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Views & Comments

Aeronautical Mobile Communication: The Evolution from Narrowband to Broadband

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1. Introduction

Air transportation is the driving force for national or regional economic development and industrial upgrading, and the aeronautical communication system (ACS) is a core infrastructure of the air transportation system (ATS), ensuring safety and a high level of efficiency. With the fast development of global ATSs, various aviation fields including air traffic control (ATC), airline operation control (AOC), and airline passenger communication (APC) have introduced higher requirements for aeronautical communication capability. However, due to outdated technologies and application barriers, the current ACS has reached its theoretical limit in terms of efficiency and data rate, and thus cannot accommodate the surging demands of diversified aeronautical communication services, such as large bandwidth, high reliability, and global coverage. According to the consensus of the global aviation community, promoting the development of the ACS from narrowband to broadband has become an inevitable choice for modern ACS construction, as well as being necessary for aviation operation safety, efficiency, and service improvement.

In recent years, with the rapid pace of technological innovation in wireless mobile communication—such as fifth-generation (5G) or beyond 5G wireless communication, satellite communication, as well as artificial intelligence (AI) technology—new possibilities are available for a future ACS paradigm shift. As the key means of ensuring safe and efficient aircraft operation, the ACS has typical characteristics in terms of technical requirements, business scenarios, and policy in comparison with other communication systems. Therefore, the development of aeronautical broadband communication (ABC) has specific challenges. This paper identifies key barriers in the development of an ABC system while considering the unique features involved, proposes promising technical strategies, and puts forward the concept of a new-generation ABC system based on the idea of a space–air–ground integrated network. Suggestions on the future development and application of the new-generation ABC system are also provided.

2. Features and barriers of ABC

An ACS is a kind of customized mobile communication system with distinctive features such as global coverage, high levels of mobility and reliability, as well as diversified services and scenarios. On the one hand, according to graphical scenarios, ACSs fall into three categories: ACSs in an airport area; ACSs in a continental area; and ACSs in an oceanic or remote area. These three categories cover all flight phases including taxiing, takeoff, enroute, landing, and parking. On the other hand, the communication services provided by an ACS are often categorized into ATC, AOC, and APC, among others [1].

At present, the aeronautical mobile airport communication system (AeroMACS) provides broadband services and is an alternative approach to air-to-ground narrowband communication systems for airport communication [2,3]. To further improve the enroute data rate, the Federal Aviation Administration and EUROCONTROL have jointly proposed the L-band digital aeronautical communication system (LDACS) [4,5]. Moreover, to provide robust data services for in-cabin communications, tests and verifications have been actively carried out for an air-to-ground (ATG) communication system based on 3G/4G wireless broadband technologies [6]. Furthermore, the International Maritime Satellite Organization plans to use K_a-band communication satellites in the 5G maritime satellite system in order to realize global broadband access services. To sum up, the new-generation ABC is an irresistible trend. However, many technical challenges remain to be solved in order for ABC to come to fruition.

(1) High-rate ATG communication with limited spectrum resources. Emerging aviation-related businesses, such as the intelligent interconnection of large-scale devices in smart airports, real-time airport video monitoring, real-time data collection and monitoring by the onboard flight data recorder, and inflight internet services for passengers, have led to higher requirements for communication capacity. However, aeronautical communication capacity is restricted by the limited dedicated spectrum. For example, the allocated frequency band for AeroMACS is 5091–5150 MHz, while LDACS is facing a dilemma of insufficient

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frequency resources. As a result, the question of how to achieve high-rate and large-capacity data transmission under a limited bandwidth becomes the problem to be solved at first in ABC.

(2) Secure and reliable communication in a highly dynamic and complex electromagnetic environment. Air traffic is closely related to passengers' physical safety, so ACS has extremely strict requirements for safety and reliability. Nevertheless, the flight altitude of an aircraft constantly changes during the takeoff and landing phases, and the cruising speed is up to 1000 $km \cdot h^{-1}$. Therefore, the ATG communication channel state changes rapidly and the Doppler effect is obvious. In addition, various radio devices with the functions of communication, navigation, and surveillance are densely installed within the limited space of each aircraft. For example, at least 30 antennas need to be installed in a Boeing 777 aircraft. As such, the airborne electromagnetic environment is complex, creating problems such as adjacent-channel, co-channel, out-of-band, and intermodulation jamming, among others. The question of how to support reliable ATG communication in a highly dynamic and complex electromagnetic environment is another challenging problem to be solved in ABC.

