Satellite-Based ADS-B for Lower Separation Minima Application

Multi-Source Study Report

D2.5

SALSA

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SALSA

SATELLITE BASED ADS-B FOR LOWER SEPARATION-MINIMA APPLICATION

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Abstract

SALSA is an exploratory research project relating to multi-source ADS-B system. A multi-source ADS-B system that combines the benefit of all possible type of relays (space, maritime, air or ground based) of ADS-B messages could provide a global surveillance system to overcome the prevailing continuous surveillance constraints in the non-radar airspace (NRA). By bringing Space based ADS-B with other sources of surveillance based on ground, air and oceanic relays, a system of system architecture is conceived; upon its benefits, new separation standards are validated through analysis using theoretical modelling for separation standard and airspace capacity, in the context of NRA. Reduction in separation minimum and in the number of standards will bring significant benefits to ATC/ATM operations with improved aircraft surveillance and airspace management. These two aspects, namely, a system-of-system concept for multi-source ADS-B architecture and analytical modelling for enhanced separation minima and airspace capacity in the context of NRA define the scope of SALSA. The analysis will also consider different scenarios of separation minima Vs. ADS-B message update rate. The study will assess the impact of performance of such a system of systems approach in the context of separation standards; it will provide an assessment of the procedural impact and impact to flight safety due to the revised minima and the system configuration. A set of recommendations to SESAR JU and other stake-holders and industry partners will be provided in order to purse the outcome of the study towards higher technology readiness level (TRL) and eventual implementation.

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1 References

1.1 Applicable documents

[A1] 699337, Grant Agreement SALSA, Issue 1, 18/03/2016

[A2] SPC-CT-00356-ABDS, SALSA Consortium Agreement, Issue 4.0, 05/03/2016

1.2 Reference documents

[1] SALSA D2.1. Multi-source ADS-B Architecture report

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[6] SALSA D1.2, ADS-B User Requirements

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2 Executive Summary

This document constitutes the Study Report of the multi-source ADS-B (Automatic Dependent Surveillance – Broadcast) system which is a System of Systems studied in the SALSA Project for the concept of multi-source ADS-B surveillance.

It provides a Multi-source ADS-B data chain model, taking into consideration the data requirements for both space-based and non-space based ADS-B.

The study report assesses all possible relays of ADS-B information over Non Radar Airspace: primarily satellites, but also vessels (if equipped with ADS-B receivers SALSA could benefit from their existing SATCOM systems to relay ADS-B traffic information), aircraft (ADS-B derived air picture could be relayed from aircraft to aircraft up to a ground or satellite infrastructure).

The use of other more advanced systems such as the High Altitude Pseudo-Satellite (HAPS) Zephyr or balloon constellations envisaged to provide internet access world-wide will be considered.

The impact on the involved ATM entities will be assessed and the potential need to upgrade existing ADS-B standards will be analyzed (in particular to convey the ADS-B situation from aircraft to aircraft).

This System of Systems aims at receiving and relaying broadcasted ADS-B signals, especially in Non-Radar Airspace, using space-based ADS, and also ADS-B In aircraft and vessels. The architecture of the multi-source ADS-B systems proposes different ways to process (receive, relay) the ADS-B Signal broadcast, whatever the deployment timeframe would be. That means, for example, ADS-B In aircraft with the ability of relaying the received ADS-B Signals concept would need feasibility and cost study, and development and certification during several years. Another example concerns the vessels used as ADS-B relays concept: vessels equipped with a HF radio unit are already operational but the HF radio unit would need to evolve in order to take into account ADS-B Signals).

The outcomes of this deliverable will be exploited by the subsequent WPs and tasks, especially tasks 2.5 ADS-B performance assessment, and by the wider ATM community.

3 Introduction

This D2.5 Multi-source ADS-B Study Report deliverable is the outcome of the project SALSA Task 2.4 "T2.4 provides a Multi-source ADS-B data chain model, taking into consideration the data requirements for both space-based and non-space based ADS-B".[1]

3.1 Purpose

The task 2.4 aims at refining Multi-source ADS-B Architecture report (deliverable D2.1) on two aspects:

- identify the physical artefacts corresponding to the defined system architecture
- Identify all possible paths of data which may be used to have an aircraft ADS-B signal to the end user

More specifically, this deliverable intends to assess the Data paths enabled by combination of ground, vessels, LEO and GEO satellites.

3.2 Structure of the document

The document is organised as follows:

Chapter 1: References

Chapter 2: Executive summary.

Chapter 3: Purpose and scope, terminology.

Chapter 4: Paths for ADS-B data communication.

Chapter 5: System taxonomy.

Chapter 6: Conclusion.

3.3 Scope

The ADS-B (ground-based ADS-B receivers) is already in use in different Airspace. One of the concerns in SALSA is to get the ADS-B data of aircraft when they are flying in Non-Radar Airspace.

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[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

The Space-based ADS-B is a new concept that would enable to get the flight information when aircraft are flying in Non-Radar Airspace. Other sources of the ADS-B data may be envisaged.

The ADS-B Signal is broadcasted by an aircraft on 1090 MHz, on a global scale (i.e. Radar-Covered Airspace or Non-Radar Airspace) the aircraft is flying in. The aircraft may be detected by different systems, depending on the range of their receiver: other aircraft (ADS-B In), radars, vessels, satellites, Once it is received by a satellite for example, the satellite has to decode this ADS-B signal and then to send it to its associated data downlink ground station.

In the multi-source ABS-B system architecture, the following assumptions are made to ease the distinction between what is to be caught and what is to be exchanged in the multi-source ADS-B system:

- an ADS-B Signal is the one which is sent by an aircraft to be detected and controlled;
- an ADS-B Message is the decoded ADS-B Signal which is exchanged with other either as a signal - when the emitter is not on the ground - or as a data - when both emitter and receiver are on the ground.

Radars are not considered as part of the multi-source ADS-B system whose architecture is reported in the current deliverable since SALSA project focuses on NRA and they are taken into account in the EATMA **[2]**.

3.4 Communication, Navigation and Surveillance (CNS)

Communications, Navigation and Surveillance (CNS) are three technologies at the very heart of Air Traffic Management (ATM) and are key to the delivery of safe and efficient air traffic.

Accurate and timely radio **communications**, both voice and data link, are essential to air safety. This is generally delivered through ground-based VHF systems in Continental airspace and HF and Satcom in Oceanic areas.

Ground and satellite radio **navigation**al equipment enables pilots to use their instrumentation to fly precisely along their intended route and to conduct precision approach and landing. Satellite based systems and supporting procedures are of growing importance to navigation.

Surveillance systems are used by ATC and others to determine the position of aircraft and provide safe separation. They fall into cooperative and non-cooperative types. Cooperative systems, such as secondary surveillance radar (SSR), need to communicate with equipment on the aircraft such as the SSR transponder. Non-cooperative systems such as primary surveillance radar (PSR) are able to locate aircraft by transmitting pulses of radio waves which reflect from the aircraft hull. The reflection is detected by the radar enabling the aircraft's position to be determined.

In order to keep track with the growing air traffic density future ATM systems need to implement new functionalities and technologies that support higher performance and efficiency in all three areas described above. As a matter of fact, planning and first implementation steps are already well under way. This is reflected for instance in the European ATM Master Plan and the SESAR JU on the European side and FAA's NextGen initiative on the US side.

In this context the concept of Performance-based ATM (P-ATM) has emerged that integrates advanced capabilities in CNS to allow the introduction of new, more efficient procedures based on different required performance metrics. With the advent and widespread adoption of satellite-based navigation through the GPS system, satisfactory navigation performance even in oceanic and remote airspace can be easily achieved. Therefore, the main focus today is on Performance-based communication and surveillance (PBCS) where emerging technologies promise significant improvements for the benefit of separation minima especially in non-radar airspace. PBCS involves globally coordinated and accepted specifications for Required Surveillance Performance (RSP) and Required Communication Performance (RCP), comprised of allocated criteria for the components of the communication and surveillance systems involved, i.e. aircraft system, aircraft operator, air navigation service provider (ANSP), satellite service provider (SSP)/communication service provider (CSP).

Procedures on separation minima depend on both Communication and Surveillance Performance as has been addressed in detail in section 5.4.6.6 of SALSA Deliverable D1.1 part 1 [5]. In particular, it was noted there that significant improvements in RSP would result in the Communications Performance becoming the bottleneck and limiting the separation procedure that could be implemented. Even with a RSP15 - corresponding to an position report updated interval of 15 s that may be achievable a multi-source ADS-B system with a space-based component – an RCP240 – implying a controller intervention time of 4 minutes – would at very best allow for 15 nautical mile (NM) lateral separation. (It should be noted, that the values given in [5], section 5.4.6.6, are conservative, current best practise based on RSP180 and RCP240 allows a 23 NM lateral separation.)

3.5 Acronyms

The following table defines the acronyms used in the present document.

