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C-Band Airport Surface Communications System Standards Development

Phase I Final Report

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December 2010

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Preface

This National Aeronautics and Space Administration (NASA) Contractor Report summarizes and documents the work performed to develop system standards for the proposed C-band (5091- to 5150-MHz[1]) airport surface communications system. This report documents the work done in Phase I. It was delivered to NASA on December 19, 2009, under the fiscal year 2009 project-level agreement.

This work was completed under the NASA Aerospace Communication Systems Technical Support (ACSTS) contract, based on direction provided by the Federal Aviation Administration project-level agreement (PLA FY09_G1M.02-02v1) for "New ATM Requirements—Future Communications" as a follow-on to the FAA/EUROCONTROL (European Organisation for the Safety of Air Navigation) Cooperative Research Agreement (Action Plan 17 (AP−17)), commonly referred to as the Future Communications Study.

[1]With a possible future extension into the 5000- to 5030-MHz band, pending a decision at the World Radiocommunications Conference in 2012.

Executive Summary

ES.1 Introduction

This report is being provided as part of the NASA Glenn Research Center Aerospace Communication Systems Technical Support (ACSTS) Contract (NNC05CA85C), Task 7: "New ATM Requirements—Future Communications, C-Band and L-Band Communications Standard Development."

Task 7 is separated into two distinct subtasks—each aligned with specific work elements and deliverable items identified in the Federal Aviation Administration's (FAA) project-level agreement (PLA) and with the FAA fiscal year 2009 New ATM Requirements—Future Communications Project and spending plan for these subtasks.

The purposes of subtask 7–1, and the subjects of this report, are the definitions of the concepts of use (ConUse), high-level system requirements, and architecture; the performance of supporting system analyses; the development of test and demonstration plans; and the establishment of operational capability in support of C-band aeronautical data communications standards to be advanced in both international (International Civil Aviation Organization, ICAO) and national (RTCA) forums.

The future C-band (5091 to 5150 MHz[1]) airport surface communication system is referred to as the Aeronautical Mobile Airport Communications System (AeroMACS).

Assumptions and constraints for this report follow:

- The 5091- to 5150-MHz spectrum allocation for AeroMACS use at the World Radiocommunications Conference (WRC–2007) is provisioned only for use on the airport surface. This allocation is within the aeronautical mobile (route) service (AM(R)S) band. Therefore, AeroMACS applications are constrained to mobile applications on the airport surface. This is interpreted to include communications for nonmobile (i.e., fixed) applications provisioned within a mobile AeroMACS network that support the safety and regularity of flight.
- The proposed AeroMACS is assumed to provide an increase in overall air-to-ground (A/G) communications systems capacity by utilizing the new spectrum (i.e., in addition to existing very high frequency, VHF).
- The scope of this ConUse and requirements report includes airport surface A/G air traffic control (ATC) communications and ground-to-ground (G/G) communications.
- AeroMACS will be designed specifically for data communication.
- This report assumes that the data communications system developed as part of the FAA Data Communications Program (Data Comm) will precede an AeroMACS implementation and deployment.
- Although some critical services could be supported, AeroMACS systems will also target noncritical services, such as weather advisory and aeronautical information services implemented as part of an airborne System Wide Information Management (SWIM) program.
- AeroMACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the C-band. Additional interference research and testing will determine if any operational constraints are to be imposed, such as limiting the number of users, the time of the day, the duration, and so on.

ES.2 ConUse

A process recommended in the "National Airspace System: System Engineering Manual" (SEM, Ref. 1) was adopted as a guide in developing ConUse and requirements for the proposed system. Figure ES–1 summarizes the steps.

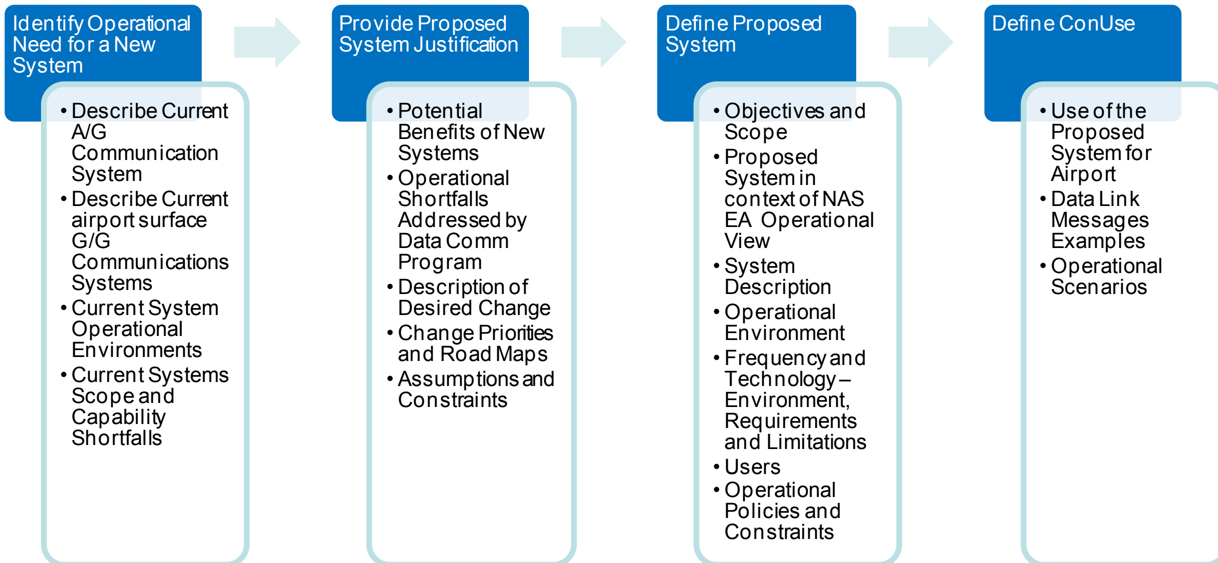

Figure ES–1.—ConUse development process. Acronyms are defined in Appendix A.

ES.2.1 Identify Operational Needs for a New System

Operational needs for a new system are supported by describing the current system and its associated problems and capability shortfalls. “System Requirements Document, Next Generation Air/Ground Communications (NEXCOM)” provides a good description of the FAA’s current analog A/G voice communications system used for ATC (Ref. 2).

The Next Generation Air Transportation System (NextGen) concept of operations (ConOps) summarizes the current attributes (and associated constraints) of the voice-based A/G communications system as follows (Ref. 3):

- Limited data communications for air traffic management (ATM) and operational control
- Limited access to real-time weather and aeronautical data
- Voice communications routine for ATM
- Analog voice
- Analog weather information display systems
- A/G and G/G communications
- Loss of communications due to beyond line-of-sight (BLOS) aircraft position (e.g., over the ocean)
- Individual ground systems for each information type brought to the flight deck
- Point-to-point aircraft communications based on ATC sectors

There are several principal shortcomings of the current A/G voice communications system, including lack of automation, limited or no data communications availability, aging infrastructure, technology limitations, and spectrum saturation. The resulting operational problems, if not addressed, could lead to service degradation and limit the introduction of new or expanded services. These, in turn, could potentially compromise safety of operation and increase operating costs. Saturation of spectrum is the problem specifically mitigated by the introduction of a new C-band system (AeroMACS); the other operational problems would also be mitigated with AeroMACS.

Current G/G communications on the airport surface are conducted predominantly over a combination of wire and optical fiber cabling and a limited number of point-to-point line-of-site radio links.

The limitations imposed by the current G/G communications infrastructure could result in restrictions in the deployment of new ATM services, resulting in the following service limitations (Ref. 4).

- Limited ATM (e.g., traffic) information on the flight deck
  Limited data shared among stakeholders for collaborative decision making (CDM) processes
- Information sharing in support of operational security performed manually instead of electronically
- Not all stakeholders able to access data they need
- Stakeholders unable to use custom data sources

ES.2.2 Provide Proposed System Justification

Rather than being a National Airspace System (NAS) service itself, G/G and A/G communications are enablers of NAS services. It is important to note that the FAA's "Final Program Requirements for Data Communications" (Ref. 5) recognizes that "the scope of the mission shortfalls identified herein [is] broader than will be addressed solely by a data communications capability." Because of the limitations and constraints of implementing data communications using very high frequency digital link (VDL) Mode 2 over a congested aeronautical VHF band, the FAA's Data Comm Program will focus principally on implementing the most critical air traffic services (ATS). This will provide opportunities for AeroMACS systems to augment data communications on the airport surface by enabling communications of less critical and essential ATSs to address the shortfalls listed. Even though each of the shortfalls listed above are meant to be addressed to some extent by Data Comm using VDL Mode 2, there are opportunities to overcome these shortfalls to an even greater extent during the later program segments of Data Comm (e.g., late Segment 2 and Segment 3) using link technologies such as AeroMACS with greater bandwidth capabilities, which could augment the benefits already attained through the earlier VDL Mode 2 Data Comm segment implementations (i.e., Segments 1 and 2) by providing a broader scope of services.

ES.2.3 Define Proposed System and ConUse

Some FAA objectives defined in the FAA's NextGen portfolio are based on the requirement to support future air traffic growth. AeroMACS will be designed and developed to help meet those objectives in part by expanding the data communications capacity in the airport surface domain. Global harmonization is being ensured by developing the proposed AeroMACS component of the FRS as a collaborative effort of the U.S. and European partners.

As recommended by the Future Communications Study (FCS) technology assessment, the proposed airport surface communications system (i.e., AeroMACS) is based on the Institute of Electrical and Electronics Engineering (IEEE) 802.16 standard and its extension, IEEE 802.16e-2005 (Ref. 6), and will be implemented in the aeronautical C-band (5091 to 5150 MHz). A new standards profile for airport applications is currently being developed within an RTCA special committee (SC–223) to operate in the C-band and make use of the scaling properties inherent in the IEEE 802.16e standard.[2]

The proposed AeroMACS could provide supplemental means to the ATC communications required by the operating rules (e.g., VHF voice communications) in continental airspace (albeit on the airport surface) and will adhere to the data link characteristics noted in the "Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace (Continental SPR Standard)" (Ref. 7).

This report focuses on the ATS and advisory data services that are defined in the communications operating concept and requirements (COCR) and are not expected to be provided by Data Comm through Segment 2. The following list shows the proposed candidates for AeroMACS:

- Flight information services
  - Data link operational terminal information service (D–OTIS)

[2]Specifically, IEEE 802.16-2009 will provide the basis of ongoing profile selection.

    - Data link surface information and guidance (D–SIG)
    - Flight plan consistency (FLIPCY)
    - System access parameters
    - Pilot preferences downlink (PPD)
- Weather advisory service
    - Data link significant meteorological information (D–SIGMET)
- Emergency information service
    - Urgent contact (URCO)—if in conjunction with other more routine services

Additional data services that may be provided via AeroMACS may be identified as NextGen and Single European Sky ATM Research (SESAR) progress. In addition, an AeroMACS could provide the means for A/G data transfer on the airport surface to support the FAA SWIM program.

Table ES–1 lists the operational scenarios and concepts envisioned for the midterm NextGen airport surface flight phase. Although most, if not all, of these concepts are currently envisioned for Data Comm, they are technology independent and, thus, equally valid for an AeroMACS implementation.

TABLE ES–1.—NEXT GENERATION AIR TRANSPORTATION SYSTEM (NextGen) MIDTERM OPERATIONAL CONCEPTS FOR THE AIRPORT SURFACE PHASE

Phase of flight	NextGen midterm communications operational concept (from Ref. 8)
Flight planning	Access to flight planning information will be available to authorized users via a secure network and will include a publish/subscribe capability so that users can receive automatic updates when conditions change along the proposed flight path.
Push back, taxi, and departure	As the time for the flight approaches, the final flight path agreement will be delivered as a data message to pilots who access the agreement before beginning the flight.

Table ES–2 illustrates the potential operational use of the proposed AeroMACS based on the COCR services previously identified as potential applications (Ref. 9).

TABLE ES–2.—USE OF THE PROPOSED AeroMACS IN THE AIRPORT FLIGHT DOMAIN
[Acronyms are defined in Appendix A.]

Operational services	Airport domain phases			
	Predeparture airport domain	Departure taxi airport domain	Arrival airport domain	Arrival taxi airport domain
Flight information services	D–OTIS D–RVR D–SIG D–SIGMET	D–OTIS D–RVR D–SIG D–SIGMET	D–OTIS D–RVR D–SIG	D–RVR D–SIG
Flight position, flight intent, and flight preferences services	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE
Emergency information service	URCO	URCO	URCO	URCO
Services suitable for Airborne SWIM (generally weather advisory and aeronautical information services)	Aviation Digital Data Service (ADDS), AWOS Data Acquisition Service (ADAS), Expanded Terminal and Tower Data Service, General Information Message Distribution Service, Information Display System (IDS) Data Service, NextGen Network Enabled Weather (NNEW) service,[a] NOTAM distribution service, TMA Flight Data Service, WARP/WINS NEXRAD service			

[a]It is possible that the information provided through the NNEW service could range from advisories for routine forecasts though safety-critical transmission of certain hazardous weather warning messages, which might limit the extent to which this service could be provided over commercial links. This requires further investigation.

ES.3 AeroMACS System Requirements

A middle-out approach was adopted to identify the high-level requirements applicable to AeroMACS. In this approach, the top-down functional requirements were derived from the ConUse and the associated functional capabilities. In parallel with that process, a bottom-up assessment of existing requirements in relevant documents such as the NAS SR–1000 (Refs. 10 and 11), the COCR (Ref. 12), and Data Comm performance requirements and their applicability to the current needs for AeroMACS was performed.

AeroMACS could provide a communication link to transfer surveillance and weather information, facilitate flight and resource management, enhance CDM, and enable the exchange of aeronautical information in the future NAS. The tables in Appendix B document the select RTCA NAS ConOps (Ref. 13) found applicable to the proposed AeroMACS.[3]

The desired AeroMACS functional capabilities have been derived from the identified NAS ConOps presented in Appendix B and mapped to (1) high-level aeronautical A/G and G/G communication functions and (2) specific COCR ATS services. Table ES–3 lists the AeroMACS high-level functional capabilities and presents this mapping. This encompasses a top-down approach to the development of functional requirements.

TABLE ES–3.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 13)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	S-1; S-3; S-4; W-2; W-3; W-8; W-9; W-10; W-12; W-13; W-14; W-15; FM-1; FM-6; FM-8; FM-12; FM-14; FM-15; FM 17; FM-23; A-2; A-6; A-12; A-15	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS D–RVR D–SIG D–SIGMET FLIPCY WAKE PPD
Support addressed communication for delivery of information to individual and multiple users	S-1; W-10; FM-6; FM-8	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS D–RVR D–SIG D–SIGMET FLIPCY PPD
Support broadcast communication for delivery of information to multiple users	S-1; S-4; W-2; W-3; W-12; W-14; FM-8; A-12	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS D–RVR D–SIG D–SIGMET WAKE
Support delivery of real-time information in a timely manner	S-1; S-3; W-16; FM-1; FM-2; FM-9; FM-10; FM-12; FM-15; FM-18; FM-25; FM-26; RM-3; RM-7; A-4; A-7; A-11		D-RVR D-SIG D–SIGMET FLIPCY WAKE PPD

[3]Although the RTCA document describes the NAS evolution in terms of three time periods—near (up to 2005), mid (2005 through 2010), and far (beyond 2010)—most concepts identified in the document are found applicable for the proposed AeroMACS, which will necessarily be implemented beyond 2010.

TABLE ES–3.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 13)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable demand, periodic, and event communication	S-1; W-12		All services
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness	S-3; W-2; W-3; A-1; A-5		All services
Support multiple quality-of-service (QoS) provisions			All services
Support authentication of users and controlled access to NAS information (security)	W-1		All services
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground users	S-1; FM-12; FM-14; FM-20; A-11		
Avoid single points of failure	RM-6		All services
Provide a scalable solution			All services
Provide standards-based solution			All services

High-level AeroMACS functional requirements were then constructed from the functional capabilities as shown in Table ES–4.

TABLE ES–4.—AeroMACS HIGH-LEVEL FUNCTIONAL REQUIREMENTS

System functions	AeroMACS high-level functional requirements
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	The system shall enable ground-to-air (G/A) communication for fixed-to-mobile users. The system shall enable G/A communication for mobile-to-mobile users. The system shall enable A/G communication for fixed-to-mobile users. The system shall enable A/G communication for mobile-to-mobile users.
Support addressed communication for delivery of information to individual and multiple users.	The system shall support addressed communications to individual users. The system shall support addressed communications to multiple users.
Support broadcast communication for delivery of information to multiple users.	The system shall support broadcast communication to multiple users.

TABLE ES–4.—AeroMACS HIGH-LEVEL FUNCTIONAL REQUIREMENTS

System functions	AeroMACS high-level functional requirements
Support delivery of real-time information in a timely manner.	The system shall support delivery of real-time information in a timely manner.
Enable demand, periodic, and event communication.	The system shall enable demand communication. The system shall enable periodic communication. The system shall enable event communication.
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness.	The system shall accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness.
Support multiple QoS provisions.	This functional capability points toward performance requirements.
Support authentication of users and controlled access to National Airspace System (NAS) information (security).	The system shall support authentication of users (security). The system shall support controlled access to NAS information (security).
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground users.[a]	The system shall support FAA ground users. The system shall support non-FAA ground users.
Avoid single points of failure.	The system shall avoid single points of failure.
Provide a scalable solution.	The system shall provide a scalable solution.
Provide a standards-based solution.	The system shall provide standards-based solution.

[a]To support increasing collaboration among NAS users, the proposed system shall accommodate a wide range of NAS users by accepting NAS data from NAS data sources, both internal and external to the FAA. Users may include aircraft, airline operation centers, service providers, FAA users, and other Government agencies.

Although the top-down approach employs the classic "clean-sheet" system engineering process, the bottom-up approach addresses how the AeroMACS fits into the existing environment.

Functions identified in the NAS SR–1000 document—plan flights, monitor flights, control traffic, support flight operations, monitor NAS operations, and plan NAS usage—cut across all the AeroMACS capabilities shown in Table ES–4.

The functional requirements applicable for an AeroMACS operating on the airport surface (shown in Table ES–5) were extracted from the NAS requirements specified in the NAS SR–1000. Unless specifically stated otherwise, these could apply to A/G or G/G communications, for fixed-to-mobile or fixed-to-fixed applications.

TABLE ES–5.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
Plan flights	Evaluate flight conditions	The NAS shall disseminate the status of special use airspace to users. (08760) The NAS shall disseminate weather information to users to support flight planning. (27150) The NAS shall disseminate aeronautical information to users to support flight planning. (27160)
	Manage flight plans	The NAS shall disseminate flight information to users. (00010) The NAS shall disseminate flight plan information to users via external data interfaces.(00410) The NAS shall disseminate flight plan information to users via air-ground data communications. (00970) The NAS shall disseminate flight data summaries to users. (00070) The NAS shall disseminate flight plans to users. (02160) The NAS shall disseminate flight plan clearances to users. (02900)

TABLE ES–5.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
Monitor flights	Collect aircraft navigation information (collect dependent surveillance information)	The NAS shall retrieve actual flight information. (10000) The NAS shall acquire actual flight information from aircraft outside of independent surveillance coverage. (03320)
	Monitor aircraft status	The NAS shall respond to emergency transmission received via radio communications. (12600) The NAS shall respond to emergency transmissions received via data link. (12620) The NAS shall disseminate essential information on missing aircraft. (13130)
	Report (disseminate) aircraft status	The NAS shall display position information, to specialists, for aircraft that were detected independent of aircraft equipage in qualifying aerodromes. (24530) The NAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations. (12820) The NAS shall disseminate aircraft flight information for each controlled aircraft to specialists. (02720) The NAS shall disseminate the current location for each participating aircraft to ATCSCC [air traffic control system command center] Specialists. (10940) The NAS shall disseminate the current location for each participating aircraft to Traffic Management Coordinators. (10980)
Control traffic	Address active aircraft conflicts	The NAS shall disseminate recommended collision avoidance maneuvers to users. (03690)
	Control aircraft	The NAS shall disseminate aeronautical information to users via air-ground data communications. (07440)
	Coordinate traffic control distribution	The NAS shall acquire pilot reports (PIREP). (05530) The NAS shall disseminate weather advisories via direct specialist to pilot communications. (09290)

TABLE ES–5.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
Support flight operations	Manage weather information	The NAS shall maintain communication links adequate to avoid user delay in gaining access. (07090)
		The NAS shall disseminate weather information to users continuously. (07110)
		The NAS shall disseminate current weather effect along the users proposed flight path.(07470)
		The NAS shall disseminate forecast weather in effect along the users proposed flight path. (07480)
		The NAS shall disseminate intensity levels of weather by route of flight to users. (08260)
		The NAS shall disseminate intensity levels of weather by geographic area to users. (08300)
		The NAS shall disseminate weather advisories to users in response to a request. (09300)
		The NAS shall broadcast the latest approved aerodrome conditions on communications media accessible by aircraft on the ground. (09340)
		The NAS shall broadcast the latest approved terminal area conditions on communications media accessible by aircraft on the ground. (09360)
		The NAS shall respond to user requests for weather information from NAS facilities through common carrier communications networks. (09370)
		The NAS shall disseminate selected weather information directly to appropriately equipped aircraft. (09420)
		The NAS shall provide flexible and convenient access to required weather information to users. (19380)
	Operate navigation aids[b]	The NAS shall disseminate navigational accuracy correction values for supplemental navigation systems to users. (17040)
		The NAS shall disseminate correction values for navigational aids to users. (16790)
		The NAS shall disseminate available supplemental terminal navigation guidance information error correction values to users. (14820)

TABLE ES–5.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
Monitor NAS operations	Monitor NAS flight operations	The NAS shall disseminate future delay advisories in effect along the users proposed flight path. (07500)
		The NAS shall disseminate traffic advisories upon user request. (09120)
		The NAS shall provide traffic advisories to aircraft on the surface. (30270)
	Maintain NAS infrastructure	The NAS shall disseminate airway usage information to users. (00030)
		The NAS shall disseminate route usage information to users. (00050)
		The NAS shall disseminate aeronautical information to users via external data interfaces. (07430)
		The NAS shall disseminate aeronautical information per user request. (07130)
		The NAS shall disseminate aeronautical information upon user request continuously. (07340)
		The NAS shall disseminate aeronautical data for a maximum of 8 specified locations per request. (07400)
		The NAS shall disseminate the status of supplemental navigation systems to users. (17010)
		The NAS shall disseminate status of supplemental navigation systems to users. (16770)
		The NAS shall disseminate flow control information to users via external data interfaces. (07920)
		The NAS shall disseminate derived restrictions to the user. (11700)
		The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)
		The NAS shall disseminate terrain information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03900)
		The NAS shall disseminate manmade obstacle information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03940)
		The NAS shall disseminate ground information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (25520)
		The NAS shall disseminate filtered terrain information to users. (25560)
		The NAS shall disseminate filtered ground information to users. (25570)
		The NAS shall disseminate filtered manmade obstacle information to users. (25580)
Plan NAS usage	Plan traffic flow	The NAS shall disseminate preferred route information at least 24 hours prior to it becoming effective. (07280)
		The NAS shall disseminate military air traffic control plans related to national emergencies. (16140)
		The NAS shall disseminate flow control information to users via external data interfaces. (07920)
		The NAS shall disseminate interfacility traffic flow plans. (11970)
		The NAS shall disseminate derived restrictions to the user. (11700)
		The NAS shall disseminate derived alternative courses of action to the user. (11720)
		The NAS shall determine flight restrictions for specific aircraft. (11760)
		The NAS shall disseminate flight restrictions to users. (11770)
		The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)
	Assess traffic flow performance	The NAS shall disseminate reports on equipment performance. (18870)
		The NAS shall disseminate reports on maintenance activities. (18880)
		The NAS shall disseminate reports on equipment repair activities. (18890)

[a]Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 10).
[b]These services are typically provided via satellite communication (SATCOM) but could be provided via a ground-based system.

Performance requirements were derived to define system capabilities based on the developed functional requirements and considering the propagation characteristic of the C-band. This report summarizes the NAS performance requirements found to be relevant to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 10). Note that these are high-level NAS requirements that do not specify how they should be implemented.

Typically high-level requirements are technology independent. Perhaps unique to the development of the AeroMACS requirements is the identification a priori, by virtue of the extensive FCS technology assessment, of the recommended technology by which AeroMACS will be implemented, that is, IEEE 802.16e. This allows the identification and development of quite specific requirements depending on the desired application or service to be provided. The report provides a preliminary approach for identifying and developing AeroMACS requirements in the context of the IEEE 802.16e broadband communications standard, and its characteristics.

Although actual parameters will depend on the architecture of the communication network, the size of the network, and the provisions for redundant communication support, typical performance parameters for the physical and link layer requirements for individual communication services are presented in Table ES–6.

TABLE ES–6.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality of service (QoS) class	Performance parameters	Typical values	Supported by IEEE 802.16e
Low to medium speed point-to-point data link	Backup for sensor cable link (i.e., weather sensor)	nrtPS	Data rate PER Delay Jitter	100 kbps 1.0×10^{-3} 1 sec 100 μsec	Yes
High-speed point-to-point data link	Backbone-linking base station (BS); link to relay gateway node in remote area	UGS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec 100 nsec	Yes
Point-to-multipoint broadcast data	Scheduled broadcast of weather info, NOTAM	nrtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 1 sec <1 μsec	Yes
Point-to-point command and control data	Remote operation of ADS–B ground station	rtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-6} 100 msec <1 μsec	Yes
Command and control network	Operation of surface devices at remote airport	Best effort	Data rate PER Delay Jitter	200 kbps 1.0×10^{-4} 200 msec <10 μsec	Yes
Digital voice network	Provide *N* circuits for ATC or AOC operations	rtPS; ERT–VR service	Data rate PER Delay Jitter	10 kbps × *N* 1.0×10^{-3} 100 msec <100 μsec	Yes
Point-to-point video link	Airport surveillance; robotic vehicle	UGS	Data rate PER Delay Jitter	600 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes

TABLE ES–6.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality of service (QoS) class	Performance parameters	Typical values	Supported by IEEE 802.16e
Basic mobile	Handoff control for voice; low-speed data sessions	UGS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 200 msec <10 µsec	Yes
Multimedia	CDM	rtPS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec <10 µsec	Yes

ES.4 Architectural Description and Initial Test Bed Requirements

The initial AeroMACS system architecture is based on the IEEE 802.16e-2005 communications standard that was recently incorporated into the IEEE 802.16-2009 standard (Ref. 14). The primary mode for operation of an IEEE 802.16e-based system is a point-to-multipoint architecture. The standard is Internet Protocol (IP) based and provides secure connectivity between users and services.

Figure ES–2 depicts a wireless point-to-multipoint system in an airport context.

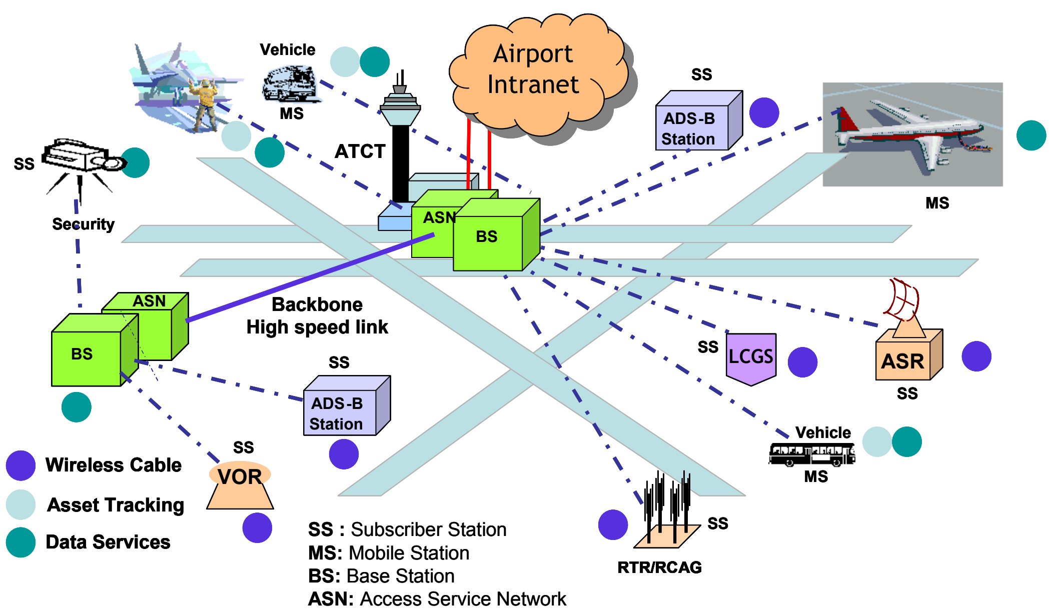

Figure ES–2.—Airport point-to-multipoint communications service. Acronyms are defined in Appendix A.

The system architecture framework can be applied at all airport locations. Deploying an AeroMACS architecture solution at a particular airport requires several tradeoffs to obtain the best performance, including the

- Location and number of base stations (BSs)
- Number of antenna sectors to employ per BS

- Type of backhaul system to support the access service network (ASN)
- Number of subscriber station (SS) terminals that can be serviced by a BS

A design process, including a site survey, coverage model, spectrum analysis, and capacity analysis, provides a formal method of adapting the standard architecture to each airport. Components will vary by airport because of differences in size, layout, and applications.

Table ES–7 lists the parameters that must be included in design tradeoffs for an AeroMACS network.

TABLE ES–7.—AeroMACS NETWORK DESIGN TRADEOFFS

Design tradeoff category	Parameters	Considerations and system tradeoff parameters
Base station (BS)	Mounting placement	Total network data throughput Line-of-sight/non-line-of-sight (LOS/NLOS) coverage area Low-level blockage avoidance
	Number of BS and base transceiver station (BTS) sectors	BS throughput Channel bandwidth and available spectrum
	Multiple input, multiple output (MIMO) order	BS cell-radius requirements Transmitter (Tx) power NLOS and blocked-path performance Multipath mitigation Mobility dropouts Interference to out-of-band users will be decreased by MIMO because total radiated power can be reduced.
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Number and placement of BSs BTS sector and subscriber station (SS) Tx power
	Controlled-pattern antennas	Use beam steering and beam-shape adaptation to increase throughput and avoid interference.
	Frequency band	5091- to 5150-MHz aeronautical mobile (route) service (AM(R)S) band approved during the 2007 World Administrative Radio Conference (WARC 2007). Addition of 5000- to 5030-MHz band is under consideration.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughput over coverage area.

TABLE ES–7.—AeroMACS NETWORK DESIGN TRADEOFFS

Design tradeoff category	Parameters	Considerations and system tradeoff parameters
SS	Mounting height	Avoid low-level structural and temporary blockages.
	MIMO order	Tx power NLOS and blocked-path performance Multipath mitigation Mobility dropout avoidance
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Tx power NLOS and blocked-path performance Multipath mitigation Mobility dropouts
	Frequency band	Controlled and set by BTS sector connection SS must have matching frequency capability.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control the direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughputs over coverage area.
Channel bandwidth	Throughput rate	Highest throughput application sets the minimum channel bandwidth.
	Mobility performance	A wider bandwidth enables better channel equalization and better tracking of multipath variations during mobility.
	Multipath performance	Better equalization of short-path multipath with wider channel bandwidths
	Efficient use of spectrum	Number of channels that fit within the 59-MHz allocated AM(R)S spectrum
	Co-interference	There are fewer options for nonoverlapping frequency reuse in a large number of cells with wide channel bandwidths.
	Hardware limitations	20-MHz channel bandwidth requires fast digital processing and may not be implemented by a particular hardware supplier.
Modulation	Adaptive or fixed	Fixed modulation requires the use of lowest order modulation and lowest data throughput; higher order modulation will cause dropouts during mobility.
	Modulation rates	Use of all specified options maximizes data throughput for fixed and mobile SSs.
	Forward error correction (FEC) coding rate	Use of all specified options maximizes data throughput for fixed and mobile SSs.
BTS power class	Fade margin	Fade margin allowance is set during network design to establish link reliability.
	Co-interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects the signal-to-noise ratio and modulation rate at the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for NLOS operation.
	Power amplifier power-output limitations	Orthogonal-frequency-division multiplexing (OFDM) modulation has a high peak-to-average ratio, making high Tx power expensive.

