Enabling the next generation in air traffic management with AeroMACS

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1. Introduction

AeroMACS, a new technology for fixed and mobile ground communications

Advances in telecommunication technologies are ushering in a fundamental shift in air traffic management (ATM), aimed at reducing flight delays, airport congestion and the environmental impact of flying, while increasing air safety and security. These improvements will come from the development of new applications and the evolution of existing ones for the exchange of data between aircraft and the ground and within elements of the ground infrastructure. This is a gradual and yet momentous move toward a better working environment for staff and a better flying experience for passengers. To make it a reality, the communication links between aircraft and ground, and within elements in the ground infrastructure have to retain the robustness, security, and reliability that they have today, but increase their bandwidth and improve their performance and efficiency. Today that evolution in ATM is crucially limited by narrowband links to the aircraft and by expensive wireline ground connectivity.

AeroMACS, the Aeronautical Mobile Aircraft Communication System, is a new wireless air interface that provides aircraft and ground infrastructure with the broadband connectivity needed to support a new generation of aircraft and an expanding range of ATM applications. It operates in the Aeronautical Mobile (Route) Service (AM[R]S) band (5091–5150 MHz) for airport ground applications for safety and traffic control worldwide, allocated by the ITU at the World Radiocommunication Conference 2007 (WRC-07). AeroMACS is one of the three core technologies of the Future Communication Infrastructure (FCI) framework, which combines the vision of the FAA's Next Generation Air Transportation System (NextGen) in the US and Europe's Single European Sky ATM Research (SESAR).

AeroMACS benefits extend beyond a higher throughput in ground communications. The technology has multiple advantages over currently used wireless solutions: quality of service (QoS) functionality to optimize traffic management; scalability and interoperability to support global deployments across aircraft types and airports; security and privacy to protect passengers and the air system; and a standards-based solution using WiMAX, a technology based on the IEEE 802.16 standard that relies on a competitive vendor ecosystem expected to reduce costs over proprietary solutions.

The standardization process is nearing completion and the regulators are finalizing spectrum policy at the country level. AeroMACS trials are under way in multiple European countries, the US, China and Japan. Initial commercial deployments are expected to begin in 2016, with large airports in North America and Western Europe taking the lead. During subsequent years, AeroMACS deployments will spread to additional airports and to new aircraft models that have more demanding data communications requirements. Eventually, the technology will become ubiquitous in airports and aircraft. The pace of adoption will largely depend on how quickly potential AeroMACS stakeholders – aviation authorities, air carriers and airports – can commit the financial and operational resources needed to support the next-generation ground ATM applications worldwide.

This first paper presents an overview of AeroMACS: the technology, the standardization efforts that define it, the applications and business model that it will enable, and the ecosystem that will provide the foundation for its success. A follow-on paper will explore the host of supported applications which AeroMACS networks will enable and how they will benefit its stakeholders.

