The Future of Ethernet in Modern Avionics

Ethernet Meets Next-Generation Avionics

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The proliferation in consumer applications has yielded a highly connected global population which has naturally led to an increased demand for commercial aircraft with a forecast of turbine-powered aircraft worth $1.999 trillion between 2016 and 2025, and the new aircraft market currently at $180 to $210 billion annually [2]. Aircraft have evolved from their initial point-to-point wiring, with analog servo-mechanical hardware, to complex subsystems integrated through virtual links. Networking protocols have also experienced leaps in advances, with commercial airliners readily adopting AFDX (ARINC 664 Part 7) over the previous AIRINC429 standard and the military also implementing Ethernet--with standards such as MIL-DTL-32546, as opposed to the prolific 1553B architecture.

Ethernet as a form of interconnectivity offers several advantages over previous generations of architectures: high speeds to serve high throughput applications, commercially available en masse versus expensive custom solutions, full duplex communication supporting both transmission and reception over the same line at the same time, and less wiring due to virtual links and therefore less weight. From coaxial cabling to twisted pairs and fiber optic runs, the Ethernet physical layer has solutions for practically any installation.

The heavy commercial and industrial utilization of Ethernet has led to major advances since its inception in the 1970s to its standardization with IEEE.802.3 in 1983. Fast Ethernet (IEEE.802.3u) released in 1995, refined the previous generations of standard Ethernet to support bit rates of 100 Mbps, this standard is also known as 100BASE-T and is by far the most commonly leveraged Ethernet technology, commercially. This is a far cry from the ARINC429 100 kbps over shielded twisted pair or the 1553B 1 Mbps speed over a twinaxial bus. The Airbus A380/A350/A400, Boeing B787 Dreamliner, COMAC C919 & ARJ21, and Sukhoi Superjet 100 all use Ethernet data communications. In addition, AFDX and ARINC 664P7 are being used as the backbone for all systems, including flight controls, cockpit avionics, air conditioning, power utilities, fuel systems, and landing gear [3]. Next generation military aircraft are incorporating gigabit Ethernet (IEEE 802.3-2008) technologies with new military standards (MIL-DTL-32546) to ensure all cabling is aircraft rated according to standardized performance. As cockpit and cabin avionics are driving higher bandwidths the system must be able to handle a high network load with large amounts of data.

Caption: The Boeing B787 Dreamliner operates with the AFDX data networking protocols.
Source: http://www.boeing.com/commercial/787/#/gallery

The Changing Landscape of Avionics Architectures

Avionics have also shifted from a distributed system with massive amounts of interconnections for redundancy, to a more centralized system known as integrated modular avionics (IMA). The centralized computing platforms call for an increase in the sophistication of software implemented where nearly 80% of the development budget for new commercial avionics going to software development [4].

Much of the R&D goes into the modularity of software for avionics to ensure that the application software is independent of the hardware, as centralized IMA architectures may require software to be hosted on different platforms. This open-source design approach has taken the place of the previous proprietary designs. The adoption of open standards in software design now offers a competitive advantage due to the more affordable switch to commercial off-the-shelf (COTS) equipment for aircraft. Manufacturers must then keep compatibility with the array of equipment purchased from different vendors. For these reasons, Ethernet has made a strong case for its implementation in avionics applications.

The constantly evolving Ethernet protocols have offered advantages in avionic applications particularly with advances such as virtual local area networks (VLANs), quality of service (QoS), and traffic shaping algorithms such as token bucket. With four different standards committees (IEEE, ITU-T, Metro Ethernet Forum, and the Internet Engineering Task Force) constantly updating Ethernet protocols, there is a metaphorical platter of data networking concepts to choose from.

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Advances in Networking Protocols

The telecom standard for Ethernet protocol is not a perfect fit for avionics applications, as it is not error-resistance and is non-deterministic, where determinism is essentially predictability in the transmission and reception of signals. Even when using modern switches that employ intelligent source address tables or even routers coupled with priority queues, trunking and redundant connections there is no guarantee a data packet will be received at a certain time or interval. In avionics applications, the stakes increase yet again with lives at risk when critical data cannot be transmitted and there is no time for troubleshooting. The need for determinism had already arisen in industrial Ethernet applications, methods have been developed that effectively eliminate this as an issue.

Determinism in Industrial and Commercial Applications

Similar to the evolution in avionics architectures, the economies of scale that Ethernet offered with a standardized infrastructure allowed for industrial manufacturers to lower costs while increasing the number of equipment vendors to choose from. Intelligent Electronic Devices (IEDs), or microprocessor-based controllers in power systems, in supervisory control and data acquisition (SCADA) and smart grid applications shifted from having serial ports to Ethernet ports. This subsequently lessened the amount of wiring necessary while increasing the complexity of software implementation. The modularity of Ethernet with innovations such as VLAN allowed for critical IEDs to be managed, analyzed, or controlled from single, or multiple, locations [6]. Newer generation IEDs now come equipped with Ethernet switches built-in to reduce the number of network connections and hardware in the network.

In avionics applications, architectures previously leveraged single-purpose Line Replaceable Units (LRUs) have been replaced with modular 'cabinets' or high power computing modules where each cabinet provide the functionality of several LRUs. Oftentimes, LRUs come equipped with serial ports for data transmission between equipment, as aircraft carried more complex subsystems such as full digital auto-flight systems, fly-by-wire flight controls, FMS, and highly automated systems management software, Ethernet compatibility has become a more feasible option to lessen the amount of interconnected wiring while limiting the expense of custom software solutions.

