

SESAR P15.2.6 – SESAR Innovation Days

SATELLITE COMMUNICATIONS DATA LINK SOLUTION FOR LONG TERM AIR TRAFFIC MANAGEMENT

EUITA, UPM | Madrid | November 25th, 2014



INDEX

00 Introduction

01 SESAR Long Term Main Drivers

02 SatCom System Description

03 ANTARES Performance Assessment

04 Long Term SatCom Verification Approach

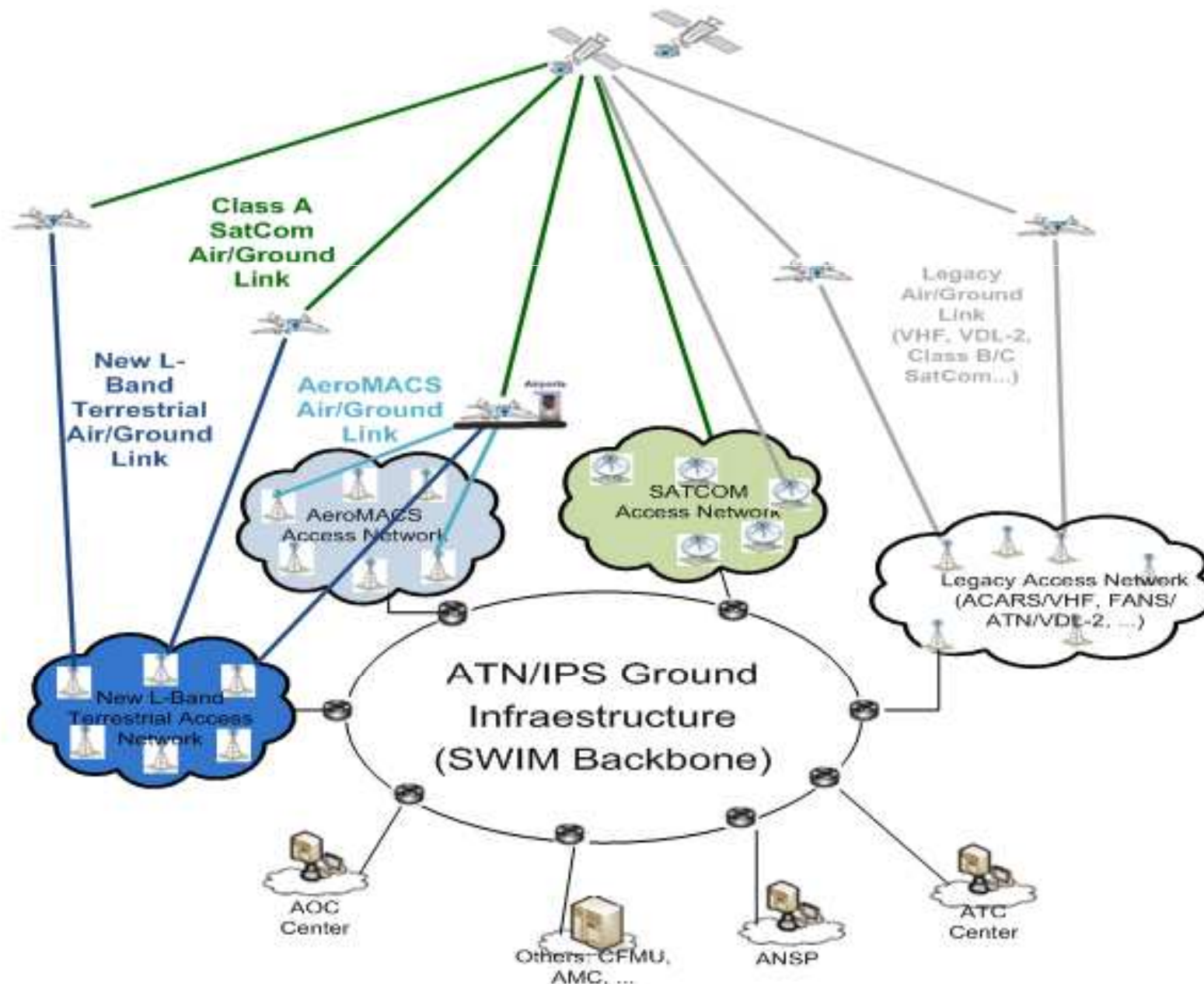
05 Conclusions

06 Long Term SatCom Technology Evolution

INTRODUCTION - BACKGROUND

- The Future Communication Infrastructure (FCI) of European ATM System is currently being defined by SESAR
- Due to the forecast of **growth** in worldwide air traffic operations, there is the need to evolve from voice based communications towards data links between the aircraft FMS and the ground ATC and AOC systems
- A **multiple link** solution is found necessary to guarantee the required availability, due to safety requirements, in the continental airspace.
- The multiple link is expected to include a terrestrial and a **satellite-based component**. The details of the multi-link concept (whether to apply load balancing when both links are available or to have the second link just in stand-by mode, etc.) are under definition by SESAR

