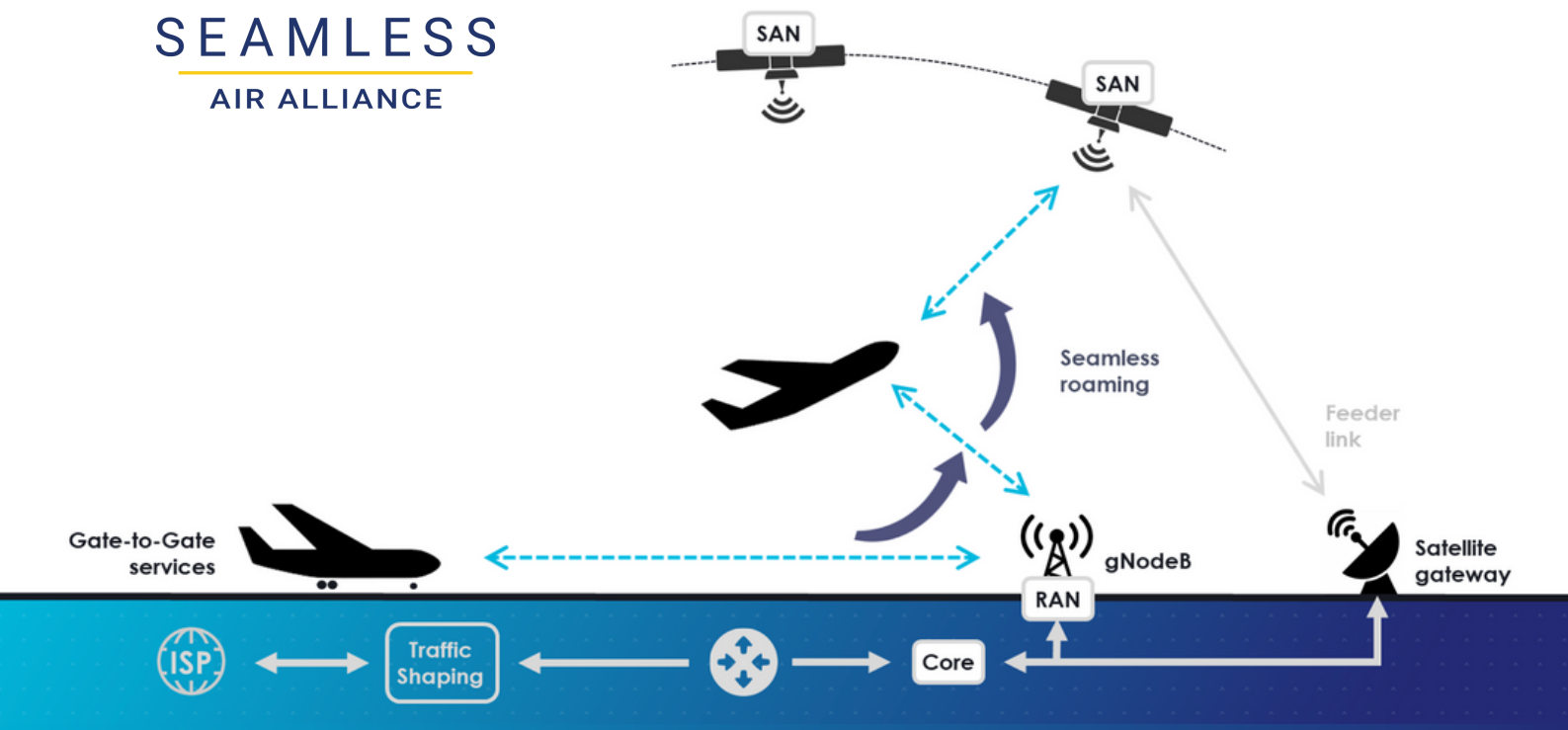
SEAMLESS
AIR ALLIANCE



3GPP NON-TERRESTRIAL NETWORKS (NTN)

FOR AVIATION CONNECTIVITY

SEAMLESS AIR ALLIANCE

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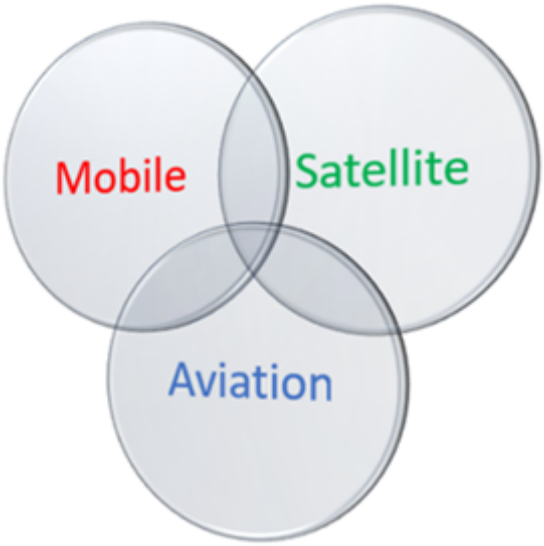
1.Executive Summary

The telecom industry is facing a major evolution enabled by multiple, emerging, satellite megaconstellations and the arrival of new Satellite-to-Phone services. Mobile Satellite Services (MSS) have developed regionally and without interoperability. MSS complexity has driven competition by feature and performance, leveraging proprietary solutions. 3GPP has been working on a global standardized solution called 5G Non-Terrestrial Networks (NTN) that would enable seamless roaming between terrestrial and satellite networks. NTN offers convergence for MSS technology, just as cellular proprietary technologies ultimately converged on GSM 3GPP. Standardization will dramatically boost the MSS market opportunity and expand every vertical market operating with a global footprint including aviation, maritime, automotive, and more.

The Seamless Air Alliance (SAA) promotes aviation requirements for inflight connectivity (IFC). The SAA is a robust organization based on a set of working groups which are composed of world-class experts in telecommunications, aeronautical, and connectivity technologies. SAA members encompass the most-important companies and organizations in the aviation industry, including airlines, airframe manufacturers, connectivity service providers, satellite operators, and equipment suppliers.

IFC communication networks are typically not inter-operable, requiring proprietary modems and customized radiating characteristics. 3GPP NTN brings an opportunity to harmonize IFC standards, moving away from proprietary solutions that limit growth, prevent technology upgrades, and inhibit interchangeability of equipment.

The aviation industry expects global passenger traffic to reach 9.4 billion passengers in 2024. The Seamless Air Alliance has a working group dedicated to ensuring the potential for 5G NTN is not lost as applied to the aviation industry. The group is co-chaired by Olivier Hauw (Airbus) and Rubén Díaz Calvo (Vodafone) and includes participation from experts across the satellite, mobile, and aviation industries.



According to NSR, the global aeronautical satcom market is expected to grow with an average cumulative annual growth rate (CAGR) of about 17% during the next decade, reaching up to $10B in 2032.

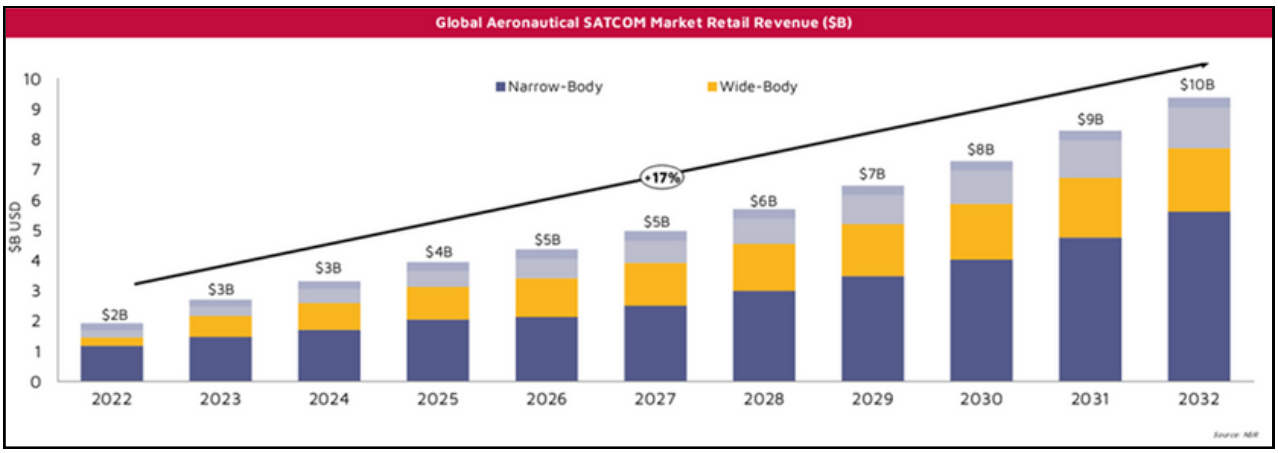


Figure 1-1 NSR "Aeronautical Satcom Markets" – April 2023 – 11th Edition

This document highlights factors for applying NTN to IFC, including the challenges and objectives, the market planned evolution for the next decade, the aviation specifics, the potential technology enablers, and an illustration of use cases.

The Seamless Air Alliance 3GPP NTN working group intends to evolve their studies into a position paper that is targeted to be presented to 3GPP in the months to come. Interested parties are invited to join the alliance and participate in this effort to ensure that the aviation industry can take full advantage of 3GPP NTN.

2.Contributors

The following Seamless Air Alliance members have contributed to the preparation of this whitepaper.

