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General Aspects

IAFI[1]

Further updates to the Working document towards a preliminary draft new Report ITU-R M.[IMT.ATG]

Systems for Non-Safety Air-Ground Communications (excluding UAS) using terrestrial IMT and other Land Mobile Technologies

1. Introduction:

This contribution provides further update and expansion to the working document, focusing on the specific role of IMT in enabling robust, high-performance Air-Ground Communications (ATG) for non-safety purposes. It complements the existing text by detailing the operational characteristics of ATG systems that are uniquely supported by IMT-Advanced and IMT-2020 (5G) technologies. These technologies offer significant advantages over previous cellular and land mobile systems, particularly in addressing the challenges of high-speed, high-altitude communication. The contribution proposes new text for the document's section on IMT-specific operational characteristics.

2. Proposal:

IAFI proposes that additional text be adopted and integrated into the working document towards a preliminary draft new Report ITU-R M.[IMT.ATG]. The new content is to be placed in the "Abbreviation and Acronyms" and "General ATG operational characteristics supported by IMT" section and other relevant areas as indicated. All changes are in track-change mode.

Annexure

[1] IAFI is a sector Member of ITU-R. For more details, please see https://iafi.in.

Working document towards a preliminary draft new Report ITU-R M.[IMT.ATG]

Systems for Non-Safety Air-Ground Communications (excluding UAS) using terrestrial IMT and other Land Mobile Technologies

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RUS

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ATG DG

Scope

[Editor's note: meeting to decide how to merge scope and introduction.]

This Report deals with the general principles, technical characteristics and operational features of terrestrial systems for non-safety communications with aircraft (excluding UAS), using IMT and land mobile technology based air-ground applications. The connectivity between OBU and user equipment of on-board passengers (e.g. smart phones, laptops, tablets, etc.) is not in the scope of this Report.

[Regarding IMT technology based ATG application, this report addresses non-safety communications between Terrestrial IMT base stations and an On Board IMT unit (OBI) mounted in an aircraft (excluding UAS). Studies of relevant usages, technical and operational aspects and capabilities supported by IMT are addressed.]

Otherwise, examples of national implementation on ATG also are included in the Annex.

[Note: The implementation of this Report is subject to compliance with the provisions of the Radio Regulations.]

[Note: Discussion on whether relevant regulatory information may be included in the report is not finalized, and further discussion is needed. However, no new regulation will be developed in this report.]

1 Introduction

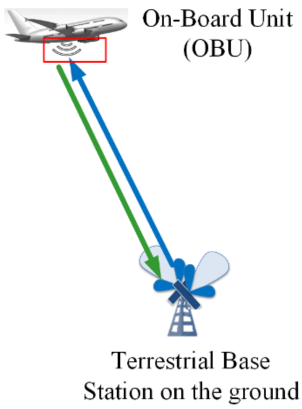
This Report addresses Air-Ground non-safety connectivity (ATG) which refers to two-way communication between aircraft On-Board Unit (OBU) and ground station using IMT and other Land Mobile technologies.

This report further covers relevant usages, technical and operational aspects and capabilities supported by IMT and other Land Mobile technologies.

The general description on ATG is shown in Figure 1. The figure shows the OBU antenna on the aircraft communicating with ground stations. The OBU includes an external antenna, typically mounted at the bottom of the aircraft to communicating with the terrestrial base station(s).

FIGURE 1

ATG scenario



Further the OBU, acts as customer premises equipment (CPE) which enable on board user equipment including but not limited to smart phone, laptops and tablets to access the broadband communications. This report does not address the communication links between the OBU and user equipment on-board the aircraft.

Finally, The Annexes to this Report provide national / regional approaches taken by certain countries/ region [wishing to share their approaches, in the planning and implementation of air-ground (ATG) in certain frequency bands that are allocated to the LMS or identified to the IMT]. These Annexes should be considered for informational purposes only.

[Editor's note: Highlighted part of above paragraph will be further checked when reviewed all annexes are done]

2 Relevant ITU-R Recommendations and Reports

[Recommendation ITU-R M.1457

Recommendation ITU-R M.2012]

Recommendation ITU-R M.2150

Recommendation ITU-T Y.3211

[Report ITU-R M.2282]

[Editor's note: If SG 5 suppresses the Report ITU-R M.2282-0, it can be removed from the section.]

3

ATG: Air-Ground Communication

4 Role of IMT and other LMS in air-ground communications

4.1 The role of IMT in air -ground communications

Compared to earlier generations of cellular technologies, IMT (IMT-Advanced and IMT-2020) offers greater speed, lower latency, and the ability to connect more devices simultaneously, making it more suitable for delivering high-quality in-flight broadband services.

4.2 The role of LMS in air-communications

[Editor's note: This section may include portions from Report ITU-R M.2282-0 and inputs from WP 5A and external organizations as received from their reply liaison statements]

[Editor's note: Text below this note has not been reviewed nor agreed at WP 5D #49.]

5 General ATG operational characteristics supported by LMS

The system should be fully compatible and capable of interfacing with the international public switched telephone network, public data network, the Internet, or any combinations thereof.

The system should have adequate bandwidth to meet the foreseeable demand for the services.

The Quality of Service should be that which meets the objectives of the system. For example, if the objective is to provide high quality voice service, then the Quality of Service should be comparable to that of the public switched network (voice and data).

The system should provide, in so far as possible, uninterrupted coverage throughout the designated service areas with the capability of coordinated operation across national borders.

The system needs to be electromagnetically compatible with other aircraft systems in accordance with appropriate regulatory requirements and should have minimal impact on aircraft engineering, maintenance and all aspects of flight operations.

The system should not cause harmful interference to other radio communication systems.

The key technical aspects of air-to-ground/air-ground systems relate to:

– use of common wireless technology standards including characteristics (including emission levels, receiver performance, and antenna characteristics) and equipment functionality (such as Doppler compensation, and auto-configuration based on geographic position-detection);

– harmonized spectrum utilization, including frequency bands and channel arrangements, to facilitate the free circulation and use of ATG between countries.

5.1 Systems inter-working

To facilitate seamless and transparent region-wide operations, regional agreement on a harmonised air-to-ground technology platform may be helpful to facilitate agreements between concerned administrations. The adoption of standards based broadband wireless access technologies for air-to-ground systems helps facilitate international harmonization operation for service operators and administrations.

In addition, to simplify in-air operations and maximise passenger usage experience, establishing harmonised emission levels/power flux densities, out-of-band emissions, and minimum antenna elevation levels facilitates seamless operation of terrestrial direct air-to-ground communications.

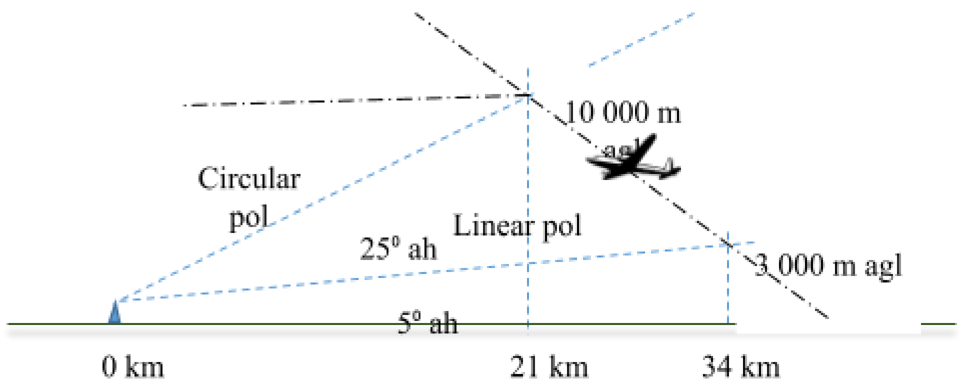
The antenna pattern and performance may be a particularly unique feature of air-to-ground/air-ground links. In general, and to provide a reliable radiocommunications link with over-flying aircraft approaching/departing from all sky directions, both the airborne and ground antennas should exhibit an illumination pattern that varies with elevation-above-horizon:

– higher gain and linear (vertical) polarization for lower elevations between about 5-25° above horizon;

– lower gain and circular polarization for higher elevations between about 25-90° above horizon.

FIGURE 4

Example of antenna elevation angle versus polarization



6 General ATG operational characteristics supported by IMT

TBD

,7 Technical characteristics

7.1 Technology aspects of ATG applied other LMS technologies

Several technology aspects should also be considered for possible harmonization to ensure a uniform approach is applied to ATG systems:

– Doppler (airspeed) compensation – while determining airspeed and consequent Doppler compensation necessary for proper receiver operation can be achieved by computational means and GNSS data within the airborne equipment, an alternative approach is to take the airspeed indication directly from the aircraft avionics data bus, and apply it as a frequency scaling correction factor;

– Altitude detection – aircraft operator may use altitude information automatically derived from the aircraft avionics data bus to enhance and provide timely safety information to the passengers in the aircraft cabin (e.g. to fasten seat belts);

– Geo-position detection – this information may be required for purposes of implementing particular national regulatory requirements, by matching against aircraft position against geographic national border location information. While this can also be derived directly from GNSS data, it is also available from the aircraft avionics data bus.

