Journal of Intelligent Computing and Mathematics (ISSN Online: 2771-9952)
April 2022 Vol.1, No.1, pp. 17-26
DOI: https://doi.org/10.55571/jicm.2022.04013

4D Publishing Group

Aeronautical Communications

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Abstract. Aeronautical communications is a discipline covering the highly specialized and mission critical communications such as aircraft-to-ground, aircraft-to-aircraft, and aircraft-to-satellite. Recent changes in this field include: advanced satellite communications installations in aircraft, and very high frequency digital radio, and data link applications reporting aircraft position in transoceanic operations, as well as airline, air traffic, and passenger services. Because of such rapid changes in this field, it is critical to aviation safety that we have an expertise in satellite and data link communications, data link and aircraft surveillance applications, aeronautical communications network, HF and VHF data link, circuit mode and packet mode communications.

Keywords. Satellite communications; High frequency digital radio; Aeronautical communications network; Packet mode communications

Citation: Thakurta M. B., Das K. and Biswas K. (2022). Aeronautical Communications. Journal of Intelligent Computing and Mathematics, Vol.1, No.1, pp 17-26. https://doi.org/10.55571/jicm.2022.04013

Publication Date: 25 April 2022

1. Introduction

Continuing growth in regional and global air travel has resulted in increasing traffic congestion in the air and on the ground. The resulting congestion, which constrains expansion of the air transportation industry, inflicts schedule delays and decreases overall system efficiency, creating a pressing need to develop more efficient methods of air traffic management (ATM). As these methods become more advanced and increase in complexity, the requirements for information generation, sharing and transfer among the relevant entities in the ATM system increase dramatically. However, current aeronautical communications systems will be inadequate to meet the future information transfer demands created by these advanced ATM systems. Therefore, the NASA Glenn Research Centre is undertaking research programs to develop communications methods and key technologies that can meet these future

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requirements. As part of this process, studies, workshops, testing and experimentation, and research and analysis have established a number of research and technology development needs. The purpose of this paper is to outline the critical research and technology needs that have been identified in these activities and explain how these needs have been determined.

2. Wireless Aircraft Cabin Management

The application that this research builds on is the Cabin Management System (CMS) of an aircraft, which is the network of most of the electronic devices inside the passenger section of an aircraft cabin. It is present in every airliner and is a major system in the aircraft. The complexity varies from reduced features in single aisle aircraft, for instance the A320, to complete systems like those in the A380 with section control, enhanced climate control or flight status displays. To follow the approaches in this research, this chapter describes the CMS and the need to develop a wireless CMS. The wireless aircraft cabin system operating in the 2.4 GHz ISM band and uses cognitive radio techniques to increase system robustness by actively and dynamically avoiding interfering signals in the same frequency band. The implementation of the basic cognitive radio functions spectrum sensing, policy enforcement and decision making, as well as their integration on a software defined radio platform together with the communication functions [1].

The network topology of a commercial aircraft uses a hierarchical structure. From the CMS server several main lines stretch throughout the cabin. Two types of main lines exist, the Passenger Line, which serves passenger related services and the Crew Line, which only handles crew and aircraft systems. The schematic of the Wireless Cabin architecture is given in Figure 1.The hardware and software for both lines is nearly identical. Both use 10 Mbit/s Ethernet full-duplex transmissions and a proprietary MAC protocol. This is due to the variation in expected traffic of the different end device types. The Passenger Line forwards mostly data from the server to the end devices; most significant are the audio channels. The Crew Line is designed to support additional end devices and a greater amount of bidirectional traffic, for instance crew intercom phones. There is usually more than one Passenger Line and Crew Line, depending on the aircraft size. A large aircraft can have two Passenger Lines for the left, centre and right cabin area, which is in total six Passenger Lines. Each line has a number of switching nodes, which are called in this work PAX-SN for the Passenger Line and CREW-SN for the Crew Line. **CMS trends** In current aircraft, the electronic equipment in the cabin requires three types of networks: the CMS network, a separate Inflight Entertainment System (IFE) network and the power distribution system. All networks have different DAL categories.

