

The Role of Satellite Systems in Future Aeronautical Communications

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1. Introduction

Recent evolutions in the context of aeronautical communications have changed the landscape and the role of the different systems that allow aircrafts to maintain a link with the ground while in flight. The increase in capacity needed to support the growth of worldwide air traffic and the need for increased communication safety are driving a transition from voice-centric procedures aided by slow data link connections to data-centric control applications executed on higher capacity communication systems. These future data links have to fulfil very stringent performance requirements. Indeed, the nature of the information they carry which is bound to become the first mean of air traffic control make their availability critical to the safety of air transportation in the future.

Satellite communication systems have many differentiating arguments when compared to terrestrial solutions. Indeed, while the deployment costs of terrestrial systems can be sustainable in high-density areas, their use in low-density remote areas is much less interesting. In high-density areas, satellite could also be useful either as a primary mean of communication or as a secondary one in order to improve the overall communication system's availability. A satellite system, by nature, is able to cover large regions of the earth and can thus provide a cost effective solution to the coverage of both high and low density areas such as oceanic regions where reliable terrestrial coverage is nonexistent.

In this paper, the interest of a satellite solution to be used as a data link for future aeronautical communications is studied. After presenting an overview of the existing satellite systems for aeronautical communication in operation today, the discussion focuses on the interest and strength of the forthcoming satellite link under definition in the frame of the ESA Iris Programme and its integration in the communication concept defined by the SANDRA EC FP7 project.

2. Designing satellite systems for aeronautical communications

This section presents the characteristics of satellite systems supporting aeronautical communications. A first part of the study presents the general architecture of such a system as well as its integration in the communication infrastructure as an access network to the aeronautical telecommunications network. In a second part, the constraints imposed by the regulatory domain on spectrum usage are presented. Finally, the most characteristic systems in place today are presented.

2.1 General architecture of a satellite aeronautical communication system

In this section, the general architecture of a satellite system for providing aeronautical communication services is presented. After presenting the role of the different segments, the integration of such systems in the aeronautical telecommunications network (ATN) specified in (International Civil Aviation Organization [ICAO], 2007) is presented.

2.1.1 Ground, space and user segments

A typical satellite communication system is divided into three different segments. These are respectively the ground, space and user segments.

The ground segment is responsible for interfacing the satellite communication system with the rest of the communication network infrastructure to which the satellite system constitutes an access network. Indeed, networking infrastructures are structured with a core network to which several access networks interconnect in order to allow end users to connect. In the ground segment of a satellite communication system, the information stream that arrives through the ground infrastructure is adapted in order to be sent out on the air interface of the satellite network gateway, which in aeronautical communication systems is known as a ground earth station (GES).

The space segment is composed of the satellite itself, the role of the space segment is to either serve as a transparent reflector for the signals sent from the ground or to receive process and re-generate a signal towards the ground in which case the satellite is called regenerative. A regenerative satellite can be used in the case where the equipment on the ground and user segments doesn't use the same modulation and coding rate for example. Another example of regenerative satellites are those used in constellations such as Iridium for which the signal is decoded in the space segment in order for it to be routed towards the appropriate satellite towards its destination.

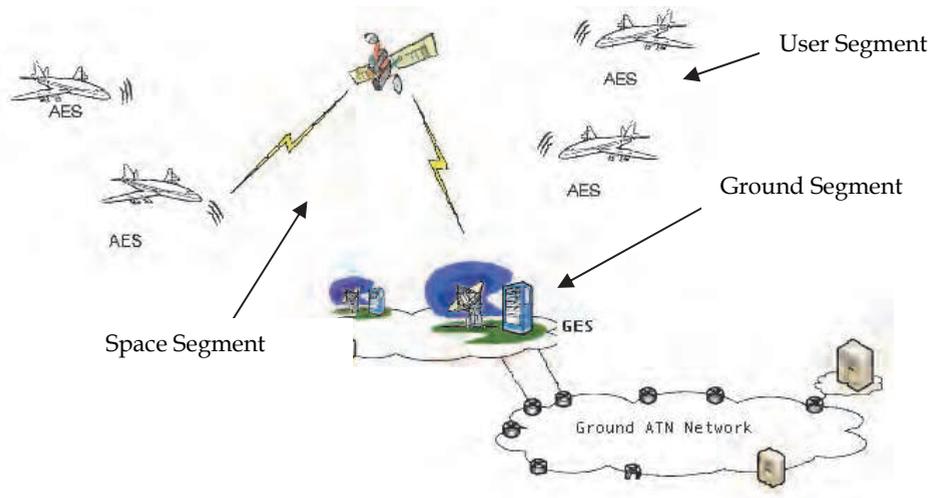


Fig. 1. Satellite system for aeronautical communications architecture as considered in (ICAO, 2010).

