Satellite Communications Data Link Solution for Long Term Air Traffic Management

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Abstract—Within the scope of ICAO AMS(R)S SARPs document [1], three classes (Class A, B and C) of communication performance requirements for Air Traffic Management (ATM) are being proposed by the EUROCONTROL NEXUS group to cover future oceanic as well as continental airspace operational needs. These classes will cover first trajectory-based operations (SESAR Step2/Class B), and later performance based operations (SESAR Step3/Class A), while maintaining compatibility with existing satellite communications (SatCom) systems for current time-based ATM operations in oceanic areas (SESAR Step1/Class C).

The objective of this paper is to introduce the (Class A) performance values that a SatCom system for ATM could be able to accomplish in supporting the most demanding SESAR services (i.e. Full 4D) in the Future Communications Infrastructure (FCI) for the long term. This SatCom system is considered a Communication Navigation and Surveillance (CNS) enabler, as expressed in the SESAR Master Plan document [2], focused mainly in providing support to communications services.

For this purpose, first are identified the long term service requirements, defined within the scope of SESAR P15.2.6 project. Then, performance values obtained after extensive simulations within the framework of the ANTARES (AeroNauTicAl REsources Satellite based) project [3], part of the ESA Iris programme [4], are presented. Within the ANTARES project, a new Communications Standard (CS) has been defined to cope with the Class A requirements, making use of innovative techniques to counteract the aeronautical mobile channel effects.

Finally, the test bed components to be put in place to verify and demonstrate the feasibility of the solution proposed [5], following the Verification and Validation (V&V) objectives stated in the SESAR P15.2.6 project are described [6].

I. INTRODUCTION

The Single European Sky ATM Research (SESAR) programme is defining, under the responsibility of SESAR Joint Undertaking (SESAR JU), the future European Air Traffic Management System (EATMS). Cockpit safety communications between air and ground are intended to move from voice to data to enable a greater capacity and safety. Data communication is expected to increase dramatically due to the new SESAR operational concepts and services (when passing from current time based operation to the future trajectory and then performance based operation). Central to the vision of future Air Traffic Management is the concept of 4D trajectory management, which drives the requirements for the Future Communications Infrastructure (FCI), notably with regard to service availability.

The use of initial 4D (i4D) will contribute to time based operations, where the focus is on predictability of the route flown by the aircraft and a controlled time of arrival. The trajectory data is obtained from aircraft by Air Control Centers (ACCs) using CPDLC (Controller-Pilot Data Link Communications) and ADS-C (Automatic Dependent Surveillance -Contract) services. The further benefit is an increased airport throughput due to the controlled time of arrival, which implies an increase on the Air-to-Ground (A/G) throughput and data link performances. Moreover, it is expected that soon the legacy A/G communication system in continental airspace will have reached capacity saturation. The EUROCONTROL NEXUS group has defined the Class B, in the Aeronautical Mobile-Satellite (Route) Service (AMS(R)S) Standard and Recommended Practices (SARPs) document, for a SatCom system to support these i4D needs.

According to the ATM Master Plan [2], there will be a further move from time based operations to trajectory/performance based operations, using data links. In the long term, a new A/G communication system will be needed, including a Class A SatCom system for performance based operations.

Voice will move away from being a control tool towards a time-critical non-routine and emergency tool, with the great majority of Air Traffic Control (ATC) instructions being issued by data link. For safety reasons, voice and data will not share the same physical medium, but will continue to be separated. However, voice will move from analogue to digital.

Full 4D operations will allow the use of multiple times of arrival, traffic synchronization and dynamic demand and capacity balancing for air traffic flow. Negotiated trajectories will lead to less interventions from controllers.

A Multi-link Communication System has been identified as the most feasible solution in which the new European ATM system can fulfil the performance requirements of the FCI in a cost efficient manner. Within this multi-link environment, SatCom is envisaged to be one of the multiple A/G Data Links (AGDL), working in parallel with terrestrial technologies (like AeroMACS and LDACS) in providing data communications for ATC and Air Operations Control (AOC).



