D2.3 ATMACA Operational Service and Environment Description (OSED)

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Abstract

This document is the Operational Service and Environment Description (OSED) for the Air Traffic Management and Communication over ATN/IPS (ATMACA) Technical Readiness Level (TRL) 2 SESAR project. The document presents an overview of the project, its operational and operating environment, along with use cases related to the solution and key assumptions. All interactions between stakeholders are analysed. Also, differences between operating methods are discussed. In the annexes, the Benefit Impact Mechanisms (BIM) are presented through a series of KPAs (Key Performance Areas) and KPIs (Key Performance Indicators).

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ATMACA

AIR TRAFFIC MANAGEMENT AND COMMUNICATION OVER ATN/IPS (ATMACA)

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1 Executive summary

The ATMACA (Air Traffic Management and Communication over ATN/IPS) project proposes an air traffic management and communication solution for the Aeronautical Telecommunication Network (ATN) based on the Internet Protocol Suite (IPS), supporting the transition from legacy ATN/OSI (ATN/Open Systems Interconnection) systems to a modern, flexible, and resilient digital infrastructure. This OSED (Operational Services and Environment Definition) describes the operational concept, environment, and service enablers introduced by ATMACA, including the rationale for the solution, its deviations from existing Single European Sky ATM Research Programme (SESAR) solution definitions, and the anticipated operational benefits.

ATMACA introduces a robust service framework centred on four key capabilities: Session Management, enabling the persistent and contextual handling of air-ground and ground-ground communications; Connection Management, ensuring reliable, secure, and redundant connectivity for operational continuity; Mobility Management, supporting seamless mobility across users, devices, services, and sessions, enabling uninterrupted operations; and Multilink Communication, optimizing communications through redundancy and load balancing across multiple networks.

The solution also includes the concept of “flight sessions”, which uniquely binds a flight to its communications, contextual data, and historical exchanges—ensuring context continuity through all operational phases and across Air Traffic Control (ATC) units.

The OSED describes in detail the operational environment, including roles (e.g., Air Traffic Controller (ATCos), pilots), CNS/ATS (Communication, Navigation and Surveillance / Air Traffic Services) infrastructure, and applicable regulations. It compares previous and new operating methods, illustrating how ATMACA enhances current practices through four representative use cases: Seamless flight handovers and session transfers between ATCos and sectors; Persistent IP-based communication sessions with enhanced continuity and context; Unified and consistent datalink operations featuring enhanced Human-Machine Interface (HMI) for controllers and pilots; Support for Green Route Operations (GRO) via real-time trajectory optimization and environmental data integration.

Key assumptions are outlined for system interoperability, infrastructure readiness, and standardisation. The validation strategy includes simulations to assess operational feasibility, scalability, and technical maturity.

ATMACA is aligned with SESAR's long-term vision and is interoperable with existing and future infrastructure components, such as System Wide Information Management (SWIM) and Future Communication Infrastructure (FCI), e.g., Proxy Mobile IP version 6 (PMIPv6), GB-LISP. It complements these frameworks by offering a scalable and context-aware platform for future Air Traffic Management (ATM) applications.

Overall, this document defines how ATMACA provides operational and technical enablers to enhance service continuity, support controller mobility, streamline communication handovers, and improve trajectory-based operations, all contributing to a greener and more resilient ATM system.

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2 Introduction

2.1 Purpose of the document

This document presents the OSED for the ATMACA project at TRL2. It provides a comprehensive overview of the operational services, the environment in which they operate, key use cases, and the interactions between involved stakeholders within the SESAR ATMACA framework. An initial draft is issued in Month 8, with the final reviewed version scheduled for release in Month 24, following the completion of validation activities.

This document provides the basis for further ATMACA specifications and assessment covering operational, safety, performance and interoperability requirements related to the SESAR ATMACA project.

This document is complemented by an appendix, which includes the identification of stakeholders and benefit impact mechanisms. The implementation of its content shall present how the SESAR Solution elements contribute (positively or negatively) to the delivery of performance benefits and costs. This is achieved through the identification of a series of Key Performance Areas (KPAs) and Key Performance Indicators (KPIs).

2.2 Scope

The main scope of this document is to detail the operational concept for the SESAR Solution ATMACA, as well as to define the operational service and environment. Moreover, this OSED provides the basis for identifying the requirements that characterise the solution. These requirements will address safety, performance, and operational aspects as well as the interoperability considerations related to the SESAR ATMACA project.

2.3 Intended readership

The intended audience for this document primarily consists of all the partners involved in the ATMACA project.

External to the SESAR project, other stakeholders are to be found among:

- ATM Stakeholders:
- Air Navigation Service Providers (ANSPs).
- ATM infrastructure and equipment suppliers.
- Aircraft manufacturers and equipment suppliers.
- Airspace users.
- Airport owners/providers.
- Affected National Supervisory Authorities (NSAs).
- Affected staff organisations.
- Regulatory and standardisation organisations: European Aviation Safety Agency (EASA), International Civil Aviation Organisation (ICAO), European ATM Standards Coordination Group (EASCG), EUROCONTROL, European Organisation for Civil Aviation Equipment (EUROCAE).
- Entities involved in ATN research.

- Other SESAR solutions partners.

2.4 Background

The OSED document describes the operational service and environment, and the specific activities and interactions between stakeholders for the SESAR Solution ATMACA.

Aeronautical communication networks face unique challenges due to their dynamic, high-mobility environments. Aircraft frequently transition between diverse coverage areas, networks, ground stations and communication technologies, including satellite and radio links. These transitions must meet stringent safety, reliability, and performance requirements, making robust communication systems essential for supporting operational services.

ATMACA is an ATM solution proposing a scalable framework-based air traffic management and communication solution over ATN/IPS, integrating a specialized datalink [15] communication protocol, advanced operational applications (including Context Management Application (CMA)), an enhanced HMI to provide efficiency, reliability, situational awareness, and green route operations in air traffic control and management. ATMACA enables single-session operations, offering multiple applications.

The background for the ATMACA solution is sustained by the review of current and planned ATN IP-based communication networks and protocols that support aeronautical applications and services. This review has been carried out in the project deliverable D2.1 “Review of Current and Future ATM Communication Networks” [30], and covered the following aspects:

- The ATN evolution from OSI to IPS;
- The main aeronautical communication data link technologies;
- The new IP-based system, FCI [19], designed under the SESAR scope to support ATN/IPS multilink capability and complete mobility between different data link systems to improve efficiency, capacity, safety, and minimize environmental impact;
- The aeronautical data link applications and services;
- The analysis of mobility management protocols and their use in Air Traffic Management, highlighting their importance for ensuring session continuity as aircraft move between different access networks;
- The data link selection problem in a multilink environment, where multiple access networks are available;
- The identification of limitations of the current mobility solutions and the discussion of open problems and challenges.

2.4.1 The mobility management challenge

The most relevant aspect for the ATMACA background is mobility management [29], particularly in a multilink environment inherent to the Aeronautical Telecommunication Network IP-based communication networks, as a critical aspect for SESAR operation. A multilink environment allows aircraft to connect to multiple communication data link channels, such as satellite, terrestrial radio, and cellular networks, either simultaneously or in succession. In this environment, one of the primary challenges in the ATN is related with the mobility, that is ensuring uninterrupted communication between airborne avionics and ground-based systems while managing data exchange across diverse communication pathways.

As aircraft travel between ANSP networks, data link communication technologies must support a handover mechanism that enables seamless transitions between different access networks based on availability, continuity, and the cost of the data link interface.

Mobility management is a key feature of the ATN/IPS to ensure service continuity and maintain the connection during handovers. Handover delay, defined as the time taken to re-establish a connection, along with packet loss, latency, and signalling overhead, are critical metrics to assess the handover performance.

The IP protocol was not originally designed to support mobile nodes, which presents challenges for mobility management. Consequently, mobility will remain a significant consideration in future aeronautical communication networks.

Two primary mobility challenges are identified in aeronautical networks: intra-domain mobility, where the aircraft remains within the same network domain, and inter-domain mobility, where it transitions between different network access providers. These mobility scenarios may involve either horizontal handovers, where the same access technology is used, or vertical handovers, where the aircraft switches between different technologies.

The ATN must guarantee seamless data transmission, regardless of the aircraft's position, network coverage and availability, or the data links in use. Beyond maintaining connectivity across multiple links, mobility management in the ATN must address three critical aspects: user, session, and service mobility. These three aspects are critical for supporting SESAR operations.

Understanding the different levels of mobility and aligning their capabilities with specific application requirements is essential to fulfilling use cases and mobility scenarios. As shown in Table 1, mobility tiers define the extent and type of mobility that must be supported.

MOBILITY TIERS	
1. TERMINAL MOBILITY	Allows a mobile client to maintain continuous network connectivity regardless of changes in its physical location.
2. USER MOBILITY	Ensures that users retain a consistent identity and access personalized services across various devices or locations.
3. SESSION MOBILITY	Enables active communication sessions to continue uninterrupted as a user switches between devices or as a device moves across different networks.
4. SERVICE MOBILITY	Ensures that users can access the same application services across different networks and devices.

Table 1: Mobility Tiers

User mobility ensures that users retain a consistent identity and access personalised services across various devices or locations. Session mobility enables active communication sessions to continue uninterrupted as a user switches between devices or as a device moves across different networks. Service mobility ensures that users can access the same application services across different networks and devices. Terminal mobility allows a mobile client to maintain continuous network connectivity regardless of changes in its physical location.

Table 2 lists key mobility management pre-requisites. To fulfil them, the technical, functional, and operational needs of systems or devices that depend on consistent and reliable connectivity during movement must be addressed.

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MOBILITY MANAGEMENT PRE-REQUISITES	
1. REGISTRATION	The network must be aware of the existence and location of the MN
2. CONFIGURATION	The MN must update its IP address dynamically as it moves between networks
3. DYNAMIC ADDRESS BINDING	The MN maintains a constant identifier regardless of its current network attachment point
4. LOCATION MANAGEMENT (IP REACHABILITY)	The network must continuously update location databases

Table 2: Mobility Management Pre-Requisites

2.4.2 Promising protocol to address the mobility challenge and its limitations

The most promising protocols to address mobility challenges are PMIPv6 (Proxy Mobile IPv6), Ground-based Locator/ Identification (ID) Separation Protocol (GB-LISP) and Session Initiation Protocol (SIP) [33]. All of them have been analysed in detail in a previous deliverable (D2.1) to identify the limitations and advantages of the state of the art regarding mobility management [30].

Current protocols, such as PMIPv6 and GB-LISP, while offering certain advantages, have limitations that hinder their effectiveness in the dynamic and demanding aviation environment. Nonetheless, among its benefits, GB-LISP separates locators and identifiers, making it well-suited for managing mobility across different network domains, such as when aircraft move between networks of different providers. In contrast, PMIPv6 is better suited for intra-domain mobility, enabling seamless handovers within a single network without changing the mobile node's IP address. While GB-LISP can manage some intra-domain mobility, it is optimised for inter-domain scenarios.

PMIPv6 is a network-based solution for local mobility management standardised by the Internet Engineering Task Force (IETF) in Request for Comments (RFC) 5213. Research from the SESAR Project recommends PMIPv6 for intra-domain mobility and GB-LISP for inter-domain mobility. However, it is not exempt from limitations. In this protocol, the aircraft (mobile node) is assigned a unique IP address as it moves within the same network service domain, allowing for seamless handovers without requiring mobility signalling from the aircraft itself. This approach reduces signalling overhead and handover delays, as signalling occurs over wired links in the ground infrastructure. While PMIPv6 is effective for managing local mobility within a single domain, it is not suitable for inter-domain mobility, as it lacks support for multilink capabilities and load balancing at the edge of the ATN/IPS core network. Additionally, although PMIPv6 reduces handover delay and mobility signalling overhead compared to host-based protocols, it may result in increased end-to-end delay.

The original reason for developing Locator/ID Separation Protocol (LISP) was the routing scalability problems in the Internet core routing. According to the IETF RFC 6831, a key concept of LISP is that end systems (hosts) operate the same way they do today. Hosts' IP addresses for sending and receiving packets do not change. LISP is primarily a routing and addressing protocol that separates endpoint identity and location, helping improve network scalability and efficiency.

LISP is a network architecture and a collection of "map-and-encapsulate" network-layer protocols developed by the IETF "LISP Working Group," as specified in RFC 6830. LISP splits IP addresses into separate numbering spaces: Endpoint Identifiers (EIDs) and Routing Locators (RLOCs), which are dynamically mapped to manage mobility and routing. Splitting EID and RLOC functions yields several advantages, including improved routing system scalability, improved multihoming efficiency, and ingress traffic engineering, as well as making scalability and security capabilities available. [30]

The SIP was standardised as IETF RFC 3261. It is an application-layer control protocol that establishes, modifies, and terminates multimedia sessions or calls. As applied to ATN infrastructure, it facilitates seamless communication between air and ground operations. One key reason for adopting SIP in aviation is its ability to support flexible, real-time communication across different service providers and systems, enhancing efficiency and safety. While PMIPv6 handles mobility locally by enabling devices to roam within a network domain without changing IP addresses, SIP [28] provides global mobility and session management [33].

As a summary, Table 3 presents the main limitations regarding the different mobility layers and the main limitations of the protocols.

<table>
<tr><th></th><th colspan="3">Protocols</th></tr>
<tr><th></th><th>PMIPv6</th><th>GB-LISP</th><th>SIP</th></tr>
<tr><td>Limitations General</td><td colspan="2">Limited Session and Connection Management: These protocols focus on mobility management, primarily ensuring devices maintain IP connectivity as they move. However, they lack native support for session management (e.g., the establishment, modification, and termination of communication sessions) and connection management (e.g., maintaining transport-layer connections), necessitating the use of additional protocols like SIP. This added complexity introduces overhead and can lead to higher latency during transitions.
Security Concerns: While security features can be implemented as add-ons, neither PMIPv6 nor GB-LISP provide inherent security mechanisms. This makes these protocols vulnerable to various cyber threats such as data interception and denial-of-service (DoS) attacks.</td><td>Signaling Overhead and Latency: SIP’s text-based signaling introduces significant overhead, leading to delays during session setup and handovers. This is especially problematic for real-time communication, where low latency is critical for services like air traffic control.
Limited Quality of Service (QoS) Support: SIP’s QoS capabilities rely on the underlying network, which can make it difficult to guarantee the quality of service for critical aviation applications. This is a significant limitation in environments where network conditions can vary rapidly.
Security Vulnerabilities: SIP is susceptible to various security attacks, including DoS, eavesdropping, and spoofing, which can compromise the integrity and confidentiality of communications. Aviation environments demand higher security assurances to protect against such threats.</td></tr>
<tr><td>User Mobility limitations</td><td colspan="2">These protocols primarily focus on terminal or network-based mobility, which ensures that devices (or nodes) maintain IP connectivity during movement. However, they lack inherent support for user mobility, which allows users to maintain a consistent identity and access personalized services across different devices and networks. This limitation means that, although devices can remain connected, user-specific settings and services may not seamlessly transition between devices and networks.</td><td>SIP supports user mobility at the application layer by enabling users to be reachable through a consistent SIP Uniform Resource Identifier (URI) across multiple devices and networks. This is achieved through dynamic registration mechanisms that update the user's location in real time. However, user mobility in SIP depends heavily on timely and reliable registration updates, and it lacks built-in support for lower-layer mobility mechanisms. As a result, it may experience delays in reachability or message delivery, especially in dynamic or intermittent connectivity scenarios common in high-mobility environments. -</td></tr>
<tr><td>Session Mobility limitations</td><td colspan="2">While these protocols handle terminal mobility, their support for session mobility is limited. In high-mobility scenarios, this can lead to disruptions in active communication sessions during handovers.</td><td>SIP supports session mobility at the application layer, allowing sessions to continue during network transitions. However, it suffers from signaling overhead and latency issues, which can degrade the quality of service, especially during handovers in high-mobility environments.</td></tr>
<tr><td>Service Mobility limitations</td><td>-</td><td>-</td><td>SIP enables service mobility, which ensures continuous access to services across different networks and devices. This is a key advantage in environments requiring seamless service transitions. However, SIP’s performance can be compromised in high-mobility environments due to its signaling overhead and limited built-in QoS capabilities, which may affect service quality during rapid network changes.</td></tr>
</table>

Table 3: State of the art limitations

2.4.3 Takeaways for the ATMACA solution

The insights gathered from this review have helped to identify state-of-the-art mobility solutions and their limitations. These challenges and limitations are considered in the ATMACA solution design and development, and in the identification of use cases and operational improvements that ATMACA will make possible.

To address the mobility challenge in the multilink environment inherent to the Aeronautical Telecommunication Network IP-based communication networks, the ATMACA solution should incorporate the following features:

- **Integrated Session and Connection Management:** Native support for session and connection management would reduce complexity and latency by avoiding reliance on separate protocols. This would ensure that sessions are maintained across transitions without the need for external mechanisms.
- **Integrated Context and Context Management (CM):** The framework should integrate context information associated with a session. It will include data from the flight plan, airspace structure, applications and previous communications. This allows all actors during the operation to access and update this information, making it easily available throughout the flight, enhancing situational awareness for ATCos and pilots.
- **Robust QoS Mechanisms:** Built-in QoS capabilities are essential to guarantee consistent service quality, especially for time-sensitive applications.
- **Enhanced Security:** The protocol must include strong, native security features to protect against cyber threats, ensuring data confidentiality, integrity, and authentication across communication channels.
- **Seamless Mobility Management**: Efficient mobility management is required to handle both user and session mobility. The protocol should allow users to maintain a consistent identity across devices and ensure that active sessions remain uninterrupted across devices or network transitions. Furthermore, it should enable service mobility, allowing seamless access to services regardless of network changes, while maintaining service quality.
- **Flexibility and Adaptability:** The new protocol must be flexible enough to adapt to evolving network technologies and changing operational requirements in aviation, ensuring scalability and futureproofing.

