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SESAR and SANDRA: A Co-Operative Approach for Future Aeronautical Communications

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1. Introduction

The air transportation sector is currently under significant stress. The sudden decrease in demand for air based transportation after 2001 events, forced most airlines to reorganize and strength their politics by operating severe cuts and by creating strong holding to reverse the negative trend. Air traffic situation returned to pre-September 2001 levels in 2005 and nowadays the demand in aircraft operations is expected to double by 2025.

There are many concerns that current air transportation systems will be able to safely cope with this growth (FAA/EUROCONTROL, 2007; SANDRA, 2011). In fact existing systems are unable to completely process flight information in real time, and current processes and procedures do not provide the flexibility needed to meet the growing demand. New security requirements are affecting the ability to efficiently transport people and cargo. Furthermore, air transportation expansion caused community concerns on aircraft noise, air quality, and air space congestion.

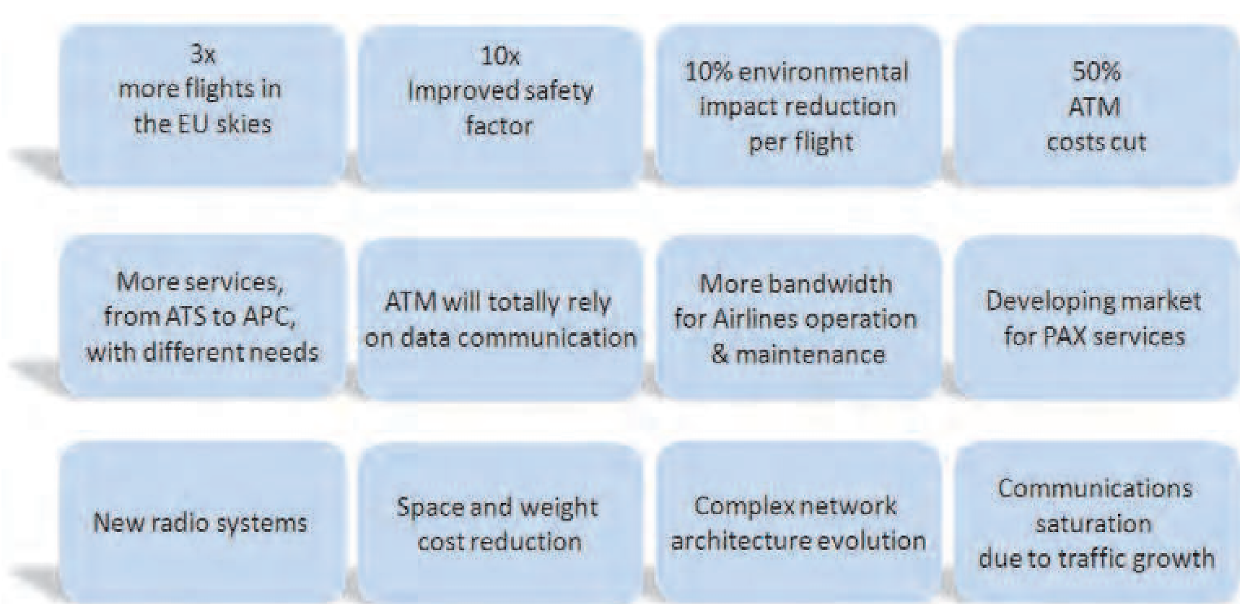

Fig. 1. The European sky in 2025.

This scenario becomes extremely important even considering that in the past 40 years, air traffic management, indispensable for a safe flight, did not significantly progress.

A possible solution for reducing congestion problems in capacity-constrained airports has been proposed by economists through peak-load pricing. However, this solution has been rejected by both legislators and customers. At the same time, most heavily congested airports in the United States and Europe have been subject to takeoff and landing constraints, that effectively impose entry restrictions in these airports while reducing the load on air traffic control systems. The expansion of existing airports, the use of secondary airports for low-cost travels, or the creation of new huge hub increases again the awareness situation. It is therefore evident the need for a substantial change in air transportation.

In order to allow future systems to be compatible with the expected air-traffic increase, some high-level requirements on communications related aspects can be identified (Fig. 1):

- pilots' situation awareness has to be improved; this includes enhanced communication with the flight controller, monitoring communication between controllers and other aircrafts, visual look-out, and navigation (including use of maps and charts);
- airports' hosting capacity, one of the main limiting structural factors, has to be increased; there is the need to cope with the growing demand by air carriers for the use of airport facilities;
- ATS (Air Traffic Services) have to be based on reliable data communications;
- AOC (Airline Operations Control) data traffic has to increase for efficient operations;
- passengers and cabin communication systems have to be further developed in terms of robustness, reliability and re-configurability;
- safety critical information should be transmitted to the ground station in a reliable and multi-modal way; there is the need for the certainty that the information has been read, understood and implemented.
- on-board network architecture, which connects each passenger seat/crew terminal to the In-Flight Cabin server, needs convergence of protocols and interfaces.

As can be easily imagined, new technologies and operation procedures cannot be easily applied in the aviation sector: the safety, the reliability, and the effectiveness of each innovation must be deeply investigated and verified. Moreover there are standardization issues that must be taken into account when changing existing avionic equipments and procedures. Furthermore, the outcome of the security-effectiveness phase must be balanced with implementation and operational costs.

For the above mentioned reasons, both Federal Aviation Administration (FAA) in the US and European Commission in Europe, are promoting and supporting intensive studies on this field. In particular, among the initiatives supported by the European Commission, in the following the SESAR (Single European Sky ATM Research) and SANDRA (Seamless Aeronautical Networking through integration of Data links Radios and Antennas) are described in Sections 2 and 3. Since both projects are related to different aspects of the same topic, it is likely that subtasks of the projects or even some of their outcomes could overlap. We believe that from the exploitation of these synergies both projects could benefit in terms of effectiveness, costs, and overall success. In Section 4 the strategy and the undergoing efforts for revealing the projects overlaps, as well as the description of the co-operation started by the two projects on the communication aspects are reported. Finally, in Section 5 some concluding remarks are drawn.

2. SESAR - Single European Sky ATM Research

The SESAR Joint Undertaking (SJU) was created under European Community law on 27 February 2007, with EUROCONTROL and the European Community as founding members. The SESAR programme is in the framework of the Single European Sky (SES) initiative to meet future capacity and air safety needs and it is one of the most ambitious research and development projects supported by the European Community.

The mission of the SJU is to develop a modernized air traffic management system in the European air transportation sector. This system will ensure the safety and fluidity of air transport over the next thirty years (SESAR D4, 2008; SESAR D5, 2008), it will reduce the costs of air traffic management and the environmental pollution.

The key performance targets to be accomplished by 2020 (SESAR D2, 2006) are strictly related to the challenges described in the introduction:

- enable a threefold increase in capacity;
- improve safety by a factor of 10;
- reduce by 10 % the environmental impact per flight;
- cut ATM costs by 50%.

These objectives are pursued by a team of 16 members belonging to the aviation community. Furthermore, some of these members are consortiums themselves and this raises the total number of companies involved in the project to 35 units.

