NOKIA

Using air-to-ground LTE for in-flight ultra-broadband

Opening the skies to new possibilities

Strategic White Paper

This paper covers both the business and technical considerations for ultra-broadband connectivity in continental aircraft fleets, and the benefits of a terrestrial cellular network approach based on 4G LTE. It describes the specifications and results of unique live experience gained in field trial campaigns of an air-to-ground prototype system, and offers go-forward considerations for telecom or satellite operators, airlines and business aviation stakeholders looking to gain competitive advantage in their service offerings.

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Introduction

The European airline market serves over 800 million passengers per year on 150 scheduled airlines and more than 4,400 commercial aircraft, according to the European Commission. Passenger traffic totals continue to rise annually, with great competition among airlines to provide best-in-class in-flight services. Key among these is broadband connectivity. Today's flyers are increasingly accustomed to broadband connections anywhere, 24/7 – driven by the need to stay in touch with family, enjoy entertainment and maintain critical business communications. When they fly, they want broadband connectivity equal to that they've experienced from terrestrial network and Wi-Fi hotspots on ground. These expectations are increasing demand for fast, seamless aircraft connectivity to the point where an airline's in-flight broadband capability has become a key competitive advantage.

The demand for in-flight bandwidth will further increase in the next few years – not only across Europe, but around the world. This demand is being driven by email, Short Message Services (SMS), streaming entertainment services and video sharing among passengers and earthbound family members through millions of smartphones, tablets and laptop computers. Almost all passengers, 97 percent, carry their own devices when traveling and 18 percent of passengers travel with a smartphone, laptop and tablet, according to a survey of 6,000-plus air travelers by the Swiss airport IT firm, SITA.

Currently, most in-flight connectivity uses satellite backhaul, with one vendor operating a satellite/ground Internet system in North America. For short- and medium-haul continental flights, these systems tend to be bulky and expensive. Additionally, current capacity is limited and exhibits high latency, especially when serving a large number of continental aircraft in a limited geographic area.

The solution: an air-to-ground (A2G) network based on 4G cellular Long Term Evolution (LTE) technology. This network will utilize ground stations connecting with aircraft flying overhead, providing an ultra-broadband backhaul infrastructure for deploying high-bandwidth in-flight connectivity to passengers and crew. While their customers and employees alike are enjoying these services, airlines will benefit from cost efficiencies and competitive offerings.

Nokia has developed a 4G LTE solution that combines the advantages of both A2G and satellites. To be deployed across the European Union by 2016, it will be the world's first truly hybrid aviation A2G solution, consisting of an S-band satellite (Europasat) and a Europe-wide S-band ground network. Based on state-of-the-art LTE technology and access to sufficient spectrum resources, this integrated network will offer airlines the world's fastest in-flight broadband connectivity service with speeds up to 75 Mb/s, far in excess of the limited capabilities of all other non-LTE A2G systems deployed in other regions.

The technical viability of this system already has been proven through several test flights in 2008 and 2012. Its commercial success can be achieved through a variety of different business models, as reviewed in this white paper.

Ultra-broadband for commercial aviation

Commercial air passengers around the world increasingly expect and require fast, reliable broadband services while in flight. This demand is increasing, mainly driven by an increase in air passenger traffic, competition among airlines to provide best-in-class in-flight connectivity services, and by millions of passengers using smartphones, tablets and laptops. These travelers expect broadband connectivity that is similar to that found on terrestrial network and Wi-Fi hotspots on ground.

