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Ethernet in Avionics Networks

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Author:
Larry Hannett, LCH Engineering

ethernet alliance | p.o. box 200757 | austin, tx | 78720-0757 | usa
www.ethernetalliance.org

Introduction

When Full-Duplex Switched Ethernet (FDSE) eliminated “collisions” normally associated with shared-media, Ethernet became viable for Avionics networks. However, by itself, FDSE still lacks certain characteristics required for use in the more “demanding” Avionics networks. The subject of this white paper is the development of FDSE for use in Avionics networks, and the desirability of simple-to-analyze and deterministic network behavior in knowing where each packet is going and how long it takes to get to its final destination.

Discussed in support of this behavior are:

- “profiled” network protocols and services;
- static network configuration;
- flow-control; and
- redundancy.

At this time, it is worth noting , Avionics networks are more the exception than the rule, when considering networks on-board the entire aircraft.

Terrestrial IP-Network-COTS

Terrestrial IP-network-COTS (Commercial Off The Shelf) technologies are used in the development of the majority of IP networks on-board the aircraft. In comparison with the life of the aircraft, In-Flight Entertainment (IFE) systems have a relatively short life-cycle and enjoy the opportunity to use state-of-the-art COTS network technologies.

The following reference-architecture figure was developed by the ARINC AEEC Aircraft Data Networks (ADN) subcommittee and has found good acceptance in the aeronautical community. It was specifically developed to facilitate the discussion on the various types of IP networks on board today’s aircraft, and to distinguish those networks that are responsible for the continued safe flight of the aircraft found in the Aircraft Control Domain.

It is important to realize that the networks within each of these domains are developed separately and may not be connected to each other. In addition, this white paper does not address the networks that exist in the Airline Information Services (AIS) or Passenger Information and Entertainment Services (PIES) domains, nor does it address the security considerations of any interconnection. (However a discussion can be found in ARINC AEEC PP664 Part 5.) This white paper does discuss a deterministic FDSE network that might be found in the Aircraft Control Domain (ACD).

