PJ14-W2-77 TRL6 CBA FCI Services

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INTEGRATED COMMUNICATION, NAVIGATION AND SURVEILLANCE SYSTEM

This Cost Benefit Analysis (Technical) / business case is part of a project which has received funding from the SESAR Joint Undertaking under grant agreement No 874478 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document contains the CBAT (Cost Benefit Analysis – Technical) / business case (BC) analysis to support a decision-making process on the next air/ground communication technologies which will need to be deployed to support ATN-B1 and ATS-B2/B3 services. The PJ.14-W2 I-CNSS project (W2 for "Wave 2") is a cornerstone in building the Future Communication Infrastructure (FCI). The FCI business case encompasses a group of SESAR Wave 2 solutions with tight dependencies, namely PJ.14-W2-60 "FCI terrestrial datalink (LDACS)", PJ.14-W2-61 "Hyper Connected ATM", PJ.14-W2-77 "FCI Services" and PJ.14-W2-107 "SATCOM Evolution towards IPS-based FCI".

The BC aims to provide a clear business analysis, for all stakeholders engaged in the deployment of the European FCI, of the cost and benefit elements of each solution scenario identified as a potential candidate for the provision of the ATC datalink service with a new communication technology. It includes a cost assessment of the different solutions, together with a qualitative assessment of other key elements which may influence the comparison and decision-making process between deployment alternatives. As a result, the analysis generates a set of recommendations for the industrialisation and deployment phases.

This document is the corresponding deliverable for Solution 77. It is largely derived from the FCI Business Case developed under the auspices of the EASA-EUROCONTROL Joint CNS Stakeholder Platform (JCSP) aiming at a decision on the FCI deployment. Solution 77 is addressed in section 8 dedicated to "Scenario 4 – Multilink / Multimode" and all details will be found in that section and in the general conclusion, section 9.5. However, a specific additional aspect relating to solution 77 is how AeroMACS is considered. The FCI Business Case did not consider AeroMACS as a realistic deployment option. Solution 77 does however include it in its scope and this is addressed in section 8 as an addendum to the FCI Business Case.

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1 Executive summary

This document contains the Future Communication Infrastructure (BC) Coast-Benefit Analysis – Technical (CBAT) / business case on the next generation of air-ground communication solutions which can support current and future ATC services (ATN-B1, ATS-B2/B3). The FCI-BC encompasses a group of SESAR Wave 2 solutions with tight dependencies, namely:

- PJ.14-W2-60 "FCI terrestrial datalink (LDACS)",
- PJ.14-W2-61 "Hyper Connected ATM",
- PJ.14-W2-77 "FCI Services”,
- PJ.14-W2-107 "SATCOM Evolution towards IPS-based FCI”.

The FCI-BC report was drawn up in close cooperation with all the industrial partners involved in the SESAR-PJ.14-related solutions, and with representatives of the airspace users (AUs) and air navigation service providers (ANSPs).

The purpose of the FCI-BC is to provide a business analysis, for all stakeholders engaged in the European FCI, of the cost of each solution scenario, together with a qualitative assessment of the benefits and other key qualitative elements which could influence the decision-making process between deployment alternatives. As a result, the FCI-BC report gives an overview of the costs and a qualitative assessment of the four PJ.14 communication solutions currently being considered by SESAR, recommends the promotion and adoption of the so-called “MULTILINK/MULTIMODE scenario”, and provides guidance for recommendations on the way forward.

This document is the corresponding deliverable for Solution 77. It is largely derived from the FCI Business Case developed under the auspices of the EASA-EUROCONTROL Joint CNS Stakeholder Platform (JCSP) aiming at a decision on the FCI deployment. Solution 77 is addressed in section 8 dedicated to “Scenario 4 – Multilink / Multimode” and all details will be found in that section and in the general conclusion, section 9.5. However, a specific additional aspect relating to solution 77 is how AeroMACS is considered. The FCI Business Case did not consider AeroMACS as a realistic deployment option and did not consider it. Solution 77 does however include it in its scope and this is addressed in section 8 as an addendum to the FCI Business Case.

THE NEED FOR A NEW TECHNOLOGY TO COMPLEMENT VDL-2

Owing to the capacity limitations of the technology and increasing air/ground ATC/AOC data traffic trends in terms of traffic volume, performance and security, the current VDL-2 network infrastructure will soon reach its limit in the European airspace core area. For this reason, several new A/G mobile technologies and services have been developed and standardised in the last few years in order to ensure increased capabilities, support more stringent requirements and provide a service-oriented and performance-based aeronautical communication infrastructure.

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The environment of applicability of the FCI business case analysis for the deployment of new communication technologies is the continental airspace of all the EUROCONTROL Member States, covering all airspace categories and phases of flight. The analysis period extends from 2021 to 2039, and includes a set of assumptions based on the evolution of the datalink service (DLS) during this period. These assumptions relate to the traffic and projection of the target fleet[1], the ATC/AOC service evolution, the ATN/OSI to ATN/IPS architecture and the establishment of a common datalink service provider for European ANSPs.

THE METHODOLOGY BASED ON THE VDL-2 REFERENCE SCENARIO

The reference scenario (do-nothing or business-as-usual scenario) is defined as continuing to invest in the current VDL-2 network with multi-frequency management. Compared with this scenario, four scenarios have been identified which introduce new communication technologies. Three of these scenarios (LDACS, OFF THE SHELF and SATCOM NG) focus on a single-communication technology. The fourth scenario (MULTILINK/MULTIMODE) analyses the mix of these new communication technologies in an ATN/OSI and ATN/IPS mobility architecture (via ground interoperability gateway services)[2].

The business case analysis measures costs and benefits in two dimensions:

- a quantitative assessment, including cost of infrastructure and aircraft equipage, and costs of service provision;
- a qualitative assessment, which compares a set of criteria such as maturity level, performance, security, safety, availability of standards, resilience, new service capabilities and scalability.

The stakeholders which are the audience for this business case analysis are aircraft operators, the industry, ANSPs and communication service providers (CSPs). These are the entities which will benefit from the deployment of the new technologies assessed, and also those which will be required to deploy in their respective sub-operating environments and incur capital and/or operational expenses.

[1] The target fleet considered in the FCI-BC comprises the majority of the aircraft flying above FL285 in the ECAC area, i.e. it represents 85% of IFR traffic above FL285.

[2] Note that the VDL-2 technology must normally remain with the ATN/OSI protocol.

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The quantitative assessment results include, for each scenario, the undiscounted[3] costs for:

- the CAPEX incurred by airspace users, looking at forward-fit equipage only. Two different figures are provided:
    - a theoretical cost, which indicates how much it will cost to equip the total target fleet by 2039;
    - a realistic cost, which provides an overview of the cumulated CAPEX over the period 2021-2039, based on more realistic deployment assumptions (start-date of deployment, equipage rate, ramp-up of equipage);
- the yearly OPEX incurred by ANSPs at full operational capability (FOC) to serve the 2039 target fleet, and the cumulated OPEX for the period of analysis (2021-2039).

All the following identified scenarios are supposed to meet the future requirements for both ATC and AOC services. It should be emphasised that a communication infrastructure as such does not bring any benefit without the related A/G applications supporting both ATC and AOC operations. In the business case, it has been considered that the new communication infrastructure will contribute to a reduction of 10% in the costs of the current delays (see 2019 traffic), hence a benefit estimated at a minimum of EUR 100 million a year.

In addition to drawing up this business case, the JCSP also held consultations on the deployment of the ADS-C/EPP services as part of CP1 (see the JCSP ATS-B2 workshop held on 7 February 2022). These initial consultations have shown that stakeholders support the deployment of common solutions for ADS-C/EPP. It should be noted that the costs of the related applications have not been considered in the FCI-BC, but the business case assumes that the new communication infrastructure will be deployed with the aim of deploying a coherent European infrastructure under the new datalink service provider (DSP).

SCENARIO 1 (LDACS)

The LDACS scenario is based on a new ground-based technology being developed by the SESAR partners. For the LDACS scenario, an investment of EUR 284 million (CAPEX) for AUs (59% fleet equipage) and operating costs of EUR 15 million year (OPEX) for ANSPs have been estimated.

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[3] Note that cost results are presented undiscounted, as the roadmap will need to be further confirmed.

SCENARIO 2 (OFF-THE-SHELF)

The OFF-THE-SHELF (OTS)[4] scenario is based on existing mobile commercial services which are currently available in the public domain, a typical example being SATCOM Ku/Ka band or 3-4-5G services. For the OTS scenario, an investment of EUR 70 million (CAPEX) for AUs (23% fleet equipage) and operating costs of EUR 8 million a year (OPEX) for ANSPs have been identified. It should be noted that a very small proportion of the required investment and operating costs has been identified, as 94% of the related OTS costs are incurred by airspace users in response to cabin passenger communications.

SCENARIO 3 (SATCOM NG)

The SATCOM new generation (NG) scenario is based on the enhancement of the current SATCOM mobile services, standardised for aviation. The current cost estimate is based on the new Inmarsat/IRIS service which has recently been launched. For the SATCOM NG, an investment of EUR 513 million (CAPEX) for AUs (60% fleet equipage) and operating costs of EUR 25 million a year (OPEX) for ANSPs have been identified.

SCENARIO 4 (MULTILINK/MULTIMODE)

The MULTILINK/MULTIMODE scenario is based on the enhancement of the communication infrastructure, with several technologies which can interoperate all together. The airlines can choose their communication equipment from an agreed list, whilst the ground (ANSPs) will have an ATC system which can operate with all the selected technologies. For the MULTILINK/MULTIMODE scenario, an investment of EUR 422 million (59% fleet equipage) for AUs (CAPEX) and operating costs of EUR 43 million a year (OPEX) for ANSPs have been estimated.

ADVANTAGES/RISKS AND QUALITATIVE ASSESSMENT

The analysis also identifies a set of advantages and risks in the deployment of the analysed alternative technologies. These risks involve delays in investment or deployment, system fragmentation, unavailability of resources such as spectrum, long certification cycles, and market risks such as oligopolistic solutions and reduced buyer power.

The FCI-BC report also contains a qualitative analysis of the various scenarios.

CONCLUSION

The FCI-BC conclusions summarised in section 9.5 and in the following paragraph were discussed with all the stakeholders at a workshop held on 21 February 2022 under the chairmanship of airspace users (A4E) and ANSPs (DSNA), and involving participants from all relevant European groups (COMSG/JCSP/NDTECH, FCI Task Force including SESAR PJ.14 partners).

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[4] Also called COTS (Commercial OFF-THE-SHELF) scenario.

Reference to relevant sections are indicated next to each ‘advantage’ in table 1.

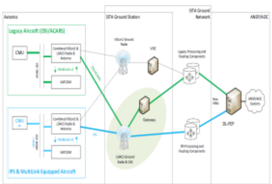
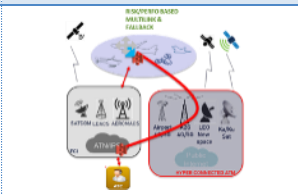
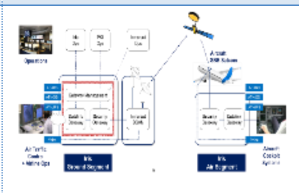
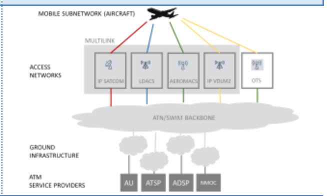
Scenario 1 LDACS	Scenario 2 OFF-THE-SHELF	Scenario 3 SATCOM NG	Scenario 4 MULTILINK/MULTIMODE
			
Advantages: • Aviation technology (5.1, 5.2.1) • Integrated CNS 5.5.2 • ATN/OSI and IPS 5.3.6 • Competition 5.1, 5.3.7.2/3	***Advantages:*** • Competition, global service 6.2, 6.3.1 • Expandable to new COTS 6.6.2, 6.3.1 • Saving investments 6.6.4 • Performance 6.4.2, 6.1.1	***Advantages:*** • Maturity: Standards and services available 7.3 • + oceanic 7.2.1 • 100% of airspace at start 7.6.1.1 • Global service 7.2.1, 7.6.1.1 • Energy-efficient 7.6.1.3	***Advantages:*** • Competition – evolution 8.7.4, 8.7.1 • Immediate start of deployment 8.5.1 bullet 5 • + oceanic 8.3.2 • Performance 8.7.3 • Resilience 10.1, 7.1.2, 5.1
Risks: - section 5.6 • Global endorsement • Spectrum (frequency criteria) • Avionics not yet mature	***Risks:*** *- section 6.7* • Maturity • Paradigm change • Interoperability • Security	***Risks:*** *- section 7.7* • Compatibility between SATCOM operators	***Risks:*** *- section 8.8* • Maturity • + complexity (ground)
Maturity: Medium	***Maturity :*** Low (ATC) High (AOC)	***Maturity:*** High	***Maturity:*** Technology-dependent
AUs CAPEX (ATC + AOC) • EUR 481 million (all new a/c by 2039) • **EUR 284 million** (59% fleet equipage by 2039)	**AUs CAPEX** (ATC + AOC) • EUR 300 million (all new a/c by 2039) • **EUR 70 million** (23% fleet equipage by 2039)	**AUs CAPEX** (ATC + AOC) • EUR 856 million (all new a/c by 2039) • **EUR 513 million** (60% fleet equipage by 2039)	**AUs CAPEX** (ATC + AOC) • EUR 769 million (all new a/c by 2039) • **EUR 422 million** (59% fleet equipage by 2039)
ANSPs OPEX (ATC only) • EUR 209 million (2025 -> 2039) • **EUR 15 million** (2039)	**ANSPs OPEX (ATC only)** • EUR 24 million (2027 -> 2039) • **EUR 8 million** (2039)	**ANSPs OPEX (ATC only)** • EUR 352 million + ? (2023 -> 2039) • **EUR 25 million** + ? (2039)	**ANSPs OPEX (ATC only)** • EUR 578 million + ? (2023 -> 2039) • **EUR 43 million** + ? (2039)

Table 1: FCI-BC results – summary table

Note: The question mark in scenario 3 / 4 means that we considered in this business case only one SATCOM NG service provider whereas at least two should normally be required.

Note: Please refer to section 3.4.1 for further explanation on the CAPEX/OPEX items of this table.

The conclusion of this business case analysis is that the MULTILINK/MULTIMODE scenario is considered the best performing and most flexible choice, paving the way for future evolutions, including the migration from the ATN/OSI to the ATN/IPS. Although it is not the least expensive choice from a purely financial perspective, it is nevertheless a solution which provides the required capacity improvement in the long term, while reducing technical and economic risks. MULTILINK/MULTIMODE is based on the gradual implementation of a communication infrastructure for air/ground ATC and AOC services following the maturity of the respective technologies and a consolidated infrastructure management approach. It will ensure the greatest possible choice for airspace users, who can freely select their preferred media, with the system ensuring the interconnection and integration of all the possible links. This will allow optimal allocation of costs as network modernisation takes place, and the maintenance of competition for the provision of ATC and AOC services over multiple technology options. It is also the most future-proof and scalable scenario, maintaining competition while ensuring resilience, high capacity, availability and security.

SATCOM NG, LDACS and OFF-THE-SHELF technologies should all play a part in the future infrastructure, providing the stakeholders with redundancy, varied functionality and choice. The off-the shelf technologies could be immediately used to offload the AOC traffic on VDL-2. Each of these technologies offers additional capacity, ATN/IPS connectivity and a way to offload the VDL-2 network, but because they are at different levels of maturity, a phased implementation approach should be adopted. SATCOM NG, having the highest level of maturity, is recommended as the first technology to be deployed for ATC services. Work to further evaluate and deploy LDACS should be accelerated so that this can be the second new technology to be deployed across Europe. Ultimately, once further degrees of maturity and safety certification are achieved, OFF-THE-SHELF technologies can be considered for ATC use.

In conclusion, it is strongly recommended that the deployment of all these technologies be encouraged, including the common ground gateways and the avionics part of the targeted fleet (forward-fit only). Incentives should be based on an agreed implementation roadmap.

2 Introduction

2.1 Purpose of the document

The objective of this business case (BC)[5] is to provide arguments to support the forthcoming decisions on the next communication technologies to be deployed in the context of the Future Communication Infrastructure (FCI) for air-ground (A/G) communication service provision, and their potential evolution. The present document also supports the commitment to SESAR to develop a cost-benefit analysis (CBA) for the following SESAR 2020 PJ.14 solutions:

- PJ.14-W2 Solution 60 – FCI terrestrial datalink (LDACS), referred to as "Scenario 1 – LDACS" for the FCI-BC
- PJ.14-W2 Solution 61 – Hyper connected ATM, referred to as "Scenario 2 – OFF-THE-SHELF" for the FCI-BC
- PJ.14-W2 Solution 107 – SATCOM Evolution towards IPS-based FCI, referred to as "Scenario 3- SATCOM NG[6]" for the FCI-BC
- PJ.14-W2 Solution 77 – °FCI Services, referred to as "Scenario 4 -MULTILINK/MULTIMODE" for the FCI-BC

[5] Note that a business case is broader than a CBA, which provides only monetary values of costs and benefits. The BC includes other qualitative and quantitative assessments in areas such as safety, security, finance, the environment, human performance and strategic fit.

[6] Note that to differentiate the new generation of SATCOM technologies from the current ones, the SATCOM solution will be referenced as SATCOM NG in this analysis.

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2.2 Intended readership

This document has been produced under the auspices of several main groups of stakeholders, which actually overlap.

Under EUROCONTROL Network Manager working arrangements:

- Members of the EASA/EUROCONTROL Joint CNS Stakeholder Platform (JCSP)
- Members of the Network Directors of Technology (NDTECH) group, advising the EUROCONTROL Network Management Board

Under the SESAR Programme:

- The SESAR Joint Undertaking and the SESAR Deployment Manager
- Team members of PJ.14-W2-77 and related solutions: PJ.14-W2-60, PJ.14-W2-61, PJ.14-W2-107 and PJ.14-W2-100
- Transversal projects of SESAR2020, in particular PJ19

Additionally, this document will be of general interest to all stakeholders having any part in the decision-making on and implementation of the elements of the Future Communication Infrastructure to be found among:

- the EC CNS Advisory Group;
- the SESAR Deployment Manager (SDM);
- ICAO and standardisation bodies (EUROCAE/RTCA, AEEC, etc.);
- air navigation service providers (ANSPs);
- communication service providers;
- airport owners/providers;
- airspace users;
- industry.

2.3 Structure of the document

This report is structured as follows:

- Section 1 provides the executive summary.
- Section 2 provides the background information, the contributors' list, the timeline for the decision-making process, the intended audience, the structure of the document and a glossary of terms and list of acronyms.
- Section 3 presents the problem addressed, the objective and scope of this business case, and the approach and methodology used for the business case analysis. It also provides a description of the reference and solution scenarios to answer the problem and the list of assumptions which have been considered for those scenarios.
- Section 4 presents the airspace users expectations of the FCI, the assumptions used for the business case and the fleet and traffic projection that were used for the analysis.
- Sections 5, 6, 7 and 8 provide a description of each of the four scenarios (LDACS, OFF-THE-SHELF, SATCOM NG and MULTILINK/MULTIMODE) analysed including a cost-benefit assessment and a risk analysis.
- Section 9 presents the overall quantitative and qualitative results of the business case, including a sensitivity analysis on the MULTILINK/MULTIMODE scenario equipage rate and the main conclusion for each solution scenario.
- Section 10 includes recommendations and next-steps.
- Section 11 includes the references and applicable documents.
- Section 12 contains the annexes.

2.4 Background

Following EASA/EUROCONTROL Joint CNS Stakeholder Platform action JCSP#4, which "approved that the COMSG, in conjunction with the SESAR partners, will complete the LDACS technical implementation scenarios with a business case to support the JCSP decision by end 2021", the Agency developed draft implementation scenarios, which were discussed with the stakeholders.

In order to proceed, it was then identified and agreed not to limit the work to the LDACS scenario alone but to extend it to the whole Future Communication Infrastructure (FCI). Consequently, the BC analysis includes the four communication projects of SESAR 2020 PJ.14 (solutions 60, 61, 107, 77) covering respectively LDACS, "Hyper-connected ATM" (i.e., commercial networks – OFF-THE-SHELF), SATCOM NG and MULTILINK/MULTIMODE.

Indeed, four solution scenarios and related assumptions were proposed and discussed with the stakeholders at a specific Webex meeting (on 23 March 2021) and at COMSG18 (on 15 April 2021) and were endorsed by the JCSP#5 (in May 2021).

A status report was made to JCSP#6, which confirmed the four proposed scenarios and asked for qualitative analysis of the aeronautical operational communication (AOC) to be further developed, given that AOC is key for the definition of the FCI.

2.5 Contributors

The FCI business case task is being led and coordinated by EUROCONTROL. The work has been split into two sub-tasks, T1.1 and T1.2:

- **Sub-task T1.1** - Development of the business case (BC) methodology and approach: The first task, from January to April 2021, consisted in defining the best approach in order to compare several new enabling communication technologies to support air traffic control (ATC) services under the Future Communication Infrastructure (FCI) project. The objective of this initial task was to identify the potential solution scenarios to analyse and to propose a methodology to compare those scenarios.

- **Sub-task T1.2** - Content development and production of a BC report: The second task, from May 2021 to May 2022, consisted in evaluating each solution scenario quantitatively and qualitatively using the agreed methodology, and producing a business case report in support of a decision-making process which will have to be endorsed by the NDTECH by the end of 2022.

A small team of EUROCONTROL experts involved in the SESAR Wave 2 projects (PJ.14 solutions 60, 61, 77 and 107) carried out the initial task, i.e., the development of the methodology to be used to compare solutions, but broad consultation of the main stakeholders involved in aviation was organised.

The BC approach was presented at several meetings (JCSP#4, the COMSG, IATA/JURG and the JCSP) and stakeholders' comments were collected through a set of webinars and awareness campaigns. Bilateral meetings were also held with representatives of key stakeholder groups to gather cost elements and inputs for cost-benefit assessment, and also to discuss and modify the methodology, scenarios and assumptions.

In a second step, partners were invited to actively contribute to the second task, i.e., the development of the content of the business case and the assessment of costs and benefits, and several companies were enrolled and participated in the development and the production of the final BC report, as indicated in Table 2.

Company	Contribution	LDACS	OFF-THE-SHELF	SATCOM NG	MULTILINK MULTIMODE
AIR FRANCE KLM	Contributor, JURG representative	X	X	X	X
AIRBUS	Contributor, OFF-THE-SHELF Co-Leader		Co-Leader	X	X
AIRTEL ATN	Contributor	X	X	X	X
COLLINS	Contributor	X			
DLR	Contributor	X			

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DFS	Contributor	X	X	X	x
DGAC	Contributor	X	X	X	X
ENAIRE	Contributor	X	X	X	X
ENAV	Reviewer	X	X	X	X
ESA	Contributor			X	
ESSP	Contributor			X	X
EUROCONTROL	FCI-BC leader, OFF-THE-SHELF Scenario Co-Leader	X	Co-Leader	X	X
FREQUENTIS	Contributor, LDACS & MULTILINK/MULTI MODE Scenario Leader	Leader	X		Leader
HONEYWELL	Contributor	X			X
IATA (JURG)	Reviewer, main contributor AOC.	X	X	X	X
INMARSAT	Contributor, SATCOM NG Scenario Leader			Leader	
LEONARDO	Contributor	X	X	X	X
NATS	Contributor	X	X	X	X
ROHDE & SCHWARZ	Contributor	X			
SDM	Observer	X	X	X	X
SITA	Contributor	X			X
THALES ALENIA SPACE	Contributor			X	

Table 2: FCI business case – contributors

2.6 Timeline

As indicated in Figure 1, the final version of this FCI business case is supposed to be completed by May 2022 (JCSP#7) for the review of recommendations in order to trigger a NDTECH decision by mid-2022.

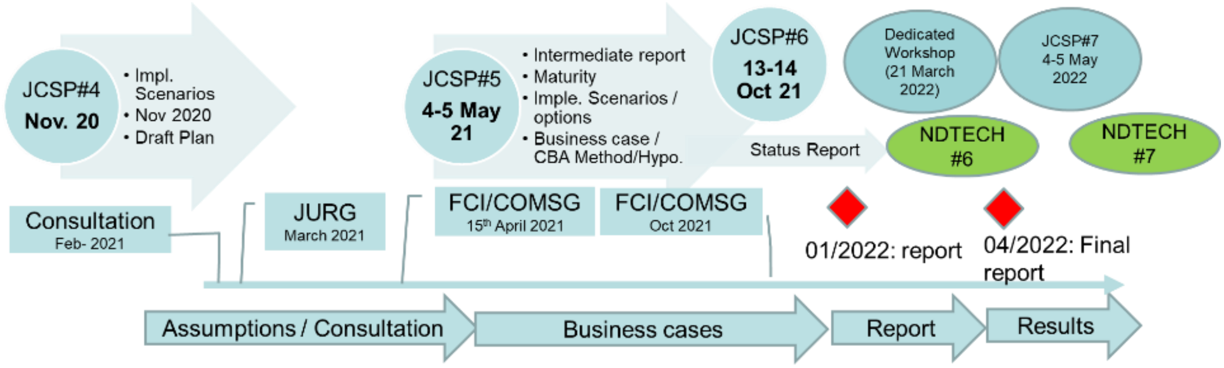

Figure 1: FCI-BC – Timeline

2.7 Glossary of terms

Term	Definition	Source of the definition
Required surveillance performance (RSP) RSP160 / RSP 180	RSP 160 is appropriate for 4DTBO and ATC Communications in support of the ATS functions, defined for ENR-1, TMA and APT airspace. The RSP 160 specification are required for the delivery of periodic/event reports, containing prediction data The RSP 180 specifications only apply to ADS-C reports which do not contain any route prediction data but rather include a number of predicted waypoints ahead of the aircraft. See below for a definition of ENR-1/-2.	ICAO Document 9869 (PBCS Manual, 2nd edition, 2017) EUROCAE ED-228A, section 6.3.2
ATN/OSI vs ATN/IPS	Aeronautical Telecommunication Network based on ISO protocols (OSI) or Internet Protocol Suite (IPS)	

Term	Definition	Source of the definition
ATN-B1	ATN Baseline 1[7], as defined by RTCA DO-280B/EUROCAE ED-110B, consists of the following datalink applications: a) Context management (CM) for datalink initiation capability (DLIC) b) Limited CPDLC for ATS communications management (ACM), ATS clearance (ACL), and ATC microphone check (AMC) Current standards are not interoperable and require dual implementations to support both remote/oceanic and domestic/en-route environments (costly, different procedures, no seamless operational transition, etc.). There is a need for global datalink standards: • ensuring operational and technical convergence; • covering all flight phases (airport, terminal, en-route) and airspace types (domestic, remote/oceanic).	RTCA DO-280B/ EUROCAE ED-110B
ATS-B2/B3	Advanced datalink Air Traffic Services (ATS) Baseline 2 should include: • initial TBO; • surface management; • The Flight Information Service; • continental and oceanic; • and be supported by enhanced (ground/) flight deck automation (FMS Loading,	RTCA SC-214 / EUROCAE WG-78 ED-228A - Safety and Performance Requirements Standard for Baseline 2 ATS Data Communications (Baseline 2 SPR Standard) (March 2016) ED-229A - Interoperability Requirements Standard for Baseline 2 ATS Data

[7] Note that ATN-B1 generally means that the datalink system on an aircraft, the ATSU ground system, and communication service provision comply with the standard as adapted by EUROCONTROL Specification on datalink Services (EUROCONTROL-SPEC-0116).

Term	Definition	Source of the definition
	message accessibility/alerting, conditional clearance monitoring, graphical display). Advanced datalink Air Traffic Services (ATS) Baseline 3 should include additional applications and messages that are not yet defined in detail but which have more stringent performance requirements than ATS-B2. An initial proposal for ATS-B3 requirements has been published in SESAR 1 Project 15.2.4.	Communications (Baseline 2 Interop Standard) (March 2016)
Business case (BC)	A tool supporting planning and decision-making. It is a detailed justification for a project, a policy or a programme proposal, requiring resource allocation and/or investment, often including a financial commitment.	ICAO (2004), doc. A35 WP 13, Report by the Council on Forecasting and Economic Planning
Cost benefit analysis (CBA)	Process of quantifying costs and benefits of a decision, programme, or project (over a certain period), and those of its alternatives (within the same period), in order to have a single scale of comparison for unbiased evaluation.	Business Dictionary (Web Finance Inc.)
ENR-1	ENR-1 airspace is a volume of controlled airspace that encloses the flight paths above and between airports where air traffic service in TMA is provided. Jet routes and airways are typically used to traverse the En-route airspace structure. The typical separation minima in this airspace are 3NM, 5NM, appropriate vertical and/or visual separation as required	SESAR PJ.14 W2 I-CNSS, solution 76, D2.2.300; ED-228A - Safety and Performance Requirements Standard
ENR-2	ENR-2 airspace is a volume of controlled airspace that is characterized by the use of procedural control and the lack of ATS surveillance service. The airspace is typically characterized by the use of flex tracks and customized trajectories but may also use fixed jet routes and	SAR PJ.14 W2 I-CNSS, solution 76, D2.2.300; ED-228A - Safety and Performance Requirements Standard

Term	Definition	Source of the definition
	airways. The typical separation minima in this airspace are 60NM to 100NM lateral, 80NM to 100NM longitudinal, 1000ft (RVSM) as required.	
Net present value	The net present value (NPV) is the sum of all discounted cash inflows and outflows during the time horizon period.	SESAR1 - 16.06.06, ATM CBA for Beginners, D26-01, October 2014
Reference scenario	The scenario against which the solution is compared, i.e., the situation without the proposed solution for SESAR (but including other improvements which have been implemented in the meantime).	SESAR1 - 16.6.X-B.5 Guidance on Scenarios & Assumptions for Primary Project Validation Exercises for Step 1
Sensitivity analysis	Sensitivity refers to the impact a single given input to the model has on the overall NPV.	**SESAR 16.06.06,** ATM CBA for Beginners, D26-01, October 2014
Solution scenario	The scenario with the proposed solution(s) included in SESAR Step 1 and other improvements which have been implemented in the meantime	16.6.X-B.5 Guidance on Scenarios & Assumptions for Primary Project Validation Exercises for Step 1

Table 3: Glossary of terms

2.8 List of acronyms

Acronym	Definition
4D/ i4D	4-dimensional/ initial 4-dimensional
3GPP	3rd Generation Partnership Project
4D/ i4D	4-dimensional/ initial 4-dimensional
4DTBO	4-dimensional trajectory-based operations
4G/5G	4^{th} and 5^{th} Generation of Mobile Telephony standards
A2G	Air to Ground
A/C	Aircraft
ACARS	Aircraft Communications Addressing and Reporting System
ACC	Area control centre
ACDLS	ATS common datalink services

Acronym	Definition
ACM	ATS communications management
ADS-C	Automatic Dependent Surveillance Contract
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Airport Communication System
A/G	Air-ground
AGBR	Air-ground boundary routers
AGMI	Air ground mobility interface
AIS	Aeronautical Information Service
AISD	Aircraft Information Services Domain
AMAN	Arrival Manager
AMC	ATC microphone check
ANSP(s)	Air navigation service provider(s)
AOA	ACARS over AVLC
AOA	ATM/ANS Organisation Approval (AOA)
AOC	Aeronautical operational communication
APNT	Alternative Positioning Navigation and Timing
APT	Airport
ASP	Access Network Service Provider
ATC	Air traffic control
ATM	Air traffic management
ATN	Aeronautical Telecommunication Network
ATS	Air traffic services
ATSP	Air traffic service provider
ATSU	Air traffic services unit
AU(s)	Airspace user(s)
AVLC	Aviation VHF Link Control
BC	Business case
BGAN	Broadband Global Area Network
CAPEX	Capital expenditure
CBA	Cost benefit analysis

Acronym	Definition
CEAB	Common European ATM Backbone
CM	Context management
CMU	Communications management unit
CNS	Communication Navigation Surveillance
COMSG	COM Steering Group (a sub-group reporting to the JCSP)
COTS	Commercial off-the-shelf
CP1	Common Project 1
CPDLC	Controller-pilot datalink communications
CSP(s)	Communications service provider(s)
DAL	Development assurance levels
DCDU	Datalink Control and Display Unit
DLIC	Datalink initiation capability
DL-FEP	Data-link front-end processor
DLS	Datalink services
DME	Distance-measuring equipment
DSD	Digital Sky Demonstrators
DSP	Datalink service provider
E2E	End-to-end
EAN	European Aviation Network
EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EFB	Electronic flight bag
EMOSIA	European Models for ATM Strategic Investment
ENR	En route (see glossary for ENR-1, ENR-2)
EPP	Extended Projected Profile
ESA	European Space Agency
ESSP	European Satellite Services Provider
EUR/NAT	European and North Atlantic
EUROCAE	European Organisation for Civil Aviation Equipment

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Acronym	Definition
FACT	Future All-Aviation CNS Technology
FANS	Future Air Navigation System
FCI	Future Communication Infrastructure
FCI-TF	Future Communication Infrastructure Task Force
FIR/UIR	Flight Information Region / Upper (flight) Information Region
FL285	Flight level 285
FOC	Full operational capability
FTE	Full time equivalent
GANP	Global Air Navigation Plan
GGBR	Ground-ground boundary router
GB-LISP	Ground-based Locator Identifier Separation Protocol
GEO	Geostationary Earth Orbit
HC	High-complexity (airport)
HW	Hardware
I-CNSS	Integrated Communication Navigation Surveillance and Spectrum
IATA	International Airline Transport Association
ICAO	International Civil Aviation Organization
IETF	Internet Engineering Task Force
IFC	In-flight connectivity
IMT	International Mobile Telecommunications'
IOC	Initial operational capability
IPS	IP (Internet protocol) suite
ISO	International Organisation for Standardisation (a United Nations Agency)
ISP	Iris service provider
JCSP	EASA/EUROCONTROL Joint CNS Stakeholder Platform
JURG	Joint Users Requirements Group
Ka/Ku	Kurz-above/Kurz-under
KPI	Key Performance Indicator
LC	Low-complexity (airport)
LCS	Light Cockpit SATCOM

Acronym	Definition
LDACS	L-band Digital Aeronautical Communication System
LEO	Low Earth Orbit
LTC	LDACS Transition Concept
LTE (LTE/4G)	Long term evolution
LoS	Line of sight
MET	Meteo
MoC	Memorandum of Cooperation
MSE	Mobility service endpoint
NAV	Navigation
NewPENS	New Pan European Network Services
NDTECH	Network Directors of Technology
NMOC	Network Manager Operations Centre
NG	Next Generation
OEM	Original Equipment Manufacturer
OPEX	Operating expenses
ORP	Oceanic, Remote and Polar
OSI/ISO	Open Systems Interconnection (ISO protocols)
OTS	Off-the-shelf
PAR	Performance Assessment Report
PAX	Passengers
PBCS	Performance-Based Communications and Surveillance
PIRM	Programme Information Reference Model
PISD	Planned In-Service Data
PJ.14-W2 I-CNSS	Project 14, SESAR2020 Wave 2, Integrated CNS and Spectrum
PKI	Public Key Infrastructure
PRB	Performance Review Body
QoS	Quality of service
RCP	Required communication performance
RCTP	Required Communication Technical Performance

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Acronym	Definition
R&D	Research and development
RF	Radio frequency
RSP	Required surveillance performance
RSTP	Required Surveillance Technical Performance
RTCA	Radio Technical Commission for Aeronautics
SAA	System Application Architecture
SAL	Security assurance levels
SATCOM	Satellite communication
SATCOM NG	SATCOM New Generation
SB-S	SwiftBroadband-Safety
SDM	SESAR Deployment Manager
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SLA	Service level agreement
SRA	Security Risks Assessment
SSR	Secondary Surveillance Radar
SUR	Surveillance
SWIM	System-wide information management
TBO	Trajectory-based operations
TMA	Terminal manoeuvring area
TMB	Top management board
TRL	Technology readiness level
U-space	Unmanned airspace
USBG	University of Salzburg
VDL / VDL-2	VHF Digital Link /VDL Mode 2
VDR	VHF data radio
VHF	Very-high frequency
VPN	Virtual private network

Table 4: List of acronyms

3 Objectives, scope and methodology of the business case

3.1 Problem statement

The current air-ground communication technologies in place for the ATM services, i.e., VHF voice, VDL-2 and the current version of the SATCOM technology, may not be sufficient to support both AOC and ATC services (ATS-B2/B3) in future and will not be able to meet the coming security requirements. There is therefore a need for a new secured communication infrastructure and technologies which will provide the expected level of performance to support new airspace design and applications, a typical example being the 4D trajectory-based operations (4DTBO), which cannot be achieved without providing a higher secured datalink communication capacity.

In addition, the VDL-2 network will rapidly reach its limit in the European airspace core area owing both to:

- the limited capacity and technical characteristics and performance of the VDL-2 technology, and
- the renewal of the fleet with new models of aircraft which will consume more data for AOC and ATC communications.

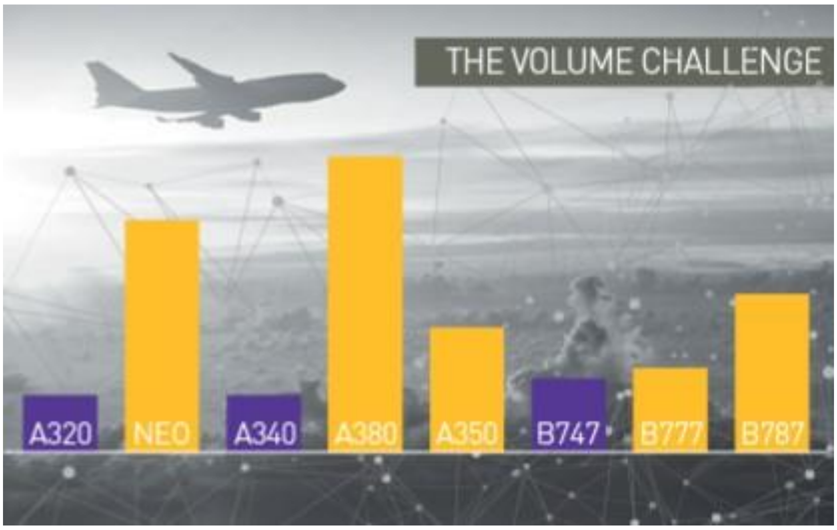

Figure 2: Data exchange with new aircraft vs. old aircraft (source: SITA)

As indicated in Figure 2, those new aircraft will contribute to increasing the congestion of the VDL-2. The current projection of AOC (aeronautical operational communication) and ATN (aeronautical telecommunication network) data traffic in European airspace reveals possible congestion between 2024 and 2027 (Figure 3), even with the off-loading of AOC traffic onto other media at the airport.

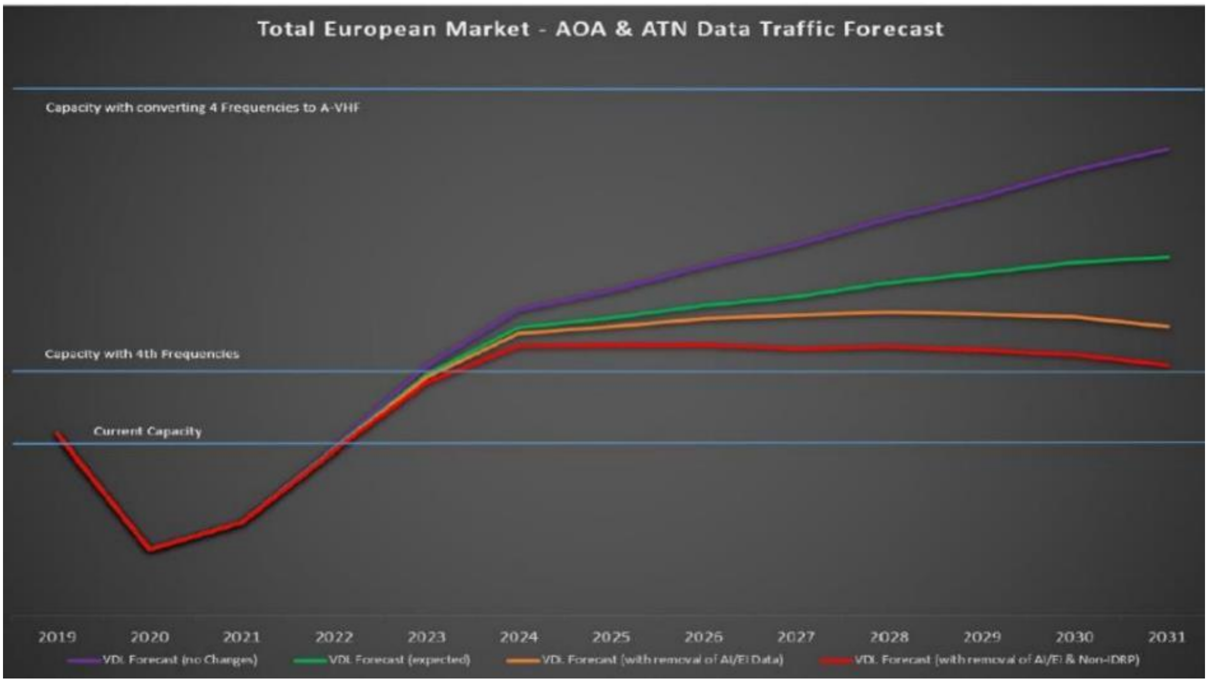

Figure 3: Congestion of VDL-2 traffic (source: Collins Aerospace)

In addition, the possibility of offloading part of the VDL-2 traffic by reducing the volume of AOC data exchanged using other means of communication such as AeroMACS or 3G / 4G at the airport remains limited. This is also true for en-route AOC traffic. According to the airlines, this could not exceed 15% of the current AOC traffic volume with the current level of equipage.

AOC data are crucial for critical applications such as the electronic flight bag (EFB), the system used for instance to calculate and optimise fuel loaded before take-off, or for the predictive maintenance of aircraft engines, which require more and more in-flight data exchange. To optimise their operations and the impact on the environment, airlines must rely on the required availability of the A/G communication infrastructure.

The VDL-2-enabled CPDLC (controller-pilot datalink communications) system can provide benefits and capacity in the short term, but in the long term it is expected to be complemented by new datalink technologies and applications with increased capabilities and performance, supporting more stringent operational requirements: satellite communications (SATCOM NG), the L-band Digital Aeronautical Communication System (LDACS) and the Aeronautical Mobile Airport Communication System (AeroMACS). The ATM Master Plan envisages that this next generation of aeronautical communication infrastructure will be service-oriented and performance-based, in order to support the rationalisation, reliability and efficiency of the communication capabilities.

VHF and VDL-2 technologies will remain operational for a long time. New technologies will therefore need to be implemented in a "soft" way in order to ensure interoperability with the existing infrastructure and to maintain safety.

3.2 Objectives of the business case

The purpose of the business case is to analyse and compare several new communication technologies which are becoming mature[8] to support air-ground communication in order to provide the Network Director of Technologies (NDTECH) group with the relevant information/justifications allowing them to recommend the best communication system for the future of ATM communications and drive future decisions. This new data communication technology, or combination of new data communication technologies, will come on top of the existing ones during a transition period, i.e., VDL-2 for the terrestrial area and the current version of SATCOM technology for the oceanic part.

The purpose of the business case is not to determine whether a new communication technology is needed. It is to identify the best communication technology and services which need to be deployed in the near future to support the air traffic management (ATM) new concept of operations as envisaged in SESAR 2020 and forthcoming SESAR3 programmes.

The business case will analyse all the potential candidate technologies which are matured enough to be deployed in the next coming two to five years. Several solution scenarios, mixing current and future technologies, will be identified and analysed, and the BC will determine which solution scenario best meets the expected requirements for the best value.

The selected solution scenario should serve a dual objective:

- In the short term, it should provide the capacity and the performance where and when needed, contributing to offloading the saturated VDL-2 datalink communications.
- In the medium to long term, the new technologies should support future ATS-B2/B3 requirements, paving the way for a truly integrated CNS infrastructure.

[8] For more information about how the maturity level will be assessed, see section 3.4.2.1.

The BC will not only look at the cost impact of implementing each technology/solution scenario separately but will also take into consideration other qualitative elements which are key for the decision-making process. Among other criteria, the business case will consider:

- the actual level of maturity of the technology;
- the ability of the technology to meet aviation safety and security requirements;
- the capability of the solution to evolve, be scalable, and to support future services, including navigation and surveillance services;
- the ease of integration with existing technologies and the ability to implement the technology quickly;
- the level of investment which might initially be required and the level of technical, commercial and financial risk generated as well as the possible mitigation actions;
- the global endorsement which could be expected from the community, without the need for binding regulations.

The high-level objectives of the FCI-BC should be to:

- provide a clear business analysis, for all the stakeholders engaged in the implementation of the European FCI (including the European Commission), of the current level of maturity and performance of the available communication technologies to support current and future ATS services.
- identify and evaluate the cost elements related to the implementation of the A/G communication infrastructure of each solution scenario.
- deliver clear outcomes to the JCSP for the preparation of a detailed communication roadmap and planning for the best solution scenario implementation.