7.2 Technology aspects of ATG applied IMT technologies

Several technology aspects should also be considered for possible harmonization and implementation to ensure a uniform approach is applied to air-ground communications (excluding UAS) using terrestrial IMT technologies:

– Supplementary Uplink (SUL). The main goal of SUL is to enhance the coverage and capacity of the uplink by introducing additional uplink frequency bands, especially in scenarios where high-frequency bands (such as C-band, millimetre waves) have insufficient coverage. The current SUL standard supports configurations where only the downlink of a TDD band is used, supplemented by an uplink from a lower-frequency FDD band. At this time, no data is transmitted in the uplink time slots of those TDD bands, and all uplink traffic is carried on the FDD uplink frequency band.

– Carrier Aggregation (CA). 3GPP Release 10 defines CA, and IMT-2020 inherits this technology and extends and enhances it. The current IMT-2020 supports the aggregation of downlink carriers of a specific FDD band with the downlink time slots of other TDD bands. At this time, no data is transmitted in the uplink time slots of those TDD bands, and all uplink traffic is carried on the specific FDD uplink frequency band.

– [TBD]

7.2.1 System architecture

TBD

7.2.2 Deployment and system characteristics

[Editor's note: This section includes the deployment and system parameters of terrestrial base stations, and the related parameters of UE served by base stations.]

This section includes the deployment and system parameters of terrestrial base stations, and the related parameters of OBI served by base stations.

7.1.2.1 System characteristic

Table X describes the typical system parameters of the ATG base station supporting IMT and the related parameters of OBI served by ATG base stations, respectively.

TABLE X

Typical system parameters of ATG

Parameter	ATG Base Station	OBI
Maximum RF output power	EIRP: 72.28 dBm (Including antenna gain)	EIRP: 3 5 dBm (Including antenna gain)
RF signal power bandwidth	Up to 100 MHz	Up to 100 MHz
BS height	45-350 m	3-10 km
ACLR	4 5 dBc	33 dBc
Noise figure	5 dB	9 dB
Protection requirement	−115 dBm/MHz	−111 dBm/MHz

6.2.2.2 Deployment characteristic

[Editor's note: network topology and other factors can be considered.]

8 Industry and standardization activities on ATG

8.1 Industry and standardization activities on ATG supported by other LMS

TBD

8.2 Industry and standardization activities on ATG supported by IMT

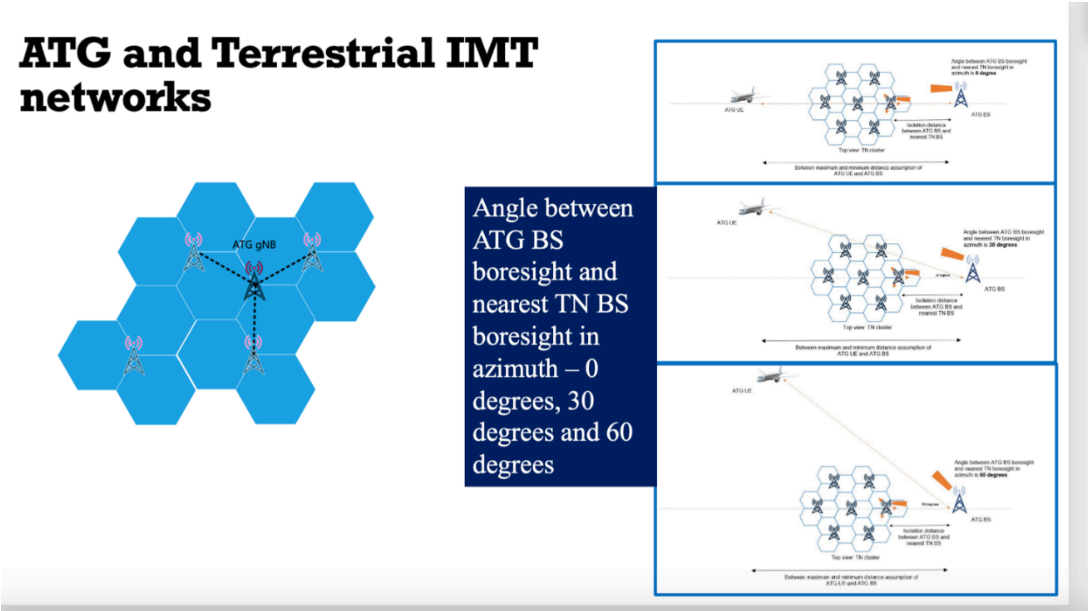
The IMT ATG system is being standardized by the 3rd Generation Partnership Project (3GPP), a global initiative that develops telecommunications standards. The most recent technical report, 3GPP TR 38.876 V18.2.0, outlines the key specifications for ATG systems, including the use of IMT-2020 technology in this context. According to the report, the OBI (or ATG UE) is designed to function as customer premises equipment, which establishes and maintains the communication link between the aircraft and the terrestrial IMT base station. One of the primary challenges addressed by the 3GPP standards is the need to maintain a stable connection despite the high speeds and altitudes at which aircraft operate. To overcome this, IMT-2020 ATG systems make use of advanced techniques such as carrier aggregation, which allows multiple frequency bands to be used simultaneously, and seamless handover, which ensures that the connection remains uninterrupted as the aircraft moves between coverage areas.

From various trials and commercial operation [https://inflight.telekom.net/ean/] of adapted LTE ATG solutions, the following characteristics are considered by the 3GPP for ATG network deployment scenarios.

a) Extremely large inter-site distance (ISD) and large coverage range: In order to control the network deployment cost and considering the limited number of flights, large ISD is preferred, e.g., about 100 km to 200 km. At the same time, when the plane is above the sea, the distance between the plane and the nearest base station could be more than 200 km and even up to 300 km. Therefore, ATG network should be able to provide up to 300 km cell coverage range.

b) Utilizing non-disjoint frequency for deploying both ATG and terrestrial networks, i.e. same operating band but ATG network and TN use adjacent carriers: Operators are interested to adopt the same frequency for deploying both ATG and terrestrial networks to save frequency resource cost, while interference between ATG and terrestrial networks becomes non-negligible and should be addressed.

c) Much powerful on-board ATG terminal capacity: On-board ATG terminal can be much powerful than normal terrestrial UE, e.g., with higher EIRP via much larger transmission power and/or much larger on-board antenna gain.



9 Challenges and future prospects

9.1 Challenge and future prospects on ATG supported by other LMS

TBD

9.2 Challenge and future prospects on ATG supported by IMT

Despite the significant progress made in the development of IMT-advanced and IMT-2020 ATG systems, several challenges remain. One of the primary concerns is the availability of spectrum for ATG communications. As more devices and services compete for access to radio frequencies, ensuring that there is sufficient bandwidth for high-speed in-flight connectivity will be crucial. Another challenge is the cost of deploying ATG infrastructure. Installing base stations capable of communicating with aircraft (except UAS) at high altitudes requires significant investment, particularly in rural or remote areas where existing infrastructure may be lacking. Looking to the future, the continued development of IMT-2020 and beyond-IMT-2020 technologies promises to further enhance the capabilities of air-to-ground communication systems. With the potential for faster data rates, lower latency, and greater network reliability, these technologies will play a key role in meeting the growing demand for in-flight connectivity in the coming decades.

10 Examples of National implementation on ATG

Technical characteristics and operational features of the systems for ATG in some countries in Region 1 are given in Annex 1.

Technical characteristics and operational features of the systems for ATG in some countries in Region 2 are given in Annex 2.

Technical characteristics and operational features of the systems for ATG using terrestrial IMT and other land mobile technologies in some countries in Region 3 are given in Annex 3.

Channel propagation effects on a terrestrial air-to-ground system are given in Recommendation ITU-R P.528-3 – Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands, which provides useful information for design of systems for public mobile communications with aircraft.

Note: The Annexes are provided by individual administrations and/or regional or sub-regional organisations for information purposes only, and do not create any obligation on other administrations to follow those implementations described in Annexes.

[X Spectrum and Regulatory aspect

[Editor's note: Next meeting should decide how to handle the text below provide by RUS and IAFI, since it is not clear whether it is information should be part of national experience or not.]

X.Y Consideration of regulatory aspects

The use of non-safety communications between base stations on ground and airborne user equipment supported by the terrestrial component of IMT should not contradict the Radio Regulations.

