Ethernet for Aerospace Applications

Ethernet Heads for the Skies

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Abstract

One of the goals of aerospace applications is to reduce the cost and complexity of avionic systems. Ethernet is a highly scalable, flexible, and popular protocol. The aerospace market is large, with a forecasted production of over 50,000 turbine-powered aircraft valued at $1.7 trillion between 2012 and 2022[1]. Boeing estimates demand for commercial aircraft by 2033 to total over 36,000 with a value of over $5 trillion [2]. In 2014 US airlines served over 750 million passengers and this is growing over 2% yearly[3]. Electronic fly-by-wire is now used for all airliners and high performance aircraft. Although Ethernet has been widely used for four decades, its use in aerospace applications is just beginning to become common. Ethernet is the universal solution in commercial networks because of its high bandwidths, lower cost, openness, reliability, maintainability, flexibility, and interoperability. However, when Ethernet was designed applications with time-critical, safety relevant and deterministic requirements were not given much consideration. Many aerospace applications use a variety of communication architectures that add cost and complexity. Some of them are SpaceWire, MIL-STD-1553, Avionics Full Duplex Switched Ethernet (AFDX), and Time-Triggered Ethernet (TTE). Aerospace network designers desire to decrease the number of networks to reduce cost and effort while improving scalability, flexibility, openness, maintainability, and reliability. AFDX and TTE are being considered more for critical aerospace systems because they provide redundancy, failover protection, guaranteed timing, and frame priority and are based on Ethernet IEEE 802.3. This paper explores the use of AFDX and TTE for aerospace applications

1. Introduction

Avionic communication has been important ever since electronic systems and controls were first used on aircraft. Aerospace avionics growth began prior to WWII with the use of independent analog systems using dedicated wired sensors, processors, and visual/audio displays. The next generation of avionics occurred in the 1960/70s when computers began to be used, but most control was done by separate control units with non-critical systems separated from critical systems that could also be time-critical. Integrated Modular Avionics (IMA) started in the 1990s with rack mounted replaceable processors and this continued with shared computing, communications, and shared I/O networks.[4] The fly-by-wire aircraft today use IMA with reliable networks with time and space partitioned software handling many functions, reducing the number of computers and control buses. [5]

Commercial Off the Shelf (COTS) systems and open systems hold potential to reduce design and operational costs. Using open standards based systems with COTS non-proprietary interfaces results in the most cost savings. Open systems are easier to design, have more price competing suppliers, and more available technical support, resulting in reduced design and maintenance costs.

2. Aerospace Network Goals

An aerospace network has more demanding goals than a commercial/industrial network. Safety in aerospace is paramount so high levels of redundancy, security, environmental resiliency, and error/failure isolation is critical. Open standards should be used to facilitate interoperability with other manufacturers systems and components. A network needs to be easily maintainable with comprehensive trouble shooting and management performance/error reporting because access may be difficult. Because of safety concerns proven performance and the use of certified standards are critical for acceptance. Future bandwidth and performance requirements will continue to increase so the ability to scale is a key requirement. The network should be capable of supporting real-time and deterministic application requirements such as fly-by-wire.

3. Overview of Common Aerospace Networks

Some of the main aerospace networks are SpaceWire, MIL-STD-1553, AFDX, and TTE. SpaceWire is based on IEEE 1355 that provides simple, low cost switched network with point-to-point links. The links are connected using low-latency, full-duplex point-to-point serial links and packet switching[6]. SpaceWire provides low cost, low error, deterministic, communications using reliable electronics. It is an asynchronous communication operating at 2-400 Mbps. SpaceWire is used by the European Space Agency and NASA[7]. MIL-STD-1553 is a military standard that is a multiplex data bus using a bus controller to control multiple remote systems. It provides multiple data paths that are fault tolerant, provides high availability, and is deterministic. It operates at 1 Mbit/s and is a proven military bus used on many U.S. Air Force aircraft. It is being replaced by IEEE 1394[8].

4. Avionics Full Duplex Switched Ethernet (AFDX)

AFDX is based on Ethernet IEEE 802.3 specific implementation of ARINC 664 (Deterministic Ethernet avionic data bus)[9]. AFDX was first designed by Airbus for their aircraft. It uses cascaded star topology to reduce wire runs and weight and provides dual-link redundancy and QoS. AFDX uses parts of the MIL-STD-1553 terminology and network layout. Systems communicating data over AFDX are named subsystems and are attached to the AFDX network by end systems. The network itself is named AFDX Interconnect including the passive physical sections of the network but does not include the switches or other devices[10].

Switches used for AFDX are specially designed for the protocol to achieve the critical timing requirements of avionic applications. Standard Ethernet switches cannot work with the AFDX protocol.

Being designed for safety critical aerospace control systems such as fly-by-wire, all AFDX end systems have full redundancy. Every subsystem has two end systems and every frame transmitted is duplicated by sending the frame on both end systems. If there are no transmission errors a duplicate frame will arrive and is removed. This is done by appending to each layer 3 frame a single byte sequence counter turning the Ethernet frame into an AFDX frame. The first frame with a valid checksum to arrive is read and frames with duplicate sequence numbers are removed. This achieves fast failover within the same network without relying on independent network redundancy[11]. (Figure 1)

AFDX Topology

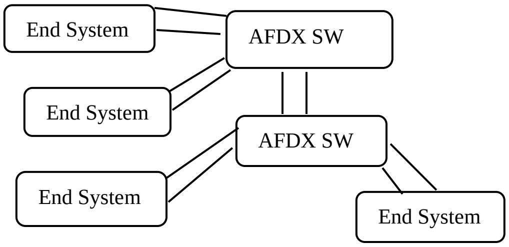

Figure 1

The AFDX protocol uses a Virtual Link Identifier to provide a timing specification that has the maximum guaranteed frame size and maximum rate the frame can be by the end system. End systems use full-duplex links to connect to switches directly. Because only two stations exist in each Layer 2, segment collisions should not happen. Store and forward switching is used for relaying packets and not cut through switching to provide integrity[12].

