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WORKING GROUP TECHNOLOGY (WGT)

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Agenda Item 5 FCS Technology Recommendations

Future Communication Study - Action Plan 17
Final Conclusions and Recommendations Report

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SUMMARY

This paper is the final report out of the joint activities of FAA and EUROCONTROL to investigate the future aeronautical communications under the Action Plan 17 of the FAA/EUROCONTROL MoC. The paper provides a summary of the work performed as well as the references where the complete information is available and concludes with the resulting recommendations and proposed actions.

ACTION

WGT is invited to use the material in this paper (in particular Section 3 and Appendix E) as the basis for the WGT Report and the Recommendations to ANC (Agenda Items 6 and 7)

1. Introduction

The need for adequate future communication capability was discussed at the ICAO Eleventh Air Navigation Conference (AN-Conf/11). In its conclusions, AN-Conf/11 agreed that the aeronautical mobile communication infrastructure had to evolve in order to accommodate new functions and to provide the adequate capacity and quality of services required to support evolving air traffic management (ATM) requirements within the framework of the global ATM operational concept.

In order to achieve these objectives, AN-Conf/11 developed three relevant recommendations:

1. Recommendation 7/3 - Evolutionary approach for global interoperability of air-ground communications. This recommendation promotes the continuing use of already implemented systems (supporting voice as well as data), the optimisation of the available spectrum utilisation, and the consideration of transition aspects.
2. Recommendation 7/4 - Investigation of future technology alternatives for a/g communications. This recommendation addresses the need for investigations to identify the technology candidates to support the future aeronautical communications, and
3. Recommendation 7/5 - Standardization of aeronautical communication systems. Finally this recommendation emphasises the need for standardisation activities for technically proven technologies which provide proven operational benefits.

At AN-Conf/11 there was a strong request particularly from the airlines (represented by IATA) for international co-operation in order to achieve the stated objectives and goals in a harmonised and globally interoperable manner, particularly for air/ground communications.

In line with the AN-Conf/11 recommendations, EUROCONTROL and the U.S. Federal Aviation Administration (FAA) decided to establish a dedicated working arrangement (Action Plan 17 of the EUROCONTROL-FAA Memorandum of Cooperation) to progress this work in a consistent manner in Europe and the U.S.. AP17 has been very closely coordinated with ICAO ACP as a means to achieve world wide consensus and global harmonisation.

2. AP17

The AP17 is a joint activity between FAA/NASA and EUROCONTROL. Under the U.S. AP17 activities, NASA Glenn Research Center (GRC) was asked by the FAA to lead the U.S. technology investigation. In Europe, France, Germany, Spain, Sweden and the U.K. have also been actively supporting and contributing in the European investigations. The work undertaken under AP17 has also been supported by MITRE and ITT Corporation in the U.S. and by QinetiQ in Europe.

The AP17 partners agreed that the activities need to allow a realistic transition for service providers and airspace users, to support air traffic services (ATS) and airline operational control (AOC) data communications for safety and regularity of flight (including air/air communications), and to address spectrum depletion in the high density regions of both Europe and the U.S.

It was agreed that in the longer term, a paradigm shift will occur in the operating concept and the prime mode of communication exchanges will be based in data exchanges rather than voice communications as it is today. Based on the outcome of the initial AP17 activities, the partners agreed to focus the investigations on data communications and consider that the existing VHF systems (analogue voice and data link) will be used as required to cover the short and medium term needs.

The AP17 progress has been closely monitored at the highest management levels of FAA and EUROCONTROL, with regular feedback and steering. In addition the progress of the work has also been regularly presented in the ACP/WGC meetings. The feedback and comments were instrumental in the continuation, focusing and steering the activities.

The AP17 activities have been closely coordinated with the relevant stakeholders in the U.S. and Europe. In the U.S. the work is being closely coordinated with the multi-agency Joint Planning and Development Office (JPDO) Next Generation Air Transportation System (NextGen) initiative. In Europe the work is being closely coordinated with the EUROCONTROL/European Commission Single European Sky ATM Research (SESAR) Programme.

In the U.S., NextGen will support the projected future increased demands in air traffic. This system of systems will support a projected vision of the U.S. National Air Space System for the 2025 time frame. This will require a transition plan which will include significant research, development and implementation of multiple technologies. The projected Concept of Operation in 2025, which includes trajectory based and performance-based operations, net-centric services and shared weather information, calls for increased data communications which can provide timely, accurate, secure and comprehensive information.

In Europe, SESAR is the European ATM modernisation programme, combining technological, economic and regulatory aspects in order to synchronise the plans and actions of the different stakeholders. SESAR will lead the definition, development and implementation of the required improvements both in the airborne and ground systems in Europe. Currently the Definition Phase is being completed, which will deliver a European ATM Master Plan covering development activities up to the 2020 timeframe. From 2008 up to 2015 will be the Development Phase of the required new improvements. These new improvements will be implemented in the Implementation Phase from 2013 onwards (with 2020 being the target to implement the required improvements). In Europe a specific entity, the SESAR Joint Undertaking (SJU), is being set up to manage the activities following the definition phase.

AP17 has been a highly collaborative study with careful work planning leading to the effective use of resources to avoid duplication, and successful information sharing. Among the major achievements of AP17, are: 1) the establishment of future aeronautical communications concepts of operation and requirements (COCR); 2) the identification of enabling technologies; and 3) the development of a roadmap for the future communications infrastructure (FCI) that covers the transitions from now through to 2030. The AP17 outcome is supporting the communication objectives of SESAR and NextGen, which are pacing the transition to the future ATM system. The very close and efficient cooperation between U.S. and European experts has enabled convergence and agreement on joint recommendations as directed by AN-Conf/11.

The AP17 work considered several Technical Tasks for progress. In addition, non-technical actions, referred to as Business Tasks, were also considered. The Business Tasks are essential to create "dynamics" and maintain commitment. Overall, there were 6 technical tasks and 3 business tasks. Appendix A provides additional information on the AP17 activities. The content of the various tasks and their achievements are summarised in the following sections.

Technical Tasks

Task 1: Improvements to Current Systems - Frequency Management

Particularly in Europe, the VHF band is already congested today. It is very difficult for example to find new frequencies for new sectors or services in core Europe. This situation is becoming worse and congestion will also appear in peripheral states as well. In Europe the 8.33 KHz programme has been introduced and is currently being expanded to provide much needed relief. However, even with the introduction and use of the 8.33 KHz channelisation, the benefits are expected to be short term as in the longer term the congestion levels will increase again in line with the expected traffic increase.

While the VHF band is also heavily utilised in the U.S., the congestion is not as critical as in Europe. Whereas the long term availability of frequencies is also of concern, there are options such as the use of 8.33 KHz spacing if required.

In the context of the AP17, it was agreed that exchanging experience and expertise on frequency management aspects could help to extend the continued use of the current systems (primarily voice) and at the same time, better prepare for the future communication system. It is generally agreed that prolonging the life time of the VHF band (i.e. to be capable to satisfy new requirements in this band for traditional ATS and AOC air-ground voice communications services) is absolutely vital to aviation, especially in the short to medium term, in which there are no other options.

A good understanding of the frequency management procedures in the two regions has been established and the experience gained will be used as appropriately. A key difference is that in U.S. there is centralised management with one body (the FAA) supervising the whole process, covering the operational requirement justification up to the implementation in the radio sites, whereas in Europe each state is responsible for managing its own frequency assignments and the cross-border coordination requires consensus.

Task 2: Identify the Mobile Communication operational concept

The outcome of the intense activities under this task is contained in the Communications Operating Concept and Requirements (COCR) document. The development of the COCR has been an intense collaborative effort of U.S. and European experts and it captures the requirements that future communications systems will need to meet for emerging ATS and AOC concepts and strategies to support the technology assessment process. The COCR covers two main phases: Phase 1 (from now to 2020) and Phase 2 (beyond 2020). Phase 1 is based on greater use of air/ground data communications, but remains largely human centric. Phase 2 is based on more extensive use of Phase 1 services and takes into account concepts emerging from the SESAR initiative in Europe and the NextGen initiative in the U.S. Key changes in Phase 2 include the use of 4D trajectory management, greater information exchange between the aircraft and the ground systems to support automated conflict resolution and the introduction of autonomous operations in some parts of the airspace.

From the operational concepts, information flows have been identified in representative test volumes of airspace i.e., ‘positions/sectors’ in airport, terminal maneuvering area (TMA), en-route, and oceanic. This includes all ATS and AOC air/ground and air/air voice and data communication including Automatic Dependent Surveillance - Broadcast (ADS-B). New types of aircraft such as micro-jets and Unmanned Aircraft Systems (UAS) have been included on the basis that they occupy the same airspace and have the same ATS communication requirements as other types of aircraft. However, while ATS communications between UAS pilots and air traffic controllers has been included within the scope of the COCR, the command and control link for UAS has not. Also, security applications such as down linking of onboard aircraft video were also considered to be outside the scope of the COCR.

From the operational concepts the communication requirements have been derived taking into account safety and security analyses. It should be noted that the requirements are technology independent. The determined requirements parameters include:

- Communications capacity needed in the various airspace types, and
- Availability, continuity, integrity and latency requirements.

The per service volume capacity requirements for air/ground and air/air communications were determined using a representative queuing model to support the identified services. In the timeframe of Phase 2, the capacity requirements for ATS and AOC air-ground communications in high density airport and en route environments were approximately 200 kbps (per service volume). For the TMA and oceanic/remote/polar environments, capacity of approximately 40 kbps (per service volume) was determined to be required.

The COCR also identified stringent requirements in Phase 2 for availability, continuity, integrity and latency both on an end-to-end basis as well as for the radio system. These requirements are necessary to support the anticipated data link services in this timeframe.

The COCR is a comprehensive document which used a top down requirements driven approach to develop future communications requirements. It has been used as the basis for the technology assessments as reported below. It was presented to various stakeholders and ACP and it was accepted as the basis for the requirements determination. In addition, the COCR was provided as input material to SESAR in Europe and NextGen in the U.S. To facilitate the technology evaluations and to ensure that a common set of performance requirements are applied equitably, a set of evaluation scenarios has also been developed based on an extension of the service volumes in COCR. These are contained in the Evaluation Scenarios document which provides a library of evaluation scenarios which can be utilised by each technology in the most appropriate manner.

Appendix B contains information (including links) on the deliverables out of this task.

Task 3: Investigate new technologies for mobile communication

Task 3 was conducted to evaluate applicable technologies to satisfy the needs of the communication concepts for the Future Communication Infrastructure (FCI) defined in the COCR. The task was performed in several phases through coordinated and cooperative efforts of two teams: a European team and an FAA/NASA/ITT team, from 2004 through 2007. The evaluation included identification of a set of over 50 candidate communications technologies; definition of an operational concept for application of the technologies to the FCI; and simulation/evaluation of technology performance and applicability.

The initial set of study activities included a joint effort to survey applicable technologies, define a concept for application of the technologies to the future aeronautical environment, and perform a technology pre-screening. Coordinated follow-on activities consisted of down selection of the most promising technologies through in-depth technology performance studies and evaluation of these technologies against well-defined criteria. Throughout follow-on activities the two study teams conducted detailed review and discussions to share results, solicit comments, and harmonize technology recommendations. A summary of the Technology Evaluation methodology is provided in Figure 1 below.

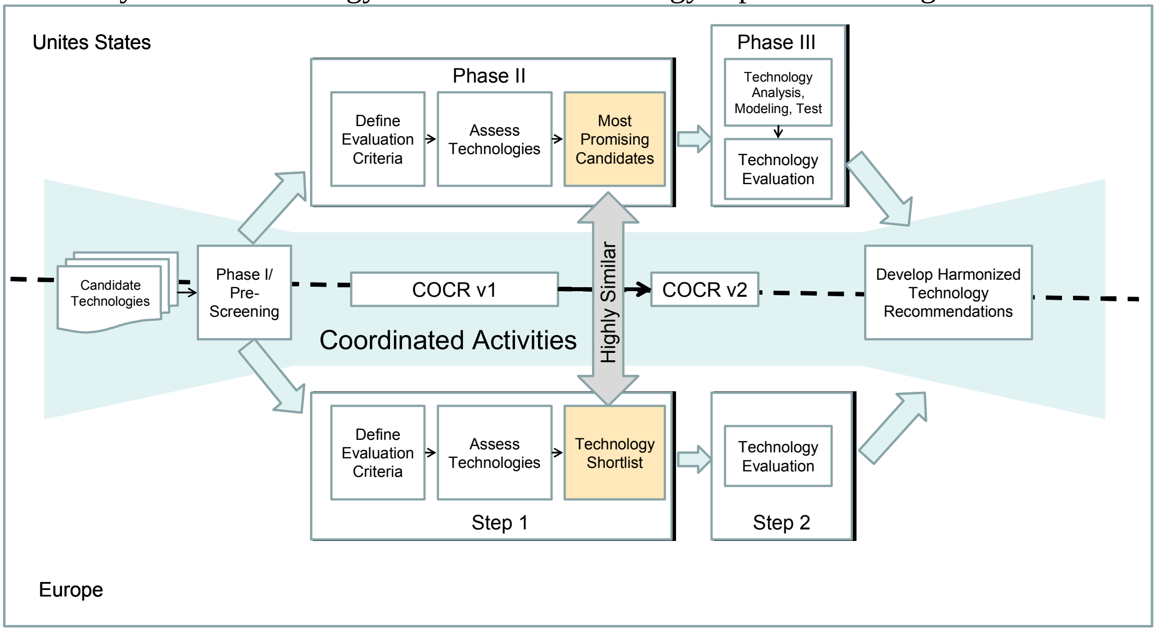

Figure 1: Technology Evaluation Methodology

An important harmonization step during the Step 1/Phase II investigations was the review of work to identify the most promising technologies for further investigation. After each team individually examined requirements and applied a subset of the evaluation criteria in a technology down select process, the teams found significant overlap in the resulting sets of most promising technologies (also called the technology shortlist). These results are shown in Figure 2 below. The technologies assessed are the following: TIA-902 (P34), L-band Data Link (LDL), Wideband Code Division Multiple Access (WCDMA), INMARSAT SwiftBroadband (SSB), Custom Satellite and 802.16e. The Broadband Aeronautical Multi-carrier Communications system (B-AMC) and the All-purpose Multi-channel Aeronautical Communication System (AMACS) have also been investigated primarily in the frame of the European activities. LDL is an evolution of the VDL3 system, B-AMC is an evolution of the Broadband-VHF (B-VHF) proposal, and AMACS is a combination of the VDL4 system and the ETDMA (Enhanced TDMA) proposal. The term, “Custom Satellite,” refers to both new commercial satellite offerings specifically designed to address FCI requirements as well as government/private initiatives for satellite designs specific to aviation communications.

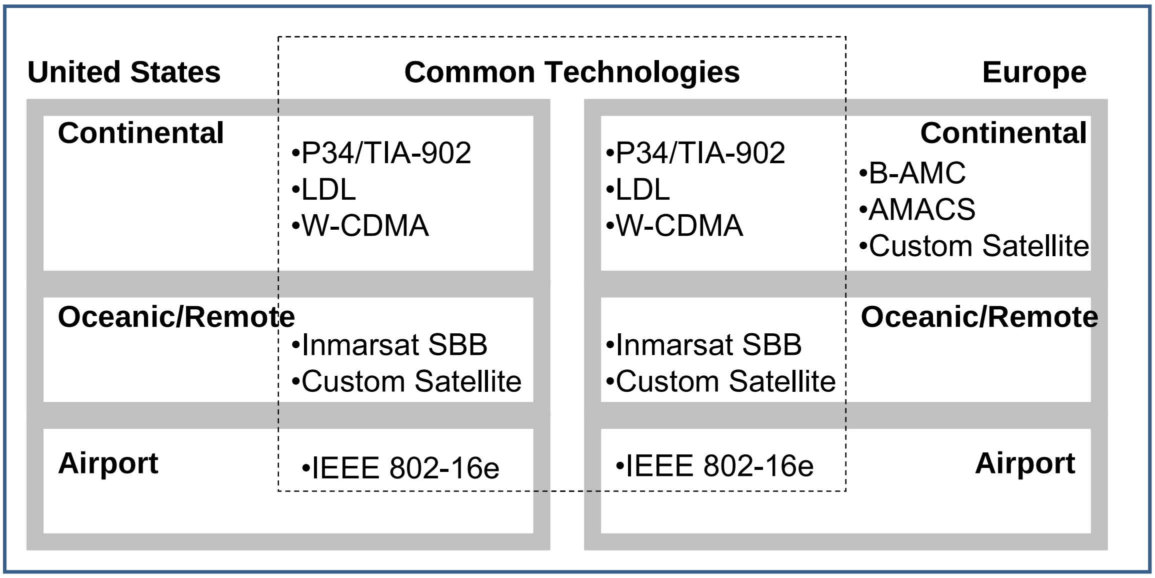

Figure 2: Evaluated Technologies: Final Shortlist

The results and recommendations of the technology investigations can be organized by proposed operating frequency bands. The following paragraphs describe study outputs organized in this manner.

C-band

Many major accomplishments were realized during the technology investigation effort. One was the joint identification and recommendation of an IEEE 802.16e-based system as the solution for the provision of dedicated aeronautical communication services on the airport surface utilizing proposed aeronautical C-band allocations. This technology, designed for short-range, high data rate communications in C-band, is well matched to the airport surface environment in terms of capability and performance. Additionally, simulation of this technology in this aeronautical channel environment yielded very favourable results. The proposal for the C-band data link builds upon currently ongoing activities including testing of the standard 802.16.

The C-band recommendations are to:

- Identify the portions of the IEEE 802.16e standard best suited for airport surface wireless mobile communications and propose an aviation specific standard to appropriate standardisation bodies;
- Evaluate and validate the performance of the aviation specific standard to support wireless mobile communications networks operating in the relevant airport surface environments through trials and test bed development; and
- Propose a channelisation methodology for allocation of safety and regularity of flight services in the band to accommodate a range of airport classes, configurations and operational requirements.

AMS(R)S Band

A second accomplishment was the harmonized definition of the role of satellite services in the FCI, particularly for support of operations in the oceanic and remote airspace domains. The study teams recognized the unique capabilities of satellite communication systems to provide adequate coverage over large and/or remote geographic areas. It is important to note, however, that the defined operational concept for the FCI (2020 and beyond) is beyond the service horizon of current satellite offerings for aeronautical mobile satellite (route) services (AMS(R)S). Some existing service offerings such as INMARSAT SBB have been identified as potentially suitable for meeting the service requirements for oceanic/remote airspace in specific geographic locations. The potential of next generation satellite systems, particularly those systems customized to meet the needs of aviation (including custom commercial solutions such as Iridium-NEXT and custom government/private solutions such as the European Space Agency (ESA) initiative (ATM SATCOM) was also recognized. In the European activities, the future satellite systems are also being investigated as a complement of the terrestrial infrastructure to jointly meet the future stringent requirements in the high density continental airspace.

An issue that was raised in the investigations was the adverse impact of the proliferation of technologies in the airborne equipment which result in multiple options for equipage. In this context, the availability of a globally applicable standard covering the requirements of the COCR may facilitate to address some of the institutional issues associated with satellites. If such a standard would be adopted by the interested parties, it would support interoperability while minimising airborne equipment requirements.

The satellite band recommendations are to:

- Continue monitoring the satellite system developments and assessment of specific technical solutions to be offered in the timeframe defined in the COCR as these next generation satellite systems become better defined;
- Update existing AMS(R)S SARPs performance requirements to meet future requirements; and
- In order to support the new AMS(R)S SARPs, consider the development of a globally applicable air interface standard for satellite communication systems supporting safety related communications.

An important feature of the satellites is the support for non line-of-sight communications. Today, this functionality is also provided by HF systems supporting both voice and low rate data communications especially in the oceanic environment. These already deployed systems will continue to be employed in the FCI. Any new HF system could also be considered in the frame of the FCI.

VHF-band

The investigation of technologies to provide future data communication capabilities in continental airspace domain (en route/terminal/surface) focused on technology concepts for deployment in the aeronautical VHF and L-bands. While none of the existing data link technologies meets the long term aeronautical requirements, some proposed technologies in the VHF-band were identified for consideration for the future radio system. However, in the end in large part due to current spectrum congestion considerations, the technology investigations focused in the L-band. In the longer term, the applicability of the VHF band may also be reconsidered.

The VHF band recommendation is to:

- In the longer term, reconsider the potential use of the VHF-band for new technologies when sufficient spectrum becomes available to support all or part of the requirements.

L-band

For en route and TMA airspace, the L-band was identified as the best candidate band for meeting the future aeronautical communications, primarily due to potential spectrum availability and propagation characteristics. As a result of this finding, another accomplishment of the technology evaluation was the recommendation to seek co-primary allocations for AM(R)S in the aeronautical L-band at the upcoming World Radiocommunications Conference (WRC-07).

In light of the importance of the L-band, significant effort was devoted to define and model the L-band channel and interference environment, including development of an initial channel model. Further work is required to refine and validate the channel model. Analyses of the legacy aeronautical L-band systems (including DME, UAT and Mode S), interference scenarios, and development of a laboratory test methodology were also performed. This work was used to conduct initial investigations of technology performance in the L-band. It is noted that the assumptions used for the interference investigations are critical for determining compatibility. As a result, primarily of the channel and interference investigations and the performance assessment of the technologies, it was concluded that a thorough evaluation of the compatibility in the band is required.

As a result it is recommended to:

- Refine and agree on the interference environment and assumptions for the L-band compatibility investigations.

As a result of the initial performance analysis of the short-list of technologies in the anticipated channel and interference environment and against defined criteria, it was found that none of the considered technologies could be fully recommended. However, the assessment of these technologies led to the identification of suitable technology features that could be used as a basis for the development of an acceptable L-band data link solution. For example, some technology features specifically address operation in a fast fading environment or have low duty cycle transmissions, which is beneficial in mitigating interference. Considering these features and the most promising candidates, two options for the L-band Digital Aeronautical Communication System (L-DACS) were identified. These options warrant further consideration before final selection of a data link technology. The first option represents the state of the art in the commercial developments employing modern modulation techniques and may lead to utilisation/adaptation of commercial products and standards. The second capitalises on experience from aviation specific systems and standards such as the VDL3, VDL4 and UAT.