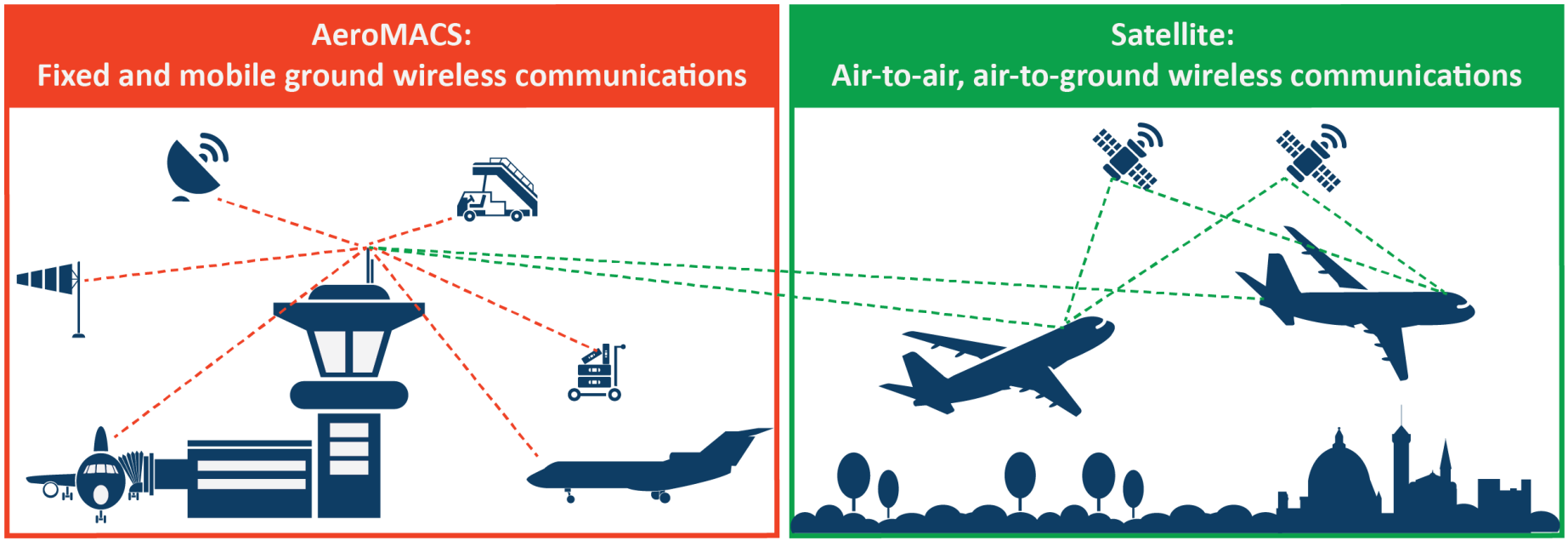
2. The role of AeroMACS in air traffic management

Sharing the benefits among the aviation stakeholders

AeroMACS is the technology that the air traffic industry and regulatory agencies have selected to provide broadband wireless communications for the next generation of ATM in the ground domain of the air transport system – that is, within airport infrastructure and in aircraft on the ground. While the aircraft is in the air, communication between the ground and aircraft will continue to rely on existing VHF Digital Link (VDL) and future L-band satellite systems. As the aircraft lands, it will establish a connection to the AeroMACS ground network to exchange data with ground infrastructure and to use ATM applications.

Operating in the 5 GHz band, AeroMACS supports both mobile and fixed connectivity. Mobile links primarily connect aircraft to airport ground infrastructure, but they could also serve vehicles and staff that operate within the airport area. Where regulation allows, fixed links could connect with surveillance cameras, multilateration equipment, gate and ground operations tracking and control devices, remote transmitter/receivers (including weather sensors), and other services.

Although the AeroMACS technology can support a wide range of applications, the ITU spectrum allocation is specifically for airport-based applications for traffic management, airport operations, safety and regularity of flight. The specific limitations are bound to vary across countries as regulators define local rules on spectrum use.



The AeroMACS ecosystem includes multiple players, whose shared commitment is necessary to ensure the successful use of the technology:

- **Aviation authorities**, to ensure that air traffic, security and safety management complies with regulations.
- **Airports**, to support airport operations and applications mandated by the regulators.
- **Air carriers**, to support air traffic, security and safety applications on aircraft, and carrier-specific applications.
- **Network operators**, to operate AeroMACS networks in airports. Aviation authorities, airports, airlines, telecom service providers or other entities may act as network operators.
- **Equipment vendors and service providers**, to provide the equipment for network infrastructure, fixed terminals and aircraft; network planning solutions; applications and management tools to operate AeroMACS networks.

3. Why AeroMACS?

Bringing reliable, secure broadband connectivity to ATM

AeroMACS adoption in the aviation community reflects a compelling need to establish a new framework for ATM, matched by the good fit that AeroMACS provides in meeting next-generation requirements.

The existing ATM ground communications infrastructure has severe performance, scalability and capacity limitations that upgrades to the current system can no longer address. It relies on a combination of narrowband spectrum allocations and wireless technologies, with bandwidth limitations that force ATM to use switched voice and paper-based communications, instead of more efficient data applications. Carriers, airports and aviation authorities are not able to benefit from precious data for traffic management or analytics that they can collect, but find it difficult to use or share.

