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SAPIENT

SATCOM AND TERRESTRIAL ARCHITECTURES IMPROVING PERFORMANCE, SECURITY AND SAFETY IN ATM

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Abstract

The SAPIENT project addresses a new innovative application in the field of CNS/ATM system focusing exploitation of the synergies of Communications and Navigation technologies and the 4D trajectory management concept.

This document contains an executive summary of the SAPIENT project, including a short description of the activities performed for each project task, a concise analysis and recommendations and technical lessons learned.



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1 Project Overview

The SAPIENT solution is a multilink/data link monitor and control system. It is aimed at providing information on the aircraft perception of the operational layout effectiveness in order to correct or operate more effectively with respect to the ATM communication goals. The main objectives are:

- Support the multilink function during the selection of the optimal Datalink;
- Foresee retroaction on the in-use data link, and change the resources during the flight, according to information obtained through it and according to the information collected from the other SAPIENT system actors;
- Retroact on multilink function in order to change the priority between data links (i.e. need of load balancing in a common coverage area with traffic hot spots).

1.1 Project progress and contribution to the Master Plan and IR

The SAPIENT simulator development and the associated SAPIENT Verification activities have demonstrated that the implementation of the SAPIENT solution provides the following positive impacts on the ATM multilink environment:

1. Enhanced efficiency of the data-links management in a multilink environment, resulting in less resources needed by ATM communication system elements, with main focus on effective and efficient use of RF spectrum.

- The SAPIENT Project has proposed a system architecture that integrates the SAPIENT solution in a multilink environment. The SAPIENT architectural proposal is in line with the current SESAR outcomes, but at the same time, proposes a revised and innovative implementation. The SAPIENT simulation has demonstrated that the proposed architecture and the SAPIENT protocol implementation can increase the efficiency use of the data link, increasing the data link availability, integrity and continuity, thanks to a more effective use of the RF spectrum and its allocation to the proper number of simultaneous A/Cs served by the same data link. The optimized use of the data link resources will avoid traffic congestion and consequent loss of service.

2. Reduced Communication issues in the ATM air/ground communication minimizing the need of tactical interventions from ATC and pilots to de-conflict situations

- The SAPIENT solution providing higher service availability, continuity and integrity, will allow a more stable datalink communication. This will bring significant reduction of ATC and pilots communications to solve critical or no-nominal situation, therefore, reducing the traffic exchanges, and again, optimizing the use of the each data link available bandwidth.

3. Reduced Communication issues in the RPAS C3 satellite DL minimizing the use of RPAS safety procedure that will limit the execution of the RPAS missions

- Like for the manned case, the increase of the service availability, continuity and integrity that is derived from a more efficient use of the data link available resources, defined by the SAPIENT solution, will bring positive impacts also in the communication for the RPAS C3. The same SAPIENT architectural approach and protocol implementation can be applied for the RPAS case, implementing the due modification, deriving the same benefits identified for the manned case. Moreover, the



higher data link availability, integrity and continuity will produce a more stable data link connection reducing the risk and the need to apply safety procedure that may impact to the RPAS mission success.

4. Reduced Air Navigation Service cost providing a cost saving obtained by improving the Air navigation Service productivity and the L band frequency usage.

- The SAPIENT solution implementation, identifying an optimized use of the multilink through the integration of the SAPIENT solution, assuring a better use of the costly bandwidth resources, reducing the traffics congestion and data exchange latency over a single data link, assuring a more stable communication service, will allow to save costs related to no-nominal and safety procedures implementation and may be useful to increase the service capacity (i.e.; the number of A/C flying over specific airspace regions, supported by the ATM communication service), proving a possible benefits to the service providers and airspace user.