To address these features, the ATMACA project will introduce a datalink communication protocol specifically designed to address the unique demands of the ATN. Inspired by the Diameter Base Protocol (RFC 6733) and the SIP (RFC 3261), the ATMACA protocol adopts and extends their features to suit the complexities of aeronautical scenarios.

The ATMACA protocol draws inspiration from SIP's flexible session management capabilities while addressing the unique requirements of aeronautical communication. It also incorporates Diameter's mutual authentication to ensure both communicating entities verify each other before data exchange, Role-Based Access Control (RBAC) to restrict access based on predefined role, and context-based authorisation to dynamically adjust permissions based on operational conditions. The use of Attribute-Value Pair (AVPs) serves as a model for structured data handling and extensibility, ensuring adaptability to evolving technologies.

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The ATMACA protocol builds upon the conceptual strengths of both SIP and Diameter and extends them to provide seamless session continuity, robust connection management, and comprehensive mobility support at the application layer.

2.5 Structure of the document

This document has the following structure:

Chapter 1 (Executive summary): contains a brief description of the document.

Chapter 2 (Introduction): contains the purpose and scope of this document. Further significant information, such as a glossary of terms and a list of abbreviations, has been included at the end of the chapter.

Chapter 3 (Operational Service and Environmental Definition): describes the detailed concepts of the ATMACA Solution. Technical and procedural enablers, as well as different endorsement strategy variations, are worked out and mapped to potential use cases of the proposed ATMACA project. The differences from the current operating method are described.

Chapter 4 (Key assumptions): lists the project's key assumptions.

Chapter 5 (References): references and applicable documents.

Appendix A: identifies stakeholders and benefit impact mechanisms applied to this solution.

2.6 Glossary of terms

Term	Definition	Source of the definition
Air Traffic	All aircraft in flight or operating on the manoeuvring area of an aerodrome.	ICAO Annex 11 - ATS
Air Traffic Control Service	A service provided for the purpose of: Preventing collisions: 1) between aircraft, and 2) in the manoeuvring area between aircraft and obstructions. Expediting and maintaining an orderly flow of air traffic.	EU 2015/340
Air Traffic Controller	A person authorized to provide air traffic control services.	EUROCONTROL ATM Lexicon
Air Traffic Management	The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management – safely, economically and sufficiently – through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.	ICAO 4444 - ATM

Air Traffic Service	A generic term meaning variously, flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service).	ICAO Annex 11 - ATS

Table 4: Glossary of terms

2.7 List of acronyms

Acronym	Name
ACC	Area Control Centre
ADS	Air Data System
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
ADSP	Air Traffic Data Service Provider
AMAN	Arrival Management
ANSP	Air Navigation Service Provider
AOC	Airline Operations Centre
API	Application Programme Interface
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATMACA	Air Traffic Management and Communication over ATN/IPS
ATN	Aeronautical Telecommunications Network
ATSP	Air Traffic Services Provider
ATSU	Air Traffic Services Unit
AVP	Attribute-Value Pair
BIM	Benefit Impact Mechanisms
CEF	Cost Efficiency

CM	Context Management
CMA	Context Management Application
COTS	Commercial Off-The-Shelf
CP	Contingency Plan
CNS	Communication, Navigation and Surveillance
CPDLC	Controller Pilot Data Link Communications
CSP	Communication Service Provider
DAC	Dynamic Airspace Configuration
DLIC	Datalink Initiation Capability
DIGI	Digitalisation
DoS	Denial-of-Service
E-AMAN	Extended Arrival Manager
EASA	European Aviation Safety Agency
EASCG	European ATM Standards Coordination Group
ETA	Estimated Time of Arrival
EUROCAE	European Organisation for Civil Aviation Equipment
EC	European Commission
EFB	Electronic Flight Bag
EID	Endpoint Identifier
EU	European Union
EUROCONTROL	European Organisation for the Safety of Air Navigation
FCA	Flight Centric Airspace
FCDI	Future Connectivity and Digital Infrastructure
FCI	Future Communication Infrastructure
FL	Flight Level
FIR	Flight Information Region

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FMS	Flight Management System
FRA	Free Route Airspace
GB-LISP	Ground-based Locator/ID Separation Protocol
GNSS	Global Navigation Satellite System
GRO	Green Route Operations
GPS	Global Positioning System
HMI	Human Machine Interface
HP	Human Performance
ICAO	International Civil Aviation Organization
ID	Identification
IETF	Internet Engineering Task Force
IFR	Instrumental Flight Rules
IPS	Internet Protocol Suite
IRS	Inertial Reference System
KPA	Key Performance Area
KPI	Key Performance Indicator
NSA	National Supervisory Authorities
OCC	Operations Control Centre
OSED	Operational Service and Environment Definition
OSI	Open Systems Interconnection
PMIPv6	Proxy Mobile IP version 6
PRD	Predictability
QoS	Quality of Service
RBAC	Role-Based Access Control
RFC	Request for Comments
RLOC	Routing Locator

SATCOM	Satellite Communications
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme that defines the Research and Development activities and Projects for the SESAR Joint Undertaking (Agency of the European Commission).
SIP	Session Initiation Protocol
SWIM	System-Wide Information
TEFF	Flight time
TMA	Terminal Manoeuvring Areas
TRL	Technical Readiness Level
URI	Uniform Resource Identifier
VC	Virtual Centres
VFR	Visual Flight Rules
VHF	Very High Frequency
WP	Work Package
XMAN	Extended Arrival Management

Table 5: List of acronyms

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3 Operational service and environment definition (OSED)

3.1 SESAR solution 0513: ATMACA - Air Traffic Management and Communication over ATN/IPS: a summary

Aeronautical communication networks encounter distinct challenges due to the highly dynamic and fast-moving nature of aviation environments. As aircraft move, they continuously switch between various coverage zones, network infrastructures, ground stations, and communication methods such as satellite and radio links. These handovers must adhere to strict standards for safety, reliability, and performance, highlighting the need for resilient communication systems to ensure seamless operational services.

The ATMACA project proposes an air traffic management and communication solution for the Aeronautical Telecommunication Network based on the IPS, which integrates the following into a single and flexible framework:

i) specialised datalink communication protocol (ATMACA datalink protocol),
ii) advanced foundational applications, including CMA,
iii) advanced mobility solutions, including “Terminal”, “Session”, “User” and “Service” Mobility,
iv) enhanced Human-Machine Interface (HMI),
v) new ATM datalink applications, including GRO. The ATMACA protocol aims to provide a reliable, scalable, and secure communication tailored to the unique demands of aeronautical environments. The vision for the ATMACA project is to establish a unified and extensible datalink communication protocol that can support various aeronautical communication needs, as well as advanced ATM capabilities and operational data exchange.

The ATMACA datalink communication protocol represents an innovative approach to addressing the unique communication challenges of aeronautical environments (interrupted Controller Pilot Data Link Communications (CPDLC) communication during airspace handovers, inability of controllers to transfer active tasks to backup devices smoothly, loss of service context during Data Authority Transfers, etc…). It seeks to address critical challenges, including mobility, multilink connectivity, and session continuity, ensuring seamless and efficient communication for operational services.

ATMACA datalink communication *protocol encompasses solutions for session management*, ensuring efficient establishment, maintenance, and termination of communication sessions; *connection management*, providing secure, reliable, and redundant connectivity; *mobility management,* enabling seamless handovers and uninterrupted services across networks; and *multilink communication*, supporting load balancing, redundancy, and optimised performance.

Designed with advanced features for session management, mobility management, and connection management, the ATMACA protocol enables seamless, secure, and reliable communication across high-mobility scenarios. Its modular and extensible architecture supports interoperability with existing systems while providing a foundation for future advancements in aviation communication.

ii) Advanced operational applications. The ATMACA project guarantees interoperability with Future Connectivity and Digital Infrastructure (FCDI) components (e.g., PMIPv6, GB-LISP) but moreover, complements the FCDI project by serving as a CMA that provides session management, mobility management, and connection management for aeronautical applications.

In the ATN/stack, CM is not implemented as a standalone, specific application like it was within the ATN/OSI architecture. Instead, its functions are either distributed across other applications or handled through standardised IP-based protocols and services that fulfil the context management requirements in the ATN/IPS environment. ATMACA complements FCDI by addressing this gap, enabling seamless context management for ATM applications. The ATMACA solution introduces a CMA that enables seamless interaction between different aeronautical applications and the underlying protocol capabilities. The CMA acts as a middleware, managing session continuity, connection stability, and mobility support.

Additionally, the ATMACA solution provides an interface for the development of new applications that can leverage protocol functionalities through context-based operations. By using this middleware, developers can create scalable and efficient ATM applications that enhance air traffic management and communication services without modifying the core protocol.

iii) Advanced mobility solutions. Moreover, while FCI (Future Communications Infrastructure) [20] ensures terminal mobility and session continuity through IP reachability, the ATMACA solution enhances and complements these capabilities by offering, not only terminal mobility and session continuity through IP reachability, but also advanced mobility solutions not yet available in SESAR, including:

- **Terminal mobility:** Terminal mobility ensures that mobile clients maintain seamless connectivity and session continuity as they move across regions or domains within the aeronautical network. That is, it allows aircraft to maintain continuous network connectivity regardless of their physical location changes.
- **Session mobility**: Session mobility ensures seamless continuity of a mobile client's session when it transitions between stationary clients (ATCos). That is, it ensures that ongoing communication sessions persist without interruption as they move across different network environments.
- **User mobility**: User mobility ensures seamless continuity of roles and sessions when users move between workstations or devices within the network. That is, it allows users (e.g., pilots, crew) to access network services consistently, regardless of their movement between terminals or devices.
- **Service mobility**: Service mobility ensures that application services remain accessible and operational during mobility events or failures. That is, it ensures that the services remain accessible and operational, even when underlying network connections change.

iv) Human-Machine Interface. ATMACA HMI enhances user interaction, providing intuitive control and situational awareness for air traffic operators.

v) New GRO datalink application. ATMACA advances upon previous developments and uses its additional capabilities and the provided context information for advanced route optimisation. Real-time weather information, such as temperature and wind, is sent to a ground station and other aircraft and used to increase the accuracy of the trajectory prediction. This allows to reduce the time uncertainty when calculating the Estimated Time of Arrival (ETA), improving efficiency and reducing fuel consumption and environmental impact.

By combining these elements, the ATMACA solution delivers a scalable and future-proof system tailored to the evolving needs of aeronautical communication networks. It provides a scalable and adaptable foundation for integrating existing aeronautical applications and SWIM-enabled applications into ATN/IPS, while also supporting the development of new datalink applications. The ATMACA solution ensures secure, reliable, and efficient communication, while its framework-based approach, enabled by the CMA, allows for seamless application integration and interoperability. By ensuring efficiency, reliability, and enhanced situational awareness, the ATMACA solution enables the seamless evolution of air traffic operations within the SESAR framework.

ATMACA's framework provides new capabilities such as context, connection, session and mobility management, which will simplify communications and provide extended flexibility for all network users (ATCos, pilots, airports, airlines, etc).

- **Connection Management** is a critical capability within the ATMACA solution. It ensures a secure, reliable connection across the aeronautical network, supporting interactions between aircraft, controllers, and application servers. It manages network connections, ensuring stability, and optimising data transfer. It focuses on establishing, maintaining, and recovering connections to support uninterrupted communication between aircraft, controllers, and application servers. It provides secure and persistent connections, optimised multilink connectivity, aircraft-to-aircraft communication and seamless handover support.

- **Session Management** is a cornerstone capability of the ATMACA solution. It maintains a stable, continuous and active session throughout all flight phases. This allows for the creation and manage the session required by aeronautical applications by dynamically updating and adjusting session parameters and providing continuous tracking of session states, link performance and connectivity quality. It handles the establishment, maintenance, and termination of communication sessions. It is designed to ensure seamless communication transitions as aircraft move across different network domains and operational sectors. It provides session, user, service and terminal mobility.

- **Mobility Management** is a key capability of the ATMACA solution. It ensures seamless communication transitions as aircraft move across network domains and operational sectors, handling dynamic routing and session handovers. It supports four types of mobility: session, user, service and terminal mobility. This capability handles dynamic challenges such as session handovers, network reconfiguration and provides inputs to maintain uninterrupted communication during mobility events.

- **CMA** acts as a middleware, enabling and managing the three previous capabilities. It is the foundational capability, as it acts as an integrative framework for the above-mentioned capabilities. It maintains, updates and synchronises operational context to enable efficient and integrated communication with seamless interaction between different aeronautical applications and the underlying protocol capabilities.

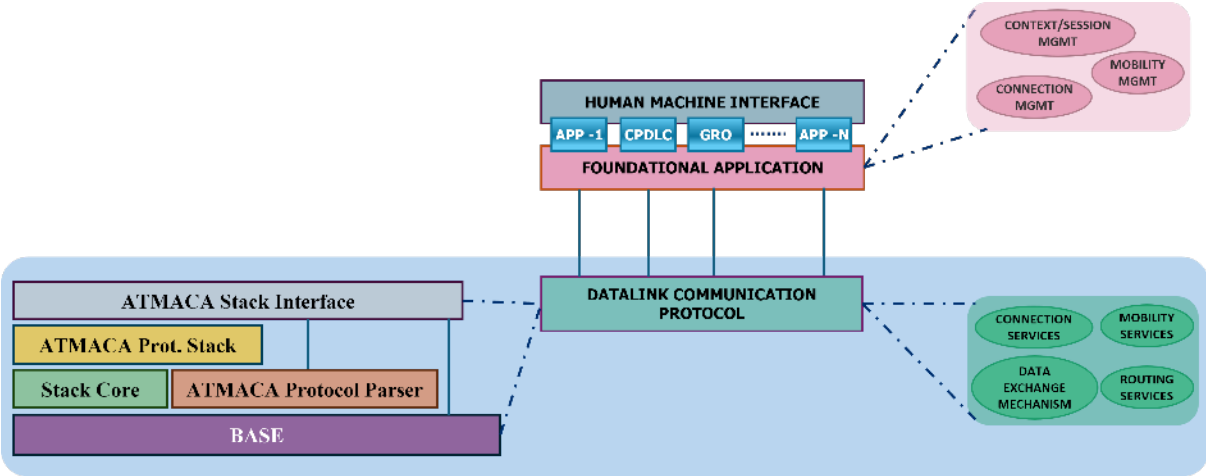

Figure 1: ATMACA solution conceptual architecture

Figure 1 presents the conceptual architecture of the ATMACA solution. As shown in the figure, the datalink communication protocol is the foundation of the ATMACA solution. On the right side of the datalink protocol box, key services implemented by the protocol are indicated, specifically the connection services, mobility services, routing services and data exchange mechanism. On the left side of the datalink protocol box, the software implementation of the protocol is indicated, including the base protocol, stack core and protocol parser, the protocol stack and the stack interface.

On top of the datalink protocol, some foundational applications of the protocol are indicated, such as connection management, context management application, session management and mobility management. The CMA acts as a middleware, bridging network protocols with higher-layer applications. By abstracting protocol functionalities, managing session continuity, and adapting dynamically to network conditions, the CMA enables efficient communication across the system. These capabilities are achieved through ATMACA nodes, which implement the protocol and interact with both the middleware and external network entities.

The higher-layer applications (ATM applications providing air traffic operational services, such as CPDLC, DLIC (Datalink Initiation Capability), GRO, or any other operational service built upon datalink communication) are external to the protocol itself. They are connected and interact with the ATMACA solution through the Application Programme Interface (API) provided by ATMACA for the development of new applications. This interface allows developers to create scalable and efficient ATM applications that enhance air traffic management and communication services without modifying the core protocol. Finally, on top of the higher-layer application, the advanced interactive HMI is indicated.

ATMACA solution uses a modular architecture for the communication protocol, with each layer addressing a specific functionality. The reference architecture of ATMACA is presented in Figure 2. The middleware layer ensures continuity across handovers, while the transport layer provides secure and reliable data transmission. This middleware role is crucial to achieving the integration, scalability, and reliability needed in modern ATM.