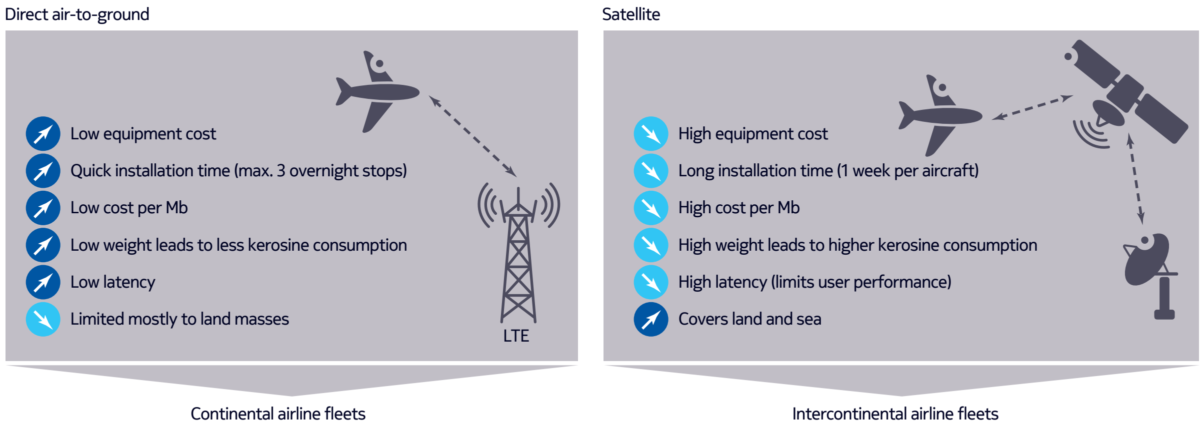
Airborne connectivity is still a relatively new phenomenon, with most services provided by satellites for aircraft flying intercontinental routes. For example, the American company Gogo offers Internet service mainly in North America through a satellite/ground network. These types of systems are capable of providing Air Passenger Communications (APC) and Airline Administrative Communications (AAC).

Today's issues

Despite the satellite and hybrid A2G systems available today, there is still no cost-effective high-bandwidth solution for in-flight broadband – especially for passenger infotainment with video on demand (VoD) and multimedia communications. Ku band and announced Ka band satellite solutions for creating the actual link between digital services and the airplane are efficient for long-haul flights on intercontinental routes over the oceans, at least in terms of coverage. However, for short- and medium-haul continental flights, a satellite-based solution is relatively costly; the equipment is heavy, bulky and expensive, and latency is high in regions with heavy air traffic. Ka band and Ku band satellite antennas are difficult to install on continental aircraft, requiring significant investments in the aircraft infrastructure.

Additionally, while Ka band satellite solutions might provide similar data rates as A2G, they entail a large transmission path from the aircraft to their geostationary orbits 36,000 kilometers above the Earth – a general hindrance for any delay-critical service.

Figure 1. Comparing A2G and satellite communications



Tomorrow's A2G LTE

On the near horizon is a solution that solves all of these problems. Currently under development and testing by Nokia and several technology partners, A2G LTE is poised to significantly enhance not only passenger experience, but also air traffic control and aircraft operations, enabling new levels of operational efficiency for airlines. Also called direct air-to-ground, it utilizes a ground-based cellular system to create a direct link between the aircraft and the ground for broadband IP connectivity without the large-delay hop via a satellite. The ground infrastructure is based on the latest global standard for wireless LTE. With a highly efficient air interface and a flat IP network architecture, LTE is an ideal, future-proof platform on which to deploy an A2G network.

Beginning in 2016, A2G LTE will be offered to some 800 million passengers per year travelling in commercial airplanes all over Europe as a valuable extension for terrestrial mobile broadband networks. The A2G LTE application itself is not a high-density service such as integrated microwave technology, but an auxiliary application to connect International Mobile Communications (IMT)-based high-density services to airplanes.

LTE A2G has several compelling advantages over existing systems:

- It offers the world's fastest in-flight broadband connectivity service with speeds up to 75 Mb/s.
- It provides higher throughput for both uploads and downloads. The A2G solution outperforms existing L band and Ku band satellite solutions in bit rates per aircraft, with the additional benefit of much simpler, lighter and less-expensive aircraft equipment, especially compared to the Ku band equipment.

- Unlike satellites, the terrestrial cellular approach allows rolling out and expanding the network capacity exactly where it is needed by adapting the cell sizes or increasing the number of cells – a flexibility that is not easily available from satellites.
- The time to install this solution on aircraft is less than three overnight stops, compared to up to five full maintenance days for satellite-based systems.
- A2G LTE also can provide multimedia services to passengers should airlines decide to offer that option.
- A2G LTE is based on fully standardized, future-proof technology.

These benefits mean that airlines can offer their passengers access to online services for work or leisure using their own devices, and with reliability and speeds previously only available on the ground. Rather than uploading recorded, often out-of-date content, the live connection allows the transfer of information at any time, opening up the possibility of offering advanced services such as live TV on flights, or video-conferencing for business passengers.

A2G LTE can be implemented as an independent cellular network, optimally under the control of one major network operator that supplies services to retail mobile operators in order to facilitate smooth system management and consistent quality-of-service (QoS) delivery.