These high-level statements may be further complemented by the following set of detailed objectives for the business case activity:

- Evaluate other non-costs related elements which are key for the decision-making process and compare the solution scenario against a set of agreed and important qualitative criteria.
- Determine the minimum level of aircraft equipage and ground investment which would be required and prepare a set of recommendations for acceleration of implementation, including potential incentives and the need for a mandate.
- Identify any risks or show stoppers in the deployment which could prevent implementation of the solution or could affect the synchronisation of air and ground investment, and propose possible mitigation actions.

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The FCI-BC provides a rough and global cost estimate for the implementation of each of the solution scenarios identified to support future ATC services. The estimate is based on a set of assumptions and does not claim to achieve 100% accuracy. Moreover, this BC does not provide results for specific local deployments or individual entities or companies. It will be the role of the SESAR Deployment Manager to confirm the assumptions and the deployment scenario approach considered in this analysis, and additional surveys may be needed at the time of deployment.

3.3 Scope of the business case and limitations

3.3.1 General scope

The FCI-BC analyses and compares the four solution scenarios (see section 3.5.1) identified and approved at JCSP#5 (May 2021):

- Three of the four scenarios identified will look at implementing a single new communication technology: LDACS, OFF-THE-SHELF technologies (such as 4G, 5G, etc.) and SATCOM New Generation (NG).
- The fourth scenario will look at a multilink approach, i.e., a mix of several new communication technologies to support future ATC services at the airports, in the TMAs and in the en-route segment. The scenario as currently developed by SESAR includes LDACS, SATCOM NG, and AeroMACS new communication technologies, but at the request of the airlines and as recommended by the JCSP#5, the BC will consider the OFF-THE-SHELF technologies (OTS) rather than AeroMACS as part of the multilink approach, in case it is confirmed that such technologies can support critical applications and provide the expected level of performance.

All scenarios look at deployment and integration into the existing infrastructure of new mature communication technologies which are planned to support ATN-B1 and ATS-B2/B3 (data) services for air/ground data exchange. All scenarios look at complementing existing technologies (VHF voice, VDL-2 on the terrestrial part) and not replacing them, at least for a certain period, until those technologies become obsolete and are decommissioned.

As indicated in Figure 4, the scope of the BC will be limited to the connection to the ground infrastructure, i.e., the connection to the Common European ATN Backbone (CEAB), and the implementation of the A/G architecture to cover the whole ICAO European region.

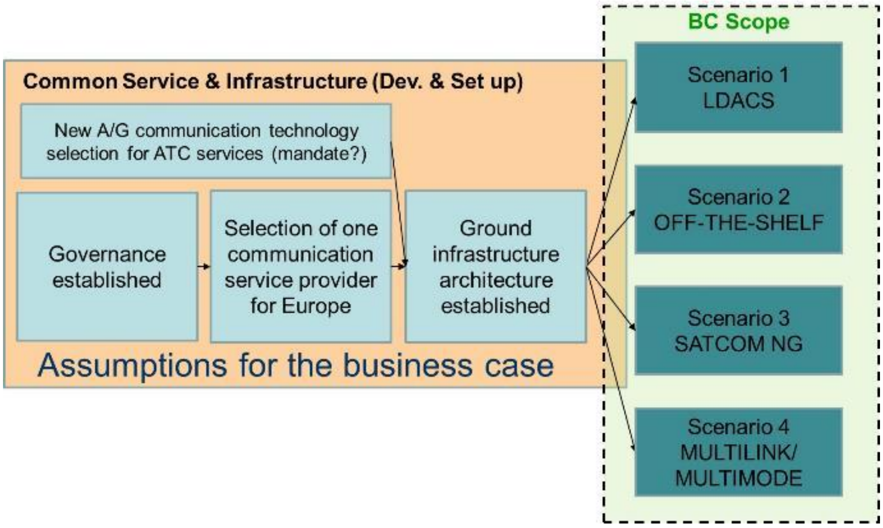

Figure 4: Scope of the FCI business case

The BC will not consider the costs and benefits of setting up the datalink service provider (DSP) or the service provision, the governance and the CEAB, and will assume that those elements will be in place before deploying one of the four solution scenarios. For more information regarding the BC assumptions and in particular those related to the DSP and the datalink service (DLS) provision, see section 4.2.

3.3.2 Operating environment applicability

Not all communication technologies are applicable and/or available in all categories of airspace and for all phases of flight. However, the FCI business case addresses all airspace categories and all phases of flight.

The FCI-BC will focus on the applicability of new communication technologies in the domestic airspace. Nevertheless, as few solutions such as the SATCOM NG also cover the oceanic area, this will be pointed out as an advantage of those technologies in the qualitative assessment.

Table 5 and Table 6 below show which communication technologies are currently used as part of the reference scenario, i.e., in the business-as-usual scenario, for each type of airspace category and phase of flight. Communication technologies are either:

- mandatory, i.e., aircraft must be equipped at the specified flight level or phase of flight; or
- available, i.e., the technology/service is available but there is no obligation to be equipped.

Flight Level / Technology	Existing COM technologies			New COM technologies		
	VHF Voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
Airspace > FL245	Mandatory	Mandatory	Available			
500 feet < airspace < FL245	Mandatory	Available	Available			
Airspace < 500 feet	Mandatory	Available	Available			

Table 5: Reference scenario – communication technologies by flight level

Phase of flight / Technology	Existing COM technologies			New COM technologies		
	VHF Voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
En-route – oceanic	Mandatory (air to air)	None	Mandatory (PBCS) (*)			
En-route – terrestrial	Mandatory	Mandatory	Available			
TMA – approach	Mandatory	Available	Available			
Airport – ground operations	Mandatory	Available	Available			

Table 6: Reference scenario – communication technologies by phase of flight

(*) the SATCOM NG terminal also provides legacy services (namely FANS 1/A) in addition to ATN services: the solution thus also covers the oceanic area.

The U-space regulations (for unmanned systems) approved on 23.04.21 are not considered in this business case for FCI because the maturity level of the U-space services is not currently compatible with the target delivery date of this document:

- The geographical zones in which the U-space regulations will apply have not yet been defined.
- The U-space services applicable in the U-space airspace have not yet been fully identified, described and specified.
- The performance requirements of the communication infrastructure supporting these services have not been published.
- The technologies supporting these communications have not yet been selected. Exploratory research projects (e.g., SESAR FACT) are currently investigating the applicability of certain COTS (commercial OFF-THE-SHELF) technologies to support certain U-space services.

U-space may be included in a future update of this FCI business case once the U-space services and the communication technologies which support them have reached a sufficient level of maturity, including standardisation.

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3.3.3 Geographical applicability

The geographical scope of the FCI business case is the domestic part of the EUROCONTROL Member States airspace, as shown in Figure 5.

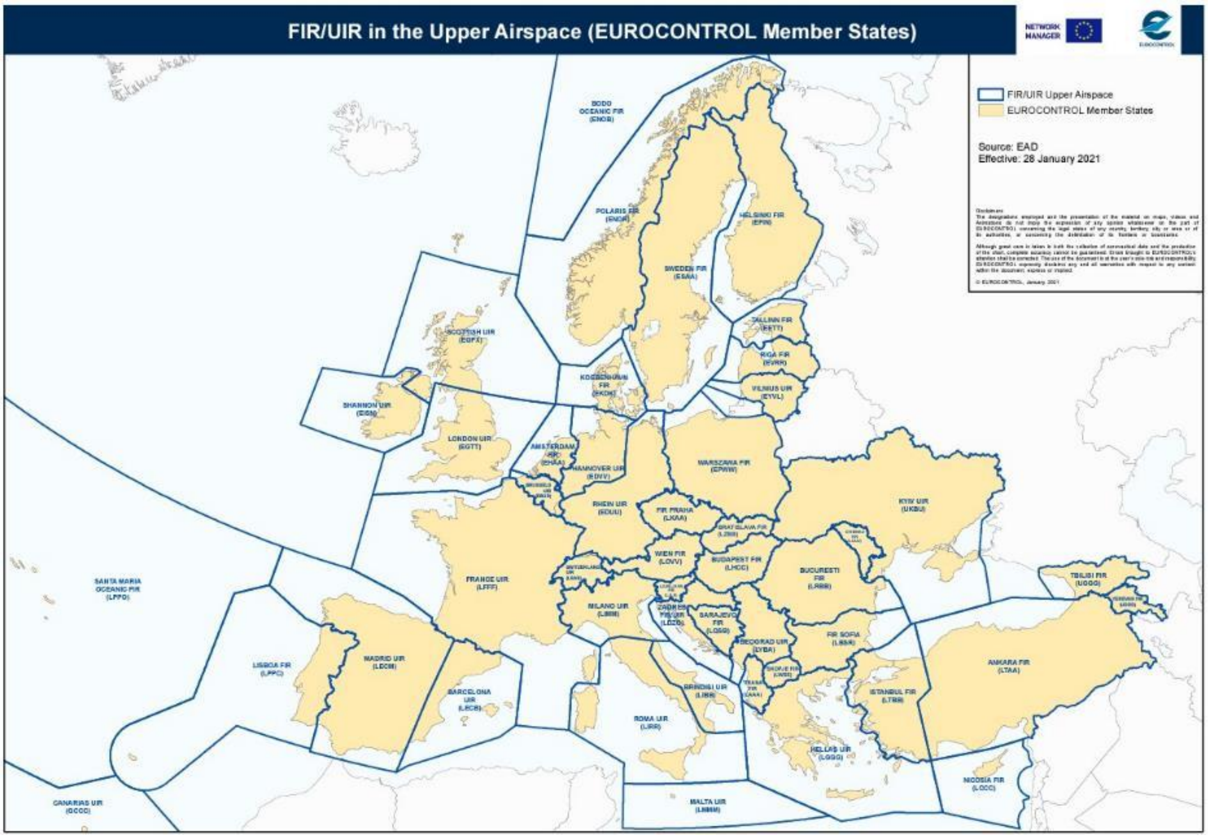

Figure 5: FCI-BC – Geographical scope

It should be noted that potential exceptions for implementation are excluded from this document and it is assumed they will be coordinated with the SESAR Deployment Manager, when it comes to regulated implementations. For example, Commission Regulation (EC) No 29/2009 (the datalink implementation rule) currently excludes the implementation and use of ATN-B1 in Sweden and Finland UIR north of 61°30´, whereas this exception is no longer mentioned in Commission Implementing Regulation (EU) No 716/2014.

3.3.4 Time horizon

The business case will consider a 19-year period for analysis (from 2021 to 2039) of all potential costs and benefits of the four solution scenarios identified.

3.4 Business Case approach and methodology

This business case uses the EMOSIA[9] methodology for cost-benefit analyses (CBA), developed by EUROCONTROL for the ATM/CNS community and extensively used in the development and production of SESAR 2020 CBAs for several operational solutions.

The objective of the EMOSIA method is to accompany R&D projects in their concept development with the objective of facilitating the decision-making by understanding the global impact on ATM performance of any operational change, thus reducing the investment risk. The outcome of a CBA is to provide an estimate of the costs and benefits of a solution with a view to its deployment.

However, the methodology has to be adapted to fit the needs of a technological solution. Operational benefits are not directly linked to the enabling technologies but to the operational changes made possible by these technologies. Only the operational solutions can estimate the gain in terms of airspace/airport capacity, flight efficiency, predictability, punctuality, etc. which the operational changes will bring.

It is therefore assumed that the new communication technologies which are considered in this analysis will provide the same operational benefit to the SESAR operational solutions they are supporting. Only the intrinsic performance of these technologies will be compared.

The methodology used to assess the different solution scenarios identified in the FCI-BC, includes the following:

1. **A cost assessment to estimate the costs of implementing each solution scenario separately**

   The cost assessment is limited in scope to the costs of the air/ground segment of the communication infrastructure (including the connection to the CEAB) and the costs of the service provision supported by the ANSPs for ATC traffic. Airborne equipage will be based on a fleet projection, which will take into account assumptions regarding the impact of COVID-19. The assessment will not consider the costs to support other CNS services such as navigation and surveillance.

[9] EMOSIA: European Models for ATM Strategic Investment

2. **A qualitative assessment of each communication technology to feed the needs of the Future Communication Infrastructure and to be rapidly implemented**

The qualitative assessment will look at a set of predefined and agreed criteria and will analyse the benefits which each technology can bring to the FCI. Those criteria, which are not necessarily easy to quantify and monetise, are essential for the decision-making process. Similarly, as the various technologies considered do not have the same maturity level, hence cannot be deployed at the same time, the benefit evaluation will also consider the benefits of early introduction of one technology for ATM and AOC. The analysis will also look beyond the communication aspect and will consider the capability of the technology to evolve and to serve other communication, navigation and surveillance (CNS) services.

The objective of this qualitative assessment is to provide a big picture of the ability of each technology to meet the performance, safety and security requirements, to evolve over time, to be implemented quickly without the need for binding regulations, and to be well accepted by all the actors.

3.4.1 Cost assessment

The business case will provide as an output a cost estimate of the following:

- **For airspace users**: an estimate of the airborne investment required to equip their aircraft (forward-fit only) with the new communication technology. It encompasses the cost of the equipment on-board and all associated costs (certification, installation and modification of existing wiring, software upgrades, etc.) including any additional OPEX (such as maintenance, recurrent training, etc.) which the new technology could generate on top of the reference scenario.

- **For ANSPs**: an estimate of the service fees which all ANSPs in the EUROCONTROL Member States area will have to support for the provision of the datalink service with the new communication technology envisaged in each of the solution scenarios.

Table 7 below indicates the cost elements which are considered/not considered in the analysis. For more information on the service provision and on the architecture assumptions, see sections 4.2.2.1 and 4.2.2.2.

Cost item	Cost element	In/out of the cost assessment
DLS governance set-up and operations	**CAPEX and one-off costs** • Initial effort and investment required to put in place the governance	OUT
	OPEX • Operating costs of the governance bodies (office rental, staff costs (permanent), effort and mission costs for participation in governance bodies, documentation, overheads, etc.)	OUT

DSP selection process	**CAPEX and one-off costs:** • Effort to launch a call for tenders, to select and establish the DSP (including the re-tendering process) and to sign an MoC with the ANSPs	OUT
DSP set-up and operations	**CAPEX and one-off costs** • Effort to set up the DSP. This includes the certification of the DSP	OUT
	OPEX • Operating costs of the DSP, including annual audit/certification costs	OUT
CEAB set-up and operations (baseline)	**CAPEX and one-off costs** • Investment and initial effort to set up the CEAB infrastructure. This includes the ground/ground (G/G) routers located in the ATN backbone and on the ANSPs' premises	OUT
	OPEX • Operating costs of the CEAB	OUT
CSP(s) selection process (launched and managed by the DSP)	**CAPEX and one-off costs** • One off costs to launch a call for tender, to select and sign a contract with one or more CSP(s) (or a consortium of CSP(s)) for the service provision for each new communication technology (including the re-tendering process) This includes the contract signed between the CSP and all the ANSPs in the ICAO European region (including the re-tendering process)	OUT
CSP(s) – costs of setting up the A/G COM infrastructure and running costs	**CAPEX and one-off costs** • Investment required for the sub-network and the service set up	IN (costs are integrated in the service fees paid by the ANSPs)
	OPEX • Operating costs of the CSP	IN (costs are integrated in the service fees paid by the ANSPs)
Interface to the CEAB of all the ANSPs (for the provision of the ATC traffic)	**CAPEX and one-off costs** • Interface for all the ANSPs to connect to NewPENS (TBC)	OUT (costs borne directly by the DSP)
	OPEX • Additional VPN required connecting to NewPENS. The new VPN will be dedicated to A/G communication with the following assumptions:	OUT (costs borne directly by the DSP)

	- Dedicated VPN, targeting all the ANSPs connected to PENS plus five external partners (industrial partners) - 500kB/s for each ANSP, 2Mbp/s for the five industrial sites which will host the servers/gateways)	
New communication technology standardisation and certification costs	**CAPEX and one-off costs** • Costs of the certification and standardisation It is assumed that: - technologies will be certified and standardised before the start of the deployment - the DSP will be certified, so that there is no need to certify the infrastructure (tbc)	OUT for the DSP IN for the certification in the a/c of the technology, as it should be included in the cost of the equipment
	OPEX • Recurrent service fees paid by the ANSPs for certification	OUT (it is assumed that the DSP will be certified by EASA)
Sub-network on-board communication equipment and associated costs	**CAPEX and one-off costs** • Cost of the on-board equipment (radio + antenna + airborne software adaptations). This includes installation costs and decommissioning of existing equipment, if required Costs are provided for forward-fit only, as it is not envisaged in the BC to retrofit aircraft • Initial training for the crew	IN (costs supported directly by the AUs)
	OPEX • Maintenance of the on-board equipment • Recurrent training for the crew and support engineers	IN (costs supported directly by the AUs but no additional OPEX are envisaged over and above the reference scenario for ATC traffic
Sub-network ground stations and associated costs	**CAPEX and one-off costs** • Gateways to connect the sub-network to the CEAB (modification for the new technology) • Supervision infrastructure for new technologies (new infrastructure or adaptation of current infrastructure) • Ground stations (radio + antenna + software development + installation costs + cost of decommissioning existing equipment, if needed + adaptation/cabling of premises) • Initial training of staff (CSP support engineers and operational staff)	IN (included in the service fees paid by the ANSPs)
	OPEX • Maintenance of all ground equipment	IN (included in the service fees paid by the ANSPs)

	• Recurrent training for the support engineers and operational staff • Communication costs (G/G and A/G)	

Table 7: FCI-BC – Scope of the cost assessment

The BC will use a delta approach, i.e., estimating the investment and operating costs required to implement each solution scenario compared with the reference scenario (see section 3.5). This means the following:

- Only the additional elements required on top of what already exists in the reference scenario will be considered in this analysis. For example, if the maintenance costs paid by airlines for the current technology on-board do not increase with the new technology, no additional OPEX costs will be recorded.
- Past investment will in principle not be considered. Nevertheless, the service fees charged to the ANSPs by the CSPs may include annual amortisation of existing equipment which is not fully amortised at the time when the solution is implemented. Service fees will be accounted for as at the IOC (initial operational capability) date. This could be the case for example for the satellite infrastructure. Note that costs included in the ANSP service fees should concern only the ATC traffic and need to be calculated proportionately.
- The vast majority of the investment will be borne by the CSPs. The one-off costs and CAPEX investment incurred by the CSPs to set up the sub-network will be amortised and charged back to the ANSPs through annual service fees, together with their operating costs (OPEX).
- Any investment borne by the ANSPs and not already included in the service fees, will be accounted for the year they occur, or split linearly between the start-date and end-date of the deployment phase. Renewal cycles up to the time horizon of the analysis should be included as well.
- For a fair comparison between solutions scenarios and if needed, the residual value of the equipment not fully amortised at the end of the time horizon may be reintegrated as part of the cost assessment (not valid for service fees).
- The cost assessment will be based on a new fleet and traffic forecast (2021-2039) taking into account the impact of the COVID-19 crisis, which will be valid for all the solution scenarios. As there is no STATFOR long-term forecast already available, the forecast will be prepared by EUROCONTROL for the purpose of this business case, taking into consideration the latest information regarding the pandemic (see section 4.3 Traffic and fleet projection). An update of the FCI-BC may be needed once the new STATFOR long-term traffic forecast becomes available after the delivery of this BC (2022).
- Airborne investment will be estimated on the basis of a projection of the fleet which is flying the most in Europe (the target fleet). The focus will be on the forward-fitting aircraft, as one of the objective of the FCI-BC is to avoid retrofitting aircraft.
- In addition, although the air and ground infrastructure will be shared between AOC and ATC traffic, the costs related to the provision of the service for AOC communication are

outside the scope of this analysis. Consequently, **any OPEX related to AOC communication needs have not been considered**, nor have the additional ground investment which the airlines may have to bear for their own AOC communication infrastructure. Nevertheless, it has been decided for purposes of clarity to present the total cost of the equipment on-board for airlines and not the cost in proportion to ATC communication needs only.

- Referring to Table **1**: FCI-BC results – summary table, the above bullet explains the absence of OPEX for AUs since AOC costs are not in the current scope (and are also not publicly released). AU A/G communication costs related to ATC needs are actually paid by ANSPs and reflected as OPEX via route charges, which also include the amortized ANSP CAPEX.
- Also note that AOC OPEX costs for AU are influenced by the technology choice they would make, i.e. LDACS/COTS/SATCOM, but this is also not taken into account. As such, **this BC should be refined with AOC costs from AU for more accurate investment predictions**.

The results of the cost assessment will be presented globally and for the main users of the service, i.e., the ANSPs and the airspace users. The costs for the industry and for the communication service providers are not presented but are included in the cost of the equipment supported by the airlines and in the service fees paid by the ANSPs.

The costs of governance, and those of the DSP and the CEAB are outside the scope of this analysis. Nevertheless, it is assumed that these costs will be the same for the four scenarios analysed.

The costs are based on the common assumptions developed in section 4.2 Assumptions for the BC. The four scenarios may however, present differences which will be further developed and assessed in the detailed analysis of the scenarios.

For a fair comparison of the different solution scenarios, all cost estimates will be made on the basis of the same hypotheses, but the timeframe for deployment linked to the maturity level of the four solutions will be taken into consideration in the presentation of the cost assessment results.

3.4.2 Qualitative assessment

In addition to estimating the deployment costs, a qualitative assessment will be made of the different scenarios in order to compare the solutions against key criteria for the decision-making process. The following criteria have been identified:

- Maturity level of the solution, including status of activities related to safety and security requirements
- Performance of the technology in terms of bandwidth, latency, availability/continuity of service, applicability to safety-critical applications and the quality of service (QoS), etc.
- Capability of the technology to support future evolutions (scalability, capacity, coverage, etc.)
- Ease of deployment (buy-in from stakeholders, synchronisation of investment, time to market, etc.)
- Financial aspect (importance of the upfront investment, need for incentive and/or regulation, third party business viability, etc.)

The FCI-BC will point out any potential differences between the four solution scenarios against those criteria.

3.4.2.1 Maturity level/operational readiness

New communication technologies have not reached the same level of maturity and are not all ready to be deployed. This will have an impact on the progressive equipment rate of the fleet and the traffic, and on the ability of the solution to decongest VDL-2 traffic. What will be important in the comparison of the four scenarios is the ability of each solution to reach a sufficient number of equipped flights when the VDL-2 network begins to be saturated, i.e., between 2024 and 2027.

Each solution has been asked to provide an estimate of their maturity level, looking at:

- the maturity of the technology, by indicating what is the current technology readiness level (TRL) and what is the expected TRL at the end of SESAR2020 Wave 2 (late 2022/early 2023). All solutions analysed in this BC are expected to reach TRL-6 no later than 2025 except the COTS which has a lower TRL;
- the state of the infrastructure, i.e., the status regarding the establishment of the infrastructure, including service delivery and operational readiness, and when the first aircraft can potentially be equipped with the new technology. An IOC (initial operational capability) date is expected to be provided for each technological solution;
- the status of the validation of the technology and related infrastructure elements. In particular, solutions should confirm whether the technology has been validated for both ATN/OSI and ATN/IPS standards and when both capabilities will be available;

- compliance with safety and security requirements. In the context of SESAR2020 work, each technological solution should carry out a safety risk assessment and a security risk assessment and each solution will have to meet the maturity gate criteria for safety and security requirements. Each solution should provide an indication of the status of safety and security activities;

  For security, reference is made to the security risk assessment methodology for SESAR 2020, which provides the methodology and practical guidance when preparing a cybersecurity risk assessment. It presents the requirements for demonstrating that ATM security has been addressed, thus ensuring that the outcome is a securable solution;

  Security risk assessment is a process to identify and mitigate the consequences of an attack. It defines a set of security requirements to ensure that if an attack takes place the consequences have been estimated, can be managed, and can contribute to the recovery of normal operations in a reasonable time;

  Note that a technological solution which does not meet the maturity gate criteria for safety and security would be considered as non-compliant for the FCI-BC and would not be considered as a potential candidate for deployment;

  If a solution can demonstrate that safety and/or security can be improved or goes beyond the minimum required, this should be pointed out as an advantage of the technology and presented as part of the qualitative assessment of the benefits of the solution;

- existence of standards and status of certification activities (ATS), i.e., whether AEEC/RTC/EUROCAE standards already exist or are under development, and when certification is expected for ATS;

- compatibility of the technology with existing aviation systems, i.e., whether spectrum allocation in the aviation domain is available for the technology and whether tests have been carried out to confirm that there is no interference with existing aviation systems which could affect safety.

3.4.2.2 Performance

Although the operational benefits are not directly related to the technology which will be selected to support ATS communications, it is important to verify that the technology is reliable and can provide the expected level of performance, and this performance can vary from one technology to another. Each solution scenario should confirm that the technology is compliant with ICAO RCP 130, which includes compliance with latency, availability, integrity and QoS requirements.

3.4.2.3 Benefits and potential evolution of the technology

Some of the solution scenarios analysed in this BC may provide additional benefits beyond just support for voice and data communications, such as support for navigation and surveillance services. These advantages should be highlighted, and the potential evolution of the technology in an integrated CNS approach is an important element to be taken into account in the decision-making in order to best optimise the FCI infrastructure and contribute to its rationalisation.

3.4.2.4 Ease of deployment and financial aspect

The success of the deployment will depend on the adoption of the technology by the main users (ANSPs and AUs), the facility with which the technology can be integrated with existing systems, the ability to synchronise ground and air investment, and the impact the solution will have on the operations and on the business model of the main players.

Each solution scenario has developed a risk analysis, identifying all critical elements which may affect the deployment of the solution, as well as possible mitigation actions, addressing the following questions:

- Is there an overall buy-in from the main stakeholders for the deployment and adoption of the new communication technology?
- Will the technology require major upfront investment for the AUs? To what extent will they be able to finance the investment? Will it be easy to reach the minimum equipage rate required without retrofitting the aircraft? Is there a need for incentives and/or regulation?
- Can we expect a global coverage on the ground or rather a scalable deployment? Will it affect the ANSPs' Single European Sky performance targets? Is there a need for incentives and/or regulation?
- What could be the impact of the new technology on the operations? Will it negatively affect the business model of the actors in place?
- Is there enough viable business for the industry? What is the minimum equipage rate required to guarantee a viable business? Is a mandate needed in order for the critical mass to be quickly reached?
- What are the possible showstoppers or constraints which could prevent the solution from being deployed, could have an impact on the overall roadmap, or increase the transition period?

3.5 Solution and reference scenarios

The business case does not compare the solution scenarios with the baseline scenario (also called the reference scenario) as it is not an option, but compares the solution scenarios with one another.

Nevertheless, it is important to understand how the reference scenario will evolve during the period of analysis, as it serves as a basis for identifying what will be the main changes brought about by each of the solution scenarios.

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3.5.1 Solutions scenarios

To answer the dual objective of offloading the VDL-2 traffic and supporting the introduction of ATS-B2/B3 in the context of the FCI, four solution scenarios are envisaged and are compared in this business case. The four scenarios are as follows:

- **Scenario-1 – LDACS**

This scenario looks at implementing a service-oriented solution, using the LDACS standardised technology operating in the aviation spectrum.

In this scenario, it is assumed that new aircraft will be equipped with both the existing technologies (VHF, VDL-2 for the terrestrial part, and the current version of SATCOM for the oceanic part, where needed) and with the LDACS technology.

At full operational capability (FOC), all ANSPs in the EUROCONTROL Member State area should provide communication services which could be based on VDL-2 and LDACS on the ground through a common contract, which will be managed by the DSP.

- **Scenario-2 – OFF-THE-SHELF**

This scenario looks at implementing a service-oriented solution using any off-the-shelf technology, i.e., commercial off-the-shelf technologies such as 4G/5G or the SATCOM Ku/Ka bands, currently available on the market and operated through an aviation or non-aviation operator.

In this scenario, it is assumed that new aircraft will be equipped with both the existing technologies (VHF, VDL-2 for the terrestrial part, and the current version of SATCOM for the oceanic part, where needed) and at least one of the off-the-shelf technologies envisaged (airline choice). There are potentially two off-the-shelf technologies which are suitable for aviation and could be implemented: 3-4-5G telephony services and SATCOM in the Ku/Ka bands.

At FOC, all ANSPs in the EUROCONTROL Member State area should provide the off-the-shelf communication service on the ground through a common contract, which will be managed by the DSP.

- **Scenario-3 – SATCOM NG (new generation)**

This scenario looks at implementing a service-oriented solution based on SATCOM NG aviation services. It should be noted that although the assumption for the BC is that the DSP will select one service provider (or a consortium), the possibility is not excluded in this scenario that there will be more than one contract signed on behalf of the ANSPs, at least with the two operators in place, in order to maintain competition in the market.

In this scenario, it is assumed that new aircraft will be equipped with both the existing technologies (VHF, VDL-2 for the terrestrial part) and the SATCOM NG (new generation), which will cover both the terrestrial and the oceanic domain, where applicable.

At FOC, all ANSPs in the ICAO EUR region should provide the SATCOM communication service on the ground through a common contract, which will be managed by the DSP on behalf of the ANSPs. It should be noted that in the context of the SATCOM scenario, the coverage will be wider than that referred to in the IOC (initial operational capability), i.e., the service will be global as from day 1.

- **Scenario-4 – MULTILINK/MULTIMODE**

This scenario looks at implementing a service-oriented solution using several new communication technologies (LDACS, SATCOM NG and OFF-THE-SHELF technologies) in a multilink approach.

In this MULTILINK/MULTIMODE scenario:

- airlines will have the choice to select, from among a set of recommended and certified technologies, the one(s) they want to install on-board. It is assumed that aircraft flying in oceanic airspace will be equipped at least with the SATCOM NG;
- all the recommended technologies will be implemented on the ground.

At FOC, all ANSPs in the EUROCONTROL Member States area should be in the position to provide the ATC datalink service for all the recommended technologies. There will be a common contract for all the ANSPs and for all the new communication technologies, which will be placed and managed by the DSP.

Whatever the scenario, all these new communication technologies will operate on top of the existing mandatory terrestrial technologies (VHF, VDL-2/ATN/OSI).

Depending on the solution scenario, the IOC and FOC dates may vary, as not all solutions have the same level of maturity. Nevertheless, it is expected that each solution scenario will be deployed in a phased approach, as described in section 4.2.3 Deployment assumptions.

In all scenarios, only forward-fit aircraft will be considered, gradually reaching 85% of the FL285 traffic (i.e., 85% of traffic involving aircraft flying above FL285). For 2019, this represents a fleet of around 6,185 aircraft (a/c), and at the horizon of 2039, a fleet of 8,564 a/c.

3.5.2 Reference scenario

The reference scenario is the scenario if none of the four solution scenarios is implemented. It can be considered the business-as-usual scenario and serves as a baseline for the solution scenarios. The main changes which could be expected in the reference scenario are described below:

3.5.2.1 Increasing congestion of VDL-2 frequencies

Although the COVID-19 crisis has dramatically affected aviation and stopped net traffic growth, traffic can be expected to increase again as soon as the pandemic is contained, as has been observed in other regions, such as China for example, after the third wave.

Consequently, in the reference scenario, investment in the VDL-2 network will continue, as more frequencies will be needed in order to meet traffic demand, especially in the core area, where the VDL-2 network is starting to be congested. The number of frequencies will increase up to the limit (i.e., currently up to six frequencies, with a potential extension to nine frequencies, see CEF-IP1) in the area where the VDL-2 traffic is already congested. Once the maximum number of frequencies has been reached, the only solution will be to impose a DLS and/or AOC service reduction and/or to use VHF for A/G communication, at least for part of the traffic.

3.5.2.2 Evolution towards ATN/IPS

Looking at potential evolution of VDL-2, standardisation groups are currently completing the development and the standardisation of the ATN/IPS stack, and hence it can be expected that for the reference scenario, conversion gateways and/or multiprotocol aircraft will have to be considered.

3.5.2.3 AOC vs. ATC traffic growth

AOC applications and related communications are vital to daily airline operations. These communications must be provided at the airport (70% of the traffic) but also in the en-route segment (30%) for all flights and for all safety-critical data which need to be exchanged with the airline operational centres, and fully integrated into their IT systems and processes (turn-around management, anticipation, etc.).

For these AOC communications, a high level of safety and availability are required, typical examples being aircraft and engine monitoring data, ground and flight operational data, and the EFB (electronic flight bag).

- Limits to offloading AOC traffic

Currently, most of this data are exchanged over ACARS/VDL-2, contributing to the load and congestion of the VDL-2 infrastructure. Airlines have identified this limitation and are therefore already offloading this low bandwidth channel by pushing AOC data to other means of communication identified as off-the-shelf technologies in the FCI-BC (SATCOM Ku/Ka band, 3-4G, etc.).

Even if they support AOC offloading, airlines consider that current offloading technologies are not mature and affordable enough to allow generalisation of AOC offloading, because of insufficient media availability and performance, high airborne installation costs, costly ground IT system required (hardware and/or licence fees), equipage conditioned to data ownership, etc.

Moreover, airlines do not have hands on some AOC content and transmission rules (airframe/engine manufacturer settings maybe be subject to contractual agreement).

Finally, some settings also require highly skilled trained personnel and tools, which are not available for a significant number of airlines.

Considering the aircraft capabilities and the changes required in the airlines infrastructure, such changes would happen mostly via forward-fitting when new aircraft will be equipped with new communication means. **Consequently, airspace users (see IATA/JURG) estimate that the current VDL-2 cannot be offloaded by more than 15% (on average).**

- Sharing the same infrastructure

AOC and ATC communication share common VHF data and voice communication channels. To avoid the multiplication of technologies on board the aircraft, airspace users consider that all safety-of-life A/G communications, i.e., AOC and ATC communications, must continue to be performed via common communication channels. The present VDL-2 communication infrastructure represents an overall costs in Europe estimated at around EUR 100 million a year for airlines for the AOC service provision.

- Evolution of the AOC communication

AOC communication will continue to increase significantly, as new aircraft exchange two to five times more data than their predecessors, and so in order to avoid saturation of the VDL-2 network, airlines are already equipping new aircraft with modern communication means (such as FANS/IPS and/or IP off-the-shelf services) for passenger and AOC non-safety-related communication. Consequently, the aviation communication infrastructure will continue to develop to reach the 21st century of communication.

4 AU expectations and BC assumptions

4.1 Airlines expectations of the FCI

The current A/G data communication network supports both ATC and AOC applications and services, and so the evolution of this data communication infrastructure will affect both services. Consequently it is important to understand what are the airlines' expectations of the FCI.

Airlines support more data communication for more ATC automation, allowing extra capacity while improving safety. These new automation-related communication requirements must, however, be combined with AOC evolutions in order to allow smooth integration on board the aircraft and enable the overall infrastructure cost to be managed. Consequently, airlines are expecting that the following:

- Any solution retained for the infrastructure need to be based on a global endorsement, avoiding any regional solution.
- Competition must be maintained for the procurement of the ATC and AOC communication service, ensuring that fair and market prices are applied.
- Airlines have a clear preference to move towards fully secured IP communication services, avoiding any proprietary and non-interoperable protocol.
- On the basis of both AOC and ATC requirements, the airlines fully support a multilink solution, allowing competition and reducing all the risks, while meeting the availability requirements and taking advantage of all current or future communication systems.
- Airlines prefer a pragmatic approach in order to optimise communication performance and investment pay back, i.e., using the best available media at the best moment for the best operational and economic performance.
- As different aircraft types/generations may be equipped with various different media, a multilink system must not limit the number of possible input media, whether VDL-2, SATCOM NG, LDACS, SATCOM Ku/Ka, the new LEO satellite system, 4G/5G, or any other off-the shelf technology.
- VDL-2 must continue to remain in operation, because it is currently and will continue be the best adapted for some small operators, and will be needed to accommodate older aircraft which cannot be upgraded with the new technologies and which will still be flying for several years.
- Airlines would appreciate being able to certify the new secured links which they are implementing to support the new AOC/ATC operations.
- Airlines identify the LDACS technology as a good example of modern CNS technology which can meet the requirements, whilst allowing further reduction of the navigation and surveillance infrastructure costs.

Airlines support a communication infrastructure based on a multilink approach which leaves to them to select the best technology/service, in addition to VDL-2, for new aircraft.

From a business point of view, direct airline communication operating costs for AOCs is representing six to ten times the ATC communication costs. In addition, according to the current observations and forecasts, AOC traffic will have more quickly increasing demand for bandwidth, and consequently the evolution of AOC communication must be taken into account in the choice of the new technology.

4.2 Assumptions for the BC

4.2.1 Common assumptions

A certain number of assumptions are generic and common to all solution scenarios.

- Only the technology which can support future FCI ATS services (ATS-B2/B3) on top of ATN-B1 services, and are matured enough to be rapidly deployed, i.e., in the next two to five years, and thus to contribute to offloading saturated VDL-2 datalink communications, are considered in this analysis. The terms ATN-B1 and ATS-B2/B3 should be understood here to mean a bundle of ATC services with common safety and performance requirements.

- Each of the new communication technologies addressed in the scenarios should be able to complement existing technologies (VHF, VDL-2) and to support current and future ATS services (B1/B2/B3).

- Only standardised communication technologies which are already (or will shortly be) certified for aviation, and which are compatible for safety-critical applications are considered in this analysis. Certification and compatibility with aviation standards and requirements should be acquired within a reasonable timeframe, i.e., with a maximum of three to five years.

- It is assumed that the new communication technologies, as enabling technologies, will have no influence on the operational benefits (in term of airspace capacity, punctuality, predictability, etc.) which the SESAR solutions they support can expect. However, the intrinsic properties of these technologies (bandwidth, latency, availability, etc.) may constitute limitations to performance and will need to be analysed and compared as part of the qualitative assessment.

- All scenarios target all terrestrial airspace and support both ATN-OSI/ATN-IPS protocols. It should be noted that the ATN-IPS is envisaged only on top of new technologies (i.e., IPS over VDL-2 is currently NOT one of the scenarios).

- All scenarios are supposed to be performance-based via European service contracts placed by the datalink service provider (DSP).

- All scenarios will assume a three-phase deployment approach, as described in section 3.5.1, with the objective of progressively equipping the target fleet with forward-fit aircraft only.

- All scenarios are based on a fleet and traffic projection developed by EUROCONTROL for the purpose of the FCI business case and described in section 4.3. This projection may be revisited if a new long-term forecast from STATFOR is available after the delivery of the FCI-BC report.

- All scenarios assume a saturation of VDL-2 traffic between 2024 and 2027.

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4.2.2 DLS and DSP assumptions

4.2.2.1 DLS service provision

- There will be a common datalink service (DLS) established for all ANSPs in the ICAO EUR NAT region, and a governance will be put in place to manage the DLS.

- There will be one service provider for the ICAO European region, the DSP (datalink service provider), to provide the communication service to support ATS. The DSP will be selected through an open call for tenders and will be placed under the authority of a single governance body, the ACDLS TMB[10] (ATS common datalink services TMB), which must coordinate with NDTECH.

- There will be a performance-based service contract established for a period of five to ten years. The DSP will have to be certified and will need to guarantee the performance of the service. The DSP may subcontract part or the services to third-party, such as the CSPs for instance.

- The DSP will act on behalf of all the ANSPs which agreed to participate in the common procurement of the services, and will charge ANSPs accordingly. It will be in charge of selecting one or more communication service provider(s) (CSP(s)) to provide the DLS-related communication service via different technologies in all the ICAO/EUR NAT airspace. There will be more than one communication technology used to support ATC services.

- It should be noted that the ACDLS DEB[11] (Datalink Executive Board) will be responsible for selecting and deciding, after consultation with the stakeholders through NDTECH, what communications technology should be implemented to support current and future ATC services. Consequently, the ACDLS will be the body responsible for the go/no-go decision to implement one of the four solution scenarios studied in this FCI business case. This strategic board will also be in charge of defining the roadmap and deployment planning.

- It is assumed that all the process to set up the DSP and to select and draw up a contract with one or more CSPs for provision of the communication service for the selected solution will be in place before implementation of the network infrastructure of the selected solution.

[10] ACDLS TMB: group of CEOs having signed the MoC (Memorandum of Cooperation) for the provision of a common datalink service.

[11] ACDLS strategic board is called DEB (Datalink Executive Board), acting under authority of the ACDLS TMB. As per ACDLS MoC, the DEB shall coordinate with NDTECH as well as with the SDM SCP Steering Group.

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4.2.2.2 DLS architecture

- There will be a common ground infrastructure, which will be set up by the DSP on behalf of the ACDLS members, the common European ATM infrastructure for the provision of datalink services, whatever the A/G communication means, which will be used in the future to support ATC services. It is assumed that all ANSPs will be connected to a common architecture such as CEAB via NewPENS before the initial operational capability (IOC) of the solution which is selected. This architecture will, amongst other things, ensure the interoperability of the ATN-OSI/ATN-IPS and FANS protocols.

- The new common A/G technology will be shared between the ATC and AOC applications, whilst the CEAB will be restricted to the ATC services.

4.2.3 Deployment assumptions

Common deployment assumptions were made solely for the purpose of estimating credible costs. These assumptions are based on a new fleet projection and traffic forecast developed by EUROCONTROL for the purpose of the BC and which take into account the impact of the COVID-19 crisis (see section 4.3).

For each solution, a three-phased approach is envisaged, namely:

- **a pioneer phase,** to test the technology on a small number of aircraft and ACCs in Europe;

- **a migration phase,** to deploy the technology where it is needed as a priority, i.e., in the core area where VDL-2 congestion is the highest. This phase should help to partially offload the VDL-2 network and confirm the potential benefits of the solution on a limited but already representative number of aircraft; **and**

- **a full operational phase,** to finalise the deployment of the technology throughout the EUROCONTROL Member State airspace. At the end of this period, a significant part of the target fleet should be equipped.

While proposing a common schedule for all scenarios, each solution will be free to adapt the start-date and end-date of the three phases in order to take into account the level of maturity of the solution, the IOC (initial operational capability) date, and the ramp-up of the fleet equipage. This will help to design a more realistic roadmap for the deployment.

4.2.3.1 Phase 1 – Pioneer / Validation

The aim of this pioneer/validation phase is to confirm that the selected technology is providing the expected service at the required level of performance, whilst contributing additional communication capacity to complement the existing VDL-2 technology. The pioneer/validation phase must also de-risk the full implementation by evaluating the new technology performance in a high-density area. For a quick start-up of the proposed phase, it is assumed that this pioneer/validation phase will be sponsored by incentives.

Phase 1 will consist of the deployment of the technology in a few ACCs in the Europe core area, covering en-route, main approaches and main airports. For the SATCOM NG, it is to be noted that there is no ground deployment and the entire service area (extent) will be immediately covered.

For a credible assessment of the benefits, a minimum of 300 aircraft (including those most flown in the core area) should be equipped and ready to operate with the new technology for both ATC and AOC (data) communication.

In the field, it is assumed that ANSPs and CSPs, and potentially a few airlines, will make the necessary adaptations in order to operate current datalink applications with the new technology and deploy the required infrastructure (except for SATCOM NG, as the infrastructure would already be operating).

These adaptations will consist of:

- deploying the related ground communication stations (if needed, see SATCOM NG) to provide – as a minimum – single coverage of the targeted airspace;
- interfacing with the CEAB infrastructure via NewPENS for the ANSPs' related services in order to allow transparent operations with the existing applications (ATN-B1 and ATS-B2). For the business case, it is assumed that gateways will be needed to perform the required translation (IPS <-> OSI for instance);
- interfacing with the CSPs, AOC data communication centres and preferably a few pioneer airline AOC centres which wish to participate in the evaluation. This is critical in order to demonstrate that the selected technology can bear the required load while managing the quality of service (QoS).

At the end of the pioneer/validation phase, an assessment will be made in order to decide on the next steps.

4.2.3.2 Phase 2 – Migration

The purpose of this migration phase is to rapidly equip the core area where a new communication technology is required to complement the VDL-2 capacity, and to increase the network automation.

Phase2 will consist of the deployment of the technology in the entire core area, covering all en-route, main approaches and main airports with an operational infrastructure which must meet the required level of performance (dual coverage, if needed).

In addition to the aircraft already equipped during the pioneer phase, it is assumed that at least an additional 1,000 aircraft (including those most flown in the core area) will be operating with the new technology for both ATC and AOC (data) communication.

For the ground infrastructure, the scope will be to equip all the ACCs, main approaches and airports in the core area, but with one difference, operating with the new technology without the need for gateways (i.e., with ATN-IPS for instance). ACCs will then be capable of operating with former (VDL-2/ATN-OSI) or new technologies (LDACS, SATCOM NG or COTS over ATN-IPS).

These adaptations will consist of:

- deploying the potential additional related ground communication stations (if needed, see SATCOM NG) in order to meet the operational requirements (availability, capacity etc.);
- interfacing with the CEAB infrastructure via NewPENS for all the ACCs and main APPs operating in the targeted area;
- interfacing with the CSPs, AOC data communication centres and airline AOC centres which wish to operate with the new technology.

At the end of the migration phase, a plan should be set up to prepare the next phase, full operational deployment including potential rationalisation of the ground infrastructure for the existing technologies (VDL-2, etc.).