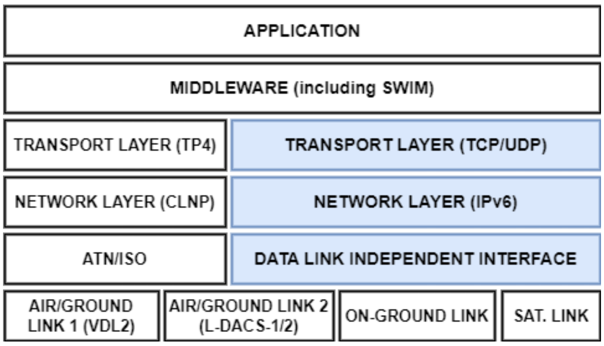

Figure 2: Reference Architecture for ATMACA protocol

The ATMACA network architecture uses a layered structure where software-defined nodes are key elements responsible for managing communication and operational tasks. These nodes include:

- **ATM Server**

The ATM Server acts as the central hub of the system, managing critical network operations, user provisioning, registration, authentication, and authorisation. It also provides information and allocates resources according to airspace structure and operational roles.
The ATM Server is responsible for performing authentication and registration of clients and agents (all nodes) upon requests. Moreover, it stores and manages airspace sectors and facilities information. That is, the ATM Server is a provision server.

After registration, it provides the ATC Agent with sectors and facilities information through the registration process.

- **Application Servers**

Deliver specialised aeronautical services to stakeholders such as pilots, controllers, and dispatch teams, meaning they host operational services (e.g., GRO).

Application servers interact with the client via the ATC Agent. After session initiation, applications are initiated based on the configuration received via the ATC Agent. These servers receive input/output commands from the HMI and return updated data.

- **ATC Agents**

The ATC Agent acts as an intermediary node, routing logging requests and maintaining seamless communication between clients and application servers. It connects the client (either stationary or mobile) with the operational services. In that way, the ATC Agent interfaces with the Application Servers to launch or restore the appropriate set of services for the user. Moreover, it manages lifecycle operations like session creation, session transfer, and replication.
The ATC Agent communicates with the ATM Server to get the user's operational configuration and initiates handovers or replications by forwarding context data through the CM Agent.

- **CM Agents**

The CM Agent manages role transitions, context registration, metadata synchronization, and status tracking to ensure service continuity, scalability, and system resilience.

It connects with clients to maintain a real-time model of the active session (e.g., open applications, user preferences, active roles/domains). This agent supports mobility use cases: when a user switches devices or replicates their session, the CM Agent ensures the operational context is restored consistently. The CM Agent receives context change notifications from the clients and updates internal state.

- **Clients**

Represent endpoints such as aircraft systems (mobile clients) and ATC workstations (stationary clients) that use ATMACA services.

Figure 3 illustrates the structure of ATMACA's network architecture. It highlights the interaction between software-defined nodes, showcasing how ATM servers coordinate dynamic updates, agents ensure efficient data routing, and application servers provide essential services. This interconnected framework ensures high scalability and enhances the resilience of the aeronautical communication network.

The data flow and functions of each node, depicted in Figure 3, are further clarified. First, all clients and agents register through the ATM Server. The ATM Server will then provide all agents with updated information about airspace structure and flight plans. This information is updated and uploaded to the ATM server through a management station. After registration, all clients and applications log on to ATMACA through the ATC Agent. It will automatically manage all connections and provide the necessary information locally. The session is authenticated through the Authentication Server. Clients can be stationary, such as ATCos, or mobile, such as pilots, if they change their location through the session. Each client is linked to a CM agent, which provides and stores all relevant context information, manages key ATMACA capabilities and provides the flight session. The Application Server manages the connection with applications, such as GRO, and shares all related information with the clients.

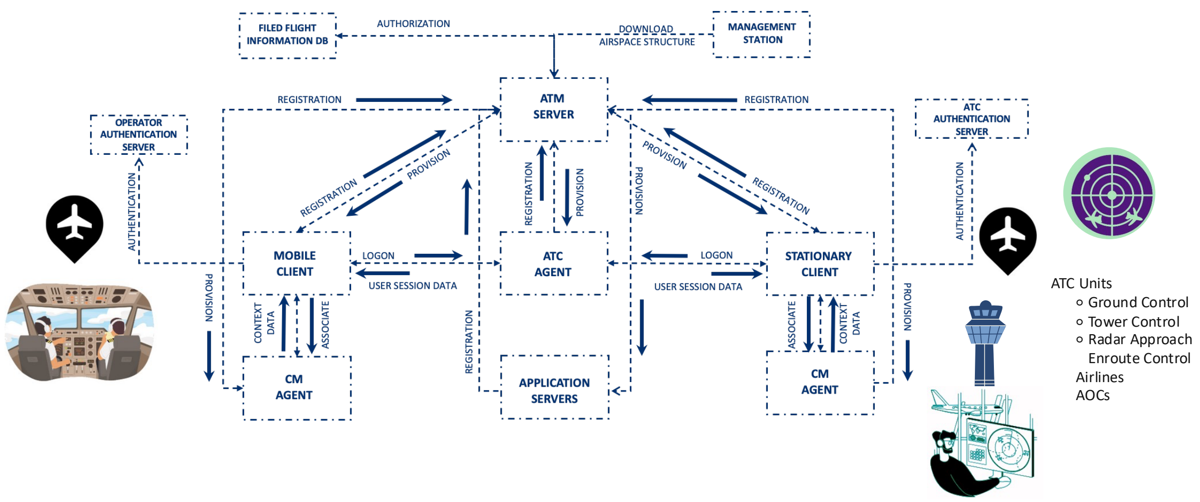

Figure 3: ATMACA Network Architecture

Substantial to these capabilities, and key for the four use cases outlined later in the OSED, is the concept of "session" and "flight session", as an operational implementation of the connection management and the session management capabilities, the new mobility concepts offered by ATMACA and the context management Application.

A session in the ATMACA protocol communication represents a logical, end-to-end communication relationship between two or more entities (e.g., a pilot and an ATCo) that persists across multiple interactions[3]. It is application-layer-oriented and focuses on managing the state of communication to support service delivery. The session facilitates:

- Maintaining contextual information, such as user identity, roles, and active tasks, ensures interaction continuity.
- Tracking the progress of ongoing exchanges, such as an aircraft's taxi clearance or data authority transfer.
- Re-establishing communication without losing the session context ensures resilience to interruptions in the underlying connection.

Effective session management in ATN/IPS-based aeronautical communications requires well-defined session information, structured data flows, and dynamic updates to ensure seamless, reliable, and secure air-ground communication.

ATMACA enlarges the concept of "session" with an operational twist by developing the concept of "flight session". A flight session is *a unified, unique and univocal association between a flight and all its Air-Ground datalink communications, relevant flight data (such as planning, radar and trajectory) and other context information. This information is integrated into a single communication session entity, a "flight session".* The concepts are illustrated in Figure 4.

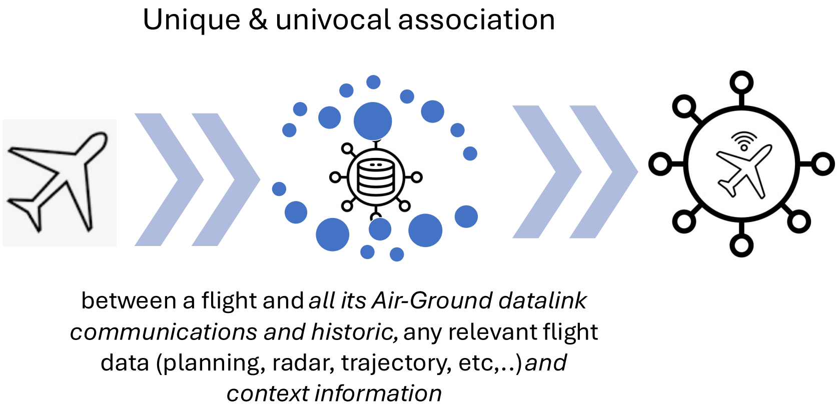

Figure 4: Flight session concept

Each flight session maintains a structured set of attributes to ensure proper tracking, continuity, and security as well as to reflect operational relevant information. Each session is dynamically updated throughout its lifecycle to reflect changes in network status and operational parameters[4]. Unlike conventional methods, this flight session might include (Figure 5):

[3] It is to be notice the difference between session and connection. Connection refers to the direct real-time communication link between two entities for data exchange, concerned with the actual transmission of packets and ensuring their delivery.

[4] Example of session Structured Attributes (further studied in D3.1) might include:

- Session Identification: Session ID, Aircraft ID, Air Traffic Services Unit (ATSU) Info, Session Start & Expiry Time, Session Status, …

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- Datalink communications and services (e.g., CPDLC, DLIC, instant messaging).
- Aircraft-Ground data exchange, including real-time telemetry and trajectory updates.
- Complete flight data, containing historical and real-time operational information.

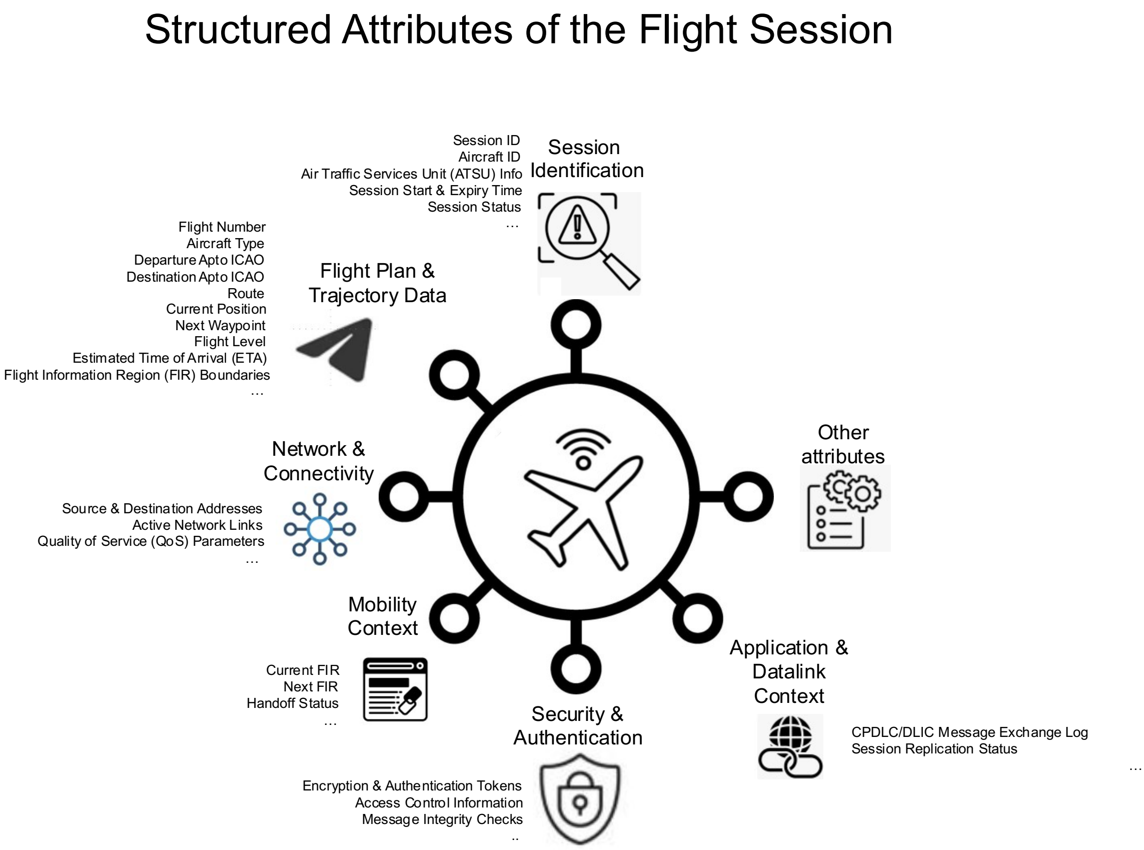

Figure 5: Possible structured attributes of the flight session

Each flight is assigned a unique IP-based communication session, which remains active throughout all flight phases, ensuring continuity regardless of ATC sector transitions. ATMACA facilitates the progression, updating, and management of the flight sessions that will evolve through the ATM system and the communication infrastructures as an IP communication-based flight session, while the flight progresses through the airspace.

- Flight Plan Data: Flight Number, Aircraft Type, Departure Airport ICAO, Destination Airport ICAO, Route, Current Position, Next Waypoint, FL, ETA, Flight Information Region (FIR) Boundaries, …
- Network & Connectivity: Source & Destination Addresses, Active Network Links, QoS Parameters
- Mobility Context: Current FIR, Next FIR, Handoff Status, …
- Security & Authentication: Encryption & Authentication Tokens, Access Control Information, Message Integrity Checks,
- Application & Datalink Context: CPDLC/DLIC Message Exchange Log, Session Replication Status

When an aircraft transitions through the ATM system along its flight, the entire enhanced IP Flight communication session is seamlessly transferred through the communication infrastructures as an IP communication-based flight session, ensuring that all relevant data is handed over to the receiving controller (flight handover via IP Communication Session transfer or sharing). This concept is indicated in Figure 6.

For example, a CPDLC session between a pilot and an ATCo remains active during a flight to exchange ATC instructions, route clearances, or updates. Moreover, it maintains all relevant information related to the flight available for consultation at any moment, enabling ATCos to build and keep a complete image of the flight status and history. Automatic handover of flight sessions and the associated datalink hand off between ATCos supported by datalink communication procedure and specifically designed CPDLC messages.

For the sake of clarity and simplification in the rest of the document, we will refer to flight session or session indistinctively.

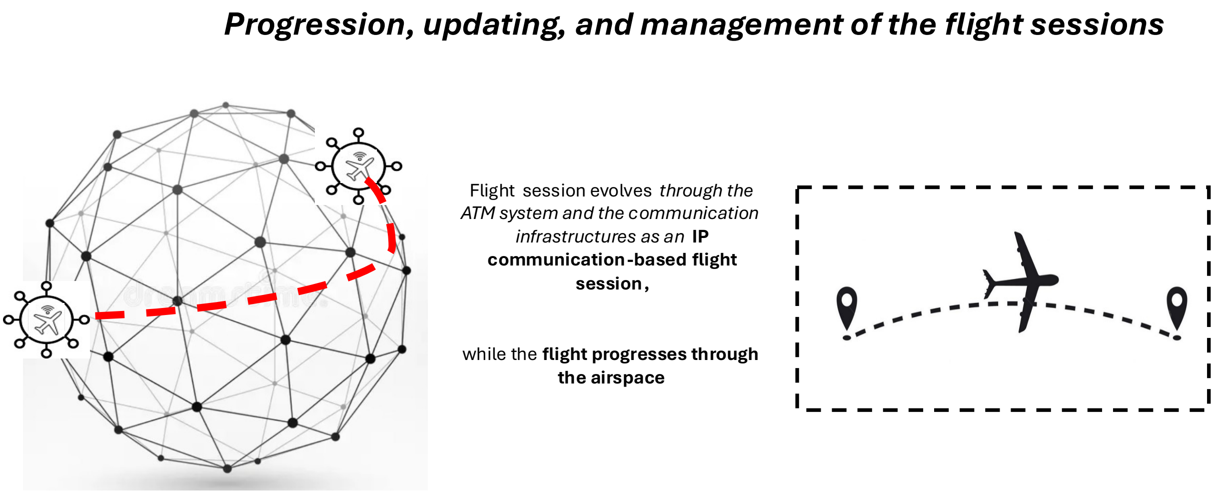

Figure 6: Progression, updating and management of the flight sessions

It is also a substantial operational feature of the flight sessions that ATMACA consolidates all datalink services within a single communication session, eliminating the need for multiple logins for each communication service. This provides pilots with a single point of registration, streamlining operations and reducing workload. ATMACA offers an automatic logon management, where the system handles logins, logouts, and service transitions without pilot intervention. Moreover, during connectivity gaps, messages and updates are stored and synchronised once reconnection is established. This unified framework ensures service continuity, preventing disruptions even in areas with intermittent datalink coverage.

he ATMACA protocol seamlessly offers session continuity and full mobility across different devices, networks, or nodes by introducing not only terminal mobility to make aircraft (mobile nodes) reachable, but also user mobility to maintain user identity and active sessions, session mobility to move the session on the current device to one or more other devices, and service mobility to remain reachable and functional as users or devices move within the concept of mobility management.

Other key ATMACA features include:

- APIs for aeronautical applications to simplify integration.

- Real-time monitoring and dynamic adaptation to network changes.
- Simplifies migration of existing applications from ATN/OSI to ATN/IPS, ensuring smooth transitions while leveraging the benefits of modern IP-based infrastructure.
- Facilitates the development of new applications by providing standardised context management interfaces, reducing complexity for developers.
- Introduce an optimised user interaction for ATM applications by adopting efficiently designed HMIs.