The first option for L-DACS includes a frequency division duplex (FDD) configuration utilizing OFDM modulation techniques, reservation based access control and advanced network protocols. This solution is a derivative of the B-AMC and TIA-902 (P34) technologies. The second L-DACS option includes a time division duplex (TDD) configuration utilizing a binary modulation derivative of the implemented UAT system (CPFSK family) and of existing commercial (e.g. GSM) systems and custom protocols for lower layers providing high quality-of-service management capability. This solution is a derivative of the LDL and AMACS technologies. Table 1 depicts the two options.

	Access scheme	**Modulation type**	**Origins**
L-DACS 1	FDD	OFDM	B-AMC, TIA 902 (P34)
L-DACS 2	TDD	CPFSK/GMSK type	LDL, AMACS

Table 1: L-DACS (the L-band data link) options key characteristics

In addition to air/ground communications capability, some of the assessed technologies could support air/air (point to point and/or broadcast) communications services. B-AMC, AMACS and TIA-902 (P34) have provisions to support such services. However this capability needs further investigation as a possible component of L-DACS.

Follow-on activities to further characterize the proposed L-DACS solutions, validate performance, and lead to a single technology recommendation for this band are required.

To complete the selection of the L-DACS solution, it is recommended to:

- Complete the investigation of compatibility of prototyped L-DACS components with existing systems in the L-band particularly with regard to the onboard co-site interference and agree on the overall design characteristics;
- Evaluate and validate the performance of the proposed solution in the relevant environments through trials and test bed development; and
- Considering the design trade-offs, propose the appropriate L-DACS solution for input to a global aeronautical standardisation activity.

General aspects

Considering also the developments in ACP/WGI, it is assumed that the FCI will employ an ATN/IP infrastructure. When finalising the selection of the new components of the FCI further testing and validation should be carried out within an end-to-end IP environment to ensure that the required Quality of Service (QoS) and performance can be achieved.

During the AP17 activities, the use of Commercial-Off-The-Shelf (COTS) products to benefit from commercial developments and synergies was recognized as a preferred solution to support the future aviation communication requirements. Results of the investigations however showed that no COTS technologies are currently available which meet all the requirements. Nevertheless, reuse of COTS components/elements is encouraged throughout future system identification and development efforts.

Additional details on the technology investigations can be found in Appendix C and in the reference documents noted in Appendix B of this document.

Task 4: Identify the communication roadmap

In line with the phased communications operating concept described by the COCR, the Communications Roadmap was developed to describe the evolution of the communication infrastructure. The roadmap recognizes the needs of the aviation users as well as air navigation service providers, ensures the judicious use and protection of spectrum allocated for aeronautical purposes, and focuses on the introduction of potential new technologies for specific airspace and services.

Figure 3 depicts an overview of the jointly agreed to approach for the implementation and evolution of aeronautical mobile communications to support the emerging and anticipated needs of air traffic management in both Europe and the U.S. This is expected to become the basis for globally harmonised communications.

Near term, air traffic control operations will continue to use the VHF spectrum for voice communications throughout the U.S. and European regions. 8.33 kHz channel spacing has been implemented for the VHF band in Europe, and will continue to expand vertically into more airspace as needed to satisfy demand for voice channels.

Initial data link using VDL2 in European airspace is being implemented to support ATC data services, such as CPDLC. Mandatory carriage of equipment to support these services is expected for certain airspaces in Europe, from 2009 (forward fit) onwards.

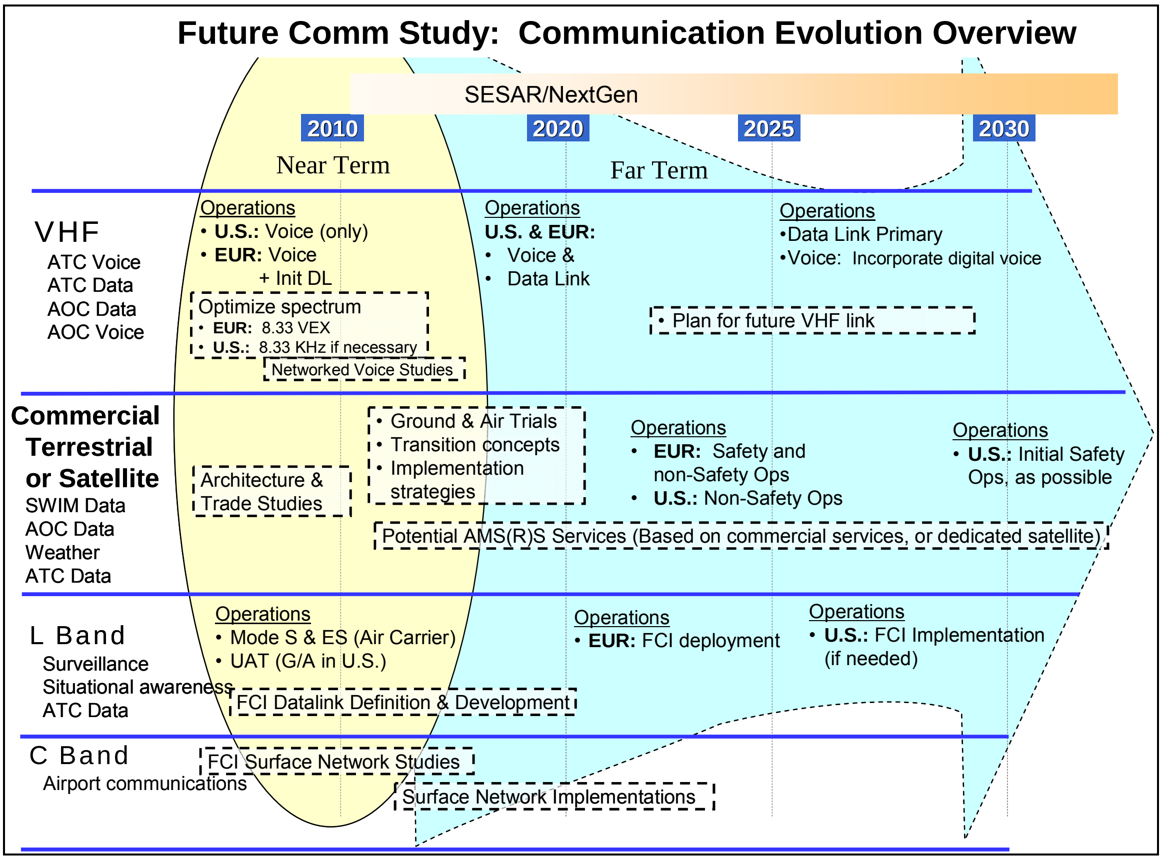

Figure 3 – Aeronautical Mobile Communications Evolution Overview

The U.S. is optimizing its use of VHF spectrum to ensure sufficient capacity for data operations, and to provide needed voice channels. In the same time frame, the FAA DATACOM program will begin to develop and implement data applications in the U.S. domestic airspace, using available communications technologies (i.e.VDL2) and aircraft equipment. 8.33 kHz voice channel spacing will be employed if necessary to increase the amount of spectrum available for data link services.

Surveillance applications in both the U.S. and Europe will continue to use L-band communications at 1030/1090 MHz for SSR/ATCRBS. In addition, both regions will support ADS-B using 1090 ES. The U.S. will also be implementing UAT to support ADS-B services. In Europe, VDL4 is also being implemented on a regional basis.

To prepare for the far term, FAA and Eurocontrol will continue to study the potential for emerging commercial terrestrial-based and satellite communications technologies for non-safety communications. In addition, the potential use of dedicated satellite systems to support safety communications is being considered in Europe. Opportunities to validate the concepts of use, or implementation strategies for these technologies would be performed through ground and airborne trials and demonstrations.

The FAA and Eurocontrol will also engage in joint activities to complete selection of the terrestrial based L-band digital link (L-DACS), to provide additional aeronautical mobile communications capacity. Regional limitations of the VHF band in Europe may drive implementation of the jointly developed terrestrial L-band digital link technology in the 2020 time frame. As circumstances dictate, the FAA will also consider the L-band digital link technology for use in the U.S. Considering the long time cycles in aviation to develop, validate, standardise and deploy a new system, it is critical that these activities are carried out expeditiously.

Wireless airport communications links using the C-band spectrum allocations at 5 GHz are recommended for deployment as surface area networks. Applications that may be considered for use in this frequency band include surveillance and weather sensor information transfer; monitor and control of aerodrome navigation and landing aids; support for information transfer between automation systems; and Electronic Flight Bag and other mobile applications supporting aircraft and surface vehicles.

Once digital data communications is established, and the operational paradigm changes to be based on digital information exchange as the prime means for safe and efficient ATC operations, it is expected that the need for data communications will grow and the nature of voice communications will change. In the long term, digital voice may also be used.

The detailed deliverable under Task 4 of the AP17 is provided in Appendix D of this document.

Task 5: Investigate feasibility of airborne communication flexible architecture

In order to ease migration towards new systems, the importance of the flexibility of the airborne architecture has already been identified. This task set out to capitalise on the on-going developments in the telecommunication industry and investigate the feasibility of a flexible airborne architecture and the appropriate enablers including multi-mode/software radio and "agile" antennas. The need for new components for the future communication infrastructure as well as the continuing use of existing technologies will result in changes to ground infrastructure as well as the avionics.

In particular the integration of new and old components onboard the aircraft is a critical area that needs careful consideration to address a multitude of issues such as interference, certification, physical space limitations, and human factors.

In this context EUROCONTROL commissioned a study "Aircraft Architecture Study" (reference details in Appendix B) to investigate the future communication architectural requirements and enablers for a flexible airborne architecture. The study investigated possible approaches to considering not only the communication elements of future aircraft architectures but also how an overall approach could be adopted to more easily introduce change. The study concluded that the future avionics architecture could see a realisation of evolving technologies to provide the functionality required of a flexible and expandable system. This will include a high degree of integration of cockpit avionics operating on a modular and extendable computing capability to provide flexibility, redundancy and support for improvement.

The EUROCONTROL study provided rationale to reduce the number of aircraft antennas and to provide more capability for each aperture in the aircraft's surface. This reduced antenna set will provide input to a number of software-defined radios (SDRs). These SDRs will provide the flexibility to adapt to changes in frequency, modulation and encoding in order to provide access to the developing communication capability. SDRs will provide their data as information services, via a robust and extendable network infrastructure, to support cockpit avionics, operational avionics and cabin information services. There could be a similar degree of integration for operational and cabin services which will be partitioned to reduce costs in certification. The net result will be adaptable and expandable avionics architecture able to evolve with the rapidly expanding communications capability.

In the U.S., NASA GRC initiated the concept and development of multi-function, multi-mode digital avionics (MMDA). GRC's objective was to demonstrate an MMDA prototype that illustrates the potential for lower total system cost and faster certification and re-certification processes, in comparison with conventional independent avionics equipment. Applied to the FCI, the MMDA concept should be considered for both the on-board and ground-based systems that implement multiple modes of communications, potentially in and across the various frequency bands allocated for safety critical communications.

Multiple preliminary assessment and analysis studies were conducted by industry partners. GRC also initiated and chaired the Avionics Special Interest Group (SIG) under the Software Defined Radio Forum. Detailed references for the above studies are provided in Appendix B.

Based on EUROCONTOL and U.S. findings, the following recommendations emerge:

- Support activities and engage with aircraft manufacturers, aircraft operators and industry standard groups to ensure that a flexible airborne architecture evolves to ease the cost and time of certification and readily accommodate new applications and technologies; and
- Encourage industry investigations into flexible airborne architectures, software defined avionics, and multi-function, multi-mode antennas.

Task 6: Identify the Spectrum bands for new system

Spectrum availability and interoperability with existing systems are primary considerations in the selection of new technologies of the FCI.

The activities in this task consisted in providing appropriate support to the ICAO group dealing with spectrum matters (ACP WGF) and relevant ITU groups involved in the WRC-07 Conference preparations.

A key outcome of this activity was the identification of the required spectrum (60 MHz for the L-band and 60-100MHz for the C-band) to support the requirements of the FCI taking into account the input out of Task 3 of AP17. The results of this task were used as inputs both in the U.S. and European sides to define their positions for WRC-07.

Currently, there are 3 options that are being considered for AM(R)S allocations at WRC-07. Taking into account the characteristics (propagation) and implications (power) for any system that may be eventually allowed to operate in the above bands and taking into account the emerging capacity requirements for the different airspace domains the optimised usage of the considered bands could be as follows:

- VHF band: upper VOR band ([112 or 116]-118 MHz)
  This band (an extension of the current 118-137 MHz) could be used to either support existing services (e.g. transition) or to allow for the introduction of new systems in all continental airspace.

- L-band: lower part of the DME band (960-[1024 or 1164] MHz)
  This band could be used to support services in all continental airspace.

- C-band: [5000 to 5010] MHz, and/or [5010 to 5030] MHz, and/or 5091 to 5150 MHz
  This band could be used to support surface applications at airport.

In order to preserve flexibility, generic AM(R)S allocations should be secured in all considered bands.

Recognizing the dependence of FCI on having sufficient and suitable spectrum available, the spectrum recommendations are to:

- Continue to provide rationale to spectrum regulators on the need for additional AM(R)S spectrum to facilitate advances in aeronautical communication capabilities;
- Provide support for compatibility studies between the FCI and other incumbent systems in any newly-allocated AM(R)S bands. This will include studies within ICAO regarding FCI compatibility with other aeronautical systems, and studies within the ITU regarding FCI compatibility with non-aeronautical systems; and
- Continue to support the need for priority to AMS(R)S in the satellite L-band.

Business Tasks

Business Task 1: Create Multi National Framework

The activities in this task were primarily focused in providing regular updates to ICAO (ACP, WGW, and WGC) and seeking feedback and comments for the continuation of the work.

In particular ACP/WGC has been continuously briefed on the progress of the work in the various tasks. The feedback and comments of the WGC participants were instrumental in the progress and the direction of the activities in all tasks and in particular to the tasks dealing with the identification of the requirements and the technology investigations.

Business Task 2: Create Industry interest

Industry interest is recognized as an important factor in contributing to the success of achieving the desired objectives of the AP17. As a result, a number of approaches were employed through out the study to help increase the awareness and involvement of potential stakeholders. As a means of gaining international consensus and converging towards a globally harmonized solution, the FAA/Eurocontrol team presented updated study results to the ICAO ACP on a frequent basis as covered in Business task 1. In addition, EUROCONTROL presented results to the Communication Team (COMT) and the Air-Ground Communications Focus Group to provide updates and gather feedback from European stakeholders including industry, and ANSPs. The FAA provided a mid-course presentation to the RTCA Air Traffic Management Advisory Committee as a mean of gathering further support and direction from the U.S. Airline Industry. The team also provided presentations at a number of open forums/conferences including the ATN 2000+ and the Integrated Communications, Navigation and Surveillance Conference (ICNS) as a means for further dissemination of the information and obtaining feedback. Finally, the study was designed to allow system specific constituents to participate in the technology design and characterization process. These industry relationships will continue to evolve through the SESAR and NextGen programs.

Business Task 3: Business Model

An important element in realizing the Future Communication Infrastructure (FCI) is consideration of technical solutions from the business perspective.

To address this topic, a business case analysis provided a high level estimate of the economic feasibility of an L-band aeronautical radio system from the perspective of a ground infrastructure provider. This initial analysis included the definition of a notional L-band ground radio system architecture that could meet the needs of the FCI as defined in the COCR. This effort included development of cost elements and estimates for development, operation and maintenance of the L-band system and then assessment of the required revenue flow to close the business case. By applying a number of assumptions (e.g. for the number of ground stations in a large area deployment; radio site configurations; element costs, etc); considering life cycle costs; and applying a standardized cost assessment methodology (Present Worth Simple Payback Method), it was found that a positive business case could be achieved within 4 years. While this high level cost estimate yielded positive results, an important feature of the study was the development of a suitable structured process for the analysis, which can be considered a framework for specifying infrastructure costs associated with an L-band system. Additional work is needed to assess the business case from the perspective of airlines. Additional details of this investigation can be found in the NASA Technology Investigation Phase II Final Report referenced in Appendix B.

In addition, a business case assessment of an ATM satellite system was also carried out under the ESA SATCOM study. There were three funding scenarios considered: Private Finance Initiative (PFI), Private Venture (PV) and Public Procurement (PP). The PFI offered the best funding arrangements and is considered the most financially attractive to both public authorities and private investors. Some of its advantages are being more robust to cost and revenues uncertainties and gives best guarantees in terms of viability and permanency over years. A PV scenario did not look financially viable. Finally PP could be considered in the absence of private investors as it reduces the initial market take up risk. The key drivers identified in the study are the financial viability including Operator exposure to various risks, user equipment ramp-up, system size vs. service, and competition from other systems. Additional details of this work can be found in the ESA SATCOM study Final Report referenced in Appendix B.

A business analysis is a key input to a decision taking process and needs to clearly address the expected benefits of the implemented operating concepts for all stakeholders. Therefore it is recommended to:

- Complete business analysis in relation to the FCI components and implementation from the perspective of the ground infrastructure and the airlines.

3. Conclusions, Key Recommendations and Actions

The FAA/EUROCONTROL Action Plan 17 (AP17) has been a highly collaborative study with careful work planning leading to effective use of resources to avoid duplication, and successful information sharing. Among the major achievements of AP17, are the following:

- Establishment of future aeronautical communications concepts of operation and requirements;
- Identification of enabling technologies;

- development of a roadmap for the future communications infrastructure (FCI) that covers the transitions from now through to 2030; and
- Development of guidance and recommendations for the future aeronautical communications infrastructure.

The AP17 outcome is directly supporting the communication objectives of SESAR and NextGen. These are the two major programmes in Europe and the U.S. which are pacing the transition to the future ATM system. The AP17 outcome identifies the communication enablers to support the future operating concepts.

The very close and efficient cooperation between U.S. and European experts has enabled convergence and agreement on joint recommendations as directed by the ICAO 11th Air Navigation Conference (AN-Conf/11). The AP17 activities have been very closely coordinated with the participants of the ICAO Aeronautical Communications Panel (ACP) as a means to pave the way for the world wide consensus and global harmonisation.

The outcome of the AP17 activities identify that the FCI will be a system of systems infrastructure, integrating existing and new technological components aiming to secure seamless continuation of operations by safeguarding investments, facilitating required transitions and supporting the future requirements.

In summary, the key recommendations out of AP17 for new data link developments are the following:

- [R1] Develop a new system based on the IEEE 802.16e standard operating in the C-band and supporting the airport surface environment
- [R2] Complete investigations (with emphasis in proving the spectrum compatibility with other systems) to finalise the selection of a data link operating in L-band (L-DACS) and supporting the continental airspace environment, aiming at a final decision by 2009, to enable system availability for operational use by 2020
- [R3]: Recognising that satellite communications remain the prime candidate to support oceanic and remote environments and that the considered future satellite systems may also be able to support continental environments possibly complementing terrestrial systems, monitor and support developments that will lead to globally available ATS satellite communications

Other key recommendations out of AP17 are:

- [R4]: Recognising the importance of spectrum for the realisation of FCI, ensure the availability of the required spectrum in the appropriate bands.
- [R5]: Promote/support activities that will enable/facilitate the airborne integration of the selected technologies.
- [R6]: Incorporate in any new data link system, provisions for supporting high QoS requirements in an end to end perspective.

Finally, it is recommended to:

- [R7]: Continue the close cooperation between the interested stakeholders and in particular between the FAA and EUROCONTROL in the realisation of the above recommendations.

The future joint FAA/EUROCONTROL activities should continue to be in the framework of the development of the required communication enablers for the NextGen and SESAR initiatives, which are leading the overall modernisation of the ATM systems in U.S. and Europe. In both regions, there is already active engagement of the key stakeholders (industry, airspace users, ANSPs, military. etc) in the NextGen and SESAR initiatives. However, the joint FAA/EUROCONTROL activities with a continuing close coordination of these activities in the frame of ICAO/ACP will reinforce and facilitate the global harmonisation.

The AP17 activities have identified a number of actions that need to be undertaken to secure the timely availability of the FCI meeting the considered requirements. Considering the long cycles in aviation to specify, validate, deploy and reach full system capability for any new system, it is critical that these activities are carried out expeditiously. The identified target date for an FCI initial deployment is 2020 and meeting this date needs continuous efforts to achieve the various milestones (validation, standardisation, commercial equipment availability, implementation decision, preoperational deployment and operations). Figure 4, as an example, depicts the key activities and the considered timings for the expedited development and deployment of the L-band component of the FCI targeting availability in 2020.

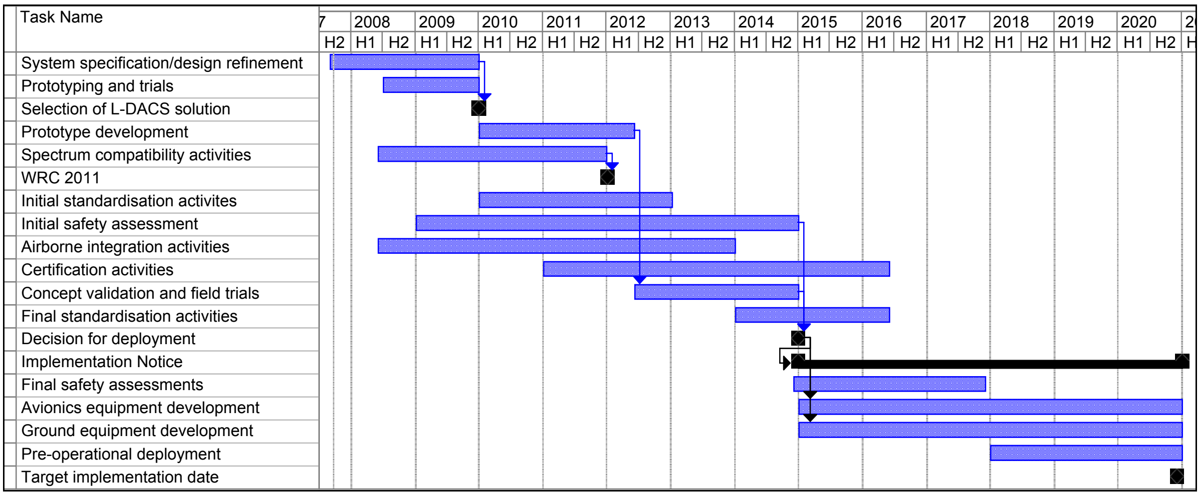

Figure 4 – Target Plan for Expedited L-DACS Development and Deployment

Based on the results of the AP17 activities a number of detailed actions emerge that need to be progressed in order to realise the key recommendations described above. There are different type of actions addressed to FAA and EUROCONTROL involving the ANSPs and the airspace users, to standardisation groups and organisations including ICAO, and Industry. The most important of these actions are presented in Appendix E grouped according to the type of the required activity and/or the entity that will need to carry them out.