AFDX generally operates at 100 Mbps but can support line speeds to 1,000 Mbps and extends Ethernet to provide deterministic timing. Because AFDX follows the OSI layer model, uses a compatible stack architecture, Internet Protocol Suite, and Ethernet, it simplifies design and facilitates the use of COTS hardware. It is currently used on many aircraft including the Airbus A380 and Boeing B787 Dreamliner[13].

5. Time-Triggered Ethernet

TTE was initially developed by the Real-Time System Group at Vienna University in 2000[14]. Other commercial firms have continued to improve the protocol and equipment. TTE combines standard Ethernet IEEE 802.3 best effort network traffic with real-time fault tolerant time-triggered traffic on the same network structure. It adds the model of time triggered frames which uses global time synchronization service to transmit frames at exact times[15]. (Figure 2)

Quality of Service is provided with three message types, all running over a single Ethernet. The first is Time-triggered messages that takes priority over other message types and are sent at predefined times providing set delivery for critical applications such as aerospace fly-by-wire. The second is Rate-constrained that has bandwidth guarantees, but is not system synchronized which may increase jitter, but could be acceptable for less critical applications such as video. Last is Best-effort that uses remaining bandwidth without transmission delay, or reception time guarantees for Ethernet traffic with limited quality of service requirements such as non-critical video monitoring. Best-effort equals standard Ethernet providing no latency guarantees or even frame delivery. If a Rate-controlled frame or Best-effort frame is about to be sent by a switch prior to a Time-triggered frame it would be held until the Time-triggered frame is sent resulting in low jitter[16]. (Figure 3)

TTE is open published as SAE AS6802 and IEEE standardization is progressing. All physical switched Ethernet layers are supported, even those with different bandwidths (10/100/1000 Mbps) and it integrates with all standard Ethernet network components. TTE provides redundancy management, fault tolerance, isolation, and a distributed clock with security[17].

Time Triggered Ethernet

Ethernet

+

Controlled Rates

+

Time-Trigger

+

Time Sync

+

Traffic Class

= Safe Communications

Figure 2

TTE communications operates in layer 2 of the seven OSI layers. The TTE services set and maintain global time using clock synchronization with the local device clocks. As a transparent synchronized protocol it can run with all other traffic types on the same physical communications network.

Quality of Service

Time Triggered TT
Rate Constrained RC
Best effort BE

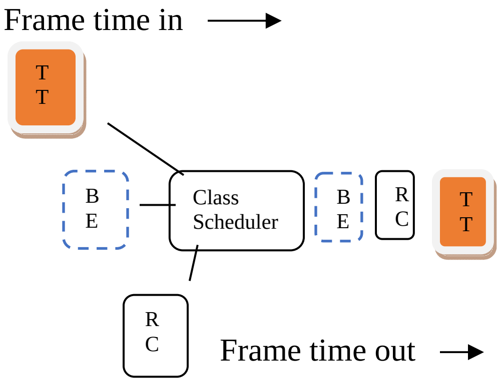

Figure 3

TTE is proven in many aerospace applications. It is used on the Airbus 380 for the airframe pressure control system and for the engine control system for the GE F110 engine for the Lockheed Martin F16 fighter jet. TTE is used for the new Boeing 787 Dreamliner for power management and pressure control systems. The Orion Multi-Purpose Crew Vehicle (MPCV) uses a high-speed backbone network based on TTE provided by Honeywell[18,19].

5. Conclusion

Both AFDX and TTE should be considered for additional aerospace, industrial, transportation, and commercial applications because they provide many advantages such as reduced latency, redundancy, and for TTE time synchronization and time-triggered transfer. TTE provides real-time deterministic communication and TCP/IP Ethernet on the same network in parallel, simplifying design and reducing costs. It can handle low priority communication applications up to the most demanding critical fly-by-wire aerospace control systems. It is open and fully compatible with Ethernet IEEE 802.3 and integrates with commercial Ethernet network components. TTE can easily scale from 10, 100, 1,000 Bbps and higher and can use copper, fiber, and other common Ethernet interfaces. Its successful track record in aerospace applications is growing. If fast, safe, deterministic, real-time communication is wanted in an Ethernet network TTE should be considered first.

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[1] Teal Group, World Aircraft Market Outlook, 3/2013

[2] Boeing Current Market Forecast 2014-2033

[3] FAA Aircraft Forecast 2014-2034

[4] Joint Advanced Strike Technology Program. 8/1994

[5] Ibid

[6] ARINC Spec 664, Part 7

[7] ECSS-E-ST-50-12C/11C, Space Wire

[8] MIL-STD-1553B, SAE AS 15531

[9] ARINC 664 Part 7 (AFDX)

[10] IEEE 802.1 “IEEE Standard for Information Technology-Specific Requirements CSMA/CD” & IEEE 802.1 “Bridging and Management”, Collection of standards from IEEE Get Program.

[11] Ibid

[12] Ibid

[13] Architecting of AFDX, International Journal of Electronics & Communication Technology Vol. 4, 6/13

[14] “The Time Triggered Ethernet Design” 8th IEEE International Symposium on Object-oriented Real-time distributed Computing, 5/2005

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