The user segment as its name indicates is where the users of the satellite communication system are located. In the case of an aeronautical communication satellite system, the user

segment is known as the aeronautical earth station (AES). The role of the user segment is to provide an interconnection mechanism between the on-board networks and systems and the satellite access network. In a way that is similar to the ground segment, the user segment provides the interface between the streams of data that are under the control of the satellite system (implementing a specific communication standard) and the outside world.

2.1.2 Satellite system integration to the aeronautical telecommunications network

A huge growth of aeronautical traffic is foreseen in the next few years. Predictions state that by the year 2020 to 2030, a new paradigm in aeronautical communications has to be envisaged to cope with this increase by defining new Air Traffic Management (ATM) concepts.

EUROCONTROL and the Federal Aviation Administration (FAA) have initiated a joint study reported in (EUROCONTROL/FAA, n.d.) to identify potential future communications technologies to meet safety and regularity of flight communications requirements, i.e. those supporting Air Traffic Services (ATS) and safety related Aeronautical Operational Control (AOC) communications.

The objective is to replace progressively voice communication for air traffic management by data communications services for safety reasons and because it supports increased automation in the aircraft and on the ground. Potential resource savings should also be possible when replacing voice by data communications. These data communications should then become the primary means for safety air-ground communication.

These data link oriented communication services will be supported by new communication infrastructures. On the ground, a core aeronautical telecommunications network will be used to interconnect the various ATC and AOC centres together. Furthermore, several technology specific access networks (i.e. Satellite, LDACS, AeroMACS, ...) will allow the aircrafts to form part of the ATN.

Fig. 2 provides a view of an end-to-end communication handled by a satellite aeronautical communication system. This view highlights both physical architecture, and logical architecture mapped on a network layers definition.

The satellite system includes the AES (aircraft on board terminal), and the GES (Earth terminal); this system is depicted in red line on Fig. 10.

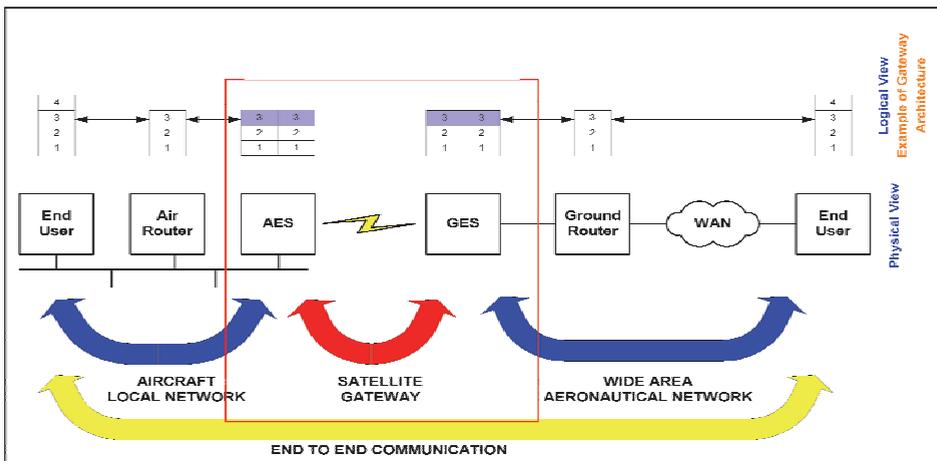


Fig. 2. SATCOM system integration in the ATN network.

The satellite is not represented in this figure, because the baseline architecture considers that the satellite payload is “transparent”. This means that, functionally, no processing exists on board the satellite, neither on the data nor on the frames; such a payload only handles a frequency conversion function.

It is interesting to note that the network layer, namely layer 3 is greyed out on the above figure. Indeed, a satellite system can either operate at layer 3 and thus appear as being an active element of the network (an IP router) or it can operate completely at layer 2 in which case it constitutes a transparent bridge equipment between several segments of the same IP network.

In future satellite systems for aeronautical communications, it is foreseen that their operation is performed at layer 3 for reasons which are linked to mobility requirements among others which are further detailed in section 3.1 hereafter.

2.2 Regulatory constraints on spectrum usage

Aeronautical communication systems used for the transport of ATC/AOC are considered as safety critical in their frequency allocation by the ITU while systems used for APC communications are not.