List of Appendices

Appendix A: FAA/EUROCONTROL COOPERATIVE R&D - Action Plan 17: Extract from 2007 Research Plan

EUROCONTROL

FAA/EUROCONTROL COOPERATIVE R&D

ACTION PLAN 17:
FUTURE COMMUNICATIONS STUDY

2007 Annual Research Work Plan

AP-3-1-17-AWP

Research Tasks – Technical / Business Themes

The proposed action plan considers several Technical Themes to be progressed. The plan also considers non-technical actions, which are felt essential to ensure a successful end for such a long-term process by creating “dynamics” and maintaining commitment. These tasks are at the level of Communication / Business / Institutional are referred to as “Business Themes” in the remainder of this document.

Technical Theme 1: Improvements to Current Systems

Objective: Improve the spectrum efficiency of the VHF analogue systems (25 and 8.33 kHz DSB-AM systems) currently used for voice services to push the spectrum congestion “wall” as far as possible.

Technical Theme 2: Identify the Mobile Communication operating concept

Objective: Identify the mobile communication-operating concept in both the US and Europe to support the ATM concepts

Technical Theme 3: Investigate new technologies for mobile communication

Objective: Progress investigation of potential communication technologies operating inside the VHF band and outside the VHF band to support the long-term mobile communication operating concept considering terrestrial and satellite based infrastructure.

Technical Theme 4: Identify the communication roadmap

Objective: Create a roadmap describing the communication infrastructure evolution.

Technical Theme 5: Investigate feasibility of airborne communication flexible architecture

Objective: To ease migration towards new systems, this task will investigate the feasibility of a flexible airborne architecture.

Technical Theme 6: Identify the Spectrum bands for new system

Objective: Identify the spectrum band where additional systems would operate and provide argument in the framework of the ITU process through the ACP WG-F.

Business Theme 1: Create Multi National Framework

Objective: Investigating the evolution of the communication infrastructure is foreseen to be a long-term task requiring up to its completion budgets which are outside the limit of both Agencies (as well they are not relevant to be supported only by these Agencies). A multi national and multi organisation framework has to be created for funding and for committing to the progress of such work. Other organisations such as NASA, ESA, and European Commission support will need to be sought.

ICAO has also an essential role to play (and especially the ACP and relevant working groups (WG-M, WG-C and WG-F). ICAO is the only organisation, which could ensure a global approach, and all this work has to be done in full co-ordination. Especially, ACP WG-C has recently produced a work programme to carry out future system investigation (specifically focussing on the ITU objective). The common work will feed the WG-C process and the two processes will need to be aligned.

Business Theme 2: Create Industry interest

Objective: Generate industry (aviation and telecommunication) interest is also felt essential for a successful achievement of the objective. A large part of the up-front investment and the global implementation and operating cost will be supported by the industry. Therefore, a particular effort is necessary right at the beginning to provide clear indication of the intention and identified way forward even if it is not felt possible to demonstrate a business case (at least at the first stages). A huge effort of communication is felt necessary.

Business Theme 3: Business Model

Objective: In parallel with the infrastructure identification, the different parties which should be involved in the development, implementation and service provision action need to be identified with a specific focus on identifying the potential sources of funding and as well as the mechanism to get revenue (in the operation phases) and to get the feeling that the solutions identified during the technical activities can be realised at the business level.

Projects and studies:

This proposed action plan intends to establish the co-ordination framework between the FAA and Eurocontrol to progress the identification of a future global communications system to support ATM operations. Furthermore, this study will include, within the US and Europe, coordinated requirements and constraints, new technology review and assessment, and initiate ICAO standards as appropriate.

Proposals for international standards:

Develop a joint approach to elaborate proposals for international standards through contribution to and participation in the ICAO Aeronautical Communications Panel (ACP).

Appendix B: Documentation and References

Reports

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Future Communications Study (AP17)

Technology Investigations: Conclusions and Recommendations

Joint Report by ITT and QinetiQ
Version 1.1

C1. Background

Under the EUROCONTROL/U.S. Federal Aviation Administration (FAA) Action Plan 17 (AP17) there are three technical themes addressing key activities relating to the identification of the most suitable technology candidates for the future communication infrastructure. These are: (1) development of requirements and operating concepts; (2) identification and assessment of technology alternatives; and (3) development of a future communications roadmap.

The first and third technical themes noted above are summarized in the ACP/WGT Working Paper that addresses the entire AP-17 study (reference ACPWGT/1-WP06: *"Future Communication Study - Action Plan 17, Final Conclusions and Recommendations Report"*). This paper is to summarize the work performed to support the second theme noted above (Technical Task 3 of the AP17 activities), that is, to investigate technologies that might be able to satisfy the requirements for the long-term mobile communications operating concepts.

This work was carried out by ITT under contract to NASA in the U.S. and QinetiQ under contract to EUROCONTROL in Europe. During the Study, interim findings were presented to FAA and EUROCONTROL senior management, NASA, European Stakeholders e.g. the Air/Ground Communication Focus Group, ICAO, Industry and to the U.S. Air Traffic Management Advisory Committee (ATMAC). There was significant feedback received as a result of the interim study results. This feedback influenced the direction of the study by identifying focus areas for in-depth evaluations and tailoring the applied evaluation methodology.

C2. Approach

The FCS technology investigation and assessment was undertaken cooperatively by two independent teams in Europe and the U.S. using similar methodologies following a common approach. This common approach included the identification and *pre-screening* of candidate technologies; a screening process to *down-select* the most promising candidates; and an in-depth *evaluation* of the most promising technologies leading to development of technology *recommendations*. An overview of the study methodologies is provided in Figure C1.

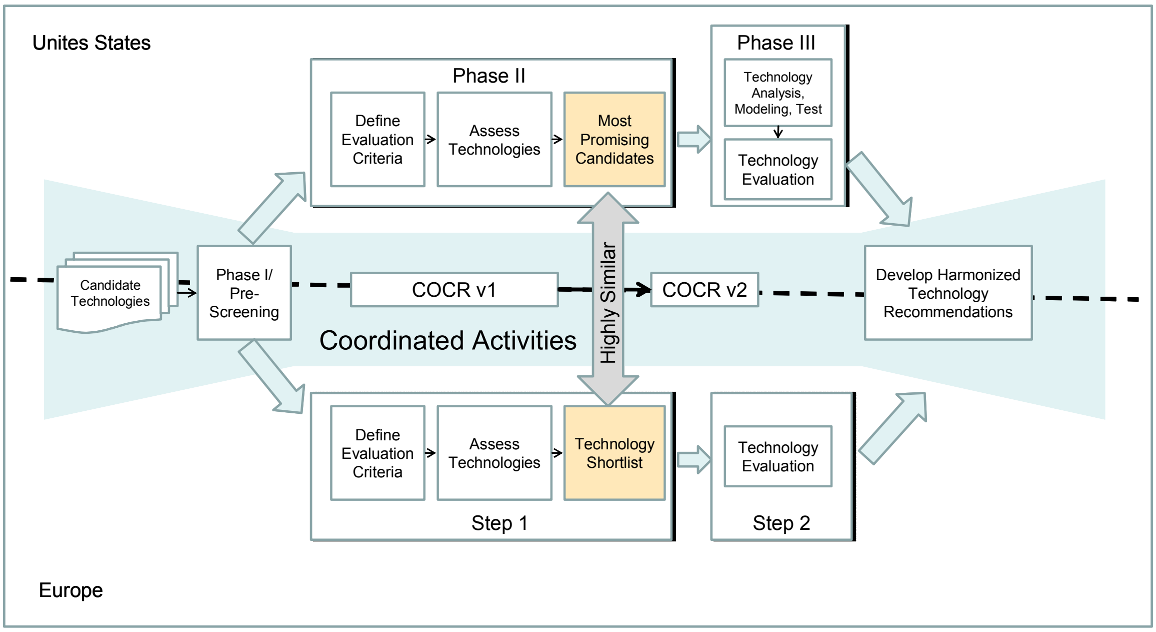

Figure C1 - FCS Technology Investigation Study Approach

The investigation was undertaken in the following stages by the two sets of activity –

- U.S. – Phase 1 (Pre-screening), Phase 2 and Phase 3
- European – Pre-screening, Step 1 and Step 2

These stages are described below.

C3. Pre-Screening Methodology

As shown in the figure, the two investigation teams participated in a closely coordinated activity called *initial pre-screening* by the EUROCONTROL team and *Phase I* by the U.S. team (henceforth to be referred to as *pre-screening* in this paper). This work included identification of candidate technologies; definition of concepts of use for the technologies within the future aeronautical environment; initial definition of evaluation criteria; and preliminary assessment of technologies. Results of the pre-screening activities are documented in the following reports:

- *Future Communication Study- Technology Pre-Screening – version 0.92, EUROCONTROL and QinetiQ, December 2004.*
- *FCS Phase I Report, "Technology Assessment for the Future Aeronautical Communications System," NASA/CR—2005-213587, NASA & ITT Corporation, May 2005. Report is available at* http://gltrs.grc.nasa.gov/reports/2005/CR-2005-213587.pdf

C3.1. Down-selection and Technology Evaluation Methodologies

During the pre-screening process described above, the U.S. and European teams developed a coordinated set of evaluation criteria and evaluated numerous technologies identified as potentially capable of supporting future aeronautical mobile communications. The initial evaluation criteria and results were presented at the ACP/WGW meeting in June 2005. Much of the discussion at that meeting focused on the criteria and the scoring based on those criteria, to the extent that the criteria were perceived to be too subjective. This prompted the down-selection and technology evaluation activities, where it was agreed that the U.S. team would re-evaluate the technologies following the initial approach, but refine the criteria based on input received from the international stakeholder community via ICAO/ACP; while the European team would work in parallel and conduct an alternative evaluation process. At the completion of this process, which featured periodic consultation between the two teams, the results were compared and it was found that the two teams came to similar conclusions with alternative methodologies, thus validating both the outcome and objectivity of the processes.

The following paragraphs describe the parallel down-selection and evaluation methodologies used by the two teams.

C3.1.1. European Team Down-selection and Technology Evaluation Methodology

Stakeholder feedback received on the pre-screening results was used to shape the parallel methodologies applied in the subsequent study activities. For the European team this included a two-step assessment process consisting of: Step 1, a down-select process to re-confirm the most promising technology candidates identified in the pre-screening phase; and Step 2, an assessment of the most promising technologies against prescribed evaluation criteria and the development of technology recommendations.

Under Step 1 technologies were screened against four high level criteria: capacity; continuity, integrity and availability. This led to the identification of the most promising technologies which were then used as input to the Step 2 technology assessment process.

In Step 2, the technologies were considered with regard to two categories of criteria: essential and desirable. Technologies were assessed as to whether or not they meet criteria specific performance metric values. In some cases available data was inconclusive to ascertain evaluation against a particular criterion. Technology classes were then defined based on profiles of how technologies meet the criteria values. For example, Class 1 was defined to address the scenario for achieving criteria performance to meet COCR requirements (ATC and AOC Phase II requirements) and provide a viable solution for deployment in 2020 (i.e. low cost/low risk solution). Meeting this performance is referred to as criteria value level 1. For each class a 'mask' was defined against which a technology could be compared.

An example of the classification system with associated mask (the dark line) is shown in Figure C2 below:

Spectrum Compatibility	Open stds	Criterion Value	RF robustness	TRL	Flexibility	Cost	Capacity	Integrity	Availability	Latency
		1								
		2								
		3								
		4								
Class 3		5								

Figure C2 - Example Technology Class 3 Profile Definition (Step 2 Assessment)

Additional Class Profiles were defined for technologies that meet different levels of criteria values and have different confidence levels for applicability in the future communication infrastructure. Based on technology performance to the criteria and the applied class profiles, technology assessment results and recommendations were developed.

Study reports associated with the Step 1 and Step 2 activities are noted below.

- *EUROCONTROL, Future Communications Infrastructure - Technology Investigations Step 1: Initial Technology Shortlist, QinetiQ, September 2006. (ACP#1 IP4)*
- *Future Communications Infrastructure - Technology Investigations Step 2: Technology Assessment Methodology – version 1.0 – April 2006 (ACP#1 WP20)*
- *EUROCONTROL, Future Communications Infrastructure - Technology Investigations. Evaluation Scenarios – version 1.0 (WG-C#11 WP29 & ACP/1 WP21)*
- *Future Communications Infrastructure - Step 2: Technology Assessment Results – version 1.0 – October 2007*

C3.1.2. U.S. Team Down-selection and Technology Evaluation Methodology

Following the pre-screening activities, the U.S. technology investigation team (including FAA, NASA Glenn Research Center and ITT participants) continued its technology assessment in two additional study Phases. The Phase II down-selection study, *Technology Screening and In-Depth Studies,* included evaluation criteria development, use of a subset of these criteria to down-select the most promising set of technologies, and an initial in-depth performance evaluation of the most promising technologies for the aeronautical environment. The Phase III technology evaluation study included a more comprehensive application of the evaluation criteria to assess the applicability of the most promising technologies for use in the future aeronautical communication infrastructure and additional technology performance assessments. An overview of the methodology for the Phase II and III study activities is shown in Figure C3.

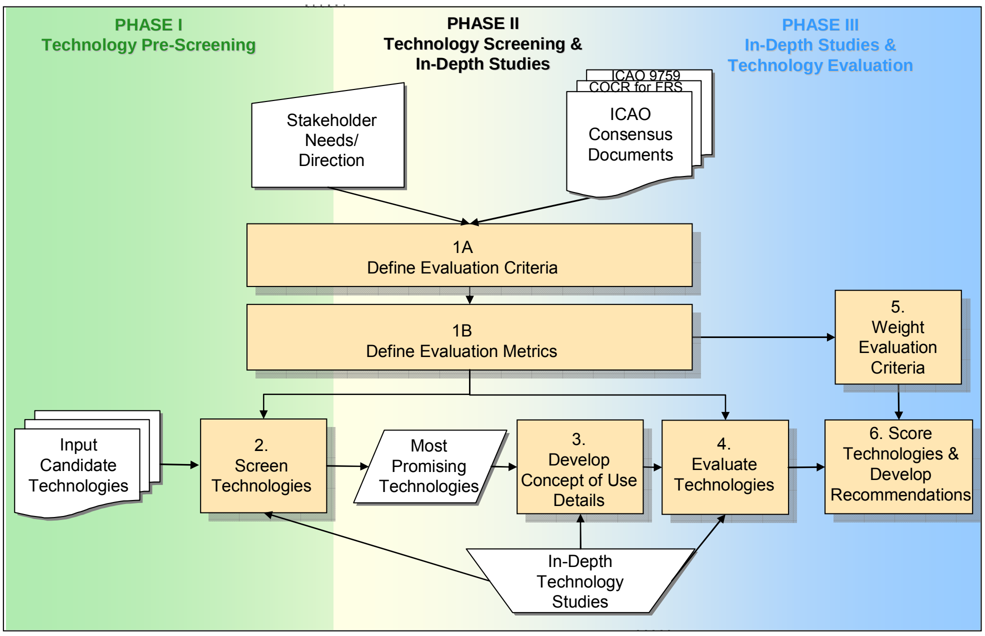

Figure C3 - Overview of Technology Evaluation Approach for U.S./ITT Evaluation Team

The Phase II down-selection activities 1A and 1B shown in the figure included derivation of evaluation criteria and associated metrics respectively. In response to stakeholder direction, a structured analysis of the COCR was undertaken to ensure traceability of these criteria to requirements. Using a small set of key technical and viability evaluation criteria, the next activity (2 in the figure) was to screen the candidate technologies identified in the pre-screening and down-select the most promising technology candidates to be subject of in-depth analysis and further consideration for use in the future aeronautical communication infrastructure.

The Phase II and Phase III activities shown in the figure (3 through 6) comprised the detailed assessment of the most promising candidate technologies. A concept of how each technology could be applied in the aeronautical environment described in the COCR was defined (3), followed by evaluation of the technology against the full set of evaluation criteria (4). Supporting these steps was in-depth analyses of the considered technologies. The process concluded with determination of the relative importance (weight) of the criteria (5) and the use of this information to assist in the identification of the best performing technologies (6). All evaluation results were used to determine the applicability of the candidate technologies for meeting future aeronautical communication needs and the development of communication recommendations (6).

Study reports associated with Phase II and Phase III activities are noted below.

- *FCS Phase II Report, "Identification of Technologies for Provision of Future Aeronautical Communications," NASA/CR—2006-214451, NASA and ITT Coporation. Report is available* *http://gltrs.grc.nasa.gov/reports/2006/CR-2006-214451.pdf, October 2006*
- *FCS Phase III Report, "Additional In-Depth Technology Studies for Provision of Future Aeronautical CommunicationsPhase III In-Depth Studies Report", NASA and*

ITT Corporation. Report is available when published at http://gltrs.grc.nasa.gov/reports/2007/CR-2007-214987.pdf, October 2007

- *FCS Technology Investigation Final Report, "Future Aeronautical Communication Infrastructure Technology Investigation Final Report", ITT Corporation, to be published November 2007*

C4. Detailed Evaluations

C4.1. Pre-Screening Evaluation

In the joint initial pre-screening technology investigation work (2004), a multi-faceted approach was used to identify candidate technologies for evaluation. Over 50 technology candidates were initially identified. The candidate technology list was later augmented to accommodate new technologies derived through involvement in ICAO ACP WG-C activities, including ACP meeting participation, review of ACP WG-C meeting reports, and review of technology definition technical papers. Additional modifications to the technology inventory to account for evolving technical definitions of a small set of candidates and other technical factors were also made.

During the pre-screening activities, the U.S. and European technology investigation teams identified the need to consider two types of evaluation criteria, those that address technical performance of technologies and those that relate to the viability of a technical solution. The technical performance criteria were to assess the ability of a technology to meet the communication requirements defined in the COCR.

The resulting candidate set of technologies as an output of the pre-screening activity is shown in Table C1.

Table C1 - Candidate Technologies for Evaluation

Technology Family	Candidates
Cellular Telephony Derivatives	WCDMA (U.S.)/UMTS FDD (Europe), TD-CDMA (U.S.)/UMTS TDD (Europe), CDMA2000 3x, CDMA2000 1xEV, GSM/GPRS/EDGE, TD-SCDMA, DECT
IEEE 802 Wireless Derivatives	IEEE 802.11, IEEE 802.15, IEEE 802.16, IEEE 802.20
Public Safety and Specialized Mobile Radio	APCO P25, TETRA Release 1, TETRAPOL, IDRA, iDEN, EDACS, TIA-902 (P34), TETRA Release 2 (TAPS), TETRA Release 2 (TEDS)
Satellite and Other Over Horizon Communication	SDLS, Swift Broadband (Aero B-GAN), Iridium, GlobalStar, Thuraya, Integrated Global Surveillance and Guidance System (IGSAGS), HF Data Link, Digital Audio Broadcast, Custom Satellite System
Custom Narrowband VHF Solutions	VDL Mode 2, VDL Mode 3, VDL Mode E, VDL Mode 4, E-TDMA
Custom Broadband	ADL, Flash-OFDM, UAT, Mode-S, B-AMC, LDL, AMACS
Military	SINCGARS, HAVEQUICK
Other	APC Telephony

C4.2. Down-selection and Technology Evaluations

Although the methodology details differed for the two investigation teams, the down-selection and technology evaluations consisted of four primary activities including: 1) derivation of evaluation criteria; 2) applying a subset of the criteria to screen a large set of candidate technologies and down-select those most promising for application in the future communication infrastructure; 3) assessing technology performance in the aeronautical channel (considering anticipated communication load and interference); and 4) evaluating the most promising technologies against the full set of evaluation criteria. A more detailed description of work performed and outputs specific to each of these activities is provided in the paragraphs below.

C4.3. Evaluation Criteria Development

C4.3.1. European Evaluation Two Step Approach Criteria Development

Following the initial pre-screening activity, a two-step approach was adopted for the remaining technology assessment. This was partially due to the difficulty in agreeing on the weighting to be applied and to the subjectivity in applying some of the criteria. Consequently a 2 Step approach was adopted to reaffirm some of the pre-screening results and to converge on the most promising technologies more quickly.

The development of the two step process was undertaken through consensus building sessions with the European ACP/WGC members. From these sessions a set of traceable criteria and metrics for technology investigations was defined. For the technology down-select process (Step 1), screening criteria to be used as a discriminator to identify those technologies applicable to a future COCR defined aeronautical environment were defined. These Step 1 criteria included the following:

- Capacity
- Continuity
- Integrity
- Availability

For the Step 2 technology assessments, a more detailed set of evaluation criteria was derived. These criteria included consideration of technical capabilities deemed *essential* for application in the future communication infrastructure as well as technology capabilities defined as *desirable* and reflective of a viable solution for the defined operational concept. These essential and desirable criteria are summarized in Table C2. Please note that the desirable criteria include three of the four initial Step 1 criteria.

Table C2 - European Step 2 Technology Evaluation Criteria

Criteria	
Essential	Spectrum Compatibility
	Openness of Standards
Desirable	Robustness of the RF link
	Technical Readiness Level
	Flexibility
	Ground Infrastructure Cost
	Capacity
	Integrity
	Availability
	Latency

A more detailed description of these is given in Appendix C1 of this paper.

C4.3.2. U.S. Team Evaluation Criteria Development

As part of its Phase II down-select activities, the U.S. evaluation team performed a functional analysis of the COCR to determine the applicability and traceability of the pre-screening evaluation criteria defined during Phase I study activities. Because solution viability criteria, such as cost and risk factors, were not explicitly identified in the COCR, but recommended by ICAO ACP; ICAO consensus documents were reviewed to identify strategic elements for future aeronautical system implementations. These elements were translated into additional evaluation criteria. A summary of this process is shown in Figure C4.

