What Next?
Fly By Wireless: Next Generation Communication Systems Concept

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***Abstract*: This paper presents an alternative approach for the existing electrical and electronic system in an aircraft. It overviews the current, wired avionics network and its functionality, analyzing the major issues and disadvantages. The new concept of wireless network is discussed, along with three different wireless specifications. Then a performance assessment of the wireless networks against the existing avionics networks is conducted to ensure that the new wireless concept is a viable replacement for the current wired system. In the discussion, new wireless technology development is suggested for aviation applications. As a result, the wireless network systems are discussed as a new method of communication in next generation aircrafts.**

Keywords: Fly-By-Wire, Communications, Avionics Networks, Wireless Technology Solutions

I. INTRODUCTION

The avionics communication system of an aircraft is a highly complex communications network, designed to increase data security, reliability and transmission. The intricacy of the network further increases with every new-generation aircraft due to the additional End Systems for increased functionality of the aircraft. The entire communication platform is a wired network with multiple layers of physical cables running along the aircraft body. In this paper, the Fly-By-Wireless concept has been introduced which aims at replacing the wired connections with wireless technologies.

The first generation aircrafts designed by man were controlled manually or mechanically using tension cables, pushrods and pulleys to transmit the forces applied by the pilot, in the cockpit, directly to the control surfaces. With time, the hydraulic flight control system was introduced in aircrafts, which consisted of two parts: mechanical circuit and the hydraulic circuit. The pilot's movement of the control stick resulted in the mechanical circuit to open the matching servo valve in the hydraulic circuit. This reduced the force required by the pilot to maneuver the aircraft. A small effort in the cockpit, resulted in a large force at the control surface. Next came the fly-by-wire (FBW) system which replaced manual flight control of an aircraft with solid-state electronic interface.

The main reason to develop aircraft control systems from ropes to electrical data, and recently even fibre optics, is the need to reduce aircraft weight and improve flight efficiency. There are two major types of communication solutions: (1) the traditional wired connection using copper cables or fiber optic cables, and (2) the fairly contemporary wireless technology using radio frequency for data transmission and reception. Both communication solutions have a variety of applications based on their specifications, advantages and limitations.

Current electrical system is robust, however, it is inefficient in terms of weight, maintainability and cost. Continuing the trend of development, communications systems designers need to explore new methods for data transmission, such as a wireless systems.

II. WIRED COMMUNICATION SYSTEMS

In this section, the current avionics system, which is a wired communication system, is discussed, along with its functionality and specifications. The main advantages and reasons to use the wired system are also discussed, as well as the main issues that arise with the current system.

Global requirements for a robust communication system have increased exponentially in the recent years due to an increasing demand for the need of complex communication networks to accomplish an array of tasks. Conventional architecture of airborne systems were based on electronic units with dedicated connections and interface types. As time progressed, the number of systems producing and consuming data increased in avionics, including critical tasks such as flight control surfaces and fly-by-wire.

Aircraft communication technology has come a long way since it began during the First World War. The current avionics network majorly comprises of three main sectors: (1) Ethernet based communication system, (2) the avionics computer systems, and (3) sensors and/or actuators. A brief architecture can be described as a communication system wherein the Avionics Computer Systems are connected to the sensors and actuators via a CAN bus or an ARINC429 bus at one end, while the AFDX interconnects the avionics End Systems. The current network architecture allows a shared resource for communication between modules, standardization of the network interface, and eradicates the necessity to design and develop different interfaces for other modules of the system. [7]

A. Current Avionics Network Specifications

The avionics network used currently is based on wired communication systems, using buses and network communication protocols such as CAN and ARINC 429 or ARINC 629 specifications, as well as advanced Ethernet communication, called

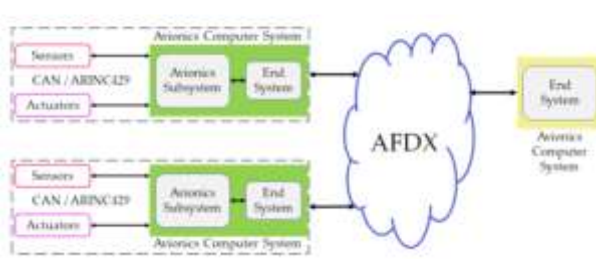

Figure 1: Current Avionics

Avionics Full-Duplex Switched Ethernet (AFDX) in Airbus, and ARINC 664 Part 7 for Boeing, as the backbone of the network. A basic architecture is illustrated in Figure 1. In this section, the various protocols and their specifications are discussed in detail. [7]