Name	Affiliation	Role
Olivier Hauw	Airbus	Co-chair NTN Standard Working Group
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3. Definitions and Abbreviations

A2G, ATG	Air to Ground (line of sight aeronautical communication using 4G/5G and proprietary protocols
AAC	Aeronautical/Airline Administrative Communication
ACARS	Aircraft Communication, Addressing, and Reporting System
ACD	Aircraft Control Domain
ACM	Adaptive Coding and Modulation
ADS-C	Automatic Dependent Surveillance – Contract
AIS	Airline/Aircraft Information Services
AISD	Airline/Aircraft Information Services Domain
AHM	Airplane Health Monitoring
ANSP	Air Navigation Service Provider (ATC)
AOC	Aeronautical/Airline Operational Communication
APC	Aeronautical Passenger/Public Communication
ARPU	Annual Revenue per User
ATC	Air Traffic Control
ATM	Air Traffic Management

ATS	Air Traffic Services
CAGR	Cumulative Annual Growth Rate
CIR	Committed Information Rate
CPDLC	Controller-Pilot Data Link Communication
D2D	Direct-to-Device (communicating directly with a personal cell phone)
EFB	Electronic Flight Bag
FEC	Forward Error Correction
FR1	frequency bands up to 7 GHz (3GPP Rel. 17)
FR2	frequency bands above 10 GHz (3GPP Rel. 18)
Gbps	Gigabit per second (data rate)
GEO	Geostationary Earth Orbit
gNB	5g Node B
GSM	Global System for Mobile Communications
HCATM	Hyper-Connected Air Traffic Management (using IFC for safety communication)
HEO	Highly Elliptical Orbit
HF	High Frequency (Shortwave)

HTS	High Throughput Satellite
IFC	Inflight Connectivity (public networks principally serving passenger communication)
IFE	Inflight Entertainment
IP	Internet Protocol (layer 3 network)
KPI	Key Performance Indicator
LEO	Low-Earth Orbit
Mbps	Megabit per second (data rate)
MEO	Mid/Medium-Earth Orbit
MIR	Maximum Information Rate
MNO	Mobile Network Operator (cellular)
MSS	Mobile Satellite Service
NOTAM	Notices to Airmen
NTN	Non-Terrestrial Network (communication where some components are in the air)
OEM	Original Equipment Manufacturer
OTT	Over the top
PBCS	Performance-Based Communication and Surveillance
PIES	Passenger Information and Entertainment Services
PIESD	Passenger Information and Entertainment Services Domain

PODD	Passenger-Owned Devices Domain
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Node
RCP	Required Communication Performance
RSP	Required Surveillance Performance
SAA	Seamless Air Alliance
SAN	Satellite Access Node
Satcom	Satellite Communication
SLA	Service Level Agreement
SNO	Satellite Network Operator
Tbps	Terabit per second (data rate)
TN	Terrestrial Network (communication where all components are on the ground)
UE	User Equipment
USD	United States Dollar
VHTS	Very High Throughput Satellite
VLAN	Virtual Local Area Network (layer 2 link/subnetwork)

4.References

The following references were considered while drafting this document

AEEC SAE-ITC

- ARINC 791 Part 1 – First generation Ku/Ka-band Aviation Satcom Terminal, Form and Fit
- ARINC 792 – Second generation Ku/Ka-band Aviation Satcom Terminal, Form and Fit
- Project Paper 793 – Third generation Ku/Ka-band Aviation Satcom Terminal, Form and Fit
- ARINC 791 Part 2 – Ku/Ka-band Aviation Terminal, Function
- ARINC 791 Part 3 – Ku/Ka-band Aviation Satcom Terminal, Information Transfer and Internetworking

Seamless Air Alliance

- SR1 System Architecture
- SR2 System Wide Information Management
- EXP 0-12 Measuring and Managing the IFC Experience
- SR6 IFC Certification Document

FUTURE CONNECTIVITY FOR AVIATION, EU/US task force White Paper, drafted in Sep 2022 by European Union Aviation Safety Agency, the Federal Aviation Administration, Airbus and Boeing

- MEF 3.0 Carrier Ethernet standards
- ETSI DVB-S/S2/S2X and DVB-RCS/RCS2
- 3GPP TS 23.501 - 5GC Service Architecture specification
- 3GPP TS 38.108 - 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Satellite Access Node radio transmission and reception (Release 18)

5. Seamless Air Alliance

The Seamless Air Alliance has published this document to promote its development of an aviation position paper relating to 3GPP NTN.

5.1 Background and Mission

SAA's mission is to enable airlines to continually provide the best possible passenger connectivity experience. As an industry-wide collaboration, SAA define interoperability standards and approval programs that drive innovation, economies of scale, and enable airlines with the most cost-effective, efficient, and flexible solutions.

SAA members envision a new inflight connectivity experience that will amaze passengers, enable new customer engagement opportunities for airlines, and extend Mobile Operator relationships from gate-to-gate anywhere in the world.

5.2 Objectives and Ambitions

The SAA aims at promoting the aviation requirements for future connectivity solutions including 3GPP (5G/6G). This includes the business and technical needs for cabin and cockpit connectivity systems.

This organization has the following specific objectives:

- Consolidate and share connectivity needs and positions for the aviation industry
- Assess business considerations
- Define use cases and associated technical requirements
- Prepare position papers on specific topics (e.g., new necessary features, regulatory constraints)
- Conduct studies and share technical reports.

5.3 SAA Expert Working Groups

The SAA has a robust organization based on a set of working groups, which are composed of world-class experts in the telecommunications and aviation connectivity fields. These experts are affiliated with the most important companies and organizations in the aviation industry, including airlines, airframe manufacturers, inflight connectivity service providers, satellite operators and equipment manufacturers.

To support technical and market assessments related to 3GPP in aviation, SAA relies on both already existing working groups such as the Airlines and Technical Forum, and as well as the 3GPP NTN Working Group under the umbrella of the current Standards Working Group.

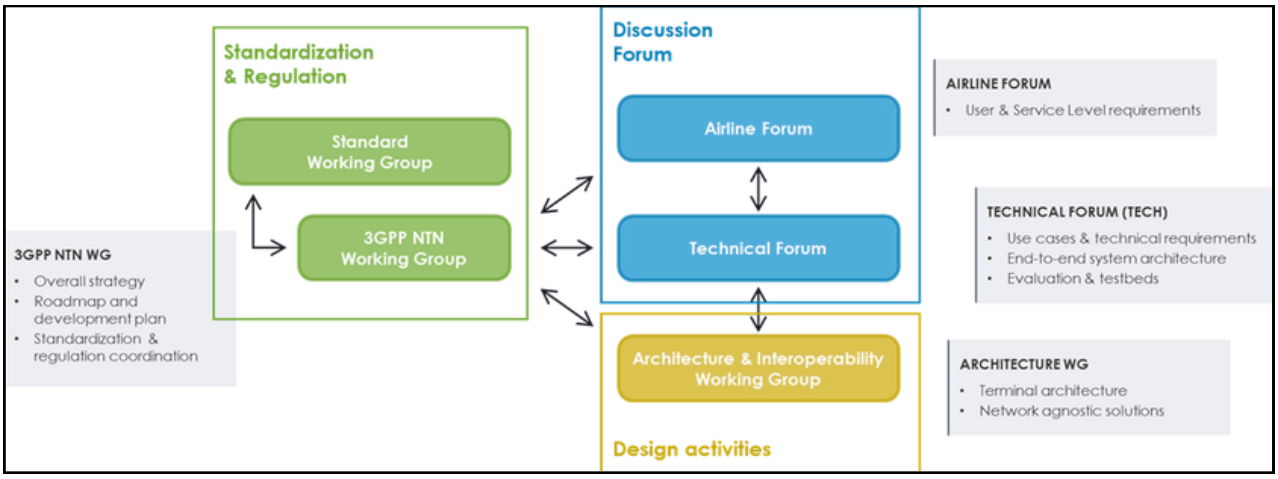

Figure 5-1 SAA Working Group structure to support 3GPP initiatives

The following working groups are or will support the effort that was launched in September 2023 to consolidate and communicate the aviation needs for 3GPP Non-Terrestrial Networks (NTN).

- **3GPP NTN Working Group:** This group has been created under the umbrella of the SAA Standards Working Group to specifically lead the standardization efforts associated with 3GPP NTN. It is expected to be the primary interface to the standardization bodies such as 3GPP and any other telecom organizations. It is also expected to manage the regulatory considerations, with potential participation in the key regulatory committees such as ITU, CEPT and FCC.

- **Airline Forum:** The Airline Forum rallies airlines around common issues, objectives, and opportunities; and to capture and share the end-user perspective on those matters. This group consolidates user requirements and clarifies service level needs.

- **Technical Forum:** The “Tech” Group is the primary instance to discuss technical matters in the SAA. It has built a solid expertise and vision around the assessment of IFC performance. This group defines use cases, associated technical requirements, and the end-to-end system architecture; and conducts technical evaluations.

- **Architecture & Interoperability Working Group:** This group focuses on designing aircraft terminals that are network agnostic. Leveraging the 3GPP protocol stack represents a great opportunity in the definition of next generation aircraft terminals.

6. Aviation Connectivity Market

The development and deployment of new megaconstellations of satellites, combined with the latest geostationary earth orbit (GEO) very high throughput satellite (VHTS) technologies, will bring a massive amount of capacity together with airtime cost reduction, as shown in the two figures below.