Since this communication link involves user equipment on-board airborne vehicles such communication falls into definition related to aeronautical mobile service. In particular:

1.32 *aeronautical mobile service:* A *mobile service* between *aeronautical stations* and *aircraft stations*, or between *aircraft stations*, in which *survival craft stations* may participate; *emergency position-indicating radiobeacon stations* may also participate in this service on designated distress and emergency frequencies.

1.81 *aeronautical station:* A *land station* in the *aeronautical mobile service*.

In certain instances, an aeronautical station may be located, for example, on board ship or on a platform at sea.

1.83 *aircraft station:* A *mobile station* in the *aeronautical mobile service*, other than a *survival craft station*, located on board an aircraft.

Based on that the basic regulatory scenario of the use of such links should be related to IMT systems deployed in the bands allocated to aeronautical mobile service. It should be noted that not all the bands identified for IMT have allocation to aeronautical mobile service. Therefore before the deployment of non-safety communications between base stations on ground and airborne user equipment the relevant compatibility studies should be performed to allow such use in some IMT bands. Situation in the IMT bands already allocated to AMS may be more favourable comparing to other bands.

Otherwise such use should follow provision **4.4** of the Radio regulations:

4.4 Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations.

To follow the principle "shall not cause harmful interference to, and shall not claim protection from harmful interference" may lead to limitation of deployment of such links within national territories at the appropriate distances from border of other countries unless agreement between the concerned administrations,

[Editor's note: it should be discussed to which extent this Report should address the compatibility and regulatory aspects noting that these issues have a great impact on the practical deployment of

non-safety communications between base stations on ground and airborne user equipment supported by the terrestrial component of IMT]

IAFI

X.Z1 Interference Scenarios

[Editor's note: This section may include various interference scenarios between ATG and Terrestrial IMT, FSS, MSS, AMS and Fixed Services. Aim is to propose interference studies and bring out scenarios for future references]

X.Z2 Spectrum Aspects of A2G

[Editor's note: This section may include spectrum aspects of ATG. Report may also suggest various frequency bands allocated to AMS which are being planned or used for ATG systems based on work already done by WP 5A. Further in regulatory aspects, cross border interference issues/coordination aspects between neighbouring administrations may also be brought out]

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Annex A

Additional text from contributions

[Editor's note: the information below provide from IAFI needs to discuss to decide if it should be incorporated into the report.]

IAFI:

[Air-to-ground (ATG) communications play an increasingly important role in modern aviation, particularly with the growing demand for in-flight connectivity. ATG communication has the advantages of high throughput, low propagation delay. Passengers expect reliable internet access while flying, which has driven innovation in ATG communication technologies. One significant advancement in this field is the use of IMT-advanced and IMT-2020 technologies, especially under the framework of the International Mobile Telecommunications Air-to-Ground (IMT ATG) systems.

Other Land Mobile Technologies also exist which provide ATG communications for in-flight broadband connectivity. These developments represent a fundamental shift from traditional satellite-based communications to more efficient, high-speed connections that provide significant benefits in terms of both performance and cost.

This article explores the role of IMT-advanced, IMT-2020 and Land Mobile Technology in ATG communications, focusing on how these ATG technologies enables in-flight connectivity by establishing communication links between terrestrial base stations (BS) and on-board ATG units mounted on aircraft. It also highlights the emerging standards, such as those set forth in 3GPP TR 38.876 V18.2.0, and discusses key trends in the aviation industry.]

Annex 1]

Systems for public communications with aircraft in some countries in Region 1

[Editor's note: the information in annex 1 was provided by WP 5A and it has not been editing or modified]

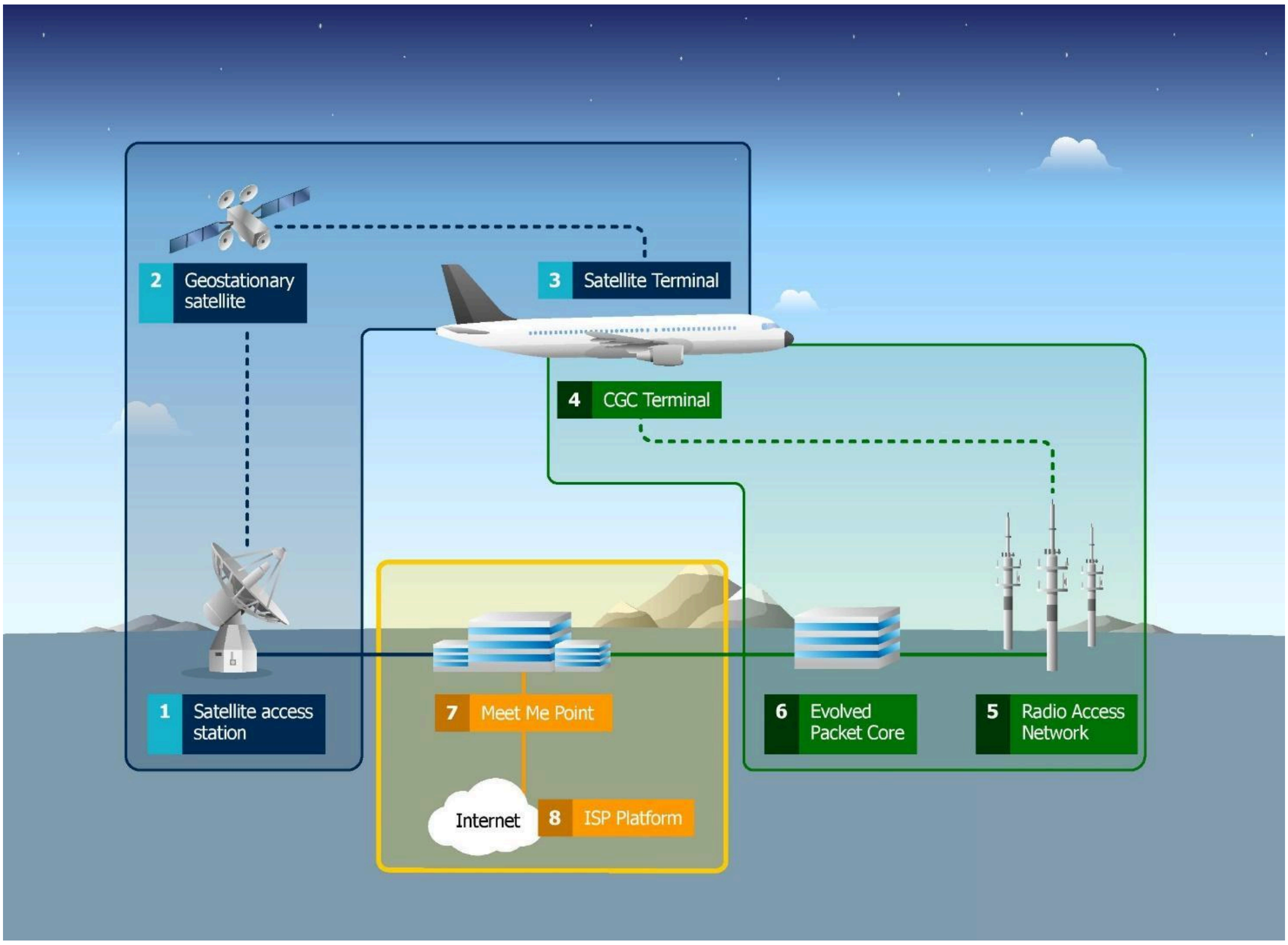
1 Broadband air-to-ground (ATG) systems within the European Conference of Postal and Telecommunications (CEPT)

1.1 European Aviation Network

The European Aviation Network (EAN) provides aerial broadband coverage across all 27 EU states and Switzerland, United Kingdom and Norway. As shown in Fig. A1-1 below, EAN is a hybrid system, with an MSS path and a broadband ATG terrestrial path configured for every aircraft. For the latter, a total of 300 Base Stations (BSs) have been deployed across the European continent.

FIGURE A1-1

European Aviation Network



NOTE – This Report only addresses the link between Base station on the ground and OBU/CGC terminal. The other portions of the figure are not relevant to this Report.

1.2 ATG of the EAN system architecture

The broadband ATG system is a complementary ground component of EAN and is based on 3GPP LTE Rel. 10+ specifications. In particular, synchronization algorithms of the OBU were modified compared to terrestrial mobile radio usage in order to cope with the high Doppler frequency shift caused by aircraft speed, and the Tx power was increased to enable very large cell sizes. In addition, the Ground Station (GS) antenna adjustment was matched to cover typical aircraft altitudes between 3 and 12 kilometres by adaptation of vertical diagrams including antenna up-tilt.

The major building blocks of the ATG radio link of the EAN system architecture are:

– broadband ATG network infrastructure on-board aircraft, e.g., OBU, interface to on-board network(s), external antenna, cabling;

– terrestrial radio access network for broadband ATG, consisting of BS that are configured with special ATG radio heads and antennas to establish high-performance radio links to aircraft. These GSs are deployed on elevated sites with clear line of sight to the horizon and are furnished with broadband backhaul links.

