Wireless Avionics Intra Communications, Zone Clusted Sensor and Distributed Integrated Modular Avionics-Potential Revolutions in Commercial Aircraft Health Management and Avionic

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***Abstract*—Recently, digitalization and connectivity seem to be the hottest topic in commercial aviation industry. But most people focus on air to ground communication, which can link the aircraft to internet, few people work on the wireless connection within aircraft itself named Wireless Avionics Intra-Communications (WAIC) which may replace traditional EWIS system. Also, distributed integrated modular avionics (DIMA) is another hot area for avionics. This paper presents a new idea of a serial sensing avionic architecture combine WAIC, zone clustered sensor and DIMA. And from the rare experience of first author as supply chain manager and avionic system engineer, the conclusion part gives explanation on feasibility of this new aircraft sensing, condition monitoring and avionic system architecture from a commercial aviation supply chain point of view.**

Keywords- WAIC, DIMA, Health Management; Avionic; Commercial Aviation

I. INTRODUCTION

Commercial aviation industry is always eager to apply new advanced technologies. In recent one decade, structure has fully turn into composite, federated architecture avionic has turn into integrated modular avionic (IMA) architecture, more electric is generated on used on aircraft and digitalization has also greatly changed how the industry work [1]. These changes seem successful and industry is talking about the new revolutions using AI and electric propulsion enthusiastically. This paper wants to give some new insights on the future of health management avionic by first introducing some technologies that could contribute to the new architecture: WAIC, zonal clustered sensor architecture, joint with distributed integrated modular avionics (DIMA). These three technologies linked could become the backbone for future aircraft sensing, transmission and processing system. And then discuss about the potential new architecture with potential applications.

II. 2.1.1 WIRELESS AVIONICS INTRA-COMMUNICATIONS

Wireless Avionics Intra-Communications include: radiocommunication between avionics components integrated or installed on the same aircraft and radiocommunication in a closed exclusive network between two or more points on a single aircraft. It covers only safety and regularity of flight related applications and does not provide air-to-ground, air to satellite, or air-to-air communications, also not for passengers' communications or in-flight entertainment. The transmission power is low (10dBm). ITU-R Report M.2197 [2] contains technical characteristics and operational objectives for WAIC systems.

A. *Benefits of Going Wireless*

The motivation for aviation industry to go wireless include reduce complexity and weight of electrical wiring and harness fabrication to generate higher fuel efficiency; significant gain in reconfigurability through improved installation flexibility e.g. for cabin elements; reliable monitoring of parameters belonging to moving or rotating parts; improved reliability of aircraft systems through mitigation of common mode failures by means of dissimilar redundancy.

Electrical Wiring Interconnection System (EWIS) in modern aircraft is a highly complex and critical system. For latest large passenger aircraft, the number of wires could reach to 100000, with a length of 470km and a weight of 5,700 kg, there is about 30% of additional weight for harness-to-structure fixation. Among these wires about 30% are potential candidates for a wireless substitute. This introduces the potential application of WAIC. The weight reduction for WAIC might be proportionally greater if engineers could reduce the wiring required to supply electricity to components. Wires that carry data, including fiber-optic cables, are typically heavier and more expensive and complex than those that carry electric power. Eliminating wires also frees up space, always at a premium on aircraft. Wires take up space themselves and need additional room for their separation.

Currently, redundant wiring routes are used in different areas within the aircraft structure to mitigate risk of single points of failure, caused by defect wiring (e.g. corrosion, chafing of isolation or loose contact) or cut wires (e.g. through particles intruding aircraft structure as in case of an engine

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blast). Safety-related connections now require two or three redundant wires to ensure functions if one of the wires chafes or fails for some other reason. And wiring routes are segregated to the farthest possible extend allowed by the aircraft geometry. The introduction of wireless transmission could provide better dissimilar redundancy and mitigates risk of single points of failure than relying solely on wires that could all fail for the same reason.