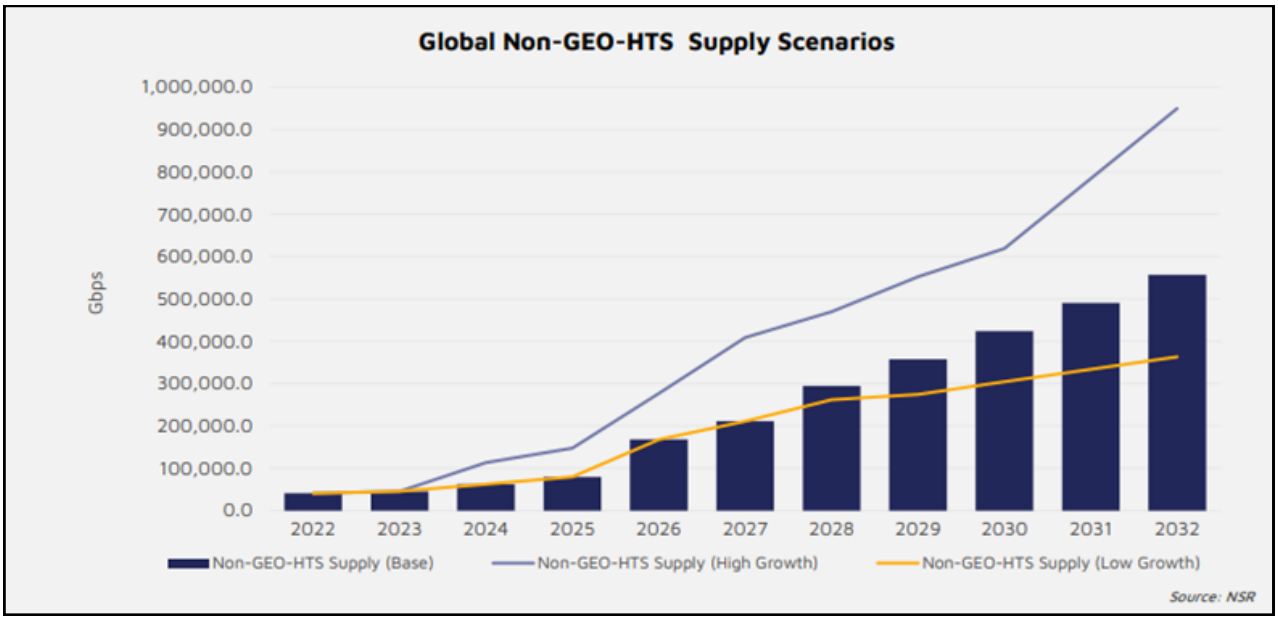

Figure 6-1 20th Edition of the NSR report "Satellite Capacity Supply & Demand" (June 2023)

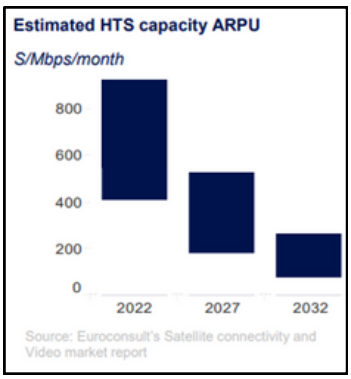

Figure 6-2 11th Edition of the Euroconsult report "Prospects for Inflight Entertainment and Connectivity" (Sept. 2023)

Beyond the numbers provided in the above figure, GEO satellites are expected to bring an additional 30 Tbps in 2032 according to the same NSR report.

The increased satellite capacity powers a significant ramp-up of adoption of connectivity by all types of aircraft, including narrowbody. Even though the number of connected aircraft is limited compared to the other connectivity market segments, the expected throughput per unit is high. Typical expected throughput down to the aircraft are in the range of 500 Mbps to 1 Gbps by the end of this decade. Inflight connectivity will support both the passenger experience and aircraft operations. The aviation market represents a significant part of the anticipated market growth in connectivity.

NSR anticipates "specific to 5G" satcom service revenues per vertical market, worldwide, as shown in the figure below.

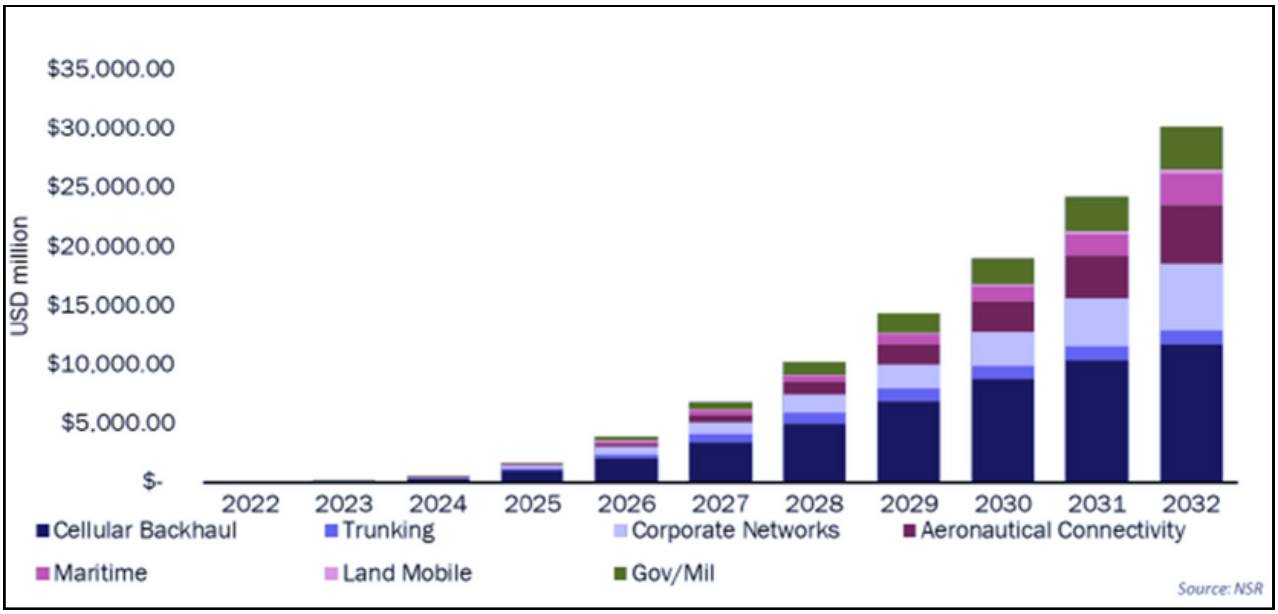

Figure 6-3 NSR 5G via Satellite, 4th Edition – opportunities for satellite players – October 2023

The mobility market (including aeronautical, maritime, and land-mobile) is expected to grow significantly notably because they rely on a 3GPP standard.

According to NSR, as illustrated below, the overall commercial aviation satcom market represents a USD62 billion dollar market over eleven years, between 2022 and 2032, with 17% cumulative annual growth rate (CAGR).

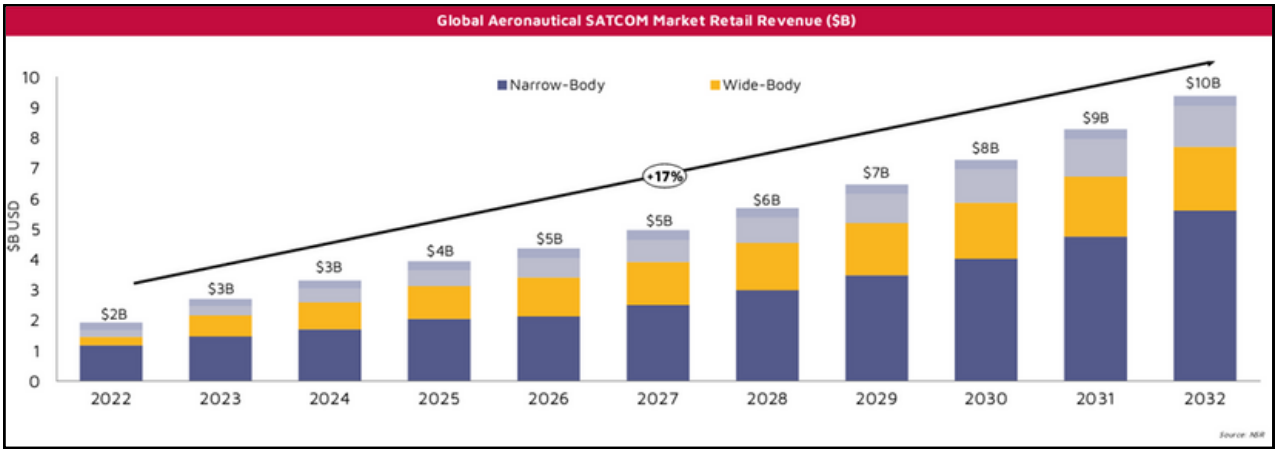

Figure 6-4 NSR Aeronautical Satcom Market" – April 2023 – 11th Edition

7. Aviation Communication

Aviation communication is essential for both safe and efficient operation and for good passenger experience.

Aviation communication categories include:

- Air Traffic Management (ATM) / Air Traffic Service (ATS)
- Aeronautical/Airline/Aircraft Operational Communication (AOC)
- Aeronautical/Airline/Aircraft Information Services (AIS)
- Aeronautical Passenger Information and Entertainment Services (PIES)
- Aeronautical Public/Passenger Communication (APC)

7.1 Air Traffic Management (ATM) / Air Traffic Service (ATS)

Air Traffic Management (ATM) relies on Air Traffic Service (ATS) communication. ATS communication involves the exchange of data between aircraft systems/pilots with air navigation service providers (ANSP) systems/radio operators/controllers.

ATS is a combination of voice and digital data communication. Time-critical exchanges (urgent/distress) are conducted with voice. Routine exchanges are increasingly shifting from voice to digital data exchanges.

Performance, continuity, and integrity are generally very demanding for information exchanges between an aircraft and air traffic control, be it for remote airspace, domestic airspace, terminal areas, or on the airport surface. This has traditionally mandated the use of connectivity links designated for safety use.

7.2 Airline Operational Communications (AOC)

Airline operation requires communication between an airplane and the operator's operations center or with other operator services. AOC relates to messages that can influence the aircraft trajectory, such as performance and flight plan optimization.

AOC have performance requirements which differ from ATS regarding reliability, availability and integrity but do not regulate strict transaction timing. AOC has traditionally mandated the use of connectivity links designated for safety use.

7.3 Airline Information Services Communications (AIS)

Airline Information Services (AIS) support strategic and tactical situational awareness by providing data to the pilot as well as gathering data from the pilot/aircraft to support a richer representation of the airspace environment.

