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The Overview of Avionics Full-Duplex Switched Ethernet

Karthik.S[1], Vinodh.S[2]

[1]Assistant Professor, Department of ECE, Mahendra Institute of Technology, Namakkal, India
[2]Assistant Professor, Department of Aeronautical, Mahendra Engineering College, Namakkal, India

Abstract—*This paper deals about basic preface about superior avionic system AFDX. Avionics Signalling and communication in avionics have been significant topics ever since electronic devices were first used in aerospace systems. To deal with the challenges introduced by the extensive use of general purpose computing in marketable avionics, standards like ARINC 419 and later on 429 were available and adopted by the trade. AFDX combines confirmed safety and accessibility functionality with recent Ethernet technology to be able to handle today's needs. These papers outlines two of the most fundamental avionics network architectures and aims at depicting the development of networking concepts and wants over the course of the past 30 years. It mainly focuses on ARINC 429 and AFDX, the most important current and past standards, but also covers two other attractive past protocols.*

Keywords—AFDX, ARINC 664, ARINC 429, Ethernet, MIL-STD-1553, avionics, fault tolerance, security, safety.

I. INTRODUCTION

Today, ARINC 429 can be found in most active and retired aircraft series. While it is well-established in the industry, it has been adapted and extensive little since the initial specifications were formulated in the late 1970s. In dissimilarity to avionics standards, multiple technological revolutions have happened in the computer industry at a fast pace. Networking of computers aboard aircraft may have been preposterous in 1970, whereas modern aircraft without any networked computers are very unusual. Legacy avionics communication standards still reflect past views on computing. eventually, a modern networking structural design for avionics use should offer a maximum of safety, the sack and security, as well as apply failsafe defaults. The ensuing infrastructure should be economically maintainable, flexible and offer a solid foundation for software development.

More recent standards reflect these demands, though few saw broader use across the industry. In contrast to the Internet, security and cost efficiency are not the key objectives in avionics; rather safety is. However, most modern networking standards are aimed at achieving traditional PC-world security objectives and only indirectly address safety requirements (by fulfilling traditional security objectives) .In ARINC 664 Part 7, also referred to as AFDX, standard Ethernet technology is extended and design objectives are built around safety.

Two of the most vital network architectures in the avionics manufacturing are outlined in this paper, and we aim at depicting the evolution of networking concepts and requirements over the course of the past 30 years. It mainly is focused on the most prominent current and past standards, ARINC 429 and 664, but also covers two other significant standards (MIL-STD-1553 and ARINC 629). These standards introduced important features into aerospace net- working design and are used as intermediate steps in this paper even though AFDX evolved originally .In this paper, a deeper considerate of Ethernet is thought; the reader should be general with redundancy and failover concepts, as well as information-security. The OSI layer model is used throughout this paper, even though it is not used within the cited avionics standards. When referring to layer 2 (L2) frames, Ethernet or AFDX frames at the data link layer are meant, while L3 and L4 refer to data structures used in the respective protocol at the network and transport layers.

Within the next segment, the most extensive standard, AR- INC 429, is explained in detail. In Section 3, the transition from federated network architectures, such as 429 to modern Integrated Modular Avionics, is depicted. Then, an investigation of the orientation operating system planned in ARINC 653 for use with included architectures is conducted. In segment 2 ARINC 629 and Mil-Std-1553, two more recent networking standards are briefly introduced. Section 5 is focused on the networking standard AFDX.

The importance is on the enhancements to Ethernet required to comply with the desires of avionics applications. The final chapter is dedicated to summarizing the advantages and disadvantages of the main two named architectures.

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II. A BRIEF HISTORY OF ARINC 664

As an evolved standard, 429 had many limitations, but it is a confirmed and normally used protocol. As time progressed and technology advanced, more bandwidth, more elastic topologies and new challenges like incorporated Modular Avionics emerged and were beyond ARINC 429's capabilities .ARINC 664 (Part VII) was initially developed by the EADS Airbus partition as Avionics Full-Duplex Ethernet switching (AFDX). however previous aircraft already deployed fully electronic fly-by-wire systems, wiring using previous principles could no longer meet the desires of modern day state-of-the-art aircraft. In the case of AFDX, the Airbus A380 prompted for a new technical base to be realize; thus, AFDX was created. Later on, Airbus' AFDX was distorted into the actual ARINC model. Figure 9 shows a simple AFDX-based Network.