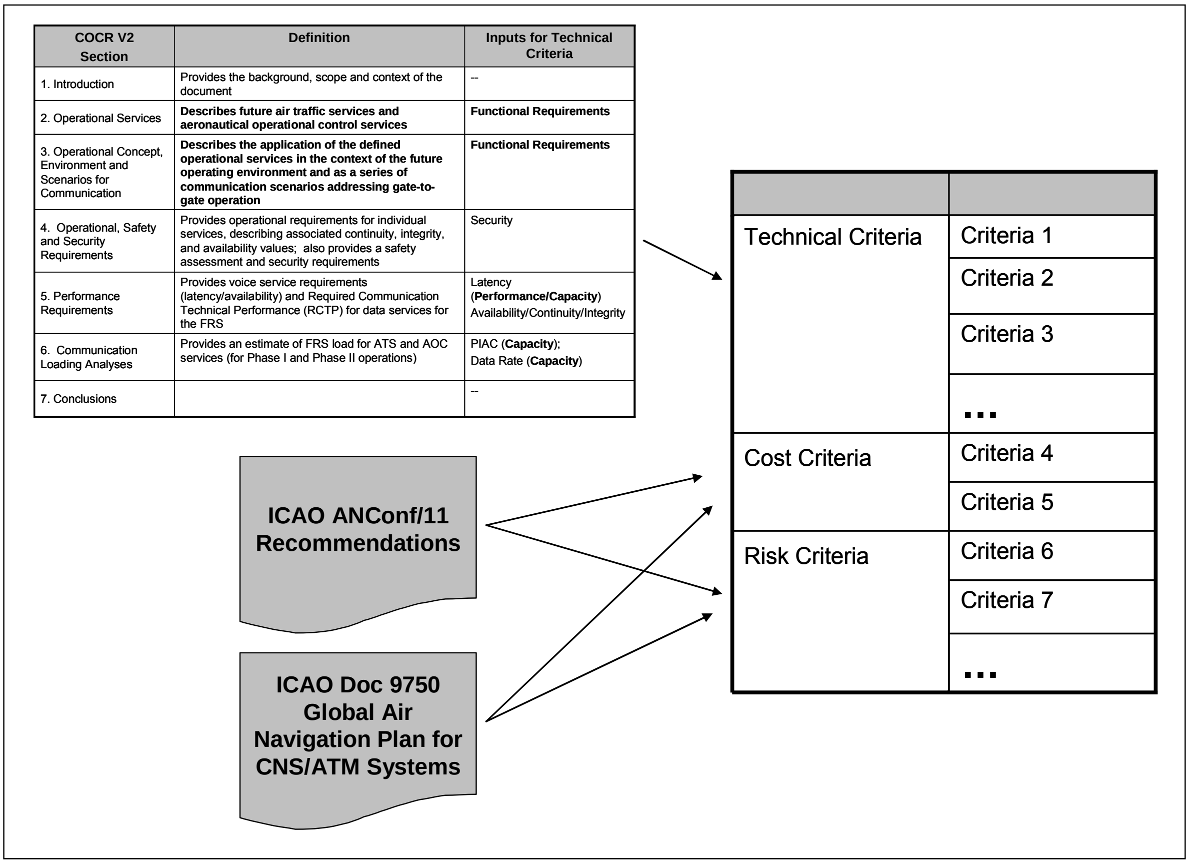

Figure C4 - Deriving Evaluation Criteria

Using the process described above, the U.S. team refined the set of 11 evaluation criteria established during the pre-screening and developed associated metrics. The general approach used to define these metrics was to utilize a tri-level "stop light" rating system where performance compliance is assessed to be green, yellow or red. For each criterion, the rating values were tailored to reflect specific performance requirements of the COCR; specific implementation needs (e.g. implementation timeframe based on the FCS roadmap); or factors that support relative comparison of technology performance/applicability. Following definition of the evaluation criteria and associated metrics, evaluation process diagrams were developed for each criterion to describe specific steps to be performed and decisions to be made for the technology assessment. This methodology is depicted in Figure C5.

For the technology down-select process performed by the U.S. evaluation team in Phase II, a subset of the defined evaluation criteria were applied. Specifically, the focus of the screening and subsequent down-select process was to define a clear and COCR traceable screening measure to support identification of the most applicable technologies within technology families (i.e. groups of technologies characterized by similarities in user requirements, services offered, and physical architectures). To select the screening measures, evaluation criteria were reviewed to identify those that provide a threshold of applicability (e.g. if the technology could not meet some aspect of the criteria, then it could not be implemented in an aeronautical environment) and/or are reflective of overall COCR performance requirements.

The selected screening measures included the following:

- Ability to use protected (safety and regularity of flight) spectrum - one aspect of the *spectrum* criterion
- Data loading capability - one aspect of the *meets ATS/AOC service requirements* criterion)

Technology communication range (relating to *meets ATC/AOC service requirements* and *cost* criteria), where specific threshold values for loading and range are traceable to the requirements of the COCR.

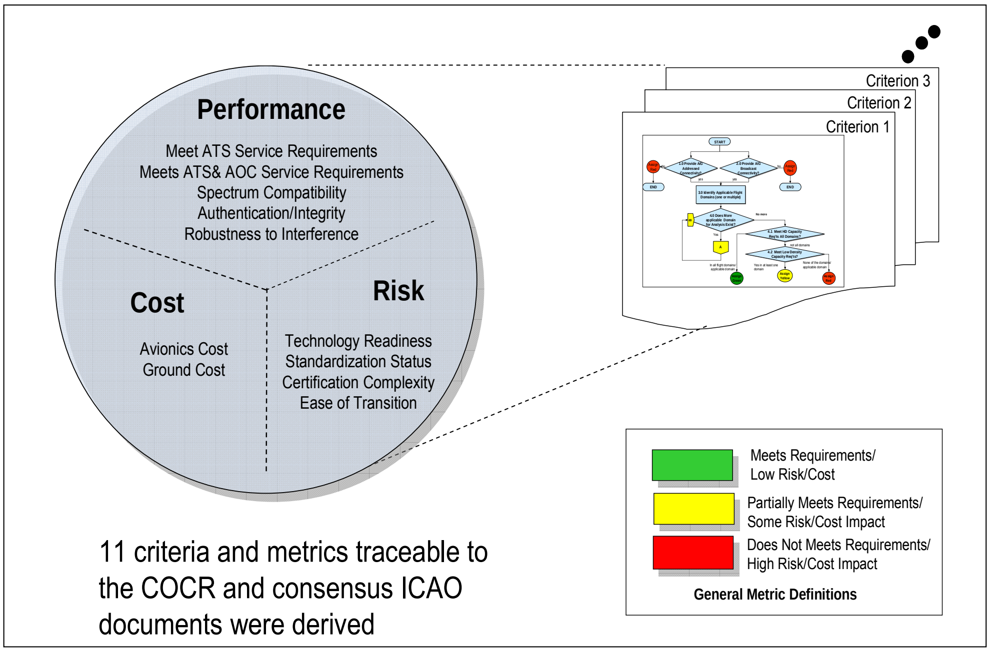

Figure C5 - U.S./ITT Phase II/III Technology Evaluation Criteria

Note that as calculated, the COCR capacity specifications are reflective of all COCR performance requirements. Specifically, the specified data rate requirements are associated with the maximum number of users, with values calculated to meet the required quality-of-service (QoS) while meeting latency requirements. Additionally, data rate requirements are directly proportional to technology coverage range/volumes. Given this rationale, the above listed parameters were considered to be appropriate selections for the technology screening filter. For the subsequent technology evaluation of the most promising technologies in Phase III, the full set of 11 evaluation criteria (introduced above) was applied. Detailed definitions of the evaluation criteria and associated metrics are provided in Appendix C2.

C4.3.3. FCS Technology Team Evaluation Criteria Comparison

Although the U.S. and European evaluation teams developed different evaluation criteria and metrics, in general, both sets of criteria address three general areas of applicability: technical performance, cost and risk. Table C3 compares the evaluation criteria developed by each FCS technology assessment team, organized into these three categories. Please note that the criteria used for the screening/down-selection process are italicized.

Table C3 - Summary of Evaluation Criteria

Evaluation Criteria Category	European/QinetiQ Criteria	U.S./ITT Criteria
Technical Performance	RF Robustness *Capacity* *Integrity* *Availability* Latency	Meets ATS Service Requirements Meets ATS&AOC Service Requirements (includes d*ata loading capability* and *communications range*) Spectrum Compatibility (includes *use of protected spectrum*) Authentication/Integrity Robustness to Interference
Cost	Openness of Standards Flexibility Ground infrastructure Cost	Avionics Cost (impacted by *communications range*) Ground Cost (impacted by *communications range*)
Risk	Spectrum Compatibility TRL	TRL Standardization Status Certification Complexity Ease of Transition

C5. Technology Evaluation

Using the identified candidate set of technologies, an evaluation process that applied a small set of key technical and viability evaluation criteria (as described in paragraphs C3.1.1 and C3.1.2) was performed. An initial evaluation of the technology inventory was conducted using COCR version 1 performance measures as reference values in the process. The evaluation process was re-applied later in the study to accommodate changes/updates in COCR version 2. Results of the screening process included the identification of technologies for further consideration as general air/ground (A/G) communication solutions for continental airspace (airport, terminal and en route airspace) and technologies for further consideration in specific airspace domains with unique operating requirements (oceanic/remote and airport).

Results of the screening process by both assessment teams are shown in Figure C6 below. Although separate approaches and criteria were applied for technology screening, this figure shows a significant overlap resulted in recommendations for the “short-list” of technologies to consider for the Future Radio System.

Supporting the application of the screening criteria was the task to define high-level technology concepts of use for the future aeronautical environment. The concept of use can be considered a mapping of a technology into a system; specific to this task, it provides the basic description of how the required COCR services would be provisioned by a technology implementation. This information is needed to support the assessment of how the technology performs against the defined screening criteria. This activity was supported by the common Evaluation Scenarios against which each technology was assessed. To create the concept of use material for the technologies, the following steps were performed:

- Review of a list of available services and architecture configurations for each technology and identification of the service(s)/architecture most appropriate for aeronautical communications
- Review of modes of operation for each technology and identification of the most applicable for this application
- Definition of the set of physical architecture parameters supporting the implementation of the identified services and operational modes (e.g. modulation, coding, data rate, range)
- Creation of a description of the integration of the candidate's architecture for aeronautical communications into the existing aeronautical infrastructure

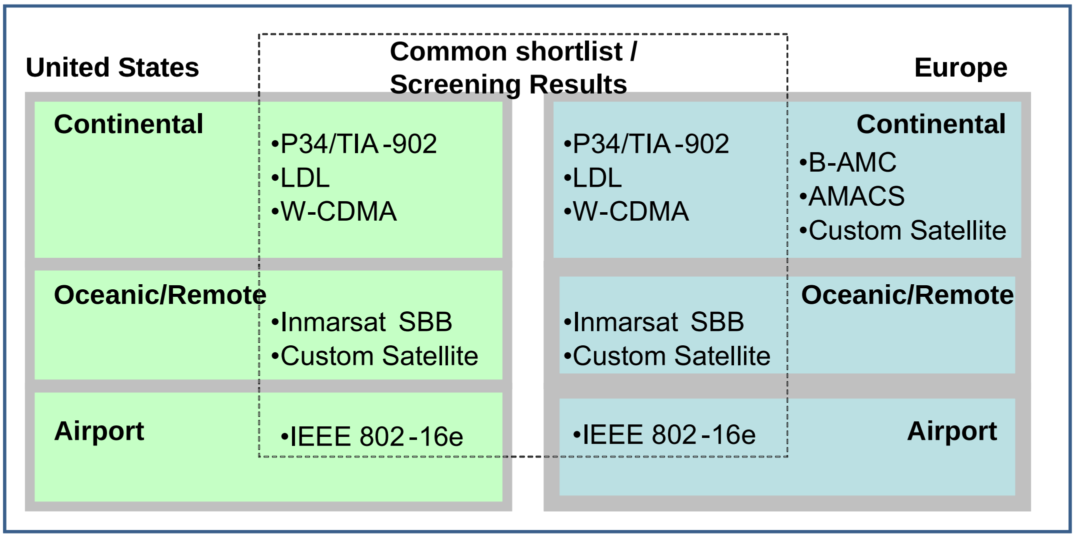

Figure C6 - Technology Screening Results

The concept of use material included the identification of the applicable spectrum band for consideration for implementation of each technology. The technology screening results can also organized by aeronautical spectrum band, as shown in Figure C7 below.

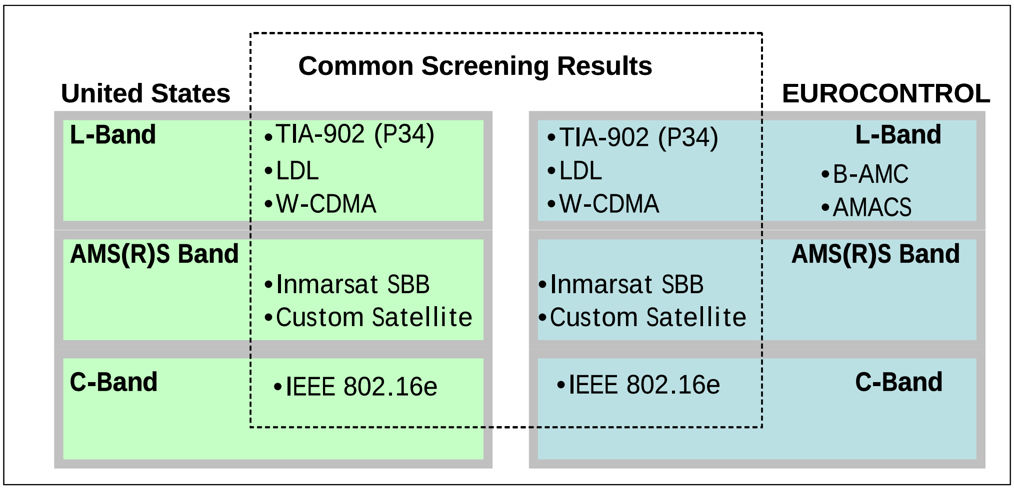

Figure C7 - Technology Screening Results by Spectrum Band

C5.1. Detailed Technology Studies

A considerable number of in-depth assessments were performed or reviewed to support the technology evaluation process and to gain a better understanding of the applicability of the most promising technologies to the future aeronautical communication environment. A full set of the in-depth analyses is provided below in Table C4. Details of the in-depth studies can be found in the supporting FCS reports as identified in paragraphs C3.1.1 and C3.1.2 above.

Table C4 - In-Depth Technology Analyses Performed

	In-Depth Study Topic	Overview	Source
1	L-Band Air/Ground Communication Channel Characterization	Created ray-tracing simulation to develop tap-delay line models of the L-band aeronautical channel (960-1024 MHz)	U.S./ITT
2	Project-34/Telecommunication Industry Association (TIA) 902 Series Standards (TIA-902 (P34)) Technology Performance Assessment	OPNET simulation of TIA-902 net entry and data transfer for supersector scenario	U.S./ITT
		MATLAB Simulink® model developed to assess TIA-902 (P34)physical layer performance	U.S./ITT
		TIA-902 (P34) performance analysis	Europe/Helios
3	TIA-902 (P34)Technology Intellectual Property Assessment	Assessment IP impact for patents claimed in TIA-902 (P34) standards	U.S./ITT
4	L-Band Digital Link (LDL) Technology Performance Assessment	MATLAB Simulink® model developed to assess LDL physical layer performance in the defined L-Band A/G channel	U.S./ITT
5	Wideband Code Division Multiple Access (WCDMA) Performance Assessment	Functional analysis of UMTS/WCDMA network architecture (FCS Phase III assessment)	U.S./ITT
		Performance assessment of WCDMA capacity	Europe/Roke Manor
6	L-Band Technology Cost Assessment for Ground Infrastructure	L-Band business case analysis for an L-Band aeronautical ground infrastructure	U.S./ITT
7	L-Band Interference Testing	UAT, Mode S interference modeling and simulation using SPW modeling tool for TIA-902 (P34) and LDL waveforms	U.S./ITT
		Bench tests to evaluate DME susceptibility to candidate FCS waveforms	U.S./ITT
		WCDMA Interference Assessment	Europe/Roke Manor
		L-Band 3G Ground-Air Communication System Interference Study	Europe/Roke Manor
		P34 L-band Spectrum Analysis	Europe/Helios
8	Satellite Technology Availability Performance	Evaluation of satellite technology availability performance using fault-tree model of RTCA DO-270	U.S./ITT
9	IEEE 802.16e Performance Assessment in Aeronautical C-Band Channel	MATLAB Simulink® modeling of 802.16e on the surface environment implementing OU aeronautical C-band channel model	U.S./ITT
10	B-AMC Performance Assessment	A series of reports on the feasibility of B-AMC	Europe/ECTL sponsored consortium

	In-Depth Study Topic	Overview	Source
11	INMARSAT SwiftBroadband Capabilities to Support Aeronautical Safety Services	Capabitlity of SwiftBroadband for ATS communication	Europe/ECTL
12	Custom Satellite Systems	ESA - ATM SATCOM PROJECT TECHNICAL DESCRIPTION including expected performance	Europe/ESA
13	AMACS Performance Assessment	A set of performance simulations	Europe/Helios

C6. Results of the Evaluation

As noted previously, technologies emerging from the evaluation process can be categorized into two general categories; those for consideration as a general solution for continental airspace (airport, terminal and en route flight domains) and technologies for consideration for specific flight domains with unique operating environments (specifically airport surface and oceanic/remote).

C6.1. Technologies for Consideration for Specific Flight Domains

Those technologies that were identified for the specific flight domains included two satellite systems/concepts (Inmarsat SBB and Custom Satellite Solutions) and a single candidate (IEEE 802.16e) for the airport surface domain.

The timeframe of the COCR operational concept is beyond the service horizon of current satellite offerings and details for follow-on or custom solutions are high-level at this time. Therefore, the value of application of the updated set of evaluation criteria (from Step 2 and Phase II/III study efforts) to trade-off performance among candidate satellite aeronautical communication solutions is not meaningful. Furthermore, the need to discriminate among candidate solutions to identify a single global recommendation is not clear (e.g. the future communication infrastructure may be defined to accommodate multiple over-the-horizon solutions). As a result, the concepts of use and initial assessments were used to draw conclusions and formulate recommendations specific to satellite solutions (rather than application of evaluation criteria to these solutions).

During the technology evaluation process, some technologies were identified as performing well with regard to offered capacity, but did not provide sufficient technical range to be considered a general purpose solution. Instead these technologies, including candidates from the cellular and 802 technology families, were considered for application in the airport surface domain. In the evaluation process, of those candidates identified for applicable in the airport domain and that offered sufficient capacity to meet COCR requirements, 802.16e was found to have the largest data capacity; a simple ground infrastructure; and a developed standard. This candidate was identified as most applicable and selected for further in-depth assessment following the assessment process. Thus, in the Step 2 and Phase II/III study efforts, rather than apply evaluation criteria (to discriminate with other technologies, which was not applicable in this case), the focus of further evaluation was defined of a concept of use and assessment of 802.16e performance. The use concept, along with the detailed assessment of IEEE 802.16e in the anticipated aeronautical channel (C-band in this case), and initial (pre-screening) evaluation of this technology, have been used to draw conclusions and formulate recommendations specific to the airport surface domain technologies (using aeronautical C-band).

C6.2. Technologies for Consideration for Continental Airspace

The focus of the following paragraphs is the evaluation of the most promising technologies for provision of future data link aeronautical communication services (focusing on air/ground communications) for continental airspace. The use concept for these technologies is for implementation in the aeronautical L-band (960-1024 [1164]MHz). Additional details on the concepts for applying these technologies to the future aeronautical communication infrastructure are provided in supporting reports. Evaluation details and results associated with the technology evaluations are described in the following subparagraphs.

C6.2.1. Application of European Criteria

Based on the application of the assessment criteria, Table C5 below indicates the Class assigned to each technology.

In ranking the technologies, 802.16e ranked highest, which indicated that it is most suited to meeting the intended required coverage area i.e. Class 2 in the airport surface environment.

For the L-band technologies all considered technologies except WCDMA had potential to be deployable in the band subject to further study and had some capability to meet some or all of the requirements. Of the proposed technologies B-AMC was evaluated highest with the most evidence in its ability to meet the requirements. The other L-band technologies (TIA-902 (P34), AMACS, LDL) were considered less advanced in demonstrating they could meet the requirements. However as each technology had particular benefits none could be recommended as the best solution at this stage without further studies.

The table below summarises the outcome of the classification for each technology, the proposed frequency of operation and application airspace.

Table C5 - Technologies Against Evaluation Class

Technology	Class	Frequency band	Application airspace
802.16e	2	C-Band	Airport surface
B-AMC	3	L-Band	Airport surface, TMA, En-route
TIA-902 (P34)	4	L- Band	Airport surface, TMA, En-route
AMACS	4	L-Band	Airport surface, TMA, En-route
LDL	4	L-Band	Airport surface, TMA, En-route

Based on the assessment WCDMA and SBB were not considered suitable for deployment within the FCI. For WCDMA, based on studies already performed, rejection was based on the inability to deploy the technology in the target band due to the difficulty in finding sufficient ‘clean’ spectrum i.e. 2 x 5 MHz in a very crowded L-band.

SBB was rejected primarily due to its inability to guarantee performance and in not being offered for use as an ATS system. In addition, the I-4 satellites reach the end of their life times around 2020 and consequently it is unlikely that this will be available for the timeframe of the FCI.

For the new satellite systems (Commercial or custom ATS), satellite-based communication will continue to offer great benefits to aviation. Currently satellite-based communication technology is limited to oceanic or remote areas of the world. In the longer term there appears to be potential for satellite communications to be used in higher density airspace to complement terrestrial systems provided that the quality of service required for safety related services can be achieved.

In the timeframe of 2020+ new satellite-based communication technologies are expected to emerge which can be used for ATS and AOC communication. A range of options for satellite communication using low-, medium- and geostationary orbit satellites are expected to be available offering mobile communication services to aircraft. These could range from commercially operated systems offering a generic service to all mobile users (land, maritime and aviation) to systems targeted to meet specific aviation requirements.

Example systems that have potential as future satellite systems have been identified in the study. Initial information is available but insufficient to support a detailed assessment. These examples are discussed below.

- ATM SATCOM: The ESA ATM SATCOM system can be described as a modernised version of the ICAO “Classic” Aero Satcom System (or AMSS). ATM SATCOM reuses some concepts of the AMSS, such as use of geostationary satellites, while overcoming the legacy system limitations with the aim to support future ATM mobile communication services with the required performance level.
- Iridium NEXT: Iridium LLC is embarking on the design of the next-generation of the Iridium satellite constellation. This new system – currently known as Iridium NEXT – is proposed to seamlessly replace satellites in the current constellation and will be backward compatible with present applications and equipment. It will provide new and enhanced capabilities with greater speed and bandwidth, and which is expected to be available to aviation.