4.2.3.3 Phase 3 – Full operation

The purpose of this full operational phase is to deploy all the new applications in all EUR airspace.

Phase 3 will consist of the deployment of the new technology in all EUR domestic airspace, covering all en-route airspace, approaches and airports. At the end of Phase 3, a gradual decommissioning of the former VDL-2 infrastructure can be envisaged. It should be noted that the potential benefit of decommissioning the former VDL-2 technology will not be considered in this business case.

In addition to the aircraft already equipped during the previous phases, it is assumed that an additional 500 aircraft a year will be operating with the new technology for both ATC and AOC (data) communication.

For the ground infrastructure, the situation should be identical to the previous phase, i.e., all the ACCs will be operating with the new technology without gateways and be capable of operating with former (VDL-2/ATN/OSI) or new technologies (LDACS, SATCOM NG or COTS over ATN/IPS).

These adaptations will consist of:

- deploying the additional related ground communication stations to cover all the EUR airspace (if needed, see SATCOM NG);
- interfacing with the CEAB infrastructure via NewPENS for all the EUR ACCs and the APPs in EUR airspace;
- interfacing with the CSPs, AOC data communication centres and airline AOC centres.

4.3 Traffic and fleet projection

A fleet survey was conducted by EUROCONTROL for the purpose of the FCI business case. This survey covered all aircraft flying above FL285 in the ECAC area in 2019 (i.e., just before the COVID-19 crisis). It should be noted that this fleet forecast is based only on statistical data and does not take into account the real intentions of airlines to renew their fleet sooner or later on the basis of commercial good deals or government incentive programmes.

Table 8 below provides an overview of the state of the fleet in terms of the number of aircraft and the number of flights, based on 2019 (full year) data. The figures are provided for the total fleet flying above FL285 but also for the "target fleet", i.e., the aircraft performing the greatest number of flights above FL285.

- **Identification of the target fleet for the FCI-BC**

The target fleet was identified by sorting all aircraft according to their annual flight volume, and selecting them until 85% of IFR traffic above FL285 was obtained. It is essentially made up of aircraft of the largest commercial airlines and business aviation operating in Europe, with a minimum of 400 flights per aircraft per year.

Table 8 shows that 85% of IFR traffic above FL285 in 2019 (around 7.07 million flights) was accounted for by only 31% of the fleet (6,185 aircraft). This fleet of 31% of the a/c is the target fleet, which must be equipped as a priority with new communication technologies in order to quickly offload VDL-2 traffic and avoid congestion in the central zone of European airspace.

IFR traffic: all aircraft flying above FL285 in 2019		Total fleet	Target fleet	Non-target fleet
Fleet	number of aircraft	**19,673**	6,185	13,488
	%		31%	69%
Traffic	million flights	**8.31**	7.07	1.25
	%		85%	15%
Average number of flights per a/c			1,142	92

Table 8: IFR traffic above FL285 in 2019 – fleet overview

A fleet forecast was developed for the target fleet, and a projection of the number of aircraft which will retire annually as from 2021 has been made on the basis of the year of manufacture of the aircraft, assuming an average aircraft lifetime of 20 years.

It should be noted that a sensitivity analysis was carried out on a 25-year and a 30-year lifetime, but the distribution of the 2019 target fleet by age of aircraft tends to confirm that the average lifetime is around 20 years (see Figure 6, in which the cumulative curve changes between the age of 20 and 21 years).

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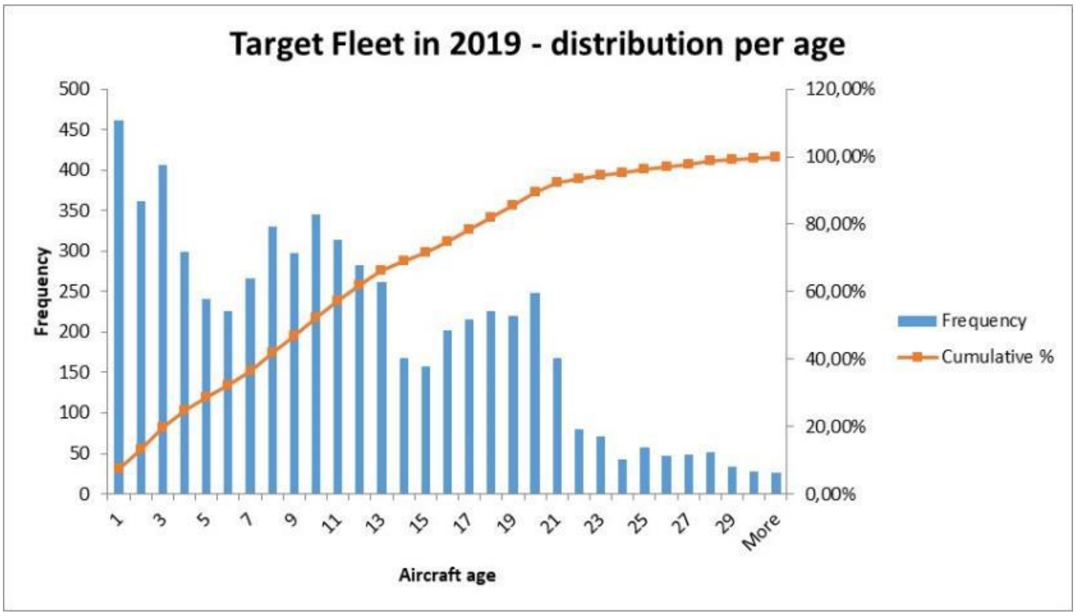

Figure 6: target fleet distribution by age

- **Projection of the number of aircraft and flights for the target fleet**

In a second step, the long-term traffic forecast used in the CBAs of the SESAR projects was adjusted to take into account the impact of the COVID-19 crisis. The new projection takes into account:

- for the short term, i.e., for the years 2021-2024, the 4-year STATFOR forecasts (2021-2024) for Europe issued in May 2021 by EUROCONTROL at the time of the third wave of COVID-19, taking into account Scenario 1 (See Annexe B);
- for the medium and long term (2025-2039), the previous STATFOR long-term forecast (2018) used in SESAR CBAs but capped at 96% to take into account the impact of COVID-19.

A new projection of the traffic was calculated for the target fleet, with the assumption that its traffic share would remain constant throughout the period 2019 to 2039 (at 64% of ECAC traffic). This new traffic forecast makes it possible to estimate for each year the number of additional aircraft which would be needed to cope with the increase in traffic to be expected after the COVID-19 crisis[12].

[12] The assumption for now is that traffic should return to 2019 levels by the end of 2024.

Figure 7 shows the projection of the number of new aircraft to be delivered by year to replace the aircraft in the target fleet which will retire and to support the increase in traffic from 2024. This fleet projection will serve as a basis for estimating the progressive equipage rate and the impact on the traffic for each of the four scenarios studied in the FCI-BC.

Scenario (20 years lifetime a/c)	20 years																					
LT TRAFFIC forecast	**2019**	**% ECAC traffic**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**TOTAL**
ECAC TRAFFIC (STATFOR 2018 LF Forecast corrected due to COVID)	**11.085.302**		6.253.000	9.286.000	10.763.000	11.650.000	11.945.280	12.203.520	12.467.520	12.736.320	13.011.840	13.293.120	13.537.920	13.788.480	14.042.880	14.302.080	14.567.040	14.759.040	14.952.960	15.149.760	15.349.440	
FL285 traffic	**8.312.970**	**75%**	4.689.182	6.963.657	8.071.273	8.736.442	8.957.875	9.151.532	9.349.508	9.551.084	9.757.699	9.968.633	10.152.211	10.340.108	10.530.885	10.725.261	10.923.957	11.067.940	11.213.362	11.360.944	11.510.686	
Target fleet & traffic:																						
Target fleet traffic (# of flights) = most flying a/c above FL285 = 85% of the FL285 traffic	**7.066.304**	**64%**	3.985.963	5.919.342	6.860.853	7.426.270	7.614.495	7.779.110	7.947.396	8.118.742	8.294.372	8.473.673	8.629.721	8.789.440	8.951.606	9.116.833	9.285.731	9.408.121	9.531.735	9.657.185	9.784.470	
Target Fleet forecast (# of a/c)	**6.185**		6.185	6.185	6.185	6.500	6.665	6.809	6.956	7.106	7.260	7.417	7.553	7.693	7.835	7.980	8.128	8.235	8.343	8.453	8.564	
New A/C deliveries for the Target fleet																						
Replacement of a/c that will go on retirement after 20 years (to maintain 2019 traffic)	6.185	Total nb of the most flying a/c (85% of FL285 traffic)	1.347	216	202	158	168	261	283	314	345	298	331	266	226	241	299	406	362	354	108	**6.185**
Traffic from retired a/c			1.253.308	226.384	212.153	179.918	213.052	322.989	348.644	395.817	438.214	374.109	431.217	332.855	264.153	262.384	348.508	502.862	429.930	433.416	96.391	7.066.304
Additional a/c needed to support traffic increase (as from 2024)	**1.142**	Average nb of flights per a/c (for the most flying a/c > FL285)				315	165	144	147	150	154	157	137	140	142	145	148	107	108	110	111	**2.492**
Traffic from additional a/c[1]						359.966	188.226	164.615	168.286	171.346	175.630	179.301	156.047	159.719	162.167	165.227	168.898	122.390	123.614	125.450	127.286	2.718.166
TOTAL New a/c per year (replacement + increase)			**1.347**	**216**	**202**	**473**	**333**	**405**	**430**	**464**	**499**	**455**	**468**	**406**	**368**	**386**	**447**	**513**	**470**	**464**	**219**	**8.564**
Traffic from new a/c (replacement + increase)			1.253.308	226.384	212.153	539.884	401.278	487.604	516.930	567.163	613.844	553.410	587.264	492.574	426.320	427.611	517.406	625.252	553.544	558.866	223.677	
Average nb of flights per new a/c			930	1.048	1.050	1.141	1.206	1.204	1.201	1.222	1.231	1.216	1.256	1.214	1.159	1.109	1.158	1.219	1.177	1.205	1.019	

Figure 7: target fleet projection for the FCI-BC (valid for all scenarios)

Disclaimer: At the time of finalisation of this report, it is difficult to predict when the COVID-19 crisis will end and what the post-crisis traffic growth will be. The fleet projection was developed for BC purposes and in the absence of a new STATFOR long-term traffic forecast. Consequently, this analysis does not claim to achieve 100% accuracy. An adjustment to the fleet projection and traffic forecast may be required after the delivery of this business case.

5 Scenario 1 - LDACS

5.1 Introduction to the LDACS scenario

The L-band Digital Aeronautical Communications System (LDACS) is a technology based on an open standard, which can be used by any CSP or ANSP to provide a corresponding datalink service.

LDACS is a terrestrial-based radio access technology designed for aeronautical communication, which supports high-rate data communications and voice and enables important future applications which will bring benefits to airlines, Air Navigation Service Providers (ANSPs) and Communication Service Providers (CSPs). This secure broadband A/G communications system for aviation addresses the limitations of existing technology and provides an invaluable opportunity for modernisation and future-proof aeronautical communication networks. Technologies such as LDACS allow for the integration of new CNS services, which will facilitate the introduction of future ATM modernisation applications leading to more efficient air travel. LDACS is a promising solution to ensure that CSP and ANSPs networks are ready for the upcoming demands. Benefits are coming from high-throughput datalinks, priority management, protected aeronautical spectrum, resilience to cyber-security risks, native IP capability, and conformance with aviation standards.

LDACS is a terrestrial aeronautical air-to-ground radio system, which allows IP-based data and voice communication between the cockpit and the ground. The IP-based (IPv6) data and voice communication is standardised by ICAO, EUROCAE and AEEC, with plans for it to be the basis for future air-to-ground data communication (digital voice is considered as complement for data communications and could complement/replace analogue voice communications in the future). It will provide efficient, secure, and high-bandwidth communication capability (voice and data), with embedded navigation capability standardised by ICAO.

> *Note*: It is anticipated that LDACS digital voice communications will be used for voice communications in the long term. Analogue VHF voice communications should run in parallel and it should be supplemented by an LDACS digital voice service. LDACS will offer the same concept of operation, so it should make no difference to pilots which technology they use.

In addition to data and digital voice communication, LDACS can also be used for ranging. The LDACS ranging capability may provide input to the alternative positioning and timing (APNT) solution.

LDACS will be deployed in the aeronautical L-band (960 to 1164 MHz), sharing the spectrum with the legacy navigation and surveillance system operating in this band. LDACS is a cellular communications system, which uses a coordinated multiple-access scheme, ensuring collision-free channel access with guaranteed low latency. LDACS is highly spectrum-efficient and is designed to be placed within those parts of the L-band where no other service could be allocated.

As an open standard, it allows the use of the same radio in the aircraft for all LDACS service providers, i.e., no new radio have to be installed in the aircraft for each new service provider (in contrast with the currently available proprietary satellite-based technologies).

Since the communication technologies used in LDACS are based on LTE/4G mobile radio technologies, LDACS is proven, future-proof technology. It enables high-throughput, low-latency datalink communications well beyond the scope of current and proposed VHF communications. Covering ATN/B1 and ATS/B2 (these terms describe a baseline for a bundle of ATC services with common safety and performance requirements, see section 2.7), LDACS is also expected to accommodate ATS/B3 as well as additional future services, including full 4D trajectory-based operations (TBO) and flight-centric air traffic management (ATM).

ICAO is developing LDACS standards to pave the way for a successful roll-out starting in 2024 (that is the applicability date of the LDACS standard). A gradual rollout is planned to occur in three phases, starting in areas where the need for high-throughput data communications is greatest, in order to complement VHF datalinks with the same communications range.

With significantly greater bandwidth and throughput than VDL-2, LDACS will offer much-needed headroom for aeronautical communications, removing barriers to innovation. The technology will also include prioritisation, allowing users to reliably transfer large amounts of essential operational data (such as engine and maintenance data, graphical weather) without delaying time-sensitive ATC data traffic. The ability to share this operational data during flights will help airlines to support better fleet management and reduce aircraft turnaround times.

The security concept of LDACS requires all entities in an LDACS network to authenticate one another in order to ensure that only trusted participants can use the air-to-ground communications system. The trust infrastructure (PKI) provided for this purpose offers mutual authentication between the aircraft and the LDACS access network during the login procedure. For logged-in users, LDACS provides protection of user and control data in the radio link layer, independent of higher-layer security mechanisms. LDACS provides comprehensive state-of-the-art cybersecurity measures aligned with the work of the AEEC and the ICAO WG-I Security SG.

5.2 Operational applicability

5.2.1 Geographical applicability

LDACS is a **terrestrial-based technology** and thus can be used in any geographical region where LDACS ground stations can be installed. LDACS cell coverage is up to 200 NM that is comparable with today's Air Traffic Control (ATC) VHF voice and data radio ranges and thus it enables ANSPs to reuse VDL Mode 2 radio sites and infrastructure.

5.2.2 Airspace and phase of flight coverage

LDACS supports communication in all except oceanic airspace (airports, TMAs, and domestic en-route airspace), and on the airport surface.

Communication technologies are either:

- mandatory, i.e., aircraft must be equipped at the specified flight level or phase of flight; or
- available, i.e., the technology/service is available but there is no obligation to be equipped.

Flight level / Technology	Existing COM technologies			New COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
Airspace > FL245	Mandatory	Mandatory	Available			Available
500 feet < airspace < FL245	Mandatory	Available	Available			Available
Airspace < 500 feet	Mandatory	Available	Available			Available

Table 9: Scenario 1 LDACS – Communication technologies by flight level

Phase of flight / Technology	Existing COM technologies			New COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
En-route – oceanic	Mandatory (air to air)	None	Mandatory (PBCS)			None
En-route – terrestrial	Mandatory	Mandatory	Available			Available
TMA – approach	Mandatory	Available	Available			Available
Airport – ground operations	Mandatory	Available	Available			Available

Table 10: Scenario 1 LDACS - Communication technologies by phase of flight

5.3 Maturity level status

5.3.1 Infrastructure status

The maturity level status of the PJ.14-W2 ICNSS Solution 60 “FCI Terrestrial datalink”, which is developing the Future Communication Infrastructure Terrestrial datalink Concept (Scenario 1), is depicted in Table 11. The LDACS datalink functionality is complemented by digital voice in another SESAR solution, i.e., PJ.33-W3-02 “LDACS Complement”.

SESAR technological solution	Enabler	Initial maturity level at the start of Wave 2	Target maturity level at the end of Wave 2/ Wave3
Solution PJ.14-W2-60 -FCI Terrestrial datalink	CTE-C02e	TRL-4 (Dec 2019)	TRL-6 (April 2023)
Solution PJ.33-W3-02 – LDACS Complement (LDACS Digital voice)	CTE-C01b[13]	TRL-2 (Dec 2020)	TRL-4 (Dec 2022)

Table 11: Scenario 1 LDACS – Maturity level status

The International Civil Aviation Organization (ICAO) included LDACS in its Global Air Navigation Plan (GANP) and initiated LDACS standardisation in 2016. It is aimed to conclude the activities and have applicable LDACS standards by end of 2024.

5.3.2 Service distribution status

In relation to the two enablers listed in Section 5.3.1:

- LDACS Datalink Service is not distributed yet (deployment shall start),
- LDACS Digital Voice Service is planned to be deployed after the Datalink Service (not yet deployed).

5.3.3 Validation status

LDACS Datalink in-flight communication performance was assessed during flight trials in March and April 2019. In this test campaign the achieved communication range, the measured end-to-end message latency, and the LDACS capability to provide quality of service (by effectively prioritizing safety-relevant data traffic) was measured.

Many other technological validation activities have been conducted within the SESAR programme (SESAR1 PJ15.02.04 and SESAR2020 PJ.14.02.01) and will be carried-out in the currently running projects SESAR PJ.14-W2-60 and PJ.33-W3-02 (another LDACS flight trial).

[13] CR06269 has been raised to create a new enabler, that shall address the development of LDACS Digital Voice

Validation of LDACS Digital Voice is planned to be carried-out in the laboratory (to reach TRL4) in August/September 2022 involving commercial Voice Communication Systems to prove digital voice communications through LDACS.

5.3.4 Safety and security risk assessment status

Scenario	Compliance expected to be achieved in	Risk assessment documented	Compliance with maturity gate requirements	Problem and/or comment
Safety risk assessment	2022	by April 2023	yes	
Security risk assessment	2022	by April 2023	yes	Will be disclosed to SESAR Security Team and not publicly available.

Table 12: Scenario 1 LDACS – safety and security risk assessment status

5.3.5 Early-implementation flights

In relation to the two enablers listed in Section 5.3.1:

- LDACS Datalink Service has been technologically validated in a flight campaign in April 2019 and will again be tested via flight trials in July 2022,
- LDACS Digital Voice Service has not been verified by means of flight test, but it is planned to demonstrate the concept through laboratory test in August/September 2022.

5.3.6 Deployment assumptions

The LDACS Transition Concept (LTC) allows LDACS air-to-ground communication to be integrated into the existing ground infrastructure and it would thus bring the core benefits of this technology without requiring any change for ANSPs.

The concept supports multiple protocols (ATN/OSI, ATN/IPS and ACARS), so it would cope with a range of avionics standards, as airline fleets are gradually upgraded to the new standards.

There are two deployment steps envisaged:

- **Step 1 – 2025-2027: LDACS over OSI**

  Since there is urgent need to mitigate the congestion of safety qualified links and to enable offloading of part of the ATC and AOC traffic onto LDACS and is predicted that the deployment of IPS in the avionics will not come until approximately 2027, there is a need to support OSI avionics in order to provide LDACS connectivity in 2025.

  This step (shown in green colour in Figure 8) provides:

  - a way of adding LDACS to forward-fit aircraft, prior to the availability of IPS avionics;

- a solution for retrofitting LDACS to aircraft which do not support IPS (and still using OSI). This would cost less than upgrading to both IPS and LDACS, so it may be attractive to airlines even when IPS avionics do become available;
- a way of adding LDACS if there is not yet a ground IPS infrastructure.

- **Step 2 – -> 2027: LDACS over IPS**

In this step (combination of green and blue route in Figure 8), ATN/OSI and ATN/IPS traffic could be exchanged via LDACS depending on the available infrastructure on the ground and in the aircraft.

Note: If IPS avionics are deployed before 2027, the ground component of this step could be accelerated.

Note: Both steps support, with no changes to the infrastructure, additional LDACS capabilities, such as for example digital voice or navigation.

5.3.7 Deployment on the ground

5.3.7.1 Overview

The LDACS Transition Concept (LTC) includes a proposed approach for the deployment of the LDACS ground infrastructure. This has been chosen to:

- minimise ground deployment costs, delays and technical risks by making use of existing ground stations and integrating the LDACS components into the existing ground infrastructure;
- enable LDACS deployments to be first targeted to areas where it is most needed and then be gradually expanded;
- minimise the avionics cost of LDACS deployment by supporting both legacy (OSI) and next generation (IPS) standards;
- retain the infrastructure, experience and expertise of current providers by copying the organisational structure of that in place for the existing terrestrial datalink network;
- Allow a model to be implemented which supports multiple CSPs and therefore helps to maintain competition, since LDACS is based on an open standard and therefore allows competition in the provision of air-ground communications services.

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5.3.7.2 LDACS integration

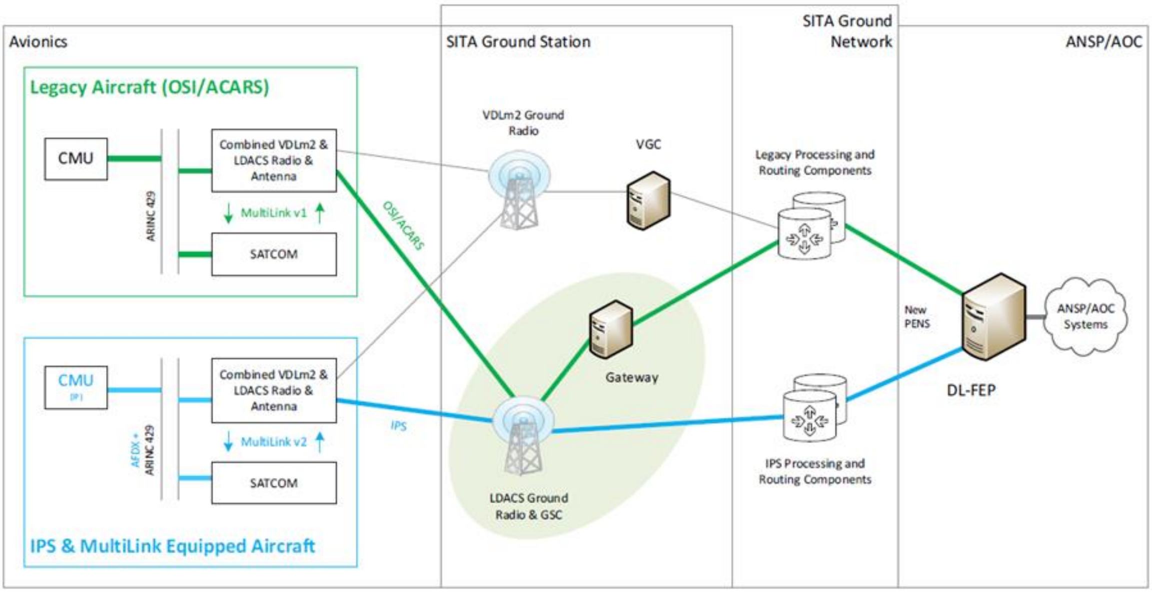

Figure 8: Potential LDACS ground deployment

Communication Service Providers (CSPs) already possess a vast network of ground stations which provide coverage over the whole of Europe. In this proposal, rather than the community incurring the costs associated with a dedicated network of new LDACS ground stations, these existing VHF ground stations would be upgraded, to become both VHF and LDACS ground stations. Since LDACS and VHF make use of different bands, this colocation is possible without any risk of interference. This is illustrated in the figure above, using SITA as an example of a CSP.

The LTC specifies an LDACS ground solution which can support both OSI and IPS avionics. This will support airspace users as they gradually transition to the IPS protocol. It allows OSI-equipped aircraft to gain LDACS connectivity with minimal avionics change.

5.3.7.3 Organisational structure

It is anticipated that, by the time the LDACS service is ready for deployment, the European DSP will be in place. In this case, the ANSPs will have delegated the direct management of the datalink communications support services to the DSP. The DSP would then contract one or more CSPs to provide LDACS air-ground connectivity in a form which can be integrated into the CEAB.

If the DSP is not in place, the ANSPs would contract directly with CSPs, as they do today for the VDL-2 service.

This organisational structure allows the existing VHF stations, which are owned by CSPs, to be reused in the ways described within this scenario, thus minimising deployment costs.

Maintaining a structure which allows for the existence of multiple CSPs allows the DSP (or the ANSPs) to have choice when selecting a provider. This competition between CSPs will drive evolution and help keep costs down.

In this structure, the DSP (or the ANSPs) would not need to invest in LDACS ground infrastructure, since this would be owned and managed by CSPs. It is assumed that the only significant cost to the ANSPs or the DSP would be the service fees paid to the CSPs. All capital expenditure for LDACS ground infrastructure would be borne by the CSP.

5.3.7.4 LDACS ground deployment phases

The LTC supports a phased approach to LDACS ground deployment. This allows for more rapid deployment to the areas which would most benefit from this connectivity and reduces risk.

Deployment phases	Deployment start	Deployment end	Protocol	Number of stations
Validation	2024 Q1	2024 Q4	OSI	2 (test)
Phase 1 ("pioneer")	2025 Q1	2025 Q2	OSI	10
Phase 2	2025 Q4	2026 Q2	OSI	60
Phase 3	2026 Q3	2027 Q4	OSI	420 (all)
Phase 4	2027 Q3	2027 Q4	OSI + IPS	420 (all)[14]

Table 13: Scenario 1 LDACS - ground deployment phases

[14] The figure of 420 is an estimate that assumes what will be necessary to upgrade the existing CSP networks.

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Validation

This phase involves deployment of validation LDACS equipment in the CSP networks in order to ensure that it can be integrated into their networks without difficulty. This validation may involve flight trials.

Phase 1

This first deployment phase will target a “selected” area within Europe where LDACS connectivity is most needed. Having a limited number of stations will serve to de-risk the larger phases to come.

Phase 2

Because the total number of stations is large, it is recommended that there should be an additional phase of deployment. This is partly due to the investments involved but also to the time needed to deploy, test and commission so many stations.

Phase 3

The previous phases provide the confidence and experience needed for this phase, where all operational VDL-2 stations are upgraded.

Phase 4

In this phase, all the LDACS stations upgraded in previous phases are integrated into the IPS ground network. The LTC design means that this does not require significant change at each station.

This element is placed at this point in the timeline, as this is when the IPS ground network is expected to be available. If that IPS ground network is available sooner, this phase could be moved forward without any major impact on the rest of the programme.

Note: Deployment of the LDACS ground infrastructure is expected to be completed with the phased approach described above. The “validation” phase and “Phase 1” would relate to “Phase-1: Pioneer/Validation (2023 – 2025)” whereas “Phase 2/3/4” above would correlate with “Phase-2: Migration (2025 – 2030)” as described in section 4.2.3.

5.3.8 Deployment in aircraft

There are several potential options for how to deploy LDACS in aircraft, but in the following we focus on a scenario which assumes that LDACS acts as a supplement to the currently deployed VDL-2 systems.

Note: A final decision about the LDACS deployment in aircraft must be made by the airborne industry (including but not limited to aircraft manufacturers and avionics manufacturers). However, for the elaboration of the business case, this option was considered as a baseline.

The multi-frequency approach in use today enables VDL-2 to use several VHF frequencies to increase network capacity. The LDACS system can be assigned a particular symbolic frequency. The communications management unit (CMU) or air traffic services unit (ATSU) will determine when to utilize VHF and/or LDACS for safety and non-safety data communication purposes. As a consequence, LDACS could support the VDL-2 system by supplementing the existing narrowband VDL-2 datalinks with high-capacity broadband LDACS datalinks in the L-band by switching to a symbolic frequency representing LDACS.

To accomplish this, it makes sense to either combine a multimode LDACS/VHF radio into a single avionics box (Option 1) or to have two separate but coordinated radios which share the same antenna (Option 2). The goal is to minimise the wiring and installation impact on the aircraft, and to reduce costs through reusing existing infrastructure on-board the aircraft as far as possible. There are pros and cons of both radio architectures (integrated or federated) but they will be determined by the industry standards which define LDACS. It is important to bear in mind that a combined LDACS/VHF avionics radio may be a more desirable approach for retrofit applications as it would not increase the number of required avionics radio slots on-board the aircraft.

If we take the original installation on an A320 as an example, there are three VHF radios on board, with the first two slots used for voice communications and the third slot used for data communications:

Figure 9: Example of the current A320 VHF radio architecture

- **Aircraft configuration Option 1: Integrated radio**

The first envisioned architecture (called "integrated radio") would combine VHF and LDACS capabilities into a single radio and install the new integrated LDACS/VHF radio in all three aircraft locations (see Figure 10).

Figure 10: Potential integrated LDACS/VHF radio architecture (Option 1)

In order to minimise the aircraft installation impact/cost, it has been proposed to introduce the LDACS functionality via the development of an integrated LDACS/VHF transceiver, which fits in the same form factor as the current VHF-only transceiver, as well as a combined LDACS/VHF antenna, which fits in the same form factor as the current VHF-only antenna. This integrated scenario may require aircraft wiring changes to accommodate the LDACS cabling requirements (e.g., to minimise loss of L-band signals).

- **Aircraft configuration Option 2: Federated radio**

The second architecture (termed "federated radio") would include the VHF radio and its interfaces on board the aircraft as at present, plus at least one new stand-alone LDACS radio installed in a new radio slot, using one new duaL-band coaxial cable and one new duaL-band antenna for both radios (Figure 11). The coaxial cable is fed first to the LDACS box and then to the VHF radios.

Figure 11: Potential federated LDACS radio architecture (Option 2)

In either the integrated LDACS/VHF scenario or the federated LDACS scenario, the communications management unit (CMU) or air traffic services unit (ATSU) on board the aircraft will require software changes, and possibly hardware changes, to accommodate the new LDACS radio functionality. These updates will include new router logic for when LDACS or VHF are to be used, including what the radio preferences are by message type (safety/non-safety) and flight phase. New radio frequency management logic will also be required for the CMU/ATSU.

An example of aircraft implementation is provided in the Figure 12 below. The new antenna cable supports both VHF and L-band frequencies and the new antenna similarly supports both VHF and L-band frequencies. A new high-speed data bus is instantiated for LDACS radio data and control by the CMU/ATSU. It should be noted that the data outputs from the LDACS radio may be connected to multiple avionics systems via a high-speed bus so that the avionics systems can take advantage of the new broadband data pipe and allow new value-added applications.

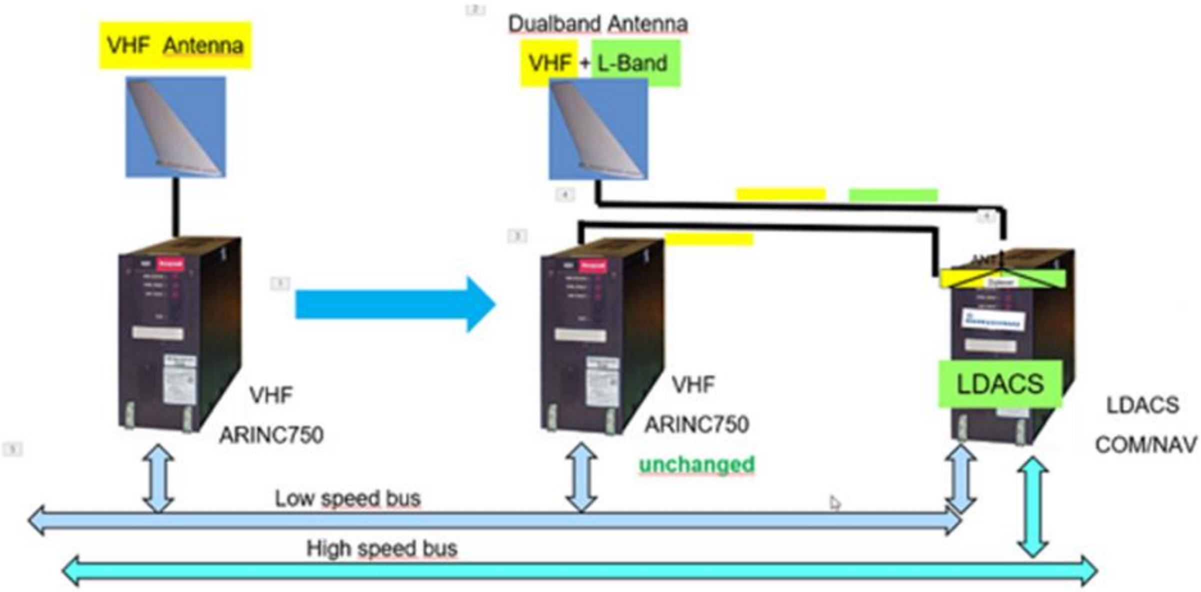

Figure 12: Potential federated LDACS radio architecture and associated wiring (in principle)

Benefits:

This will keep the existing VDR installation (partly) in place and extends/exchanges with additional LDACS radios. This will add very low operational risks to in-service aircraft. LDACS radios can be attached to low and additionally to high speed data interfaces (as soon as these are used in aircraft). Initial investment costs are expected to be lower (replacing VDR as needed).

A separate box has the advantage of a completely independent use of VHF and L-band but may need additional space within the avionics bay if the current VDR installations are kept. The recommendation is therefore to replace one or more VDR radios with LDACS radios. The separate box can always be connected to high-speed busses for best performance of LDACS.

Both concepts use a replacement of the single-band VHF antenna by a dual-band antenna with the same footprint. This would allow or include replacement of the RF cable as well. The aircraft manufacturers will advise on the feasibility of replacing the RF cable.

The major drivers of non-recurring expenses for industry to introduce LDACS avionics radios include:

- Development, test, qualification, and certification of new LDACS/VHF or stand-alone LDACS avionics radio
- Integration of the new LDACS radio into aircraft installations
- Deployment of the new LDACS radio to retrofit and/or forward-fit aircraft

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5.4 Cost assessment

As described in section 3.4.1, the scope of the cost assessment is limited to the provision of:

- a global estimate of the airborne investment required to equip the target fleet (see section 4.3) by the end of 2039 with the LDACS technology;
- a global estimate of the ANSPs service fees required to support ATC datalink service provision with the LDACS technology, covering the entire EUROCONTROL Member States area (only the terrestrial part).

5.4.1 Cost assumptions

5.4.1.1 AUs cost assumptions

- The equipment cost shown in Table 14 has been estimated by EUROCONTROL on the basis of current knowledge of the technology and input provided by project and airborne industry experts. It does not claim to be 100% accurate. The level of confidence reflects the uncertainties on the cost value.
- A base value has been used to estimate the overall costs between 2021 and 2039 (forward-fitting only).
- It has been assumed that the cost of installing the LDACS radio in the aircraft is of the same order of magnitude as in the other scenarios. Consequently, to calculate the "AU forward-fit costs" a similar percentage mark-up to the HW-only costs has been applied.
- The cost of the aircraft equipment includes everything (hardware, software, certification, installation costs, etc.) and covers both ATC and AOC traffic. Consequently, the AU investment is not calculated in proportion to ATC communication needs. Airlines have been consulted in order to confirm the order of magnitude of the investment.
- The estimate of the AU investment by deployment phase presented in Table 15 has been estimated by EUROCONTROL on the basis of the inputs provided by the partners in the LDACS team for the progressive equipage rate of new delivered aircraft and on the fleet projection developed specifically for the BC (see section 4.3). The ramp-up goes from 5% of new aircraft equipped in 2025 with the LDACS to 100% of new aircraft equipped as from 2031 and up to 2039).
- The projection of the costs throughout the time horizon takes into account the maturity level of the solution and reflects the uncertainties about the deployment dates, the time to obtain the standard, to get the certification for the technology and to set up the service provision for the users.
- Only forward-fit costs have been considered in the cost assessment. At this stage, it is not envisaged to retrofit aircraft with new communication technologies as indicated in the list of assumptions (see section 4.1.1).

5.4.1.2 ANSPs cost assumptions

- The cost value indicated in Table 16 represents the service fees which all the ANSPs in the EUROCONTROL Member State area will pay to the DSP for the provision of the ATC datalink service using the LDACS technology (through a selected CSP or a consortium). It covers all the cost elements identified in Table 7 (see section 3.4.1 on the scope of the cost assessment).
- It includes the amortisation of the LDACS ground infrastructure and the running costs of the CSP.
- The service fees do not cover governance, the DSP and the CEAB costs. Those costs will come on top of the LDACS service fees and will be shared with other communication means (existing and new technologies).
- The ANSP service fees have been estimated by EUROCONTROL on the basis of inputs provided by the partners in the project, i.e., ANSPs, ground and air industry, OEM and aircraft manufacturers. It is based on the current knowledge of the technology and does not claim to be 100% accurate. The level of confidence reflects the uncertainties on the cost value.
- The service fees cover all continental airspace, i.e., the provision of the service in the en-route segment, in the TMAs and at airports.
- It is assumed that a ramp-up of three years will be needed to achieve 100% ground equipage. The cost of the service fees is aligned with the ramp-up and the progressive number of ground stations which will be deployed. Nevertheless, a minimum level of service charge has been accounted for the first year in order to cover the initial investment.

5.4.2 Cost assessment results

5.4.2.1 AU costs

Table 14 presents the cost of the on-board equipment for the LDACS scenario and the theoretical cost for the airborne investment if we equip 100% of the 2039 target fleet (i.e., 8,564 a/c).

Airborne equipment cost (unit cost)	Base	Level of confidence	Target fleet theoretical cost (8,564 a/c)
LDACS equipment cost per aircraft (forward-fitting)	**EUR 56,200**	+/- 20%	**EUR 481 million**

Table 14: Scenario 1: LDACS - AU unit cost and target fleet theoretical cost

Table 15 presents the airborne investment that the airlines will have to bear by deployment phase. It is based on expert judgment regarding realistic assumptions for LDACS deployment dates.

Fleet equipage rate and total airborne investment by phase	**Phase 1 (2023-2025)**	**Phase 2 (2026-2030)**	**Phase 3 (2031-2039)**	**TOTAL**
Expected target fleet equipage (as a percentage of a/c numbers)	0.2% of the target fleet	18% of the target fleet	59% of the target fleet	
Total airborne investment	EUR 0.9 million	EUR 72.9 million	EUR 210.2 million	**EUR 284 million**

Table 15: Scenario 1: LDACS - AU costs by phase of deployment

5.4.2.2 ANSP costs

Table 16 presents the cost of service fees per year which will have to be supported by all the ANSPs for the DLS provision with the LDACS technology in the entire EUROCONTROL Member State airspace.

ANSP service fees	Base	Level of confidence	
ANSP service fees per year at FOC (full operational capability) and for the entire EUROCONTROL Member State area	**EUR 14.8 million**	+/- 20%	

Table 16: Scenario 1: LDACS - ANSP annual service fees

Table 17 presents the progressive equipage rate on the ground based on realistic deployment assumptions and presents the annual service fees and cumulated costs that will be borne by the ANSPs for the service provision with the LDACS technology.

	Phase 1 (2023-2025)	Phase 2 (2026-2030)	Phase 3 (2031-2039)	TOTAL
Expected ground equipage (as a percentage of total service fees)	41%	100%	100%	-
Annual service fees at the end of each period	EUR 6.1 million per year	EUR 14.8 million per year	EUR 14.8 million per year	-
Total ANSP service fees (cumulated by phase)	6.1 M€	69.6 M€	133.2 M€	209 M€

Table 17: Scenario 1: LDACS - ANSP annual and total costs by phase of deployment

5.4.2.3 Overall cost projection

In the LDACS scenario, it is assumed that the technology will start to be deployed in 2025 and 5% of new delivered aircraft will be equipped with the technology (equals to 17 aircraft).

It is expected that the migration phase will last from 2026 to 2030, and there will be a rapid ramp-up from 20% to 90% of new aircraft equipped at the end of this second phase. 18% of the target fleet should be equipped by 2030 (1,314 aircraft).

At the same time, there will be a rapid deployment of ground stations, with the objective of equipping 100% of the ground by 2027, in order to ensure that newly equipped aircraft can benefit from the technology anywhere in European domestic airspace.

The full operational phase will start in 2031, and at the end of the time horizon (2039) 59% of the target fleet is expected to be equipped. This may sound optimistic, but LDACS technology is considered to be the secured and performant technology which can potentially replace VDL-2. It is therefore not entirely unrealistic to assume that all new aircraft will be equipped with this new technology, as is the case today with VDL-2, especially in a scenario where only one new communication technology is introduced and if this technology can also bring additional benefits in the navigation and surveillance domains.

Scenario 1 - LDACS	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
Ramp up of fleet equipage (% of new a/c equipped with LDACS technology)	0%	0%	0%	0%	5%	20%	30%	60%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Nb of a/c equipped per year	0	0	0	0	17	81	129	278	399	409	468	406	368	386	447	513	470	464	219	5.054
Cumulated a/c equipped	**0**	**0**	**0**	**0**	**17**	**98**	**227**	**505**	**904**	**1.314**	**1.781**	**2.187**	**2.555**	**2.940**	**3.387**	**3.900**	**4.371**	**4.834**	**5.054**	
% Target fleet equipage	**0%**	**0%**	**0%**	**0%**	**0,2%**	**1%**	**3%**	**7%**	**12%**	**18%**	**24%**	**28%**	**33%**	**37%**	**42%**	**47%**	**52%**	**57%**	**59%**	
Nb of flights equipped per year	0	0	0	0	20.064	97.521	155.079	340.298	491.075	498.069	587.264	492.574	426.320	427.611	517.406	625.252	553.544	558.866	223.677	
Cumulated flights equipped	**0**	**0**	**0**	**0**	**20.064**	**117.585**	**272.664**	**612.962**	**1.104.036**	**1.602.106**	**2.189.370**	**2.681.944**	**3.108.264**	**3.535.874**	**4.053.281**	**4.678.533**	**5.232.077**	**5.790.942**	**6.014.619**	
% Target traffic equipage	**0%**	**0%**	**0%**	**0%**	**0,3%**	**2%**	**3%**	**8%**	**13%**	**19%**	**25%**	**31%**	**35%**	**39%**	**44%**	**50%**	**55%**	**60%**	**61%**	
% FL285 traffic equipage	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*3%*	*6%*	*11%*	*16%*	*22%*	*26%*	*30%*	*33%*	*37%*	*42%*	*47%*	*51%*	*52%*	
% ECAC traffic equipage	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*2%*	*5%*	*8%*	*12%*	*16%*	*19%*	*22%*	*25%*	*28%*	*32%*	*35%*	*38%*	*39%*	
AUs - Forward fit costs	**0,0**	**0,0**	**0,0**	**0,0**	**0,9**	**4,6**	**7,3**	**15,6**	**22,4**	**23,0**	**26,3**	**22,8**	**20,7**	**21,7**	**25,1**	**28,8**	**26,4**	**26,1**	**12,3**	**284**
Ground equipage rate	0,0%	0,0%	0,0%	0,0%	41%	70%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
ANSPs - Service fees	**0,0**	**0,0**	**0,0**	**0,0**	**6,1**	**10,4**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**14,8**	**209**

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Figure 13: Scenario 1: LDACS - Overall cost projection and fleet equipage

5.5 Qualitative assessment

5.5.1 Performance

The ICAO Performance-Based Communications and Surveillance (PBCS) Manual (Doc 9869) defines a performance framework to quantify the datalink system performance needed to meet operational requirements. It introduces two concepts:

- Required communication performance (RCP) applicable to two way controller-pilot datalink communication (CPDLC) dialogues, and
- Required surveillance performance (RSP) applicable to one-way transfer of surveillance data by contract-based automatic dependent surveillance (ADS-C).

On the basis of these concepts, EUROCAE ED-228A/RTCA DO 350 specifies specific sets of requirements, RCP130 and RSP160 respectively, which are applicable to ATS-B2 applications in continental en-Route and TMA airspace.

Note: For the future ATS B3 applications, another more stringent set of requirements will be specified, which is expected to be supported by LDACS, as well.

To support these future services, LDACS can provide data throughput of up to 2.6 Mbit/s depending on the adaptive coding and modulation scheme selected. This is up to 200 times higher than the throughput of the VDL Mode 2 system currently in operation.

LDACS in-flight communication performance was assessed during flight trials in March and April 2019. In this test campaign, the communication range achieved, the end-to-end message latency, and the LDACS capability to provide quality of service (by effectively prioritising safety-relevant data traffic) was measured.

The results from the flight tests clearly confirm that LDACS is able to support RCP400/A2, RCP240 and RCP130/A1 operations as defined in “ICAO Doc 9869: Performance-based Communication and Surveillance (PBCS) Manual,” (second edition, 2017“). The manual specifies that the required communication technical performance of the communication service provider (RCTPCSP), i.e., the LDACS radio, should be lower than 10 s, 100 s, and 10 s respectively in the 95th percentile. Moreover, the results from flight tests clearly confirm the LDACS support for RSP400/A1 and RSP180/D surveillance operations, since they require a data delivery time of less than 270 s and 84 s respectively in the 95th percentile.