Examples of AIS communication include:

- Administrative data transfer (e.g., logbook, aircraft movement reports, crew reports)
- Takeoff power and speed settings
- Airplane system maintenance (trend and event reports)
- Engine maintenance (trend and event reports)
- Software delivery
- Weather reports (e.g., winds, temps, moisture, ice)
- Turbulence reports
- Notice to airmen (NOTAM)

Airline Information Services exchanges are permitted over any available connectivity link. While safe airplane operation is not predicated on the availability of AIS communication, efficient operation is hampered when AIS communication is not available or is corrupted.

7.4 Passenger Information and Entertainment Services (PIES) Communication

Passenger information and entertainment services (PIES) corresponds to inflight entertainment (IFE), including the following services:

- Transaction processing (e.g., credit card)
- Streaming entertainment (e.g., live television)
- Flight information (e.g., connecting gates, flight status)
- Access to airline portal (e.g., ticketing, customer service)

PIES communication is permitted over any available connectivity link. While safe airplane operation is not predicated on the availability of PIES communication, passenger satisfaction is hampered when PIES communication is not available or is corrupted.

7.5 Aeronautical Public/Passenger Communication (APC) / Inflight Connectivity (IFC)

Inflight Connectivity (IFC) is provided principally for passenger communication. Passenger communication relates to the exchange of information between passenger devices and the internet.

8.Aeronautical Communication Network Architecture

Aeronautical Communication is comprised of onboard networks that connect devices to a backhaul radio service. The backhaul radio service is a gateway to terrestrial networks such as the internet. Satellite network operators (SNO) operate aeronautical backhaul radio services. The devices onboard include those owned by passengers, those operated by crew members, and a variety of avionic systems.

A high-level communication architecture network is portrayed in the following figure:

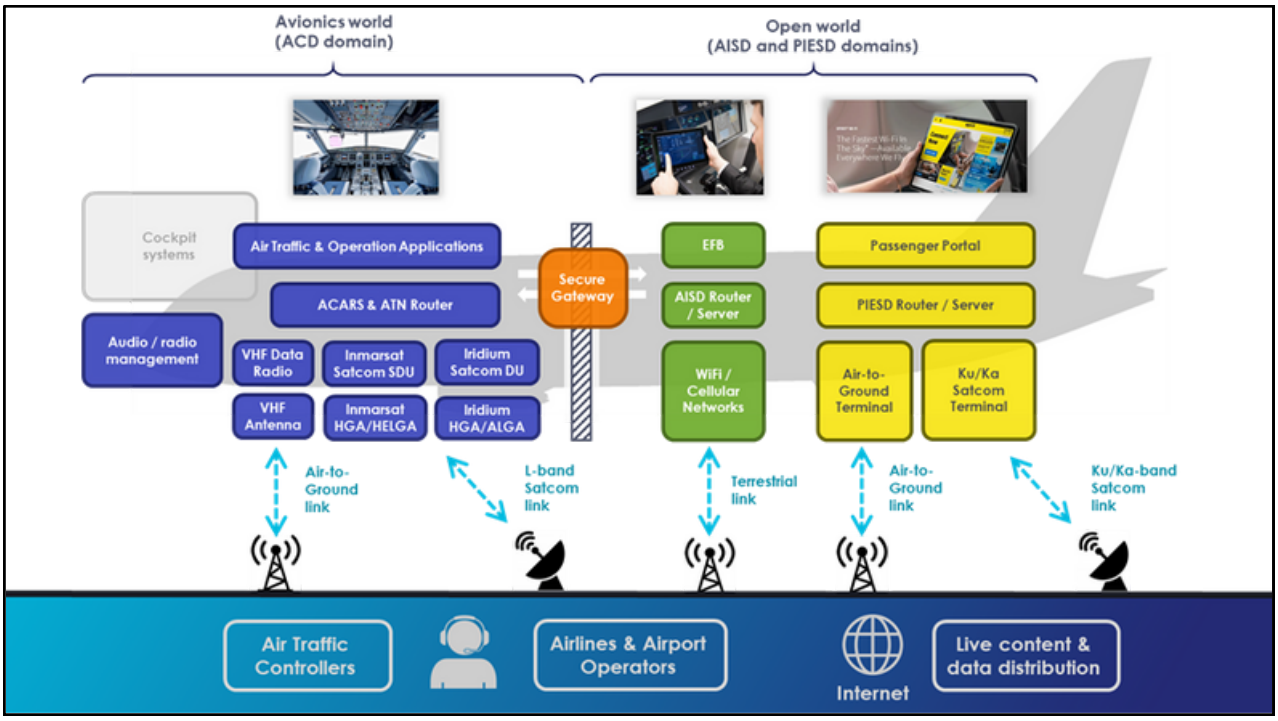

Figure 8-1 Aircraft Communication Architecture

Broadband Cabin Connectivity systems are based on Ku/Ka-band Satcom Terminals or 4G/5G Air-to-Ground communication solution providing Internet services mainly to passengers. Other connectivity networks include those designated for safety applications (VHF, L-band Satcom, HF) and those designated for non-safety applications (L-band Satcom, 3G/4G/5G Terrestrial Networks) but are either not applied to passenger communication or applied only with significant limitations (e.g., messaging applications only). Connectivity solutions are expected to provide seamless and ubiquitous services with minimized service degradation.

Aeronautical satellite networks are typically customized to a particular operator based on unique licensed spectrum, proprietary onboard antenna/terminal, proprietary space vehicle characteristics, and proprietary network management. While an antenna might be used by more than one satellite network, the terminal typically must host a proprietary onboard modem for each network.

Passengers are prohibited from using their cell phones to communicate directly with overflown mobile network operators (MNO).

Broadband satellite networks operate in what is termed as Ka band or Ku band. These networks have historically utilized Geostationary-Earth Orbit (GEO) satellites. Low-Earth Orbit (LEO), Mid-Earth Orbit (MEO), and Highly Elliptical Orbit (HEO) satellite networks are becoming available, as either a stand-alone network or in a hybrid combination with GEO networks.

8.1 Designations, Divisions, Domains

Aeronautical Communication is characterized in several different ways. Communication is either originated by passengers through their own devices or originated by non-passenger devices (avionics). Connectivity in an aircraft is based on multiple radio bearers and routers that may be classified as passenger and/or non-passenger communication systems.

Radio frequencies are designated as “Route” or “Off-Route”. Broadly, Route refers to communication that factors into the trajectory of the airplane and is characterized as a safety service. Everything else is non-safety, “Off-Route”.

The figure below portrays the boundaries between all the designations relating to aeronautical communication.

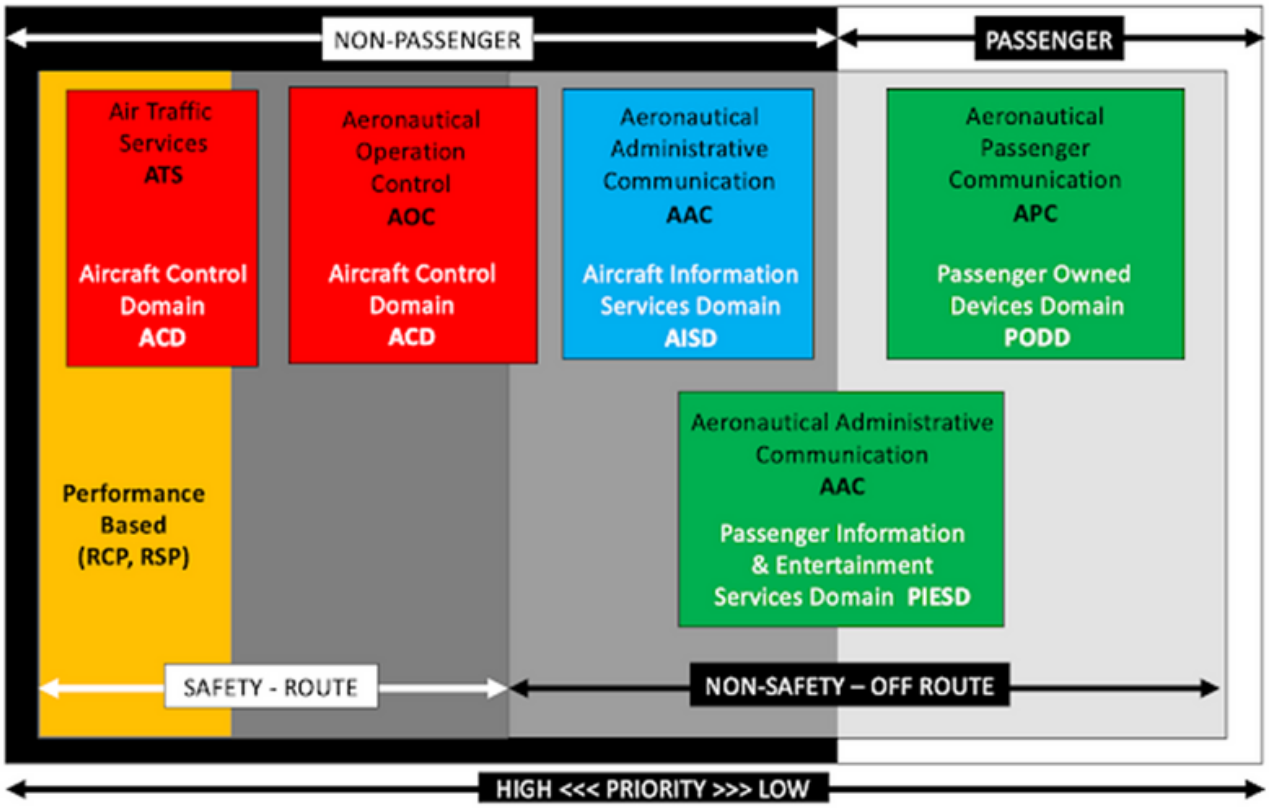

Figure 8-2 Aeronautical Communications Designation Boundaries

8.2 Onboard Network Domains

Aviation network architectures are decomposed into multiple aircraft domains, which have specific performance and security requirements and that are segregated to prevent cyberattacks, especially those targeted at critical systems.