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SatCom data link contributes to the improvement of SESAR JU capacity Key Performance Area (KPA), in particular to en-route capacity Key Performance Indicator (KPI). It will improve efficiency by allowing the implementation of full 4D operations, which will allow smaller separations between aircraft. SatCom data link, as enabler of the FCI, contributes to the other SESAR KPAs: environment (CO₂ emissions reduction), cost-efficiency and safety. SatCom data link contributes also to the ICAO KPA interoperability, facilitating air-ground data sharing.

The overall objectives of the SESAR Project P15.02.06 "Future mobile satellite communication" are to define the requirements for the future ATM aeronautical satellite communication system, to perform the complementary (to the ESA Iris Programme) activities of validation and to support the standardization of the new satellite link.

Iris programme is the European Space Agency (ESA) answer to the European Commission (EC) request to support SESAR programme in the definition of new A/G communication system for ATM. The ANTARES (AeroNauTicAl REsources Satellite based) project, part of the ESA Iris Programme, is aimed to study and design a purpose-built satellite data-link system to cope with the long term requirements. A new CS has been generated, as one of the main results from the project.

The structure of this paper is as follows. Section II introduces the long term service requirements driving the SatCom system technology needed for future ATM. These requirements have been defined within the scope of SESAR project P15.2.6, in order to be able to serve the most demanding full 4D services. Section III performs a description of the needed SatCom system architecture and boundaries. Section IV presents the performance values and limits reached within the framework of the ANTARES project, as part of the ESA Iris programme. These results have been obtained by analysis of the simulation results done to validate the CS defined for this purpose. Section V describes the test approach and the test bed demonstration means to be put in place to verify the feasibility of the solution proposed, as well as the mission requirements that are going to be verified within the SESAR P15.2.6 project. Section VI extracts some conclusions from the work.

II. SESAR LONG TERM MAIN DRIVERS

The starting point for the SESAR SatCom data-link V&V is the P15.02.06 SatCom Mission Requirement Document (MRD) [7], which will contain the expectations of all the involved stakeholders: Air Navigation Service Providers (ANSPs), airspace users, Communication Service Providers (CSPs) and regulators. The current version of the MRD has been developed in coordination by all P15.02.06 participants, airspace users and ESA.

SatCom mission requirements address a number of key areas aiming at achieving a balance between performance, safety and low cost. As the multi-link framework definition is ongoing, several assumptions have been made, in coordination with P15.2.4. While ongoing work in P15.2.4, performance requirements are preliminarily based on those stated in COCRv2 [8], which are expected to be the most stringent performances.

A. Data services

The nominal sizing of the SatCom system is based on a high air traffic growth (High A as defined in EUROCONTROL Long Term Forecast). The role of SatCom in each airspace, in particular in airport surface, is to be confirmed by P15.2.4. The nominal sizing must account for CPDLC and ADS-C used by all aircraft in oceanic airspace and for 30% of flying planes in all airspaces using AOC services.

The SatCom system is expected to include monitoring and reporting of performances and loss of service to the Multilink Operation Control Centre (MLOCC), in order to support the multi-link concept of seamless operation and selection of the best available A/G link in any situation, including time, location and duration of service loss.

Due to operational needs, the SatCom service must support two-way unicast ground/air and one-way broadcast/multicast ground/air data communications. It must support ATC applications & Systems (ATS) and AOC applications, but also Network Management applications and legacy ATS applications.

Safety usage entails demanding requirements in terms of delay, continuity, integrity and availability. These requirements drive both the choices for the communication protocols and the system design in terms of redundancy and design assurance level choices. Moreover, in terms of security the SatCom system must be transparent to security measures implemented at upper layers (e.g. IPsec) and must be protected against Denial of Service (DoS), data flooding attacks, maliciously crafted messages, signal replays, spoofing and masquerading and intrusions from terrestrial networks.