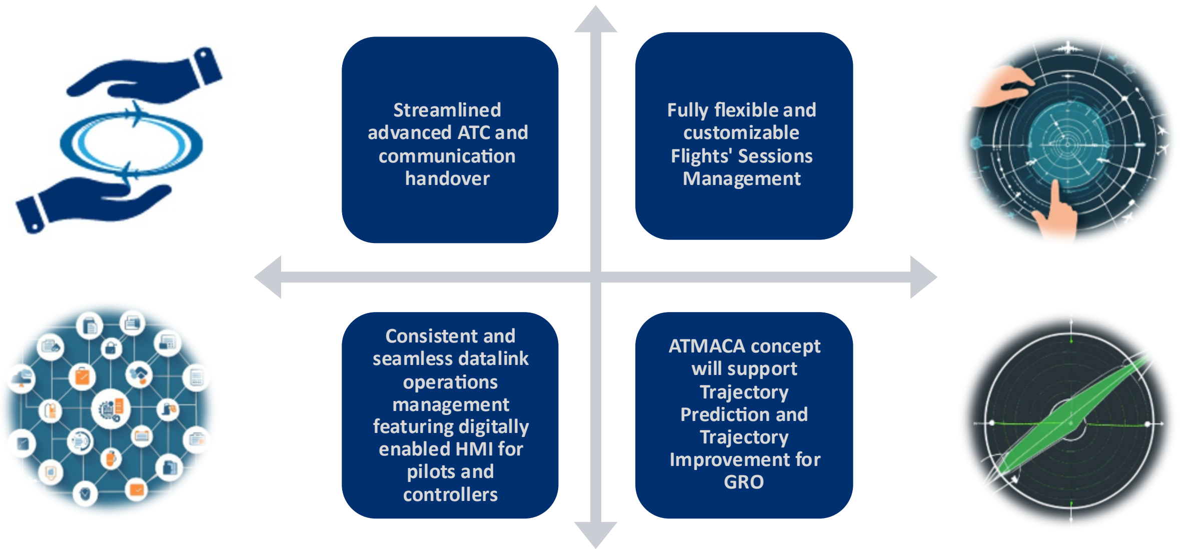

Figure 7: Key operational improvement aimed by ATMACA

Based on the previous technical capabilities, the ATMACA project aims to achieve four key operational improvements in air traffic management, which are illustrated through the following four use cases, as indicated in Figure 7.

1. First operational improvement seeks to **streamline advanced ATC and communication handovers.**

ATMACA allows for a flexible and seamless integrated management and handover between ATCos of all Air-Ground datalink communications, together with associated flight data and context information, over the ATN/IP communication infrastructure in a streamlined, automated, fast, cohesive, and synchronised manner. This ATC and communication handovers process will require minimal intervention from pilots and air traffic controllers (ATCos) and will maximise flexibility in flight management and the allocation among ATCos.

Flight handover between ATCos involves three differentiated processes by different Providers: ATC responsibility transfer (by the Air Traffic Services Provider (ATSP)), datalink transfer (by the Communication Service Provider (CSP)) and ATM/flight data transfer (by the Air Traffic Data Service Provider (ADSP)). The transfer of flight responsibilities between controllers relies on predefined and not flexible schemes, procedures and architectures involving these three entities (ATSP, CSP, ADSP). A highly dynamic, flexible and seamless allocation and transfer of flights between ATCos is essential to maximise the flexibility and benefits of advanced SESAR concepts, such as Dynamic Airspace Configuration (DAC), Flight Centric Airspace (FCA) or Virtual Centres (VC), etc.

With ATMACA, flights can be transferred and handed over from one controller to another with complete flexibility. ATMACA allows an ATCo to transfer all, some, or specific flights under his responsibility to any other ATCo, regardless of the ATCo's geographical location and area of responsibility, and regardless of whether ATC is based on sector, or a flight-centric approach. This is possible thanks to the progression, updating, and management of the flight sessions that will evolve through the ATM system and the communication infrastructures as an IP communication-based flight session, while the flight progresses through the airspace. Moreover, automatic handover of flight sessions and the associated datalink handoff between ATCos will be supported by datalink communication procedure and specifically designed CPDLC messages.

2. The second operational improvement focuses on providing **fully flexible and customizable flight session management**, enabling greater adaptability in managing flights. By enabling continuous flight sessions and seamless communication, it enhances operational efficiency for both ATCos and pilots.

ATMACA facilitates an ATS session-based system which offers greater operational flexibility for ATCos[5]. ATMACA allows ATCos to group, aggregate, transfer, replicate, or divide flight sessions or responsibilities and implement new and flexible operational methods, in particular:

- **Presence Information:** ATMACA protocol provides presence information for aircraft (connected/disconnected, online/offline) and controllers (roles, workstations, availability). After registration and logon, the system provides up-to-date status information for aircraft under control (and adjacent controllers) while maintaining situational awareness, including Data Authorities availability.
- **Capability to manage multiple sessions on a single workstation (Managing Sessions for a Role in a Single ATC Workstation).** The ATMACA solution allows ATCos, responsible for different operational domains (Delivery, Ground, Tower), to manage concurrently multiple active sessions from a single workstation. Each session represents a specific aircraft and is displayed independently, providing a clear, organised view. This enables ATCos to handle a high volume of flights without losing operational clarity or compromising safety.
- **Managing Sessions for a Role in Multiple ATC Workstations.** It refers to ATCo's ability to replicate active sessions on multiple devices under their user account, such as a primary workstation, secondary workstation, or portable device (e.g., tablet or laptop), maintaining the same user. This ensures that the ATCo has uninterrupted access to all active session data, regardless of their physical location, allowing quick transition and immediate response in varying operational contexts[6].
- **Managing Sessions for Multiple Roles in a Single ATC Workstation. (Multiuser session aggregation).** The ATCo's workstation can host sessions from multiple domains, allowing the

[5] In ATMACA aircraft (including their A-G communication, their context information and flight data) are represented by flight sessions. Actors and functions, such as pilots or ATCOs functions (clearance delivery, ground, local, departure, enroute,) are represented by roles. And finally, controller working positions are referred to as workstations

[6] It will allow the ATCO to move freely within or outside the control room, supporting situational awareness and decision-making from various locations. This is useful in large control facilities or situations requiring the ATCO to collaborate from different positions (Enhanced mobility). It will provide support for contingency situations providing continuous service even during disruptions. It will also support shadow mode operation, shift transition between ATCos, multisector planner operation, supervision in the operational room as well as supervision during training.

ATCo to operate in different roles (ATC functions), such for example, Delivery, Ground, and Tower controller, within the same setup. Each session corresponds to an aircraft operating in one of these domains, giving the ATCo centralised control and visibility over activities typically managed by separate roles. (Cross-Domain Session Management).

3. The third operational improvement aims to ensure **consistent and seamless datalink operations management,** incorporating an enhanced HMI for both pilots and controllers.

ATM applications over datalink [24] are increasing in volume and scope, with multiple datalink services currently available and under development. Manually handling datalink logon/off processes and dealing with disconnections and discontinuities increases the workload for both pilots and ATCos if not handled properly.

With ATMACA, all data link services and applications are managed through a simple supportive interface for pilots and ATCos. Pilots and controllers will only need to open a session into the ATMACA system at the beginning of the flight or duty period. The system will automatically manage for them all logon/off, connections & disconnections across all required data link services with a unified and fluid digital HMI. The system automatically detects communication or service failures and resumes the connection as soon as possible without human intervention.

The session remains active throughout all flight phases, even during temporary signal losses. This means that, although a connection may be interrupted, the session persists and automatically resumes once communication is restored, eliminating the need for repeated manual authentications by pilots and air traffic controllers. Additionally, this continuity is independent of the access technology and data link service used, significantly benefiting long-haul flights (where communication technology changes frequently) and complex environments where switching between access technologies shall not disrupt service continuity. This functionality allows ATCos not only to access individual messages but also to retrieve the entire flight context at any time, regardless of connection status, enabling better decision-making based on historical and real-time information.

4. **The fourth operational improvement** will support trajectory prediction and trajectory improvement for GRO, enhancing the accuracy and efficiency of flight planning and execution.

The ATMACA communication protocol enables aircraft to share their onboard weather information with the ground units. During the project, two use cases will be addressed at the laboratory level, one in the Terminal Manoeuvring Areas (TMA) and another one in the en-route phase:

- Enhanced trajectory prediction. The Arrival Management (AMAN) sequences traffic through the TMA entry point by Mach regulation, but time uncertainty leads to aircraft holding. ATMACA allows aircraft which have already passed the TMA entry point to share real-time on-board wind and temperature data with ground stations. These measurements are used to refine wind and temperature grids, which are subsequently relayed to incoming aircraft. With this updated information, the onboard Flight Management System (FMS) calculates a more precise ETA at the entry point and communicates it to air traffic control (ATC). The improved ETA data supports Extended Arrival Management (XMAN), enabling ATC to generate better sequencing strategies and relay them to aircraft.
- Optimised trajectory for a specific Flight Level (FL): In free-route airspace, aircraft flying at a constant altitude have multiple route options from their entry point to their exit point. The choice of the optimal route depends heavily on the availability and precision of wind data. ATMACA ensures that, at any given flight level, the fuel-optimal trajectory is determined based

on real-time wind and temperature updates from surrounding aircraft. This data is shared via an air-ground datalink network by aircraft that have already flown through the airspace, transmitting their wind and temperature readings to ground stations. The wind grid is updated on the ground and transmitted to the aircraft, which uses it to compute the fuel-optimal trajectory at each moment.

The four operational improvements discussed are not an exhaustive list of all the operational improvements that ATMACA might make possible, but just four of them prioritised considering the operational profile of the ATMACA consortium, which includes an airline and pilots, as well as air traffic control service provider and air traffic controllers; and considering also the interaction with users and stakeholders and their feedback. At a meeting with the project advisory board, additional use cases were outlined regarding:

- Enhance pilot situational awareness and decision making by notifying restrictions in the TMA and AIRPORT, enabling them to autonomously manage themselves. For example, sharing any potential restricted time of arrivals at holding points or at TMA entry points and passing that information to the aircraft to allow them to use their own methods of slowing their arrival down based on, perhaps, company cost indexes or other company efficiency targets.

- Airport - Aircraft improved communications. Datalink communication and flight session concept to enhance aircraft-airport operation centre communication, specifically for capacity and arrival management purposes. ATM can leverage these features when facing situations with:

    - Airport capacity exceeded: Providing support in diverting an aircraft to an alternate airport when capacity is exceeded, based on aircraft-provided information.

    - Contingency scenarios: Providing support to large-scale contingencies by coordinating mass diversions, assisting controllers, and providing real-time operational updates.

    - AMAN–Airport integration: Enhancing real-time information sharing on delays and emergencies by enabling direct pilot-airport communication, improving decision-making and emergency response.

- Flight sessions management to improve trajectory negotiation: Enabling early trajectory negotiations, allowing adjustments for wind conditions and potential diversions. Additionally, supports better coordination and real-time trajectory updates through direct communication with the Network manager.

Those additional use cases will be retained for future stages and TRLs if the feasibility of the ATMACA solution is proven in this project.

ATMACA goes beyond the state-of-the-art IP-based datalink communication solutions by providing mobility management in the application layer with a seamless handover mechanism between moving aircraft and stationary ground stations, achieved through a mechanism that reduces handover delay. Moreover, unlike existing solutions, ATMACA will enable the use of Commercial Off-The-Shelf (COTS) equipment while adhering to existing international and industry standards. The solution introduces a seamless handover mechanism, allowing continuous communication between moving aircraft and stationary ground stations, even in complex and high-density airspaces. By integrating mobility management within the application layer, ATMACA significantly reduces handover delays, ensuring uninterrupted communication during critical phases of flight. Additionally, ATMACA is designed to be compatible with COTS equipment, enabling easier adoption and compliance with existing international standards. This advanced solution also enhances user interaction through a next-generation Human-Machine Interface (HMI), which is tailored to meet the evolving needs of air traffic controllers handling increasingly complex data sets.

Decoupled the session (e.g., data management and exchange) from the connection management, ATMACA aims at offering an uninterrupted flight information access and supports further performance under multilink connections, with the goal of increasing ATCos knowledge and familiarisation with ongoing operations. The project provides key operational benefits, including flexible workload distribution among ATCos, seamless handovers between sectors and control centres, and an integrated communication environment that simplifies pilot operations. Additionally, ATMACA features GRO, a trajectory optimisation application that leverages real-time weather and environmental data to enhance fuel efficiency and reduce emissions.

ATMACA offers significant advantages for ATCos by enhancing flexibility, resilience, and efficiency in air traffic management. One of its key benefits is the ability to seamlessly transfer airspace responsibilities to other controllers, even across different Area Control Centres (ACCs), allowing for more dynamic traffic distribution. Additionally, ATCos receive complete flight session information rather than fragmented data, improving decision-making and reducing the risk of miscommunication. ATMACA also enhances resilience by ensuring that flight sessions remain accessible even during connection losses, with pending instructions automatically transmitted upon reconnection. Furthermore, it improves contingency management by enabling ATCos to redistribute workload effectively in high-traffic situations or emergencies, ensuring continued operations even in evacuation scenarios.

For pilots, ATMACA simplifies communication and enhances operational efficiency by streamlining data link services and reducing workload. The system introduces a single logon process, allowing pilots to register once at the start of the flight while ATMACA automatically manages all data link services throughout the journey. This eliminates the need for multiple logins and minimises administrative burden. Additionally, ATMACA supports instant messaging capabilities, reducing reliance on voice communication for non-critical flight phases and enhancing overall efficiency. The system also integrates multiple applications into a unified interface, ensuring seamless access to various data link services and improving the overall user experience.

This document defines the operational improvements brought by ATMACA, assesses its benefit and impact mechanisms on ATCos and pilots, and establishes the baseline requirements for its successful deployment within future SESAR operational scenarios.

SESAR solution ID	SESAR solution title	SESAR solution definition	Justification (why the solution matters?)
0513	Air Traffic Management and Communication over ATN/IPS	The ATMACA project addresses issues associated with mobile scenarios by introducing a seamless handover mechanism during the transition from ATN/OSI to ATN/IPS. The seamless handover mechanism allows continuous communication between moving aircraft and stationary ground stations, even in complex and high-density airspaces. By integrating mobility management within the application layer, ATMACA significantly reduces handover delays, ensuring uninterrupted communication during critical phases of flight. Additionally, ATMACA is designed to be compatible with COTS equipment, enabling easier adoption and compliance with existing international standards. This advanced solution also enhances user interaction through a next-generation Human-Machine Interface (HMI), with efficient system design to process higher quality data and meet human factor requirements for controllers. This HMI is tailored to meet the evolving needs of air traffic controllers handling increasingly complex data sets, since existing HMIs are not suitable for future datalink communication due to increased flight information data that need to be processed.	The solution enables effective, seamless, interoperable air-to-ground data link communication technologies and a digital flight monitoring and management environment for pilots and air traffic controllers through ATN/IPS within all domains, including airports, Terminal Manoeuvring Areas (TMAs), as well as en-route and oceanic flight segments based on gate-to-gate philosophy. Expected benefits of ATMACA includes: • Enhanced air-to-ground communication and air traffic management through improved data handling and user interaction via advanced HMI design. • Seamless communication handovers between aircraft and ground stations, reducing the risk of communication loss. • Supports the use of COTS equipment, reducing costs and simplifying the adoption process.

Table 6: SESAR solution 0153: ATMACA -Air Traffic Management and Communication over ATN/IPS scope

3.1.1 Deviations with respect to the SESAR solution definition

No deviation with respect to the SESAR solution definition was identified.

3.2 Detailed operational environment

3.2.1 Operational characteristics

The ATMACA solution enables effective, seamless, interoperable air-to-ground data link communication technologies and a digital flight monitoring and management environment for pilots and air traffic controllers through ATN/IPS within all domains, including airports, Terminal Manoeuvring Areas (TMAs), as well as en-route and oceanic flight segments based on gate-to-gate philosophy.

Therefore, the operational environment refers to European airspaces and airports, without any restriction or limitation.

Regarding the traffic environment, ATMACA's operational environment includes any Instrument Flight Rules (IFR) or Visual Flight Rules (VFR) traffic, provided it is equipped with IP connectivity.

3.2.2 Roles and responsibilities

ATMACA solution is relevant for all ATM stakeholders. However, the use cases outlined in this project are focused on two main operational actors: pilots and air traffic controllers.

The ATMACA solution considers two primary categories of clients: stationary clients and mobile clients, each with distinct characteristics and functions tailored to the operational needs of ATM. The ATMACA clients represent endpoints such as aircraft systems (mobile clients) and ATC workstations (stationary clients) that use ATMACA services.

Stationary clients comprise ATC workstations or other devices used by ATCos, dispatchers, airline Operations Control Centers (OCC), airport authorities, and ground handling companies. The term stationary signals that they are persistently associated with a single ATC agent, regardless of their physical movement. So, these clients are confined to a single network domain and do not move between domains. However, their ATC software can also be deployed on mobile devices to improve operational flexibility. Regardless, Stationary clients are mainly intended to operate from predefined, fixed locations, such as ATC centres or airport control towers.

For the sake of the use cases considered in this project, stationary clients are ATCos in any airport, TMA and en-route function. Within the scope of ATMACA, ATCos perform the following functions:

- Manage and coordinate air traffic services, including CPDLC and data authority transfers.
- Enable real-time monitoring of sessions, mobility events, and network operations.
- Support operational decisions and issue clearances to mobile clients (e.g., pilots).
- Ensure seamless integration of the HMI with existing systems to enhance usability and operational efficiency for both ATCos and pilots.

Mobile clients are characterised by their ability to dynamically change their point of attachment to the ATC network as they move across control areas, FIR boundaries, or communication domains. In contrast to stationary clients, mobile clients do not maintain a fixed association with a single ATC Agent. Instead, they initiate agent reassignment and context handovers as they traverse different operational regions. They are dynamic endpoints, such as aircraft or portable devices, that move across network domains while maintaining connectivity and communication. They transition between network domains (e.g., airspace sectors) and are supported by ATMACA's mobility management capabilities.

