The Satellite Communications System for Safe and Secure Air Traffic Management Data Links and Voice

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1. Executive Summary

The satellite-based Iris system is ready to be a key element in a successful European implementation of Data Link Services for Air Traffic Management and could underpin a global solution.

Iris is a Data Link Service (DLS) satellite system funded and promoted by the European Space Agency (ESA). It is based on Inmarsat SwiftBroadband-Safety technology that is already approved for Air Traffic Service (ATS) oceanic use, which is soon to be extended for use in continental airspace for the provision of Data Link ATS services (referred to as ATN B1 and ATS B2) and of Airline Operational Communications (AOC).

Developed for ESA by a world-class industrial consortium led by Inmarsat, Iris is already contributing to the European Commission's (EC) Aviation Strategy and worldwide aviation community; nonetheless additional institutional and programmatic steps from the Air Traffic Management (ATM) community are needed for the integration of Iris into the ATM communication network and for its use by the airlines and Air Navigation Service Providers.

The deployment of the terrestrial technology system known as VDL2 (which was mandated by the European Commission (EC) regulation 29/2009) is clearly showing difficulties in reaching the due DLS performances, thus affecting the effective operational use of the ATM network. The Report on DLS Architecture and Deployment Strategy drafted by SDM and submitted to the EC calls for "the need to support the implementation of the complementary communication technologies as soon as possible, offloading the VDL M2 channels".

Europe already has one of the world's most congested airspaces and air traffic is expected to double by 2035. The DLS capability uncertainty may jeopardize the ambitious goals set by the EC through the European Aviation Strategy published in December 2005.

Even in a time when COVID-19 is strongly affecting the world economy, including the aviation sector with a severe passenger traffic collapse, the integration without hesitation of all suitable and available technologies into a DLS architecture is the right opportunity for Europe to achieve the digital transformation and green deal so much pursued by the EC. This crisis might spark a digital transformation for industry to immediately raise efficiency and cut costs, while at the same time prepare for the future when performance, safety and capacity requirements will become more stringent[1].

[1] "This crisis provides nothing more than some "breathing space" for an ATM infrastructure that had already reached its structural capacity limits. The pressure on the ATM infrastructure to embrace a more digital future to become more cost efficient, resilient, and scalable to fluctuations (up or down)

Iris is a ready-technology that can timely deliver the required ATS performances, in a complementary fashion to terrestrial VDL Mode 2; it requires that a critical mass of users are equipped with Iris when needed as well as an appropriate number of ANSPs to provide the service. This calls for a suitable deployment plan and a regulation package including a funding scheme and incentives for airlines and ANSPs to be immediately implemented, to have a ready service timely with the passenger traffic re-growing expectations.

In agreement with SESAR Joint Undertaking (SJU), Iris was designed to comply not only with standards, technical performance, and requirements, but also to support air-ground services for both ATS and data-hungry AOC services, providing enough capacity in the near-term with an easy scalability potential for future needs. A recent capacity study, performed by the Iris consortium in line with SESAR Deployment Manager assumptions, has indeed confirmed that Iris has the needed capacity, with large margins, to support both the volume of data expected to be offloaded from VDL2 and the traffic increase in the coming years.

Furthermore, Iris supports ADS-C applications (EPP) which are key enablers for i4D which can deliver route optimizations, reduced fuel consumption due to fewer holding patterns and related reductions in CO2 emissions per flight, overall much better aviation efficiency. The use of ADS-C applications can have a significant impact on major airports hubs both for national, continental, and intercontinental flight arrivals, by reducing delays and traffic congestion and so improving traffic flow.

In summary: Iris is a readily available solution enabling EC's Aviation strategy. It is based on the following main pillars:

- Compliance with ATS safety and performance requirements for both short and medium term (ATN B1 and ATS B2 respectively, including ADS-C).
- Immediate coverage of Europe and scalability to become a global worldwide component to support air-ground ATM communications.
- High capacity, guaranteeing the required performances for ATS safety services whilst also supporting the data-hungry AOC services needed for airline operations.
- Resilience to malicious attacks, due to end-to-end secure and redundant mechanisms.
- Continuity, becoming a core part of the future air-ground communication infrastructure supporting future ATS needs.

- Scalability and cost viable solution using the multi-mission[2] nature of satellite communications infrastructure, serving a large customer base that will constantly demand new, high-performance features.
- Future proofing, as upgrades to the existing system can be gradually implemented to fulfil future requirements for improved performance in compliance with upcoming ATN-IPS standards.
- Ready to interconnect to the Common European ATM infrastructure.

The results achieved so far draw on the involvement of leading European institutional stakeholders (EC, SESAR Joint Undertaking, SESAR Deployment Manager, EASA and EUROCONTROL). ESA is committed to continue this cooperation with European institutions in support of the Single European Skies policy set by the EC. To this end, ESA has signed Memorandum of Cooperation with the SESAR Joint-Undertaking (SJU), the SESAR Deployment Manager (SDM) and EASA to guarantee the compliance of Iris to the required standards and regulations. Exchanges between the involved parties aim to provide full visibility and full confidence on the outcome of all Iris-related activities carried out or planned by ESA.

Iris technology is a reality based also on important milestones of technical validation achieved within the SESAR1 programme, where Iris is solution #109 of the SESAR catalogue. Additional validation activities have been carried out in ESA's Iris Programme through several flight trial campaigns (the latest in July 2018), demonstrating that Iris meets target ATM performance requirements[3].

The Iris system is getting ready for the execution of a large-scale validation using certified avionics flying on revenue flights from commercial airlines (the so-called "Iris Early-implementation" in 2022-2023. The observed performances will be analysed with the support of several European ANSPs in cooperation with EUROCONTROL/Network Manager, while the airlines will exploit Iris commercial and operational benefits.

"Iris early implementation" will pave the way to the full implementation of the Iris system, which will rely on a common validation and deployment roadmap that ESA is defining with major European stakeholders.

Major ATM stakeholders already recognise that SATCOM is one of the most mature solutions available today for complementing VDL2 in the short to medium term, while having strong potential for supporting global ATS air-ground communications in the long term.

From a regulation point of view, under EC mandate, EASA is already working on the definition of a new DLS-IR. This should lead to a performance-based approach

[2] Including non-aviation missions
[3] RCP 130 RSP 160 for ATN B2

focusing on services and associated performances rather than on technology for DLS provision (further details of which are provided in this paper). Explicit recognition by EASA of the Iris technology as an acceptable means of compliance to such new legislation will be the key to unlocking funding for airlines and other stakeholders and thereby enabling a critical mass of aircraft to be equipped with Iris.

Keeping the leading position of Europe in this process in a united European front will give European industry a competitive advantage compared to other world players, whilst also contributing greatly to common global aviation goals.

2. Air Traffic Management European and Global Context

In December 2015, the EC shaped a comprehensive European Aviation Strategy[4] for implementing a new Air Traffic Management administrative, operational, and technical concept.