1. <u>CAN Bus</u>

Controller Area Network or CAN is the most widely popular communication protocol for a network, providing adequate functionality, reliability and low-cost due to high production volumes. Developed by Bosch in 1983 as an automotive data bus, CAN buses are used extensively in avionics communications as it is competent with the requirements of safety critical applications. [7, 14]

CAN allows various interconnection methods such as bundle splice or daisy-chaining, making the installation process effortless and robust in an aircraft, as seen in Figure 2. It can be used with different types of connectors, as well as with shielded or unshielded cables, increasing the flexibility of the network design and implementation. [7, 14]

The data rate of the CAN bus depends on the length of the network. The maximum data rate is 1 Mbps, with a high level of electromagnetic immunity (EMI) and high common mode rejection when used with a $\pm$2.5 V differential transmission. The minimum load resistance of a CAN bus driver determines the maximum number of nodes that can be attached to the network. [7, 14]

CAN bus has an object-oriented approach for data transmission, and operates according to an event-triggered paradigm where messages are transmitted using priority-based access mechanism. It has a data frame with a payload size of 0 to 8 bytes, preceded by a CAN identifier. [7, 14]

The data bus works by using a producer/consumer communication scheme based on the CAN identifier. The identifier determines the priority of the data frame, the lowest numerical value has the highest

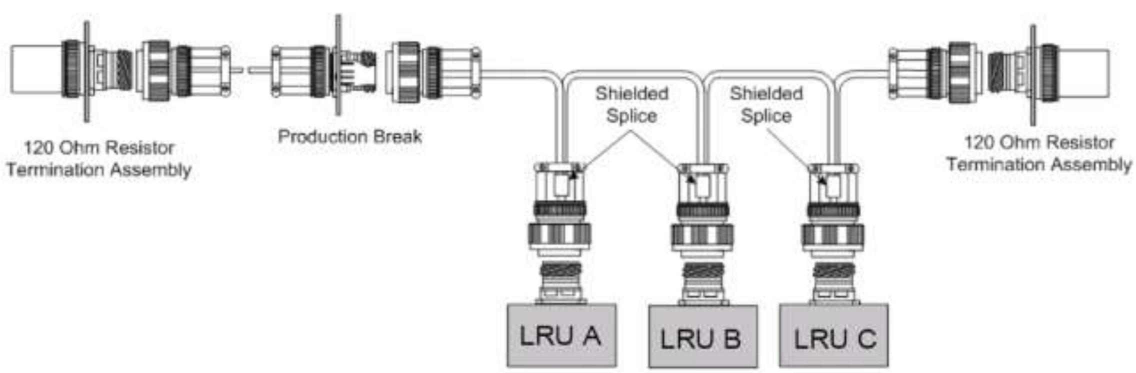

Figure 2: Typical design of CAN bus installation in an aircraft [2]

priority. In a situation where several modules are attempting to transmit on the data bus at the same time, the data frame with the highest priority is transmitted first. Once the CAN messages are broadcast on the bus, each module then filters the data based on the CAN identifier which uniquely identifies the data frame allowing the data payload to be processed correctly in the receiving nodes. [7, 14]

The collisions on the bus are resolved using a sophisticated error detection and handling protocol (CSMA/CR protocol or Carrier Sense Multiple Action / Collision Resolution protocol), which consists of a 15-bit CRC (Cyclic Redundancy Check), frame structure, data acknowledge checking and bus signal monitoring. The data corruption rate for CAN bus is as low as $\sim 4.7 \times 10^{-11}$ per message transmission, according to its manufacturing company, Bosch. [7, 14]

2. <u>ARINC 429</u>

Established in 1929, ARINC or Aeronautical Radio Incorporation provides systems engineering solutions and transport communications for many industries including aviation, airports, defense, government, healthcare, networks, security, and transportation. [1, 2]

The ARINC 429 (or Mark 33 Digital Information Transfer System [DITS]) technical standard was the initial specification designed to specifically for the avionics applications in 1978. Developments based on the ARINC 429, such as the ARINC 629 and ARINC 829, are used in newer aircrafts with higher requirements. However, the ARINC 429 standard remains the most widespread communication data bus used for commercial aircrafts. [1, 2]

429 technical standard requires a 78Ω shielded, twisted pair cable that uses balanced differential bipolar RZ (or return-to-zero) waveform for physical transmission of data. It uses a self-clocking, self-synchronizing protocol with the transmitter and receiver on separate ports. The LRUs (or Line Replaceable Units) are directly wired using the shielded, twisted pair based interface and can connect peers with maximum 90 metres distance between them. The transmitter continuously transmits to the line of communication, and the receiver always reads data from it. The transmitter sends 32-bit data words, or if no data is available for sending, it sends NULL state or zero voltage. All lines are simplex connections, where the transmitter is limited

