Spectrum considerations for Air-to-Ground communications

SkyFive AG
Willy Messerschmitt-Strasse 1
D-82024 Taufkirchen
Germany
https://skyfive.world
info@skyfive.world

Towards the digital sky

Broadband connectivity is a key enabler of digitization in almost any industry, and the penetration of Internet access in a country is strongly correlated with its economic output. Over the previous decades, countries have been investing significantly in Information and Communication Technology (ICT), to build the essential infrastructure for connecting everybody and everything. Deploying and evolving fixed and mobile networks constitutes a major portion in such initiatives.

The sky, however, has been largely exempted from investments in connectivity. Airlines, in the absence of alternatives, have been relying on global satellite providers to connect parts of their fleets. Today, it is state of the art for a connected aircraft to drag along a narrowband data pipe, which trombones 36.000km into space and the same distance back to the surface, where it connects to the Internet, in the country the satellite provider has deployed the nearest ground station in.

For developed and developing economies, aviation is or is becoming one of the major means of transportation. The current number of air travellers worldwide is already 4 billion; by 2036, this number is expected to almost double to 7.6 billion, with most of the growth being contributed by emerging markets. Given the strategic importance of the aviation industry, countries should extend their broadband strategies into the sky, which would yield an array of socio-economic benefits:

- In today's business world, sitting unconnected for one or several hours translates to a factual reduction of **productivity**. Market research suggests that 90% of passengers would like to connect in the aircraft, but less than 10% do so, as fees are high, and performance is poor – too poor especially for cloud applications. The reverse conclusion is that, once inflight Internet access becomes affordable (or free) and fast, most passengers would use it as naturally as anywhere else on the ground.

- **For passengers, the end-to-end travel experience could be significantly improved**. Air travel would become more predictable and pleasant, despite the total number of passengers increasing year on year. Airlines could manage disruptions proactively, by proactively starting an online dialogue with the passenger who will not make his connecting flight and offer rebooking or an overnight stay, instead of queuing up people at transfer desks. Arriving passengers could accurately estimate the time when exiting the airport, and book ground transportation accordingly. Foreign visitors could already immigrate with an officer in flight, and simply walk through passport control once on the ground.

- By connecting their aircraft, **airlines could reduce fuel consumption and associated emissions** in several ways. Contingency fuel could be planned more accurately, allowing to reduce the amount of fuel carried unnecessarily. Real time weather and traffic information updates would allow aircrews to continuously optimize their flight paths. Weight could be reduced by replacing in-seat entertainment systems with video streaming to passengers' own devices, and by replacing trolley sales with online shopping and pickup of purchases at the arrival airport. Tele-diagnosis of sick passengers by competent medical staff on the ground would eliminate unnecessary diversions.

- The above-mentioned initiatives allow **airlines to recover from the COVID-19 crisis** more quickly. In the post-pandemic world, operational efficiency, ancillary revenue generation, and a safe travel experience are critical for airlines to restore air transportation services for residents and tourists.

- **Airports could increase their efficiency** by optimizing resources based on data exchanged between the aircraft, the airline, and the airport, instead of relying on static rosters and heuristic planning methods. Aircraft ground times would become predictable, as maintenance records would be transmitted to the ground crew in flight, so that staff, tools, and parts can be prepared appropriately.
- The effectiveness of **airborne public safety missions** could be improved significantly, for example, by introducing live video transmission for law enforcement helicopters, and by enabling inflight transmission of comprehensive patient data between ambulance flights and hospitals.
- In the medium term, a connected sky would **facilitate the commercial introduction of novel forms of individual air transport in large cities and megacities, i.e. air taxis** (eVTOL). These aircraft will extensively rely on real time data communications to safely navigate urban airspaces, rather than following the spoken instructions of air traffic controllers.
- Countries can foster a **multi-faceted ecosystem around the new possibilities of digital aviation**. Like the rise of the Internet on the ground has been fueling the ICT industry for several decades, the Internet in the sky could stimulate a new wave of innovation in areas like seamless travel, online avionics, connected airline operations, logistics, tourism, and more. The one who first creates competence centers with specific R&D capabilities is likely to grab a majority share of the local market and expand into other markets worldwide.