C6.2.2. Application of NASA/ITT Criteria

The evaluation of technologies by the U.S. assessment team included the application of the evaluation criteria from Figure C5 (following the steps in the associated flow diagrams) to the concept of use defined for each technology to develop technology scores. Each individual criterion has a defined set of metrics that describe the tri-level rating measures used for evaluations (see Figure C3 and Appendix C2). Following the steps of the evaluation process flow diagrams and documenting the corresponding score, technology performance was rated as green, yellow or red for each factor. These scores provide a barometer of how applicable the technology is for meeting the requirements and operational environment for a future aeronautical air/ground data link, where green indicates criteria for which the technology meets requirements or provides low cost/risk performance; red indicates areas for which the technology cannot meet requirements and/or has significant hurdles to being an applicable, viable solution; and yellow covers areas in between. A summary of the evaluation results is provided in Table C6. Not shown, but documented in the U.S. FCS Final Evaluation report is the substantiating detail that describes how the evaluation scores were computed.

Table C6 - Technology Evaluation Results

	Evaluation Criterion		TIA-902 (P34)	LDL	WCDMA	B-AMC	AMACS
1	Provides ATS A/G Data Services within Requirements (sans A-EXEC)	A – Capacity					
		B - PIAC					
		C - QoS					
		D - Environment					
2	Provides ATS AOC A/G Data Services within Requirements (sans A-EXEC)	A – Capacity					
		B - PIAC					
		C - QoS					
		D - Environment					
3	Technical Readiness Level						
4	Standardization Status						
5	Certification						
6	Ground Infrastructure Cost						
7	Avionics Cost						
8	Spectrum						
9	Authentication and Integrity						
10	Robustness to Interference						
11	Transition						

The evaluation results and supporting results of the in-depth technical assessments can be used for the development of technology recommendations. As no one technology is a clear best performer, interpretation of the results can be aided with a determination of the relative importance of the evaluation criteria and further review of the results with this knowledge. This work was addressed by weighting criteria. To explore a range of evaluation options, and to address concerns about the perceived complexity of a quantitative weighting, two criteria weighting approaches were implemented. The first was a qualitative ranking of criteria and the second was a more rigorous application of weights based on a process known as the Analytical Hierarchy Process (AHP). Both approaches made use of documented stakeholder positions with regard to relative importance of factors influencing future communication system decisions.

As an example of the weighting process, for the qualitative approach to criteria weighting, based on documented stakeholder positions, evaluation criteria were organized into the following three categories:

- Most Important – in general, these factors have been specifically noted by stakeholders as important factors and should be given the greatest consideration; success with regard to these criteria is necessary to have an applicable aeronautical solution
- Very Important – in general, these factors are also addressed in some manner by stakeholders and are also very important aspects of a aeronautical communication system decision; success with regard to these criteria is important for understanding the viability of an aeronautical solution
- Important – these criteria have been found to not be specifically addressed in stakeholder position

The resulting organization of criteria to these qualitative weight definitions and the corresponding evaluation results are shown in Table C7.

Table C7 - Evaluation Results with Qualitative Criteria Weighting Applied

	No.	Evaluation Criterion		TIA-902 (P34)	LDL	WCDMA	B-AMC	AMACS
Most Important	8	Spectrum						
	1	Provides ATS A/G Data Services within Requirements (sans A-EXEC)	A - Capacity					
			B - PIAC					
			C - QoS					
			D - Environment					
Very Important	3	Technical Readiness Level						
	6	Ground Infrastructure Cost						
	7	Avionics Cost						
	2	Provides ATS AOC A/G Data Services within Requirements (sans A-EXEC)	A - Capacity					
			B - PIAC					
			C - QoS					
			D - Environment					
Important	4	Standardization Status						
	5	Certification						
	9	Authentication and Integrity						
	10	Robustness to Interference						
	11	Transition		•				

A qualitative weighting approach was also applied by considering stakeholder inputs based on positions documented in stakeholder plans, recommendations and positions. This documented "voice of the customer" information was used to develop a relative ranking of criteria importance, assign criteria weights, and compute overall technology scores based on evaluation results and criteria weights. Figure C8 shows the criteria weighting factors used for the evaluation.

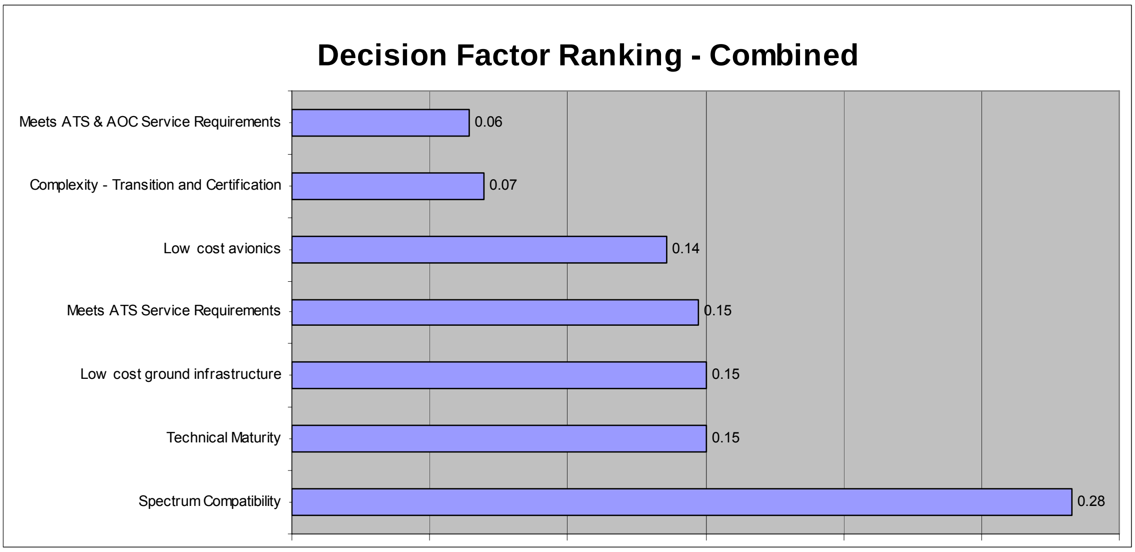

Figure C8 - Weighted Decision Factors

As indicated in the figure, evaluation results (and associated weighted results) were strongly influenced by the spectrum criteria evaluation results. This criterion was identified as having significant importance to all stakeholders, as would be expected. Resulting scores for TIA-902 (P34) and LDL were in similar regions of the normalized scale, with TIA-902 (P34) achieving the highest technology rating and WCDMA performing slightly lower than the other two technologies. Because some criteria were not ranked for B-AMC and AMACS due to insufficient information, their numerical values were not provided for the AHP comparison matrix; therefore, numerical score results were not calculated for the B-AMC and AMACS technologies.

Based on the specific candidate technologies evaluated and their evaluated performance against the criteria, certain technology attributes desirable for applicability of a technology in the context of an aeronautical L-band communication capability can be inferred. A list of these attributes and a mapping of the technologies to these desirable attributes (based on evaluation results) is provided in Table C8. Please note that these do not represent a clean-sheet identification of desirable attributes and are not requirements for a future radio system, rather these are the technology attributes that resulted in favourable evaluation results.

Table C8 - Comparison of Candidate L-Band Technologies with Desirable Attributes

Desirable Features	TIA-902 (P34)	LDL	WCDMA	B-AMC	AMACS
Power efficient modulations within the defined L-band channel, specifically, multi-carrier modulation techniques	Meet	Not Meet	Partially Meet[1]	Meet	Not Meet
Bandwidth efficient modulations	Meet	Meet	Meet	Meet	Meet
Channels that are at most broadband, but not wideband	Meet	Meet	Not Meet	Meet	Meet
Low duty cycle waveforms	Not Meet	Meet	Not Meet	Meet (long-term)	Meet (long-term)
Efficient Channel Reuse	Meet	Meet	Meet	Meet	Meet
Provision QoS	Meet	Meet	Meet	Meet	Meet
Flexibility to decouple sector coverage from radio coverage	Meet	Partially Meet	Meet	Meet	Meet
Provides authentication and integrity check	Meet	Partially Meet	Meet	TBD*	TBD*
Availability of existing commercial/aeronautical standards	Meet	Partially Meet	Meet	Not Meet	Not Meet
Available prototypes or products	Meet	Partially Meet	Meet	Not Meet	Not Meet
Implement service set specific to aeronautical needs	Meet	Meet	Not Meet	Meet	Meet

C7. Study Observations and Findings

Based on the combined results of the U.S. and European technology investigation activity, the following findings and observations are made:

1. The new communications elements of the FCI will primarily support data communications
    - The FCS has investigated a wide range of emerging technologies and standards which have the potential to support ATS and AOC communications. Although there will be further development in communication technology, due to the time to deploy and the need for stable technology solution, the choice of emerging systems offers the lowest risk

[1] WCDMA does not employ multi-carrier modulation and is an interference limited system; however, proper design can lead to good BER performance can be achieved for low Eb/No (influenced by factors including spread bandwidth, number of interfering users, and information bit rate)

option. Some of the technologies considered are available as commercial-off-the-shelf (COTS) solutions for the area of application for which they were designed.

- The results of the FCS has not identified any technology considered that does not require some form of modification. Therefore a COTS solution that can be deployed as they are designed without any modification is not feasible. The minimum modification is to change the frequency of operation to one of the FCS target bands to support safety aeronautical communications. Other designs changes are dependent on the design of the technologies and often are related to modification of the physical layer e.g. the modulation scheme. However there are considered to be benefits in adopting COTS components wherever possible to minimise design effort, reduce risk and to shorten time to deployment.

2. The new communication components introduced into the FCI will reuse emerging technology and standards to the maximum extent possible

- The FCS has identified four types of service volumes –
  - Airport surface
  - Airport zone/TMA/En route
  - Oceanic/Remote/Polar
  - Autonomous Operation Area
- The airport surface volume is typified by high volumes of data over a short range (up to a few kilometres). The airport zone, TMA, and en route represent the bulk of the requirements for communications service with ranges typically being up to 200 km. The oceanic, remote and polar volume is typically beyond line of sight of terrestrial systems and can only be realistically be served by satellite based solutions.
- The propagation conditions to some extent determine which band is able to support which types of volume. The airport surface is best served by short range systems operating in the C-band due to the attenuation conditions at this frequency. The airport zone, TMA and en route volumes are currently served by the congested AM(R)S VHF band which has good propagation properties. The L-band propagation properties are almost as good as VHF.

3. No single technology meets all future aeronautical communication requirements across all operational flight domains

- The future aeronautical operating concept will require a complementary set of communication capabilities across multiple frequency bands to provide required voice and data communication services.

4. Technologies that currently provide or are planned for aeronautical communications in the VHF band, providing dedicated voice and data services, should be used to their fullest extent; due to congestion in the VHF band (to support near-term voice and data communication requirements), provision of future communication services outside the VHF band must be considered

- For the VHF aeronautical spectrum, the band will continue to be used to provide DSB-AM voice communications and an initial data link capability that is driven by other external forces than the FCS technology investigation

- A long-term strategy for use of the VHF aeronautical band requires further consideration

5. The aeronautical L-band spectrum (960-1024 [1164[2]] MHz) is a candidate band for supporting a new data link communication capability
    - There is a potential large spectral region to support future aeronautical communication systems
    - However it is a challenging environment for aeronautical communications due to the aeronautical channel characteristics and the current usage of the band
        - Estimated RMS delay spreads for this channel, on the order of 1.4 μs, can lead to frequency selective fading performance for some technologies
        - Interference to and from existing aeronautical L-band systems for a proposed communication technology requires detailed examination, including validation measurements and testing
    - Co-allocation of AM(R)S with the existing ARNS allocation in a portion of this band (960-1024 [1164] MHz) is required (as is being proposed in WRC-2007, supporting a FCS Phase I study output) for use of communication technologies in this band
6. The aeronautical L-band (960-1024 [1164] MHz) spectrum provides an opportunity to support the objectives for a future global communication systems; however no evaluated technology (as defined) for supporting data communication in this band fully addresses all requirements and limitations of the operating environment
    - Initial co-channel interference testing indicates potential interference of evaluated candidate technology waveforms to existing navigation systems (further evaluation, including consideration of duty cycle effects on interference, is required to determine collocation feasibility (with on-tune channels, off-tune channels or cleared spectrum))
    - Each technology was identified as having some technical, cost or risk concerns that require modification of the technology specification for applicability and/or willingness to assume moderate levels of cost/risk
    - Due to unique requirements, a technology adapted from existing standards wherever possible is recommended for this band
7. Desirable features for an aeronautical L-band (960-1024 [1164] MHz) technology include:
    - Existing standard for safety application with some validation work performed (reducing time for standardization, increasing TRL, and reducing risk of certification)
    - Multi-carrier modulation (power efficient modulation for the aeronautical L-band fading environment)
    - Low duty cycle waveform with narrow-to-broadband channels (more likely to achieve successful compatibility with legacy L-band systems without clearing spectrum)
    - Adaptable/scalable features (improving flexibility in deployment and implementation, and adaptability to accommodate future demands)
    - Native mobility management and native IP interface (increasing flexibility and providing critical upper layers compatibility with worldwide data networking standards)

[2] Figures in square brackets [xx] are subject to the outcome of the WRC-07.

8. For the aeronautical L-band (960-1024 [1164] MHz), some of the evaluated technologies include desirable features that could support a standardization effort, potentially reducing cost and risk

   - Two options for a L-band Digital Aeronautical Communication System (L-DACS) were identified. These options warrant further consideration before final selection of a data link technology. The first option represents the state of the art in the commercial developments employing modern modulation techniques and may lead to utilization/adaptation of commercial products and standards. The second capitalizes on experience from aviation specific systems and standards such as the VDL 3 and 4 and UAT.
   - The first option for L-DACS includes a frequency division duplex (FDD) configuration utilizing OFDM modulation techniques, reservation based access control, and advanced network protocols. This solution is a derivative of the B-AMC and TIA-902 (P34) technologies. The second L-DACS option includes a time division duplex (TDD) configuration utilizing a binary modulation derivative of the implemented UAT system (CPFSK family) and of existing commercial (e.g. GSM) systems and custom protocols for lower layers providing high quality-of-service management capability. This solution is a derivative of the LDL and AMACS technologies. Table C9 depicts the two options.

Table C9 - L-DACS Options Key Characteristics

L-DACS Option	Access Scheme	Modulation Type	Originating Technologies
L-DACS Option 1	FDD	OFDM	B-AMC, TIA 902 (P34)
L-DACS Option 2	TDD	CPFSK/GMSK type	LDL, AMACS

9. Evaluation of the economic feasibility of implementing an L-band aeronautical ground infrastructure considering life cycle costs and applying the Present Worth Simple Payback Method (with Minimum Attractive Rate of Return = 5%) indicates that a positive business case can be achieved for a commercial service provider within in 4 years.

10. For the aeronautical C-band [5000 to 5010] MHz, and/or [5010 to 5030] MHz, and/or 5091 to 5150 MHz, there is capacity that is not utilized and, given the severe path loss issues, this band is most applicable to the airport surface where the distances are relatively short

    - Some concepts for surface management communications require substantially higher data rates than are needed in other airspace domains and may warrant a specific technology solution

11. Specific to aeronautical C-band [5000 to 5010] MHz, and/or [5010 to 5030] MHz, and/or 5091 to 5150 MHz, 802.16e is extremely well matched to the aeronautical surface in terms of capability and performance

    - This technology is designed to work in this band and initial IEEE 802.16e performance evaluations in the modelled aeronautical MLS band channel show favorable results

- Private service providers have shown interest in the 802.xx family of wireless protocols (favorable business case that may be driven by factors beyond ATS and AOC communications, and may involve private service providers, including airport authorities)

12. For aeronautical satellite systems, these systems offer unique services that can be applied to large and/or remote geographic areas and provide supplemental coverage to the terrestrial communication infrastructure
    - The systems provide communication capability in oceanic, remote and Polar Regions where typically, there is no other alternative that provides the needed capacity and performance.[3]
    - The systems can be used to provide communication coverage to en-route domains with historically sparse aircraft densities where it may be more cost effective
    - As the evaluated operation concept is beyond the service horizon of existing offerings and follow-on system details are not firm, the application of evaluation criteria cannot provide adequate discrimination among candidates
13. It has been assumed that the FRS will operate within an IP infrastructure. Further work on finalising the selection of the FRS should include verification that the required performance can be achieved on end-to-end basis within the FCI. This should include appropriate methods of assuring the required quality of service for safety related applications can be maintained across the entire communication system.

The foregoing findings can be summarized to indicate the applicability of technologies against airspace type; this is shown in Table C10.

Table C10 - Applicability of Technologies Against Airspace Type

Airspace Type	Applicable Technology
Airport Surface	• IEEE 802.16e, • L-DACS may be possible in some areas
Airport, TMA, Enroute	• L-DACS • Satellite-based may be possible in some areas
Oceanic/Remote/Polar	• Satellite-based
Air/Air	• L-DACS

C8. Conclusions and Recommendations

The technologies noted in the earlier section and in the following paragraphs have been identified as the most suitable for the target bands of operation described above. These results take into account a variety of criteria the most of important of which is co-existence in the target band with current users. The FCS technology investigation recommendations are summarized in the following sections, organized according to applicable spectrum band/airspace domain.

3 This includes areas like the Gulf of Mexico, where terestrial infrastructure can not provide radio coverage.

C8.1. C-band – Airport Airspace

The C-band recommendations are to:

- Identify the portions of the IEEE 802.16e standard best suited for airport surface wireless mobile communications, identify and develop missing required functionalities and propose an aviation specific standard to appropriate standardisation bodies
- Evaluate and validate the performance of an aviation specific standard wireless mobile communications networks operating in the relevant airport surface environments through trials and test bed development
- Propose a channelisation methodology for allocation of safety and regularity of flight services in the band to accommodate a range of airport classes, configurations and operational requirements
- Complete the investigation of compatibility of prototyped C-band components with existing systems in the C-band in the airport surface environment and interference with other users of the band.

C8.2. Satellite-band – Oceanic/Remote and Continental Airspace

The satellite band recommendations are to:

- Continue monitoring the satellite system developments and assessment of specific technical solutions to be offered in the timeframe defined in the COCR as these next generation satellite systems become better defined
- Update the existing AMS(R)S SARPs performance requirements to meet future requirements
- In order to support the new AMS(R)S SARPs, consider the development of a globally applicable air interface standard for satellite systems supporting safety related communications.

C8.3. L-band – Continental Airspace

For en route and TMA airspace, the L-band was identified as the best candidate band for meeting the future aeronautical communications, primarily due to potential spectrum availability and propagation characteristics. L-band recommendations include the following:

- Define interference test requirements and associated outputs that can be used to determine compatibility of future candidate aeronautical communication technologies with existing aeronautical L-band systems
- Pursue detailed compatibility assessment of candidate physical layers for an L-band aeronautical digital link, including interference testing
- Pursue definition/validation of technology that is derived or adapted from existing standards for use as an L-band Data-link Aeronautical Communications System (L-DACS) that can be used to initiate an aeronautical standardization effort (and meet ICAO requirements for such an effort)

- Complete the investigation of compatibility of prototyped L-DACS components with existing systems in the L-band particularly with regard to the onboard co-site interference and agree on the overall design characteristics
- Considering the design trade-offs, propose the appropriate L-DACS solution for input to a global aeronautical standardisation activity
- Considering that B-AMC, AMACS and TIA-902 (P34) have provisions to support air to air services, conduct further investigation of this capability as a possible component of L-DACS

C8.4. VHF-band – Continental Airspace

The VHF band recommendation is to:

- In the longer term reconsider the potential use of the VHF for new technologies when sufficient spectrum becomes available to support all or part of the requirements.

APPENDIX C1 - EUROPEAN ASSESSMENT CRITERIA

This Appendix contains a description of the criteria against which the technologies have been assessed. In general the technologies were reviewed against the following criteria –

Essential criteria

- Compatibility in the target band
- Openness of standards

Desirable criteria

- Robustness of the RF signal
- Technology Readiness Level
- Flexibility in deployment
- Ground infrastructure costs
- Performance

In applying the criteria the following specific aspects were noted.

A1 Essential Criteria

A1.1 Compatibility in the target radio band

As the new communication system is being targeted for operation in existing aeronautical bands which are occupied, compatibility with the existing users is essential. The use of these bands are subject to WRC-07 approval of co-prime allocation to AM(R)S. The target bands being considered are –

- VHF Band – [112 – 116] – 117.975 MHz (upper end of the VOR band) for airport, TMA and en-route communication
- L-Band – 960 to 1164 MHz for airport, TMA and en-route communication.
- C-Band - 5091 - 5150 MHz for airport surface communication

Note: To date no technology was proposed for deployment in the extension VHF band at this stage. In the long term the whole VHF band could be considered for deployment of a new system provided sufficient spectrum can be made available.

Due to the propagation constraints of systems operating in the C-band (e.g. atmospheric effects) the L-band is considered the main option for deploying a new long-range communication system. Consequently the main areas of study have been interference measurements for the candidate technologies proposed for the L-band against the current systems operating in the band e.g. DME. Before any new communication systems can be allowed to share spectrum with DME, a compatibility analysis must be performed to assess potential degradation of DME system performance.

A review has been undertaken of the candidate technologies in the following interference scenarios –

- Co-site onboard an aircraft
- Air-to-air
- Air-ground
- Ground-to-ground.

Due to the difficulty in separating antenna sufficiently far apart on an aircraft, the co-site scenarios were the most demanding environments. The next most demanding scenario was the ground-to-ground one where an aircraft could be close to a radio transmitter. However in general this is less severe than the aircraft co-site scenario.

A1.1.1 RF interference rejection/signal robustness.

The FRS will have to exist in an environment where interference will come from existing users of the target band therefore the ability to handle a certain level of interference is vital. This will include 'own' interference due to non-perfect frequency re-use, synchronisation, etc. Major aspects of interference rejection to be considered are –

- Forward error corrector (FEC) mechanism; and
- Modulation scheme.

Consideration of these topics and the design choices made in the candidate FRS must be provided as part of the system description.

A1.1.1.1 Acceptance

Acceptance was based on demonstrating that agreed interference values such as desired-to-undesired signals levels could be achieved. It is recognised that a complete interference analysis is a very complex and a time consuming process and was unlikely to be completed within the timeframe of the FCS. However sufficient evidence should have been provided to demonstrate compatibility at least theoretically but preferably through limited practical trials.

If this criterion cannot be met then the technology is rejected.

A1.2 Openness of the Standard

This criterion is designed to determine if sufficient information is available on the technical standards on a fair and equitable basis. Availability of sufficient technical details is necessary to determine the characteristics of the technology and carry out some independent evaluation and validation if necessary. This information should be made available through an appropriate ICAO body.