Onboard networks are subdivided into four domains:

- Aircraft Control Domain (ACD)
- Aircraft Information Services Domain (AISD)
- Passenger and Entertainment Services Domain (PIESD)
- Passenger-Owned Devices Domain (PODD)

The Aircraft Control Domain (ACD) is applied to the Aircraft Communication, Addressing and Reporting System (ACARS). ACARS communication is most properly applied to ATS and AOC safety communications. Some ACARS traffic is not safety related.

Aeronautical Information Services Domain (AISD) is characterized as Airline Administrative Communication (AAC). Beyond airplane health monitoring (AHM) and maintenance, AISD includes connectivity with the Electronic Flight Bag (EFB).

The Passenger Information and Entertainment Services Domain (PIESD) can include passenger-oriented transactions (such as credit card processing). Some PIESD traffic relates to passenger devices (the airline portal, transaction processing, streaming entertainment). The remainder of PIESD traffic is between the IFC components, for example for content update and for maintenance and control of the IFC system. In some cases, PODD traffic is switched through PIESD.

The Passenger-Owned Devices Domain (PODD) includes networks that communicate with the passenger device.All communication with passenger devices is considered APC. PODD is considered a major cybersecurity attack plane requiring considerable efforts to restrict passenger devices to PODD and to not have access to any other domain.

The boundaries between cockpit and cabin systems are becoming increasingly blurred, as new cyber gateways are being deployed to enable communication between domains. Aviation connectivity services are expected to support future concepts such as the Hyperconnected ATM, which will allow to use cabin bearers to transport safety services (if certified and adopted)

9.Aviation Use Cases and Performance Metrics

Aviation connectivity is expected to be able to support a wide variety of use cases and not to be a limiting factor for passenger experience or enhanced aircraft operations.

9.1 Network Performance and Quality of Experience

Network performance and Quality of Experience (QoE) highly depend on the considered use cases. In the future, the connectivity service is expected to deliver similar performances as the one provided on the ground.

Aviation connectivity performance assessment and Service Level Agreements (SLA) have been based on network performance. Key Performance Indicators (KPI), such as availability, latency, jitter, packet loss and bandwidth; provide a first indication of the health and capability of the supporting network. Nevertheless, those are not sufficient to assess and monitor user experience. A new generation of metrics have been defined by the Seamless Air Alliance to measure and interpret IFC Quality of Experience.

The Quality of Experience metrics are measures of user satisfaction utilizing application-level KPIs. For instance, assessment of Web QoE is performed by loading one or multiple reference webpages while measuring associated metrics. For streaming applications, other metrics are used to characterize the performance of the system from a user perspective.

9.2 Background Information

Before starting the description of the aviation use cases, the text below presents a list of key definitions and general statements.

- Aviation architecture is decomposed into multiple aircraft domains, which have specific performance and security requirements and that are segregated to prevent cyberattacks, especially on the critical systems
- Aircraft domains are: Aircraft Control Domain (ACD), Aircraft Information Services Domain (AISD), Passenger and Entertainment Services Domain (PIESD), Passenger-Owned Devices Domain (PODD).

- Connectivity in an aircraft is based on multiple radio bearers and routers that can be classified as cockpit or cabin communication systems
- Aviation connectivity is expected to be able to support a wide variety of use cases and not to be a limiting factor for passenger experience or enhanced aircraft operations
- In terms of performance, the connectivity solutions are expected to provide seamless and ubiquitous services with minimized service degradation
- It is expected that in the future, the boundaries between cockpit and cabin systems will become increasingly blurred as new cyber gateways will be deployed to enable communication between domains
- Aviation connectivity services are expected to support future concepts such as the Hyperconnected ATM, which will allow to use cabin bearers to transport safety services (if certified and adopted)

9.3 Aviation Use Cases

The 3GPP NTN use cases first defined by the Seamless Air Alliance are focused on cabin and cockpit connectivity decomposed by each type of service and their associated technical requirements.

Use Case #1: Internet Access for Passengers (Inflight Connectivity)

The first use case corresponds to passenger internet access services. The inflight connectivity (IFC) service providers deliver internet services to passengers, while such capability may also be used by the crew to provide cabin services.

Such services are provided “gate-to-gate”, which means that the passengers have access to the internet from the departure of their journey when boarding the plane until their arrival at the gate. The IFC system shall then provide consistent performances during all phases of flight.

Using satcom systems while the airplane is on the ground may be challenging and inefficient. In addition, ground transmissions in a hot environment can impact availability and reliability of the satcom antenna. The use of satcom may not be favored for communication on the ground. A combination of satcom, cellular networks and potentially Air-to-Ground (A2G) networks may offer an efficient approach to deliver high performing solutions.

IFC services are predominantly delivered using Ka-band or Ku-band satcom solutions based on GEO satellites, with upcoming systems taking advantage of lower latency provided by LEO and MEO constellations. 4G or 5G Air-to-Ground communication systems are also in operation today.

An illustration of the internet access use case is provided in the following figure.

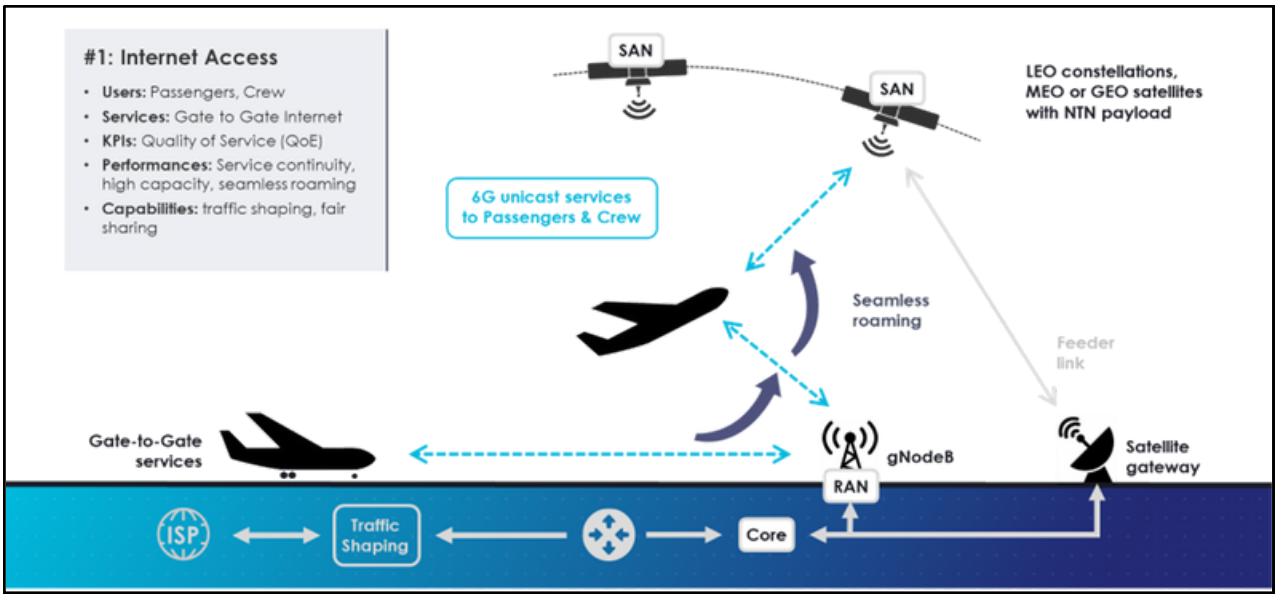

Figure 9-1 3GPP NTN Passenger Internet Access Use Case

The internet access use case has the following key features:

- Unicast services to users (passengers, crew)
- Consistent high data rate capability that can be shared between a high number of users
- Fair-use sharing of the available data rate between users is essential
- Traffic shaping and Deep Packet Inspection (DPI) control utilization and meeting SLA commitments
- Latency should be minimized as much as possible, e.g., for web browsing and interactive applications
- Service continuity is maximized by optimizing antenna, modem, and network contributions to beam / satellite switches
- Seamless network roaming capabilities are required in a multi-network environment

Service Level Agreements provided to airlines are based on Quality of Service (QoS) metrics such as availability and bandwidth (or data rate) commitments. The data rate provision is usually described with two dimensions; CIR (Committed Information Rate) and MIR (Maximum Information Rate). Quality of Experience (QoE) metrics have been defined by the Seamless Air Alliance in addition to QoS.

The Key Performance Indicators include:

- Quality of Service metrics using forward and return network assessments
  - Availability, data rate, latency, jitter, packet loss

- Quality of Experience metrics
  - Web browsing application scoring
  - Streaming video application scoring

Use Case #2: Multicast / Live Television for Passengers

The live television use case includes applications which utilize multicast services based on cabin connectivity services. One example is IPTV (Internet Protocol Television), which delivers live television services using IFC as an Over-The-Top (OTT) service. Live television is based on a ground infrastructure that distributes live content such as sport and news television channels, which are then transported over satellite multicast.

Operational data or content can be broadcast to a group of aircraft using multicast service distribution. For example, broadcasting periodic updates to a cache of streaming content in onboard servers across an airline's fleet.

OTT services have a strong dependency on the performance of the IFC. Specific mechanisms are needed to eliminate packet loss caused by beam or satellite switches. Strong FEC (Forward Error Correction) and Adaptive Coding and Modulation (ACM) may be required to correct bit errors for the most disadvantaged airplane. A return networking connection may allow for individual retransmission of lost packets.

Roaming between networks should be managed carefully to maintain synchronization between multicast services whenever switching.

An illustration of the multicast / live television use case is provided in the following figure.