The key to enabling true broadband connectivity in the sky is to take advantage of the latest developments in wireless technologies, and to deploy a high-speed network on the ground, with skywards-pointing antennas that cover the airspace up to the typical cruising altitude of 10-12 km. Such an aviation network outperforms any satellite service by 1 or 2 orders of magnitude, is a moderate investment, and scales to the future demands of the aviation industry.

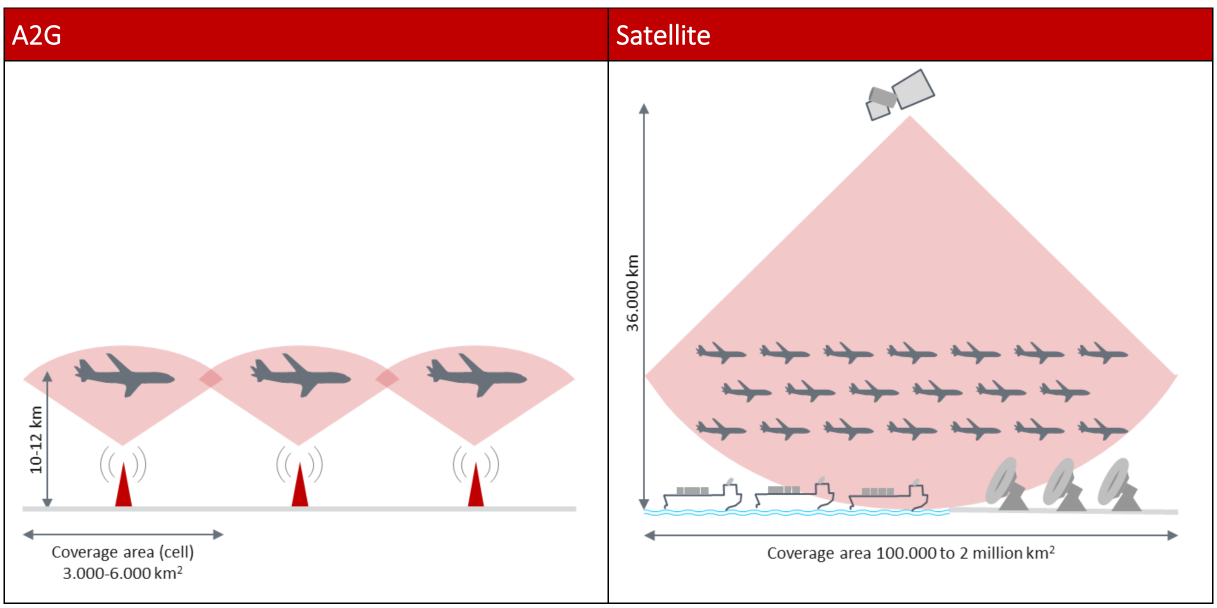
While satellite services have mostly been the business of specialist global companies, establishing an aviation network that covers the airspace above one or several countries is more likely going to become the task of a national player. For example, the European Aviation Network, a single aviation network covering the skies of 35 countries, has been jointly deployed by Inmarsat in the United Kingdom and by Deutsche Telekom in Germany.

Following the success of the European Aviation Network, similar initiatives to deploy dedicated aviation networks are well underway in other markets that experience solid growth in airline passenger traffic, and where the strategic importance of the aviation industry and its digitization has been recognized. It is important to align these national initiatives and ensure compatibility between the different aviation networks, such that aircraft can flexibly connect to different networks when flying across borders.

Inflight connectivity based on Air-to-Ground communications

The key inhibitor to the wider adoption of inflight connectivity has been the lack of a suitable broadband technology for reliably connecting high and fast flying aircraft. To date, satellite communications has been the main means, but compared with state-of-the-art wireless technologies on the ground these systems are severely limited in per-user throughput, total capacity, transmission latency, scalability, and cost per bit. Furthermore, the total cost of installing and operating a satellite communications system on an aircraft is significant.