Vendor support for AeroMACS		
Cisco	Honeywell	Siemens
Exelis	Indra	Telrad
Gemtek	ITT	Thales
General Electric	Rockwell Collins	Selex
Harris	Saab Sensis	
Hitachi	Sequans	

With the introduction of new aircraft models, equipment vendors and airlines have started to develop advanced applications that use the more accurate and detailed information that becomes available. The communications requirements escalate, but the new applications open the opportunity to improve ATM, relieve traffic congestion, reduce delays, minimize the environmental impact of flying, and contain costs.

To reap these benefits, the aviation industry has to move beyond legacy systems that have shown remarkable longevity and reliability. Transitioning to a new system requires difficult financial and operational decisions. Initially the new technology will have to coexist with the existing ATM systems, and all the stakeholders have to commit and contribute to creating an efficient, end-to-end ATM framework.

AeroMACS has many features that will facilitate this transition. It is based on WiMAX, a technology that has been widely deployed commercially, both in public networks to provide fixed and mobile broadband connectivity, and in vertical markets – notably in the utilities, oil and gas, and transportation sectors. WiMAX combines state-of-the-art performance and advanced functionality, such as QoS, with the reliability and maturity that are crucial requirements in the aviation environment.

AeroMACS inherits WiMAX's proven performance levels, and a well-developed vendor and service provider ecosystem. Many of these companies are actively developing interoperable equipment and solutions specifically geared to aircraft-to-ground and ground-to-ground ATM applications, and for use in the AM(R)S band.

For an aviation industry long accustomed to unyielding and often expensive proprietary solutions, AeroMACS has been greeted with tremendous anticipation for a more flexible and cost-effective adoption. Airlines will be able to select aircraft equipment from multiple vendors that will work at any airport with an AeroMACS network. Similarly, airports will be able to support a wide range of devices to connect to the network for ground applications that may have embedded AeroMACS modules and that are likely to be provided by an equipment vendor different from the one supplying the network infrastructure (i.e., base station transceivers).

AeroMACS benefits to the aviation industry
Standard-based solution: WiMAX Forum profile based on IEEE 802.16-2009.
Global spectrum allocation: AM(R)S band (5091–5150 MHz), with 5 MHz channels, OFDMA modulation (QPSK, QAM16, QAM64), TDD.
Dedicated spectrum band: Spectrum allocations reserved to aviation applications eliminates interference from co-located networks and contention with other devices, which affects heavily used Wi-Fi and cellular networks that are shared with other users.
Broadband IP-based wireless connectivity: 2–10 Mbps average downlink data rates, up to 5 km range, supporting data, voice and video applications.
Efficient use of network and spectrum resources: QoS enables networks to prioritize traffic flows, manage mission-critical traffic, and promote coexistence of multiple applications and traffic flows with different requirements and priority levels.
Cost-effectiveness and quick installation: Low cost to install and maintain compared to wireless technologies that require line of sight (LOS), and to wireline links that require expensive and time-consuming trenching.
Security and privacy: AAA (PKMv2, EAP), encryption, digital certificates (ITU.T X.509, AES), and VPN supported.
Interoperability and equipment certification: AeroMACS profile (EUROCAE, RTCA, WiMAX Forum); CRSL (WiMAX Forum); SARPs* (ICAO); FFF standards* (AEEC); MASPS* (EUROCAEMOPS (RTCA, EUROCAE); PICS; Technical Manual* (ICAO). * = Ongoing
Market competition: WiMAX ecosystem with multiple vendors ensures vendor support, interoperability, and cost savings.

The WiMAX Forum support for AeroMACS

- Define the network and air-interface requirements for WiMAX and, more specifically, for AeroMACS, by developing system profiles.
- Develop and manage a certification program to ensure equipment conformity to AeroMACS requirements and interoperability across certified equipment solutions.
- Collaborate with the aviation industry to finalize standardization processes, through partnerships with the FAA, EUROCAE, EUROCONTROL, ICAO and RTCA.
- Encourage country regulators to allocate spectrum for the AM(R)S band in their markets according to the ITU recommendations.
- Support WiMAX and AeroMACS technology to speed up adoption and expand the ecosystem.