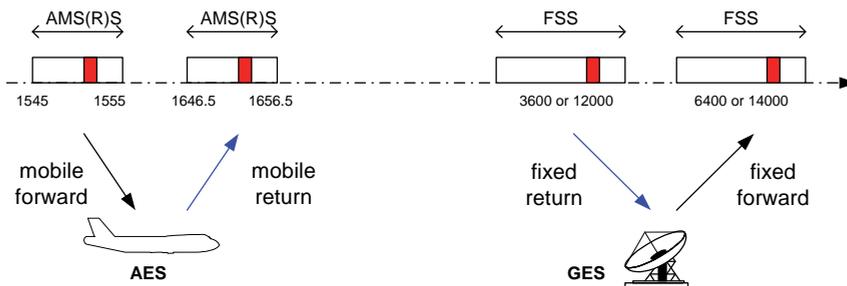


Fig. 3. Typical frequency bands used for safety aeronautical communications via satellite. These band allocations are managed by the ITU.

The principle of transmission in the safety satellite system is shown in Fig. 3:

- The mobile link, between the satellite and the aircraft, is built on a safety satellite spectrum allocation, based on AMS(R)S standard;
- The satellite is in charge of signals frequency conversion, simultaneously from C or Ku band to L band for the forward link, and from L band to C or Ku band for the return link;
- The fixed link, between the ground and the satellite, is built on a fixed satellite spectrum allocation, based on FSS standard.

In following sections, the regulatory situation in the L band for safety and non-safety services is exposed, as well as for the Ku band.

2.2.1 L band situation

The L band is defined as the Mobile Satellite Service allocation in the frequency ranges 1525-1559 MHz and 1626.5-1660.5 MHz.

Although the whole band is generically for Mobile Satellite Service (MSS) use, in certain portions of the band, safety related services are afforded a specific status in the ITU radio regulations, as shown on Fig. 4.

In the sub-band 1646.5-1656.5 MHz and 1545-1555 MHz, the communications in the AMS(R)S are afforded priority over other types of communications, through the footnote 5.357A of the Radio Regulations (International Telecommunications Union [ITU], 2008).

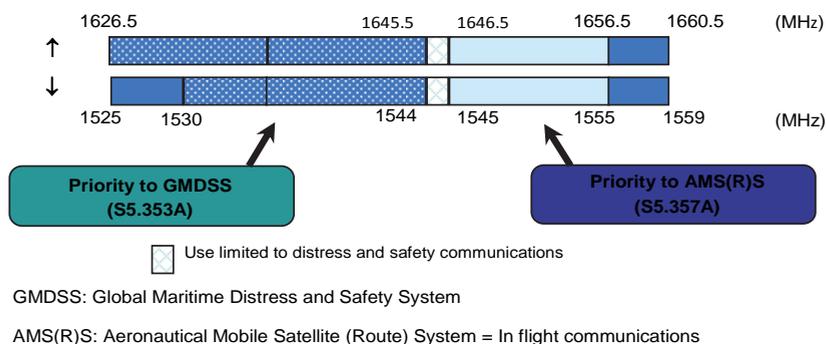


Fig. 4. AMS(R)S L band allocation for SATCOM.

The concerned communications are those falling under categories 1 to 6 of Article 44 of the Radio Regulations, as listed below:

1. Distress calls, distress messages and distress traffic.
2. Communications preceded by the urgency signal.
3. Communications relating to radio direction finding.
4. Flight safety messages.
5. Meteorological messages.
6. Flight regularity messages.
7. Messages relating to the application of the United Nations Charter.
8. Government messages for which priority has been expressly requested.
9. Service communications relating to the working of the telecommunication service or to communications previously exchanged.
10. Other aeronautical communications.

In the specific context of the L band, given the technical nature of satellite systems involved, it has been felt more efficient to have multilateral meetings among the concerned parties instead of solely relying on Article 9 of the Radio Regulation (ITU, 2008). In effect, the terminals in the L band have poor directivity which impacts any satellite network operating in visibility of that terminal, which leads to segmentation of the spectrum among systems. Given the high demand for spectrum in the L band, it is difficult for a new entrant to have spectrum granted, even if this is for safety services. For non-safety services it is seen as impossible to have significant spectrum allocated for a new entrant.

2.2.2 Ku band situation

In this section, the discussion is limited to the downlink portion of the Ku band, i.e. the portion dedicated to the reception by the aircraft.