If standards exist but have a royalty payment associated with them or are subject to some form of limited usage, this could be acceptable. However has to be considered as an element of the implementation cost.

If no standard currently exists then the system will be judged as passing provided that the entity progressing the system intends that the technical information will be made available in an open manner through an appropriate standardisation body including ICAO.

The lack of standardisation activity could indicate lack of maturity of the technology, which will probably be reflected in the TRL level. It is also likely to increase the risk that the technology can be deployed within the relevant timeframe.

If the technical standards are not open to aviation in any form then the technology is rejected.

A2 DESIRABLE CRITERIA

Desirable criteria are those for which a range of possible values can be determined in various configurations. No one technology will meet or exceed all the requirements therefore assigning values to these criteria will assist in comparing candidate technologies against each other in a common way.

The importance of each desirable criterion is assigned in the ranking process.

The set of desirable criteria is split into two main categories – general and performance based. The two categories are briefly introduced below.

A2.1 Generic Criteria

The general criteria cover those attributes of potential technologies which are major discriminates in comparing one against the other. Other criteria have been considered but the following were chosen to be the most relevant –

- Robustness of the RF signal
- Technology Readiness Level
- Flexibility
- Ground Infrastructure Cost

These criteria are described in more detail below.

A2.2 Performance based Criteria

Another set of key selection criteria is those associated with meeting the required capacity, integrity, availability and latency performance values. The performance values are defined in the Evaluation Scenarios document [Ref. 2] and have been determined for each of the following locations based on the requirements defined in the COCR [Ref. 1] namely:

- Airport Surface
- Airport Zone
- Terminal Manoeuvring Area

- En-Route
- Oceanic Remote and Polar

For each of the locations, each technology will be evaluated as to its ability to meet the requirements.

A2.3 Generic Criteria

A 2.3.1 Robustness of the RF signal

It is assumed that the integrity and security of the message, on an end-to-end basis, is handled through authentication, integrity and encryption (if applied) features outside the FRS. Consequently this criterion is aimed at determining the robustness of the technology to interference of the RF signal. For the evaluation this is defined as the intentional manipulation of the S/N ratio of a victim radio in such a way that it is no longer operational.

The defines the following security requirements for services which have “high – severe”, “high – catastrophic” or “medium” availability requirements which covers most of the ATS and AOC services –

Requirement Id	Requirement	Associated FCI Requirements
R.FRS-SEC.1a	The FRS shall provide a measure of resistance against deliberate insertion of RF interference when providing services with “high – severe” or “high – catastrophic” availability ranking.	R.FCI-SEC.1
R.FRS-SEC.1b	The FRS should provide a measure of resistance against deliberate insertion of RF interference when providing services with “medium” availability ranking.	R.FCI-SEC.1

The test for this criterion is dependent on the specific technology. A radio system using much more bandwidth than the bandwidth needed to transfer the information data rate is likely to be resistant to interference.

Criterion level	**Interference resistance**
1	Robust to interference – greater than 15dB
2	Not completely robust to interference – greater than 5dB
3	Low tolerability to interference – 5dB or less

In assigning a value, evidence must be provided of any specific measures should be provided.

A2.3.2 TRL

The TRL value assigned under this criterion is based on the current level of development of the technology as a whole i.e. the target FRS as to be deployed in the target band supporting the designated services. The standard definition of TRL level as shown in Figure A-9 is to be used.

It should be noted that typically there is a relationship between the TRL and the length of time to deploy a technology. The lower the TRL value the less mature the technology, the longer the development phase and consequently there is a greater the risk in achievable deployment by a certain date. The timescale envisaged for this criterion is 2020. By this time the FRS must have reached a high level of maturity i.e. TRL level 9 and then be deployed by 2015 to allow a period of pre-operational use before entering operational service in 2020.

The TRL will be assigned based on the information supplied by the proponent of the technology on tests and evaluations undertaken to date in the development of their system.

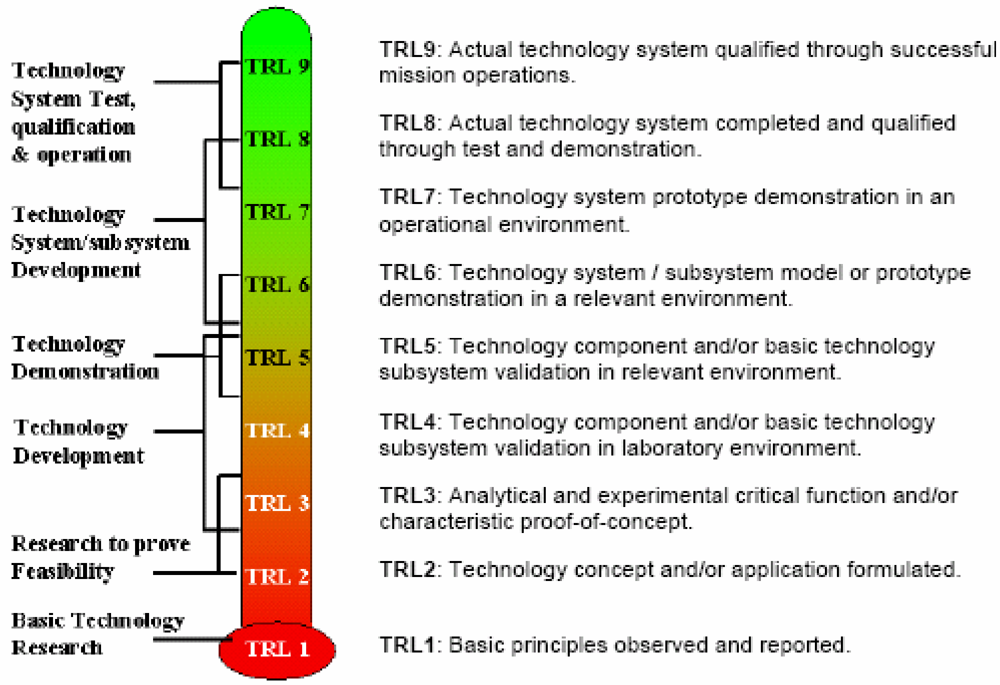

Figure A-9 TRL stages

For the technology evaluation the following grouping of TRL has been assigned.

Criterion level	TRL number
1	Technology is TRL 8 or 9
2	Technology is TRL 6 or 7
3	Technology is TRL 4 or 5
4	Technology is TRL 2 or 3
5	Technology is TRL 0 or 1

This criterion is important to gauge the maturity of the candidate technology. The TRL of a particular technology is highly correlated to its technical risk to be deployed within a given timeframe. A low value of TRL is likely to be high-risk and one would expect to see convincing evidence for how that risk was to be managed, including minimisation and mitigation strategy. In addition the lower the TRL level the longer until operational use. A system under development can progress more quickly to higher TRL levels depending on the amount of interest and investment to progress the technology through the development phases. In ate aviation world, system that have been deployed for safety related communications have taken between 8 to 15 years (or longer) to come to maturity for operational use. This is illustrated in the simple figure below.

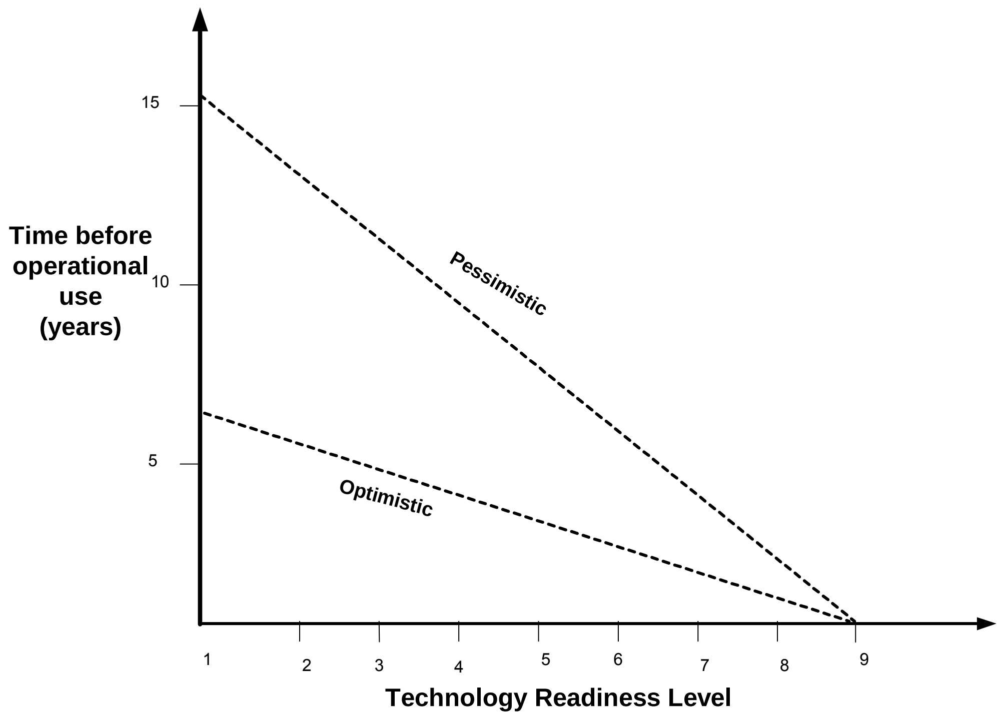

Figure A-10 Illustrative figure of TRL against time to operational use

In the case of the new components for the FCI, a target date of around 2020 is assumed. This date is just about achievable for TRL values of above 3 provided activity to progress them starts immediately.

For each technology a TRL value has been assigned. Although a generic description of the TRL levels were initially identified these cannot be applied objectively. Consequently a refinement of the TRL levels specifically applicable to the FRS was developed. The description of the TRLs as applied the FRS is shown below in Table A1-1.

TRL	Step 2 TRL Description	Generic TRL definition	Performance	Level of integration	Design Stability	Reliability	Sources of Evidence	Life Cycle stage
9	FRS deployed at desired locations and is in operation supporting the designed aircraft population	Actual technology system qualified through successful mission operations	In-Service performance of technology is successful.				In service reports.	In Service
8	Production FRS available for end-to-end testing and demonstration at one or few sites including flight trials with several aircraft	Actual technology system completed and qualified through test and demonstration	Performance validated	Final production design validated demonstrating internal and external integration.	Design stable subject to minor modifications	Reliability is proven on final design	Acceptance trials. User feedback	Manufacture Demonstrati on
7	Prototype FRS available for limited end-to-end testing at a chosen test site include limited flight tests	Technology prototype demonstration in an operational environment	Performance of technology as part of the prototype meets the requirements	Fully integrated with prototype System interfaces qualified in an operational environment.	Design baselined for full production phase.	Prototype demonstrat es reliability model.	Trials reports, configuratio n audits.	Demonstrati on Assessment
6	Technology demonstrator available operating in the correct band and using representative components for the final design in an end-to-end chain	Technology system/ subsystem model or prototype demonstration in a relevant environment	Performance of technology gives high confidence that requirements can be met	Interfaces demonstrated at system level in a synthetic / high fidelity environment.	Technology design is baselined as part of the complete prototype	Reliability data indicates requiremen t is met	Integration trials / user feedback	Assessment
5	Components of the FRS available for individual test in a representative	Technology component and/or basic technology subsystem validation in relevant	Lab performance demonstrates viability –	Interfaces partially demonstrated at System/Subsystem level in a synthetic environment.	Basic design of technology is stable with only minor changes		Field test reports	Assessment

TRL	Step 2 TRL Description	Generic TRL definition	Performance	Level of integration	Design Stability	Reliability	Sources of Evidence	Life Cycle stage
	environment.	environment	may be at a sub system level	Impact on other systems is understood, specified and quantified e.g. on board tests of FRS with other systems	forecast.			
4	Individual modules or ‘layers’ of the FRS tested individually	Technology component and/or basic technology subsystem validation in laboratory environment	Lab testing requirements met	Interface requirements specified and understood. The likely impact on interfaced systems are generally understood. Practical L-Band interference studies undertaken in laboratory	Initial technology design complete.		Lab test reports Sub system Designs	Assessment
3	Computer simulation or analysis of the elements of the FRS	Analytical and experimental critical function and/or characteristic proof-of concept	Performance investigated through analytical experimentation and/or modelling.	Analytical assessment conducted to establish interface requirements.	Refinement of initial design based on analysis and experimentation	Component reliability drivers understood.	Component Designs	Assessment Concept
2	Refinement of design into specific components	Technology concept and/or application formulated	Performance predictions refined	Theoretical L-Band interference studies undertaken			Analytical Studies	Concept
1	Paper design based on perceived key requirements	Basic Principles observed and reported	Performance predictions established.	Interface requirements understood at concept level only. Impact on other systems is understood at a concept level only.	Fluid	Predictions of reliability made	Published Research	Concept

Table A1-1: FRS descriptions

A2.3.3 Flexibility

This general criterion is aimed at identifying options in the deployment of a technology which could enable a range of data rates/bandwidth to be chosen to meet the requirements in a particular service volume or to be tailored to a specific radio band. For example, the technology could offer a number of data rates, modulation options and channel bandwidths which can be chosen to meet the requirements.

More options in the technology provide better flexibility to deploy the technology to meet local requirements or constraints.

Criterion level	Flexibility Value
1	The technology can be deployed in several ways to provide a variety of performance values.
2	The technology can be deployed in only one way and provides fixed performance values.

A2.3.4 Ground Infrastructure Costs

This criterion is used to indicate the typical cost to deploy the ground element of the FRS technology within a region compared with a VHF system.

Note - Avionic costs are not considered as they are not a discriminator between technologies at this stage of development. An estimate of the avionics costs of each technology will be similar due to this immaturity. All avionics are expected to be implemented in similar ways e.g. a new unit which will be required with its own antenna.

This criterion is used to indicate the typical cost to deploy the ground element of the FRS technology within a region (e.g. ECAC or NAS). The cost will be based on the number of radio units needed to achieve coverage in the proposed service volume of the target system.

It is recognised that a single technology may not be designed to achieve entire coverage in all service volumes. In this case the technology assessment will aggregate the costs of a combination of technologies to achieve entire coverage in the region. For example a technology may be aimed at airport surface coverage only. This would need to be augmented by an air/ground service technology and therefore its cost would be added.

In determining the cost, the number of ground stations is derived from the technology deployment plan for each system. This cost is compared to that of an equivalent service offered by a VHF data radio system. The comparison will be done based on a regional implementation i.e. in ECAC airspace.

Criterion level	Cost Value
1	100 times less than the cost of VHF ground data radio system
2	10 times less than the cost of VHF ground data radio system
3	Similar cost to VHF ground data radio system
4	10 times the cost of VHF ground data radio system
5	100 times the cost of VHF ground data radio system

A pragmatic approach has been taken to apply this criterion by comparing the FRS system against the coverage achieved by current VHF RTF radio system. The simple approach of mapping overlapping cells across the designated coverage area at green field locations was considered to be too simplistic and not representative of how the FRS is likely to be deployed. It is expected that the FRS will be deployed at some or all existing legacy sites to minimise costs – the time and cost of deploying new radio sites is time consuming and expensive. Consequently an approach was taken whereby a typical area was identified and the siting of current VHF radio sites examined to identify a typical siting plan.

To compare the coverage achieved by current technology a typical deployment of VHF transmitters in a part of a region was determined. Figure A-3 and Figure A-4 below show the deployment of a radio sites to achieve TMA and en route coverage in typical large area. In the figures each site has been assumed an arbitrary number.

The number of sites and their placement has been determined based on a number of reasons –

- The designated coverage volume to meet the operational requirement
- Use of existing sites to their maximum extent rather than the expensive alternative of a new green field site
- The maximum number of frequencies that can used at a single site which requires additional sites
- The environmental acceptability of the radio site at that location

In the figures the typical coverage volumes of the sites has been illustrated. It will be noticed that there is considerable overlapping coverage which is a combination of the need for redundant coverage and the limitation of number of frequencies that can be handled at one site. To support en-route and TMA communications a system operating in the L-band is preferred. The propagation characteristics are similar to VHF based systems and hence deployment of VHF sites represents a useful indication of deployment of an L-band system.

For communications with aircraft operating in the en route airspace a minimum FL of 245 was assumed. For aircraft operating in TMA aircraft were assumed to operate around FL100. Based on these values, it was concluded that if the FRS could provide coverage of up to 200NM in an en-route environment the cost would be the same as the current. Lower ranges would require more sites and hence high cost.

Similarly, for TMA a range of 107NM was chosen and again lower ranges would require more sites and hence high cost.

It was assumed that each airport would continue to be covered by the same VHF sites as currently deployed, as at airports the line of sight requirement remains valid. The coverage assumed was as in the COCR. It should be pointed out that there are a significant number of these sites so the number of airports being deployed mainly determines FCI infrastructure costs.

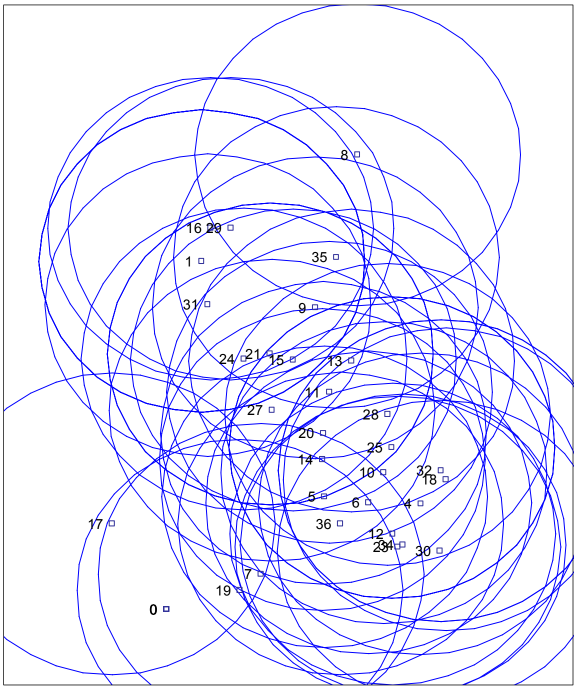

Figure A-11 Coverage of a typical set of VHF radio stations (200Nm – FL350)

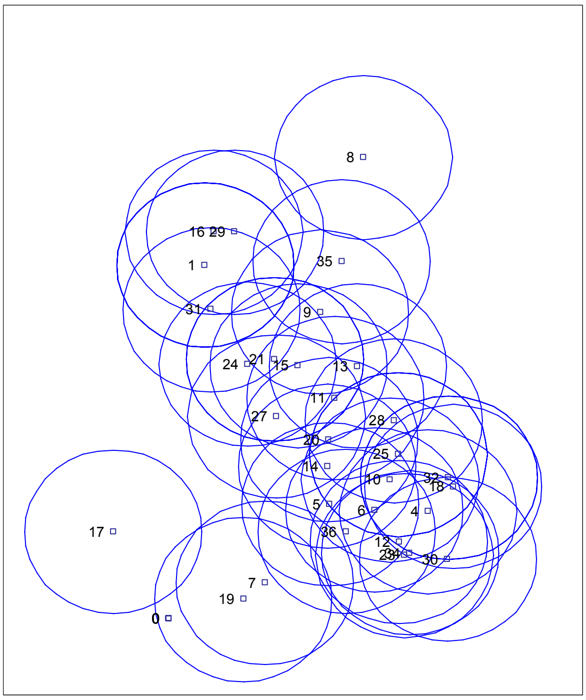

Figure A-12 - Coverage of a typical set of VHF radio stations (107NM – FL100)

A2.4 Performance Based Criteria

The performance of the candidate system will be evaluated against the requirements defined in the Evaluation Scenario document for each airspace location.

Values used for this criterion range from 1 to 3. Value 1 means that the candidate technology as designed exceeds the requirements in the location for which it being assessed. A value 3 means that the technology does not meet the requirement in that particular location. A technology must meet requirements in one location from the following –

- Airport Surface
- Airport Zone
- Terminal Maneuvering Area
- En-Route
- Oceanic Remote and Polar

Criterion level	**Capacity**	**Integrity**	**Availability**	**Latency**
1 = exceeds requirement	1,2 or 3	1,2 or 3	1,2 or 3	1,2 or 3
2 = meets requirement	1,2 or 3	1,2 or 3	1,2 or 3	1,2 or 3
3 = does not meet requirement	1,2 or 3	1,2 or 3	1,2 or 3	1,2 or 3

It is important to note the significance of the 'quantified' and 'validated' assessment criteria where the performance requirement is an absolute, quantifiable value. Quantified means that the technology has specified a value that it can meet whereby validated will mean that this quantified figure has been demonstrated by simulation or experimentation.

Taking integrity as an example, the system may be designed to exceed the COCR requirement and hence this would result in a good assessment level score for the 'quantified' category, but without some sort of demonstration, the 'validated' score would remain low.