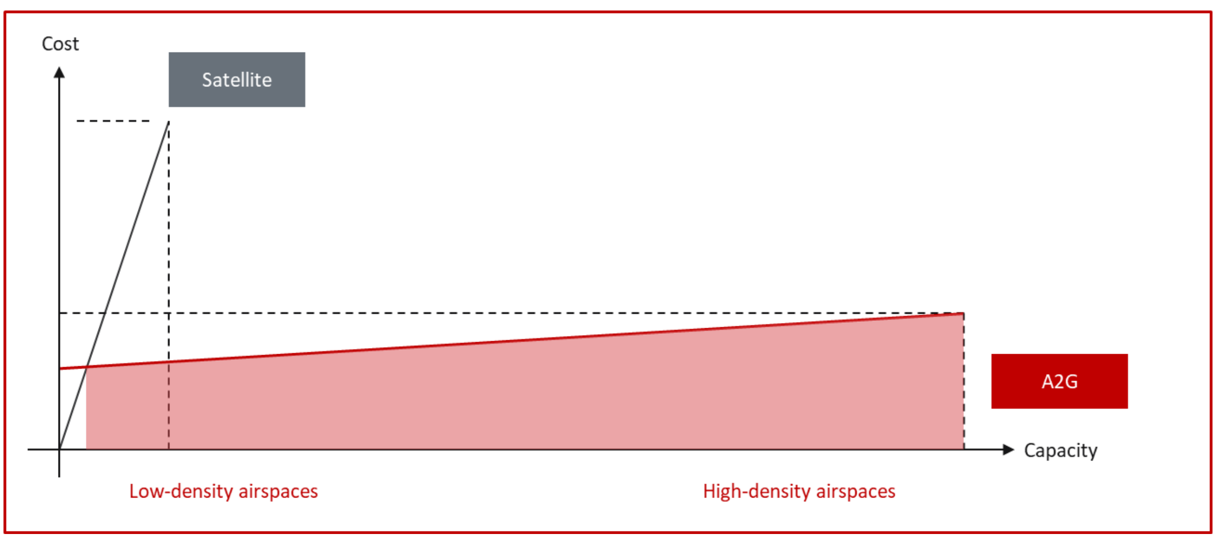
Air-to-Ground (A2G) communications takes a completely different approach. Built upon standard 3GPP technologies, aircraft are connected from the ground (transmission distance 10 kilometres) rather than from space (transmission distance 72.000 kilometres). An A2G network is a cellular network in the sky, set up by A2G base stations with skywards-pointing antennas. Cells can be of giant size, given that nothing obstructs the radio signals when traveling from the ground to the aircraft and back. The aircraft just needs a compact A2G terminal with a palm-sized antenna mounted under its belly.



An A2G solution based on 3GPP standards has compelling advantages over satellite systems and inherits the fast feature evolution of standard terrestrial networks and the economies of scale resulting from large scale public mobile network deployments. When comparing both technologies with each other the advantages of A2G communications become obvious:

	A2G	Satellite (L, Ku, Ka band)
Throughput per aircraft	Up to 1 Gbps per aircraft (spectrum-dependent)	1-5 Mbps per aircraft
Area within which the bandwidth is shared among all aircraft	One A2G base station sector, which covers between 3.000 and 6.000 km^2 of airspace	One satellite beam, which covers between 100.000 and 2 million km^2 of airspace
Scalability	Additional A2G base station sectors for densification	1 or 2 spot beams can be added per geography (e.g., continent)
Dedicated to aviation	Yes	No, bandwidth is shared among all users within the satellite beam
Ground connectivity at airports	Yes	No (too many aircraft in a very small area and insufficient antenna cooling)
Radio latency	< 1 millisecond	500 milliseconds
Data traffic kept in country	Yes	Depending on location of satellite ground station
Time to retrofit aircraft	8 hours, 3 engineers	5-15 days, 30 engineers
Structural aircraft changes	No	Yes
Additional weight on aircraft	7.25 kg	200 kg

The relation of cost versus capacity is conceptually depicted below. Satellite communications has a cost advantage only over continental and oceanic airspaces with very low aircraft densities. The significant cost advantage of A2G communications materializes in most continental airspaces with medium to high aircraft densities.