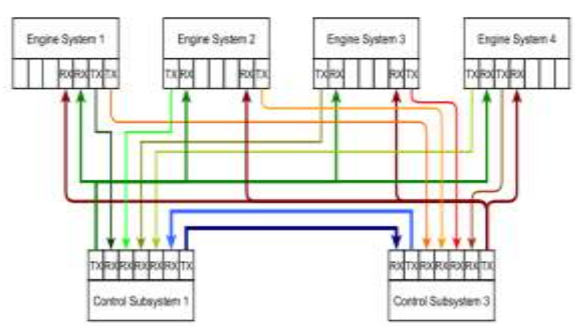

Figure 3: Complexity of the ARINC 429 system containing only two controlling subsystems and four data-consuming components [3]

to a single twisted shielded pair cable and multiple recipients (maximum of 20). [13]

The ARINC 429 operates at *Low Speed* as well as *High Speed*, hence also referred to as *multi-drop bus*. The *Low Speed* has an ostensible throughput of 12 to 14 kbps with a variable clock rate. However, the *High Speed* mode uses a fixed clock rate and a throughput of 100 kbps. [13]

Each chunk of data transmitted via point-to-point protocol is 32-bits and is referred to as *word*. A data packet can consist up to 512 words, however typically, data is transmitted as one word per packet. The small message size increases safety, reliability and resilience, as minimized data packets ensure low latency, decreasing any delays during processing, and providing end-to-end delay guarantee. The high level of responsiveness of the ARINC 429 standard makes it a widely acceptable choice for use in aircrafts where a small time delay of milliseconds can result in major disturbances. [2, 13]

The word format of the data transmitted using ARINC 429 consists of various fields such as illustrated in Figure 4 and listed below as: [2]

- Parity bit (1 bit)
- Sign / Status Matrix or SSM (2 bits)
- Sign or S (1 bit)
- Data (18 bits)
- Source / Destination Indicator or SDI (2 bits)
- Label (8 bits)

The parity bit for the ARINC 429 standard must be odd. The parity bit toggles between 0 and 1 in order to ensure that the total number of ones in the word is odd. [2, 13]

The SSM or Sign / Status Matrix contains the information regarding hardware status, data validity, or operation mode, depending on the device type (defined by the Label). SSM can be either in BCD (Binary-Coded Decimal) or BNR (Binary Numbers) datatype. Messages vary for the two datatypes, for instance, 00 depicts Failure Warning (FW) in BCD datatype and Verified Data, Normal Operation in BNR datatype. [2, 13]

The single-bit Sign field depicts the whether the number is positive or negative. The binary bit 0 indicates Plus, North, East, Right, To, Above. The binary bit 1 indicates Minus, South, West, Left, From, Below. Other bit patterns and data encoding variants have

MSB LSB

32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
P	SSM		MSB									Data									LSB	SDI					Label				

Figure 4: ARINC 429 32 bit Word Format [4]

different predefined meanings supported by LRUs to maintain compatibility. [2, 13]

The next 18 bits are dedicated to data, following a certain datatype. Common datatype examples are the BNR and BCD. [2]

The Source Destination indicator (SSI) provides the information of the receiver. In the ARINC 429 standard, there are multiple receivers or LRUs. The SSI identifies the destination of the data packets. [2, 13]

The Label field presents the encoding format and accompanying parameters. It is used as a header frame to identify the datatype, and provide information to the LRUs to select the appropriate messages. The high-order-bit (MSB) is sent first in a Label, whereas for the rest of the message, the least-significant-bit is sent first. [2, 13]

3. AFDX

The Avionics Full-duplex Switched Ethernet (or AFDX) is a data communication network developed by Airbus to operate the complex avionics systems data networks on the new, commercial, next-generation aircrafts. The newly developed data network is used for safety-critical applications that require dedicated communication bandwidth and provide deterministic quality of service (QoS). [3, 5]

The AFDX is based on the Ethernet (IEEE 802.3 standard) which reduces the costs and development time as it allows the use of commercial off-the-shelf hardware devices. Ethernet is a widely used standard, however, the base requirements for avionics applications, such as reliable data packet transport, and bounded transport latency, are not covered by the standard. [4]

Special extensions to the network protocol and a fixed topology were specifically developed to address the real-time issues of the fly-by-wire system on the A380, and later adopted to the new-generation A350 avionics network as well. It was then used as a base to develop the ARINC 664 Part 7 specification. [3, 5, 13]

The basic Ethernet standard treats each node on the network equally. A peer transmits packets onto the network continuously. If the media is occupied, a collision occurs and the peer backs up. It tries again until the data packet is transmitted successfully, or until a predefined amount of