Upgrading equipment on today's jets can be a major workload, but with the new wireless link approach mechanics would just have to replace the component and attached module, rather than disentangle, remove and safely replace bundles of wires. Especially for new aircraft, installing wireless devices could be much easier than installing all those connecting wires.

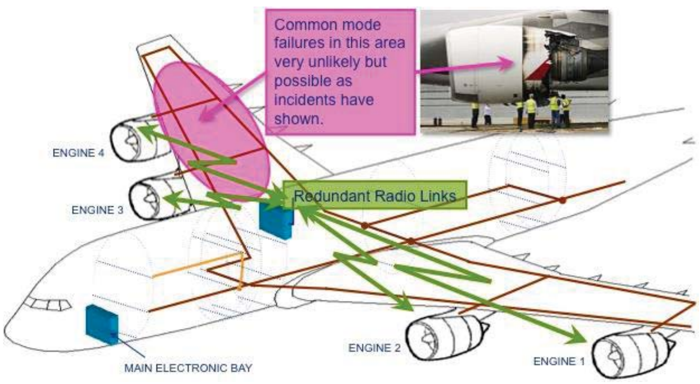

Figure 1. Wireless Transmission Could Provide Dissimilar Redundancy [3]

B. Potential Applications

Examples of Potential WAIC Safety Applications [3]

Smoke Detection

Fuel Tank/Line

Proximity

Temperature

EMI Incident Detection

Humidity/Corrosion Detection

Cabin Pressure

Emergency Lighting

Ice Detection

Landing Gear (Position Feedback, Brake Temperature, Tire Pressure, Wheel Speed, Steering Feedback)

Flight Controls Position Feedback

Door Sensors

Engine Sensors

FADEC-to-Aircraft Interface

Air Data

Flight Deck & Cabin Crew Imagery/Video (safety-related)

Avionics Communications Bus

Structural Health Monitoring / Structural Sensors

Active Vibration Control

Oleo pressure monitoring

All functions above deliver real-time safety-related system status information to the pilot.

C. Research and Development Steps

Not much research work is presented in academic area. [4] gives an example of using probability method to evaluate performance of different industrial wireless protocols, namely low latency deterministic network (LLDN), WirelessHART and wireless interface for sensors and actuator (WISA), under high reliability situation. The observation is the performance rank may change under extremely high reliability circumstance.

Reference [5] presented a review of the emerging area of wireless avionics intra-communications. Several issues and current design trends have been presented which range from physical-layer, such as propagation, power consumption and interference, to medium access control (MAC), radio resource management (RRM) and application layer features such as security, integration with current avionics communication systems.

Some of the world's top avionic and airframe experts have worked on WAIC coordinated by Texas A & M University's Aerospace Vehicle Systems Institute (AVIS). The work is self-funded by participating organizations and includes a growing list of avionics companies and aircraft manufacturers. Giant suppliers Honeywell, United Technologies and GE Aviation have been involved, as well as Airbus, Boeing, Bombardier, Embraer and Gulfstream. Most recent to join are NASA, Lufthansa Technik, Thales and Zodiac Aerospace. They will contribute their expertise to laboratory and flight tests. Aerospace Vehicle Systems Institute AVSI is coordinating research to help the Radio Technical Commission for Aeronautics (RTCA), an association founded in 1935, to establish performance standards for WAIC equipment. A key aim is to ensure that WAIC applications won't interfere with those on other aircraft, with each other or with radio altimeters.

Wireless nodes must be light, small, low power and cheap if they are going to be attractive and realistic replacements for wires. How to power the nodes remains a major question. Lithium batteries and harvesting ambient energy and storing it in super capacitors are among the options, but there is a third idea. Passive radio-frequency identification tags might remain dormant until powered briefly by signals from the RFID readers that interrogate them.