The downlink portion of the Ku band is divided in allocations to various services:

- FSS planned band: These bands are regulated by Appendix 30B of the Radio Regulations. In these bands, every country member of the ITU has access to a reserved orbital position for national coverage. There are few operational systems in this band

- FSS unplanned bands: these bands host most of the Ku band satellite systems, because of the flexibility of its regulation. In many areas, this band is fully occupied by operational systems.
- BSS planned bands: these bands are regulated by Appendix 30 of the Radio Regulations (RR, 2008). In these bands, every country member of the ITU has access to a reserved orbital position and determined number of TV channels for national coverage. There is a significant number of operational systems in this band

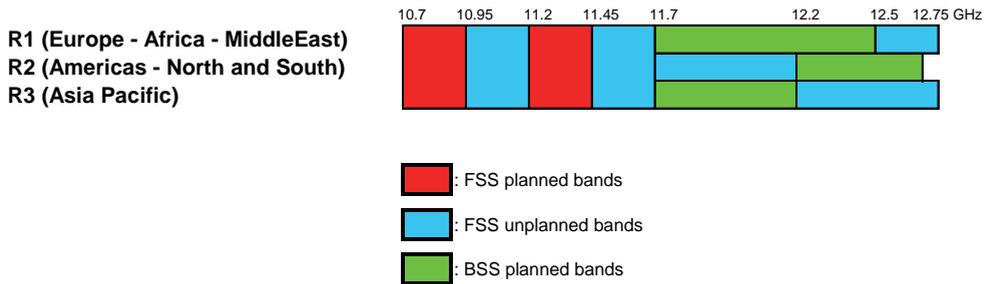


Fig. 5. Ku band allocation for SATCOM downlink.

The Ku band downlink allocations are depicted in the diagram presented on Fig. 5. Most of operational Ku band satellites operate in the Ku FSS unplanned band (in blue). Therefore it is likely that the capacity for APC services could be found in this portion of the spectrum, although the others are not excluded.

It should be noted that it would be more correct from a regulatory point-of-view to use Mobile Satellite Service allocations for the service since an aircraft can be considered as a mobile terminal. However, it is possible to use FSS allocations, as long as the services do not entail regulatory requirements higher than those of a classical FSS use.

Regarding inter-service sharing, the band 10.7-11.7 GHz is shared with terrestrial Fixed and Mobile services worldwide, with a majority of fixed use. In Region 3, the band 12.2-12.75 GHz is also shared with terrestrial services, as well as in Middle East and Africa for 12.5-12.75 GHz.

In order to enable sharing, there are power flux density limits applying to satellite transmissions in these bands (In these shared bands, the satellite systems for aeronautical communications receiver may experience bursty interference events due to fixed links interference).

Intra-service sharing concerns the potential interference among satellites systems sharing the same band. In order to maximize the use of the orbit, the ITU has developed recommendations on off-axis gain of earth stations (ITU, 2003), (ITU, 2010), (ITU, 2010a)

In satellite systems for aeronautical communications, the Ku band would be used in Receive only mode, therefore without risk of interference from the earth stations towards other systems.

2.3 Frequency allocation and spot beams definition

Considering the restrictions presented above, the different aspects of system dimensioning that need to be taken into account when designing an aeronautical communication system

are presented. Indeed, the use of several carriers, the frequency at which these carriers operate but also the geographical extend of these frequency domains on the ground (known as spot beams) are elements that need to be specifically adapted to the aeronautical context.