4. Drivers to adoption

A transition to richer, more effective applications

The limited data capacity of current ground communications networks places a severe and undue burden on applications and their functionality in the aviation industry. Existing networks support the basic functionality necessary to manage air traffic, but a shift to a broadband communications platform, such as that supported by AeroMACS, enables the aviation industry to increase the richness, scope and effectiveness of current applications, and to launch new ones. The figure in the next page shows examples of potential applications that require AeroMACS or will benefit from it.

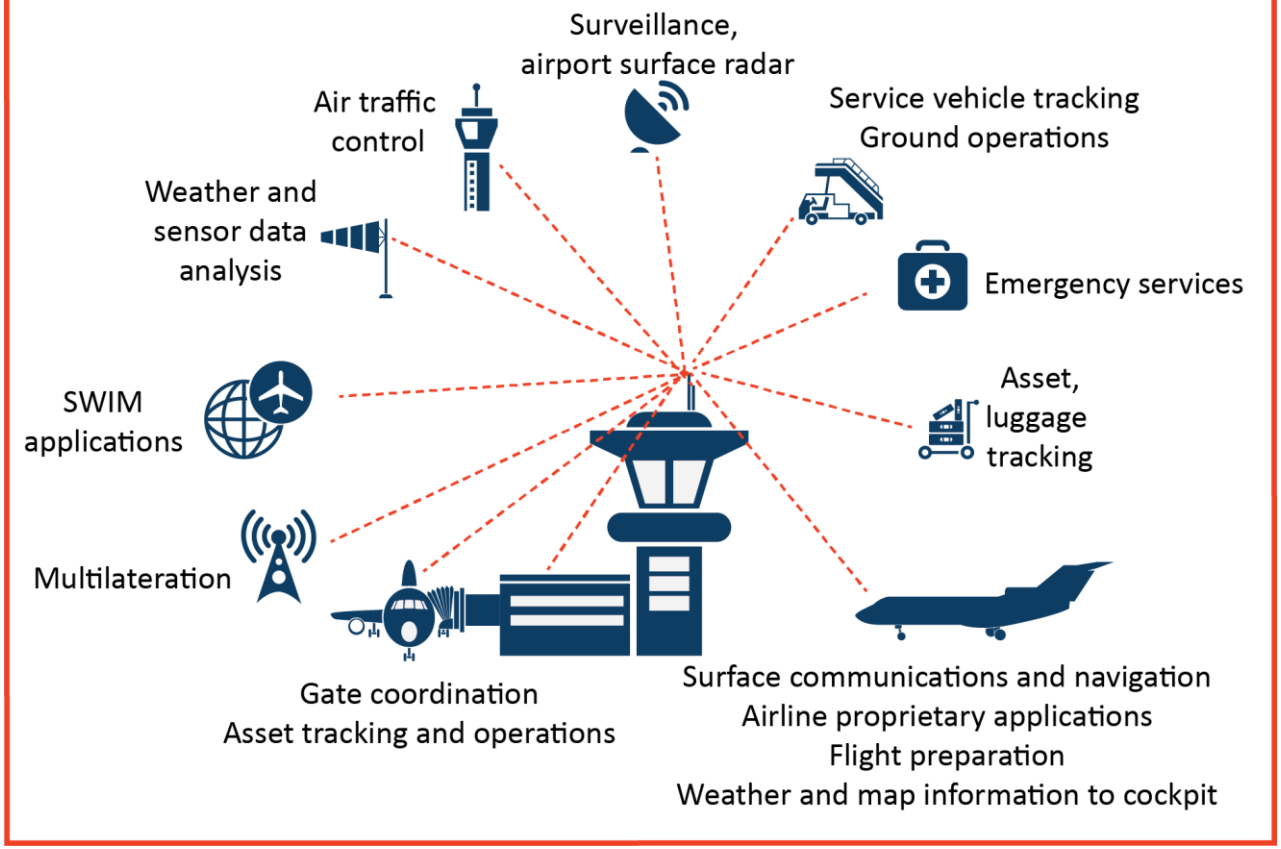
Within the ground domain, AeroMACS makes it possible to connect to a larger number of fixed infrastructure elements (e.g., sensors, weather stations, and radars), and mobile assets (e.g., service and emergency vehicles) and to collect and continuously update more detailed information. For instance, an AeroMACS network can use QoS to give priority to mission-critical and real-time applications (e.g., aircraft ground navigation, or emergency calls).