Latest research and development indicate the wireless transmission would first go with wiring for non-avionics functions, such as control of cabin lighting and passenger audio-video equipment or devices gathering routine health-management data from around the plane. Next might be safety-related wiring linked to smoke detectors, emergency lighting, cabin-pressure sensing and avionics, and eventually even commands that move the plane's flight-control surfaces. United Technologies expects the minimum operational performance standard for WAIC to be developed by mid-2019. And AVIS expects certified WAIC applications in about four years. United Technologies have developed transceiver modules weighing less than 13 grams that would be installed on components throughout the plane. Each would send data from the component or receive commands from the flight crew or automated systems[6]. To power these modules, UTC is considering different methods. Any batteries would be non-recharging to avoid risks of overheating and fire. These transceiver modules, or nodes, would be connected to remote data concentrators, weighing less than 200 grams, located strategically around the plane. These concentrators, similar to routers in homes and buildings, would be powered by the aircraft's electrical system. They would collect data from (or send it to) transceiver modules and route it where it needs to go. That could mean to the aircraft interface device for transmission to the ground by radio, broadband or cell network. If the crew needed to see the data, it would be transmitted to a cockpit tablet interface module that would be connected wirelessly or by wires to tablet PCs for display to the pilots.

And since most of the sensors related to the aircraft condition monitoring and health management function. The newly developed component should follow industry standards in [7] [8].

Safety-related radio frequency spectrum is considered as one of the corner stones for the airworthiness of future WAIC systems. ICAO will develop Standards and Recommended Practices (SARPS) for providing the technical basis for certification of future WAIC systems. It took from 2008 to 2015 to take the first regulatory step: securing a dedicated WAIC frequency of 4,200 to 4,400 megahertz from the World Radiocommunication Conference

https://waic.avsi.aero/about/airworthiness/

A calculation of WAIC spectrum requirements is given as [2]:

$$F = \frac{P_{\text{eff}} * \alpha * \beta * m}{\eta * 1000} \tag{1}$$

where P_{eff} is Net average application data rate;

α is Protocol overhead factor a figure that takes into account all protocol overhead including physical layer, medium access control layer and above;

β is Channelization overhead factor accounts for additional spectrum required to achieve sufficient isolation between adjacent RF-channels, and can be expressed as a ratio of channel spacing to occupied channel bandwidth;

m is Multiple aircraft factor accounts for multiple aircraft with WAIC systems installed operating in close proximity to one another, most likely in the airport environment;

η is Modulation efficiency (η) refers to the data rate that can be transmitted over a specific bandwidth.

Detailed calculation could be seen in the reference report. The result shown "low data rate inside" WAIC systems will require a maximum of 11 MHz of spectrum. "Low data rate outside" WAIC systems require a maximum of 40 MHz of spectrum. "High data rate inside" WAIC systems will require a maximum of 32 MHz of spectrum. "High data rate outside" WAIC systems will require a maximum of 62 MHz of spectrum. The total spectrum required for all application categories is 145 MHz.

III. New Avionic Architecture

This section gives a new thinking on the future development of commercial aircraft health management and general avionics. Specifically, WAIC will combine with Zone Clustered Sensor and DIMA to form a stream line of future aircraft avionic system backbone.

A. *Zonal Clustered Sensor with DIMA*

Using wireless technology, the range of transmission becomes one of the main considerations. That would naturally generate a thought to divide all the sensors by its physical location and divide the aircraft into several sensor zones. Gathering and processing all sensors' data locally which will keep the wireless transmission in allowable range and reduce the need of long range transmission by wires. Figure below shows the zonal clustered architecture of aircraft sensor and communication between different zones.

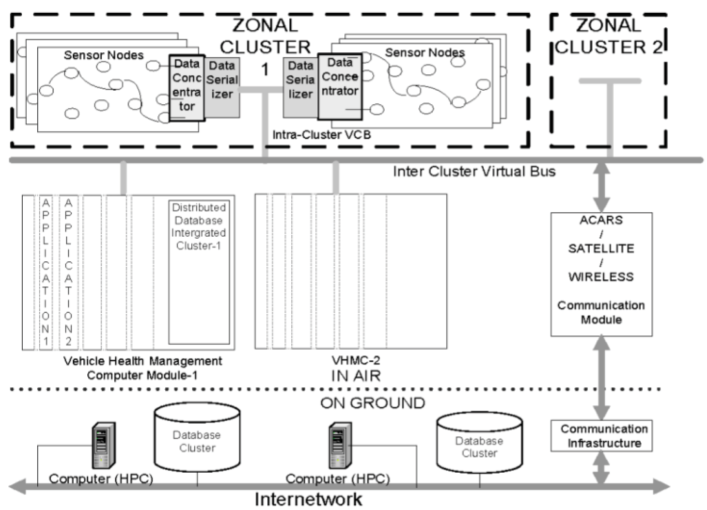

Figure 2. Architectural Framework of a Zonal Clustered IVHM System [9]