However, the latency figures introduced by the LDACS sub-system for IPv6 based data communication are much lower than required and have been estimated to be less than 1 second (on the basis of results retrieved from laboratory measurements). The latency values provided are the 95% percentile latency. The less restrictive 99.9th percentile latency requirement was also fulfilled for all considered RCPs and RSPs.

It is assumed that LDACS can complement the VDL-2 network and create a datalink service infrastructure which matches the most likely evolution of datalink use in Europe.

To support future services, LDACS can provide data throughput up to 2.6 Mbit per second—more than 200 times higher than the throughput of the current system. It offers guaranteed bandwidth, high continuity of service, and latency values that make it suitable even for safety-critical real-time applications. LDACS can also reliably transfer large amounts of operational data, e.g., engine and maintenance data, without interrupting air traffic control data. Ideally suited for the dense traffic areas typical in Europe, LDACS will also work hand in hand with the upgraded satellite-based communications which will serve large areas with little air traffic (such as oceanic regions).

LDACS provides a future-proofed communication network bandwidth, resiliency, and scalability, which will benefit European air space users and ground entities for several more decades, which is impossible with the constrained VHF communication network used today.

Table 18 below summarises the latency performance for CPDLC and ADS-C:

Ground-initiated CPDLC Technical round trip delay	**99.9%** (sec.)	**99%** (sec.)	**95%** (sec.)	**Mean** (sec.)	**Transaction**
RCP130 RCTP (end-to-end)	32		20		
ADS-C One way end-to-end latency	**99.9% (sec.)**	**99% (sec.)**	**95% (sec.)**	**Mean (sec.)**	**Reports**
RSP160 $RSTP_{ATSP}$ (end-to-end)	14		7		

Table 18: Scenario 1: LDACS – Latency validation results

LDACS supports communication in all airspaces except oceanic (airport, TMA, and Domestic en-route), and on the airport surface. LDACS is one of the technologies considered for the Future Communication Infrastructure (FCI) and will thus contribute to higher availability of future datalink communications as part of the multilink concept (see Scenario 4).

5.5.2 Potential evolution of the technology

- **Built-in navigation and surveillance**

  The significant increase in bandwidth means that LDACS can provide additional features such as surveillance and navigation functions. LDACS is highly spectrum-efficient, designed to be placed within those parts of the L-band where no other service could be allocated.

  It should be noted that LDACS offers a native APNT function which can be provided by LDACS without requiring additional bandwidth, i.e., LDACS provides a ranging capability that can be used without requiring more bandwidth than that which is already needed for the datalink communications.

- **Digital voice**

LDACS digital voice capabilities will deliver better quality than analogue VHF voice, as well as allowing new concepts such as flight centric operation. It will also provide a foundation for new features such as aircraft authentication and pilot/air traffic controller identification.

5.5.3 Safety, security and QoS aspects

- **Data security**

  LDACS will use a dedicated aeronautical public key infrastructure, with end-entity certificates to cryptographically ensure the identity of all participants, creating a chain of trust to guarantee secure transmission of voice and data.

  Furthermore, LDACS provides several security capabilities:

  - to ensure the availability and continuity of the system;
  - to protect the integrity of messages in transit;
  - to ensure the authenticity of messages in transit;
  - to ensure non-repudiation of the origin of messages in transit;
  - to protect confidentiality/privacy;
  - to authorise the permitted actions of users of the system;
  - to establish mutual authentication between the LDACS airborne and the LDACS ground subsystem;
  - to prevent the propagation of intrusions within LDACS domains and towards external domains (if LDACS provides interfaces with multiple domains);
  - to protect its services against service attacks to a level consistent with the application service requirements.

- **Data prioritisation**

  With the current technology, there is a significant risk that long data messages transmitted by an aircraft will block air traffic control messages. An in-built quality of service (QoS) function will enable some services to be prioritised over others (e.g., air traffic communications versus airline operational communications), giving precedence to critical information in order to enhance safety.

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5.5.4 Ease of deployment and financial aspects

- **Cost-efficiency**

  It is hard to find and develop new radio sites. LDACS operates in a frequency band different from the band used by the legacy radio infrastructure, so it can be deployed at existing radio sites without the risk of interference. This protects the large investments in building, telecommunication, and energy infrastructure, as well as avoiding the considerable time and expense involved in finding and developing new sites. For a similar cost to today, LDACS equipment can provide a bandwidth which is 50 to 200 times higher than the bandwidth of the current system.

- **Scalability**

  In high-density areas containing multiple airports and numerous aircraft, LDACS cells can be adapted to demand and to optimise performance. For greater efficiency in less-busy areas, the cells can be increased in size, while transmitting power is adapted as appropriate. LDACS can be deployed step by step, starting in high-density areas with the greatest need for secure broadband communications.

- **Decentralised solution**

  As a distributed system with no central single point of failure, LDACS is more resilient than satellite-based systems. It also provides a maintenance approach which allows coverage from another site during repairs, further reducing downtime.

5.6 Risk and mitigation

5.6.1 Technical risk

Risk	Likelihood	Impact	Possible mitigation
Frequencies in L-band	**Medium**	Legacy L-band systems, i.e., DME and SSR, may require more spatial separation as calculated, limiting the choices to assign spectrum to LDACS and install in sites close to such legacy installations.	L-band frequency planning

Table 19: Scenario 1: LDACS – Technical risk and mitigation

5.6.2 Implementation risk

Risk	Likelihood	Impact	Possible mitigation
"Fragmented" ground deployment in Europe	**Low**	Decreased motivation for airlines to invest hence the bandwidth benefits of LDACS can only be fully used later	Enable LDACS deployments to be first targeted to areas where it is most needed and then gradually expanded and establish a solid plan for a pan-European deployment

Table 20: Scenario 1: LDACS – Implementation risk and mitigation

5.6.3 Business and financial risk

Risk	Likelihood	Impact	Possible mitigation
AUs/ANSPs delay investment in LDACS	**Low/Medium**	No solution available in time to alleviate VDL-2 saturation	Solid plan for a pan-European deployment and incentives for early AUs, especially for the early movers
Deployment starts too late: also requiring retrofitting (in addition to forward-fitting) to reach the critical mass of users		Increase in the total airborne deployment cost Operational benefits (fuel savings, reduced delays) will come later	Agree asap on a smooth deployment plan starting as early as possible.

Table 21: Scenario 1: LDACS – Business and financial risk and mitigation

6 Scenario 2 – OFF-THE-SHELF

6.1 Introduction to the OFF-THE-SHELF scenario

6.1.1 Context and vision of the OFF-THE-SHELF scenario

Aircraft safety-critical communications are currently supported by legacy systems (e.g., aviation VHF, HF and authorised L-band satellite systems), based on aging wireless technologies, which operate within dedicated and protected spectrum bands. The process for the evolution of these systems is intrinsically slow, for good reasons, given the time necessary for international standardisation, implementations and deployment.

The aircraft safety-critical communication systems can cope with current needs, but with increasing difficulties. While standardisation of future replacement safety-critical systems (LDACS, SATCOM NG) is under way, these might not be deployed on a worldwide basis for a long time. Furthermore, the evolution of these safety-related communication systems is planned according to projected (long-term) evolutions of the global air traffic management (ATM)) system, and risk being unsuitable or too late to meet potential shorter term safety-related communication requirements arising with new disruptive aircraft concepts, e.g., to integrate new entrants, such as unmanned aircraft and suborbital flights.

On the other hand, public, non-safety commercial communication systems, like public 4G (soon 5G) cellular networks, or commercial Ku/Ka-band "New Space" satellite communication services, are being increasingly used on aircraft to support non-safety-critical communications, for instance passengers' internet browsing or pilot-airline interactions, for optimisation of aircraft operations. Moreover, these systems are regularly evolving towards enhanced and cheaper services, as they can benefit promptly from technological advances implemented for public wireless telecommunication markets.

The OFF-THE-SHELF scenario anticipates that it could become feasible and beneficial, in the short to medium term, to use public non-safety commercial communication networks to support aircraft safety communications, at least partly.[15] The feasibility and acceptability of the OFF-THE-SHELF scenario rely on innovative "overlay control mechanisms" studied within SESAR 2020 solution PJ.14-W2-61 "Hyper Connected ATM" and described in the next subsection.

[15] "Partly" means that the OFF-THE-SHELF scenario does not intend to rely only (100%) on public networks. Rather the intent is to initially propose a hybrid solution where a public commercial link can be used "when/while it works" i.e. "partly" and where a failover on a (fallback) safety links can timely be done when necessary. The concept also considers strategies of multi-transmission (duplicate) of safety critical messages over the safety and commercial links, which can reduce the amount of retransmissions that we have today on safety links

6.1.2 Technical principles of the OFF-THE-SHELF scenario

The COTS (commercial off-the-shelf) scenario considers that safety communications could be enabled over the existing (and future) ground, airborne and air-ground public communication infrastructure available to support passenger communications or non-safety (e.g., AOC/EFB/maintenance) crew communications.

The COTS scenario is based on a hybrid approach, whereby COTS networks are used in combination with a qualified safety network (e.g., VDL-2) which is available as a fall-back in the event of service interruptions or degradations on the commercial public links. The hyperconnected ATM functions comprise mechanisms to detect loss or degradation of the connectivity through the public commercial links and to automatically and promptly failover traffic over the available safety link(s). If a commercial link ceases to be available or experiences degradations, the Aircraft concerned can nevertheless stay connected for safety communications through the “fall-back” safety link. This hybrid strategy leverages commercial infrastructure where and when possible, but can always revert to the baseline safety infrastructure where and when necessary. It assumes that the baseline infrastructure provides sufficient capacity in cases where the COTS networks fail in a region, or that a reversion to voice communication will be operationally used in the worst case in the event of insufficient capacity on the baseline infrastructure at the moment of the COTS networks failure.

The COTS scenario is believed to be feasible thanks to the introduction of surrounding and overlay “control and failover” functions. These functions are specifically designed within SESAR Solution 61 “Hyper Connected ATM” to work around and complement the COTS networks limitations, and to ensure that the resulting end-to-end communication service remains compliant with the applicable requirements (and notably with the applicable safety, performance, security, certification, and spectrum requirements).

The surrounding and overlay “control and failover” (also called “hyperconnected ATM” or HYPERCATM) functions introduced to enable the COTS scenario are represented in Figure 14.

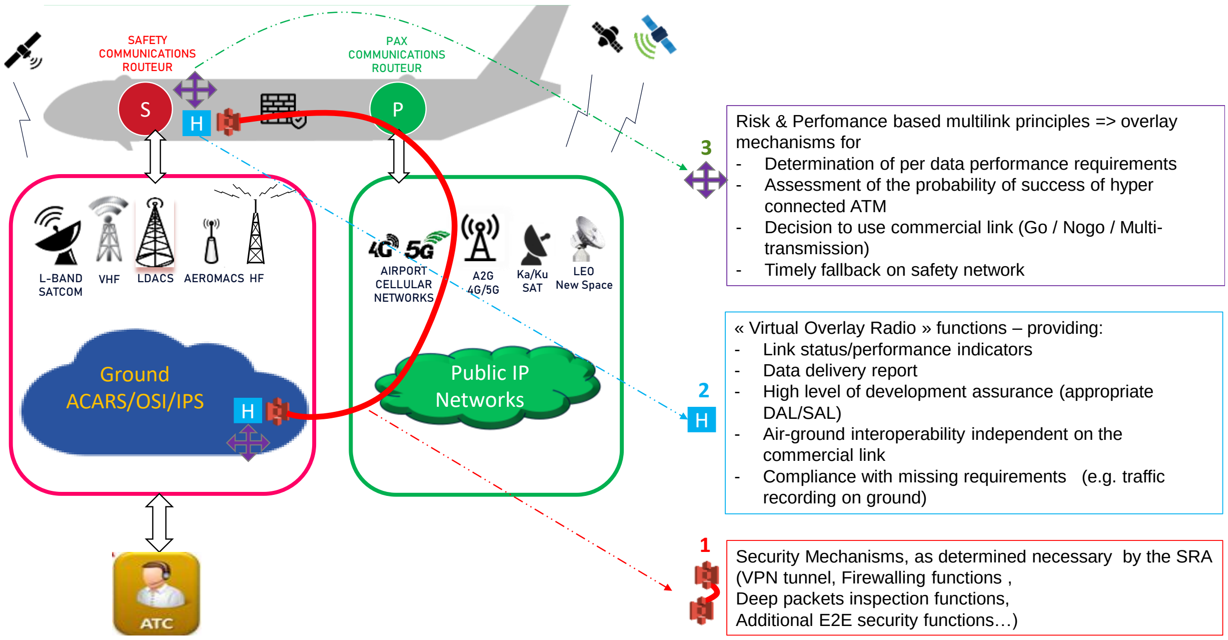

Figure 14: Overview of the COTS scenario technical principles (1)

Figure 15 is the same as Figure 14 but with a different modern graphic code.

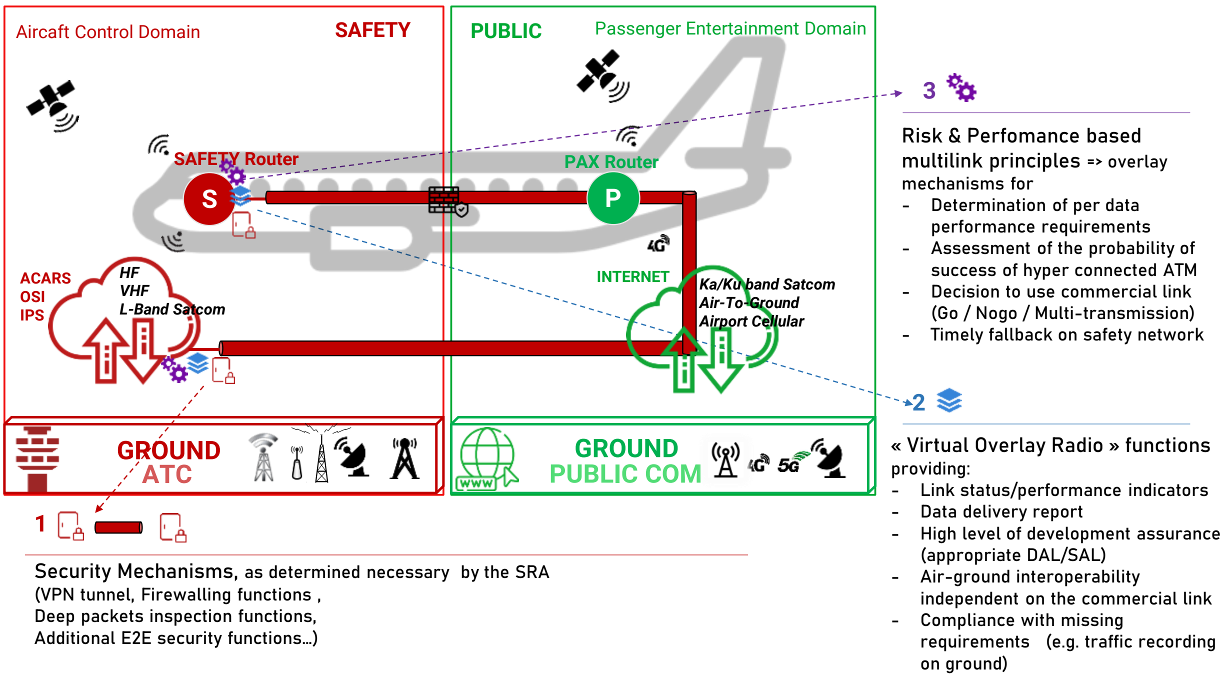

Figure 15: Overview of the COTS scenario technical principles (2)

As illustrated by Figure 14 or Figure 15, the COTS scenario relies on the combination and collaboration of three classes of mechanisms, which complete each other to ensure that the end-to-end communication requirements of the client safety-critical applications are met. These three classes of mechanisms are introduced at the edges of the safety communication domains in the aircraft and on the ground, and interface with the COTS communication systems. These mechanisms consist of the following:

1. Secured tunnelling functions

These are functions responsible for the following services:

- the establishment and the maintenance of one (or several) protected virtual private network (VPN) connection(s) across the supporting commercial link(s) and public internet infrastructure, in between the airborne endpoint at the edge of the aircraft control domain and a ground peer endpoint at the edge of the network of a trusted organisation involved in aeronautical safety communications (e.g., in a CSP domain);
- messages inspection/firewalling, to filter out any incoming and outgoing messages which are not allowed to be received or sent over this interface;
- other functions (security monitoring and events logging, kill-switch mechanisms).

The secured tunnelling functions provide a very high level of confidence that any security attacks that may come from the public links and public internet can be detected and countered. These functions are intended to be hosted within trusted domains of the aircraft (typically in the so-called aircraft control domain) and for the ground counterpart, within the infrastructure of a trusted organisation involved in aeronautical safety communications (typically a CSP). As these functions are independent and separate from systems providing the commercial links and public internet connectivity, these functions can be developed with the appropriate development and security assurance levels (DAL and SAL).

2. Virtual overlay radio function

The end-points of the above tunnel are viewed as kinds of “virtual radios”, with a “virtual airborne radio” on the airborne side, and a “virtual ground station” on the groundside. These form a couple, exchanging protocol data units over the secured tunnel, in a way functionally similar to what real airborne radios (e.g., VDR, SATCOM AES) and ground stations (e.g., VGS, SATCOM GES) do. The key difference is that the “virtual radios” use the secured tunnel for the data transmission, whereas real radios use direct RF propagations.

The virtual radio functions host mechanisms to provide indications on the status and the performance of the air-ground “virtual link”, for instance on the currently expected delivery time (latency). They also provide data delivery reports, confirming or infirming that data transmitted have been received in a timely manner at the other end of the tunnel. The mechanism used to monitor the status and the performance of the links and to provide confirmed data delivery services can be defined independently from the underlying commercial links and public internet connectivity characteristics. This allows for interoperability between the airborne and the ground “virtual radios”, regardless of the underlying commercial OTS air-ground technology being used.

In addition, these functions can be developed with the appropriate development and security assurance levels (DAL and SAL), independently of the commercial systems.

Additionally, the "virtual ground station" is an appropriate location to perform traffic recording, in support of the required overall safety and performance monitoring activities.

3. Risk and performance-based multilink functions

These are functions where the decision is taken on whether or not to use the commercial link(s) for the transmission of data towards its remote destination. Here, different decisions can be taken: "Go", "No Go", multi-transmission (parallel simulcast) of the data over two links (a safety link and a commercial link). The Go/No-Go/"other strategies" decision is based on a number of variables, including notably:

- the performance requirements (RCP) and the safety-criticality of the data to be transmitted ; this variable requires a network-wide monitoring function involving end users and CSPs to determine the level of performance offered by each link at a given period of time;
- the available links (safety and non-safety), and dynamic information on their status and performance;
- possibly, the knowledge of specific local regulations and constraints, to know whether use of commercial links is authorised in the current area of the flight;
- possibly, experience gained with previous attempts;
- an assessment of the time it will probably take to transfer the data over the commercial link.

The other very important function of the risk and performance-based multilink functions is the fall-back mechanism introduced earlier in this section. It is responsible for:

- timely detection when an attempt to transfer a message over a commercial link may have gone wrong,
- timely retransmission of the message on a safety network, in due time to remain compliant with the end-to-end RCP time and continuity requirements; when there is sufficient time, the fall-back mechanism could possibly attempt retransmission(s) on the commercial link(s) first;
- signalling the change in the link selection to the peer in the network, and reporting link degradation to monitoring entities.

It is important to note that, with the above mechanisms, the COTS scenario is designed to be deployed over existing COTS and safety networks, without expecting any changes to be made inside these COTS networks and to their constituting elements (airborne and ground radios, satellites, etc.).

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6.2 Operational applicability

6.2.1 Geographical applicability

Scenario 2 is applicable everywhere in-flight connectivity systems (SATCOM-based or terrestrial A2G based) are available to provide IFC communication services to passengers. It is also applicable at airports where 4G/5G IMT services can be in the range of aircraft moving or parked on the ground. Scenario 2 therefore has the potential to be applied during any phases of flight, and almost everywhere in the world, with coverage being possibly better positioned initially in regions where traffic levels are higher and IFC services are in greater demand/more popular, and on routes operated by airlines offering premium services to passengers.

6.2.2 Airspace and phase of flight coverage

COTS supports communication in all airspaces, including in dense continental areas (domestic en-route airspace, TMAs, and on the airports surface) and in oceanic, remote and polar areas.

Communication technologies are either:

- mandatory, i.e., aircraft must be equipped at the specified flight level or phase of flight; or
- available, i.e., the technology/service is available but there is no obligation to be equipped.

Flight level / Technology	Existing COM technologies			New COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
Airspace > FL245	Mandatory	Mandatory	Available		Available (SATCOM Ku/Ka, terrestrial ATG)	
500 feet < airspace < FL245	Mandatory	Available	Available		Available (SATCOM Ku/Ka, terrestrial ATG)	
Airspace < 500 feet	Mandatory	Available	Available		Available (SATCOM Ku/Ka, terrestrial ATG and 4G/5G IMT at Airport surface)	

Table 22: Scenario 2: COTS – Communication technologies by flight level

Phase of flight / Technology	Existing COM technologies			New COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
En-route – oceanic	Mandatory (air to air)	None	Mandatory (PBCS)		Available (SATCOM Ku/Ka)	
En-route – terrestrial	Mandatory	Mandatory	Available		Available	
TMA – approach	Mandatory	Available	Available		Available	
Airport – ground operations	Mandatory	Available	Available		Available	

Table 23: Scenario 2: COTS - Communication technologies by phase of flight

6.3 Maturity level status

6.3.1 Infrastructure status

The COTS scenario relies on two enablers which have a different maturity level status:

- The first enabler is the set of underlay COTS networks originally designed and deployed to support non-safety communications, and notably to support passengers' or AOC communications. This enabler currently includes mature public/commercial networks that have already been deployed and are already in operational use, sometimes on a relatively large fleet of aircraft and often also for other non-aeronautical use cases (e.g., ground mobile telephony, maritime communications, etc.). These networks are generally based on well-recognised and validated open or industry standards (e.g., 3GPP, IETF, etc.), and on proven professional equipment demonstrated during months or years of exposition in many different fields. These COTS networks are, for instance; the public 4G or 5G IMT network available at airports, the European Aviation Network (EAN) hybrid satellite and air-to-ground network built by Inmarsat and Deutsche Telekom, Inmarsat Global Xpress (Ka SATCOM Ka), and many others. The list of COTS networks that could be used within the COTS scenario, and their maturity, is analysed in detail in the PJ.14-W2-61 TRL-2 Hyper Connected ATM – Survey of candidate Open Networks [13].

- The second enabler consists of the hyperconnected ATM overlay "control and failover" functions introduced in the previous section. The definition of the hyperconnected ATM mechanisms has started in SESAR solution PJ.14-W2-61 at the lowest TRL (TRL-0) and is progressing with the aim of reaching TRL-2 at the end of Wave 2. A demonstration of the concepts will be exercised in 2022. A continuation project is also expected to take place as part of SESAR 3.

On this basis, it is proposed to depict the maturity level status of the COTS scenario as in Table 24.

SESAR technological solution	Enabler	Initial maturity level at the start of Wave 2	Target maturity level at the end of Wave 2/ Wave3
COTS network infrastructure (air/air-ground/ground) available to support the COTS scenario	COTS infrastructure	Already deployed and operational (TRL-9)	Already deployed and operational (TRL-9)
Solution PJ.14-W2-61 Hyper Connected ATM	New enabler(s)	TRL-0 (Dec 2019)	TRL-2 (Dec 2022)

Table 24: Scenario 2: COTS – Maturity level status

Overall, when considering the balance between the mature components and the low TRL components, it must be noted that the weightiest part is the COTS networks infrastructure (i.e., the available 4G/5G, air-to-ground, Ku/Ka satellite airborne radios and air-ground networks)) and that this part is already fully mature and deployed. By comparison, the new “low TRL” hyperconnected ATM component is only a very small fraction of the overall COTS scenario infrastructure: this “low TRL” component consists of relatively light however important interfacing and adaptation functions.

Thus, when considering the maturity of the different components versus their “weight” in the overall infrastructure involved in the COTS scenario, it can be said that the maturity barycentre is close to the high TRL.

There could be an opportunity to place the development of the new “low TRL” hyperconnected ATM component in a ‘fast-track innovation and uptake’ innovation pipeline, making possible to transition within 5 years the global COTS scenario to full technical readiness. Once this is achieved, it should be comparatively easier and faster to get a mature COTS scenario infrastructure deployed.

6.3.2 Service distribution status

In relation to the two enablers introduced in the previous section:

- The service is already operational and distributed for the first enabler.
- The second enabler is not a distributed service yet.

6.3.3 Validation status

In relation to the two enablers introduced in section 6.3.1:

- The first enabler is already fully validated and operational.
- The second enabler will reach TRL-2 validation in 2022.

6.3.4 Safety and security risk assessment status

Scenario	Compliance expected to be achieved in	Risk assessment documented	Compliance with maturity gate requirements	Problem and/or comment
Safety risk assessment	2022	Yes (TRL2)	Yes	TRL2 assessment
Security risk assessment	2022	Yes (TRL2)	Yes	TRL2 assessment

Table 25: Scenario 2 COTS – Safety and security risk assessment status

6.3.5 Early-implementation flights

In relation to the two enablers introduced in section 6.3.1:

- The first enabler is already used on flights.
- The second enabler has not been demonstrated with flights yet.; the concept is being demonstrated with laboratory tests.

6.4 Deployment assumptions

6.4.1 Assumptions with regard to COTS scenario initial deployment

The hyperconnected ATM concept allows for initial deployment of the COTS scenario where existing COTS air-ground networks (such as 4G/5G IMT networks at airports, existing air-to-ground or Ku/Ka SATCOM networks, etc.) can be integrated into the existing datalink ground infrastructure. This could provide the core benefits of this technology and of the already available COTS airborne and ground infrastructure without requiring ANSPs any changes.

The concept can support multiple protocols (ACARS, ATN/OSI, and ATN/ IPS) and would therefore cope with a range of avionics standards, as airline fleets are gradually upgraded to the new internetworking standards.

There are three deployment phases/routes envisaged:

- **Phase 1**

  This phase (shown in green in Figure 16 below, i.e., COTS scenario for ACARS and ATN/OSI) can occur before the deployment of ATN/IPS in order to reap immediate benefits from available COTS networks and installed airborne passenger in-flight connectivity (IFC) systems. The green route covers these scenarios:

  - A way of adding hyperconnected ATM functions to retrofit aircraft, this is more likely for aircraft which are being retrofitted anyway with an IFC system.
  - A way of adding hyperconnected ATM functions to forward-fit aircraft directly equipped with an IFC system.

- **Phase 2**

In this phase (combination of green and blue route in Figure 16 below), ATN/OSI and ATN/IPS traffic could be exchanged via the COTS scenario systems depending on the available infrastructure on the ground and in the aircraft.

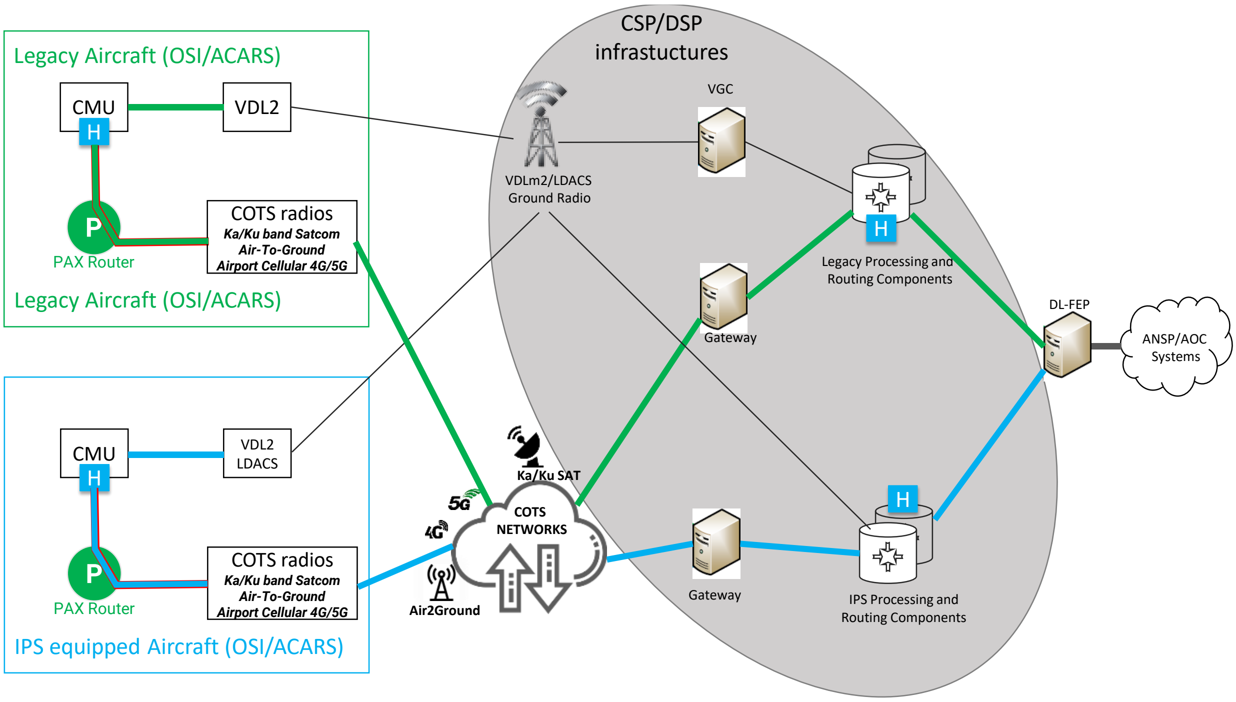

Figure 16 Assumptions with regard to COTS scenario initial deployment

6.4.2 Assumptions with regard to the possible long-term evolution of the initial concept

The concept assumes that, in a first step, hyperconnected ATM will be used only when at least one safety link is available which can be used at any time, notably to mitigate problems occurring on commercial links and the public internet.

It is envisioned, however, that in subsequent steps, in the longer term, following years of observation of/experience with the performance of COTS links, and taking into consideration possible improvements that COTS links operators may be willing to make, there could be some relaxation of the requirement to systematically have a fall-back safety link. For instance, there could be relaxation:

- in temporary conditions: the COTS scenario could be enabled, even if safety links are temporarily down;
- in geographical conditions: the COTS scenario could be allowed, in geographical areas not covered by safety links;
- in equipment failure scenarios;
- depending on the safety criticality of the communication (e.g., COTS scenario allowed for applications with minor safety impacts that can be mitigated with voice communications).

The transition to this long-term evolution might be dependent on:

- enhancements that will be made to commercial link technologies (e.g., in 6G or 7G 3GPP standard);
- on the possible willingness of COTS links operators to offer improved services supporting new business segments (public safety, telemedicine, V2V autonomous cars communications, etc.);
- the opportunities to make these available also for the aeronautical sector.

6.4.3 Deployment on the ground

Once one or several COTS networks are interconnected with the current ground datalink DSP infrastructure or backbone using hyperconnected ATM gateways, there is no need for a specific ANSP deployment plan on the ground: the ANSPs will indirectly be connected to the COTS infrastructure via the existing datalink backbone and/or via NewPENS.[16]

All elements of the ground-ground connection are already in place (re-use of the existing ACARS and ATN/OSI, and later ATN/IPS, infrastructure interfaces). This makes the roll-out of the COTS scenario easy, quick and cost efficient. As soon as the service is declared operational, all European ANSPs and all airspace users equipped for the service will be able to use it seamlessly.

The next steps towards ANSPs being able to use the service depend on the approval of the safety case by the ANSPs. Safety approval could be considerably facilitated by the planned EASA certification of the COTS scenario.

Activation of the COTS scenario, for a given ANSP could then be carried out through a simple reconfiguration of the ground “hyperconnected ATM” gateway once the ANSP has officially accepted the use of this technology in its airspace.

6.4.4 Deployment in aircraft

It is not expected that the COTS scenario will be a reason for operators to equip their aircraft with a passenger in-flight connectivity (IFC) system. However, on aircraft equipped with a passenger IFC system, it will be possible to install the COTS scenario mechanisms. It is anticipated that the installation of these mechanisms could involve:

- the upload of an additional “hyperconnected ATM” software library;
- the installation of additional security software in the ACARS/ATN-OSI or ATN/IPS CMU;
- possibly (if not already provisioned) the installation of additional wiring fully localised inside the avionics e-bay in between the CMU and an interface point to the IFC system.

[16] CONOPS and Safety Case validation are probably the key elements missing to actually trigger the deployment of a COTS scenario. It might be that incentives will be needed to convince ANSPs to launch a validation process up to Safety case validation, because mixing ATC Safety sensitive data with public COTS network maybe considered as a showstopper until saturation of dedicated ATC links have been actually faced.

If the certification of the COTS scenario for ATC communications is confirmed, the same level of aircraft equipment as for IFC systems can be expected. However, this will only be possible if the expected benefits are confirmed, namely enhanced continuity of ATC communications and a reduced cost for AOC communications, with the assumption that the cost for the ATC service will represent only a tiny part of the total IFC system installation costs.

In addition, in order to decrease the risk for early airline pioneers and stimulate a critical mass of users which will make visible the immediate operational benefits as early as possible, EC incentives would be welcome.

Although IFC systems are primarily deployed on long-range aircraft today, it is anticipated that IFC systems will be increasingly deployed on single-aisle aircraft operated on regional routes. Since a key motivation for the COTS scenario is to contribute to solving the VDL-2 capacity congestion problems, the most appropriate deployment strategy would be to target the aircraft families that represent the largest part of aircraft flying in continental Europe, i.e., to certify the COTS scenario on single-aisle aircraft (A319/A320/A321/A220 and B737) first. Certification on long-range aircraft would be less essential or urgent, because proportionally they do not take up much of the VDL-2 capacity.

6.4.5 Preliminary roadmap and fleet equipage

As an indication, Table 26 proposes a first draft schedule for the deployment of the COTS solution, including an assessment of the number of new aircraft that could be equipped with the technology per year.

Deployment phase	Start	End	Ground equipage	Aircraft equipage	Objective and main milestones
Validation Phase	2021	2022			First proof of concept validation of hyperconnected ATM (in SESAR 2020 W2 Solution 61)
	2023	2026			Standardisation of the concept (ICAO/EUROCAE/RTCA) and pre-operational (TRL-6+) validations;
Phase 1 - Pioneer	2027	2028		50% of new long-range (provisions) 10% of new single-aisle (provisions)	Certification: airborne system and integrated end to end service; activation of the pioneer airlines
Phase 2 - migration	2029	2030		50% of new long-range 20% of new single-aisle	Activation of the service for pioneer airlines/ANSPs Target: Single Aisle Aircraft (A319/A320/A321/A220 and B737) first
Phase 3 – full operation	2031	2039		50% of new long-range 40% of new single-aisle	

Table 26: Scenario 2: COTS – timeline and possible roadmap

Note that the long-range fleet represents 22% of the 2019 target fleet, and the single-aisle fleet 78%.

It may be the case that preliminary/reduced adaptations of the COTS scenario concept, limited to the redirection of AOC traffic through IFC and terrestrial IMT systems (so not usable for ATC traffic), are deployed with an accelerated timeline.

6.5 Cost assessment

As described in section 3.4.1, the scope of the cost assessment is limited to the provision of:

- a global estimate of the airborne investment required to equip the target fleet (see section 4.3) by the end of 2039 with one of the OFF-THE-SHELF technologies;
- a global estimate of the ANSPs service fees required to support ATC datalink service provision with one of the OFF-THE-SHELF technologies, covering the entire EUROCONTROL Member State area (continental and oceanic airspace).

6.5.1 Cost assumptions

6.5.1.1 AU cost assumptions

- The equipment cost shown in Table 27 has been estimated by EUROCONTROL on the basis of current knowledge of the technology and input provided by project and airborne industry experts. It does not claim to be 100% accurate.
- As part of the OFF-THE-SHELF scenario, on-board equipment will support all kinds of communications: ATC, AOC but also in-flight connectivity (IFC), i.e., passenger (PAX) communications. For a fair comparison with the alternative scenarios, the equipment cost has been broken down to reflect only the ATC and AOC part, using the following ratio:
  - ATC represents 1% of the traffic flow,
  - AOC represents 5% of the traffic flow,
  - PAX represents 94% of the traffic flow

  It should be noted that the low value of the traffic share estimated for the ATC part (but also for the AOC) is owing to the assumption that the cost of the equipment will be entirely paid for by the passenger communications business model and that the ATC cost should therefore be negligible. If the PAX business model is not profitable, it means that the proportion of the cost allocated to ATC and AOC traffic should be much higher, and even higher than the costs of the equipment in the alternative scenarios.

  However, if the COTS scenario solution becomes popular, it can be hoped that it will eventually become integrated as a standard feature of the aircraft CMU. The extra fee, if any should in any case be recovered quickly by AUs, thanks to the reduction in the communication costs that could result from the offloading of AOC traffic and of ORP ATC traffic on COTS networks. The consumption by the COTS scenario of passenger traffic bandwidth should be calculated as an opportunity cost of a single premium service passenger.
- A base value of EUR 585,000 has been used as a starting point for the total cost of the IFC equipment, the proportionate amount corresponding to ATC and AOC needs being calculated at EUR 35,000. The cost amount includes everything (hardware, software, certification,

installation costs, etc.). The level of confidence reflects the variation in costs depending on the type of aircraft (long range or single aisle).

Airlines have been consulted to confirm the order of magnitude of the IFC equipment cost. They indicated that the cost of the equipment could go up depending on the technology used, the applications required to meet the passenger needs, the complexity of system, its integration with the other equipment on board (EFB, etc.), and the additional ground investment that could be required for AOC infrastructure. However, it seems that new COTS equipment using Ku/Ka band will be cheaper than what currently exists. The average value of EUR 585,000 has been chosen for the BC.

- The estimate of the AU investment by deployment phase presented in Table 15 has been estimated by EUROCONTROL on the basis of the inputs provided by the partners in the COTS team and on the fleet projection developed specifically for the BC (see section 4.3). It also takes into consideration the market penetration that can be expected in terms of the number of new aircraft that will be forward-fitted with the technology every year.
- The projection of the costs throughout the time horizon takes into account the maturity level of the solution and reflects the uncertainties with regards to the deployment dates and the time it will take to obtain the standard, to get the certification for the technology and to set up the service provision for the users.
- Only forward-fit costs have been considered in the cost assessment. At this stage, it is not envisaged to retrofit aircraft with new communication technologies as indicated in the list of assumptions (see section 4.1.1).

6.5.1.2 ANSP cost assumptions

- The cost value indicated in Table 29 represents the service fees which all the ANSPs in the EUROCONTROL Member State area will pay to the DSP for the provision of the ATC datalink service using COTS technology (through a selected CSP or commercial telecom operator). It covers all the cost elements identified in Table 7 (see section 3.4.1 on the scope of the cost assessment).
- The costs of the CSP (or the telecom operator) will be embedded into the mobility service fees distributed across the ANSPs and AUs. The ANSP or AOC groundside of the mobility solution could be provided as a service by the DSP/CSP. In this case, the ANSP will see only a pure OPEX cost.

  Since AU-related traffic will be significantly higher on HYPERCATM than ANSP-related traffic, the same cost-sharing ratio indicated above for the AU investment has been used to calculate the cost in proportion to ATC communication needs only (1% of the traffic flow).
- As the COTS infrastructure will be shared with other domains of application (such as the telecommunications or maritime communications market, for example), the service fees are calculated in proportion to aviation needs. Only incremental costs needed for the usage of HYPERCATM links are considered here. It is assumed that a working FCI ground infrastructure is already available at the time of the COTS scenario deployment.

- The cost of the service fees covers the CSP (or telecom operator) infrastructure amortisation, as well as their running costs, including business overhead costs (marketing, sales, CRM, administration, legal, insurance, risk management, compliance, certification, etc.). It will also have some profit and tax components.

- Service fees have been estimated by EUROCONTROL based on inputs provided by telecom operators in the COTS market with regard to the service pricing for in-flight connectivity for commercial airlines. It is based on current knowledge of the technology and does not claim to be 100% accurate.

  The values were provided per type of aircraft and per year. The ATC component of the service pricing was calculated by looking at the target fleet distribution (long-range vs single-aisle), and using the traffic share ratio of 1% for the ATC part, as indicated above. A projection of the annual service fees was then calculated per year based on the progressive number of aircraft that will be equipped with the COTS technology.

- An ANSP with an existing FCI ground-ground boundary router (GGBR) would most likely fully reuse that node. The over-the-top probing and performance management functions plus the special administrative policing functions might require the additional installation of some more software components or hosting devices.

  Therefore, on top of the cost for the service provision, service fees include a recurrent cost for the maintenance of the gateways that are needed for the ANSPs to access the service. This has been estimated at EUR 1 million per year overall for all ANSPs in the EUROCONTROL Member State area.

- The service fees do not cover the governance, DSP and CEAB costs. These costs will come on top of the COTS services fees and will be shared with other communication means (existing and new technologies).

- The service fees cover all continental airspace, i.e., the provision of the service in the en-route segment, in the TMAs and at airports as well as in oceanic airspace.

6.5.2 Cost assessment results

6.5.2.1 AU costs

Table 27 presents the cost of the on-board equipment for the COTS scenario and the theoretical cost for the airborne investment if 100% of the 2039 target fleet (i.e., 8,564 a/c) is equipped.

Airborne equipment cost (unit cost)	Base	Level of confidence	Target fleet theoretical cost (8,564 a/c)
COTS equipment cost per aircraft (forward-fitting)	EUR 35,000 (representing around 6% to 7% of the cost of the IFC equipment)	+/- 15 %	**EUR 300 million**

Table 27: Scenario 2: COTS - AU unit cost and target fleet theoretical cost

Table 28 presents the airborne investment that the airlines will have to bear by deployment phase. It is based on expert judgment regarding realistic assumptions for COTS deployment dates.

Fleet equipage rate and total airborne investment by phase	Phase 1 (2027-2028)	Phase 2 (2029-2030)	Phase 3 (2031-2039)	TOTAL
Expected target fleet equipage (as a percentage of a/c numbers)	2% of the target fleet	6% of the target fleet	23% of the target fleet	
Total airborne investment	EUR 5.9 million	EUR 9.0 million	EUR 55.0 million	**EUR 70** million

Table 28: Scenario 2: COTS - AU costs by phase of deployment

6.5.2.2 ANSP costs

Table 29 presents the cost of service fees per year which will have to be borne by all the ANSPs for DLS provision with the COTS technology in the entire EUROCONTROL Member State airspace.

ANSPs service fees	Base	Level of confidence	
ANSP service fees per year at FOC (full operational capability) and for the entire EUROCONTROL Member State area.	**EUR 8.3** million	+/- 20%	

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Table 29: Scenario 2: COTS - ANSP annual service fees

Table 30 presents the progressive equipage rate on the ground based on realistic deployment assumptions and presents the annual service fees and cumulated costs that will be borne by the ANSPs for the service provision with the COTS technology.

	Phase 1 (2027-2028)	Phase 2 (2029-2030)	Phase 3 (2031-2039)	TOTAL
Expected ground equipage (as a percentage of total service fees)	14%	16%	33 %	**-**
Annual service fees at the end of each period	EUR 1.1 million per year	EUR 1.4 million per year	EUR 2.7 million per year	-
Total ANSP service fees (cumulated by phase)	EUR 2.2 million	EUR 2.6 million	EUR 19.2 million	**EUR 24 million**

Table 30: Scenario 2: COTS - ANSP annual and total costs by phase of deployment

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6.5.2.3 Overall cost projection

Figure 17 presents the cost projection and fleet equipage for Scenario 2 – OFF-THE-SHELF.

The deployment of the technology is expected to start in 2027 with a short two-year pioneer phase. The rate at which new aircraft are equipped with OFF-THE-SHELF technologies will depend on whether airlines decide to equip their fleet with an IFC system for passenger communications. The ramp-up of the scenario 2 fleet is based on expert judgment of potential narrow-body and wide-body equipment.

The migration phase will also last two years, from 2029 to 2030, and as from 2031, 42% of new aircraft should be equipped with one of the OFF-THE-SHELF technologies every year. At the end of the time horizon, 23% of the target fleet should be equipped in scenario 2.

With regard to the evolution of ground costs, since the service costs are directly linked to the equipment of the fleet, there will be a gradual evolution in the annual service costs from EUR 1.1 million in 2027 to EUR 2 .7 million in 2039 to support 23% of the equipped fleet.