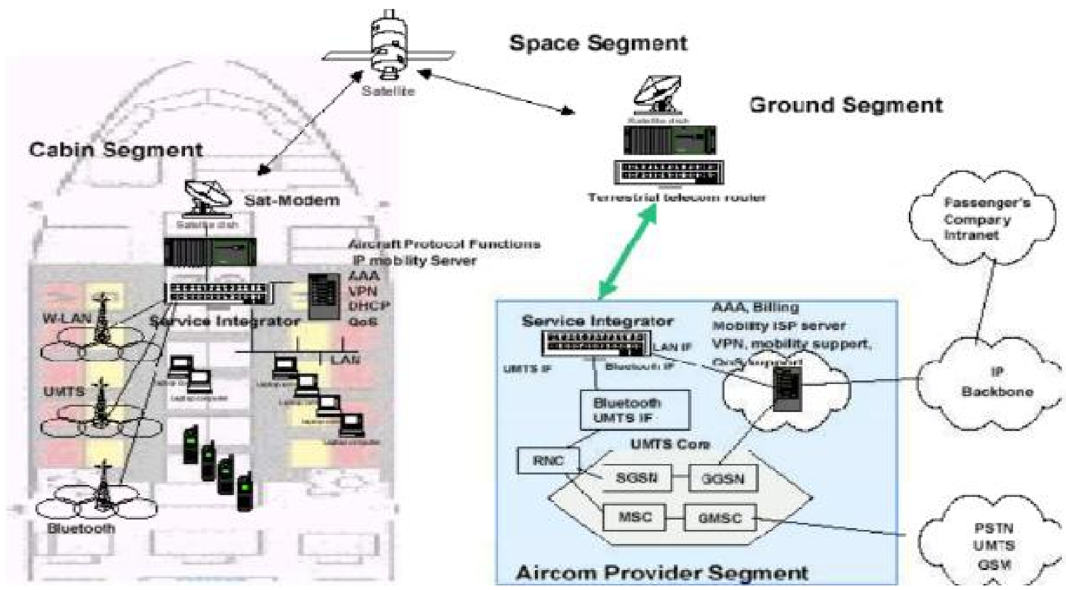

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Figure 1. Wireless Cabin architecture.

Full-IP The possibility of using Ethernet and Internet Protocol (IP) com10 communication with an event-based application protocol is being investigated. An event driven approach requires much less network utilization and additional services can be included in the network.

Hybrid The hybrid approach is an extension of the existing implementation to support IP packets. Instead of using a 10 Mbits/s interface, a 100 Mbits/s will be used.

Power-over-data Combining the communication network and power distribution network reduces the complexity, maintenance effort and weight of an aircraft.

Data-over-power Same reasons as for power-over-data, but it is technologically more challenging.

2.1. Wireless communication

Reduction of cable harness, flexibility of cabin design and device localization are only some advantages of wireless communication. The different approaches can be combined, especially the full-IP and wireless concept with power-over-data or data-over-power. All approaches, including the existing system, have in common a server at one end of the aircraft and several main communication lines along the aircraft. A number of switching nodes are placed along each line, which connects to the end devices. For a wireless enhancement this basic infrastructure with a server, backbone lines and switching units can be assumed.

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2.2. Wireless system requirements, criteria and policies

As the use of wireless networks on-board aircraft is a new field, the capabilities and risks of the technology still need to be worked out. No strict requirements catalogue exists. The research is done in close cooperation with Airbus and the requirements definitions are part of the project. Wireless technology is the most astonishing area in Communications and Networking. Emergence of a variety of standards for Wireless Communication Networks in culmination with advances in Radio Access Technologies offer better range, greater capacity, improved Quality of Service (QoS) and many more things, while reducing energy consumption and deployment costs, paving the way for new applications and services in mobile broadband access [3].

However, the project has two fundamental objectives. The first one is to get the certification for the wireless system. This is a must. It has however proven to be very difficult to get details on the requirements that make a system certifiable. In the past, systems with at least DAL-C classification were completely deterministic, at least for the cabin communication. It had to be shown that for a worst-case scenario the system will not fail.

There is a strong tendency from aircraft designers and airlines to use standard products and components, for example IP protocols or standard Ethernet devices. This often is in direct conflict with the determinism demands from the certification. The strategy of this work is to use as many standard components as possible to create a reliable and robust wireless communication system. However, these are not part of this work.