III. FROM ETHERNET TO AFDX

Architectural Changes

Ethernet has been in use for decades outside of the aerospace industry and proved to be a robust, low-cost, extensible and flexible technology. However, it cannot offer indispensable functionality required for high availability and reliability. Thus, it is not directly suitable for avionics. 664 offers mod- ern day transfer rates, while construction on top of the previously much-loathed Ethernet standard 802.3 . AFDX inherits parts of the MIL-STD-1553 terminology and overall setup. Devices transmitting data via the network are called sub- systems, which are attached to the network via end systems. The full-duplex network itself is called AFDX Interconnect ; in Ethernet terms, this includes all passive, physical parts of the network, but not switches and other active devices .

The mainly well-known hindrance for using Ethernet network- ing in avionics is Ethernet's non-determinism. A single laid off MIL-STD-1553 bus network with hardware and device roles predefined for provisioning second fail-over bus C. paths. In highly heaving setups, switches may even drop packets on purpose if buffer limits have been reached2 .

In Ethernet, collisions are handled via CSMA/CD, but up- per layers may encounter packet loss. There, protocols (e.g. TCP, SCTP, etc) in the operating system's network stack have to deal with packet loss . However, this is not a viable solution in safety-critical environments. convinced applications require bandwidth guarantees, while others may demand timing performance to remain within strict borders. Neither can be offered by Ethernet. No hard quality of ser- vice guarantees are available in vanilla Ethernet, and soft scheduling is only offered through protocol extensions such as Ethernet-QOS IEEE 802.1p.

The same applies to band- width allocation, which can not be guaranteed in Ethernet on a per-flow level, but is implemented using various dissimilar algorithms. While there are several proprietary approach for making Ethernet usable in real-time environments, none of these principles is directly usable in avionics. Thus, the new standard requisite determinism to make it usable in avionics .Upper layers, such as a station's operating system or applications, are supposed to handle these issues by de- sign. If a message is lost or corrupted during agenda, it will simply be begrudge or its loss fully mitigated.

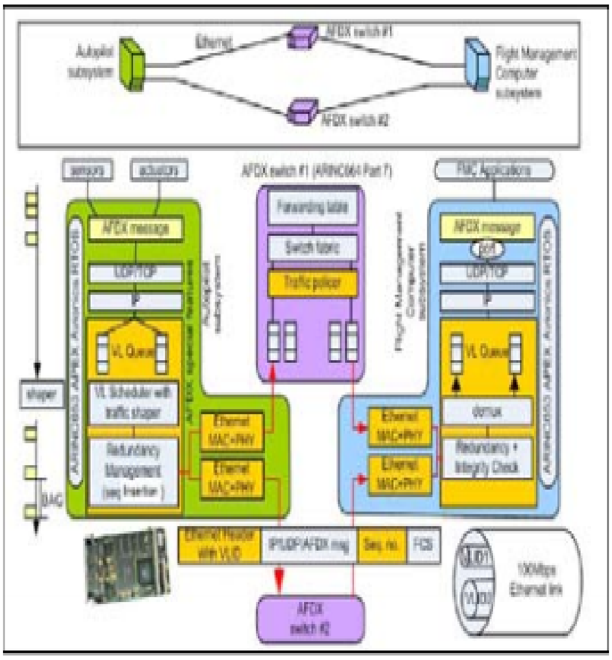

Fig .1: Redundancy in AFDX Network

When sending data on a non micro segmented network, collisions may occur in each segment, forcing all stations involved in the collision to resend. Transmission of packets is retired after a random time interval by whichever station starts first. Again, a smash may occur which may lead to next to in- distinct repeating, and this may subsequently result in a jammed bus .Another variable feature of Ethernet networking and subsequently ARINC 664, are switches/bridges.

While they add flexibility to networking, additional non-determinism is introduced, as frames may be reordered or manipulated in transit. Switches offer micro-segmentation of network segments, but in turn also increase the number of hops a frame takes from source to destination.

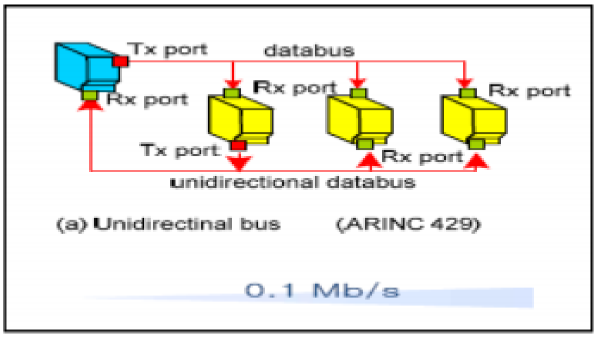

Fig .2: ARINC 429 STD Unidirectional Bus

Virtual Links are designated using so called Virtual Link Identifiers (VLID). The VLID replaces MAC-address based delivery, occupying the bits normally used for the destina- tion MAC. To retain compatibility with Ethernet, AFDX splits the destination-MAC field into several parts: the initial bits are set to reflect a locally administered MAC- address (site-local), the final 16 bits store the VLID .Only one subsystem may send data using a given VLID, thus Virtual Links are again unidirectional.