The other major building blocks of the ATG of the EAN system architecture are listed below, but are out scope of the report:

– service access network infrastructure on-board the aircraft, e.g., Wi-Fi coverage and Mobile Communications on board Aircraft (MCA), both already standardized and certified for on-board implementation;

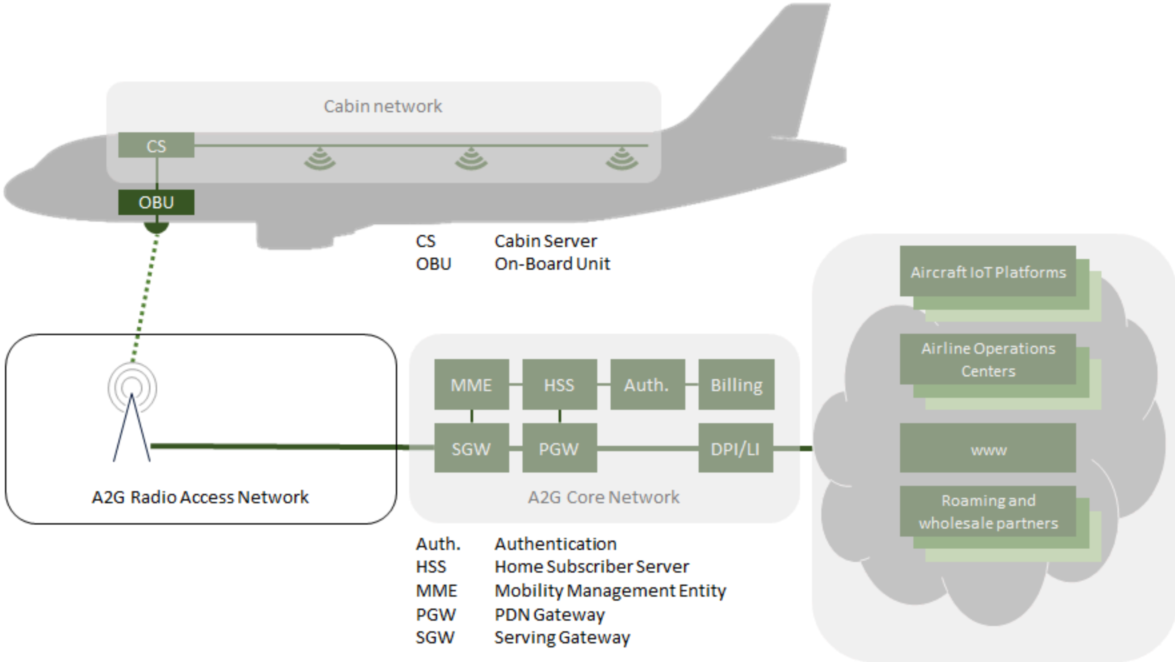
– dedicated mobile core network for session, mobility, subscriber and security management providing IP connectivity to external packet data networks (e.g., intranet, Internet, IP Multimedia Subsystem (IMS));

– central network components required for O&M, billing, etc. in the ATG network;

– various IP-based service delivery platforms, e.g., for passenger services or for airline or aircraft repair/manufacturer internal applications.

FIGURE A1-2

System architecture for the broadband ATG of the EAN system



NOTE – This Report only addresses the link between Base station on the ground and OBU/CGC terminal. The other portions of Fig. A1-2 are not relevant to this Report.

1.3 ATG of EAN spectrum aspects

EAN has been licenced by European countries under their national regulations to provide public communications with commercial aircraft operated within the European airspace. The authorisations are based on ECC Decision (06)09 and applicable EC Decisions that designates the frequency bands 1980-2010 MHz and 2170-2200 MHz for use by systems in the Mobile-Satellite Service including those supplemented by a Complementary Ground Component (CGC). Paired spectrum of 2 × 15 MHz has been licenced for the operation of EAN.

1.4 User experience

EAN is in live commercial operations since 2018. The system reset the benchmark for connectivity in the skies with regards to capacity, latency, per-aircraft throughput, network densification flexibility, aircraft retrofit time, aircraft retrofit cost, and cost per bit.

Key properties of the ATG of the EAN system include:

– the radio link between the BS and the OBU in the aircraft is established at distances of up to 150 kilometres from the sites to the aircraft, with aircraft flying at speeds up to 1 200 km/h and altitudes up to 12 000 metres;

– peak data rates of up to 100 Mbit/s in the forward link (ground-to-air) and 30 Mbit/s in the reverse link (air-to-ground), as well as round-trip times of less than 50 milliseconds are consistently being achieved;

– cell ranges are designed in consideration of local air traffic densities, spanning from 30 kilometres around the major aviation hubs to 150 kilometres in sparsely flown areas;

– the traffic mix is dominated by streaming applications and messaging applications, thus the user behaviour resembles that of terrestrial services.

2 Broadband Air-to-Ground (ATG) systems within the Saudi Arabia

2.1 Introduction

A broadband air-to-ground (ATG) system constitutes an application for various types of telecommunication services, such as Internet access and mobile multimedia services, during flights. It aims to provide access to broadband communication services during domestic and regional flights. With 200 million air passengers annually, the Middle East is one of the largest aviation markets and home to some of the largest airlines worldwide.

The main application field is Air Passenger Communications (APC). In addition, a broadband ATG system can also support Airline Administrative Communications services (AAC) and thus improve aircraft operation. Safety-relevant communications such as Air Traffic Control (ATC) and related services are not intended to be covered.

2.2 ATG system architecture

The ATG system is based on 3GPP LTE Rel. 10+ specifications. In particular, synchronization algorithms of the OBU are modified compared to terrestrial mobile radio usage in order to cope with the high Doppler frequency shift caused by aircraft speed, and the Tx power is increased to enable very large cell sizes. In addition, the GS antenna adjustment is matched to cover typical aircraft altitudes between 3 and 12 kilometres by adaptation of vertical diagrams including antenna up-tilt.

The major building blocks of the ATG system within Saudi Arabia are the same as those listed in section 1.2 and shown in Fig. A1-2.

2.3 Spectrum aspects in Saudi Arabia

In April 2021, the Communications, Space and Technology Commission (CST) of Saudi Arabia has launched its Spectrum Outlook for Commercial and Innovative Use 2021-2023[2]. The spectrum outlook details Saudi Arabia's path to becoming a world leader in radiocommunication and wireless technologies by attracting investments, meeting current data and connectivity demands, and proactively anticipating future needs. Correspondingly in this outlook, CST aims to leverage innovation in spectrum management by expanding its range of resources and services, while ensuring the digital ecosystem is ready to unlock its full potential. Drafting this outlook followed a transparent and collaborative process that involved public consultation and engagement with more than 65 wireless technology organizations from different 20 countries. The broad aim of this Spectrum Outlook is to adopt a range of measures to provide transparency and predictability for all spectrum users in the Kingdom, providing spectrum users certainty over the amount of spectrum available in different bands. One of these measures referred to the release of the bands 1 980-2 010 MHz and 2 170-2 200 MHz in a technology-neutral auction in 2021, which acknowledges industry interest to deploy a ATG system in these bands. Such a system would be compatible with the ATG component of the European Aviation Network, which already provides aerial broadband coverage across 30 European states.

2.4 ATG trial network and test flights in Saudi Arabia

In 2018, Saudi Arabia was the first country in the Middle East to deploy a ATG system for trial purposes. A total of 10 ATG BSs and a dedicated ATG core network were deployed to cover the air routes between Riyadh and Jeddah, which is the busiest city pair with regards to domestic air travel.

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[2] Spectrum Outlook for Commercial and Innovative Use 2021-2023, CST (2021).

The system architecture of the ATG trial system was a subset of the system architecture described above and resembled the ATG system architecture of EAN, including the same bands 1 980-1 995 MHz and 2 170-2 185 MHz for FDD operation. A test aircraft was equipped with Wi-Fi access network infrastructure and ATG network infrastructure (OBU) and flown for 10,000 kilometres on different routes between Riyadh and Jeddah during a structured flight test campaign.

Key results of the trial included:

– downlink (ground-to-aircraft) throughput above 90 Mbit/s and uplink (aircraft-to-ground) throughput above 30 Mbit/s;

– round trip time (RTT) of less than 50 milliseconds;

– various high-bandwidth-low-latency applications demonstrated, e.g., video conferencing, OTT video, social networking, and enterprise applications with VPN;

– live high-definition video conference between the test aircraft and an exhibitor's booth at the GITEX 2018 exhibition in Dubai;

– maximum distance between BS and aircraft 120 kilometres.