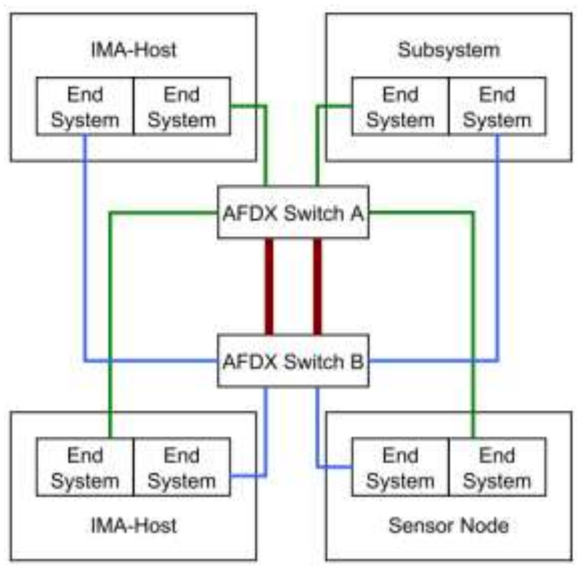

Figure 5: AFDX Topology example [13]

time has elapsed, thus producing varying latency lengths which is undesirable for safety critical applications. This network topology was changed in the AFDX. [5, 13]

In the AFDX, the data packets are forwarded based on a connection table by regular switches. The connection table is build and updated while the switches are in operation and it learns and forgets the peers connected to the network, thus making it convenient for networks with temporary peers that can be attached and detached from the net. However, the latency is still of variable length. To tackle this issue, the AFDX switch forwards packets according to a static table as well, in which all the peers and their respective network addresses are statically defined. [3, 5, 13]

The network availability is increased by developing redundancy on the physical layer. Two Ethernet controllers transmit data packets on separate wire using physically separate switches. At the receiving end, two individual controllers receive the data frame. A redundancy management algorithm in the protocol layer forwards at most one of the two identical packets appropriately to upper layers. [3, 5, 13]

The AFDX system architecture consists of End Systems and switches. Any system, such as a part of the avionics or an aircraft subsystem, connected to the AFDX network that is configured to handle AFDX protocol operation is called an End System. The switches are located between the End Systems on the data path for communication. The number of switches depends on the network hierarchy. [3, 5, 13]

In order to implement the same connection concept as ARINC 429, the point-to-point and point-to-multipoint connections are defined using Virtual Links (VL), a unidirectional private line with bounded latency and guaranteed bandwidth. For a point-to-point topology, a single VL is connects exactly two End Systems. For a point-to-multipoint, a single VL can connect one transmitting End System to multiple receiving End Systems.

There are two main characteristics of the VL - Bandwidth Allocation Gap (BAG) and Maximal Frame Size (MFS). The BAG signifies the minimum inter-arrival time between two consecutive frames, ranging in powers of 2 from 1 to 128 milliseconds. The MSF represents the largest frame that can be sent during each BAG, ranging from 64 bytes to 1518 bytes. [3, 5, 13]

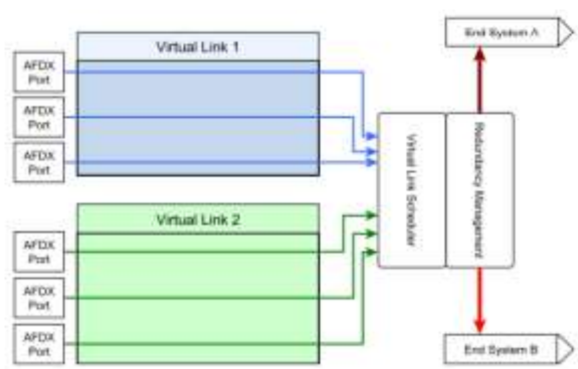

Figure 6: Virtual Link layout in the AFDX network [13]

B. *Advantages of Wired Aircraft Communication System*

In modern aircrafts, the communications systems are of critical importance as almost all the activities on board, such as navigation, path guidance, control surface movement, engine monitoring, pressure maintenance, etc., are heavily dependent on the communication network in order to operate. The current avionics network is a wired communication system using the different data buses for different tasks.

The main advantages of the current avionics system installed in the aircrafts are listed below: [7]

- *Data Rates of the System:* The avionics communications system transmit data at the rate of 100 kbps for the ARINC 429, 1 Mbps for the CAN Bus and 100 Mbps for the AFDX system.

- *Hard Real Time and Determinism:* Data transmission latencies are bound and function within the deadline constraints, hence ensuring a predictable manner of communication and timeliness of data guaranteed for determinism concerns.

