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Comparative Study of Wireless Network Technology for Avionic Sensor-Actuator Networks

Industrial wieless communication Technology for avionic systems

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Abstract—**This paper compares the performance of wireless communication technologies to replace the wired networks by wireless networks on avionic sensor-actuator networks communication. Due to the drawbacks of the wired network, such as complexity, weight, maintenance cost and scalability, it leads to the high data rate and network traffic demands of avionics systems. Therefore, in WAIC(Wireless Avionics Intra-Communication) system suggested by ITU(International Telecommunication Union), based on environment of avionics system and requirements of a wired network, wireless network structures are defined to solve the problems of wired networks. In this paper, we consider features, advantages and disadvantages of wireless communication technologies which can be used for wireless avionics network, and we propose suitable wireless communication technology candidates for wireless avionics sensor-actuator networks in WAIC environments.**

Keywords— **Wireless networks, Avionic systems, High reliability, Real-time network, WAIC.**

I. Introduction

Avionic is the latest technology and use the safest parts and components to overcome extreme environmental changes. In addition, it use a reliable network-based management system that prevents, detects, and predicts all types of failures and eventually eliminates them[1][2].

The in-flight management system of avionic manages the entire operation of the avionic. In existing systems, all devices are connected through a wired network and proprietary interfaces and protocols are used. For this reason, the existing wired communication network satisfies the requirements of the avionic network, but the installation and management cost increases due to a large amount of wires and connection devices. In order to construct a wired network, many connectors are connected in a complex manner, and cable pairs are not properly connected during installation and maintenance. To solve these problems, the International Civil Aviation Organization (ICAO) and the International Telecommunication Union (ITU) are currently studying WAIC (Wireless Avionics Intra-Communication) technology standards and frequencies. In particular, considering the influence of radio interference in avionic, it is a similar technology to wireless LAN which is widely used in the room. However, considering the influence of electromagnetic interference, radio wave utilization technology that is higher than 22GHz band has been studied. In 2015, the ITU allocated 4.2 GHz to 4.4 GHz band as the communication frequency between avionics devices [3][4]. However, in consideration of future avionic requirements, the 5GHz band wireless network technology and the millimeter wave wireless network technology of 22GHz or more need to be studied.

However, current wireless network technologies are sensitive to radio interference, and there are problems such as reliability and real-time communication conditions required by avionic networks. Wireless network technologies applicable to avionic wireless networks include ultra-wideband frequencies such as IEEE 802.15.3c and UWB, allowing control of systems inside and outside avionic classified by WAIC. It is also possible to apply IEEE 802.11n and IEEE 802.15 WPAN (Wireless Personal Area Networks) as a service for each passenger on board. These wireless network technologies have been developed for industrial communication networks, sensor networks, mobile services, Internet of Things(IoT), and home network services. These technologies have advantages such as high data rate and wide transmission range but they do not satisfy the reliability such as stability and security compared to existing wired avionic sensor-actuator networks[5].

This paper is organized as follows. In Section II, we show the problems of the existing wired avionic sensor-actuator network. In Section III, we analyze the technology and requirements for the avionic network. In Section IV, the characteristics of the wireless network technologies based on the requirements for the avionic wireless network are analyzed and conclusions are described in Section V.

II. Problem Formulation

A. *Problem analysis of wired avionic networks*

The network architecture of A380, A400M, A350 is composed of wired backbone network with high data rate using AFDX (Avionics Full Duplex Switched Ethernet) to connect major end systems. It also connects subsystems to sensors and actuators using a wired data bus that provides low data rates such as ARINC429, MIL-STD-1553, and CAN. Table I shows the characteristics of typical wired avionic network technology[6][7]. These avionic wired network systems use proprietary interfaces and protocols. Such an in-flight management system has all the rights of system operation in the avionic. For example, the existing

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TABLE I. WIRED AIVONIC NETWORK TECHNOLOGY

	ARINC 429	MIL-STD 1553	AFDX
Data rate	0.1Mbps	1Mbps	100Mbps
feature	Messages consist of 32bit	Messages consist of 32bit	Messages consist of 32bit
	point to multi-point	half duplex transmission	A full-duplex, Switched Ethernet
	multi-drop bus with up to 20 receivers	Remote Terminal, Bus Controller, Bus Monitor	Support exchanged data using VL(Virtual Link) and policing mechanisms