The advantages of AeroMACS in ground-to-aircraft communications are bound to be even greater, because wireline communications are not a viable alternative and the current wireless networks have extremely limited bandwidth. Broadband wireless connectivity is necessary to support new or expanded applications – for example, to accurately guide aircraft moving on the ground, transmit detailed real-time data, and give pilots up-to-date information on their flight, maps or weather forecasts. A broadband connection capable to track the position of aircraft, mobile devices and fixed devices on the ground and transmit detailed real-time data increases the reliability and speed of surface communications, so that applications can be automated, freeing limited and expensive human resources.

Increased capacity and higher bandwidth will promote the introduction of new services too. For instance, health emergency services in aircraft today have to rely on voice or narrowband data. Video connectivity enables remote

preliminary assessment of health emergencies to determine the appropriate response of medically skilled personnel, as well as initial, time-critical actions the crew can perform. Similarly, remote mechanical diagnostics allows airlines to uncover problems before the aircraft reaches the gate and ensure the needed resources are available.

Examples of potential AeroMACS applications



5. Emerging business models

Sharing costs among stakeholders makes next-gen ATM cost-effective

Deploying new technologies is often expensive, especially because the legacy ones are still operative during the transition. In the aviation industry, where aircraft and other infrastructure elements have a long life span, that transition phase is long.

Stakeholders recognize the financial and operational advantages of AeroMACS and of the platforms, such as NextGen and SESAR, that it enables. But the question they raise most frequently is whether the overall aviation industry can afford AeroMACS deployments.

AeroMACS and the new ATM platforms will be successful only if all stakeholders, worldwide, embrace them. Even if every airport had an AeroMACS network installed, the system would be of limited value if airlines did not install AeroMACS equipment on their aircraft. Similarly, if AeroMACS equipment were to become ubiquitous aboard aircraft, it would be of little value if only a small fraction of airports supported it.

A mutual dependency of this type could trigger a wait-and-see attitude, with each stakeholder waiting for the others to implement AeroMACS first. However, the foundation for global adoption has already been set by the harmonized spectrum allocation and standardization process, along with vendors' commitment to interoperability.

Not surprisingly, aviation authorities are leading the way in most countries. They see AeroMACS as a pivotal tool in the evolution toward improved safety in air transportation. As a result, we expect airport-based AeroMACS infrastructure (i.e., network and devices) to become established first in airports and then gradually in the aircraft. Because of the high cost and complexity of adding new equipment in the aircraft, this is a sensible transition path to keep costs under control.

At the same time, the airlines' commitment is necessary to ensure that strong business models that benefit all stakeholders emerge. The success of AeroMACS as an enabler of ATM depends on network effects – i.e., on adoption on both ground and aircraft. The financial viability of AeroMACS is similarly predicated on finding a good framework to share the cost of building and operating the infrastructure, and to allocate network resources.

Different models are likely to work in different regions, due to differing regulatory regimens and ecosystem value chains. For instance, in some countries airport authorities have a major role in managing air traffic, while in others the aviation authorities have a more active role. Airlines may have an active interest in controlling and owning the AeroMACS infrastructure, but only in airports where they have a strong presence.

The table below summarizes the key issues of the ongoing assessment of the business case. Spectrum allocations allow multiple AeroMACS networks to coexist in the same airport, and many airports are likely to host multiple AeroMACS networks, as this approach provides a competitive environment for price and performance of AeroMACS services and access flexibility.