In the frame of the SAPIENT Project definition, these expected positive impacts have been translated in data link measurable performances, that have been assessed and verified with the **SAPIENT simulator tool**, in the frame of a dedicated the verification campaign.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
CNS-001A	Rationalization of CM system/infrastructure for Step 1	Identification of a new datalink quality monitoring strategy and related new protocol improvement in ATM environment that can include one single data link (i.e. VDLM2)	TRL0	TRL2
CNS-001B	Rationalization of CM system/infrastructure for Step 2	Identification of a new datalink quality monitoring strategy and related new protocol improvement in ATM a multilink environment (including two or more data links)	TRL0	TRL2

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CNS-001C	Rationalization of CM system/infrastructure for Step 3	Identification of a new datalink quality monitoring strategy and related new protocol improvement in ATM a multilink environment	TRL0	TRL2
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Table 1: Project Maturity

The SAPIENT project has provided a contribution, through the dissemination activities and dedicated teleconferences to:

- SESAR 2020 **Solution PJ.14-02-02**: Future Satellite Communications data link is focused on the near and long satellite data link technologies for both continental and oceanic regions. It will also include digital voice as an element of the Future Communications Infrastructure (FCI).
- SESAR 2020 **Solution PJ.14-02-04**: FCI Network Technologies incl. voice solution and 278 military interfaces seeks to develop and standardise the FCI elements that integrate all the future terrestrial data link systems viz. LDACS, SatCom and AeroMACS, delivered respectively by solutions PJ14-02-01, PJ14-02-02, and PJ14-02-06.

1.2 Project achievements

The main SAPIENT achievements can be divided in the activities described hereafter:

- **SAPIENT Solution benefits identification.** The definition of the intended objectives of the SAPIENT System and the justification of these objectives vs. the current prescriptions and the standards for ATM communications and their roadmap. The initial estimation of the achievable benefits from SAPIENT System.
- **Identification of appropriate Key Performance Indicators (KPI)**, suitable to quantify the quality of both the terrestrial (i.e., LDACS) and the satellite ATM air/ground datalink. In this task, all potential candidate KPIs were analyzed in terms of their measurability within the SAPIENT system architecture. Later just those KPIs with the highest potential regarding the assessment of air/ground data link performance were further evaluated. For each retained KPI the corresponding rationale was provided and KPIs, considered as being suitable for measuring and processing within the SAPIENT system architecture, were proposed and described in full detail. Moreover, the selection was guided by a comprehensive analysis of each candidate KPI regarding its possibility of measuring it at available (and accessible) SAPIENT system interfaces under real operational conditions.



- **Definition of the 4D-Tagging methodology and 4D-MAP protocol.** In order to support the SAPIENT solution, a new set of protocols and processes have been introduced. They will allow integrating the data obtained by dynamic monitoring and measuring of the performance of the ATM Air/Ground data links with the estimation of the 4D trajectory of the aircraft. The objectives were, thanks to the information collected, to support the multilink function during the selection of the next data link and generate a retroaction mechanism to ensure a continuous and secure communication between the aircraft and the air traffic controller. Then a set of functions that have the objective to associate a time, position and validity tag to the KPI information generated from the system's elements have been introduced and named "4D-Tagging process". Moreover in order to generate a four Dimensions Map of the area of interest that characterizes each point with the information needed by the aircraft to choose the most proper data link and to define how the information is exchanged, a 4D MAP (Multilink Administration Protocol) protocol has been defined.
- **Definition of the SAPIENT System Architecture:** starting from a general reference architecture, different options have been studied in order to evaluate different modalities to exchange the KPI information and to assess at which point of the architecture position the ML (Multi-Link) functions. As output of the trade-off activity, a reference SAPIENT system scenario both for Manned Aircraft and for Unmanned Aircraft has been identified.
- **Definition of the security requirements for the SAPIENT system,** starting from a threat modelling and risk evaluation activity. In particular, a clear distinction between the security requirements that the SAPIENT system has to fulfil and the security requirements that have to be fulfilled by the data links and infrastructure hosting the SAPIENT system have been identified. Starting from the security requirements, architectural solutions aimed at fulfilling those requirements have been identified. The SAPIENT packet structure aimed at guaranteeing confidentiality, integrity and data origin authentication according to an authenticated-encryption scheme has been defined. Furthermore, the employment of the Internet Key Exchange v.2 (IKEv2) for key exchange between SAPIENT components can be suggested. Finally, an early evaluation of performance of IKEv2 by means of the SAPIENT simulator has been performed. Simulations have shown promising results. In particular, they have shown that a proper choice of the packet retransmission time makes it possible to achieve a good trade-off between network traffic overhead and the probability of a successful security association establishment.
- **SAPIENT Solution Preliminary Verification.** The evaluation of the SAPIENT system benefits was done using the **SAPIENT system-level simulator**. First, the scenarios for the SAPIENT system performance assessment, leveraging partners and stakeholders expertise have been defined. Then the SAPIENT system has been simulated in the above scenarios, and compared to a baseline solution not employing SAPIENT. The results show that SAPIENT is actually able to improve the performance of the AEROCOM system (i.e., by increasing the availability,



distributing the load among neighboring cells, etc.), and that it has a tolerable cost in terms of overhead.