TABLE ES–7.—AeroMACS NETWORK DESIGN TRADEOFFS

Design tradeoff category	Parameters	Considerations and system tradeoff parameters
SS power class	Fade margin	Fade margin allowance is set during network design to maintain link reliability.
	Co-interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects signal-to-noise ratio and modulation rate from the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for mobile operation.
	Power amplifier power-output limitations	OFDM modulation has a high peak-to-average ratio, making high power expensive.
Media Access Control (MAC) layer and physical layer	Maximum mobile speed	120 km/hr is a value derived from other specified parameters and provides guidance about achievable maximum speed. The communications operating concept and requirement (COCR) is 160 kn (296 km/hr) Institute of Electrical and Electronics Engineering (IEEE) 802.16 specification does not directly support COCR 160-kn requirement. A cost/benefit analysis is needed to assess the benefits of achieving this speed.
	Repeater operation (IEEE 802.16j)	IEEE 802.16j is a potential future amendment to IEEE 802.16 standard BS repeater functionality may provide fill-in coverage in shadow areas with minimal added radiation and interference.
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	C-band AM(R)S spectrum allocation width does not support cost-effective FDD operation.
Quality of service (QoS)	Time delay	Services such as voice, and command and control applications will require guarantees on maximum time delay allowed.
	Time jitter	Services that are sensitive to jitter are to be identified. The use of frame buffering should be considered for each sensitive application.
	Message priority	Safety and reliability requirements will help specify message priorities.
	Scheduling	The scheduling algorithm will take message priority into account along with QoS requirements.
	Message integrity	Security and message integrity guarantees will depend on the type of QoS service flow selected.

ES.5 Test Bed Performance Evaluation

Developing an AeroMACS solution based on the IEEE 802.16e standard requires detailed analysis, simulation, and test measurements on actual airport surfaces. An AeroMACS test bed will aid in validating requirements and act as a prototype deployment. Such a communications, navigation, and surveillance (CNS) test bed has been installed and is running at NASA Glenn and the adjacent Cleveland Hopkins International Airport (CLE) in Cleveland, Ohio. This so-called NASA–CLE CNS Test Bed is designed to implement many of the AeroMACS features and requirements that support modern data communications at an operational airport to help verify the performance of AeroMACS and validate some of the ConUse.

Figure ES–3 shows the placement of the AeroMACS network on Glenn property and the adjacent CLE airport surface.

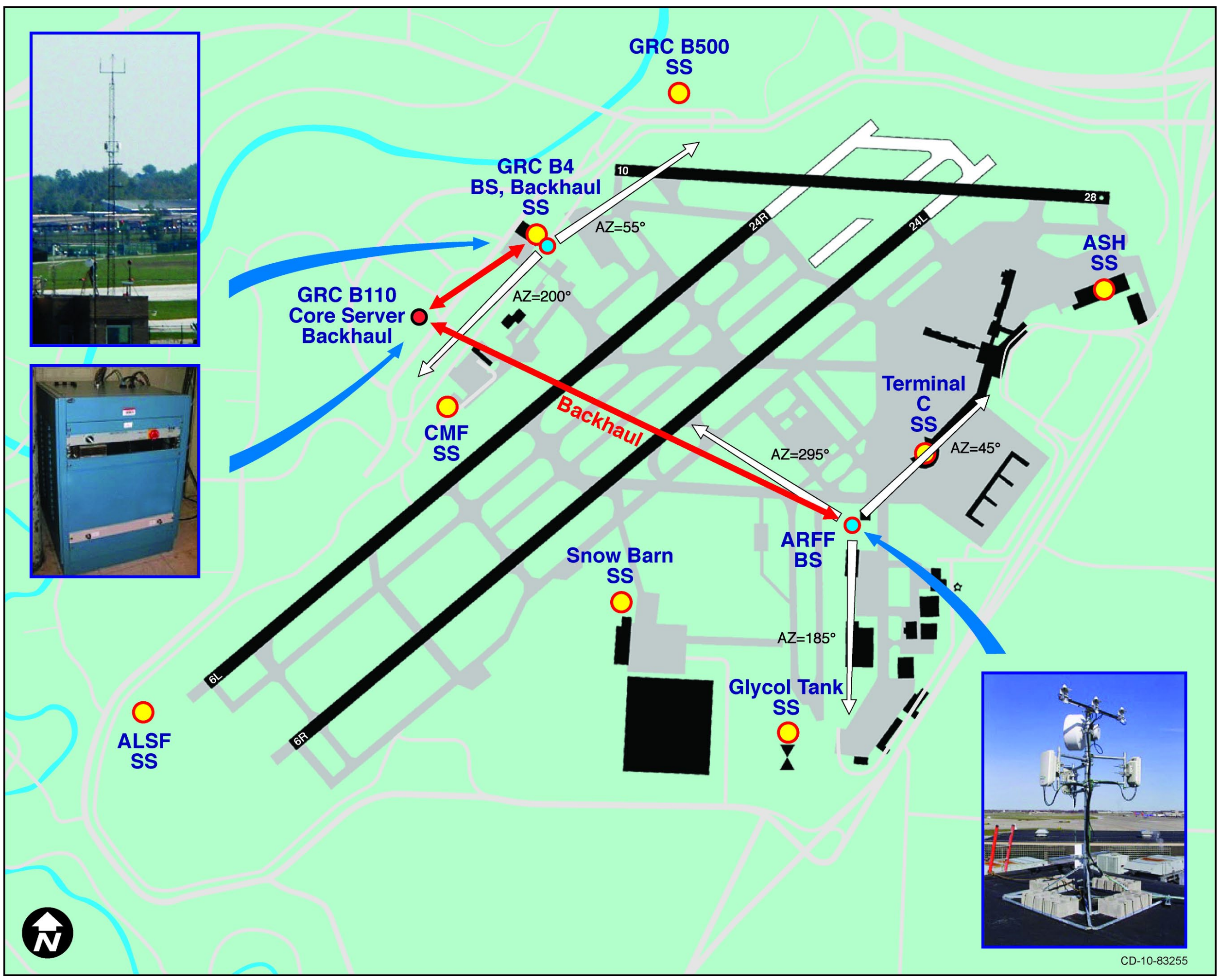

Figure ES–3.—NASA–CLE CNS Test Bed base station, backhaul, and core server locations. Acronyms are defined in Appendix A.

The test bed network uses two BSs, one on Glenn property (Building 4) and another on airport property on top of the Aircraft Rescue and Fire Fighting (ARFF) building. These BSs are linked to core servers located in Glenn Building 110 by microwave data backhaul radios operating outside of the AM(R)S spectrum. Fixed-location SSs are located at two positions on Glenn property (Buildings 4 and 500) and six positions on airport property. Tests are planned that will include mobility with vehicle- and aircraft-mounted SSs.

Expected AeroMACS link performance for fixed-position SSs was analyzed using the Cellular Expert analysis program developed by HNIT–BALTICFOOT.[4] Results are shown in Figure ES–4 on the basis of highest achievable modulation rate across the airport surface. Except for where links are physically shadowed by obstructions, the analysis predicts that the highest data throughput modulation rate supported by the IEEE 802.16e standard will be achieved across a significant majority of the airport surface.

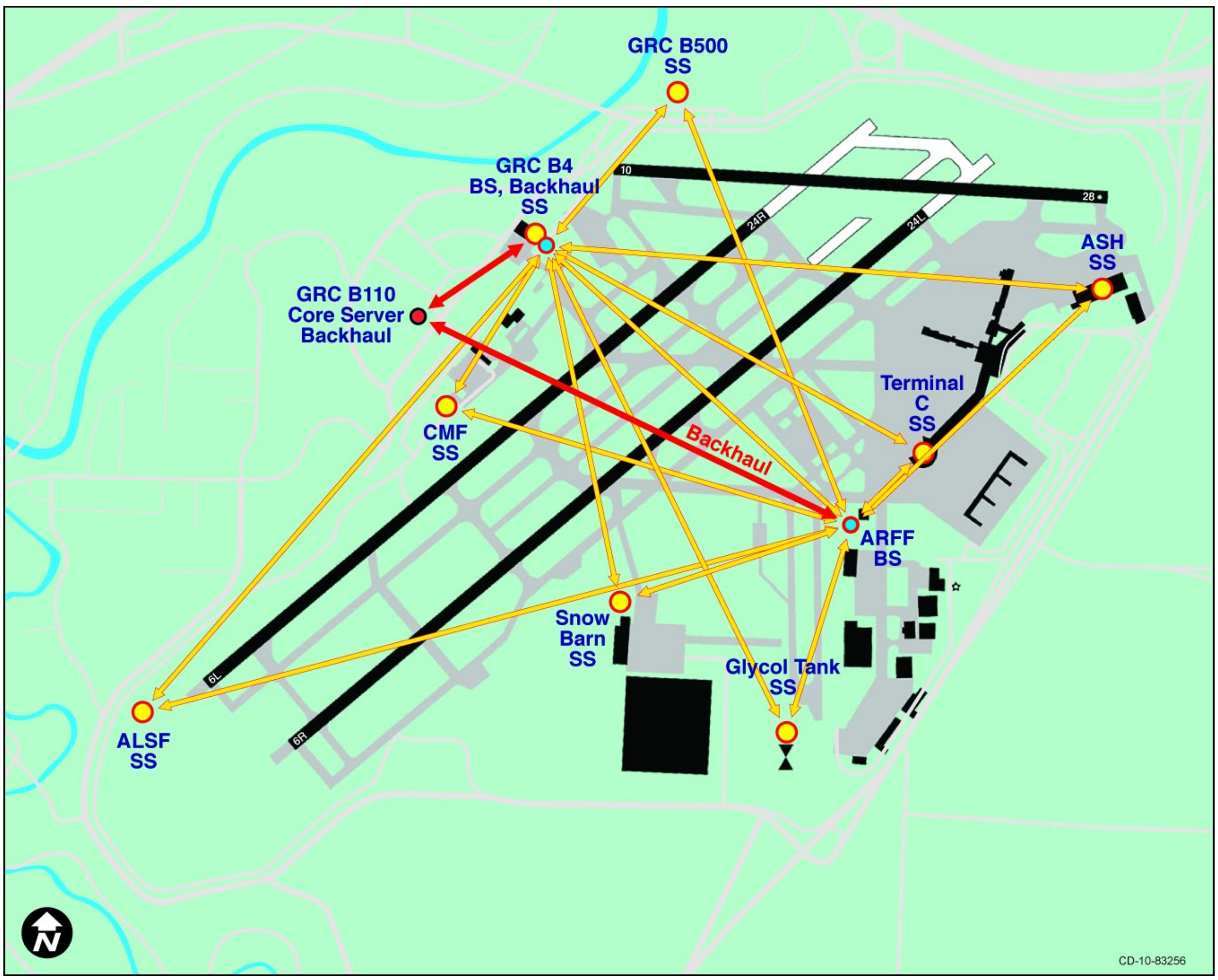

Figure ES–4.—Received signal strength indication (RSSI) plot for 17-dBi directional subscriber station mounted at 12 ft. Acronyms are defined in Appendix A.

[4]http://www.hnit-baltic.lt/.

The testing and evaluation of the IEEE 802.16e network can be grouped into two sets:

(1) Baseline performance tests within the project scope that will be reported in this document
(2) A set of tests designed to support development of an aviation profile and to evaluate the support of FAA applications

Eleven baseline performance network test cases have been defined to establish basic operating capability, including security with authentication and encryption, data throughput and channelization, quality-of-service (QoS) data prioritization, mobility, and reliability during extended operation.

Table ES–8 presents a collection of test cases designed to evaluate AeroMACS parameters in the airport environment. The "Design tradeoff category" column defines broad parameter categories, whereas the "Parameters" column lists detailed parameters within the category. The "Evaluation test" column describes test conditions for exploring the tradeoff space of a category.

TABLE ES–8.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
Base station (BS)	Mounting placement	Analyze or simulate Verify analysis or simulation model Survey signal strength across airport surface Determine line of sight (LOS) and non line of sight (NLOS)
	Number of BSs and base transceiver station (BTS) sectors	Analyze, considering coverage area and composite throughput
	Multiple input, multiple output (MIMO) order	Test without MIMO Test with up to 2×2 MIMO Test with $N \times N$ MIMO Test with LOS and NLOS or blockage
	Antenna polarization	Evaluate internal cross-polarization antennas versus external spatially separated antennas
	Maximum cell range	Extend with Media Access Control (MAC) changes within Institute of Electrical and Electronics Engineering (IEEE) 802.16e specification Evaluate IEEE 802.16m amendment
	Controlled-pattern antennas	Test with advanced BTS sector antennas Identify and evaluate steerable multibeam antennas
	Frequency band	Analyze minimum spectrum versus needed throughput
	Spectrum co-user interference (i.e., Globalstar satellite)	Analyze
Subscriber station (SS)	Mounting height	Analyze
	MIMO order	Test without MIMO Test with up to 2×2 MIMO Test with $N \times N$ MIMO
	Antenna polarization	Evaluate internal cross-polarization antennas versus two external single-polarization antennas
	Maximum cell range	Extend with MAC changes within IEEE 802.16e specification Evaluate IEEE 802.16m amendment
	Frequency band	Analyze minimum spectrum versus needed throughput Test frequency reuse methods including $N = 1$ (all sectors on same center frequency)
	Spectrum co-user interference (i.e., Globalstar satellite)	Analyze on the basis of power class requirements and frequency reuse method

TABLE ES–8.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
Channel bandwidth	Throughput rate	Test mixed mobile SS and fixed SS traffic including • Sources of highest expected data rate • Channel bandwidths of 5, 10, and 20 MHz
	Mobility performance	Test mobility throughput over speed range and cell radius including • Multiple mobile SS • Channel bandwidths of 5, 10, and 20 MHz
	Multipath performance	Evaluate performance in terminal area Evaluate mobile performance in building areas
	Efficient use of spectrum	Evaluate multiple mobile SS operation concurrent with fixed SS of differing data streams
	Hardware limitations	Test throughput versus expected at 20-MHz bandwidth
Modulation	Adaptive or fixed	Measure mobility throughput measurements across cell radius with fixed high and low modulation rates
	Modulation rates	Compare measured versus expected throughput versus modulation coding rate, including • Ranges from cell center to cell edge • LOS and NLOS
	Forward error correction (FEC) coding rate	Compare measured versus expected throughput versus error coding rate, including • Ranges from cell center to cell edge • LOS and NLOS
BTS power class	Fade margin allowance	Test long-term LOS throughput Conduct mobility tests in NLOS and high-multipath conditions
	Co-interference	Test throughput versus power between isolated sectors at the same center frequency in a frequency-reuse system
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Analyze interference on the basis of minimum power required to provide coverage across airport surface
	Range	Determine cell radius versus number of BSs
	Power amplifier power-output limitations	Analyze
SS power class	Fade margin allowance	Test long-term LOS throughput Conduct mobility tests in NLOS and high-multipath conditions
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Analyze interference on the basis of minimum power required to provide coverage across the airport surface
	Range	Determine cell radius versus the number of BSs
	Power amplifier power-output limitations	Analyze
MAC layer and physical layer (PHY)	Maximum mobile speed	Conduct high-speed mobility tests for throughput and dropouts
	Repeater operation (IEEE 802.16j)	Test IEEE-802.16j-enabled BS when available for filling in poor coverage areas, including • Outside cell radius • NLOS regions
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	Analyze

TABLE ES–8.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
Quality of service (QoS)	Time delay	Measure end-to-end time delay through AeroMACS network from SS input through communication, navigation, and surveillance (CNS) output port for all five QoS levels
	Time jitter	Measure end-to-end time jitter through AeroMACS network from SS input through CNS output port for all five QoS levels
	Message priority	Test high QoS and best-effort traffic Test until throughput overload Verify that high QoS priority is maintained
	Scheduling	Test high QoS and best-effort traffic Measure statistics of scheduling accuracy Measure scheduling performance as throughput is increased to overload
	Message integrity	Test high QoS and best-effort traffic Test continuous and burst traffic Verify packet error rate and that there are no dropped packets for high QoS traffic

Initial network performance data were collected to assess the data throughput capacity of links between Glenn Building 500 and the two BS sectors located at Glenn Building 4. Test data streams were generated by Ixia Chariot[5] software hosted on the single-board computers at each end of the link. The results shown in Table ES–9 are for the downlink (DL: BS to SS) and the uplink (UL: SS to BS) directions. The measured throughput exceeded the manufacturer's estimated rates in all cases.

TABLE ES–9.—AeroMACS NASA–CLE TEST BED LINK TEST RESULTS

BTS sector	Measured DL throughput, Mbps	Expected DL throughput, Mbps	Measured UL throughput, Mbps	Expected UL throughput, Mbps
BTS1_1	6.82	6.5	5.4	4.0
BTS1_2	6.54	6.5	4.19	4.0

ES.6 Specification Recommendations

NAS growth and improvement will provide continued safety, efficiency, and reliability to the flying public. The AeroMACS solution is designed to help increase airports' capacity for departures and arrivals, as well as the safety and efficiency of surface movement, the security and flexibility of airport surface operations, and the situational awareness for airport surface users and stakeholders. AeroMACS will also help reduce delays, fuel consumption, and emissions. Finally, AeroMACS will be developed in cooperation with the European Organisation for the Safety of Air Navigation (EUROCONTROL) to advance the establishment of global standards and interoperability to effectively and efficiently enable rapid and thorough airport improvements as new applications augment and replace legacy systems.

Special committee SC–223 was established within the RTCA aviation industry consortium to establish standards for AeroMACS. The principal products of this special committee are a set of system profile recommendations to be delivered in September 2010 and a Minimum Operational Performance Standards (MOPS) document to be delivered in September 2011. EUROCONTROL established a similar

[5]http://www.ixiacom.com.

work group, WG–82, that is chartered to develop an AeroMACS profile. SC–223 and WG–82 will work cooperatively to develop a common profile document that will be provided as recommendations for consideration by ICAO.

Sets of system parameter profiles have been recommended for AeroMACS within this study. These profiles are based on the existing IEEE 802.16e standard. System profile parameter values were selected within the IEEE 802.16e standard to maximize the reuse of commercial off-the-shelf Worldwide Interoperability for Microwave Access (WiMAX) hardware and software. In addition, parameter options are included that give the system designer flexibility to accommodate the applications and environment that will be unique to each airport. Table ES–10 summarizes key parameter selections for the five profile areas that are defined in the IEEE 802.16e standard and that are recommended for an AeroMACS standard profile. The five profile areas listed in the table correspond to the five profile areas that distinguish mobile WiMAX profiles. A working group within RTCA SC–223 is tasked with further developing the AeroMACS profile and deciding whether parameters are mandatory or optional to implement.

TABLE ES–10.—SUMMARY OF FINAL RECOMMENDATIONS FOR AeroMACS PROFILE

Profile area	Key parameter selections
Radiofrequency and radio parameters	
Frequency band, MHz	5091 to 5150
Channel bandwidths, MHz	5, 10, and 20
Channel center frequencies	See Table 38
Power class	
Maximum downlink transmitter (Tx) power	6.3.4—Unchanged from IEEE 802.16(e)
Maximum uplink Tx power	6.3.4—Unchanged from IEEE 802.16(e)
Duplex mode—time-division duplex (TDD) or frequency-division duplex (FDD)	TDD
Physical layer	Performance profiles—minimum performance defined in IEEE 802.16(e) and
M-ary quadrature amplitude modulation (QAM) range	Table 35 for 5-MHz channels
	Table 36 for 10-MHz channels
Coding options	Table 37 for 20-MHz channels
Multiple input, multiple output (MIMO)	
Media Access Control (MAC) layer	All parameters unchanged from IEEE 802.16(e)
Automatic repeat request	
Security protocols	
Mobile protocols	
Quality-of-service (QoS) options	
Mesh options	

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1.0 Introduction

1.1 Background

During the past 4 years, the NASA Glenn Research Center and ITT Corporation have conducted a three-phase technology assessment for the Federal Aviation Administration (FAA) under a joint FAA–European Organisation for the Safety of Air Navigation (EUROCONTROL) Cooperative Research Action Plan (AP–17), also known as the Future Communications Study (FCS). NASA/ITT provided a system engineering evaluation of candidate technologies for the future communications infrastructure (FCI) to be used in air traffic management (ATM). Specific recommendations for data communications technologies in the very high frequency (VHF), C, L, and satellite bands, and a set of follow-on research and implementation actions have been endorsed by the FAA, EUROCONTROL, and the International Civil Aviation Organization (ICAO). In the United States, the recommendations from AP–17 are reflected in the Joint Planning and Development Office's (JPDO) "Next Generation Air Transportation System, Integrated Plan" (Ref. 15) and are represented in the "National Airspace System (NAS) Infrastructure Roadmaps" (Ref. 16).

Action Plan 30 (AP–30), a proposed follow-on cooperative research to AP–17, is expected to start in fiscal year 2010 (FY10) to ensure coordinated development of FCI to help enable the advanced ATM concepts of operation (ConOps) envisioned for both the Next Generation Air Transportation System (NextGen) in the United States and EUROCONTROL's Single European Sky ATM Research program in Europe. Follow-on research and technology development recommended by ITT and Glenn and endorsed by the FAA was included in the FAA's NextGen Implementation Plan 2009. The plan was officially released at the NextGen Web site (http://www.faa.gov/about/initiatives/nextgen/) on January 30, 2009. The implementation plan includes a FY09 solution set work plan for C-band and L-band future communications research in the section, "New Air Traffic Management (ATM) Requirements."

On February 27, 2009, the FAA approved a project-level agreement (PLA FY09_G1M.02-02v1) for "New ATM Requirements—Future Communications," to perform the FY09 portion of the FAA's solution-set work plan; this includes the development of concepts of use (ConUse), requirements, and architecture for both a new C-band airport surface wireless communications system and a new L-band terrestrial en route communications system. The work described in this report covers ITT's portion of the project-level agreement tasks related to C-band airport surface wireless communications development.

This report is being provided as part of the Glenn Contract NNC05CA85C, Task 7: "New ATM Requirements—Future Communications, C-Band and L-Band Communications Standard Development." Task 7 is separated into two distinct subtasks, each aligned with specific work elements and deliverable items identified in the FAA's project-level agreement and with the FAA FY09 spending plan for these subtasks. The purpose of subtask 7–1, and the subject of this report, is to define the C-band airport surface ConUse, systems performance requirements, and architecture in a future C-band (5091 to 5150 MHz[6]) air-to-ground (A/G) communication system referred to as the Aeronautical Mobile Airport Communications System (AeroMACS).

[6]With a possible future extension into the 5000- to 5030-MHz band, pending a decision at the World Radiocommunications Conference in 2012.

1.2 Systems Overview

Systems covered by this document provide the following airport surface communications services shown within the dashed red boxes in Figure 1.

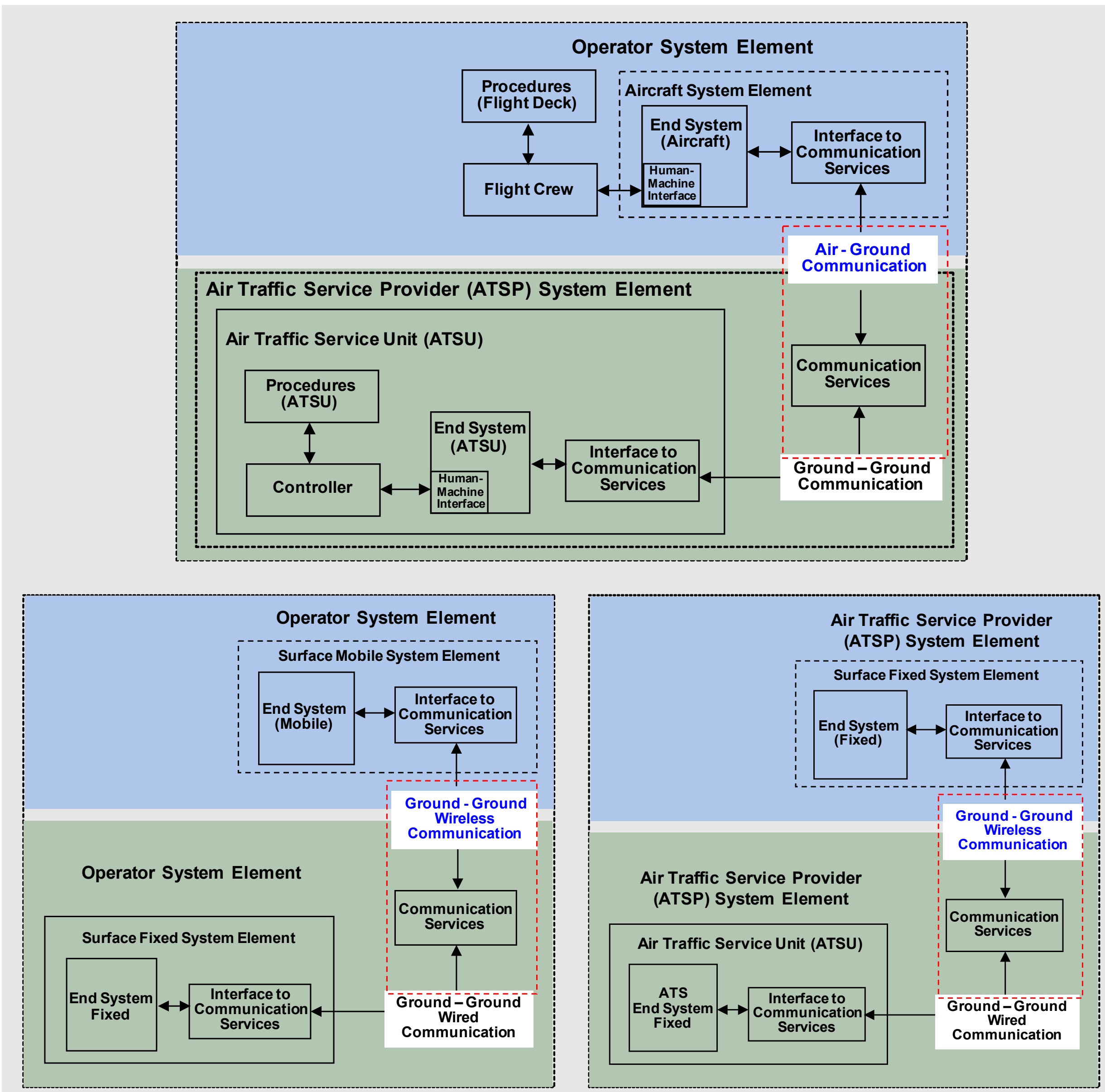

Figure 1.—Communications systems covered by this ConUse document (slightly altered version of Figure 1–1 in Ref. 7).

- Air traffic services (ATS) A/G flight safety communications between fixed ATS provider (ATSP) system elements and an aircraft
- ATS ground-to-ground (G/G) communications between fixed ATSP system elements (e.g., to provide connectivity between the components of a NAS surveillance system).
- G/G communications between fixed and mobile operator (e.g., airline) system elements (e.g., to provide connectivity for aeronautical operational or administrative messages supporting the operation or maintenance of facilities provided for the regularity of aircraft operations as described in Ref. 17).

On the ground, these systems typically consist of radio ground station subsystems—including radios, antennas, cabling, power systems, environmental systems, towers, monitoring and control functionality, and other systems to provide wireless communications services; networking subsystems to provide G/G communications service connectivity to end systems and users; and usually some centralized functionality to monitor and control system operations and performance. Aircraft and other mobile components include radio equipment, antennas, and associated cabling.

1.3 Document Overview

This document is organized as follows:

- Section 1.0 provides background system information and describes the document scope, organization, and references.
- Section 2.0 presents the ConUse and the processes for developing the requirements.
- Section 3.0 is devoted to the ConUse of the proposed AeroMACS. After describing the ConUse development process, it presents the operational need for AeroMACS by describing current A/G and G/G communications systems and their associated problems and capability shortfalls. Section 3.3 shows the potential benefits of the new systems and describes the desired changes. The proposed system is then described. ConUse are presented, along with references to RTCA's NAS concept of operations (ConOps) guidance documents and descriptions of FAA's Data Communications Program (Data Comm) operational scenarios, NextGen operational concepts, and AeroMACS operational concepts based on the airport surface flight domain as well as those derived from the communications operating concept and requirements (COCR).
- Section 4.0 presents AeroMACS system requirements. It describes the development process for system requirements and presents results for the "middle-out" approach.
- Section 5.0 describes preliminary systems performance requirements and an initial network architecture.
- Section 6.0 describes modifications to the NASA Glenn/Cleveland Hopkins International Airport (NASA–CLE) Communications, Navigation, and Surveillance (CNS) Test Bed to add Institute of Electrical and Electronics Engineering (IEEE) 802.16 (Ref. 18) capability and testing and evaluation results using simulation, emulation, and or test bed tests. It also provides initial data to be input to the aeronautical mobile-specific IEEE 802.16 design specifications.
- Section 7.0 provides concluding requirements and specification recommendations for use by standards-setting bodies.
- Appendix A defines acronyms and abbreviations used in this report.
- Appendix B summarizes the RTCA NAS ConOps applicable to the proposed AeroMACS.
- Appendix C provides hierarchical diagrams of the functional requirements for the AeroMACS C-band communication system.

2.0 ConUse and Requirements Development Processes

ConUse are part of a hierarchy of documents that capture concepts related to the NAS. As defined in the FAA's NAS System Engineering Manual (SEM), there are two general types of concepts documents associated with system engineering in the NAS: ConOps and ConUse. ConOps describe "what is expected from the system, including its various modes of operation and time-critical parameters" (Ref. 19), whereas a ConUse is "an extension of a higher level ConOps with an emphasis on a particular NAS system and its operating environment" (Ref. 19). Figure 2 depicts the three hierarchical levels of concept documents typically used in the NAS and defined in the SEM: two levels of ConOps and the ConUse.

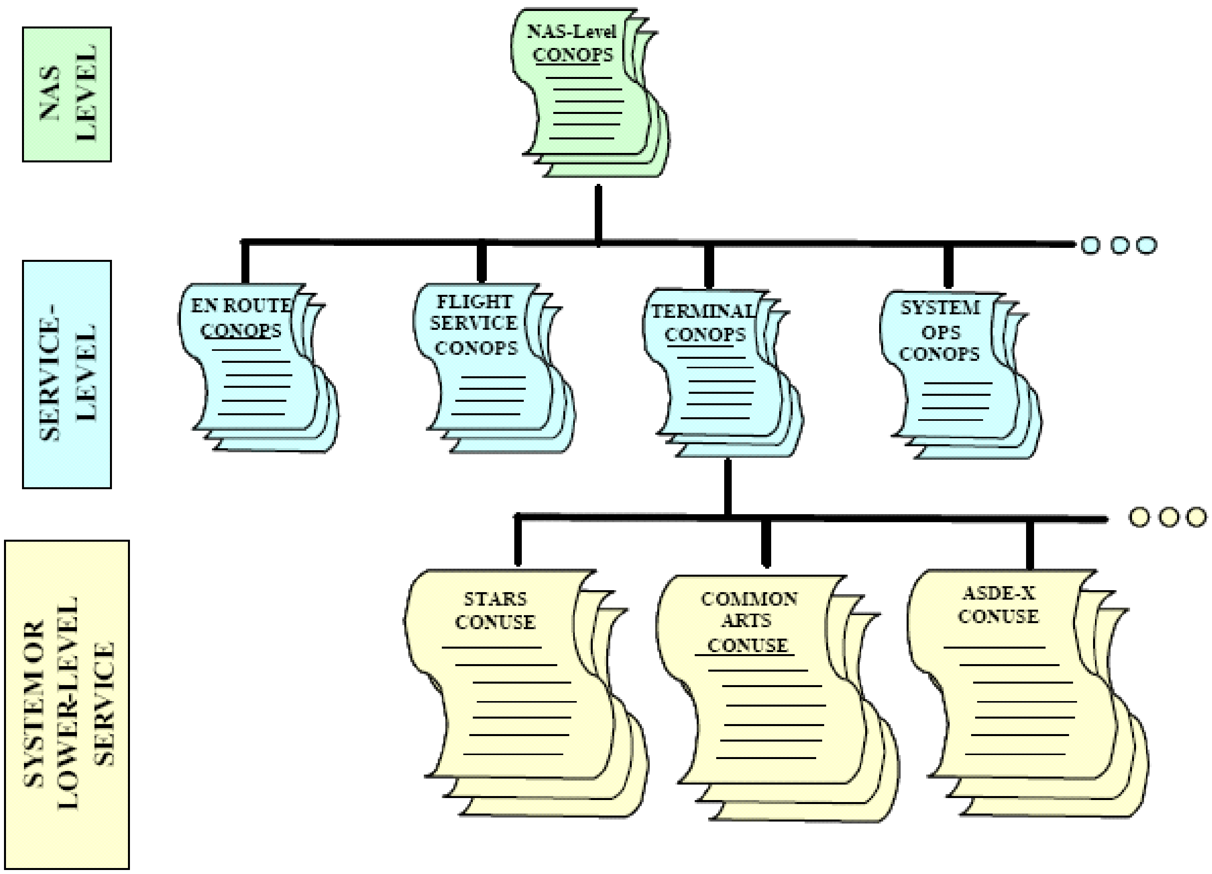

Figure 2.—National Airspace System (NAS) engineering concept document hierarchy (Ref. 19). Acronyms are defined in Appendix A.