The expected benefits to Air-Traffic-Management (ATM) stakeholders are to enable a three-fold increase in capacity, which will reduce both ground and air delays; improve safety by a factor of 10; enable a 10% reduction in the effect's flights have on the environment; and provide ATM services to airspace users at a cost that is at least 50% lower.

To support such an ambitious goal, the Single European Sky ATM Research (SESAR) programme has issued the ATM Master Plan[5] outlining the essential operational and technological changes required to achieve improvements in terms of operational efficiency, capacity, safety and security.

SESAR has recognized the technological modernisation of the Air-Ground Air Traffic Service (ATS) Data link as a key enabler of a transformation towards Trajectory-Based Operations (TBO). Through TBO, flight trajectories will be continually updated during flight and shared among the relevant Air Traffic Service Units to maintain, by strategic actions, an optimal trajectory to destination, allowing air traffic control to offer better routings, sequence aircraft far in advance and maximise airport and airspace capacity. The combined effect of optimizing aircraft trajectories will be less fuel burn, reduced delays, and lower emissions of carbon dioxide.

Furthermore, the continuous increase of traffic for both general aviation and new domains (e.g., UAVs) represents a major challenge for ATM systems, which are being required to handle a larger amount of data whilst also ensuring an improved level of

[4] Brussels, 7.12.2015 COM(2015) 598 final
[5] https://www.atmmasterplan.eu/

safety[6] and security[7]. Aviation safety requires robustness and hence a solid redundancy approach, while the integration of security in the end-to-end chain of the data link is already needed and will be vital for the ATM of the future.

Finally, the same novel technology will also be exploited from a more commercial perspective by AOC services[8] which are capacity-hungry services and are in continuous evolution; they are also fundamental for airline operations.

3. Data Link Services

Trajectory-based operations (TBO) is at the core of the European ATM Masterplan. TBO relies entirely on an efficient means of exchanging trajectory data between the aircraft and Air Traffic Control (ATC). In order to meet the objectives of the Masterplan, a data communications system with adequate quality of service, such as SATCOM, is a prerequisite.

In the medium term, the target is to create a “converged”[9] data link system that will operate globally according to the current and next generation of data link services. Safety, performance and interoperability requirements are maturing, and standards have now been published for ATS Baseline 2 (ED-228 and ED-229): it includes the 4DTRAD service dealing with trajectory negotiation and exchanges, ADS-C EPP being a subset of it mandated by the EU’s PCP Regulation.

ICAO has endorsed it in the Global Air Navigation Plan (GANP). The strategy was developed in close co-ordination with the Federal Aviation Administration’s NEXTGEN[10] Programme. EUROCAE and RTCA jointly developed the standards.

In the longer term (from 2040 onwards), after further R&D and taking the lessons learned from ATS B2 initial and partial implementation, another evolution step is expected when all aircraft will be fitted with these capabilities to reap the full benefits of TBO; this is the “Full 4D Business Trajectories”. This new operational context will

[6] Aviation safety means the state of an aviation system or organisation in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level.

[7] Aviation security is the set of measures and resources implemented to prevent malicious acts (terrorism) targeting aircraft, their passengers and crew members. Whilst air transport is the safest means of transportation in the world, its security has always been at the heart of the aviation industry's concerns.

[8] The AOC communications depend on the strategies defined by the airline companies for the operational procedures. Hence, messages are specific to the airline needs and can be different from one company to the other. The AOC services are dedicated to flight plan management, air traffic operations and maintenance activities.

[9] Converged: capable of aggregating all ATM data links available in oceanic and continental airspaces.

[10] The Next Generation Air Transportation System, or NextGen, is the FAA-led modernisation of America's air transportation system to make flying even safer, more efficient and more predictable

lead to the revision of the current ATS B2 requirements; this is not yet fully mature at this time, but under study in the SESAR programme. In this perspective, the ongoing collaboration of ESA with SESAR JU is key, especially on the performance requirements evolution (operational performance, safety and security) of the future ATS communication infrastructure, in order to ensure that SATCOM is one of the core systems in this future ATS infrastructure.

Furthermore, in addition to ATS data link services, the data link system through appropriate design will be able to support the increased use of airline operational communications (AOC) by airline crews, dispatchers, schedulers and strategic planners, while maintaining required performances for ATS. AOC communications are of a strategic nature for flight operations ensuring regularity of flight and, as such, need to be included (securely) in the main data link service stream.
Data Link Services Evolution is summarised in Figure 1 below.

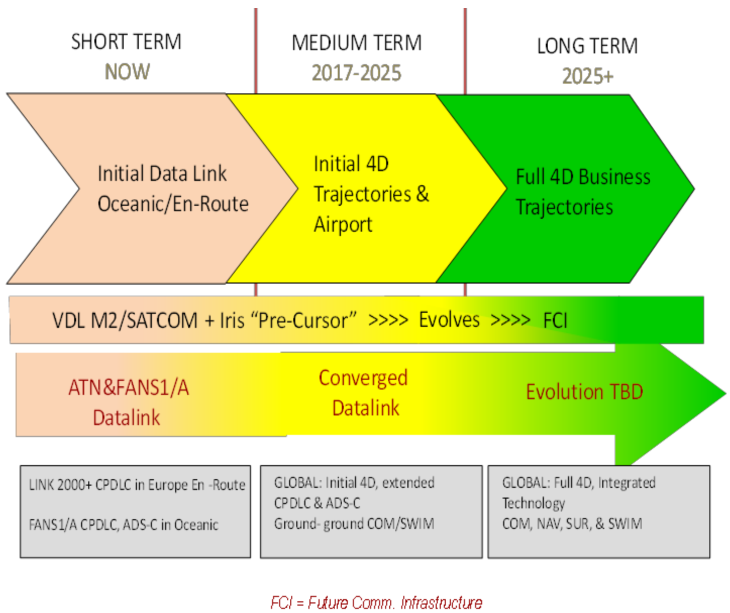


Figure 1: Data Link Service Evolution

4. Satellite Data Link Services in the context of SESAR

Satellite communications have an important role to play in the ATS communication infrastructure both in Europe and in the rest of the world, providing advantages in terms of global coverage[11], improved reliability and increased capacity.

[11] FANS1/A has been in operation in oceanic and remote areas for over 20 years, based on ACARS messaging. FANS1/A is installed on many long-haul aircraft and is supported by the long-established Inmarsat Classic Aero Service. In the short term, Iris would support existing ACARS operation through the enhancements already made to SwiftBroadband for oceanic safety services.

Satellite systems are already used in oceanic and remote regions where they are the only available data link technology. A converged air-ground communication solution relying on both a terrestrial component and a satellite component will increase the robustness and resilience in case of failures, thus improving service availability. Lastly, a satellite component will provide additional bandwidth (and thus increased data link capacity) for European continental operations. This may be of significant value considering that data link capacity is much needed to boost the development of new applications and services.