INTRODUCTION – THE MULTI-LINK CONCEPT



INTRODUCTION – OBJECTIVES

- Assess the **feasibility** of using a SATCOM System for ATM in continental airspace operations and provide design options, describing the Communication Standard to use and the System Architecture, allowing seamless operation with terrestrial communication standards used for ATM
- Demonstrate the **capacity** of the SATCOM technology to fulfill the short term “i4D” and long term “Full4D” ATM service performance requirements, granting its **competitiveness and harmonizing** also medium term transition in front of other solutions.

INDEX

00 Introduction

01 SESAR Long Term Main Drivers

02 SatCom System Description

03 ANTARES Performance Assessment

04 Long Term SatCom Verification Approach

05 Conclusions

06 Long Term SatCom Technology Evolution

SESAR LONG TERM MAIN DRIVERS (I)

■ Data Services

- Two-way unicast ground/air data communications
- One-way broadcast/multicast ground/air data communications

- **Communication Performances (QoS) preliminarily, based on COCRv2 (FAA & EUROCONTROL), updated with 2010 forecasts**
 - Most stringent performances for data communications
 - Latency (TD95 and messages sizes => bit rate, capacity)
 - Continuity (ET) => Need for ARQ, PER<1e-3
 - Availability (no single point of failure)
 - Integrity (CRC-32)

SESAR LONG TERM MAIN DRIVERS (II)

■ Voice Services

- The SatCom System must support **data applications** mainly, but also **voice for emergency** situations
- **Communication Performances (QoS)**
 - Maximum initialization time 100 ms
 - Latency < 485 ms (ITU-T Rec. G.114)
 - MOS 4 => PER < 1%

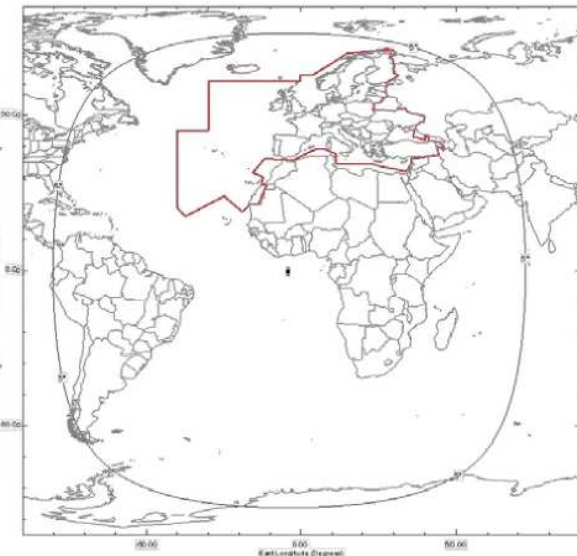
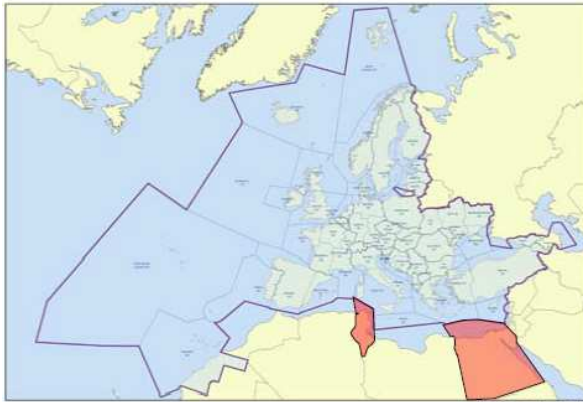
■ Frequency Bands