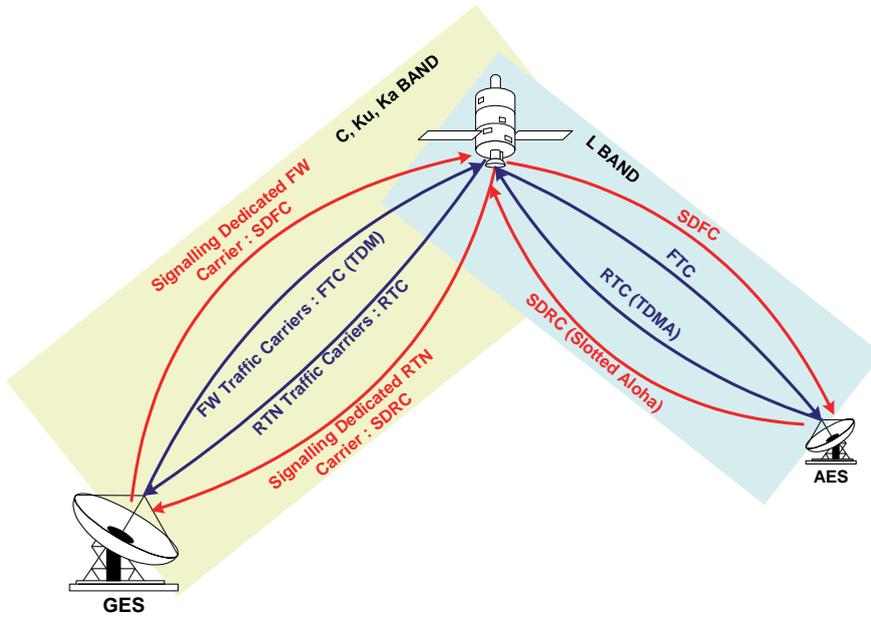


Fig. 6. Typical channel allocation.

A typical channel allocation between the GES and the AES for aeronautical communication systems via satellite is presented on Fig. 6, as it can be seen, the feeder link channels (between the GES and the satellite) are operated in C, Ku or Ka bands while the user link (between the satellite and the AES) are operated in the L frequency band.

Typical satellite architecture for aeronautical communications should include the following frequency carriers:

- Global Beam (meaning a common carrier on forward and return link for the whole system) shall be used for initial signaling meaning for initial system information, log-on and initial synchronization.
- The carriers for the global beam are named SDFC (Signaling Dedicated Forward Carrier) for the Forward Link and SDRC (Signaling Dedicated Forward Carrier) for the Return Link on the figure herein.
- On the opposite, within a spot beam one or more carriers can be used and are named FTC (Forward Traffic Carrier) and RTC (Return Traffic Carrier).

This architecture is summarized on Fig. 6, while these carrier names are not standard, they are logically implemented by most systems used for aeronautical communications.

Spot beams are required in the system to use the capacity more efficiently. A spot beams hypothesis is important in particular when the frequency allocation plan is realized. Spot beams also have the advantage of enabling the system to have a pattern for re-using frequencies. This permits to have more capacity on the global system given that one frequency is used several times in the global coverage.

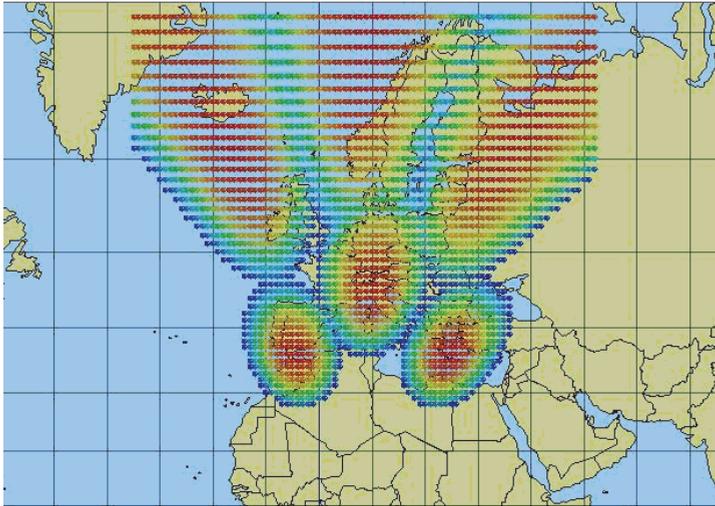


Fig. 7. Illustration of the interest of using spot beams in satellite system. In this example, when the overall available spectrum is limited, the gain provided by frequency reuse between non-adjacent spots can be visually verified.

2.4 Existing satellite systems in operation for aeronautical communications

2.4.1 Inmarsat and MTSAT

The Inmarsat service was initially targeted to providing a maritime communication service to the community for safety of life related issues. However, Inmarsat soon began to provide service to other communities such as aircraft and mobile users.

The space segment of the Inmarsat system is a constellation composed of several geostationary satellites (the number of satellites depend on the service as not all of them support all the services) that cover the earth with the exception of the poles. Aeronautical services supported by the system are currently ATS and AOC services. These can either be used through the legacy ClassicAero service or the recently introduced SwiftBroadband service (based on the BGAN technology adapted to the aeronautical context). The Inmarsat satellites use three different types of spot beams, one global spot beam for initial signalling and specific services, a set of regional spot beams (since the 3rd generation satellites) and very small spot beams (radius in the order of hundreds of kilometres) used for the BGAN service and allowing for smaller antennas to be used on the handheld terminals.

In terms of frequencies, the Inmarsat system operates the feeder link in Ku bands and the user link in AMS(R)S reserved portions of the L band.