Term	Definition
ADD	Architecture Description Document
ADS-B	Automatic Dependent Surveillance – Broadcast
ASTERIX	All Purpose STructured Eurocontrol suRveillance Information EXchange
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSAW	Airborne Traffic Situational Awareness
CNS	Communication, Navigation, Surveillance
DM	Data Model
EATMA	European ATM Architecture
FIR	Flight Information Region
HF	High Frequency
ICAO	International Civil Aviation Organization

Term	Definition
MBSE	Model-Based System Engineering
NAF	NATO Architecture Framework
NATO	North Atlantic Treaty Organization
NMM	NAF Meta-Model
NOV	NATO Operational View
NRA	Non-Radar Airspace
NSV	NATO System View
SALSA	Satellite-Based ADS-B for Lower Separation Minima Application
SATCOM	Satellite Communications
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SWIM	System Wide Information Management
TRL	Technology Readiness Level (TRL)

4 Paths for ADS-B data communication

The following figure (NOV-1) has been developed as part of the architecture modelling [1] to illustrate the main operational nodes concerned with the multi-source ADS-B system studied in project SALSA - in green boxes - together with the different systems which may be used to have the aircraft broadcasted ADS-B information displayed to the ADS-B information user (the ATCo).

It also indicates the potential communication paths allowing to route this information. In other terms, these different systems are the ones considered in the multi-source ADS-B system by focusing on ADS-B Signal transmission in Non-Radar Airspace (NRA).

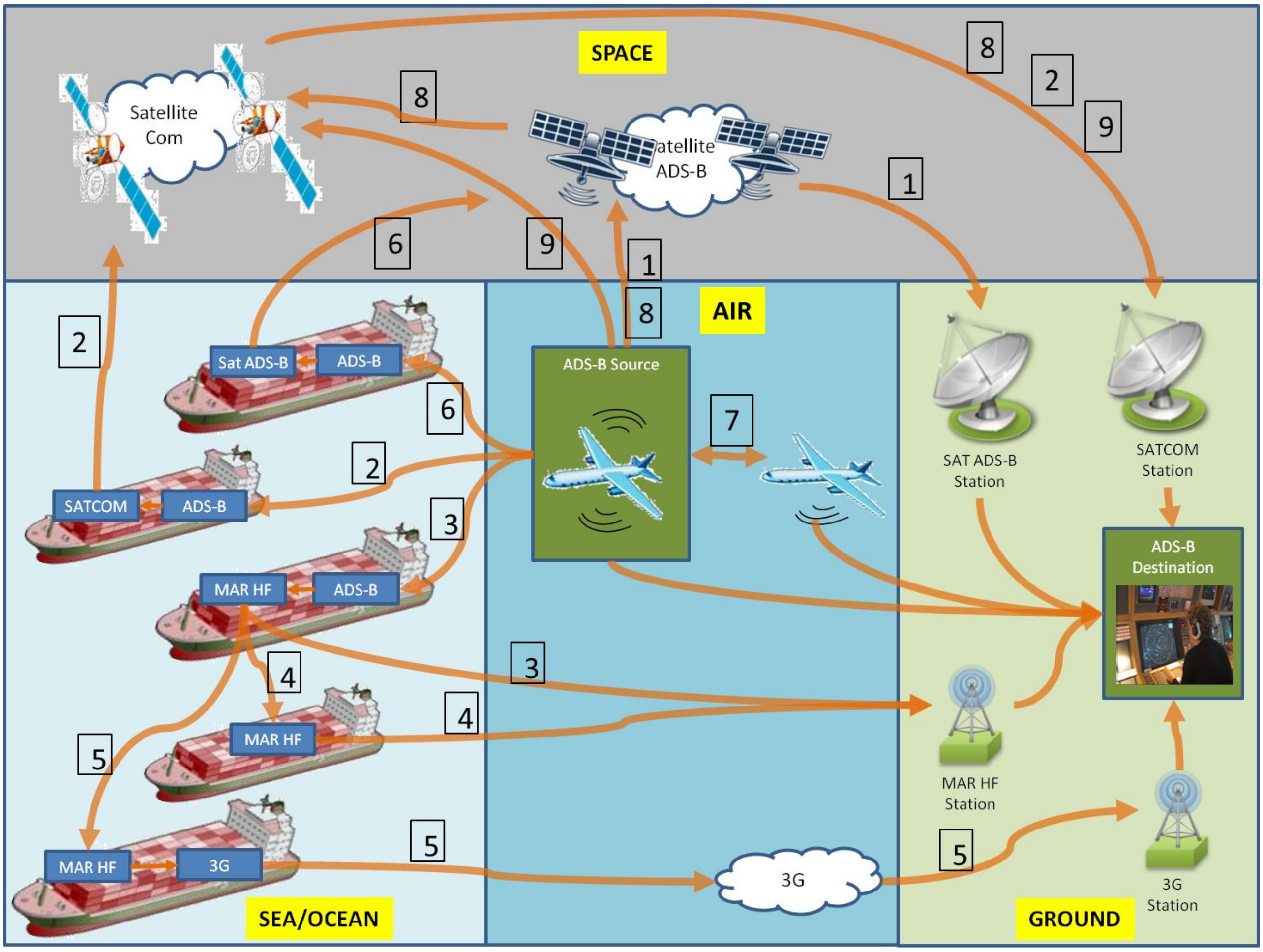


Figure 1: High-Level Operational Concept Description (NOV-1)

Originally ADS-B was developed for ground-based reception only in order to partially substitute costly primary and secondary radar stations due to significantly reduced infrastructure requirements. The ground-based ADS-B receivers can be integrated into ATM system [5], if it complies with the necessary requirements on performance and availability/reliability. One important performance measure is the latency, i.e. the time elapsed between the reception of the message at the ground station until it is available at the ATC processing system for the controller. Ideally, the time of applicability of the data – i.e. the time when the measurement of the data (e.g. position data) has occurred – should be taken as the starting point for the latency. However, as the 1090ES messages do not contain a timestamp, the moment of reception at the ground station is typically taken. The aberration from the time point of measurement then contains the transmission latency – i.e. the delay between measurement and message transmission – plus the signal travel time.

In NRA – i.e. in oceanic or otherwise remote areas – currently no means for air-traffic surveillance are available. Multi-source ADS-B – with space-based, maritime and perhaps other assets – intends to remedy this surveillance gap, by placing additional ADS-B receivers in or over these areas. However, as explained above, reception of the ADS-B signal is not enough. The surveillance information needs to be transferred to the Air Traffic Controllers in a very timely manner – depending on the ATC procedures to be implemented in these areas a latency of at most a very few seconds is mandated [6]. Unfortunately, this latency needs to be achieved for the remote areas where there is not just a surveillance gap, but usually also a communications deficit. Therefore, sophisticated data paths as shown in figure (NOV-1) need to be utilized.

The ADS-B OUT standard is reserved for the broadcast of the ADS-B signal from the originating airliner into its environment. Therefore, the various assets of the multi-source ADS-B system cannot directly re-broadcast this signal. Rather, the individual receivers have to first decode the 1090ES signal to extract the ADS-B message (containing for instance the aircraft identification, position or velocity) and then format the message for further transmission along one of the data paths displayed in figure (NOV-1) onward to the end user. Since the individual 1090ES ADS-B message broadcast by aircraft does not contain a timestamp, it is absolutely necessary that upon reception a timestamp is recorded and transmitted along with the message content to the Air Traffic Controller. After all, it is clearly possible that the same ADS-B message is received by different assets of the multi-source ADS-B almost simultaneously. If the same message then arrives at the Controller from different assets through different data communication paths with possibly differing latencies, confusion can only be avoided, if the individual messages are associated with a precise timestamp.

There are many ways to format the messages for the transmission along the data path – from transferring just each individual message (with associated timestamp) independently or to aggregating multiple messages into surveillance or target reports. A very common format that is also employed with ADS-B ground stations is the ASTERIX CAT 21 format for ADS-B target reports [7]. For a given data source – i.e. airliner emitting an ADS-B OUT signal – it assembles various data items like position, velocity, altitude, etc. together with the precise timestamps for the reception of the respective messages.

Clearly, the entry node, where the ADS-B message enters into the multi-source ADS-B system, has the critical task of receiving the message, timestamping it, formatting it – into a format that still needs to be fixed – and sending it on its way onto one of the communication paths towards the Air Traffic Controller who needs it – for it to arrive there hopefully with a latency of just 1-2 seconds.

The various data paths are further described in following table.

	Source	Entry Node	Relay 2	Relay 3	Destination
Current situation	Airliner no ADS-B				ADS-B destination (ATC station)
P1 - Satellite ADS-B	Airliner ADS-B	Satellite ADS-B constellation	Satellite ADS-B Station		ADS-B destination (ATC station)
P2 - Vessels ADS-B via SatCom	Airliner ADS-B	Vessel (SatCom)	Satellite Com	SatCom station	ADS-B destination (ATC station)
P3 - Vessels ADS-B via HF single relay	Airliner ADS-B	Vessel (MAAR HF)	MAAR HF Station		ADS-B destination (ATC station)
P4 - Vessels ADS-B via HF multiple relay	Airliner ADS-B	Vessel#1 (MAAR HF)	Vessel#2 (MAAR HF)	MAAR HF Station	ADS-B destination (ATC station)
P5 - Vessels ADS-B via 3G	Airliner ADS-B	Vessel (MAAR HF)	3G	3G Station	ADS-B destination (ATC station)
P6 - Vessels ADS-B via ADS-B Sat	Airliner ADS-B	Vessel (ADS-B Sat)	Satellite ADS-B Station		ADS-B destination (ATC station)
P7 ADS-B out ADS-B in	Airliner ADS-B				Airliner ADS-B
P8 ADS-B SAT SatCom	Airliner ADS-B	Satellite ADS-B constellation	Satellite Com	SatCom station	ADS-B destination (ATC station)
P9 ADS-B information to SatCom	Airliner ADS-B	Satellite Com	SatCom station		ADS-B destination (ATC station)

Table 1 : Paths considered to build the scenarios.