In 2022, a first regular commercial aircraft of an airline (Airbus A321) was equipped with a ATG system and received certification by the General Authority of Commercial Aviation. Flight test results were consistent with the results of the trial in 2018. The aircraft was not dedicated to a test campaign but flew on its regular route schedule and automatically connected to the network whenever reaching the coverage area. The results were publicly shared at the "Connecting the World from the Skies" event, that was organized by ITU and CST.

Annex 2

Systems for public communications with aircraft in some countries in Region 2

[Editor's note: the information in Annex 2 was provided by WP 5A and it has not been editing or modified]

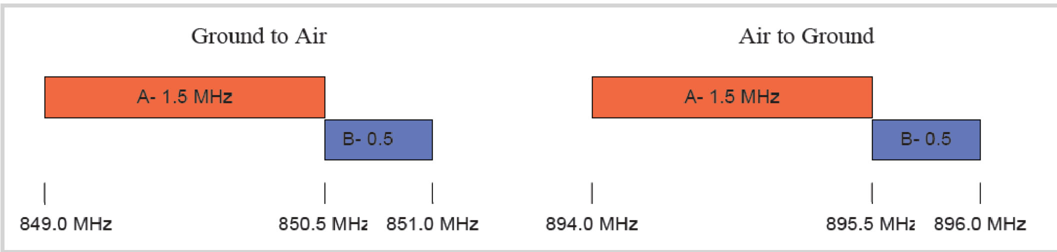
1 System for public communications with aircraft in Canada and United States of America

In Canada[3] and the United States of America[4], the band pair 849-851 MHz and 894-896 MHz is allocated to the aeronautical mobile service for public correspondence with aircraft. These bands are designated for paired nationwide exclusive assignment to the licensee or licensees of systems providing radio telecommunication services, including voice telephony, broadband Internet and data transmission service, to persons on-board aircraft. However, fixed services and ancillary land mobile services are not permitted.

In Canada and the United States of America, the band plan, described below in Fig. 5, is based on two block pairs: 849-850.5/894-895.5 MHz and 850.5-851/895.5-896 MHz. The band 849-851 MHz is limited to transmissions from ground stations and the use of the band 894-896 MHz is limited to transmissions from airborne stations.

FIGURE 5

The band plan for aeronautical mobile service in Canada and the United States



The technical rules for certification and systems deployment in the band in the United States and Canada are technology neutral. The maximum effective radiated power (e.r.p.) limits for ground stations and airborne stations are as follows:

Ground station	500 W e.r.p.
Airborne station	12 W e.r.p.

In the United States of America, the air-to-ground radiotelephone service falls under the U.S. Federal Communications (FCC) Part 22 rules, Subpart G. Commercial aviation air-ground systems may use any type of emission or technology that complies with these technical rules.

3 Refer to http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09134.html.

4 Refer to: http://www.gpo.gov/fdsys/pkg/CFR-2010-title47-vol2/pdf/CFR-2010-title47-vol2-part22-subpartG-subjectgroup-id140.pdf.

2 An example commercial aviation air-to-ground system operating in the United States consistent with IMT-2000 CDMA multi-carrier as described in Recommendation ITU-R M.1457

2.1 Introduction

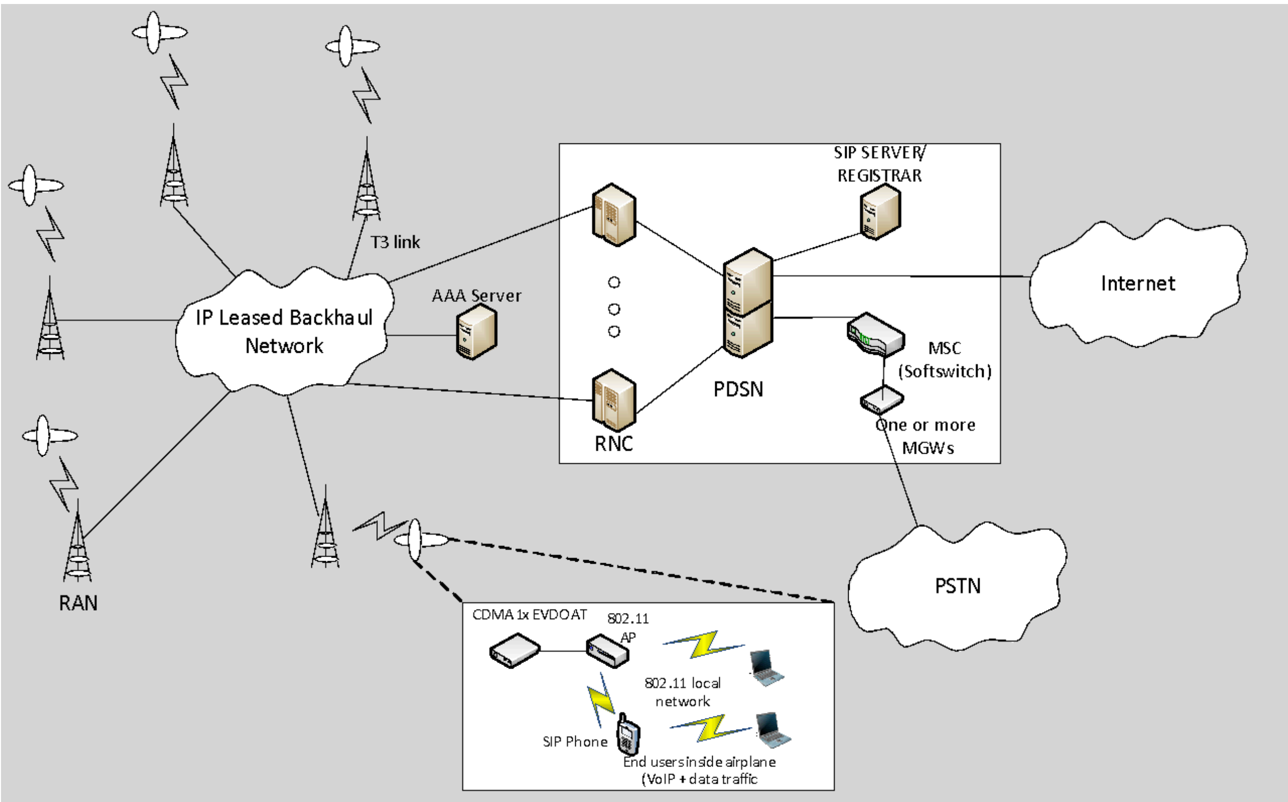
This air-to-ground system is currently deployed and operational in continental United States and part of Alaska[5]. It operates in the 849-850.5 MHz and 894-895.5 MHz bands and offers in-flight broadband services to all Wi-Fi enabled laptops, notebooks and smartphones. It uses a modified version of the IMT-2000 CDMA[6] Multi-Carrier network to provide a high-speed connection directly from the aircraft to the ground. Some of the characteristics features of this network are: high capacity of 300 kbit/s to 500 kbit/s with peak rates of 3.1 Mbit/s, very large cell size (up to 400 km radius), modifications made to the IMT-2000 CDMA Multi-Carrier1xEV-DO air interface to accommodate extended cell coverage and airplane speed, deployment using off the shelf components such as Radio Access Networks (RANs) and Radio Network Controllers (RNCs).

2.2 System architecture

The overall end-to-end system architecture of this air-to-ground system is illustrated in Fig. 6.

FIGURE 6

IMT-2000 CDMA multi-carrier air-to-ground system network architecture



5 http://www.gogoair.com.

6 CDMA2000 High Rate Packet Data Interface Specifications, 3GPP2 C.S0024-A Version 1.0, March.

NOTE – This Report only addresses the link between Base station on the ground and aeronautical terminal. The other portions of Fig. 6 are not relevant to this Report.

Each Radio Access Network (RAN) supports 1 carrier and 6 sectors. Each sector can generate about 2.2 Mbit/s peak throughput.

2.3 Modifications to the IMT-2000 CDMA multi-carrier air-interface

The following sections describe the various enhancements made to the IMT-2000 CDMA multi-carrier 1xEV-DO air interface in order to enable its application as a viable air interface technology for air-to-ground communication.

2.3.1 Expanded range of Doppler shifts

Airplanes travel at speeds far greater than is usual for the operation of cellular mobile units, including high speed trains. For the worst-case orientation of a plane traveling at 340 m/s and at a carrier frequency of 850 MHz, the Doppler frequency shift seen by the airborne access terminal is approximately 964 Hz. When the terminal transmits, the Doppler shift perceived by the base station is approximately doubled to 1 928 Hz. The different searching operations at both the base station and the access terminal needed to be modified to accommodate the extended range of the observed Doppler shifts.