The Classic Aero service is mainly used for establishing circuit oriented connections for low and medium quality voice and fax. In addition to these services, packet data services such as ACARS and ADS can also be used.

The SwiftBroadband service offers much higher data rates than Classic Aero and takes advantage of the small spot beams of the fourth generation satellites to provide users with these data rates. The SwiftBroadband service is based on the use of the IP protocol at network layer and is mainly used to provide passengers with Internet access.

In addition to the Inmarsat satellite constellation, the Classic Aero protocol is also used by the MTSAT system operated for the Japanese Civil Aviation Bureau (JCAB). The MTSAT

system as described in (Oikawa & Kato, 2006) offers ATS and AOC services to airlines in the Asia/Pacific area and provides increased availability by using two specifically located geostationary satellites (MTSAT-1R and MTSAT-2).

2.4.2 Iridium

In addition to the Inmarsat and MTSAT satellite systems presented above, the Iridium low earth orbit constellation of telecommunication satellites also provides aeronautical communication services.

The Iridium constellation is comprised of 66 active satellites that provide complete coverage, including the earth poles. The feeder and inter-satellite links are operated in Ka frequency band while the user link is operated in the L band.

Services offered by the Iridium constellation are based on the GSM standard and include both voice and data oriented communications. In addition to these services, one-way paging services are also possible.

The Iridium constellation and services has recently been undergoing the authorization process required to be used for AMS(R)S services. However, initially, the system will be used to provide voice-oriented communication between controllers and pilots for the needs of ATS services.

3. The future satellite link: challenges

3.1 Overview of the future aeronautical communication infrastructures

Currently, in continental areas, ATM mobile communications use a narrowband VHF (Very High Frequency) voice system combined with a VHF digital data link, e.g. VDL (VHF Digital Link) Mode 2 (Fig. 8 represents a VDL network architecture). The VHF network is composed of terrestrial antennas connected with gateway routers to a backbone network in which the services are located. Although VHF is a very mature and reliable technology, it presents some disadvantages. It requires several remote ground stations to achieve the coverage that implies high operating cost due to links between ATC centres and remote radio stations. The coverage is limited to line of sight so the number of required station increases in non-flat areas.

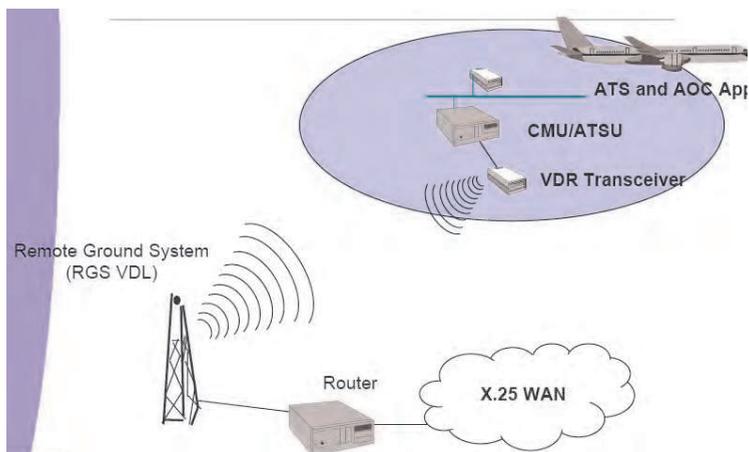


Fig. 8. VDL architecture.

In remote areas and over oceans, HF (High Frequency) and SATCOM (SATellite COMmunications) voice and data link systems are used. HF network has the same architecture as the VHF one but it is not limited to line of sight propagation, it can also be used with ground wave propagation and sky wave propagation (through reflexions on various atmosphere layers). The main drawback of HF communications is its poor link overall quality due to fading. HF tends to be replaced by satellites links in oceanic areas because of the higher quality of satellites communications. But the currently implemented satellites links are not efficient enough to be economically viable on a large-scale deployment. Fig. 9 depicts the general architecture of ATM network.