“Entry Node” is meant to indicate that at the first entry point of the ADS-B message into the multi-source ADS-B system there is more to be done than simple relaying.

The reminder of this chapter provides a description of the various data communication paths

4.1 P1 - Satellite ADS-B

This data path is the “nominal” communication path to route ADS-B messages.

The ADS-B signals are received by the satellite ADS-B antenna, demodulated and decoded by the on-board receiver and formatted according the the system standard. Achieving low latency transmission of the formatted message from the satellite to the Air Traffic Controller on ground poses a significant challenge.

If there is a ground receiving station “visible” from the satellite, i.e. within the field of view of the satellite’s downlink antenna, each ADS-B message or the associated target report can be almost immediately transmitted to the ground, provided on-board processing and data-handling do not cause significant delays. With a high-speed ground-based data connection between receiving station and the ADS-B destination center, a latency of the order of 1 – 2 seconds can definitively be achieved.

Clearly, dedicated regional downlink stations can be a viable concept locally for timely delivery of the ADS-B messages. However, in order to guarantee such a sufficient latency performance globally, a large number of ground receiving stations – probably more than one hundred – need to be implemented. An alternative is to equip the individual ADS-B satellites with inter-satellite links, i.e. RF communication means, between each other. In this concept, the ADS-B satellites act as relays passing the ADS-B messages or target reports on to those satellites that are within reach of one of a set of very few (< 10) ground stations that would need to be strategically placed across the globe typically in higher latitudes to provide for global coverage. Typically these inter-satellite relays would contribute up to 200 ms to the latency.

A further option for the data transmission from the ADS-B satellites is path 8 described in section 4.1.5.

4.2 P2 - Vessels ADS-B via SatCom

SatCom enables the air-ground voice and data communication with aircrafts via satellites. It combines satellites and satellites ground stations with their equipments.

SatCom is used as a primary system for oceanic and remote regions and as a secondary (to complement) to terrestrial systems in continental regions. SatCom may be provided by commercial Telecom providers Communication Systems (e.g. Inmarsat, Iridium, SES). Typical systems implemented on vessels are Inmarsat, Iridium and VSAT systems.

Irirdium is used as part of the LRIT (long-range identification and tracking) which is mandatory on numerous vessels. The system reports ship positions in regular time interval via the Iridum link. LRIT shall not be confused with AIS (Automatic Identification System) which is operating in VHF band. LRIT is only an application of the Iridium system which provides e.g. voice and data services.

Inmarsat terminals are implemented on numerous ships and are used for telephony and data services.

In the recent past maritime VSAT systems have become more and more popular, providing mainly Internet access to the vessels.

All these systems provide transparent data links that might be used to relay ADS-B information from ship to the terrestrial users.

4.3 Vessels ADS-B via HF

This family of datapaths relies on ADS-B transfer over HF. Several configurations are envisioned as described below.

4.3.1 P3 - Vessels ADS-B via HF single relay

Maritime Radio navigation service or Global Maritime Distress and Safety System (GMDSS) is an internationally agreed-upon set of safety procedures, types of equipment, and communication protocols used to increase safety and make it easier to rescue distressed ships, boats and aircraft.

This data path is considered as providing a foundation to complement the routing of ADS-B messages.

The main systems used in GMDSS are:

- Emergency position-indicating radio beacon (EPIRB) in relation with international satellite-based search and rescue system
- NAVTEX an international, automated system for instantly distributing maritime safety information (MSI)
- Inmarsat, a set of satellite systems to provide ship/shore, ship/ship and shore/ship telephone, telex and high-speed data services, including a distress priority telephone and telex service to and from rescue coordination center
- high-frequency (HF), a radiotelephone and radiotelex (narrow-band direct printing) equipment, with calls initiated by digital selective calling (DSC). The IMO also introduced digital selective calling (DSC) on MF, HF and VHF maritime radios as part of the GMDSS system. DSC is primarily intended to initiate ship-to-ship, ship-to-shore and shore-to-ship radiotelephone and MF/HF radiotelex calls. DSC calls can also be made to individual stations, groups of stations, or "all stations" in one's radio range. Each DSC-equipped ship, shore station and group is assigned a unique 9-digit Maritime Mobile Service Identity.

High Frequency (HF) only would be considered for datapath P3, P4 and P5.

4.3.2 P4 – Vessels ADS-B via HF multiple relay

This data path makes every vessel as a “MAR HF” relay for messages towards neighbouring vessels, until it reaches destination.

4.3.3 P5 – Vessels ADS-B via HF relay and 3G

This data path is only valid when vessels are few miles away from coasts where a 3G communication network is deployed. Therefore this path is no longer a construction for Non Radar Airspace (NRA) and may prove to compete with existing means such as secondary radar.

4.3.4 P6 – Vessels ADS-B via HF and ADS-B SAT

This data path makes ADS-B messages out from an aircraft to be relayed by ADS-B equipped vessels, and ADS-B satellite. This data communication path consists in retransmitting ADS-B messages in the ADS-B system. Relaying received ADS-B messages may make them circling indefinitely through the system, unless additional features are provided to prevent this effect.

4.4 P7 – Airliner ADS-B out ADS-B in

This data path makes ADS-B messages out from an aircraft to be received by other aircrafts or vessels. The receiving aircraft needs to be either equipped with the ADS-B IN functionality or to have installed a separate ADS-B antenna and receiver. As already mentioned int the introduction to Chapter 4, the ADS-B standard does not allow the simple retransmission of the received ADS-B signal.

Rather, the message needs to be decoded, timestamped as well as reformatted and then transmitted to the Air Traffic Controller through the aircraft communication system – possibly via relay nodes.

Clearly, this data path requires significant adaptions on the receiving aircraft well beyond what is currently mandated (even ADS-B IN is not mandated). Therefore, its widespread implementation in the near future is highly questionable.

4.5 P8 - ADS-B SAT SATCOM

This variant of data path would be envisioned when Satellite ADS-B and Satellite Com have no common earth coverage.

As discussed in section 4.1.1 guaranteeing globally a low latency data transmission from the ADS-B satellites to the Air Traffic Controller on ground is challenging. Using geostationary satellites as a relay between the ADS-B satellites and the ground provides a further viable option. Utilizing just 3 – 4 GEO Satcom satellites could already provide nearly global coverage in near-realtime. Switching and signal transmission (either RF or optical) down to the Satcom would add just a few hundred milliseconds to the latency provided also that sufficiently high-speed data connections are used on-ground to the Air Traffic Controller. Suitable GEO satellites and services are already in operation, the ADS-B satellites need to be configured accordingly to be able to link into these services.

4.6 P9 ADS-B information to SatCom

The aircraft to SatCom path relies on sending the information that is contained in the ADS-B messages (but not the signal itself) through the aircraft-satcom channel. Of course, this implies that the aircraft is equipped accordingly, i.e. that this information is provided periodically by the Flight Management System or by the ADS-B transponder. Such a system is currently not mandated and therefore not the case for all aircraft. However, satellite communications service provider such as Iridium and Inmarsat offer connectivity services, that would allow appropriately equipped aircraft to send suitable flight information, but currently still at quite a high cost. In particular, ADS-C (Automatic dependent surveillance – contract – see also section 3.4 in [5]) has been established and certified for use in Air Traffic Control. The contract with the Air Traffic Services Unit (ATSU) specifies the type of reporting (periodic, demand or event based) and the information to be transmitted. ADS-C uses the same sources (typically the Flight Management System) on board as ADS-B to automatically collect similar information – like aircraft position, velocity etc – however, only the contracting ATSU will be able to receive the information via the specified data links – that typically include a satcom link when the aircraft is out of reach for terrestrial stations. In addition to the standard ADS-B contents, the ADS-C reports can obtain additional information on predicted route, projected intent (i.e. the following two waypoints) as well as meteorological data.

5 Systems taxonomy

This section provides description of the systems or solutions along with their key characterics.

Whenever possible, a clear link between the datapath described earlier in section 4 and the systems shown in this section is provided.

This section explores HAPS / Balloon constellations, Low Earth orbit Satellites, Geo Earth Orbit satellites and HF Maritime networks.

Some systems might appear in 2 categories e.g. Iridium can be seen at SATCOM and SAT ADS-B depending on the actual communication payload considered.

Following view is global System functionality description extracted from ADS-B architecture report [1]. It lists a number of functions/systems from which related datapaths can be extracted. Description of the functions are provided in [1]

However, as SALSA project progresses, this functional view may need consolidation. This study report has identified the following potential evolutions:

- The ADS-B standard does not allow the simple retransmission of the received ADS-B message. This may imply that an additional function “Process ADS-B Message”is considered for the ADS-B IN path or that it replaces “Relay ADS-B Message”. This may apply to other paths, e.g. Vessel relaying ADS-B messages.
- The link from “Geostationary data relay satellite”to "Post process ADS-B Surveillance Data" was questioned and was proposed to originate from “Geostationary data Ground Station”.