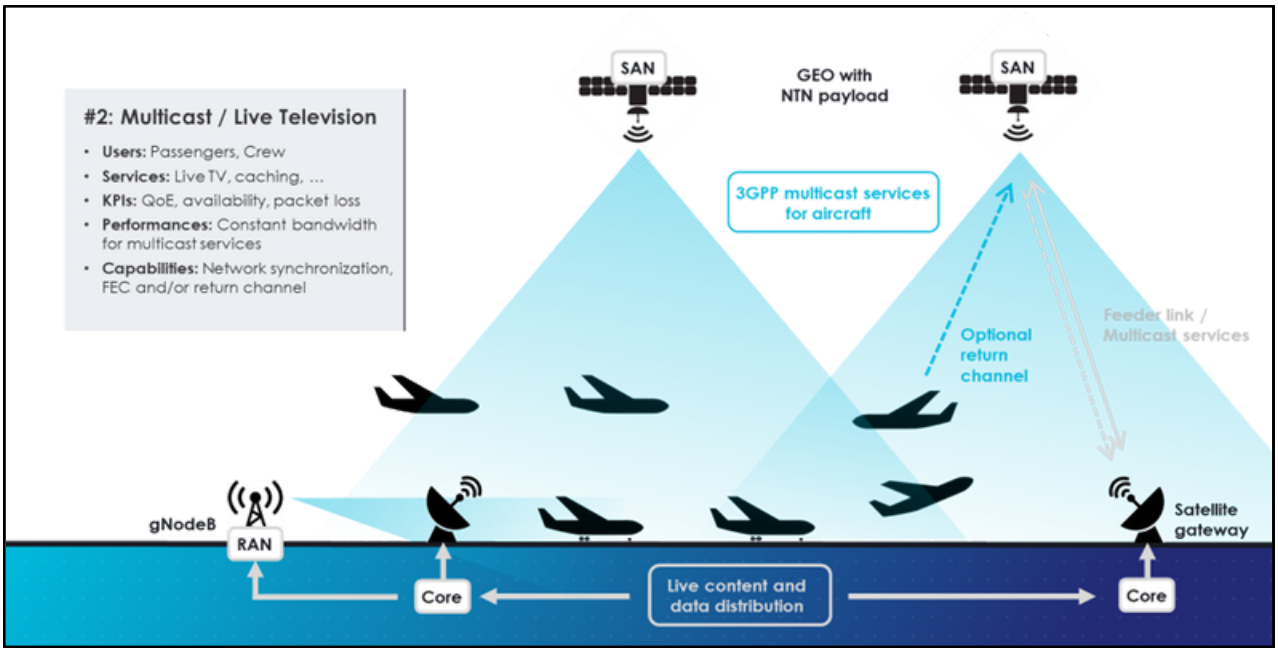

Figure 9-2 Multicast / Live Television Use Case

Multicast/Live television use case has the following key features:

- Multicast services to users (passengers, crew) or to onboard systems
- Constant bandwidth dedicated to multicast services over the coverage region
  - Coverage region may have multiple beams and networks
- System latency is not critical
  - Delay between source stream and playback device should be managed
- Service continuity managed using robust Forward Error Correction and Adaptive Coding and Modulation
  - Optional return channel path to recover from beam/satellite switches and roaming impacts
- Synchronization between networks is required to minimize impact when roaming

Key Performance Indicators are usually based on:

- Synchronization between network (roaming capabilities)
- Quality of Service metrics for the forward channel
  - Availability, guaranteed data rate, packet loss
- Quality of Experience metrics
  - Live television application performance

The Service Level Agreements for live television are usually based on:

- Availability
- Number of channels for Live TV
- Quality of Experience (QoE) scoring

Use case #3: Airline & Airport Administration and Operation

Airline & airport administration and operation are supported by systems and applications belonging to the ACD, AISD, and PIESD onboard network domains. One avionics example is the Electronic Flight Bag (EFB), which hosts a variety of applications that assist flight crews.

Non-Passenger services that use IFC require specific priority to ensure that the crew or avionics operations can be conducted efficiently.

On-board gateways are used to securely tunnel AOC (Airline Operational Control) information from the protected ACD network across to AISD or PIESD networks offering IFC.

AISD networks, such as those hosting EFB, can connect directly to IFC with appropriate security protection (such as Aircraft Interface Device, AID), or L-band satcom, or terrestrial cellular systems while on the ground.

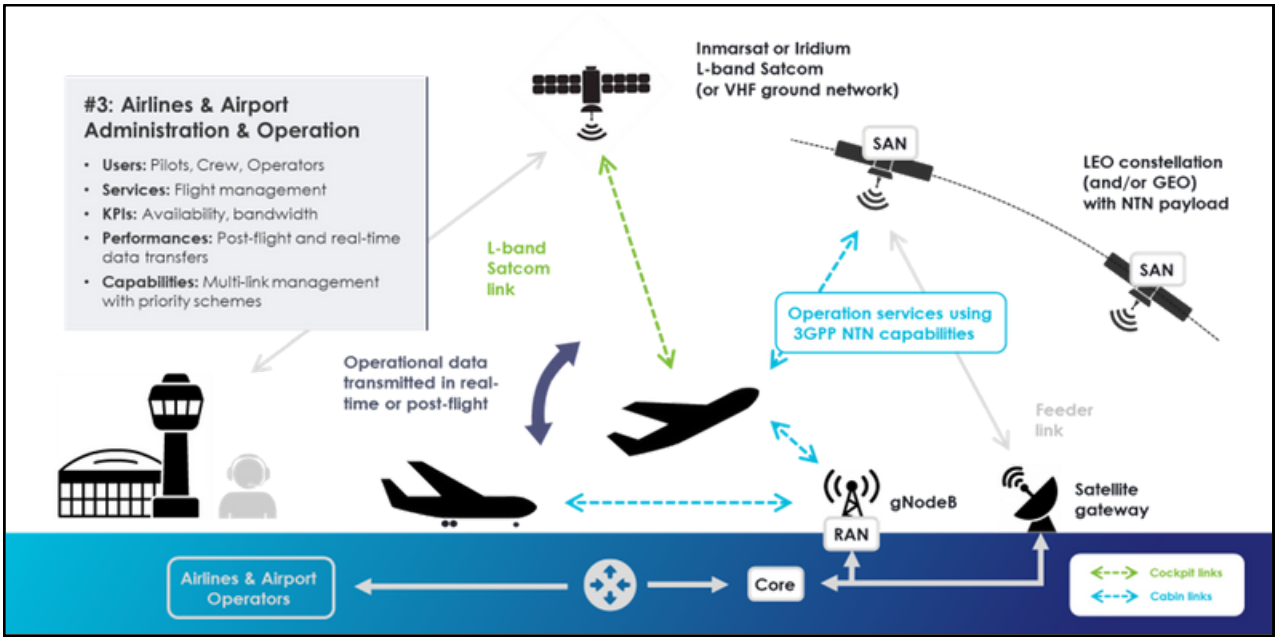

Figure 9-3 Airline & Airport Administration and Operation Use Case

The Airline & Airport Administration and Operation use case has the following key features:

- Unicast services to support communications between crew and airline operators (or operator systems)
- Support administrative and operational data traffic
- Operational data may take advantage of multiple connectivity links to meet service requirements
- Some inflight data may be cached and transmitted postflight
- Some data must be exchanged in (near) real time (e.g., weather data)

Key Performance Indicators (KPI) are mainly based on availability and data rate. It shall be noted that data rate and utilization requirements are much lower than for the internet-access use case.

Use Case #4: Hyperconnected ATM

Air Traffic Control (ATC) utilizes cockpit connectivity systems with protected spectrum for safety communications such as VHF and L-band Satcom systems. Pilots and air traffic controllers use both voice and data to communicate. Example of ATC data applications are controller/pilot data link communication (CPDLC) for messaging services and automatic dependent surveillance – contract (ADS-C), which transmits aircraft position to air traffic control systems hosted by air navigation service providers (ANSP).

Existing ATC communication cost of the bandwidth is high and data rate is usually quite limited. Many airline fleets are now equipped with IFC. The Hyperconnected ATM (air traffic management) initiative has been launched to take advantage of IFC by securely tunneling safety data communication services.

Hyperconnected ATM is being developed as part of the European Single European Sky ATM Research (SESAR) program and supported by the FAA Performance-Based Aviation Rulemaking Committee (PARC) Communication Working Group (CWG).