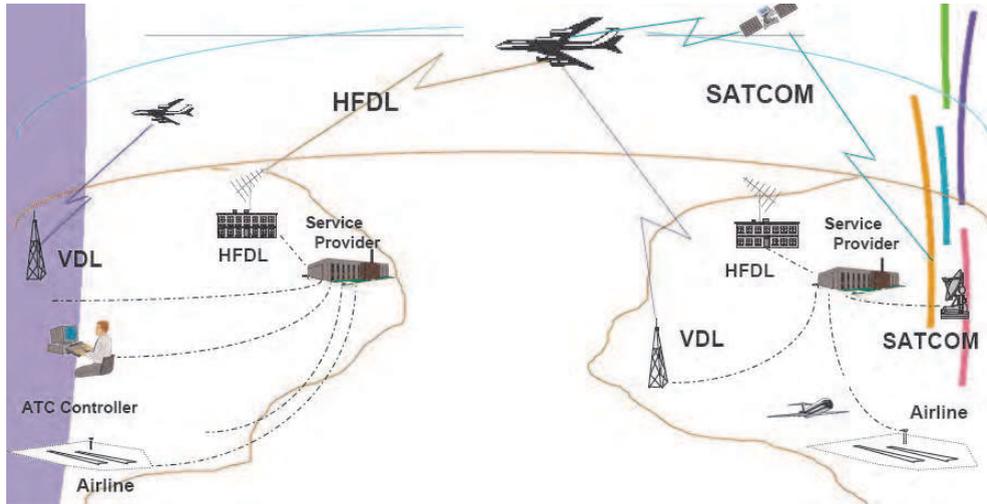


Fig. 9. ATM network global architecture.

The evolution from voice to data links for ATC is motivated by safety reasons and by saturation of voice links in dense areas. Indeed, data transmission allows using less bandwidth and safer communications. With the considerable increase of the air traffic last few years and the expected increase in the next coming years the current ATM network will not be able to handle all the traffic with the requirements associated to ATC services. In dense area managed airspace the objective is thus to increase ATM capacity while having even higher level of safety and getting rid of aeronautical routes. In low density managed airspace the objective is to have a higher communication quality and more flexibility in trajectories of aircrafts.

Future aeronautical communication architectures, which are currently being defined by initiatives and programmes in both Europe (through the SESAR programme) and the USA (through the NextGen programme), will allow for onboard end systems to communicate with other end systems located on the ground through potentially more than one radio link at a given time. From a topology point of view, this functionality can be illustrated as shown on Fig. 10.

On the airborne side of the network, several functional entities are represented, from passenger end systems which will mainly use the network architecture in order to access the Internet and specific passenger services to ATS/AOC applications which will communicate

with ATS/AOC service providers on ground through the use of potentially multiple access networks technologies including the satellite link.

On the ground side of the network, the counterpart to several of the airborne side functional entities are presented. Indeed, in order to provide its service, the network architecture relies on functionalities provided on the ground by Mobility Information Services as well as Security Services. Finally, the figure also presents the ATS/AOC service providers, which are the onboard systems and applications counterparts.

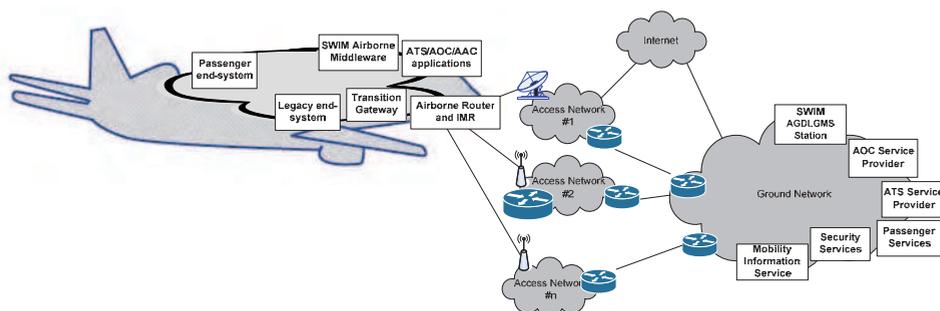


Fig. 10. Example of satellite link integration in the Future Aeronautical Communications infrastructure.

In order to maintain a global connectivity between airborne and ground networks, the network layer shall be implemented using the IPS protocol suite (ICAO, n.d.) which is strongly inspired by the IETF defined IPv6 protocol (Deering & Hinden, 1998). Furthermore, the onboard equipments are located on an IPv6 network that can be considered as being a mobile network according to the definition provided by the Mobile IPv6 standards (Johnson et al.). Indeed, throughout a flight, the airborne router (and the airborne network behind it) might from one access network to another (i.e. a switch from terrestrial LDACS to a satellite link during a transatlantic flight). In addition to being mobile, future architectures foresee that the airborne router establishes connections to multiple access network technologies at the same time. In this case, the network mobility extensions to Mobile IPv6 (Devarapalli et al., 2005) have to be complemented by specific strategies (Ng et al., 2007) to handle these multiple links.