This initial thinking needs consolidation and shall be addressed in one of the future deliverable like for instance D 3.2 “Assessment of Separation Minima for different Space Segment configuration and Impact Analysis”.

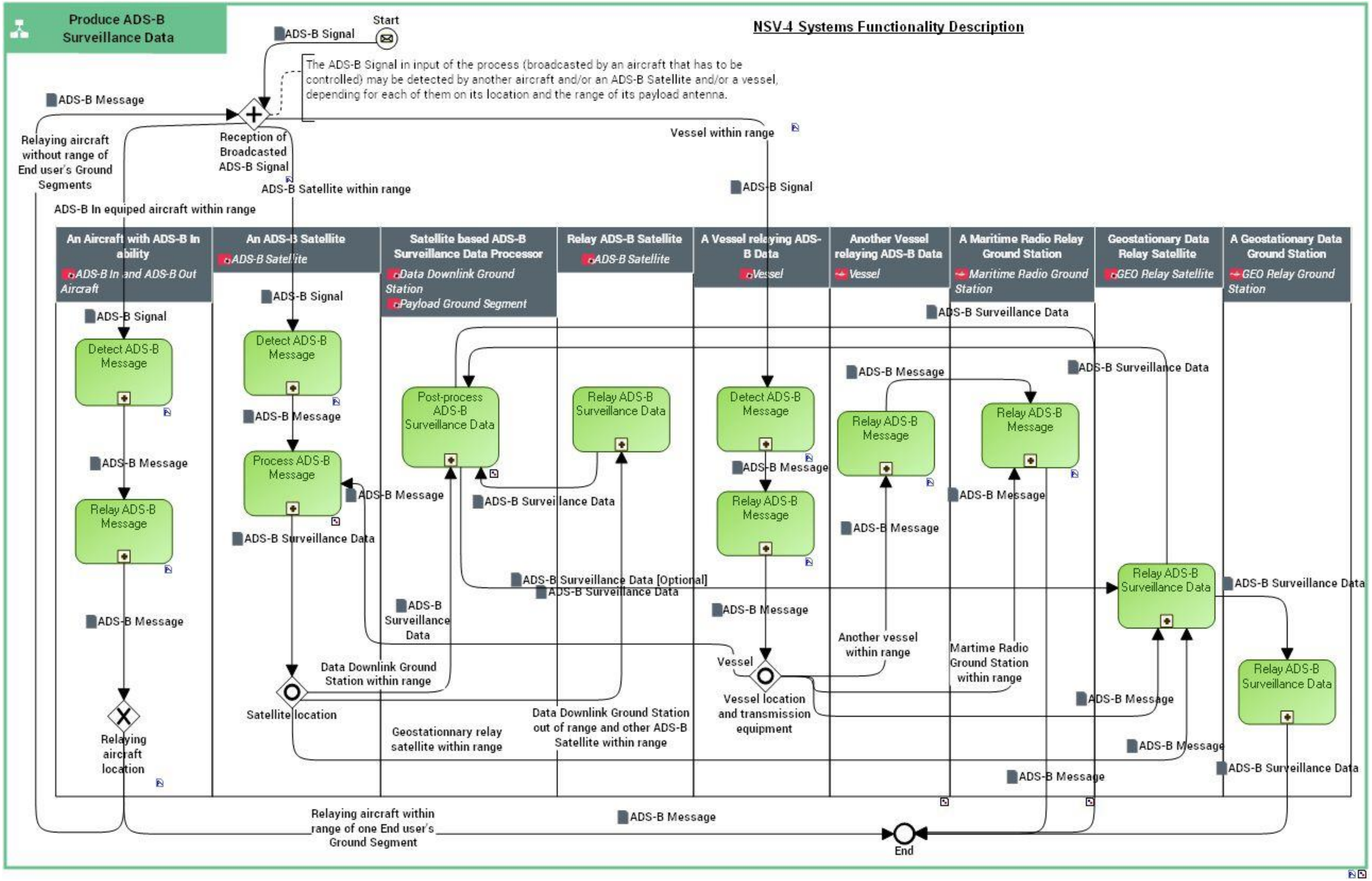


Figure 2 : Produce ADS-B Surveillance Data -System Functionality Description (NSV-4)

5.1 HAPS / Balloon constellations

Even though not explicitly mentioned in section 4, so-called High-Altitude Pseudo Satellites (HAPS) can take over the role of satellites in Figure [NOV-1]. Flying at significantly lower altitudes than satellites – typically at a range from 20 to 50 km – the link budget will be much better, but also the coverage area much smaller. Unlike satellites, they can hover – at least for a limited time – over a certain area to give a local coverage for an extended period of time.

They can serve either in the ADS-B SAT function, i.e. feature an ADS-B receiver, or in the SatCom function having communications means to relay messages from aircraft, vessels or other HAPS on towards their final destination. In principle, both functionalities could be embarked on the same platform, however, currently there are severe resource constraints (mass, power, etc) that may make that impossible.

5.1.1 Zephir

Zephir is a solar HAPS flying at 20km altitude at a fixed location. Zephyr can see over 400km to the horizon and provide persistent high resolution imagery and high bandwidth communications to areas in excess of 1,000km2.

Most regions of the World do not enjoy the communications provided by Fibre optic, wireless and 4G networks. The Geo-stationary Satellites that provide communications to these regions fly at 36,000km above the Earth and as such are limited by their capacity and latency – increasingly important with the continuing demand for greater bandwidth and speed.

HAPS operating at 20km altitude can provide fast, high bandwidth communications to these regions, which can then be linked together by radio or laser links – where the thin air and lack of clouds makes optical links much simpler.

Zephyr has already demonstrated communications relay over a 400km range and Airbus are now using their proven satellite communications expertise to develop broadband systems suitable for HAPS operation.

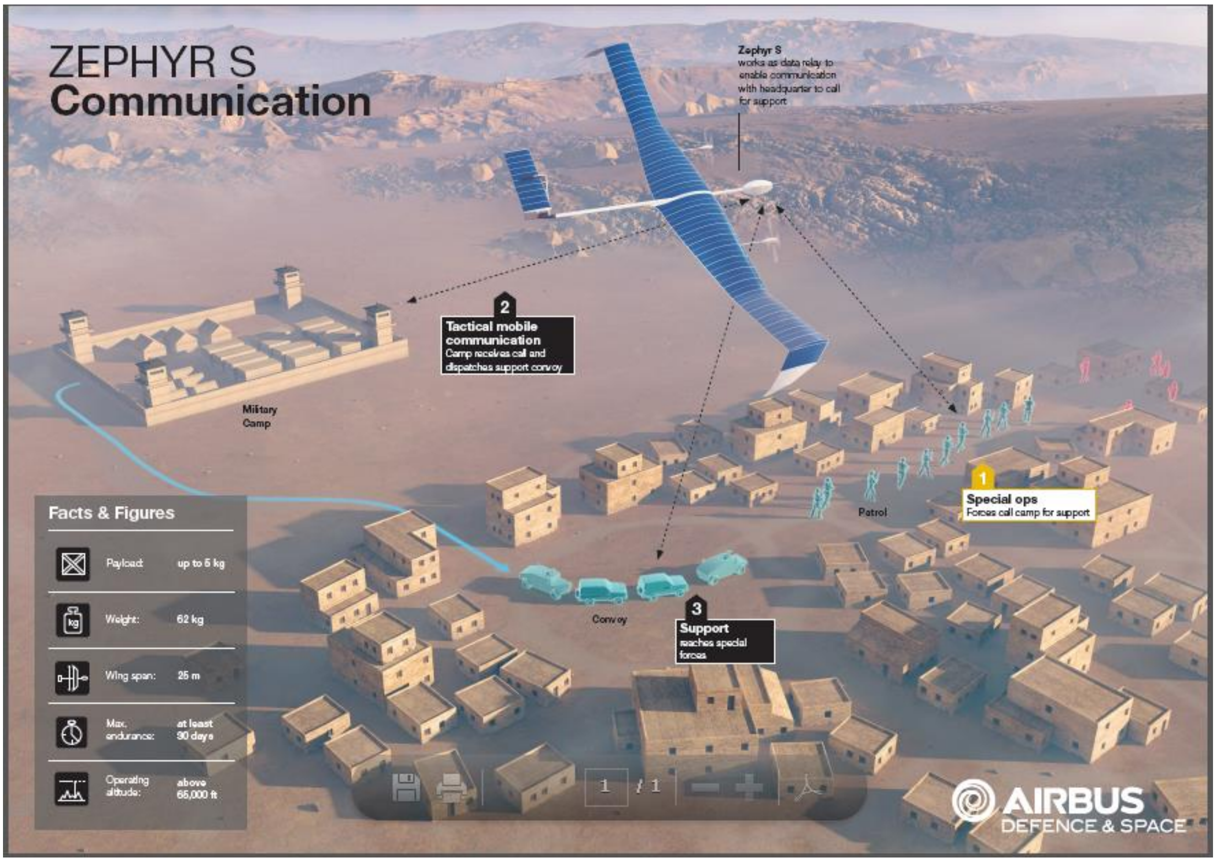


Figure 3 : ZEPHIR S Communication

Airbus has developed and proven its high resolution imaging and high bandwidth communication services[3]:

- HD Optical / IR Video
- NIIRS 6 imagery
- AIS
- Narrowband mobile comms (e.g. Tetra)
- 100 Mbps broadcast

Zephir has significant endurance longer than any other UAV, but need be landed for maintenance or payload improvement. It is operable globally as a “Constellation”.