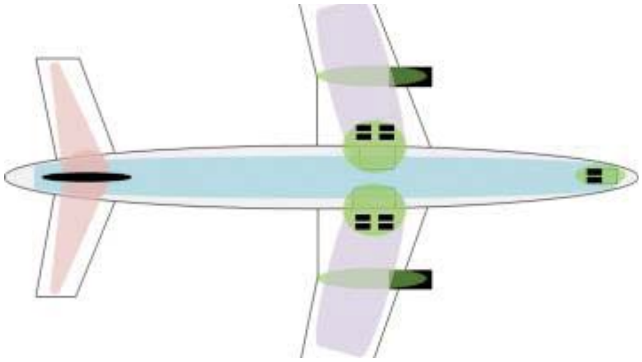

Figure 3. Zonal Clustered Senesing

This framework consists of multiple zonal clusters [9] of wired / wireless sensor nodes through which health data are acquired. An aircraft consists of multiple zones and multiple clusters of sensors like fuselage, engine, cabin pressurization, control surfaces, actuators, structural health monitoring etc. for data capturing. These sensor nodes inside the cluster communicate the acquired data to data concentrators wired or wirelessly depending upon application requirements.

The zonal data concentrator consists of edge computing capabilities where it immediately works on the raw data received to separate and prioritize useful data based on events or deviations. It converts the data to efficient storage format as per configuration and transmits it wirelessly over a virtual communication bus for distributed storage and processing. Data concentrators also get data from LRUs on board the aircraft, then update its format and send them for processing to a central vehicle health management computer (VHMC) over a virtual communication bus.

ITU Report ITU-R M.2283-0 express the similar idea to set up wireless transmission by aircraft compartments shown in figure below.

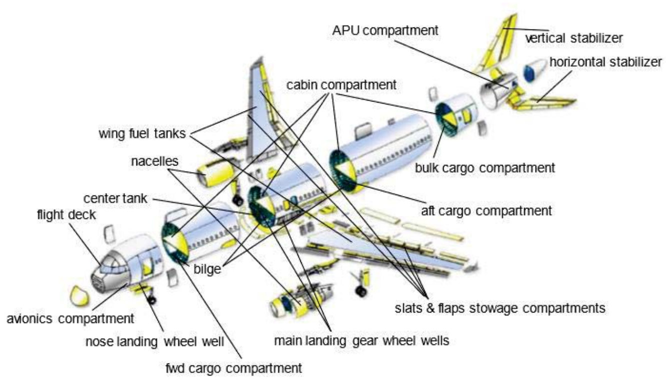

Figure 4. ITU Reports set up wireless transmission by aircraft compartments [2]

With a local processing idea, DIMA seems natural born with this zone clustered idea. Zonal data concentrator will locate all across the aircraft that could connect to aircraft computational resource more easily with DIMA architecture. For embedded computing applications in aerospace, Integrated Modular Avionics (IMA) are an important driver in achieving flexibility. With distributed avionics gaining new popularity as a way of achieving IMA, aircraft designers are taking advantage of recent advances in packaging to make distributed systems simpler and more cost-effective.

The zone cluster sensing architecture could be a wall breaker to sensing architecture divide by subsystem. The new idea is to gather sensor data wirelessly regardless which subsystem it belongs, just depend on the sensors' physical location, for example zonal data concentrator on wing can collect nearby flight control, fuel and structural sensor data all together wirelessly. In the future a good design could be combine zonal data concentrator with DIMA processing module which comprise a fully integrated sensing and edge computing [10] nod.