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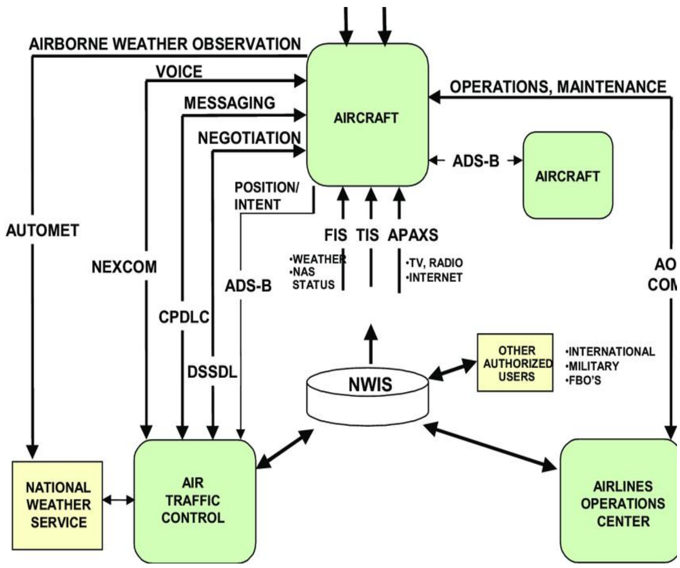

Figure 2. Functional-aeronautical-communication-system-architecture.

The second target is to have the same performance for the wireless system, as for existing wired CMS. So the design goal of the wireless performance is to match the existing systems. The functional-aeronautical-communication-system-architecture is described in Figure 2. Further, the use of fly-by-wire technology for aircraft flight controls have resulted in an improved performance and reliability along with achieving reduction in control system weight. Implementation of full authority digital engine control has also resulted in more intelligent, reliable, light-weight aircraft engine control systems. The first step towards fly-by-wireless control systems is likely to be the introduction of wireless sensor networks (WSNs)[2].

2.2.1. Address Space

In the current CMS with a proprietary time deterministic protocol each single sign or button is seen as a port. In a mid-size aircraft with about 190 PSUs with 16 ports each and 15,118 light modules and some extra devices, the system support more than 18,400 ports. However, for the new CMS a new application protocol and an IP protocol is assumed. Thus, many components will be grouped with a common address. A rough estimation for this case can be seen in Table 1. From Table 1 one can clearly see that the number of wireless devices becomes very large. An A380 or A350 cabin has dimensions of about 60 × 6 m. Even without IFE there would still be 1000 nodes on 360 m^2. The A380 has two decks, thus the node density and interference become even worse.

Table 1. Number of devices for an A350 like aircraft

Unit type	Number	Description
PSU	190	170 seat groups, 20 additional for crew rest, galley, lavatory, etc.
Cabin sensors	200	Estimation; currently an aircraft has seventy smoke detectors
Cabin illumination	400	Estimation; single deck aircraft has about 300 illumination units for the cabin without door area and galley lighting
Video surveillance cameras	25	
Crew adapters	20	Crew related devices
FAPs and mobile devices	20	
Extra devices	50	Various signs, buttons, etc.
In-flight entertainment	555	One per seat
Total:	**1460**	

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2.2.2. Delays

There are strict constraints on the delays in the CMS. This is due to two reasons: undistracted passenger announcements and synchronized playback.

Table 2. Delay requirements for the CMS

Unit type	Number	Description
PSU	190	170 seat groups, 20 additional for crew rest, galley, lavatory, etc.
Cabin sensors	200	Estimation; currently an aircraft has seventy smoke detectors
Cabin illumination	400	Estimation; single deck aircraft has about 300 illumination units for the cabin without door area and galley lighting
Video surveillance cameras	25	
Crew adapters	20	Crew related devices
FAPs and mobile devices	20	
Extra devices	50	Various signs, buttons, etc.
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Total:	**1460**	

The first reason requires a short delay between speaking into the microphone and the actual playback in the speakers. The second reason requires a synchronized playback of the speakers in the cabin to obtain a clear voice and no hall effect. Table shows requirements on timing delays specified in.

2.2.3. Ultra-Wide-Band Technology

UWB is a signal form first used for radar applications in the late 1960's. At that time there was work done on UWB communication systems, but they did not become widely used until some years ago. In 2002 the Federal Communications Commission (FCC) (regulatory agency in the US) has specified the signal characteristics and power limits of UWB for communication. The frequency range and power levels from UWB and other technologies is presented in Figure 3.By definition an UWB signal has an emitted signal bandwidth of at least 500 MHz or 20% of the center frequency. Compared to other systems, such as Wi-Fi or mobile phone networks, which usually have cohesive bandwidth of less than 100 MHz, UWB has much more frequency resources but also brings with it new challenges.