Scenario 3 - OFF THE SHELF	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
Ramp up of fleet equipage(% of new a/c equipped with OFF THE SHELF technology)	0%	0%	0%	0%	0%	0%	19%	19%	27%	27%	42%	42%	42%	42%	42%	42%	42%	42%	42%	
Nb of a/c equipped per year	0	0	0	0	0	0	82	88	135	123	196	170	155	162	188	216	197	195	92	1.998
Cumulated a/c equipped	**0**	**0**	**0**	**0**	**0**	**0**	**82**	**170**	**305**	**427**	**624**	**794**	**949**	**1.111**	**1.298**	**1.514**	**1.711**	**1.906**	**1.998**	
% Target fleet equipage	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**1%**	**2%**	**4%**	**6%**	**8%**	**10%**	**12%**	**14%**	**16%**	**18%**	**21%**	**23%**	**23%**	
Nb of flights equipped per year	0	0	0	0	0	0	98.217	107.761	165.738	149.421	246.651	206.881	179.054	179.596	217.311	262.606	232.488	234.724	93.944	
Cumulated flights equipped	**0**	**0**	**0**	**0**	**0**	**0**	**98.217**	**205.978**	**371.716**	**521.136**	**767.787**	**974.668**	**1.153.723**	**1.333.319**	**1.550.630**	**1.813.236**	**2.045.724**	**2.280.448**	**2.374.392**	
% Target traffic equipage	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**1%**	**3%**	**4%**	**6%**	**9%**	**11%**	**13%**	**15%**	**17%**	**19%**	**21%**	**24%**	**24%**	
% FL285 traffic equipage	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*2%*	*4%*	*5%*	*8%*	*9%*	*11%*	*12%*	*14%*	*16%*	*18%*	*20%*	*21%*	
% ECAC traffic equipage	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*2%*	*3%*	*4%*	*6%*	*7%*	*8%*	*9%*	*11%*	*12%*	*14%*	*15%*	*15%*	
AUs - Forward fit costs	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**2,9**	**3,1**	**4,7**	**4,3**	**6,9**	**6,0**	**5,4**	**5,7**	**6,6**	**7,5**	**6,9**	**6,8**	**3,2**	**70**
Ground equipage	0%	0%	0%	0%	0%	0%	13%	14%	15%	16%	18%	20%	22%	23%	25%	28%	30%	32%	33%	
ANSPs - Gateways Service fees (fixe cost all over the timehorizon)	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	13,0
ANSPs COM Service fees (OPEX cost = depends on nb of cumulated a/c equipped per year)	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,3	0,4	0,5	0,7	0,8	0,9	1,1	1,3	1,5	1,6	1,7	11,0
TOTAL ANSP service fees (Sum of the ANSPs Gateway costs + ANSP Com service fees)	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**1,1**	**1,1**	**1,3**	**1,4**	**1,5**	**1,7**	**1,8**	**1,9**	**2,1**	**2,3**	**2,5**	**2,6**	**2,7**	**24,0**

Figure 17: Scenario 2: COTS - Overall cost projection and fleet equipage

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6.6 Qualitative assessment

This scenario has the following main benefits:

6.6.1 Performance

The primary ambition of the COTS scenario is to support and consolidate the performance which is already expected to be met by the safety datalink infrastructure deployed in the targeted airspace. The COTS scenario does not claim to improve the guaranteed minimum baseline performance, given that it falls back on the minimum performance of the available safety links, when the COTS links are not available or are operating in a degraded mode.

The expected performance of Scenario 2 will therefore typically be:

- RCP240 and RSP180 in oceanic regions where such performance is expected to be achieved with the baseline datalink infrastructure;
- RCP130 and RSP160 in continental regions where such performance is expected to be achieved with the baseline datalink infrastructure;
- other applicable RCP/RSP wherever this is expected to be achieved by the supporting baseline datalink infrastructure.

Beyond this baseline, the COTS scenario has the unguaranteed potential to enhance the level of compliance with the applicable RCP/RSP, and to increase some performance figures in nominal conditions. It is expected notably that, during nominal periods, the COTS scenario will:

- Increase the overall datalink capacity available to airspace users, because the scenario allows for part of the ATC and AOC data traffic to be offloaded onto COTS links and therefore for more data to be transferred globally;
- enhance the continuity, because the use of multiple parallel and alternative legacy and COTS links in support of end-to-end safety communications will increase the resilience to communication problems on these individual links;
- reduce the technical transaction times, because it is expected that COTS links and networks have shorter latency in nominal conditions;
- possibly enhance availability, if use of the COTS scenario is also permitted when the fall-back safety links are temporarily unavailable;
- make available a higher bandwidth than what would be possible with safety qualified links. The additional capacity may enable support for current datalink services (e.g., Baseline 1 and 2), as well as for future new services;
- possibly make the long-term evolution discussed in section 6.4.2 become more feasible and potentially faster to achieve in the case of those HYPERCATM networks which are already upgraded to very high-availability configurations.

6.6.2 Potential evolution of the technology - scalability

The COTS scenario, once in place, will be easily extensible to new COTS networks and technologies that will be deployed in the future (e.g., 6G, New Space satellite constellations, future growth in Q/V bands).

6.6.3 Safety, security and QoS aspects

The COTS scenario can contribute to reducing the congestion of safety-qualified links, thanks to ATC/AOC traffic being offloaded onto COTS links.

End-to-end communication resilience and transit times will also be improved, thanks to the extended range of usable links and the use of generalised performance-based multilink hyperconnected ATM mechanisms able to select the most appropriate link.

The hyper connected solution requires safety-critical network availability as back-up for the COTS. The most important reason being the lower guaranteed reliability of COTS. For example, denial of service attack (DDoS) on passenger inflight service would make the COTS unavailable for safety critical services due to the lack of prioritisation capability.

6.6.4 Ease of deployment and financial aspects

The COTS scenario is assumed to be a small incremental investment on top of an existing infrastructure. It should be cost effective, as it reuses existing airborne and ground COTS infrastructure.

It provides immediate worldwide coverage and worldwide interoperability because COTS networks are available almost everywhere, and based on global industry standards.

The COTS scenario introduces a possible way forward when faced with the limitations to aviation spectrum and the slow evolution and deployment of new aeronautical safety communications solutions. It also introduces an easy playground for fast experimentation with and validation of new datalink concepts.

The COTS scenario will benefit from the high dynamicity of the in-flight connectivity market, with its potentially high rate of equipage, and from the increasing quality of services stimulated by the open competition.

Quick deployment is achievable because the COTS scenario reuses an already deployed and mature (public) networking infrastructure. Validation/standardisation/certification of the hyperconnected ATM mechanisms could be accelerated if there is a consensus to push this solution forward and fast-track its deployment.

6.7 Risk and mitigation

6.7.1 Technical risk

Risk	Likelihood	Impact	Possible mitigation
Overall quality of the COTS connectivity service	Low	Low, since the aviation link is used in parallel.	This can be mitigated by increased redundancy. For example, the EAN was upgraded in summer 2021 to an infrastructure that does not include any single point of failure, and the failure detection and failover is fully automated. It is expected that this will improve the performance with regard to the safety requirements in such a way that even long-term evolution deployment would become feasible.
Availability of the communication means owing to the fact that the commercial network is not entirely dedicated to aviation	Low	If COTS uses the commercial spectrum, there is a technical/business risk regarding how aviation users will be served compared with others. Will there be a priority mechanism established by the operator (increasing OPEX) or not (and thus not guaranteeing the QoS)?	As described in [13], there are multiple independent infrastructures and providers for the HYPERCATM connectivity services. That means that business risk relating to overall service availability is mitigated by the high level of diversity.

Table 31: Scenario 2: COTS – Technical risk and mitigation

6.7.2 Implementation risk

Risk	Likelihood	Impact	Possible mitigation
The technical means of compliance for certification has not been fully worked out or approved by the competent authorities.	**Low to Medium**	Impact on the roadmap to deploy the technology.	This still needs to be established to make the COTS scenario deployable in production.
The addition of the functionality needed for hyperconnected ATM to the aircraft ATN/IPS router would impact the certification of those devices.	**Low to Medium**	This might require a major effort and may take a longer time.	Reducing the needed functionality to the absolute minimum needed would mitigate this problem.

Table 32: Scenario 2: COTS – Implementation risk and mitigation

6.7.3 Business and financial risk

Risk	Likelihood	Impact	Possible mitigation
The PAX business model is not profitable and the cost for ATC traffic is no longer "negligible"	**Medium to high**	Risk to drastically increasing the cost of ATC service provision.	Ensure that the airlines will support the risk and limit the possible cost variation in the contract placed by the DSP.
			Because of the diversity of providers and business models, there is significant competition, so the connectivity service costs could be kept under control and maintained below the estimated threshold. If the Seamless Air Alliance (SAA) standardisation efforts (see [13]) are successful, then even the on-board and ground equipment could easily be replaced node by node with a best-of-breed solution selected through competitive procurement.

Table 33: Scenario 2: COTS – Business and financial risk and mitigation

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7 Scenario 3 – SATCOM NG

7.1 Introduction to the SATCOM NG scenario

The SATCOM NG scenario is based on Inmarsat/Iris as it is the only service provider that communicated costs indication. It shall be noted that other similar potential services could be operated in the future.

Below a brief description of the system:

7.1.1 System architecture

The Iris services builds on Inmarsat SwiftBroadband - Safety (SB-S) infrastructure. This is an evolution of Inmarsat Classic Aero services, which have served airlines for over 25 years. SB-S supports simultaneous voice and broadband data, with IP data at up to 1.7 mbps, and IP data streaming on demand at 32, 64, and 128 kbps.

The Iris system is an evolution of the SB-S system. Iris introduces ATN/OSI and security gateways in both the air and ground segments. ATN gateways encapsulate ATN/OSI traffic in the SB-S IP data connection. The gateways present standard interfaces defined in the ICAO ATN Manual (ICAO 9880) for integration into ground-ground networks within the European ATM network and, through minor modification, into the ATSU/CMU on board the aircraft. The security gateways create an IPsec VPN to protect ATS datalink traffic against potential controller masquerade and replay/modification attacks. Additional mechanisms deployed in the air and ground segments mitigate denial of service attacks and prioritise ATS application access to the available SB-S service resources.

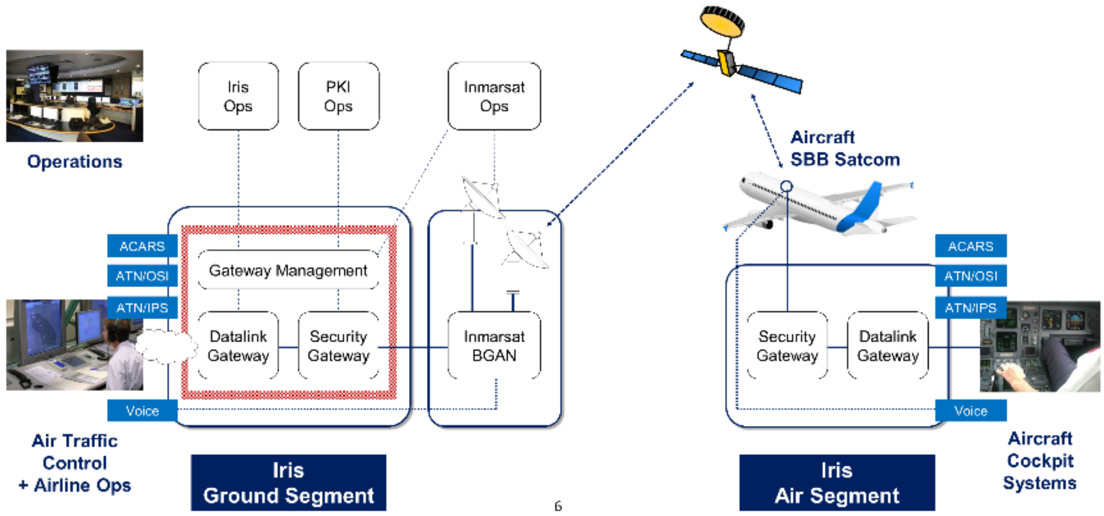

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Figure 18: SATCOM NG architecture

7.1.2 Satellite network

The Iris network is designed specifically to provide high levels of network availability and operates over Inmarsat's fourth generation satellites.

The I4 satellites form a sophisticated commercial constellation, with redundancy engineered into both space and ground segments. The network is based on highly resilient L-band links, which are unaffected by rain fade that degrades links in other bands. The I4 constellation consists of four satellites, EMEA (Alphasat), MEAS (Middle East – Asia), APAC (Asia Pacific) and AMER (Americas), in geosynchronous orbit which provide near-global L-band coverage. The coverage map is show below in Figure 19.

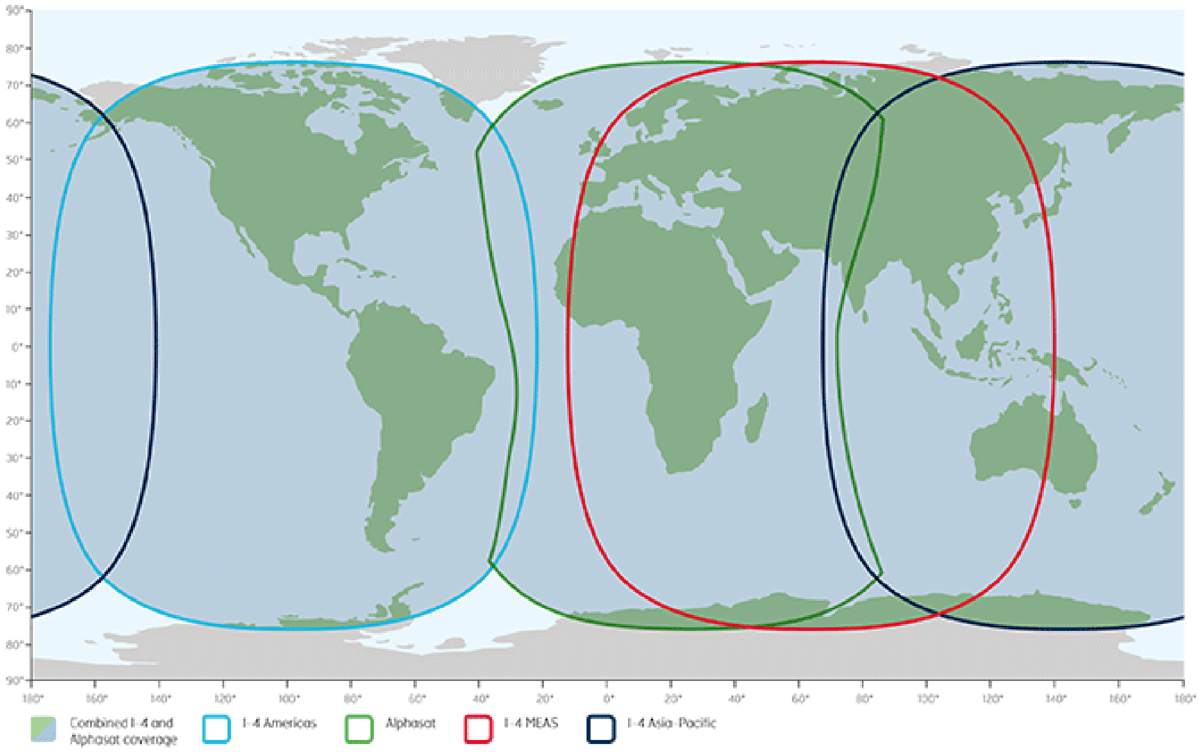

Figure 19: SATCOM NG coverage map

7.1.3 Services running on the Iris SATCOM terminal

- ATN service (Iris service), initially ATN/OSI; adding ATN/IPS once the standard is consolidated
- Legacy ACARS and FANS service (CPDLC/ADS-C)
- IP service for EFB (IPv4)
- Satvoice

7.2 Operational applicability

7.2.1 Geographical applicability

The coverage area for this scenario is the EUROCONTROL Member States' airspaces and it includes the oceanic domain. The extension to a global service is planned with the migration from ATN/OSI to ATN/IPS as the geographical footprint of the Inmarsat service is global by design. Inmarsat has anticipated the change to the future global ATN/IPS standard and will be validating the first prototype of ATN/IPS gateways (both ground and airborne) in 2022. It is very important to note that the update of the avionics from ATN/OSI to ATN/IPS is expected to take the form of a software change. The main change to the infrastructure will be a new version of the Iris Aerorack for ATN/IPS (also a software change). Inmarsat is already working with the industry partners developing the ATN/IPS capability. The Iris service will thus become truly global once ATN/IPS starts to develop in the rest of the world, as a minor additional cost element.

7.2.2 Airspace and phase of flight coverage

SATCOM NG supports communication in all terrestrial airspace (airports, TMAs, and en-route airspace), as well as in the oceanic airspace.

Communication technologies are either:

- mandatory, i.e., aircraft must be equipped at the specified flight level or phase of flight; or
- available, i.e., the technology/service is available but there is no obligation to be equipped.

Flight Level / Technology	Existing COM technologies			New COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
Airspace > FL245	Mandatory	Mandatory	Available	Available		
500 feet < airspace < FL245	Mandatory	Available	Available	Available		
Airspace < 500 feet	Mandatory	Available	Available	Available		

Table 34: Scenario 3: SATCOM NG – Communication technologies by flight level

Phase of flight / Technology	Existing COM technologies			New COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
En-route – oceanic	Mandatory (air to air)	None	Mandatory (PBCS)	Available		
En-route – terrestrial	Mandatory	Mandatory	Available	Available		
TMA – approach	Mandatory	Available	Available	Available		
Airport – ground operations	Mandatory	Available	Available	Available		

Table 35: Scenario 3: SATCOM NG - Communication technologies by phase of flight

The Iris service was primarily designed for the en-route phase of flight (>FL245); however, Iris could also serve the airspace below FL245 as well as below 500 feet, as it does not have the same constraints as the ground VHF technology. During the Iris early-implementation flights, some ANSPs expressed an interest in assessing the use of Iris for CPDLC at low altitude.

7.3 Maturity level status

The Iris service will be ready for deployment in 2023: the infrastructure elements (space, ground and airborne) are either fully developed and validated (ground) or in the final phase of validation and integration (airborne) for commercialisation. Iris distribution does not need a complex infrastructure on the ground and will use the existing (and future) ATN infrastructure. A technical partner, ESSP, has been selected to proceed with the certification of the service provider in time for Q2 2023. Today, Iris is a uniquely mature technology to complementing VDL-2.

7.3.1 Infrastructure status

Space segment:

As explain above, the space segment is the one already used for the commercially available SB-S service.

Ground segment:

The ground gateway (“Aerorack”: ATN and security gateways) commercial product is in final validation after integration into Inmarsat BGAN. The initial version of the Iris service builds on ATN/OSI, whilst the ATN/IPS version is being developed now for testing in 2022. This means that the service will be available immediately to all stakeholders using the existing ATN infrastructure. The change to ATN/IPS will involve only software upgrades to the infrastructure (airborne and ground elements), and once the ATN/IPS protocol starts to be deployed, the Iris service will have benefited from several years of operational usage.

Airborne elements:

There are two products available on the market for Iris services:

- The Honeywell ASPIRE 400 was developed and validated up to black label avionics. It includes the Iris ATN service as an option. Since then, Honeywell has also developed the CMU adaptation for the ATN service over Iris. Both avionics are ready for a certification programme for a first airline customer. Honeywell avionics was tested during flight trials with NLR test aircraft (2019) as well as in 2021 on Honeywell Embraer test aircraft.
- The SATCOM terminal "Light Cockpit SATCOM" (LCS) developed by Cobham is a commercial product available since the end of 2020 for A320 and A330. It will be available for A350 in 2022. The ATN/OSI function in the SATCOM terminal is being finalised and will be certified in October. The function is a software upgrade to the terminal. The ATSU adaptation for the ATN service over Iris is also in the final stages of development and a commercial certified product should be available in Q3 2022. The first test by Airbus for the new products have started in June 2021.

SESAR technological solution	Enabler	Initial maturity level at the start of Wave 2	Target maturity level at the end of Wave 2/Wave 3
Solution PJ.14-W1-109 Air traffic services (ATS) datalink using iris precursor	SATCOM Class B (ATN/OSI)		TRL-6 (achieved in SESAR1) Solution in 2021 catalogue
Solution PJ.14-W2-107 SATCOM Evolution towards IPS-based FCI	SATCOM Class A (ATN/IPS)	TRL-4 (Dec. 2019)	TRL-6 on-going (Dec 2022)

Table 36: Scenario 3: SATCOM NG – Maturity level status

7.3.2 Service distribution status

- Iris service distribution: The ATN services (B1/B2) will be delivered to ANSPs via an EASA-certified service provider (Iris service provider – ISP). There is virtually no ground infrastructure to deploy, as the services will be distributed using the existing/planned ATN infrastructure. The ISP will require an ATM/ANS Organisation Approval (AOA) granted by the European Aviation Safety Agency (EASA). In 2021, ESSP and Inmarsat signed a cooperation agreement establishing ESSP as the technical partner to proceed with the certification of the service provider. The certification application to EASA was submitted in December 2021 with the aim of obtaining certification by Q1 2023.

- Dual link concept: A concept of operation of the Iris service in complement to the VDL-2 service has been established and agreed with stakeholders in its initial version. The ConOps (concept of operations) provides for a set-up of the avionics as “SATCOM primary-VDL-2 secondary” for Iris-equipped aircraft. This routing policy will be configured in the ATSU/CMU and will allow an aircraft equipped with SATCOM to use it throughout the flight anywhere in European airspace, without any changes to the ground infrastructure, and in a transparent manner for the pilot and ANSPs. In the event of a failure of the SATCOM link, the airborne router will automatically fall back to VDL-2. The on-going validation in the Iris test facility and in the future with the first Iris airline (end of 2022/beginning of 2023) will demonstrate the viability of this set-up. This version of the ConOps could evolve in the future; this is being addressed by the SDM in an ad-hoc working group.

7.3.3 Validation status

Iris technology is validated:

- SATCOM Class B was validated in SESAR2020 Wave 1 PJ.14.2.2, achieving a TRL-6 (V3). The TRL has increased further outside the scope of SESAR within the ESA Iris programme. The solution will be ready for deployment in 2022.
- SATCOM evolution towards IPS FCI will be validated at "TRL-6 ongoing" in SESAR2020 Wave 2 PJ.14-W2-107. This validation will include Honeywell AES and Iris IPS ground equipment. In addition, the ATN/IPS capability was demonstrated in Boeing's ecoDemonstrator programme: a Boeing 737-9 aircraft operated by Alaska Airlines was equipped with an SB-S SATCOM unit from Cobham including an ATN/IPS layer. The aircraft was connected to a Boeing test end system in Seattle. CPDLC and AOC services were demonstrated across America and Europe over the air on the Inmarsat network.

Many validation activities have been conducted within and outside the Iris programme, within SESAR1 programmes as well as by aircraft and avionics manufacturers' own development programmes. All validation activities provided confirmation that the Iris service meets the performance requirements (see section 6.6.1). The validation activities will not be detailed here but full reports can be made available on request:

- February 2016: SESAR 15.2.5 Airbus flight trials with Honeywell avionics. Following lab-based testing and evaluation, a flight test was performed with Airbus 330 MSN871 on 23 February 2016. During the flight, ADS-C was exercised for two hours, with i4D extended profile reports sent at 20-second intervals, maintaining contracts with both a test tool in Toulouse, and at EUROCONTROL MUAC. Various CPDLC exchanges were also performed. The Iris technology is now SESAR solution 107 in the SESAR catalogue.
- October 2016: flight trials with the NLR and prototype systems – five flights (12 hours 55 minutes of flight time). Honeywell avionics.
- June-July 2018: flight trials with NLR Citation II (10 hours 44 minutes of flight time) with the new Honeywell AES development, which has the Iris Precursor functionality native to the box, along with real ATSU and DCDU avionics providing the ATN capability on the aircraft. During phase 2, the end-to-end chain goes from an Airbus ATSU connected to a Honeywell SATCOM equipment (Aspire 400 + AMT-3800 HGA Antenna) to the CM/CPDLC ground end-system(s) and ACARS ground systems.
- June 2021: flight trials with Honeywell test aircraft (Embraer). Approximately 7 hours of flight, with CPDLC, ADS-C (more than 700 ADS-C reporting) as well as two simultaneous 100-minute calls and constant AISD, PISD data connection delivered over SATCOM. No in-flight failures were observed and performance was good (on-going detailed analysis by SITA).
- July 2021: first Airbus ATN flight test (15 July). Cobham avionics. Expecting results.

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7.3.4 Safety and security risk assessment status

Scenario	Compliance expected to be achieved in	Risk assessment documented	Compliance with maturity gate requirements	Problem and/or comment
Safety risk assessment	2022	Started undergoing EASA certification.	Yes	
Security risk assessment	2021	Achieved	Yes	PKI implemented on SB-S

Table 37: Scenario 3: SATCOM NG – Safety and security risk assessment status

7.3.5 Early-implementation flights

EasyJet has chosen to become the first airline to demonstrate Iris capabilities during commercial flights. EasyJet will equip 10 A320 aircraft with commercial avionics and will demonstrate the value of all Iris-supported services, namely classic AOC, IP AOC, Satvoice, FANS and ATN, as from Q2 2022. The first aircraft equipped is expected in May 2022 and will start evaluating all services except for the ATN service, which will be introduced at the end of 2022. The flight demonstrations are expected to end in March 2023 and will lead to the launch of the operational service with an EASA-certified service provider.

A truly pan-European deployment will provide a seamless datalink service throughout European airspace and will allow for rationalization of service costs.

7.4 Deployment assumptions

7.4.1 Deployment on the ground

There is no need for a specific deployment plan on the ground: the ANSPs are connected to Iris via the existing ATN backbone and/or via NewPENS.

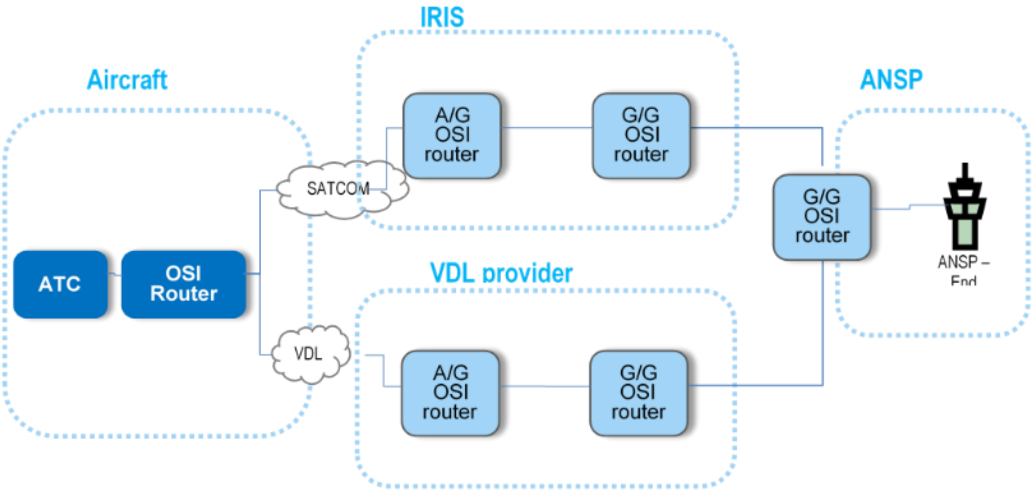

Figure 20 SATCOM NG –Overview of the ground infrastructure

All elements of the ground-ground connection are already in place (re-use of the existing ATN/OSI infrastructure). This makes the roll-out of the Iris service easy, quick and cost efficient. As soon as the service is declared operational, all European ANSPs and all airspace users equipped for the service can use it seamlessly.

The next steps towards ANSPs being able to use the service depend on the approval of the safety case, which relies on the safety assessment drawn up by the ANSPs and approved by the national supervisory authorities (this step should mainly make use of the certification work carried out by EASA), as well as the establishment of SLAs with the future Iris service provider. Safety approval will be considerably facilitated by the planned EASA certification of the Iris service provider. In addition, the 13 ANSPs[17] that are contributing to the ESA Iris project have started drafting the safety assessment plan to allow for the flight demonstrations at the end of 2022 as well as preparing for the operational use of the Iris service by mid 2023.

[17] BULATSA, the DFS, the DSNA, ENAIRE, ENAV, EUROCONTROL EEC, HungaroControl, the LFV, the LVNL, MUAC, NATS, NAVPortugal, ROMATSA, Skyguide

In addition, the discussion on the certification of an Iris service provider started some years ago and are progressing well. The application for certification by the Iris service provider is expected by mid-2022, in time for certification to be obtained by mid-2023, when the flight demonstrations come to an end.

Service provision: It is assumed that the SATCOM service will be procured centrally by the DSP. Inmarsat's plan is to establish a certified Iris service provider that will act as an intermediate player between Inmarsat (technology provider) and the future DSP.

7.4.2 Deployment in aircraft

7.4.2.1 Inmarsat capacity analysis: airborne view

The entry into service of the complementary technologies is driven mostly by the growing problems that the VDL-2 infrastructure is forecasted to face in the medium term.

Inmarsat has conducted an analysis to develop Iris equipage scenarios consistent with the objective to offload some traffic from VDL-2 before its capacity starts to become insufficient. This was achieved by calculating the percentage of offload from VDL-2 to SATCOM required to avoid the VDL-2 breaking point (saturation of the network), which led to a theoretical number of aircraft which would need to be required with Iris. The analysis and simulations were carried out with the support of the University of Salzburg (USBG). The assumptions for VDL-2 capacity are those developed by the USBG for the EC capacity study.

The simulation was conducted in 2018, and the COVID-19 crisis affected some of the assumptions (traffic level, saturation point for VDL-2). However, although the pandemic and decreased traffic may have delayed the saturation of VDL-2 by a few years, they do not significantly change the medium to long-term picture, hence the results of the simulations.

In order to successfully offload VDL-2 to extend its lifespan after 2030, 4,000 aircraft would need to be Iris equipped by 2040. As deployment is scheduled to start by 2023, this means that a quite steep ramp-up will be needed for the narrow-body fleet operating in Europe (traditionally not equipping with SATCOM).

7.4.2.2 Airborne deployment scenario adopted

EUROCONTROL had initially developed specific equipage scenarios for this FCI business case. The scenario (common to all future technologies) anticipated a larger equipage rate than the assumptions above, reaching around 7,000 aircraft by 2040. In particular, the medium-term perspective for the 2030-2040 period in the EUROCONTROL scenario "plans" for +500 new aircraft equipped each year. After discussion, it was agreed that a more realistic deployment scenario, in line with the views from the industry, should be considered. The number of aircraft equipped is depicted in the diagram below.

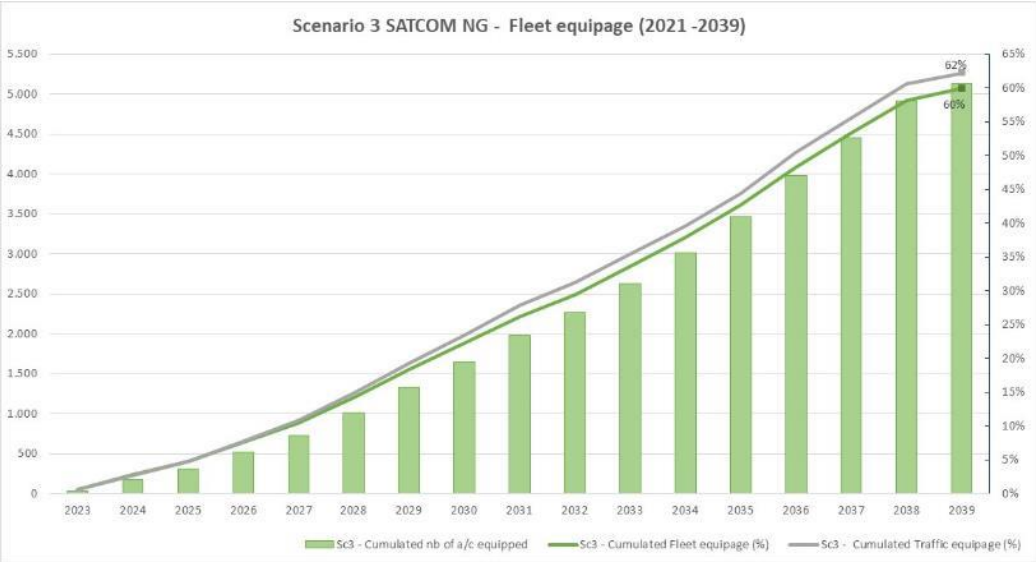

Figure 21 SATCOM NG – Fleet equipage

7.4.2.3 Target fleet

The single-aisle fleet (A320 and B737 and other regional aircraft) for European airspace users is the main category of aircraft for the deployment. Today, only a small share of these aircraft is equipped with SATCOM. The Airbus and Boeing SR + LR fleet carry out close to 70% of all European flights.

As mentioned earlier, Airbus will offer the Iris SATCOM solution for ATN/OSI by the end of 2022 as a line fit option for all SR and LR range models (the retrofit kit is also being finalised).

Boeing, however, has not yet announced a specific plan for ATN/OSI over SATCOM and it may well directly target an ATN/IPS version of it. It could then be assumed that the critical mass of Boeing single-aisle aircraft will be equipped with Iris slightly later than the Airbus fleet. A similar assumption could be considered for regional aircraft. Compliance with the CP1 mandate for EPP download may positively impact this aspect.

7.4.2.4 Incentives

As is often the case in ATM, a significant share of the investment for deploying a new technology is borne by the airspace users up front. The rate of equipage is instrumental for the optimum provision of datalink services. Even when the CBA ratio is sufficient to justify the investment in avionics, the pay-back periods span many years, which is not in line with most airlines' expectations for investments of that kind.

Financial incentives could be used to decrease the risk of late equipage by airspace users.

Today, airlines have not yet planned to equip with the technology. For the forecasted ramp-up to be triggered, the following would be required:

- a clear deployment roadmap from the EC/SESAR, explaining the rationale, objectives and benefits of adding a new datalink technology;
- EC incentives to decrease the risk for early airline pioneers and to encourage the critical mass of users to reap the operational benefits as early as possible. This could in particular be a way to stimulate a deployment in the Boeing fleet.

7.5 Cost assessment

As described in section 3.4.1, the scope of the cost assessment is limited to the provision of:

- a global estimate of the airborne investment required to equip the target fleet (see section 4.3) by the end of 2039 with the SATCOM NG technology;
- a global estimate of the ANSPs service fees required to support ATC datalink service provision with the SATCOM NG technology, covering the entire EUROCONTROL Member State area (continental and oceanic airspace).

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7.5.1 Cost assumptions

7.5.1.1 AU cost assumptions

- The equipment cost shown in Table 38 has been estimated by EUROCONTROL on the basis of current knowledge of the technology and input provided by the SATCOM NG team and airborne industry experts. It does not claim to be 100% accurate. The level of confidence reflects the uncertainties on the cost value.

- A base value has been used to estimate the overall costs between 2021 and 2039 (forward-fitting only). It should be noted that the estimation of the airborne costs is based on the catalogue price of the Airbus fleet, which is already known.

- The cost of the aircraft equipment includes everything (hardware, software, certification, installation costs, etc.) and covers both ATC and AOC traffic. Consequently, the AU investment is not calculated in proportion to ATC communication needs. Airlines have been consulted in order to confirm the order of magnitude of the investment.

- The estimate of the AU investment by deployment phase presented in Table 39 has been estimated by EUROCONTROL on the basis of the inputs provided by the partners in the SATCOM NG team for the progressive equipage rate of new delivered aircraft and on the fleet projection developed specifically for the BC (see section 4.3). The ramp-up goes from 20% of new aircraft equipped in 2023 with the SATCOM NG to 100% of new aircraft equipped as from 2033 and up to 2039).

- The projection of the costs throughout the time horizon takes into account the maturity level of the solution and reflects the uncertainties about the deployment dates, the time to obtain the standards, to get the certification for the technology and to set up the service provision for the users.

- Only forward-fit costs have been considered in the cost assessment. At this stage, it is not envisaged to retrofit aircraft with new communication technologies, as indicated in the list of assumptions (see section 4.1.1).

7.5.1.2 ANSP cost assumptions

- The cost value indicated in Table 40 represents the service fees which all the ANSPs in the EUROCONTROL Member State area will pay to the DSP for the provision of the ATC datalink service using the SATCOM NG technology (through a selected CSP or a consortium).

- The service fees will provide all European ACCs and all airspace users with access to the ATN service from 2023: the unique feature of SATCOM, namely immediate coverage of the entirety of the European airspace from day one, really justifies a pan-European deployment scenario, where equipped aircraft can use the service wherever they fly in Europe. This is the most beneficial deployment approach from an operational and cost efficiency perspective: an aircraft that invest in the SATCOM technology will be able to use the service wherever it flies, instead of facing restrictions in some areas. It is also the scenario that provides greater economies of scale, as the total cost could be shared by all ANSPs. It is unclear today if this pan-European approach will be supported by individual ANSPs.

- The service fees include all the cost elements identified in section 3.4.1, covering:
  - the cost of the ground/space SATCOM infrastructure, including the tools developed for delivering and monitoring the service by Inmarsat and the ISP;
  - the cost of the required bandwidth to serve the total target fleet;
  - Inmarsat and the ISP resources to provide the 24/7 service;
  - the cost of initial EASA certification of the Iris service provider as well as maintenance of the certification.

  It is based on the current knowledge of the technology and does not claim to be 100% accurate. The level of confidence reflects the uncertainties on the cost value.

  It should be noted that the cost of the service has been estimated assuming that there would be only one NG SATCOM service provider although there are currently two SATCOM service providers in place. The cost of the service charge could potentially be doubled.

- The service fees do not cover governance, the DSP and the CEAB costs. Those costs will come on top of the SATCOM NG service fees and will be shared with other communication means (existing and new technologies).
- The service fees cover all continental airspace, i.e., the provision of the service in the en-route segment (ENR-1), in the TMAs and at airports, as well as in oceanic airspace (ENR-2).
- The service fee will increase over time, reflecting the resources (FTEs, bandwidth, etc) that will gradually be allocated to the service delivery. The service fee starts at around EUR 10 million as there are incompressible costs to launch the service. In 2033, the service fee is estimated to cover the service requirements for the target fleet.

7.5.2 Cost assessment results

7.5.2.1 AU costs

Table 38 presents the cost of the on-board equipment for the SATCOM NG scenario and the theoretical cost for the airborne investment if 100% of the 2039 target fleet (i.e., 8,564 a/c) is equipped.

Airborne equipment cost (unit cost)	Base	Level of confidence	Target fleet theoretical cost (8,564 a/c)
SATCOM NG equipment cost per aircraft (forward-fitting)	**EUR 100,000**	+/- 10 %	**EUR 856 million**

Table 38: Scenario 3: SATCOM NG - AU unit cost and target fleet theoretical cost

Table 39 presents the airborne investment that the airlines will have to bear by deployment phase. It is based on expert judgment regarding realistic assumptions for SATCOM NG deployment dates.

Fleet equipage rate and total airborne investment by phase	**Phase 1** (2023-2025)	**Phase 2** (2026-2030)	**Phase 3** (2031-2039)	**TOTAL**
Expected target fleet equipage (as a percentage of a/c numbers)	5% of the target fleet	22% of the target fleet	60% of the target fleet	
Total airborne investment	EUR 31.5 million	EUR 133.9 million	EUR 347.8 million	**EUR 513 million**

Table 39: Scenario 3: SATCOM NG - AU costs by phase of deployment

7.5.2.2 ANSP costs

Table 40 presents the cost of service fees per year which will have to be borne by all the ANSPs for DLS provision with the SATCOM NG technology in the entire EUROCONTROL Member State airspace.

ANSPs service fees	Base	Level of confidence	
ANSP service fees per year at FOC (full operational capability) and for the entire EUROCONTROL Member State area.	**EUR 25 million** (for 1 CSP)	+/-10 % ?	

Table 40: Scenario 3: SATCOM NG - ANSP annual service fees

Table 41 presents the progressive equipage rate on the ground looking at realistic deployment assumptions and presents the annual service fees and cumulated costs which will be borne by the ANSPs for service provision with the SATCOM NG technology.

	Phase 1 (**2023-**2025)	Phase 2 (2026-2030)	Phase 3 (2031-2039)	TOTAL
Expected ground equipage (as a percentage of total service fees)	52 %	92 %	100 %	**-**
Annual service fees at the end of each period	EUR 13 million per year	EUR 23 million per year	EUR 25 million per year	-
Total ANSP service fees (cumulated by phase)	EUR 33 million	EUR 94 million	EUR 225 million	**EUR 352 million**

Table 41: Scenario 3: SATCOM NG - ANSP annual and total costs by phase of deployment

7.5.2.3 Overall cost projection

Figure 22 shows the fleet equipage ramp-up and related estimated costs throughout the time horizon for the SATCOM NG scenario.

In the SATCOM NG scenario, the technology will be operational as from 2023, and at the end of the pioneer phase (2023-2025), 5% of the target fleet should be equipped (315 aircraft).

The migration phase will last from 2026 to 2030, and there will be a progressive ramp-up from 50% to 70% of new aircraft equipped. At the end of this second phase, 22% of the target fleet should be equipped (1,654 aircraft).

As in scenario 3, only the SATCOM NG technology is envisaged. It is expected that 100% of new aircraft will be equipped as from 2033, and that at the end of the time horizon (2039), a large part of the target fleet should already be equipped (60%).

Regarding the costs of providing the service, a minimum investment of EUR 10 million is required to set up and operate the service. The cost of the service will then increase progressively according to the volume of users, i.e., according to the number of equipped planes.

Scenario 2 - SATCOM NG	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
Ramp up of fleet equipage (% of new a/c equipped with SATCOM NG technology)	0%	0%	20%	30%	40%	50%	50%	60%	65%	70%	70%	70%	100%	100%	100%	100%	100%	100%	100%	
Nb of a/c equipped per year	0	0	40	142	133	203	215	278	324	318	327	284	368	386	447	513	470	464	219	5.132
Cumulated a/c equipped	**0**	**0**	**40**	**182**	**315**	**518**	**733**	**1.011**	**1.336**	**1.654**	**1.981**	**2.265**	**2.633**	**3.019**	**3.466**	**3.979**	**4.449**	**4.913**	**5.132**	
% Target fleet equipage	**0%**	**0%**	**1%**	**3%**	**5%**	**8%**	**11%**	**14%**	**18%**	**22%**	**26%**	**29%**	**34%**	**38%**	**43%**	**48%**	**53%**	**58%**	**60%**	
Nb of flights equipped per year	0	0	42.431	161.965	160.511	243.802	258.465	340.298	398.998	387.387	411.085	344.802	426.320	427.611	517.406	625.252	553.544	558.866	223.677	
Cumulated flights equipped	**0**	**0**	**42.431**	**204.396**	**364.907**	**608.709**	**867.174**	**1.207.472**	**1.606.470**	**1.993.857**	**2.404.942**	**2.749.744**	**3.176.064**	**3.603.674**	**4.121.080**	**4.746.333**	**5.299.876**	**5.858.742**	**6.082.419**	
% Target traffic equipage	**0%**	**0%**	**1%**	**3%**	**5%**	**8%**	**11%**	**15%**	**19%**	**24%**	**28%**	**31%**	**35%**	**40%**	**44%**	**50%**	**56%**	**61%**	**62%**	
% FL285 traffic equipage	*0%*	*0%*	*1%*	*2%*	*4%*	*7%*	*9%*	*13%*	*16%*	*20%*	*24%*	*27%*	*30%*	*34%*	*38%*	*43%*	*47%*	*52%*	*53%*	
% ECAC traffic equipage	*0,00%*	*0,00%*	*0,39%*	*2%*	*3%*	*5%*	*7%*	*9%*	*12%*	*15%*	*18%*	*20%*	*23%*	*25%*	*28%*	*32%*	*35%*	*39%*	*40%*	
AUs - Forward fit costs	**0,0**	**0,0**	**4,0**	**14,2**	**13,3**	**20,3**	**21,5**	**27,8**	**32,4**	**31,8**	**32,7**	**28,4**	**36,8**	**38,6**	**44,7**	**51,3**	**47,0**	**46,4**	**21,9**	**513,2**
Ground equipage rate	0%	0%	40%	40%	52%	56%	68%	76%	84%	92%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
ANSPs - Service fees	**0,0**	**0,0**	**10,0**	**10,0**	**13,0**	**14,0**	**17,0**	**19,0**	**21,0**	**23,0**	**25,0**	**25,0**	**25,0**	**25,0**	**25,0**	**25,0**	**25,0**	**25,0**	**25,0**	**352**

Figure 22: Scenario 3: SATCOM NG - Overall cost projection and fleet equipage

7.6 Qualitative assessment

7.6.1 Benefits

This chapter provides a high-level view of the benefits specific to the SATCOM NG scenario. They are based on previous cost-benefit analyses carried out as part of the Iris project and will have to be added to those common to all scenarios (see section 4.2). Overall, Satcom MG will bring benefits that are common to all datalink technologies through the applications they are enabling (e.g. CPDLC, TBO, etc…). However, SatcomNG includes some clear benefits that are specific to the technology and should be taken into account when planning deployment as they can make a significant difference to the airspace users and ANSPs business case. They are detailed in section 7.6.1.1 below.