Due to the large spectrum of activities within SESAR, it has been partitioned in 16 Work Packages, each of them devoted to the main areas of involvement, namely (SESAR, 2011):

- Operational activities:
    - WP 4 En-Route Operations: to provide the operational concept description for the En-Route Operations and perform its validation;
    - WP 5 Terminal Operations: to manage, co-ordinate and perform all activities required to define and validate the ATM Target Concept (i.e. Concept of Operations and System Architecture) for the arrival and departure phases of flight;
    - WP 6 Airport Operations: to refine and validate the concept definition, as well as the preparation and coordination of its operational validation process;
    - WP 7 Network Operations: to cover the evolution of services in the business development and planning phases to prepare and support trajectory-based operations including airspace management, collaborative flight planning and Network Operations Plan (NOP);
- System development activities:
    - WP 9 Aircraft Systems: it covers the required evolutions of the aircraft platform, in particular to progressively introduce 4D trajectory management functions in mainline, regional and business aircraft;
    - WP 10 En-Route & Approach ATC Systems: it designs, specifies and validates the En-route & TMA ATC Systems evolutions for enhancing Trajectory Management, Separation Modes, Controller Tools, Safety Nets, Airspace Management supporting functions and tools, Queue Management and Route optimization features;
    - WP 11 Flight and Wing Operations Centres / Meteorological Services: it deals with the development of the Flight and Wing Operations Centres and with the provision and utilization of Meteorological Information services, needed to support the performance requirements of the future ATM system;

- WP 12 Airport Systems: it encompasses all Research & Development activities to define, design, specify and validate the Airport Systems needed to support the SESAR ATM target concept;
- WP 13 Network Information Management System: it covers the System and Technical R&D tasks related to the Network Information Management System (NIMS), the Advanced Airspace Management System (AAMS) and the Aeronautical Information management System (AIMS);
- WP 15 Non-Avionic CNS System: it addresses CNS technologies development and validation also considering their compatibility with the Military and General Aviation user needs;

- System Wide Information Management:
  - WP 8 Information Management: it aims at developing SWIM
  - WP 14 SWIM Technical Architecture: it is the follow-up of the SWIM SUIT FP6 Commission.
- Transverse activities:
  - WP 3 Validation Infrastructure Adaptation and Integration
  - WP 16 R&D Transversal Areas: it analyzes the improvements needed to adapt the Transversal Area management system practices to SESAR as well as towards an integrated management system.
  - WP B Target Concept and Architecture Maintenance
  - WP C Master Plan Maintenance.

Among the described activities, one of the focal points in SESAR is the definition of the communication architecture (SESAR D3, 2007). The SESAR ATM concept requires advanced data communication services and architectures able to support specific features such as: 4D-trajectory management in order to be able to update and revise the Business Trajectory of the aircraft, ASAS separation to allow the crew to perform some tasks related to separation or spacing, thereby reducing the workload of the controller, and SWIM operations, as described in the following (SWIM, 2011).
The SWIM (System Wide Information Management) is one of the focal aspects in the approach proposed in SESAR. It aims at the replacement of data level interoperability and closely coupled interfaces with an open, flexible, modular and secure data architecture that is able to support users and their applications in a transparent and efficient manner, see Fig. 2.

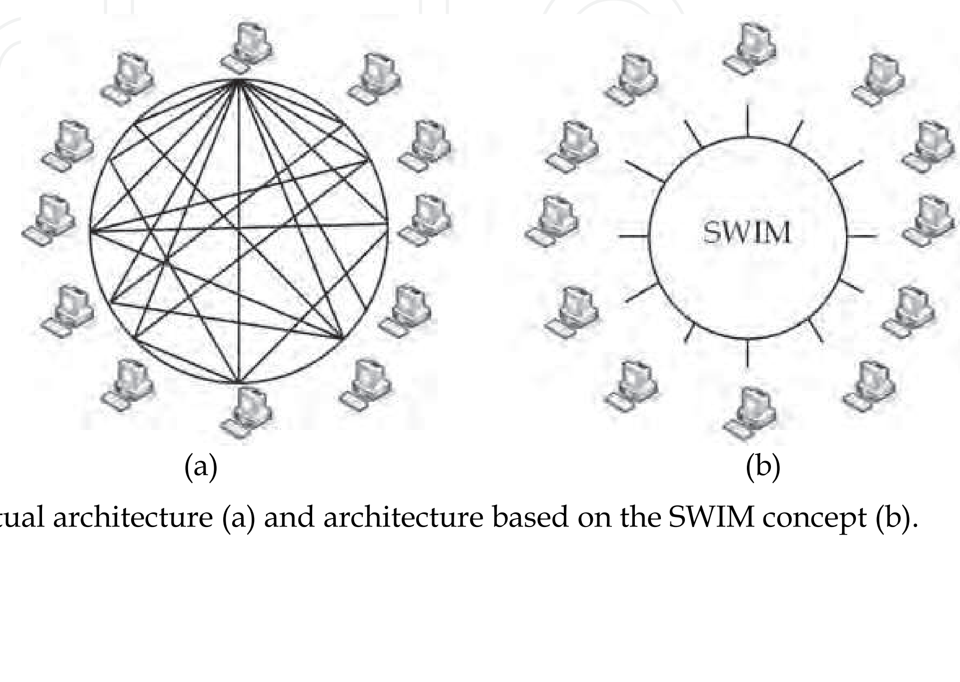

Fig. 2. Actual architecture (a) and architecture based on the SWIM concept (b).

SWIM will be used for enabling data sharing between ATM services across the whole European ATM system. Even if a complete definition of the SWIM has not yet been reached, interoperability and standardization are key elements and SWIM is expected to play an important role in the revolution of the aeronautical scenarios.

Toward this direction, ATM stakeholders will cooperate in the development of SWIM requirements, prototypes, roadmaps, and deployment plans.

In particular SWIM will provide benefits to:

- pilots during takeoff, navigation and landing operations by guaranteeing a reliable communication with the air traffic controller who will give support and instruction based on data collected and validated from different sources;
- Airport Operations Centers, managing departures, surface movements, gates and arrivals, building schedules, planning flight routings and fuel uplift, ensuring passenger connections and minimizing the impact of delays;
- Air Navigation Service Providers (ANSPs), organizing and managing the airspace over a country and with Air Traffic Services – managing air traffic passing through their airspace;
- Meteorology Service Providers for weather reports and forecasts;
- Military Operations Centers, planning missions, securing airspace during training operations, fulfilling national security tasks.