As in ARINC 429, a subsystem can assume different roles in multiple VLs using different ports (see below), and multiple recipients may contribute in a Virtual Link. Subsystems are not clearly addressed, as in common Ethernet where MAC addresses are used, but the meaning of a Virtual Links identifier is defined Sampling ports have committed buffer-spaces in which one single memo can be read and stored. If a new message arrives, previous data will be overwritten. A queuing port's buffer may contain up to a fixed number of messages that are stored in a FIFO queue; upon reading the oldest message, it is removed from the queue. Handler services for communication ports need to be provided according to the ARINC 653 specifications . BAGs and LMAX of a VL should be set accordingly to the collective requirements of all ports participating in a link .

Virtual Links

Ethernet is independent of physical connections and allows logical endpoints to be defined. Multiple physical or virtual devices may thus share one link, supporting virtual sub- systems or virtual machines in IMA [12, 13, 18]. Multiple applications or devices may require different timing charac- teristics or a fixed minimal amount of bandwidth .

Virtual point-to-point connections implement the same con- cept as used in ARINC 429. In contrast to 429, they do not exist physically, but as logical links. They are implemented as Virtual Links (VL) on top of the AFDX Ethernet layer. An example of virtual channels is given in Fig. To a certain degree, VLs are quite similar to VLAN tagging as defined in IEEE 802.1Q , but offer additional information in addition to network remoteness. Each virtual channel has three properties besides its channel ID: the Bandwidth Allocation Gap, the maximum L2 frame size, called LMAX or Smax, and a bandwidth limit .

LMIN and LMAX are used to set a predefined smallest and largest common Ethernet frame size along the path a packet 2 In a properly laid out AFDX network, buffer overruns should never actually occur. The network parameters are configured based on values calculated during the planning phase of an aircraft using a mathematical support.

Redundancy

High availability environments also require redundancy on the bus as well as within stations. Again, Ethernet does not offer any sort of fail-over by default, however, optional link aggregation as defined in IEEE 802.1AX can of- fer such functionality. 664 by design specifies sophisticated redundancy concepts for end stations as well as cabling by providing two dedicated networks (network A and B). After scheduling of Ethernet frames, redundancy is introduced.

Each AFDX subsystem has two interfaces called end systems. Redundancy is added transparently by sending each frame via both end systems, applying the frame sequence number . Assuming no transmission errors occurred, one spare will arrive at the destination for each frame transmitted .

AFDX Switches

Most features AFDX consists of can also be implemented using regular Ethernet hardware, if special AFDX-stack implementations are run. While purely software-based implementations exist , these solutions can not guarantee determinism. They cannot keep jitter within boundaries im- posed by AFDX and are useful for basic interoperability testing only. To achieve determinism, specialized hardware to enforce the Virtual Link rules, which are based on the VL parameters. introduced by ARINC 664 is needed.

AFDX switches fill this role and enforce latency, bandwidth constraints for VLs and provide a dependable, fixed configuration. This set is read at boot up and remains constant at run time to avoid fluctuations in the network's topology and provide uniform timing behaviour. For honesty reasons, store-and-forward circuit switching is used when relaying packets, in contrast to most mod- ern day high-speed Ethernet switches, which perform cut- through switching The configuration for all Virtual Links (LMIN, LMAX, BAG, priority) and switch parameters should be set according to a one of the mathematical proofing models in use today .

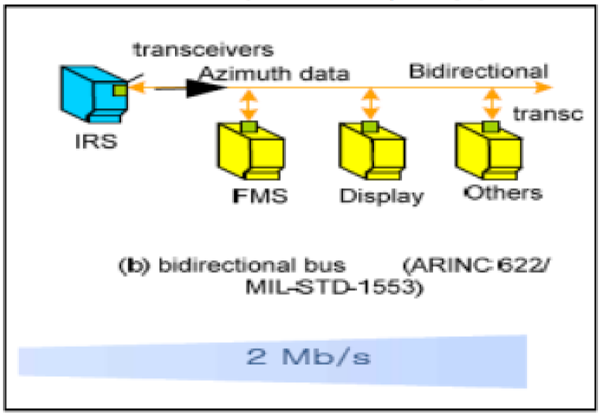

Fig. 3: Full Duplex Ethernet Network

By fixing network parameters at boot-up, changes at run-time are prevented and the network retains constant timing properties and a static layout throughout operation. Non- fault generated deviations off default settings may not hap- pen and are taken into account when calculating global parameters mathematically . Switches isolate Virtual Links from each other and execute scheduling for passing-through frames based on their VLID. Other parameters specified in switch and system configuration include priority, LMIN (equivalent to LMAX) and jitter for Virtual Link. Ports have a fixed maximum delay and buffer-size .