There are several innovations in industries outside of avionics that have led to a more deterministic Ethernet. Industrial facilities with automated equipment controlled through Ethernet need precise and consistent control of motor starters, actuators, and monitoring instruments with little room for error. Protocols such as Precision Time Protocol (PTP), Network Time Protocol (NTP), GPS, and Time Triggered Protocol (TTP) have been developed to synchronize clocks throughout a computer network in order to achieve clock accuracy in the sub-microsecond range for motion control. This serves the avionics applications that require accuracy in flight-critical transmissions between aircraft equipment with low latency and jitter.

Caption: Time synchronization protocols achieve sub-microsecond accuracies that are ideal for time-sensitive data in avionics applications.
Source: http://www.siweia.com/index.php?r=article/Info/index&content_id=141

Quality of Service (QoS) is an aspect of Ethernet switches that controls the flow of traffic through complex prioritization processes to map traffic classes, also known as Class of Service (CoS). For instance, when an Ethernet switch is overloaded with traffic, faster than it can process, it can send messages to its immediate neighbors to slow down. With network traffic prioritization, critical data can jump ahead of normal network traffic. Audio/Video (AV) applications operate with high QoS requirements, for example, keeping multiple digital speakers properly in phase within a professional environment (or even in a modern vehicle) requires synchronization within 1 microsecond [5]. Audio/Video Bridging (AVB) and Time Sensitive Networking (TSN) is the future of reliable, time bound, and prioritized traffic delivery over Ethernet and wireless [6]. QoS, CoS, and traffic shaping algorithms that enable time synchronization can offer a great advantage in avionics applications and have been implemented in the AFDX protocols along with two redundant Ethernet networks for determinism.

Caption: Ethernet advances such as AVB and TSN offer solutions for advanced driver assistance systems (ADAS) in automotive applications but have also added value in the avionics domain for its deterministic characteristics.
Source: https://www.ixiacom.com/solutions/iot/automotive-ethernet-testing

Gigabit Ethernet

Accomplished over optical fiber, twisted pairs, or shielded balanced copper cables, gigabit Ethernet builds upon the conventional Ethernet protocols and supports backward compatibility and increases the speed of fast Ethernet at least tenfold at 1 Gbps. With 40 Gbps Ethernet already introduced in commercial telecommunications and talk of 100 Gbps protocols, civil transport and military aircraft upgrades are soon to follow. Aircraft have already adopted fast Ethernet and are starting to incorporate 1 Gbps Ethernet technology. In 2013, the F-16 jet fighter upgrade program for the U.S. Air Force and other nations already include rugged gigabit COTS Ethernet switches [10]. The Naval Air Systems Command (NAVAIR) in collaboration with the Society for Automotive and Aerospace Engineers (SAE) released MIL-DTL- 32546 and SAE AS6070 in 2015, this is the standardization of high-speed data cables for aircraft. Commercial RJ45 connectors, Cat5 to Cat7 twisted pair cable material and shielding are generally not rated for the aircraft operating environment and installation guidance is not available for aircraft installation [11]. This military standard ensures a qualification for aerospace parts while still having the advantage of operating with Ethernet protocols.

Wireless Sensor Networks

Essentially, the goal for any aircraft is to be able to send and receive information reliably and seamlessly. From this perspective, the medium with which these packets of information are sent is of little consequence so long as there is a level of determinism to it. Ideally, aircraft would not need the level of wiring employed currently due to the added complexities, cost, and weight. However, there is currently no effective method in implementing wireless inter- and intra-communications between all subsystems. The emerging wireless sensor network (WSN) technology in commercial applications such as smart thermostat systems, smart bulbs, smart locks, and smart washer/dryer units could be transposed onto aircraft and fleet operations. The proposal for having an Avionics Wireless Network (AWN), currently being developed by multiple aerospace working groups, promises reduction in the complexity of electrical wiring harness design and fabrication, reduction in wiring weight, increased configurability, and potential monitoring of otherwise inaccessible moving or rotating aircraft parts [8]. In November 2015 at the World Radiocommunication Conference, the International Telecommunication Union (ITU) granted the 4.2 to 4.4 GHz frequency band for wireless avionics intra-communications (WAIC) systems. Similar to the internet of things (IoT) concept in commercial applications, WAIC systems consist of short-range communications and are a potential candidate for passenger entertainment systems, smoke detectors, engine health monitors, tire pressure monitoring systems (TPMS), and other kinds of aircraft maintenance systems.

While there are still many obstacles in terms of network security, traffic control, and technical challenges, future WAIC can enable real-time seamless communications between aircrafts and between ground teams and aircrafts as opposed to the discrete points of data leveraged today in aircraft communications. Ethernet is an enabling technology for WSNs and will allow for smoother transition over legacy custom proprietary protocols. A migration toward WSNs will require manufacturers to continue to mandate compatibility with COTS-based networks when specifying new sensors, machines or systems [9].

Caption: While there are still significant challenges towards the spread of WAIC systems, Ethernet protocols provide a platform to more readily upgrade.
Source: http://airspace.airbus.com/explore/#

In order to compete in the modern market, more and more aircraft manufacturers are seeing Ethernet as the default interconnect. The implementation of Ethernet in avionics systems offer a slew of advantages to manufacturing capabilities while lowering costs and staying competitive in an ever-growing market of new aircraft. Modular software solutions could significantly cut the cost of development and new aircraft time-to-market, this is a welcome change over the aircraft industry's notorious delays over supply chain issues. With passenger traffic predicted to grow by 4.8 percent over the next two decades and the doubling of global commercial aircraft fleets in that time, the rise in the demand of aircraft may force supply chain to modernize [12].

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