For the sake of the use cases considered in this project, mobile clients are aircraft and pilots operating in the airspace of interest at any flight phase. Within the scope of ATMACA, ATCos perform the following functions:

- Request services from the Application Server, such as weather updates, route optimizations, or clearances.
- Maintain active communication sessions during transitions between domains.
- Provide real-time data (e.g., position, wind conditions) to support collaborative applications like GRO.

3.2.3 CNS/ATS description

The ATMACA solutions build upon SWIM [18] and FCI [22] by providing a unified and extensible protocol that enhances the efficiency, security, and interoperability of aviation communication.

FCI, along with SWIM, sets the basis for the later deployment and operation of ATMACA, enhancing the highly valued capabilities of the latter. However, this connection will not be proved during the ATMACA project life, but in later phases once the feasibility of the solutions is proven.

- **Integration with SWIM.**

ATMACA solution is designed to integrate with European SWIM and is adaptable for international SWIM, ensuring seamless and efficient information exchange across global aviation networks.

SWIM functions as middleware by providing standardised methods for information exchange that connect various operational systems across the ATN/IPS framework. The ATMACA datalink communication protocol works alongside SWIM, which also functions as middleware, by providing standardised communication protocols and data sharing across aviation networks. The ATMACA protocol ensures reliable session management, secure connections, and mobility support, while SWIM enables the sharing and integration of aviation data across multiple stakeholders.

Together, ATMACA and SWIM form a unified middleware layer that optimises system efficiency. By utilising a middleware layer, the datalink communication protocol can seamlessly interact with SWIM services, maintaining compatibility with standardised data formats while ensuring secure information transfer.

The Application Server within the ATMACA network will interface with the SWIM infrastructure through standardised APIs and protocols. The Application Server will host and deliver SWIM-enabled services, acting as a central node for sharing and disseminating aeronautical information.

For SWIM-enabled services, the SWIM Gateway ensures continuity by forwarding requests to the appropriate SWIM-enabled application server based on geolocation or network policies. Intermediate nodes forward requests for SWIM-enabled services to the SWIM Gateway deployed in the network. The SWIM Gateway handles compliance checks, metadata validation, and routing to the appropriate SWIM-enabled application servers. The updated location is synchronised with the SWIM Gateway for SWIM-enabled services to ensure service continuity across geolocations. SWIM integration ensures the ATMACA Application Server communicates effectively with global systems, such as regional SWIM networks.

- **Integration with FCI.**

FCI (Future Communications Infrastructure) is the background for ATMACA.

The FCI [23] is a new IPS System providing digital and secure communication capabilities supporting integrated CNS [26]. It provides the network functionality necessary to interconnect air and ground end-systems via multiple IP broadband air/ground datalink (multilink) subnetworks and core networks to support aeronautical data and voice applications for safety [21] and regularity of flight operations.

The FCI is based on communication standards, including Aeronautical Telecommunications Network [11] over IPS (ATN/IPS) [25] and SWIM to define the interoperability features needed for data exchange and network management functionality. The FCI is also expected to interface with external networks

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for legacy ATN/OSI system accommodation, civil-military coordination and information exchanges with commercial IP networks.

Within the CNS infrastructure, the role of the FCI is the provision of digital communication services (IP-based data and digital voice). FCI provides network functions common to all services, implementing instances of the supported communication profiles as part of the deployment within the SESAR Airspace Architecture. It specifies an architecture encompassing multiple connected networks which include high-performance air/ground data link technologies. FCI's air-ground data link services can use various technologies to meet end-to-end communication requirements for future ATM.

It supports advanced ATS [12] and Airline Operations Centre (AOC) services with demanding high air-ground communication capacity and high performance. Moreover, FCI enables real-time sharing of 4D trajectories, provides timely access to ATM data and information services, and supports network-centric SWIM architectures, moving towards an "hyper-connected ATM" environment. In addition, FCI eliminates fragmentation in the communication services and allows multilink connection.

- **Interface with onboard and ATC systems.**

ATMACA's interfaces with onboard systems and ATC systems are not implemented as part of this TRL2 project. Operational HMIs are developed as standalone interfaces and are not integrated into pilot and ATCo systems.

- **On board wind and temperature data.**

GRO applications rely on the accessibility of onboard weather data (wind and temperature). For the sake of this project, GRO will be developed and tested in a lab and simulated environment only, with offline wind and temperature data, and no real-time connection with onboard systems.

3.2.4 Applicable standards and regulations

This section lists the regulations and standards that are affected by ATMACA.

- ATMACA concept relevant standards:

ICAO Doc 9880, Manual on Detailed Technical Specifications for the Aeronautical Telecommunication Network (ATN) using ISO/OSI Standards and Protocols, First Edition - 2010 [7]

ICAO Doc 9896, Manual for the ATN using IPS Standards and Protocols, 1st edition [8]

ICAO Doc 9750 (Global Air Navigation Plan for CNS/ATM Systems) [9]

ICAO Doc 10039 (Manual on System Wide Information Management (SWIM) Concept) [10]

ICAO Annex 10 (Aeronautical Telecommunications) [11]

ICAO International SARPs, Annex 11 Air Traffic Services, Fifteenth Edition – July 2018 [12]

ICAO PANS ATM (Procedures for Air Navigation Services Air Traffic Management) [13]

Manual on System Wide Information Management (SWIM) Concept, Doc10039 AN/511 [14]

The **regulations** that are applicable to the ATMACA concept.

- EASA/EU Regulations:

EC Regulation no 29/2009 (Data Link Implementation Rule) [15]

Easy Access Rules for Air Traffic Management/Air Navigation Services (ATM/ANS) Equipment (Regulations EU 2023/1769 & EU 2023/1768. [16]

- Guidance Material:

Future Connectivity for Aviation – White paper [17]

PJ14-W2-100 Deliverable D7.2.120 "SWIM TI Purple Profile for Safety Critical Information TS/ Inertial Reference System (IRS) TRL4 [18]

SESAR 2020 PJ.14-W2-77 "FCI Services" [19]

PJ.14-W2 D5.1.500 Future Communication Infrastructure Business Case (FCI BC) - April 2022 [20]

ICAO WG-I/21, Work Package (WP) 6 "Safety considerations and their impact on the ATN/IPS standardisation work" - May 2016 [21]

3.3 Detailed operating method

This section describes the previous operating method (reference/baseline) and all relevant aspects, as well as the new proposed SESAR operating method (solution).

3.3.1 Previous operating method

This section describes the previous operating method and the reference scenario, before ATMACA's implementation.

3.3.1.1 Communication and infrastructure

The current ATM system relies on multiple independent service providers for communication and data exchange. The reference scenario will rely on FCI, which ensures aeronautical communication using an IP-based network, integrating multiple subnetworks for air-ground data link services. However, communication remains fragmented, requiring manual intervention for reconnections and handovers. The current infrastructure supports basic trajectory sharing and data exchange, but lacks seamless integration, leading to inefficiencies in coordination between ATCos and pilots.

Regarding datalink services, current ATM operations rely on CPDLC, Automatic Dependent Surveillance - Broadcast (ADS-B), Automatic Dependent Surveillance - Contract (ADS-C), and other data link applications, but these services operate independently from one another. Pilots must manually log in and out of different services throughout the flight, leading to operational inefficiencies. In addition, flight data transfers occur separately from air-ground communication handovers, requiring ATCos to complete both processes manually. This fragmentation results in delays, increased workload, and a higher risk of errors.

Reference communications are limited for reconnection management. Flight crew must manually establish communication with each control centre and reinitiate contact if disconnections occur. Connection gaps due to limited coverage, network congestion, or system failures require manual intervention from both pilots and ATCos, increasing workload and the risk of miscommunication.

3.3.1.2 ATC operations

Nowadays, ATCos play a critical role in managing air traffic. In the reference scenario, flight handovers are managed through a sequential process, which requires the participation of several users, defining a highly fragmented operation. The ATSP oversees airspace management, while CSPs facilitate voice and data communication. ADSPs transmit flight data across sectors but operate separately from the communication systems. Moreover, the demand in the current ATM system is rapidly increasing, leading to an increased workload.

The handover process follows these steps:

- Handover preparation – The current ATCo gathers flight information (e.g., position, altitude, speed) and prepares coordination with the receiving sector.
- Handover coordination – ATCos communicate manually via voice or data link, exchanging necessary flight details.
- Handover execution – The receiving ATCo assumes control, updates flight data, and integrates the aircraft into their sector.
- Post-handover update – The previous ATCo logs the handover, while the receiving controller updates the flight's trajectory.

New developments, such as remote control centres, allow for handover and monitoring of traffic on different ACCs. This additional flexibility allows for increasing the capacity and managing traffic in contingency scenarios. This new technology improves availability and reliability.

Other advanced surveillance systems provide additional information, allowing for better prediction of trajectories and monitoring flights.

Future developments should provide additional capabilities, with new technology and information, facilitating the en-route ATCo's role.

3.3.1.3 Pilot role

Pilots use on each flight many different types of communication. These include CPDLC applications who play a critical role in operations, providing valuable data. ATM Applications over datalink are increasing in volume and scope, with multiple datalink services currently under development. Pilots manually handle datalink logon/off processes and deal with disconnections and discontinuities. This results in an increase in the pilot's workload.

3.3.1.4 Operational limitations

Despite advancements in SESAR concepts, current ATC operations still depend on manual coordination and voice-based communication. The lack of an integrated system for flight data and communications creates several key limitations:

- High ATCo workload – non-automatized flight handovers and separate communication/data transfer processes increase workload and reduce efficiency.
- Limited situational awareness – ATCos only receive fragmented flight data, leading to less informed decision-making.

- Communication interruptions – Disruptions in connectivity require manual reconnections, causing delays and operational inefficiencies.

- Sector-based constraints – Flight management is restricted to predefined geographical areas, reducing flexibility in airspace allocation.

Overall, the conventional ATM system [13] lacks seamless automation, real-time data integration, and dynamic airspace management, highlighting the need for a more efficient and flexible solution like ATMACA.

3.3.2 New SESAR operating method

The targeted ATMACA future operating method will rely on the key elements being part of the reference scenario but will implement on top of them some new key features and capabilities.

ATMACA significantly enhances the reference scenario by introducing integrated flight sessions that unify communication, flight data, and operational context, ensuring seamless handovers and reducing manual coordination. For ATCos, this means instant access to full flight history and real-time updates, which further supports flexibility in workload distribution and reduces the risk of miscommunication. Automated session transfers eliminate redundant tasks, allowing controllers to focus on traffic management rather than procedural handovers. For pilots, ATMACA simplifies operations by providing a single logon system, automatically handling data link services and maintaining connectivity even during disruptions. This ensures that clearances and instructions remain accessible, reducing pilot workload and enhancing operational efficiency. Ultimately, ATMACA transforms ATM by creating a more resilient, flexible, and automated environment that improves safety, efficiency, and scalability across the airspace.

How is ATMACA useful for ATCos?

ATMACA offers a wide range of ATM functionalities that ATCos can leverage in a simple and efficient way. The new operational scenario introduced by ATMACA brings several significant benefits for ATCos, including:

- **Flexible traffic distribution:** Traditionally, ATCos are limited by geographical constraints and the static nature of flight strips. With ATMACA, controllers can redistribute flights -even those managed across different ACCs- to other ATCos. This capability greatly enhances airspace flexibility and resource allocation.
  - An ATCo can seamlessly transfer part or his entire airspace to another ATCo, anywhere, through the network.
  - Normal, prescheduled handovers are performed seamlessly between collateral ATCos. ATMACA manages the transitions and transfers the flight, deleting the need for ATCo-ATCo communication.
  - In contingency scenarios, an ATCo can reduce the workload to properly manage increasing traffic or transfer it completely if, for example, an emergency requires to evacuate the TWR or ACC. ATMACA also enables ATCos to switch to portable devices while keeping control of the aircraft if evacuation is required.

- **Complete flight context information:** Instead of receiving fragmented flight data, ATCos have access to a full flight session. This means every clearance, communication, and data update is available from the moment an aircraft registers into the system. Such comprehensive visibility allows for more informed decision-making, smoother handovers between sectors, and a reduction in the risk of miscommunication.

- **Resilience to connection gaps:** By separating the session layer from the underlying connection management, ATMACA ensures that even if there are temporary connection losses, ATCos can continue to monitor and manage flight sessions. Clearances or instructions that are generated during these gaps are automatically queued and dispatched once the connection is reestablished.

In summary, these enhancements empower ATCos with greater situational awareness, improved workload management, and more robust control over the dynamic allocation of airspace resources, all under simpler flight operations.

How is ATMACA useful for pilots?

For pilots, ATMACA's unified approach to data management and communications translates into a range of operational improvements, mainly on enhanced security and simpler communications:

- **Single logon:** Rather than manually logging into multiple datalink services for various applications (CPDLC, ADS-C, DLIC, etc.), pilots log into ATMACA once at the beginning of their flight. During the flight, ATMACA will automatically connect and manage all communications from the system and services, such as CPDLC, DLIC or other applications. Hence, manually registration into all the different services during the flight will no longer be needed. Consequently, the pilot workload is reduced. For example, if the connection is missed, the system will automatically reconnect as soon as possible and store all the relevant information linked to the flight.

- **Instant message capabilities:** Reduce the need for voice communications in non-critical phases of flight.

- **Integrated support for multiple applications:** ATMACA is an integrative framework, so it not only consolidates communications but also provides a unified interface that supports various datalink services. Pilots benefit from an easy-access, single-registration set of services which improve operation.

Ultimately, by reducing manual intervention and ensuring the availability of complete flight data, ATMACA allows pilots to focus more on flight operations rather than managing multiple communication channels.

What about GRO?

A standout component of the ATMACA project is the GRO application. GRO represents an innovative approach to trajectory prediction and flight planning that directly addresses the growing need for fuel efficiency and environmental sustainability in aviation. Key aspects of GRO include:

- **Real-time weather information integration:** GRO continuously incorporates live weather and wind data into its trajectory calculations. This enables the system to predict more accurate flight paths and to adjust routes dynamically to avoid severe weather conditions.

- **Fuel optimisation:** GRO enables dispatch teams to optimise fuel loads and route planning for aircraft before departure by leveraging real-time environmental data, such as wind, weather, and airspace conditions. This will reduce fuel consumption, minimise emissions, and ensure efficient flight operations.

- **Optimised routing:** By leveraging data from previous flights and current atmospheric conditions, GRO not only improves trajectory predictability but also identifies more fuel-efficient horizontal and vertical routes, based on updated environmental conditions, such as wind, turbulence, and air traffic constraints. This can result in significant reductions in fuel consumption and emissions.

- **Enhanced decision-making:** The comprehensive flight session data available through ATMACA means that GRO can consider a complete set of variables -ranging from real-time environmental conditions to historical flight performance- in its predictions. This integration distinguishes GRO from other projects that might focus solely on static flight planning without real-time adjustments.

These features collectively ensure that GRO provides a superior level of operational efficiency and environmental benefit compared to traditional flight planning systems, making it a critical element of the ATMACA concept.

3.3.2.1 Enhanced communications

The ATMACA future ATM scenario builds upon existing SESAR infrastructure, introducing a unified flight session that integrates all air-ground communications, trajectory data, and operational context. Each flight is assigned a unique IP-based communication session, which remains active throughout all flight phases, ensuring continuity regardless of ATC sector transitions. Unlike conventional methods, this session includes:

- Datalink communications and services (e.g., CPDLC, DLIC, etc).

- Aircraft-Ground data exchange, including real-time telemetry and trajectory updates.

- Complete flight data, containing historical and real-time operational information.

This approach eliminates fragmented communication and ensures that handover between ATCos occurs seamlessly, with no manual intervention required to re-establish lost connections or exchange flight data.

Regarding datalink connection, ATMACA consolidates all datalink services (e.g., CPDLC, ADS-C) within a single communication session, eliminating the need for multiple logins. This provides pilots with a single point of registration, streamlining operations and reducing workload. In other words, ATMACA offers an automatic logon management, where the system handles logins, logouts, and service transitions without pilot intervention. Moreover, during connectivity gaps, messages and updates are stored and synchronised once reconnection is established.

This unified framework ensures service continuity, preventing disruptions even in areas with intermittent datalink coverage.

3.3.2.2 Enhanced handovers

The ATMACA handover process is fully automated and ensures that an aircraft's communication session, along with all associated data, is transferred instantly to the next ATC sector. The process consists of:

Pre-handover:

1. The ATC system identifies the need for handover and prepares the full session (session management).
2. The system notifies the receiving ATCo about the imminent handover.
3. The session is duplicated and shared with the receiving sector, ensuring ATCOs have full situational awareness before assuming control.

Handover execution:

4. The receiving ATCo is granted full access to the flight session without requiring manual data exchange.
5. The flight crew is notified automatically, eliminating the need for verbal confirmations.

Post-handover:

6. The session remains fully synchronised, ensuring no loss of communication even in cases of connection gaps.

This seamless handover mechanism significantly reduces ATCo workload, minimises communication errors, and enhances efficiency in high-traffic airspace.

3.3.2.3 Enhanced flexibility and support for dynamic airspace

ATMACA brings unprecedented flexibility to air traffic management by enabling dynamic flight session transfers between ATCos, regardless of geographical location or sector boundaries. Controllers can seamlessly redistribute traffic to other ATCos, even across different ACCs, optimising workload distribution and enhancing airspace adaptability. In contingency situations, such as emergencies or control centre evacuations, ATCos can transfer active sessions to alternate locations or portable devices, ensuring uninterrupted operation and safety. This capability allows controllers to retain control remotely, maintaining situational awareness and decision-making without delays. By decoupling session management from physical workstations, ATMACA supports a highly flexible, scalable, and resilient ATM system, capable of adapting to real-time traffic demands and unforeseen disruptions.