Moreover, the SatCom service must have the capability and sufficient storage to log, record, store and retrieve last 30 days of the records indicated by ICAO ([9] and [10], Vol. 2., Section 3.5). On request, it must be able to securely store any and all records in accordance with ICAO Annex 11 [9] Sec. 6.1.1.4 and ICAO Annex 10 [9], Vol. 2, Section 3.5.1.5. No time limit specified for the time to be stored, which must be performed using a non-proprietary format.

B. Voice service

Voice service must be supported for emergency situations in oceanic/remote space, moreover to data services (CPDLC and ADS-C). The requirement is to support voice calls, all with the same Quality of Service (QoS), a maximum initialization time of 100 ms, a latency lower than 485 ms (derived from ITU-T Rec. G.114) and good perceived voice quality, which means packet losses lower than 1% for most commonly used Voice over IP (VoIP) codecs (without voice packet concealment).

C. Aeronautical channel specificities

The SatCom mobile link must operate in the frequencies identified by ITU for AMS(R)S, allocated worldwide from 1545 to 1555 MHz (from satellite to User Terminal (UT)). The



SatCom system feeder links must operate in the frequencies identified for Fixed Satellite Services (FSS). The SatCom system must be resistant to known and unknown Radio Frequency (RF) interferences and intentional jamming. It must not interfere with other on-board services.

One of the main challenges for the system design is related to the low gain antenna on the UT side, with limited airborne terminal gain and power (to keep avionics cost low), jointly with the L-band aeronautical mobile propagation channel (characterized by multipath effects and fast degradations), the limited L-band spectrum resources (allocated in nonnecessarily contiguous chunks of 200 kHz), the support of aircraft mobility (with speeds up to 2.5 Mach) and any type of aircraft type under Instrument Flying Rules (IFR), either fixed or rotary-wing aircraft. In this sense, specific constraints are to be respected for the installation of UTs on-board aircraft, in terms of volume, mass, thermal behaviour and overall costs.

D. Scalability, Modularity, Reliability and Safety

The SatCom system must support world-wide deployment and coverage, site diversity and multiple satellite constellations, i.e. it must be a system without architectural restrictions in place, in order to provide the flexibility to support a variety of operational and business concepts (multiple ATC and AOC centres, airspace users, Communication Service Providers (CSP) and Satellite Service Providers (SSP)) and thus facilitate competition among service providers. It must be possible for one airspace to get service from multiple CSP simultaneously, one for ATS and another for AOC, moreover to get both from the same CSP. The SatCom system must support also an incremental deployment in parallel to legacy services. The service must be provided independently of the number of ground stations deployed in the coverage area. The SatCom service must be scalable to support an increasing number of aircraft equipped, according to the estimated equipage rate (4% per year after 2030 and until decommissioning of the service).

The SatCom service performance must not degrade during any element maintenance operations. The service must be provided on a 24x7 operational basis. Site diversity and satellite and Ground Segment (GS) element hot redundancy and real-time switch-over are required to meet the stringent availability requirements imposed on ATM communications systems. Seamless interoperability from the user point of view is a key requirement. Compliance to international standards by regionally deployed systems will enable globally interoperable services. Seamless handover between beams, satellites and satellite networks is therefore key to the proper functioning of the system. For example, bulk handover (switch-over), i.e. transferring all traffic in a beam or satellite, is important both to redundancy and interoperability issues in the system.

E. Networking Protocol Stacks and QoS

Finally, the SatCom system must assure interworking with the future Internet Protocol (IP) Suite based Aeronautical Telecommunication Network protocol stack (ATN/IPS), in compliance with ICAO 9896 document [11], and with the currently deployed protocol stack (Aeronautical Telecommunications Network / Open Systems Interconnection (ATN/OSI) [12]). For the schedulers in the SatCom system UT and GS to apply traffic prioritization and scheduling it is necessary to be able to derive QoS parameters for each incoming network layer packet. In the ATN/IPS case voice and data services require a differentiated treatment in terms of QoS, because of this, ATN/IPS must support different Classes of Service (CoS).

Note that the higher the granularity in the CoS defined in ATN/IPS for data services and CoS defined in [8], the higher the efficiency of the SatCom system in meeting the QoS requirements. However, CoS for data services are set by the end users originating the applications and therefore outside the SatCom system boundaries. Currently deployed ATN/OSI based services all use the same priority, so all the ATN/OSI network layer packets can be transmitted with the same priority on a best effort basis.