(3) Low-latency seamless communication for global wide-area flights. ACS should have global wide-area coverage capabilities for the global flight of aircraft. Furthermore, the introduction of the four-dimensional trajectory-based operation concept requires aircraft to have time-control capability with second-level accuracy, which results in higher requirements for the real-time performance of command-sharing. However, during the cruise period, aircraft are far away from satellite or ground communication infrastructure. Therefore, the question of how to maintain continuous and low-latency communication capabilities during a high-speed, long-distance flight is an essential technical challenge for ABC.

(4) Multi-scenario and multi-service adaptive fusion communication. Different types of aircraft such as manned and unmanned aircraft, different types of flight activities such as commercial aviation and general aviation, and different applications such as ATC, AOC, and APC are mixed together, creating diversified performance requirements for ABC. Consequently, the question of how to provide communication services with adaptive performance requirements under various types of flight activities and business scenarios is another open issue in ABC.

3. Technical strategies for new-generation ABC

Promising technologies to address the aforementioned challenges affecting ABC are distilled in some detail as follows.

(1) Develop efficient spectrum utilization technology to solve the problem of high-rate ATG communication with limited spectrum resources. New-generation 5G/beyond 5G air interface technologies—including emerging modulation, coding, and multiple access technologies [7]; massive multiple-input–multiple-output technology [8]; full-duplex communication; and physical expansion technologies for wireless transmission, such as reconfigurable intelligent surfaces [9]—can effectively solve the problem of limited spectrum resources in ACS. In addition, the integration of communication, navigation, and surveillance enables spectrum reuse between communication, navigation, and surveillance systems. Moreover, cognitive radio allows the full utilization of any idle spectrum in order to improve spectrum efficiency. However, due to the flexible and dynamic characteristics of ACS, the transmission environment is complex and time-variant, making it difficult for conventional spectrum allocation and access schemes to ensure efficient spectrum utilization. To solve this issue, AI technologies such as machine learning can realize intelligent spectrum allocation, which is a promising candidate to support high spectrum efficiency in ABC.

(2) Carry out anti-jamming and airworthiness compliance technology to address the challenge of secure and reliable communication in a highly dynamic and complex electromagnetic environment. To address the problem of highly dynamic environment in ACS, time-frequency synchronization technology can enable the anti-frequency offset of ATG communication. Furthermore, strong pulse-jamming elimination technology based on compressed sensing and wavelet transform can effectively solve the anti-jamming problem in a complex airborne electromagnetic environment. For the new-generation avionics system, breakthroughs in basic theory and key technologies for airworthiness compliance verification and certification are more than necessary to support the development of airborne broadband communication avionics [10].

(3) Develop space–air–ground integrated ACS to solve the problem of low-latency and seamless communication in global wide-area flights. Bringing advantages such as dynamic networking and self-organization [11], an aircraft air-to-air communication network, together with an ATG data network and an aviation mobile satellite communication system, can form a space–air–ground integrated network, which can support seamless global coverage. The space–air–ground integrated network [12] has a complex architecture that includes multiple communication systems in space, in the air, and on the ground. Each system includes many nodes with different capabilities. Therefore, it is essential to design safe, reliable, and efficient network interfaces and communication protocols to ensure that information is smoothly transmitted among different systems when aircraft are switching among systems. Some nodes are highly dynamic; therefore, low latency, high efficiency, a robust network structure, and flexible node networking mechanisms are important to deal with the frequent handover of space-based access nodes.

(4) Design heterogeneous aviation networking intelligence technologies to overcome the problem of self-adaptive fusion of diversified scenarios and services. The ABC system involves multiple types of heterogeneous communication networks, such as satellite communication, airport surface communication, and ATG communication. The use of digital sensors, smart terminals, holographic optical transmission, and 5G, AI, and other key technologies of intelligent networking [13] are required for the design of a safe, reliable, stable, and efficient network interface that can realize the interconnection and intercommunication of heterogeneous networks and protocol conversion between new and old communication systems. 5G core network technologies [14] such as network function virtualization and network slicing can dynamically manage heterogeneous network resources to adapt to different business needs and meet different quality-of-service requirements, while edge computing, AI, and other technologies can further comprehensively optimize aircraft mobility management and other services.

4. The concept of the new-generation ABC system

The new-generation ABC system is expected to provide services with universal coverage and seamless connections through an integration scheme of space-based, air-based, and ground-based platforms built on a space–air–ground integrated network. As shown in Fig. 1, the space-based platform consists of high-/medium-/low-earth-orbit satellite networks. The air-based platform includes an airborne avionics system as well as aeronautical ad hoc networks, and the ground-based platform covers ground stations, airport communication systems, and so forth.