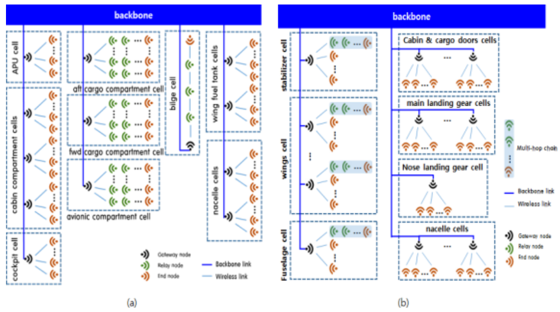

Figure 1. Network topology of WAIC system (a) Inside of the avionic (b) Outside of the avionic

avionic models A380 ~ 800 series, the maximum number of wired cable installation is up to 100,000, the total length is 470km. And the most important problem of wired network in avionic operation is weight of 5,700kg. And a weight of about 30% is added to the installation of the harness structure for fixing and installing the cable. Due to the structure of such a wired network, many connectors are complicatedly connected and the cable pairs are not correctly connected during installation and maintenance. The defects caused by deterioration of connectors and wires can cause fire risk or malfunction. This is not suitable for avionic systems that require high reliability because they can cause huge damage to small defects.

III. Requirements of WAIC Standard for Wireless Avionic Sensor-Actuator Networks

A. *WAIC(Wireless Avionics Intra-Communication)*

In World Radio-communication Conference (WRC) 2015, the next proposed Aero internal wireless communication network system is based on the exchange of information between avionic internal equipment using short-range wireless communication network. Currently, the International Civil Aviation Organization (ICAO) and the International Telecommunication Union (ITU) are studying the technical standards of avionic wireless networks, and in particular are examining the effects of radio interference in avionic. An avionic-type wireless network is similar to wireless LAN, which is widely used in buildings such as building offices recently, but there is a difference in that it uses safe radio waves in consideration of electromagnetic wave interference [3].

The avionic wireless communication network system is classified into the low-inside (LI), low-outside (LO), high-inside (HI) and high-outside (HO) to explain the network structure and the radius of wireless communication. The flight information of inside the avionic that requires a transmission rate of 10 kbps or less in various flight information is classified as LI (Low Inside), and external information necessary for steering such as proximity sensor and avionic structure sensor is classified as LO (Low Outside). The flight information which requires high data rates at inside of avionic such as digital voice communications, video cameras and video communication is classified as HI(High Inside). In addition to the above three categories, information which has high-data-rate at outside of avionic such as detecting sensors that work outside of avionic.

B. *Requirements of WAIC*

As shown in Fig. 1, the WAIC system consists of network topologies that are used inside and outside the avionic. In order to reduce the number of wired cables used to connect sensors and effectively cope with the increase of sensors, sensors and actuators configured for each function of the avionic are connected wirelessly with gateway nodes, gateway nodes are wired. In Fig. 1, The topology varies depending on the functional area of the avionic and also depends on the inside and outside of the airplane. This is due to the fact that each zone uses a suitable topology because the properties required by each zone are different. For example, a star topology may not be a problem for small areas inside an avionic, but a multi-star topology is used for compromises between reliability and data rate in larger areas. At this time, in order to connect the wireless communication network of avionic to the outside of the avionic body, it is necessary to consider the range of the radio wave appropriate to each part.

IV. Comparative Analysis of Wireless Network

A. *IEEE 802.11*

IEEE 802.11 is a protocol suitable for Wireless Local Area Networks (WLANs) that communicate at 900 MHz, 2.4, 3.6, 5, and 60 GHz bands. IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g have lower transmission rates than 100Mbps, and IEEE 802.11ah, which is recently attracted by long distance wireless communication, has a low transmission rate and uses a bandwidth of less than 1 GHz, It is difficult to apply it to wireless communication for avionic considering high-speed communication. Therefore, it is considered that IEEE 802.11n and IEEE 802.11ac, which have high transmission speed in the IEEE 802.11 series, are likely to be used for avionic wireless communication network technology. Unlike the previous series, IEEE 802.11n is widely used by increasing the transmission rate to 600Mbps by applying Multiple Input Multiple Output (MIMO). Also, it is widely used in existing industrial and telecommunication fields, so it can be said that performance and reliability are verified. The basic

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TABLE II. COMPARISON OF WIRELESS COMMUNICATION TECHNOLOGY FOR AVIONIC NETWORKS.