There is no plan yet for an ADS-B surveillance payload, but as technology advances, Zephyr can be landed (unlike satellites), re-equipped to take full advantage of the next generation of payloads and re-deployed in short timescales.

5.1.2 Google project loon

Project Loon is a global network of high altitude balloons. The balloons ascend like weather balloons until they reach the stratosphere, where they sail at an altitude of roughly 20 km (65,000 ft), safely above the altitudes used for aviation. While weather balloons burst after only a few hours in the air, Loon balloons are superpressured, allowing them to last much longer. Loon balloons are also unique in that they can sail the wind to travel where they need to go, they can coordinate with other balloons as a flock, and their electronics are entirely solar powered.

Project Loon is a research and development project being developed by X (formerly Google X) with the mission of providing Internet access to rural and remote areas. The project uses high-altitude balloons placed in the stratosphere at an altitude of about 18 km or above (11 mi) to create an aerial wireless network with up to 4G-LTE speeds. It was named Project Loon, since even Google itself found the idea of providing Internet access to the remaining 5 billion population unprecedented and "crazy."

The balloons are maneuvered by adjusting their altitude in the stratosphere to float to a wind layer after identifying the wind layer with the desired speed and direction using wind data from the National Oceanic and Atmospheric Administration (NOAA). Users of the service connect to the balloon network using a special Internet antenna attached to their building. The signal travels through the balloon network from balloon to balloon, then to a ground-based station connected to an Internet service provider (ISP), then onto the global Internet. The system aims to bring Internet access to remote and rural areas poorly served by existing provisions, and to improve communication during natural disasters to affected regions.

The balloons use patch antennas - which are directional antennas - to transmit signals to ground stations or LTE users. Some smartphones with Google SIM cards can use Google Internet services. The whole infrastructure is based on LTE; the eNodeB component (the equivalent of the "base station" that talks directly to handsets) is carried in the balloon.

5.2 Low Earth orbit Satellites

In-orbit experiments [9] have shown that ADS-B signals emitted by aircraft can very well be received by satellites in Low Earth orbit. Encouraged by these successful demonstrations the concept of an ADS-B Sat constellation for the worldwide reception of 1090 MHz Extended Squitter ADS-B messages has been suggested with suitable ADS-B Receivers embarked on a fleet of LEO satellites. The typical system architecture is shown in Figure 3.

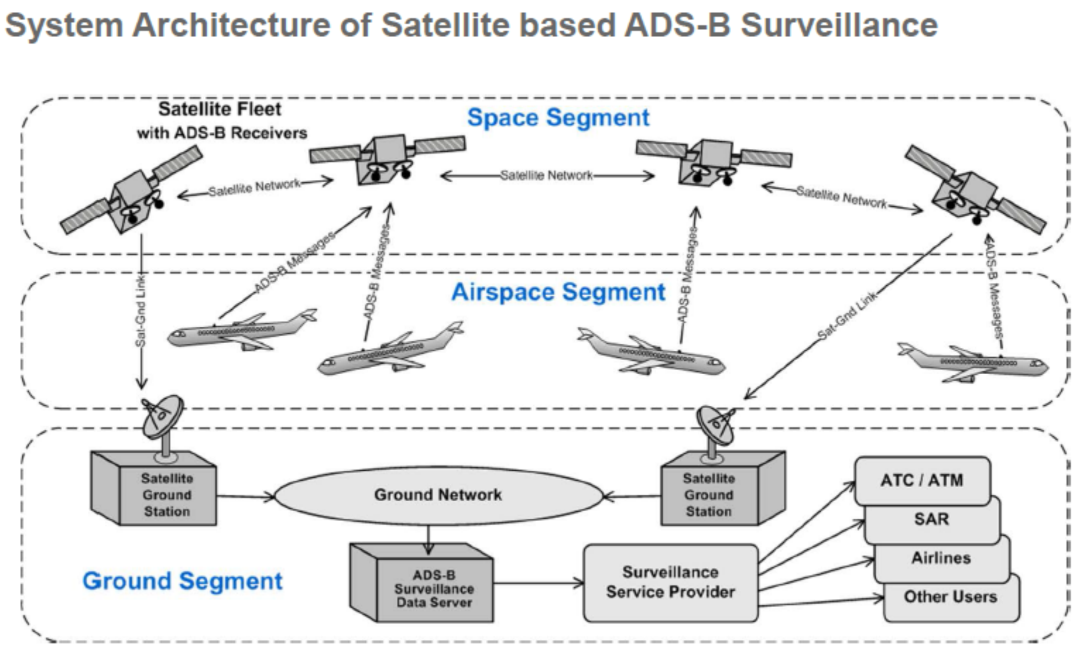


Figure 4: Schematic architecture for Space-based ADS-B[10]

Recently also an increasing number of concepts have been suggested for SatCom in LEO. In order to achieve coverage comparable to geostationary SatCom systems a larger number of satellites – i.e. a constellation of satellites – needs to be deployed. It is expected that at least a few will be in service in the near future.

The following sections describes LEO satellite constellations that are in planning or deployment stage and identifies their use with respect to the overall concept description in Figure (NOV-1)

5.2.1 Iridium

Iridium Communications Inc. owns the only mobile voice and data satellite communications network that spans the entire globe. A technology innovator and market leader, Iridium enables connections between people, organizations and assets to and from anywhere, in real time. Iridium's 66 low earth orbiting (LEO) cross-linked satellites – the world's largest commercial constellation – operate as a fully meshed network.

Reaching over oceans, through airways and across the polar regions, Iridium® solutions are ideally suited for industries such as maritime, aviation, emergency services, mining, forestry, oil and gas, heavy equipment, transportation and utilities. Iridium also provides service to subscribers from the U.S. Department of Defense, as well as other civil and government agencies around the world. Together with its ecosystem of partner companies, Iridium delivers an innovative and rich portfolio of reliable solutions for markets that require truly global communications. As such already with its current constellation can act as a provider of SatCom services for vessels and aircraft.

Iridium commercial aviation solutions help keep crew, aircraft and passengers secure with global flight safety services such as:

- Air Traffic Service (ATS) Safety Voice
- Future Air Navigation System (FANS) over Aircraft Communications Addressing and Reporting System (ACARS)
- Aeronautical Operational Control/Airline Administrative Control (AOC/AAC) communications
- Flight Following/tracking
- Electronic Flight Bag (EFB) data streaming

In 2010 the Performance based Operations Aviation Rulemaking Committee has found that Iridium is viable for CPDLC/RCP 240 and ADS-C/type 180 (RSP) operations. Consequently, the U.S. Federal Aviation Administration (FAA) has authorized aircraft operating in oceanic airspace to use Iridium's satellite data service for critical air traffic control communications effectively certifying ADS-C and CPDLC services for ATM usage.

With these services Iridium can provide the SATCOM component for data paths P2, P8 and P9.

The company has a major development program underway for its next-generation network – Iridium NEXT. This new generation of satellites will replace its ageing fleet, thereby preserving the continuity of its SatCom services. In addition, Iridium has offered to host payloads in these Iridium NEXT platforms for additional services. A founding member of the Hosted Payload Alliance, Iridium is a leader and visionary in making space more accessible. Iridium PRIMESM is the world's first turnkey payloads solutions on standalone satellites, designed to reduce the complexity and costs of access to space-based services.

Iridium also secured one of the industry's largest deals to date for the primary hosted payload space on Iridium NEXT with AireonSM The partnership with leading ANSPs and investors from around the world, including NAV CANADA, ENAV, Irish Aviation Authority and Navair, will revolutionize global air traffic surveillance by providing global visibility of all equipped aircraft [8]. As a results the Iridium NEXT constellation can act as both the SatCom and the ADS-B Sat component in the High-Level Operational Concept Description in Figure 1. The Aireon architecture concept for space-based ADS-B is shown in figure 4, with the ADS-B Sat functionality using the communications backbone of the Iridium NEXT infrastructure.