- The SatCom mobile link must operate in the frequencies identified by the ITU for Aeronautical Mobile Satellite (Route) Service (**AMS(R)S**), allocated worldwide in L-band, from 1545 to 1555 MHz (from satellite to UT) in non-contiguous chunks of 200 kHz
- The System feeder links must operate in the frequencies identified for Fixed Satellite Services (**FSS**) (e.g. Ku band)

SESAR LONG TERM MAIN DRIVERS (III)

■ Aeronautical Channel Specificities

- The System is applicable to **all aircraft** flying under IFR, fixed and rotary wings
- It must support aircraft **mobility** (with speeds up to 2.5 Mach)
- **Coverage**
 - European airspace, including EUROCONTROL and EU Member States as a minimum
 - Extended coverage to Northern areas under European responsibility
 - Optional AOC services over a broader area over the Ocean and/or over Africa



SESAR LONG TERM MAIN DRIVERS (IV)

■ Scalability, Modularity, Reliability and Safety

- 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, EUROCONTROL High A Long Term Forecast)
- The system shall be **modular**, enabling interchangeability of constituents for a high availability
- The system shall have **redundancy**, real-time and seamless switch-over and handover and fault tolerance of critical constituents (single point of failure avoidance)
- System shall not generate harmful **interferences** and shall be resistant to RF interferences and intentional jamming
- **Independent** of navigation information (no need of GPS information)
- The service performance must not degrade during any element **maintenance** operations
- The service must be provided on a **24x7** operational basis
- The **cost** of the service must be **minimized**

SESAR LONG TERM MAIN DRIVERS (V)

■ Networking Protocol Stacks

■ Protocol Stacks

■ ATN/OSI

- Current network protocol

■ ATN/IPS

- Future network protocol (IPv6)

- The Communication Standard must be Open to be endorsed by ICAO

■ Monitoring and reporting capabilities

- There must be monitoring, **logging** and reports generation capabilities at all network elements (UT, GES, NCC, NMC) of communication performances (latency, availability, integrity and continuity) for at least **one year** using a non-proprietary format
- Loss of service reporting to the Multi-link Operation Control Centre (MLOCC), in order to support the **multi-link** concept of seamless operation and selection of the best available link in any situation, including time, location and duration of service loss

SESAR LONG TERM MAIN DRIVERS (VI)

■ Accounting capabilities

- Usage based billing
- Detailed accounting functions
 - Voice calls duration
 - Number of bytes transferred per UT and CoS (Class of Service)

■ Security

- Transparent to upper layers security measures (e.g. IPsec)
- Protected against
 - Denial of Service (DoS)
 - Data flooding attacks
 - Maliciously crafted messages
 - Signal replays
 - Spoofing and masquerading
 - Intrusions from terrestrial networks

■ Environmental impact

- Minimization (e.g. preference for low drag antennas)

