizing optical signaling. 1000BASE-SX uses multi-mode optical fiber and can allow for signaling over 220 to 500 meters. 1000BASE-SX is ideal for use for long cable runs within large office buildings.

UPPER LAYER PROTOCOLS

Internet based protocols such as Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) are commonly used to provide upper layer network, transport and session services to applications. IP provides the network services which support the interconnection and communications across multiple Ethernet sub-networks. UDP provides connectionless communications services and TCP provides session or connection oriented services.

In standard 802.3 Ethernet type networks, the IP, UDP, and TCP protocols are most commonly implemented in host software. In deterministic Ethernet networks such as ARINC-664 and AS6803, the upper protocol layers are offloaded from the host and implemented in the network interface hardware modules.

LAN networks using 802.3 Ethernet and Internet protocols place high priority on ease-of-use, scalability, and plug-and-play operations. To achieve these qualities, Ethernet based local area networks (LANs) typically employ adaptive and dynamic configuration techniques which utilize relatively complex and intelligent management protocols. As a result, these networks are easy-to-use and require little or no configuration by users. A side effect is that these networks provide less predictable quality of service. In avionics networks, determinism, low latency, and fault tolerance are key design considerations. These were the key qualities considered when defining the ARINC-664 and AS6802 deterministic Ethernet protocols.

ARINC-664 OVERVIEW

ARINC-664 networks utilize IEEE 802.3 Ethernet as the physical and data link protocol layers. In standard Ethernet networks, Layer 2 switches are used to route frames based on the six byte Ethernet destination address. Standard 802.3 networks provide best effort services with no guaranteed latency or acknowledgment of successful data delivery. Because the network resource is shared with no segregation of data, it is possible that a faulty node could flood the network resulting in degraded services for all network users. Standard 802.3 also does not provide any inherent fault tolerance.

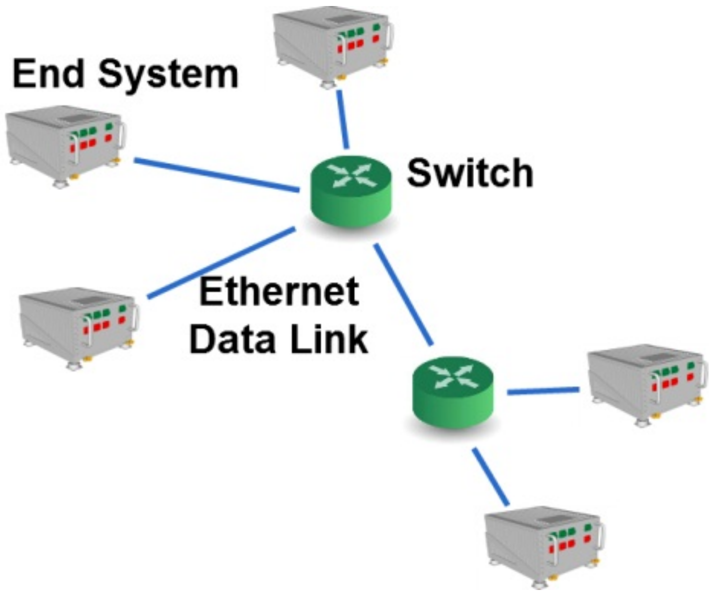

Figure 2: Star Network Topology

Because the networks utilize a star topology, it is possible that a single faulty network switch can disrupt all network communications. ARINC-664 provides enhanced network services by utilizing the concept of Virtual Links (VLs) to segregate communication paths and provide guaranteed level of service. Redundant network architectures are used to provide fault tolerance.

VIRTUAL LINKS

VLs are the core mechanism used in ARINC-664 networks to provide deterministic and guaranteed maximum latency. A VL is characterized as a logical data channel through the shared network. VLs provide simplex, or unidirectional, data paths from a single data source to one or more destinations.

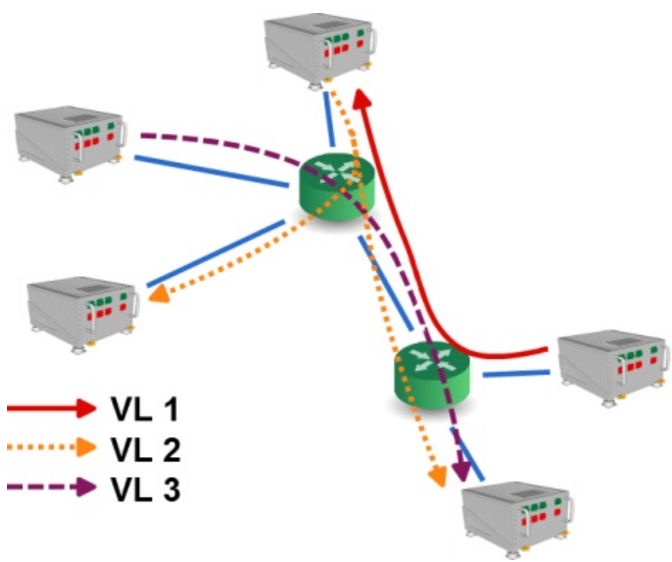

Figure 2: ARINC-664 Virtual Links

The lowest 16-bits of the Ethernet destination address are used to identify the VL to which a frame belongs [1]. The network switches use these 16-bits to route frames. Switches are statically configured, before the network become active, with VL tables that define the switch port a VL's frames is allowed to be received at. The static configuration also defines the port, or set of ports, through which a VL's frames must be sent.