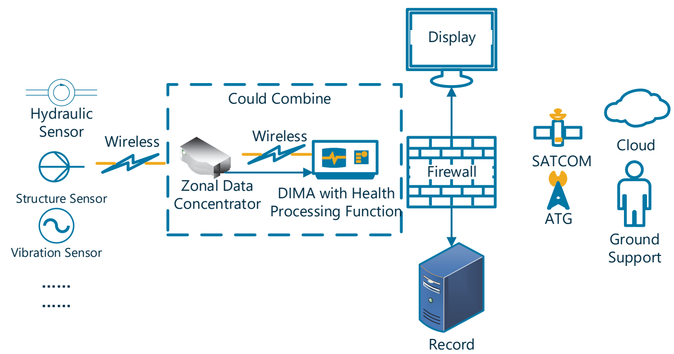

Figure 5. New sensing architecture

Currently, onboard health management function is achieved by on board maintenance system (OMS) hosted in IMA. introduced in [11]. The future usage of DIMA may create an opportunity to distribute some of the condition monitoring and performing fault diagnostic logic now done by Central Maintenance Function in OMS to local DIMA module which direct gathering the sensor data and processing it. In a word, what should be decentralized is not only the IMA hardware but also the health management software function itself. With rapid growth of computational capacity, more and more sophisticated machine learning diagnosis and predictive algorithm could be added to the onboard health management system.

As a starting point it is possible to demonstrate the wireless health management and DIMA architecture first with a half physical simulation platform like [12]

B. New Application—Internet of Thing (IoT)

Besides traditional sensor using for aircraft condition monitoring and health management. The new combined wireless and distributed sensor architecture will increase the commercial aircraft state awareness to a new level by allow more hardware connected into the aircraft avionic system which enables new applications such as IoT in the cabin.

The connected cabin will provide airlines, flight crews and passengers with significant benefits. For flight crews, it means that they can access an integrated platform which keeps pre-flight and real-time data in one place, while passengers will receive a more personalized travel experience. And for airlines, the platform would allow them to use the aggregated cabin equipment usage trends (of the connected elements) to perform predictive maintenance analytics over their entire fleet – thus improving the overall cabin service reliability, quality and performance on board all their aircraft. The platform will also allow wireless streaming to passengers and will enable airlines to host third-party applications for movies.

Airbus has proceeded with an IoT platform concept study for the cabin, known as the Airbus Connected Experience with three best-in-class partners: gategroup, Stelia Aerospace and Recaro Aircraft Seating – with more to join. The platform will link in real-time interconnected core cabin components, including the galleys, meal trolleys, seats, overhead bins and other cabin elements. As well as allowing data exchange throughout the cabin for the crew, it is also planned that consolidated information could also be uploaded to the Skywise cloud for subsequent trend analytics [13].

IV. CONSLUSION

Last year two significant merges happened in aviation industry. United Technologies Aerospace Systems purchase Rockwell Collins Avionics, followed by Safran merge with Zodiac Aerospace. Most analyzes focused on commercial effect of these activities, few people noticed the potential technical effect that could bring to the industry and the future aircraft design. After last year's two significant acquisitions the international commercial aviation supplier have converge to US two giants Honeywell, Collins Aerospace and Europe two giants SAFRAN, Thales. Each single giant could cover almost all aircraft systems. This result could make the supplier breaking the system wall to form a more unified sensing system like the zone clustered architecture in this paper.

For wireless sensing and transmission to provide feasible wireless links, the following issues have to be addressed properly [14]:

- Immunity to jamming signals (including unintentional interference).
- Interference to other on-board wireless systems.
- Interference between multiple wireless communications for different WAIC.
- Low detectability to unintended parties.
- The information content transmitted by WAIC should be encrypted so that even if the communication is intercepted and detected, it is hardly possible for the eavesdropper to break the encryption code to retrieve the information content.

Finally, the design of new architecture could induce huge changes in all systems, MBSE method [15] should be included in the design work.

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