III. SATCOM SYSTEM DESCRIPTION

The future SatCom system is part of a multi-link system that will allow the aircraft to use the ATS and AOC safety services by a satellite link during the oceanic and remote flights, but also in continental airspace as the satellite A/G data link able to implement the Multi-Link Operation Concept (MLOC) with other terrestrial data links (LDACS and AeroMACS), as shown in Figure 1



Fig. 1. Future Aeronautical Communications (source: [13]).

Figure 2 presents the SatCom system physical and logical architecture and components, as well as its boundaries and interfaces (physical and logical) with the ATM network and the end users (ATC and AOC).

The SatCom system is composed of the three following segments:

• The Space Segment (SPS) is composed of several satellites carrying dedicated ATM payloads operating in



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Fig. 2. System reference model (source: [14]).

the AMS(R)S frequency band (L-band spectrum reserved for aeronautical safety services) in the mobile link, whilst either C, Ku or Ka frequency band is used for the feeder link. The SPS is expected to be a multi-beam system for the mobile link and a single beam for the feeder link.

- The Ground Segment (GS) that is mainly composed of three network entities:
 - Network Control Centre (NCC) that performs the control of the satellite network system resources and elements.
 - Ground Earth Station (GES) that provides the feeder link to the Space Segment and makes use of communication resources assigned to it to communicate with the aircraft, providing voice and data traffic services. The Air Ground Router (AGR) is part of this element.
 - Network Management Centre (NMC) in charge of the management of the overall SatCom system.

The Ground Segment elements support their interconnection through a terrestrial or satellite WAN (Wide Area Network), but the CS should allow the system to operate the user and control planes also without the need of a WAN interconnecting them, and without an external time or frequency reference for synchronization or coordination.

• The User Segment that is composed of the mobile UTs, which are the avionics equipment on-board the aircraft that implement the communication protocol and provide the interface to other on-board elements via an on-board network.

These elements are regarding the mission of the SatCom data link, moreover, the SatCom system has the control segment, with the SOCC (Satellite Operations Control Centre) for satellite control by the satellite operator, not shown, as it is not part of the data link mission.

The point of attachment of the aircraft network to the ground (that is the AGR) changes in some handover situations managed by Mobile IPv6 (MIPv6) [15] in the case of using the ATN/IPS protocol stack. A similar protocol is used in the case of ATN/OSI [5].

The AGRs are included at the SatCom system boundaries, while the Ground Ground Routers (GGRs) are located within

the European Air Traffic Management Network (EATMN), external to the SatCom system. Both routers must implement the Border Gateway Protocol-4 (BGP-4), as specified in [16], for inter-domain routing with ATN/IPS, with support of multiprotocol extensions as specified in [17].

The Airborne router (ABR), located at the aircraft, is the point of attachment of the satellite A/G data link. This element is considered outside of the scope of the SatCom system.

The SatCom protocol stack for the user plane is derived from the general protocol stack architecture for IP networking. The SatCom system is a Layer 2 network, bridging the terrestrial and airborne IP networks. Neither the UT nor the GES have any Layer 3 (L3) functionalities. Airborne L3 functionalities are implemented in the ABR.

Recommended aircraft node IPv6 address configuration method is the stateless auto-configuration method using a component of the Neighbour Discovery Protocol (NDP) [18], as it implies less satellite link message exchanges between the aircraft and the AGR, compared to a stateful address configuration (e.g. using Dynamic Host Configuration Protocol version 6 (DHCPv6)).

Regarding mobility protocols, the Home Agent (HA) in the AGR is a routing element in the Mobile Node (MN) home network which represents the MN while not attached to the home network. It maintains the registration of MN and the Care-of-Addresses (CoAs) that are currently being used by the MN. While the MN is away from home, the HA intercepts packets on the home network destined to the MN's home address and forwards them to the MN's registered CoA through an IP tunnel. Mobility management is based on MIPv6 [15].