Each VL in an ARINC-664 network is configured with a Bandwidth Allocation Gap (BAG). The BAG is specified in milliseconds, with a resolution of 500uS. A VL's BAG is used to constrain the bandwidth utilized by the VL by specifying the minimum allowed time gap between the transmissions of consecutive Ethernet frames for the VL. It is the responsibility of the source End System to regulate the output data flow so that the BAG is not violated for the VL. The network switches are responsible for policing the VLs by discarding a VL's frames when the BAG is violated.

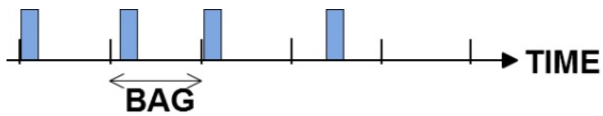

Figure 3: Virtual Link BAGs

In addition to a BAG, VLs are also configured with a maximum frame size which defines the largest frame that is allowed to be transmitted on the VL. Together with the VL's BAG, this configuration parameter can be used to calculate the maximum network bandwidth consumed by the VL. System designers can use these parameters to ensure that no data link in the network is over utilized. Because the network bandwidth used by a VL is constrained, the ARINC-664 network ensures that in fault situations the level of service provided to other VLs sharing the network resource is not adversely affected. The VL concept allows the segregation of data traffic flows through the common network resource.

REDUNDANCY

ARINC-664 networks utilize a redundant architecture. Each end system communicates with the network via redundant Ethernet interfaces. Duplicate switches are used to provide two independent networks. At the transmitting end system, all frames are transmitted simultaneously on both network interfaces. At the receiving end system a redundancy management function is employed at Layer 2 to identify and eliminate duplicate Ethernet frames before forwarding to the upper layer protocols. A "first valid frame wins" scheme is used. Duplicate frames are identified on a per VL basis using a VL sequence number which is inserted at the end of the frame. The transmitting end system is responsible for managing and inserting an incrementing sequence number for each output VL.

JITTER

Another key characteristic of an ARINC-664 VL is jitter. A VL's jitter is defined as the difference between the maximum and minimum latency from the data source to its destination. The cause of jitter in the ARINC-664 network is contention for the data links. The BAG for a VL does not define a communication schedule or time at which a VL may be used to transmit an Ethernet frame. Instead, a VL defines a constraint. That is, a minimum amount of time that the source must wait after transmitting the previous frame for the VL. This means that it is possible that more than one VL on a data link can have frames eligible for transmission at the same time. So, an eligible frame may have to wait for access to the shared Ethernet data link. In the worst case, an eligible frame could have to wait for frames from all other VLs sharing the data link. In the ideal case, a VL's frame has no data link contention and is transmitted immediately. Because jitter is caused by data link contention, the more VLs that share a data link, the higher the jitter. In ARINC-664 networks actual jitter values can approach 500uS.

AS6802 OVERVIEW

One of the key drawbacks of an ARINC-664 network is the fact that as network utilization increases the overall jitter experienced on VLs also increases. In some cases, the jitter may increase to a level that is not tolerable by the hosted avionics applications. An AS6802 network can be used as a solution to this problem. In AS6802 networks, jitter values of less than 1uS can be achieved even in cases of high network utilization.

The AS6802 protocol can be viewed as a superset of the ARINC-664 protocol. AS6802 supports all of the features and functions of an ARINC-664 network but adds an additional level of service in order to provide very low latency jitter. While ARINC-664 can be described as asynchronous, AS6802 can be described as adding a support for synchronous communications via the use of time triggered virtual links. In addition to adding synchronous communications services, AS6802 also adds the ability to use the same network to host standard Ethernet data traffic.

TRAFFIC CLASSES

AS6802 defines two classes of network traffic. Critical Traffic (CT) is the high priority traffic class that provides deterministic latency and jitter. Best Effort (BE) traffic is the low priority traffic class that is essentially standard Ethernet traffic which does not provide guaranteed levels of service. In the AS6802 network, CT frames are identified by a constant value, the CT marker, in the upper 4 bytes of the Ethernet destination address [2]. All CT frames are transmitted through the network via VLs. Just like ARINC-664, the VL of a frame in an AS6802 network is identified in the lower 2 bytes of the Ethernet destination address. BE frames are identified as any frames not containing the CT marker in the upper 4 bytes of the Ethernet destination address. At all transmitters in an AS6802 network, CT frames are always given priority over BE frames in instances of link contention.