An illustration of the Hyperconnected ATM use case is provided in the following figure

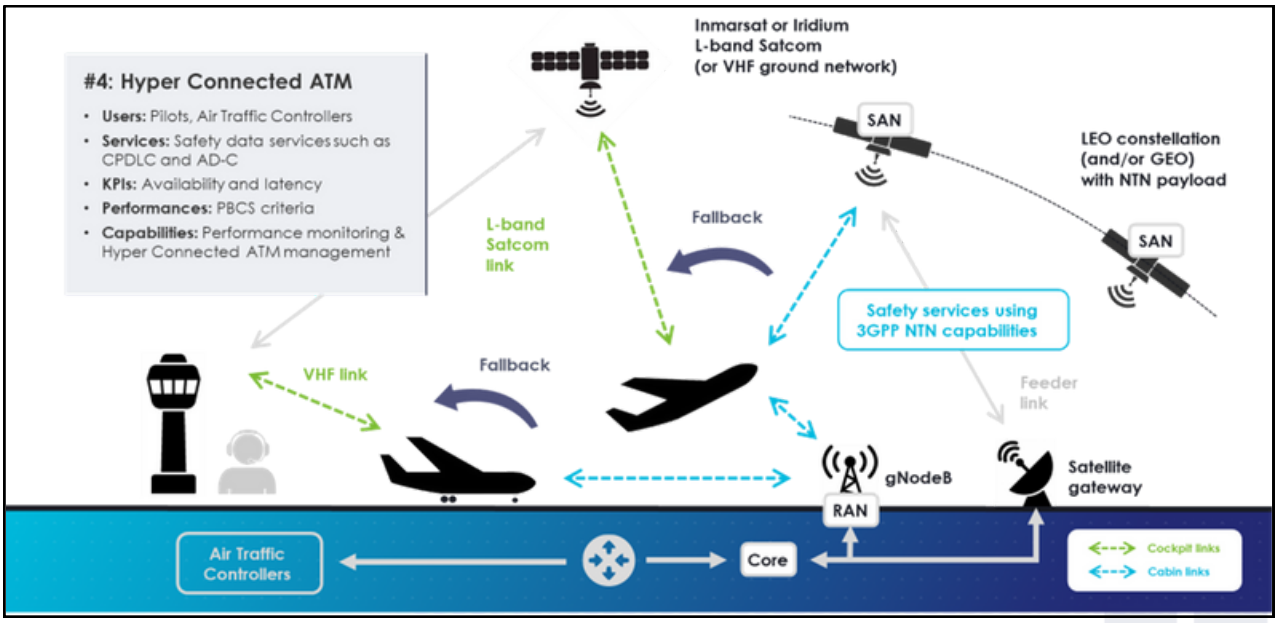

Figure 9-4 Hyperconnected ATM Use Case

The Hyperconnected ATM use case has the following key features:

- Unicast services to support communications between pilots and air traffic controllers
- Support IP data traffic only
  - No voice communications at this stage
- Performance targets based on PBCS criteria and budgeting
- Must monitor performance of the IFC, with the objective to fallback to L-band Satcom or VHF when IFC performances has degraded unacceptably
- Hyperconnected ATM function hosted by a Communication Manager

Key Performance Indicators (KPI) are based on availability, continuity, integrity/reliability, and message transfer times; which are associated with the PBCS criteria as described above for each data service.

10. Challenges

The aviation industry heavily relies on standards because it provides interoperability and long-term stability.

As of today, airline operators are facing a very fragmented connectivity market with different heterogeneous and proprietary solutions. There is a mix of safety and non-safety connectivity solutions which aim to tackle the different needs for the different domains.

VHF Data Link, narrowband L-band satcom networks, and HF; are applied to safety services.

Narrowband L-band satcom networks, broadband Ku/Ka IFC satcom networks, (proprietary, 4G, 5G) Air to Ground networks (line of sight), Wi-Fi gatelink, and 3G/4G/5G cellular gatelink are applied for non-safety services. Gatelink is a connectivity solution used only while the airplane is on the ground (not inflight).

Every single connectivity solution comes with its set of infrastructure components (on the ground, onboard the aircraft, and when applicable in outer space). These solutions are not interoperable, expensive to equip and maintain, and may be saturated.

The aviation industry heavily relies on standards because it provides interoperability and long-term stability. Connectivity networks applied to safety applications are typically standardized in form, fit, function, and system interfaces. Connectivity solutions applied to non-safety applications may have some standardization (form, fit, system interfaces) but otherwise are largely proprietary. This complexity and lack of standard make it difficult to natively integrate onboard the aircraft when it is not made mandatory.

The latest technology evolutions and the massive on-going increase of satellite capacity (GEO market moving to megasatellites combined with the launch of multiple LEO/MEO megaconstellations), make it possible to consider that connectivity will now be widely adopted by the aero market. These changes are expected to bring significant costs reduction (refer to section 6 above).

The objective for the aviation industry is to leverage the on-going commercial connectivity market (r)evolution to provide useful broadband access to passengers to increase passenger satisfaction and for digital information services transformation.

11. Potential Technology Enablers

The primary benefit for moving towards 3GPP standards in the aviation connectivity market is to move away from proprietary solutions that limit growth, prevent technology upgrades, and inhibit interchangeability of equipment.

The aviation connectivity market is driven by different stakeholders, each with differing objectives.

- **Airline Operator** – seeks to provide the lowest cost (both procurement and operating) communications systems that provide the minimum needed or desired functionality to improve the service offering available to their passenger customers.
- **Airframe Manufacturer** – seeks to provide required communications equipment for the worldwide services described above in a manner conducive to low cost, assembly-line manufacturing while meeting the varying requirements of different airline and leasing-company customers.
- **Communications Service Provider** – seeks to provide differentiated offerings at best costs to win airline and system integrator contracts. These providers must meet performance requirements specified by their customers and may deploy specialized, proprietary technologies that provide different competitive advantages.
- **Communications System Integrator** – seeks to integrate and certify communications equipment suites that simultaneously meet airline and airframe manufacturer requirements, while complying with and/or leveraging the competitive advantages of specific service providers.
- **Communications System Equipment Supplier** - seeks to develop, certify, provide, and support equipment that meet the combined requirements of the system integrators, service providers, airframe manufacturer, and airlines; while meeting stringent cost targets for low-volume, customized communications system functions.

The differing objectives from each stakeholder when combined with the high cost for development, installation, certification, and operation of aeronautical systems, slows the change to implementations installed on aircraft. It is more likely for wholesale equipment replacement rather than incremental upgrades of individual components and technologies. Both legacy and forward-looking technologies must often work side-by-side, as decades-old aircraft interoperate with new designs.

The creation and deployment of standards allows for a gradual transition away from proprietary, non-interoperable communications systems towards interoperable and/or interchangeable systems and system components that are simpler to develop and certify into the highly regulated aircraft environment. The deployment of standards-based systems will decrease the customization of individual hardware and integrated systems while increasing the volume of individual designs allowing a reduction in overall cost to each of the stakeholders. These standards-based deployments must overcome the competitive business-case advantages of proprietary systems deployed today.

As standards-based solutions become commonplace, the scalability and ability to deploy technology advances, especially those that are software-based rather than hardware-based. That will provide both advantages to continually grow deployed capabilities while minimizing cost impacts. Even technology advances that require hardware component replacement will be able to be more focused into individual components instead of complete communications system replacement.

Key elements that will favor quick adoption of new connectivity solutions include:

- Technologies such as Wi-Fi Passpoint for hotspots to enable seamless passenger experience while protecting airline operator's business interests
- Global, consistent broadband coverage
- IFC connectivity open standard to enable multi-layer approach, interoperability and global operation while reducing the CAPEX and OPEX for the airline operators

11.1 Network Agnostic Solutions

Standards can be applied in a layered approach, such that each layer can be managed independently from the others.

The application layer sits on top of the network layer. Applications have unique attributes regarding integrity, and confidentiality that can be managed at the application layer. Applications can levy performance and reliability requirements upon the network layer. Application-specific security implementations can be used to secure the data

The network layer largely is defined as Internet Protocol (IP). The network layer can be switched within the link layer (virtual local area network identification, VLAN ID) to provide differing network performance (network slicing). Intelligent routing mechanisms can be employed to route the data through the optimal path to the destination.

The link layer is customized to each connectivity solution. This includes the radio frequency signal-in-space, radiating and receiving characteristics, antenna performance and beam steering, link management, link establishment, and resulting data link quality of service (data rate, latency, packet drop).Connectivity standards applied at the link layer such as ETSI DVB-S/S2/S2X and DVB-RCS/RCS2 have opened the door to commonality in each of these aspects.

Redundancy and resiliency can be established by using multiple communications links with network-layer routers. Standards simplify the aggregation of multiple communication links using a common link-layer terminal.

11.2 Integrated Terrestrial and Non-Terrestrial Networks

Aviation broadband connectivity has historically utilized bespoke service attributes and definitions. This has required service providers to promote unique service tools and manage aircraft services independent of other broadband markets when providing a backhaul network to each aircraft.

Connectivity providers employing MEF 3.0 Carrier Ethernet standards can simplify aviation backhaul implementation. This allows aviation service providers to manage large networks of aircraft in similar fashion to large terrestrial networks, as well as other mobility markets.

By integrating high-volume terrestrial standards and technologies into the low-volume and highly regulated aircraft environment, economies of scale can be employed to reduce overall terminal costs for the aircraft. The wide deployment of these technologies in the terrestrial environment drives a large research and development effort for advancing not only the core technology but also the applications and opportunities that the technology provides.

These advances become available to the aviation market without requiring separate and costly development and certification efforts.

As an example, modems deployed within aircraft are often priced in the multiple-thousand-dollar range, far exceeding their desktop equivalents due to the rigorous environmental and certification requirements found onboard aircraft. Terrestrial 3GPP developments hold the promise of driving the core chipset electronics costs down to tens-of-dollars or less, creating an opportunity for perhaps an orders-of-magnitude reduction in airborne modem costs. These highly integrated chip sets can reduce component count and therefore the specialized development and certification costs often required for the unique aviation environment.

11.3 Virtualized and Independent Networks

Because of the long, slow evolution of the modern aircraft, most of the existing connectivity systems onboard aircraft have been developed and deployed as specialized, single-purpose items. The simplest way to prevent undesired interaction between connectivity systems and to preserve safety was to keep connectivity systems isolated, not only on the aircraft but with regards to the radio links off of the aircraft as well.

Only recently have systems begun to be integrated and decades-old legacy airframes and systems must continue to interoperate with newer, more advanced, and more integrated aircraft. The digitization of data, data processing, and communications systems onboard the aircraft is a recent phenomenon and creates new approaches and opportunities to implement and manage safety and security.

Network domains that have been kept electrically separate on the aircraft may soon be combined through VPN techniques that keep the data separate logically and VLAN ID network slicing and prioritization that provides for differing levels of quality of service. By creating logical channels, data can be transmitted across a multiple of physical radio channels, increasing the potential for resiliency and redundancy while maintaining security and authentication. Non-privileged safety-critical data may be transmitted over higher-bandwidth non-safety-certified links with potentially improved overall network performance, reverting to the lower-performing but highly reliable, safety-certified links when necessary. This virtualization of on-board networks and data and availability of independent external communications links will allow for new approaches to maintaining ubiquitous and reliable communications and a proliferation of applications for airborne users.