3.3.2.4 Use cases

The new capabilities that define ATMACA are presented through four different use cases that depict its provided advantages.

3.3.2.4.1 Use Case 1: Streamlined advanced ATC and communication handover

ATMACA foresees operational improvements based on an ATM solution that manages data link communications and the exchange of flight data:

- In an automated, quick, simple, fluid, integrated and synchronised way.
- With minimal intervention from pilot and ATCos.
- Through the ATM system [16] and the ATN/IPs communications infrastructure.
- While maximising the flexibility of flight management and allocation between ATCos.

Flight handover or flight transfer involves changing the ATCo responsible for controlling the aircraft by issuing clearances and providing instructions and relevant information. It includes three distinct processes managed by different Providers: ATC responsibility transfer, which relay on the ATSP, datalink transfer performed by the CSP and ATM/flight data transfer under the control of the ADSP.

Some advanced SESAR concepts rely on predefined schemes and architectures:

- Unbundle core ATC services and decouple them from physical control centres.
- Flight-based division of airspace according to flight characteristics rather than geographic boundaries: FCA.

A highly dynamic, flexible and seamless allocation and transfer of flights between ATCos is essential to maximise the flexibility and benefits of advanced SESAR concepts. With ATMACA flights can be transferred and handed over from one controller to another with complete flexibility. ATMACA allows an ATCo to transfer all, some, or specific flights under his responsibility to any other ATCo, regardless of the ATCo's geographical location and area of responsibility, and regardless of whether ATC is sector-based or flight-centric.

ATMACA allows for a flexible and seamless integrated management and handover between ATCos of all Air-Ground datalink communications, together with associated flight data and context information, over the ATN/IP communication infrastructure. This will be possible thanks to the three capabilities illustrated in Figure 8:

- Unique and univocal association between a flight and all its Air-Ground datalink communications and historic, any relevant flight data (planning, radar, trajectory, etc.) and context information, and its integration into a single entity "flight session".
- Progression, updating, and management of the flight sessions that will evolve through the ATM system and the communication infrastructures as an IP communication-based flight session, while the flight progresses through the airspace.
- Automatic handover of flight sessions and the associated datalink hand off between ATCos supported by datalink communication procedure and specifically designed CPDLC messages.

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Unique & univocal association between a flight and *all its Air-Ground datalink communications and historic,* any relevant flight data (planning, radar, trajectory, etc,..) *and context information, and its integration into **a single entity "flight session"***

*Progression, updating, and **management of the flight sessions*** that will evolve *through the ATM system and the communication infrastructures as an* **IP communication-based flight session,** while the flight progresses through the airspace

Automatic handover of **flight sessions** and the associated ***datalink hand off between*** ATCos supported by datalink communication procedure and specifically designed CPDLC messages.

Figure 8: Handover and transfer of flights in ATMACA scenario

3.3.2.4.2 Use Case 2: Fully flexible and customizable Flight Sessions Management

In the future advanced scenario supported by ATMACA, an IP communication session is created for each flight. In this scenario, each flight is assigned a unique IP-based communication session. The communication session integrates not only the datalink communication between the pilot and the controller, but also all instant messages interchanged between air and ground. It also contains all the trajectory and flight data associated with the aircraft, as well as any context information, including:

- Data link Pilot-to-Controller Communications: e.g., CPDLC or any instant messaging.
- Aircraft-Ground system communication: Real-time telemetry, trajectory updates, and system status reports.
- Flight Data: The entire trajectory, intent data, and historical flight information.

When an aircraft transitions through the ATM system along its flight, the entire enhanced IP Flight communication session is seamlessly transferred through the communication infrastructures as an IP communication-based flight session, ensuring that all relevant data is handed over to the receiving controller (flight handover via IP Communication Session transfer or sharing). This is called Session Management**.**

A session represents a "cloud" or logical entity linked to the aircraft and the ongoing flight operation, which encompasses:

- Aircraft and flight identification data, including the flight plan.
- A complete record of communications from both parties (ATCos and pilots), as well as clearances, requests, and responses exchanged.
- The current operational status of the aircraft, including position, flight level, and other relevant information such as weather conditions.

Thus, the session serves as the cornerstone of the ATMACA platform, centralising the operational context, real-time flight status, and future operational planning. All necessary communication and control actions revolve around this session. A critical and distinguishing feature is the session's independence from the link technology and airspace sector: the information encapsulated within the session is not restricted to a specific ATS nor ADS provider, as seen in SESAR, but adapts automatically to changes in the operational environment. This design breaks the dependence on a single type of link (Very High Frequency (VHF), Satellite Communications (SATCOM), etc.) and prioritises session continuity over the characteristics of the connection.

Consequently, sessions remain active from the beginning of the operation, throughout all flight phases, until the flight concludes at the destination airport. This functionality ensures continuity of information and supports the creation of context and situational awareness for ATCos involved in the operation. This feature is particularly leveraged during planned sector changes, contingency situations, or role reassignments. The new ATCo (the receiving ATCo in these session handovers) gains instant access to the flight history, enhancing familiarization and response speed, thereby avoiding potential delays. Additionally, it is possible to replicate the session on the receiving ATCo's workstation prior to the handover, allowing for preparation and situational awareness before taking control of the aircraft.

To illustrate the concept of a session more intuitively, consider the following analogy:

A session is akin to a messaging service, such as WhatsApp, where previous messages remain accessible despite connectivity interruptions. Using WhatsApp, for example, requires registering the phone number of the intended contact (performed by the flight crew). If the number is correct, communication with that contact becomes possible. The recipient (the ATCo) verifies the sender and determines if the message is valid (in aviation, this corresponds to aircraft credential authentication). If the credentials are valid, the chat (session) is opened, establishing a connection for text and multimedia exchange. This conversation does not close due to signal loss but instead awaits reconnection, resuming interaction without data loss. Similarly, sessions remain active even in regions where gaps occur. Moreover, as the terminal (mobile phone) moves, the connection to the proper/closer network is performed automatically. ATMACA operates similarly, as it automatizes connections and reconnections, as well as multilink selection.

The multimedia aspect mentioned can be valuable in the aeronautical context, where future communication innovations could include sending complete "routes" drawn on a map in image format, for example, to indicate taxiing paths. Numerous functionalities can be developed using this audiovisual communication concept. Regardless of their format, all exchanges will be recorded and available for consultation at any time, thanks to the session structure.

Session Management is a cornerstone capability of the ATMACA system, ensuring the establishment, maintenance, and seamless transition of flight communication sessions across all operational phases of air traffic management. It ensures:

- Presence information management,
- Sessions are initiated, maintained, transferred, and terminated efficiently,
- Real-time monitoring,
- Session continuity during disruptions, and
- Efficient handover mechanisms between roles and sectors.

The session-based system offers greater operational flexibility for ATCos, allowing them to group, transfer, replicate, or divide sessions or responsibilities. This enhances workload distribution and optimises airspace sector management and the operational environment.

3.3.2.4.3 Use case 3: Consistent and seamless datalink operations management featuring advanced HMI for pilots and controllers

ATM Applications over datalink are increasing in volume and scope, with multiple datalink services currently and under development. Manually handling datalink logon/off processes (Figure 9) and dealing with disconnections and discontinuities could increase pilots' and ATCos workload, if not handled properly.

With ATMACA, all data link services and applications are managed through a simple supportive interface for pilots and ATCos. Pilots and controllers will only need to open a session into the ATMACA system at the beginning of the flight or duty period. The system will automatically manage for them all logon/off, connections & disconnections across all required data link services with a unified and fluid digital HMI, as shown in Figure 10. The system automatically detects communication or service failures and resumes the connection as soon as possible without human intervention. This preserves data flow integrity and minimises downtime.

The session remains active throughout all flight phases, even during temporary signal losses. This means that, although a connection may be interrupted, the session persists and automatically resumes once communication is restored, eliminating the need for repeated manual authentications by pilots and air traffic controllers. Additionally, this continuity is independent of the access technology and data link service used, significantly benefiting long-haul flights (where communication technology changes frequently) and complex environments where switching between access technologies shall not disrupt service continuity. This functionality allows ATCOs not only to access individual messages but also to retrieve the entire flight context at any time, regardless of connection status, enabling better decision-making based on historical and real-time information.

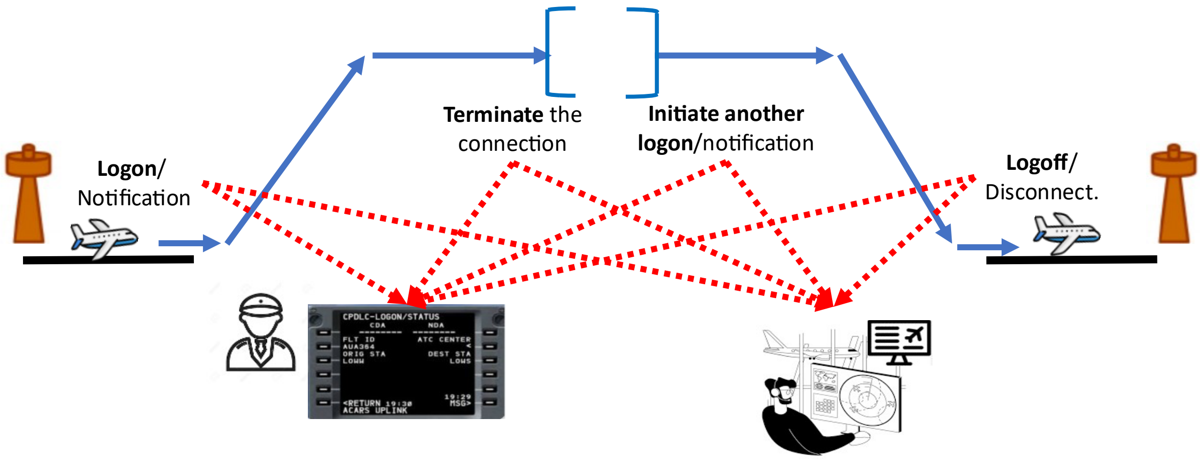

Figure 9: Manual handling of datalink logon/off processes

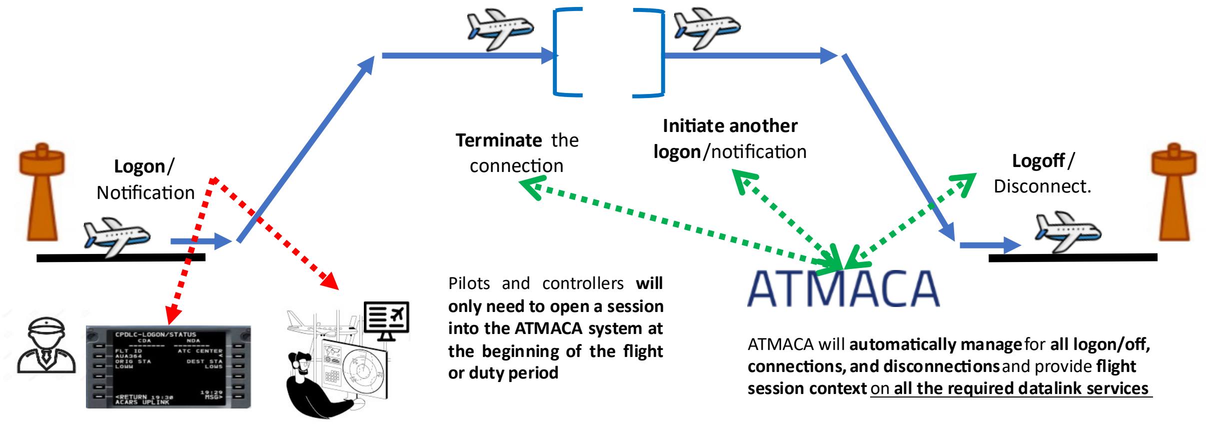

Figure 10: Automated handling of datalink logon/off processes in ATMACA

3.3.2.4.4 Use case 4: Trajectory Prediction and Trajectory Improvement for GRO

ATMACA will also promote the development of new data link applications such as GRO. The new ATMACA communication protocol and its Air-to-Ground instant text message capability will enable aircraft to share their own weather information (wind and temperature) with the ground units.

In particular, accurate real-time weather info will facilitate:

- Enhanced Trajectory Prediction.
- Trajectory planning improvement for a given FL.

This will result in better traffic flow management, reduction of holdings in TMA thanks to better ETA prediction (and therefore fuel consumption), and improved trajectory efficiency.

Enhanced Trajectory Prediction

The Extended Arrival Manager (E-AMAN) sequences traffic through the TMA entry point by Mach regulation. However, time uncertainty leads to aircraft holding to maintain safe separation in the sequencing process, as illustrated in Figure 11. This creates safety risk as well as increases fuel consumption.

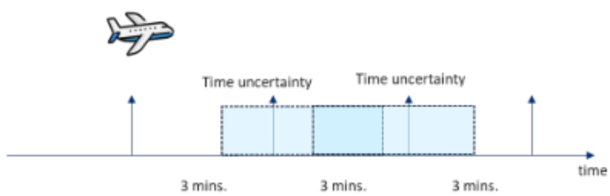

Figure 11: Uncertainty at TMA entry point

With ATMACA, information regarding the wind and temperature measured on board by aircraft that have previously flown over the TMA area is transmitted to the ground station. This information is used to update wind and temperature grids, and the updated grid information is transmitted to the aircraft entering the TMA. With this updated information, the onboard FMS computes a more accurate ETA to the entry point and sends this information to the ATC service through datalink. Improvement of the ETA at the entry point is used by the TMA for E-AMAN. ATC then produces a better sequence and communicates the associated speed regulation to the aircraft. This process is illustrated in Figure 12. Trajectory prediction is improved by continuously updating wind information using wind information from aircraft that have previously flown over the same airspace. Previous uncertainty is reduced, as well as holding and fuel consumption.

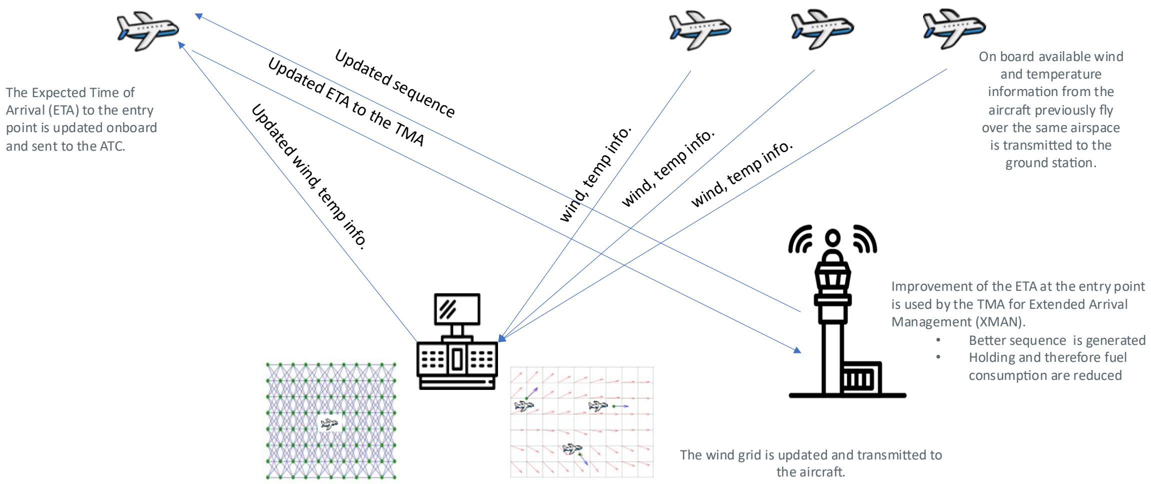

Figure 12: Enhanced trajectory prediction concept

Trajectory planning improvement for a given FL

In a free route airspace, aircraft on levelled flight have several alternative routes from an entry point to the exit point. Selection of the best route in each case is dependent on the availability and accuracy of wind information. ATMACA will improve the wind and temperature prediction in the airspace flown by the aircraft, thanks to the updated wind/temperature provided by surrounding aircraft over an air-ground datalink communication network. This updated prediction will be used by the trajectory planning algorithm to minimise the fuel consumption. Having a better wind prediction will help the algorithm to benefit more often from the tailwind along the route or reduce the headwind.

Onboard wind and temperature information from aircraft that have previously flown over the same airspace is transmitted to the ground station. The wind grid is updated on the ground and transmitted to the aircraft, where it is used to compute the fuel-optimal trajectory at each moment. The concept is illustrated in Figure 13.