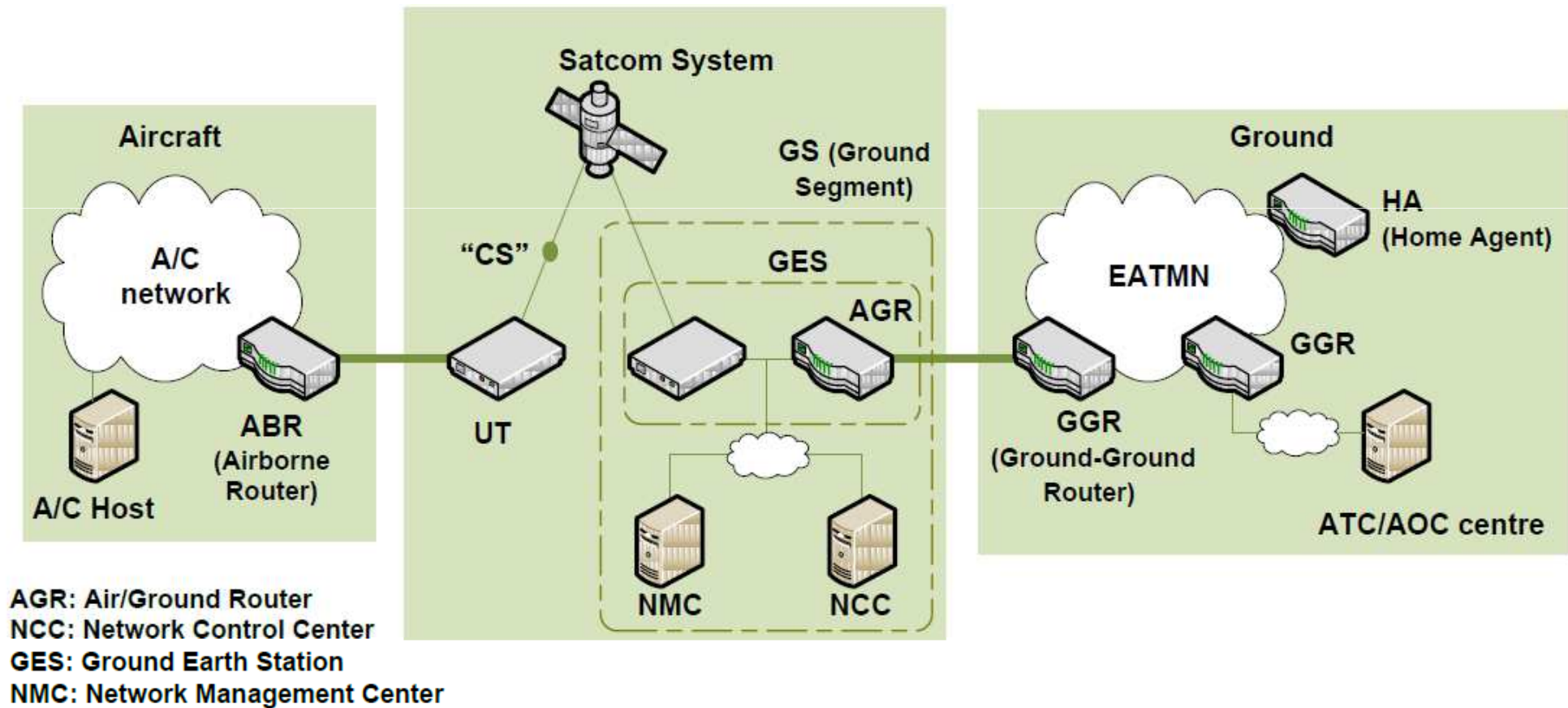
INDEX

- 00 Introduction
- 01 SESAR Long Term Main Drivers
- 02 SatCom System Description**
- 03 ANTARES Performance Assessment
- 04 Long Term SatCom Verification Approach
- 05 Conclusions
- 06 Long Term SatCom Technology Evolution