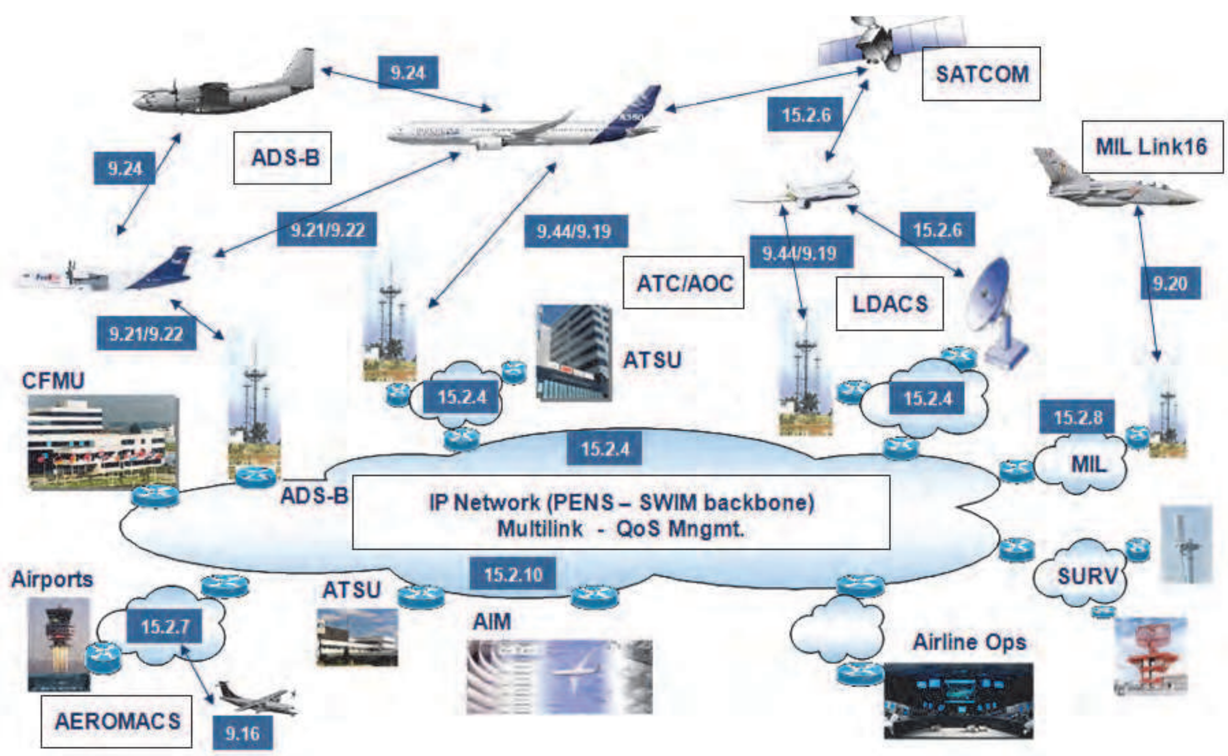

Fig. 3. Communication architecture.

A reliable and efficient communication infrastructure will have to serve all airspace users providing the appropriate Quality of Service (QoS).

It is useful to underline that QoS is a complex concept but in an air/ground communication link it can be roughly measured by using three parameters: communication delay, data integrity, and system availability. As demonstrated by many studies, the real quality requested by a communication system is strictly dependent on the particular service and operational scenario. The relative importance of the identified parameters is determined according to the particular application: for instance the real time communication between the pilots and air traffic management system in high density traffic area requires the delay to be as short as possible, to have high data integrity, and high service availability. At the same time, the data link adopted for delivering or predicting meteorological conditions for low-density airspace, might accept longer delays, less integrity, and lower availability. In a modern communication scenario, other parameters can influence and contribute to the overall QoS, as the fulfillment of the authentication, authorization, and accounting requirements, the customer satisfaction, and so on.

Last, it should be also mentioned that the provisioning of QoS strongly reflects on service costs: the exact estimate of the QoS required by the application may avoid increased-unjustified costs thus preventing the service from being used.

As shown in Fig. 3, the overall QoS will be guaranteed to the particular application, through a communication scenario involving both mobile and fixed entities. While the definition and the provisioning of QoS in fixed communication systems has been studied and achieved during the last fifty years, the same goal for mobile communication is still far to be reached. The noisy nature of the communication media itself, together with security concerns, and the need of fusing different communication approaches, can be considered a big challenge for present and future communications.

In SESAR, the mobile part of this infrastructure will be based on a multilink approach, composed of different sub networks:

- a ground-based L-band line of sight data link as the main system in continental airspace;
- a satellite-based system (in cooperation with the European Space Agency) to serve oceanic airspace whilst complementing ground-based data link;
- a system dedicated to airport operations, derived from WiMAX, providing a broadband capacity to support the exchange of a significant amount of information;
- to allow interoperability with military operations, a gateway is being defined to interconnect the ATM system and the military Link 16 system.

At architectural level this future infrastructure will incorporate the legacy networks as VHF/VDL and the growth capability toward eventual future evolutions (SESAR D3, 2007).

3. SANDRA - Seamless Aeronautical Networking through integration of Data links Radios and Antennas

SANDRA is a project partially funded by the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement n. 233679 (SANDRA, 2009; SANDRA web, 2011).

This project aims at the definition, the integration, and the validation of a reference communication architecture, SANDRA Airborne Communication Architecture, directly related to the Service Oriented Avionics Architecture envisaged in the Future Communications Study (FAA/EUROCONTROL, 2007).

The SANDRA consortium consists of 30 partners from 13 countries across Europe composed by industrial partners, research organizations, universities and highly specialized SME (Small and Medium Enterprises).

This project defines specific targets to be accomplished in order to face the new needs in the aeronautical transportation sector. These can be achieved by integrating existing and novel heterogeneous communication media into an overall architecture able to:

- provide and manage seamless service coverage across any airspace domain and aircraft class;
- support the increasing trend of the service market and to enable easy plug-in of future radio technologies by means of a modular and reconfigurable approach;
- be upgraded, easily reconfigured and independent on the specific radio technology used;
- be distributed on ground-base and airborne sub-networks thus ensuring full interoperability.

The novelty of the SANDRA approach consists in pursuing integration at different levels:

- service integration: integration of a full range of applications (ATS, AOC/AAC, APC);
- network integration: based on interworking of different radio access technologies through a common IP-based aeronautical network whilst maintaining support for existing network technologies (ACARS, ATN/OSI, ATN/IPS, IPv4, IPv6);
- radio integration: integration of radio technologies in an Integrated Modular Radio platform;
- antenna integration: L-band and Ku-band link antennas will be used to enable an asymmetric broadband link;
- WiMAX adaptation for integrated multi-domain airport connectivity.

Ultimately, SANDRA pursues the architectural integration of aeronautical communication systems using well-proven industry standards like IP, IEEE 802.16 (WiMAX), DVB-S2, Inmarsat SwiftBroadBand, a set of common interfaces, and standard network protocols having IPv6 as final unification point to enable a cost-efficient global and reliable provision of distributed services across all airspace domains and to all aircraft classes.

The SANDRA validation activity will show the ability of the proposed integrated architecture to easily reconfigure and adapt for the flexible implementation of new communication services.

In terms of overall working structure, SANDRA is structured in eight Sub Projects (SP), each one dedicated to a specific aspect (Fig. 4). In more detail, SP1 is related to the project management. In SP2 the "top-down" approach, the scenarios, the overall framework and architecture are defined and developed. SP2 is therefore the central conceptual integration activity in the project.

Moreover, the project structure clearly reflects the focus on the four major SANDRA elements, namely:

- Seamless Networking (SP3): SANDRA networking solutions are designed to allow integration and interoperability at different levels, with IPv6 as final unification point (target 2025 and beyond):
    - Link level: Interworking of different link technologies (ground-based, satellite-based, airport systems as main streamline for validation, air-to-air MANET as long term extension);
    - Network level: Interoperability of network and transport technologies (ACARS, ATN/OSI, IPv4/IPv6) to ensure a realistic transition;
    - Service level: Integration of operational domains (ATS, AOC/AAC, APC). This integrated networking approach of SANDRA is a key enabler for the efficient implementation of a range of applications addressing the ACARE SRA2 objectives,

that are the development of a customer oriented, time efficient, cost efficient, green and secure air transport system. The SANDRA networking solution is also a key enabler for most SESAR Key Performance Areas (KPAs) as defined in SESAR deliverable D2 (SESAR D2, 2006).