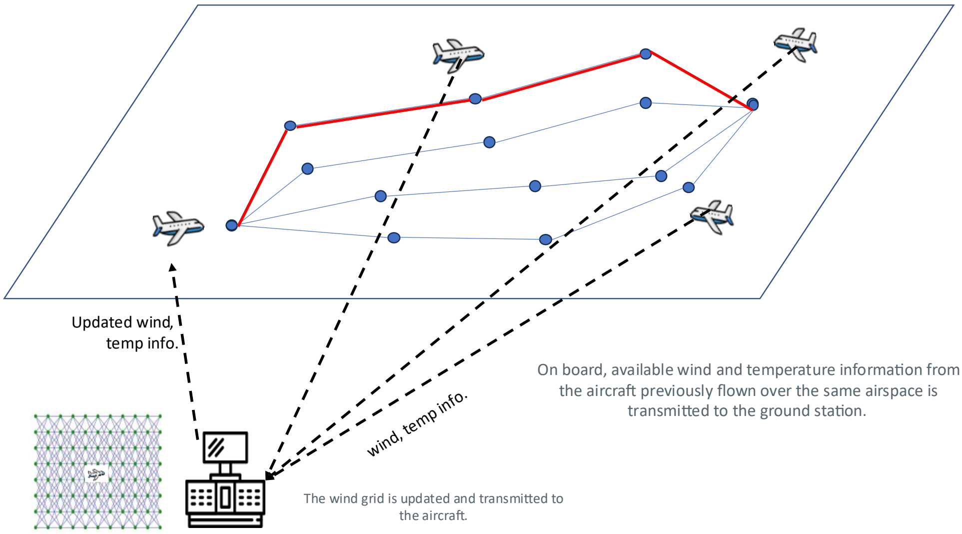

Figure 13: Trajectory improvement for a given flight level concept

3.3.3 Differences between the new and previous operating methods

There are several differences between the new and previous operating methods. These relate to the described use cases and ATMACA's new capabilities.

3.3.3.1 Previous Operating Method

ATCos have limited flexibility to transfer traffic and reallocate their workload. ATCos do not have the capability to coordinate with external ACCs for transferring sessions and merging roles. They also have fragmented flight data available from ATM and surveillance systems [27]. Moreover, current resilience in connection gaps is limited, having the flight crew to manually reestablish the communication.

Pilots have access to an increasing number of applications but must deal with them manually. This increases their workload, having to connect and disconnect from services during the flight. The type of data that can be transferred through current technology is also limited.

Current GRO applications integrate ground data without real-time information from the aircraft. Due to that, their accuracy and functionality are reduced.

3.3.3.2 New Operating Method according to Use Case 1 (Streamlined advanced ATC and communication handover)

In the new operating method (Table 7), the ATCo can transfer part or the entirety of the controlled flights to any airspace. ATMACA also provides additional context information through the flight session, which is essential for improving future ATC instructions. Automatically managing connection gaps in contingency scenarios ensures that connections are swiftly reestablished and no relevant information or messages are lost.

Business functions / business services[4] impacted by the SESAR solution	Current operating method	New operating method
Contingency events	Published Contingency Plans (CP), declaring TRAs if needed and absorbing the aircraft managed flying the affected ACC/FIR by adjacent centres. Information limitation affects the operational response. Geographical location affects reallocation flexibility.	Transfer traffic to other ACC or control flights through portable devices. Automatically manage connections to reestablish them. Neither information scope nor geographical location of the receiving ACCs limits the operational response.
Available information	Limited information, provided by surveillance systems and ATM available data.	All the information linked to the flight is available through the flight session, including communication history, clearances issued, and presence information.
Flight handover	Communication between controllers to authorise and monitor the process. Handovers restricted to geographical locations and operating method.	Seamless transition managed by ATMACA, including session responsibility, flight data, and data link communications. Independent of operating method (e.g., sector-based or FCA).
Workload reallocation	Highly limited workload distribution, reduced to local (e.g., intra ACC) operations.	Highly flexible reallocation of workload, allowing for session transfers through differentiated ACCs and area of responsibility. Geographical location is no longer a limitation.

Table 7: Differences between the new and the previous operating method – Use case 1

3.3.3.3 New Operating Method according to Use Case 2 (Fully flexible and customizable Flight Sessions Management)

ATMACA automatically handles connections, eliminating the need to manually manage each one. The instant message capabilities reduce the need for voice communication, allowing to easy transfer of many different types of information to other aircraft, applications or ATC. Furthermore, ATMACA's single session allows access to all the required services for each phase of the flight in a unified interface. These differences are shown in Table 8.

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Business functions / business services[5] impacted by the SESAR solution	Current operating method	New operating method
Pilot and ATCo communications.	Pilot and ATCos communicate through limited datalink or voice communications.	ATMACA instant message provides easy and improved communication, reducing the use of voice communication.
Information continuity.	Information provision is dependent on specific ATS or ADS.	ATMACA liberates information from specific providers, as well as from communications access technologies, enabling information availability along the whole operation in a seamless and automated manner.
Response to connection gaps.	Connection gaps are dealt with in a manual manner, requiring the flight crew to reestablish the connection. No communication nor clearance can be performed during gaps.	ATMACA automates the reconnection when facing gaps, eliminating the need for manual action. Moreover, flight data is conserved within the flight session, which remains active regardless of the connection status. Clearances can be issued during connection interruptions, which are stored and sent automatically after overcoming the gap.
Communications and data link services handovers.	Limited and fragmented transfer of aircraft data.	Flight session is completely transferred, which includes the control, A/G communications, datalink services and flight data. This transfer is performed as a whole and seamlessly.

Table 8: Differences between the new and the previous operating method – Use case 2

3.3.3.4 New Operating Method according to Use Case 3 (Consistent and seamless datalink operations management featuring digital enable HMI for pilots and controllers)

Through ATMACA's session pilots can access and automatically manage all the required datalink applications through the flight. The HMI reduces the workload and simplifies the process, presenting all the essential information related to the system in an optimal way.

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Business functions / business services[6] impacted by the SESAR solution	Current operating method	New operating method
Applications registration.	Manually registers into each of the applications needed during the flight.	ATMACA provides a single communication session, along with a single point of registration, eliminating the need for multiple logins.
Applications management.	Manually manages the applications to be used during the flight.	Automatically accesses and manages every application needed on each phase through a single session. This approach eliminates fragmented communication and ensures that handover between ATCos occurs seamlessly.
Communication IP assignments.	Non-consistent IP direction during the operation. Dynamic assignment depending on geographical area and connection technologies.	Single and unique IP for each aircraft operating, eliminating the need for continuous changes and mitigating possible operational issues.
Dynamic and particularized ATC HMI.	Reduced flexibility in session transfers includes role-restricted HMI.	ATC HMI dynamically adapts to role and responsibility changes, differentiating the relevant information and possible operations. Workload reallocations are seamlessly represented. Merging of domains is seamlessly represented, and each domain can be accessed both simultaneously and separated.

Table 9: Differences between the new and the previous operating method – Use case 3

3.3.3.5 New Operating Method according to Use Case 4 (ATMACA concept support for Trajectory Prediction and Trajectory Improvement for Green Route Features)

The new GRO improvements (Table 10) enable higher accuracy. This is made possible by the additional data that ATMACA can process in real time. This will improve trajectory prediction, minimising costs, fuel usage and environmental impact, as well as improving capacity and providing better weather information to all users.

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Business functions / business services[7] impacted by the SESAR solution	Current operating method	New operating method
Real-time wind, temperature and weather data	Ground systems rely on ground weather stations and voice communications are the only way to obtain some real-time data from aircraft.	Aircraft communicate to ground systems real-time wind, temperature and weather data.
Improved trajectory optimisation	Trajectories cannot be optimised in real time; the current systems allow only for minor improvements derived from ATC actions or use of Free Route Airspace (FRA).	Updated weather data is used to automatically calculate the trajectory and optimise it, providing a more accurate ETA and allowing for optimal Air Traffic Flow and Capacity Management (ATFCM) measures.
Improved meteorological model	Current systems use ground or satellite data to provide meteorological information to aircraft. This information is updated with a predefined frequency.	Additional aircraft data provides an improvement for real-time weather information provision to other users, optimizing operations with enhanced decision making.

Table 10: Differences between the new and the previous operating method – Use case 4

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4 Key assumptions

- **Operational assumptions**
  - Compatibility and interoperability: ATMACA will be fully compatible and interoperable with existing data link communication protocols. New CPDLC and DLIC implementations will use existing interfaces and will not cause disruption or reconfiguration of existing onboard systems. The ATMACA protocol and solution are assumed to be compatible with existing avionics and ground infrastructure, ensuring seamless integration.
  - Compatibility with legacy systems: ATMACA will allow backwards compatibility with legacy aeronautical communication systems.
  - Onboard hosting system: an Electronic Flight Bag (EFB) class 3 is assumed to be available onboard and ready to host ATMACA protocol, with the required data provisioned and/or relayed. If an EFB class 3 is not available, alternative hosting systems are assumed to be available onboard (e.g., a dedicated ATMACA unit). This will convey all required data, including weather, position, and intent. The system is assumed to provide continuous real-time data updates through interfaces with onboard avionics, including the Air Data System (ADS), Inertial Reference System (IRS), Global Positioning System (GPS), Global Navigation Satellite System (GNSS), and other relevant sensors.
  - ATC hosting system: A hosting system at the ATC level is assumed to be available and ready to host the ATMACA protocol, with the required data provisioned and/or relayed.
  - End user acceptance: pilots and controllers will find the protocol and associated Human-Machine Interfaces (HMIs) intuitive, easy to use, and operationally beneficial. This assumption is based on preliminary theoretical analyses and early consideration of pilot and controller workflows and needs. However, usability, intuitiveness, and acceptance by end users must be validated through comprehensive user-centred assessments at higher maturity levels.
  - Network availability and coverage: The ATMACA communication protocol is based on multi-link selection capability. The data-link communication protocols are assumed to ensure full coverage and reliable communication links.
  - Scalability assumptions: The protocol will support the increasing number of aircraft, ensuring scalability as air traffic demand grows, while also accommodating the expanding number of air traffic services and applications, both onboard and on the ground. Additionally, ATMACA will provide multi-platform support for different aircraft manufacturers and ATC systems.
  - Compatibility: ATMACA is compatible with COTS equipment, enabling easier adoption and compliance with existing international standards.
  - Gate to Gate operation: ATMACA solution enables effective, seamless, interoperable air-to-ground data link communication technologies and a digital flight monitoring and management environment for pilots and air traffic controllers through ATN/IPS within

all domains, including airports, Terminal Manoeuvring Areas (TMAs), as well as en-route and oceanic flight segments based on gate-to-gate philosophy.
    - SWIM and FCI: ATMACA solutions build upon SWIM and FCI, and it is fully compatible with them.

- **Safety assumptions**
    - Efficiency, reliability and redundancy: safety-critical data exchanges, such as ATC clearances, trajectory modifications, and emergency messages, will be prioritised and supported by failover mechanisms. The protocol will maintain a minimum safety-critical performance level.
    - Security: It is assumed that the protocol will integrate with existing communication security mechanisms, including encryption, authentication, and authorisation, to protect against unauthorised access and ensure data integrity. These mechanisms will comply with recognised aviation cybersecurity standards.
    - Integration: the protocol will coexist with safety-critical systems, ensuring no interference, degradation, or unintended alterations to existing avionics (both onboard and on the ground) systems such as collision avoidance systems, flight management systems (FMS), autopilot, etc.
    - Alignment with EASA standards and regulations: ATMACA will be fully aligned with EASA standards, ensuring that all developed technologies and protocols will comply with the rigorous safety and operational regulations set forth by the agency. This adherence guarantees that the solution not only meets the technical demands of future aviation but also maintains the highest levels of safety and reliability.
    - Protocol design: The protocol design is compliant with recognised aviation safety standards and is assumed to undergo comprehensive safety validation, risk assessment, compliance analysis and testing before deployment.

- **Performance assumptions**
    - Bandwidth: The protocol leverages existing implementations for dynamic link selection, bandwidth aggregation, and failover/recovery, ensuring seamless, efficient, and resilient connectivity. It is assumed that these existing implementations will provide satisfactory performance.
    - Real-Time communication: the protocol will maintain minimum safety-critical performance standards in all operational conditions and provide low-latency and high-reliability communication, meeting operational QoS requirements.
    - Data management: the protocol's mobility solution at the application layer uses SWIM. It is assumed that SWIM and the existing data management infrastructure will ensure consistent data synchronisation between onboard and ground systems, as well as real-time updates of aircraft data.
    - Fulfilment of safety critical requirements for air/ground information exchange: ATMACA will allow the uplink and downlink distribution of safety-critical information through services over the aeronautical telecommunications network/Internet protocol suite (ATN/IPS). ATMACA will comply with the SWIM purple profile for safety-critical information sharing: security, performance, safety, accessibility, maintainability and reliability.

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- **Other assumptions**
    - Regulations: It is assumed that the ATMACA solution is compliant with recognised aviation safety standards and is assumed to undergo comprehensive safety validation, risk assessment, and compliance verification, operational deployment.
    - Onboard hosting system: The onboard hosting system is assumed to be standalone and will not alter any existing systems or configurations. If any integration or alteration of existing avionics is required, it is assumed that such changes will undergo the appropriate certification and approval processes prior to deployment.
    - Human operational assumptions: It is assumed that both pilots and air traffic controllers will receive the necessary training to operate and interact with ATMACA systems as intended. Pilots and controllers are expected to adhere to standard operating procedures, maintain situational awareness when using ATMACA applications, and act on data link messages promptly. The introduction of ATMACA is not expected to alter existing roles or reduce human oversight in critical decision-making. It is expected that ATMACA will simplify certain operational tasks, reduce communication workload, and support more efficient information exchange between air and ground users.

5 References

5.3 Applicable documents

This OSED complies with the requirements set out in the following documents:

Content integration

[1] Common Taxonomy, ed. 01.00, 07/02/2023

[2] Content Integration – Executive Overview, ed. 00.01, 16/02/2023

Content development

[3] SESAR operational concept document 2023, 09/11/2023

Project and programme management

[4] 101167070 ATMACA Grant Agreement, 25/06/2024

[5] SESAR 3 JU Project Handbook – Programme Execution Framework

5.4 Reference documents

[6] EUROCAE ED-78A Guidelines for Approval of the Provision and Use of Air Traffic Services supported by Data Communications, December 2020

[7] ICAO Doc 9880, Manual on Detailed Technical Specifications for the Aeronautical Telecommunication Network (ATN) using ISO/OSI Standards and Protocols, First Edition - 2010

[8] ICAO Doc 9896, Manual for the ATN using IPS Standards and Protocols, 1st edition

[9] ICAO Doc 9750 (Global Air Navigation Plan for CNS/ATM Systems)

[10] ICAO Doc 10039 (Manual on System Wide Information Management (SWIM) Concept)

[11] ICAO Annex 10 (Aeronautical Telecommunications)

[12] ICAO International SARPs, Annex 11 Air Traffic Services, Fifteenth Edition – July 2018

[13] ICAO PANS ATM (Procedures for Air Navigation Services Air Traffic Management)

[14] Manual on System Wide Information Management (SWIM) Concept, Doc10039 AN/511

[15] EC Regulation no 29/2009 (Data Link Implementation Rule)

[16] Easy Access Rules for Air Traffic Management/Air Navigation Services (ATM/ANS) Equipment (Regulations EU 2023/1769 & EU 2023/1768

[17] Future Connectivity for Aviation – White paper

[18] PJ14-W2-100 Deliverable D7.2.120 "SWIM TI Purple Profile for Safety Critical InformationTS/IRS TRL4f

[19] SESAR 2020 PJ.14-W2-77 "FCI Services"

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[30] ATMACA-SESAR, Deliverable D2.1, Review of Current and Future ATM Communication Network, 2024

[31] J. Rosenberg, H. Schulzrinne, G. Camarillo, A. Johnston, J. Peterson, R. Sparks, M. Handley, and E. Schooler, "SIP: Session Initiation Protocol," RFC 3261, Jun. 2002

[32] V. Fajardo, J. Arkko, J. Loughney, and G. Zorn, "Diameter Base Protocol," RFC 6733, Oct. 2012

[33] S. A. Baset, V. K. Gurbani, A.B. Johnston, H. Kaplan, B. Rosen, J. D. Rosenberg, "The Session Initiation Protocol (SIP): an evolutionary study," in Journal of Communications, 7(2), 2012. https://doi.org/10.4304/jcm.7.2.89-105

[34] ICAO Annex 11 (Air Traffic Services)

[35] ICAO Doc 4444 (Air Traffic Management)

Appendix A. Stakeholder identification and benefit impact mechanisms (BIM)

A.1 Stakeholders' identification and expectations

The ATMACA project involves multiple stakeholders, each with distinct roles in air-ground communication, automation, and operational efficiency. The key stakeholders, their involvement, and their expectations regarding the ATMACA solution are summarised in the following table:

Stakeholder	Involvement	Why it matters to the stakeholder
ATCos - Tower / Approach	Tower ATCos could leverage ATMACA to have seamless, instant communications and streamlined AMAN procedures. In the ATMACA project, they will participate in testing and validation of ATMACA HMI solutions and provide operational feedback for session management and connection improvements.	ATCos need clear and uninterrupted communication to ensure operational efficiency and safety. The reduction of cognitive burden and improved situational awareness directly impact their effectiveness.
ATCos - En-Route	En-route ATCos could leverage ATMACA to have clear and seamless communications, session management, mobility management, and automatic hand over. In the ATMACA project, they will engage in evaluation of seamless session mobility and automatic handover mechanisms; contribute to defining user interface requirements.	Ensuring efficient communication and seamless handovers is critical for reducing risks associated with miscommunication, especially in high-traffic environments.
Pilots	Pilots could leverage ATMACA to have clear and seamless communications, automatic switch between ATCos in different sectors, and access to real-time weather data. In the ATMACA project, they will provide feedback on HMI usability and interaction; test real-time weather data	Pilots require reliable and intuitive communication systems to maintain situational awareness, ensure safety, and reduce in-flight distractions.

	integration and automatic communication handover.	
ANSPs, Airlines and Airports	ANSPs, Airlines and airports could leverage ATMACA to reduce fuel consumption and flight delays, also enhance trajectory prediction thanks to real-time weather data. In the ATMACA project, they may support the deployment and integration of ATMACA solutions in operational environments and help assess the impact on trajectory prediction and flight efficiency.	ANSPs, Airlines and airports benefit from reduced operational costs, improved flight efficiency, and better predictability in air traffic management.