Nokia has successfully demonstrated the LTE-based A2G system solution in field trials to major airlines and involved regulatory bodies in Europe.

A2G LTE cost efficiencies

The A2G LTE solution offers cost-effective, optimized operations for airlines. A2G LTE is based on off-the-shelf technology – with a wide, established ecosystem of components such as chipsets, antennas, modems and mobile devices, and with billions of users. It therefore is less expensive to acquire, deploy and operate than satellite systems, with less “downtime” for maintenance, and a relatively low weight (as compared to satellite) for more efficient fuel consumption.

In addition to providing advanced passenger communications and entertainment services, airlines can upload and download essential flight data via a broadband connection rather than through time-consuming hard disk data transfers at ground stops. This reduces the time the aircraft needs to spend on the ground, improving its productivity. A2G LTE also can enhance maintenance. By offering real-time problem identification, maintenance crews can minimize the time for diagnosis and go straight to fixing the issue.

The LTE A2G solution can be expanded further for cost-effective, higher-bandwidth services related to gate preparation, taxiing, takeoff, initial climb, approach, and landing – including operation below 3,000 meters, to the extent that regulatory agencies and airlines allow.

Challenges

Despite A2G LTE's many advantages, competing against the satellite option will only be possible if there is a viable business for an operator. Such models exist, and are profiled in this strategic white paper. Nevertheless, the upfront investments are significant, in particular for the mobile network operator setting up the infrastructure on the ground.

Additionally, A2G LTE crucially depends on the availability of sufficient spectrum resources to ensure high-speed broadband services to users. Too little spectrum allocated to more than one A2G LTE operator could negatively impact the quality of the service, and thus limit the benefits versus satellite based broadband access. Dedicated spectrum is mandatory to provide a consistent quality of service and to ensure interference-free network operation.

LTE: The next-generation platform for A2G

LTE is the global standard for the fourth generation (4G) of mobile multimedia broadband communications (data, video and voice). Defined by the global 3rd Generation Partnership Project (3GPP), it has been massively deployed worldwide by many mobile operators. LTE offers interoperability, scalability and high reliability. It also provides low latency (down to less than 10 milliseconds) and high data throughput (up to several hundred Mb/s). It also can operate in a wide spectrum range. As such, it provides a highly efficient and effective platform solution for advanced multimedia services, innumerable mission-critical applications for airlines, and a broad range of devices. Its advanced processing and spectral efficiency provide optimal support for day-to-day operations.

Secure, mission-critical architecture

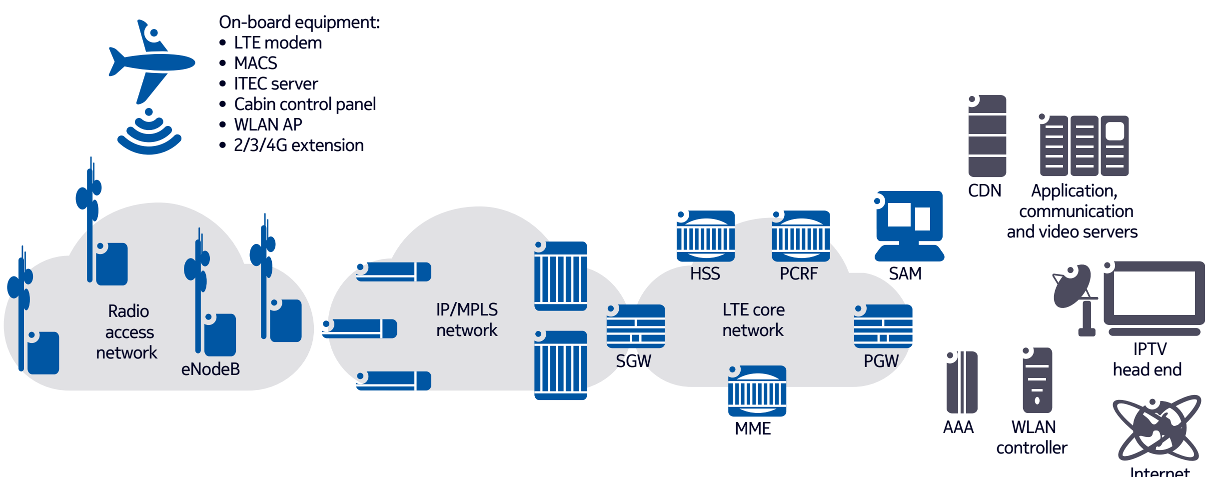
LTE-based solutions use an all-IP architecture that, combined with geographic redundancy, reduces potential points of failure and provides the high availability required by airlines and their customers. This also allows operators to build a complete, highly cost effective end-to-end network, including core, backhaul, LTE Radio Access Network (RAN) and modem or end-user devices. Its end-to-end QoS, from the core down to the terminal or user, allows mission-critical services and passenger connectivity on the same infrastructure.