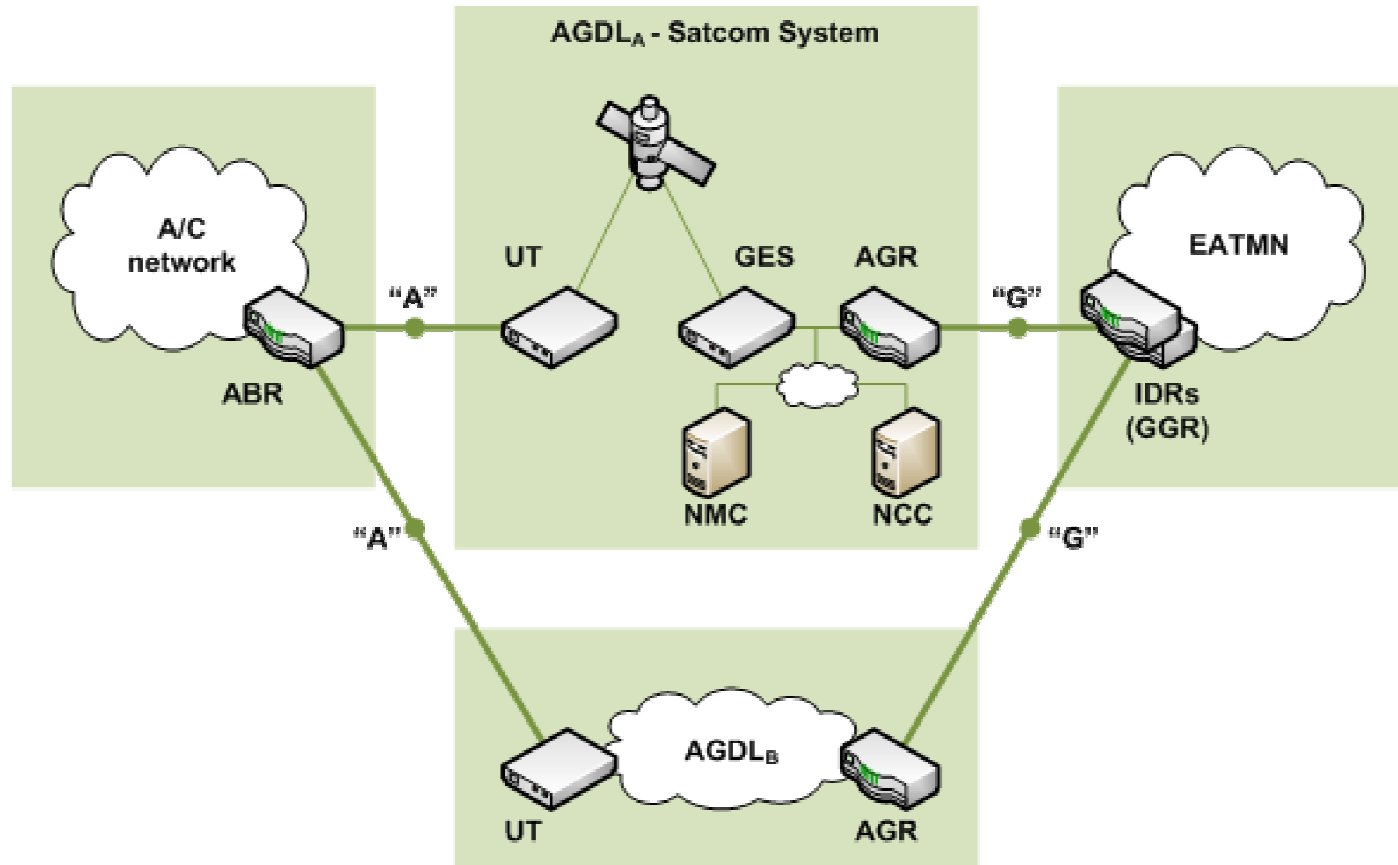
SATCOM SYSTEM DESCRIPTION – DEFINITION

- **SATCOM System can be divided into**
 - **Communication Standard (CS)**
 - Specification of the air interface protocol stack from the network to the physical layer
 - **User Terminal (UT)**
 - Physical element allowing SatCom on board the aircraft
 - **Space Segment**
 - Satellites constellation → GEO and HEO
 - **Ground Segment**
 - Communications related
 - Ground Earth Station (GES)
 - Network Control Centre (NCC)
 - Network Management Centre (NMC)
 - Space segment related
 - Satellite Control Centre (SCC)
 - Satellite Operation Centre (SOC)

SATCOM SYSTEM DESCRIPTION – REFERENCE MODEL



SATCOM SYSTEM DESCRIPTION – MULTI-LINK



■ SATCOM System external interfaces

■ Aircraft interface

■ SATCOM UT

- Physical (A)
- Logical (ATN/OSI & ATN/IPS)

■ European ATM System interface

■ NMC and GES

- Physical (G)
- Logical (ATN/OSI & ATN/IPS)

■ SATCOM UT

- Logical (ATN/OSI & ATN/IPS)

INDEX

- 00 Introduction
- 01 SESAR Long Term Main Drivers
- 02 SatCom System Description
- 03 ANTARES Performance Assessment**
- 04 Long Term SatCom Verification Approach
- 05 Conclusions
- 06 Long Term SatCom Technology Evolution

ANTARES PERFORMANCE ASSESSMENT

■ Communication Standard Design (I)

■ Waveform

- Physical layer designed to counteract the aeronautical channel
 - Multipath
 - Doppler
- **BPSK 1/3** and Turbo Convolutional Codes (**TCC**) of mobile systems (3GPP, S-UMTS) in the **RTN** link
 - Good performance at low Eb/No with multipath propagation and bursty traffic (ATM traffic profile)
 - Long interleavers (80 ms)
 - Counteract too shadowing effects of rotary blades (50 ms period)
- Linear modulations (**M-PSK**) and Irregular Repeat and Accumulate (IRA) Low Density Parity Check (**LDPC**) coding in the **FWD** link
 - Continuous transmission
 - Large frames
 - **ACM** (Adaptive Coding and Modulation) (up to 2 bit/s/Hz efficiency)

Modulation	QPSK	8-PSK	16-APSK
Code rate	$\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$	$\frac{1}{2}$, $\frac{2}{3}$	$\frac{2}{3}$

ANTARES PERFORMANCE ASSESSMENT

■ Communication Standard Design (II)