- **Communication, dissemination and exploitation activities:** a website (<http://sapient-project.eu/sju/>) has been defined to both introduce SAPIENT in terms of Project and Consortium, with a clean exposition of information and a readable text, and to use it as mean of performing dissemination activities publishing relevant deliverables. The SAPIENT Consortium has so far released 3 Newsletters, sent by email to an identified subscribers list, composed of contacts belonging to all target groups. Then a dedicated workshop, following SJU approval, was organized in Rome, at Thales head office, on 3rd July 2017 and all interested stakeholders, belonging to the First Target group, which includes ANSPs, AUs, ESA and SJU, were invited. Finally, two papers about SAPIENT will be presented during the 23rd Ka and Broadband Communications Conference and the 35th AIAA International Communications Satellite Systems Conference.

1.3 Project Deviations

The SAPIENT project has not implemented any remarkable deviation with respect to the scope and the objective described in the PMP. Anyhow, the link to the 4D trajectory needs further elaboration and verification/validation.

1.4 Project Deliverables

The following table presents the deliverables that have been produced by the project.

Reference	Title	Description
D1.1	Executive Summary	This document summarizes the whole project. It contains a brief statement of the project, description of the activities, concise analysis and main conclusions.
D1.2	Project Management Plan	It is the Project Management Plan.
D2.1	SAPIENT System objectives and target benefits	The document includes: 1) intended objectives of the SAPIENT System and justification of these objectives vs. current standards for ATM communications 2) initial estimate of the achievable benefits from SAPIENT System
D3.1	Evaluation of SAPIENT results and benefits assessment	The document is a techno-economic preliminary assessment including: key added value of the solution over the currently available technologies, preliminary estimation of OPEX/CAPEX, SWOT analysis, SAPIENT design and development plan
D4.1	Terrestrial and Satellite	The document includes:

	DL KPIs and Requirements for Measurement and Processing Issue 1	1) definition of the KPIs of terrestrial and SATCOM DLs 2) definition of the requirements for SAPIENT system requirements
D4.2	Terrestrial and Satellite DL KPIs and Requirements for Measurement and Processing Issue 1	The document includes the revision : 1) definition of the KPIs of terrestrial and SATCOM DLs 2) definition of the requirements for Measurement and Processing of the KPIs
D5.1	Contribution to D4.1	Contribution to D4.1 for: 1) Guidelines for KPI Measurement and Processing requirements allocation to SATCOM DL 2) Preliminary SAPIENT architecture identification 3) Definition of the SAPIENT System requirements
D5.2	Contribution to D4.2	Contribution to D4.2 for: 1) Guidelines for KPI Measurement and Processing requirements allocation to SATCOM DL 2) Revision of the SAPIENT System requirements
D6.1	Definition of KPI 4D Tagging and 4D-MAP protocols	The document includes: 1) Definition of the SAPIENT 4D-Tagging approach 2) Definition of the 4D-MAP Protocol
D7.1	SAPIENT System threat analysis and security architecture	The document includes the definition of threats, assessment risks and severity and identification of the security architecture
D8.1	SAPIENT System functional architecture design and justification	This document includes overall design of the SAPIENT functional architecture, definition of requirements for the SAPIENT system segments for ATM, voice and RPAS communications
D8.2	SAPIENT System external and internal Interface requirement definition and justification	The document contains the definition of the SAPIENT external and internal interfaces for ATM, voice and RPAS communications.
D9.1	SAPIENT simulator requirements	The document defines SAPIENT simulator objectives and requirements
D9.2	SAPIENT simulator architecture design and justification	The document defines SAPIENT simulator architecture and justify choices
D9.3	SAPIENT simulation plan and procedures	The document defines the plan and procedures for the simulation campaign
D9.4	SAPIENT Simulator execution report and resulting SAPIENT performance	This document summarises simulation results and cross-check them with respect to plans and procedures