Fig. 11 illustrates a possible instantiation of the previously described situation. In this scenario, the mobility tunnels are established between the airborne router and the home agent through each of the available data links. In this context, the loss of a given data link connection has the effect of removing one of the tunnels between the aircraft and its home agent. The advantage of this solution lies in the fact that no routing updates are required when new connections are established or existing connections are lost.

3.2 Role of the satellite systems

The current ATM network is very heterogeneous and the past evolutions of this network have been done without considering the need for global interoperability and a constant quality of services. Several networks and protocols stacks are used for different services. The next evolution will be to move toward a single data transport network supporting all the services and IP technology is the natural evolution to this objective.

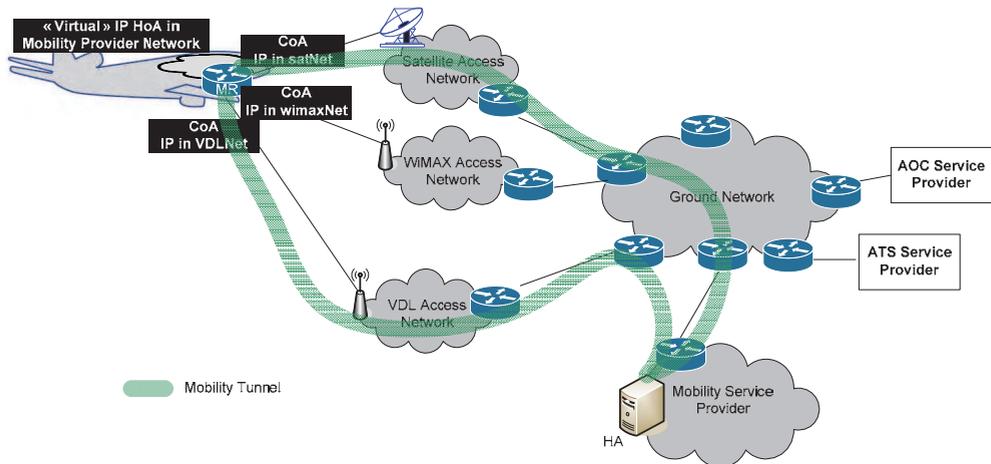


Fig. 11. Possible situation where mobility tunnels are added on top of the multiple data links to access the ATM networks. This illustration makes use of a dedicated mobility service provider that at the present time is not identified as a system actor.

On Fig. 12 is presented the synoptic of the new ATM network that was proposed in the definition Phase of IRIS (European Space Agency [ESA], 2009).

In regards to the requirements concerning future ATM network that were presented in the previous section, satellite systems have substantial assets in providing access to AES. These assets are presented hereafter.

The constant quality of service on the covered area required by such systems will be possible by the mean of a global coverage that only satellites can provide. Besides the satellite can provide high safety guarantees along with a constant deployment and maintenance cost all over the coverage (conversely to terrestrial technologies) and permits to get rid of aeronautical routes.

For all these reasons, the satellite shall play a major role in the future aeronautical communication network.

Either the satellite will be used as a primary mean for future ATM communications in all areas ensuring a constant quality of service and safety communication that could potentially be backed up by terrestrial technologies (such as LDACS), if needed.

Or, the terrestrial access could be used as a primary mean of ATM communication in the dense area managed airspace while the satellite could be used as a primary communication mean in low-density area managed airspace and as a backup communication mean in dense areas.

A last option would be to use concurrently several access technologies including satellite access to provide future ATM communications. This last solution would permit to increase the overall availability of the network while reducing handover delay in case of a technology breakdown, as all available technologies would be used in parallel. This approach could also permit to maintain a constant Quality of Service for ATM communications, as the access technology the most adapted to the QoS requirements would be used.

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There are well-founded concerns that current air transportation systems will not be able to cope with their expected growth. Current processes, procedures and technologies in aeronautical communications do not provide the flexibility needed to meet the growing demands. Aeronautical communications is seen as a major bottleneck stressing capacity limits in air transportation. Ongoing research projects are developing the fundamental methods, concepts and technologies for future aeronautical communications that are required to enable higher capacities in air transportation. The aim of this book is to edit the ensemble of newest contributions and research results in the field of future aeronautical communications. The book gives the readers the opportunity to deepen and broaden their knowledge of this field. Today's and tomorrow's problems / methods in the field of aeronautical communications are treated: current trends are identified; IPv6 aeronautical network aspect are covered; challenges for the satellite component are illustrated; AeroMACS and LDACS as future data links are investigated and visions for aeronautical communications are formulated.

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