SkyFive A2G solution overview

The SkyFive A2G solution comprises the ground network, complete aircraft solutions for commercial aviation and public safety, and the Service Operations Center.

- The ground network consists of A2G base stations with skywards-pointing antennas optimized for airspace coverage, which create very large cells in the sky. Given that, unlike on the ground, radio signals can freely propagate, a single base station provides broadband services to aircraft flying within a 100-150 km range, up to speeds of 1.200 km/h. SkyFive implements patented algorithms to operate cellular technologies within such extreme parameters.
- The aircraft solution for commercial aviation consists of the A2G terminal (including a palm sized antenna mounted under the belly), the cabin server, and one or several Wi-Fi access points. Due to its compact size and low weight, smaller aircraft can be fitted with it as well. Installing the complete aircraft solution takes 8 hours or less from nose to tail and can be accomplished during an overnight break by a skilled team.
- The SkyFive Service Operations Center performs all functions of an Inflight Connectivity provider, including the 24/7 tasks of managing all airborne and ground components, assuring that Service Level Agreements are fulfilled, and providing real time availability and performance dashboards to airlines.

The SkyFive A2G solution establishes a data pipe between the aircraft and the ground. Different services can run through that pipe and be distributed within the aircraft at one end and forwarded to different backend systems on the ground. A service mix could comprise cabin, cockpit, and aircraft IoT services, which can all be treated with different Qualities of Service. The A2G connection is transparent and can be shared among several providers of airline and passenger services.

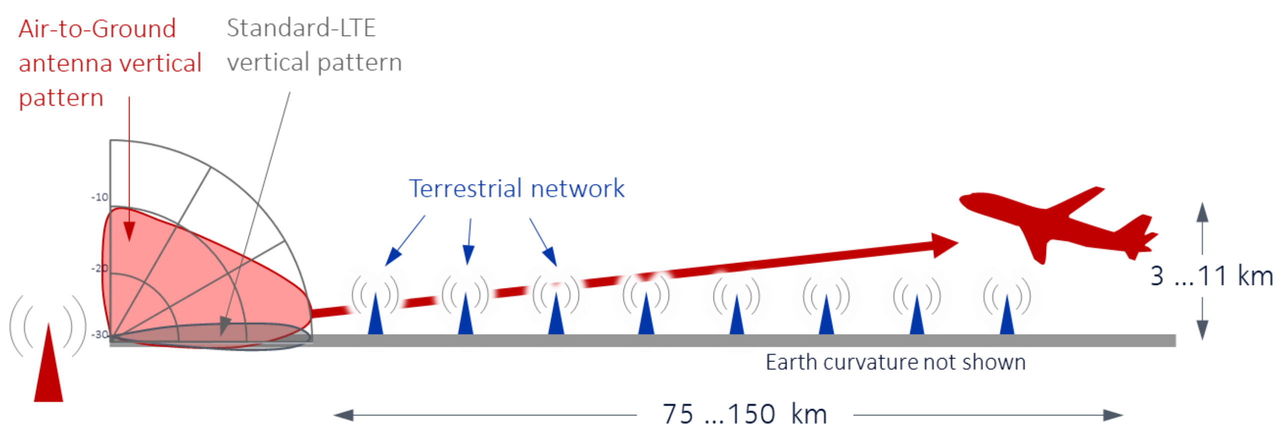
Passengers on board connect to one of the Wi-Fi-hotspots in the aircraft cabin, which work on the unlicensed ISM bands – thus no spectrum needs to be assigned. The passengers' uplink data is encapsulated into encrypted traffic flows and forwarded through the A2G network to the central core network on the ground. There, the individual Wi-Fi sessions are terminated and further routed to the Internet. In contrast to satellite systems, all data traffic stays in country.

An A2G network can be deployed over continents and bordering seas. Airlines can utilize it as their sole means of connectivity, for aircraft flying on short haul and medium haul routes (which typically constitute 70-80% of the fleet), or in combination with existing satellite systems, for aircraft flying on long haul routes that include segments where A2G coverage is not available (yet). Aircraft roaming, that is, connecting to an A2G network of another operator, is also supported.

