THAUMAS: Study on Swift Broadband Improvement for Compliance with SESAR Requirements

Laurent Bouscary, Jean-Christophe Dunat, and Ababacar Gaye

Astrium Satellites, 31 rue des Cosmonautes, 31402 Toulouse, France
{laurent.bouscary,jean-christophe.dunat,
khalifa-ababacar.gaye}@astrium.eads.net

Abstract. Future Air Traffic Management (ATM) communications will rely on advanced satellite and ground based communication means. THAUMAS studies the possibility of using, for the satellite based component, an extension of the Inmarsat SwiftBroadband (SB) satcom service, the current version being already widely deployed and successfully operated by many airlines. This document summarizes the overall THAUMAS approach for the system design. Starting from the analysis of the current limitations of SB, this approach is based on a gradual evolution starting from the key upgrades while starting as early as possible feasibility studies on topics judged as less urgent regarding today's ATM needs. The final result will be the so called SwiftBroadband-Safety (SB-S).

Keywords: ATM, SESAR, SwiftBroadband, safety, sitcom.

1 Introduction

To modernize the existing solutions and to anticipate on future needs, the European Union is moving towards the implementation of the Single European Sky ATM Research (SESAR), a new Air Traffic Management (ATM) framework (combining technological, economic and regulatory aspects). Satellite communications for Air/Ground communications (voice and data exchanges between cockpits and flight control centres) have an important role to play in this future ATM infrastructure, both in Europe and in the rest of the world.

In coordination with the European Commission, Eurocontrol, Air Navigation Service Provider and the SESAR consortium, the ESA[1] ARTES 10 Programme ("Iris") intends to define and develop the use of Satcom for ATM communications in the future ATM system defined by SESAR. As part of the activities endorsed by ESA, THAUMAS is working on extending the Inmarsat SwiftBroadband system. Still within Iris, several operator studies are on-going to define business cases for the use of satcom for ATM.

Within THAUMAS, the system proposed to support future ATM communications is based on an extension of the Inmarsat Swift Broadband satcom service, the current version being already widely deployed and successfully operated by many airlines.

[1] SA : European Space Agency.

G. Giambene and C. Sacchi (Eds.): PSATS 2011, LNICST 71, pp. 50–59, 2011.

The current Swift Broadband system is already compliant with a large portion of the Iris System Requirements Document (SRD) [2] requirements, but not fully compliant, thus explaining the rationale for its extension. It is to be noted that the overall features required by the SRD correspond to an objective (in terms of performances, safety, coverage, etc) that could be required in a real operational environment by 2020+ (to let some time for the technologies to maturate; the aircrafts and human operators to adapt, and the market to develop).

The objective of THAUMAS is to propose a satellite communication system to SESAR compatible with mandatory International Civil Aviation Organisation (ICAO) provisions that best answers: the users' requirements, the end-to-end concept of operations, at the least possible cost for the airspace users and finally which can be operated by a certified Communication Service Providers (CSP). Ultimately this satellite communication infrastructure is intended to be included in the SESAR ATM Master Plan.

2 Review of SRD Requirements

A first important objective of the study consisted in reviewing the SRD requirements and in determining the areas of current compliance, and the areas of requiring upgrades to finally reach a full compliance with most of the SRD requirements.

The review of the requirements has shown that the current SB protocol, as it is defined today, does not fully comply with all the requirements, but still offers a very good baseline for a future system that could offer:

- Compatibility with low gain aircraft antenna: additional bearers (i.e. coding rate, modulation scheme and symbol rate) will be made available to ensure compatibility with low gain antenna, even in low elevation situations,
- Improved transmission latency for small messages, using improved random access mechanisms and satellite resources management between regional and narrow beams[2],
- Fast system recovery and efficient redundancy management to minimize unavailability of service,
- Options for a decentralised ground segment architecture,
- Interface with ATN[3]/OSI[4] and ATN/IPS[5] protocols, through the implementation of dedicated gateways.

It was identified that partial compliance may remain on transmission latencies, and service area.