Indeed, terrestrial VDL Mode 2 introduction has been impeded and delayed by its unexpected limitations, especially in terms of capacity. The original intention of the EC was to have the ATN B1 services operationally used across Europe above FL 285 by 2015. However, due to VDL Mode 2 infrastructure performance issues, this deployment has now been delayed to 2020. This negatively affects the implementation of new ATM functionalities that rely on efficient and high-performance data links, delaying the benefits associated with such new capabilities. In this context, the capability of SATCOM to provide performance compliant services in complement to the VDL Mode 2 (adding considerable capacity) represents a key asset for Europe to meet the ATM Master Plan objectives without further delays.

In the context of the ADS-C application, it is to be noted that SATCOM will also play a key role in optimized flight arrival management operations (A-MAN) for example at major European airport hubs particularly for intercontinental flight arrivals. ATC will be capable of sequencing aircraft earlier while they are flying at higher altitudes over the ocean thus improving traffic flow (on time arrival), reducing costs (less fuel burn), and reducing emissions.

5. Iris: ESA's contribution to the ATS Data Link Services

In 2008, ESA kicked off the Iris programme as a contribution to the ATS data link services to contribute to the Single European Sky objectives set by the EC. Close working relations have been set up with the SESAR Joint Undertaking and now with the SESAR Deployment Manager to ensure coordination and consistency of all the European efforts in that domain.

After a six-year research phase involving major European space companies, in 2012 ESA started the development and validation/demonstration phase of a first-generation "precursor" based on the SwiftBroadband-Safety (SB-S) service of Inmarsat and relying on the L-band satellite infrastructure of this satellite operator.

What is Iris?

Iris is a service running on the enhanced Inmarsat SwiftBroadband Safety (SB-S) service and broadband global area network (BGAN), for delivering operational DLS to airlines and Air Navigation Service Providers (ANSPs). Iris extends SB-S oceanic/remote service to busy continental areas, starting with Europe and scalable to global coverage by enhancing safety and security. Iris supports safety services for the current and future Aeronautical Telecommunication Network (ATN-B1 and ATN-B2) and any other ATM application requiring an efficient data link. This includes other data-hungry services in the AOC domain.

Iris' key features include:

- Compatibility with safety requirements for ATS data link services (ED-120 for ATN B1, ED-228A for ATN B1 and ATS B2).
- ATN/OSI functionalities to be integrated within the existing ATS data link infrastructure.
- Security procedures for providing secured link connections between aircraft and ground network.
  - Delivering secure end-to-end (from cockpit to ground CSP/ANSPs interface) communication links for data path[12], thus greatly reducing existing common threats and risks.
  - Providing stronger controls for mutual authentication and data integrity that do not exist in today ATS communication links.
- Plans for a pan-European Iris service provider certified by EASA.

Iris Added Value to ATS Data Link Services

Iris is well positioned to work in a dual-link or multi-link configuration, together with the terrestrial-based VDL Mode 2 component, to provide far greater data link capacity and availability. The resulting available bandwidth and throughput enable the growth of ATS data communications and offer a solution to demanding new AOC services. From the cost/benefit standpoint, it should be underlined that Iris benefits of the multipurpose and existing SB-S Inmarsat infrastructure (e.g., sharing maritime and land mobile services), making Iris economically viable as opposed to developing a dedicated ATM system.

Immediate main benefits deriving from Iris adoption for Europe:

[12] Iris also provides similar secure services for voice communications (it is more relevant for oceanic areas/remote airspace)

- Extend the lifetime of VDL Mode 2 and the data link infrastructure already deployed for CPDLC and accelerate the delivery of CPDLC benefits.
- Support the continuous growth of AOC communications.
- Support operational use of ANT B1 services.
- Support operational introduction of ATS B2 services (i.e., 4DTRAD services) including ADS-C EPP as a first step towards trajectory-based operations in partnership with SESAR, ANSPs and airlines.
- Global service coverage built in.

Initial assessment of Iris specific benefits identifies the following elements:

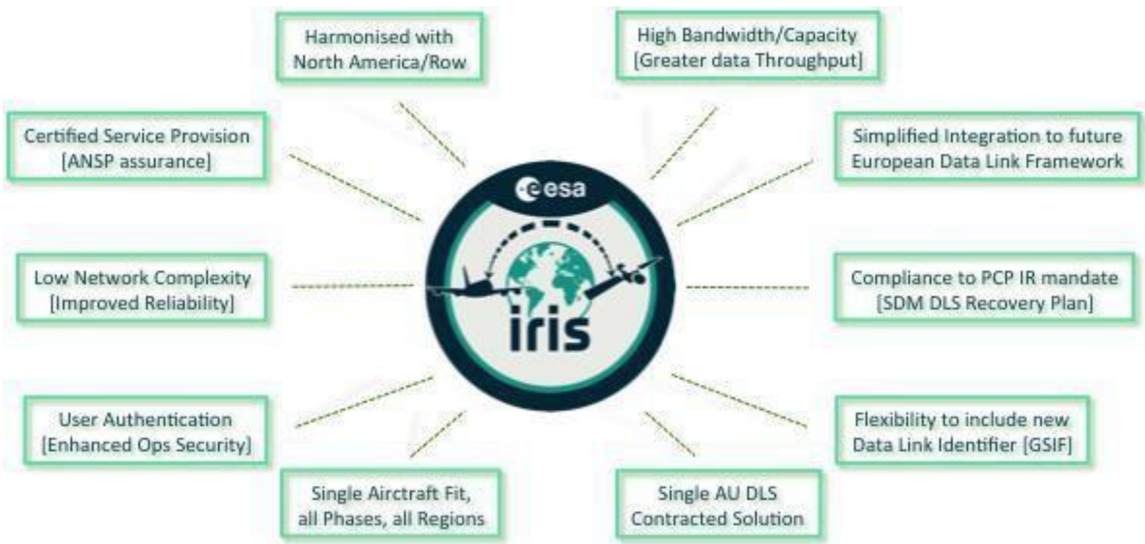


Figure 2: Iris Specific Benefits

Iris Services

Iris has been designed (in agreement between ESA and the SESAR Joint Undertaking) to support air-ground communications services for ATS and AOC. Major ATM stakeholders recognise that Iris is a candidate available for complementing VDL Mode 2 in the short to medium term, while having strong potential for supporting global ATS data communications in the long term (ICAO Global Air Navigation Plan).

Iris communications service will deliver the following:

ATN/OSI Data Safety Services supporting the following applications:

- **ATN Baseline 1** - the current set of ATS data link services, a CPDLC subset of which is mandated through the DLS Implementing Rule.

- **ATS Baseline 2** - the proposed future set of ATS Data link services envisaged for the introduction of trajectory-based operation, with only a small subset covered by the PCP Implementing Rule (i.e., ADS-C EPP service).