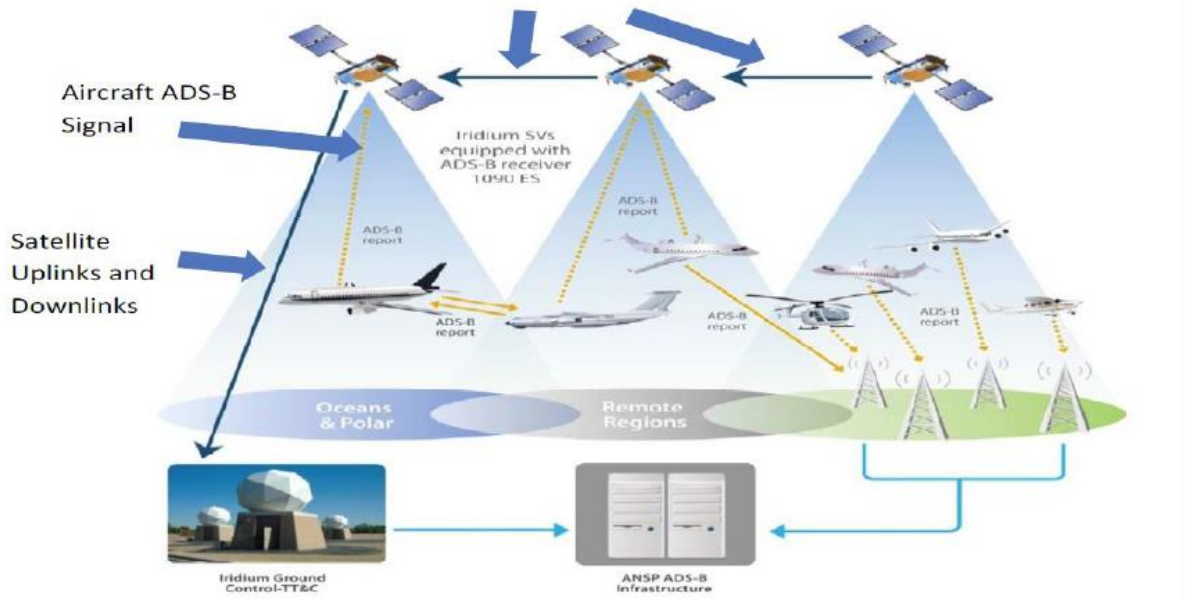


Figure 5 Satellite ADS-B

A significant step forward for ADS-B is the reception by space based satellites of the ADS-B signal. This is being deployed by [Aireon]() on the [Iridium]() satellite network, a LEO (Low Earth Orbit) satellite network that was originally created to deliver phone and data service anywhere on the planet. By capturing ADS-B position data from aircraft flying below the satellite, the network will give the following capabilities:

- Full air traffic control will be possible over water, in areas that radar does not currently cover.
- As is currently possible in radar covered areas, a position history will be available for lost aircraft, a la Malaysia airlines flight 370.

The system only receives ADS-B on aircraft broadcasting on the 1090 MHz frequency. This limits the system generally to airliners and business aircraft, despite the fact that small aircraft are frequently off radar due to mountains blocking the signal at low altitudes. The system would may be compromised by smaller, private aircraft with exclusively belly mounted ADS-B antennas, due to the aircraft itself blocking the signal.

The rationale for using the Iridium satellite network for this new capability was due to:

- The Iridium satellites fly very low, and thus can receive the ADS-B out signals more reliably (transponders and ADS-B were designed for ground reception).
- Iridium satellites are replaced relatively frequently due to the increased air friction at their lower altitude, and thus lower lifespan. Thus the system would be deployed on iridium faster.
- Iridium provides worldwide coverage, including the poles.

In September 2016, Aireon and FlightAware announced a partnership to provide this global space-based ADS-B data to airlines for flight tracking of their fleets and, in response to Malaysia Airlines Flight 370, for compliance with the ICAO Global Aeronautical Distress and Safety System (GADSS) requirement for airlines to track their fleets.

Thus Iridium NEXT with the Aireon service can also offer data path P1.

5.2.2 Globalstar

Globalstar is a low Earth orbit (LEO) satellite constellation for satellite phone and low-speed data communications, providing mobile satellite voice and data services somewhat similar to the Iridium satellite constellation. The Company's products include mobile and fixed satellite telephones, simplex and duplex satellite data modems and satellite airtime packages. Globalstar satellites are simple "bent pipe" analog repeaters. A network of ground gateway stations provides connectivity from the 40 satellites to the public switched telephone network and Internet. A satellite must have a Gateway station in view to provide service to any users it may see.

The second generation Globalstar constellation consists of 8 orbital planes with a 3 satellites each for a total of 24 satellites. Globalstar orbits have an inclination of 52 degrees allowing a coverage from 70° S to 70° N latitude but with no coverage in polar areas. At an orbital height of approximately 1400 km, the orbiting period is 114 minutes and the latency is still relatively low (approximately 60ms).

Globalstar is also offering aviation services, most notably its Pilotphone™, but here the primary focus is on General Aviation. However, in cooperation with Alaska-based company “ADS-B Technologies” promotes satellite augmented ADS-B through its constellation of LEO satellites. It requires the installation of ALAS – the ADS-B Link Augmentation System – on the aircraft, that feeds the output of the standard ADS-B transceiver to the Globalstar transceiver for transmission via the satellites and the Globalstar gateway to the ATC network where a similar ALAS system feeds the signals to the ground-based transceiver. When an ADS-B equipped aircraft is not visible from the ADS-B ground stations the Globalstar Constellation merely provides an alternative delivery path for the ADS-B signal using the so-called “bent-pipe” concept.

ALAS is a simple, low cost peripheral that is designed to be compatible with virtually any ADS-B avionics installation. It also does not interfere with the aircraft's normal ADS-B transmissions. ALAS prototypes have been flying successfully since 2010 and a successful full-scale flight demonstration was conducted by ADS-B Technologies in cooperation with Globalstar in August 2014 covering more than 7000 nautical miles from Alaska to the Gulf of Mexico and back. While this technology can in principle be used for data path P9 – of course depending on the installation of the ALAS system in the aircraft – the service offering of Globalstar is more tailored to small general aviation aircraft rather than to commercial airliners.

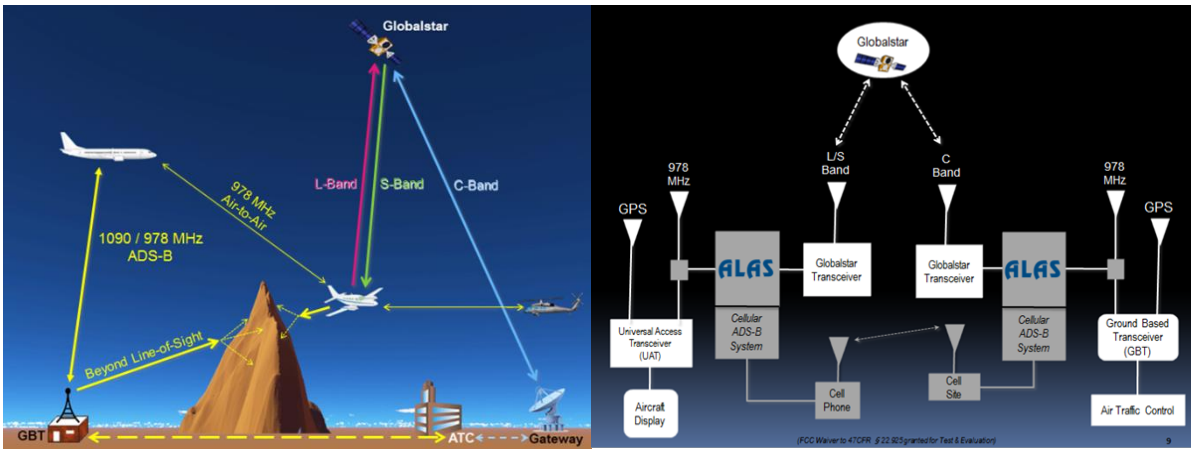


Figure 6 Globalstar Satellite ADS-B concept

5.2.3 OneWeb

OneWeb LLC, formerly known as WorldVu, is a Channel Islands-based global communications companyfounded by Greg Wyler. The company plans to launch the OneWeb satellite constellation, a network of 648[2] Low Earth orbit microsatellites, starting in late 2018. Its intended goal is to "reach hundreds of millions of potential users residing in places without [existing] broadband access". It has secured $500 million in funding including launch deals with Virgin Galactic and Arianespace. In June 2015, OneWeb entered a deal with Airbus Defence and Space for the construction of its broadband Internet satellites after a competition among U.S. and European manufacturers.

The initial constellation of LEO microsatellites will see 36 satellites in 18 orbital planes at an inclination of 87.9° and an orbit height of 1200 km. Additional in-orbit spares will be placed in the orbital planes to assure un-interrupted service at constant performance levels. First launches are planned for 2018 with deployment of the constellation beginning in earnest shortly thereafter. The satellites will be launched in batches with launch provider Arianespace and operational service is scheduled to start in the 2019/2020 timeframe.

OneWeb – with its user links in Ku-band and gateway links in Ka-band – aims at providing a global affordable internet broadband service for its subscribers. In addition it plans to expand in-flight connectivity by providing low latency broadband at 30000 Ft.

The system will provide business jet, commercial airline and military aviation customers with airtime services that will include weather, navigation and health monitoring of the aircraft. Together we can bring the benefits of affordable, low‑latency Internet to 30,000 ft. In this way OneWeb can fully act as the SatCom component both towards vessels and aircraft and perhaps even towards the ADS-B Sat (this has to be investigated with respect to the achievable performance). Generation 1 of the OneWeb constellation has already passed major design gates – an ADS-B payload is not included in this setup due to resource constraints. Therefore OneWeb will be able to offer SATCOM services for data paths P2 and P9 – while connection to the ADS-B Sat assets is in principle also possible (path P8), the vicinity of the orbits will not allow for a continuous SATCOM connection leading to significant gaps in the data transmission.

As an interesting side product of the OneWeb program, additional recurring OneWeb Platforms, i.e. excluding the OneWeb mission specific Payload, will be produced and commercially sold to external customers for the so called “3rd party” missions. Based on the design experience and the capabilities of the high throughput production line, this offers a uniquely affordable and powerful solution to the 150 kg class of satellites. It could be envisioned that a constellation of OneWeb Platforms with dedicated ADS-B payloads will be designed, built and deployed in orbit within a timeframe of 3 – 5 years.