Impact On OSI-Layer 3 and Above

AFDX adderes to the OSI layer model and is based on common protocols from the Internet-world. Subsequently, familiar protocols like IP, UDP and IP-multicast are used. Alien networking environments, such as ARINC 429 links, can be transported within a Virtual Link transparently to the individual applications, thereby reducing development effort. In fact, virtually any previous network standard which does not exceed ARINC 664 in capabilities can be implement on top of it .At Layer 3, the IPv4 protocol is deployed, though the fields usually used for source and destination IP-addresses have been reassigned, as depicted in Figure 12. The top packet- version shows an IP packet being directed to an individ- ual system using the VLID, while the bottom packet uses multicast-addressing. The 32 bits of the source IP address field are separated into:

- The single bit class identifier,
- 7 bit private address,
- User-defined 16 bit ID,
- As well as an 8 bit partition identifier.

The partition identifier is used to address virtual subsystems in a virtualized IMA environment .The Destination IP is either used to designate a multicast IP address, or contains a field of 16 bits prefixed to the VLID. The first 16 bits contain a fixed number (specified by the standard), while the second part contains the VLID, if direct IP-addressing and IMA is used .Due to the guarantee provided by AFDX, certain features usually introduced at higher OSI layers (e.g. packet-loss handling and reordering of packets) are already implemented by the underlying L2/3-networking structure. In business networking, protocols such as TCP or SCTP are used to provide this functionality. In AFDX, transmission control and integrity is already provided at the lower layers, thus, UDP was chosen to be the default protocol in AFDX .

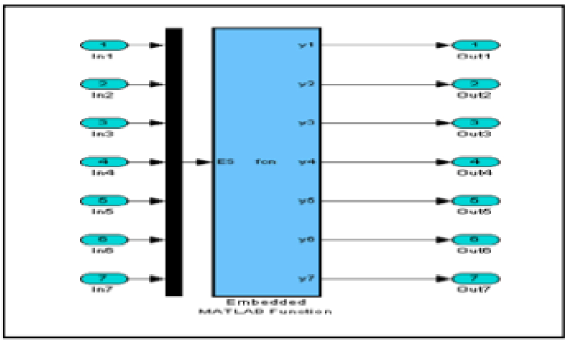

Fig. 4: Full Duplex Ethernet Network

AFDX-Ports are mapped directly at UDP's source and destination port fields. AFDX-flows are identified by using a combination of the following parameters:

- Destination MAC address (containing the VLID),
- Source and destination IP address,
- Source and destination UDP port,

Due to architectural restrictions, the minimum payload size for packets transmitted inside a AFDX-L3 packet is 144 bits. If an UDP packet's length drops below this limit, padding is added at the end of the L4 packet .The standard also defines monitor to be performed via SNMP, and intra-component data transfer through TFTP. Payload transferred inside the L4-structure usually has no fixed predetermined meaning, in contrast to earlier standards. However, ARINC 664 defines a number of common data structures, such as floating point number formats and booleans. These do have no direct impact on network pay- load, but offer common ground for software development.

IV. CONCLUSION

ARINC 429 was developed at a time when the use of consistent, programmable subsystems aboard aircraft was simply not reasonable due to aspects such as size, energy spending, fragility and hardware cost. 429 solely treats data transfer between systems at a per-device level, interconnecting systems on a pin level. Though it has advantages over more modern standards, it clearly had reached its confines once multipurpose computers are interconnected. However, AFDX combines proven safety and ease of use functionality with modern technology to be able to handle today's re- quirements.

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It adheres to the OSI-layer-model and outlines a well-matched stack architecture, while allowing to emulate previous communication standards on top. Besides, the In- ternet Protocols Suite (IP/UDP) and Ethernet are used and only slight alterations to the individual data structures are applied, which lowers the bar for designing hardware and developing software in avionics considerably. For certain parts of an AFDX network, COTS hardware can be used in coincidence with matching software, though AFDX hardware implementations must be used to retain determinism. Still, by adding standard Ethernet hardware in conjunction with an AFDX-stack implementation in the op- erating system, non-AFDX hardware could be used without further alterations Changes to the overall network layout do not negatively im- pact individual Virtual Links or ports of the individual end- and subsystems, due to the added abstraction.

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