ACARS Data Safety Services - existing FANS1/A data link communications for remote and oceanic regions, as implemented for the current SBB Oceanic Safety.

Cockpit Voice Service for oceanic airspace - circuit-switched (CS) and prioritised packet-switched (PS) channels will be provided for cockpit voice communications, using the same solution already in operation under the SwiftBroadband Oceanic Safety.

AIS/AOC Data Service - airline information and operational control services.

The delivered ATS data link services fulfil the set of operational safety, performance and interoperability requirements applicable, as shown below:

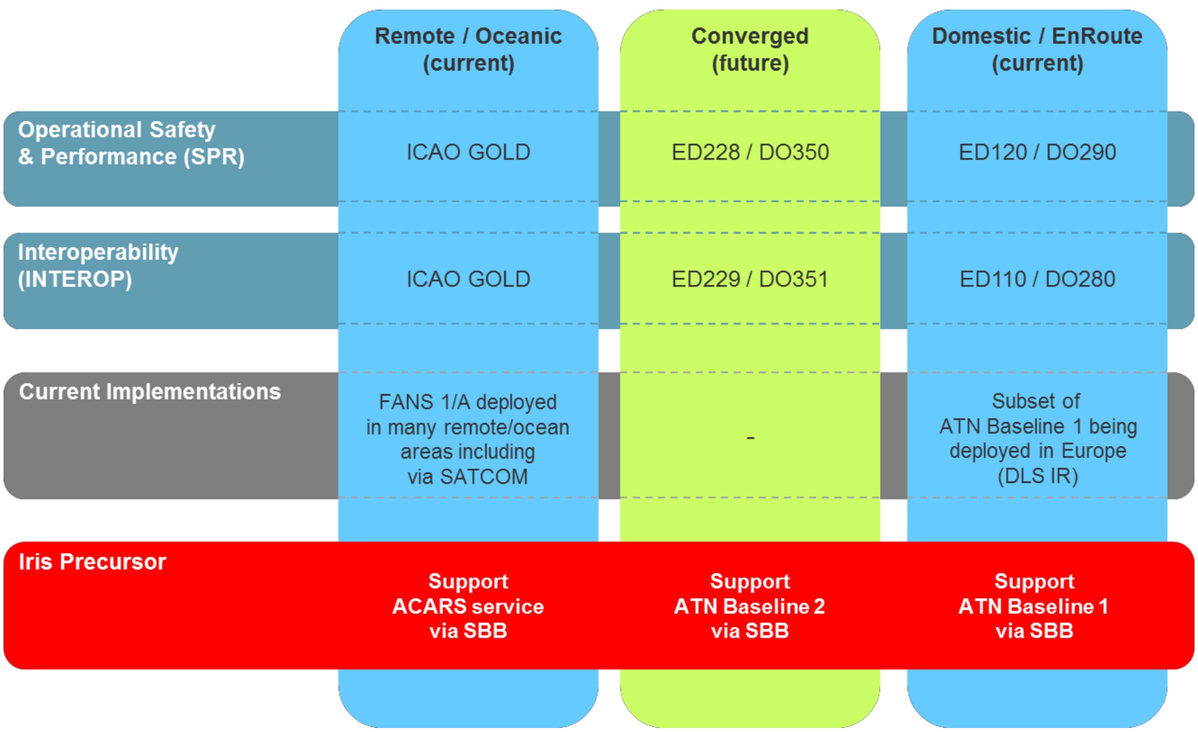


Figure 3: Safety, Performance and Interoperability Requirements

6. Iris System

Iris System Architecture

A high-level architecture of the Iris concept for ATN and ACARS, omitting redundancy, is shown in Figure 4.

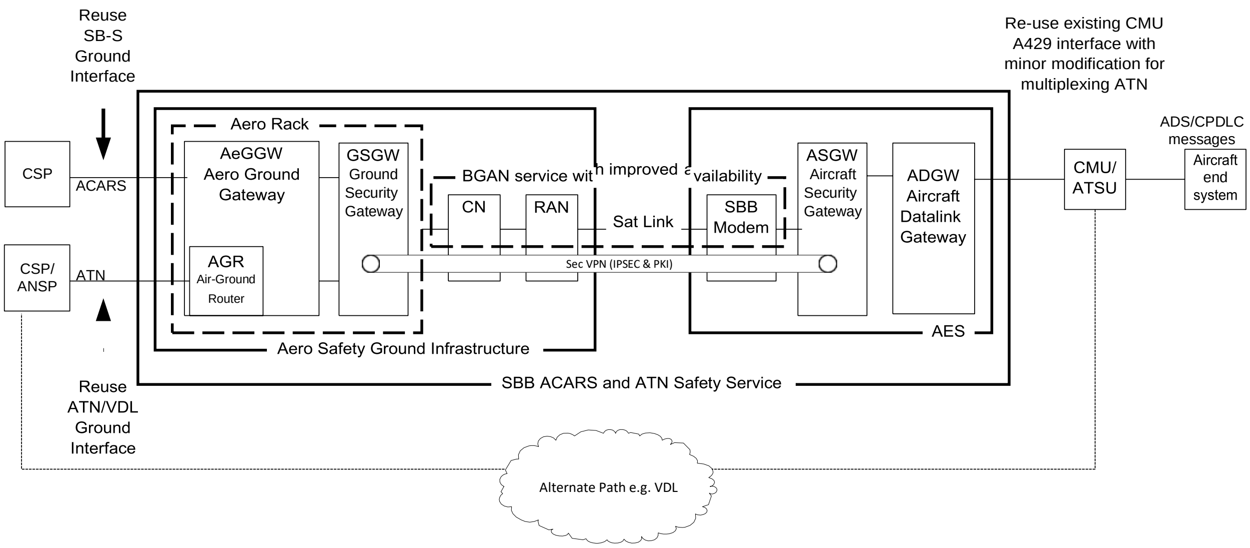


Figure 4: Iris High Level Architecture

The high-level Iris architecture consists of three main components: Ground Segment, Space Segment (Satellite) and Aero Segment (Aircraft).

The main **Iris ground segment components** are integrated in the Aero Rack, which includes the following elements:

AeGGW Aero Ground Gateway – a new component for this system. The AeGGW is the physical entity handling ATN/ACARS traffic to/from an AES. It contains the GDGW and the Air-Ground Router (AGR). The AGR is an ATN/OSI router software function within the AeGGW that peers with the ATSU/CMU on the aircraft. The AeGGW routes/receives ATN/OSI packets on the terrestrial interface through the AGR and delivers these over the satellite link through the GDGW. **GSGW** Ground Security Gateway is the peer of the ASGW and terminates the IPSec secure VPN tunnel established by the AES.

GDGW Ground Datalink Gateway supports combined delivery of ATN and ACARS traffic over the satellite link, expanding on similar functions developed and operational for the SB Oceanic Safety ACARS service. Its peer is the ADGW on the aircraft.