5.2.4 SpaceX mega constellation for internet provision (announced)

SpaceX intends to deploy a mega constellation of about 4000 satellite flying at an altitude of 1200 km. This constellation is supposed to deliver the internet access to the world

those communication satellites will be targeted at the smallsat-class of 100-to-500 kg (220-to-1,100 lb)-mass, and are intended to be orbiting at an altitude of approximately 1,100 kilometers (680 mi). Initial plans as of January 2015 are for the constellation to be made up of approximately 4000 cross-linked satellites.

It is however unclear what will be the payload capability and whether the bus will be designed to accommodate with an ADSB transponder capable to relay the messages from the aircraft to the ground.

“In July 2015, Musk (SPACEX CEO) said that the constellation is still in the early planning stages and that SpaceX is being careful not to overextend the company with the project. SpaceX hopes to launch a test satellite in 2016.”

The test satelltes (or demo) MicroSat 1a, 1b were announced for launch in 2016, but apparently the flight was cancelled. (the demo was supposed to fly at an altitude of 625 km)

Following a battle between Intelsat / FCC and SpaceX, the situation is unclear, no further information is currently available on that topic. Intelsat was claiming more information from SpaceX project, in order to evaluate correctly the risk of interference with GEO satellites and collision probability with other LEO satellites (onsidering the full mega constellation to would be deployed later, following the demo)

Currently not many details are known about this constellation. Therefore it cannot yet be determined whether it will solely be able to act as the SatCom component or also include a ADS-B Sat functionality.

5.3 Geo Earth Orbit satellites

Typically GEO satellites will only be employed in the SatCom function for the Multi-source ADS-B system. Studies have shown that to receive ADS-B signals at an altitude of about 35786 km, large receiving antennas with a size of 10 m or more are necessary to close the link budget. In addition, the possible field of view for GEO orbit to Earth limb (i.e. the horizon) is so large that it will contain thousands of aircraft with a high probability of signal collisions and interferences – degrading the surveillance performance significantly. This can only be remedied by dividing the field of view into serveral subbeams, thereby increasing complexity and cost of the antenna further.

Therefore only GEO SatCom satellites will be described in the following sections.

5.3.1 Inmarsat

Satellite provide stable and performant links. Inmarsat satellites footprint is all oceanic zones with the exception to polar zones. Inmarsat provides a variety of channels with multiple bitrates that are operated by private opérators. Several terminal types are available ranging from security beacon up to full internet access.

Classic Aero services and SwiftBroadband

With the introduction of SwiftBroadband and to reinforce the long-term commitment to aviation safety services, Inmarsat now offers Classic Aero services over the Inmarsat-4 (I-4) satellites – enabling the simultaneous operation of both through a single installation. More than 95% of the world’s transoceanic aircraft use Inmarsat’s safety and operational services for communication and surveillance today – around 11,500 aircraft in total.

Classic Aero delivers established operational and safety-critical services such as ADS-C (see section 4.3.4) and Controller-Pilot Data Link Communications (CPDLC) communications between the cockpit and air traffic control. SwiftBroadband–Safety is Inmarsat’s next generation flight deck communications platform offering global, high-speed, secure, IP connectivity for the cockpit – offering three types of connections:

With Aircraft Communications Addressing and Reporting System (ACARS) over IP, the powerful Air Traffic Services applications that have enabled the expansion of oceanic airspace by over 300% will be faster, stronger, and more reliable. An IP channel allows Airline Administrative Control (AAC) and Aeronautical Operational Control (AOC) applications to provide passenger information to the destination. And the prioritised IP connection will bring real-time data streaming, position reporting, and power the Electronic Flight Bag. Inmarsat is able to offer SATCOM services for data paths P2, P8 and P9.

5.3.2 Iris Precursor

Figure 7: Iris Precursor - Credits ESA

In Europe, satellite communications are considered as a complement to terrestrial systems in order to meet in the long term the future service provision performance requirements as well as in the short term to complement the VDL2. Furthermore, the availability of a single global aviation standard for future aeronautical communications would facilitate the adoption and implementation of such a standard and discourage technology proliferation in general. In particular for the satellite communications, it is expected that the availability of such an open and global standard and its implementation in the future by different satellite service providers will facilitate interoperability and help boost avionics equipage (single SATCOM avionics equipment) and at the same time allow for multiple (regional and global) satellite communications service providers.

Iris Precursor focuses on the development and deployment of secure satellite-based data link communications to significantly optimise European airspace capacity, leading to overall reductions in flight times, fuel burn and CO2 emissions.

Iris Precursor aims to complement existing terrestrial data link communications (VDL2), which are expected to reach capacity in the near future.

5.3.2.1 Leading companies

Inmarsat is conducting the Iris Precursor programme with a consortium of leading companies from across the air traffic management, air transport, aeronautics and satcom industries, under the European Space Agency (ESA) umbrella.

The programme, which is supported by ESA's programme of Advanced Research in Telecommunications Systems (ARTES), will deliver services via Inmarsat's secure next-generation SwiftBroadband-Safety platform.

Four test flights were conducted from Amsterdam under an initial phase to validate the use of satellite-based data link for secure communications and surveillance applications, and compare the capabilities to existing terrestrial data link communications.

5.3.2.2 Tested extensively

Inmarsat has successfully completed the first flight trials for Iris Precursor, a ground-breaking project to enhance and modernise air traffic management over European airspace.

They were operated on aircraft from the Netherlands Aerospace Centre (NLR) using a prototype of the Iris terminal developed by Honeywell and connected to Inmarsat's next-generation SwiftBroadband-Safety service through Inmarsat's aviation partner, SITA, the world's leading air transport IT and communications specialist.

Each of the flights travelled in different routes, covering all directions to ensure connectivity was maintained as the aircraft crossed satellite beams. The end-to-end connection between the aircraft and SITA's Controller Pilot Data Link Communication (CPDLC) test ground system was tested extensively and allowed air traffic control messages to be exchanged using Aeronautical Telecommunications Network and Security gateways.

While the Iris Precursor programme will initially focus on continental Europe, it will also benefit air traffic management in other regions around the world in the longer term.

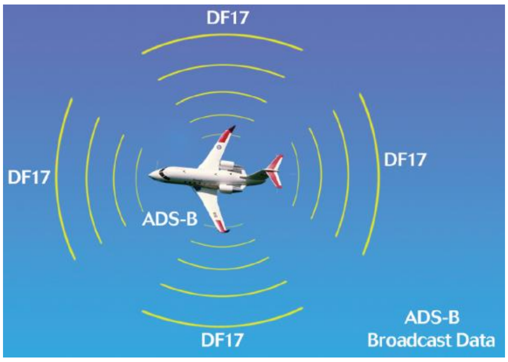
5.3.2.3 Results

The flight trials complement a separate test flight that Airbus conducted with Inmarsat and other partners in March last year, as part of the Single European Sky ATM Research (SESAR) programme, which successfully performed initial 4-dimensional/4D flight path control and CPDLC exchanges between aircraft and air traffic control.

Inmarsat is now working toward a second phase of flight trials for Iris at the end of next year. At this point, Iris technology will be considered fully validated. The next phases of the programme include pre-operational validation by flying Iris technology on commercial flights in a real air traffic management environment. The Iris Initial Operational Capability will go live as early as 2019, complementing terrestrial systems and bringing enhanced security, safety and efficiency.

Though the IRIS precursor presented above and its subsequent deployment phases are aimed at using ADS-C technology, the content of the messages transmitted from the aircraft to the ground controllers are similar, the ADS-B messages being in reality a sub-set of the ADS-C "messages library". The ADS-B standard defines the following messages types (Downlink Format 17) that are regularly transmitted from the aircraft :

- Aircraft identification
- Surface position
- Airborne position (w/ Baro Altitude)
- Airborne velocities
- Airborne position (w/ GNSS Height)
- Other messages types reserved for future uses



There are actually more messages that could be transmitted in the ADS-B communication link, in the so called Mode-S Extended Squitter (1090ES). Those mode-S messages provide air traffic controller with more information that what is included in the ADS-B (a.k.a Mode-S Short Squitter). It responds to ATC Secondary Surveillance Radar, and broadcast specific parameters non-independently. Hence it is only available in the area where ATC is present. This particular case will not be included in our study since we are mostly focusing in the oceanic and polar region where the terrestrial Primary Surveillance Radar and Secondary Surveillance Radar network cannot operate and thus cannot provide the required follow-up of the air traffic.

It is important to mention that all the basic messages given above can also be transmitted in the ADS-C communication link and can then be also processed at ATC. The controller has then the ability to use these information for separation minima management (or even self separation since the aircraft crew can also manage the separation minima on his own through the ADS-C channel).

Also, at the end of the demonstration made in by the IRIS precursor, some recommendations were addressed to SESAR in the close-out report and can be summarized as follows:

1. Since the demo was performed using only the SATCOM link as the sole means of ATN communication (VHF was disabled onboard), and given it is currently not allowed for an aircraft to fly without VDL2M at the minimum means of communication. Combining both SATCOM and VDL2M may cause multi link issues. This topic shall be verified.

2. During the demo, only 1 airframe was considered, hence the network capacity and load could not be realistically tested, so multi-airframe shall be extensively simulated, tested or demoed at a very large scale.

Those observations are pretty much in line with our study and are fitting perfectly with our goals. They will, of course, be considered carefully in the simulations runs planned along the SALSA project.