Table 11: Stakeholders' expectations and involvement

A.2 Benefits impact mechanisms (BIM)

The ATMACA project employs several mechanisms to deliver the anticipated benefits to each stakeholder group. The following table outlines the key performance indicators and key performance areas that are going to be considered to assess the benefits of the solution.

KPI ID	Related KPA	KPI Definition
CEF1	Cost Efficiency (M)	Direct ANS gate-to-gate cost per flight
CEF2	Cost Efficiency (M)	Flights per ATCO-Hour on duty
CEF3	Cost Efficiency (M)	Technology cost per flight
HP1	Human Performance	Consistency of human role with respect to human capabilities and limitations
HP2	Human Performance	Sustainability of technical system in supporting the tasks of human actors
HP3	Human Performance	Adequacy of team structure and team communication in supporting the human actors
HP4	Human Performance	Feasibility with regards to HP-related transition factors
ENV1	Environment	Actual average CO2 emission per flight
FEEF1	Operational Efficiency	Actual average fuel burnt per flight

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TEFF1	Operational Efficiency	Gate-to-gate Flight time
PRD1	Operational Efficiency	Average of Difference in actual & Flight plan or RBT durations
PRD2	Operational Efficiency	The variance of difference in actual & flight plan or RBT durations
SAF1	Safety	Total number of estimated accidents with ATM contribution
DIGI1	Digitalisation	Digitisation
DIGI2	Digitalisation	Connectivity
DIGI3	Digitalisation	Data Sharing
SEC1	Security	A security risk assessment has been carried out

Table 12: Key Performance Indicators and Key Performance Areas considered in ATMACA

Hereafter is a high-level description of the BIM for each impacted Stakeholder. These benefit mechanisms might also be refined in the context of the different Validation Exercises related to the Solution.

The Benefit and Impact Mechanism consists of the measurement of different KPIs that will be calculated during validation exercises by comparing base scenarios with new scenarios.

The BIM diagram has been organised in columns:

Feature: Key functionality of the ATMACA solution
Changes: Short description of a change brought about by the related feature
KPI: Aspects which can be measured (or calculated from other metrics) to identify if the expected positive and negative impacts are realised. These need to be things that can be measured in the validation exercises.

KPA: The KPA, which is related to the Impact, as defined in the SESAR2020 Performance Framework

The arrows between the boxes show the relationship among the elements in the different columns

The green arrows in the KPIs column show the expected impact, applying the following code:

Arrow	**Indication**
	A beneficial increase
	A beneficial decrease

	A detrimental increase
	A detrimental decrease
	A change in the indicator, a positive or negative impact, is expected but with the current knowledge the direction is still not clear

Table 13: Impact indicators for KPIs

The following figures describe for each main stakeholder each change that is expected to take place because of the use of the solution, the variation for each KPI and the KPA (focus area) impacted. It is worth mentioning that the final OSED will contain the final benefits mechanism after the validation exercises' results are taken into consideration.

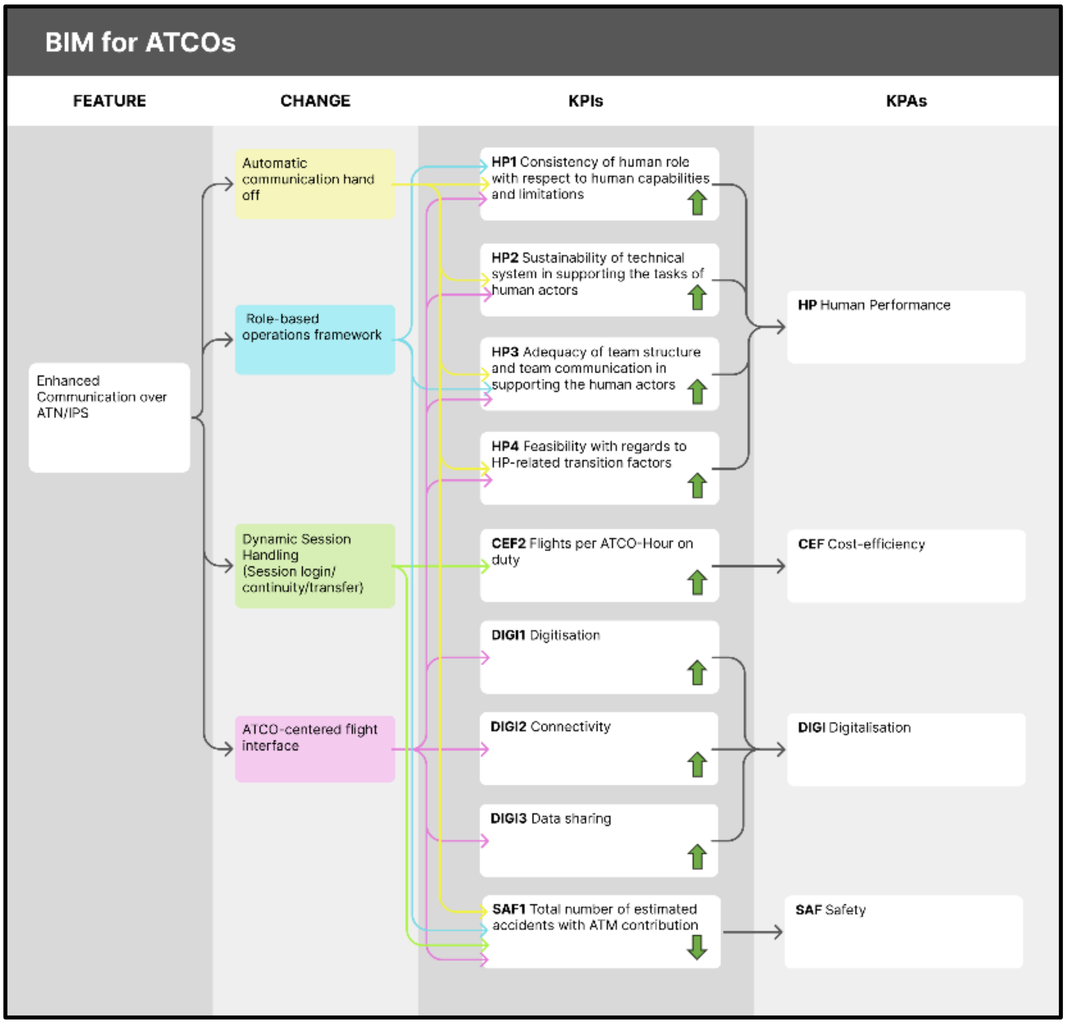

Figure 14: Benefit impact mechanism for ATCOs

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Figure 14 demonstrates the benefits of the ATMACA solution and the types of impacts they are expected to bring about for the ATCos. The key functionality of ATMACA that could be beneficial for ATCos is the enhanced communication over ATN/IPS. This would benefit the ATCos in terms of:

- Automatic communication handoff
- Role-based operations framework
- Dynamic session handling (session login/continuity/transfer)
- ATCO-centred flight interface

As a result, it is expected to make a positive impact on the KPIs: HP1, HP2, HP3, HP4, CEF2, DIGI1, DIGI2, DIGI3, SAF1, that would overall improve KPAs: Human Performance (HP), Cost-efficiency (CEF), Digitalisation (DIGI), Safety (SAF).

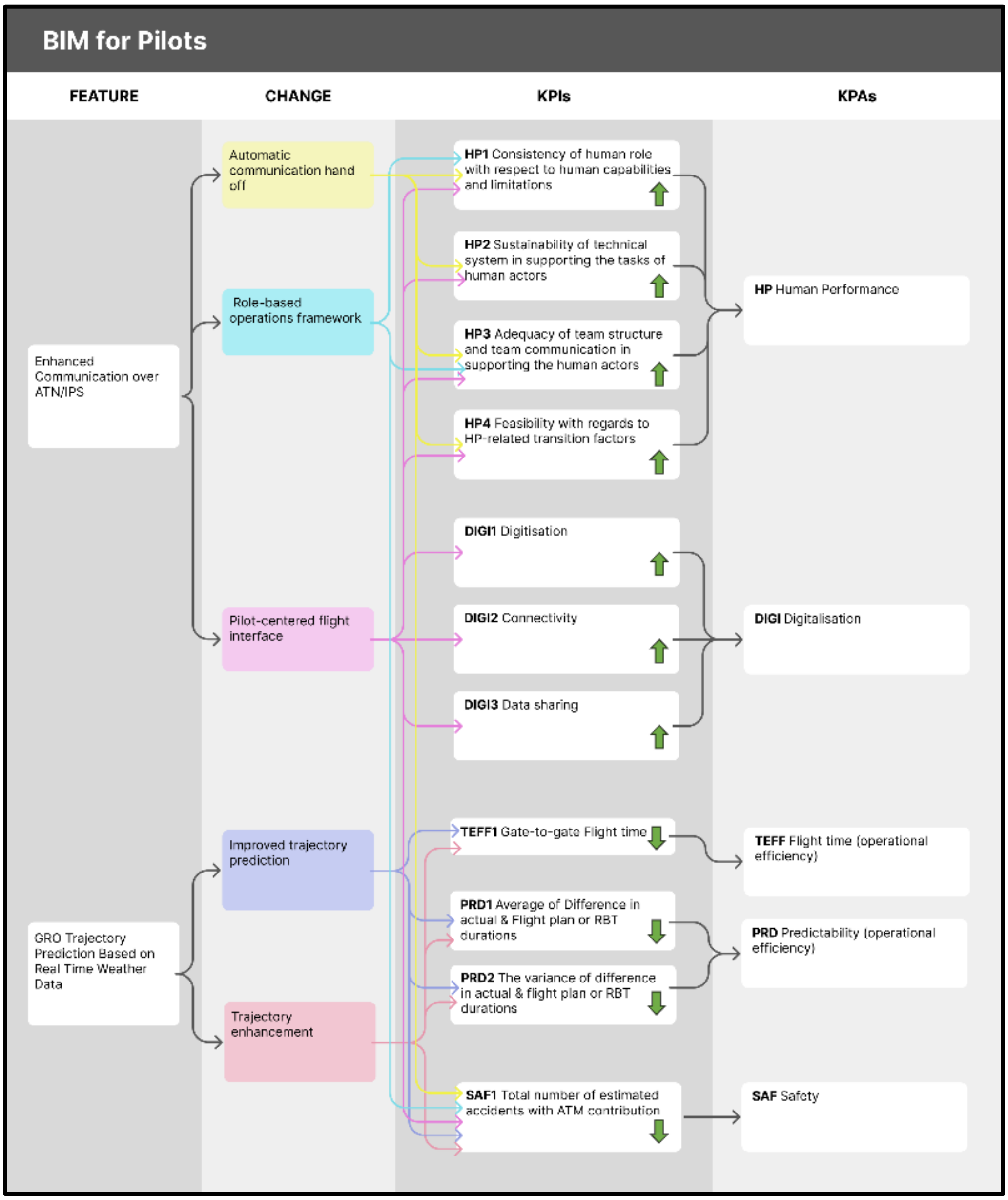

Figure 15: Benefit impact mechanism for Pilots

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Figure 15 demonstrates the benefits of the ATMACA solution and the types of impacts they are expected to bring about for the Pilots. The key functionalities of ATMACA that could be beneficial for Pilots are the enhanced communication over ATN/IPS and GRO trajectory prediction based on real-time weather data. These would benefit the Pilots in terms of:

- Automatic communication handoff
- Role-based operations framework
- Pilot-centred flight interface
- Improved trajectory prediction
- Trajectory enhancement

As a result, it is expected to make a positive impact on the KPIs: HP1, HP2, HP3, HP4, , DIGI1, DIGI2, DIGI3, TEFF1, PRD1, PRD2, SAF1, that would overall improve KPAs: Human Performance (HP), Digitalisation (DIGI), Flight time (TEFF), Predictability (PRD), Safety (SAF).

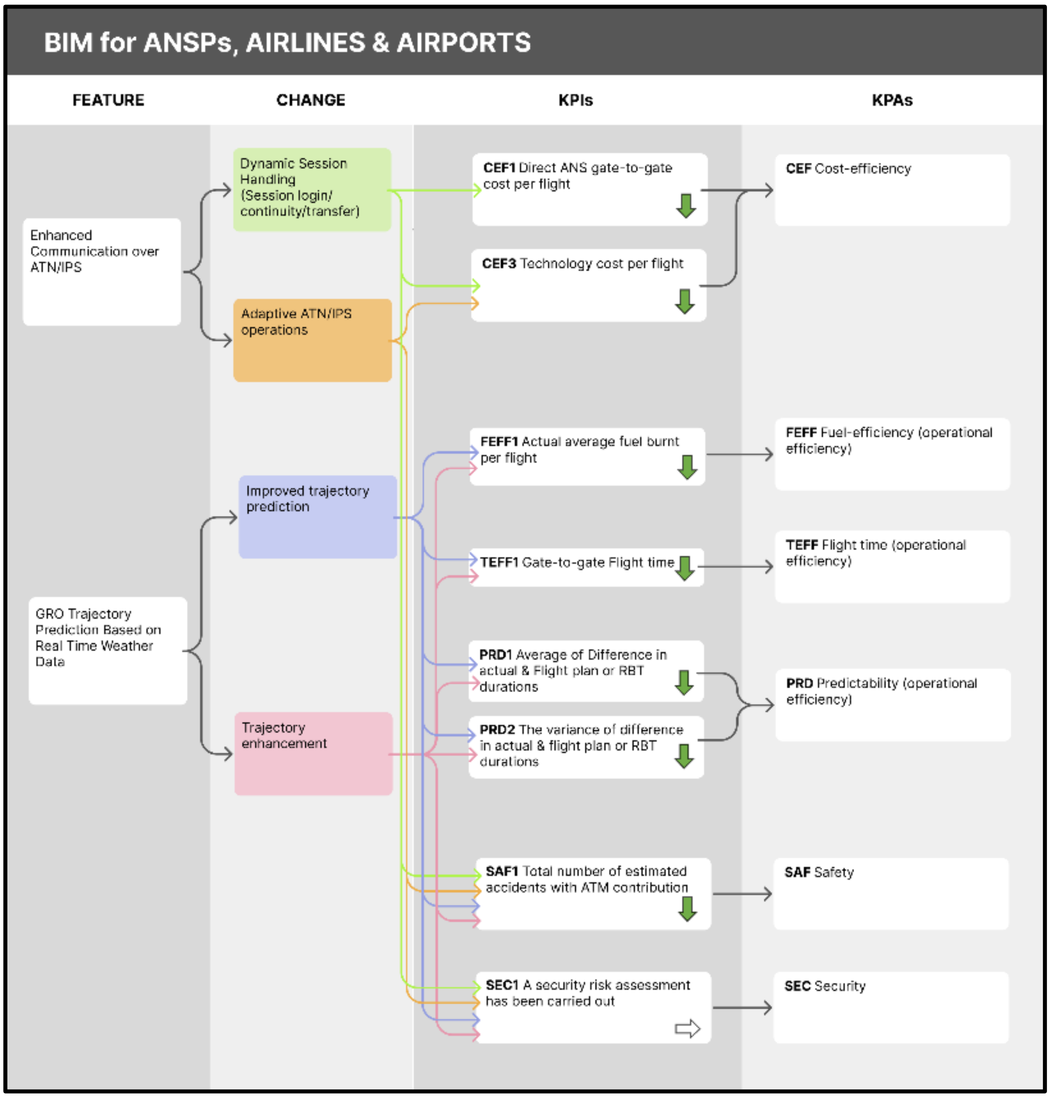

Figure 16: Benefit impact mechanism for ANSPs, Airlines and Airports

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Figure 16 demonstrates the benefits of the ATMACA solution and the types of impacts they are expected to bring about for the ANSPs, Airlines and Airports. The key functionalities of ATMACA that could be beneficial for ANSPs, Airlines and Airports are the enhanced communication over ATN/IPS and GRO trajectory prediction based on real-time weather data. These would benefit the AIR s, Airlines and Airports in terms of:

- Dynamic session handling (session login/continuity/transfer)
- Adaptive ATN/IPS operations
- Improved trajectory prediction
- Trajectory enhancement

As a result, it is expected to make a positive impact on the KPIs: CEF1, CEF3, FEEF1, TEFF1, PRD1, PRD2, SAF1, SEC1, that would overall improve KPAs: Cost-efficiency (CEF), Fuel-efficiency (FEEF), Flight time (TEFF), Predictability (PRD), Safety (SAF), Security (SEC).