In addition to competition, establishing a framework that facilitates and encourages resource sharing is another prerequisite to the success of AeroMACS. Aviation authorities, airports, airlines, and companies providing services to them are bound to find ways to share the AeroMACS airport

infrastructure, as it would be prohibitively expensive – and ultimately inefficient – for each shareholder (e.g., each airline) to build its own network.

The ownership of airport AeroMACS networks is a major topic of discussion. Aviation authorities may have an interest in controlling the AeroMACS infrastructure, but may not have the necessary funding or may want to exercise a less hands-on role. As a result, they may delegate their role to airport authorities or independent contractors, which could be telecommunications operators or other service providers.

Similarly, airport authorities may see ownership and control of the AeroMACS infrastructure as crucial to fulfilling their role in ATM, but prefer not to be directly involved with the ownership or day-to-day operations of the network.

At the same time, airlines may be unwilling to rely on a network they see as the monopoly of the airport authority, or that is controlled by one of their competitors. In these environments, multiple networks or ownership from a neutral third party may be instrumental in gaining a strong commitment from all the stakeholders. In some locations, an air carrier may want to build its own network in a hub airport, but elsewhere lease network access from an AeroMACS operator.

As AeroMACS moves from the current trial phase to full deployments, multiple business models are currently being evaluated. Because all stakeholders have an essential role in making AeroMACS a success, business models that provide equitable access to all players will prevail.

AeroMACS network operators	AeroMACS tenants
Single operator to keep costs down and optimize network utilization; or **multiple operators** to provide competition and flexibility.	**Multiple tenants** to share costs and to enable all stakeholders to benefit from network.
Operate, deploy and possibly own the network. May or may not be a tenant.	Run applications that may be proprietary or shared with other stakeholders.
Possible entities: - Aviation authorities - Airport authorities - Airlines - Telecommunication operators, other service providers	**Target tenants:** - Aviation authorities - Airport authorities - Airlines - Aviation service providers
Business case: upfront investment in network and ongoing operating expenses; revenues from AeroMACS tenant and/or have control of network for own applications.	**Business case:** access to network without an initial financial and operational investment, treating AeroMACS access as an ongoing opex item.

Operator or tenant?

- Regulation may require or exclude some entities to operate AeroMACS networks.
- Assessment by airports and airlines of the financial and operational advantages of owning, building and controlling the infrastructure.

6. From trials to deployments

The AeroMACS timeline

AeroMACS is getting ready for commercial deployments. The core standardization work and spectrum allocation have been completed, with an industry-wide agreement that WiMAX-based AeroMACS will be the technology enabling the future ATM framework. We are now in the middle of a busy trial phase, driven by aviation agencies, and conducted in collaboration with equipment vendors, service providers, airports and airlines. Trials such as those conducted in France at the Toulouse airport, in the US at the Cleveland Hokins International Airport, and in the Sendai test bed in Japan have confirmed the potential of AeroMACS. Vendors and aviation authorities expect to see early deployments by 2016, mostly in large airports in the US and Europe. The table below summarizes the stages of AeroMACS development, from the initial spectrum allocation at WRC-07 to the expected full deployment around 2022.