- Integrated Modular Radio (SP4): As all of the radios will never be used simultaneously, there is opportunity to build a new radio system in which each single radio element can be independently reconfigured to operate in a specific radio link as required. This will considerably reduce the amount of radio sets in the vehicle thus reducing weight and consequently the operational costs. Furthermore, the different type of radios will be replaced by one software-reconfigurable equipment, thus simplifying spares and maintenance operations. The adoption of software defined radio based equipments greatly simplifies the seamless transition from one link to another that is the goal of the networking aspects of the SANDRA programme. Another progress will be the ease of integrating the radios into the overall avionics system as they will have identical interfaces both in software and hardware terms. Also, pilots' workload will be reduced, not only because the radio operation will be simpler, but also because the seamless networking capability of the overall system removes the need for the pilots to manually select radios. Finally, just as IMA (Integrated Modular Avionics) allows the avionics to be updated with new applications by means of software change only, similarly the IMR will allow future communications waveforms and protocols to be updated by software alone.
- Integrated Antennas (SP5): A key requirement for future aeronautical communications systems is the provision of broadband connectivity within aircraft cabins at an affordable price. One of the key enablers is an electronically steered Ku-band phased array. Ku-band phased arrays in which the same elements are used for both transmission and reception are not possible with mature technologies. Consequently, for Ku-band two arrays would be required. Given the undesirability of increasing the number of antennas, such a solution is not acceptable in the market place. However the amount of data agglomerated over a range of passenger services (VoIP, Web, Email, SMS, MMS) and over a range of flights (SH, LH), is highly asymmetrical, with the inbound traffic being about 5 times higher than the outbound. The inbound traffic requires the availability of a broadband Ku-band antenna in receive mode only, which is feasible. A further benefit of a receive only system is that the beam width restriction to avoid inadvertent irradiation of other satellites can be reduced; this is a particularly useful amelioration as it means that the phased array can be used (maybe, at slightly reduced data rates) at low elevation angles, where the beam tends to flatten out. The other key element in making this link work in totality is the asymmetrical networking aspect of using different bearers for the forward and return link. A dedicated signaling system will be developed in SANDRA as a general concept of IP based data exchange using asymmetric bearers.
- Airport Connectivity with WiMAX (SP6): Airports are the nexus of many of the Air Transport transformation elements to achieve air traffic management (ATM), security, and environmental goals. Accordingly, the sustainability and advancement of the airport system is critical to the growth of the air transportation system. To enable these progress and vital concepts like "fast turnaround", SANDRA will define and validate a new generation Airport Wide Area Network, supporting a large variety of vital

aeronautical applications and services. This network is envisioned as a high-integrity, safety-rated, wireless network, with mobile terminals on the ground, on aircraft as well as other surface vehicles and improved information distribution.To respect the high level of security needed in the aeronautical environment, SANDRA will consider security measures into the design at all layers. The new system will be based on WiMAX standards for ATS/AOC communications and will provide lower cost, safer and more efficient airport surface operations, compliant with SESAR/FCI recommendations, giving strong input in know-how to the SESAR initiative.

Finally, the overall SANDRA system encompassing prototypes of the integrated router, the integrated modular radio and the integrated antenna will be validated in SP7 in laboratory test-bed and in-flight trials using the ATRA (Advanced Technology Research Aircraft) an Airbus A-320 of the German Aerospace Center (DLR)..

Exploitation and dissemination activities are coordinated in SP8 where a particular emphasis is put on the coordination with SESAR.

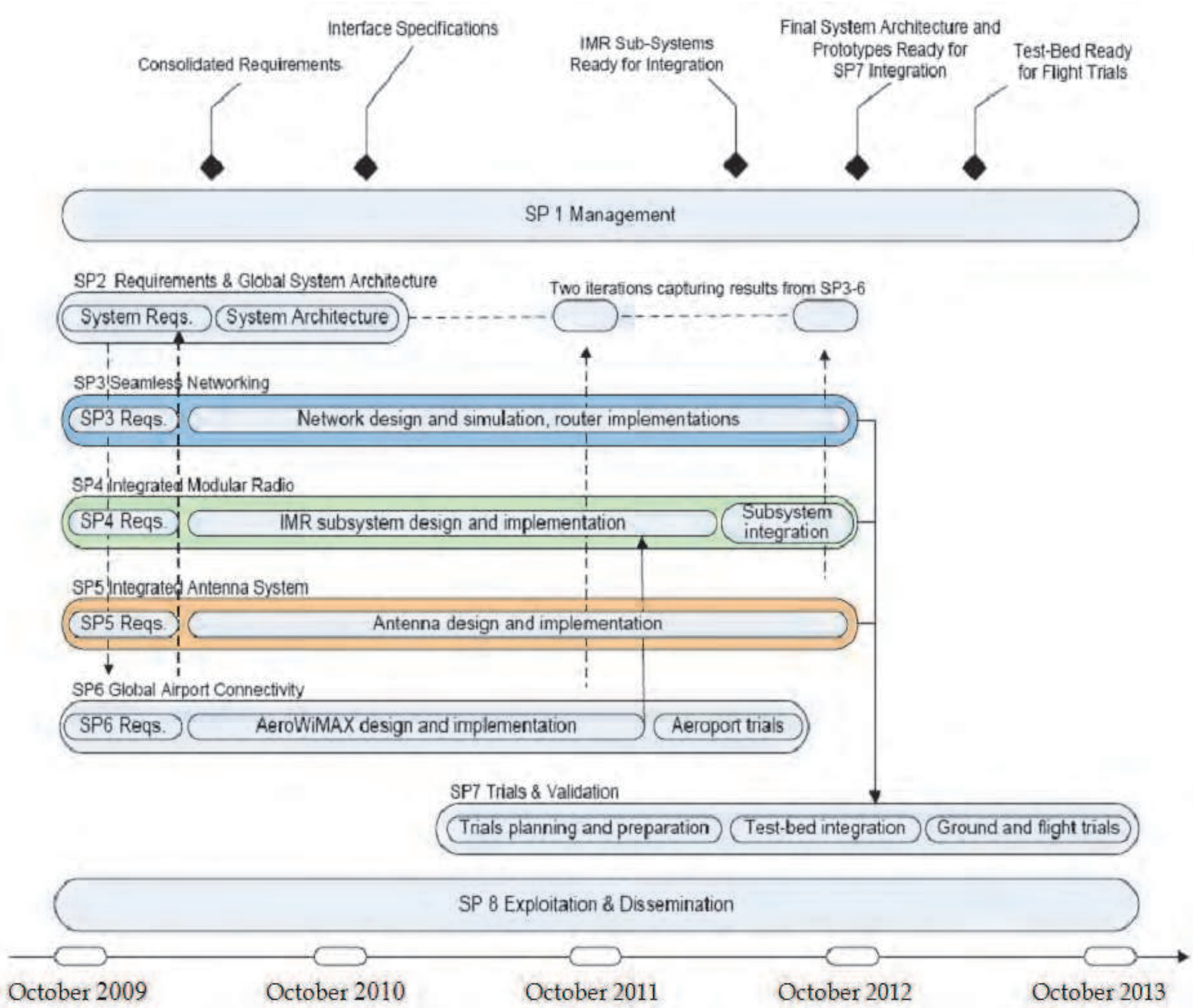

Fig. 4. SANDRA study logic and key milestones.