These three levels can be summarized as follows:

- NAS-level ConOps comprise "a high-level narrative of the user community's desired change with some performance indicators. The document indicates from the user's perspective the desired end-state for respective systems in the NAS. It often uses various operational scenarios to illustrate the desired operational concept" (Ref. 19).
- Service-level ConOps provide "conceptual insight into a particular service of the NAS." These give "more detail and in-depth information about the desired operations within the service" (Ref. 20).
- ConUse are extensions of the NAS-level ConOps and a particular service-level ConOps, "with an emphasis on a particular NAS system and its operating environment." ConUse are more detailed and substantial, but they still express "the user's needs regarding a specific system within the NAS" (Ref. 20).

NAS-level and similar level international ConOps driving this ConUse and its associated requirements include RTCA's "National Airspace System: Concept of Operations and Vision for the Future of Aviation" (Ref. 13), the "Concept of Operations for the Next Generation Air Transportation System" (Ref. 4), and the ICAO's "Global Air Traffic Management Operational Concept" (Ref. 21). At the next lower layer, EUROCONTROL's "Operating Concept of the Mobile Aviation Communication Infrastructure Supporting ATM Beyond 2015" (Ref. 22) was used with the service-level ConOps—"Communications Operating Concept and Requirements for the Future Radio System" (Ref. 12)—to provide reference guidance for A/G operating concepts and requirements directly applicable to this ConUse. On a similar level to this ConUse, but with a different scope and intended for different services, are the operating concepts and requirements presented in "Data Communications Safety and Performance Requirements" (Ref. 23) and "Final Program Requirements for Data Communications" (Ref. 5).

It should be noted that the ConOps and ConUse documents just referenced relate primarily to the provision of safety-critical A/G air traffic control (ATC) communications services; however, they also are applicable to the provision of airport surface G/G communications links that support other NAS safety critical services, such as surveillance, weather, flight planning, and aeronautical information. NAS ConOps applicable to the provision of aeronautical operational and administrative messages over G/G communications systems and supporting the regularity of flight operations are not available for reference, perhaps because NAS ConOps typically apply to the provision and operation of safety-critical services.

The ConUse and performance requirements described in this document apply to a future airport surface-band (5091- to 5150-MHz[6]) communication system referred to as AeroMACS that will provide A/G and G/G communications services similar in scope to those described in the "FCI Aeronautical Data Services Definition Task Report" (Ref. 9) as well as other services shown in Figure 1. The 2009 FCI report follows from the previous FCS technology evaluation study (Ref. 24), which identified the IEEE 802.16e standard (Ref. 18) as the recommended candidate for further development because it best meets the FCS technology assessment criteria and is designed for the C-band spectrum, which is a recommended band for supporting new data link communications capabilities for airport surface communications.

Typically, the development of concepts documents and requirements for new systems for the NAS are based on the process depicted in Figure 3, which illustrates the top-down iterative process and general relationships among concepts, requirements, and architectures. Because many, if not most, NAS systems are not entirely new, but rather, evolutionary improvements of existing NAS systems, a top-down process is not always sufficient. Instead, a "middle-out" approach is taken. This is a combination of a top-down process, which takes into account new concepts and missions needs, and a bottoms-up approach, which takes into account existing concepts, systems, and requirements. Figure 4 shows the middle-out approach adopted for the ConUse and requirements developed for AeroMACS. As shown in the figure, operational concepts and requirements of higher level concepts documents flow down to this document, providing high-level guidance and direction in the form of required functions and flows for the services of interest, namely A/G and G/G communications services. In addition to this top-down process, a bottom-up process of identifying and evaluating specific concepts and requirements developed for specific communications systems, such as Data Comm, Next Generation Air/Ground Communication (NEXCOM), and Link 2000+, along with appropriate NAS System Requirements (SR−1000, Refs. 10 and 11) and IEEE 802.16e requirements (Ref. 18), was employed for this document.

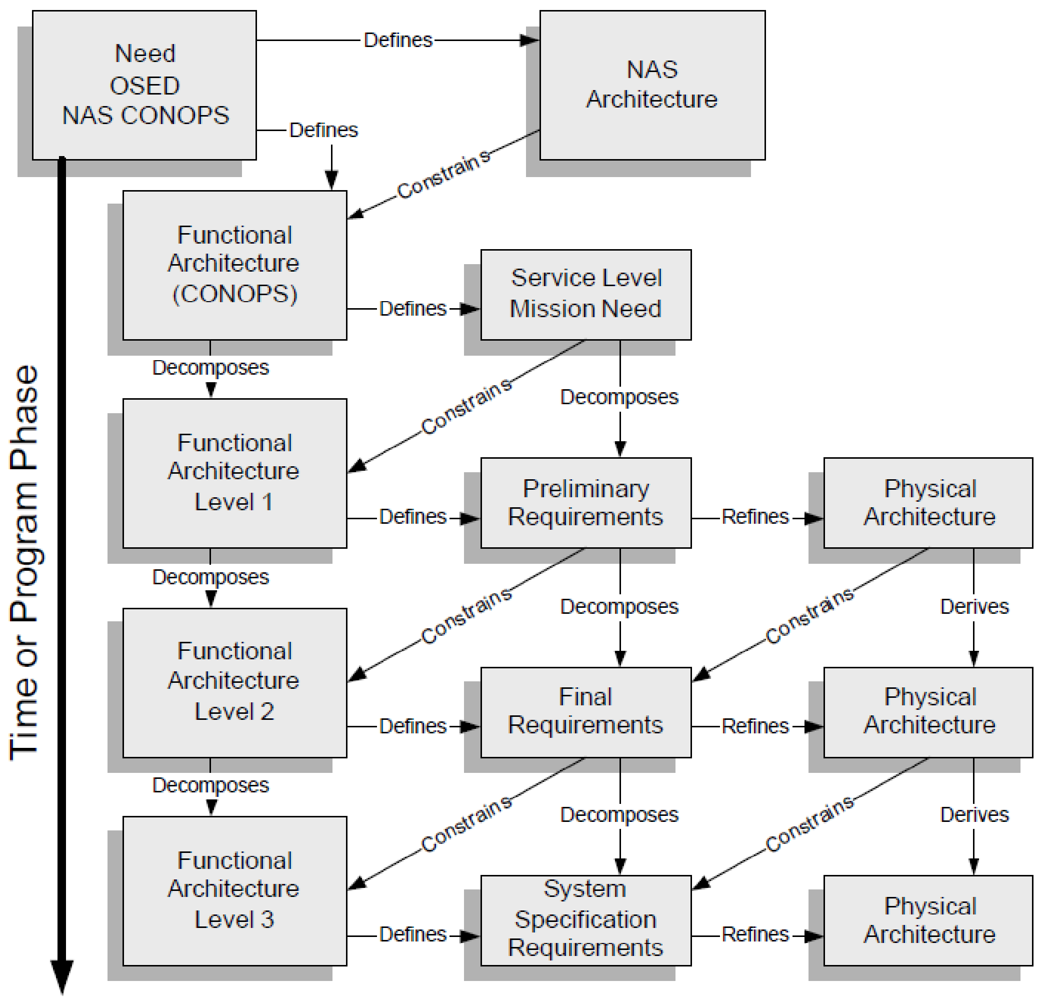

Figure 3.—Requirements management process flow (Ref. 25). Acronyms are defined in Appendix A.

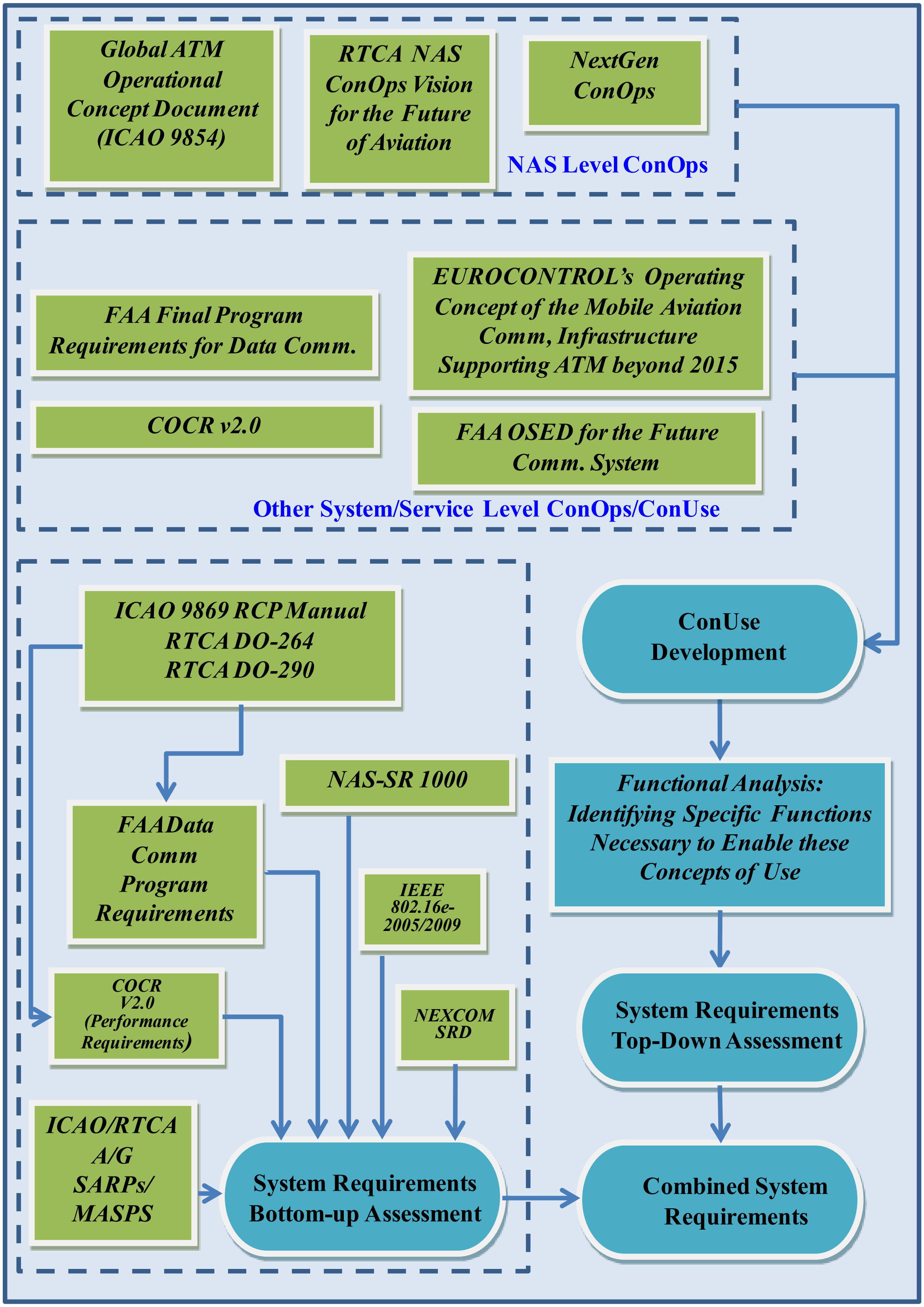

Figure 4.—AeroMACS ConUse and system requirements development flow chart. Acronyms are defined in Appendix A.

3.0 ConUse

3.1 ConUse Development Process

A process recommended in the NAS system engineering manual (SEM, Ref. 1) was used as a guide in developing ConUse for the proposed AeroMACS. Figure 5 summarizes the steps. The following sections describe the findings for each of the steps shown in the figure.

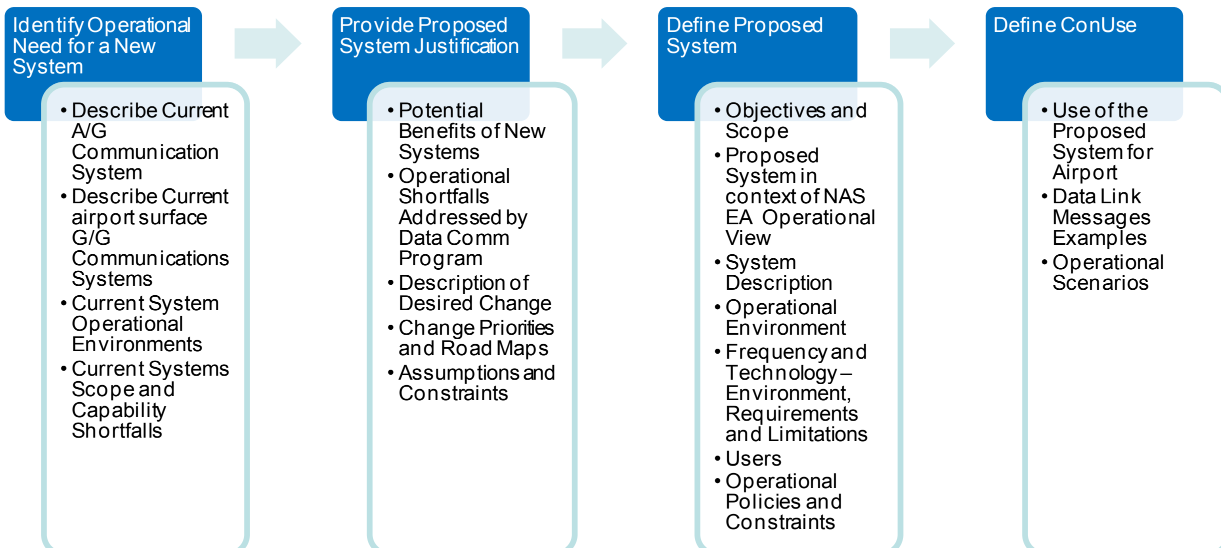

Figure 5.—ConUse development process. Acronyms are defined in Appendix A.

3.2 Operational Needs

This section defines the operational needs for AeroMACS by describing current and planned airport surface communications systems and their associated problems and capability shortfalls. Though not a current system, the planned data communications networks services A/G data communications system being developed under the FAA's Data Comm Program is discussed here because it is expected to be implemented before an AeroMACS system is likely to be implemented for airport surface A/G communications. Data Comm should mitigate many of the current operational problems and short-comings while leaving room for AeroMACS to provide additional gains in overcoming current A/G communications problems and shortcomings.

3.2.1 Current Airport Surface Communications Systems

3.2.1.1 Current Air-to-Ground Communication System

The “System Requirements Document, Next Generation Air/Ground Communications (NEXCOM)” provides a good description of the FAA’s current analog A/G voice communications system used for ATC (Ref. 2):

> The current A/G Communications System for ATC consists of voice-based networks that use DSB-AM [double-sideband amplitude-modulation] radios and operate in the 117.975 to 137 Megahertz (MHz) VHF band for civil aircraft and the 225- to 400-MHz UHF [ultra-high-frequency] band for military aircraft. The radios operate with the same frequency used for controller-to-pilot (uplink, UL) and pilot-to-controller (downlink, DL) transmissions in a simplex “push-to-talk” mode. There is a dedicated, non-interconnected radio network for each operational environment (En Route, Terminal, airport surface, and flight service). In the event of a control facility power loss, engine generators provide back-up power. In the event of equipment failure, A/G communications are provided Back-Up Emergency Communications (BUEC) in the En route, Emergency Communications System (ECS) in the large TRACONS [terminal radar approach control facilities] and portable transceivers in the smaller TRACONS and Air Traffic Control Towers (ATCT).
>
> The current A/G communications system architecture is roughly the same for all operational environments. The specific equipment used in the A/G communications string can differ among the various facilities. Different control facility types have different voice switches, with each type of switch having a unique interface.

Figure 6 shows this system for en route A/G communications. Similar architectures are in place for terminal area and airport surface area A/G communications. Figure 7 depicts a typical remote transmitter/receiver (RTR) site configuration used for A/G communications for the Terminal Area and for the airport surface. Appendix A of the NEXCOM System Requirements Document provides a good, detailed description of the current A/G voice communications architecture and facilities.

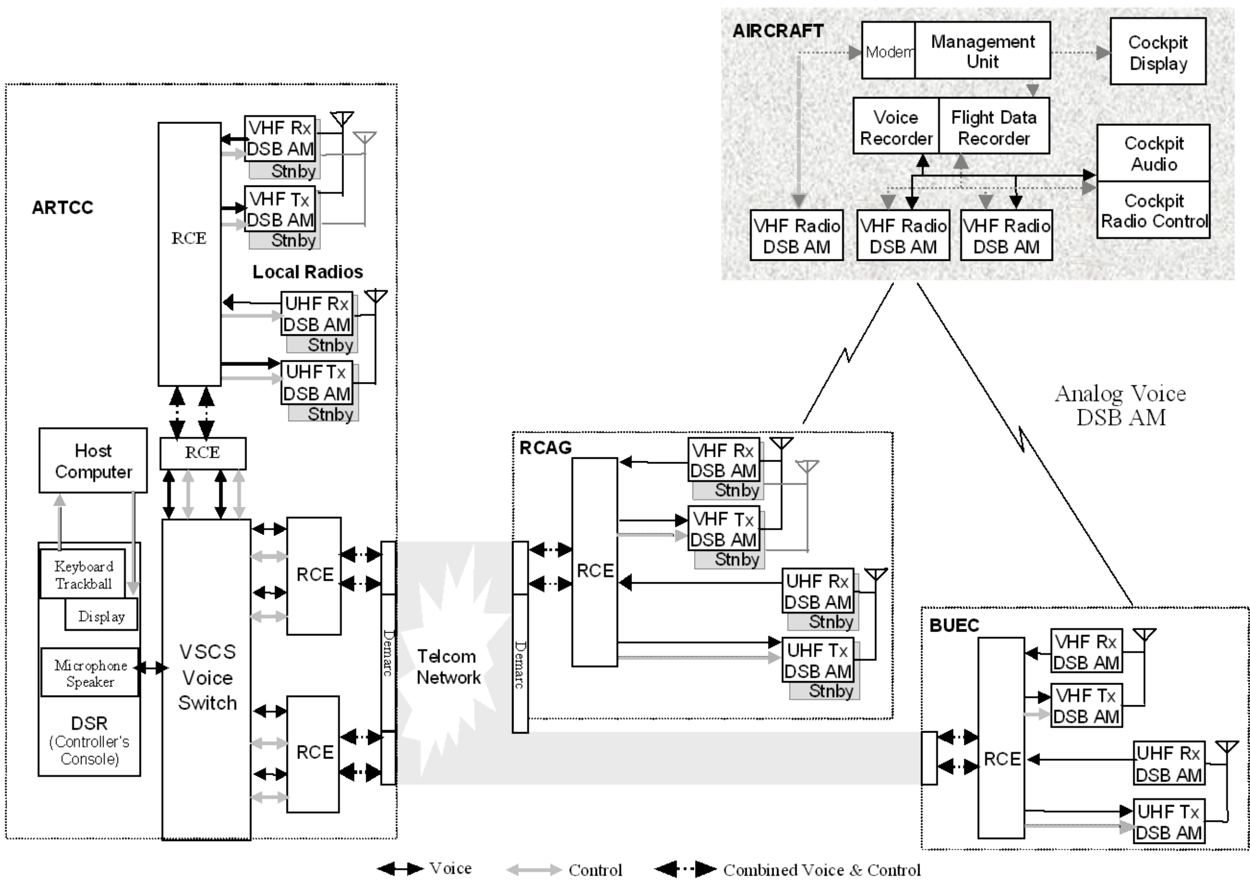

Figure 6.—Current en route air-to-ground (A/G) communications system (Ref. 26). Acronyms are defined in Appendix A.

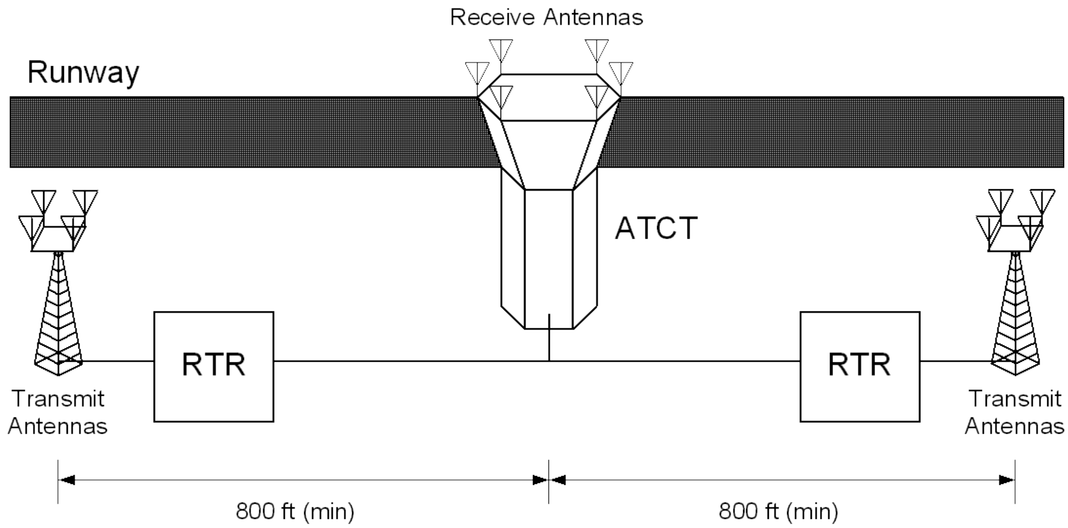

Figure 7.—Typical remote transmitter/receiver (RTR) site configuration (Ref. 27). ATCT, air traffic control tower.

3.2.1.2 Current Airport Surface Ground-to-Ground Communication Systems

Current G/G communications on the airport surface are conducted predominantly over a combination of wire and optical fiber cabling and a limited number of point-to-point line-of-sight (LOS) radio links. Most often, airport surface systems are interconnected by direct telecommunications services, including underground cable systems implemented by the airport.

Shielded, twisted-pair copper lines carry low-data-rate and voice communications between fixed locations. Fiber-optic cables perform a similar function but have expanded bandwidth capability. Point-to-point radio links can handle narrow to wide data bandwidths without the use of difficult-to-install underground cables.

G/G communications handle data exchanges between a wide variety of applications on the airport surface. Table 1 lists examples of present and future applications that require G/G communications.

TABLE 1.—AIRPORT SURFACE SYSTEMS THAT COULD BE SUPPORTED BY AeroMACS

Service	Airport Surface Systems Supported
Sensor data collection/ dissemination for situational awareness	Multilateration (MLAT) Airport Surface Detection Equipment, Model X Automatic dependent surveillance—broadcast (ADS–B) ground sites Air surveillance radar Airport lighting systems Network-enabled weather data; automated surface observation systems (ASOS), low-level wind shear alert system, Terminal Doppler Weather Radar, Integrated Terminal Weather System, icing
Cable/Telco replacement and augmentation	Backup and primary alternative to cabled connections Extend cable loop infrastructure to remote surface assets Temporary fixed-asset connection during surface construction or service restoration Remote transmitter/receivers (RTRs)

3.2.2 Current System Operational Environments

According to the SEM (Ref. 28), the operational environment of a system consists of

> the conditions in which the mission or function is planned and carried out. Operational conditions are human-created conditions involving operations such as air traffic density, communication congestion, and workload. Part of the operational environment may be described by the ***type of operation*** (air traffic control, air carrier, general aviation); ***phase [of flight]*** (ground taxiing, takeoff, approach, en route, transoceanic, landing); or ***rules governing the operation*** (Instrument Flight Rules versus Visual Flight Rules).

Rather than being a NAS service itself, G/G and A/G communications are *enablers* of NAS services and provide the following functionality (Ref. 11):

> Communications enables the NAS to exchange information with users, specialists, ATC facilities, and other Government agencies. Communications enables air traffic control operations within the NAS by employing appropriate technologies to exchange voice and data. This information is transported over land lines and wireless connectivity utilizing government and commercial assets. Communications defines how data is moved across the NAS to accomplish flight planning, control functions and navigation services for ground and space based systems. This enabler provides end-to-end service to pilots to include disseminating and coordinating the flight plan and defines how controllers provide service throughout the flight while coordinating with other facilities and government agencies. The communications enabler supports collaboration between users and specialists for traffic synchronization and flow services. Communications support the exchange of navigation and surveillance information across the NAS. Information includes electronic signals emanating from ILS [instrument landing system], VOR [VHF omnidirectional range] and space based systems and aircraft transmitted beacon code data.

Reference 29, which gives an as-is system view 2 (SV–2) of the NAS, describes how NAS interfaces, as identified in Reference 30 (NAS SV–1) are supported by physical media.

Pertinent information about communications systems, communications links, and communications networks is presented as a pictorial view of system interactions and telecommunications service characteristics along with implementation technologies. The as-is SV–2 views were developed depicting an overall telecommunications infrastructure and providing separate views for five information flow areas:

- Surveillance
- Weather
- Command and control
- Flight data
- Aeronautical information

3.2.2.1 Current Air Traffic Control Air-to-Ground Communications System Operational Environments

Figure 8 presents an overview chart depicting an SV–2 telecommunications view and associated data for the command and control functional flow area. Note that the "Terminal Voice" link depicted in the figure also would include airport surface voice communications between aircraft on the ground and radio equipment (typically RTR sites, as shown in Figure 8) serving ATCTs.

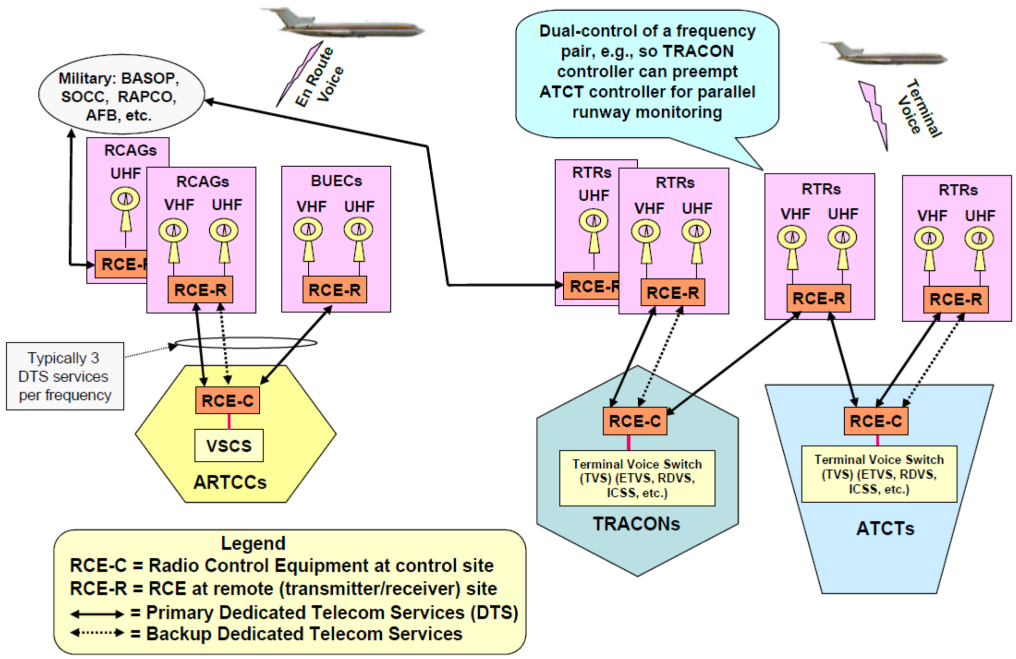

Figure 8.—System View 2 (SV–2) command and control detailed air-to-ground communications view for 2009 to 2010 (Ref. 29). Acronyms are defined in Appendix A.

Specifically, A/G communications is mainly used for communications between air traffic controllers or specialists on the ground and manned aircraft pilots to enable the following required NAS functions (Ref. 10)[7]:

- Manage flight plans (plan flights)
- Monitor aircraft status (monitor flights)
- Control aircraft (control traffic)
- Manage weather information (support flight operations)
- Maintain NAS infrastructure (monitor NAS operations)
- Plan traffic flow (plan NAS usage)
- Assess traffic flow performance (plan NAS usage)

For the most part, these functions are currently implemented in the NAS via voice communications; though the NAS SR–1000 (Ref. 10) includes requirements for some functions that explicitly designate data communications as the means of A/G communications and other requirements that do not specify the A/G communications type.

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[7]In the listing, the subfunction is shown, followed by the parent function in parentheses.

The NAS functions listed above are needed to provide several of the NAS service capabilities defined in the NAS SR–1000. Table 2 provides a mapping of NAS-level functions to the NAS service capabilities enabled by those functions. An “x” at a row-column intersection in the table indicates that the particular function in that row is needed to provide the NAS service capability in that column. Of particular interest for this report are the functions that can be enabled by A/G voice communications to provide specific NAS service capabilities. For example, A/G voice communications is used to implement some of the functionality needed to manage flight plans in support of the flight-planning service capability. This A/G voice-communications-specific mapping is indicated by the blue boxes in the table. Thus, as shown in the table, A/G communications is needed to support the following NAS service capabilities (denoted with blue boxes in the service “Capability” row):

- Flight planning
- Separation assurance
- Advisory services
- Traffic flow management
- Emergency services
- Infrastructure and information management

TABLE 2.—MAPPING AIR-TO-GROUND VOICE COMMUNICATIONS FUNCTIONS TO NATIONAL AIRSPACE SYSTEM (NAS) SERVICE CAPABILITIES (REF. 31)
[Acronyms are defined in Appendix A.]

Function \ Capability	Flight Planning	Separation Assurance	Advisory Services	Traffic Synchronization	Traffic Flow Management	Emergency Services	Navigation Services	Airspace Management Services	Infrastructure and Information Management
Evaluate Flight Conditions			X						
Manage Flight Plans	X								
Collect Surveillance Information	X	X	X	X		X	X		
Determine Aircraft Trajectory		X		X					
Monitor Aircraft Status	X					X	X		
Disseminate Aircraft Status	X	X				X			
Manage Separation Information		X							
Synchronize Traffic		X	X	X	X				
Control Aircraft		X							
Coordinate Traffic Control Distribution		X							X
Manage Weather Information			X						
Operate NAVAIDS							X		
Monitor NAS Flight Operations			X		X				
Maintain NAS Infrastructure		X	X			X			X
Plan Traffic Flow					X				X
Assess Traffic Flow Performance					X				
Manage Airspace Configuration	X	X				X	X	X	X

Some of the NAS service capabilities listed earlier, such as separation assurance and A/G-communications-enabled flight planning service capability, are considered to be safety critical for the NAS. Because of the need to support such NAS critical services, A/G voice communications latency and availability performance requirements are fairly stringent. Typically, this has resulted in requirements for 0.99999 availability and an end-to-end latency of 250 msec[8] for the most critical voice communications services.

For continental airspace, A/G voice communications is provided in the terminal maneuvering area (TMA), en route, and in airport surface domains, with the current architecture as described in Section 3.2.1. Voice communications is used for all phases of flight: that is, from gate to gate.

3.2.2.2 Current Airport Surface Ground-to-Ground Communications System Operational Environments

Besides the various NAS service capabilities and functions enabled by A/G communications for command and control as described in the preceding section, numerous surveillance, weather, and aeronautical data NAS services are supported by systems operating on the airport surface. For the most part, these systems are interconnected by direct telecommunications services, including underground cable systems implemented at the airport. The NAS services potentially supported by systems operating on the airport surface are indicated by red dashed boxes in Figure 9.

[8]This performance value for end-to-end A/G voice communications latency was provided in earlier versions of NAS SR–1000, but is not in current versions.