■ Multiple Access

- Asynchronous Code Division Multiple Access (**A-CDMA**)
 - Use of advanced multiple access techniques based on Successive Interference Cancellation (**SIC**) on the return link (Air to Ground) for safety systems, to mitigate Multiple Access Interference (MAI)
 - The random access nature of A-CDMA requires **Congestion Control** (CC) mechanism, based on MAI estimation, by measuring the **Noise Rise**, to identify the real traffic load, which is broadcasted back to UTs
- Multi Frequency Time Division Multiple Access (**MF-TDMA**)
 - For the forward link (Ground to Air), provides a flexible system that can accommodate different Ground Segment architectures (centralized or distributed) while adapting efficiently to the traffic profile

ANTARES PERFORMANCE ASSESSMENT

■ Communication Standard Design (III)

■ ARQ protocol

- Cumulative ARQ protocol to avoid transport layer retransmissions and satisfy continuity requirements

■ Encapsulation

- CRC-32 at frames to satisfy integrity requirement
- Custom encapsulation scheme to minimize overhead
 - Based on DVB-S2/RCS2 standards encapsulations
 - RLE (Return Link Encapsulation) in the RTN link
 - GSE (Generic Stream Encapsulation) in the FWD link

■ Packet Scheduling

- Left open in the FWD link for manufacturers differentiation, not in the RTN link due to the CC
- Reference implementation provided in the CS Implementation Guidelines
 - Strict Priority (SP) and Earliest Deadline First (EDF) scheduling policies

■ IP header Compression

- Based on RObust Header Compression (ROHC) (for IPv6)

ANTARES PERFORMANCE ASSESSMENT

■ Communication Standard Design Performance (I)

■ Assessment by analysis & simulation

- Continuity requirements ✓
- Latency requirements (TD95) ✓

L=100 B	FWD	RTN	L=1500 B	FWD	RTN
TD95	0.5 s	1.0 s	TD95	0.6 s	2.1 s
TD99.9	1.0 s	2.9 s	TD99.9	2.1 s	3.5 s
PLR	$<10^{-5}$	$<10^{-5}$	PLR	$<10^{-5}$	$<10^{-4}$

■ PLR – Packet Loss Rate at L3

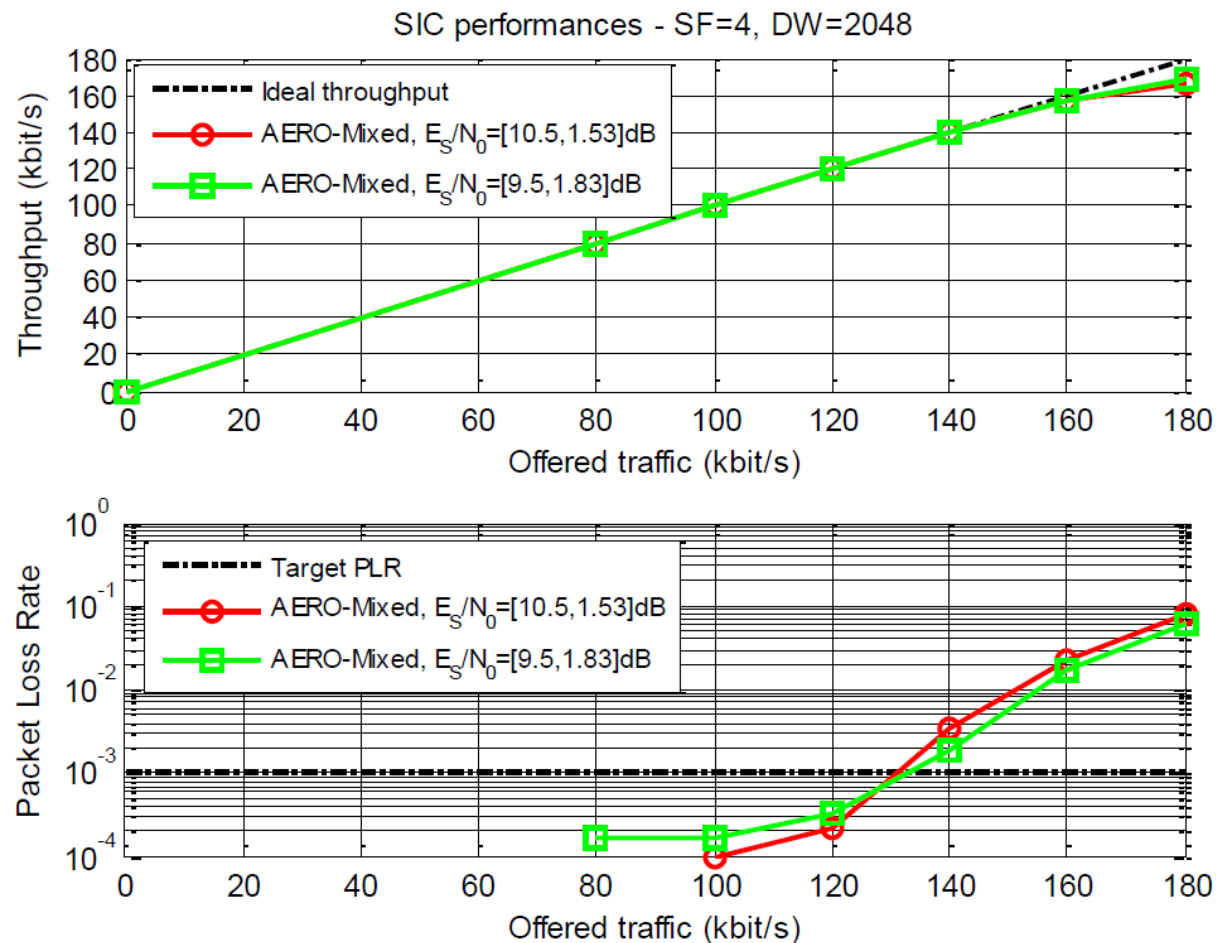
- $TD > 5s$ (100 B) or $TD > 8 s$ (1500 B)