SANDRA shall use and build upon other project results at different levels. In some cases only the knowhow about emerging/future communication technologies, requirements and interfaces will be reused, i.e. no hardware and software will be carried over. In other cases, reuse will be done also of platforms and development items. This interaction is summarized in the following list:

- Future Communication study for technologies requirements (voice and data), description and conclusions on next steps (such as AeroWiMAX, need for new Satcom, L-DACS 1/ 2);
- ESA IRIS study for new satellite ATM data link;
- Studies and reports from SESAR, COCR and NASA MCNA for requirements, concept and architectures;
- Previous EC projects such as Wireless cabin, E-CAB, MOWGLY, ANASTASIA, NEWSKY for requirements and architectures (system architecture and on-board architecture) for ATM and APC communications;
- ICAO WG-I (Internetworking) and corresponding ATN/IPS documents for IP protocols for safety related communications, IETF for possible evolution of IP protocols for aeronautical applications;
- EUROCONTROL IP study and NASA MCNA studies for architecture and protocols;
- SWIMSUIT EC project and SESAR for SWIM and SOA concepts for ATM networks, and their impact on the architecture;
- NEWSKY for preliminary integrated network architecture design supporting ATS, AOC and APC;
- SESAR Master Plan and NEWSKY for Road Map and transition aspects;
- ANASTASIA the concept of a hybrid dual-frequency L/Ku antenna, preliminary dual band patch designs and first prototype radio architecture with a completely Software modem;
- Future Communication Studies and E-CAB for AeroMACS requirements (safety critical and not) ;
- B-AMC for consideration of load sharing between terrestrial and satellite communication systems; performance enhancement of terrestrial system;
- NATALIA ESA project and Flysmart (NL) for design and technologies related to full electronically steerable Ku-band antenna with broadband optical beam forming;
- SAFEE for risk assessments, security analysis for the communications domains, Security for existing architectures;
- Requirements from Logistic & Health Management Oriented projects to assure SOA interoperability (i.e. ECAB).

Fig. 5 shows the existing connections between SANDRA and the above-mentioned projects and standardization activities.

4. The SANDRA-SESAR collaboration

4.1 Context

In 2009 the SANDRA Consortium, the DG Research, and the SESAR Joint Undertaking established a co-operation. The aim of this agreement is to share resources with a flexible approach and to provide the European community with benefits obtained both by individual and integrated outcomes of the two projects. Moreover, it is fundamental for Europe to show a unified approach in the aeronautical field.

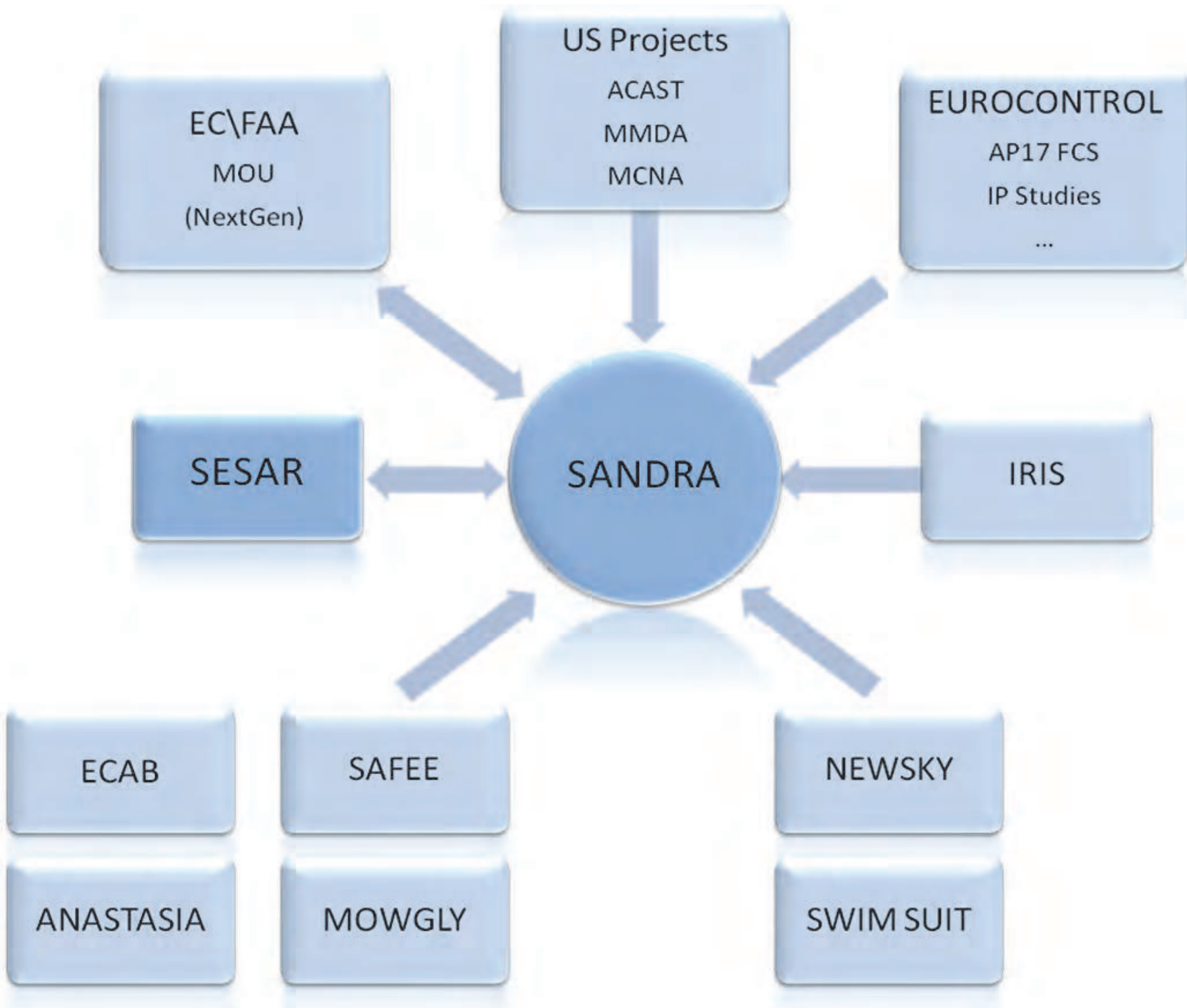

Fig. 5. Relationship between SANDRA and other projects and activities.

To achieve this ambitious collaboration, a set of Work Areas (SANDRA, 2011; SESAR D6, 2008) were identified:

- definition of requirements,
- multilink and QoS management,
- flexible communication avionics,
- airport wireless communication systems,
- architecture, networking, and SWIM airborne.

The proposed approach reflects the need to optimize the common efforts. This is achieved by gradually exploiting the results obtained by the single research programmes also considering their peculiarities as time scheduling, final objectives, and required competencies.

Fig. 6 shows the tight connection between projects and studies in the SANDRA-SESAR co-operation that will be analyzed in the following sections.

Similarly, in USA the Federal Aviation Authority has proposed the NextGen project. The goal of this project is to fuse different competencies in the field of National Airspace System and projects for realizing a more convenient and dependable travel system, while ensuring the safety and security of the flight.

According to the project developers, the outcome of this cooperation will optimize the economic aspects, the impact on environment (pollution), the information delivering and exploitation, the safety management and prevention, the interaction among the different actors (users, travel companies, airports, cargo systems, ground transportation and services), and will increase the overall security.