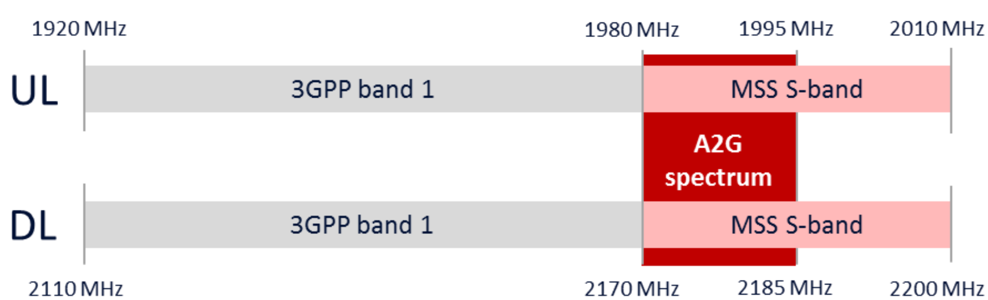
Spectrum for A2G communications

Assigning adequate spectrum resources is key to making true broadband services available in the sky. The assigned spectrum must be dedicated to A2G communications, in order to avoid interference with terrestrial cellular networks. As conceptually shown below, reusing terrestrial spectrum for an aerial network is not feasible, as two vertically separated layers cannot be established in practice.

Furthermore, the spectrum should be assigned to a single A2G network operator, as fragmentation would impair the performance and therewith the quality of the service.



For the European Aviation Network, which is the first A2G network based on 3GPP standards, 2x15MHz of Frequency Division Duplex spectrum in the 2.1GHz range were assigned:



This band, commonly referred to as Band 65a (i.e., the lower half of band 65), allows achieving a downlink throughput of 100 Mbps for each connected aircraft. The required ground network and aircraft terminal equipment is available and in extensive commercial use in Europe. Assigning the same band in other markets will assure:

- the shortest time to A2G-based services in these markets
- the lowest investment level, as no new ground and aircraft equipment must be developed and certified
- full compatibility with other A2G markets

While 2x15 MHz will be enough at service start, also earmarking the upper half of Band 65 (1995-2010 MHz / 2185-2200 MHz) for A2G is generally advisable to cater for future bandwidth demands.

Status of A2G spectrum standardization

The mentioned 2x15 MHz FDD spectrum is well established across different standardization bodies and rulemaking organizations. Part of the standardization process were extensive studies on compatibility, interference, and emission requirements. This, together with the experience from the European Aviation Network, assures the technical feasibility and performance of A2G communications in Band 65a.

ITU	Draft recommendation on harmonization for broadband air-to-ground, Annex 11 to Document 5A/976-E: use of 1980-2010 and 2170-2200 MHz for A2G
European Commission	EU commission decision of 14 February 2007 on the harmonized use of radio spectrum in the 2 GHz frequency bands for the implementation of systems providing mobile satellite services (notified under document number C(2007) 409) (2007/98/EC)
	Request to EU member states to assign the frequency bands 1980 to 2010 MHz and 2170 to 2200 MHz for MSS (incl. avionics purposes)
	Decision No 626/2008/EC of the European Parliament and the council of 30 June 2008 on the selection and authorization of systems providing mobile satellite services (MSS)
	EU commission decision of 13 May 2009 on the selection of operators of pan-European systems providing mobile satellite services (MSS) (notified under document number C(2009) 3746) (2009/449/EC). Applies also for avionics and includes A2G.
	Directive 2014/53/EU requesting the production of a European Standard for A2G
CEPT ECC Electronic Communications Committee	ECC Report 233: compatibility studies for aeronautical CGC systems operating in the bands 1980-2010 MHz and 2170-2200 MHz
ETSI	Harmonized European Standards ETSI EN 302 574-1 and ETSI EN 302 574-2: ground and mobile stations for A2G

Market status of A2G

The European Aviation Network (EAN), a partnership of Inmarsat and Deutsche Telekom, is the first A2G network based on 3GPP standards. It has been deployed all over Europe and is in commercial service. Inmarsat owns the spectrum and provides Inflight Connectivity services to airlines. Deutsche Telekom owns the ground network, which was designed and delivered and is being operated by Nokia and SkyFive.