At the base station, the access channel searching algorithm is extended to additional frequency bins that cover the expected Doppler range of the airborne system. Furthermore, in case of handoff searching, when a sector gets added to the access terminal’s (AT) active set, the newly added sector needs to search and start demodulating the AT’s signal. However, the newly added sector may not be managed by the same base station that was already demodulating the access terminal, and hence the new base station needs to perform the same search procedure that is used for the access channel. When the access terminal tracks one sector and monitors other sectors for handoff, there could be a frequency offset differential due to different Doppler shifts between the serving sector and the candidate sectors. This means that there is an underestimation of the true SINR of the candidate pilot, because the SINR estimator suffers from phase coherence loss due to frequency error. SINR estimation for non-serving sectors needs to be compensated using estimates of Doppler frequency shifts.

2.3.2 Expanded cell radius

The airborne system supports cell radii of up to 400 km. The cell radii for a typical terrestrially-based cellular system are in the order of a few kilometres. In order to cope with large cells, modifications to the baseline reverse link demodulation algorithms are needed. A larger traffic search window is required to search for multipath components, and the multipath search window is extended to 256 chips. The reasoning for this is that the existence of strong multipath components is much more unlikely in the airborne system than in typical terrestrial cellular systems due to radio propagation conditions. Nevertheless, if a signal multipath component were to exist, then the lag difference between the main line-of-sight path and the multipath will most likely be much greater than the few chips (normally less than 10) that is typical in terrestrial communications. For this reason the search window sizes should be extended to 256 chips, corresponding to ~64 kilometres. Furthermore, due to larger cell radii as compared to the conventional terrestrial cellular systems, a much bigger access channel search window is required. If the cell radius is assumed to be R km, then the maximum possible time of arrival difference between two airplanes inside the cell (measured in chips) is given by the following equation.

$$\Delta = 2R * 10^3 \frac{1.2288 * 10^6}{c}$$

where c is the speed of light in m/s. For R = 400 km, we obtain $\Delta \sim$ 3 333 chips. This quantity is how large the total access channel search window needs to be.

Changes to some search parameters are also needed on the AT side to support large cell radii. In order for the AT to find neighbouring sectors and correctly perform active and candidate set management, the neighbour search windows have to be increased. This is because with large cell radii, the differential delay between the serving sector and transmissions from candidate sectors can be quite large. Given the geometry of the network, it should be sufficient for the neighbour search windows to be expanded by a factor of 8, and this can be accomplished by reinterpreting the search window size field in the neighbour list message[7].

Additional changes need to be made for increasing the data rate control (DRC) length. In the IMT-2000 CDMA multi-carrier 1xEV-DO system, the access terminal continuously sends its desired forward link data rate on the DRC to the base station. The DRC word can extend 1, 2, 4 or 8 reverse link slots. Right after the access terminal has finished sending a given DRC, it expects that the next forward link slot directed to it will be encoded according to its last DRC request.

The reverse link timing of the DRC channel is advanced by one-half slot with respect to the forward link timing for the base station to allow the base station enough time to process the last DRC sent by each AT. This 1 024-chip budget is more than enough for regular terrestrial communications since the cell radii are of the order of a few km. However, for the airborne system, this is insufficient since the one-way propagation delay to the edge of a base station covering 250 kilometres is already around 1 024 chips. The solution lies in choosing a long DRC length and, at the base station side, decoding the DRC word before the whole length of it has been received.

2.3.3 Handoff

The IMT-2000 CDMA Multi-Carrier 1xEV-DO airborne system uses multiple transmit and receive antennas on the access terminal side. The system uses four antennas, two sets of cross-polarization pairs. The access terminal has two antenna ports and a switch matrix to control multiplexing of the four antenna inputs into the two antenna ports on the access terminal. To provide spatial diversity in demodulation of the serving sector, the system combines the two antenna inputs belonging to the best or strongest polarization. Occasionally, the access terminal needs to search other antenna ports for possible transmissions from other sectors. To do so without breaking the connection to the serving sector, the access terminal effectively switches to single antenna demodulation. At the same time, the antenna port connected to the antenna with weaker input is switched to other antenna inputs to search for pilot transmissions from sectors on the AT's neighbour list. When this brief search is done, the AT resumes dual antenna demodulation.

The purpose of the IMT-2000 CDMA multi-carrier 1xEV-DO airborne system handoff procedure is to ensure that the access terminal is communicating with the access network (AN) through the best or strongest serving sector while using its best polarization pair of antennas for forward link demodulation. At the same time, the access terminal should transmit on the reverse link using its best antenna in orientation and polarization. The complexities of the airborne handoff procedure arise from the fact that as the serving sector changes, so does the concept of best antennas on the forward and reverse links.

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[7] Refer to http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09134.html, § 9.7.6.2.5.

3 System for general aviation air-to-ground radiotelephone within the United States of America

3.1 General aviation air-to-ground radiotelephone service

This service operates in the 454-459 MHz band and can provide a variety of telecommunication services to private aircraft such as small single engine planes and corporate jets. CFR47[8] § 22.805 contains the channel allocations for the general aviation air-to-ground service. These channels have a bandwidth of 20 kHz and are designated by their centre frequencies in megahertz.

TABLE 1

Signalling channel pair for general aviation air-ground systems

Ground	Airborne mobile
454.675	459.675

a) Channel 454.675 MHz is assigned to each and every ground station, to be used only for automatically alerting airborne mobile stations of incoming calls.

b) All airborne mobile channels are assigned for use by each and every airborne mobile station.

Communication channel pairs

Ground (MHz)	Airborne mobile (MHz)
454.700	459.700
454.725	459.725
454.750	459.750
454.775	459.775
454.800	459.800
454.825	459.825
454.850	459.850
454.875	459.875
454.900	459.900
454.925	459.925
454.950	459.950
454.975	459.975

The transmitting power of ground and airborne mobile transmitters operating in the general aviation air-ground radiotelephone service on the channels listed in CFR 47 § 22.805 must not exceed:

a) Ground station transmitters: the effective radiated power of ground stations must not exceed 100 Watts and must not be less than 50 Watts, except as provided in CFR 47 § 2.811.

b) Airborne mobile transmitters: the transmitter power output of airborne mobile transmitters must not exceed 25 Watts and must not be less than 4 Watts.

[8] Refer to: http://www.gpo.gov/fdsys/pkg/CFR-2010-title47-vol2/pdf/CFR-2010-title47-vol2-part22-subpartG-subjectgroup-id140.pdf.

Annex 3

Systems for ATG using terrestrial IMT and other land mobile technologies in some countries in Region 3

[Editor's note: the information in Annex 3 was provided by WP 5A, however it has been editing and modified by WP 5D.]

1 Air-to-ground communication system based IMT-2020 in China

1.1 Introduction

On 6 January 2020, the focus of the 2020 National Civil Aviation Work Conference clearly required "to strengthen smart civil aviation research and accelerate the promotion and application of new technologies". The development of ATG service needs the cooperation of basic service resources such as wireless spectrum, BS address and transmission network. In order to effectively save spectrum resources, make full use of wireless network resources of operators, and reuse existing frequencies with ground mobile communication service, the appropriated choice is to carry out ATG ground-air communication service.

Meanwhile, according to the 2017 Statistical Bulletin on the Development of the Civil Aviation Industry issued by the Civil Aviation Administration of China in May 2018, the passenger traffic volume of the whole industry in 2017 was 551.56 million, an increase of 13.0% over the previous year, and the passenger traffic volume of domestic routes was 496.11 million, an increase of 13.7% over the previous year. It is estimated that the number of domestic air passengers will exceed 1.2 billion in 2025, as shown in Table A2-1.