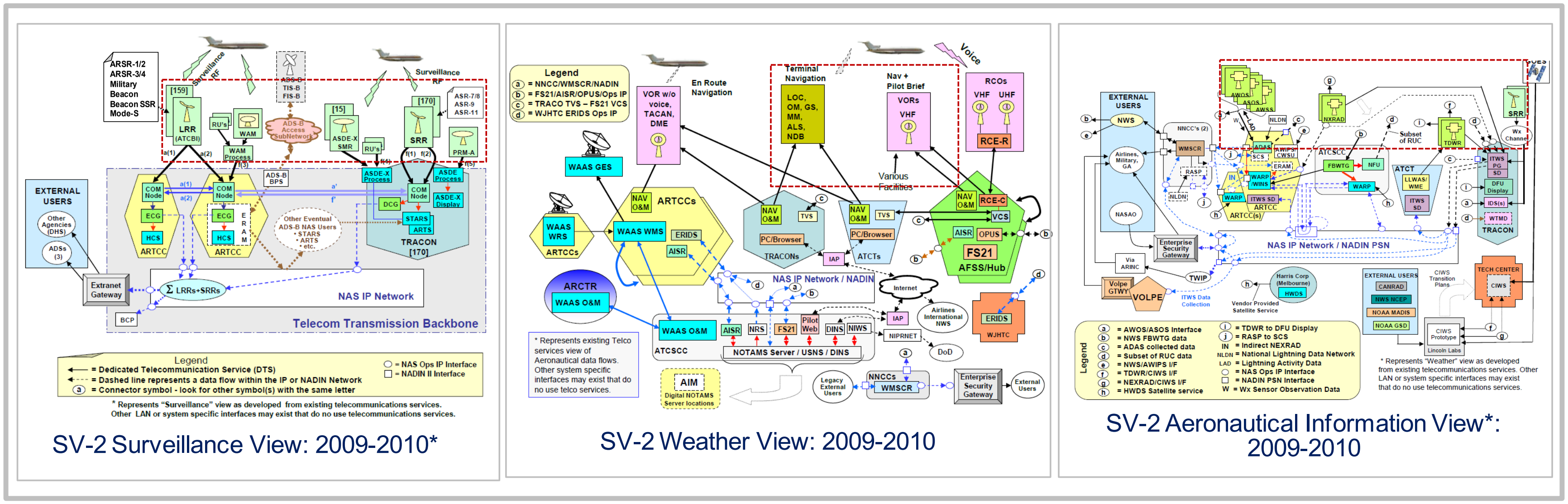

Figure 9.—System view 2 (SV–2) 2009 to 2010 data flow views (Ref. 29). Acronyms are defined in Appendix A.

3.2.3 Current System Users

The users of the current VHF A/G and G/G communications systems include the following:

(1) Scheduled air transport carriers (including international, trunk, regional, commuter, and air freight carriers)
(2) Nonscheduled air carriers
(3) General aviation (including operators of turbine-powered and reciprocating–engine aircraft)
(4) Operators of unpowered aircraft (including gliders and lighter-than-air aircraft)
(5) Operators of various military aircraft
(6) Operators of certain ground and maritime vehicles (e.g., airport service vehicles and those vehicles coordinating in a search-and-rescue mission)
(7) ATS providers
(8) Aeronautical operational control (AOC) service providers (Ref. 32)

3.2.4 Current System Scope and Capability Shortfalls

3.2.4.1 Current Air Traffic Control Air-to-Ground Communications System Scope and Capability Shortfalls

The objectives of the current A/G communications system are consistent with the provisions of the NAS service capabilities and performance requirements listed in Section 3.2.2.1. Currently, they are characterized by (Ref. 33), “high availability, low end-to-end latencies, the ability to convey human feelings, flexibility of dialogue, provision of a party-line, and use for nonroutine, time critical, or emergency situations.”

Some of these characteristics actually offer an advantage to voice communications as compared to data communications; however, there are several disadvantages of voice communications that motivate the need for data communications for many applications.

The NextGen ConOps has summarized the current attributes (and associated constraints) of the voice-based A/G communications system as follows (Ref. 3):

- Limited data communications for ATM and operational control
- Limited access to real-time weather and aeronautical data
- Voice communications routine for ATM
- Analog voice
- Analog weather information display systems
- A/G and G/G communications
- Loss of communications due to beyond line-of-sight (BLOS) aircraft position (e.g., over the ocean)
- Individual ground systems for each information type brought to the flight deck
- Point-to-point aircraft communications based on ATC sectors

Currently continental A/G voice communications systems operate over the VHF and UHF aeronautical mobile (route) service (AM(R)S) frequency bands, and the scope of operation is constrained to be radio LOS, which dictates the need for networks of ground radio stations to provide radiofrequency (RF) coverage for the entire airspace volume for which the NAS service is to be provided.

Figure 10 summarizes several principal shortcomings of the current A/G voice communications system, including lack of automation, limited or no data communications availability, aging infrastructure, technology limitations, and spectrum saturation. The resulting operational problems, if not addressed, could lead to service degradation and limit the introduction of new or expanded services. These, in turn, could potentially compromise safety of operation and increase operating costs.

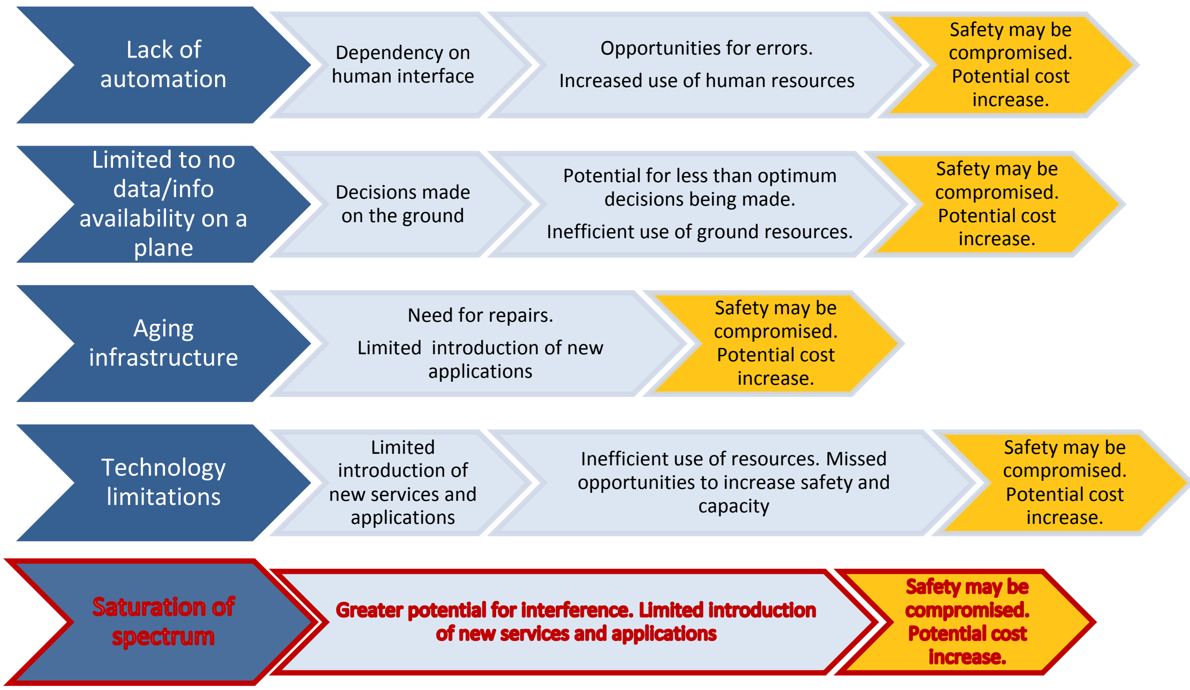

Figure 10.—Current National Airspace System air-to-ground communications operational problems.

Though saturation of spectrum is highlighted in red as the problem specifically mitigated by the introduction of a new C-band system (AeroMACS); the other operational problems would also be mitigated with AeroMACS.

As the NAS evolves to achieve the JPDO's and FAA's NextGen vision and ConUse, many of the transformational services and planned operational improvements will be enabled via data communications. Unfortunately, the current A/G communications system lacks data communications capability for ATS. In moving toward NextGen, this shortcoming will become more acute and will lead to several significant shortfalls in safety, capacity, efficiency, and productivity. As part of the investment analysis process for Data Comm, a fairly comprehensive list of these shortfalls has been developed. These are repeated in Table 3 to specifically identify the shortfalls that Data Comm intends to address.

It is important to note that the "Final Program Requirements for Data Communications" (Ref. 5) recognizes that "the scope of the mission shortfalls identified herein is broader than will be addressed solely by a data communications capability." Because of the limitations and constraints of implementing data communications using very high frequency digital link (VDL) Mode 2 over a congested aeronautical VHF band, Data Comm will focus principally on implementing the most critical ATSs. This provides opportunities for AeroMACS systems to augment data communications on the airport surface by enabling communications of less critical and essential ATSs to address the shortfalls listed in Table 3.

Even though Data Comm means to use VDL Mode 2 to address, to some extent, each of the shortfalls in Table 3, there are opportunities to overcome these shortfalls to even a greater extent during the later program segments of Data Comm (e.g., late Segment 2 and Segment 3) using link technologies such as AeroMACS with greater bandwidth capabilities, which could augment the benefits already attained through the earlier VDL Mode 2 Data Comm segment implementations (i.e., Segments 1 and 2) by providing a broader scope of services.

TABLE 3.—CURRENT SHORTFALLS RELATED TO AIRPORT SURFACE AIR-TO-GROUND VOICE COMMUNICATIONS
[From a subset of the shortfalls described in Ref. 34.]

Safety shortfalls
Situations conducive to producing errors, confusion, and read-back and hear-back errors arising from voice congestion and voice communication quality
No alternative means to enable A/G communication support for contingency plans when the primary voice communication is not available
Capacity shortfalls
Inability to rapidly and accurately communicate complex clearances containing multiple latitude/longitude-defined route elements
Inefficient dissemination of airspace congestion, weather advisory, and NAS infrastructure status information
Inefficient communication of complete departure clearances and revisions necessitated by traffic management initiatives
Inability to provide for the maximum efficient use of the airspace and strategic plans by adjusting individual flights to reduce contention for resources and ensure that no resource is allowed to remain idle in the face of demand
Limited ability to use four-dimensional trajectories associated with flight objects and the airspace plan to identify areas of congestion, and the potential need for flow control initiatives to mitigate severe congestion
Efficiency and productivity shortfalls
Inability to support airspace user operational requirements, utility, performance, and other flight operations preferences—Avionics and airframe manufacturers need consistent global communication capability requirements.
Inability to exchange user-preferred trajectories in real time; limited decision-support tools to communicate and ensure user preferred routing, integrated sequencing, and spacing of arrivals and departures in terminal radar approach control (TRACON) airspace
No synchronization between onboard avionics, such as flight management systems, with ground flight data processing systems—Lack of synchronization between airborne and ground-based ATC increases controller and flight crew workload, imposes additional communications requirements, and introduces risks of operational errors and incidents. Providing for synchronization between aircraft flight management systems and ground-based ATC data-processing systems would increase predictability for flights and allow aircraft operators to reduce costs, optimize flight routes, improve utility, and reduce dependency on voice communications.
No integration of A/G communications with other aspects of the automation environment— Instructions to and requests from airspace users must be independently exchanged via voice A/G communications and then manually updated in automation systems such as the flight data processor leading to system errors and less efficient movement of aircraft through the airspace.
Inability to automate many repetitive and time-consuming tasks; precludes labor resources from focusing on more productive tasks.
No capabilities inherent in modern, network-based communications; therefore, less efficient dynamic resource management

3.2.4.2 Current Airport Surface Ground-to-Ground Communications Systems Scope and Capabilities Shortfalls

The existing airport communications infrastructure lacks the flexibility for reconfiguration and for accepting new services because of its limited bandwidth and interface capabilities. In addition, many control, signal, and communications cables serving FAA facilities at major airports are 25 to 30 years old. In many cases, the cables are badly deteriorated, lack remote maintenance monitoring functions, and do not provide redundant paths for critical functions. Underground cables are also at risk from inadvertent "cable cuts." It is expensive to deploy and maintain underground cabling as a replacement for existing cables or an expansion for new services.

The limitations imposed by the current G/G communications infrastructure could result in restrictions in the deployment of new ATM services, resulting in the following service limitations (Ref. 4):

- Limited ATM (e.g., traffic) information on the flight deck
- Limited data shared among stakeholders for collaborative decision making (CDM) processes
- Information sharing in support of operational security performed manually instead of electronically
- Not all stakeholders able to access data they need
- Stakeholders unable to use custom data sources

3.3 New Airport Surface Communications Systems Justification

3.3.1 Potential Benefits of New Airport Surface Communications Systems

3.3.1.1 Potential Benefits of New Airport Surface Air-to-Ground Air Traffic Control Communications Systems

The NextGen ConOps states that transforming the ATM system in NextGen is "necessary because of the inherent limitations of today's system, including limits driven by human cognitive processes and verbal communications" (Ref. 35). Likewise, the joint EUROCONTROL/FAA FCS conducted for AP–17 concluded 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" (Ref. 36).

The following excerpts (Ref. 37) from JPDO's NextGen ConOps comprehensively describe NextGen A/G network services. These excerpts are repeated here because they effectively communicate the full envisioned scope, benefits, and advantages of these services and the importance of data communications in enabling them:

> With the transformed role of the flight crew and flight deck in NextGen, data communications are critical to ensuring that data is available for flight deck automation (i.e., avionics to support flight crew decision making). … Data communications are also needed to provide real-time data to the ANSP [air navigation service provider] on the operational aspects of flights. In certain defined airspace, data communications are the primary means of communicating clearances, routine communications, and 4DT [four-dimensional trajectory: latitude, longitude, altitude, and time] agreements between the ANSP and flight deck. … Voice communications are used to supplement data communications for tactical situations and for emergencies to augment procedural responses or risk mitigations. Voice communications are used to communicate with lesser-equipped aircraft in appropriate airspace. …
>
> One of the key transformations is that air-ground voice communications are no longer limited by the assigned frequency-to-airspace sector mapping. This allows greater flexibility for developing and using airspace/traffic assignments in all airspace. Communications paths, including both voice and

data, are controlled by an intelligent network. Communications between the ANSP and the flight deck are established when the flight is activated and are maintained continuously and seamlessly. This capability is linked to the flight data management function so that the system automatically manages who has authority to interact with the flight deck based on the type of agreement being negotiated or information being exchanged. Labor-intensive transfers of control and communication are automated. Data and voice communications are automatically transferred in the flight deck as the aircraft moves between ANSPs.

Data communications are central to TBO [trajectory-based operations], including the use of 4DTs (pushback and taxi inclusive) for planning and execution on the surface, automated trajectory analysis and separation assurance, and aircraft separation assurance applications that require flight crew situational awareness of the 4DTs and short-term intent of surrounding aircraft.

In addition, as indicated above, there is increased sharing of improved common data between the flight deck, operator, and ANSP. In classic airspace where data communications will be available but not required, information exchange can take place with data communications for participating aircraft to provide an operational advantage. Common data includes ATC clearances, current and forecast weather, hazardous weather warnings, notices to airmen (NOTAMs), updated charts, current charting, special aircraft data, and other required data. Data communications also include weather observations made by the aircraft that are automatically provided to ANSPs, weather service providers, and flight operators for inclusion in weather analysis and forecasts. Each of these data communications functions are managed by required communications performance (RCP) standards.

The trend toward 2015 and beyond features a decreasing use of voice, with data becoming the primary communication link. This is shown in Table 4, which illustrates a projected allocation between voice and data communications during this period. As suggested by the table, on the airport surface, voice would remain the primary mode of communications for low delay and high availability pilot-ATC exchanges, with a data link used as a primary service for other messages and data-intensive services such as graphical weather. In all domains, voice communication would remain a backup for any data service.

TABLE 4.—COMMUNICATION ALLOCATION BETWEEN VOICE AND DATA LINK (D/L)
[Information from Ref. 38.]

		Airport surface	
		Primary	Backup
Pilot-controller dialog	Emergency messages	Voice	D/L
	Tactical clearances	Voice and some D/L	Voice and D/L
	Strategic clearances	D/L	Voice
	Information messages	D/L	Voice
Other exchanges and broadcasts	Pilot-pilot dialog	Voice[a]	D/L
	Flight information exchange	D/L	Voice
	Air traffic management exchange	D/L	Voice
	Information broadcast	D/L	Voice
	Air-to-air surveillance	D/L	

[a]No specific requirement identified except current Traffic Information Broadcast by Aircraft (TIBA) procedure.

Although a gradual addition of data communications to the existing VHF voice systems should accommodate capacity requirements in the near term to midterm, additional spectrum is required to provide enough capacity to satisfy a growing demand for data communications in the far term. An AeroMACS built to augment VHF voice and data communications systems already in place, including those implemented as part of Data Comm, would increase overall communications system capacity, thus relieving congestion and allowing for the introduction of additional services.

3.3.1.2 Potential Benefits of New Airport Surface Ground-to-Ground Communications Systems

The benefits of a new broadband and networked airport surface G/G communications system are similar to those enabled by improved A/G communications in that common data can readily be provided to the flight planners and the flight deck. Current NAS modernization and the future NextGen air traffic system will increase the demands for CNS information sharing and standardization among stakeholders. An AeroMACS could provide the following benefits:

- Standardized ATM information (e.g., surveillance and weather information) provided to the ANSP, flight deck, and aircraft operators[9]
- Information sharing among security stakeholders, facilitating collaboration, risk management, and decision making
- Reliable and secure integration of voice, video, and data at all airport surface locations
- System Wide Information Management (SWIM) networked integration of data sources and users
- Flexible, expandable, and affordable delivery of needed information and services, independent of user physical location
- Reduced VHF spectrum congestion

3.3.2 Operational Shortfalls Addressed by Data Comm

The FAA intends for Data Comm to significantly mitigate the safety, capacity, efficiency, and productivity shortfalls described in Table 3. It is anticipated that Data Comm will support the following improvements in airspace use and capacity (Ref. 39):

- Improved airspace use and capacity
- A more efficient A/G information and clearances exchange mechanism
- An additional means of communication between flight crews and controllers
- Reduced congestion on the voice channels
- Reduced operational errors and flight crew deviations resulting from misunderstood clearances and read-back errors
- Trajectory-based operations
- Reduced controller and flight crew workload

[9]G/G communications would provide connectivity between weather and surveillance sensors and associated network equipment, while an A/G link would provide the end product (e.g., weather or surveillance data) to the aircraft.

Data Comm is planned to be implemented in three segments (Ref. 40; see Figure 11):

- The first segment will facilitate data communications deployment and introduce initial 4–D routes.
- The second segment will introduce conformance management and initial 4–D agreements.
- The third segment will expand 4–D agreements and provide an operational environment that allows the transfer of some separation assurance tasks from the ground to the air.

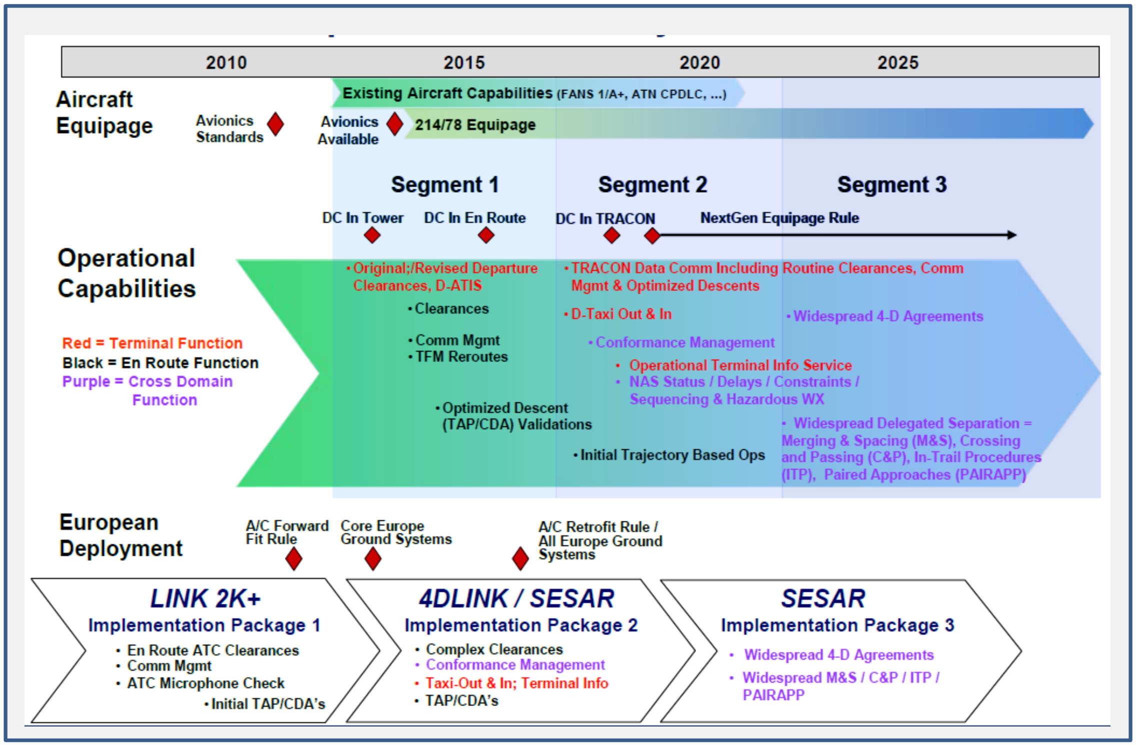

Figure 11.—Operational capabilities of Data Comm (Ref. 41). Acronyms are defined in Appendix A.

An AeroMACS implementation in the United States might follow or overlap Segment 2 (VDL Mode 2 implementation) and enable additional services and operational capabilities not covered by VDL Mode 2 for Data Comm. Figure 11 depicts the planned capabilities for Data Comm and, for comparison, the European planned deployment of data communications capabilities. Those operational capabilities and the associated services shown in the figure for Segment 3, for example, the services needed to provide widespread 4–D agreements (on the airport surface), might benefit from a higher performance technology implementation like AeroMACS. In addition to potentially augmenting the critical data communications services provided by VDL Mode 2 for Data Comm, AeroMACS could enable new noncritical services.

3.3.3 Description of Desired Changes

3.3.3.1 Desired Changes for Air-to-Ground Air Traffic Control Communications Systems

Data Comm will provide data communications as an enhancement to and potential replacement of A/G voice communications as the primary A/G link in an ATC operational environment. This additional mode of communications will contribute to improvements in airspace use and capacity. An AeroMACS system could further reduce congestion on VHF voice channels and increase A/G communications capacity on the airport surface by offering spectrum for additional services not offered by Data Comm.

With Data Comm and AeroMACS, the overall A/G information exchange could become more dynamic and efficient, potentially reducing operational errors and improving safety.

For airport surface A/G ATC communications, AeroMACS is not proposed to replace any current systems or services; rather, it is proposed to augment them. Furthermore, it is assumed that the critical services proposed for implementation by Data Comm as an addition and/or replacement of voice communication will be in place by the time AeroMACS is implemented.
The proposed AeroMACS is being designed to limit interference to the existing services and operations in the C-band. No operational changes are expected for C-band incumbent systems.

3.3.3.2 Desired Changes for Airport Surface Ground-to-Ground Communications Systems

The desired changes for G/G communications have many similarities to the changes desired for A/G communications by contributing to improvements in airspace use and capacity. Deployment of AeroMACS for G/G information exchange would augment and/or replace existing airport surface G/G communications systems by providing more flexible data exchange—new communications nodes could be added much more quickly and at significantly reduced costs in comparison to changes to the current cabled systems. Communications would become more dynamic and efficient, potentially reducing operational errors and improving safety.

3.3.4 Change Priorities and Roadmaps

Figure 12 demonstrates how the C-band system development fits into the FCS proposed communications evolutional roadmap for European and U.S. ATM (as envisioned in 2007).

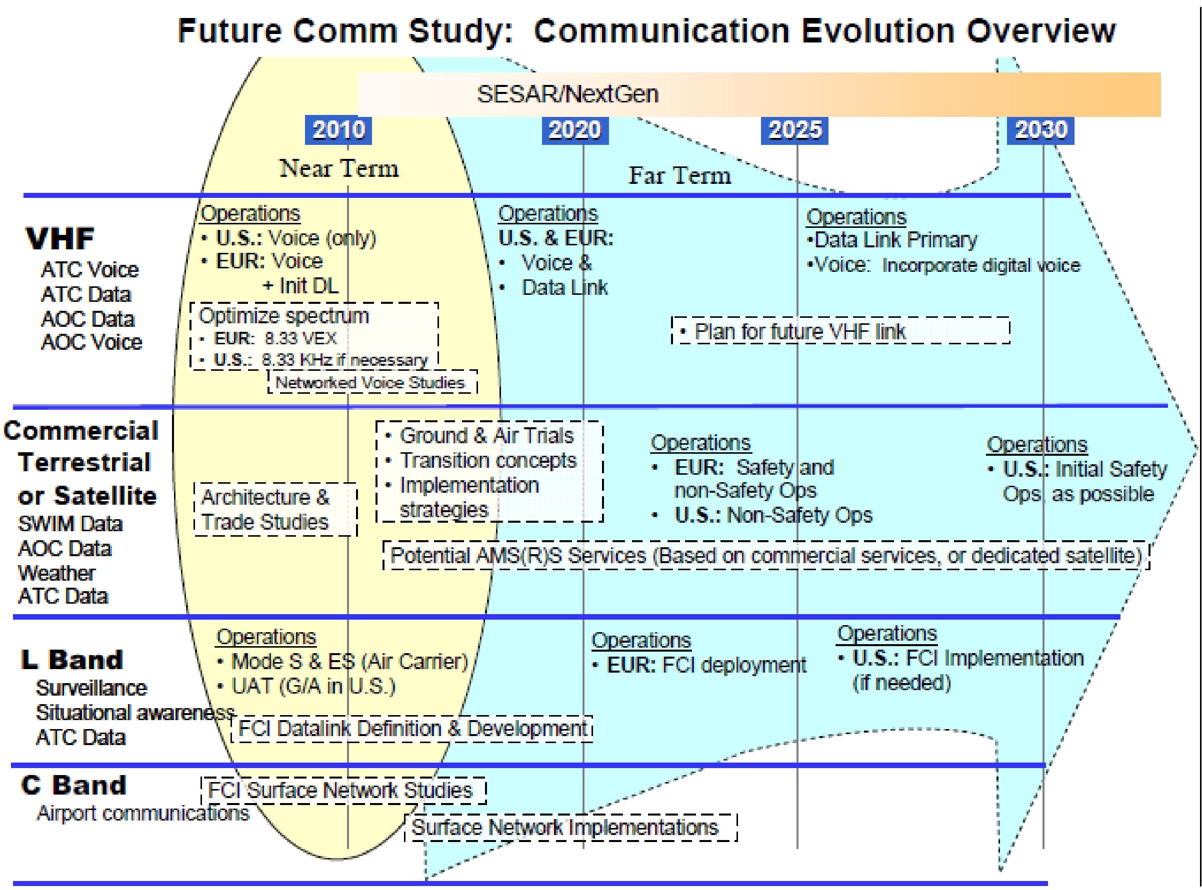

Figure 12.—Evolution overview of aeronautical mobile communications (Ref. 42; note that this schedule is subject to change). Acronyms are defined in Appendix A.

Figure 13 depicts the proposed C-band (and L-band) communications systems far-term strategy as part of the NAS Enterprise Architecture Communication Infrastructure Roadmap.

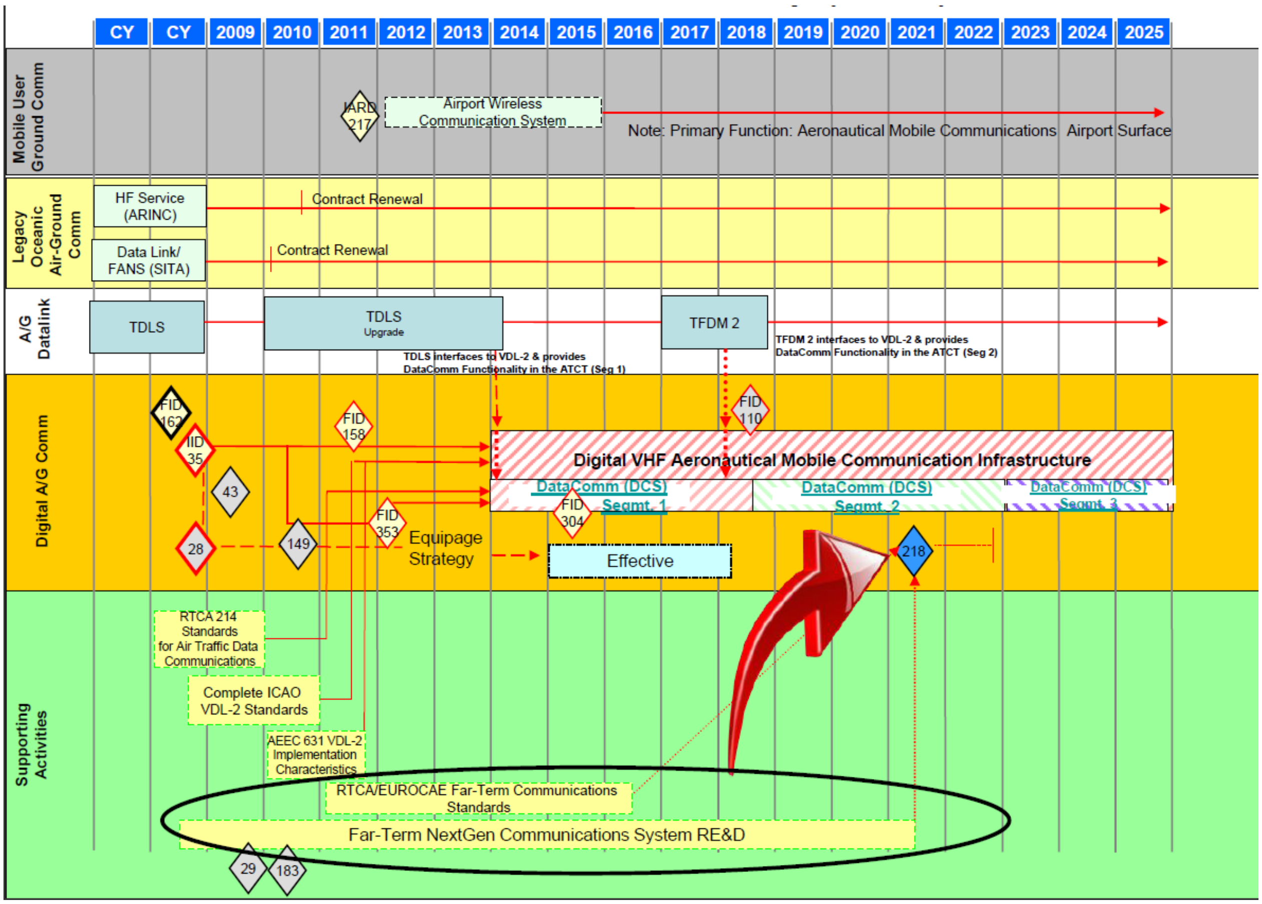

Figure 13.—Federal Aviation Administration communications roadmap (Ref. 43). Acronyms are defined in Appendix A.

3.3.5 Assumptions and Constraints for AeroMACS

Assumptions and constraints for this document follow:

- The 5091- to 5150-MHz spectrum allocation provisioned for AeroMACS at the World Radiocommunications Conference (WRC–07) is only for use on the airport surface. This allocation is within the AM(R)S band. Therefore, AeroMACS applications are constrained to mobile applications on the airport surface. This is interpreted to include communications for nonmobile (i.e., fixed) applications that support the safety and regularity of flight.
- The proposed AeroMACS is assumed to provide an increase in overall A/G communications systems capacity by utilizing the new spectrum (i.e., not VHF).
- As mentioned earlier, the scope of this ConUse and requirements document includes airport surface A/G ATC communications and G/G communications.
- AeroMACS will be designed specifically for data communication.
- As noted earlier, this document assumes that the data communications system developed as part of Data Comm will precede an AeroMACS implementation and deployment.

- Although some critical services could be supported, AeroMACS systems will also target noncritical services, such as weather advisory and aeronautical information services implemented as part of an Airborne SWIM program.
- AeroMACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the C-band. Additional interference research and testing will determine if any operational constraints are to be imposed, such as limiting the number of users, the time of the day, duration, and other parameters.

The economic feasibility of AeroMACS systems may be evaluated as part of Phase II of Task 7.