Europe has one of the most congested skies in the world, with more than one billion passengers and 11 million flights per year. To date, ground sites have been rolled out in 34 countries. An additional 9 small countries are being served from sites in neighbouring countries. Several adjacent countries are in the process of joining EAN or are considering doing so. Already with the current proliferation, EAN covers the airspace over the countries that contribute 24% of the global Gross Domestic Product.

The success of EAN has been a catalyst for the interest in A2G-based Inflight Connectivity in all markets that see robust growth in air passenger traffic, and where airspace density and absolute passenger numbers preclude the use of satellite communications. Spectrum consultations are underway or have already concluded in several of these markets.

Spectrum assignment considerations

Regulators contemplating the assignment of A2G spectrum should consider the following specifics of A2G services, which differ significantly from terrestrial mobile services provided by Mobile Operators:

- Neutrality: the A2G solution establishes a data pipe between the aircraft and the ground. The customer of that service, typically an airline, can independently decide on the use of that pipe. It could provide cabin Wi-Fi services by itself or cooperate with terrestrial Communication Service Providers, one or several.
- Transparency: the above-mentioned data pipe established by the A2G solution is transparent to the services that it carries. The pipe can be shared among several providers of airline and passenger services and supports a sophisticated Quality of Service scheme for service differentiation, if required.
- Airworthiness certification: the A2G terminal installed on the aircraft must undergo a comprehensive certification process. The SIM card inside the terminal is considered a part of the specific aircraft, therefore any change of the SIM card would invoke costly re-certification. Airlines therefore have strong reasons to stay with their existing A2G service provider.
- Roaming: the A2G solution, which is based on 3GPP standards, allows aircraft to roam into other A2G networks. Utilizing the same A2G spectrum across different networks facilitates roaming and ascertains that both domestic and international air traffic can be served, and therewith avoids the implementation of country-specific “island” solutions.
- Cross-border leasing: a considerable percentage of commercial aircraft is not owned by the airlines but leased. After the lease term, the A2G terminal should not deinstalled but could be

utilized by the next airline leasing the aircraft. Utilizing the same A2G spectrum across different networks facilitates this scenario.

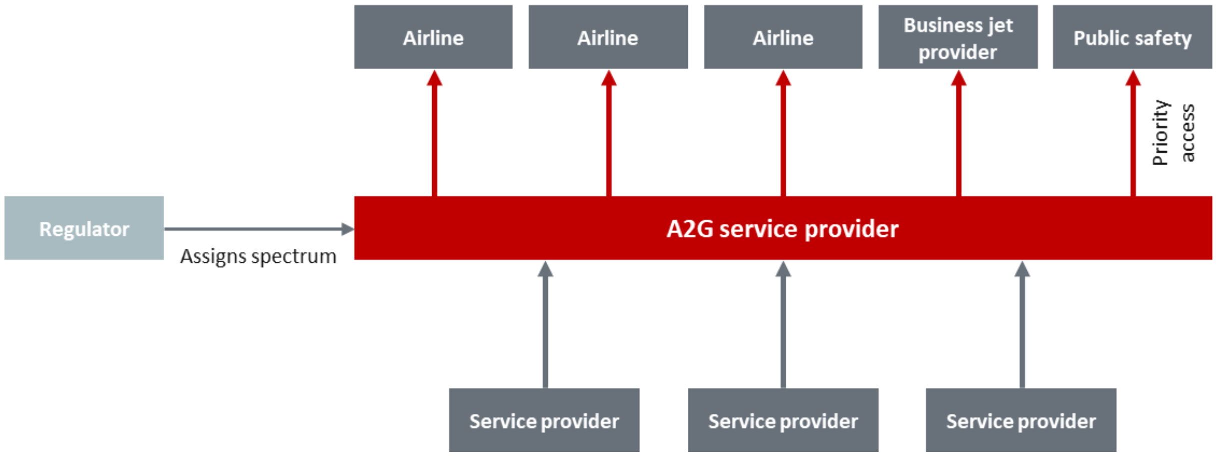
- **Exclusivity**: for the stated interference reasons, the A2G spectrum should be assigned exclusively for the purpose of A2G communications.
- **Lateral coverage**: for commercial aviation, A2G coverage needs to be initially established at least on the main air routes. As actual flight paths will vary due to weather and traffic, and air routes will change over time, A2G coverage planning needs to cater for wide corridors rather than narrow lanes between air navigational aids. If the A2G network should also serve public safety authorities (e.g., police, Search & Rescue) then full airspace coverage needs to be established. In Europe, with its many city pairs, the European Aviation Network was built for 100% airspace coverage right from the beginning.