For ATN/OSI mobility support, for legacy services, when interfacing the ABR or AGR, the SatCom system will use the Mobile SNDCF (Sub-network Dependent Convergence Function) for the use of Connectionless Network Protocol (CLNP) over ATN Mobile Sub-network [12], and the ISO/IEC 9542-ES-IS [19] routing information exchange protocol, for support of the route initiation procedures. ATN/OSI bases its mobility procedure on routing. A specific tunnelling mechanism termed IP SNDCF is defined for ATN/OSI applications over an IP network.

In this safety of life system, required performances for availability and continuity are challenging, even when shared with a terrestrial technology. Full system redundancy for this Geostationary Orbit (GEO) system is likely to require at least 2 operational satellites serving the coverage area simultaneously. Moreover, an operational payload is likely to include redundant transponders for every beam. At least a redundant NCC/GES is needed also for availability purpose. Integrated into the NCC/GES, several Communication Spectrum Monitoring agents (CSMa), duplicated for redundancy, one per beam, are envisaged for satellite failure detection and satellite carrier performance monitoring.

A GEO system covering all the Earth's surface visible gives inherent advantages for airlines flying inter-continentally. However, a main drawback with the choice of a GEO orbit is



the lack of coverage over high latitudes (i.e. North Scandinavia and Polar routes). In fact it is not possible to maintain a minimum 5-degree elevation above 74 degrees North. Coverage of high latitude airspaces under the responsibility of European countries is envisaged to be addressed by interoperable Medium Earth Orbit (MEO) or Highly Elliptical Orbit (HEO) systems (most cost-efficient).

IV. ANTARES PERFORMANCE ASSESSMENT

A CS is being prepared to be proposed as a global standard for satellite based ATM communications. This standard envisages seamless global service provision through enabling the interoperation of regional, compliant satellite systems. It also addresses key peculiarities of ATM communications such as needs for low user costs and high performances, particularly in terms of availability. The satellite-based CS is able to cope with future ATC and AOC communication needs, allowing seamless operation with terrestrial standards.

A. ANTARES CS description

The standard is envisaged to employ Asynchronous Code Division Multiple Access (A-CDMA) with an innovative Successive Interference Cancellation (SIC) in the GS, to mitigate the effects of Multiple Access Interference (MAI) on the return link (A/G). The random access nature of the return link access demands the definition of a Congestion Control (CC) mechanism, based on the estimation of the MAI, by measuring the noise rise, and identifying the real traffic load. The broadcast of this load information by the GS to the UTs allows return link transmissions control.

Figure 3 depicts simulation results of the received throughput and Packet Error Rate (PER) vs. the offered traffic in kbit/s in the return link for a configuration using a spreading factor (SF) of 4. Results show that the technique exhibits a high efficiency and achieves the target PER<1e-3.



Fig. 3. SIC performances for SF 4 & 2048 block (source: [3]).

The ANTARES CS has designed a waveform to counteract the effects of the aeronautical mobile channel impairments, introducing long interleavers (80 ms). It has been proved later that it is able to counteract too, with a small degradation, the specific case of the effects of the rotary blades masking period of commonplace helicopters (50 ms).

In the forward link, the standard uses Multi-Frequency Time Division Multiple Access (MF-TDMA) with linear modulations (MPSK) and several mechanisms to counteract the aeronautical channel impairments, such as channel coding (based on Irregular Repeat and Accumulate (IRA) Low Density Parity Check (LDPC) codes, intra-burst symbol interleaving (in order to exploit time diversity without impacting on latency) and adaptive equalization (taking advantage of pilot symbols). In particular, the forward link is intended also to employ Adaptive Coding and Modulation (ACM) based on link quality measurements (behaviour of the LDPC decoder) to ensure efficient spectrum use while maintaining required communication performance.