TABLE A2-1

Forecast of civil aviation broadband communication in China

Year	2020	2021	2022	2023	2024	2025
Number of Civil aircraft	4 039	4 524	5 067	5 675	6 356	7 118
Passenger (Million)	69.312	77.630	86.645	97.379	109.064	122.152

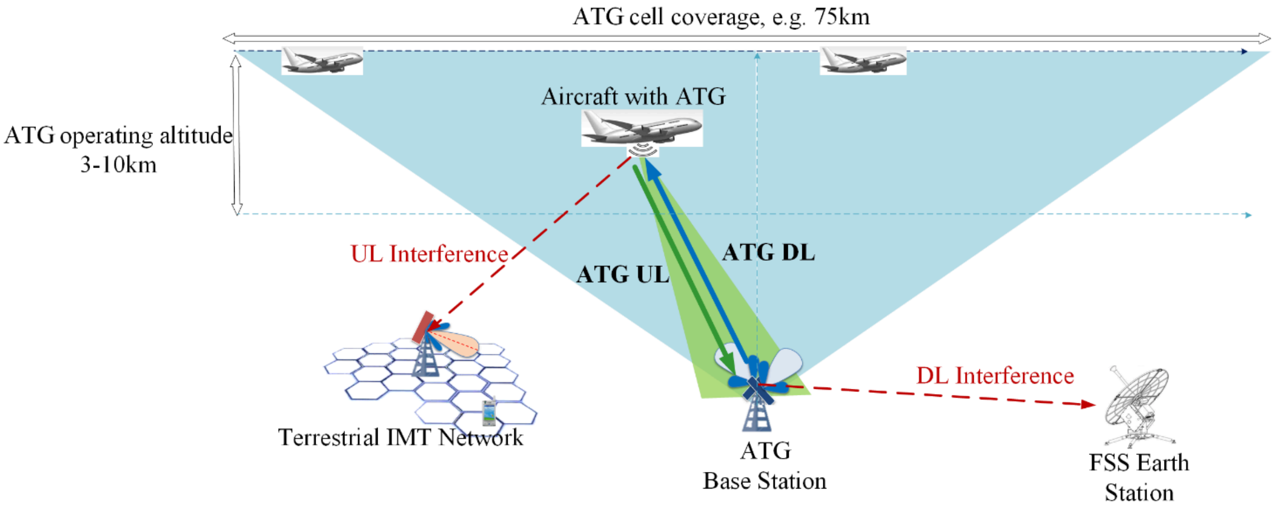
1.2 Spectrum aspect in China

The candidate frequency bands currently planned for ATG system are 1.9 GHz for ATG Uplink; 3.5 GHz for ATG Downlink in China.

ATG network architecture and interference scenarios are shown in Figure A2-1. In ATG network, ATG ground BSs are deployed to provide connectivity for aircraft. As seen in Figure A2-1, downlink (DL) of ATG system is defined as a communication link from base station on the ground to OBU of the aircraft. Moreover, regarding aircraft aspects, it can be seen as mobile terminals in ATG network, mainly operates approximately up to 10 km in the altitude level. Possible interference scenario between ATG DL and fixed-satellite service (space-to-Earth) can be considered; while other interference scenarios is for further study.

FIGURE A2-1

An example of ATG network architecture and interference scenarios



Therefore, China is researching that frequency range 1.9 GHz, or portions thereof, could be developed for ATG UL; while frequency range 3.5 GHz, or portions thereof, could be applied to ATG DL. It is notable that 3.5 GHz is necessary to improve its spectrum efficiency, thus expending ATG area is an excellent attempt to enhance frequency utilization of 3.5 GHz.

1.3 Operational and technical aspects in China

Operators in China are planning to develop ATG network for future commercial operation. Take China Telecommunications Corporation (China Telecom) for example. Since 2014, China Telecom has cooperated with China Eastern Airlines, China Southern Airlines, Xiamen Airlines, Hainan Airlines and Air China to provide aviation Internet services for China Airlines flights worldwide. Additionally, regarding China Mobile Communications Corporation, it will sign aviation airborne communication framework cooperation agreements with Air China, China Eastern Airlines, China Southern Airlines, Xiamen Airlines and other enterprises to create a new upgrade experience of Internet plus civil aviation.

The 3.5 GHz band ground-to-air transmission of the ATG BS is realized by a 3.5 GHz band active antenna processing unit (AAU). The 3.5 GHz frequency band is only used for one-way ground-to-air transmission, not for air-to-ground reception. See Table A2-2 for the 3.5 GHz band index of the ATG BS.

TABLE A2-2

Example on ATG BS system parameter

Parameters	Values
Frequency band	3.5 GHz
System bandwidth	100 MHz
Resource block (RB)	273
Subcarrier spacing (SCS)	30 kHz
Antenna uptilt	15°
Number of antenna ports	64
Type of polarization	dual-polarization

Parameters	Values
TRP	200 W
Antenna element gain	10 dBi

2 Air-to-ground communication system in Japan

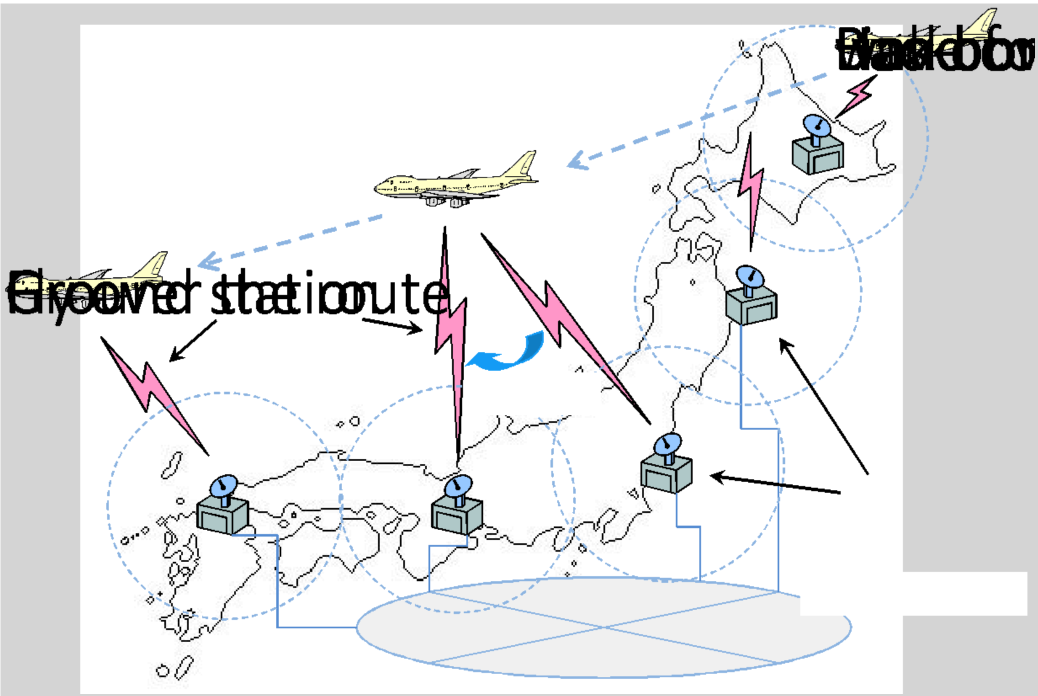
2.1 Background

Demand has increased for better mobile phone and wireless local area network (LAN) access for people on-board aircraft. Now, several airlines have started cabin use of cellular phones with a system involving satellites. Meanwhile, in Japan, the air-to-ground (ATG) communication system with aircraft, which achieves over 100 Mbit/s transmission speed, is also being studied. In the system, the 40 GHz band facilitates broadband wireless communications on airplanes and on the ground. As shown in Fig. 8, airplanes fly over ground tracking antennas arranged at regular intervals.

As the aircraft passes overhead, the antennas hand over service one after another to the aircraft. The 40 GHz band is not used heavily in commercial applications and is expected to facilitate the broadband communication system.

FIGURE 8

Over 40 GHz wave broadband wireless direct communication system between air and ground operated in Japan



2.2 Descriptions of system architecture and communication equipment

The specifications of the proposed communication system and the airborne/ground equipment are described below. The frequency bands of the up and down links are supposed to use the 40 GHz frequency range and are tentatively given at 44 and 46 GHz bands, respectively for the prototype development. Table 2 summarizes the specification of the proposed communication system.

TABLE 2

Specifications of the communication system

Item	Specifications	Remark
Coverage area	10 km ~ 50 km in radius	Depend on weather conditions and communication speed.
Transmission rate	Up to 100 Mbit/s or over	Variable
Protocol	Full-duplex	
Frequency	Downlink: 44.45 GHz ± 100 MHz Uplink: 46.8 GHz ± 100 MHz	The frequencies are tentatively allocated.

The system uses the frequency division multiplex (FDM) method for communication.

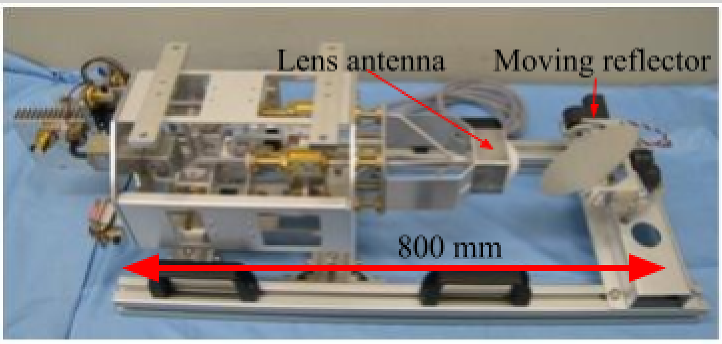
Considering the characteristics of the millimetre wave and the spectrum efficiency, both the airborne and the ground antenna track each antenna position. Therefore, the antenna system needs to consider the characteristics of the millimetre wave and the geographical dimensions.
For example, the ground-based tracking antenna must continuously track the aircraft with a high degree of accuracy. Meanwhile, the airborne antenna must track the ground-based antenna based on the aircraft attitude and position, and must be also compact and lightweight.