The main **Iris Aero Segment components** that constitute the peer entities of the ground segment are implemented within the Satellite Data Unit (SDU) on the Aircraft Earth Station (AES) SATCOM terminal and include the following elements:

ASGW Aircraft Security Gateway, responsible for establishing the Secure VPN tunnel between the aircraft and its peer GSGW, for the provision of an IPSec VPN for secure air-ground datalink communication.

ADGW Aircraft Datalink Gateway, expands on similar functions developed and operational for the SBB Oceanic Safety ACARS service. It is a functional block within the AES that is responsible for encapsulating ATN/ACARS messages in an IP wrapper to allow them to be sent to the ground via SBB; and to de-encapsulate received ATN/ACARS IP messages for transmission to the aircraft CMU.

Also on the aircraft is the CMU (Communication Management Unit). The CMU manages aircraft communication across multiple sub-networks such as Terrestrial HF, VHF radio and satellite-based communications, selecting which subnetwork to use based on availability and local routing policy.

ATN-OSI traffic (i.e., CM, CPDLC and ADS-C) is provided to ANSPs via the GGRs of the CSPs that connect to the AGR in the AeGGW (see Figure 4). It is expected that the Iris ground network can be easily customized to interconnect to the future CEAB once requirements and specs become available.

The main **SATCOM-related components** for delivering Iris Swift Broadband (SBB) based services include the following key components.

CN (Core Network) provides the services, switching and routing of traffic to and from the AES, via the RAN towards external terrestrial networks. The CN consists of a suite of UMTS network nodes having separate Packet and Circuit Switched domains.

RAN (Radio Access Network) is responsible for all radio-related aspects of the Inmarsat BGAN ground system. It controls AES communications over the satellite to the ground network. Each Inmarsat satellite is served by at least one RAN.

The INMARSAT **I4 satellite fleet and Alphasat** are deployed worldwide and cover around 98% of the Earth's surface (with the exclusion of some polar regions above 70-80 degrees latitude).

Iris Redundancy Architecture

The Iris system needs to meet stringent targets in terms of network availability and service outages. In order to meet these demanding operational requirements, a comprehensive redundant system solution has been conceived, with no single points of failure and the ability to detect and switch over quickly to standby equipment in the event of failures.

Figure 5 below shows the Iris approach for redundancy implementation:

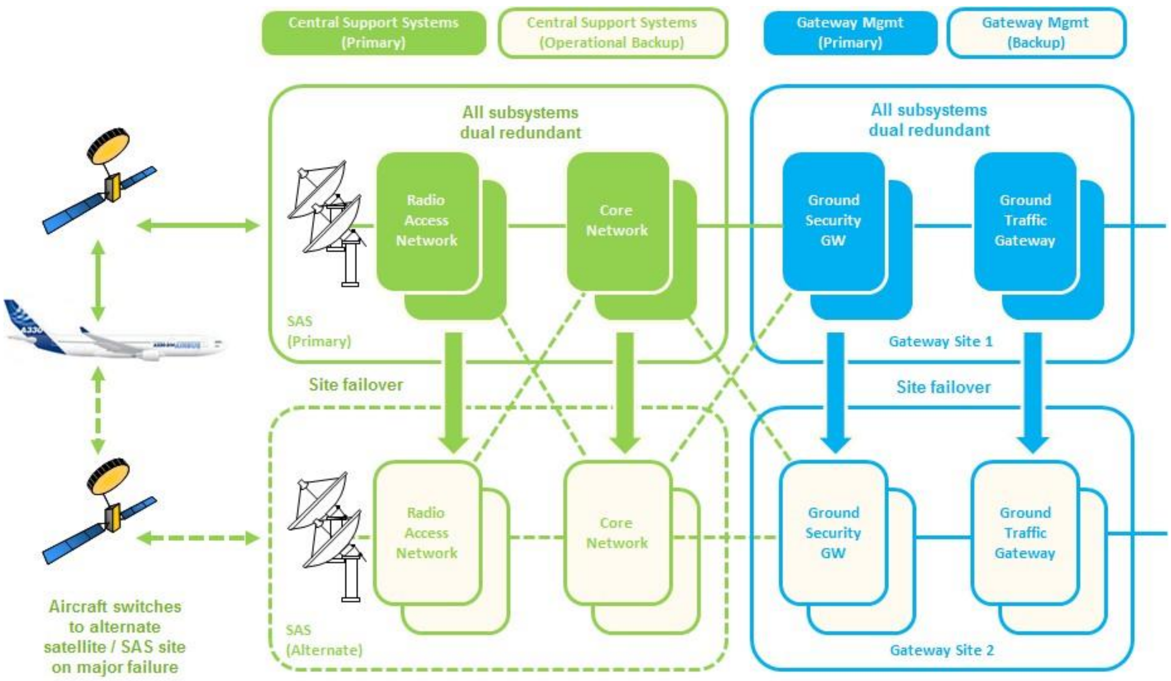


Figure 5: Iris Redundancy Architecture

Iris Security Architecture

The Iris solution also includes security mechanisms to ensure the end-to-end authenticity and integrity of ATS data link exchange. This approach aims at establishing secure domains for Iris services in the ground and air segments for delivery of ATS data link traffic; it also foresees the implementation of the necessary controls to ensure that the equipment within these domains are managed securely.

Figure 6 shows Iris Security Architecture approach:

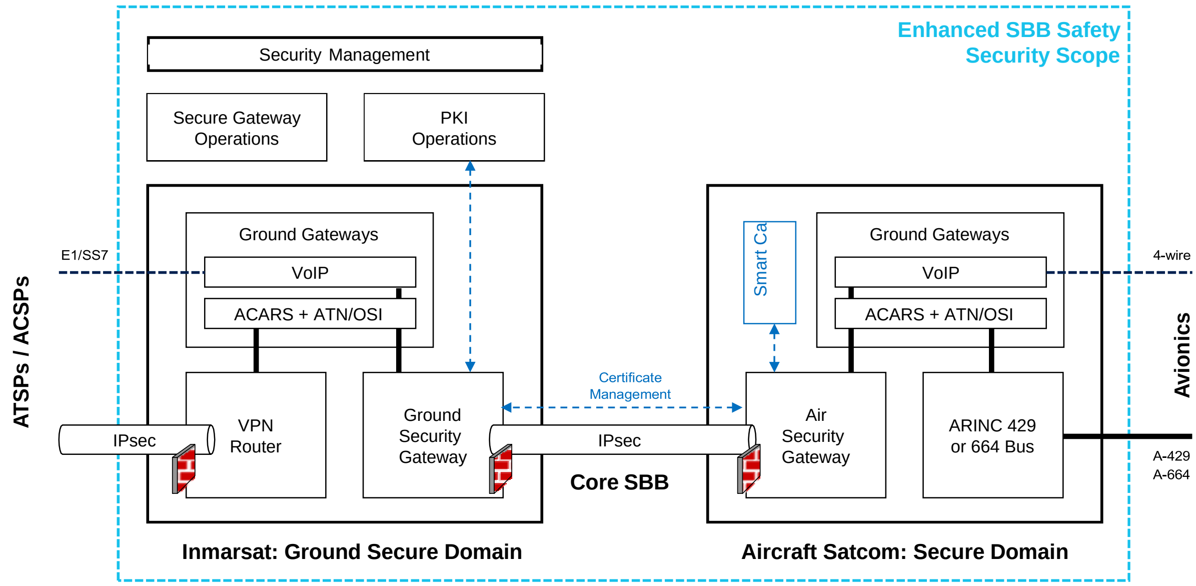


Figure 6: Iris Security architecture

Capacity and Equipage rate

The Iris consortium has performed a capacity study, under the supervision of ESA, whose results demonstrate that the existing Inmarsat satellite infrastructure (based on the so-called L-band I4 operational satellite constellation and Alphasat) is capable of supporting the traffic demand required to alleviate VDL2 until 2040 and beyond. This applies both to the bandwidth demand in each satellite spot beam as well as to the demand at overall system level, over the European continental area (ECAC region).

The other important assessment carried out by the study estimates the required Iris aircraft equipage rate from 2024 onwards. This is then compared with current industrial projections, highlighting the need for appropriate incentives from the EC that would fill the gap between actual Iris equipage rate and the required equipage rate (if incentives are available) to substantially off-load VDL2.
The results of the study are presented hereafter.

The Iris aircraft equipage industrial scenario has been updated based on expected market opportunities and considering the latest information available on the possible COVID-19 impact on aircraft deliveries. However, a constant monitoring of the evolving situation is deemed necessary to reach a more detailed understanding of the impact on the aviation eco-system. The readily integration of Iris into a DLS architecture is indeed the right opportunity for Europe to achieve the digital transformation and green deal to immediately raise efficiency and cut costs, while at the same time prepare for the future when performance, safety and capacity requirements will become more stringent due to increase of traffic.

The capability to accommodate the required data traffic is a key aspect of the Iris solution as a complementary technology to VDL2. Indeed, a study to characterise the performance of the VDL2 network, conducted under SDM supervision, has highlighted that the current VDL2 implementation is already facing a capacity shortage. Even considering possible mitigations, such as making available additional VDL2 frequencies, the current terrestrial ATM network will suffer a severe capacity crunch by middle of this decade.

The immediate introduction of complementary ATM communication technologies is the only viable solution for both the short and long term, in order to have a timely satisfactory service when passenger traffic will grow again after the effects of COVID-19 crisis are over.

Iris is the only ready-technology, based on the existing Inmarsat network, which can immediately deliver the required ATS performances to overcome such capacity shortage. The capacity study conducted under the supervision of ESA and based on the same scenarios, services, and applications assumptions considered by SDM, has clearly shown that the Iris system has wide margins in terms of available spectrum to effectively complement VDL2 by off-loading traffic that otherwise would not be supported by existing VDL infrastructure.

The capacity assessment carried out by the Iris Consortium spans across the years 2024-2040 and considers two channelization options for the VDL2: four frequencies plus the Common Signalling Channel (CSC), which is designated as C4A, and six frequencies plus the CSC, designated as C6A.

Iris capacity simulations take input traffic (under the same assumption of the exercise carried out by SDM pre- COVID), including both ATS and AOC, and estimate the number of SATCOM carriers required to carry such traffic, by accurately modelling the Iris system, in line with the delay requirements of each application.

The results show that the underlying SATCOM infrastructure can carry the traffic required to off-load VDL2, both when four or six frequencies are considered for the terrestrial system. In particular, the most bandwidth consuming scenario corresponds to the year 2040, assuming a high traffic growth profile, where a maximum of three 200 KHz Iris carriers are needed in the most loaded SATCOM beam for the return link. At Iris system level around 50 carriers are needed across the entire coverage area: the current Inmarsat system can handle this capacity demand, which is well below the overall system capabilities boundary.

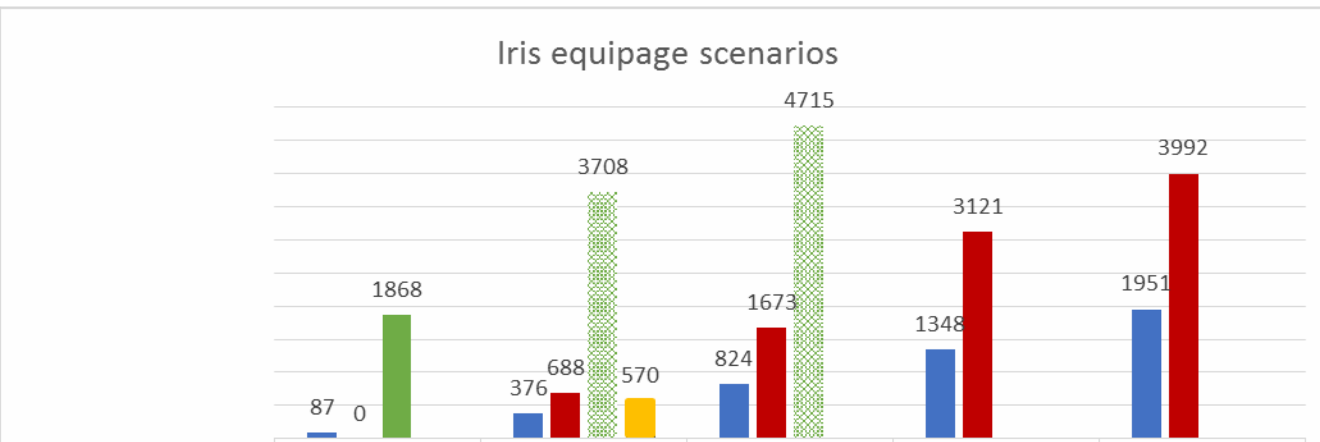
The study has also identified the required the number of Iris equipped aircraft to be deployed in order to timely enable effective offload VDL2 network from the traffic in excess (i.e., to avoid saturation), yet to be updated taking into consideration the impact of COVID-19.

The following figure presents a comparison between the current Iris equipage rate forecast, also called industrial scenario, and the theoretically required number of Iris equipped aircraft considered in the Iris capacity study.

The industrial scenario is based on industrial and market plans developed with expert knowledge from aircraft manufacturer Airbus in particular, as Airbus family aircraft are likely to constitute a large share of the early Iris users. It does not consider the possible incentives available to airlines when Iris is defined as an essential enabler to delivering the ATM Master plan.

Furthermore, the industrial scenario considers the latest information available on avionics development and best understanding today of the possible COVID-19 impact on aircraft deliveries, although still to be confirmed.