As the ATM communications are categorized as safety communications, the MODulation and CODing (MODCOD) selection prioritizes the link availability rather than the spectral efficiency optimization. Simulations considering different aircraft trajectories, which cover a wide range of propagation conditions, have been carried out to evaluate the performances of the forward link ACM mechanism. Results show that an average spectral efficiency between 1.7 and 2 bit/s/Hz can be achieved, improving a Constant Coding and Modulation (CCM) based mechanism.

BPSK 1/3 is used in the return link. MODCODs supported by the ANTARES CS in the forward link are reported in table I.

 TABLE I

 MODCODS SUPPORTED BY THE ANTARES CS FORWARD LINK [3]

Modulation	QPSK	8-PSK	16-APSK
Code rate	1/4, 1/3, 1/2, 2/3	1/2, 2/3	2/3

Simulations of the forward link receiver process have been carried out in different aeronautical channel conditions, in which the performances have been evaluated in terms of PER. Figure 4 presents the PER vs. E_b/N_0 curves for the most robust MODCOD (QPSK 1/4) in all identified aeronautical scenarios. Figure 4 shows that the system can guarantee the required PER performance (PER<1e-3) in any situation. The support of an Automatic Repeat reQuest (ARQ) protocol ensures that the continuity requirement is satisfied by triggering the retransmission of data that is not received by the UT or the GS.

1) Forward Link Multiple Access: The Forward Link Multiple Access (FLMA) intends to efficiently manage the multiplex of user and signalling traffic that the GS transmits towards UTs. It enforces the satisfaction of the QoS requirements for the ATM traffic profile as shown above in section II: latency (95th percentile delay) and continuity (related to Expiration Time), providing several levels of priorities using a

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Fig. 4. Forward link PER vs. E_b/N₀ for MODCOD QPSK 1/4 (source: [3]).

combination of Strict Priority (SP) and Earliest Deadline First (EDF) scheduling policies. Capacity assessment simulations have determined that the bandwidth (in Hz) necessary to fulfil the traffic QoS requirements depends on latency requirements. Figure 5 shows that all the services latency requirements are satisfied.



Fig. 5. Forward link delay cumulative density function for DG-D services.

Simulations with the emulation of real traffic situations over the European Civil Aviation Conference (ECAC) area were carried out to verify the fulfilment of the communication performance requirements and estimate the required spectrum. As an example, in a case of peak traffic in the ECAC area, around 13 carriers of 200 KHz were enough for the forward link.

2) Return Link Multiple Access: In the return link, based on A-CDMA, the capacity assessment has been done for SIC efficiencies from 70 to 95%. With a full frequency reuse factor, up to 10 carriers (200 kHz each) are required for the return link.

B. Reference satellite system performance

The following tables II and III provide reference values for the performance target that could be supported by the ANTARES satellite system. Performance values are provided for a 100 bytes and for a 1500 bytes network layer packet length.

TABLE II ONE-WAY LATENCY & CONTINUITY PERFORMANCE FOR L = 100B (L3 PACKET) (SOURCE: [13])

	FWD	RTN
TD95	0.5 s	1.0 s
TD99.9	1.0 s	2.9 s
PLR	$< 10^{-5}$	$< 10^{-5}$

TABLE III ONE-WAY LATENCY & CONTINUITY PERFORMANCE FOR L = 1500B (L3 PACKET)(SOURCE: [13])

	FWD	RTN
TD95	0.6 s	2.1 s
TD99.9	2.1 s	3.5 s
PLR	$< 10^{-5}$	$< 10^{-4}$

Tables II and III values are derived based on simulations with ANTARES traffic profile, based on COCRv2 [8], considering nominal load conditions, without header compression. Packet Loss Rate (PLR) refers to % of discarded network layer packets. Network layer packets are discarded if one-way delay exceeds either 5 s for table II or 8s for table III.

V. LONG TERM SATCOM VERIFICATION APPROACH

Operational implementation of full 4D trajectories and associated infrastructure is envisaged beyond 2028, but verification and validation activities must be carried out in a much shorter time frame to enable the execution of required development and certification activities (by ICAO and EUROCAE/RTCA), in particular for the service provision.