3.4 Proposed AeroMACS Systems

3.4.1 Objectives and Scope

Consistent with the need to overcome the specific current communications system problems and shortfalls discussed earlier, the two primary general drivers for a future radio system are (1) "to provide an appropriate communications infrastructure to support future air traffic growth" and (2) "to provide a consistent global solution to support the goal of seamless air traffic management" (Ref. 44). Some FAA objectives defined in the FAA's NextGen portfolio are based on the requirement to support future air traffic growth. AeroMACS will be designed and developed to help meet those objectives in part by expanding the data communications capacity in the airport surface domain. Global harmonization is being ensured by developing the proposed AeroMACS component of the FRS as a collaborative effort of the U.S. and European partners.

3.4.1.1 AeroMACS as Part of the Next Generation Air Transportation System

Figure 14 illustrates the proposed NextGen operational view 1 (OV−1) in 2025, listing six of the seven solution sets of the FAA’s NextGen portfolio.[10] AeroMACS could fulfill part of the proposed NextGen vision by supporting implementation of the following solution sets:

- Initiate trajectory-based operations
- Increase arrivals and departures at high-density airports
- Improve collaborative ATM

Figure 14.—Next Generation Air Transportation System (NextGen) operational view in 2025 (Ref. 45). Acronyms are defined in Appendix A.

[10]The seventh solution set, not shown in the figure, is “safety, security, and environment.”

The following three subsections briefly describe the specific operational improvements (OIs) that could be enabled by AeroMACS for these three solution sets.[11]

Initiate trajectory-based operations (excerpts from Ref. 46)

OI 101103—Provide Interactive Flight Planning From Anywhere: Flight planning activities are accomplished from the flight deck as readily as any location. Airborne and ground automation provide the capability to exchange flight planning information and negotiate flight trajectory contract amendments in near real-time.

OI 104121—Automated Negotiation/Separation Management: Trajectory management is enhanced by separation management automation that negotiates with properly equipped aircraft and adjusts individual aircraft Four-Dimensional Trajectories (4DTs) to provide efficient trajectories, manage complexity, and ensure separation assurance.

OI 104126—Trajectory-Based Management—Gate-To-Gate: All aircraft operating in high density airspace are managed by Four Dimensional Trajectory (4DT) in En Route climb, cruise, descent, and airport surface phases of flight to dramatically reduce the uncertainty of an aircraft's future flight path in terms of predicted spatial position (latitude, longitude, and altitude) and times along points in its path.

Integrating separation assurance and traffic management time constraints (e.g., runway times of arrival, gate times of arrival), this end state of 4DTbased capability calculates and negotiates 4DTs, allows tactical adjustment of individual aircraft trajectories within a flow, resolves conflicts, and performs conformance monitoring by Air Navigation Service Providers (ANSPs) to more efficiently manage complexity, ensure separation assurance, and enhance capacity and throughput of high-density airspace to accommodate increased levels of demand. This will be enabled by the trajectory exchange through data communications, as well as many new surface automation and 3D (x, y, and time) trajectory operations.

Increase arrivals and departures at high-density airports (excerpts from Ref. 47)

OI 102153—Limited Simultaneous Runway Occupancy: Runway capacity is increased through the allowance of more than one aircraft on the runway, at a given time, for specific situations.

OI 104117— Improved Management of Arrival/Surface/Departure Flow Operations: This Operational Improvement (OI) integrates advanced Arrival/Departure flow management with advanced Surface operation functions to improve overall airport capacity and efficiency. Air Navigation Service Provider (ANSP) automation uses arrival and departure-scheduling tools and four dimensional trajectory (4DT) agreements to flow traffic at high-density airports. Automation incorporates Traffic Management Initiatives (TMIs), current conditions (e.g., weather), airport configuration, user provided gate assignments, requested runway, aircraft wake characteristics, and flight performance profiles. ANSP, flight planners, and airport operators monitor airport operational efficiency and make collaborative real-time adjustments to schedules and sequencing of aircraft to optimize throughput.

OI 104125—Integrated Arrival/Departure and Surface Traffic Management for Metroplex: Metroplex traffic flow is more efficiently managed through arrival/departure and surface scheduling automation, integrated with all available constraint information, including weather impacts, optimizing traffic throughput by eliminating potential gaps in unused capacity, thereby increasing regional/metroplex capacity.

Data communications is a key element of super-density operations, allowing the Air Navigation Service Provider (ANSP) to maximize access for all traffic, while adhering to the principle of giving advantage to those aircraft with advanced capabilities.

[11]These descriptions are extracted from the NAS Enterprise Architecture web portal (https://nasea.faa.gov).

OI 104206—Full Surface Traffic Management with Conformance Monitoring: Efficiency and safety of surface traffic management is increased, with corresponding reduction in environmental impacts, through the use of improved surveillance, automation, on-board displays, and data link of taxi instructions.

Equipped aircraft and ground vehicles provide surface traffic information in real-time to all parties of interest.

OI 104208—Enhanced Departure Flow Operations: Enhancements to surface traffic management incorporate taxi instructions, surface movement information, and aircraft wake category to enhance departure flow operations. Clearances are developed, delivered, monitored and provided in graphical or textual format that is used by the flight deck display to support taxi, takeoff and departure flows in all conditions. At high-density airports clearances and amendments, requests, NAS status, airport flows, weather information, and surface movement instructions are issued via data communications.

Surface decision support and management systems use ground and airborne surveillance and a scheduling and sequencing system to develop and maintain schedules of departing aircraft within a defined time horizon. Information is sent to participating aircraft and the air navigation service provider via data communications or voice and adjustments are made to push back times, taxi instructions, etc. to maintain schedules.

OI 104209—Initial Surface Traffic Management: Departures are sequenced and staged to maintain throughput. ANSP automation uses departure-scheduling tools to flow surface traffic at high-density airports. Automation provides surface sequencing and staging lists for departures and average departure delay (current and predicted).

ANSP automated decision support tools integrate surveillance data. This includes weather data, departure queues, aircraft flight plan information, runway configuration, expected departure times, and gate assignments.

Improve collaborative air traffic management (excerpts from Ref. 48)

OI 101102—Provide Full Flight Plan Constraint Evaluation with Feedback: Timely and accurate national airspace system (NAS) information enables users to plan and fly routings that meet their objectives. Constraint information that impacts the proposed route of flight is incorporated into air navigation service provider (ANSP) automation, and is available to users. Examples of constraint information include special use airspace status, SIGMETS [data link significant meteorological information], infrastructure outages, and significant congestion events.

OI 103305—On-Demand NAS Information: National Airspace System (NAS) and aeronautical information will be available to users on demand. NAS and aeronautical information is consistent across applications and locations, and available to authorized subscribers and equipped aircraft. Proprietary and security sensitive information is not shared with unauthorized agencies/individuals.

OI 105207—Full Collaborative Decision Making: Timely, effective, and informed decision-making based on shared situational awareness is achieved through advanced communication and information sharing systems.

Stakeholder decisions are supported through access to an information exchange environment and a transformed collaborative decision making process that allows wide access to information by all parties (whether airborne or on the ground), while recognizing privacy and security constraints. Decision-makers request information when needed, publish information as appropriate, and use subscription services to automatically receive desired information through the net-centric infrastructure service.

3.4.1.2 AeroMACS Operational Environment for Next Generation Air Transportation System

Along with the "as-is" SV–2 views of the NAS developed by the FAA Air Traffic Organization (ATO) planning organization, such as shown in Figure 9, were a series of separate "to-be" views for 2025. Figure 15 presents an SV–2 2025 rollup data flow view for the proposed NAS. The figure was annotated with labels and dashed red boxes to highlight the five NAS information flow areas that may be enabled by AeroMACS:

- Surveillance
- Weather
- Flight information
- Command and control
- Aeronautical information

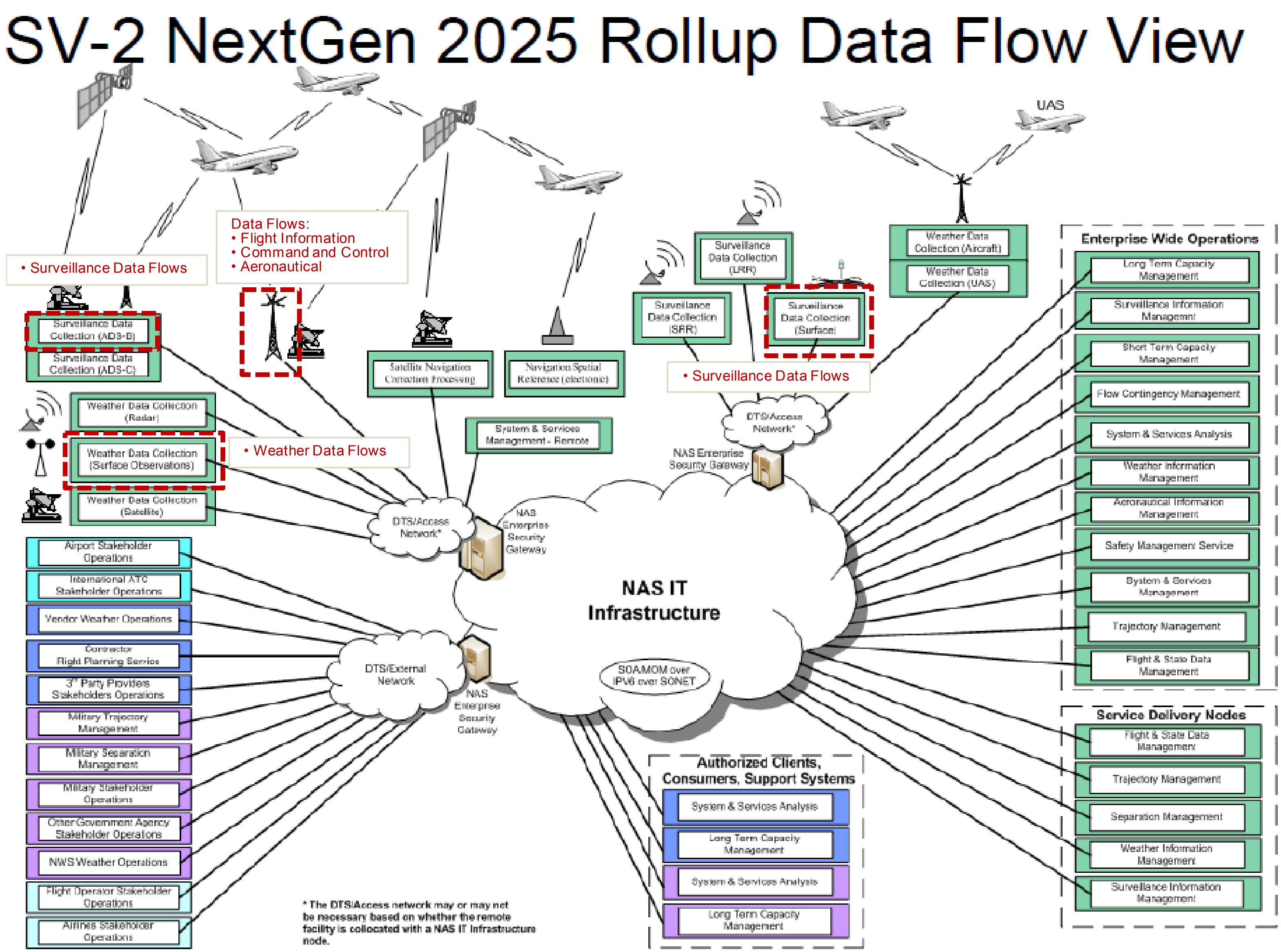

Figure 15.—System view 2 (SV–2) Next Generation Air Transportation System (NextGen) 2025 rollup data flow view (Ref. 49). Acronyms are defined in Appendix A.

3.4.2 Proposed System Description: AeroMACS

As noted earlier, the FCS technology assessment recommended a system based on the IEEE 802.16 standard and its extension, IEEE 802.16e-2005 (Refs. 6 and 18) implemented at the aeronautical C-band as the preferred technology to implement a future airport surface communications system (i.e., AeroMACS). The waveforms described in IEEE 802.16e standard are very flexible and scalable to handle a wide range of communication services. The Worldwide Interoperability Microwave Access (WiMAX) Forum, an industry consortium that promotes the use of wideband wireless systems based on a carefully selected and agreed upon subset of the IEEE 802.16 standards, has developed several profile applications that will be supported by device manufacturers. A new standards profile for airport applications is currently being developed within an RTCA special committee (SC–223) to operate in the C-band (5091 to 5150 MHz) and make use of the scaling properties inherent in IEEE 802.16e standard.[12] IEEE 802.16e standard defines the waveform capabilities needed for various uses. It has considerable flexibility at the physical and Media Access Control (MAC) layers that will lead to a number of tradeoffs in adapting this type of waveform to the needs of an AeroMACS. Some of the tradeoffs to be considered follow:

- Bandwidth (capacity) versus number of base stations (BSs)
- Allocation methodology for mapping channel assignments
- Number of power control levels
- Allocation of capacity for voice circuits

The proposed AeroMACS could provide supplemental means for the ATC communications required by the operating rules (e.g., VHF voice communications) in continental airspace (albeit on the airport surface) and will adhere to the data link characteristics noted in the “Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace (Continental SPR Standard)” (Ref. 7).

3.4.3 AeroMACS Frequency and Technology: Environment, Requirements, and Limitations

The following observations regarding airport surface communications and the suitability of the aeronautical C-band resulted from the “Future Aeronautical Communication Infrastructure Technology Investigation” (Ref. 24):

- 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 because of the attenuation conditions at this frequency.
- There is capacity that is not utilized in the aeronautical C-band (5000 to 5010 MHz, 5010 to 5030 MHz, and/or 5091 to 5150 MHz). Because of severe path-loss problems, 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.
- For the aeronautical C-band (5000 to 5010 MHz, 5010 to 5030 MHz, and/or 5091 to 5150 MHz), IEEE 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 modeled aeronautical microwave-landing-system band channel show favorable results
    - Private service providers have shown interest in the IEEE 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]Specifically, IEEE 802.16–2009 will provide the basis of ongoing the profile selection.

These conclusions help to drive the AeroMACS ConUse and system requirements presented in this document.

3.4.4 User Impact

Users of the system will include service providers and airspace users (on the airport surface) of A/G and G/G communications:

- Safety and regularity of flight—addressed by air traffic controllers and NAS specialists on the ground and flight crews in aircraft at the airport
- Commercial data transfer related to airline operations and provisions of services to passengers

The introduction of AeroMACS is expected to increase communications system capacity, thus allowing the addition of new services and expanding the user base. Figure 16 illustrates the effect of the new system on the user base.

It should be noted that the relationship between the capacity demand and changes in the user base can be viewed as a repeating cycle of events. The proposed introduction of an AeroMACS will increase the overall capacity of the system and open up opportunities for addition of data services not provided under Data Comm. Many of those, most notably services associated with the Airborne SWIM Program, would provide for wider system use. Not only more users would be expected to take advantage of the new data communications capabilities, the types of users allowed to participate would increase as well.

As more data services are introduced and become part of day-to-day operations, the demand for additional services, and therefore capacity, is expected to grow. The availability of a new frequency band, such as C-band, in addition to the VHF frequencies supporting the existing voice and data communications services, will alleviate long-term capacity problems.

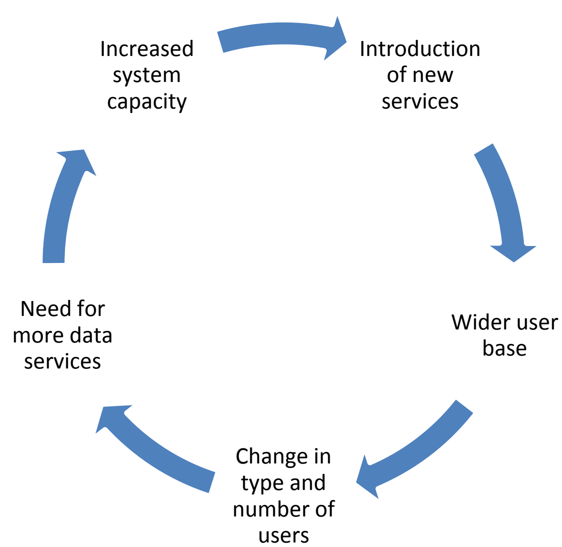

Figure 16.—Communication system capacity demand and user base changes.

The expanded use of advanced technologies in general and of AeroMACS in particular, along with increased capacity, is expected to improve aviation safety and enhance operational efficiency for NAS users. The continued migration from a NAS based on a ground infrastructure and voice communication to a system that encompasses both ground and airborne components and utilizes the exchange of digital data as the primary type of communication, will (Ref. 50)

> …support the human in doing what they do best—choosing alternatives and making decisions, while the technology accomplishes what it can do best—the acquisition, compilation, evaluation and exchange of information.

NextGen communications systems will enable users to play a more active role in each of the NAS service areas:

- NAS management (strategic flow and resource management): SWIM capability will enable stakeholders' access to relevant information. Users will become key participants in the planning of traffic flow management and will utilize a comprehensive information exchange process to improve flight operations planning according to capacity and traffic conditions to minimize congestion and delays.
- Flight planning and emergency alerting services: Users will have interactive flight planning capabilities with an immediate access to real-time data. User-preferred routing will become available to properly equipped aircraft for both domestic and international flights.
- Surface operations: Increased data-exchange capabilities will provide more users at more airports with flight clearances, airport information, positions of other aircraft, taxi routes, and weather conditions (current, forecast, and hazardous). Users will have improved real-time planning with continuous update of the flight profile.

3.4.5 Operational Policies and Constraints

Operational aspects of aeronautical communications are changing with an increased emphasis on safety and cost reduction achieved via increased automation and efficiency, fewer delays, and other improvements.

General issues such as cost, spectrum availability, technology choice, and standards development, as well as the logistics of system rollout will all influence operational policies and constraints.

The NextGen ConOps details operational policy issues that would affect the NextGen system (Ref. 51). To support the proposed AeroMACS development and implementation, policies might need to be developed and/or revised in the following areas:

- International and domestic regulations
- Safety management standards
- Processes to streamline certification and reduce costs of aircraft and ground equipment
- Privacy and liability legal concerns related to information sharing,
- Communications priority and congestion relief (e.g., market-driven versus aircraft type)
- Government role versus private sector role
- Financing and maintenance responsibilities

3.5 AeroMACS ConUse

3.5.1 RTCA National Airspace System Concepts of Operation Guidance

As noted in Section 2.0, the definitions of the AeroMACS ConUse were based on guidance and information provided by several higher order ConOps. A key NAS ConOps source driving the AeroMACS ConUse was RTCA's NAS ConOps (Ref. 13). Appendix B presents a comprehensive listing derived from Reference 13 of future communications concepts applicable to airport surface operations to enable the transfer of the following NAS information types:

- Surveillance
- Weather
- Flight planning

- Aeronautical information
- Resource management

3.5.2 Data Comm Operational Scenarios

Operational scenarios can illustrate how proposed system capabilities could be used in an operational environment. The scenarios can demonstrate how the services offered by the new communications system could help to

- Minimize operational errors, including those resulting from misunderstood instructions and read-back errors
- Improve efficiency
- Provide further automation of traffic control
- Enable more decisions to be made off the ground

The Data Comm FPR (Ref. 5) lists operational scenarios envisioned to be enabled by the data communications system. In general, these scenarios would also be applicable to an AeroMACS implementation, especially those presented for Segment 2 and beyond, during which Data Comm VDL Mode 2 operational capabilities could be augmented by AeroMACS. Operational scenarios from Segments 2 and 3 of Data Comm that are applicable to the airport surface environment follow (Ref. 52).

- Departure Airport (Tower) Scenarios
    - (S2,3) Proposed routes including standard routing through traditional airspace, and 4-D trajectory based routing for transit through High Performance Airspace are developed and loaded into the flight management system via A/G data communications for aircrew review.
    - (S2,3) At the request of the flight crew, ATM-related operational data for the flight (e.g., departure sequence, collaborative decision making agreements, and slot-time allocations) are relayed by data communications to the flight crew in preparation for departure.
    - (S2,3) After issuance of the departure clearance, the automation system generates a request via data communications to the aircraft automation to report its active route. This information is compared with the departure clearance to verify consistency.
    - (S2,3) Once the flight crew compares and validates the departure clearance against the filed flight plan, the flight crew requests a taxi route instruction using data communications. The assigned controller reviews the taxi route instruction suggested by the automation for the aircraft, and upon approval, sends the taxi route instruction via data communications. Taxi revisions via data communications are now provided not only to reroute aircraft, but also to reorder aircraft.
    - (S2,3) Enhanced capabilities and increased access to surface data and flight status provide traffic management automation with information about the flight's location, taxi sequence, and the departure queues. As a result, the TFM [traffic flow management] automation provides departure clearance revisions at an operationally appropriate amount of time in advance of the departure.
    - (S2,3) Once the aircraft has been cleared for takeoff via voice, data communications manages the data communications eligibility transfer to the TRACON position and surface ATC data communications cease.
    - (S3) In advance of a planned departure, users now file 4D trajectory-based flight plans for operations in HPA [high-power amplifier]. Users and air traffic service providers [ATSPs] collaboratively negotiate 4-D trajectory agreements from take-off to approach, based on user requests and anticipated constraints. This agreement is embedded in the departure clearance. The final point in the clearance also includes the required time constraint for the arrival fix.

- Arrival Airport (Tower) Scenarios
    - (S2,3) The tower ground controller clears the flight crew to taxi via voice or data communications depending upon the dynamics of the situation and monitors the traffic situation as they maneuver the aircraft to the arrival gate.
    - (S3) After the aircraft lands, the tower runway controller confirms the previously provided runway exit and directs the flight crew to contact the ground controller.

3.5.3 Proposed Services for AeroMACS

3.5.3.1 Air Traffic Services

Reference 9 classifies all of the COCR ATS data services as safety critical. It further identifies services that are not planned to be implemented by Data Comm through Segment 3 and identifies them as possible candidates for implementation via C-band and/or L-band. It must be stressed that both C-band and L-band systems are being developed for the future communications infrastructure to accommodate the safety and regularity of flight services. These are designed to operate over a protected spectrum for aviation, so any COCR ATS could be allowed to be implemented via one or the other of these links (as appropriate).

As described earlier, this document focuses on the COCR ATS data services that are not expected to be provided by Data Comm through Segment 2, which are proposed as candidates for AeroMACS:

- Flight information services
    - Data link operational terminal information service (D–OTIS)
    - Data link surface information and guidance (D–SIG)
    - Flight plan consistency (FLIPCY)
    - System access parameters
    - Pilot preferences downlink (PPD)
- Weather advisory service
    - Data link significant meteorological information (D–SIGMET)
- Emergency information service
    - Urgent contact (URCO), if in conjunction with other more routine services

Additional data services that may be provided via AeroMACS may be identified as NextGen and Single European Sky ATM Research (SESAR) progress.

3.5.3.2 Airborne System Wide Information Management (SWIM) Suitable Services

SWIM, an FAA technology program designed to facilitate the sharing of ATM system information (airport operational status, weather information, flight data, status of special-use airspace, and NAS restrictions), can be implemented via G/G, A/G, and air-to-air (A/A) communications infrastructure components. Each of these components would enable efficient data exchange between authorized users in the respective domain. An AeroMACS could provide means for the A/G data transfer on the airport surface.

An implementation of AeroMACS would facilitate meeting the primary objective of the SWIM Program: that is, to improve the FAA's ability to manage the efficient flow of information through the NAS. When used to enable Airborne SWIM capabilities, an AeroMACS could be designed to ensure that its use provides the following desired SWIM features:

- Reduced costs for NAS users to acquire NAS data and exchange information
- Increased shared situational awareness among the NAS user community
- FAA compliant secure data exchange among the NAS user community

Figure 17 shows how Airborne SWIM (with the communication links potentially provided via AeroMACS) fits in the overall FAA A/G communications plan and illustrates interactions of SWIM elements with the other NextGen programs, such as automatic dependent surveillance—broadcast (ADS–B) and Data Comm.

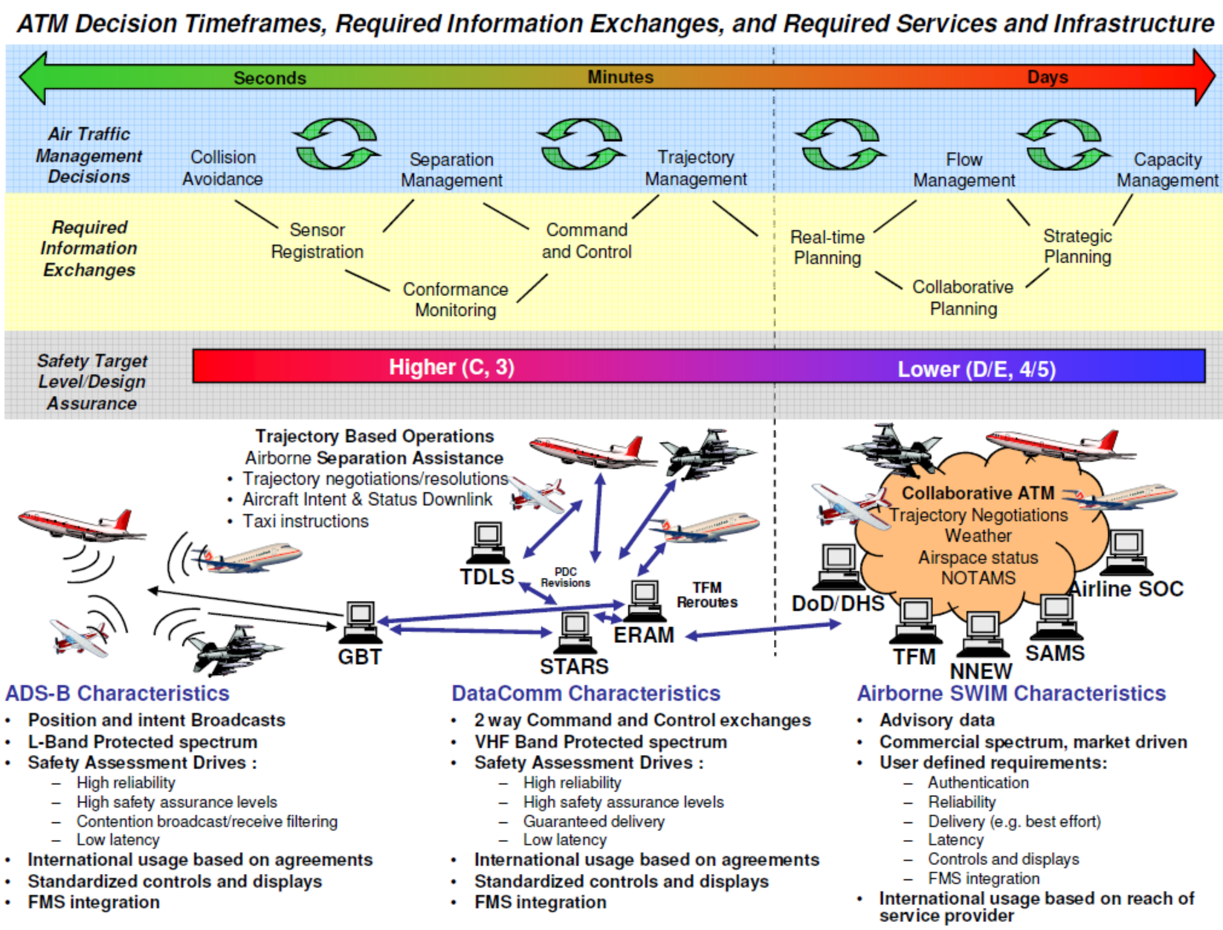

Figure 17.—Airborne System Wide Information Management (SWIM) and other Next Generation Air Transportation System (NextGen) Programs (Ref. 53). Acronyms are defined in Appendix A.

As shown in the figure, AeroMACS links will have lower safety targets when used to provide SWIM-related services compared with the other data communications services. For example, Figure 17 shows a required level of C3 (medium risk) for Data Comm and D/E 4/5 (low risk) for SWIM (see Ref. 54 for more information). Although it is anticipated that some Airborne SWIM services could be provided over the commercial (i.e., unprotected (non-AM(R)S)) spectrum—as shown in the figure—it is likely that other Airborne SWIM services could make use of protected spectrum to support regularity of flight.[13] These later services would be suitable targets for an AeroMACS implementation.

As part of SWIM, AeroMACS would enable the exchange of information between diverse users adopting a service-oriented architecture. Services would be offered from individual providers as well as centralized providers.

[13]For example, current aeronautical (airline) operational control (AOC) communications is conducted over the AM(R)S spectrum to support regularity-of-flight operations rather than safety-of-flight operations.

Figure 18 shows the A/G and G/G SWIM elements. It depicts Airborne SWIM (potentially provided over AeroMACS) as a facilitator of NAS data exchange, such as surveillance, flight, aeronautical, meteorological, air traffic flow and capacity management (ATFCM) scenario, and demand and capacity data.

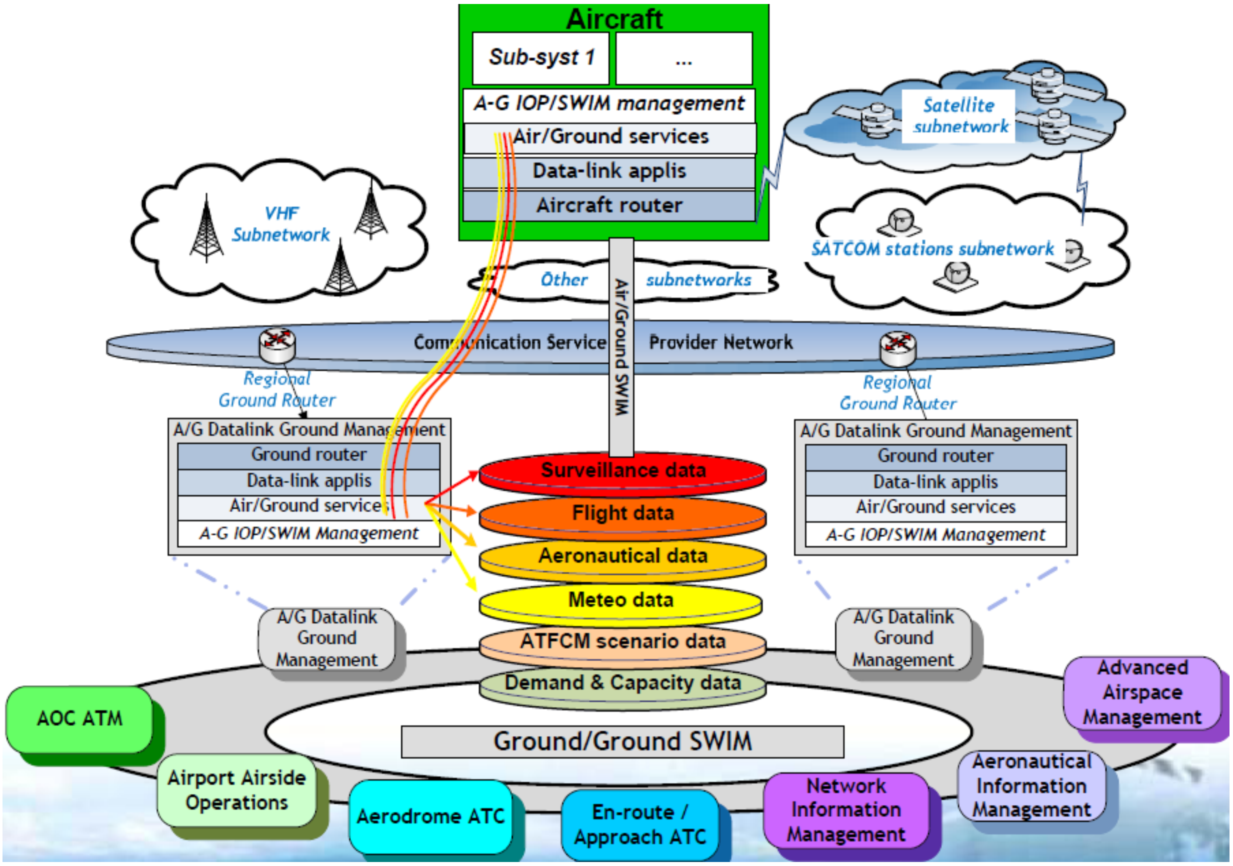

Figure 18.—Air-to-ground data link management and aircraft participation in System Wide Information Management (SWIM) (slightly modified from Ref. 55). Copyright Thales Air Systems; used with permission. Acronyms are defined in Appendix A.