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[2] Each Inmarsat 4 satellite provides one global beam, 19 regional beams and around 228 narrow beams. Although communications can be managed within the regional beams, traffic is usually handled in narrow beams to take advantage of better satellite performances. The management of the terminal (when in standby) is done using the regional beams.

[3] ATN: Aeronautical Telecommunications Network.

[4] OSI : Open Systems Interconnection.

[5] IPS : Internet Protocol Suite.

Transmission latencies will be deeply investigated in the next steps, looking in parallel at the end-to-end performances (also considering proposed improvements), as well as potential updates in the definition of the latency requirements (more suitable with GEO[6] satellites constraints).

For the service area, issues come from high latitude where the visibility of the satellite may not be possible during manoeuvres. Various options could be considered. Like additional antenna could be installed on-board the aircraft (this is not the preferred option from an airliner perspective), additional satellites with non-GEO orbits (for instance HEO[7]) could be used, but the business case could be more tricky, or availability of the services could be relaxed during manoeuvres. This last option seems the most realistic one, although implies a decision from aviation to relax requirements in some specific operational cases.

Some critical points were raised during the requirements' review. They concern the geographical area over which the satcom service will be delivered, the definition of the concept of operation for future communication means, the targeted ground segment infrastructure and the communication standard performances.

2.1 Main Geographical Area

Looking at traffic estimations and predictions, ECAC[8] is not a homogenous domain since air traffic is mainly concentrated in Central Europe. It has been proposed to concentrate the analysis on the FABEC[9] area (the Functional Airspace Block composed of Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland) as the requirements for this high density airspace will include the need of the other airspaces.

In parallel, investigations will be required on the need for service provision in high latitude countries would dramatically constrain the system design for a relatively small part of the traffic.

It was stressed that the use of satcom in TMA[10] airspaces is a challenging requirement, especially at high latitudes. In those types of airspace, aircraft are manoeuvring to maintain separation constraints. Should the requirement on the satcom system remain equivalent to the ones on the L-DACS[11] system (very high availability and short message latency), it will be necessary to install multiple antenna on-board the aircraft to keep the satcom link alive. This complex (and costly) installation will be required for TMA only, since ENR[12] and ORP[13] airspaces have less stringent requirements.

In addition, TMA area will be equipped with both VDL-2[14] and L-DACS capabilities, covering rather restricted areas around the airport, hence living room for

6 GEO: Geostationary Earth Orbit.
7 HEO: Highly Elliptical Orbit.
8 ECAC: European Civil Aviation Conference.
9 FABEC : Functional Airspace Block Europe Central.
10 TMA : Terminal Manoeuvring Area.
11 L-DACS : L-band Datalink Air-ground Communications System.
12 ENR: En –Route.
13 ORP: Oceanic, Remote, Polar.
14 VDL-2 : VHF Data Link mode 2.

efficient frequency re-use. Thus, the provision of a third data link over satcom in TMA could be considered less mandatory than in ENR (and obviously ORP) regions, especially in low/medium density airspaces.

All those aspects will have to be considered for the consolidation of the satcom usage in TMA airspaces.

2.2 Dual Data Link Concept and Boundaries of the System

The current concept of operation proposed by the SESAR Definition Phase is based on the idea that the future satcom system will work jointly with the future L-DACS systems, both of them working “in complement of VDL2/ATN to support the new most demanding data-link services” (refer to [3]).

It is understood that SESAR JU still have to clarify and to confirm both the dual-link concept (in the sense L-DACS + satcom) and the integration of the new dual-link with other communications means (especially VDL2).

The dual link concept could be interpreted either as a simultaneous transmission approach, the messages being duplicated over the two links or as a complementary approach with transmission over a nominal link, the other one being kept for hot redundancy. The comparison of the two concepts concluded that the latter approach seems more appropriated. The basic idea is to consider the satcom system and the terrestrial system as complementary in the sense that messages can be transmitted either by one or the other system, each system providing a backup mode in case of the failure of the other one.