UT development and airworthiness certification are on the critical path in terms of the time required before an associated service can be made operational. Final certification of the service will require the usage of the operational systems [20], but the boundaries of the P15.2.6 verification activities go up to the network layer (layer 3), not the applications. Although some user tools can be used for the verification, they will not be verified by P15.2.6.

The reference of SESAR P15.02.06 for the system verification is the European Operational Concept Validation Methodology (E-OCVM) [21], in particular the V2 and V3 phases. The E-OCVM is used to create the link between research and its application in operational use. It provides general guidelines for research and development rather than a strict set of rules.

The E-OCVM approach, as defined by SESAR Programme, is flowed down to the Iris Programme in charge of Sat-Com data link development ensuring compliance according to SESAR P15.2.6 MRD [7]/ICD needs [14].



The E-OCVM maturity levels can be mapped to the Technology Readiness Levels (TRL) proposed by NASA, as shown in Table IV.

TABLE IV VALIDATION METHODS AND E-OCVM LEVEL VS. TECHNOLOGY READINESS LEVELS (TRL) (SOURCE: [22])

Method	E-OCVM	TRL
	Level	
Literature	V1	TRL 1: basic principles observed and re-
Study/Prior		ported
work		
Analysis	V1	TRL 2: Technology concept formulated
and		
Inspection		
Judgemental	V1	TRL 2: Technology concept formulated
Tech-		
niques		
Fast-Time	V2	TRL 3: Analytical & experimental critical
Modelling		function or characteristic proof-of-concept
Prototyping	V2	TRL 4: component/subsystem validation in
		laboratory environment
Real-Time	V3	TRL 5: system/subsystem/component valida-
Simula-		tion in relevant environment
tion		
Shadow	V3	TRL 6: system/subsystem prototyping
Mode		demonstration in relevant E2E environment
Trials		(ground or space)
Live Tri-	V3	TRL 7: System prototyping demonstration
als		in an operational environment (ground or
		space)
Operational	V4/V5	TRL 8: Actual system completed and "mis-
Systems		sion qualified" through test and demonstra-
		tion in an operational environment (ground
		or space). TRL 9: Actual system "mission
		proven" through successful mission opera-
		tions

Starting from the results of the Iris Programme, any further verification need to be met, including verification against the MRD [7], will be performed by the SESAR P15.02.06, which will carry out the verification exercises in order to assess the MRD compliance of the SatCom data link, in particular, some verification tests with SatCom integrated within the EATM (European Air Traffic Management) Network, avoiding the repetition of stand-alone tests already performed within ESA Iris Programme.

In order to ensure MRD compliance by the Iris Programme, the P15.02.06 shall define a high-level V&V strategy describing the objectives to be pursued and the activities to be undertaken in the V2 and V3 phases, although V3 test execution, test reporting and V3/V4 transition evaluation are out of scope of P15.02.06. P15.02.06 is a system development project and for this reason operational validation is not in the scope of the project, which will be focused on the system technical verification. Validation, i.e. the confirmation that the proposed solution satisfies stakeholders' needs, is responsibility of the SESAR operational projects (WP4, WP5 and WP6).

In the context of the Iris Programme and the ANTARES project a combination of in-lab and on-flight verification test beds will be developed to demonstrate the E-OCVM V2 and V3 phases maturity levels.

A. V2 phase

The V2 phase deals with the feasibility and depends heavily on analysis, modelling and simulation (fast and real-time, i.e. emulation), and may include some initial prototypes and emulators (CS Verification Test Bed (VTB)). Performance, interoperability and coverage aspects are the primary concerns. The CS VTB is developed within the ANTARES project and it is currently in the Assembly, Integration and Test (AIT) phase.

In V2 phase, simulation is expected to be used to verify by analysis the QoS in the target coverage area, the inter-system and intra-system handover procedures, the early return link SIC mechanism with voice and data traffic and the support of new services. This requires the V2 test bed to implement the SatCom system CS and the possibility to perform complete, but also reduced coverage area traffic processing simulations, assuming the most demanding performance. Logon avalanche simulation support is required to the V2 test bed in order to analyse whether the SatCom service can accept the logon of all equipped aircraft during all flight phases over the coverage area. Jamming signals simulation is also required to the V2 test bed in order to check that the service provision can be performed in presence of RF known and unknown interferences. Integrity computation and reliability and availability computation and simulation are features also required to the V2 simulation test bed, to check whether the SatCom service can be provided with the required integrity, availability and reliability.