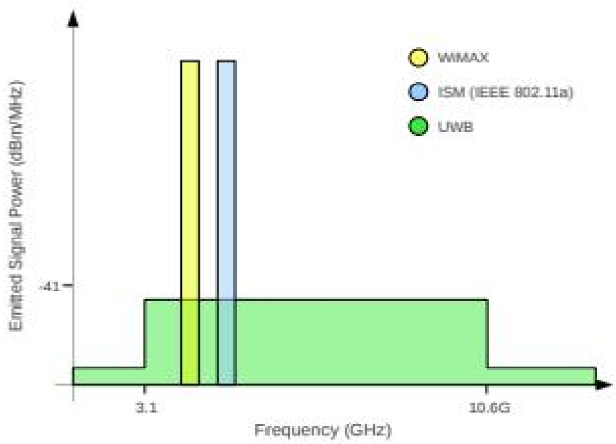

Figure 3. Frequency range and power levels from UWB and other technologies.

3. Overview of Wireless Communication Standards

3.1. Transparent wireless communication

As pointed out in the previous paragraph, the wireless components need to be compatible with wired

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components. The additional devices or protocols from the wireless system shall not effect the application layers. No differences for the system or users must be perceptible.

3.2. Fail-safe and redundant

Since the speakers are DAL-C components, the wireless system must be fail-safe and redundant. The exact requirements are not defined, but the maximum possible reliability shall be implemented.

3.3. Overview of wireless communication standards

Space internet protocol SCPS-TP was used in satellite communication system Based on the Vegas congestion control used in space internet protocol SCPS-TP, learning from the congestion window growth strategy in slow-start phase of TCP Hybla protocol, modifying the threshold changes of congestion window and slow start when occurring packet loss and timeout, an improved Vegas strategy that is more fit for satellite communication [4]. SCPS-TP is a transport protocol for space communications, and it is suitable for satellite networks. Theory analysis and simulation experiments have been made to evaluate the performance of SCPS-TP in LEO satellite networks[5].Many common standards with respect to their transmission range and maximum data rate. As the standards exist in many variations, a clear categorization is not easy. The most common range and data rate parameters of common systems are shown. The planned audio and video content requires a standard with moderate data rates. The low data rate technologies, such as Bluetooth, DECT, ZigBee or other wireless sensor network protocols do not provide capabilities for several video and audio channels in the aircraft scenario. The remaining technologies are summarized in the following, with focus on the aircraft related environment:

ECMA-368 The ECMA-368 standard, defined by the WiMedia alliance, is an UWB technology supporting up to 1024 Mbit/s. It has 14 non-overlapping channels and uses a Time Division Multiple Access (TDMA) channel access. The transmit range is about 10 m and no infrastructure is required to operate the network.

UMTS and LTE The modern cellular phone networks can also provide good data rates. The maximum transmission range of the technologies is larger than needed, but pico or femto cells have shown, that they can also be used in small areas. One problem with this technology is the frequency management, since it requires dedicated bands for the aircraft usage.

IEEE 802.11a/g The Wi-Fi technology, commonly known from wireless networking with laptops, achieves up to 54 Mbit/s in the 2.4 GHz and 5 GHz ISM bands; hence it is free of any frequency regulation. The infrastructure and ad-hoc modes allow easy and flexible usage with transmit ranges of 40 m indoor and 140 m outdoor. Originally IEEE 802.11a/g had 11-13 channels (depending on the country), but for IEEE 802.11g the channels are overlapping with only three non-overlapping channels available.

IEEE 802.11n is the most recent Wi-Fi standard. It uses Multiple Input, Multiple Output (MIMO) techniques and achieves up to 600 Mbit/s, thus it has similar data rates as WiMedia. But still it works in the ISM bands and requires a large amount of the total available resources when operated with 600 Mbit/s.

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	ECMA-368	IEEE 802.11n	IEEE 802.15.3c
Traffic density (Mbit/s/m^2)	2.4	1.4	16
Product availability in about 3 years time (from 2006)	Good	Very good	Products are likely
Signal characteristics	Good propagation in aircraft; many resources available	Good propagation in aircraft; few resources	Requires LOS
Expected interference	Little interference due to spatial containment	Many interference from other systems on ISM bands	Little interference due to spatial containment

Figure 4. Study of wireless protocols for aircraft

IEEE 802.15.3cprotocol is one of the first 60 GHz standards. It achieves up to 3 Gbit/s and has a transmit range of 10 m. The disadvantage of 60 GHz communication is that it is strictly Line of Sight (LOS). Obstacles and moving objects can heavily influence the signal quality.