2.3 Ground Segment Architecture

Considering the ground segment of the satcom system, one point to be confirmed is the need for a distributed architecture. According to the FAB evolution, in the coming years, air traffic flows will not be constrained anymore by national boundaries and ground communication infrastructures will thus be rationalized. Satcom infrastructures for ATM will have to follow this new trend. Hence, the probability of a need for one ground Earth station (GES) per country seems very low, and ground satcom infrastructure is more likely to be shared among all FABs.

The satcom system would have to be able to support the handover of an aircraft from one FAB to another. This would not necessarily mean a GES handover, but rather a handover between FABs performed at an upper layer.

2.4 Communication Standard Performances

The definition of the communication standard requirement is a tricky point. So far, performances requirements are defined for a single user, based on the information available in Communications Operating Concept and Requirements (COCR) [1]. However, there is a need to define the test conditions, i.e. load conditions of the network, under which those performances should be reached.

In other words, the implementation of the SRD requirements into system specifications is suitable to verify the performances required per aircraft.

For the full traffic aspects, the critical point remains to define the way to validate that the overall behaviour of the system is in line with the end-users’ expectations.

Concerning voice services, for the time being, the use of satcom is mainly foreseen in oceanic and remote areas. In addition, voice will essentially be used as a safety back-up means of communication in case of a) incoherence/erroneous data transmission: in this case, point to point communication between the pilot and the controller could be sufficient or b) loss of the data link: in case of satcom, the voice communication will probably not be available either. In this case, considering satcom voice as back-up to satcom data link may not be of interest.

The operational conditions for the usage of voice shall be specified together with the associated performance requirements as soon as possible.

3 System Design Evolutions

The SB system already offers flexible adaptation to propagation channel, as well as flexible resources management. This system has been designed taking benefit from the last generation of Inmarsat 4 satellites. The satellite payload has a transparent, bent-pipe digital signal processor (DSP) that provides very fine granularity in the allocation of bandwidth to the various beams, and also enables the generation of a variety of different types of beams, with the required pointing.

The overall so called SB-S (Swiftbroadband-Safety) system is being defined to comply with "Iris System" definition specified in the SRD.

3.1 Decentralized Ground Segment

Some of the requirements expressed in the current SRD do not seem to come from technical aspects, but more from institutional issues. The requirement for defining a system compatible with a decentralized architecture is one of them. This point is critical, with major impacts on the telecommunication resources management.

The current BGAN resource management scheme is centralized by design and is based on the following components to ensure an optimized allocation:

- Payload Control System (PCS): optimizes the payload configuration to accommodate the channels demand (received by the GRM).
- Frequency Planning System (FPS): analyses the resource usage and tries to anticipate (long-term trend) the future demands to prepare adequate frequency planning in advance of peaks.
- Global Resource Manager (GRM): manages the radio resource (channels) for the entire satellite. It answers channel requests from LRM and request for additional missing channels to PCS.
- Local Resource Manager (LRM): allocates slots within its channels and analyses the demands from beams up to requesting for additional channels to GRM.

Using this architecture, the current capacity and resources allocation to LRM (located in GES) can be static, semi-static or dynamic, the current mode of operation being the dynamic one, in order to maximize the satellite capacity usage.

Several resource management architectures have been studied: from partially to fully decentralized. The current version of SB is partially compliant with ground segment Iris requirements as it does not currently support a fully decentralized architecture. However, moving to a decentralized architecture is nevertheless feasible, even if some components require staying centralized (e.g. the PCS is a central component linked to the satellite payload). Note that in the light of these requirements, a decentralized approach (not only applicable to the SB case) would have several impacts on the existing elements by reducing the system flexibility and the efficiency of the resource usage, thus leading to:

- A lack of resource availability in one GES whilst other GES resources are underused
- Over-dimensioning of communication resources capacity to mitigate this risk
- Pre-emption is less efficient (a GES can only pre-empt resources within the local entity)

At this stage, resource management aspects have been qualitatively evaluated in front of the SRD requirements. Once the communications scenarios will be mature enough, quantitative study will complement this qualitative work on in the next phases, focusing on capacity analysis and sizing, reconfiguration time for each type of nominal scenario and reconfiguration time for each type of fault-back/recovery scenario.