Emulation is expected to be used in V2 phase to verify by test the provision of the SatCom service to the UT, which requires the full implementation of the CS. In order to calculate the performance associated to the provision of data link services, i.e. latency (TD95) and continuity, packet capture and analysis capabilities are required to the V2 emulation test bed. Voice quality testing capabilities are required to evaluate the performance in the provision of the voice service: latency and set up time for voice resources. The V2 emulation test bed must support ATN/IPS, ATN/OSI and multicast protocols.

Finally, certain requirements to be validated in V2 by analysis and tests require the implementation of SatCom system elements prototypes, like an UT with management functions. A prototype of the network management and monitoring system is required to verify the provision (real-time and off-line) of statistics on traffic and service performances, including a spectrum analyser to check the performance impact of RF interferences, which leads to the need of a jamming generator/emulator.

The next V2 tests are foreseen for integration into SESAR Releases for 2015/2016: data and voice performance requirements evaluations, taking special care of the SIC mechanism behaviour, protection from corruption tests and required coverage compliance.

B. V3 phase

The V3 phase deals with pre-industrial development and integration and it aims to progress on the verification by preparing the transition of the SatCom system from research



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to industrialization. Verification in this phase is mainly concerned with interface and integration requirements. It requires pre-industrial prototypes and representative system platforms. It includes the use of real-time simulations and shadow mode/live trials, allowing exposure to representative operational context environments to evaluate the Required Communications Performance (RCP), excluding availability.

The next V3 tests are foreseen for integration into SESAR Releases: compliance of the external interfaces to the ICD [14] (reporting all the standards necessary to assure the interoperability with the EATMN), the compliance of the SatCom MRD [7] data link performance parameters from AGR to ABR (up to the network layer) in terms of transfer delay and continuity, including the evaluation of the final version of the return link SIC mechanism, the analysis of the availability and integrity of the service, the compliance to coverage requirements, the verification of lack of interferences to external aeronautical systems and the verification of the possibility of handover to other AGDLs (to be fully verified by P15.2.4).

C. Considerations for V4/V5 phases

Certification of service providers is completed in V4, while validation performed in V5 is related to the final SatCom system to be deployed in the context of the large scale demonstrations proposed within current and future version of SESAR ATM Master Plan [2] (both phases are out of scope of SESAR). The SatCom system prototypes used in V2 and V3 should be developed with certification in mind (EASA Airworthiness Certification), especially regarding the aeronautical UT and SW Assurance Levels (SWAL), so they could be reused in subsequent phases, but DAL E would be enough for the test beds components. Because of this intended later reuse, the verification infrastructure must be built so it can be scalable to the full availability and capacity case. Regarding certification, each aircraft equipped with SatCom must be certified. Certification process and requirements will be further clarified by the ATM SatCom Safety Board roadmap for V&V.

VI. CONCLUSION

In the frame of SESAR P15.2.6 it has been proposed a SatCom system as a CNS enabler, as expressed in the SESAR Master Plan document [2], focused mainly in providing support to communications services. In this sense, the long term requirements driving the SatCom system selection have been summarized, then it has been shown a description of the SatCom system, including external interfaces and boundaries.

The paper also shows performance results compliant with the long term requirements presented, for a new and innovative satellite-based Communications Standard, which is the result of the ANTARES Project, the design Phase B of the ESA Iris Programme. This demonstrates SatCom technology feasibility to fulfil the required performance, by using seamless handover, a flexible architecture for the ground segment and advanced techniques such as Congestion Control (CC) and Successive Interference Cancellation (SIC) in the return link. Finally, the validation approach proposed for the SatCom system has been described, which is based on the E-OCVM methodology for V2 and V3 phases, as defined by the SESAR Programme.

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