WiMAX is an emerging technology that has similar capabilities as cellular phone networks in terms of range and data rate; but the focus is on data packets, not phone calls. For the aircraft scenario it suffers from the same problems as UMTS or LTE. Furthermore, the availability of this technology and the availability of any future mass market production.

3.4. Wireless CMS Architecture

A wireless cabin network can be implemented in different ways. This section describes the design of the UWB network and the design of the complete aircraft cabin network. The aircraft cabin network is a large system composed of multiple sub-networks.

3.4.1. Architecture concepts

With ECMA-368 as the protocol of choice two general approaches for the network topology are possible. The first approach (full-wireless) would have a completely wireless network and infrastructure. Near to the aircraft server one or more gateways provide the access from the server, or wired aircraft network, to the wireless network. The wireless network can either be a fully meshed topology, just composed of the end devices themselves. Transmissions are routed on multiple hops from the gateways to the end devices. Alternatively, it would also be possible to create an overlay network with relay nodes that have two UWB transceivers: one to communicate to the end devices and a second to build an overlay network between the relays and gateways. The second approach (AP-based) is a combination of a wired backbone network and several Access Points (APs) throughout the cabin. The APs serve as gateways from the wired backbone to the wireless network. The concept is similar to the usage scenario of Wi-Fi APs for office environments. The first approach has some drawbacks. First of all it provides a bottleneck close to the gateways. All traffic must be routed over the gateways, which will have the highest traffic density. With the AP-based solution, the APs will serve some wireless end devices and are connected to a high speed wired network, which could be a Gbit/s connection or optical fibre. Thus, the highest data density would be in the wired network, which is assumed to have higher capacities. Second drawback is the frequency management for the full-wireless concept. The completely meshed topology requires all nodes to operate on the same channel, which results in more nodes per channel and a low bandwidth per end device. With the wireless relay topology frequency diversity can be used, but one channel must be reserved for the relay channel (or wireless backbone). Both solutions are less efficient than the AP-based approach, where neighbouring APs can have different channels. The overall throughput of the network increases; hence the AP-based approach is preferred and used as a foundation of this work.

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3.4.2. Backbone based system

Wireless communication systems inside aircraft cabins can be disturbed more easily than wired systems. This can be natural interference from the devices in the environment, blocked frequencies in specific countries, devices with the same technology or even hostile attacks. To increase the availability and reliability of the wireless communication a second independent interface is foreseen. It should use a different physical transmission scheme. Possible candidates are optical or 60 GHz systems.

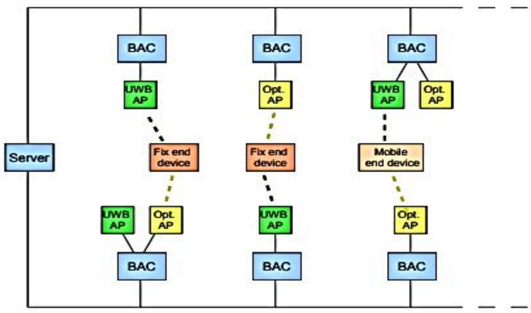

Figure5. Wireless CMS system. The BACs are connected to the server by backbone lines. The UWB and optical Aps are linked to the BACs. End devices have an UWB and optical transceiver

3.4.2.1. Node density

When defining a new wireless transmission standard there will always be conflicts as parameters have to be agreed and fixed. This will result in hard limitations to the performance. Dynamic parameters will increase the complexity and indeterminism of the protocol. An example of dynamic mechanisms is the use of Carrier Sense Multiple Access (CSMA). The nodes can access the channel when it is free, without any coordination. The disadvantage is the possibility of collisions. In a coordinated Time Division Multiple Access (TDMA) network collisions hardly occur since the access is coordinated. Therefore decisions such as timing the access, number of data slots or number of reservations have to be harmonized. The ECMA-368 uses a TDMA access with a beaconing mechanism. Several fixed parameters create a strict limitation for the number of nodes in the network. For the aircraft scenario a high node density can be expected, depending on the amount of systems using wireless connections.

3.4.3. Communication with ATC

Controller–pilot data link communications (CPDLC), also referred to as controller pilot data link (CPDL), is a method by which air traffic controllers can communicate with pilots over a datalink system.

The standard method of communication between an air traffic controller and a pilot is voice radio, using either VHF bands for line-of-sight communication or HF bands for long-distance communication (such as that provided by Shanwick Oceanic Control).