- *Reliability and Availability:* The avionics network communication takes place over minimum three layers of redundancy, hence has a high criticality level and a probability of failure of less than 10^{-9} per flight hour. This is ensured by the application of necessary fault detection and recovery mechanisms. The avionics network have an expected lifetime of 20 to 30 years, hence are mature enough to last a long term.

- *Security:* The current avionics network guarantees data confidentiality, integrity and authentication, by providing a secure, guaranteed communication lines with mechanisms to prevent unauthorized access to data.

- *Electromagnetic Compatibility:* The working conditions of the avionics communication systems involves harsh physical environments such as vibration, variation in temperature and humidity, pressure, as well as constant presence of intense radio frequency noise. The current avionics network is capable to handle the harsh environment with continuous and periodic maintenance over time.

III. PROBLEM STATEMENT: DISADVANTAGES OF THE WIRED COMMUNICATIONS SYSTEMS

In this section, the main shortcomings of the current wired avionics systems are discussed. The disadvantages are weighed against the possibility of a better solution for the next-generation aircrafts.

As the years pass by, the ramification of the communication systems on board the aircrafts becomes increasingly intricate. The load on the network is increased due to the rising demands of data for development, research, maintenance and monitoring purposes. The end result of the inflammation of complexity of avionics communications systems is an upsurge in electrical wires, as all the systems and subsystems depend upon cables and connectors to provide data, power, grounding and time-synchronization throughout the aircraft's lifetime.

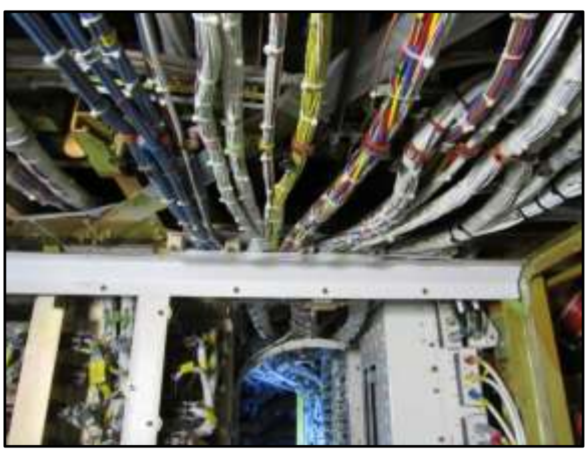

Figure 7: An insider's look into the avionics bay of the B777 [20]

Figure 8: Wire chaffing due to vibrations [19]

Many improvements and developments have been made to the current avionics systems, but their heavy dependencies on wires has never eliminated the wiring and connector problems, and therefore being the key reasons for flight delays and increase in maintenance costs. New systems also lead to increase in weight not only in the form of cables, but also insulation, bulkheads, brackets, connectors, cable trays, structural attachment and reinforcements. [7]

For a better understanding, cable related costs during fabrication and installation are estimated to about $2000 per kilogram of wire. In an average commercial aircraft, the total wire count adds up to approximately 100,000 cables with an approximate total length of 450 to 470 kilometers. The weight of the cables alone ranges from 5000 to 5,700 kilograms, and additional 30% weight for the harnesses. The overall weight sums up to almost 2 – 5% of an aircraft's weight. Financially, it costs around $14 million for an A320 and

Figure 9: Wire aging in aircrafts [18]

approximately $50 million for a B787. The Airbus 380, largest commercial aircraft to date, consists around 500 km of cables which are one of the main reasons for production delays and cost overruns, costing up to an estimate of $2 billion. For perspective, the operating empty weight of an A380 is roughly 277,000 kg. Considering the wiring to weigh 2.5%, the cables and harnesses together weigh almost 7 tons. [7]

Another major downside to the wiring systems, apart from increase in weight, is the problems that arise due to wire aging. As an aircraft ages, the electrical system also ages and the insulation becomes brittle and cracks over the kilometers of cables laid out in the aircraft structure. The vibrations cause the insulation to chafe as wires rub against each other, a tie-down or any other surfaces. Insulation can also breakdown in the presence of moisture, generally spawned due to the varying humidity levels during flight. Chaffing can lead to exposed wires causing arcs, shorts and electromagnetic emission and interference. [7]

Unlike the distinctly visible cracks on the airframe or engine parts, damaged wire is extremely difficult to detect as the wires are tied down to the aircraft frame, twisted around fuel tanks and hydraulic lines, making it extremely difficult to reach for maintenance. In many situations, maintenance of electrical wires requires dismantling of external aircraft structures, which requires longer periods of time, and hence increases overall maintenance costs. [16]