7.6.1.1 Benefits specific to SATCOM

- **The maturity of the technology is high, the technology is proven** (has been used in the ocean airspace during decades). This means that Satcom NG can complement VDL2 efficiently any tome from 2023. SATCOM will be ready for deployment in 2023. The last steps towards the operational service will be carried out in 2022, and mainly involve finalising the service delivery tools and obtaining the certification of the future Iris service provider. The certification element is a significant “guarantee” of maturity and performance. A very gradual and cost-efficient ramp-up of the aircraft equipage can start by the end of 2022 (avionics package certified) with new aircraft deliveries starting in early 2023. Even if there are uncertainties as to when the QoS of VDL-2 will start to degrade significantly, it is certain that VDL-2 will not be sufficient to address the needs in the medium term. The maturity and readiness of the technology allows for a smooth transition plan to be established with no technical/operational risks to airspace users and ANSPs. Because of its readiness, SATCOM NG allows for effective mitigation of the risk from VDL-2 QoS degradation (sooner or later), which no other technology can provide as their maturity is lower.

- The pan-European coverage does not need aground infrastructure. By design, the SATCOM technology provides immediate and seamless coverage of the target airspace and beyond. Once an aircraft is logged onto the SATCOM service, the aircraft can use the link wherever it flies. This can bring additional benefits to airspace users compared with terrestrial-based technologies at the boundaries of European airspace (e.g., to aircraft arriving from the North Atlantic oceanic airspace or from the Middle East or Africa).

- Beyond the continental airspace coverage, the FANS1/A service is provided using the same airborne satcom terminal. From an airline perspective, this means that a European airline choosing the solution will access additional services on a global basis on top of ATN in Europe. This is a clear immediate benefits for the long range aircraft and also to the Narrow Bodies that fly outside of Europe (ETOPS) and using the TANGO routes. For long-range aircraft flying oceanic routes, all services (FANS/ATN/ACARS/IP) areavailable on the same terminal globally for a seamless transition from oceanic to continental airspace.

- Global expansion is also an important benefit from the airline perspective: once ATN/IPS is deployed and used, the ATN service will be available globally with only software changes to the airborne and ground infrastructure. This represent astrong enabler to TBO operations implementation in a consistent manner throughout many regions. ESA/Inmarsat are assessing how to manage the extension of Iris from the ground perspective outside Europe (the satellite network is already global).

7.6.1.2 Benefits outside of Europe

Even if this document is limiting the cost and benefit assessment to the specific European airspace, it is worth mentioning briefly the other benefits for airspace users. Extending the ATN service outside of the region is already evaluated (China in particular) and some demonstrations will materialise in 2023-2024. The service extension does not specifically need some infrastructure in the new region as the existing gateways developed by Inmarsat for Europe can be used elsewhere. However, for political reasons, some countries may want to have a specific SATCOM Gateway in the country. Service distribution agreement will need to be established but in a nutshell, extending the service is easy and will quickly benefit airspace users with in particular the support to i4D operations extension. Traffic flow management between Europe and other regions will be improved for all the long haul operators.

7.6.1.3 Greening the CNS infrastructure

The SATCOM NG technology does not need an energy-hungry infrastructure on the ground as is the case with the terrestrial technologies. Recent analysis conducted by EUROCONTROL demonstrated that European ANSPs "are estimated to consume 1,140 GWh of electricity annually, roughly equivalent to 55% of the annual electricity consumption of Malta". It is also mentioned in the article on "Greening European ATM's ground infrastructure" (October 2021) that "switching to renewable energy and making energy-efficient investments could save ANSPs over 311,000 tonnes of CO_2 every year". SATCOM is one of these energy efficient investments that can help ANSPs meet their target for the reduction of Scope 2 CO_2 emissions.

7.6.2 Performance

The ICAO Performance-Based Communications and Surveillance (PBCS) Manual (Doc 9869) defines a framework to quantify the datalink system performance needed to meet operational requirements. It introduces two concepts:

- required communication performance (RCP) applicable to two-way controller-pilot datalink communication (CPDLC) dialogues, and
- required surveillance performance (RSP) applicable to one-way transfer of surveillance data by contract-based automatic dependent surveillance (ADS-C).

Based on these concepts, EUROCAE ED-228A/RTCA DO 350A specify sets of requirements, RCP130 and RSP160 respectively, which are applicable to ATN B2 applications in continental en-route (ENR-1) and TMA airspace. Iris compliance is measured against these performance requirements.

7.6.2.1 Capacity

Two satellites cover Europe, providing resilience in the unlikely event of a satellite failure. Alphasat (AF1) is the primary European satellite and covers the "Iris area" (EUROCONTROL Member States area) with approximately 16 beams. Capacity is dynamically allocated to beams in response to traffic demand, with multiple 200-kHz channels being assigned to each beam to support traffic.

Inmarsat and partners have run a capacity assessment[18] as part of the Iris project. The objective of the study was to demonstrate that the Iris network can manage the ATC and AOC traffic that can be expected in various scenarios of VDL-2 saturation. The simulations demonstrated that the BGAN system, the baseline for the Iris service, can support the Iris traffic in all scenarios considered with a spectrum margin of 100%. It is important to note that the system model and assumptions were defined with a conservative approach. On the contrary, the traffic growth forecast assumptions were optimistic. This led to simulating a worst-case scenario from the requirement perspective up to 2040.

Prioritisation of the ATC traffic was not simulated although this functionality exists today in the system – there was no need to simulate it given that capacity demand was lower than available resources. To be noted: Inmarsat, USBG and TAS-I have run additional capacity simulations specifically focusing on AOC services and anticipating a significant growth for AISD+ AIS/MET in Europe, these have confirmed that the system does not need to be scaled up.

It can be concluded that Iris can be relied upon to complement the VDL-2 network and create a datalink service infrastructure that is aligned with the most likely evolution of datalink usage in Europe.

7.6.2.2 Latency

The final phase of Iris Precursor flight trials was performed in June-July 2018 on the NLR Citation II. Table 42 below summarises the latency performance for CPDLC and ADS-C:

Ground Initiated CPDLC Technical round trip delay	99.9% (sec)	99% (sec)	95% (sec)	Mean (sec)	Transaction
RCP130 RCTP (end-to-end)	32		20		
Measured TRT	13.6	7.4	5.2	3.8	1135
ADS-C one way end-to-end latency	**99.9% (sec)**	**99% (sec)**	**95% (sec)**	**Mean (sec)**	**Reports**
RSP160 $RSTP_{ATSP}$ (end-to-end)	14		7		
Measured latency	~7.9	6.8	4.5	2.6	134

Table 42: Scenario 3: SATCOM NG – Latency performance

This section will be completed with additional material from more recent performance assessments.

[18] This report has been shared with many stakeholders and is available on request.

7.6.2.3 Availability

Redundancy in the space segment needs to be sufficient to support service availability requirements.

The baseline is the current fleet of Inmarsat 4 GEO satellites (3xI4 + Alphasat), which will be replaced with Inmarsat 6 GEO satellites in the early 2020s. This may be augmented with further GEO satellites for availability (at least 3 GEO satellites)[19] . Non-GEO satellite constellations could be investigated to plug residual GEO coverage gaps below 70° N latitude, or coverage extension above 70°N latitude.

Satellite design and pre-developments to offer higher availability are ongoing as part of the Iris programme.

7.6.3 Potential evolution of the technology

The ATN/OSI version of Satcom NG is ready for deployment by 2023 with a planned evolution towards the ATN/IPS version by 2024-2025. Inmarsat is continuously improving its infrastructure, includig the space and ground parts. The next generation of satellite with an L-band payload ("ELERA") will bring additional performance including to aviation users. The first "I6" satellite was launched last year, the second one will be launched in 2023.

7.6.4 Safety, security and QoS aspects

Satcom NG was developed against the safety service performance targets. Performance and QoS are detailed in chapter 7.6.2. Also, as mentioned in section 7.6.1.1, the satcom NG service has engaged with EASA for certification, with a target for an operational service by mid-2023.

7.6.5 Ease of deployment and financial aspects

Deployment is detailed in section 7.4. The main benefit of satcom is that there is no ground deployment. This is a significant game changer compared to all ground technologies, mitigating risks, cost, boosting global usage as well allowing a rapid roll-out to an entire airspace in a very unique manner.

7.7 Risk and mitigation

7.7.1 Technical risk

Risk	Likelihood	Impact	Possible mitigation
Delay to the possible upgrade to the satellite segment or ground network to meet	Low	Possible degradation of performance if the developments are not finalised in a timely manner	Organise the developments and validation activities in a timely manner. Pre-developments are

[19] This part is of the analysis developed in Iris, Doc Ref "IRIS-S2-OS-REQ-INM-0131", May 2020

increased performance requirements after 2030			already planned in the next Iris programme. Inmarsat is also starting to launch the new satellite generation (first I6 launched at the end of December 2021).

Table 43: Scenario 3: SATCOM NG – Technical risk and mitigation

7.7.2 Implementation risk

Risk	Likelihood	Impact	Possible mitigation
"Fragmented" ground deployment in Europe vs. pan-European deployment (e.g., if some ANSPs are not supporting SATCOM use)	Low	Decreased motivation for airlines to invest, delaying uptake by the critical mass of aircraft in order to alleviate VDL-2 (back to risk 1)	Robust plan for pan-European deployment
Lack of Boeing forward-fit programme for ATN over SATCOM		Difficult to reach the deployment target for the European fleet	The early implementation phase could leverage the existing solution from Honeywell for a first certification programme (e.g., SESAR3 DSD funding?)

Table 44: Scenario 3: SATCOM NG – Implementation risk and mitigation

7.7.3 Business and financial risk

Risk	Likelihood	Impact	Possible mitigation
Airspace users/ ANSPs start investing in the technology later than 2023	Medium	No solution in place to mitigate VDL-2 QoS degradation and thus possible impact on the gaining of CP1 benefits	Robust plan (or mandate) for pan-European deployment and incentives for early AUs (and ANSPs)
Limited ramp-up of the equipage, beyond the minimum required number of aircraft to alleviate VDL-2 over the years	Medium	Limited improvement to the datalink services beyond what is necessary for CP1 benefits	Same as above
If deployment starts late, this may result in a higher proportion of retrofitting as opposed to linefitting in order to reach the critical mass of users	Medium	Increased in the total airborne deployment cost for airspace users Delay of the operational benefits (fuel savings, reduced delays)	Agree as soon as possible on a smooth deployment plan by 2023. This plan could include an early adoption phase and benefit from the planned market uptake measures (defined in the SESAR3 programme, including the Digital Sky Demonstrators)

Table 45: Scenario 3: SATCOM NG – Business and financial risk and mitigation

8 Scenario 4 – MULTILINK / MULTIMODE

8.1 Clarifications on the use of the term Multilink

During the work on the Scenario 4, it has become clear to the team, that in the Community of FCI Stakeholders, the same term “Multilink” is used with no differentiation to address very different scenarios:

- a Short-Term Transitional Scenario[20], in which
  - one of the new Datalink Radio Technologies able to support the Internet Protocol (IP) is equipped on board of aircraft in addition to the already operational VDL-2 OSI Datalink, but used to transfer only ATN-OSI protocol messages
  - the ATN Protocol Stack implemented by the aircraft CMUs/ATSUs remains the ATN-OSI only, with ATN-OSI protocol messages being transmitted over
    - either the existing VDL-2 OSI
    - or over one of the new IP-enabled Datalink Radio Technologies by encapsulating the ATN-OSI protocol into an IP layer[21]
- the Medium-Long Term scenario, scope of the SESAR 2020 PJ.14-W2 Solution 77 “FCI Services” project (see Contextual Note, [20]) and of the ICAO WG-I ATN-IPS Standardization, in which
  - the Datalink Radio Access Technologies equipped on board of aircraft are only the IP-enabled ones addressed in the Single Link Scenarios (LDACS, SATCOM NG, OFF-THE-SHELF) – no VDL-2, under the assumption that VDL-2 is not used for ATN-IPS communication
  - the ATN Protocol Stack implemented by the aircraft CMUs/ATSUs is only the ATN-IPS one, transmitted over the two or more equipped IP-enabled Datalink Radio Technologies addressed in the Single Link Scenarios (LDACS, SATCOM NG, OFF-THE-SHELF)

[20] Note that this is not the only possible transitional scenario, but it is considered in this business case because it is the one for which the cost estimations reported in section 8.6have been made.

[21] This OSI-over-IP solution has no relationship to the ICAO ATN-IPS Standards.

- the scenario called "Multilink" [22], which covers the need for the Ground Infrastructure to support **both** the ATN-OSI and the ATN-IPS Protocol Stacks, during the whole transition towards ATN-IPS, in order to accommodate ATN-OSI-only aircraft and ATN-IPS-only aircraft. This is actually an Interoperability Scenario, which has nothing to do with the SESAR multilink concept (solution 77). In order to avoid misunderstandings on which scenario the different identified benefits, risks, costs, deployment options and, more in general, statements relate to, throughout the chapter 8 Scenario 4 – MULTILINK / MULTIMODE we use the following terms to unambiguously identify the different scenarios:

- ATN-OSI Multilink → the Short-Term Scenario with aircraft equipped with VDLM2 OSI and 1 IP-enabled Datalink Radio Technology

- ATN-IPS Multilink → the Medium-Long Term ICAO & SESAR scenario, with aircraft equipped with only the ATN-IPS Stack and IP-enabled Radio Technologies

- ATN-OSI/ATN-IPS Interoperability → the Transitional Ground Scenario for contemporary support of both ATN-OSI and ATN-IPS

The analysis in terms of assumptions, deployment scenarios, risks and benefits, reported in the following sections of chapter 8, focuses only on the ICAO & SESAR ATN-IPS Multilink scenario, with the following rationale:

- Only the ATN-IPS Multilink brings multilink-specific benefits additional to the ones already considered for each of the single link scenario (see chapters 5, 6 and 7)

- the ATN-OSI Multilink transitional scenario is based on:

    - an already deployed and operational Datalink Radio Technology, VDL-2, and an ATN-OSI Protocol Stack, for which no business case analysis is needed.

    - a single additional IP-enabled Datalink Radio Technology, whose Deployment options, Risks, Benefits etc. are already covered in the corresponding Single Link Scenario (chapters 5, 6 and 7)

The cost estimations for the final target ATN-IPS Multilink scenario are going to be addressed in the SESAR 2020 PJ.14-W2 Solution 77 Cost Benefit analysis deliverable, which is planned to be available in SESAR by the end of 2022.

[22] The concept of and the term "multilink" (the capability of using multiple different datalink technologies) is applicable only to the aircraft perspective, where the aircraft is able to use multiple Datalink Radio Technologies. Instead, the concept that the Ground Infrastructure has to support both the ATN-OSI Protocol Stack and the future ATN-IPS Protocol Stack, providing de facto a Ground Dual OSI/IPS Stack, has nothing to do with the "multilink" SESAR concept, but it is rather a concept of providing IPS/OSI Interoperability to accommodate aircraft equipped with either an ATN-OSI-only or an ATN-IPS-only Protocol Stack.

8.2 Introduction to the ATN-IPS Multilink Scenario (ICAO & SESAR)

The complete ATN-IPS Multilink concept developed in SESAR PJ.14-W2 I-CNSS Solution 77 "FCI Services" is based on four ATN-IPS air/ground datalink technologies provided for in the network topology depicted in Figure 23 (ref [12]):

- Long-term IPS SATCOM (SESAR 2020 PJ.14-W2 Solution 107) (also called SATCOM NG)
- LDACS (SESAR 2020 PJ.14-W2 Solution 60)
- AeroMACS
- IP VDL-2[23]

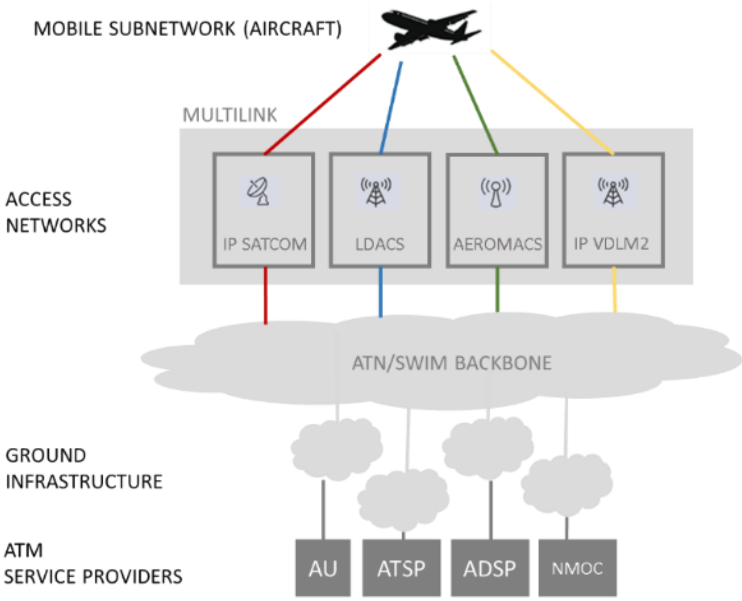

Figure 23: ATN-IPS Multilink – Network topology of the SESAR PJ-14-W2 Solution 77 FCI

However, the four scenarios identified in this business case, which have been approved by the JCSP Committee, do not include AeroMACS but off-the-shelf datalink technologies (see section 6).

Therefore, in order to reflect the four scenarios in the scope of this business case analysis and maintain consistency throughout the document, the multilink network architecture that we consider for Scenario 4 deviates from that developed and validated in SESAR PJ.14-W2-77 "FCI Services".

[23] In the business case, IP VDL-2 will not be considered, as it is not included in the four scenarios identified given the current position in Europe to not implement it.

The SESAR PJ.14-W2-77 solution, in fact, does not have in its scope a multilink implemented with off-the-shelf datalink technologies, it does not develop for it any ConOps (Concept of Operations) or requirements, and does not validate it.

However, recent developments in the AeroMACS community as presented in several fora (e.g. AEEC Datalink User Forum on 31 Jan. 2022, FCI Task Force 17 on March 16, 2022) indicate a possible inclusion of AeroMACS in the 'COTS' scenario. Indeed, the obsolescence of Wimax on which AeroMACS is based is triggering initiatives to base the so-called 'AeroMACS 2' on COTS solutions such as 5G. Early discussions are taking place at the time of writing, aiming at acceptance of this alternative and update of the existing AeroMACS standards. As such we consider in this document that the FCI Business Case remains valid for SESAR solution 77 in that the 'COTS' scenario, included in this Business Case, is possibly going to include a 5G technology as the basis of AeroMACS 2.

In any case, an economic analysis for AeroMACS '1' as currently standardised is available in a deliverable of SESAR2020 Wave 1, ref. [17].

An additional point that must be added to the FCI Business Case to make it more relevant to solution 77 is the fleet equipage assumption. Indeed, the FCI BC assumed that AUs would equip with either or several of the new technologies to varying degrees (LDACS, SATCOM NG, COTS), while solution 77 considers coexistence of multiple new links on board at the same time, with consequences on the costs. Additional simulations reflecting this are part of the sensitivity analysis described in section 9.4.

Figure 24 depicts the Scenario 4 logical network architecture.

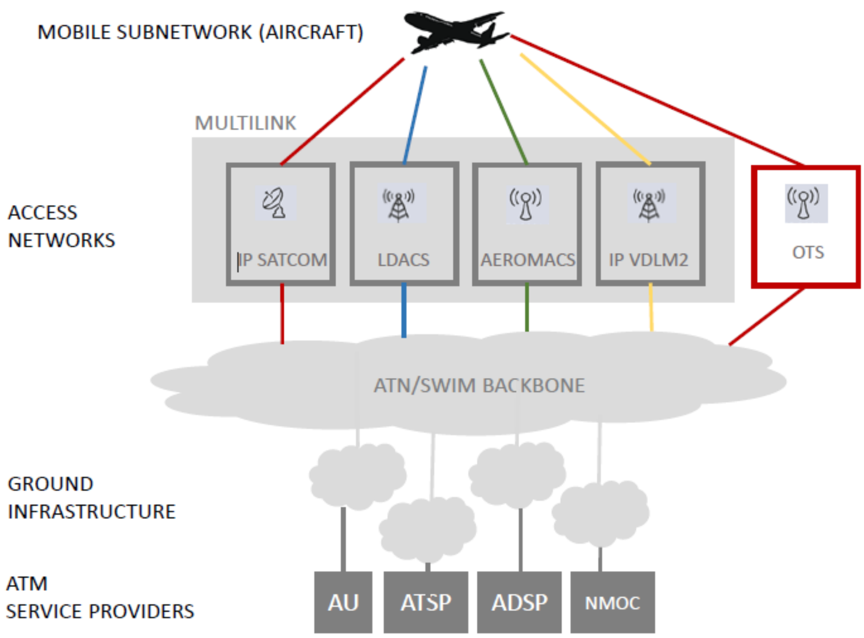

Figure 24: ATN-IPS Multilink – Network topology considered in Scenario 4

The ATN-IPS Multilink functionality, developed in SESAR PJ.14-W2-77 "FCI Services", is currently being standardised in the ATN-IPS Manual by ICAO (WG-I Work Group). It allows, through monitoring of the status of the different links and traffic prioritisation based on QoS/CoS, for the adoption of a performance-based approach with optimised routing and increased availability of air/ground communications for safety-critical applications.

Furthermore, it supports an “administrative policy”-based approach, through implementation of link preferences, which coexists with the previous one.

Only under the assumption that the off-the-shelf datalink technologies will incorporate every functionality[24] and network element standardised by ICAO for ATN-IPS implementation, can the ATN IPS multilink approaches developed in SESAR PJ.14-W2-77 “FCI Services” also be applied to the reference network architecture of Figure 24.

Below is a brief summary of the two approaches; for more details, please see the TRL-6 FCI ConOps ([12]) section 2.4.2 “Target scenarios”.

8.2.1 ATN-IPS Multilink – performance-based policy

This scenario represents the selection of alternative datalinks among available radio access technologies for an IPS-equipped aircraft, according to the acceptability of the performance level achieved. Figure 25[25] illustrates the scenario depicting different overall levels of performance (GREEN for high, YELLOW for medium, RED for low)[26] for different datalinks, which are simultaneously available to an aircraft. This scenario is complementary with administrative multilink policies.

[24] See later in section 8.5.2 Network elements and functionalities for ATN-IPS mobility and multilink

[25] The figure depicts the use case analysed in the FCI ConOps developed by SESAR 2020 PJ.14-W2-77 “FCI Services” and, as such, shows AeroMACS and IP VDL-2. For the purposes of this Scenario 4 in the business case, off-the-shelf technologies can be considered as included.

[26] Colour codes do not have an intrinsic significance in FCI. They are just to illustrate that datalinks can offer different levels of performance. Note that the assignment of a colour to a specific datalink is arbitrary and does not intend to convey the capacity or limitations of a particular technology.

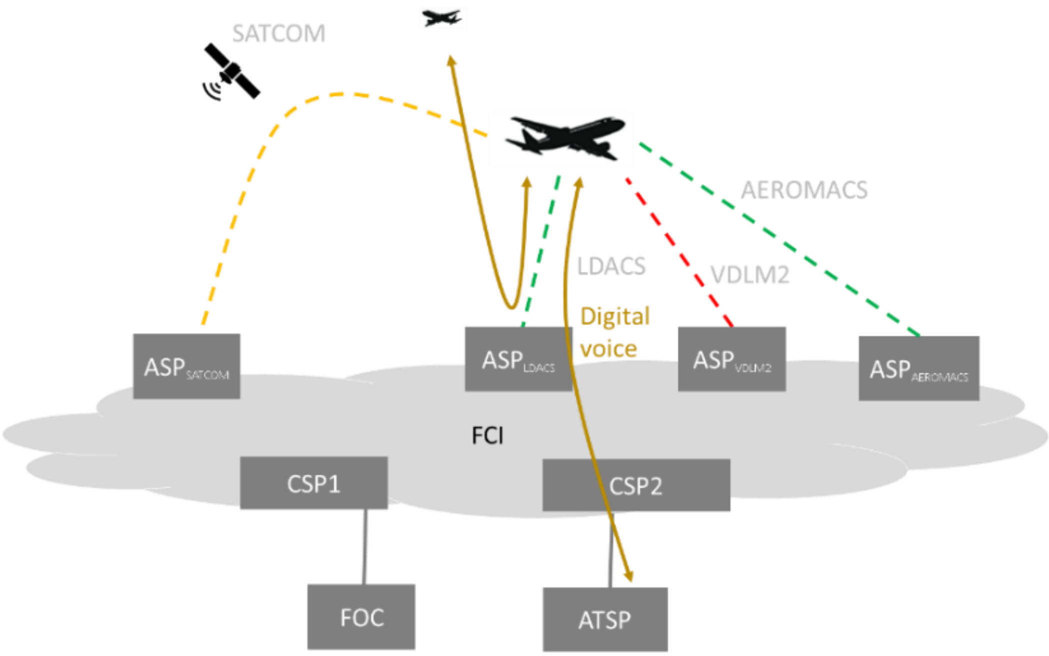

Figure 25: ATN-IPS MULTILINK - Performance-based multilink policy

The actors present in the scenario are:

- the ATSP(s), providing datalink services (ATS-B2/B3, AIS/MET, flight information) and digital voice to aircraft, and end-to-end service monitoring. The ATSP may be associated with a specific airspace volume (oceanic or continental) or may provide services in accordance with another operational scope;
- FOC, providing AOC services to aircraft, and end-to-end service monitoring;
- the CSP(s), providing network connectivity and monitoring between the ATSP or FOC and aircraft. The radio access segment of the air/ground communications is supported by an ASP[27] specific to a datalink technology. The CSP either operates one or more access networks or establishes agreements with an ASP to support its communication services;
- aircraft equipped with an IPS mobile subnetwork and IPS datalink radio systems.

Under performance-based multilink, link selection is based on the acceptability of datalink quality to guarantee the performance levels for a particular application. A datalink will not be authorised for the provision of an ATM service whose required performance is above that considered to be guaranteed by the access network. As a result, different services (e.g., ATS, AOC, digital voice) may use different datalinks depending on whether they are considered by the system to comply with the QoS parameters configured for the CoS assigned to the service. When two different services are transmitted over the same datalink, QoS configuration allows for prioritisation.

Performance-based multilink has the goal to maximise not only performance but also availability of the service. As a result, the performance-based policy executes mechanisms of traffic rerouting to other acceptable links, and/or pre-emption of low priority traffic to reserve limited resources to high priority traffic.

Moreover, performance-based multilink optimised on QoS/CoS[28] also covers the current need for the offloading of AOC data.

[27] Access Network Service Provider (ASP) is a term defined in the PJ14-W2-77 Conops to indicate a potential service provider of only the Radio Access Technology network segment

[28] Quality of service / Class of service

8.2.2 ATN-IPS Multilink – administrative policy

This scenario represents the selection of alternative datalinks among available radio access technologies for an-IPS equipped aircraft, based on the preferences and constraints defined by administrative policies. Figure 26 [29] illustrates this scenario, depicting an aircraft flying in different flight domains with different associated multilink policies. This scenario is complementary with performance-based multilink.

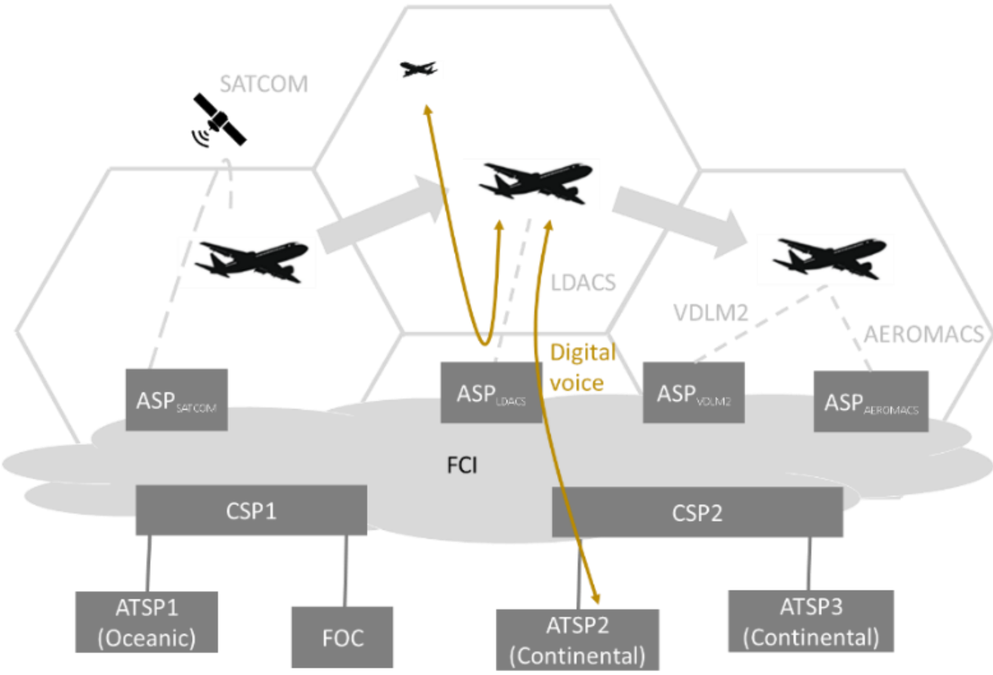

Figure 26: ATN-IPS MULTILINK - Administrative multilink policy

[29] The figure depicts the use case analysed in the FCI ConOps developed by SESAR 2020 PJ.14-W2-77 "FCI Services" and, as such, shows AeroMACS and IP VDL-2. For the purposes of this Scenario 4 in the business case, off-the-shelf technologies can be considered as included.

The actors present in the scenario are:

- the ATSP(s), providing datalink services (ATS-B2/B3, AIS/MET, flight information) and digital voice to aircraft, and end-to-end service monitoring. The ATSP may be associated with a specific airspace volume (oceanic or continental) or may provide services in accordance with another operational scope;
- FOC, providing AOC services to aircraft and end-to-end service monitoring;
- the CSP(s), providing end-to-end network connectivity and monitoring between ATSPs, or between the ATSP or FOC and aircraft. The radio access segment of the air/ground communications is supported by an ASP specific to a datalink technology. The CSP either operates one or more access networks or establishes agreements with an ASP to support its communication services.
- aircraft equipped with an IPS mobile subnetwork and IPS datalink radio systems.

The selection of datalink(s) to be used depends on pre-defined policies or preferences. Policies set by national regulators can be mandatory (e.g., datalink not certified for use) or recommended, and must be endorsed by AUs and ATSPs in the applicable region. Link preferences respond to the preferences of or constraints from the current ATSP or the airspace user, and criteria such as geographical location, altitude, airspace region, or phase of flight.

Such preferences or constraints can be for commercial, regulatory, or other reasons. This results in ATM service providers making use of the datalinks which are preferred, or authorised, among the available datalinks. CSPs maintain the connectivity and network routes to accommodate end-to-end communication over the selected access network.

Note: It is assumed that the datalinks remain within acceptable performance. Performance-based datalink selection is described in the previous scenario.

Link selection policy may be defined for each application. For example, ATS and AOC may be configured to follow different paths. This is implemented via defined classes of service (CoS) which drive the routing policies associated with the configured administrative policies. Following the preferences defined for each CoS, different applications can be transmitted over different datalinks, or over the same datalink (for which different priorities and QoS parameters may be applied).

8.3 Operational applicability

8.3.1 Geographical applicability

Both the ATN-OSI and ATN-IPS Multilink scenarios have the advantage of providing the widest possible geographical coverage, since they cover, through the encompassed technologies, all airspaces, including oceanic airspace.

8.3.2 Airspace and phase of flight coverage

Both the ATN-OSI and ATN-IPS MULTILINK/MULTIMODE scenarios support communication in all terrestrial airspaces (airports, TMAs, and en-route airspace), as well as in the oceanic airspace. Communication technologies are either:

- mandatory, i.e., aircraft must be equipped at the specified flight level or phase of flight; or
- available, i.e., the technology/service is available but there is no obligation to be equipped.

Flight level / Technology	Existing COM technologies			New IP enabled COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
Airspace > FL245	Mandatory	Mandatory	Available	Available	Available	Available
500 feet < airspace < FL245	Mandatory	Available	Available	Available	Available	Available
Airspace < 500 feet	Mandatory	Available	Available	Available	Available	Available

Table 46: Scenario 4: ATN-OSI / ATN-IPS Multilink – Communication technologies by flight level

Phase of flight / Technology	Existing COM technologies			New IP enabled COM technologies		
	VHF voice	VDL-2 OSI	SATCOM OSI (current)	SATCOM NG	OFF-THE-SHELF	LDACS
En-route – oceanic	Mandatory (air to air)	None	Mandatory (PBCS)	Available	Available	None
En-route – terrestrial	Mandatory	Mandatory	Available	Available	Available	Available
TMA – approach	Mandatory	Available	Available	Available	Available	Available
Airport – ground operations	Mandatory	Available	Available	Available	Available	Available

Table 47: Scenario 4: ATN OSI / ATN-IPS Multilink - Communication technologies by phase of flight

8.4 Maturity level status

8.4.1 Infrastructure status

The maturity level status of the ATN-IPS Multilink developed in SESAR PJ.14-W2 ICNSS Solution 77 “FCI Services”, whose validation scope does not include off-the-shelf technologies, is depicted in Table 48.

SESAR technological solution	Enabler	Initial maturity level at the start of Wave 2	Target maturity level at the end of Wave 2/ Wave3
Solution PJ.14-W2- 77- FCI Services	CTE-C04	TRL-4 (2020)	TRL-6 (Q4-2022)
Solution PJ.14-W2- 77- FCI Services	A/C-95	TRL-4 (2020)	TRL-6 (Q4-2022)

Table 48: Scenario 4: ATN-IPS Multilink – Solution 77 Maturity Level Status

Starting from TRL-4 achieved in Wave 1 of SESAR 2020, the aim is to achieve TRL6 maturity at the end of Wave 2 (Q4 2022).

The validation of the ATN-IPS Mobility and Multilink Technology is done, in PJ.14-W2 ICNSS Solution 77 with three Datalink Technologies that either have reached TRL6 in SESAR 2020 Wave 1 (AeroMACS), or are targeting the TRL6 maturity in Wave 2 (IPS SATCOM, LDACS) deployed in multiple Labs, geographically interconnected by a distributed Global Mobility (GB-LISP) Backbone, implemented with B2B VPNs among different EU locations (Vienna, Brno, London, Rome) - the original idea was to use NewPENS, but this could not materialize due to several different issues. No Flight Trials are planned in the SESAR 2020 Wave 2 project.

The above Validation Environment and Setup has been assessed as fully representative of the target scope of Solution 77 "FCI Services", which is not to validate the single Datalink technologies (i.e., RF performances, Doppler impacts, etc.), as this is a task covered already by the other SESAR PJ.14 Solutions validating such technologies (Sol 60 for LDACS, Sol 107 for IPS SATCOM), but it is to validate the Network Functionalities of ATN-IPS Mobility and Multilink, assuming the Datalink technologies compliant to their respective Standards and Specifications.

8.4.2 Service distribution status

By definition, the multilink service provision will need as a pre-requisite a definition of service provision for each single link part of the multilink, as such referring to sections 5.3.2, 6.3.2 and 7.3.2 of this report.

Furthermore, the current service provision envisaged for ATN-B1 and ATS-B2 under the ACDLS project, ref. [18], should be, once defined, applicable to the ML service distribution. This on-going work is not finalized at the time of writing and does not allow to be more precise on this topic.

The ML implementation roadmap being developed by the SESAR Deployment Manager at the time of writing will have to develop this point further.

8.4.3 ATN-IPS Multilink validation status

Solution PJ.14-W2-77 has proceeded to validation exercises which are documented in detail in the TVLAR document, ref. [19].

8.4.4 ATN-IPS Multilink safety and security risk assessment status

Scenario	Compliance expected to be achieved in	Risk assessment documented	Compliance with maturity gate requirements	Problem and/or comment
Safety risk assessment	2022	Dec. 2022	yes	
Security risk assessment	2022	Dec. 2022	yes	Not publicly available.

Table 49: Scenario 4: ATN-IPS Multilink – Safety and security risk assessment status

The ML implementation roadmap being developed by the SESAR Deployment Manager at the time of writing will also have to develop this point further.

8.4.5 Early-implementation flights

Although solution 107 featured demonstrations of OSI Multilink with VDL2 and Class B Satcom, no flights have taken place so far based on IPS multilink. This may be the object of proposals in future SESAR projects.

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8.5 Deployment assumptions

8.5.1 ATN-IPS Multilink general assumptions

Below are the main assumptions on which the business case for the Multilink scenario is based:

1. The ATN-IPS Multilink addressed by Scenario 4 of the business case deviates from the multilink concept developed in SESAR PJ.14-W2-77 “FCI Services”, with inclusion of off-the-shelf datalink(s), and is based on ATN-IPS LDACS (Scenario 1), off-the-shelf technologies supporting ICAO ATN-IPS (Scenario 2) and ATN-IPS long-term SATCOM NG (Scenario 3).

2. The aim of Scenario 4 is to provide the BC analysis for having ground infrastructure capable of providing the ATN-IPS Multilink service (i.e., a minimum of two ATN-IPS datalink radio technologies), whilst having aircraft equipage which is driven by AUs’ preferences, targeting the “use of the ML services” by AUs in the longer term rather as a pre-requisite for the equipage cost estimations.

3. The off-the-shelf technologies are considered as complementary to the safety technologies, and not as an alternative to them (see “Scenario 2 – OFF-THE-SHELF” for further clarifications on the maturity of the technology considered).

4. The ICAO ATN-IPS standards will standardise, as a default mandatory functionality to be supported in the air and on the ground when deploying ATN-IPS, the mobility and multilink solution developed in SESAR 2020 PJ.14-W2-77 “FCI Services”.[30]

5. Under assumption 2, there should be only minor aircraft equipage costs specific to ATN-IPS Multilink, mainly in terms of CAPEX for the various avionic radio terminals and OPEX for activities like configuration of parameters and SW maintenance (e.g., SW upgrades), compared with the costs that Scenario 1, Scenario 2 and Scenario 3 have to consider in relation to the deployment of ATN-IPS.

6. In Europe, VDL-2 stays only on ATN-OSI.

7. ANSPs use the European DSP business model.

8. A performance-based mandate, and not a technology-based one, will regulate the future scenarios. This assumption[31] has the consequence that the ground infrastructure will have to support all the technologies which are proven to achieve the required performance.

9. For the ground equipage, the assumption in the ATN-IPS Multilink scenario is that, in order to offer to AUs the services in every sector, the total ground costs of each single-link scenario are reached quite quickly, compared with the aircraft equipage rates.

10. With regard to aircraft equipage, the same assumptions for the ramp-up profiles are used as in the other three single-link scenarios (Scenario 1, 2, and 3), but with the maximum share of new aircraft equipped per year limited to 50% for LDACS and SATCOM NG technologies, and 33% for off-the-shelf technologies by 2039.
    - For the LDACS technology, initial equipage projections consider the projections from Scenario 1 – LDACS (see section 5.4.1.1).
    - For the SATCOM NG technology, initial equipage projections consider the projections from Scenario 3 – SATCOM NG (see section 7.4.2.2).
    - For the off-the-shelf technologies, initial equipage projections consider the projections from Scenario 2 – OFF-THE-SHELF (see section 6.4.5).
11. The deployment of off-the-shelf technologies will be on a needs basis, depending on the number of aircraft that airlines will equip for the cabin market. The off-the-shelf equipment will operate on top of LDACS or SATCOM NG equipment.
12. The ramp-up of ground equipage is based on the progressive costs of the service (see the various single-link scenarios), rather than on the amount of ground equipment.

8.5.2 Network elements and functionalities for ATN-IPS mobility and multilink

The overall architecture of the Future Communication Infrastructure developed in SESAR 2020 PJ.14-W2 Solution 77 “FCI Services” consists of different network elements and functionalities, necessary to support ATN-IPS mobility and multilink described in section 8.1.

It is important to note that the multilink functionality herein considered, based on ATN-IPS future technologies, is closely intertwined with the ATN-IPS mobility functionality and cannot be isolated from it, as clearly provided for in the ICAO standardisation process. This translates into the fact that multilink and ATN-IPS mobility share the same network elements and new functionalities required for their implementation.

One example of this intimate relationship is the new air ground mobility interface (AGMI) protocol, which has been designed specifically to support both aircraft mobility over the different radio access network technologies (LDACS, long-term SATCOM, etc.) and the ATN-IPS Multilink approach based on link preferences and link status.

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[30] See section 8.5.2 for the details.

[31] It is important to emphasise that the consequence mentioned is not driven by use of multilink but by the performance-based mandate.

The network elements and logical functionalities needed to support ATN-IPS mobility and multilink are as follows:

- **Airborne side**
  - The airborne ATN-IPS system, as standardised by the AEEC IPS Subcommittee in ARINC PP858, which includes the functionalities of ATN-IPS airborne router, airborne AGMI endpoint, security, and others
- **Ground side**
  - GB-LISP[32] mobility ground-ground boundary routers (GGBR)
  - GB-LISP mobility air-ground boundary routers (AGBR)
  - GB-LISP ground mobility service endpoint (MSE)
  - AGMI ground proxy [33]

Consequently, in Scenario 4 the focus will be on only the above components.

However, given assumption 1 of section 8.5.1 that the ICAO ATN-IPS standards will include, as a default mandatory functionality, the ATN-IPS mobility and multilink functionality based on the GB-LISP and AGMI protocols, all the above functionalities and network elements will HAVE TO be deployed in ALL domains (airborne and ground) as part of the deployment of ATN-IPS, regardless of whether or not aircraft in a certain region equip with multiple datalink technologies to make use of the available ATN-IPS Multilink.

This means that no CAPEX costs for the ground infrastructure and no significant OPEX costs related only to ATN-IPS Multilink provision are identified in addition to the costs of deployment of ATN-IPS, which the different datalink radio access networks (i.e., the single-link scenarios, Scenario 1, 2 and 3) will have to sustain anyway for the transition to ATN-IPS. With regard to on-board equipment, the additional CAPEX would be only in relation to equipage of the second chosen datalink radio terminals.

The only identifiable OPEX costs are related to network management activities for configuration on board as well as on the ground of the specific ATN-IPS Multilink parameters/functionality (e.g., link preference configuration, administrative routing policy configuration) and for the maintenance

[32] For details on the GB-LISP mobility solution, see the ICAO WG-I report "GB-LISP Mobility solution for ATN/IPS", version November 2020, or any later update.

[33] The AGMI ground proxy is a logical function, not a physical network element, which can be deployed following different deployment scenarios. In our analysis for this business case, we consider the deployment of the AGMI ground proxy on the air-ground boundary routers (AGBR).

activities related to them. These costs are estimated to be negligible, compared with the ATN-IPS deployment and operation costs that have to be taken into account in the single-link scenarios.

It is worth highlighting that in the mixed ATN-OSI/ATN-IPS scenario, which will be there during the migration to ATN-IPS, all the single-link business case scenarios must include the costs of the deployment and operation of IPS/OSI gateways in support of the OSI/IPS interoperability. As mentioned already in a previous section, this interoperability has nothing to do with ATN-IPS Multilink concept, but it is necessary to accommodate ATN-IPS-only and ATN-OSI-only aircraft for communication with ATN-OSI-only and ATN-IPS-only ATSUs, respectively.

8.5.2.1 Deployment scenarios for AGBRs, GGBRs, MSE and AGMI proxy

Although any specific ATN-IPS Multilink costs are assessed as negligible, compared with the costs for the deployment and operation of ATN-IPS, it is nevertheless worth analysing which deployment scenarios can be envisaged for the ATN-IPS mobility and multilink network elements and functionalities.

8.5.2.1.1 Ground-ground boundary routers (GGBRs)

For the GGBRs, two deployment sub-scenarios can be identified:

1. The CSP already has in-field routers which are directly reusable for the GB-LISP GGBR functionality and the connected ANSP(s) does(do) not require the capability to directly[34] influence the link selection by means of ground link preferences managed via technical functionalities.
2. The CSP's in-field GGBRs do not directly support the GB-LISP functionality, in which case the two sub-scenarios are as follows:
    - Only the upgrade of existing routers with models that support GB-LISP is needed. In this case, a HW replacement deployment model has to be considered.
    - New equipment installations are needed.
3. Multiple GGBRs per ANSP boundary interface must be considered, as redundancy is an essential safety requirement (no single points of failure).
    - Recommendation: consider at least two units per ANSP boundary interface
4. Whether the IP Infrastructure currently deployed by an ANSP for the provision of the ATN-OSI services is impacted by changes and/or integrations of GGBRs, depends on the choice[35] taken by the ANSP between two possible models:
        - GGBRs owned and operated by the ANSP, in order for the ANSP to have full control of the mobility and multilink uplink policies that are configured in the routers,
        - GGBRs provided as a service to the ANSP by an external provider, for example CEAB, and potentially shared among multiple ANSPs.

Under the assumption of the single European DSP, there are no technical changes identified as necessary in the ANSP domain.

[34] Indirect influence by means of contractual agreements is always possible

8.5.2.1.2 Air-ground boundary routers (AGBRs)

AGBRs require specific mobility/multilink functionality (e.g., the AGMI Ground Proxy7); consequently, the following cases must be considered as necessary:

1. The CSP can upgrade already deployed routers to add the additional functionality.
2. New equipment installations are needed and must be considered.
3. Multiple AGBRs per ASP must be considered, as redundancy is an essential safety requirement (no single points of failure):
    - consider two sub-scenarios, defining a range:
        - 2 AGBRs per ASP in 2 different geographical locations (site diversity),
        - 4 AGBRs per ASP in 2 different geographical locations (site diversity).