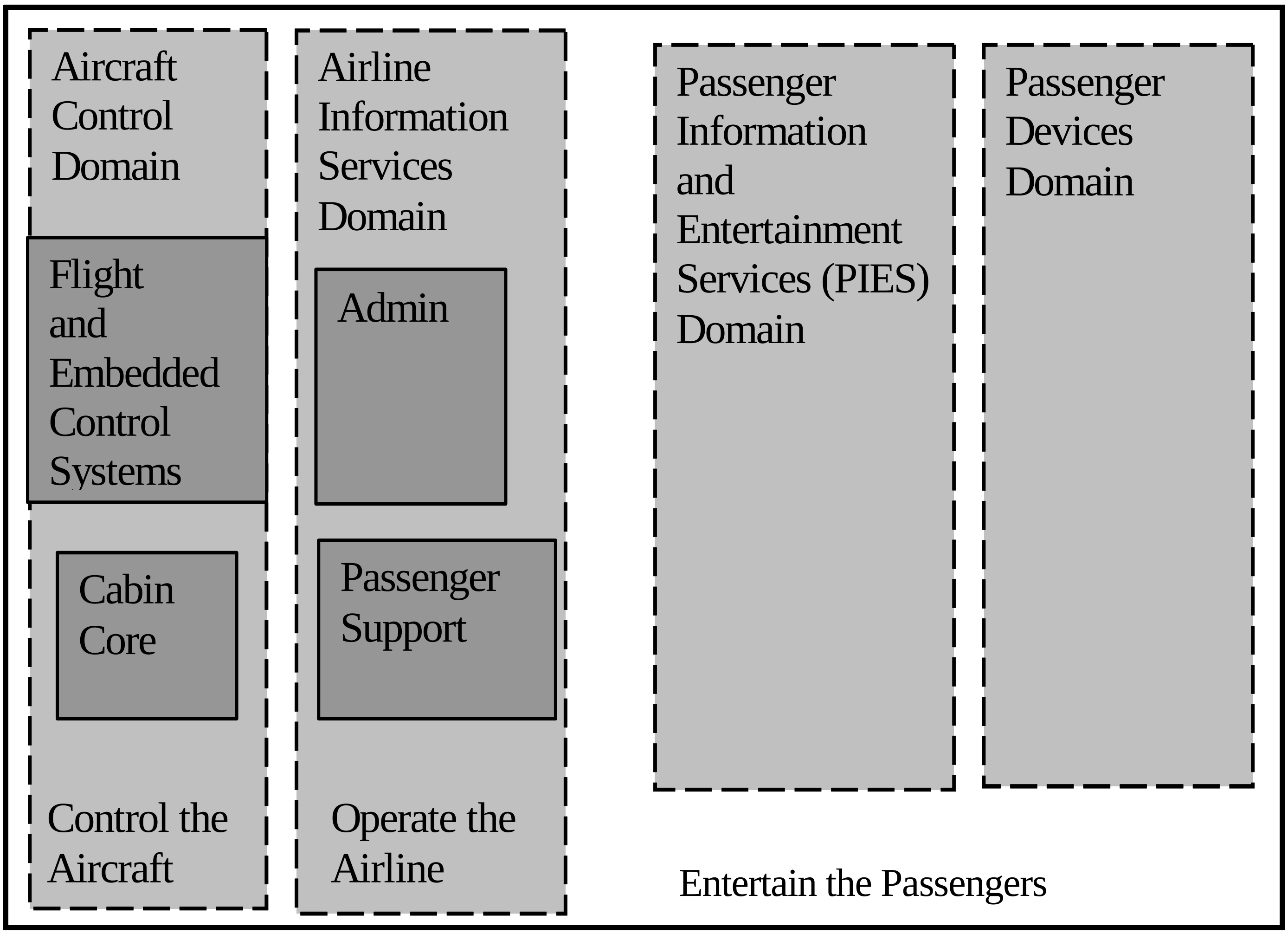

Figure 1. Aircraft Domain Reference Model

Aircraft Control Domain

The Aircraft Control Domain (ACD) is dominantly-characterized by its long life cycle which is roughly equal to the airframe of 30+ years, and the fact that systems within this domain are responsible for the continued safe-flight of the aircraft and subject to regulatory agency certification. In this domain, it is an important consideration that the safety aspects of networks and interconnection of systems/devices be simple and understood by the regulatory agencies.

In contrast to terrestrial network design, many ACD network-architecture design decisions are made to facilitate the safety analysis/certification process rather than to achieve extra-performance. The following presents a brief history of previous ACD digital communications and older digital buses to clarify some of the initial FDSE network design-trade-offs.

ARINC 429 Digital Buses

ARINC 429 digital buses have been used to connect digital equipment since the 1970's. This bus consists of a single transmitter connected to one or more receivers allowing a piece of equipment to transmit to several others. In IP terms, this is viewed as multicasting. Basic sets of data parameters are multicast to the receiving equipment at rates up to 100/sec. The connection of equipment and functions is deterministic, and can be readily determined using the wiring interconnect documents.

In the 1980's, system buses were developed that used various shared-media in time-division multiple access (TDMA) schemes. The data could be received by the equipment transmitted in their appropriate time-slot, and any equipment needing the data - a multicast paradigm. In this case, pre-stored data tables described which equipment and functions received the data of others.

Today, it should not be surprising to see multicast remain the dominant form of communication in the ACD. For IP networks, UDP is the natural choice for multicasting. In addition, since networks within the ACD are reliable in a bit-error-rate sense, TFTP over UDP can be used for the relatively small file transfers necessary in this domain. SNMP over UDP is also supported.

Similar to the simplicity of UDP, IP can be simplified. For example, in a closed ACD network, IP packet sizes can be controlled to the point where IP fragmentation and reassembly aren't necessary. The simplification of IP networks within the ACD was discussed at length during ARINC AEEC ADN Subcommittee meetings where the concept of "compliant" and "profiled" IP networks emerged. These concepts are documented in ARINC PP664 Part 3. Compliant networks are compliant to IEEE RFCs. A profiled network is an allowed simplification for networks in the ACD in order to ease the safety-of-fight analysis and certification. The IP networks in the Aircraft Control Domain can simply avoid the use of TCP and use UDP. SNMP uses UDP, and TFTP over UDP can be used for the relatively small file transfers.

ACD Network Lifecycles

As previously mentioned, the ACD networks have a relatively long lifecycle and the configuration of these networks is modified very infrequently. Equipment might be replaced due to failure, but equipment additions to the network are few and far between. As a further simplification, ACD networks are largely statically-configured and defined. The switches used in ACD networks are pre-configured with both the multicast fan-out, and which equipment receives any piece of data. This allows for instant deterministic behavior with the reception of the first packet. The switch does not have to discover the addresses of the connected equipment.