LTE systems also offer extensive self-optimizing capabilities for simplified network operations, maintenance and self-healing. They are secure by default, with integrated encryption, access control and authentication.

Compared to other communication technologies, 4G LTE can reduce the cost to deliver each gigabyte by 50 percent from day one. When used in wholesale mode, it can reduce end-user prices by 90 percent, closing the gap between mobile telephony and mobile broadband. LTE is available in a wide spectrum and can accommodate different channel bandwidths.

LTE Release 10, approved in 2011, and subsequent releases of LTE, are commonly designated as LTE Advanced, or LTE-A, offering a smooth evolution of the LTE standard with enhanced capabilities. These enhancements are already producing major benefits, including the potential for ultra-wide bandwidth – up to 100 MHz of spectrum, if available – with ultra-high data rates and greater capacity to support more sophisticated applications. Therefore, LTE is future-proof, opening an evolutionary path to the next generation, 5G.

Figure 2. A2G end-to-end architecture



LTE Optimized for A2G

A2G LTE will not replace satellite broadband, but will complement it while providing unprecedented levels of performance for in-flight connectivity. The system is built upon off-the-shelf technology, with specific algorithms managing the specific characteristics of air-to-ground operations, including large cells (100 to 150 kilometers) and high speeds (up to 1,200 kilometers per hour).

The onboard aircraft equipment is modular and highly versatile. It includes one or two small antennas mounted below the fuselage, along with a compact and low-weight A2G On Board Unit (OBU) with a transceiver, acting as a hub and ground interface. Bell Labs has developed and flight-tested

OBU technology and algorithms that afford high-speed, high-bandwidth communications at high velocity. Even with aircraft speeds of 1,200 kilometers per hour, and spanning distances of up to 150 kilometers between base stations, the connection with the ground infrastructure is not lost. Flight altitude is of no concern either, with service unimpeded at the long-haul altitude of 13 kilometers, or 37,000 feet.

The OBU supports a wide variety of onboard access technologies. Passenger connectivity is implemented through Wi-Fi or cellular (2G, 3G and 4G), and the aircraft entertainment systems as well as the flight deck applications can be connected through Ethernet. Several QoS classes in the fully IP-based system ensure compatibility with existing Wi-Fi or GSM On Board Aircraft (GSMOBA) systems, and also support future applications and services.

Other technical considerations

To enable a terrestrial-based connection, the A2G LTE network requires a dedicated infrastructure decoupled from established cellular networks designed for “normal” terrestrial mobile broadband applications. The cellular structures of typical mobile broadband networks are much denser (ranges up to 10 kilometers), and cannot provide broadband services to aircraft without major interference risks to their own operations. Therefore, it is a precondition that A2G LTE operates in a dedicated frequency band on a dedicated cellular network. Additionally, a harmonized frequency band is an important element for ensuring A2G LTE’s viability when the network is spread out over different countries and national administrations.

Ground buildout

The ground buildout of infrastructure will be a major undertaking. It will require large cells with ranges of up to 150 kilometers, with the actual range determined by air traffic density. These can be dedicated or shared towers. The technology will also need to address Doppler Effect, which impacts transmissions to and from high-speed aircraft. At low altitudes, the propagation conditions change from line-of-sight to multipath, but the aircraft speeds are lower. Separate antennas and Remote Radio Heads (RRH) may be required.

Nokia is investigating all of the possibilities on how to utilize an integrated satellite and ground-based infrastructure to support the entire travel chain, including the operational and administrative communication needs for airlines, airports and passengers alike.