System	IEEE 802.11n	UWB	ECMA-368	IEEE 802.15.3c
Frequency (GHz)	2.4, 5	3.1-10.6	3.1-10.6	57-64 59-66 57-66
Bandwidth (Mhz)	20, 40	≥500	500~7680	7000
Maximum data rate (Mbps)	600	100, 200, 480	53.3~ 480	3000
Maximum transmission range (m)	~70	~10	~10	~20
Channel access method	DCF(CSMA/CA), CF(Polling)	TDMA or CSMA	TDMA or CSMA	TDMA
Modulation	BPSK/ QPSK/ 16, 64QAM	DSSS/ OFDM	QPSK/ DCM/ MB-OFDM	OFDM/SC-FDE

characteristics of IEEE 802.11n satisfy the requirements of speed, distance, and reliability, which are performance requirements of avionic wireless networks, and have the longest maximum transmission distance among short-range wireless communication technologies. IEEE 802.11ac supports multi-user multiple input multiple output (MU-MIMO), which improves reliability, coverage, and coverage in wireless communications and low power consumption. However, IEEE 802.11ac has a wide channel width of 80 MHz, but uses similar bandwidths to other technologies, making it more susceptible to RF interference from Wi-Fi channels. Also, since the 80MHz channel width is equivalent to using four 20MHz channels as compared with other series, routers using DCS (Dynamic Channel Selection) have a disadvantage that the selection of other channels is reduced [8].

Overall, it is expected to be most likely because the PHY layer is similar to the 5GHz band similar to the 4GHz band adopted by the ITU as IEEE802.11 wireless communication network suitable for WAIC. However, since the MAC layer uses the CSMA / CA scheme, it is difficult to guarantee real-time performance

B. *UWB(Ultra Wide Band)*

UWB (Ultra Wide Band) is a technology capable of operating in a wide frequency band and has a higher data transmission rate than IEEE 802.11n. It is possible to receive signals with a lower spectral density than other technologies, and thus has a high penetration power to be used for detection of mines and wall penetration in the past US military. In addition, interference can be reduced when using heterogeneous networks simultaneously. This has great advantages in the internal network environment of avionic composed of complex equipment. However, it is recommended to use it within the range shorter than the maximum transmission distance to maintain the reliability because it has a short transmission distance and the reliability is suddenly exceeded. Therefore, reliability within the available range can be said to be suitable for avionic wireless network system. In addition, it has the advantage of less influence on other communication networks and it is advantageous to overcome the complicated structure inside the avionic with high permeability. To utilize these advantages of UWB, there are various protocols such as IEEE 802.15.3a and IEEE 802.15.4a, and new protocols have been proposed to use existing protocols more efficiently [9].

C. *ECMA-368*

ECMA-368 is also one of the most promising network technologies for configuring wireless networks for avionic. ECMA-368 is WiMedia-compliant high-speed short-range wireless communication based on UWB, which has similar characteristics to UWB and is attracting attention as a next generation communication method. And is being used for AV streaming and docking devices by ultra-high-speed short-range wireless communication. The CSMA / CA scheme is highly available, but has the disadvantage of low timing accuracy and low reliability. This is somewhat difficult to satisfy the priority reliability in operating the avionic, but it cannot be excluded because it can be applied to the avionic wireless network by improving the reliability through the performance improvement. It is also applicable to passenger infotainment systems that require relatively high reliability in avionic networks [10].

D. *IEEE 802.15.3*

The standards that exist under the IEEE 802.15 WG range from IEEE 802.15.1 to IEEE 802.15.10 and include Bluetooth, mesh networking, body area networks (BAN), and wireless communication standards that provide near-field WPAN (Wireless Personal Area Networks) .

IEEE 802.15.3c is a high-speed uncompressed wireless transmission technology that is a next-generation wireless communication standard that was revised to support the IEEE 802.15.3 standard announced in 2005 to support 2Gbps or higher in the 60GHz band. And it is used for national intelligence agencies and military satellite communications because of its high security because of point-to-point communication. In addition, high data rate can be obtained and strong linearity, which is less influenced by interference from the surrounding environment. On the other hand, since the attenuation due to the oxygen molecules in the air is serious, the communication distance is short and the Line of Sight(LoS) and the directionality must be considered, which can be a great disadvantage in the construction of the avionic network. Although IEEE 802.15.3c has wide bandwidth and high security, it is concerned about serious deterioration and deterioration of quality due to visibility. However, if it can overcome such disadvantages, it is more applicable than the above technologies, is required.

IEEE 802.15.3c or ECMA-368 has a large difference in PHY layer, but it guarantees real-time performance in MAC layer and transmission speed is high. Therefore, when considering increasing requirements in the future.

We analyze each advantages and disadvantages to investigate the wireless network technologies that can optimize the environment of avionic wireless network according to WAIC standard. Table II shows the performance of representative wireless communication network technologies applicable to avionic wireless networks.