8.5.2.2 Mobility service endpoint (MSE)

The MSE is a centralised network function essential to the global mobility and multilink management, regardless of how many access networks are currently operational. A loss of the MSE would cause the whole FCI (with all available access networks) to lose the mobility and multilink functionality. Therefore, the MSE must have robust redundancy and geographical diversity.

Recommendation: consider sub-scenarios, defining a range:

- 2 MSEs per CSP in 2 different geographical locations (site diversity),
- 4 MSEs per CSP in 4 different geographical locations (site diversity).

8.5.3 Deployment on the ground

Deployment considerations on the ground can be found above for each potential link, sections 5.3.7, 6.4.3, 7.4.1, and 8.5.2 for IPS multilink itself.

Practical deployment options for ML are being considered at the time of writing, potentially for demonstration purposes part of SESAR3, and are still to be further discussed, considered not mature for mention in this document.

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[35] There are no technical reasons that mandate an ANSP to have to own and operate the GB-LISP capable GGBRs; the only technical requirement is that the GB-LISP GGBRs are necessary to implement the ATN-IPS Mobility & Multilink, either in the CSP domain, or in the ANSP domain.

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The ML implementation roadmap being developed by the SESAR Deployment Manager at the time of writing will have to develop this point further, based on a detailed ATN infrastructure transition study.

8.5.4 Deployment in aircraft

The same caveat as for the ground deployment options is applicable this section.

8.6 Cost assessment

As described in section3.4.1, the scope of the cost assessment is limited to the provision of:

- a global estimate of the airborne investment required to equip the target fleet (see section 4.3) by the end of 2039 with the new technologies introduced in the ATN-OSI Multilink approach (VDL-2 OSI plus an IP-enabled datalink among SATCOM NG, LDACS and OFF-THE-SHELF, carrying only ATN-OSI protocol messages).
- a global estimate of the ANSPs service fees required to support ATC datalink service provision with all the IP-enabled Multilink radio technologies, covering the entire EUROCONTROL Member State area (continental and oceanic airspace).

It is important to understand that the deployment of the “full ATN-IPS” operational concept as developed in the SESAR ATM Master Plan and standardized in ICAO will take a relatively long time to implement. It requires equipping aircraft with at least two technologies based on ATN-IPS. Insofar as the new communication technologies are not all at the same level of maturity, although the roadmap for the deployment of the ATN-IPS exists in ICAO and in the ATM Master Plan, a relatively long transition period can be foreseen, before being able to set up the full Multilink concept.

Therefore, the cost assessment results presented in section 8.6.2 are based on the implementation of a transitional phase of the Multilink concept, which consists of implementing all the new communication technologies on the ground and equipping aircraft with at least one ATN-IPS technology in addition to the current VDL-2 technology, which remains based on ATN-OSI.

8.6.1 Cost assumptions for the short-term ATN-OSI Multilink

8.6.1.1 AU cost assumptions

- The airborne investment in the Multilink scenario has been estimated based on the cost values provided by the other three scenarios, assuming that the cost of the multilink function is negligible and that there will be no additional cost for the equipment on board.

- The cost of the aircraft equipment presented in Table 50 for each technology, is the same as that estimated in the single-link scenario. The cost assessment includes everything (hardware, software, certification, installation costs, etc.) and covers both ATC and AOC traffic. Therefore the AUs' CAPEX investment is not calculated in proportion to the ATC communications only. For more information on the cost assumptions, refer to the Scenario 1, 2 and 3 cost assumption sections.

- The level of confidence indicated in Table 50 reflects the maturity level of each technology and the uncertainties with regard to their respective deployment dates.

- In the multilink approach, it is assumed that 50% of the new aircraft delivered will be equipped with SATCOM NG and 50% with LDACS, after a ramp-up period. No more than 33% of the new aircraft delivered every year will be equipped with one of the off-the-shelf technologies, which is considered as a complementary technology.

  This final target equipage rate for each technology has been used to estimate the costs of AUs' CAPEX. As explained previously, this should be considered as a transition towards the implementation of the full multilink concept developed by the SESAR Solution 77, i.e., when a critical mass of aircraft will be equipped with at least 2 IPS based technologies.

  The ramp-up of equipage will follow the same curve as in each of the single-link scenarios, but will be limited to the ratio of 1:2 for SATCOM NG and LDACS, and the ratio of 1:3 for OFF-THE-SHELF. Note that to estimate the overall equipage rate of the target fleet at the end of the time horizon (2039) in the Multilink Scenario, only the SATCOM NG and LDACS equipage rate have been considered to avoid double counting (see results in 8.6.2.1).

- The cost estimation of AUs' CAPEX investment by deployment phase in Table 51 takes into account the maturity level of each technology.

- Only forward-fit costs have been considered in the cost assessment.

8.6.1.2 ANSP cost assumptions

- The service fees include all the costs that all the ANSPs in the EUROCONTROL Member State area will pay to the DSP for the provision of the ATC datalink service using any of the Multilink technologies, i.e., cost for the provision of the service using SATCOM NG, LDACS and OFF-THE-SHELF technologies (through one or several selected CSPs or consortia). It includes the amortisation of the ground infrastructure required for any of these new technologies and the running costs of the CSPs, but does not include the set-up and running costs of the DLS governance, the DSP and the CEAB.

- The service fees cover all continental airspace, i.e., the provision of the service in the en-route segment, in the TMAs and at airports, as well as in oceanic airspace for the technologies concerned.

- Although no more than 50% of new aircraft will be equipped with LDACS and 50% with SATCOM NG, ANSP service fees will be equivalent to a 100% equipage rate for each of those two technologies.

    - The rationale with regard to LDACS is that aircraft will have to be supported throughout European airspace as described in section 3.3.3 Geographical applicability, and that this requires the deployment of the same number of ground stations as in the Scenario 1.

    - With regard to SATCOM NG, the explanation is that the service will need a lot more resources when many users use it: more bandwidth, more support staff for managing clients (both for airlines and ANSPs). This is the reason why the service charge is lower at the start of operations. The more ANSPs share the service, the lower the cost per ANSP will be.

- The cost of the gateways is included in the cost-of-service fees for each technology.

8.6.2 Cost assessment results for the short-term ATN-OSI Multilink

8.6.2.1 AU costs

Cost category	Base	Level of confidence	Target fleet theoretical cost (8,564 a/c)
Multilink equipment cost per aircraft (forward-fitting):			
LDACS	EUR 56,200	+/- 20%	**EUR 241 million** **(1 in 2 a/c** **4282 a/c)**
OFF-THE-SHELF	EUR 35,000 (representing around 6% to 7% of the cost of the IFC equipment)	+/- 15%	**EUR 100 million** **1 in 3 a/c** **2855 a/c)**

 Co-funded by the European Union

SATCOM NG	EUR 100,000	+/- 10%	**EUR 428 million** **1 in 2 a/c** **4282 a/c)**

Table 50: Scenario 4: ATN-OSI Multilink – AU unit cost and target fleet theoretical cost

	Phase 1 (2023-2025)	Phase 2 (2026-2030)	Phase 3 (2031-2039)	TOTAL in 2039
Expected target fleet equipage (as a percentage of a/c numbers)				
LDACS	0.1%	9%	30%	**30%**
OFF-THE-SHELF	0.0%	2%	8%	**8%**
SATCOM NG	2.4%	11%	30%	**30%**
TOTAL (LDACS + SATCOM NG only)	**2.5% of the target fleet**	**20% of the target fleet**	**59% of the target fleet**	**59%**
Airborne investment (2021-2039)				
LDACS	EUR 0.5 million	EUR 36.4 million	EUR 105.1 million	**EUR 142 million**
OFF-THE-SHELF	EUR 0.0 million	EUR 5.0 million	EUR 18.3 million	**EUR 23 million**
SATCOM NG	EUR 15.8 million	EUR 66.9 million	EUR 173.9 million	**EUR 257 million**
Total airborne investment	**EUR 16.2 million**	**EUR 108.4 million**	**EUR 297.3 million**	**EUR 422 million**

Table 51: Scenario 4: ATN-OSI Multilink – AU costs by phase of deployment

Taking into consideration the assumptions regarding the equipage rate between the different new communication technologies in the Multilink scenario (see section 8.6.1.1), the target fleet equipage at the end of the time horizon is expected to reach 59% with only 8% of the aircraft equipped with at least 2 IPS based new technologies. This scenario has been considered as the most realistic scenario but a sensitivity analysis has been performed on the equipage rate of the Multilink scenario (see section 9.4).

8.6.2.2 ANSP costs

	Base	Level of confidence	% of the total costs
ANSPs service fees per year at FOC (full operational capability) and for the entire EUROCONTROL Member State area.			
LDACS	EUR 14.8 million	+/- 20%	34%
OFF-THE-SHELF	EUR 3.4 million	+/- 20%	8%
SATCOM NG	EUR 25.0 million	+/- 10%	58%
TOTAL	EUR **43.2** million	**+/- 15%**	

Table 52: Scenario 4: ATN-OSI Multilink – ANSP annual service fees

	Phase 1 (2023-2025)	Phase 2 (2026-2030)	Phase 3 (2031-2039)	TOTAL in 2039
Expected ground equipage (as a percentage of the total service fees)-				
LDACS	41%	100%	100%	100%
OFF-THE-SHELF	0%	33%	46%	46%
SATCOM NG	52%	92%	100%	100%
TOTAL	**44%**	**90%**	**96%**	**96%**
Annual service fees	**Per year**	**Per year**	**Per year**	**Per year**
LDACS	EUR 6.1 million	EUR 14.8 million	EUR 14.8 million	**EUR 14.8 million**
OFF-THE-SHELF	EUR 0.0 million	EUR 1.1 million	EUR 1.6 million	**EUR 1.6 million**
SATCOM NG	EUR 13.0 million	EUR 23.0 million	EUR 25.0 million	**EUR 25.0 million**
TOTAL	**EUR 19.1 million per year**	**EUR 38.9 million per year**	**EUR 41.4 million per year**	**EUR 41.4 million per year**
Total ANSP service fees (cumulated by phase)				
LDACS	EUR 6.1 million	EUR 69.6 million	EUR 133.2 million	**EUR 209 million**
OFF-THE-SHELF	EUR 0.0 million	EUR 4.3 million	EUR 12.4 million	**EUR 17 million**
SATCOM NG	EUR 33.0 million	EUR 94.0 million	EUR 225.0 million	**EUR 352 million**
TOTAL	**EUR 39.1 million**	**EUR 167.9 million**	**EUR 370.6 million**	**EUR 578 million**

Table 53: Scenario 4: ATN-OSI Multilink – ANSP annual and total costs by phase of deployment

8.6.2.3 Overall cost projection for ATN-OSI Multilink

Figure 27 shows the fleet equipage ramp-up and related estimated costs throughout the time horizon for Scenario 4. As a reminder, the assumption for the base case is that 50% of new aircraft will be equipped with LDACS technology and 50% with SATCOM NG technology. In addition, 33% of these aircraft will also be equipped with one of the OFF-THE-SHELF technologies. To estimate the incremental equipping of the target fleet, the same ramp-up designs as in the single-link scenarios were used, but limited to the percentages shown above for each of the three technologies.

At the end of the time horizon, the equipage rate should be equal to that expected in Scenario 1 and 3 (around 59% of the target fleet) but AU CAPEX investment will be medium compared with these two scenarios. However, Scenario 4 has the highest service delivery costs (EUR 43 million at FOC).

Scenario 4 - MULTILINK		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
Sc 4 / LDACS		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
% of new a/c equipped	50% Equipage rate	0%	0%	0%	0%	3%	10%	15%	30%	40%	45%	50%	50%	50%	50%	50%	50%	50%	50%	50%	
Nb of a/c equipped per year		0	0	0	0	8	41	65	139	199	205	234	203	184	193	223	257	235	232	110	2.527
Cumulated a/c equipped		0	0	0	0	8	49	113	253	452	657	891	1.093	1.277	1.470	1.694	1.950	2.185	2.417	2.527	
% LDACS fleet equipage		0%	0%	0%	0%	0%	1%	2%	4%	6%	9%	12%	14%	16%	18%	21%	24%	26%	29%	30%	
LDACS - AUs CAPEX	€ 56.200 Unit cost	0	0	0	0	0	2	4	8	11	12	13	11	10	11	13	14	13	13	6	142
LDACS - ANSPs Service fees	14,8 M€ per year	0	0	0	0	6	10	15	15	15	15	15	15	15	15	15	15	15	15	15	209
Sc 4 / SATCOM NG		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
% of new a/c equipped	50% Equipage rate	0%	0%	10%	15%	20%	25%	25%	30%	33%	35%	35%	35%	50%	50%	50%	50%	50%	50%	50%	
Nb of a/c equipped per year		0	0	20	71	67	101	108	139	162	159	164	142	184	193	223	257	235	232	110	2.566
Cumulated a/c equipped		0	0	20	91	158	259	367	506	668	827	991	1.133	1.317	1.510	1.733	1.990	2.225	2.457	2.566	
% SATCOM NG fleet equipage		0%	0%	0%	1%	2%	4%	5%	7%	9%	11%	13%	15%	17%	19%	21%	24%	27%	29%	30%	
SATCOM NG - AUs CAPEX	€ 100.000 Unit cost	0	0	2	7	7	10	11	14	16	16	16	14	18	19	22	26	24	23	11	257
SATCOM NG - ANSPs Service fees	25,0 M€ per year	0	0	10	10	13	14	17	19	21	23	25	25	25	25	25	25	25	25	25	352,0
Sc 4 / COTS		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
% of new a/c equipped	33% Equipage rate	0%	0%	0%	0%	0%	0%	6%	6%	9%	9%	14%	14%	14%	14%	14%	14%	14%	14%	14%	
Nb of a/c equipped per year		0	0	0	0	0	0	27	29	45	41	65	57	52	54	63	72	66	65	31	666
Cumulated a/c equipped		0	0	0	0	0	0	27	57	102	142	208	265	316	370	433	505	570	635	666	
% COTS fleet equipage		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
% COTS fleet equipage (Real figures)		0%	0%	0%	0%	0%	0%	0%	1%	1%	2%	3%	3%	4%	5%	5%	6%	7%	8%	8%	
COTS - AUs CAPEX	€ 35.000 Unit cost	0,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,6	1,4	2,3	2,0	1,8	1,9	2,2	2,5	2,3	2,3	1,1	23
COTS - ANSPs Service fees	3,4 M€ per year	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	17
Sc 4 TOTAL		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	TOTAL
Nb of a/c equipped per year		0	0	20	71	75	142	172	278	362	364	397	345	368	386	447	513	470	464	219	5.093
Cumulated a/c equipped		0	0	20	91	166	308	480	758	1.120	1.484	1.881	2.226	2.594	2.980	3.427	3.940	4.410	4.874	5.093	
% Target fleet equipage		0	0%	0%	1%	2%	5%	7%	11%	15%	20%	25%	29%	33%	37%	42%	48%	53%	58%	59%	
Nb of flights equipped per year		0	0	21.215	80.983	90.287	170.661	206.772	340.298	445.037	442.728	499.175	418.688	426.320	427.611	517.406	625.252	553.544	558.866	223.677	
Cumulated flights equipped		0	0	21.215	102.198	192.485	363.147	569.919	910.217	1.355.253	1.797.981	2.297.156	2.715.844	3.142.164	3.569.774	4.087.181	4.712.433	5.265.976	5.824.842	6.048.519	
% Target traffic equipage		0	0%	0%	1%	3%	5%	7%	11%	16%	21%	27%	31%	35%	39%	44%	50%	55%	60%	62%	
% FL285 traffic equipage		0	0%	0%	1%	2%	4%	6%	10%	14%	18%	23%	26%	30%	33%	37%	43%	47%	51%	53%	
% ECAC traffic equipage		0	0%	0%	1%	2%	3%	5%	7%	10%	14%	17%	20%	22%	25%	28%	32%	35%	38%	39%	
TOTAL AUs - Forward fit costs		0,0	0,0	2,0	7,1	7,1	12,4	15,3	22,8	29,0	28,9	31,8	27,6	30,5	32,0	37,1	42,6	39,0	38,5	18,2	422
Ground equipage rate		0	0%	23%	23%	44%	56%	76%	81%	85%	90%	95%	95%	95%	95%	95%	95%	95%	96%	96%	0
TOTAL ANSP service fees		0,0	0,0	10,0	10,0	19,1	24,4	32,8	34,8	36,9	38,9	41,0	41,0	41,1	41,1	41,2	41,2	41,3	41,3	41,4	578

Figure 27: Scenario 4: ATN-OSI Multilink – Overall cost projection and fleet equipage

8.7 Qualitative assessment

8.7.1 Performance

The FCI is designed according to ATS-B2/B3 requirements which also drive the design of the new data links part of FCI, i.e. LDACS and SATCOM NG.

Safety and Performance ATS-B2 requirements are documented in ED-228A and other references. SESAR 1 also derived initial QoS requirements for ATS-B3 which have not yet been validated/contradicted at the time of writing.

8.7.2 Potential evolution of the technology

Reference shall be made to the corresponding sections of this report for the new data links LDACS and SATCOM NG, which are obviously strongly correlated to evolution of the FCI itself.

8.7.3 Safety, security and QoS aspects of the ATN-IPS Multilink

- **Safety**

  According to the safety analysis carried out in SESAR since the first work on FCI multilink and the conclusions of ICAO WG-I, and after several years of work on the ATN-IPS standards, the main advantage of deploying and using the ATN-IPS mobility and multilink solution would be to achieve the performances necessary to comply with the availability requirements of aeronautical standards, such as EUROCAE ED-228A, which are derived from safety requirements. Indeed, according to the expert opinions developed in both ICAO and SESAR, complete fulfilment of these requirements would not be possible with just a s ingle link.

- **Optimisation of communication routing**

  ATN-IPS Multilink supports optimised performance-based communication routing (see section 8.1), enabling not only a solution for the current need to offload AOC traffic but even more functionalities in support of future ATS-B3 services.

- **Standardisation and interoperability**

  ATN-IPS Multilink is the only concept that provides a standardised framework, which allows for the integration and interoperability of the future technologies. An example is the support provided for future ATM applications using Simulcast (i.e., transmission of the same messages over multiple datalinks).

  An additional benefit resulting from the migration to ATN-IPS is that accessing a much broader community of experts worldwide, whereas ATN-OSI is very specific and currently developed by only very few companies.

  Finally, the ATN-IPS Multilink concept enables seamless interoperability between related datalink technologies. Without the multilink concept, and with airlines able to independently select the datalink technology to be used, the ground infrastructure would have to implement all proposed datalink radio technologies, involving additional gateways and network coordination functionalities and, therefore additional costs.

8.7.4 Ease of deployment and financial aspects

- **Increased competition for airlines**

  The ATN-IPS Multilink scenario fosters more competition in the on-board flexibility and configurability of the different datalinks, providing AUs with more options to choose from when optimising their operations. Such a benefit is in fact a key factor for airspace users.

8.8 Risk and mitigation

Reference is made to corresponding sections of the FCI in each solution chapter.

8.8.1 Technical risk of the ATN-IPS Multilink

Risk	Likelihood	Impact	Possible mitigation
One technical risk, which is in fact shared with the single-link scenarios, concerns the security of the global mobility backbone, which is common infrastructure shared by all datalink technologies involved in the ATN-IPS Multilink concept. In case the backbone is compromised, this will also have an impact on the single-link access networks. This risk should be considered also in all the single-link scenarios of this business case.	See sections 5.6.1, 6.7.1, 7.7.1.	See sections 5.6.1, 6.7.1, 7.7.1.	See sections 5.6.1, 6.7.1, 7.7.1.

Table 54: Scenario 4: ATN-IPS Multilink – Technical risk and mitigation

8.8.2 Implementation risk of the ATN-IPS Multilink

Risk	Likelihood	Impact	Possible mitigation
ATN-IPS Multilink solution is applicable only if all functionalities and network elements standardised by ICAO for ATN-IPS implementation are available. There is therefore a risk that the standards are delayed for ATN-IPS implementation. All implementation risks already considered by each of the single-link scenarios in relation to the deployment of ATN-IPS are also applicable to the ATN-IPS Multilink scenario.	See sections 5.6.1, 6.7.12, 7.7.12.	See sections 5.6.1, 6.7.12, 7.7.12.	See sections 5.6.1, 6.7.12, 7.7.12.

Table 55: Scenario 4: ATN-IPS Multilink – Implementation risk and mitigation

8.8.3 Business and financial risk of the ATN-IPS Multilink

Risk	Likelihood	Impact	Possible mitigation
Not all European ANSPs might agree to or be mandated to deploy on the ground all the datalink technologies supporting the ATN-IPS Multilink concept, even under the assumption of the European DSP model.	See sections 5.6.13, 6.7.13, 7.7.13.	See sections 5.6.13, 6.7.13, 7.7.13.	See sections 5.6.13, 6.7.13, 7.7.13.
Deployment does not happen all at once, but rather over the course of a transition phase, lasting for years and during which new technologies become available for use in different regions with different timelines.	See sections 5.6.13, 6.7.13, 7.7.13.	Longer deployment than expected, increase in the transition costs and delay in the rationalisation of current VDL-2 infrastructure	See sections 5.6.13, 6.7.13, 7.7.13.
Financial risks for the AUs is brought by the need to equip multiple (at least 2) different radio access technologies on board of the aircraft.	See sections 5.6.13, 6.7.13, 7.7.13.	See sections 5.6.13, 6.7.13, 7.7.13.	**See sections 5.6.13, 6.7.13, 7.7.13.**

Table 56: Scenario 4: ATN-IPS Multilink – Business and financial risk and mitigation

9 Main results of the business case

This section provides an overview of both the cost assessment and the qualitative assessment results.

- Section 9.1 provides a synthetic view of the total costs for the AUs (airborne investment) and the ANSPs (service fees) for the entire 2021-2039 period. This section also indicates:
  - what the total costs for the AUs would be if 100% of the target fleet is equipped by 2039 (8,564 a/c);
  - what the maximum annual service fees would be which all the ANSPs in the EUROCONTROL Member State area would have to bear for ATC datalink service provision.
- Section 9.2 provides a qualitative and quantitative overview of the main operational benefits, common to all scenarios.
- Section 9.3 provides a synthetic view of the qualitative assessment results with regard to the selected set of criteria. It also summarises what the main technical, business, financial and implementation risks are when deploying a solution.
- Section 9.4 provides the results of the sensitivity analysis on the ATN-IPS Multilink scenario.
- Section 9.5 summarises the main conclusions for each solution scenario.

9.1 Overall cost comparison

9.1.1 AU cost assessment results

Table 57 provides a rough and global estimation of the airlines CAPEX required for each solution scenario. Costs have been calculated based on expert judgement with regard to deployment assumptions (start year of implementation, level of equipage, ramp-up of equipage). These estimates do not claim to be 100% accurate.

The cost assessment shows a significant variation in the total investment required to equip 100% of the target fleet by 2039 (theoretical cost) depending on the solution scenario, ranging from EUR 300 million to EUR 856 million.

Not all solutions have reached the same level of maturity. Consequently, the equipage rate of the target fleet that could be expected by 2039 varies with the different scenarios, and accordingly, so does the level of investment required to reach such a level of equipage:

- 60% for Scenario 3 – SATCOM NG (airborne investment of EUR 513 million)
- 59% for Scenario 1 – LDACS (airborne investment of EUR 284 million)
- 59% for Scenario 4 – MULTILINK/MULTIMODE (airborne investment of EUR 422 million)

EUROPEAN PARTNERSHIP

Co-funded by the European Union

- 23% for Scenario 2 –OFF-THE-SHELF (airborne investment of EUR 70 million

It is important to note that the on-board equipment will be used for both ATC and AOC traffic. Although the FCI business case focuses on ATC communication requirements, the airborne investment presented in Table 57 covers the needs of all ATC and AOC communications.

(a)		(b)	(c)	(d)			(e)	(f)
Scenario **(F) Target fleet** **(T) Target traffic**		**IOC date**	**Ramp-up assumption** (percentage of new a/c equipped per year)	**Equipage rate Target fleet and flights** (most flying a/c >FL285)			**AUs costs (2021-2039) based on airborne equipage assumptions**	***AUs theoretical costs if 100% target fleet equipped in 2039*** *(8,564 a/c)*
				2025 (d1)	2030 (d2)	2039 (d3)		
LDACS		**2025**	**Ramp-up from 5% to 100%**	**F: 0.2% T: 0.3%**	**F: 18% T: 19%**	**F: 59% T: 61%**	**EUR 284 million**	**EUR 481 million**
COMMERCIAL OFF-THE-SHELF		**2027**	**Ramp-up from 19% to 42%**	**F: 0.0% T: 0.0%**	**F: 6% T: 6%**	**F: 23% T: 24%**	**EUR 70 million**	**EUR 300 million**
SATCOM NG		**2023**	**Ramp-up from 20% to 100%**	**F: 5% T: 5%**	**F: 22% T: 24%**	**F: 60% T: 62%**	**EUR 513 million**	**EUR 856 million**
MULTILINK	LDACS	2025	Ramp-up from 2% to 33%	F: 0.1% T: 0.1%	F: 9% T: 9%	F: 30% T: 31%	EUR 142 million	EUR 241 million
	COTS	2027	Ramp-up from 6% to 14%	F: 0.0% T: 0.0%	F: 2% T: 2%	F: 8% T: 8%	EUR 23 million	EUR 100 million
	SATCOM NG	2023	Ramp-up from 7% to 33%	F: 2.4% T: 2.4%	F: 11% T: 12%	F: 30% T: 31%	EUR 257 million	EUR 428 million
	TOTAL			**F: 2.5% T: 2.5%**	**F: 20% T: 21%**	**F: 59% T: 62%**	**EUR 422 million**	**EUR 769 million**

Table 57: FCI-BC – AU cost assessment results

Table 57 provides the following information:

- IOC (initial operational capability) date: date when the first aircraft will be equipped and will be operational with the new communication technology (column b)
- Ramp-up assumptions: percentage of new aircraft to be delivered on the market that will be forward-fitted with the new communication technology every year, from IOC date up to 2039 (column c);
- Equipage rate: data snapshot of the target fleet traffic equipage at three points in time (column d1, d2, d3);

  Depending on the IOC date, there will be a progressive equipage rate of the fleet flying above FL285 and associated flights. A snapshot of the target fleet and traffic equipage is provided for the years 2025, 2030 and 2039. The first percentage corresponds to the target fleet equipage, and the second percentage to the target fleet traffic equipage.
- AU costs (2021-2039): sum of the airborne investment throughout the time horizon (2021-2039) based on the equipage rate and ramp-up assumptions (column e);
- AU theoretical costs: estimation of the total airborne investment required if 100% of the 2039 target fleet is equipped, i.e., if 8,564 aircraft are equipped (column f).

For a fair comparison with the other solution scenarios, the airborne investment in the COMMERCIAL OFF-THE-SHELF scenario has been calculated in proportion to ATC and AOC communication needs only, even though the equipment on board will be mainly used for passengers communications. For more information, refer to section 6.5.1.1 AU cost assumptions.

Note that the numbers should be taken with caution, as the outcome of the cost assessment is highly dependent on:

- the fleet projection for the target fleet that has been designed for the purpose of this business case;

  This is based on pure statistics and does not reflect the real intention of airlines to renew their fleet sooner or later and/or to acquire/rent new aircraft. The projection is based on the assumption that aircraft will retire after a lifetime of 20 years (on average) and that the average number of flights per aircraft for the target fleet will remain constant throughout the 2021-2039 period.

- the long-term traffic forecast and when the COVID-19 crisis is expected to be over;

  The assumption is that ECAC traffic should return to 2019 levels by the end of 2024. At the time of finalising this business case report, it is difficult to predict when the COVID-19 crisis will end and when we will return to 2019 traffic levels. The fleet and traffic forecasts that have been developed are based on STATFOR four-year forecasts published in May 2021. It is difficult to predict what traffic will look like in the coming months. Therefore, adjustment may be required in the future.

- the equipage rate and the ramp-up assumptions that have been made by the experts in each solution scenario to estimate how many new aircraft could be equipped per year with the new communication technologies per year;

- the IOC date, i.e. when the first aircraft will be equipped with the new technology and when it could be ready for deployment;

  This date reflects the level of maturity of the solution. Any delay in validation, safety and security risk assessment, spectrum protection requirement, standardisation and certification activities, as well as in the establishment of service provision, could have an impact on this IOC date and therefore on the ramp-up of the equipment of the target fleet.

- the assumption in the COMMERCIAL OFF-THE-SELF scenario that the cost of the equipment will be mainly borne by the passenger communications business model.

  If the passenger business model is not profitable, the cost sharing could be different and the share of the airborne investment allocated to ATC and AOC traffic could be much higher or even much higher than the other scenarios.

9.1.2 ANSPs cost assessment results

Table 58 gives an overview of the estimated service fees that will have to be borne by the ANSPs for each solution.

It should be noted that although the air and ground infrastructure will serve both ATC and AOC traffic, the estimated costs cover only the ATC part. For the COMMERCIAL OFF-THE-SHELF solution, the on-board equipment will also serve the passenger communications, but as for the other solutions, the service fees indicated cover only the cost of the ATC service provision, which has been calculated proportionately.

The results of the cost assessment show that the service fees incurred annually by the ANSPs at full operational capability (FOC) range from EUR 8.3 million to EUR 43.2 million per year depending on the solution.

(a)		(b)	(c)	(d)			(e)	(f)
Scenario		**IOC date**	**Ramp-up assumption** (progressive ANSPs equipage on the ground)	**Equipage rate in the ground** (as a percentage of FOC annual service fees)			**Total ANSPs service fees (2021-2039) based on ground equipage assumption**	***ANSPs annual service fees at FOC*** *(for serving the 2039 target fleet)*
				2025 (d1)	2030 (d2)	2039 (d3)		
LDACS		**2025**	**Ramp-up from 41% to 100%**	**41%**	**100%**	**100%**	**EUR 209 million**	***EUR 14.8 million***
COMMERCIAL OFF-THE-SHELF		**2027**	**Ramp-up from 13% to 33%**	**0%**	**16%**	**33%**	**EUR 24 million**	***EUR 8.3 million***
SATCOM NG		**2023**	**Ramp-up from 40% to 100%**	**52%**	**92%**	**100%**	**EUR 352 million** *(1 CSP)*	***EUR 25.0 million*** *(1 CSP)*
MULTILINK	LDACS	2025	Ramp-up from 41% to 100%	41%	100%	100%	EUR 209 million	*EUR 14.8 million*
MULTILINK	COTS	2027	Ramp-up from 30% to 46%	0%	33%	46%	EUR 17 million	*EUR 3.4 million*
MULTILINK	SATCOM NG	2023	Ramp-up from 40% to 100%	52%	92%	100%	EUR 352 million	*EUR 25.0 million*
MULTILINK	**TOTAL**		**Ramp-up from 23% to 96%**	**44%**	**90%**	**96%**	**EUR 578 million**	**EUR 43.2 million**

Table 58: FCI-BC – ANSP cost assessment results

As with the AU cost assessment, ANSP figures must be taken with caution. The following elements have been considered when assessing the costs:

- Although it is assumed that all ANSPs will join the DSP, a phased approach has been considered in all the scenarios. For the LDACS scenario, there will be a progressive implementation of the ground stations, with the objective of first covering the core area where VDL-2 congestion is higher.
- In the SATCOM NG and in the COMMERCIAL OFF-THE-SHELF scenario, the ANSP service fees evolve with the progressive fleet equipage. However, to cover the initial investment that will be required to set up the service, a minimum level of service fees has been considered in the ramp-up of the ground costs for the SATCOM NG scenario.

9.2 Operational benefits common to all scenarios

9.2.1 Avoiding capacity reduction due to VDL-2 congestion

The benefits of establishing an FCI infrastructure are linked to the risks and cost of the reference scenario, i.e. the “do-nothing scenario” or business-as-usual scenario.

Previous studies and monitoring performed by the Network Manager have demonstrated that as from 2027, there will be a lack of ATC capacity due to VDL-2 frequency congestion, and the Performance Review Body (PRB) has estimated that a 10% capacity loss would generate an extra cost of EUR 1 to 1.3 billion per year (see Performance Review Report 2020 [16]). If nothing is done to reduce the congestion, by offloading the AOC traffic for example, the cumulated costs at end of 2039 will reach EUR 12 billion. EUROCONTROL has estimated that at least 50% of the benefits of using datalink services (compared with voice) can be attributed to technology enablers (the remaining 50% is attributed to the applications implemented by ANSPs, e.g., i4D, extended AMAN, etc.).

Even if, taking a conservative approach, only 1% of capacity is lost, this will generate a cost of about EUR 100 million per year.

Moreover, VDL-2 traffic may become congested sooner than expected, i.e., between 2024 and 2027, due to the conjunction of several elements:

- increasing demand for the DLS service, as not all equipped aircraft are currently using CPDLC;
- the fact that with the COVID-19 crisis, some airlines may decide to benefit from price cuts and to renew their fleet sooner than expected;
- the growth of AOC traffic, which will be greater than ATC traffic with the arrival of new aircraft, which consume five times more data than the old ones.

Compared with the VDL-2 annual service fees of EUR 16 million of that the ANSPs are currently paying for CDPLC, it is clear that investing in new communication technologies will be beneficial for the community.

9.2.2 Optimisation of airlines operations

Previous analysis conducted by the London School of Economics (LSE) in partnership with Inmarsat has confirmed that flight optimisation (fuel burn and emissions), fleet utilisation (delays, diversions) and maintenance (staffing, inventory, predictability) will benefit from the live connectivity updates, especially when using the IP pipe. The order of magnitude of savings established by the LSE was between 1% and 2% of total operating cost.

The airlines interviewed in summer 2021 during the CBA analysis could not support the establishment of a consolidated view of which applications and services will benefit from the increased quality of service compared with ACARS and VDL-2. Although this survey was developed specifically for the purpose of the IRIS SATCOM CBA, the same kind of operational benefits could be expected with the other three scenarios analysed in the FCI-BC, but with a different timeframe due to the differences in the maturity level of each technology. Experts are, however, confident that AOC services will experience a somewhat similar expansion to that in the phone industry. Indeed, the explosive growth in the services available today on our smartphones was driven by the availability of the phone technology. In order to remain on the conservative side, experts have estimated that there will be savings of 0.7% in the cost of maintenance and 0.4% in the fuel burn of equipped aircraft. This translates into additional benefits over the period 2023-2038 (assuming 50% of aircraft are equipped). Combining the AOC and ATN benefits, the cost-to-benefit ratio is 10:1.

9.2.3 Supporting the CP1 benefits / advanced digitalisation and automation

Additional benefits are expected to materialise from CP1 deployment, developing from 2028 onwards, when ADS-C EPP will become mandatory for first applications of the management of 4D trajectories and better CPDLC than through VDL-2 will likely be required. The expected benefits of CP1 depend on the communication technology enabler (in particular on AF#6) and will be put at risk if the enablers are not present.

Similarly, the communication enabler is needed to achieve the full Master Plan capabilities (as described in the Airspace Architecture Study), expected to develop after CP1, i.e., beyond 2030, when state-of-the art CPDLC and ADS-C will be required for a machine-to-machine dialogue aiming at designing and maintaining optimised 4D trajectories throughout the flight. As a reminder, the Airspace Architecture Study (AAS) evaluates the accumulated benefits for the 2019-2035 period at between EUR 42 billion and EUR 47 billion. These improvements need in particular the following investments: ”next generation performance-based air-ground communications environment (EUR 3.9 billion)”. This communication infrastructure represents around 33% to 55% of the total investment of EUR 7 billion to EUR 11 billion. Hence, in the longer term, deploying efficient air-ground communication infrastructure will prove very beneficial for the airspace users.

9.3 Qualitative assessment comparison

Table 59 provides a synthetic view of the qualitative assessment results for the previously agreed set of criteria.

Criteria	Scenario 1 LDACS	Scenario 2 COMMERCIAL OFF-THE-SHELF	Scenario 3 SATCOM NG	Scenario 4 MULTILINK/ MULTIMODE
Maturity Level:				
• **Technological Readiness Level (TRL) expected at the end of SESAR Wave 2 (i.e., end of 2022)**	TRL-6 * LDACS voice TRL-4	TRL-2 (for overlay and security mechanisms) TRL-8 for radio communications (4G/5G IMT, Ka/Ku Satcom, A2G)	• **SATCOM Class B already TRL-6** (S2020 W1) • SATCOM IPS FCI should reach TRL-6 at the end of S2020 Wave 2	TRL- 6 Based on TRL for each technology supported
• **Infrastructure status**	LDACS over ATN/OSI (2025) LDACS over ATN/IPS heavily depends on the availability of the IP infrastructure (2027?)	Available today for AOC only	Service provided for ATN/OSI as from 2023. ATN/IPS tested in 2022 (prototype), migration to an operational system in 2024	Prototype
• **Validation status**	Validation to TRL6 at the end of Wave 2 Test flights in Wave 3 Project PJ.33 solution 2 Thread 1 Test flights also out of SESAR in Germany project MICONAV	Validated and available today for AOC only New mechanisms for ATS communications validated to TRL2 at the end of Wave 2	Several ATN flight campaigns (NLR, Airbus, Honeywell). Next Airbus ATN test flights with 3 ANSPs in March 2022.	Validation to TRL6 at the end of Wave 2

Criteria	Scenario 1 LDACS	Scenario 2 COMMERCIAL OFF-THE-SHELF	Scenario 3 SATCOM NG	Scenario 4 MULTILINK/ MULTIMODE
• **Service distribution status**	None	Available today for AOC only	No need for ground infrastructure to be deployed, as the services will be distributed using the existing /planned ATN infrastructure. EASA certification planned Q1 2023	None
• **Early-implementation flights**	Germany test flights in MICONAV project	None for ATS In use for AOC	Starting in November 2022 (with EZY), 10 aircraft	None
• **Standard/Certification (ATS)**	YES	Based on mature COTS standards Sol 61 overlay and security mechanisms to be standardised	YES	YES
Safety (compliance with SESAR requirements)	YES	YES	YES	YES
Security (compliance with SESAR requirements)	YES	YES	YES	YES
Compatibility with aviation systems	• ICAO standard available (applicability: 2024) • EUROCAE standard (applicability 2024)	• No ICAO/ EUROCAE standard yet; • ARINC and COTS standards available (for AOC part)	• ICAO standard available end 2024 • EUROCAE ED-228A	• Based on each technology standard available • Standard IPS available end 2024
Performance:				
Bandwidth (max per a/c)	2.6 Mbps	10 Mbps	1.7 Mbps	Dependent on underlying technologies
Latency (round-trip delay)	200 ms	Under 200 ms (expected)	3.8 sec	Dependent on underlying technologies
Availability/Continuity of service	High	High	High	Very high
Applicability to safety critical applications	Yes	Yes To be validated	Yes	Yes

Criteria	Scenario 1 LDACS	Scenario 2 COMMERCIAL OFF-THE-SHELF	Scenario 3 SATCOM NG	Scenario 4 MULTILINK/ MULTIMODE
QoS (quality of AOC/ATC service management, priority management)	Yes		Yes	Yes
Sensitivity to denial of service attacks	Low	High	Low	Medium/high
Evolution of the solution/ Technology	Digital voice, complementing VHF communications, Navigation, Surveillance	Air-ground voice, air-air data and voice	Voice, Global IoT. Easy expansion to global service with ATN/IPS	IP mobility architectures
Ease of deployment	• It can be deployed at existing radio sites without risk of interference • Protects current investments in infrastructure • Scalable for high-density areas • Distributed, avoids single point of failure	• Ground infrastructure and service is available for commercial services • Additional standardisation and certification for ground and air systems	• Global coverage from day 1. • No ground investment required for ATC service provision • Service distribution already in place	• Incremental network infrastructure (gateway and airborne router), no additional radio compared with scenarios 1-3 • Additional end-user training • Management of link selection policies by stakeholders and regulators
Financial aspect	N/A	• May require incentive to achieve a critical mass of a/c equipped	• SATCOM NG is one of these energy efficient investments • Perceived by the users as an expensive and monopolistic solution	

Table 59: FCI-BC – Overall qualitative assessment results

9.4 Sensitivity analysis

9.4.1 Sensitivity of the equipage rate in the MULTILINK/MULIMODE scenario

This sensitivity analysis integrates the cost assessment of section 8.6, fully covering the Enablers developed by PJ14-W2-77 "FCI Services" (see Table 48)

- CTE-C04
- A/C-95

9.4.1.1 Equipage rate – base case

A sensitivity analysis has been performed on the equipage rate in the MULTILINK/MULTIMODE scenario for the various technologies (LDACS, SATCOM NG and OFF-THE-SHELF). The base-case assumption is that:

- 50% of new aircraft would be equipped with the SATCOM NG technology;
- 50% of new aircraft would be equipped with the LDACS technology;
- 33% of new aircraft would be equipped with one of the OFF-THE-SHELF technologies.

In the MULTILINK/MULTIMODE base-case scenario, only 33% (at a maximum) of the new aircraft will be equipped with two new IP-based technologies, on top of the current VDL-2 technology (ATN/OSI-based). This scenario can be considered as a realistic objective in terms of equipment given the level of maturity of each new communication technology. Taking into consideration the ramp-up design of each new communication technologies, it may take some time to deploy a full multilink concept, i.e., once all new aircraft are equipped with two new IP-based communication technologies with automatic switching function. **With such assumptions, at the end of the period only 8% of the target fleet will be equipped with two IPS-based technologies.**

Table 60 and Table 60 recall the results of the base case for the MULTILINK/MULTIMODE scenario respectively for the AUs and ANSPs.

Scenario (F) Target fleet (T) Target traffic		IOC date	Ramp-up assumption (percentage of new a/c equipped per year)	Equipage rate Target fleet and flights (most flying a/c >FL285)			AUs costs (2021-2039) based on airborne equipage assumptions	*AUs theoretical costs if 100% target fleet equipped in 2039 (8,564 a/c)*
				2025 (d1)	2030 (d2)	2039 (d3)		
MULTILINK	LDACS	2025	Ramp-up from 2% to 33%	F: 0.1% T: 0.1%	F: 9% T: 9%	F: 30% T: 31%	EUR 142 million	*EUR 241 million*
	COTS	2027	Ramp-up from 6% to 14%	F: 0.0% T: 0.0%	F: 2% T: 2%	F: 8% T: 8%	EUR 23 million	*EUR 100 million*
	SATCOM NG	2023	Ramp-up from 7% to 33%	F: 2.4% T: 2.4%	F: 11% T: 12%	F: 30% T: 31%	EUR 257 million	*EUR 428 million*

	TOTAL			**F- 2.5% T- 2.5%**	**F- 20% T-21%**	**F- 59% T- 62%**	**EUR 422 million**	**EUR 769 million**

Table 60: Sensitivity – Multilink Scenario Base case - AUs equipage rate and costs

Scenario		**IOC date**	**Ramp-up assumption** (progressive ANSPs equipage on the ground)	**Equipage rate on the ground** (as a percentage of FOC annual service fees)			**Total ANSPs Service fees (2021-2039) based on ground equipage assumption**	***ANSPs annual service fees at FOC*** *(for serving the 2039 target fleet)*
				2025 (d1)	2030 (d2)	2039 (d3)		
MULTILINK	LDACS	2025	Ramp-up from 41% to 100%	41%	100%	100%	EUR 209 million	*EUR 14.8* million
	COTS	2027	Ramp-up from 30% to 46%	0%	33%	46%	*EUR* 17 million	*EUR 3.4* million
	SATCOM NG	2023	Ramp-up from 40% to 100%	52%	92%	100%	*EUR* 352 million	*EUR 25.0* million
	TOTAL		**Ramp-up from 23% to 96%**	**44%**	**90%**	**96%**	***EUR* 578 million**	***EUR* 43.2 million**

Table 61: Sensitivity – Multilink Scenario Base case – ANSPs equipage rate and costs

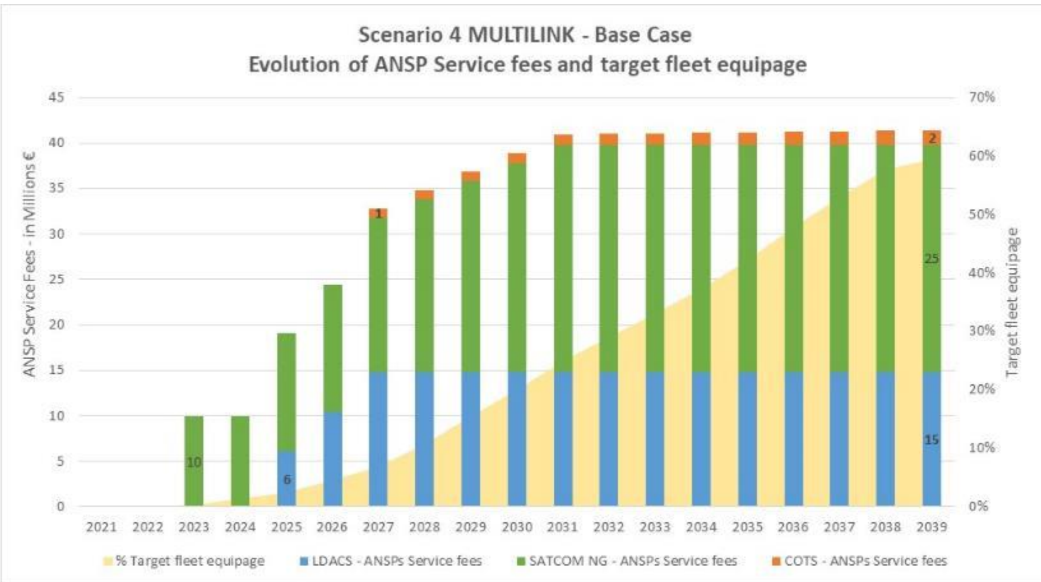

Figure 28 Scenario 4: MULTILINK/MULTIMODE – Base Case – Evolution of ANSP service fees and target fleet equipage

It should be noted that only SATCOM NG and LDACS equipage are presented in Figure 28 to avoid double counting in the overall estimation of the MULTILINK/MULTIMODE scenario equipage rate. As

OFF-THE-SHELF technologies are considered as complementary technologies, the progressive equipage of new aircraft with COTS technologies will not increase the overall fleet equipage.