APPENDIX C2 – US ASSESSMENT

Table A2-1: U.S. Evaluation Team Evaluation Criteria & Metrics

	Evaluation Criterion		Metrics
1	Provides ATS A/G Data Services within Requirements (sans A-EXEC)	A - Capacity	**GREEN**: Provides capability to provision ATS services meeting capacity requirements for Phase II/High Density across all continental flight domains (or applicable domain for domain-specific analysis) **YELLOW**: Provides capability to provision ATS services meeting capacity requirements for Phase II/High Density in at least one (but not all) flight domain (or in the applicable flight domain for domain-specific analysis); or meeting capacity requirements for Low Density in at least one flight domain (or in the applicable flight domain for domain-specific analysis) when High Density capacity requirements are not met in any flight domains **RED**: Does not provide sufficient capability to provision ATS services meeting capacity requirements for Phase II High and Low Density in any flight domain (or for the applicable domain for domain-specific analysis)
		B - Number of Users (PIAC)	**GREEN**: Provides capability to provision ATS services meeting PIAC requirements for Phase II/High Density across all continental flight domains (or applicable domain for domain-specific analysis) **YELLOW**: Provides capability to provision ATS services meeting PIAC requirements for Phase II High Density in at least one (but not all) flight domain (or in the applicable flight domain for domain-specific analysis); or meeting PIAC requirements for Low Density in at least one flight domain (or in the applicable flight domain for domain-specific analysis) when High Density capacity requirements are not met in any flight domains **RED**: Does not provide sufficient capability to provision ATS services meeting PIAC requirements for Phase II High and Low Density in any flight domain (or for the applicable domain for domain-specific analysis)
		C - QoS	**GREEN**: Provides capability to offer class of service (e.g. prioritization) capability for ATS services **YELLOW**: Technology can be readily modified to offer class of service (e.g. prioritization) capability for ATS services **RED**: Technology cannot be easily modified to offer class of service (e.g. prioritization) capability for ATS services
		D - Environment	This provides a measure of a technology's ability to provision ATS services within the COCR-defined airspace environment (accounts for time varying and time dispersive channel effects) **GREEN**: Technology performance in intended channel is characterized by flat/slow fading **YELLOW**: Technology can be readily modified to be characterized by flat/slow fading (e.g. physical layer modifications; equalization techniques) **RED**: Technology cannot be easily modified to be characterized by flat/slow fading
2	Provides ATS & AOC A/G Data Services within Requirements (sans A-EXEC)	A - Capacity	**GREEN**: Provides capability to provision ATS & AOC services meeting capacity requirements for Phase II/High Density across all continental flight domains (or applicable domain for domain-specific analysis) **YELLOW**: Provides capability to provision ATS & AOC services meeting capacity requirements for Phase II/High Density in at least one (but not all) flight domain (or in the applicable flight domain for domain-specific analysis); or meeting capacity requirements for Low Density in at least one flight domain (or in the applicable flight domain for domain-specific analysis) when High Density capacity requirements are not met in any flight domains **RED**: Does not provide sufficient capability to provision ATS & AOC services meeting capacity requirements for Phase II High and Low Density in any flight domain (or for the applicable domain for domain-specific analysis)

	Evaluation Criterion		Metrics
		B - Number of Users (PIAC)	**GREEN**: Provides capability to provision ATS & AOC services meeting PIAC requirements for Phase II/High Density across all continental flight domains (or applicable domain for domain-specific analysis) **YELLOW**: Provides capability to provision ATS & AOC services meeting PIAC requirements for Phase II High Density in at least one (but not all) flight domain (or in the applicable flight domain for domain-specific analysis); or meeting PIAC requirements for Low Density in at least one flight domain (or in the applicable flight domain for domain-specific analysis) when High Density capacity requirements are not met in any flight domains **RED**: Does not provide sufficient capability to provision ATS & AOC services meeting PIAC requirements for Phase II High and Low Density in any flight domain (or for the applicable domain for domain-specific analysis)
		C - QoS	**GREEN**: Provides capability to offer class of service (e.g. prioritization) capability for ATS services **YELLOW**: Technology can be readily modified to offer class of service (e.g. prioritization) capability for ATS services **RED**: Technology cannot be easily modified to offer class of service (e.g. prioritization) capability for ATS services
		D - Environment	This provides a measure of a technology's ability to provision ATS services within the COCR-defined airspace environment (accounts for time varying and time dispersive channel effects) **GREEN**: Technology performance in intended channel is characterized by flat/slow fading **YELLOW**: Technology can be readily modified to be characterized by flat/slow fading (e.g. physical layer modifications; equalization techniques) **RED**: Technology cannot be easily modified to be characterized by flat/slow fading
3	Technical Readiness Level		Anticipated need (per FCS roadmap) is implementation in about 12 years; TRL 6 or above is consider to be achievable with low risk; TRL 3 or below has significant risk **GREEN**: Technology is at level 6 or above **YELLOW**: Technology assessed at level 4 or 5 **RED**: Technology is assessed at level 3 or below
4	Standardization Status		This criterion is an indicator of technology maturity. Existence of some standardized technical descriptions is indicative of some level of technology maturity. Existence of aeronautical specifications, required for an aeronautical system, e.g. ICAO, RTCA, Eurocae specs, is indicative of high level of maturity for the application of interest (e.g. FRS). The existence of aeronautical standards is significant risk mitigation factor for implementation; standardization of the technology in other forums (e.g. commercial forums) provides some implementation risk mitigation **GREEN**: Technology has publicly available aeronautical standards **YELLOW**: Technology are supported by a publicly available commercial standard **RED**: Technology for which supporting standards does not exist or is not publicly available

	Evaluation Criterion	Metrics
5	Certification	This criteria is another indicator of technical maturity; Technologies that are certified or are in the certification process pose significantly less risk for implementation while those technologies specifically developed for safety related services may also provide risk mitigation for meeting certification requirements **GREEN**: Technology (products) developed for the aviation industry and either currently certified or known to be in the certification process **YELLOW**: Technology developed for safety related services (public safety and the like) but not currently in the aviation certification process **RED**: All other cases other than Green or Yellow
6	Ground Infrastructure Cost	Relative cost to replace or upgrade infrastructure with the necessary availability and diversity requirements for critical services, as a replacement to VHF DSB-AM it is evaluated as the relative cost to provision services in the defined evaluation scenarios (as either a sector-based or area-based implementation). A candidate not able to project a signal at a large range from a single ground station would require multiple replacement ground stations; The evaluation accounts for unusual maintenance requirements of a candidate (to include leased services, maintenance of Network Operational Centers, extraordinary Telco bandwidth requirements and the like) **GREEN**: low relative cost **YELLOW:** moderate relative cost **RED:** high relative cost
7	Avionics Cost	This criterion provides a measure of the relative cost to upgrade avionics with a new technology Relative cost to upgrade avionics with new candidate data link technology but maintain VHF DSB-AM capability **GREEN**: low relative cost **YELLOW:** moderate relative cost **RED:** high relative cost
8	Spectrum	Gauges the likelihood of obtaining the proper allocation of the target spectrum and the compatibility of proposed technology with existing aeronautical systems in target band (second component not included in pre-screening) **GREEN**: Technology proven (e.g. tested) to deployable in target spectrum band without either reallocation of existing equipment frequencies or requiring modification to existing aeronautical equipment (based on co-site tests) **YELLOW**: Technology considered to deployable in intended band without either reallocation of existing equipment or requiring modification to existing aeronautical equipment (based on co-site considerations) **RED**: Technology requires reallocation of existing equipment frequencies or modification to existing aeronautical equipment for deployment in target spectrum band
9	Security – Authentication and Integrity	Provides an assessment of technology authentication and data integrity capabilities to address COCR FCI security requirements on this topic (R.FCI-Sec2.a, R.FCI-Sec2.b "…FCI shall support message authentication and integrity…") **GREEN**: Candidate technology provides authentication and integrity functionality **YELLOW**: Candidate technology can be modified to provide authentication and integrity functionality **RED**: Candidate cannot support and cannot be modified to provide authentication and integrity functionality

	Evaluation Criterion	Metrics
10	Security – Robustness to Interference	Provides a relative assessment of technology robustness to interference to address COCR security requirements that indicate need for FCI to provide "reliability and robustness to mitigate denial of service attacks"; Inherent technology capability (e.g. frequency hopping multiple access techniques) may address these requirements; Excess link margin in technology deployment can also support these requirements **GREEN**: Technology provides significant robustness to interference (e.g. technology uses specific techniques for interference protection (such as frequency hopping) or can be effectively deployed with significant excess margin (e.g. ≥12 dB)) **YELLOW**: Technology provides moderate robustness to interference (e.g. technology does not provide specific techniques for interference protection, but can be effectively deployed with excess margin (3 to 11 dB)) **RED**: Technology does provide specific techniques for interference protection nor can it effectively be deployed with excess link margin (e.g. margin is less than 3 dB)
11	Transition	Assesses acceptable transition characteristics, including: • Return on partial investment • Ease of technical migration (spectral, physical) • Ease of operational migration (air and ground users) • **GREEN**: Technology meets all of the following conditions: • Can be deployed to achieve ROI (i.e. service provision/benefit) without requiring full investment/deployment • Can be operated simultaneously (in adjacent airspace) with legacy A/G comm systems (i.e. you can bring the new system up incrementally while bringing down the legacy system incrementally) • Initial transition can be nearly operationally transparent (i.e. initially users do not have to significantly alter procedures) or features that drive changes in operational procedures can be employed incrementally **YELLOW**: Cases other than defined in GREEN or RED **RED**: Technology meets all of the following conditions: • Provides little or no ROI without full investment/deployment • Requires operation of legacy A/G comm to be widely discontinued in order to operate • Initial transition requires significant changes to operational procedures

Appendix D: Communication Roadmap Document (version 2.0)

Introduction and Overview – Aeronautical Mobile Communications

This paper presents the Communications Roadmap for aeronautical mobile communications, developed as part of the joint Eurocontrol/FAA Future Communications Study (identified in Technical Theme 4 of Action Plan 17). It describes the evolution of communications capabilities and technologies, expected as the basis for globally harmonized communications, and supports the anticipated future operating concepts for example as defined in the FCS Communications Operating Concept and Requirements (COCR) and the NextGen and SESAR programmes.

Figure 1 depicts an overview of the jointly agreed to approach for the implementation and evolution of aeronautical mobile communications to support the emerging and anticipated needs of air traffic management in both Europe and the U.S.

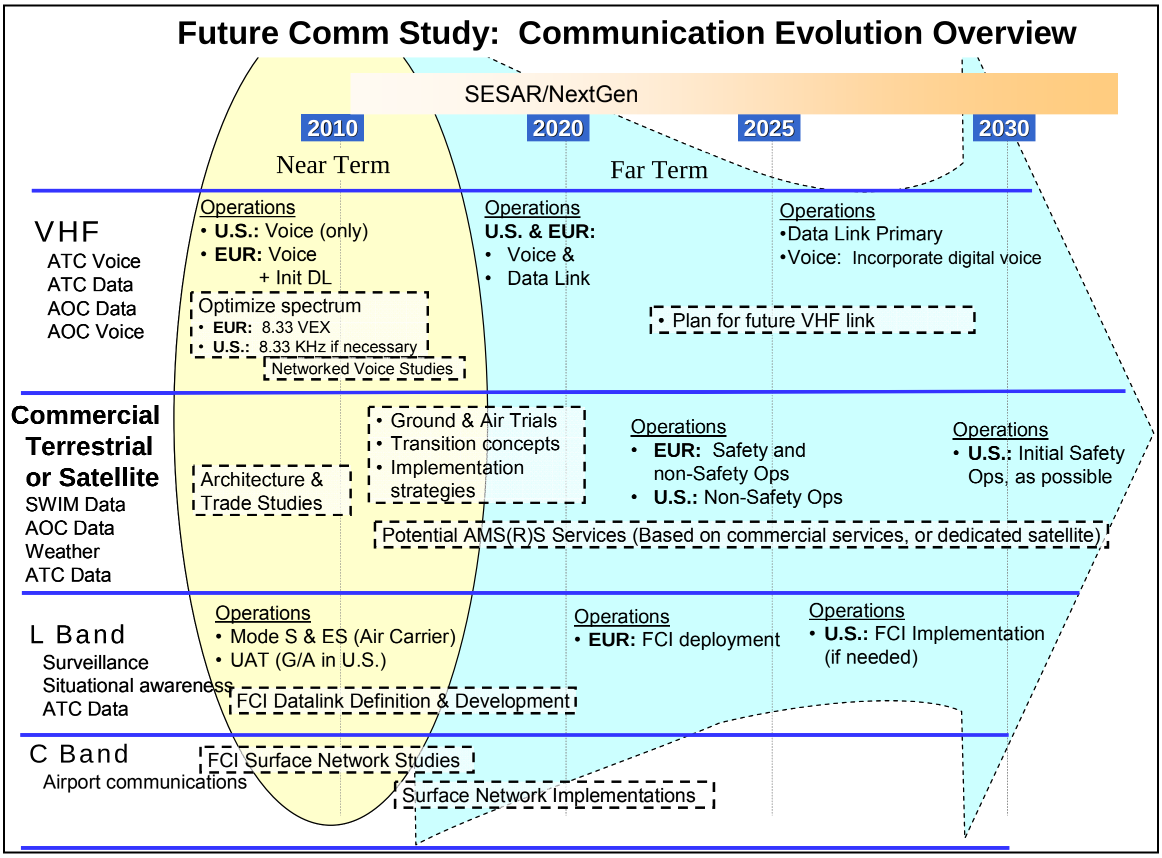

Figure 1 Aeronautical Mobile Communications Evolution Overview

Near Term: In the near term, air traffic control operations (as well as aeronautical operations control – AOC) will continue to use the allocated VHF spectrum (118-137 MHz) for voice communications throughout the U.S. and European regions. (Military voice communications currently operating in the UHF band are not addressed here, but will continue to be supported throughout the time frame.)

In order to service continued demand for additional voice channels, Europe has implemented 8.33 kHz channel spacing in the VHF band in designated airspaces, and will continue the vertical expansion of 8.33 kHz as necessary to satisfy demand for voice channels. It should be noted that even with 8.33 kHz for voice channels, the European VHF band is still expected to become saturated necessitating use of additional systems to share the load.

In Europe, implementation of data link performed by Air Navigation Service Providers and airspace users are coordinated in the context of EUROCONTROL programs such as the LINK2000+ program. ATC services (described in the COCR) planned for implementation (starting in 2008) supported by the CASCADE program, include automatic CPDLC, Digital OTIS, Data Link Taxi Clearance, and Data Link Alert. Europe expects to mandate ATC data link services above FL285, from 2009 onwards for new A/C, and 2014 for retrofit.

In this time frame, the FAA will also develop and begin to implement data applications in its domestic airspace, which will use existing communications technologies utilized for AOC communications, such as VDL Mode 2.

Preparations will be made in the U.S. to optimize the utilization of VHF spectrum to ensure sufficient capacity for increased data operations anticipated in the future, and provide the needed voice channels using 8.33 kHz voice channel spacing if required.

In both the U.S., and Europe, surveillance applications will continue to use L-band communications at 1030/1090 MHz for SSR/ATCRBS, and begin to support ADS-B using 1090 ES. The FAA will also deploy Ground Based Transceivers using Universal Access Transceiver (UAT) technology in the L-Band for surveillance applications using ADS-B technology. The primary user for the UAT technology in the U.S. in this time frame is General Aviation. In Europe, there will be implementation of ADS-B based ground stations beginning in 2008 by the CASCADE program.

As an R&D activity to prepare for the flexible voice communications needs in the far term, and to maximize the efficient use of communications spectrum in the VHF band, the FAA will study networked voice capabilities (such as VoIP) to effectively operate over ICAO defined digital links, for air traffic services to provide flexible, reliable and efficient voice communications for air traffic managers in a digital network centric environment.

Working together with industry, FAA and Eurocontrol will continue to study the potential for emerging commercial terrestrial-based and satellite communications technologies, including the use of these offerings for advisory and other non-safety critical communications. In addition, the potential use of dedicated satellite systems to support safety communications is being considered in Europe. Concepts to implement and transition to the operational use of these communications services would be developed for any promising technologies. Opportunities to validate the concepts of use, or implementation strategies for these technologies would be performed through ground and airborne trials and demonstrations.

The FAA and Eurocontrol will also engage in joint activities to complete selection of a terrestrial based L-Band digital link (i.e. L-DACS) to provide additional aeronautical mobile data capacity. The candidate technologies will consider effects of co-site interference with other systems operating in this band and identify and address common certification issues for both Europe and the U.S. This joint effort will lead to a harmonized L-Band digital link (i.e. L-DACS), to be carried through the international standardization process.

Wireless airport communications links using the C-Band spectrum allocations at 5 GHz are recommended for deployment as surface networks. Applications that may be considered for use in this frequency band (assuming performance requirements can be met) include surveillance and weather sensor information transfer; monitor and control of aerodrome navigation and landing aids; diversity path provisioning for high availability voice communications service; support for information transfer between automation systems, such as between TRACON and tower; and Electronic Flight Bag and other mobile applications supporting aircraft and surface vehicles.

Far Term: Once digital data communications is established, and the operational paradigm changes to be based on digital data exchange as the prime means for safe and efficient ATC operations, it is expected that the need for data communications will grow and the nature of voice communications will change.

In this time frame, to support the expected growth of data link operations, the FAA will utilize VHF digital links, enhanced as needed to support safety related services in the U.S. It is anticipated that expansion of commercial communications services for aeronautical mobile communications will also be utilized in the NAS, with the greatest potential for these services expected to provide advisory information and support non-safety related services to users in the NAS.

In parallel, because of regional limitations within the VHF band, Europe will deploy the jointly developed terrestrial L-Band digital link technology (L-DACS) to support its users. The FAA will monitor the implementation of this technology in Europe, and as circumstances dictate, will evaluate the use of L-band digital link technology in the U.S. For example, during this term, the FAA will study the integration of Mode S ES and UAT capabilities for ATC data applications, as well as study, the potential for using the jointly defined L-band digital link. It is foreseen that since Europe will also require an alternative ADS-B link in this time frame, this internationally standardized L-band digital link will be studied as a potential candidate.

Due to changing controller functions, and the ability to dynamically configure airspace during this time, initial implementation of networked digital voice operations in the en route airspace of the U.S. is anticipated to provide a flexible and efficient voice communications capability.

VHF Operations – Maximizing and Reforming Use of the VHF band

The concept behind reforming the VHF band in the U.S. is illustrated in Figure 2. Analog voice communications will be maintained and operated throughout the time frame, and 25 kHz spacing will be maintained for users who do not require digital services and operate at low altitudes, as well as for certain specific services such as Unicom. If necessary, 8.33 kHz spacing will be employed in U. S. en route airspace to liberate VHF spectrum for additional safety related digital communications services. Air traffic management services that operate on VDL-M2 will be maintained throughout the time span. Enhancements to VHF digital link systems to support the safety related services will be implemented in the VHF spectrum liberated through strategic spectrum management actions. To support emerging concepts related to flexible airspace boundaries and dynamic workforce assignments, digital ATC voice would first be implemented in the en route airspace.

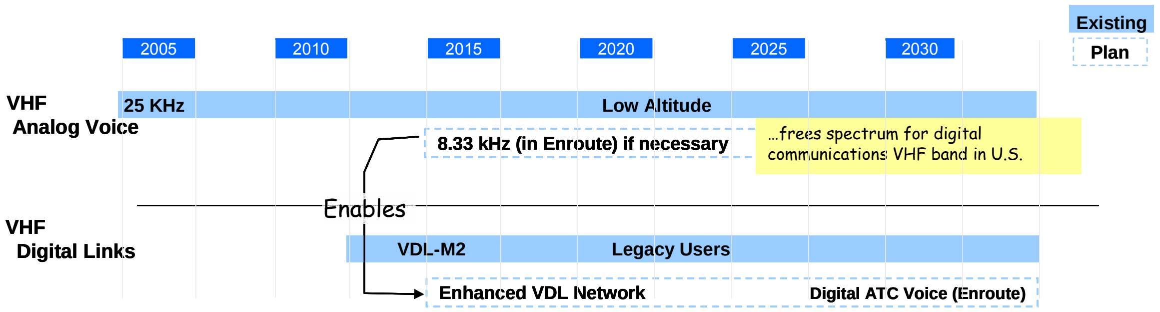

Figure 2 U.S. VHF Band Reforming

Use of the VHF band in Europe is illustrated in Figure 3. Analog voice communications will be maintained and operated throughout the time frame. 8.33 kHz channel spacing has been introduced to alleviate VHF congestion. Today, the carriage and operation of 8.33 kHz capable equipment is mandatory above FL195 in ICAO EUR Region. (8.33 kHz channel spacing has been implemented above FL195 in the ICAO EUR Region, with a mandatory carriage date of 15 March 2007.) Eurocontrol is progressing toward the full implementation 8.33 kHz below FL195 in 2013. The ATC data link services for CPDLC use VDL-M2. Airline Operations Control (AOC) data link services also use VDL-M2, in addition to legacy ACARS services in the VHF band. Given the saturation of the VHF band in the core of Europe, the existing spectrum to support these services will be maintained, but few additional frequencies are expected to be allocated. VDL-M4 is also being implemented in the VHF band to support regional ADS-B services outside of the spectrum saturated core of Europe.

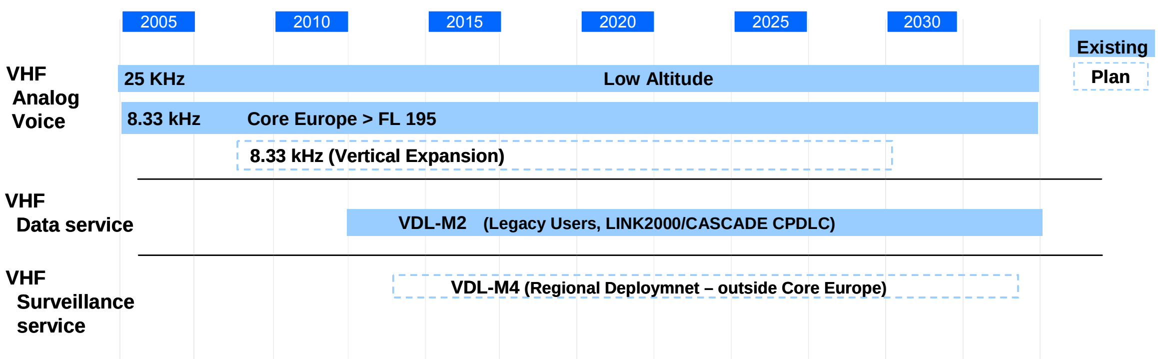

Figure 3 Europe VHF Spectrum Use

Commercial Terrestrial and Satellite Communications – Potential opportunities

Figure 4 illustrates the potential use of commercial terrestrial and satellite communications capabilities. Through value added resellers such as SITA and ARINC, commercial satellite systems, (e.g. Inmarsat) have supported air traffic management in Oceanic airspace, providing AMS(R)S voice and data services to equipped users, and reducing the use of HF voice communications. These satellite services will continue, and potentially expand as additional service providers, such as Iridium, have their systems standardized to provide AMS(R)S communications services to their customers. Other commercial offerings (such as XM Radio - Aviator, Teledyne Wireless Groundlink® or AirCell) may emerge to provide AOC applications not currently offered.

As supported by their business cases and customers, commercial satellite and terrestrial communications service providers may provide advisory and non-safety information using the System Wide Information Management (SWIM) capabilities now being envisioned. If these commercial providers are successful, and can be certified to provide safety services for air traffic management in other domains, then they may eventually also be able to provide safety related services, expected initially in the en route environment.

Europe and the U.S. will also give consideration to the use of satellite packages dedicated to air navigation services to provide Aeronautical Mobile Satellite (Route) Services, such as Japan's MTSAT. The European Space Agency, with the support of EUROCONTROL is investigating the development of a satellite communications system for aviation.