Possible business model and license regime

From the previous considerations it becomes clear that an A2G network differs substantially from a regular terrestrial network serving mobile subscribers:

	A2G network	Terrestrial network
Customer of the network provider	Airlines, public safety authorities, other aircraft operators	Mobile subscribers (consumers and businesses)
Number of subscriptions	Hundreds to a few thousands	Millions to hundreds of millions
Spectrum award process	Assigned	Auctioned
Number of service providers	One (neutral)	Several (competing)
Spectrum division	No division - single block	Equal or unequal blocks

To make best use of the spectrum resource and take the specifics of A2G communications into account, a single A2G service provider should be established to provision data pipes between aircraft and the ground as a set of white label services with different bandwidth and Quality of Service attributes. These could then be utilized by different providers of airline and passenger services, based on non-discriminatory access. Public safety authorities could be granted priority access for accomplishing critical missions.



Given that an A2G ecosystem already exists, the assignment of spectrum should be conditioned to the start of commercial A2G services within 24 months. The spectrum should be assigned for at least 15 years, with an option to extend thereafter, to be aligned with the investment cycles of the aviation industry. Furthermore, it should be assured that the A2G service provider passes the TCO benefits of the A2G technology on to its customers, resulting in affordable prices for airlines and passengers.

The proposed model has several advantages:

- Different service providers can compete for their airline and passenger customers, giving choice and making best use of the spectrum asset.
- Airlines can rely on a single high-speed network that is compatible also with other markets, therewith ensuring maximum investment protection and economies of scale.
- Public authorities get priority access to an aviation network with minimum own investment.
- Services to airlines and passengers are provided at an affordable price point, as no auction is required, and spectrum fees can be set at a level that is appropriate for connecting hundreds of aircraft in a closed private network rather than connecting millions of subscribers in a public network.
- Services are provided in the shortest possible time.
- The model can be extended to adjacent countries, to form a regional cluster like the European Aviation Network.

Conclusion

Broadband connectivity is a key enabler of digital aviation. Providing a high-speed aviation network yields an array of socio-economic benefits, including productivity of business travellers, an improved end-to-end travel experience, significant fuel and CO_2 savings, quicker recovery from COVID-19, integrated airline-airport operations, more effective airborne public safety missions, and in the medium term the commercial introduction of urban air taxis.

A2G technology based on 3GPP standards is mature, as has been proven with the European Aviation Network, which provides broadband connectivity in the airspace above 35 countries. Similar initiatives are well underway in other markets that experience solid growth in airline passenger traffic. It is now important to align these initiatives and ensure compatibility between the different aviation networks, so that aircraft can seamlessly fly from one network into another.

Assigning adequate and dedicated spectrum resources is a key success factor. The band 1980-2010 MHz and 2170-2200 MHz (Band 65a) has already been assigned in countries that contribute 24% of the global Gross Domestic Product. Using this band also in other markets will ensure the shortest time to commercial services, the lowest cost (as no new ground and aircraft equipment must be developed and certified), and compatibility with all markets that have already assigned that band.

The spectrum license regime needs to be different than for terrestrial mobile services for consumers. A viable model would be to establish a single A2G service provider, which provisions data pipes between aircraft and the ground as a set of white label services with different bandwidth and Quality of Service attributes. These can then be utilized by different providers of airline and passenger services, based on non-discriminatory access.