According to a recent study conducted by a research firm, Lectromechanical Design Co., based in Virginia, USA, more than 3000 cracks were found over approximately 240km of wires in a Lockheed L-10 11 that was in service for several years. Each crack can be a potential cause for catastrophic arcing that may lead to electrical fires in an aircraft. [16]

Unfortunately, there have been a few incidents caused due to bad wiring and electrical failures. For example, in 1989, United 811 met with a fatal accident due to improper wiring which indicated the aircraft door was locked, when in fact it was unlocked, causing the door section to breakdown during flight. Another mishap occurred in 1996, when flight TWA 800 (Figure 9) exploded mid-air due to a short circuit near the central wing fuel tank. One more disaster occurred with Swissair 111 in 1998, where an electrical fire caused due to arcing in the IFE system led to fatal demise of all 299 persons on board. [8, 9, 10, 16]

Figure 10: TWA 800 after the fatal accident in 1998 [17]

To summarize the problem statement addressed in this paper, the main disadvantages of the current wired communications systems are listed below: [17]

- *Performance:* The increase in weight due to wires directly impacts fuel consumption and aircraft flight performance. In order to maintain reliability, the communication systems are made redundant with minimum three layers of wiring systems. This heavily increases the overall weight of the electrical system which is a bane for aircraft performance efficiency.

- *Failure of wires and connectors:* Most of the troubleshooting and maintenance overruns are caused by issues related to cables and connector failures.

- *Direct Costs:* Wiring system measurement justification, design and implementation, structural provisions, inspections, tests, logistics, vendor availabilities, etc. mount to a huge cost for airliners and aircraft manufacturers.

- *Price of Copper:* The increase in price of copper over the last decade has heavily impacted the electrical wires industry.

- *Electromagnetic Interference:* Wiring constitutes to more than 50% of the cases of electromagnetic interference on board the aircraft by radiating high amounts of energy. The cables behave as antennas, collecting unwanted energy that can impact the immunity of interconnected systems.

- *Cost of change/inflexibility:* Since the introduction of composite structure materials, health monitoring systems have become an essential addition to the system. However, sensors are limited due to wiring weight restrictions. Also, the system architecture is not flexible enough and requires huge costs to allow easy attachment / detachment of new End Systems to the network.

IV. PROPOSED SOLUTION: WIRELESS COMMUNICATIONS SYSTEMS

The proposed solution for the current wired avionics communications system is discussed in this section. The wireless system is detailed and network implementation is explained as a possibility for future aircraft communication systems.

The complications that arise with complexity of avionics networks can be reduced by eliminating physical connections, i.e. replacing wires and cables with a wireless communication line between the systems. The 'Fly-By-Wireless' paradigm has the potential to improve efficiency and flexibility, while reducing weight, fuel consumption and maintenance costs. The steep development in technology has allowed the communications to take place wirelessly in a cost effective manner due to their simplicity, maturity and ubiquity. A good example of real time wireless application is wireless sensors network and wireless industrial networks. [7]

Some of the major advantages of substituting a wired system with wireless communication are listed below: [15]

- *Weight Reduction:* The main reason to replace the existing wired system is the bulky nature of hardware connections that increase the system's weight.

- *Cost effective:* Wireless systems offer solutions that efficaciously reduce the cost and time related with wiring harness design, harness installation design, aircraft manufacturing time, and aircraft lifecycles costs. Maintenance costs are also drastically decreased due to the presence of less wires.

- *Redundancy:* In the aircraft, wireless communication paths can be made redundant more easily and with higher cost efficiency through the use of mesh networks, which could not be implemented in a hardwired system due to weight and cost limitations.

- *Back Up:* The wireless communication system can also be implemented as a backup for the main wired avionics network to increase reliability and safety in case of failure.

- *Additional Features:* Wireless technologies can provide new functionalities to aircraft manufacturers and operators that could not be provided by wired systems due to various limitations. Additional functions such as affordable health monitoring systems, easy addition of new sensors including engine rotor bearing monitoring, wireless transmission of sensor information, wireless crew communication including voice, video and data to provide enhanced aircraft safety.

In the following sections, the Fly-By-Wireless implementation methods are discussed in detail. Section (A) accounts the possible wireless solutions using commercial off-the-shelf technology, and section (B) discusses the possible system architecture using wireless technology.

A. *Commercial Off-The-Shelf (COTS) Technology*

The avionics communication system is quite a complex network of End Systems transmitting and receiving time-critical data. In order to reduce development costs, pre-existing devices and solutions, called commercial off0the-shelf technology (or COTS), can be adapted for the avionics network applications. Selecting an appropriate wireless technology with the required specifications that are equal to or better than the current wired avionic network.