D10.1	SAPIENT Dissemination and Promotion Plan	The document includes the plan for the dissemination activities to guarantee that dissemination and promotion are properly and effectively addressed to relevant end-users and stakeholders
D10.2	SAPIENT Project Website	Project website in order to promote activities and results
D10.3	SAPIENT user community dissemination outcomes	The document summarises dissemination activities and Communities feedbacks
D11.1	POPD – Requirement No. 2	This document contains detailed information on the informed consent procedures that will be implemented
D11.2	M - Requirement No. 1	This document contains further measures to prevent malevolent/criminal use of research findings
D11.3	POPD – Requirement No. 5	This document contains detailed information on the procedures that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation
D11.4	DU - Requirement No. 4	This document contains details on potential dual use implications of the project and risk-mitigation strategies

Table 2: Project Deliverables

1.5 Contribution to Standardisation

In the frame of SAPIENT WP6, the requirements of a new protocol for ATM communications over SATCOM DL (4D-MAP protocol) have been defined. At the current stage of maturity of the SAPIENT solution (TRL2), the protocol definition is not considered sufficient to effectively contribute to a standardisation process. Anyhow, once the SAPIENT protocol will be mature enough, it could contribute in the standards definition, in particular for the ones related to the ATM Multilink.

During the SAPIENT project execution no actual contribution to Standardization has been possible in view of the tight timings of the activities.

Indeed the need to start the process of dissemination and fertilisation of SAPIENT, even at its present relatively low TRL may now start and a first action will be put in place during Y17/Q4 with EUROCAE WG 82.

Further contributions and an action plan will be prepared towards Standardization WGs, during future activities, see also the section 1.6.

1.6 Project Conclusion and Recommendations

The SAPIENT Project has successfully defined at TRL 2 a Solution CNS/ATM, that aims at improving predictability, efficiency and performance of ATM Datalinks by monitoring and controlling in real time aeronautical Safety Datalinks tightly exploiting Trajectory based operation in Single European Sky according to 4D concepts.



The main conclusions that can be derived from the body of work and results achieved by SAPIENT Project are:

- The Project has confirmed the presence of a gap in the current definition of ATM Datalinks, in terms of real time awareness and knowledge of the actual achieved effectiveness and efficiency of Datalink resource allocation with respect to current and planned airspace capacity needs
- The project has proved the important role of a Solution to monitor and control ATM Datalinks in order to be proactively avoid or, at worst, mitigate through quick reaction any abnormal conditions in Datalink exploitation for Safety and Efficiency ATM CNS
- The project has highlighted the important role of a Solution to monitor and control ATM Datalinks, exploiting monitoring and control both local – by Aircraft means - and global – by Ground/System means
- The project has verified the important role of a unified set of KPI processed by all air ground datalinks to collect, disseminate and exploit 4D status information about the operation of Datalinks
- The project has focused the important role of a unified set of KPI for both manned and remotely piloted/unmanned aircraft flying not segregated in Single European Sky
- The project has emphasized the relevance that the SAPIENT Solution is defined, designed, verified and validated as an external “enabler” that complements transparently the capability set of existing and/or planned Datalinks, to effectively meet the QoS requirements of the CPDLC, ADS-C, AIS/MET and AOC applications in all relevant airspaces
- The project has shown the relevance that the SAPIENT Solution is defined, designed, verified and validated as an element of the Multilink Solution currently in definition as part of SESAR2020 P 14.2.4, to effectively meet the QoS requirements of the CPDLC, ADS-C, AIS/MET and AOC applications in continental airspaces
- The project has [directed attention to](#) the important topic that a the KPI enabled collection, dissemination and exploitation of Datalink 4D status information is able to improve the overall behaviour of ATM/CNS Datalinks in several abnormal conditions, such as frequency handover, Datalink cell overload, CNS/ATM application overload, etc.
- The project has given prominence to that the long term SATCOM service shall be interoperable with respect to the legacy services and to other future services, as soon as the same communication protocol is applied
- The project has generated the SAPIENT requirements and initial business case scenario
- The project has defined the unified set of KPIs to perform cost-effectively the monitor and control of ATM Datalinks and Multilinks

In order to consolidate the SAPIENT Solutions and to continue its verification, the following main recommendations are raised:

- To consolidate the coordination with SESAR 2020 CNS projects, to achieve mutual benefits from the information exchanges
- To identify and to interact with SESAR projects addressing Datalinks definition and Validation, in order to collect useful inputs, feedbacks and recommendations



- To improve and consolidate the technical design, focusing with priority on SAPIENT Solution CONOPS, Interface Requirements and Architectural Baseline definition, clarifying among the others applicability of the Solution to either or both ATN/OSI and ATN/IPS suites
- To consolidate the verification and validation strategy, by injecting more representative models of the datalinks and gathering feedbacks of the actual FOMs (Figure of Merit) of the Solutions, in order to have a formal input to CBA
- To improve cooperation and contribution with the European and not European standardization bodies (i.e. EUROCAE, RTCA, ICAO, etc.) to disseminate the Solution analysis outcomes, to retrieve benefits from the feedbacks of expert stakeholders and to keep track or influence the standardization evolutions

1.7 Technical Lessons Learned

The SAPIENT solution definition and the associated SAPIENT Verification activities, performed via SAPIENT simulator, have demonstrated that the implementation of the SAPIENT solution provide positive impacts on the ATM multilink environment, that have been translated in data link measurable performances that can be assessed and verified with the developed tool:

- **The integrity improves** by reduction of data losses (bit, packet or frame). The SAPIENT solution implementation should allow to reduce the Packet Loss Rate (PLR), the Bit Error Rate (BER) or the Frame Error Rate (FER) depending on the selected performance indicator and the applied protocol for DL, therefore it is expected an increased service integrity
- **The service continuity improves** with respect to a system not implementing the SAPIENT solution.
- **The service availability improves** with respect to a system not implementing the SAPIENT solution.

These technically measurable benefits have been derived and verified thanks to the:

- Definition of the ad hoc KPIs, that equal for the Satellite and Terrestrial data link
- Definition of the Reference architecture and internal/external interfaces to support the SAPIENT solution
- Definition of SAPIENT new protocol
- Definition and development of the SAPIENT simulator and specific test campaign execution

The SAPIENT solution has been able to demonstrate that previously technical improvements could be achieved with respect to the state of the art of the ATM communication.

The innovative aspects addressed in the SAPIENT Project are related to the TAS-I patent “System for Aeronautical Safety of Life Applications Providing Adaptation of Services and Communication Resources for Maximized Safety and Capacity Performance” [6] . Significant references for the ATM Datalink aspects are the activities undergoing in SESAR on VDL2 (VHF Digital Link Mode 2) [7] and other new generation digital datalinks and in ESA on Iris [8].



In addition, from the specific project execution point of view, the following main lessons have been learned:

- **Timely operation scenarios and high level architectures definition.** The Consortium has started the definition of the SAPIENT operation scenarios and high level architectures options, in advance with respect to the baseline planning, in order to properly allow the identification of the SAPIENT KPIs and their element originators in the ATM selected domains
- **Expected benefits consolidation.** The Consortium has revised the SAPIENT solution expected benefits list, thanks to the matured solution definition achieved only during the SAPIENT protocol and architecture definition. The expected benefits assessment has been repeated also at the end of the project in order to assure their coherence with respect to the better defined SAPIENT solution
- **Solution verification extended needs.** The Consortium has modified the planning for the SAPIENT simulator design, advancing the start of the SAPIENT simulator specifications in order assure the full execution of needed verification activities
- **Preliminary specifications need.** The Consortium has verified the need to properly define the SAPIENT system, protocol and simulator, providing a preliminary set of requirements that have been of major importance also to allow the traceability, guide the verification definition and allow the benefits assessment

The technical achievements matured in the frame of the current phase of SAPIENT Project should be further analysed in a possible future phase, mainly addressing:

- SAPIENT CONOPS and Use Cases. Addressing CA and RPA applications in civilian non segregated airspace, under 4D TBO
- SAPIENT Specification and Design. Improvement of the specification and of the algorithm(s) for the major applications (handover, overload, etc.)
- SAPIENT Interface Specification. Improvement of SAPIENT interfaces to selected Datalinks and Multilink architecture
- SAPIENT Simulation and verification. Improvement of the SAPIENT simulator in order to support an higher TRL achievement

A dedicated SAPIENT website has been set for dissemination purpose: <http://sapien-project.eu/sju/> [9].



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Appendix A Key Additional Information

N/A





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