These mostly weather advisory and aeronautical information services include

- Aviation Digital Data Service (ADDS)
- AWOS Data Acquisition Service (ADAS)
- Expanded Terminal and Tower Data Service
- General Information Message Distribution Service
- Information Display System (IDS) Data Service
- NextGen Network Enabled Weather (NNEW) service[14]
- NOTAM distribution service
- TMA flight data service
- Weather and Radar Processor (WARP)/Weather Information Network Server (WINS) Next Generation Radar (NEXRAD) service

[14]It is possible that the information provided through the NNEW service could range from the advisory for routine forecasts through safety critical information for certain hazardous weather warning messages, which might limit the extent to which this might be provided over commercial links. This requires further investigation.

Figure 19 illustrates the introduction of SWIM services over time. Implementation of the proposed AeroMACS is likely to overlap with SWIM Segments 3 and 4 when Airborne SWIM is introduced.

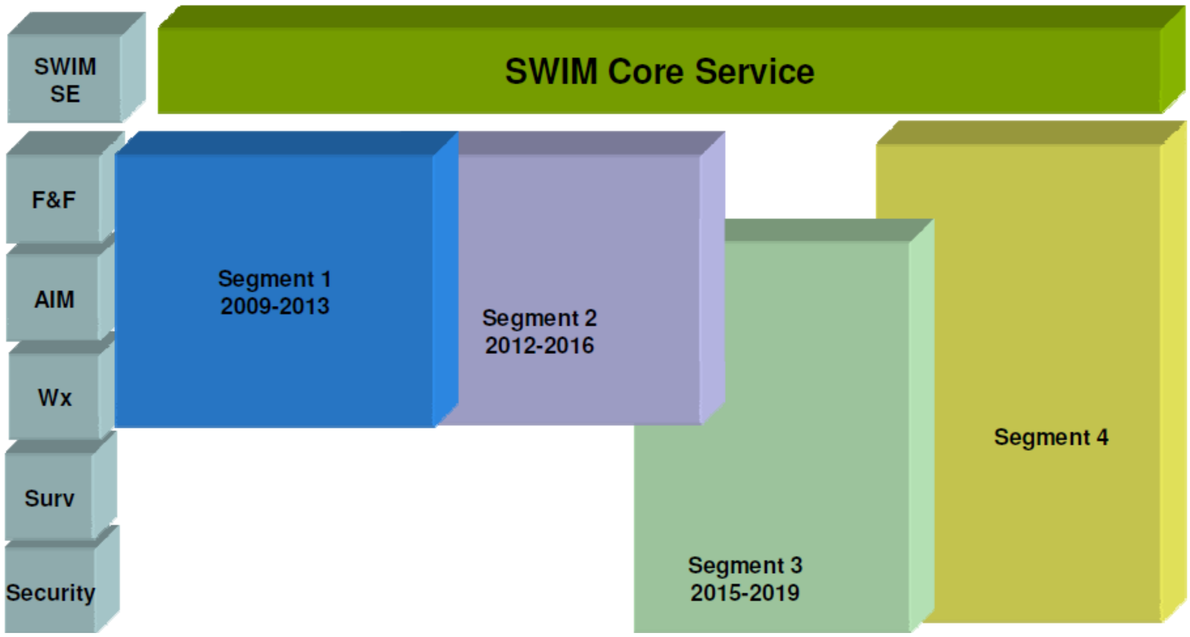

Figure 19.—System Wide Information Management (SWIM) execution by segments (Ref. 53). Acronyms are defined in Appendix A.

3.5.4 Next Generation Air Transportation System Communications Operational Concepts

Figure 20 shows a typical flight profile and the ATS functions supporting users in each domain.

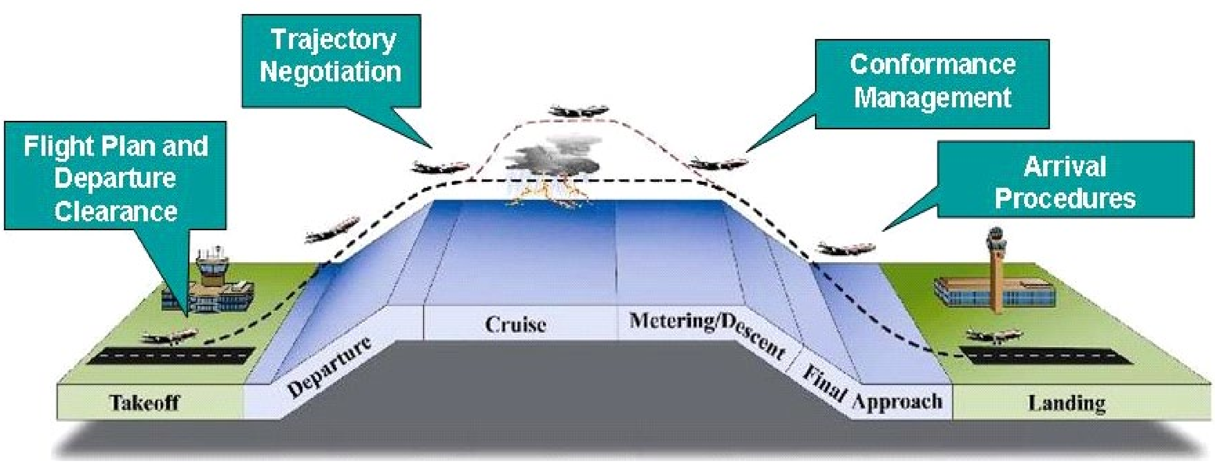

Figure 20.—Typical National Airspace System (NAS) flight profile and air traffic services (ATS) functions (Ref. 5).

Table 5 lists the operational scenarios and concepts envisioned for the midterm of the NextGen airport surface flight phase shown in Figure 20. Although most, if not all, of these concepts are currently envisioned for Data Comm, these are technology independent and, thus, equally valid for an AeroMACS implementation.

TABLE 5.—NEXT GENERATION AIR TRANSPORTATION SYSTEM (NextGen) MIDTERM OPERATIONAL CONCEPTS FOR THE AIRPORT SURFACE

Phase of flight	NextGen midterm communications operational concept (from Ref. 8)
Flight planning	Access to flight planning information will be available to authorized users via a secure network and will include a publish/subscribe capability so that users can receive automatic updates when conditions change along the proposed flight path.
Push back, taxi, and departure	As the time for the flight approaches, the final flight path agreement will be delivered as a data message to pilots who access the agreement before beginning the flight.

3.5.5 AeroMACS Operational Services and Scenarios Derived from the Communications Operating Concept and Requirements

3.5.5.1 Potential AeroMACS Operational Services Derived from the Communications Operating Concept and Requirements

Operational concepts also can be defined according to the different geographic flight domains. Table 6 illustrates the potential operational services suitable for implementation via AeroMACS for the airport surface based on the COCR services previously identified as potential applications (Ref. 9).

TABLE 6.—USE OF THE PROPOSED AeroMACS IN THE AIRPORT FLIGHT DOMAIN
[Acronyms are defined in Appendix A.]

Operational services	Airport domain phases			
	Predeparture airport domain	Departure taxi airport domain	Arrival airport domain	Arrival taxi airport domain
Flight information services	D–OTIS D–RVR D–SIG D–SIGMET	D–OTIS D–RVR D–SIG D–SIGMET	D–OTIS D–RVR D–SIG	D–RVR D–SIG
Flight position, flight intent, and flight preferences services	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE
Emergency information service	URCO	URCO	URCO	URCO
Services suitable for Airborne SWIM (generally weather advisory and aeronautical information services)	ADDS, ADAS, Expanded Terminal and Tower Data Service, General Information Message Distribution Service, IDS Data Service, NNEW service,[a] NOTAM distribution service, TMA Flight Data Service, WARP/WINS NEXRAD service			

[a]It is possible that the information provided through the NNEW service could range from advisories for routine forecasts though safety-critical transmission of certain hazardous weather warning messages, which might limit the extent to which this service could be provided over commercial links. This requires furtherer investigation.

Examples of operational messages that could be transmitted over the proposed AeroMACS data link in support of the services for the airport surface flight domain are presented in Table 7. The messages are grouped according to the information type, as defined by the function identifications (IDs) in Appendix C.

TABLE 7.—EXAMPLE AeroMACS DATA LINK MESSAGES

Information type (including corresponding function ID)	Message examples
Transceive air traffic service (ATS) to on-ground aircraft message C.1.1.1.2	Contract requesting data Contract acknowledgements Operational terminal information service (OTIS) reports, addressed or broadcast communications Operational en route information service (ORIS) reports, addressed or broadcast communications Significant meteorological information (SIGMET) reports, addressed or broadcast communications, event basis only Airport data to be displayed on board (Data Link Surface Information and Guidance, D–SIG) Runway visual range (RVR) information, addressed or broadcast communications Available alternative routes (dynamic route availability, DYNAV), addressed communication Urgent contact message (URCO), addressed and/or broadcast communications
Transceive on-ground aircraft to ATS message C.1.1.2.2	Requests (i.e., demand, periodic, or event contract) for reports Contract acknowledgements Current and periodic position (flight plan consistency, FLIPCY), addressed communications Meteorological data (FLIPCY), addressed communications Ground speed (FLIPCY), addressed communications Indicated heading, indicated air speed or match, vertical rate, selected level, and wind vector (system access parameters), addressed communications Broadcast of aircraft wake turbulence (WAKE) characteristics (e.g. aircraft type, weight, and flap and speed settings) Flight limitations (e.g., maximum acceptable flight level) (pilot preferences downlink, PPD), addressed communications Pilot flight preferences (PPD), addressed communications Flight plan modification requests (e.g., desired route or speed limitations) (PPD), addressed communications URCO, addressed and/or broadcast communications

3.5.5.2 AeroMACS Operational Scenarios Derived from the Communications Operating Concept and Requirements

Table 8 shows examples of operational scenarios for the proposed AeroMACS according to specific services identified earlier (Ref. 9) as proposed AeroMACS applications (services that are not planned to be implemented by Data Comm through Segment 2). The scenarios are a subset of those provided in COCR Version 2.0.

TABLE 8.—EXAMPLE OPERATIONAL SCENARIOS

Flight domain	Communication scenarios
Pre-departure airport domain	• The flight crew initiates a request for a data link operational terminal information service (D–OTIS) contract for the departure airfield. The flight information service system response provides all relevant information for the weather, Automatic Terminal Information Service (ATIS), and field conditions, plus the local Notices to Airmen (NOTAMs). • In low-visibility conditions, the flight crew may also use the data link runway visual range (D–RVR) service to request RVR information for the departure and the destination airports. For data-link-equipped aircraft preparing to taxi, the current graphical picture of the ground operational environment is uplinked and loaded using the data link surface information and guidance (D–SIG) service. • The flight crew specifies preferences that should be considered by the controllers using the pilot preferences downlink (PPD) service.

4.0 AeroMACS System Requirements

4.1 AeroMACS Functional Requirements Development Process

Figure 4 in Section 2.0 presented an overview of the ConUse and system requirements development process used for this task. As stated in Section 2.0, a middle-out approach was adopted to identify the high-level requirements applicable to AeroMACS. In this approach, the top-down functional requirements were derived from the ConUse and the associated functional capabilities. In parallel with that process, a bottom-up assessment of existing requirements in relevant documents such as the NAS SR–1000 (Refs. 10 and 11), the COCR (Ref. 12), and Data Comm performance requirements and their applicability to the current needs for AeroMACS was performed. Thus, the top-down approach employs the classic “clean-sheet” system engineering process, and the bottom-up approach addresses how AeroMACS fits into the existing environment.

4.1.1 AeroMACS Functional System Requirements—Top-Down Approach

This section presents a top-down determination of functional requirements through (1) a functional analysis for generic aeronautical communications systems based on prior work and (2) a functional analysis based on the ConUse defined in Section 3.0.

4.1.1.1 Prior Functional Analysis Applicable to AeroMACS

A functional architecture can be interpreted as a hierarchical arrangement of functions and interfaces that represents the complete system from a performance and behavioral perspective (Ref. 1). For its top-down functional analysis, this report leverages prior functional analysis work performed to characterize generic aeronautical A/G, G/G, and A/A communications systems: the “National Airspace System Communications System Safety Hazard Analysis and Security Threat Analysis” (Ref. 56). Figure 21 depicts the hierarchy at the highest level. Appendix C presents a more complete hierarchical decomposition of functions as diagrams and in an outline format derived from this reference document, but modified as appropriate for AeroMACS (e.g., A/A functions are deleted).

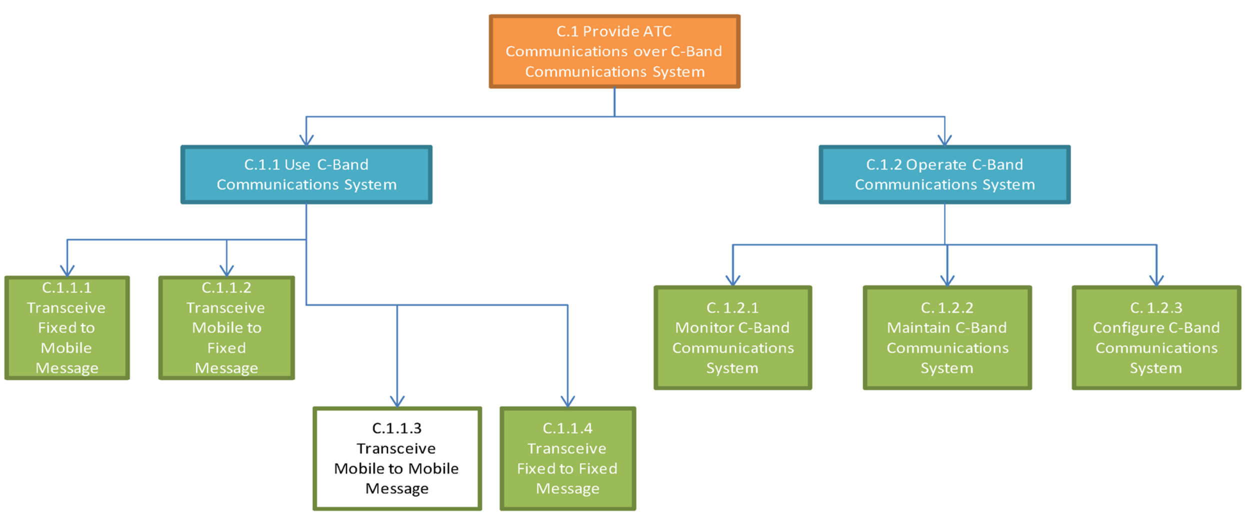

Figure 21.—High-level hierarchy of C-band communications system. Acronyms are defined in Appendix A.

4.1.1.2 AeroMACS Concepts-of-Operations-Based Functional Analysis

AeroMACS could provide a communication link to transfer surveillance and weather information, facilitate flight and resource management, enhance CDM, and enable exchange of aeronautical information in the future NAS. The tables in Appendix B document the select RTCA NAS ConOps (Ref. 13) found to be applicable to the proposed AeroMACS.[15]

The desired AeroMACS functional capabilities were derived from the identified NAS ConOps presented in Appendix B and mapped to (1) the high-level aeronautical A/G and G/G communication functions described in Section 4.1.1.1 and (2) specific COCR ATS services. Table 9 lists the AeroMACS high-level functional capabilities and presents this mapping. This encompasses a top-down approach to the development of functional requirements.

TABLE 9.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 13)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	S-1; S-3; S-4; W-2; W-3; W-8; W-9; W-10; W-12; W-13; W-14; W-15; FM-1; FM-6; FM-8; FM-12; FM-14; FM-15; FM 17; FM-23; A-2; A-6; A-12; A-15	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS D–RVR D–SIG D–SIGMET FLIPCY WAKE PPD
Support addressed communication for delivery of information to individual and multiple users	S-1; W-10; FM-6; FM-8	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS D–RVR D–SIG D–SIGMET FLIPCY PPD
Support broadcast communication for delivery of information to multiple users	S-1; S-4; W-2; W-3; W-12; W-14; FM-8; A-12	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS D–RVR D–SIG D–SIGMET WAKE
Support delivery of real-time information in a timely manner	S-1; S-3; W-16; FM-1; FM-2; FM-9; FM-10; FM-12; FM-15; FM-18; FM-25; FM-26; RM-3; RM-7; A-4; A-7; A-11		D-RVR D-SIG D–SIGMET FLIPCY WAKE PPD

[15]Although the RTCA document describes the NAS evolution in terms of three time periods—near (up to 2005), mid (2005 through 2010) and far (beyond 2010)—most concepts identified in the document are applicable to the proposed AeroMACS, which will necessarily be implemented beyond 2010.

TABLE 9.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 13)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable demand, periodic, and event communication	S-1; W-12		All services
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness	S-3; W-2; W-3; A-1; A-5		All services
Support multiple quality-of-service (QoS) provisions			All services
Support authentication of users and controlled access to NAS information (security)	W-1		All services
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground users	S-1; FM-12; FM-14; FM-20; A-11		
Avoid single points of failure	RM-6		All services
Provide a scalable solution			All services
Provide standards-based solution			All services

High-level AeroMACS functional requirements can then be constructed from the functional capabilities in a straightforward manner, as shown in Table 10.

TABLE 10.—AeroMACS HIGH-LEVEL FUNCTIONAL REQUIREMENTS

System functions	AeroMACS high-level functional requirements
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	The system shall enable ground-to-air (G/A) communication for fixed-to-mobile users. The system shall enable G/A communication for mobile-to-mobile users. The system shall enable A/G communication for fixed-to-mobile users. The system shall enable A/G communication for mobile-to-mobile users.
Support addressed communication for delivery of information to individual and multiple users.	The system shall support addressed communications to individual users. The system shall support addressed communications to multiple users.
Support broadcast communication for delivery of information to multiple users.	The system shall support broadcast communication to multiple users.
Support delivery of real-time information in a timely manner.	The system shall support delivery of real-time information in a timely manner.
Enable demand, periodic, and event communication.	The system shall enable demand communication. The system shall enable periodic communication. The system shall enable event communication.
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness.	The system shall accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness.
Support multiple QoS provisions.	(This functional capability points toward performance requirements.)
Support authentication of users and controlled access to National Airspace System (NAS) information (security).	The system shall support authentication of users (security). The system shall support controlled access to NAS information (security).
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground users.[a]	The system shall support FAA ground users. The system shall support non-FAA ground users.
Avoid single points of failure.	The system shall avoid single points of failure.
Provide a scalable solution.	The system shall provide a scalable solution.
Provide a standards-based solution.	The system shall provide standards-based solution.

[a]To support increasing collaboration among NAS users, the proposed system shall accommodate a wide range of NAS users by accepting NAS data from NAS data sources, both internal and external to the FAA. Users may include aircraft, airline operation centers, service providers, FAA users, and other Government agencies.

4.1.2 AeroMACS Functional System Requirements—Bottom-Up Approach

4.1.2.1 National-Airspace-System-Level Functional Requirements for AeroMACS Services

Functions identified in the NAS SR−1000 (Ref. 10)—plan flights, monitor flights, control traffic, support flight operations, monitor NAS operations, and plan NAS usage—cut across all the AeroMACS capabilities shown in Table 9. Table 2 in Section 3.2.2.1 mapped NAS-level A/G communication functions to NAS service capabilities, highlighting services potentially enabled by A/G voice communication. As expected, the NAS functions potentially enabled through an AeroMACS go well beyond those shown in Table 2. Consequently, Table 11 highlights the capabilities of the proposed AeroMACS enabling NAS functionality specified in the NAS SR−1000. The colored boxes denote services potentially enabled by A/G communication, with the blue boxes representing voice and/or data communication and the green boxes representing data communication only.

TABLE 11.—MAPPING RELEVANT NATIONAL AIRSPACE SYSTEM (NAS) COMMUNICATIONS FUNCTIONS TO NAS SERVICE CAPABILITIES (REF. 31)

Function \ Capability	Flight Planning	Separation Assurance	Advisory Services	Traffic Synchronization	Traffic Flow Management	Emergency Services	Navigation Services	Airspace Management Services	Infrastructure and Information Management
Evaluate Flight Conditions			X						
Manage Flight Plans	X								
Collect Surveillance Information	X	X	X	X		X	X		
Determine Aircraft Trajectory		X		X					
Monitor Aircraft Status	X					X	X		
Disseminate Aircraft Status	X	X				X			
Manage Separation Information		X							
Synchronize Traffic		X	X	X	X				
Control Aircraft		X							
Coordinate Traffic Control Distribution		X							X
Manage Weather Information			X						
Operate NAVAIDS							X		
Monitor NAS Flight Operations			X		X				
Maintain NAS Infrastructure		X	X			X			X
Plan Traffic Flow					X				X
Assess Traffic Flow Performance					X				
Manage Airspace Configuration	X	X				X	X	X	X

In Table 12, functional requirements applicable for an AeroMACS operating on the airport surface were extracted from the NAS requirements specified in the NAS SR–1000. Unless specifically stated otherwise, these could apply to A/G or G/G communications, for fixed-to-mobile or fixed-to-fixed applications.

TABLE 12.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
[Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 10).]

NAS functions		Communication requirements
Plan flights	Evaluate flight conditions	The NAS shall disseminate the status of special use airspace to users. (08760) The NAS shall disseminate weather information to users to support flight planning. (27150) The NAS shall disseminate aeronautical information to users to support flight planning. (27160)
	Manage flight plans	The NAS shall disseminate flight information to users. (00010) The NAS shall disseminate flight plan information to users via external data interfaces.(00410) The NAS shall disseminate flight plan information to users via air-ground data communications. (00970) The NAS shall disseminate flight data summaries to users. (00070) The NAS shall disseminate flight plans to users. (02160) The NAS shall disseminate flight plan clearances to users. (02900)
Monitor flights	Collect aircraft navigation information (collect dependent surveillance information)	The NAS shall retrieve actual flight information. (10000) The NAS shall acquire actual flight information from aircraft outside of independent surveillance coverage. (03320)
	Monitor aircraft status	The NAS shall respond to emergency transmission received via radio communications. (12600) The NAS shall respond to emergency transmissions received via data link. (12620) The NAS shall disseminate essential information on missing aircraft. (13130)
	Report (disseminate) aircraft status	The NAS shall display position information, to specialists, for aircraft that were detected independent of aircraft equipage in qualifying aerodromes. (24530) The NAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations. (12820) The NAS shall disseminate aircraft flight information for each controlled aircraft to specialists. (02720) The NAS shall disseminate the current location for each participating aircraft to ATCSCC [air traffic control system command center] Specialists. (10940) The NAS shall disseminate the current location for each participating aircraft to Traffic Management Coordinators. (10980)
Control traffic	Address active aircraft conflicts	The NAS shall disseminate recommended collision avoidance maneuvers to users. (03690)
	Control aircraft	The NAS shall disseminate aeronautical information to users via air-ground data communications. (07440)
	Coordinate traffic control distribution	The NAS shall acquire pilot reports (PIREP). (05530) The NAS shall disseminate weather advisories via direct specialist to pilot communications. (09290)

TABLE 12.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
[Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 10).]

NAS functions		Communication requirements
Support flight operations	Manage weather information	The NAS shall maintain communication links adequate to avoid user delay in gaining access. (07090)
		The NAS shall disseminate weather information to users continuously. (07110)
		The NAS shall disseminate current weather effect along the users proposed flight path. (07470)
		The NAS shall disseminate forecast weather in effect along the users proposed flight path. (07480)
		The NAS shall disseminate intensity levels of weather by route of flight to users. (08260)
		The NAS shall disseminate intensity levels of weather by geographic area to users. (08300)
		The NAS shall disseminate weather advisories to users in response to a request. (09300)
		The NAS shall broadcast the latest approved aerodrome conditions on communications media accessible by aircraft on the ground. (09340)
		The NAS shall broadcast the latest approved terminal area conditions on communications media accessible by aircraft on the ground. (09360)
		The NAS shall respond to user requests for weather information from NAS facilities through common carrier communications networks. (09370)
		The NAS shall disseminate selected weather information directly to appropriately equipped aircraft. (09420)
		The NAS shall provide flexible and convenient access to required weather information to users. (19380)
	Operate navigation aids[a]	The NAS shall disseminate navigational accuracy correction values for supplemental navigation systems to users. (17040)
		The NAS shall disseminate correction values for navigational aids to users. (16790)
		The NAS shall disseminate available supplemental terminal navigation guidance information error correction values to users. (14820)

TABLE 12.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
[Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 10).]

NAS functions		Communication requirements
Monitor NAS operations	Monitor NAS flight operations	The NAS shall disseminate future delay advisories in effect along the users proposed flight path. (07500) The NAS shall disseminate traffic advisories upon user request. (09120) The NAS shall provide traffic advisories to aircraft on the surface. (30270)
	Maintain NAS infrastructure	The NAS shall disseminate airway usage information to users. (00030) The NAS shall disseminate route usage information to users. (00050) The NAS shall disseminate aeronautical information to users via external data interfaces. (07430) The NAS shall disseminate aeronautical information per user request. (07130) The NAS shall disseminate aeronautical information upon user request continuously. (07340) The NAS shall disseminate aeronautical data for a maximum of 8 specified locations per request. (07400) The NAS shall disseminate the status of supplemental navigation systems to users. (17010) The NAS shall disseminate status of supplemental navigation systems to users. (16770) The NAS shall disseminate flow control information to users via external data interfaces. (07920) The NAS shall disseminate derived restrictions to the user. (11700) The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790) The NAS shall disseminate terrain information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03900) The NAS shall disseminate manmade obstacle information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03940) The NAS shall disseminate ground information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (25520) The NAS shall disseminate filtered terrain information to users. (25560) The NAS shall disseminate filtered ground information to users. (25570) The NAS shall disseminate filtered manmade obstacle information to users. (25580)
Plan NAS usage	Plan traffic flow	The NAS shall disseminate preferred route information at least 24 hours prior to it becoming effective. (07280) The NAS shall disseminate military air traffic control plans related to national emergencies. (16140) The NAS shall disseminate flow control information to users via external data interfaces. (07920) The NAS shall disseminate interfacility traffic flow plans. (11970) The NAS shall disseminate derived restrictions to the user. (11700) The NAS shall disseminate derived alternative courses of action to the user. (11720) The NAS shall determine flight restrictions for specific aircraft. (11760) The NAS shall disseminate flight restrictions to users. (11770) The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)
	Assess traffic flow performance	The NAS shall disseminate reports on equipment performance. (18870) The NAS shall disseminate reports on maintenance activities. (18880) The NAS shall disseminate reports on equipment repair activities. (18890)

[a]These services are typically provided via satellite communication (SATCOM) but could be provided via a ground-based system.

4.1.2.2 National-Airspace-System-Level Functional Requirements for AeroMACS Infrastructure

The following is a summary of NAS infrastructure (communications) requirements found applicable to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 10). The list supports the high-level functional requirements presented in the document.

- The NAS shall provide data channels in the frequency band appropriate for air-ground data communications equipment for data communications coverage for both civil and military users. (19940)
- The NAS shall automate communications capabilities to reduce specialist and user workload. (20210)
- The NAS shall provide air-ground communications continuously… (part of 20330)
- The NAS shall provide reconfiguration of communications capabilities without degradation of air-ground voice or data communications. (20380)
- The NAS shall support peak busy hour exchange of data including short-term peaks that may occur within the peak hour, with minimal change in the data transmission response times and no loss of data. (20760)
- The NAS shall reconfigure communication capabilities to support changes in operating responsibilities. (20800)
- The NAS shall provide processing and communications capacities to support the required backup capabilities and to meet the response time requirements while maintaining safe separation of all aircraft receiving ATC services (i.e., both normal and backup sectors) from the backup facilities. (21670)
- The NAS shall provide configurable communications. (32120)

4.2 AeroMACS Performance Requirements

4.2.1 National-Airspace-System-Level Performance Requirements Applicable to AeroMACS

Performance requirements were derived to define system capabilities based on the functional requirements developed in preceding sections and considering propagation characteristic of the C-band. Table 13 summarizes NAS performance requirements found to be relevant to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 10). Note that these are high-level NAS requirements that do not specify how they should be implemented. A/G and G/G communications are considered to be possible implementation solutions.

TABLE 13.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 10.]

NAS function	Performance requirement
Control traffic	The NAS shall disseminate hazardous weather avoidance recommendations to users within 1 minute of request. (08440)
	The NAS shall communicate aircraft actions to users within 1 minutes of implementing a weather avoidance plan. (08460)
	The NAS shall alert participating aircraft to predicted conflicts with obstructions within 10 seconds of prediction. (09170)
	The NAS shall notify users of non-adherence to ATC clearance within 10 seconds of the detection of the deviation. (02010)
	The NAS shall alert appropriately equipped users to the collision danger within 10 seconds after the prediction is made. (03660)

TABLE 13.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 10.]

NAS function	Performance requirement
Support flight operations	The NAS shall disseminate a requested summary of hazardous weather for any airspace in the continental United States within a mean response time 3.0 seconds of the request. (08060)
	The NAS shall notify users affected by the presence of hazardous weather within 2 minutes of acquisition. (08170)
	The NAS shall update hazardous weather broadcasts at least once every 30 minutes. (09400)
	The NAS shall disseminate automated weather observations once per minute to designated interfaces. (05270)
	The NAS shall disseminate Terminal area hazardous weather information to users within one minute of detection. (06990)
	The NAS shall display requested routine weather information to the user within a mean response time of 3.0 seconds of the request. (23380)
	The NAS shall display requested routine weather information to the user within a 99th percentile response time of 5.0 seconds of the request. (23390)
	The NAS shall display requested routine weather information to the user within a maximum response time of 10.0 seconds of the request. (23400)
	The NAS shall disseminate a requested summary of hazardous weather for any airspace in the continental United States within a 99th percentile response time of 5.0 seconds of the request. (23510)
	The NAS shall disseminate a requested summary of hazardous weather for any airspace in the continental United States within a maximum response time of 10.0 seconds of the request. (23520)
Monitor NAS operations	The NAS shall alert users to a full navigation system failure affecting NAS operations within 10 seconds of the failures detection. (17110)
	The NAS shall alert users to a partial navigation system failure affecting NAS operations within 10 seconds of the failures detection. (17130)
	The NAS shall disseminate the results of Traffic Management Coordinator capacity projection requests within 99th percentile response time of 5.0 seconds of the request. (10820)
	The NAS shall disseminate the results of Traffic Management Coordinator capacity projection requests within a maximum response time of 10.0 seconds of the request. (10820)
	The NAS shall disseminate the results of Traffic Management Coordinator demand projection requests within the 99th percentile response time of 5.0 seconds of the request. (10850)
	The NAS shall disseminate the results of Traffic Management Coordinator demand projection requests within a maximum response time of 10.0 seconds of the request. (10850)

TABLE 13.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 10.]

NAS function	Performance requirement
Plan NAS usage	The NAS shall disseminate requested flow control advisory information to users within a mean response time of 3.0 seconds of the request. (07890)
	The NAS shall disseminate scheduled flight activity information in military special use airspace within 1 minute of request. (08900)
	The NAS shall disseminate requested delay advisory information to users within a mean response time of 3.0 seconds of the request. (07900)
	The NAS shall alert users not more than 10 seconds after any failures of navigation guidance affecting operations within the NAS. (16810)
	The NAS shall alert users not more than 10 seconds after any failures of portions of navigation guidance affecting operations within the NAS. (16820)
	The NAS shall alert users within 10 seconds, of failures to navigation guidance that affect operations. (17150)
	The NAS shall alert users within 10 seconds, of failures to portions of navigation guidance that affect operations. (09590)
	The NAS shall assure ground-air transmission time for data messages not exceed 6 seconds. (20090)
	The NAS shall provide retrievable air-ground data messages within 30 minutes and from “off-line” storage within 60 minutes. (20270)
	Individual air-ground data messages shall be retrievable from “off-line” storage within 5 minutes of a request by authorized NAS personnel. (20280)
	The NAS shall strive to restore critical system service to users/specialists within 6 seconds of failure (22900)
	The NAS shall strive to restore essential system service to users/specialists within 10 minutes of failure. (22910)
	The NAS shall disseminate requested aeronautical information to users within a mean response time of 3.0 seconds of the request. (23580)
	The NAS shall disseminate requested aeronautical information to users within a 99th percentile response time of 5.0 second of the request. (23590)
	The NAS shall disseminate requested aeronautical information to users within a maximum response time of 10.0 seconds of the request. (23600)
	The NAS shall disseminate requested flow control advisory information to users within a 99th percentile response time of 5.0 seconds of the request. (23950)
	The NAS shall disseminate requested flow control advisory information to users within a maximum response time of 10.0 seconds of the request. (23960)
	The NAS shall disseminate requested delay advisory information to users within a 99th percentile response time of 5.0 seconds of the request. (23970)
	The NAS shall disseminate requested delay advisory infozrmation to users within a maximum response time of 10.0 seconds of the request. (23980)

4.2.2 Communications Operating Concept and Requirements (COCR) Performance Requirements Applicable to AeroMACS

The performance requirements shown in Table 14 resulted from the operational performance assessment conducted as part of the COCR (Ref. 12). That assessment determined the performance that a system or service must achieve and led to a determination of the availability, integrity, and transaction times. Performance requirements were driven by operational needs and safety requirements as well as other assessments (e.g., information security) to determine overall communication performance requirements.