Three of the most appropriate wireless technologies for avionics systems have been explored, and the most appropriate standard selected to be implemented. [7]

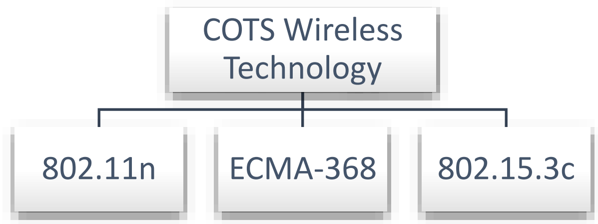

Figure 11: Three COTS wireless technologies studied

1. <u>802.11n</u>

The Institute of Electrical and Electronics Engineers or IEEE develops communication standards and specifications for various applications. The IEEE 802.11 is one of the most widely used communication standard. The proposed option for application in avionics is a variation of the basic, namely 802.11n. [7, 11]

The 802.11n is an amendment that improves upon the previous standards by having the additional facility of multiple-input multiple-output antennas (MIMO). It has a data rate of 600 Mbps, six times faster than the current AFDX standard, and hence can be used as the avionics backbone network. [7]

The variant operates at 2.4GHz and 5GHz with two bandwidths of 20MHz or 40MHz. One drawback is the general purpose frequency of 2.4GHz which is the same for commonly used Wi-Fi, hence creating security concerns. However, the standard has a good maximum range of 30 metres and provides 3 non-overlapping channels that can be used for different End System communications. [7]

MAC protocol applied in the 802.11n standard is based on CSMA/CA mechanism. For ad-hoc mode it gets integrated with Distributed Coordination Function or DCF protocol. For infrastructure mode, it integrates with contention free Point Coordination Function or PCF protocol. The 802.11n uses Automatic Retransmission ReQuest (ARQ), at the MAC layer, with different acknowledgement status messages such as immediate-ACK, delay-ACK and block-ACK. At the PHY layer, the Forward Error Code (FEC) and Low-Density Parity-Check (LDPC) are implemented to control errors and improve reliability. [7]

For increased security, IEEE 802.11n standard adopts weak RC4 stream cipher as well as Advanced Encryption Standard (AEC) algorithm to ensure security against brute force attack. [7, 11]

2. ECMA-368

Developed by the European Computer Manufacturers Association, the ECMA-368 is a High Rate Ultra-Wideband (HR-UWB) PHY and MAC Standard for a high-speed, short-range wireless network, utilizing all or part of the large spectrum bandwidth ranging between 3.1GHz to 10.6GHz. The large frequency band is divided into 14 non-overlapping channels, out of which channels 9, 10 and 11 are not in use for any application and available all over the world, hence making it quite appropriate as it can be reserved specifically for avionics applications. [12]

The data rate supported by the ECMA-368 is 110Mbps for a range of 10 metres, 200Mbps for 6 metres range, and 480Mbps for a small distance of 2 metres. The data rate is faster when compared to the 100Mbps of the AFDX standard. [12]

There are two MAC protocols supported by the ECMA-368. The Prioritized Contention Access (PCA) is a contention based protocol with prioritized Quality of Service. The other protocol is the Distributed Reservation Protocol (DRP) which is TDMA based and guarantees a contention-free access. [7, 12]

The ECMA-368 ensures reliability by supporting FEC convolutional code with different coding rates at PHY layer and re-transmission mechanisms with Immediate Acknowledgement (Imm-ACK) and Block Acknowledgement (B-ACK) at MAC layer. [7]

It supports peer-to-peer topology and uses AES algorithm with Pairwise Transient Key (PTK) for unicast communications, and Group Transient Key (GTK) for multicast and broadcast communications. [7, 12]

3. <u>802.15.3c</u>

The IEEE 802.15.3c is a very recent development and is of interest for the avionics application purely because of its high speed data rate of 3000Mbps. It operates on 60GHz frequency with a 7GHz bandwidth with a single non-overlapping channel. [7]

The main drawback of this IEEE variant is the severe attenuation caused due to oxygen absorption. Hence, the 60GHz is based on directional antennas with Line-of-Sight (LoS) communication to reach the high speed of 3GHz. [7]

B. Proposed System Architecture

The wireless avionics network must be designed to be able to support 60-80 nodes or End Systems, have a data rate equal to or higher than 100Mbps, provide end-to-end delay and reliability guarantee, support peer-to-peer topology for secure communications, and also be able to handle the physical harsh environments that occur during aircraft flight. The commercially available off-the-shelf technologies reduce development costs but have their own limitations as they are not designed for the specific application of avionics communications.