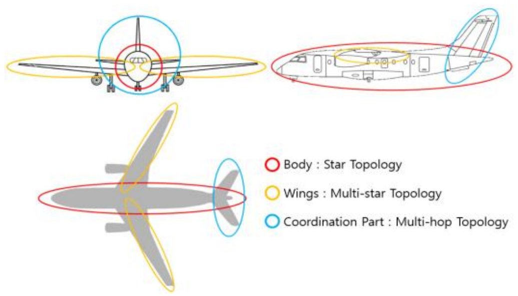

Figure 2. Wireless network topology of WAIC system.

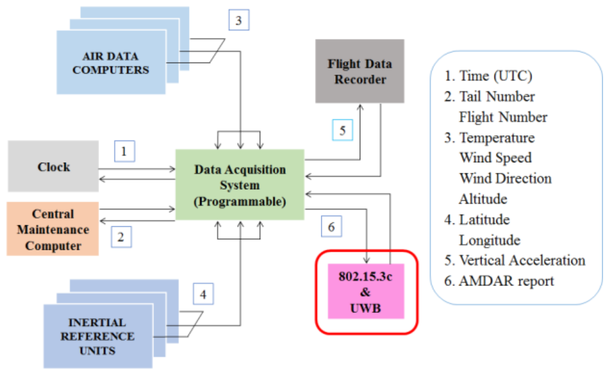

Figure 3. Avionic network structure for IEEE 802.15.3c and UWB.

V. Conclusion and Future Works

We have compared the advantages and disadvantages of each wireless network candidate technology for avionic wireless networks. In order to apply such technologies to avionic wireless networks, reliability and safety are the most important priorities. It is also necessary to consider the network structure required according to the classification of the applications classified according to the WAIC standard proposal. Fig. 2 shows the network architecture based on the WAIC standard. In the case of a narrow space such as a cockpit, adoption of a star topology structure is easy. For networks that occupy a large space, such as a room or a cargo compartment, a multi-star topology structure is advantageous for compromise between link reliability and data rate. In the area equipped with avionics equipment, serious scattering and attenuation of the radio wave is expected, so that the reliability can be reduced due to the network configuration through the multi-hop topology structure. Fig. 3 shows the position and propagation area of the cell installed in the external fuselage of avionic. The network should be classified into three areas: the body, the wing, and the steering surface. This classification only considers the data transfer rate and internal and external location. In addition, it is necessary to consider the characteristics of the channel to suit the avionic environment where the intended use is significant, such as the wing and the engine, the obstacle between the cockpit and the room, the landing gear, and the transceiver outside the fuselage.

Fig. 4 shows the structure of the wireless sensor-actuator communication network in the avionic using IEEE 802.15.3c and UWB technology. In this way, it is necessary to combine technologies requiring high data rates such as image and video streaming services in a wireless network

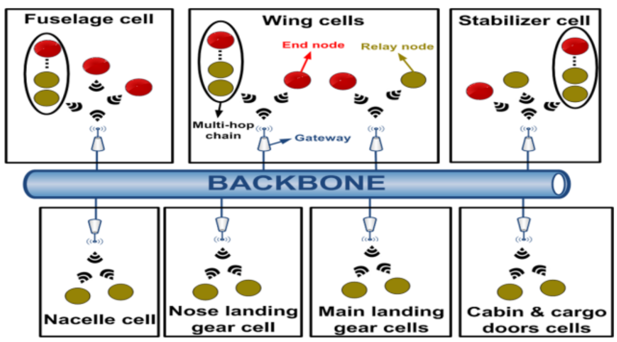

Figure 4. Network structure of categorized cells in WAIC system.

system for next generation avionic. It is important to select antennas that are optimized to meet the visible range conditions, such as IEEE 802.15.3c and UWB, technologies that use the 60GHz band, as in the comparison of the wireless network technologies described above.

Additional considerations are needed to apply technologies that are not optimized for avionic networks. Unlike the existing wired network environment, the wireless network environment minimizes the influence on the external and internal electromagnetic interference through EMI / EMC testing to prevent external interference and EMP attack in the case of the fighter, Should be selected. The second lowest error rate should be maintained. Especially in avionic sensor-actuator networks, small errors are directly linked to safety accidents. In the existing wired avionic network, the error rate is 10^{-9}, but the error rate of the existing wireless network technology is relatively higher than that of the wired network. Therefore, it is necessary to satisfy the error rate of 10^{-5}, which is the minimum error rate that can be realized by the existing wireless communication network technology. Third, reliability should be ensured through fault detection and recovery algorithms and real-time performance should be satisfied. Finally, due to the nature of the wireless network structure for avionic, it is an environment that is constructed inside the avionic. Since it is difficult to obtain the visible range due to the equipment and the wall, it is highly possible to apply the communication network technology having high penetration characteristics.

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