As anticipated, it is to be noted that the COVID-19 impact on the traffic level and therefore on the required number of aircraft derived from the capacity study has not been taken into account: the traffic growth originally (pre-COVID-19) defined "realistic" is considered and both results for four and six frequencies options are shown.



	2024	2027	2030	2035	2040
Industrial scenario	87	376	824	1348	1951
VAR-OFF-E5-C6A-TR	0	688	1673	3121	3992
VAR-OFF-E5-C4A-TR	1868	3708	4715	0	0
SDM objective	0	570	0	0	0

Industrial scenario · VAR-OFF-E5-C6A-TR · VAR-OFF-E5-C4A-TR · SDM objective

Figure 7: Comparison between forecast of Iris equipage rate (industrial scenario) and Iris capacity study findings for the 4 (VAR-OFF-E5-C4A-TR) and 6 (VAR-OFF-E5-C6A-TR) channels scenarios

The above figure shows that:

- There is a significant gap between the industrial scenario and the needs (except in 2024 with six frequencies available for the VDL2).
- Even considering a working assumption of at least 5% of the flights equipped with complementary communications by 2027 is not sufficient in both options with four and six frequencies on VDL2. (The 5% target was set up in discussion with SDM).
- Depending on the ability to implement the VDL2 network transition from four channels to six channels, the situation may be critical in 2024 or even before.

Even if the six channels scenario is implemented as from 2024, the fleet equipage should start in 2022/2023 for reaching the 2027 objective (688 A/C) with a realistic ramp-up. This would require significant EC incentives for accelerating the Iris equipage of the ECAC fleet.

Based on the available data, a strategy that would include incentives from the EC[13], boosting the Iris forward fitting rate and addressing partially also the retrofit, would allow to fill the gap between current expected number of Iris equipped aircraft and the number of required Iris equipped aircraft.

The following conclusions can hence be drawn:

- Iris system has sufficient capacity to accommodate for the ATM traffic exceeding VDL2 until 2040.

- The off-load of VDL2 can be effectively implemented with the support of EU incentives in order to timely reach a critical mass of equipped aircraft.

Iris Validation

The activities for the validation of Iris are performed in collaboration with SESAR-JU, through the SESAR1 and SESAR2020 Programmes. Thanks to the achieved results, Iris has been included as solution #109 of the SESAR catalogue (SESAR1).

Coordinated and complementary pre-operational validation of the Iris end-to-end communication system was carried out within ESA Iris Precursor and SJU framework through several flight trial campaigns (the last one in July 2018), demonstrating that

[13] In addition to the SDM incentive strategy targeting at least 5% (SHALL WE UPDATE THIS?) of the aircraft operating within ECAC countries are equipped by 2027 with complementary communications

Iris meets the target performance requirements [14]. Validation was successfully conducted using Honeywell aero terminals and Airbus test-bench Toulouse.

Iris is currently completing the industrialisation of all its components operating with Multilink, to be a certified and operational system compliant to ATN B1 and B2 by Q1 2022, with some delay to be expected following COVID-19

The next phase of Iris to accomplish this objective is intended as a large-scale validation. The Initial Operational Capability (IOC) includes a key milestone in the implementation roadmap of the system, the so-called Iris "Early Implementation" or Iris Pilot. It will equip certified avionics flying on revenues flights (to be with selected airlines) for a 12-18-month period (TBC) in 2022-2023, enabling demonstration of compliance with end-to-end Safety and Performance Requirements for ATN B1 and ATS B2 in operational conditions.

Iris performances will be monitored by Eurocontrol in its role of Network Manager for air traffic network functions of the Single European Sky with the support of several European ANSPs. Meanwhile, involved airlines will analyse the benefits of Iris for AOC services. EASA will be given full visibility of this phase and will actively monitor Iris Early Implementation by providing feedback and advice.

This phase should be complemented by very large scale demonstrations, to be executed under the SESAR2020 programme. Upgrades to Iris for the longer term are under study to assess how future performance requirements will be met from 2030 onwards.

7. Multilink short term solution and long term vision

The following information is still draft and will be updated shortly following the conclusions of the technical discussions between Iris industrial team, major stakeholders, and SESAR solutions teams

Multilink is a key enabler for the effective integration of Iris into the existing ATN/OSI datalink infrastructure. To streamline its adoption, Iris leverages the multilink concept defined and validated by SESAR JU as part of the PJ14.2.2 Task 6. The Iris industrial consortium has further worked out the implementation details of this validated concept with contributions from CSPs, ground industry providers, avionics and aircraft manufacturers, and ANSPs.

[14] **Short term:** ED-120, SPR Standard for Initial Air Traffic Data Link Services in Continental Airspace. Referred to as ATN baseline 1, in force through the DLS implementing rule EU 29/2009.

Medium term: ED-228A, SPR standard for the proposed future set of ATS data link services in converged airspace but not yet subject of an EU implementing rule. This standard is referred to as ATS Baseline 2.

Principles of Multilink Operation

When multiple ATN subnetworks are available onboard an aircraft (e.g., Iris Satcom and VDLm2), one of them is pre-selected as 'preferred' and used by default for communication whenever it is operational. Airlines identify such preferred link on a per aircraft basis. Preferences can be set independently for ATC and AOC traffic and are in any case handled and enforced separately.

Airline preferences are statically stored in the Iris ground system and are periodically updated to ensure synchronisation with aircraft configurations. Upon aircraft ATN/OSI service logon, such preferences are subsequently propagated from the Iris Air Ground Router to adjacent ATN entities (CSPs or ANSPs), using Inter Domain Routing Protocol (IDRP) and ATN standard procedures.

The Airborne Router uses the preferred link as statically configured on the aircraft ATSU/CMU. With the Airbus ATSU, the mean for doing so is for the Airborne Router to set additional routing path attributes to either Satcom or VDL2 routes in compliance with the aircraft static configuration.

To downlink ATN/OSI traffic, the Airborne Router selects, on a per packet basis, the air-ground subnetwork corresponding to the route with higher precedence according to ATN standard procedures. Following a similar strategy to uplink ATN/OSI traffic, the Ground Anchor Point[15] selects the air-ground subnetwork corresponding to the route with higher precedence according to ATN standard procedures. Symmetric routing of uplink and downlink traffics will have to be guaranteed.

The dynamic nature of air-ground connectivity, inherent to the aeronautical mobile communications, demand for additional provisions enabling a timely handover to the alternative link whenever the preferred link becomes unavailable.

To this aim, subnetwork availability is constantly monitored on the air and ground sides. On-board the aircraft, any change in subnetwork availability will be notified by the communication equipment (SATCOM Satellite Data Unit and VDL2 Datalink Radio) to the Airborne Router, which in turn will update the routing information accordingly. On the ground side, any change in subnetwork availability will be notified to the Air Ground Router. The Iris Air Ground Router will then be responsible for advertising the changes in Iris subnetwork availability to the ATN network using IDRP standard mechanisms. Handover is thus handled leveraging already existing protocols and techniques.