System performance

A2G LTE is capable of providing download speeds of up to 75 Mb/s to planes and 25 Mb/s from aircraft at distances of 100 kilometers and speeds of 1,200 kilometers per hour, using 2x15 MHz FDD licenses in the Mobile Satellite

Service (MSS) S-band, with these built-in advantages:

- A short transmission path compared to satellite technology, along with the low latency of LTE, reduces the delay for the critical services while simplifying system design for best-effort services.
- QoS-aware architecture in a fully IP-based system ensures compatibility with existing Wi-Fi or GSMOBA systems, but also supports future applications and services.
- LTE can be integrated with existing airline networks, as well as with the satellite systems now providing broadband services for international flights.

Comparison with other non-LTE A2G solutions

A U.S. hybrid A2G system operates in the 800 MHz band with a small bandwidth of only 2 x 1.5 MHz. This makes the efficiency and capacity of this approach rather limited. A2G LTE as deployed in Europe will operate with the most advanced 4G mobile technology (LTE) in the 2 GHz-band and within 2 x 15 MHz. Thus, A2G LTE will deliver far better performance compared to the U.S. system, which is currently running into capacity problems.

Flight trial results

Working with a complete ecosystem of partners, Nokia has demonstrated A2G LTE's performance in several live flight trials. These trials showed that with advanced ground antenna technologies supported by LTE and simple aircraft antennas, the A2G network architecture provided peak IP-layer bit rates of 50 Mb/s to the aircraft and 17 Mb/s from the aircraft (10 MHz FDD mode) at distances of 100 kilometers. The short transmission path compared to satellite technology, along with the low latency of LTE, enabled the system to reduce the delay for critical services while simplifying system design for best-effort delivery.

Passengers onboard the trial aircraft were able to conduct HD video conferencing without any delays, along with web surfing, connectivity to corporate IT infrastructure via VPN, SIP voice calls and a unique remote-controlled buggy demonstration, all with dedicated QoS classes. A two-site, three-sectored ground station setup ensured fast and reliable intra- and inter-site handover execution.

Specific service results included:

- Successful Internet access
- Connectivity with quality of service (QoS)
- Video conferencing (3 Mb/s downlink to aircraft, 2 Mb/s uplink from aircraft)

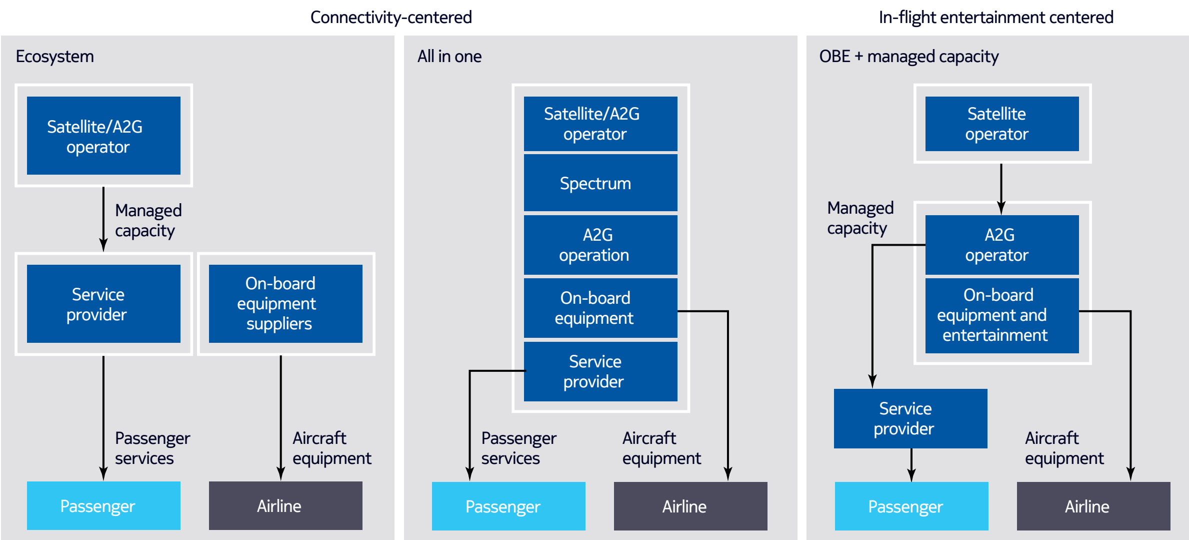
- Buggy on ground remote controlled from the aircraft (4 Mb/s DL, 1 Mb/s UL)
- Wi-Fi Internet access
- 110 kilometers maximum connectivity distance between aircraft and ground antenna at up to 800 kilometers per hour
- Use of passengers' own devices, including laptops, tablets and smartphones
- Fast access to Internet applications such YouTube, and a football game on live television
- Login to corporate VPNs
- Skype sessions between passengers and also to partners at a ground location
- Latencies averaging 50 to 60 milliseconds
- Successful handovers between cells
- Participation of eight major European Airlines and two European regulators
- Very positive feedback from participants

Business models for broadband LTE A2G

Mobile operators embarking on A2G LTE must consider many factors. These include startup costs, operating and capital expenditures (OPEX and CAPEX), expected revenues, available spectrum, commercial wireless services and the political environment.