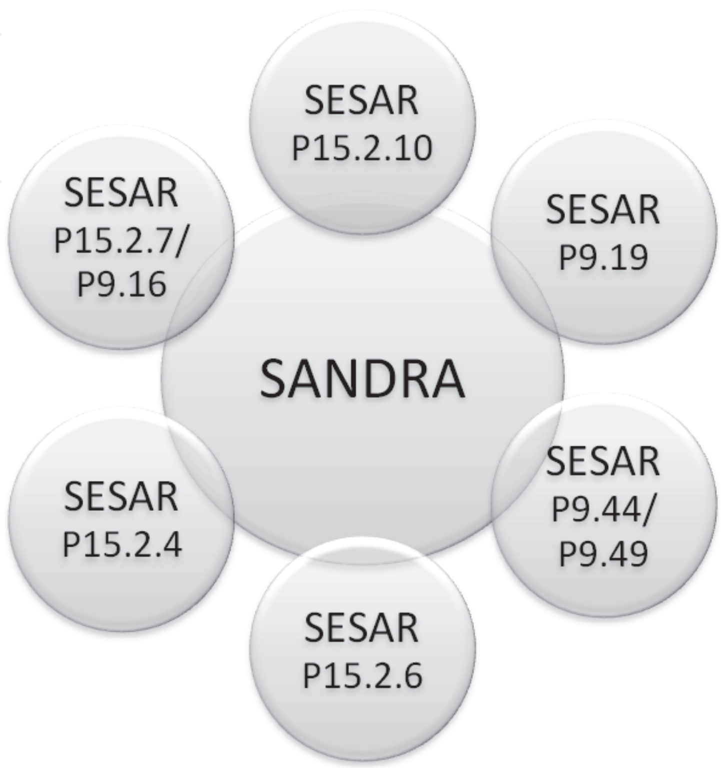

Fig. 6. List of feeder projects, studies and initiatives.

4.2 Overall concept and architecture comparison

In order to understand the relation between the programmes and their possible synergies, the conceptual differences in the approaches has been investigated. Several outputs of the SESAR Definition Phase (2006-2008) were used as inputs for the requirement definition and functional architecture design. In particular:

- Deliverable 3 - 'Future ATM Target Concept' (SESAR D3, 2007) describes the main concept of operations, the architecture for future ATM System, the set of identified enabling technologies, the outline of total costs, and the positive outcomes of the feasibility study;
- Deliverable 4 - 'Deployment Sequence - Develop Options and Select 'Best' Practices' (SESAR D4, 2008) contains the confirmation of feasibility (technical, financial, institutional, etc.), the development of options and the recommended approach for the deployment phase, and the definition of deployment packages (transition from legacy systems/framework);
- Deliverable 5 - 'ATM Master Plan' (SESAR D5, 2008) details the plan of actions that all organizations need to implement, the possible outcomes to be used in future business plans, RT/D plans, risk assessment studies, and it envisages future management processes.

The SANDRA system interfaces have been defined taking into account on the Air-to-Ground interoperability requirements specified in SESAR. The relation between SANDRA and SESAR is extremely important since SANDRA aims at defining an architecture that is compliant with SESAR IP3 communication baseline as exposed in SESAR WP2.5/D4 'Technology Assessment' (SESAR D4, 2008)

For what concerns the technological aspects, a detailed analysis has been conducted to confirm SANDRA's fundamental coherence with the SESAR concept.

Following a detailed analysis of the two projects, significant correspondences have been identified in five macro areas concerning Software Defined Radio (SDR) Architectures, Integration, Network architecture, Security, and Airport Wireless LAN.

Those aspects are highlighted in Table 1- Table 5.

Table 1 reports the approach followed by the two projects on the SDR Architectures topic. For example it can be noticed that in both projects the flexibility in radio resources exploitation is a key investigation element. To achieve the desired flexibility both projects envisage the use of SDR.

SDR Architectures	
SESAR	SANDRA
Software defined radios are available for avionic integration and global interoperability.	Minimization of the radio hardware equipment by reconfigurable avionic radios. Flexible radio resources: key enabler in the planning of the new links being undertaken by SESAR.
Flexible development and rapid evolutions (e.g. through SDR technology) are desirable	A scalable architecture that allows a flexibility in the radio resources to be added to the aircraft according to the number of users, availability and integrity requirements.
SESAR is mainly focused on AOC and ATC operations.	The main objective of SANDRA is the flexible integration of networks and technologies envisaging the convergence of ATM, AOC, APC communications for radio and routing in any operational phase.
Additional data link performance is required to support advanced services such as 4D trajectory management and increasing traffic growth. A dual link system is likely to be needed.	The Integrated Modular Radio reconfigurability is a key factor enabling efficient implement the dual link concept. SANDRA will define and implement a network layer and the various data link layers to guarantee independence of routing from links, support of critical functions over low-bandwidth links and link topology, availability, quality will be indicated to the router.

Table 1. Relationship on SDR Architectures.

Table 2 is related to the integration concerning the management of flexible aeronautical routing. Also in this case both projects are concerned with radio exploitation for an effective and reliable routing path delivery.

Integration	
SESAR	SANDRA
Integration of both continental and oceanic routing with radio capabilities.	The main objective of SANDRA is the integration of networks and technologies envisaging the convergence of ATM, AOC, APC Communications for radio and routing in any operational phase.

Table 2. Relationship on integration.

Network architecture	
SESAR	SANDRA
The transport and internetworking layers will have to be meet QoS requirements and safety and performances needed by ATS.	SANDRA enhanced routing protocols will manage all aircraft mobility and prioritize traffic end-to-end in compliance with QoS requirements. Policy based routing will be available to enable the selection of the appropriate link for every data flow. Better integrity and safety-of-flight due to the reuse of all available connections in critical conditions. SANDRA Network management will operate and integrate all the communications technologies.
Sharing with other uses (such as AOC) is envisaged.	SANDRA envisages the architectural convergence of communications domains and is fully in line with and for some aspects exceeds the SESAR vision.
Could be based on improvements to ATN or a specific augmented IP layer.	The SANDRA IPv6 orientation and the development of interoperability concepts are fully in line with the SESAR vision. Interfacing ATN networks will be considered in specific activities.

Table 3. Relationship on information network architecture.

Table 3 shows the impact of QoS and security requirements on the Network Architecture. This fundamental task is approached by both projects by designing a IPv6-based communication system allowing the interoperability among different domains.
Table 4 analyzes the approach carried out on the security aspect. The presence of a security system architecture based on encryption and AAA (Authentication, Authorization and Accounting) services, is investigated in both projects.
The correspondences in the airport wireless LAN for airport usage are detailed in Table 5. In both architectures, a tuning of the communication standard 802.16 (IEEE 802.16, 2009) is used for optimizing the communication link.

Security	
SESAR	SANDRA
Security Applications like firewalls, encryption, and authentication will be needed.	SANDRA will address an information security (INFOSEC) architecture to guarantee the separation between the different domains on the SANDRA system architecture.
Resistance to voluntary interference is analyzed.	SANDRA will consider link encryption, access authentication, accounting and link protection at RF level (anti jamming frequency hopping, etc…).

Table 4. Relationship on secure data exchange.

Airport Wireless LAN	
SESAR	SANDRA
Terrestrial data link for airport surface supporting ATS and AOC with QoS management. Initial 802.16 for AOC may provide a learning platform to define the suitable ATS surface datalink operating in a protected band.	SANDRA will define the optimum WiMAX profile, based on multiple representative airport surface propagation characteristics. The maximization of spectral efficiency, cell-planning, the management of interferences and the minimization of airport base stations, the study of infrastructure and on-board WiMAX complexity and cost, will be addressed. Traffic flow monitoring will enable fine-tuning of the WiMAX profile to optimize the waveform to all airport propagation characteristics.

Table 5. Relationship on terrestrial point to point data link for airport usage.