Initial standardization: From 2007	**Trials: 2008-2012**	**Initial deployments: 2013-2016**	**Full deployment: 2022 and beyond**
WRC-07 spectrum allocation in the AM(R)S band worldwide. Selection of WiMAX, based on the IEEE 802.16-2009 standard, as the air interface and network technology for AeroMACS. Definition of requirements and technology assessment, resulting in further standards definitions (e.g., AeroMACS profile, MOPS, PICS, CRSL).	Definition of country-based regulation (channelization, supported applications and allowed services, entities granted access to spectrum). Further standardization activity on SARPs; Form Fit and Function (FFF); MASPS; and Technical Manual. Definition of the certification process by national multi-national agencies. Trials at airports in Europe, US, China and Japan to test performance and propagation, assess impact of interference, and test applications. Initial assessment of business models and cost-effectiveness of AeroMACS.	Commercial equipment available from multiple vendors, for both ground infrastructure and aircraft installation. Deployments to start mostly in large airports in the US and Europe. In the US, the initial focus is on ground-to-ground applications ahead of system-wide airline adoption. Development and launch of applications and services within the NextGen and SESAR frameworks that leverage the improved connectivity enabled by AeroMACS. Trials and initial deployments by airlines, starting with new aircraft models with more demanding connectivity requirements.	AeroMACS availability to spread to: - More airports, including medium and small ones. - More countries hosting AeroMACS in their airports. - More airlines installing AeroMACS on their aircraft. The increased availability of AeroMACS will create the economies of scale to reduce network and aircraft equipment and installation costs. More advanced applications to deliver improved performance and robustness, leading to next-generation ATM levels of performance.

7. Implications

Synergy among aviation stakeholders to drive global adoption of AeroMACS

AeroMACS is a key enabler for the new ATM platform. It provides the innovation, scalability and advanced functionality the aviation industry needs to address rising congestion, improve the flying experience and reduce the environmental impact of air traffic, while enhancing profitability. Although existing ATM infrastructure has long played a central role in ensuring air traffic safety and efficiency, upgrades to the old technology are no longer enough to address its limitations; the aviation industry has to adopt new technologies. The industry-wide endorsement of AeroMACS as the next-gen technology for ground communications – fixed for connectivity within the airports, and mobile to connect aircraft to the airport infrastructure after landing -- demonstrates the awareness that change is necessary, as well as the commitment to move forward with the transition.

After the initial standardization and spectrum harmonization efforts, we have entered a second phase. Aviation stakeholders are finalizing AeroMACS features and requirements, vendors are demonstrating interoperability, and trials are assessing the performance of the technology. These efforts are crucial, because the intended stakeholders – aviation agencies, airports and airlines – have voiced a clear preference for the adoption of a standards-based technology that is available globally from multiple vendors and that provides the flexibility and market competition that is common in commercial-off-the-shelf (COTS) equipment, but not yet common in the aviation industry. Wide rollouts will require a few years, as all stakeholders will have to play their individual roles in building the end-to-end AeroMACS infrastructure.

This carefully planned approach is necessary to ensure a smooth and safe transition to new applications and services that take advantage of new technologies and richer data. On the ground, AeroMACS will drive a shift from voice, paper, and narrowband communications to data. New applications will be able to leverage more granular information about traffic, weather, assets and operations. AeroMACS is capable of higher data rates, increased reliability and greater security of the links; it also makes available tools such as QoS to prioritize and manage traffic. With these advantages, AeroMACS will not only enable an efficient use of the spectrum assets available, it will also sustain an environment in which applications can coexist within the same network, and in which stakeholders will be able to share the costs and benefits of the new ATM platform.

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Glossary

AAA	Authentication, authorization, and accounting
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Aircraft Communication System
AES	Advanced encryption system
AMRS	Aeronautical Mobile (Route) Service
ATC	Air traffic control
ATM	Air traffic management
CRSL	Certification Requirements Status List
EAP	Extensible Authentication Protocol
EUROCAE	European Organisation for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FFF	Form, fit and function
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet protocol
ITU	International Telecommunication Union
LOS	Line of sight
MASPS	Minimum Aviation System Performance Standards
MOPS	Minimum operational performance standards
NextGen	Next Generation Air Transportation System
OFDMA	Orthogonal frequency division multiple access
PICS	Protocol Implementation Conformance Statement
PKMv2	Privacy and Key Management Protocol Version 2
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quadrature phase-shift keying
RTCA	Radio Technical Commission for Aeronautics
SARPs	Standards and Recommended Practices
SESAR	Single European Sky ATM Research
SWIM	System Wide Information Management
TDD	Time division duplex
VDL	VHF Digital Link
VPN	Virtual private network
WiMAX	Wireless Worldwide Interoperability for Microwave Access
WRC	World Radiocommunication Conference

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