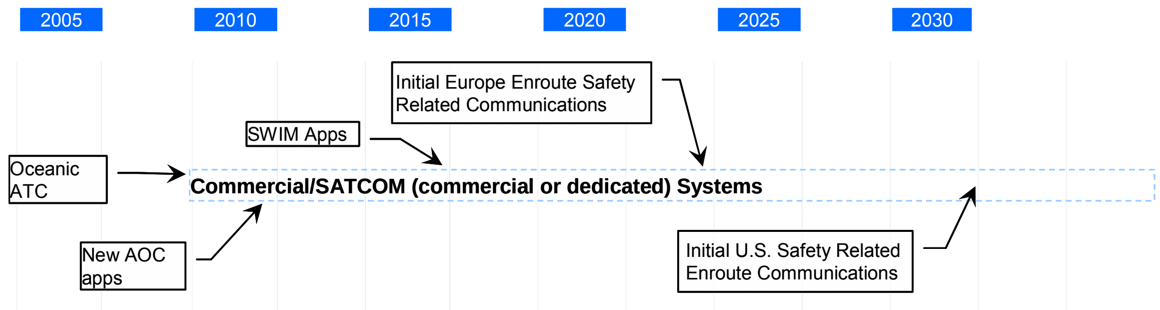

Figure 4 Commercial Terrestrial and Satellite Communications

L-Band Communications – Provides Digital Broadband Capabilities

Figure 5 illustrates the use of L-Band spectrum defined within the scope of the Future Communications Study. Initially, this spectrum will support surveillance and potentially situational awareness functions using 1090 Extended Squitter with properly equipped aircraft using Automatic Dependant Surveillance – Broadcast (ADS-B). The goal is to have global standards and digital communications systems operating in the L-Band, which can address the advanced communications needs in both European and U.S. airspace.

The FAA is planning to augment the 1090 Extended Squitter (ES) capability designed for ADS-B applications and used by air transportation and cargo aircraft, with Universal Access Transceiver (UAT) technology to support General Aviation users. In the U.S., the UAT system is also expected to supplement air transportation and cargo users when and if, in the future 1090 ES capacity is exceeded. In Europe, if 1090ES capacity is exceeded, VDL-4 could provide a supplement, but only on a regional basis outside the core of Europe, where VHF spectrum would be available to support this technology. L-DACS is being considered as a potential ADS-B technology.

This Future Communications Study has investigated technologies for standardization within ICAO, which could effectively operate an aeronautical mobile digital link in the L-band, without adversely affecting existing systems already operating in this band. Results of these investigations have been published as part of the Future Communication Study, and identify the characteristics of an aeronautical mobile technology to operate in L-band that will be pursued for standardization by Eurocontrol and the U.S. Because of an already depleted VHF band in Europe, Eurocontrol is studying data link capability in the L- band based on this future standard. The U. S. is also considering this capability, but would only deploy the jointly developed L-Band digital link if the needed data capacity could not be supported by the VHF band in the U.S., and after the successful implementation of these links in Europe.

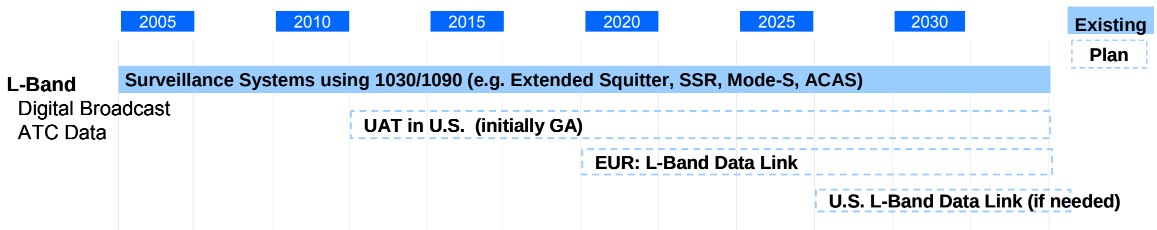

Figure 5 Use of L-Band Links

C-Band Communications – WLAN for Surface Applications

Part of the C-Band spectrum (between 5000 – 5250 MHz) is internationally allocated to the aeronautical radionavigation service (ARNS). Some of this allocation could allow for operation of an airport Local Area Network, supporting a variety of vital aeronautical applications and services, as shown in Figure 6. This network is envisioned as a high-integrity, safety-rated, wireless local area network (WLAN) for the airport service, with communications terminals envisioned on the ground, on aircraft as well as other surface vehicles.

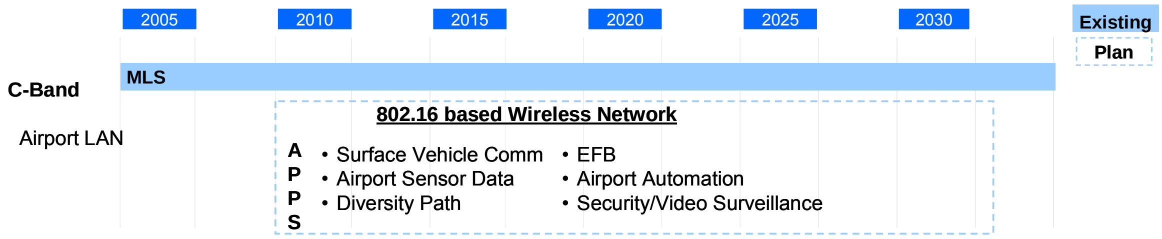

Figure 6 Use of C-Band Links

Operation of this airport network could provide significant improvements in safety, security, and productivity in the airport surface environment. This network could support applications facilitating communications and coordination among all vehicles operating on the airport surface. The network could provide connections to nomadic sensors on the airport grounds, providing weather, status and control of navigation aids. The network might also support video and security surveillance information applications, or provide a diversity path to provide the necessary high availability for critical communications elements. Research into the potential use and most effective implementation of these surface applications will continue.

Based on the Future Communications Study technology assessments, an aeronautical standard based on IEEE 802.16e, and using this spectrum sub-band is anticipated to be defined and developed to facilitate improved surface operations over the next decade.

Flexible Avionics Architecture – Enables Integration of Future Communications Capabilities

Essential to an aircraft using any communications services, are its avionics. This study has concluded that the future communications environment can not be described as access to a single ubiquitous communications technology, but as access to a "system-of-systems", consisting of a collection of communications capabilities targeted at specific operational settings. Integrating these functions onto an aircraft in the form of specific hardware and software solutions presents significant challenges, not least of which is retrofitting a large fleet of already existing aircraft.

For European Civil Aviation Authorities, as well as the FAA, a goal is to deploy common communications technologies as demand for new functionality arises. Traditionally, communications systems are implemented in aircraft as individual federated systems consisting of individual Line Replaceable Units (LRUs), each designed to perform a small number of specific functions within the system, as shown below in Figure 7. Such configurations do not easily accommodate changes in communications technology, architecture, or capabilities. This presents considerable challenges especially in terms of integration into existing airframes. As the introduction of new communications capabilities will involve changes to ground infrastructure, to take advantage of these new capabilities, airborne communications equipment will need to adapt. Moreover the new systems must be compatible with, and interoperate with systems already present on the airframe.

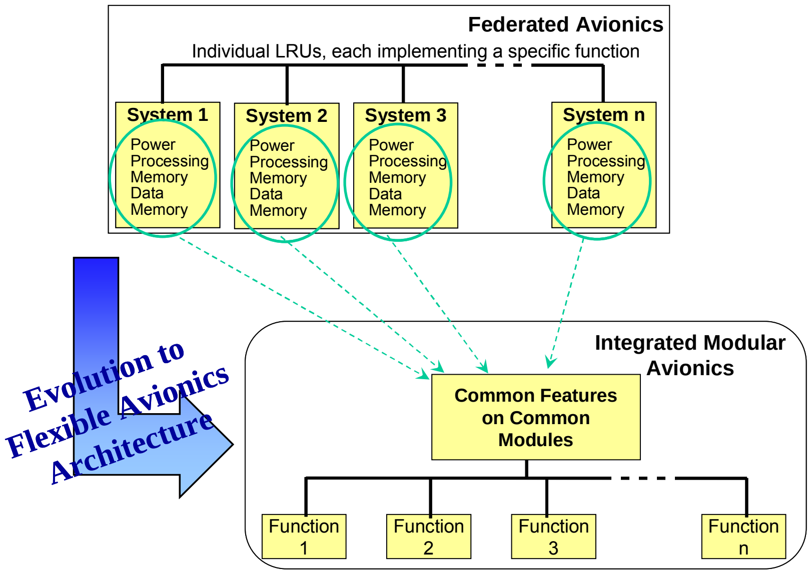

Figure 7 Evolution of Avionics Architecture

Since the regional needs for new communications capabilities will not evolve simultaneously, avionics need to be implemented in such a way as to provide for flexibility in the future communication architecture, as well as to allow for future sustainable growth. This trend to integrate functionality in communications avionics is already visible today to some extent, with the introduction of the VHF Data Radios (VDR), taking advantage of Software Defined Radio techniques, and integrating several communications capabilities in the VHF band (DSB-AM 25 kHz or 8.33 kHz voice and VHF digital links).

An approach known as Integrated Modular Avionics, shown in Figure 7, reduces integrated hardware and software solutions, in favour of software applications running on modular, general purpose, hardware platforms. In this respect, Integrated Modular Avionics is a shared set of flexible, reusable, upgradeable, and interoperable hardware and software, providing the resources interconnected by a distributed real-time computer network on board the aircraft to host applications performing aircraft functions.

One concept, called Multi-function, Multi-mode Digital Avionics (MMDA), initiated in the U.S. by NASA defined a process, shown in Figure 8, by which an open, integrated and modular architecture for MMDA hardware and software for civil aviation applications could be developed. It was determined that for such an architecture to be flexible, open and extendable, it must: (1) lower total system cost and reduce time for certification; (2) address the number of waveforms that need to be incorporated, 3) leverage the best commercial standards and innovations as they emerge over time, and 4) provide flexibility for users to decide which capabilities they need, and when they are needed.

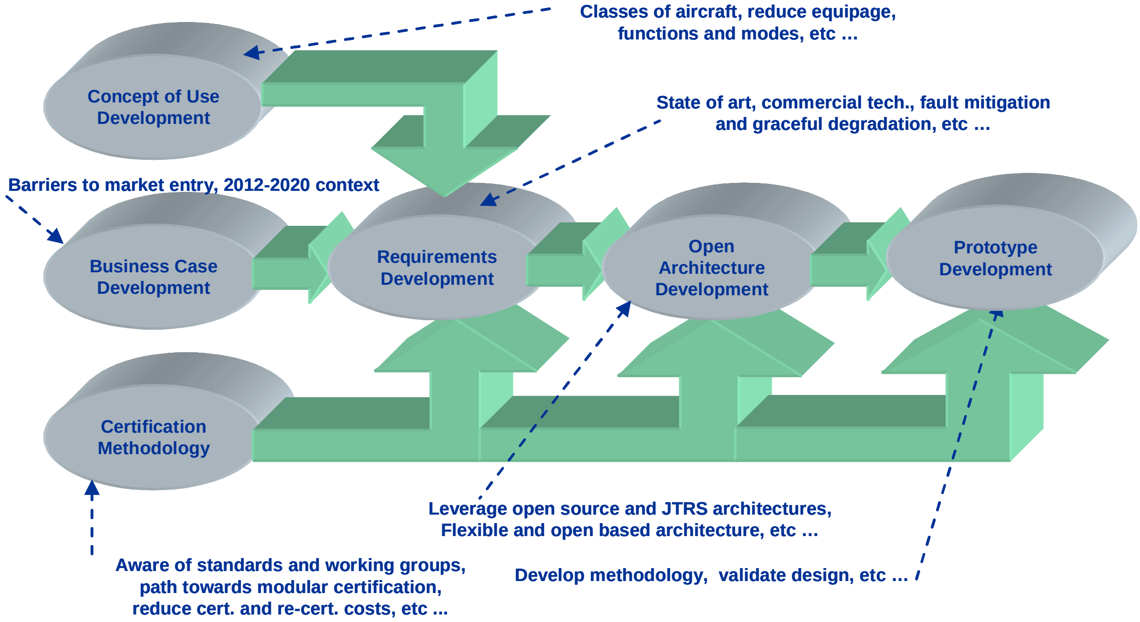

Figure 8 MMDA Architecture Development Process

There is also a trend towards server-based and Service Based Architectures (SOA) where the source of data and information is hidden from the user. Coupled with Integrated Modular Avionics, this approach further integrates avionics systems, and increases flexibility by removing the close coupling of a system and its sensors, making sensor data available to other systems that may not have previously identified a need for it (Figure 9).

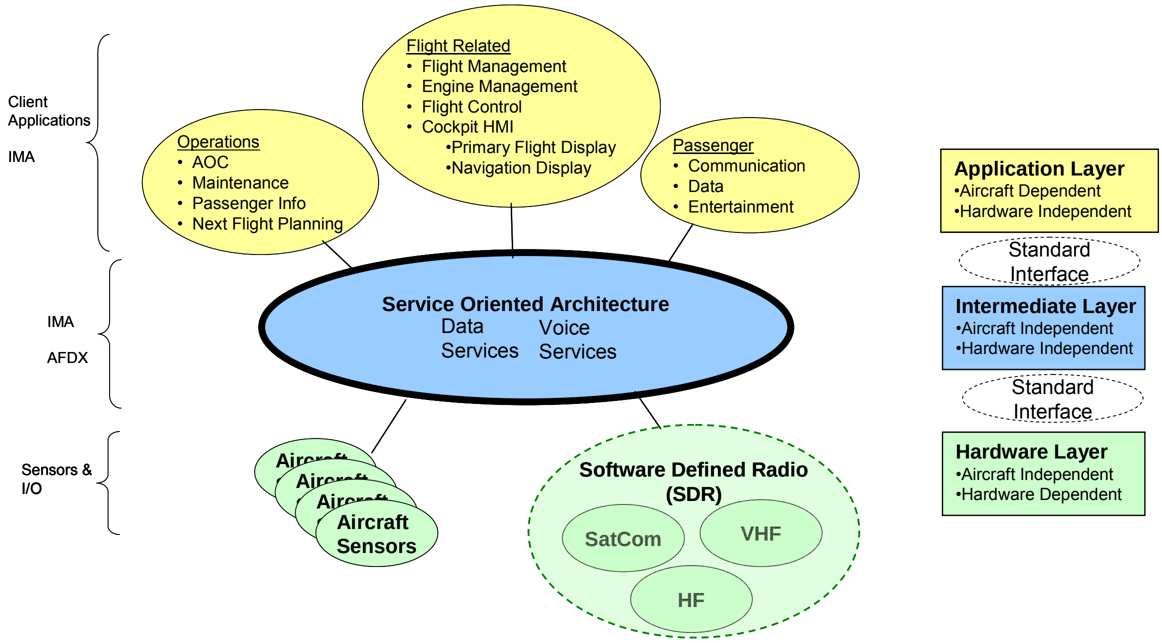

Figure 9 Service Oriented Avionics Architecture

As both Boeing and Airbus are already developing their next generation aircraft, they are also proposing Integrated Modular Avionics (IMA) as an enabling capability. A key design driver for these airframe manufacturers is to reduce the amount of custom hardware, and its associated size, weight and power footprint, as well as to gain flexibility and re-usability across platforms. Boeing and Airbus also both recognize the service-oriented architecture (SOA) as a key element of future avionics architecture providing flexibility to support communications enabled capabilities of tomorrow's air traffic management systems.

Input from Aviation Users and States

The FAA has received input and recommendations from its users, represented by the RTCA Air Traffic Management Advisory Council (ATMAC). Similar recommendations have also been received by Eurocontrol from the European States. These inputs have been considered and incorporated into this joint approach to the future implementation of aeronautical mobile communications for air traffic management.

Specific recommendations, from the RTCA ATMAC, were that the FAA:

- Sustain voice communications in VHF Band as long as possible
  - Make optimum use of current equipage
- 8.33 kHz channel spacing is the preferred first alternative only when current 25- kHz spectrum no longer meets operational needs
- New technical solutions should be pursued only after all non-equipment solutions have been exhausted
  - Spectrum allocation
  - Policies and procedures
- Aeronautical Data Link System (ADLS) is important
  - Use existing VHF capabilities / equipment to provide ADLS until Future Communications Study decisions and milestones are set
    - VDL Mode 2, 1090 MHz, Universal Access Transceiver (978 MHz)
- Commit to a data link technology, schedule, funding by 2007. Implement - 2015
- AOC should remain separate from ATS communication

Recommendations received from the European States are to:

- Sustain future operation of voice communications in the VHF band
  - by expanding 8.33 services into the upper VOR band and secure this band in CEPT
  - by assessing practical considerations and cost issues to enable avionics to tune below 118MHz
- Foresee a change in paradigm in the 2020 time frame where additional capacity is provided by making data the primary mode of communications
  - Given this short timescale to develop and implement new technologies, a decision has to be made soon
- Target a global solution, but one that focuses on the requirements of the high-density core areas
- Demonstrate a solid business case for the introduction of future systems
  - In the case of Satellite communications, consider options of having a dedicated ATM system vs. sharing the infrastructure with other services.
- Facilitate the transition to a new system by considering the introduction of a digital voice service. This is a desirable step but not critical.

Summary

In support of the time phased operational concepts defined by the NextGen and SESAR programmes, as well as those introduced in the Communications Operating Concepts and Requirements (COCR), developed as a parallel effort within the Future Communications Study, this roadmap has been jointly developed by Eurocontrol and the FAA. It provides an evolution path for interoperable communications infrastructures supporting common future air traffic management operations.

The roadmap recognizes the needs of the aviation users as well as air navigation service providers, ensures the judicious use and protection of spectrum allocated for aeronautical purposes, and focuses on the introduction of potential new technologies for specific airspace and services.

The roadmap allows provisions for the innovative use of commercial technologies to provide communications services, and allows for worldwide harmonization of communications services.

Continued research, development, testing and evaluation between Eurocontrol and the FAA will allow the realization of capabilities described.

Appendix E: AP17 - Resulting Actions

Based on the results of the AP17 activities a number of detailed actions emerge that need to be progressed in order to realise the high level recommendations. The most important of these actions are presented in the following paragraph grouped according to the type of the required activity or the entity that will need to carry them out.

FAA and EUROCONTROL involving ANSPs and Airlines (in conjunction with the SESAR and NextGEN related activities)

General/Miscellaneous (Actions A0.X)

- [A0.1] (supporting recommendation R7) Continue close cooperation in carrying out the following actions and relevant activities;
- [A0.2] (supporting recommendation R5) Support activities and engage with aircraft manufacturers, aircraft operators and industry standard groups to ensure that a flexible airborne architecture evolves to ease the cost and time of certification and readily accommodate new applications and technologies;
- [A0.3] (supporting recommendation R5) Encourage industry investigations into flexible airborne architectures, software defined avionics, and multi-function, multi-mode antennas; and
- [A0.4] (supporting recommendation R1, R2 and R3) Complete business analysis in relation to the FCI components and implementation from the perspective of the ground infrastructure and the airlines.
- [A0.5] {supporting recommendation R6) In order to finalise the selection of the new components of the FCI, carry out testing and validation within an end-to-end environment to ensure that the required QoS and performance can be achieved.

C-band data link (Actions 1.X supporting recommendation R1)

- [A1.1] Identify the portions of the IEEE standard best suited for airport surface wireless communications, identify and develop any missing functionality and propose an aviation specific standard to appropriate standardisation bodies;
- [A1.2] Evaluate and validate the performance of the aviation specific standard to support wireless mobile communications networks operating in the relevant airport surface environments through trials and test bed development;
- [A1.3] Propose a channelisation methodology for allocation of safety and regularity of flight services in the band to accommodate a range of airport classes, configurations and operational requirements.
-

L-band data link (Actions 2.X supporting recommendation R2)

- [A2.1] Refine and agree on the interference environment and assumptions for the L-band compatibility investigations;
- [A2.2] Develop L-DACS prototypes for testing and trials to facilitate the technology investigations for the selection of the L-band data link;
- [A2.3] Complete the investigation of compatibility of candidate L-band data link with existing systems in the L-band particularly with regard to the onboard co-site interference and agree on the overall design characteristics;
- [A2.4] Complete evaluation of performance of candidate L- band data link against the appropriate requirements in the various environments; and

- [A2.5] Considering the design trade-offs, propose the appropriate L-DACS solution for input to a global aeronautical standardisation activity; and
- [A2.6] Evaluate and validate the performance of the proposed solution in the relevant environments through trials and test bed development.

Satellite data link (Actions 3.X supporting recommendation R3)

- [A3.1] Continue monitoring the satellite system developments and assessment of specific technical solutions to be offered in the timeframe defined in the COCR as these next generation satellite systems become better defined;
- [A3.2] Update existing AMS(R)S SARPs performance requirements to meet future requirements; and
- [A3.3] In order to support the new AMS(R)S SARPs, consider the development of a globally applicable air interface standard for satellite communication systems supporting safety related communications.

Spectrum (Actions 4.X supporting recommendation R4)

- [A4.1] Continue to provide rationale to spectrum regulators on the need for additional AM(R)S spectrum to facilitate advances in aeronautical communication capabilities;
- [A4.2] Provide support for compatibility studies between the FCI and other incumbent systems in any newly-allocated AM(R)S bands. This will include studies within ICAO regarding FCI compatibility with other aeronautical systems, and studies within the ITU regarding FCI compatibility with non-aeronautical systems; and
- [A4.3] Continue to support the need for priority to AMS(R)S in the satellite L-band.
- [A4.4] In the longer term, reconsider the potential use of the VHF-band for new technologies when sufficient spectrum becomes available to support all or part of the requirements.

Standardisation and Certification groups (including ICAO, RTCA, EUROCAE) (Actions B1.X supporting recommendations R1, R2, R3 and R5**)**

- [B1.1] Initiate development of appropriate aviation specifications covering the 802.16e based system operating in the C-band;
- [B1.2] Await the outcome of actions 3.X to initiate development of appropriate aviation specifications covering the selected L-band data link;
- [B1.3] Update existing AMS(R)S SARPs performance requirements to meet future requirements;
- [B1.4] Consider the development of a globally applicable air interface standard for satellite communication systems supporting safety related communications; and
- [B1.5] Consider the optimisation of certification procedures and/or development of an integrated SW development environment in order to decrease certification cost for future components (particularly SDR)

Industry (Actions C1.X supporting recommendation R5**)**

- [C1.1] Investigate the feasibility of a flexible airborne architecture and enablers such as software defined avionics, and multi-function, multi-mode antennas; and
- [C1.2] Support activities to ensure that a flexible airborne architecture evolves to ease the cost and time of certification and readily accommodate new applications and technologies.