The more stringent of the safety objectives and operational requirements for each parameter was used to determine the communication performance requirements. The operational requirements are driven by the type of exchange (e.g., trajectory change and general information) and the domain in which the service was offered.

Values in Table 14 are based on COCR ATS future radio system performance requirements (Ref. 57) for the select services with the most stringent requirements presented. For example, the WAKE service is a driving service for defining the latency requirements in the airport, TMA, and en route domains.

Performance requirements should be revisited at a later stage in the system development process to reflect the most current ConUse and services selection.

TABLE 14.—AeroMACS DATA REQUIREMENTS

Service type	Confidentiality	Latency, sec	Integrity	Availability of provision
		Airport		
Addressed	Medium	0.4	5.0×10^{-8}	0.999995
Broadcast	Medium	1.4	5.0×10^{-8}	0.999995

4.3 Other AeroMACS Requirements

4.3.1 Spectrum Requirements Applicable to AeroMACS

One of the main objectives of the proposed AeroMACS system is to increase communications system capacity. A channel plan will be developed driven by frequency availability to support broadband services.

The proposed system should provide seamless operations around the globe. International standards are being developed to achieve full interoperability.

Table 15 summarizes NAS spectrum requirements applicable to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 10).

TABLE 15.—NATIONAL AIRSPACE SYSTEM (NAS) SPECTRUM REQUIREMENTS APPLICABLE TO THE PROPOSED AeroMACS
[Numbers in the table correspond to performance requirements in the NAS SR–1000 (Ref. 10).]

Category	Performance requirement
Secure Spectrum with the Federal Aviation Administration (FAA)	The NAS shall secure and protect national radio spectrum for the FAA and the US Aviation community. (32470) The NAS shall coordinate national spectrum allocation programs. (19190) The NAS shall establish new systems spectrum development activities compatible with projected national use. (19290)
Secure frequency for the FAA	The NAS shall establish national frequency allocation programs. (19170) The NAS shall establish new systems frequency development activities compatible with current national use. (19230) The NAS shall establish new systems frequency development activities compatible with projected national use. (19270)
Secure international spectrum	The NAS shall establish new systems spectrum development activities compatible with current national use. (19250) The NAS shall comply with national standards to avoid the interference of new systems with existing systems. (19310) The NAS shall coordinate national spectrum management assistance programs. (19210) The NAS shall disseminate en route navigational guidance such that ambiguities in guidance information have a minimal impact on NAS operations. (13960)
Manage international spectrum	The NAS shall comply with international standards to avoid the interference of new systems with existing systems. (32090)

4.3.2 User Requirements Applicable to AeroMACS

Table 16 summarizes aviation user requirements based on those documented in Reference 58 and found to be potentially applicable to AeroMACS.

TABLE 16.—AVIATION USER REQUIREMENTS

The system shall be capable of supporting all categories of users including the following (Ref. 58): 1. Scheduled air transport carriers (including international, trunk, regional, commuter and air freight carriers) 2. Nonscheduled air carriers 3. General Aviation (GA) (including operators of turbine-powered and reciprocating–engine aircraft) Scheduled air transport carriers (including international, trunk, regional, commuter and air freight carriers) 4. Nonscheduled air carriers 5. General Aviation (GA) (including operators of turbine-powered and reciprocating–engine aircraft) 6. Rotorwing Aircraft (including helicopters and gyrocraft) 7. Unpowered aircraft (including gliders and lighter-than-air) 8. Military aircraft 9. Certain ground and maritime vehicles (e.g., airport service vehicles, those vehicles coordinating in a search-and-rescue mission)
The new system shall satisfy any data communications requirements for use in any authorized category of communications service including ATS, AOC, and AAC.
The avionics equipment shall communicate with any compatible ground system. The new system shall be capable of implementation and operation anywhere in the world.

4.3.3 Regulatory Requirements Applicable to AeroMACS

The following list summarizes regulatory requirements based on those documented in Reference 32 and found to be potentially applicable to AeroMACS.

- The system shall comply with AM(R)S spectrum allocation requirements.
- The system shall comply with the U.S. ATS and AOC service rules and regulations.
- The system shall comply with the U.S. Federal aviation regulations.
- The system shall support the requirements for message priority capability.

4.3.4 Safety and Security Requirements Applicable to AeroMACS

A fundamental safety requirement is that new communications systems shall not cause degradation in safety when compared with the existing communications systems. The overall objective is to improve safety. A C-band initial safety and security analysis and the associated requirements applicable to AeroMACS are covered in separate documents (Refs. 54 and 59).

4.4 Guidance for the Development of AeroMACS Requirements Based on IEEE 802.16e

The preceding sections presented high-level functional and performance requirements applicable to AeroMACS that encompass most of the known A/G and G/G communications services for mobile-to-fixed and fixed-to-fixed applications on the airport service. They should be considered high (NAS) level guidance in the development of specific system requirements necessary for any particular service for which AeroMACS is proposed to implement.

Typically high-level requirements are technology independent. Perhaps unique to the development of the AeroMACS requirements is the identification a priori, by virtue of the extensive FCS technology assessment, of the recommended technology by which AeroMACS will be implemented, that is, IEEE 802.16e. This allows the identification and development of quite specific requirements depending on the desired application or service to be provided. The following sections provide a preliminary approach for identifying and developing AeroMACS requirements in the context of the IEEE 802.16e broadband communications standard and its characteristics.

4.4.1 Introduction

The applications discussed in Section 3.0 require the support of several types of communication services. Much of the initial requirements analysis work was done in the COCR study (Ref. 12), which conducted analysis to specify requirements for continuity, integrity, availability of provision, and availability of use for various ATS communication services. The services analyzed were primarily narrowband services, but the study indicated the level of performance that would be needed by a wideband service as well.

An initial safety analysis was carried out for future airport surface communication systems that considered the possibility of wideband communication systems (Ref. 54). This analysis dealt with various aspects of hazards and safety risks relative to ConUse and provided initial top-level risk assessments. Safety risk assessments deal with the criticality of communication services and the ability of these services to maintain levels of performance in operation. The results from a safety and reliability analysis will help determine link performance requirements and the level of redundancy needed in the communication system. In addition, a safety analysis will help determine the monitoring and maintenance intervals needed for the communication system and the supporting network management functions.

Security levels and services also are considered in developing requirements that can be applied at the link/MAC and physical layers. At the physical layer, transmission security may be required to prevent unauthorized monitoring or spoofing of the transmitted signals. At the MAC layer, low-level authentication and identification may be needed. Security above the link and local network layers will include message encryption and higher level authentication services.

These are important inputs to developing a quality-of-service (QoS) protocol/policy and physical layer requirements for AeroMACS.

4.4.2 Classes of Communications Services for AeroMACS

The applications described in Section 3.0 require communication services to perform their functions. The following subsections give brief descriptions of classes of communication services that may be required. For this discussion, a “point” is a central source or user of data, and “multipoint” means that the data traffic is sent to multiple users. This does not refer to the AeroMACS network architecture of a central BS (point) servicing multiple subscriber stations (SSs—multipoint).

4.4.2.1 Low-to-Medium-Speed Point-to-Point Data Link

This link transports data from a sensor or ground station to a processing or monitoring unit. Data rates are low to moderate (<200 kilobits per second (kbps)). These links can be part of a polling network where several links are tied to the central station.

4.4.2.2 High-Speed Point-to-Point Data Link

A high-speed data link can be used to link sensors that produce high-speed data to a central processor, or to link multisensor network access points or a subnetwork to a larger network. Data rates ≥200 kbps are needed.

4.4.2.3 Point-to-Multipoint Broadcast Data

This type of communication service enables the multicast or broadcast of scheduled or priority messages to a large group of users or a selected subset of users (multipoint). Data updates and critical messages will have low to moderate data transmission rates (<200 kbps).

4.4.2.4 Point-to-Point Command and Control Data

This type of service is for near-real-time control of a device or system. It relies on short-turnaround feedback from the device being controlled. Control of runway lighting is one example for this type of service. The command UL and feedback link are low rate (<100 kbps), but they require low error rates. The UL may carry higher data rates (e.g., video at <2 megabit per second (Mbps)) and can tolerate higher error rates than the control link.

4.4.2.5 Voice Network

Digital voice networks have several advantages over analog voice circuits. For example digital voice circuits can be encrypted. However, they have requirements on maximum delay corresponding to the human response times (typically less than 200 msec one way). This usually dictates a time-division multiple-access (TDMA) system to guarantee maximum delay time. Capacity requirements will depend on the number of voice circuits used.

4.4.2.6 Video Link

Depending on the resolution and frame rates needed for an application, video transmission can require significant capacity, typically on the order of 1 Mbps for a single link. Thus, a relatively small number of video circuits per BS sector (in comparison to a voice circuit) are likely to be supported in a multiservice communication system.

4.4.2.7 Multimedia

Multimedia services combining voice, data, and video can require a large amount of communication resources depending on how the services are combined for use. For CDM, voice plus data (graphics) may be all that is needed. An example would be an application like Net Meeting. The addition of video to CDM will require a significant increase in demand for capacity from the network.

4.4.2.8 Basic Mobile

This class of communication service requires the necessary QoS and network functions for handoff between BS sectors to support basic voice and data services.

4.4.2.9 Enhanced Mobile

This class of mobile service provides increased capacity to handle interactive applications such as CDM while on the move.

4.4.3 Developing AeroMACS Service Quality-of-Service Requirements Based on IEEE 802.16e

Developing a QoS function for a modern communication system involves three main areas of consideration:

(1) Defining a set of QoS parameters and metrics that can be used to monitor and classify different grades of communication services
(2) Determining service priorities and preemption if needed
(3) Developing a protocol for managing and scheduling services

The IEEE 802.16e standard includes five QoS categories. These categories use a number of performance parameters to quantify performance. The five QoSs included in the IEEE 802.16e standard follow:

(1) Unsolicited grant service (UGS) supports fixed-size data packets and allocated capacity. Digital voice circuit over the Internet (VoIP) is an example.
(2) Real-time polling services (rtPS) are designed to support networked video and voice applications on a high-speed network that supports multiple streams.
(3) Non-real-time polling service (nrtPS) supports delay-tolerant data streams that transmit at periodic intervals, such as file transfers.
(4) Best-effort service provides a best effort for delivering data packets without guaranteeing delivery. This is the type of service normally provided by the Internet.
(5) Extended real-time variable rate (ERT–VR) service supports real-time applications that can have variable packet sizes. Digital voice with silence suppression is an example.

Table 17 relates the five QoS categories to the applications that will benefit from the QoS category and the parameters that define each QoS category (Ref. 60).

TABLE 17.—IEEE 802.16e QUALITY OF SERVICE CATEGORIES AND DEFINING PARAMETERS

Defining parameters	Unsolicited grant service, UGS	Real-time polling service, rtPS	Non-real-time polling service, nrtPS	Extended real-time polling service	Best effort
	Applications				
	Traffic over T1 or E1 lines (T1/E1), VoIP[a] without silence suppression	Streaming audio and streaming video	FTP and TCP[b] applications that require a minimum data rate	VoIP with voice-activity detection (bursty traffic)	Web browsing and file transfer
Real-time service flow	X	X		X	
Fixed-size data packets	X			X	
Scheduled packet transmission	X	X		X	
Minimum reserve rate		X	X		
Maximum sustained rate		X	X		X
Maximum latency tolerance		X			
Time jitter tolerance	X			X	
Traffic priority		X	X	X	X
Dynamic traffic allocations				X	
Unicast polls (guaranteed service request opportunities in congestion)			X		

[a]VoIP, digital voice over Internet Protocol.
[b]FTP, File Transfer Protocol; TCP, Transmission Control Protocol.

4.4.4 Quality of Service Support of AeroMACS Communication Services

Table 18 shows an analysis of the communications services that were discussed in Section 4.4.2 with example airport applications and applicable QoS service classes. Typical values of performance are included for data rate, packet error rate (PER), delay (time latency), and time jitter.

TABLE 18.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality-of-service (QoS) class	Performance parameters	Typical values	Supported by IEEE 802.16e
Low-to-medium-speed point-to-point data link	Backup for sensor cable link (i.e., weather sensor)	nrtPS	Data rate PER Delay Jitter	100 kbps 1.0×10^{-3} 1 sec 100 μsec	Yes
High-speed point-to-point data link	Backbone-linking BS; link to relay gateway node in remote area	UGS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec 100 nsec	Yes

TABLE 18.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality-of-service (QoS) class	Performance parameters	Typical values	Supported by IEEE 802.16e
Point-to-multipoint broadcast data	Scheduled broadcast of weather info, NOTAM	nrtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 1 sec <1 μsec	Yes
Point-to-point command and control data	Remote operation of ADS–B ground station	rtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-6} 100 msec <1 μsec	Yes
Command and control network	Operation of surface devices at remote airport	Best effort	Data rate PER Delay Jitter	200 kbps 1.0×10^{-4} 200 msec <10 μsec	Yes
Digital voice network	Provide *N* circuits for ATC or AOC operations	rtPS; ERT–VR service	Data rate PER Delay Jitter	10 kbps × N 1.0×10^{-3} 100 msec <100 μsec	Yes
Point-to-point video link	Airport surveillance; robotic vehicle	UGS	Data rate PER Delay Jitter	600 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes
Basic mobile	Handoff control for voice; low-speed data sessions	UGS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes
Multimedia	CDM	rtPS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec <10 μsec	Yes

These typical performance parameters are for the physical and link-layer requirements for individual communication services. The actual values will depend on the architecture of the communication network, the size of the network, and the provisions for redundant communication support. The performance values shown in the table are typical of the type of communication service offered. For example, one-way voice delay is derived from subjective analysis involving human reactions in human conversation with push-to-talk communications. Jitter requirements are somewhat dependent on the implementation—for example, the extent to which data buffering is used. Packet error rate performance typically depends on the use of retransmissions and the size of the message. Future work should refine these performance values according to the specific services to be implemented.

The final column of Table 18 is an assessment of whether the requirement is supported by the performance of a system that is based on the IEEE 802.16e standard. The communications systems and their operating requirements are expected to be supported in all cases that were examined.

5.0 Architectural Description and Initial Test Bed Requirements

5.1 Initial Surface Communications System Architecture

This section describes a system architecture framework for an airport surface communications reference model that can be applied at all airport installations. The number of components to be deployed will vary according to the size and data capacity needs of the airport. The communication architecture is based on the IEEE 802.16 standard for the network functions with the IEEE 802.16e-2005 amendment (Ref. 18) for the mobile air interface.

5.2 Overview

The primary mode for operation on an IEEE 802.16e-based system is a point-to-multipoint architecture. Figure 22 depicts a wireless point-to-multipoint system in an airport context.

In this architecture, SSs, which include fixed and portable nodes, and mobile stations (MSs) are wirelessly linked to the BS access points. The BSs are linked to a common access service network (ASN) which manages services between BSs. The ASN can include one or more BSs and could be localized to one part of the airport (for example, an area assigned to a major carrier). For a small number of BSs, distributed ASN functions can be used that are installed at each BS. The ASNs are linked to a Connectivity Service Network (CSN) through gateways (not shown in Figure 22). The CSN provides access to services on the airport intranet and fire-walled access to the Internet.

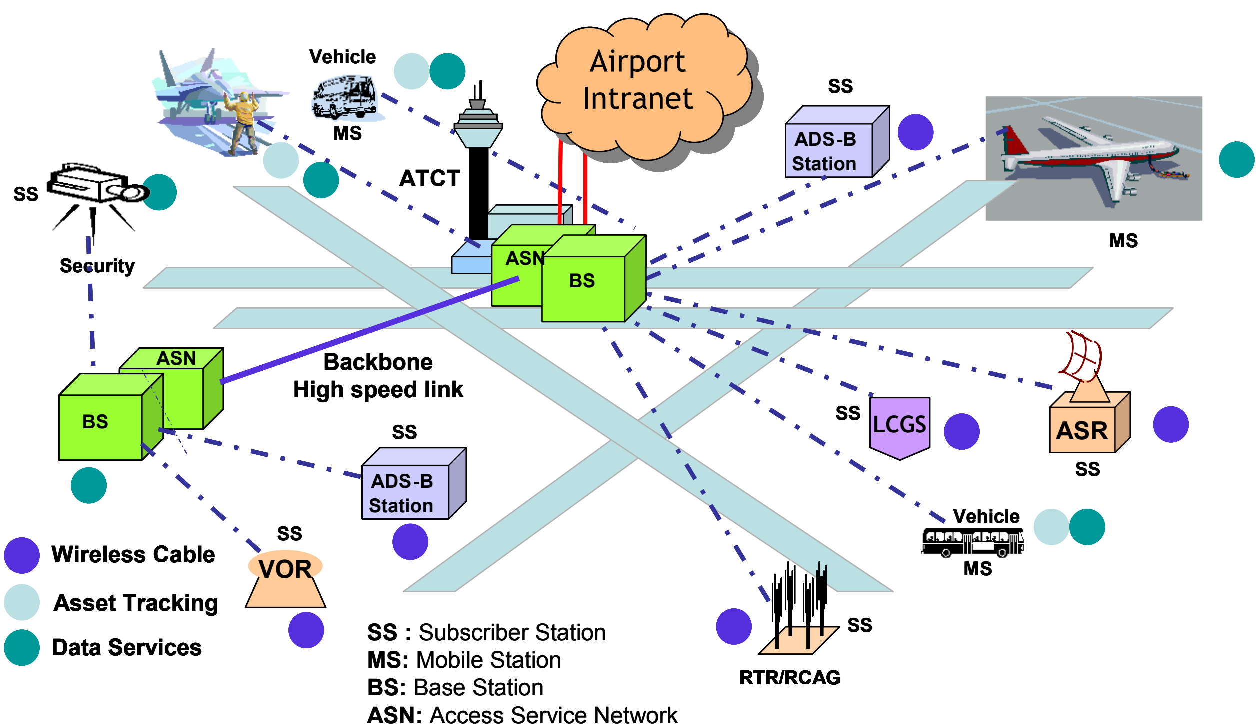

Figure 22.—Airport point-to-multipoint communications service. Acronyms are defined in Appendix A.

5.3 IEEE 802.16 Network Architecture

The IEEE 802.16e Network Working Group has developed a network reference model to assist in the deployment of IEEE-802.16e-based systems. It is designed to enable interoperability of vendor equipment and to provide a structure for the deployment of new systems. The architecture is Internet Protocol- (IP) based, meaning it relies on IP addressing to provide secure connectivity between users and access to common services. Figure 23 depicts a top level view of this architecture.

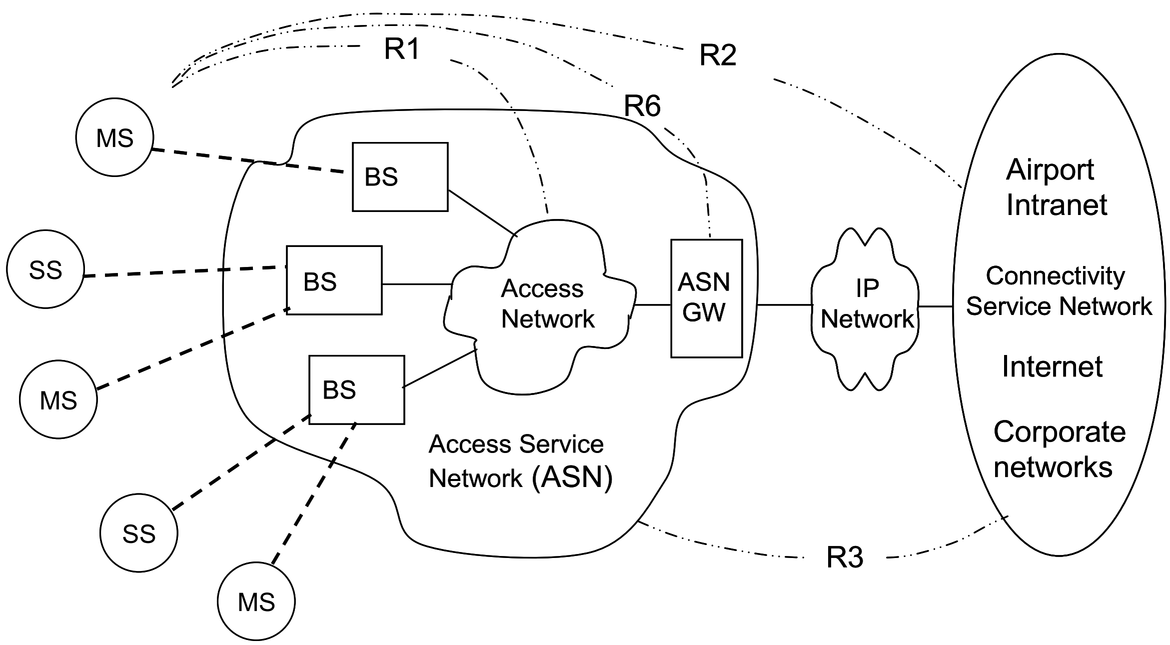

Figure 23.—IEEE 802.16e IP-based network architecture. (Based on Fig. 2.3 in Ref. 61.)

The MS nodes can be anything mobile: aircraft, service vehicles, emergency vehicles, or other vehicles. The SS nodes are stationary sites that could be surveillance weather stations, radar sites, or operations buildings located on the airport surface. In AeroMACS, MS and SS nodes are both referred to as SS. The hardware for both is compliant with the mobile standards, whether physically mobile or stationary.

SS nodes are linked through wireless connections to the BS access points. There can be multiple SS nodes assigned to a single BS. Mobile SS nodes are transitory and must be serviced by a handoff protocol that enables the mobile SS to maintain connected service while moving between access point coverage areas. The BSs are connected to an access network that includes a gateway IP router. The access network manages the ASN to ensure its proper operation at the physical and MAC levels. This includes the management of mobile and stationary SSs operating within the ASN. It also provides access to higher level services through the access service network gateway (ASN–GW). The CSN provides connectivity to the airport intranet. The airport intranet hosts local IP-based servers which provide various data services and applications to authorized airport users.

The ASN–GW aggregates subscriber and control traffic from BSs within an access network. It has an important role in subscriber management, network optimization, and forwarding of all SS traffic.

The BS nodes identified in this architecture will often have multiple coverage sectors using multiple radios, each with a directional transmit/receive antenna. Each radio and antenna pair forming a coverage sector is referred to as a base transceiver station (BTS).

The IEEE 802.16e network architecture further defines functional interfaces between the major components of the model as listed in Table 19. Eight functional interfaces that are defined within the network and between networks are listed in the table. The four interfaces shown in the figure (R1, R2, R3, and R6) are defined in Table 19. Three interfaces (R4, R5, and R7) are defined that would apply to airports with more than one ASN, gateway (GW), or CSN, such as when multiple service providers are present.

TABLE 19.—SELECTED IEEE 802.16e NETWORK INTERFACE DEFINITIONS
[Acronyms are defined in Appendix A.]

Interface reference point	Functional entities	Functions
R1	SS and the ASN	Implements the air interface (IEEE 802.16e) specifications and may additionally include protocols related to the management plane.
R2	SS and CSN	Provides authentication, service authorization, IP host configuration management, and mobility management. This is only a logical interface and not a direct protocol interface between the ASN and CSN.
R3	ASN and CSN	Supports AAA [authentication, authorization, and accounting], policy enforcement and mobility management. R3 also encompasses the bearer plane methods (e.g. tunneling) to transfer IP data between the ASN and the CSN.
R4	ASN and ASN	A set of control and bearer plane protocols that originate/terminate within the ASN that coordinates SS mobility between ASNs.
R5	CSN and CSN	A set of control and bearer plane protocols to support mobility between networks if multiple networks (airports) are supported by multiple CSNs and mobility handoff is needed.
R6	SS and ASN–GW	A set of control and bearer plane protocols for communication between the BS and the ASN–GW. Consists of intra-ASN bearer paths and IP tunnels for mobility tunnel management. R6 may also be a conduit for exchange of MAC states information between neighboring BSs.
R7	ASN–GW–DP and ASN–GW–EP	An optional set of control plane protocols for coordination between the two groups of functions identified in R6.
R8	BS and BS	A set of control plane message flows and possibly bearer plane data flows between BSs to facilitate fast and seamless handovers.

Figure 24 provides details about the functions that pass through the R1, R3, and R6 interfaces. The R2 interface is not indicated in the figure because it deals with services that pass between the SS node stations and the CSN. Interface R8 applies if, in the future, local mesh or ad hoc networking between SSs is implemented in an amendment to the standard.

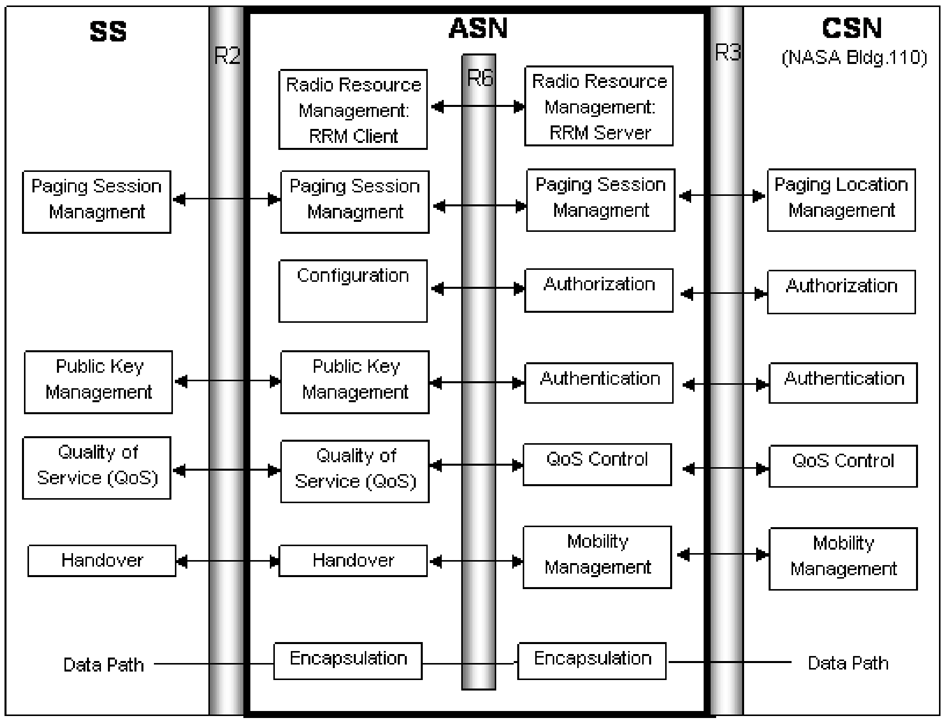

Figure 24.—Network interfaces and functions. Acronyms are defined in Appendix A.

Each airport location can be considered as a small enterprise with data communications occurring in the immediate vicinity of the airport property. Because of this, frequency planning for the R1 interface can consider only the BS sectors at a single airport unless other airports are within the radio LOS. Plans can be made to reuse the BS sector frequency within the C-band allocation within that small enterprise.

Commercial IEEE 802.16e hardware that is presently available can be procured with either a centralized ASN–GW or a distributed ASN–GW in which the gateway function is resident in each BS. The use of a centralized ASN–GW server versus a distributed function presently depends on the number of BSs in a network, with the distributed approach typically supporting up to six BSs.

The functions at the R3 interface between ASN and CSN can be supported for relatively long distances over a secure IP network. One CSN will be able to support multiple small enterprises and could potentially support all airport surface communication networks across a national region.

The number of multisector BS sites to be installed at an airport will depend on many factors including the physical size of the airport, the expected data load requirements, and factors that affect wireless signal propagation such as terrain and building shadowing and the need for high QoS. Network reliability will improve with at least two BS visible to each SS for the majority of the coverage area. This will provide reliable wireless linkage in the case that one of the available paths between an SS and BS is interrupted by an obstruction or hardware failure. Each airport will be somewhat unique in these factors and will require customized designs for the placement and quantity of BS sites to provide the needed QoS.

Many options exist to implement a physical R3 interface between an ASN–GW and the CSN that is typically located at a central point and can be widely separated from the BSs. Making the R3 connection may be complicated by the lack of existing IP network infrastructure in the airport environment. Positioning of the BS to achieve airport surface coverage may place it distant from an existing IP-based network. A microwave backhaul link may be used to connect BSs to an IP network to avoid the installation of cables. Another option is to use an SS to establish an in-band backhaul link to establish a limited-bandwidth connection.

5.4 Physical System Architecture and Design Process

The general network architecture was outlined in Section 5.3. Designing an AeroMACS network at an airport will require several tradeoffs to obtain the best performance, including

- Location and number of BSs
- Number of antenna sectors to employ per BS
- Type of backhaul system to support the ASN
- Number of SS terminals that can be serviced by a BS

The following sections describe the system design process for new airport installations.

5.4.1 Introduction

An essential element in designing and deploying an AeroMACS network is a comprehensive RF design. An accurate design will ensure that the deployed wireless network will provide the necessary coverage, capacity, and reliability, with minimal interference, that satisfies the service requirements. Although it is possible to gauge the performance of radio links through theoretical means, real-life deployments must take into account variables from the environment to achieve optimal performance and minimize coverage holes and RF cochannel interference.

5.4.2 Airport AeroMACS Network Design Process

The network design process begins with a physical site survey to gather information about the deployment location. A site survey provides an opportunity to validate any topography mapping information that may be available. It is also used to identify suitable installation locations for AeroMACS equipment. A site survey will also provide input to the next three phases of the RF design process:

(1) Coverage model
(2) Spectrum analysis
(3) Capacity analysis

5.4.3 Coverage Model

The coverage model requires a map of the site along with coordinates of potential locations for BSs and SSs. The coverage model must account for the impact of the environment on the RF transmissions, including the effects of the topography, physical obstructions, and foliage. These effects introduce propagation delays that have been cataloged in reference models. In addition, clutter models or obstruction densities are also modeled in this phase. Clutter models represent the density of obstructions in the deployment site. Typical options include rural, urban, and suburban clutter models. An airport surface with its relatively open runways and taxi areas and congested terminal areas will be a combination of the three models.

In addition to considering site topology and propagation delays, general parameters of the AeroMACS solution must be identified. Notable parameters include BS and SS transmit/receive power, antenna gains, feeder losses, BS and SS heights, and orthogonal-frequency-division multiple access (OFDMA) radio-access-related parameters. In addition, the following are system design parameters:

- Radio access method
- Fade margin
- Antenna sensitivity and diversity
- Cochannel interference margin
- Duplex mode
- Modulation
- Error correction
- UL/DL ratios and throughput
- BS and SS noise figure
- Maximum output/input power

Finally, a link budget must be calculated that specifies the maximum path loss between each BS and SS. Receiver sensitivity of the equipment for supported modulation schemes can be obtained from the BS and SS vendor data sheets. Characteristics of the BS and SS and information about the placement and types of antennas are used to generate an accurate coverage map.

5.4.4 Spectrum Analysis

The spectrum analysis phase of radio planning involves analyzing the potential site for interference from frequencies that may interfere with the AeroMACS. An analysis involves measuring the maximum transmitter signal levels to determine how much energy is present in the surveyed RF band. The spectrum analysis can be conducted at ground level, but it is typically conducted from elevated locations including rooftops and tower sites at least 50 ft high.

5.4.5 Capacity Analysis

The capacity analysis involves calculating how much traffic can be supported given the UL/DL ratio and the anticipated traffic patterns with the specified bandwidth and modulation scheme. The parameters used for capacity calculations include

- Time-division duplexing (TDD) UL/DL ratio
- Mode of operation
- Channel bandwidth
- Subcarrier allocation scheme
- Guard ratio timing

The theoretical physical layer (PHY) throughput calculation per modulation scheme can be calculated using the following formula (Ref. 62):

$$R_b = R_s\, MC/R_r \tag{1}$$

where

M	modulation gain (2 for quadrature phase-shift keying (QPSK), 4 for 16-quadrature amplitude modulation (QAM), and 6 for 64-QAM)
C	coding rate (1/2, 3/4, 2/3, or 5/6)
R_r	repetition rate (1, 2, 4, or 6)
R_b	bit rate
R_s	symbol rate

Equation (1) accounts for the pilot overhead but does not account for the signaling overhead, which depends on the number of active connections and the service types used. Studies have found that signaling overhead may vary from 4 to 10 percent of PHY throughput. Estimating capacity using RF design tools takes into consideration the impact of multiple input, multiple output (MIMO) antenna schemas to enhance coverage and/or capacity.