[15] The Ground Anchor Point is a Ground-Ground Router located in the ATN backbone network and/or the ANSP network depending on the deployment scenario.

8. Iris Deployment

ESA and the Iris Industrial Consortium led by Inmarsat are implementing and co-funding all activities that will deliver Iris IOC from 2024, this requires full integration between the ground and the airborne elements. Two avionics suppliers are developing the SATCOM terminals and changes to communication units (ATSU/CMU). Certification is planned in 2022 in line with Iris Early Implementation phase.

The activities related to the implementation of Iris will be performed in cooperation with SESAR DM, with the final goal of creating a global ATN communication network where the implementation of the SATCOM component is the result of a combined ESA and industry effort.

In this context, Iris Early Implementation can be considered as the first milestone of a common validation/implementation process, where all the major institutional partners of ESA (among which: SJU, SDM, EASA, Eurocontrol) will provide their expertise and contribution and will be kept up-to-date on Iris deployment and evolution, which eventually could lead to a shared deployment programme to support the pan-European roll-out of Iris as an element of the DLS strategy

9. Iris Service Distribution

Inmarsat plans to distribute the Iris services via an Iris Service Provider (ISP). Inmarsat is working on selecting the best partner to become the ISP. The ISP will be responsible for the delivery of the Iris services to the ANSPs, in compliance with EU regulations.

The organisation of service distribution will be finalised by 2022 (this is not facilitated by the current economic context as a result of COVID-19) and will be compatible with the data link services re-organisation defined by the SESAR Deployment Manager under EC mandate. The ISP is expected to apply for approval to EASA under regulation 2017/373 prior to the commercialization of Iris services in Europe. In the meantime, ESA and EASA have established an advisory group with the objective to inform and align the certification preparation activities with the new EU legislation pertaining CNS services in aviation.

10. Iris in the Future

In line with the expectation of the aeronautical community, the EC is preparing for a full digital transformation in ATM, towards a higher level of automation and virtualisation. The goal is to meet the increasing level of performance and capacity required by European aviation, which is moving from conventional aircraft to potentially hundreds of thousands of highly connected and automated air vehicles/devices offering advanced data-driven services.

In this context, Iris aims to become a key enabler for the modernisation and rationalisation of ATM operations, as a primary component enabling the European Communication-Navigation-Surveillance (CNS) infrastructure to deliver improved services.

By consolidating and capitalizing upon the results of Iris with Initial Operational Capability (Iris IOC), the Iris Programme supports:

- **Iris Service Provider ground segment upgrades.** Iris will develop the SATCOM interface to the common European ATN backbone for an operational use of Iris in a multi-link environment. In close collaboration with SESAR Deployment Manager the Iris Service Provider will transition Iris towards full operational deployment.

- **System and Technology Development for Iris global evolution**. Iris is preparing the migration to internet protocols (ATN-IPS) in compliance to standards that are being defined at ICAO level. In this context ESA is co-operating with several SESAR-JU ongoing projects (107 and 77) in order to validate IPS end-to-end scenarios and to gather validation data to use in support of ICAO standardization. These IPS activities will pave the way for Iris operational evolution, which will envisage supporting both ATN-OSI and ATN-IPS for ATM.

- Iris will also continue supporting the Hyper Connected ATM – i.e., future ATS and AOC (Airline Operation Communication) services - that will demand higher capacity and higher performance.

- **Enhancement of Iris to become a primary component of the European Communication-Navigation-Surveillance (CNS) infrastructure**. Technology developments are being planned to integrate communication with navigation and surveillance services, in a rationalised CNS infrastructure for optimising air traffic management. The evolution of satellite constellations will support current and future ATM operations for all phases of flight.

11. Conclusions

ESA's satellite-based Iris system, developed by a world-class industrial consortium led by Inmarsat, represents a building block of the digital transformation of Europe's ATM and a significant contribution to the EC's Aviation Strategy and the worldwide aviation community.

As all Iris industrialization activities are being finalised and the system end-to-end integration is approaching its completion, Iris is moving forward towards its operational use in the European skies to deliver a complementary solution to VDL2 through ATN B1 and B2 applications. It is now essential to define a clear deployment framework so that ATM stakeholders can plan required investments into the service.

Main preparatory activities for Iris operation phase include:

- Safety case under elaboration by European ANSP's
- Iris Performances Monitoring procedures to be carried out by Network Manager.
- Selection of Iris Service Provider for a commercial exploitation of Iris services.

As shown by attached Iris Roadmap, target entry into full service is planned by 1st Q 2023 (COVID-19 impact to be analysed).

Whilst it has been shown that the Iris system can effectively complement VDL2 by providing much needed extra capacity, it requires a number of aircraft to be equipped with Iris as well as a number of ANSPs to provide the service. This calls for an agreed deployment plan and regulatory framework in line with the European strategy for DLS relying on complementary technologies. Incentives for airlines and Air Navigation Service Providers would speed up Iris equipage (forward fit and retrofit), in order to efficiently mitigate the expected overload of the VDL2 system and support the digital transformation of European skies.

ESA is currently supporting SDM in the definition of the best deployment strategy that can take advantage of Iris solution for the benefit of aviation community in Europe.

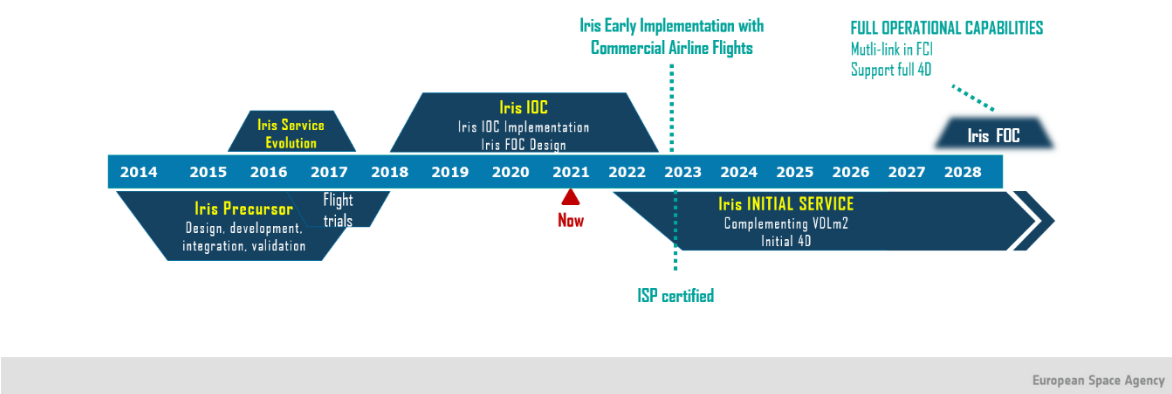


Figure 8: Iris Status and Deployment Programme Roadmap