There are three primary business models for the A2G solution. The first two, "Ecosystem" and "All In One," are centered on passenger connectivity, while the third, called "OBE + Managed Capacity," goes even further, with enhanced in-flight connectivity. All of these business models match the tradeoff between objectives (short-, mid- and long-term) and constraints.

Figure 3. A2G business models



Ecosystem

In this model, several players in a consortium or other partnership provide their own contributions to the service.

The satellite or A2G operator, owning the spectrum and the A2G LTE network, provides the A2G network capacity and connectivity to a service provider reselling the connectivity service to passengers in the plane. The satellite or A2G operator acts as a wholesaler of network capacity. The service provider manages the commercial relationship with the passengers and the roaming agreements, if any, with other telecommunication service providers in cases where 2G/3G/4G access is available on board. (There is no roaming if only Wi-Fi is available on board.)

Other players who are part of the ecosystem sell and manage the on-board equipment (OBE) for the airline companies. The OBE usually includes A2G antennas, A2G modems and controllers, Wi-Fi access points and sometimes a complete In-Flight Entertainment Communication (IFEC) system, as well as cellular Base Transceiver Station (BTS) or eNodeB equipment when cellular radio service is provided on board.

All in one

With this model, a single provider does everything. It owns the spectrum and the A2G LTE network, and manages the direct commercial relationship with the end customer (passengers), while selling and managing the on-board equipment.

OBE and managed capacity

In this model, the satellite operator owns the spectrum and rents it to a single company that owns the A2G communication network and sells the OBE to the airline companies with full in-flight entertainment services, and possibly multimedia content. The service provider owns and manages the commercial relationship with passengers, as in the Ecosystem model.

This list of business models is not exhaustive. A2G LTE is a new subject in a domain (aviation) where there are several existing players (satellite operators, OBE suppliers, IFEC operators, telecom operators, airline companies, aircraft manufacturers and others). Business models will continue to evolve in coming years as new companies – such as over-the-top (OTT) players and others – enter the market.

Deployment considerations

Service providers and mobile operators wishing to embark on A2G LTE deployment must consider factors such as budget, regulatory issues, internal resource constraints, coverage and reliability targets, available spectrum (S-Band frequency and bandwidth), and the number of end users when choosing the best overall design and business model. They also must take into account their customers' needs with regard to internal services such as uploading and downloading essential flight data during ground stops, enhanced maintenance, and internal high-bandwidth services during gate preparation, taxiing, takeoff, initial climb and approach.

Airlines and potential customers in business aviation have their own set of considerations requiring expert guidance, including the choice of Wi-Fi or 3G/LTE small cell for on-board connections, the type of aircraft to be modified, compatibility with existing systems for internal communications and maintenance, budget and the backhaul provided through network service providers.

Stakeholders in all areas of the A2G LTE ecosystem should cooperate to the fullest extent possible in design and specification to assure success. Regardless of the model chosen, the network must be defined through an end-to-end service-centric approach, which enables operational support to be maintained from the core through the network to the end user.

A full-cycle analysis by a trusted partner can provide deep and actionable insight into which model and variation is the best choice, both financially and operationally, for each stakeholder. A consulting service is key to defining the dashboard and ensuring success.

Ideally, this partner should offer highly qualified personnel, fully defined support processes and solutions expertise. The partner should also do the following:

- Assist in testing and ensuring that the new A2G LTE system meets the requirements of the service specifications, and those of the airline and business aviation customers.
- Make sure that all devices, applications and individual components within the system are working properly.
- Internally test the end-to-end A2G LTE solution and provide expertise and experience during the design and implementation stages.

Bell Labs can support planning activities and make recommendations for any A2G LTE stakeholder, providing such services as assessing the viability and capacity of backhaul/backbone facilities, traffic modeling, studying coverage scenarios, assessing the reliability of particular architectures based on potential site locations, total cost of ownership analyses and business modeling.