12. 3GPP NTN as a Potential Solution

Beyond the very well-known Terrestrial Networks (TN) connectivity industry, the 3GGP organization has recently started to standardize the Non-Terrestrial Networks (NTN). Rel.17 started NTN within the FR1 Frequency Range which covers frequency bands up to 7.125 GHz, typically L and S bands. Continuing, Rel.18 extended NTN to the FR2 Frequency Range with a work item dealing with NTN frequencies which correspond to frequency bands starting above 10 GHz, typically Ku and Ka bands (Ka band being the only one being standardized so far). NTN standardization has just started and will continue until it is natively integrated in the 3GPP 6G standard.

12.1 Direct to Device (D2D)

Some LEO networks have already begun to support direct-to-Handheld (commonly known as direct-to-device, D2D) service to terrestrial cell phones. These services are typically carried across MNO licensed spectrum or satellite service provider licensed spectrum.

When it comes to the aviation industry, it may be possible that D2D can operate through an aircraft window to a passenger's cell phone (see figure below). This may be suitable for some instances within general aviation and business aviation.

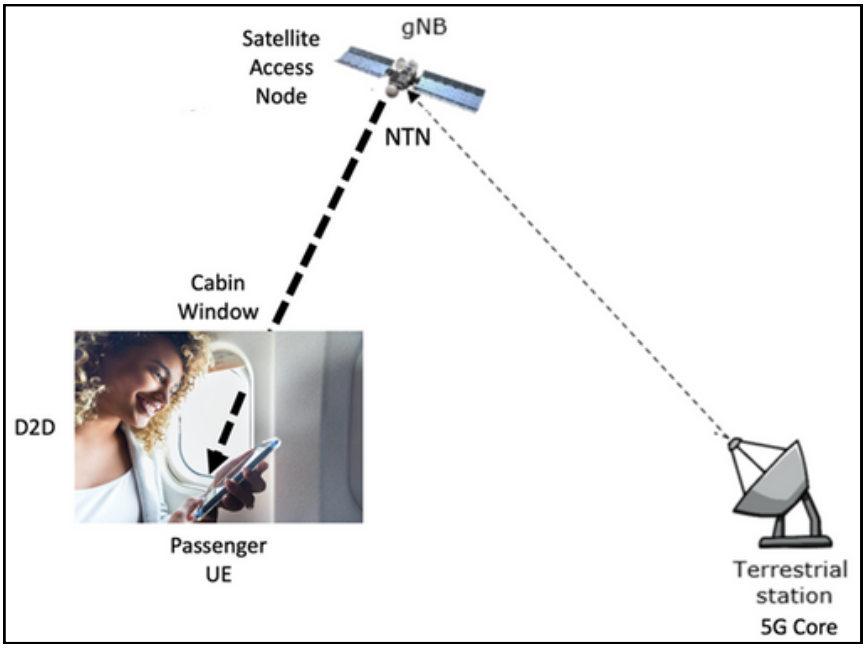

Figure 12-1 3GPP D2D through a cabin window

A D2D service is not considered a relevant solution for commercial aviation. Indeed, D2D will not be reliable, nor compatible with expected throughput per device communicating through an air transport cabin window, given the marginal and dynamic transmission path.

12.2 3GPP NTN Broadband Connection (Wi-Fi)

The main expectation, and most attractive option, is a standardized 3GPP NTN broadband connection. The broadband connection would aggregate all passenger traffic from the cabin and route it via a 3GPP NTN modem, using the FR2 spectrum licensed to a Ku/Ka-band satellite operator. The 3GPP NTN standard modem could also be used to connect to terrestrial MNO infrastructure when at the airport or a 3GPP NTN Air To Ground network, if available. Alternatively, the FR1 spectrum, including both 3GPP FR1 NTN standardized frequency bands (e.g., n255, n256) or L-band satellite operator licensed spectrum, could be used to provide narrowband or wideband services to the aircraft via a 3GPP NTN standard modem.

A standard 3GPP NTN broadband connection may represent a major evolution. This would enable a fully standard, interoperable terminal solution for aviation connectivity to have access to more connectivity providers. A standard 3GPP NTN connection could allow for managing differing Quality of Service (QoS) levels (network slices) applied to the different onboard networks that support onboard devices (passenger, entertainment, and avionics).

The passenger connects to a Wi-Fi access point using unlicensed ISM spectrum, then the cabin traffic is aggregated. The 3GPP NTN modem connects to a 3GPP core network on the ground through a Satellite Access Node providing NR NTN radio access network.

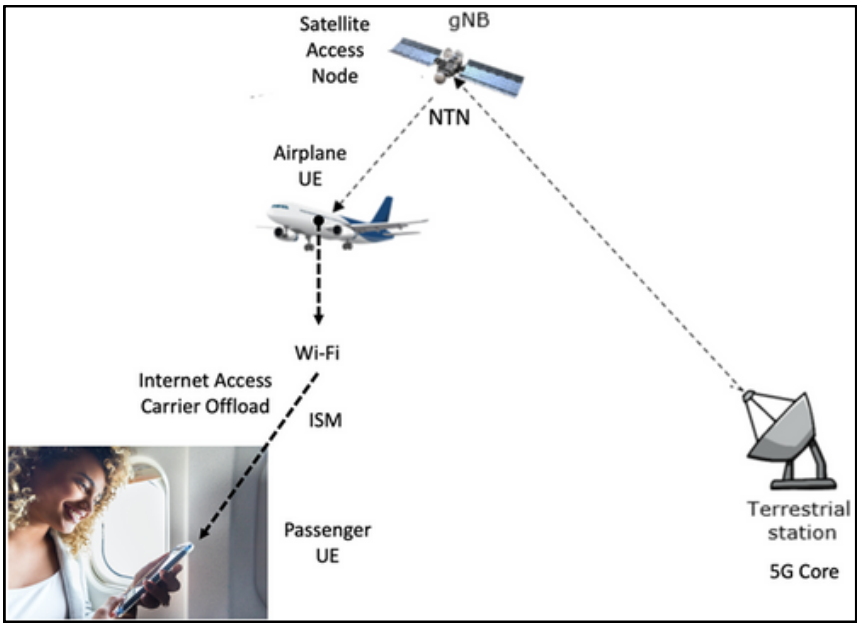

Figure 12-2 3GPP NTN Broadband Connection

12.3 3GPP NTN Repeater/Relay

A 3GPP NTN satellite access node may provide a backhaul network connection to an onboard gNB. The onboard gNB provides 3GPP connectivity (4G, 5G...) inside the cabin to passenger user equipment, using conventional TN 3GPP radio access technology. The onboard gNB will be seen as a base station by the passenger user equipment, while it will be seen as a user equipment by the Satellite Access Node (e.g.; IAB node).

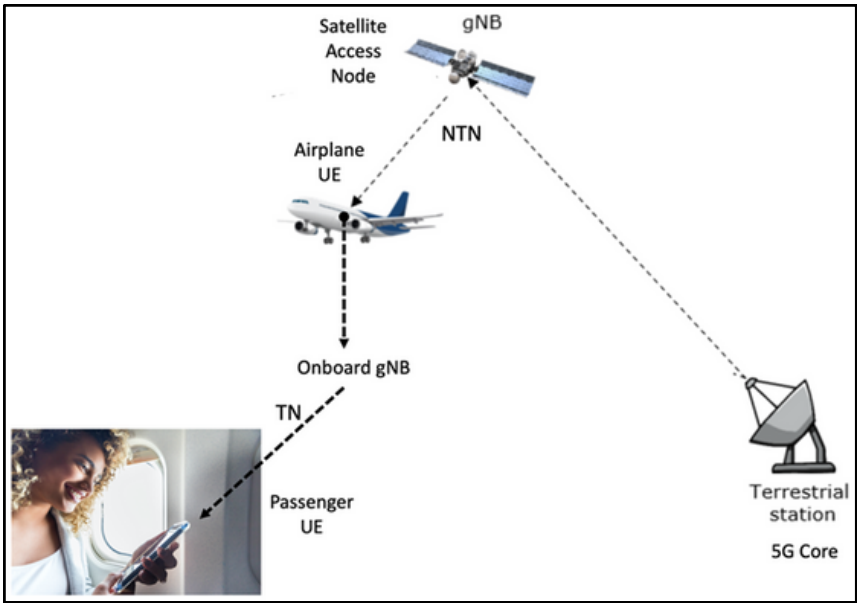

Figure 12-3 3GPP NTN Repeater/Relay

13. Next Steps

Today's aviation connectivity market is fragmented with numerous heterogeneous and proprietary solutions. This lack of standardization has resulted in proprietary solutions that are not interoperable, expensive to equip and maintain, and prohibit interchangeability of equipment.

The Seamless Air Alliance seeks to couple the aeronautical satellite industry with 3GPP telecommunications standards to address the issues of such proprietary solutions. The Seamless Air Alliance strongly believes that broadband 3GPP NTN using FR2 spectrum can meet commercial aviation expectations.

There is no quick fix. Standardization takes time to define and permeate throughout the industry. The future benefits are worth the effort for all stakeholders of the connectivity industry.

The objective of the Seamless Air Alliance is to engage with the 3GPP standardization body to introduce the initiative and establish a collective working group, including satellite connectivity providers, Mobile Network Operators, chipset and core network / gNB vendors, as well as aviation industry stakeholders.

The Seamless Air Alliance aims to become a Market Representative Partner to the 3GPP. Inputs to these discussions include clear industry objectives, well defined industry use cases, and the resultant detailed specific aviation industry requirements including an associated gap analysis with the current 3GPP standard version.

In the months to come, the Seamless Air Alliance and its members will advance the content of this paper in multiple forums to raise the attention of the 3GPP community.