Keeping the requirements of the current avionics system and the limitations of the COTS wireless technologies in mind, a *Hybrid Architecture* is suggested for the Wireless Avionics Network, i.e. the system consists of wired and wireless technology. [7]

Figure 12: Proposed hybrid architecture as possible solution

From the three wireless technologies discussed above, the most suitable for the avionics application is the ECMA-368 as it satisfies the desired data rate, supports peer-to-peer topology, and provides high level of data encryption and reliability, hence ensuring data security and guarantee. Moreover, the ECMA-368 has 3 channels available that are not being used. These channels can be reserved for avionics application, increasing the data security as no other application will be valid at the same frequency. [7]

The hybrid architecture is designed keeping 1Gbps Full Duplex Switched Ethernet as the base and interconnected to three clusters on the three channels (9, 10 and 11) via gateways. The gigaswitch is connected with the three gateways using a wired Full Duplex connection. The gateways are connected with the various End Systems via the wireless ECMA-368 standard. In order to increase reliability, the multicast network supports positive and negative acknowledgment between the peers. [7]

The system ensures data reliability and security, as well as feasibility with this hybrid design. Overall weight of the communications systems also reduces as a major chunk of cabling is eliminated by the implementation of wireless technology for data packet transmission and reception by End Systems.

V. ASSESSMENT OF WIRELESS TECHNOLOGIES

In this section, the application of the hybrid architecture and the possible need for development of new wireless technology for the avionics network application is discussed.

The next generation aircrafts are being designed to enhance the functionality, reliability and efficiency of the system, but at the same time maintain or increase the system security. In order to reduce the overall aircraft weight and improve the performance, inclusion of wireless technologies for communication systems is suggested. However, due to the lack of desired specification in the current commercial off-the-shelf wireless technology, the proposed design is a hybrid architecture consisting of both wired and wireless communication systems.

The future of aviation, nevertheless, is rapidly heading towards wireless technology. In order to implement a 100% wireless avionics communications network while maintaining the current standards for data security, reliability and data rate, new wireless technology must be developed specifically to satisfy the requirements of avionics systems applications.

The avionics systems have a complex network and safety-critical applications, and hence require a dedicated wireless specification. The Wireless Avionics Intra-Communications project is conducted by the Aerospace Vehicles Systems Institute (AVSI), a group of companies that, together with NASA, FAA and ICAO, are working towards developing new avionics centered wireless technology. Their aim is to "provide communications over short distances between aircraft stations installed on a single aircraft" and believe approximately 30% of

Figure 13: Group of leading aircraft manufacturing companies working on WAIC project [16]

electrical wires are viable candidates to be substituted with wireless technology. [15]

To begin with, the objective of the organization is to develop wireless systems for safety and flight regularity applications that require low transmission power (up to 10dBm) such as provide data from sensors wirelessly. Other applications can include data for ice detection, cabin pressure, engine sensors, landing gear position, door sensors, and many more. [15]

The AVSI group was successfully allocated a worldwide radio frequency spectrum for wireless avionics at the 2015 World Radiocommunication Conference (WRC-15). This is a major step towards the development of wireless avionics technology as it enables a globally applicable licensing process, as well as provides harmonization of the technical and operational conditions across regions and countries. The frequency allocation also allows the systems to be designed universally and with ease within the aeronautical frequency bands. [15]

The wireless technology is a feasible solution with the help and development of projects such as the Wireless Avionics Intra-Communication project, as it allows the engineers, designers and manufacturers to explore and enhance advanced communications systems, in addition to increase the capability of aircraft communication systems.

VI. CONCLUSION

The future of avionics communications systems and networks has been discussed in this paper. The history of aircraft communication system is introduced, as well as a detailed description of the current wired avionics network, including the three main communication buses used in aircrafts, namely the CAN bus, ARINC 429 bus and the AFDX system.

The problem statement has been defined as the main disadvantages of the wired communication systems, such as increased weight, high installation and maintenance cost, wire aging liabilities, as well as fatal aircraft accidents caused due to electrical failures.

Use of wireless technology for avionics communications has been proposed as a possible solution to overcome the challenges faced by wired systems. The benefits of wireless technology has been discussed, along with possible COTS wireless standards that can be viable candidates in aircraft communications systems. The ECMA-368 standard was recommended and a hybrid architecture using the wireless standard and a wired Full Duplex Ethernet system has been suggested to better understand the methods of implementation for avionics application.

Lastly, the outlook of a completely wireless communication avionics system is discussed by suggesting developing new wireless technology specifically for avionics systems. Work done by the AVIS on the Wireless Avionics Intra-Communications (WAIC) project is mentioned, detailing the project aim of 100% wireless communications in aircraft, in addition to the impacts of frequency allocation to the project for avionics applications.

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