The result should be an integrated operational model that fully meets the needs of all of the stakeholders to be served.

Ultra-broadband for the skies

Air-to-ground technology is well-suited to provide broadband connectivity to continental aircraft flights. It has significant technical and cost advantages over existing and future satellite solutions. Commercial off-the-shelf technology and a dedicated spectrum are required to leverage the technology and cost advantages of air-to-ground communications.

Nokia is globally recognized as a trusted partner for transportation, with a proven record of expertise and know-how in the unique field of A2G. It offers established ecosystems of partners that can serve as operators (carrier and satellite), on-board equipment suppliers, and aircraft manufacturers. Nokia already has conducted live trials showing that A2G systems can be designed and deployed to provide cost-effective in-flight broadband that offers the best-possible services to airlines and their valued passengers.

As a market leader in LTE, Nokia offers a comprehensive ultra-broadband solution for aviation that is designed for scalability and high reliability, supporting mobile operators and their aviation customers in every step of their communications transformation. It provides experienced delivery and maintenance of A2G LTE networks from a single source, supported by a comprehensive suite of LTE and IP/MPLS products and a worldwide presence. Nokia launched extensive internal A2G activities in 2008. It has conducted intensive research collaboration with tier-1 industry leaders since 2009, including the world's first A2G LTE flight trials in 2011 with its own OBE prototype, and several flight trials in 2012 with all major European airlines. This has resulted in end-to-end turnkey expertise for designing, delivering, rolling out and maintaining a complete, next-generation A2G LTE solution.

Acronyms

3G	The third generation of mobile telecommunications technology, based on a set of standards used for mobile devices and infrastructure
3GPP	3rd Generation Partnership Project
4G	The fourth generation of mobile telecommunications technology, based on a set of standards used for mobile devices and infrastructure
A2G	Air to Ground communications
AAA	Authentication, Autorization and Accounting server
AAC	Airline administrative communications
APC	Air passenger communications
BTS	Base Transceiver Station, an equipment that facilitates wireless communication between user equipment (UE) and a network
CAPEX	Capital expenditures
CDN	Content Delivery Network. A set of distributed servers across a network to ease the broadcast of content
DL	Downlink
E-UTRA	Evolved Universal Terrestrial Radio Access. It is the air interface of 3GPP's LTE upgrade path for mobile networks
E-UTRAN Node B	Also known as Evolved Node B, (abbreviated as eNodeB or eNB), is the implementation of E-UTRA in LTE
EPC	Evolved Packet Core, the core network architecture of the LTE communication standard
FDD	Frequency-division duplexing
GHz	Gigahertz

GSM	Global System for Mobile Communications, a standard developed by the European Telecommunications Standards Institute (ETSI)
GSMOBA	Global System for Mobile Communications On Board Aircraft, a GSM standard specifically adapted for use while in flight
HSS	Home Subscriber Server
IFEC	In-Flight Entertainment Communication
IMT	Integrated Mobile Communications requirements issued by the International Telecommunication Union to support 4G mobile phone and Internet access service
IP	Internet Protocol
IPTV	Internet Protocol TeleVision
LTE	Long Term Evolution, a standard for high-speed mobile data and voice services
m	Meter
MACS	Mid-air Anti-Collision System
Mb/s	Megabits per second
MHz	Megahertz
MME	Mobility Management Entity
MNO	Mobile Network Operator
MPLS	Multiprotocol Label Switching
ms	Millisecond
MVNO	Mobile Virtual Network Operator
MSS	Mobile Satellite Service
OBA	On-Board Aircraft System
OBE	On-Board Equipment
OBU	On-Board Unit
OPEX	Operating Expenditures
OTT	"Over-the-Top" business model where one firm delivers one or more of its services across the public Internet or telco cloud services via an existing corporate VPN
PCRF	Policy and Charging Rule Function

PPP	Public-Private Partnership
QoS	Quality of Service
RAN	Radio Access Network
RLAN	Radio local area network
RRH	Remote Radio Head: An aircraft cockpit radio system that connects to a remote radio transceiver
SAM	Service Aware Manager. A network management platform
SLA	Service Level Agreement
SMS	Short Message Services
UL	Uplink
VoD	Video On Demand
VPN	Virtual Private Network
WLAN	Wireless Local Area Network. Also called Wi-Fi

Contacts

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