Finally, as shown in Table 6, there is a strong correlation between the expected SANDRA outcomes (SP3 to SP7) and the communications enablers identified in SESAR D4 for implementation packages (IPs) 2 and 3.
The most correlated topic is the New Airport Datalink. It involves with major impact the SESAR IP2 with SANDRA SP3, SP4, SP6, and SP7. Even if the connection impact is not as strong as in the above mentioned cases, SANDRA Sub –Projects are related to SESAR IP2 and IP3 also on the Enhanced VHF Digital Mode 2 (VDL2) Air/Ground Data Link investigation, the Ground IP Network, the Digital Air-Ground Voice, and the Air to Air Datalink.
From the above considerations it is evident that the exploitation of redundancy between the two projects can result in optimization of both efforts and outcomes.
Despite the mentioned interactions, SANDRA and SESAR present a different approach to the architecture: SANDRA proposes an integration of information domains characterized by

safety needs, and it aims at maximizing the reconfigurability and minimizing the costs of avionic platforms. On the other hand SESAR is more oriented to the ATM field.

		SANDRA SP3	SANDRA SP4	SANDRA SP5	SANDRA SP6	SANDRA SP7
SESAR IP2	Enhanced VHF Digital Mode 2 (VDL2) Air/Ground Data Link	X	X	-	-	X
	New Airport Datalink	X	X	-	X	X
	VoIP for Ground Segment of Air-Ground Voice	-	-	-	-	-
	Ground IP Network	O	-	-	-	O
	High performance Air Ground Datalink	X	X	-	-	O
SESAR IP3	Digital Air-Ground Voice	O	-	-	-	O
	Air to Air Datalink	X	-	-	-	-

Table 6. SANDRA expected impact on SESAR IP2 and IP3 communications enablers. X stands for 'major impact' and O for 'impact'.

Based on the analysis of these different points of view, it has been agreed that SANDRA will contribute to SESAR Development Phase providing its technological outcomes and preliminary work.
SANDRA will also define the standardization activities for ATM and the exploitation efforts that will be finalized by SESAR.
This synergy is possible because SANDRA architectural integration concept of different domains is fully compatible with SESAR. As mentioned before it maximizes the reconfigurability aspects and it minimizes the costs of avionic platforms thus representing a possible evolution for the SESAR system.

4.3 Working approach

In the previous sections the similarities between the two projects have been highlighted. As a consequence, in order to merge SANDRA and SESAR work plans, several collaboration working areas have been identified (Section 4.4).
The adopted procedure for the integrated working approach is based on the following guidelines:

- for each working area, an agreement on a common work plan is established and used by both teams at working level. This is crucial for synchronization; Fig.7 shows the foreseen interaction timeline between the projects;
- on a regular basis (e.g. every six months) meetings are scheduled for assessing progress, reviewing common work plans, analyzing eventual variation on scopes or contractual agreements such as SANDRA Description of Work and SESAR Project Initiation Reports.

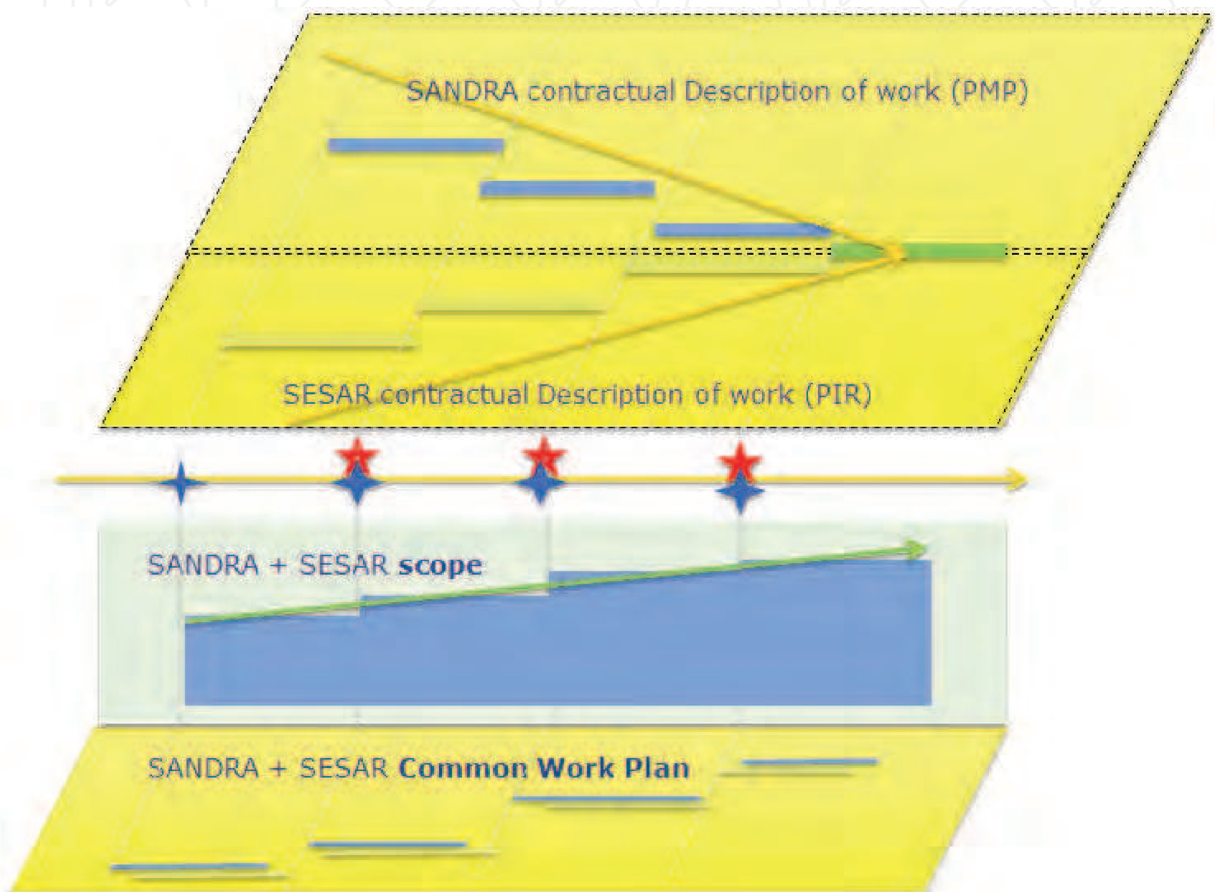

Fig. 7. Timeline of the interaction between SANDRA and SESAR.

Concerning this agreement, the European Community board showed its support to the co-operation between the projects but it required the fulfillment of the final goals of each single project: SANDRA and SESAR can exploit the beneficial aspects of sharing selected tasks but this interaction does not have to interfere with the finalization of the objective of each individual programme.
Moreover the definition of such agreement lead the two involved projects to foresee the possibility of project modifications through a Change Request Process.
The operative approach for work sharing depends on the particular working areas:

- activities can be shared between SANDRA and SESAR teams (e.g. airport communication system),
- results can be shared (input-output mode) when activities are time-sequential,
- a mixed approach can be adopted: input-output mode at the beginning and activity sharing during the following phases.

It has been agreed that the approach to be used will be identified on a case-per-case basis depending on the particular conditions.