3.2 Redundancy Management

The impact of the use of two satellites (one for redundancy purpose) and the need for a fast switching (meaning in less than a given duration defined at system level) and safe switching (meaning that all the ATM traffic on the nominal satellite shall be preserved and fit on the backup one) between the nominal and the backup satellite on the PCS has also been investigated. Several options have been envisaged such as:

- The backup satellite is pre-configured with the same channels as the ones of the nominal
- The backup satellite (when in backup mode) does not host any non ATM traffic or hosts only a limited non ATM traffic
- The backup satellite (when in backup mode) hosts non ATM traffic without limitation

All options are technically achievable, and the final selection of the final solution is still to be done, considering the impact on the business model.

3.3 Interoperability with “Non THAUMAS” Elements

Non-THAUMAS elements (or non-Iris elements) correspond to other satcom systems than the ones specified by the SRD (ie GEO/HEO L-band satellites using SB-S protocol for THAUMAS) as well as terrestrial solutions. It’s worth mentioning that the definition of the rules for choosing a communication means or another (for instance between terrestrial and satcom technologies) has been considered outside of the scope of the system design activities.

Interoperability between the designed system and “non-THAUMAS” elements concerns other satcom systems, as well as the terrestrial ATM backbone.

Interoperability with other GEO systems could be achieved by re-using the same aircraft terminals and protocol stack. In order to achieve interoperability, the performances of the space segments must be equivalent and the ground segments must be compliant with the future system specifications.

Concerning HEO systems, interoperability could be achieved either by defining a single protocol stack compatible with both GEO and HEO satellites or by using two protocol stacks taking benefits from Software Define Radio technologies, which is the preferred solution. Another option is to consider the HEO system as an independent one, similar to a terrestrial network.

This third approach is also valid for interoperability with LEO[15] systems and it is proposed to keep it for the future system since it seems difficult to define a single communication standard compatible with both GEO and LEO types of orbits. Defining a unique interface between the aircraft Communication Management Unit (CMU) and the various Satellite Data Units (SDU), as it is currently the case for the provision of ACARS services (Iridium units essentially emulate an Inmarsat SATCOM SDU), would overcome the difficulty.

When it comes to interoperability with the terrestrial ATM backbone, the THAUMAS ground segment connectivity will have to be aligned with the network concepts brought by the PENS project (Pan European Network Services). This initiative from EUROCONTROL and ANSPs aims at providing a common IP based network service across the European region covering voice and data communication and providing efficient support to existing services and new requirements that are emerging from future Air Traffic Management (ATM) concepts.

The key requirements for support of ATN-IPS relate to the support for IPv6 service, which is a native service offering of 3GPP[16] networks, on which the Family-SL communication standard is based.

The future ATN-IPS IPv6 network architecture, addressing and routing policies require further clarification; however, the implementation and configuration of an IPv6 service capability is not seen as a significant risk item for the Swift Broadband.

4 Protocol Upgrades

In order to reach compliance with the ESA Iris system requirements, the most required system improvements are:

- Support of low gain antenna
- Reduction of the message transmission delay through signalling optimization
- Improvement of the random access scheme

These upgrades, complementary to those explained in the previous section, would be built on top of the SB baseline protocol, leading to the SB-S service adapted to safety aeronautical operations.

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[15] LEO: Low Earth Orbit.

[16] 3GPP : 3rd Generation Partnership Project.