Within the CT traffic class, two types of VLs are utilized. Rate Constrained (RC) VLs are ARINC-664 compliant VLs and are defined by a maximum frame size and a BAG. The RC VLs are asynchronous. A frame can be sent at any time as long as the BAG is not violated. Time Triggered (TT) VLs provide synchronous communications. For each data link traversed by a TT VL, a pre-configured communication schedule is used. This static schedule is a configuration item loaded into the network switches and end systems. The transmitter of the TT VL's frames knows the times when data can be transmitted on the VL and the VL receiver(s) also know the precise time to expect frames on the VL. As a result of the pre-configured schedule, for TT VLs data link contention is eliminated reducing the theoretical jitter to zero. TT VLs are given priority over RC VLs to ensure that the RC traffic does not contend with the TT traffic.

TIME TRIGGERED COMMUNICATIONS

Time triggered communications require that all transmitters and receivers utilize a common and precise communication schedule. As a result, all network nodes participating in the time triggered communications must have a common notion of time. A global clock for the network must exist. To realize a global notion of time, all of the local clocks of the networks end systems and switches must be synchronized. AS6802 specifies a clock synchronization service that is implemented using a special protocol which exchanges synchronization messages over the same Ethernet network hosting the BE and CT traffic. The clock synchronization protocol is designed to tolerate faults conditions so that a single malfunctioning network node cannot disrupt the overall clock synchronization of the network.

BRIDGING ARINC-429 AND ETHERNET

In existing aircraft implementations of ARINC-664 Part 7 networks, data concentrator network nodes are used to multiplex ARINC-429 data into the ARINC-664 network and vice versa. The data concentrators employ a data encoding scheme defined in the ARINC-664 specification. In this case a formal specification for how to encode ARINC-429 labels into the UDP payload of ARINC-664 network packets is defined. ARINC-664 networks provide ideal interconnection between legacy ARINC-429 data producers and consumers due to the guaranteed maximum latency and jitter provided by the ARINC-664 VLs.

In cases where there are requirements for very low jitter and AS6802 type network could be used by taking advantage of the encoding scheme defined in ARINC-664 Part 7. Just like the VLs of an ARINC-664 network, the TT VLs of an AS6802 network can carry UDP datagrams. So, the ARINC-429 data labels can be packed into the UDP datagrams of an AS6802 network just the same as for ARINC-664. In cases where no guaranteed level of service is required, a standard IEEE 802.3 Ethernet network could also be used to transfer UDP datagrams packed with ARINC-429 labels formatted in accordance with ARINC-664.

BRIDGING CAN BUS AND ETHERNET

While there is no open standard defining the bridging of CAN Bus data and Ethernet, specific aircraft programs, such as the Dreamliner, have defined program specific requirements for multiplexing CAN bus data into the UDP payload of ARINC-664 messages. As with ARINC-429, due to guaranteed services levels ARINC-664 and AS6802 type Ethernet networks provide ideal services for interconnection of CAN bus nodes. And also because the CAN bus data can be multiplexed into the UDP datagram payload standard IEEE 802.3 can also be used for applications with no latency or guaranteed service requirements.

STREAMING MIL-STD-1553 OVER ETHERNET

IRIG Standard 106 is a telemetry standard developed to ensure interoperability in telemetry applications. Chapter 10 of the standard defines an Ethernet streaming interface for flight test data recorders. This streaming interface is specifies the use of standard IEEE 802.3 Ethernet and the IP and UDP protocols to carry MIL-STD-1553 and ARINC-429 data captured by data recorders. Specific instructions are defined for encoding the MIL-STD-1553 and ARINC-429 bus data (with time stamps) into UDP datagrams.

Because IEEE 802.3 Ethernet together with IP and UDP only provide best effort transport services, the IRIG 106 streaming interface cannot be formally proven to provide guaranteed and timely delivery of data. If guaranteed timely delivery is required at the Ethernet nodes consuming the streamed MIL-STD-1553 and ARINC-429 data, either an ARINC-664 or AS6802 type Ethernet network must be used. Because both ARINC-664 and AS6802 networks are capable of transporting UDP datagrams, the payload formats defined in IRIG 106 Chapter 10 can be utilized to stream ARINC-429 and MIL-STD-1553 data over these deterministic Ethernet networks.

CONCLUSIONS

Ethernet based networks will continue to become more common on new aircraft platforms. Also, for the foreseeable future, legacy data bus technologies like ARINC-429 and MIL-STD-1553 will retain a presence on these same aircraft platforms. As a result, standardized methods of bridging data between standard IEEE 802.3, ARINC-664, and AS6802 will need to be more formally defined and analyzed in order to ensure interoperability. In systems where deterministic and reliable levels of service are required, it will be necessary to employ avionics focused Ethernet protocols such as ARINC-664 and AS6802.

REFERENCES

1. 664P7-1 Aircraft Data Network, Part 7, Avionics Full-Duplex Switched Ethernet Network, 09-2009
2. Time-Triggered Ethernet, SAE AS6802
3. IRIG Standard 106011 (Part 1) Chapter 10, June 2011

CONTACT INFORMATION

Troy Troshynski
Avionics Interface Technologies
Email: troyt@aviftech.com
Tel: +1 402-796-9644 ext. 25
3703 North 200th Street
Omaha, NE 68022