It is also important to notice that for each working area, the common work plan has to address at least the following items:

- Work Breakdown Structure (WBS): to efficiently synchronize the common work packages and the technical activities that have to be carried out;
- Organizational Breakdown Structure (OBS): needed to share and organize the responsibilities for project management;
- Information workflow: it is necessary for the correct co-operation execution. It is mainly based on documents exchange but also on dedicated meetings;
- Respect of Intellectual Property Rights (IPR): in order to ensuring the non infringement of SANDRA and SESAR IPR rules and by analyzing case-per-case the presence of potential issues regarding the intellectual IPR violation;
- Non Disclosure Agreement (NDA): the involved parties agree to protect the confidentiality of the information disclosed in the common work.

4.4 Areas of collaboration

Starting from the analysis performed in Section 4.2 in which the architecture comparison is performed, nine common working areas have been identified and listed in Table 7. The corresponding SANDRA SPs and SESAR Projects are highlighted.

Working Area	SANDRA SP	SESAR Project
Requirements	SP2	15.2.4
Multilink management	SP3	15.2.4
Networking and architecture	SP3	15.2.4
Airport WiMAX comms	SP6, SP7	9.16, 15.2.7
QoS management	SP3	15.2.4
Software Defined Radio	SP4	9.44
Trials	SP7	All
Standardisation	SP8	All
Service Integration	SP2, SP3	9.19, 14
Airborne Infrastructure	SP2	9.44, (9.49), 9.19

Table 7. Identified working areas.

4.5 Cooperation with U.S.

Europe and the United States, being the main actors in the airspace field, are developing modernized ATM systems and their interoperability is of primary importance. However, as previously mentioned, the European aeronautical scenario is not unified and therefore there is the need for a common view.

The existence of a unified approach in the European countries, ease the relationship with the International Civil Aviation Organisation's (ICAO) Global ATM Operational Concept (ICAO, 2011). This connection is of primary importance because ICAO provides governments and industry with objectives for the design and implementation of ATM and it supports communication, navigation and surveillance systems.

To this aim a strong effort has been devoted in the SANDRA/SESAR collaboration framework in order to share the technology and procedures under development with ICAO and aviation authorities, as well as standardization bodies such as EUROCAE (EUROCAE, 2011) and RTCA (RTCA, 2011). A practical example is the coordinated effort in exchanging information with the relevant U.S. Stakeholders on the airport wireless technologies. Currently the definition of a common standard is foreseen and SANDRA and SESAR participants actively co-operate in this investigations.

4.6 Open issues

Some open issues remain, in particular when dealing with the relationships between two programmes that present different objectives, timescales and extension:

- definition of rules for solving possible project conflicts,
- definition of sharing information methodology,
- definition of a co-operating team,
- selection of an executive board.

These issues are still open and a final solution has to be found. In the next future the co-operation will lead to the definition of rules in order to maximize the synergy and the impact of the programmes on the global research and on the development in the field of aeronautical communications.

4.7 Case study: airport wireless communications

During a preliminary analysis it resulted that the operating Airport communication systems was effective and that it could be used as a pilot for this coordinated approach. The main goal of this working area is the definition and implementation of an IEEE 802.16e (IEEE 802.16e, 2009) dedicated wireless network profile, specifically tailored to aeronautical airport applications. This system is named AeroMACS and it is envisioned to operate in the 5091-5150 MHz band assigned by WRC 2007. As can be easily understood, the development and standardization of a unique profile for both European Union and United States is strongly desirable.

During the analysis, the following objectives for the common work were identified: requirements definition (including security aspects), profile definition, channel modeling, tools specification, standardization processes and trials set up.

In this process a team composed by representatives from a number of relevant sub projects was identified:

- SANDRA:
  - SP6: its main objective is the design of an aeronautical standard based on IEEE 802.16e (WiMAX) and that will use the MLS sub-band for airport surface operations, following the Future Communications Study technology assessment recommendations.
  - SP7: a test-bed for validation purpose of the overall SANDRA concept and architecture will be implemented in this SP. On-ground and in-flight trials will be used to show and prove the integrated SANDRA approach and its benefits with respect to existing aeronautical communications systems based on single radio technologies, thus incapable to overcome limitations of individual radio access systems, e.g. limited coverage of direct A/G data links, high delay of satellite systems, etc.

  - SP8: this SP is devoted to the investigation of key themes from FCS to speed up standardization and adoption processes, to develop transition and exploitation concepts integrated with SESAR approach and to contribute technological results and preparatory work envisaging standardization and exploitation effort being finalized in SESAR.
- SESAR:
  - 9.16 - New Communication Technology at Airport: this is designed to define, validate and demonstrate a technical profile and an architecture for a new generation of airport surface system to enable advanced surface CNS systems and improved information distribution and provide lower cost, safer and more efficient airport surface operations
  - 15.2.7 - Airport surface Data Link: its main objective is to define, validate and demonstrate a new surface communication link that will be based on the IEEE 802.16e standard, adapted for ATS/AOC communications and compliant with FCI recommendations.

The team work activities are focused on the definition of virtual work packages that specify the activities to be completed and a planning to avoid eventual overlapping. In addition the process has been identified:

- the 'prime' of each activity: that is the responsible for all technical and management issues related to that activity;
- the role of each participant: in order to optimize the common efforts,
- a list of potential risks (e.g. timeframe) that can be found in the work development and consequent recovery actions.

5. Conclusions

In 2009 the SANDRA Consortium, the DG Research and the SESAR Joint Undertaking established a collaboration for sharing resources and for providing the European community with an extensive set of results. Since both projects are related to different aspects of the same topic, subtasks of common interest have been identified.

In particular five Work Areas were highlighted: requirements, multilink and QoS management, flexible communication avionics, airport systems, and architecture, networking, SWIM airborne.

In this chapter a detailed description of the two projects and their co-operation was presented (together with a case study) to show and highlight interactions between programmes, the working approach, and the co-operation with USA.

In this chapter it has been shown that research and industrial programmes can efficiently collaborate and that the key objective expected is the coordination of the effort in a sector, the Aeronautical Communications, which presents an enormous competition among few well harmonized stakeholders. This is an important result for resource optimization reasons, and for investigating a novel way to maximize the impact of the advanced research in the European environment.

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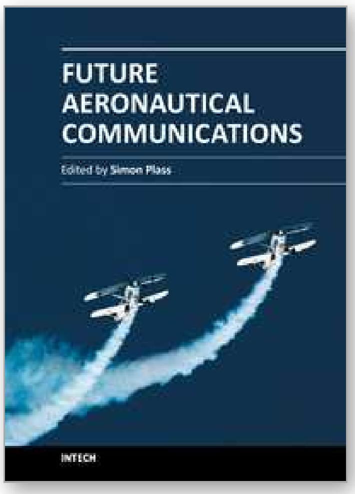

Future Aeronautical Communications
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There are well-founded concerns that current air transportation systems will not be able to cope with their expected growth. Current processes, procedures and technologies in aeronautical communications do not provide the flexibility needed to meet the growing demands. Aeronautical communications is seen as a major bottleneck stressing capacity limits in air transportation. Ongoing research projects are developing the fundamental methods, concepts and technologies for future aeronautical communications that are required to enable higher capacities in air transportation. The aim of this book is to edit the ensemble of newest contributions and research results in the field of future aeronautical communications. The book gives the readers the opportunity to deepen and broaden their knowledge of this field. Todayâ€™s and tomorrowâ€™s problems / methods in the field of aeronautical communications are treated: current trends are identified; IPv6 aeronautical network aspect are covered; challenges for the satellite component are illustrated; AeroMACS and LDACS as future data links are investigated and visions for aeronautical communications are formulated.

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