ANTARES PERFORMANCE ASSESSMENT

■ Communication Standard Design Performance (II)

■ Successive Interference Cancellation (SIC) (RTN link)

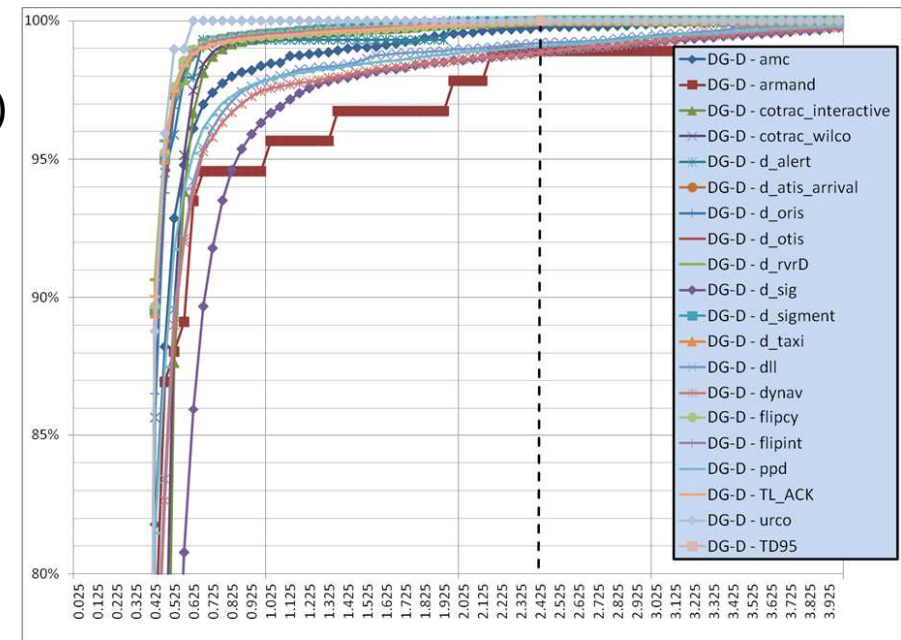
- Based on ESA patent (E-SSA)



ANTARES PERFORMANCE ASSESSMENT

■ Capacity Assessment

- **Simulations** allow determining bandwidth (200 kHz carriers) needed to fulfil latency QoS requirements for the given traffic profile in the ECAC area
- **13 carriers** in the **FWD** link
 - (with frequency reuse factor 3)
- Up to **10 carriers** in the **RTN** link
 - Full frequency reuse
 - 70 to 95% SIC efficiency
- Needed ~4.6 MHz
- 10 MHz available (L-band)



INDEX

- 00 Introduction
- 01 SESAR Long Term Main Drivers
- 02 SatCom System Description
- 03 ANTARES Performance Assessment
- 04 Long Term SatCom Verification Approach**
- 05 Conclusions
- 06 Long Term SatCom Technology Evolution

LONG TERM SATCOM VERIFICATION APPROACH

■ E-OCVM (European Operational Concept Validation Methodology)

■ Maturity Levels (can be mapped to NASA TRL)

■ V2 Phase (TRL 3 & 4): Feasibility

■ (What?)