The new-generation ABC system is expected to meet the requirements of all flight phases. It should provide reliable broadband data links and enhanced application to air traffic controllers, airlines, airports, passengers, and unmanned aerial systems, among

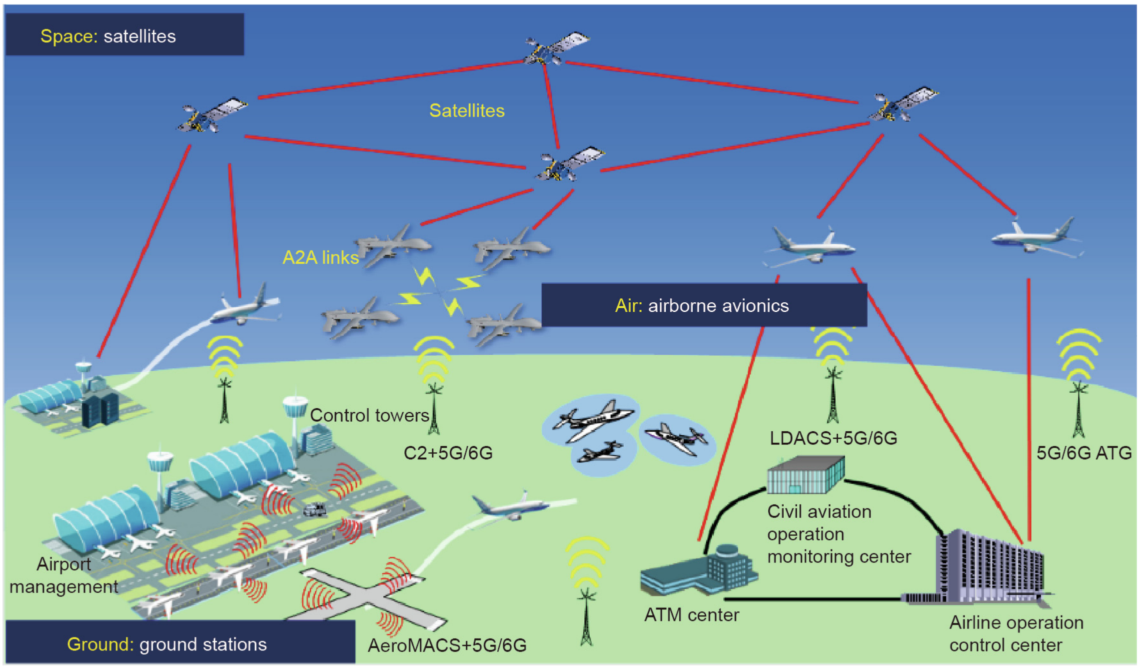

Fig. 1. The system architecture of the new-generation ABC. A2A: air-to-air; ATM: air traffic management; C2: command and control.

others. Moreover, it is intended to support the realization of smart civil aviation under various scenarios in the future. These scenarios include: ① a smart airport consisting of a transport system with unmanned airport vehicles, a smart taxiing guidance system, and an insensible security check for passengers; ② a smart ATC covering four-dimensional flight right-on-time arrivals, autonomous air traffic operation, and the integrated operation of manned/unmanned aircraft; and ③ smart airlines with intelligent piloting, smart passenger services, and smart logistics systems.

5. Conclusions and suggestions

Taking a panoramic view of global technological development, the accelerative integration of new-generation mobile communication technologies within the ACS will stimulate its self-renewal and intergenerational development. As this article has highlighted, ACS has extremely high requirements of airworthiness, security, and standardization, which call for appropriate top-level design and scientific planning for the development and application of the new-generation ABC system in the future.

(1) Design the development path of new-generation ABC. Because of the differences in the various levels of airworthiness requirements, it is suggested that the application of ABC services follow a step-by-step approach; that is, starting with the easier tasks before moving on to the more difficult ones. In particular, ABC services are expected to be applied first to general and unmanned aviation, followed by transport aviation. In the area of transport aviation, ABC should be deployed to provide in-cabin non-safety-critical communication services for passengers before being used for fore-cabin safety-critical communication services.

(2) Strengthen collaborative planning with spatial information infrastructure. The new-generation ABC system will surely depend on the spatial information infrastructure (SII) at the national or even universal level, such as internet satellites. Therefore, the development of the new-generation ABC should be synergized with the construction of SII. In addition, the spectrum resources allocation, spatial loading design, and system operation control of SII should be handled well to meet the requirements of usability, continuity, and integrity in the new-generation ABC.

(3) Reinforce coordination and cooperation among international organizations. The development and application of the new-generation ABC requires reinforced cooperation among international organizations and countries. In particular, cooperation among the International Civil Aviation Organization, International Telecommunication Union, and international organizations for aviation standardization is crucial in order to coordinate and optimize the spectrum resources for aeronautical communication, as well as lay down the technical standards and regulations for the new-generation ABC.

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