9.4.1.2 Equipage rate – low case

Table 62 presents the results of the sensitivity analysis for the low case, with the following assumption:

- 33% of all new aircraft will be equipped with one of the three new technologies (SATCOM NG, LDACS and one of the OFF-THE-SHELF technologies).

Scenario (F) Target fleet (T) Target traffic		IOC date	Ramp-up assumption (percentage of new a/c equipped per year)	Equipage rate Target fleet and flights (most flying a/c >FL285)			AUs costs (2021-2039) based on airborne equipage assumptions	*AUs theoretical costs if 100% target fleet equipped in 2039 (8,564 a/c)*
				2025 (d1)	2030 (d2)	2039 (d3)		
MULTILINK	LDACS	2025	Ramp-up from 2% to 33%	F: 0.1% T: 0.1%	F: 6% T: 6%	F: 20% T: 20%	EUR 95 million	*EUR 160 million*
	COTS	2027	Ramp-up from 6% to 14%	F: 0.0% T: 0.0%	F: 2% T: 2%	F: 8% T: 8%	EUR 23 million	*EUR 100 million*
	SATCOM NG	2023	Ramp-up from 7% to 33%	F: 1.6% T: 1.6%	F: 7% T: 8%	F: 20% T: 21%	EUR 171 million	*EUR 285 million*
	TOTAL			**F: 1.7% T: 1.7%**	**F: 15% T: 16%**	**F: 47% T: 49%**	**EUR 289 million**	**EUR 545 million**

Table 62: Sensitivity – Multilink scenario low case – AU equipage rate and costs

The delta costs between the low case and the base case for the overall airborne investment are – EUR 133 million (289 - 422).

In this multilink approach, only one new IP-based technology is on board on top of the VDL-2 technology. This low-case scenario could constitute an initial step towards the implementation of the ATN-IPS Multilink concept, where the multilink concept is deployed only on the ground, and airlines can choose the on-board equipment they want among a set of agreed and certified technologies. In this approach there is no IP-based automatic switching function provided as the VDL-2 technology is assumed to be ATN-OSI-based only.

Note that there is no change in the ANSP service fees as the OFF-THE-SHELF scenario has not changed compared with the base case and because the service fees for the LDACS and SATCOM NG scenario will be the same regardless of the equipage of the target fleet.

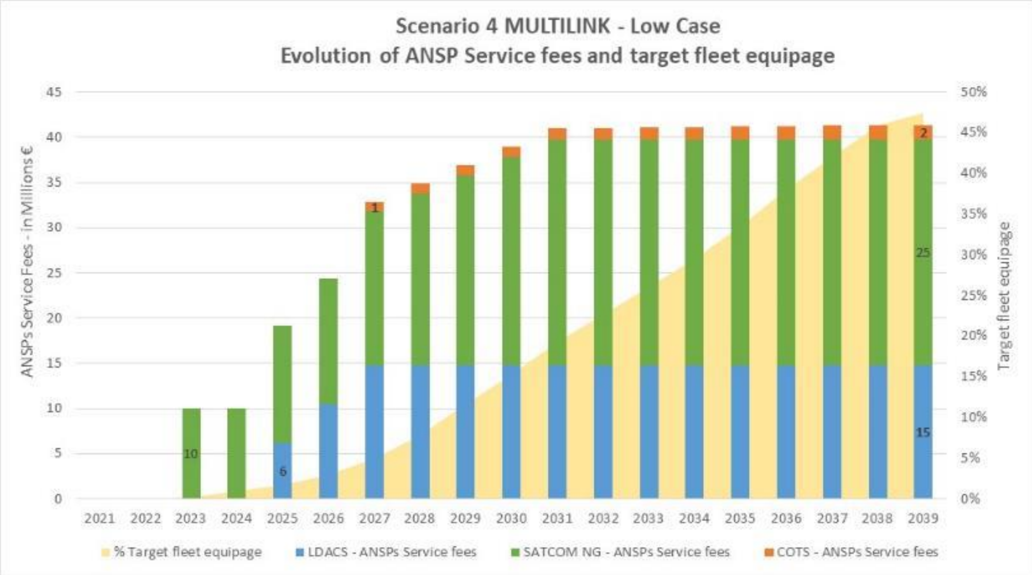

Figure 29 Scenario 4: MULTILINK – Low Case – Evolution of ANSP service fees and target fleet equipage

9.4.1.3 Equipage rate – high case

Table 63 presents the results of the sensitivity analysis for the high case with the following assumptions:

- 75% of new aircraft will be equipped with SATCOM NG technology.
- 75% of new aircraft will be equipped with LDACS technology.
- 75% of new aircraft will be equipped with OFF-THE-SHELF technologies (but these are considered as a complementary technology, not as a primary technology for ATC).

In the high case, it is expected that at the end of the time horizon, new aircraft should be equipped with two new IP-based communication technologies and will benefit from the automatic switching function, addressing the “full” multilink concept. **With such assumptions, at the end of the period (2039) 68% of the target fleet will be equipped but only 39% of this target fleet will be equipped with two IPS-based technologies.**

The delta costs for the overall airborne investment in the multilink scenario is are + EUR 228 million (650 – 422) compared with the base case.

Scenario (F) Target fleet (T) Target Traffic		IOC date	Ramp-up assumption (percentage of new a/c equipped per year)	Equipage rate Target fleet and flights (most flying a/c >FL285)			AUs costs (2021-2039) based on airborne equipage assumptions	*AUs theoretical costs if 100% target fleet equipped in 2039 (8,564 a/c)*
				2025 (d1)	2030 (d2)	2039 (d3)		
MULTILINK	LDACS	2025	Ramp-up from 4% to 75%	F: 0.2% T: 0.2%	F: 13% T: 14%	F: 44% T: 46%	EUR 213 million	*EUR 361 million*
	COTS	2027	Ramp-up from 14% to 32%	F: 0.0% T: 0.0%	F: 4% T: 5%	F: 18% T: 18%	EUR 52 million	*EUR 225 million*
	SATCOM NG	2023	Ramp-up from 15% to 75%	F:3.5% T: 3.6%	F: 17% T: 18%	F: 45% T: 47%	EUR 385 million	*EUR 642 million*
	TOTAL			**F: 3.7% T: 3.8%**	**F: 28% T: 30%**	**F: 68% T: 71%**	**EUR 650 million**	**EUR 1.228 million**

Table 63: Sensitivity – Multilink scenario high case – AU equipage rate and costs

As indicated in Table 64, the ANSP total costs of the service provision of OFF-THE-SHELF technologies will increase by EUR 4 million compared with the base case (EUR 21 million instead of EUR 17 million) and the annual service fees for the OFF-THE-SHELF technologies should go up to EUR 6.5 million per year at FOC.

Scenario		IOC date	Ramp-up assumption (progressive ANSPs equipage on the ground)	Equipage rate on the ground (as a percentage of FOC annual service fees)			Total ANSPs Service fees (2021-2039) based on ground equipage assumption	*ANSPs annual service fees at FOC (for serving the 2039 target fleet)*
				2025 (d1)	2030 (d2)	2039 (d3)		
MULT	LDACS	2025	Ramp-up from 41% to 100%	41%	100%	100%	EUR 209 million	*EUR 14.8 million*
	COTS	2027	Ramp-up from 16% to 35%	0%	20%	35%	EUR 21 million	*EUR 6.5 million*
	SATCOM NG	2023	Ramp-up from 40% to 100%	52%	92%	100%	EUR 352 million	*EUR 25.0 million*
	TOTAL		**Ramp-up from 22% to 91%**	**41%**	**84%**	**91%**	**EUR 582 million**	**EUR 46.3 million**

Table 64: Sensitivity – Multilink scenario high case – ANSP equipage rate and costs

The overall ANSP service fees in the high case MULTILINK/MULTIMODE scenario will increase by EUR 4 million throughout the period 2021- 2039 (582 - 578) and annually by EUR 3.1 million (46.3 - 43.2) at full operational capability (FOC).

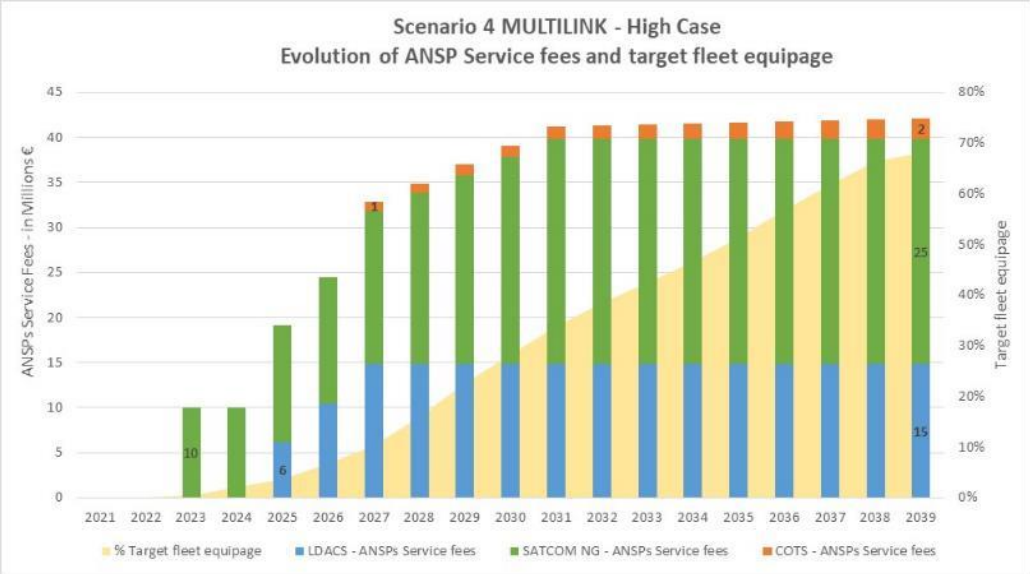

Figure 30 Scenario 4: MULTILINK/MULTIMODE – High Case – Evolution of ANSP service fees and target fleet equipage

As for the base case, only SATCOM NG and LDACS equipage are presented in Figure 30 in order to avoid double counting in estimating the overall fleet equipage.

9.4.1.4 Equipage rate – Highest rate

For the sake of comparison, an additional simulation has been performed compared to the FCI Business Case to assess the cost impact of 'true multilink' at still higher equipage rates.

The following hypotheses have been taken in this case:

- Equipage of new a/c with full multilink concept, i.e. 2 IPS techno on board (considering only the two fastest technologies to deploy: LDACS & SATCOM NG).
- Equipage rate for new a/c (Target at the end of the period): 100% of the new a/c equipped per year for each technonology
- Same ramp up used for both technologies as from 2025 (since LDACS is not ready before 2025). The ramp up is aligned with the slowest ramp up that we used previously (i.e. the LDACS technology).

As a result, at the end of the period, we would have the same number of a/c equipped (5.054 a/c) for LDACS and for SATCOM NG. This represents **59% of the Target fleet equipage in 2039, and 61% of the traffic of the Target fleet** (i.e. the most flying a/c above FL285, which represents 85% of the FL285 traffic).

-

The resulting cost for AU with such assumptions **would be 789 M€, compared to 650 M€ for the high case and 422 M€ for the base case.**

Finally with the same hypotheses above, the maximum theoretical cost of equipping 100% of the Target fleet in 2039 (composed of 8564 a/c) is obtained below.

If we consider that all those a/c should be equipped with both SATCOM NG (100 k€ per a/c) and LDACS (56,2 K€ per a/c) the theoretical cost should be:

8564	100000	856.400.000
8564	56200	481.296.800
		1.337.696.800

i.e. **1.337 million Euros**.

This is to be compared to 1.228 million Euros for the high case, section 9.4.1.3 and 769 million Euros for the base case, section 9.4.1.1.

To understand these figures, Section 9.1.1 shall be reviewed since it highlights the cost differences of single technology deployment vs. multilink, while the present section provides a sensitivity analysis on the costs based on ramp up and equipage rates.

9.5 Main conclusion for each solution scenario

9.5.1 Scenario 1: LDACS – Main conclusion

LDACS is a new ground-based technology currently developed within the SESAR Programme. It is based upon a non-proprietary, open standard that allows for competition (as several manufacturers could make us of it) and it is a highly-scalable technology that offers improved performance and high availability for safety-critical services.

The radio spectrum is a scarce natural resource with finite capacity for which demand is constantly increasing. LDACS supports the concept of integrated Communication, Navigation and Surveillance (iCNS), since it is not only a communication system, but can also provide navigation and surveillance capabilities. This makes LDACS a perfect candidate to make more efficient use of the limited aviation spectrum.

Apart from the datalink services LDACS also supports the exchange of safety critical digital voice communications that will complement and can replace the existing analogue Air traffic control (ATC) service provided by air traffic controllers to aircraft through a given section of controlled airspace, and can provide advisory services to aircraft in non-controlled airspace to ensure safe flight operations.

LDACS introduces unprecedented security to air-to-ground communications, helping stakeholders meet one of their highest priorities at a time when cyberattacks are increasing.

The envisaged transition concept supports legacy protocols and integration into the existing datalink ground infrastructure, and requires no changes to ANSP equipment regardless of the existing implementation method of datalink services (ATN or FANS). The LDACS deployment can be targeted to specific geographic areas if required, and the network can gradually be expanded in line with demand. The existing ground datalink infrastructure will be reused and thus, the existing investments in this infrastructure will be protected, meaning deployment will be quicker, cheaper and involve lower technical and regulatory risks. This approach results in relatively low deployment costs for ANSPs and AUs, since the existing ground networks and the existing footprint on aircraft will be reused.

LDACS standards are planned to be applicable from end of 2024 and the maturity of LDACS shall reach TRL6 by the end of April 2023.

Overall, the LDACS scenario looks very promising. It is an opportunity to get additional capabilities at reasonable costs and minimal risks, which can be a strong positive for Airspace Users and ANSPs, in many geographical areas. It is therefore important that the deployment planning and cost assumptions for LDACS be progressed and matured as a priority in the coming months, in order to enable the technical benefits defined in this report.

9.5.2 Scenario 2: OFF–THE-SHELF – Main conclusion

The OFF-THE-SHELF scenario has the unique particularity to leverage state of the art “at hand” commercial radio infrastructure already deployed and available on the ground, on aircraft and in space, and used to serve the growing needs of connectivity for passengers’ satisfaction and for optimized aircraft and flights operations. Also, it will easily scale up to expand with any break-through public air/ground communications systems that may come in the future, such as the future IMT systems generations (6G, …) and “new space” LEO mega constellations.

Because available commercial radio infrastructures are reused, the OFF-THE-SHELF scenario has the potential to be deployed with relatively low CAPEX and low risk on the invested capital. The scenario is anyway destined be partly deployed, demonstrated, popularized and amortized with the transfer of an increasing proportion of the AOC traffic. Offloading the AOC traffic from legacy safety communication links will be a first essential contribution of this scenario, allowing the regain of some capacity for ATS on these links.

Another key particularity of the COTS scenario is that it is defined only as a complementary approach, and not as an alternative to other safety link technologies: it is not assumed or proposed that COTS links alone could be used to support ATS datalink services in the future. It is rather envisioned that COTS links could be coupled with another safety link to serve as an alternative to equipping the aircraft with a second safety link, when multilink configurations become the most reasonable solution to enhance end-to-end datalink services availability, continuity and capacity. The COTS scenario may complement an aircraft equipped with SATCOM NG, or one equipped with LDACS, and bring the second leg of a multilink configuration. The COTS scenario could also be relevant on aircraft only equipped with VDL2, as a possible way to attenuate VDL2 congestion issues during the transition period before the other scenarios are well deployed at the concerned geographical areas.

With the COTS scenario, the complementary performance is offered without strong (e.g., contractual) guarantees. There is a “best effort” dimension around the enhanced datalink service performance coming with this scenario, which by nature is not at the same level of determinism as what can be obtained with the deployment of a new safety link. The COTS scenario allows “augmenting” the different “single link” configurations (VDL2 only, LDACS only, SATCOM-NG only); but an “augmented VDL2” configuration may offer less guarantees of performance than a LDACS-only, or SATCOM-NG-only single link configuration; and an “augmented LDACS” or “augmented SATCOM-NG” configuration may offer less guarantees of performance than a dual safety links (LDACS and SATCOM-NG) configuration. This limitation is however to be balanced with the opportunity to get extra flexibility and performance at reasonable costs and risks and with the fact that COTS networks are increasingly reliable and show impressive performance (high capacity, low latencies) within usual nominal conditions.

Regarding maturity, the COTS scenario is composed of a mix of very mature elements (the already deployed COTS infrastructure, used for Passengers' and increasingly for AOC communications) and of some new (but proportionally small) additional mechanisms at TRL2. Overall, it can be considered that the maturity barycentre is close to the high TRL. A minimum of 5 years looks however necessary before deployment on ground and certification on first aircraft of the whole solution (usable for ATS datalink) can be completed. Support from the community will be required, and standardisation activities should be started soon to ease stepping over the paradigm change that is the use of commercial spectrum bands for aeronautical safety communications.

Overall, the COTS scenario looks very promising. It is an opportunity to get additional capabilities at reasonable costs and risks, which can be a strong positive for ANSPs and Airspace Users, in many geographical areas, and during datalink services transition periods. It is therefore important that the deployment planning and cost assumptions for LDACS be progressed and matured as a priority in the coming months, in order to enable the technical benefits defined in this report.

9.5.3 Scenario 3: SATCOM NG – Main conclusion

Of all the individual scenarios evaluated into the FCI business case, the SATCOM NG scenario is the scenario offering the most mature, flexible and lowest risk approach.

In terms of maturity, all the required infrastructure is or will be ready soon, i.e., before the end of 2023, well before the i4D mandate and VDL2 capacity issues hit the road:

- Certified Avionics will be available from end of 2022 onwards and provisions can already be purchased by airlines;
- Satellite infrastructure is available now and the service underpinning Iris is operational, including the most advanced cybersecurity available to date for datalink communications;
- Capacity studies have shown that there is ample SATCOM capacity to cope with the most aggressive aircraft equipage ramp-up with no additional investment required on the space segment;
- Certification of the IRIS Service Provider with EASA is on-going and should be completed before end of 2023.

From the flexibility standpoint,

- SATCOM NG can and will provide immediately a pan-European ATN service. The ATN service is easily expandable to other places of the World once the ATN/IPS standard is finalised and adopted;
- Because of the global footprint offered by satellites, all other services (FANS, ACARS, IP, voice) are also available in Europe and globally;
- SATCOM NG can be seamlessly integrated with ANSPs that are already compliant with the DLS IR by simply connecting G/G routers to the Iris service, thereby offering an easy path for ANSPs to migrate to a multilink approach;
- SATCOM NG will support both the ATN/OSI and ATN/IPS standards with no need for airlines to migrate their avionics (if ANSPs can agree with developing proper gateways on the ground);
- Aircraft equipped with suitable avionics will be able to operate both over the oceanic and domestic airspaces, fulfilling all air navigation communication mandates required for FANS 1/A, PBCS, and i4D communications;
- The AOC service will be supported through a single set of avionics which can either communicate using legacy ACARS services or IP connectivity.

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The main issue with the SATCOM NG scenario concerns the investment required by airlines and ANSPs which is sensibly higher than for the other scenarios. While a multi-link approach can help mitigate these costs and provide as well an evolutionary path for VDL2, the following points need to be highlighted:

1. The hardware costs that have been used to estimate the required Airline Capex investment corresponds to a catalogue price of $100K with no volume discount nor price reduction that should happen overtime when OEMs and terminal vendors have amortised their developments. Nevertheless, this represents a substantial investment which needs to be considered carefully and justified in light of both AOC and ATC benefits that Airlines will derive from procuring this equipment, as it is unlikely that the cost of adding a second constellation will reduce the cost of terminals.
2. There will be no Capex investment required from ANSPs as these have already been made by key industry stakeholders with the support of ESA (Inmarsat principally).
3. The OPEX for the ANSPs are also sensibly higher than for the other scenarios and can be explained by several concurrent factors, i.e.,
    a. The need for the industry to recover from its initial investment (as per 2.), in exchange of which, again, European ANSPs will not be required to invest any further Capex
    b. The anticipated operational expenditures required to operate and integrate a certified Satellite service into the European airspace, and
    c. The need to prepare in advance for Satellites replacement and to provision sufficient funding to ensure service sustainability over the very long term (2040 and beyond)
4. In order to ensure these costs are not seen as a show stopper to both airlines and ANSPs:
    a. Airlines should be engaged as early as possible to get their aircraft equipped and given guarantees by ANSPs to obtain the corresponding ATC benefits in a reasonable time (as per existing mandates)
    b. European ANSPs need to consider the service provided by the SATCOM NG infrastructure as a whole and share the cost between them, instead of considering this as an optional service among others

Last but not least, the Iris programme is already evaluating how the Iris service could fulfil the need of UAV BVLOS requirements which is out of scope of the FCI study but could be covered by future studies.

9.5.4 Scenario 4: MULTILINK/MULTIMODE – Main conclusion

In the Community of FCI Stakeholders, the same term "Multilink" is used with no differentiation to address very different scenarios:

- a Short-Term Transitional Scenario[36], in which
    - one of the new Datalink Radio Technologies able to support the Internet Protocol (IP) is equipped on board of aircraft, in addition to the already operational VDL-2 OSI Datalink, but used to transfer only ATN-OSI protocol messages
    - the ATN Protocol Stack implemented by the aircraft CMUs/ATSUs is only the ATN-OSI one
- the Medium-Long Term scenario, scope of the SESAR 2020 PJ.14-W2 Solution 77 "FCI Services" project and of the ICAO WG-I ATN-IPS Standardization, in which
    - the Datalink Radio Access Technologies equipped on board of aircraft are only the IP-enabled ones covered in the Single Link Scenarios chapters of this BC (LDACS, SATCOM NG, OFF-THE-SHELF) – no VDL-2, under the assumption that VDL-2 is not used for ATN-IPS communication
    - the ATN Protocol Stack implemented by the aircraft CMUs/ATSUs is only the ATN-IPS one
- In order to bring clarity and remove any possible confusion, in this Business Case we use two distinct unambiguous terms:ATN-OSI Multilink → the Short-Term Scenario with aircraft equipped with VDLM2 OSI and 1 IP-enabled Datalink Radio Technology
- ATN-IPS Multilink → the Medium-Long Term ICAO & SESAR scenario, with aircraft equipped with only the ATN-IPS Stack and IP-enabled Radio Technologies

The benefits identified and detailed in section 8.7 are going to be available only when the Medium-Long Term ATN-IPS Multilink is deployed and operational.

[36] Note that this is not the only possible transitional scenario, but it is considered in this business case because it is the one for which the cost estimations reported in section 8.6 have been made.

Summarizing them:

- ATN-IPs Multilink is the only scenario, based on the assessment of ICAO and SESAR experts conducted over multiple years, able to comply to the challenging EUROCAE ED-228A Availability Requirements

- ATN-IPS Multilink enables more competition in the flexibility and configurability on board of the different datalinks, allowing AUs more options to choose from for optimization of their operations

- ATN-IPS Multilink supports Performance Based communication routing, which allows to achieve optimized communication routing, enabling not only a solution for the current need of AOC traffic offload, but even more functionality in support of future ATN-B3 services.

- ATN-IPS Multilink is the only concept that provides a standardized framework, which enables the future technologies to be integrated and interoperable

- ATN-IPS Multilink allows leverage of a much broader community of experts worldwide, whereas ATN-OSI is very specific and currently developed only by few companies.

- ATN-IPs Multilink enables a seamless Interoperability among the related datalink technologies

From ANSP perspective, there are two possible deployment scenarios of the ATN-IPS Multilink, which can have impact on their IP network infrastructure or not, depending on whether they want in the future to have full control of ground-based link preferences routing policies, or else whether they prefer to delegate this control to the European DSP and related contracted CSPs:

- In case of desire for full control of link preferences routing policies, the Ground Ground Boundary Routers of the ANSP Domain need to support the GB-LISP Mobility Protocol, which can bring a potential update and/or replacement of existing IP Routers, if they do not already support it

- In case of full delegation to the DSP, no impact is foreseen on the ANSP existing IP Routing infrastructure

From Airspace Users perspective, since the Multilink functionality is being standardized by ICAO as part of the ATN-IPS Baseline (Doc 9896), the deployment scenario of the Multilink coincides with the equipage of ATN-IPS.

Overall, the ATN-IPS Multilink and all its benefits will become available to ANSPs and Airspace Users in a specific region, as soon as the ATN-IPS Stack and at least two IPS-enabled Datalink technologies from the Scenarios 1, 2 and 3, become operational in that region.

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10 Recommendations and next steps

10.1 Conclusions

On the basis of the outcome of previous agreement (see ANC 2011) on the Future Communication Infrastructure and the discussions which took place with the stakeholders during the development of this business case, a certain number of common agreements can be reached:

- The FCI will be used to support both AOC and ATC services in order to limit the amount of equipment that is required on board the aircraft, AOC communication constituting the major part of communication costs and bandwidth usage and ATC communication being more demanding with regard to safety and availability.

- The Future Communication Infrastructure cannot be based on one technology only in order to mitigate the risk of global failure and maintain competition.

- The FCI will be based on a global deployment and will avoid a regional solution/service.

- The new technologies will support the ATN/IPS protocol identified as the only communication protocol that will remain in the future.

- In the case of multilink deployment, gateways and protocol conversion will be performed on the ground to avoid multiple stacks on board the aircraft. The infrastructure will be based on the hypothesis that a maximum of two stacks (dual stack) should be required on board the aircraft to support both AOC and ATC communications.

On the basis of the costs presented in chapter 9, the qualitative assessment of the various scenarios, and the requirements of both ANSPs and airspace users, the following can be concluded:

- A decision on the Future Communication Infrastructure needs to be taken in 2022/2023 as the older technologies (VDL-2) cannot meet future ATC and AOC requirements. The FCI is identified as a main enabler to support ATM automation, and thereby reduce capacity congestion and related delays, the cost of which is estimated at between EUR 1 and 1.3 billion per year (based on 2019 traffic figures). Consequently, with an increase in operating costs that is below EUR 70 million per year (0.7% of the route charges), significant improvements in capacity can be anticipated. These improvements are dependent on the new ATC applications (ATN-B1/ATS-B2) that will be deployed, hence they are difficult to estimate. However, without an efficient data communication infrastructure, no improvements can be expected.

- The four scenarios have different implementation costs, advantages and risks, which are summarised in the following table:

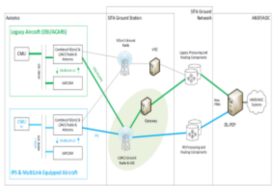
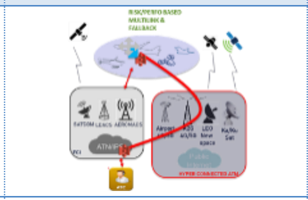
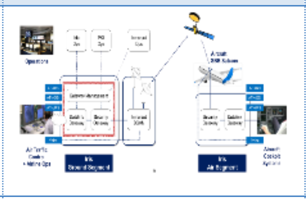
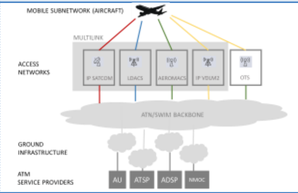
Scenario 1 LDACS	Scenario 2 OFF-THE-SHELF	Scenario 3 SATCOM NG	Scenario 4 MULTILINK/ MULTIMODE
			
Advantages: • Aviation technology • Integrated CNS • ATN/OSI and IPS • Competition	***Advantages:*** • Competition, global service • Expandable to new COTS • Saving investments • Performance	***Advantages:*** • Maturity: Standards and services available • + oceanic • 100% of airspace at start • Global service • Energy-efficient	***Advantages:*** • Competition – evolution • Immediate start of deployment • + oceanic • Performance • Resilience
Risks: • Global endorsement • Spectrum (frequency criteria) • Avionics not yet mature	***Risks:*** • Maturity • Paradigm change • Interoperability • Security	***Risks:*** • Compatibility between SATCOM operators	***Risks:*** • Maturity • + complexity (ground)
Maturity: Medium	***Maturity :*** Low (ATC) High (AOC)	***Maturity:*** High	***Maturity:*** Technology-dependent
AUs CAPEX (ATC + AOC) • EUR 481 million (all new a/c by 2039) • **EUR 284 million** (59% fleet equipage by 2039)	**AUs CAPEX** (ATC + AOC) • EUR 300 million (all new a/c by 2039) • **EUR 70 million** (23% fleet equipage by 2039)	**AUs CAPEX** (ATC + AOC) • EUR 856 million (all new a/c by 2039) • **EUR 513 million** (60% fleet equipage by 2039)	**AUs CAPEX** (ATC + AOC) • EUR 769 million (all new a/c by 2039) • **EUR 422 million** (59% fleet equipage by 2039)
ANSPs OPEX (ATC only) • EUR 209 million (2025 -> 2039) • **EUR 15 million** (2039)	**ANSPs OPEX (ATC only)** • EUR 24 million (2027 -> 2039) • **EUR 8 million** (2039)	**ANSPs OPEX (ATC only)** • EUR 352 million + ? (2023 -> 2039) • **EUR 25 million** + ? (2039)	**ANSPs OPEX (ATC only)** • EUR 578 million + ? (2023 -> 2039) • **EUR 43 million** + ? (2039)

Table 65: FCI-BC results– summary table

Note: The question mark in scenario 3 means that we considered in this business case only one SATCOM NG service provider whereas at least two should normally be required.

Considering the results of the qualitative assessment, namely:

- the need to avoid any monopolistic situation while having a maximum of two protocols on board aircraft (i.e., FANS/ATN/OSI or FANS/ATN/IPS);
- the need to limit the number of different communication services on the ground to maintain interoperability while maintaining reasonable service costs;
- the need to consider only global technologies;
- the need to offload as soon as possible the VDL-2 with the AOC services that could be pushed to off-the-shelf technologies.

Considering the costs of the different scenarios compared with the gains which can be achieved through the deployment of the different technologies, it is concluded that MULTILINK/MULTIMODE is the scenario which reduces the overall technical risk whilst maintaining the competition for the A/G services, for both ATC and AOC. Indeed, the MULTILINK/MULTIMODE scenario:

- offers the benefits of all the scenarios (ramp-up, performance, etc.) whilst slightly increasing the overall costs, mainly for the ANSPs;
- provides the appropriate resilience in order to maintain a high level of availability whilst avoiding single points of failure;
- keeps the door opened for modernisation by offering the possibility to quickly implement new technologies that could potentially be less expensive;
- allows for gradual implementation based on the maturity of the technologies and services, helping to reduce the load on the current VDL-2 infrastructure for both AOC and ATC services;
- provides flexibility for airspace users to choose the technology they believe is the closest to their needs;
- allows the various technologies with high and medium maturity levels for a timely deployment whilst mitigating the VDL2 issues;
- is compatible with a global approach where airspace users will not be mandated a specific technology but rather a performance target.

It is therefore proposed to initiate FCI implementation by taking the following steps:

- Regroup under the Datalink Service Provider (DSP) services the management of the overall data communication infrastructure, i.e., establishing one contract on behalf of a large number of European ANSPs (if not all) for the procurement of the ATC services, the AOC services being provided by the CSPs.
- Gradually implement the new agreed technologies whilst ensuring the interoperability via ground gateways.

The FCI-BC therefore concludes that:

- now is the time to implement new technologies for A/G communication in order to prevent VDL-2 limitations and saturation that will jeopardise the modernisation of the infrastructure, which has an estimated cost of more than EUR 1 billion per year from 2027 onwards;

- the MULTILINK/MULTIMODE scenario is the best approach for risk mitigation and capacity improvement. The MULTILINK/MULTIMODE scenario requires that the ground infrastructure architecture and services evolve towards European services for protocol conversion in order to avoid multitask/multiprotocol implementation on-board new aircraft.

  Given that the MULTILINK/MULTIMODE scenario combines several technologies with different levels of maturity, it is proposed to develop a phased implementation, which could be based on the following main steps:

  - Support the use of off-the-shelf technologies for AOC services in order to offload VDL-2, and start using SATCOM NG for ATC operations while the other technologies (LDACS, OFF-THE-SHELF) are not yet available for ATC services.
  - Gain experience in the use of SATCOM in continental airspace, with the vision that the MULTILINK solution, including ATN/IPS, will be required in the long term.
  - Take a go or no-go decision concerning LDACS based on the FCI-BC results, and mitigate the risk of LDACS remaining a European-only solution.
  - Encourage and support the ‘OFF-THE-SHELF’ scenario initiative, e.g., for a short-term deployment for AOC, and medium-term deployment for ATC, in order initially to offload VDL-2 traffic while other technologies are maturing and being validated.
  - Gain operational experience in and foster the maturation of the use of COTS (SATCOM Ku/Ka, 3-4G) as alternative links for safety, with the vision that a mixture of dedicated/public links could be beneficial in the long term.

10.2 Workshop conclusions

The FCI-BC conclusions summarised in the previous paragraph were discussed with all the stakeholders at a workshop held on 21 February 2022 under the chairmanship of airspace users (A4E) and ANSPs (the DSNA), and involving participants from all relevant European groups (COMSG/JCSP/NDTECH, the FCI Task Force (SESAR PJ.14 partners)).

The following proposed recommendations were discussed at the workshop, in which the SDM expressed the need for further discussion on recommendations c and d.

a) Note and agree that the current VDL-2 communication infrastructure cannot meet the future ATC, AOC and security requirements, hence support the need for the deployment of new A/G communication technologies to meet the requirements of new A/G applications (full ATS-B2 and new AOC applications).

b) Note and discuss the different scenarios on the basis of the cost estimation and the estimated benefits (including trajectory-based operations and related environmental benefits). Note that without deploying new A/G application such as ATS-B2, no benefits can be expected from only the infrastructure enhancement.

c) Recommend to synchronise the deployment of the selected scenario together with the implementation of extended use of ATS-B2 applications (ADS-C, EPP, etc.).

d) Support the further development of the multilink scenario, targeting a communication infrastructure based on ATN/IPS over multiple commercial or aviation-dedicated physical secured links.

e) Invite the JCSP to develop a synchronised FCI and applications (ATS-B2) detailed implementation map and get ANSPs’ commitments before investing in any communication services, except those that could help to reduce the VDL-2 load in the short term.

f) Invite the S3JU, the SDM and the SESAR partners to complement the validation and standardisation of this multilink scenario in order to confirm the capacity and performance of these technologies.

g) Invite EASA to encourage the enhancement of the DLS regulation with a performance-based approach to allow for operation through these new communication links.

h) Invite the European Commission to consider a strong incentive programme, based on the JCSP FCI and ATS-B2 deployment plan to support this critical modernisation step.

i) Support the communication of the proposed solution to global international groups in order to get the buy-in of the other ICAO regions, moving towards a global solution.

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11 References and applicable documents

11.1 Applicable documents

[1] SESAR 2020 Project Handbook v2.0 for W2;

[2] Guidelines for Producing Benefit and Impact Mechanisms;

[3] Methods to Assess Costs and Monetise Benefits .

[4] SESAR 2020 Cost-Benefit Analysis Model[37]

[5] Cost Benefit Analyses – Standard Input

[6] Cost Benefit Analyses – Method to assess costs

[7] ATM CBA Quality checklist

[8] Methods to Assess Costs and Benefits for CBAs

11.2 Reference documents

[9] Common assumptions

[10] European ATM Master Plan Portal https://www.atmmasterplan.eu/

[11] Performance Framework

[12] D5.1.600 - PJ.14-W2-77 TRL6 Overall Concept of Operation FCI Services, Ed 01.01.00

[13] D4.1.700 - PJ.14-W2-61 TRL2 Hyper Connected ATM – Survey of candidate Open Networks, Edition 01.00.00. 15 February 2021

[14] D4.1.610 - PJ.14-W2-61 TRL2 Hyper Connected ATM concept definition v1, Edition 01.01.00. 11 June 2021

[15] EC REG 716/2014 (Pilot Common Projects) (EUR-Lex - 32014R0716 - EN - EUR-Lex)

[16] Performance Review Report 2020 (PRR 2020 – Draft final report (29 March – 23 April 2021))

[17]SESAR2020 PJ14.02.06, Deliverable D7.1.030 TVALR_01_00_02, 10 Oct. 2019, Appendix I.

[37] This reference is no longer accessible from Programme library but it is now available in ATM Performance Assessment Community of Practice.

[18]'The ATS Common DataLink Services ACDLS Governance', presented at COMSG21, 20 Oct. 2022, COMSG - Communication Team - Home (sharepoint.com), https://eurocontrol.sharepoint.com/sites/comm-COMSG/

[19]SESAR2020 PJ.14-W2-77, D5.1.400, TVALR, Dec. 2022

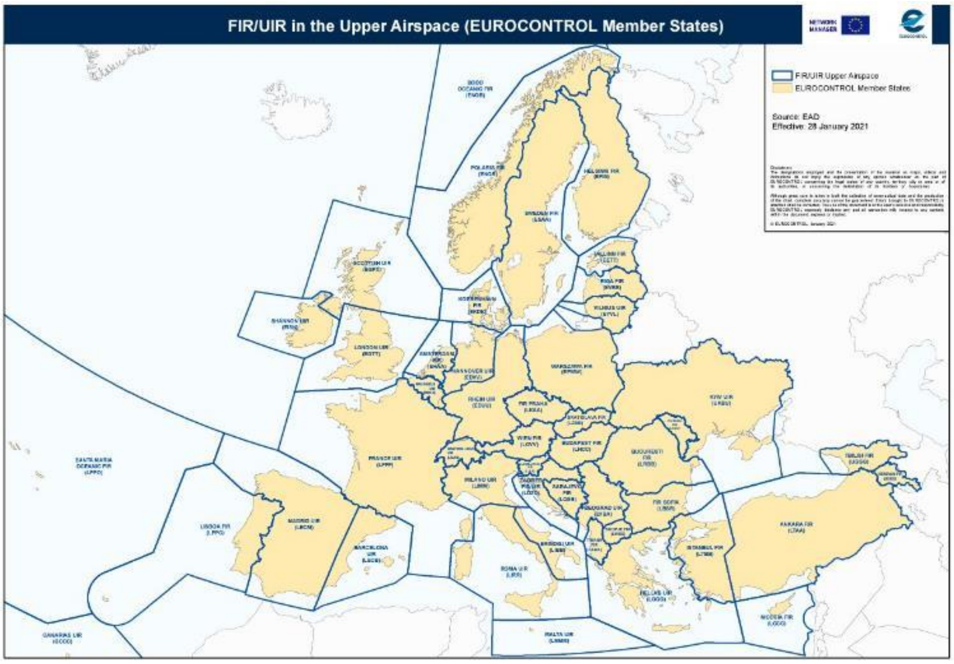
[20]SESAR2020 PJ.14-W2-77, D5.1.950, Contextual Note, Dec. 2022

12 Annexes

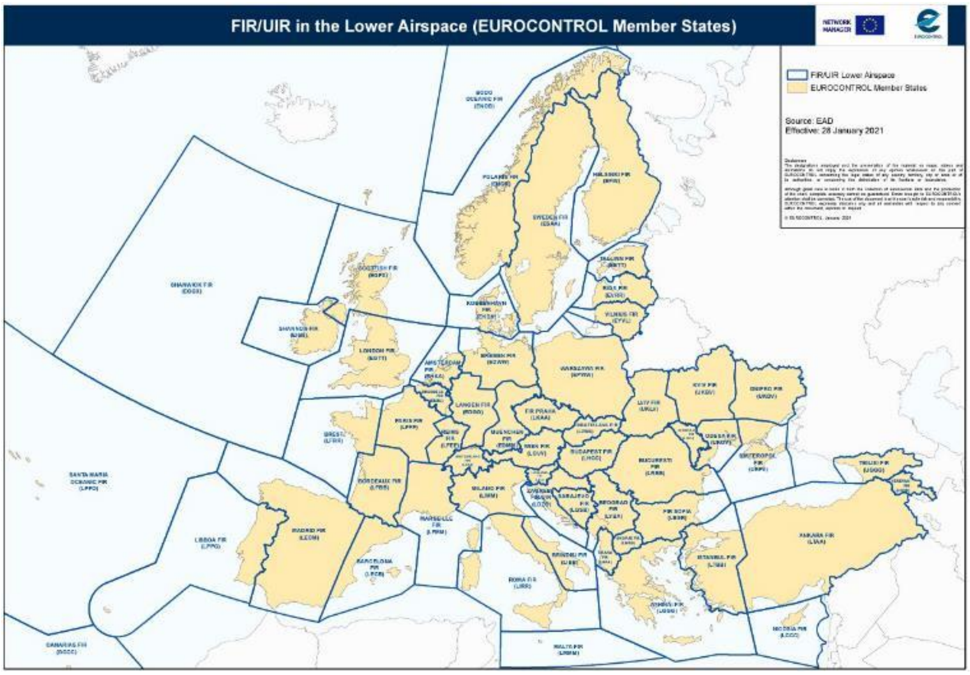
ANNEX A – List of FIRs/UIRs for the EUROCONTROL Member States

Source European AIS database (EAD) - Effective: 28 January 2021

1/ List of FIRs/UIRs for upper airspace

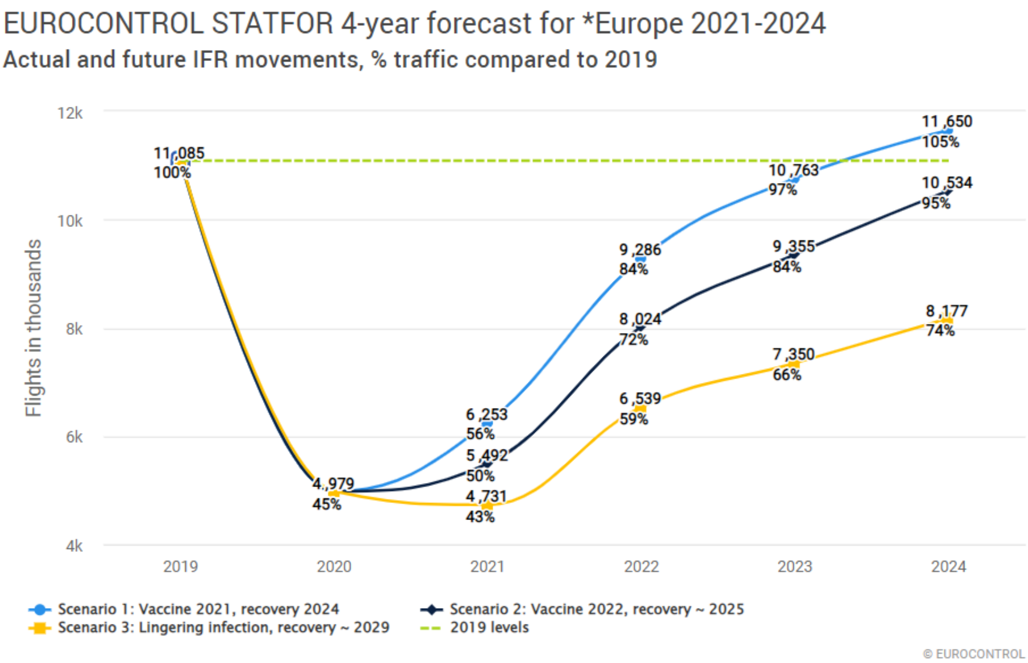


2/ List of FIRs/UIRs for lower airspace



ANNEX B – STATFOR four-year forecast 2021-2024

Forecast issued by EUROCONTROL on 21 May 2021, looking at the possible evolution of domestic and international air traffic in Europe over the years 2021-2024, taking into account the expected evolution of the COVID-19 pandemic.



*Europe = ECAC 44 Member States

This forecast updates the previous version, which was issued in November 2020, with new information related to the expected evolution of the COVID-19 pandemic.

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ANNEX C – Outcome of the FCI-BC workshop (21 February 2022)

Relevant documents of the JCSP and NDTECH meetings shall be consulted for this item.

END OF DOCUMENT-