A) Ground station antenna

The ground station has a mechanically controlled reflector to direct the antenna beam in a specific direction by tilting the reflection disk mechanically as shown in Fig. 9. With a reflector controlling the antenna beam in the system, the mechanism provides a cost-effective, power-efficient tracking antenna. Furthermore, a radio wave was separately transmitted at 44.55 GHz, in addition to the communication signal wave so that the system could execute the mono-pulse tracking technique by monitoring the reception level of the radio wave signal.

FIGURE 9

Prototype of ground tracking antenna with lens antenna

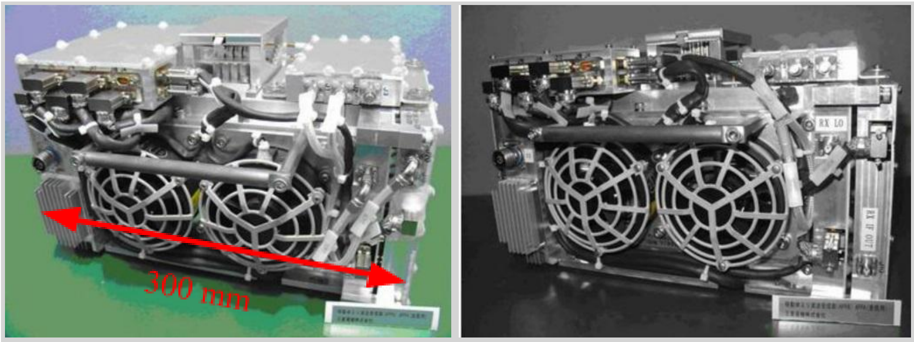


B) Airborne antenna

As shown in Fig. 10, the airborne antenna consists of a transmission (left) and a reception (right) components using active phased array antenna (APAA) technology, which is capable of two-dimensional electronic antenna scanning. The APAA is composed of 64 elements in an eight-by-eight array. The approximate weight of the antenna is 11 kilogrammes. Each element of the APAA is connected to the transmitting/receiving module to control the antenna beam direction by changing the phase component with 4-bit resolution. In addition, the directional control of the antenna is limited to ±45 degrees as a device specification.

FIGURE 10

Appearance of transmission and reception components of active phased array antenna



2.3 Verification tests and results

To verify the overall performance of this system, several trial flights with the prototype equipment were successfully conducted in 2012. This verification was mainly for the basic property of the airborne antenna, the ground tracking antenna, access control equipment and some other equipment. An airplane with the APAA was used as the airborne station. Table 3 presents an overview of the airborne verification test, and Fig. 11 illustrates a diagram of the airborne verification test.

The transmission and reception frequencies were allocated as 46.8 GHz and 44.45 GHz, respectively, for simultaneous transmission. The data transfer rate was 141.7 Mbit/s when QPSK modulation with a symbol rate of 78 Msymbol/s was applied. The 106.3 Mbit/s transfer rate was realized when 8PSK modulation with a symbol rate of 39 Msymbol/s was applied.

The antenna control information, such as the reception level and antenna directional data, was stored in the control sections. The modem signal and the error information of Bit Error Rate (BER) or Packet Error Rate (PER) (circuit quality) were also stored in the modem sections at both the airborne and ground stations. The flight data, which consist of airplane position/attitude information, were stored only on the aircraft. The ground station treats the transmitting and receiving data through millimetre waves.

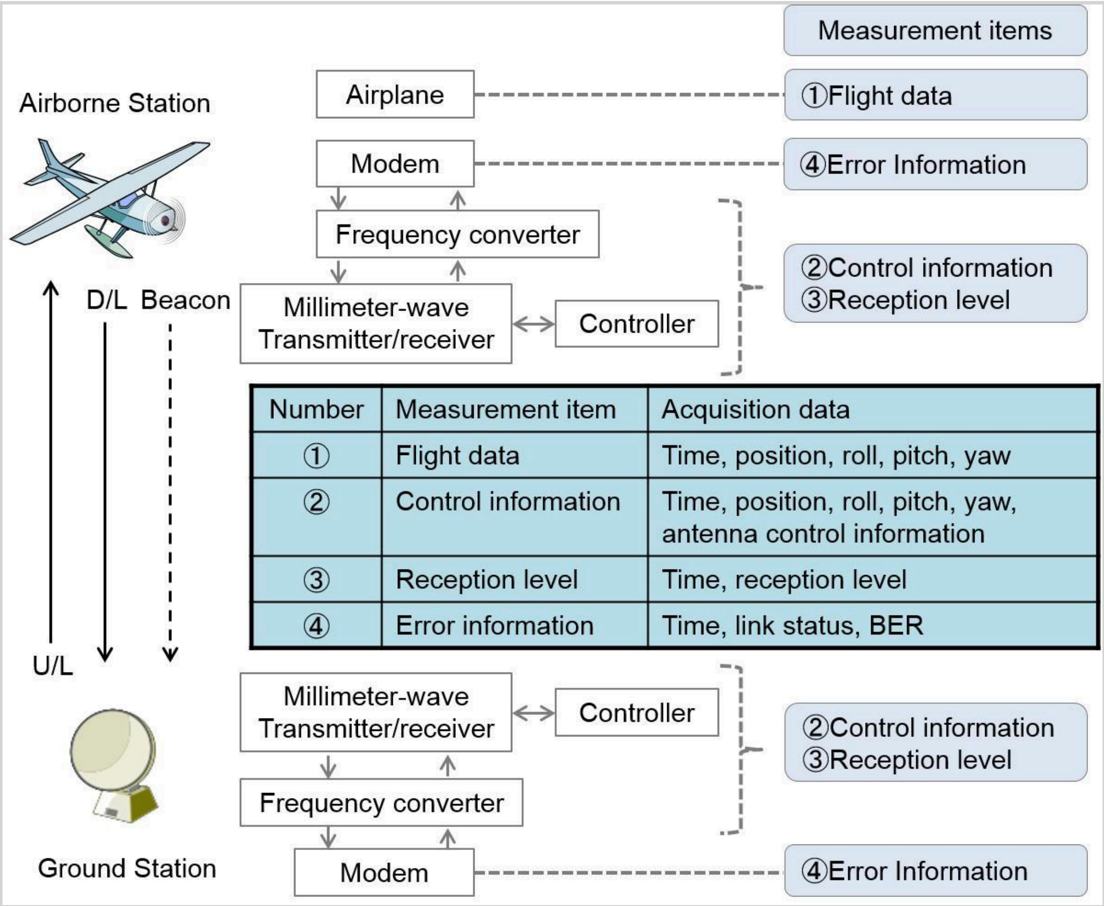
TABLE 3

Airborne verification test overview

Item	Contents
Airborne station	Active phased array antenna
Ground station	Millimetre-wave transmitter/receiver with mechanical driven antenna
Frequency	Uplink: 46.8 GHz Downlink: 44.45 GHz
Data transfer rate	141.7 Mbit/s at 78 Msymbol/s (QPSK) 106.3 Mbit/s at 39 Msymbol/s (8PSK)
Acquisition data	– Control information such as reception level and antenna directional data. – Modem signal, error information of packet error rate or bit error rate. – Flight data (airborne status such as position/attitude information).

FIGURE 11

Airborne verification test system



Number	Measurement item	Acquisition data
①	Flight data	Time, position, roll, pitch, yaw
②	Control information	Time, position, roll, pitch, yaw, antenna control information
③	Reception level	Time, reception level
④	Error information	Time, link status, BER

We evaluated the following items in the airborne verification test:

a) antenna pattern measurement,

b) tracking ability test,

c) communication capability test and mass volume data transfer test, and

d) communication distance test.

Finally, the results confirmed the success of the airborne verification tests as follows:

a) The beam width of the antenna was observed at about 8 degrees in the airborne tests, while it was observed at 10 degrees in an anechoic chamber. Although the width becomes approximately 2 degrees narrower than that of the designed value, the characteristics of the antenna beam were almost identical.

b) The system with tracking mode could track each antenna position correctly when the maximum angular ground speed was 229.65 km/h at an altitude of 785.47 m, which corresponds to 4.7 degrees per second in calculation.

c) Reception level and BER characteristics were measured and confirmed when the modulation types were QPSK and 8PSK and the flight altitude was approximately 2 000 m.

d) The results indicated that communication was established for a horizontal distance of 2 380 m and a flight altitude of 1 816 m, thus the communication distance was approximately 3 km. At this time, the angle of elevation sighting the airborne station from the ground station is 38 degrees, which was confirmed as a minor difference compared to the device specification of 45 degrees for the beam scan range of the APAA used on the airborne station.

Application of these results to various aircraft shall establish an environment that enables mass volume downloading with bidirectional IP communication.