One of the major problems with voice radio communications used in this manner is that all pilots being handled by a particular controller are tuned to the same frequency. As the number of flights air traffic controllers must handle is steadily increasing (for instance, Shanwick handled 414,570 flights in 2007, an increase of 5% - or 22,000 flights - from 2006), the number of pilots tuned to a particular station also increases. This increases the chances that one pilot will accidentally override another, thus requiring the transmission to be repeated. In addition, each exchange between a controller and pilot requires a certain amount of time to complete; eventually, as the number of flights being controlled reaches a saturation point, the controller will not be able to handle any further aircraft.

Traditionally, this problem has been countered by dividing a saturated air traffic control sector into two smaller sectors, each with its own controller and each using a different voice communications channel. However, this strategy suffers from two problems: (i) Each sector division increases the

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amount of "handover traffic". That is the overhead involved in transferring a flight between sectors, which requires a voice exchange between the pilot and both controllers, plus co-ordination between the controllers. (ii) The number of available voice channels is finite, and, in high density airspace, such as central Europe or the Eastern US Seaboard, there may not be a new channel available.

3.4.4. Use of CPDLC

Controller–pilot data link communication (CPDLC) is a means of communication between controller and pilot, using data link for ATC communication. At the highest level, the concept is simple, with the emphasis on the continued involvement of the human at either end and the flexibility of use.

The CPDLC application provides air-ground data communication for the ATC service. This includes a set of clearance/information/request message elements which correspond to voice phraseology employed by air traffic control procedures.The pilot is provided with the capability to respond to messages, to request clearances and information, to report information, and to declare/rescind an emergency. The pilot is, in addition, provided with the capability to request conditional clearances (downstream) and information from a downstream air traffic service unit (ATSU). A “free text” capability is also provided to exchange information not conforming to defined formats. An auxiliary capability is provided to allow a ground system to use data link to forward a CPDLC message to another ground system.

The sequence of messages between the controller and a pilot relating to a particular transaction (for example request and receipt of a clearance) is termed a ‘dialogue’. There can be several sequences of messages in the dialogue, each of which is closed by means of appropriate messages, usually of acknowledgement or acceptance. Closure of the dialogue does not necessarily terminate the link, since there can be several dialogues between controller and pilot while an aircraft transits the ATSU airspace.

All exchanges of CPDLC messages between pilot and controller can be viewed as dialogues.

The CPDLC application has three primary functions: the exchange of controller/pilot messages with the current data authority, the transfer of data authority involving current and next data authority, and downstream clearance delivery with a downstream data authority.

Simulations carried out at the Federal Aviation Administration's William J. Hughes Technical Center have shown that the use of CPDLC meant that "the voice channel occupancy was decreased by 75 percent during realistic operations in busy en route airspace. The net result of this decrease in voice channel occupancy is increased flight safety and efficiency through more effective communications." The current trends in the area of aeronautical passenger communication toward personal and wireless in-cabin communications and multimedia data networks. Technological challenges are summarized as well as market potentials and regulatory issues [6]. The current trends in aeronautical spectrum management followed by the major applications and contributions of cognitive radio in solving the spectrum scarcity crisis in the aeronautical domain. Also, to cope with the evolving technological advancement, researchers have prioritized the issues in the case of cognitive radio that needs to be addressed depending on the domain of operation. The proposed cognitive aeronautical communication systems should also be compliant with the Aeronautical Radio Incorporated and Aerospace Recommended Practice standards [7].

4. Conclusion

Current trends are towards high data rate communication services, in particular Internet applications. In an aeronautical scenario global coverage is essential for providing continuous service. There-fore satellite communication becomes indispensable, and together with the ever- increasing data rate requirements of applications, aeronautical satellite communication meets an expansive market. Wireless Cabin (IST -2001-37466) is looking into those radio access technologies to be transported via satellite to terrestrial back-bones.

The project will provide UMTS services, W-LAN IEEE 802.11 b and Blue tooth to the cabin passengers. With the advent of new services, a detailed investigation of the expected traffic is necessary in order to plan the needed capacities to fulfill the QoS demands. This paper will thus describe a methodology for the planning of such system.

In the future, airliners will provide a variety of entertainment and communications equipment to the passenger. Since people are becoming more and more used to their own communications equipment, such as mobile phones and laptops with Internet connection, either through a network interface card or dial-in access through modems, business travelers will soon be demanding wireless access to communication services.

Conflicts of Interest

The authors indicate that they have not received any research funding, direct or indirect financial support, or any other assistance. They also declare that there is no conflict of interest.

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