- Analysis, modelling and simulation
- Voice and data performance (QoS)
 - SIC mechanism **early** evaluation
- Interoperability (handovers) and coverage
- Availability and reliability (jamming resistance)

■ (How?)

- Initial prototypes and emulators
- Full implementation of CS
- CS VTB (currently in AIT phase)

■ V3 Phase (TRL 5, 6 & 7)

- Pre-industrial development and integration
- From research to industrialization

LONG TERM SATCOM VERIFICATION APPROACH

- **V3 Phase (TRL 5, 6 & 7): Pre-industrial development and integration**
 - **(What?):** From research to industrialization
 - Voice and data performance (QoS)
 - Return link SIC mechanism full verification
 - Interface and integration requirements
 - EATMN interfaces
 - Multi-link interfaces (to be fully verified by 15.2.4)
 - **(How?)**
 - Representative pre-industrial prototypes and systems
 - Real-time test in operational context environments
 - Shadow mode
 - Live trials
- **V4 Phase: Industrialization (TRL 8)**
 - Out of scope of SESAR
 - to be considered reusability of elements (SW DAL)
 - Certification of service providers in V4
- **V5 Phase: Deployment**
 - Large Scale Demonstrations, programmed installations and executed operational test campaigns within SESAR

INDEX

00 Introduction

01 SESAR Long Term Main Drivers

02 SatCom System Description

03 ANTARES Performance Assessment

04 Long Term SatCom Verification Approach

05 Conclusions

06 Long Term SatCom Technology Evolution

CONCLUSIONS

- The SatCom System has been proposed as a CNS enabler, as expressed in SESAR Master Plan document for the provision of Full 4D services
- SatCom technology simulations have demonstrated the **feasibility** to fulfil stringent performance requirements to convey more demanding ATC and AOC safety services
- The V&V approach proposed within SESAR project P15.02.06, in two steps (V2 and V3) has been described according to the E-OCVM methodology

INDEX

- 00 Introduction
- 01 SESAR Long Term Main Drivers
- 02 SatCom System Description
- 03 ANTARES Performance Assessment
- 04 Long Term SatCom Verification Approach
- 05 Conclusions
- 06 Long Term SatCom Technology Evolution

LONG TERM SATCOM TECHNOLOGY EVOLUTION – IRIS (I)

■ INDRA participation

- ICOS (2008-2009) <http://artes.esa.int/projects/icos-iris-communications-system-design-study-phase>



- Iris Phase A
 - SatCom for ATM concept development and feasibility (technical and economic)

- ANTARES (2009-2014) <http://artes.esa.int/projects/antares>

- Iris Phase B
 - Preliminary Communications Standard (CS) design
 - Phase B1
 - SRR and Bridging Phase
 - Phase B2
 - CS Design
 - CS Verification Test Bed (VTB) (on going test campaign, planned to be finished Q1 2015)



LONG TERM SATCOM TECHNOLOGY EVOLUTION – RPAS

■ ESA ARTES 1 RPAS BRLOS link related projects (C3 and Mission):

- **SUAV:** SoA analysis and preliminary requirements definition
- **CERES:** Consolidation of the certification requirements based on the following methodology: (*meeting the ERSG roadmap action 18D*)
 - **Top-down approach:** RCP apportionment to C3 link (C2-RCP and ATC-RCP)
 - **Bottom-up approach:** Evaluation of reference systems at FSS, C and L AMS(R)S bands.

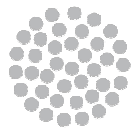
■ ESA ARTES 20 RPAS applications demonstrations:

- **SINUE:** demo preparation by simulations and identification of potential users and technology available.
- **DESIRE 1:** First flight demonstration for RPAS integration into non-segregation airspace supported by satellite comms. (*aligned with ERSG roadmap action 18E*).



■ Participation in WG73, in particular in SG3: C3 and security

■ Working in SESAR JU and participating as reviser in WA1.5 (15.2.4)



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