With a static configuration, other network service simplifications become possible in a "Profiled" network. As an example, the Internet-based protocol for the mappings of IP addresses to MAC addresses is Address Resolution Protocol (ARP). But this service is not necessary when the network configuration is known to the system integrator, and the resolution accomplished via pre-stored lookup tables. ARINC PP664 Part 3 describes profiled services and protocols.

Flow Isolation and Independence

Flow isolation and independence developed for ACD FDSE networks gets its basis from the characteristics of the older digital buses. In the older data bus systems, each equipment and function was allocated and guaranteed a pre-defined amount of data-throughput, and expected to receive data with a predefined data latency. When the network's data latency is guaranteed by the network to be within a fixed amount, (2 mSec might be typical), then the behavior of the connected equipment and functions can be readily analyzed. In other words, in the older data buses, any given data packet arrived at its destination in a bounded amount of time. This concept is embraced by FDSE in the Aircraft Control Domain as a "bounded latency" or bounded delay.

Another desirable characteristic is that if an equipment or function fails, it does not affect the system beyond what was previously analyzed and anticipated. In older data bus types, this task is relatively straightforward when the equipment/function effect on the system is bounded by its TDMA time slot, or the "wired" listeners attached to the other end of the wires. In the case of using FDSE, a method of preserving this analytical capability was needed.

Statically-Defined-Network-Configuration and Flow-Control

One method used to isolate the effect of one equipment/function from others is through the use of a statically-defined-network-configuration and flow-control. Basically, the static configuration of both the End Systems (ES) and Intermediate System Switches (Switch) contain enough information to schedule and police the amount of data flowing from any application or function. In the case of a failed or misbehaving function, if the amount of data is being output too frequently, the packets are simply discarded by the switch, preserving the flow characteristics of the "other" functions. Since both the end system and switch contribute to flow control and isolation, for any given piece of equipment to experience an excess-of-data from another function, both the ES scheduler and switch would have to fail.

Redundancy

The last subject of this paper is redundancy. In the Aircraft Control Domain, Equipment and Systems have multiple redundancy instances, so if one instance fails, another instance takes over. In addition, the failure of any instance is anticipated and analyzed as part of the aircraft certification process. In the case of using 16 port switches for IP network connection in the ACD, the loss of all 16 ports, or some combination of switch ports, is difficult to analyze and overcome. One solution is to use redundant switches where necessary. Any given piece of equipment can be connected to another through two switches. The data packets of the transmitting equipment are duplicated and the receiving unit simply discards the second one received. At this time, the bounded latency and "tagging" helps in this second received determination. Depending upon how the network is configured, the complete loss of a switch might have "No-Effect" on the proper operation of the system.

Summary

In summary, many aircraft systems can use IP networks completely built using COTS technologies. But in the case of the ACD, COTS technologies can be augmented to provide long-established network characteristics. Independence of multicast data-flows is addressed by a scheduler in the end systems and flow-budget-policing by the switches. Also, many of the aircraft IP networks are developed as standalone networks so it should not be assumed that networks in the ACD are connected to publicly accessed, untrusted networks.

The design trade-off made for TDSE to support Avionics applications was simplicity and ease-of-analysis over performance and topology-flexibility. The specific trade-offs included:

- UDP is used in favor of TCP;
- Protocols and Services are "profiled" to reduce unneeded functionality; and
- FDSE is statically configured.

Further detail on FDSE for use in the ACD can be found in ARINC AEEC PP664 Part 7 which describes the basis for the FDSE implementation that are being used on Airbus and Boeing new generation aircraft.

About the Author

Larry Hannett is the Senior Staff Engineer at LCH Engineering. He previously worked 30 years at Honeywell with the Digital Avionics Systems and Networking. He was the FAA Designated Engineering Representative for Systems and Software, and participated on the following committees: RTCA SC-152 and SC-167 subcommittees working DO-178 Software Standards; SAE Systems Integration Requirements Task Group writing ARP 4754 for Certification Considerations; and numerous ARINC AEEC subcommittees working Digital Avionics Architectures and Networking Security. You many contact Larry at hannert@qwest.net.