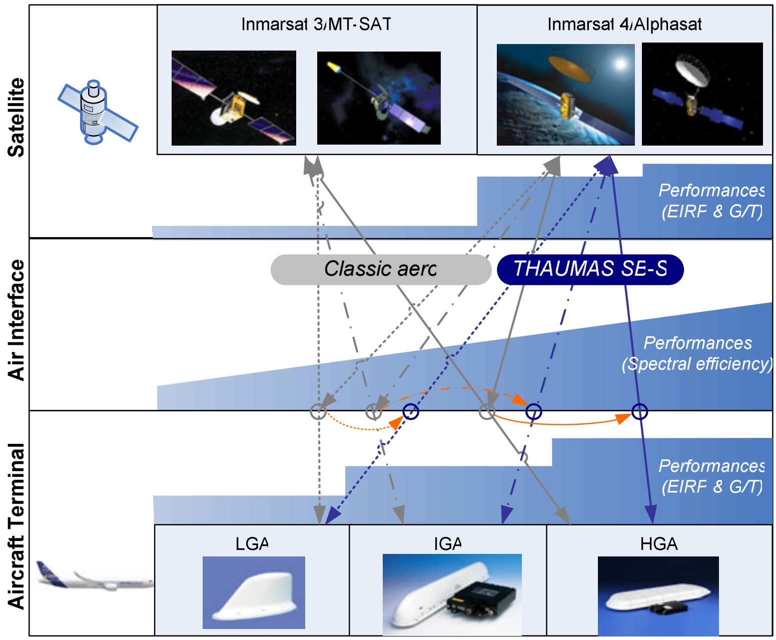

Fig. 1. Overview of Technical Improvements

4.1 Low Gain Antenna Support

To support the omni-directional mobile terminals, new physical bearers have been defined that allow robust operation for fixed-wing and rotary-wing aircraft at low elevation angles. The introduction of the new bearer types into both the Radio Access Network and the Mobile Terminals is the key development that needs to be undertaken to support this capability.

The support of low gain antenna is accompanied with a strategy of defining an optimized terminal architecture in terms of number of antennas, coverage, redundancy, price, dynamic configuration.

4.2 Reduced Message Transmission Latency

The default behaviour of the Swift Broadband system is to release the Radio Access Bearers (RAB, the logical connection across the radio interface) after a configurable period of non-use (typically 60 seconds). The reason for this is to enable the spot beam resources to be released and re-used in another beam if no traffic is being carried in a beam. With the low-latency requirements of the COCR [1] traffic this is considered unacceptable behaviour, so additional mechanisms need to be implemented to ensure RABs remain persistent and are supported in either spot beams or regional beams depending upon the loading within a spot beam.

Such a modification in the protocol signalling would reduce the protocol overhead of re-establishing a RAB after inactivity. This gain would be particularly important for bursty traffic.

4.3 Improved Random Access Scheme

Transmission latency will be improved for small messages, using improved random access mechanisms and satellite resources management between regional and narrow beams. It was identified that partial compliance may remain on very short transmission latencies, where the transmission delay toward the geostationary satellite is not negligible, and on service area, especially considering high latitude where the visibility of the satellite may not be possible during aircrafts manoeuvres.

The planned improved random access scheme would allow the simultaneous transmission of several packets into the same timeslot while coming from different terminals. For very short latency messages of a bursty traffic, there is no much time to spend in exchanging signalling messages to reserve and prepare for the transmission of this short latency message. As a consequence, the proposed random access scheme would replace the reservation effort for a slot by a random (but more successful) access into a specific-slot.

5 Conclusions

The first phase of THAUMAS has identified that there is a need to clarify the concept of operation and the future usage of the satcom link within the dual-link concept. The overall envelop of requirements considered so far certainly includes “nice to have” features that could dramatically increase the cost of the service for the end users. Concrete proposal have been done in this direction. In particular, it seems important to focus the effort on the key objectives that will support the improvement of air traffic situation in the dense area of the European airspace.

Despite these uncertainties in the usage landscape, it has been demonstrated that the SwiftBroadband system has been designed in a flexible way, using up to date techniques and as such it constitutes a very good basis to contribute to the consolidation of the requirements of the future satcom system for ATM. Indeed, it takes benefits of the strong background of Inmarsat in the aeronautical services provision.

For cost reason, the current implementation of the system does not take benefit of all potential options, but could be implemented. In addition, whenever required, further improvements and functionalities have been identified to achieve compliance with the end users requirements in the core area of Europe, leading to the SB-S system.

Remaining partial non compliance to the current requirements (that may be updated in the future) are linked to the use of geostationary satellite, and will therefore be the same for any system based on this kind of constellation. Compliance could be achieved using other types of constellations, but cost and business case issues have to be carefully considered before moving in this direction.

The next phase of this THAUMAS initiative will consolidate technical trade-off initiated in phase 0, and will confirm system design validation through simulation activities.

References

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