IRIS precursor is clearly an important player in the exploratory research activity our consortium is currently undertaking.

5.4 HF Maritime

HF maritime provides messages for direct communication between ships.

5.4.1 AIS

The Automatic Identificiation System (AIS) is a system which is mainly used for collision avoidance between ships. It is mandatory aboard ships with gross tonnage above 300 GT and all passanger ships. The ships use an VHF link to exchange information like position, course, identification (MMSI) and other relevant information.

The AIS system also supports adressed binary messages directly between ships, which was investigated as possible relay system for ADS-B data.

Several limitations have been identified:

- As a result of the Self Organizing TDMA (SOTDMA), the ships organize themselves into small cells in which communication between the ships is possible. As a ship is connected to one cell at a time, there is no easy way to relay the data over long distances.
- AIS has very limited capacity. The data rate that is shared between all ships within a cell is 9600 bits/s per AIS channel. The achievable net rate will be much lower due to the required overhead. As a result ADS-B relaying might easily flood the AIS cells.
- It is unlikely that regulatory entities will allow to use AIS for other than maritime purposes

Additional VHF channels are available for SAT-AIS only which allows ship to transmit their position to specialized S-AIS satellites. Also here several limitations have been identified.

- The capacity of the VHF link is even more precious, as the field of view of a satellite is much larger than an AIS cell. The ships only transmit once every 3 minutes to avoid collisions (as it happens in high densitiy regions like German Bight or South East Asia)
- As for normal AIS, it is unlikely that regulatory entities will allow use for S-AIS for other than maritime purpose
- Performance paramters for ADS-B are much more demanding then for AIS. While for ships timeliness of a message in the range of several tenths of minutes might be acceptable, for ADS-B more then few seconds would not be acceptable. This implies a continuous link to ground station or a ISL, which might no necessary be in place for all S-AIS satellites

It was concluded that neither normal AIS nor satellite AIS might be used in large scale for ADS-B data relay, as required for the purpose of the study.

5.4.2 Cognitive Network HF

Cognitive Networked HF (CNHF) radio system enables long distance communication and global coverage [4]. This CNHF respond as an alternative to a satellite in long distance communication: if Satcom goes down, there is no longer communication. HF radio is able to transmit data up to 10000 km and can provide IP connectivity on a large scale.

The CNHF radio shall be seen as communication node with unique opportunity to utilize the HF spectrum as one of the gateways to the IP-network. Radio has also build in cellular, WiFi and LAN-connections for providing IP-connectivity to base station or another CNHF terminal in ship having internet connection.

In the 1st phase, email, IP/file transfer, chat messages and built-in location tracking are offered. Expanding the capacity with larger number of users enables new applications like VoIP and Internet browsing in the 2nd phase. ADS-B transfer is not planned yet.

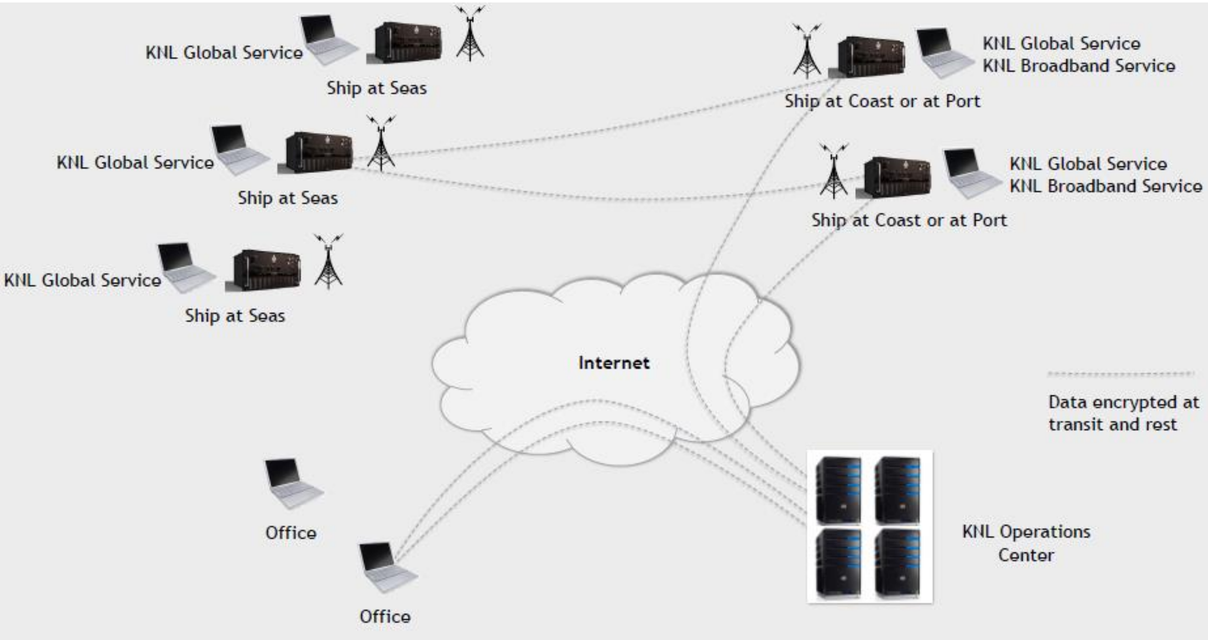


Figure 8 Cognitive Network High Frequency

This innovative solution is not mandated yet for vessels wich makes its deployment restricted today. Therefore, its widespread implementation in the near future is highly questionable.

6 Conclusion

This study report allowed to describe a multi-source ADS-B system which combines different possible types of relays of ADS-B messages to provide a surveillance system especially in Non-Radar Airspace (NRA). The operational activities concerned with the multi-source ADS-B system are defined to set the operational context, and also the functions of the systems.

This report identifies which physical systems could be used and the associated possible paths of data to have an aircraft ADS-B signal available to the end user. It is concluded that a re-broadcasting of the original ADS-B signal – either by other aircraft, ships or even satellites – for the purpose of relaying towards the Air Traffic Controller is not compliant with current regulations. As messages could be multiplied and circle indefinitively in the ATM system, it cannot be envisioned that the regulations can be adapted to allow such re-broadcasting. Rather, the individual receivers have to first decode the 1090ES signal to extract the ADS-B message and then format the message for further transmission along the possible data paths onward to the end user. As it is conceivable that the same message is received by different assets simultaneously and forwarded to the end user via different data paths, it is necessary to timestamp the message upon reception and decoding to facilitate identifying duplicated messages.

While some means exist for communication from ship to ship or aircraft to aircraft no universal standard way was identified that could be efficiently employed for relaying ADS-B messages to the end user. In addition, the movement of these assets make continuous establishement of relay routes extremely challenging in particular if global coverage is targeted. Every node will increase latency and every interruption of the relay chain, will reduce system availability and continuity. At the very least standards that have to be established for multi-source ADS-B would need to take account of that.

Since in oceanic and remote areas there is typically not just a surveillance gap, but usually also a communications deficit, only a very few data paths remain – all typically involving satellite assets. The data paths identified as most promising are:

- P1 – Aircraft to ADS-B SAT and from there either
  - Directly to a local ground station
  - Via intersatellite links (ISLs) to the Sat ADS-B in view of a local ground station
- P2 – Aircraft to Vessel and then via SATCom to the user
- P8 – Aircraft to ADS-B SAT and then via SATCom to the user
- P9 – Aircraft (eitherdirect or after reception through ADS-B IN to SATCom via Aircraft Coms (not ADS-B Out) and from there to user

Even for these, coming close to ground-based systems with respect to latency will turn out to be challenging and may need to be reflected in future regulations and standards accordingly.

The study describes in detail current and planned satellite assets that can represent the SATCom and ADS-B Sat component. In particular, established SATCom providers like Inmarsat (geostationary) and Iridium (Low Earth Orbit) offer global or near-global data relay services for aviation, but also for vessels and ground assets. Of course, the aircraft (or vessel or ground station) needs to have suitable equipment proprietory for the respective provider. Iridium and Inmarsat have been certified for ATC applications, however, this equipment is not mandated and therefore only a fraction of all aircraft have it installed. New players like Globalstar or OneWeb are striving to enter the market in the near future each with their respective proprietary solution. High altitude Pseudo-Satellites that are also quickly gaining acceptance, will be able to take over typical satellite functions, but with their specific characteristics: They can basically hover over an area for an extended period of time thereby offering continuity, but at the price of a very limited field of view. They can therefore provide very locally ADS-B Sat as well as SATCom services, but they will not be able to guarantee global coverage.The proliferation of SATCOM services will bring the added benefit of improving connectivity between air traffic controller and pilot. The communication performance needs to be enhanced to reduce the controller intervention time commensurate with the advances in surveillance performance due to multi-source (and primarily space-based) ADS-B. Only then can the full potential for the reduction of separation minima. The IRIS initiative that is currently pursued by an Inmarsat-led consortium and supported by ESA, promises to significantly improve secure satellite-based data-link communications. While first flight trials are currently being prepared and conducted, full implementation of this system with all the required qualifications and certifications will most likely not be possible before the middle of the coming decade.

In summary, this study report clearly identifies the relevant data paths for the realization of a future end-to-end multi-soucre ADS-B system as well as concrete assets that are or will be in place to offer appropriate services. Such a system will then be able to provide significant improvements in the global air traffic surveillance performance.