Although theoretical and software-based tools provide a baseline for determining the capacity of an AeroMACS network, it will be necessary to make minor adjustments once the network has been implemented. Such optimization involves selecting appropriate network parameters that will support the QoS requirements. A test drive through the deployed network is the final step for collecting network data for analysis and optimization.

Table 20 lists many parameters that must be included in design tradeoffs for an AeroMACS network. The "Design tradeoff category" column defines broad parameter categories, and the "Parameters" column lists in detail the parameters that interrelate during the design process. The "Considerations and system tradeoff parameters" column gives recommendations for the system tradeoffs, many of which are unique to the airport surface environment.

TABLE 20.—AeroMACS NETWORK DESIGN TRADEOFFS

Design tradeoff category	Parameters	Considerations and system tradeoff parameters
Base station (BS)	Mounting placement	Total network data throughput Line-of-sight/non-line-of-sight (LOS/NLOS) coverage area Low-level blockage avoidance
	Number of BS and base transceiver station (BTS) sectors	BS throughput Channel bandwidth and available spectrum
	Multiple input, multiple output (MIMO) order	BS cell-radius requirements Transmitter (Tx) power NLOS and blocked-path performance Multipath mitigation Mobility dropouts Interference to out-of-band users will be decreased by MIMO because total radiated power can be reduced.
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Number and placement of BSs BTS sector and subscriber station (SS) Tx power
	Controlled-pattern antennas	Use beam steering and beam-shape adaptation to increase throughput and avoid interference.
	Frequency band	5091- to 5150-MHz aeronautical mobile (route) service (AM(R)S) band approved during the 2007 World Administrative Radio Conference (WARC 2007). Addition of 5000- to 5030-MHz band is under consideration.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughput over coverage area.

TABLE 20.—AeroMACS NETWORK DESIGN TRADEOFFS

Design tradeoff category	Parameters	Considerations and system tradeoff parameters
SS	Mounting height	Avoid low-level structural and temporary blockages.
	MIMO order	Tx power NLOS and blocked-path performance Multipath mitigation Mobility dropout avoidance
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Tx power NLOS and blocked-path performance Multipath mitigation Mobility dropouts
	Frequency band	Controlled and set by BTS sector connection SS must have matching frequency capability.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control the direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughputs over coverage area.
Channel bandwidth	Throughput rate	Highest throughput application sets the minimum channel bandwidth.
	Mobility performance	A wider bandwidth enables better channel equalization and better tracking of multipath variations during mobility.
	Multipath performance	Better equalization of short-path multipath with wider channel bandwidths
	Efficient use of spectrum	Number of channels that fit within the 59-MHz allocated AM(R)S spectrum
	Co-interference	There are fewer options for nonoverlapping frequency reuse in a large number of cells with wide channel bandwidths.
	Hardware limitations	20-MHz channel bandwidth requires fast digital processing and may not be implemented by a particular hardware supplier.
Modulation	Adaptive or fixed	Fixed modulation requires the use of lowest order modulation and lowest data throughput; higher order modulation will cause dropouts during mobility.
	Modulation rates	Use of all specified options maximizes data throughput for fixed and mobile SSs.
	Forward error correction (FEC) coding rate	Use of all specified options maximizes data throughput for fixed and mobile SSs.
BTS power class	Fade margin	Fade margin allowance is set during network design to establish link reliability.
	Co-interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects the signal-to-noise ratio and modulation rate at the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for NLOS operation.
	Power amplifier power-output limitations	Orthogonal-frequency-division multiplexing (OFDM) modulation has a high peak-to-average ratio, making high Tx power expensive.

TABLE 20.—AeroMACS NETWORK DESIGN TRADEOFFS

Design tradeoff category	Parameters	Considerations and system tradeoff parameters
SS power class	Fade margin	Fade margin allowance is set during network design to maintain link reliability.
	Co-interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects signal-to-noise ratio and modulation rate from the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for mobile operation.
	Power amplifier power-output limitations	OFDM modulation has a high peak-to-average ratio, making high power expensive.
Media Access Control (MAC) layer and physical layer (PHY)	Maximum mobile speed	120 km/hr is a value derived from other specified parameters and provides guidance about achievable maximum speed. The communications operating concept and requirement (COCR) is 160 kn (296 km/hr) Institute of Electrical and Electronics Engineering (IEEE) 802.16 specification does not directly support the COCR 160-kn requirement. A cost/benefit analysis is needed to assess the benefits of achieving this speed.
	Repeater operation (IEEE 802.16j)	IEEE 802.16j is a potential future amendment to the IEEE 802.16 standard BS repeater functionality may provide fill-in coverage in shadow areas with minimal added radiation and interference.
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	C-band AM(R)S spectrum allocation width does not support cost-effective FDD operation.
Quality of service (QoS)	Time delay	Services such as voice, and command and control applications will require guarantees on maximum time delay allowed.
	Time jitter	Services that are sensitive to jitter are to be identified. The use of frame buffering should be considered for each sensitive application.
	Message priority	Safety and reliability requirements will help specify message priorities.
	Scheduling	The scheduling algorithm will take message priority into account along with QoS requirements.
	Message integrity	Security and message integrity guarantees will depend on the type of QoS service flow selected.

5.5 Test Bed Architecture

The AeroMACS test bed architecture is based on the WiMAX definitions that were outlined in Section 5.3. Design of an AeroMACS system requires detailed analysis and simulation as well as test measurements on candidate airport surfaces. Test bed measurements carried out on candidate airport surfaces should provide sufficient data to calibrate key performance tradeoffs that will be modeled by computer simulations. One or more mobile SSs should be part of the test bed experiments to assess UL and DL performance coverage for initial measurements related to mobile operation.

5.5.1 Test Bed Objectives

The test bed should provide initial quantitative data to aid in the installation of the first phase of an IEEE 802.16e-based AeroMACS system at other airports of similar complexity. Specific objectives include the following:

- Assess the full range of aviation profile options for the physical and MAC layer specification, and recommend initial values for each parameter in the profile.
- Verify functional operation of the physical and MAC layers within the recommended profile.
- Obtain measurements at various locations on the airport surface to calibrate coverage models for the UL and DL systems. The UL is defined as the transmission from the SS to the BS. The DL is from the BS.
- Measure multichannel performance with sectored antennas to support BS location analysis.
- Validate operation of AeroMACS while connected to other airport network systems; for example, connected to an airport IP network.

In addition, data collected from a test bed at a specific airport location should be analyzed relative to other experimental data from airport measurements. This will help to reinforce conclusions and uncover inconsistencies.

5.5.2 Test Bed Approach

In order to meet the test bed objectives, it is recommended that at least two BSs be utilized that have overlapping coverage on the airport surface. In addition, fixed and mobile SSs should be utilized to obtain UL and DL coverage data and to be able to evaluate parameter settings under a variety of conditions.

An AeroMACS system having these considerations and conforming to the architecture described in Section 5.3 is now implemented in the NASA–CLE CNS Test Bed. The physical installation is described in Section 6.0.

6.0 Test Bed Performance Evaluation

6.1 Test Bed Implementation

The AeroMACS test bed implemented within the NASA–CLE CNS Test Bed is designed to implement many of the features that are required to support data communications at an operational airport. Two BSs are included to provide coverage redundancy and at least two opportunities for an SS to link with a BS. Multiple BTS sectors are implemented at each BS to increase link sensitivity and data capacity. The network includes ASN–GW and CSN functions to provide QoS control, user authentication and authorization for security, and mobility handoff between multiple BTS sectors.

This section describes the hardware and network layout that is implemented in the NASA–CLE CNS Test Bed. Many of the decisions about network layout in Cleveland were driven by the need to use readily available mounting structures for the BS and SS sites, the desire to integrate with already-determined test bed sensor sites, and the fact that this network is intended for test purposes and does not interact with airport operations.

The design process and system tradeoffs that would be used to design an operational deployment at an airport were discussed in Section 5.4. Each SS installation includes an IEEE-802.16e-compliant radio transceiver, a single-board computer, a managed Ethernet switch, and power supplies in a weatherproof enclosure. The single-board computer hosts a Linux operating system and Ixia Chariot software for network performance tests. The Chariot software generates test data streams that are used to test communication link capabilities. A test console is located at the core server in Glenn Building 110 to coordinate the execution of tests, collect Chariot test results through the network, and compute statistics of network performance. Airport sensors, such as the MLAT surveillance remote units, can be connected as data sources in place of or in addition to the Chariot software test data streams. A port on the managed switch is the interface for IP-based sensors.

Figure 25 shows the placement of the two BS sites and their sectorized coverage in the NASA–CLE CNS Test Bed. The BS at Glenn's Flight Research Building (Building 4) hangar office has two BTS sectors that are directed 55° and 200° azimuth from "true north." The Aircraft Rescue and Firefighting (ARFF) building located on airport property has three BTS coverage sectors directed 45°, 185°, and 295° from true north. The coverage area of each sector is 90° in azimuth as determined by the –3-dB pattern rolloff of the BTS sector antenna. These sector-coverage placements provide a high-degree of redundant coverage across the desired coverage area, including the runways, most of the taxiways, and much of the ramp areas.

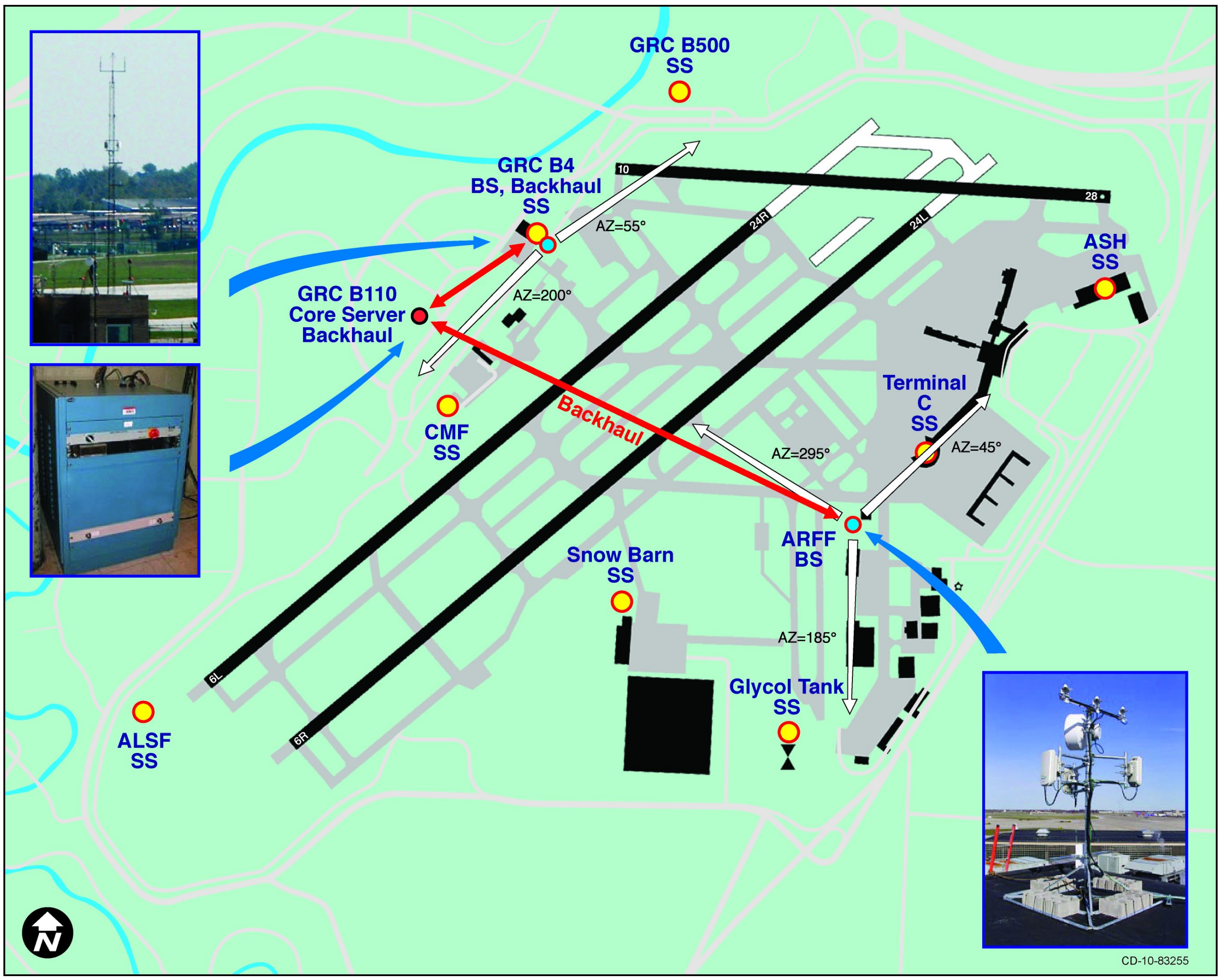

Figure 25.—NASA–CLE CNS Test Bed base station, backhaul, and core server locations. Acronyms are defined in Appendix A.

Figure 26 shows the placement of SSs at eight fixed sites. Each of these sites was chosen for their co-location with MLAT surveillance equipment already present in the test bed. Each SS can be used to wirelessly transport MLAT data to a central surveillance data processor located within the test bed. Each fixed SS has LOS to both BSs using directional antenna coverage.

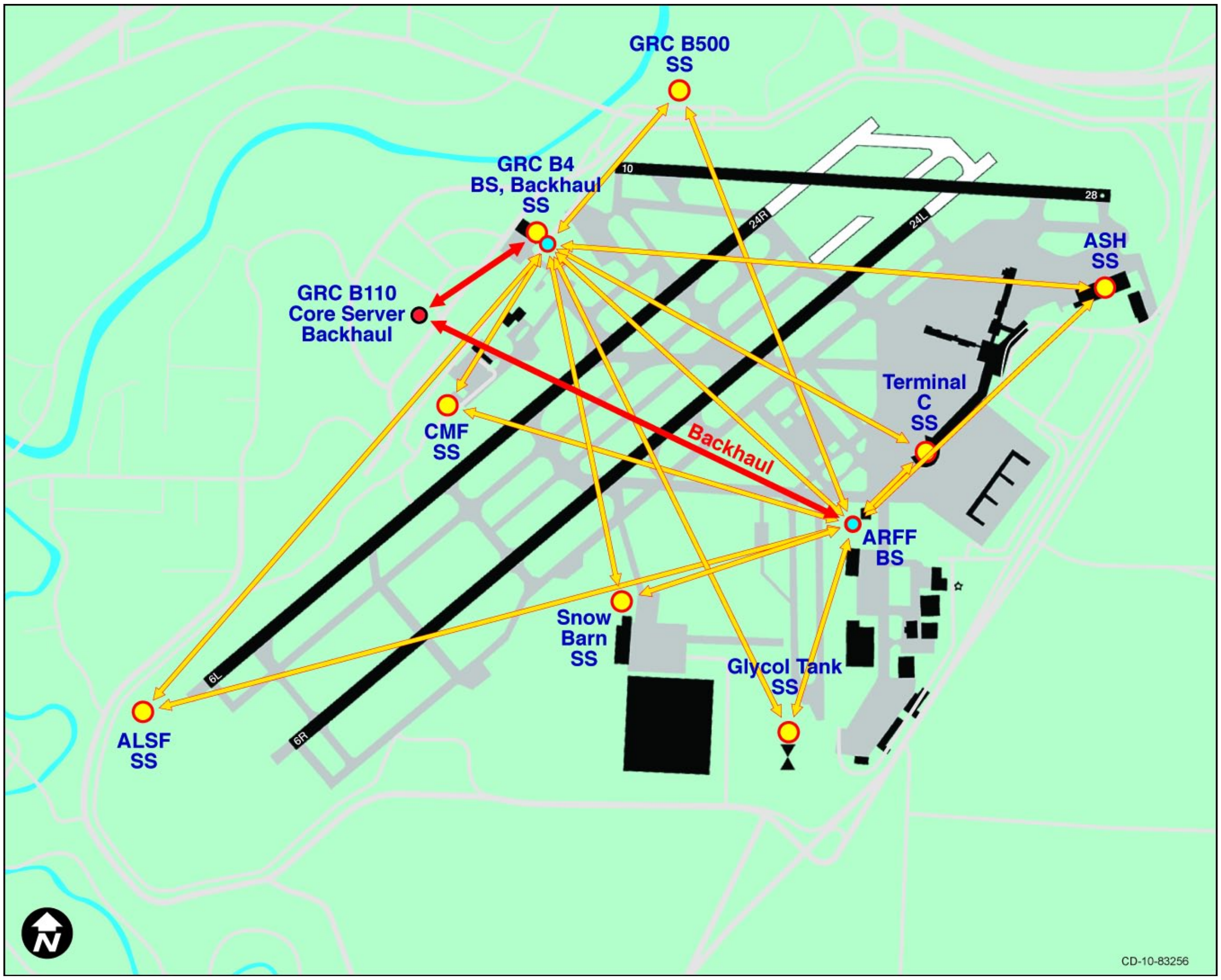

Figure 26.—NASA–CLE CNS Test Bed subscriber station locations and links. Acronyms are defined in Appendix A.

Data from each BS site is transported to the core server using wireless backhaul links that operate in an 11-GHz commercial band. A pair of these microwave radios is used on the roof of Glenn's Building 110 (Space Experiments Lab) in full duplex operation between each BS site and the core CSN servers located in Building 110. Table 21 shows the frequency assignments for the data backhaul radios.

TABLE 21.—BACKHAUL RADIOFREQUENCY ASSIGNMENTS
[Acronyms are defined in Appendix A.]

Transmitter data radio location	Receiver data radio location	Frequency assignment, MHz
CLE ARFF building	Glenn Building 110	10 915.0
Glenn Building 4	Glenn Building 110	10 795.0
Glenn Building 110	Glenn Building 4	11 285.0
Glenn Building 110	CLE ARFF building	11 405.0

Each SS installation includes the IEEE-802.16e-compliant radio transceiver, a single-board computer, a managed Ethernet switch, and power supplies in a weatherproof enclosure. The single-board computer hosts a Linux operating system and Ixia Chariot software for network performance tests. The Chariot software generates test data streams that are used to test communication link capabilities. A test console located at the core server in Glenn’s Building 110 coordinates the execution of the tests, collects Chariot test results through the network, and computes statistics of network performance. The test setup can be reconfigured to use data streams from airport sensors, such as the MLAT surveillance remote units, instead of Chariot software test data streams. A port on the managed router is the interface for IP-based sensors.

As described earlier in this section, five BTS sectors are used in the test bed in order to provide wide airport surface coverage and a high degree of link redundancy. The transceiver supporting each coverage sector is given a frequency channel assignment. Sector channel bandwidths are selectable to be 5 or 10 MHz, with 20 MHz available in the future firmware upgrade.

Sectors having overlapping surface coverage are placed on different channels to avoid co-channel interference. Reuse of channel assignments is a possibility for larger-area airport surface deployments where not all sectors have overlapping coverage. Deployment of the AeroMACS network in the NASA–CLE CNS Test Bed is expected to initially use five channels; one per sector, spaced at 5 or 10 MHz centers across the 5091- to 5150-MHz spectrum allocation to avoid co-channel interference.

Center frequencies for the five channels are set using the AeroMACS RF profiles defined in Table 22. The radios are programmable for either 5- or 10-MHz channel bandwidths and could be upgraded to have a 20-MHz channel bandwidth option.

TABLE 22.—NASA–CLE CNS TEST BED 5-MHz CHANNEL-FREQUENCY ASSIGNMENTS

5-MHz channel	Lower frequency, MHz	Center frequency, MHz	Upper frequency, MHz
1	5092.5	5095	5097.5
2	5097.5	5100	5102.5
3	5102.5	5105	5107.5
4	5107.5	5110	5112.5
5	5112.2	5115	5117.5

Channel frequency assignments for 5- and 10-MHz channel bandwidths for the five sectors of the NASA–CLE CNS Test Bed are listed in Table 22 and Table 23.

TABLE 23.—NASA–CLE CNS TEST BED 10-MHz CHANNEL-FREQUENCY ASSIGNMENTS

10-MHz channel	Lower frequency, MHz	Center frequency, MHz	Upper frequency, MHz
1	5095	5100	5115
2	5115	5120	5125
3	5125	5130	5135
4	5135	5140	5145
5	5145	5150	5155

C-band AeroMACS hardware units that are installed at BS and SS test bed sites are shown in Figure 27. The BTS sector outdoor unit is highly integrated, with each outdoor unit containing two 90° by 8° sector-coverage antennas for second-order diversity operation and RF and digital circuitry for all radio and digital processing functions. The SS outdoor unit is similarly integrated, having two integrated high-gain antennas, C-band radios, and digital processing electronics.

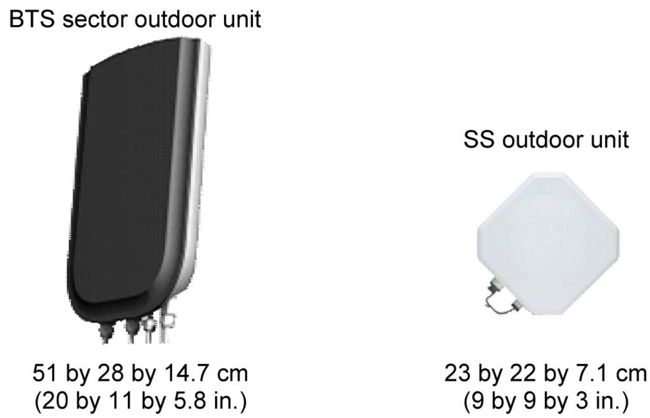

Figure 27.—NASA–CLE CNS Test Bed base transceiver station (BTS) and subscriber station (SS) outdoor units.

Second-order diversity operation is implemented in each AeroMACS transceiver in a MIMO configuration. Each transceiver has 2×2 MIMO: two transmitters and two receivers operating in the transmit/receive TDD mode. Each transmitter/receiver pair is connected to one of the two internal antennas. The antennas operate in a cross-polarization mode so that two independent propagation paths are formed.

The test bed SS transceivers also have two built-in cross-polarized antennas. This case uses 2×1 MIMO: two receivers and a single transmitter are connected to the antennas to support diversity propagation paths.

The general specifications shown in Table 24 apply to the BTS and SS radios installed in the test bed. The radios operate in a TDD mode. The IEEE 802.16e-2005 standard specifies adaptive modulation coding that sets the modulation level from QPSK to 64–QAM, according to link conditions, in order to maximize data throughput rates. The standard specifies multicarrier orthogonal-frequency-division multiplexing (OFDM) modulation in the OFDMA mode which enables simultaneous data transfer from/to multiple applications through a single SS unit. Forward error correction (FEC) coding is adaptively set for coding rates between 1/2 and 5/6 for the chosen modulation level to maximize the data throughput for the current link conditions.

TABLE 24.—GENERAL RADIO SPECIFICATIONS

Item	Description
Operation mode	Time-division duplex (TDD)
Modulation	Orthogonal-frequency-division multiplexing (OFDM) modulation, 1024/512 fast Fourier transform points, quadrature phase-shift keying (QPSK), 16 quadrature amplitude modulation (QAM), 64–QAM
Access method	Orthogonal-frequency-division multiple access (OFDMA)
Forward error correction (FEC)	Convolutional turbo coding: 1/2, 2/3, 3/4, and 5/6

Table 25 shows specifications for each single-sector BTS outdoor unit implemented in the NASA–CLE CNS Test Bed. Each outdoor unit is tunable over a wider frequency range than is needed for the present AM(R)S allocation of 5091 to 5150 MHz and supports operation in the 5000- to 5030-MHz segment if it is allocated to AM(R)S. Channel bandwidths can be set for 5 or 10 MHz in the initial test bed hardware, with a planned upgrade that would include 20-MHz channel bandwidth capability. The built-in antennas provide two high-gain directive patterns with orthogonal polarization to support dual-channel second-order diversity MIMO operation for improved link sensitivity. Operating frequency and channel bandwidth are controlled by configuration parameters that are set up in the CNS core server by the network operator.

TABLE 25.—5100-MHz BASE TRANSCEIVER STATION SPECIFICATIONS

Frequency, GHz	4.900 to 5.350
Supported bandwidths, MHz	5 and 10 (20 after future expansion)
Transmitter (Tx) power range, dBm	0 to 21 (in 1-dBm steps)
Tx power accuracy, dB	± 1
Maximum input power (at antenna port), dBm	
Before saturation	–50
Before damage	–10
Diversity	Second order (multiple input, multiple output, MIMO)
Antenna pattern	2 by 15 dBi in the 4.9- to 5.9-GHz band, 90° azimuth by 8° elevation sector antenna, dual-slant ±45° polarization
Height by width by depth, mm	510 by 280 by 147
Weight, kg	10.7
Power source, Vdc	40 to 60

Similar to the BTS outdoor unit, the SS outdoor unit is highly integrated with RF and digital electronics and a dual-polarization antenna in a single package. The antenna description is provided in Table 26. SS unit operating frequency, channel bandwidth, and transmit power level are all controlled by the BS it connects to within the network.

TABLE 26.—C-BAND SUBSCRIBER STATION SPECIFICATIONS

Polarization	Dual slant
Gain, dBi	17
Beamwidths	24° azimuth by 18° elevation

Mobility tests will initially be conducted with an SS installed in Glenn’s Terrestrial Hybrid Environment for Verification of Aeronautical Networks (THEVAN, Figure 28) or a similar vehicle. SS hardware that has been modified to support an external antenna will be installed. Link coverage will be provided with an antenna with omnidirectional azimuth coverage mounted on top of the van.

Figure 28.—Glenn’s mobile test vehicle: THEVAN.

NASA Glenn’s Viking S3 aircraft (Figure 29) is available for mobility tests and demonstrations in an aircraft mobile environment. Tests will be conducted while the aircraft is taxiing on the CLE airport surface. Again, modified SS hardware that supports the use of external antennas will be used.

Figure 29.—Viking S–3 mobile platform.

6.2 Simulation, Emulation, and Testing Results and Evaluation

Evaluation of the C-band IEEE 802.16-based AeroMACS network installed in the NASA–CLE CNS Test Bed consists of a study of system tradeoffs, link performance analysis, and performance test measurements of the installed network. This report presents an analysis of the test bed configuration layout shown in Figure 25 and Figure 26. The test bed was analyzed using the Cellular Expert analysis program developed by HNIT–BALTIC. Analysis results are followed by results of over-the-air tests for the same test bed configuration along with comparisons between analysis predictions and actual network performance.

6.2.1 Network Simulation Evaluation Results

The Cellular Expert analysis program was used to predict AeroMACS performance for the NASA–CLE CNS Test Bed installation. This tool can predict data throughput rates that are achievable for locations across the airport surface. The program utilizes the parameters of the IEEE 802.16e hardware and the radio signal propagation properties, which are affected by antenna mounting heights, ground terrain profiles, and shadowing caused by buildings and structures. Results are based on analysis of the as-installed bed network and a summary report completed by Alvarion (Internal report: BreezeMAX Extreme. Nortel Govt. Solutions. Radio Network Plan Report. Alvarion Technical Report, ITT/FAA, Sept. 4, 2009).

The Radio Network Plan included the following simulations and procedures:

- The BS antenna sector pointing was analyzed.
  - Azimuth pointing angles were determined manually.
  - Antenna down-tilt angles were selected to provide the widest coverage area on the airport surface.
- 3D representations of buildings and structures were entered to add accuracy to the coverage predictions.
- Plots of signal strength and best sector grids were run after the sectors were arranged.
- Plots were run at 12- and 25-ft SS mounting heights to account for the varying mounting heights used in the test bed.
- Channel frequency plans were validated within the available 5100-MHz AeroMACS spectrum.

Figure 30 is an aerial map of the Glenn and CLE properties with building footprints that were included in the model highlighted.

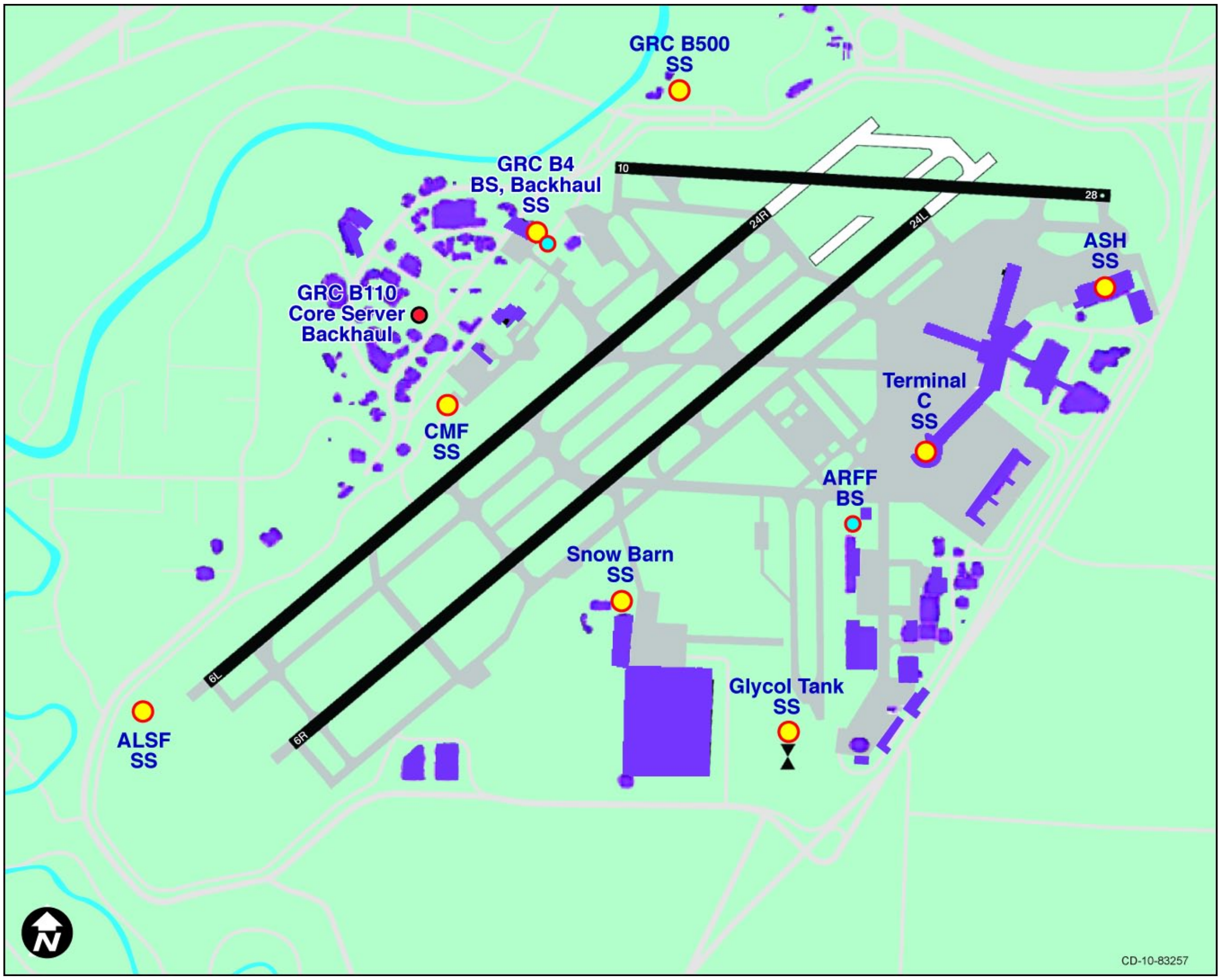

Figure 30.—Cleveland Hopkins International Airport with building footprints highlighted. Primary CPE refers to customer premise equipment—referred to as subscriber stations (SSs) in other places in this document. Acronyms are defined in Appendix A.

The analysis used the BTS sector and SS performance parameters summarized in Table 25 and Table 26. The channel assignments and antenna pointing angles are defined in Table 27. Center frequency assignments used for the BTS sectors in the analysis are defined in Table 28. The frequency assignments used in the test bed physical implementation were similar to those used in this analysis but were shifted to conform to the AeroMACS profile.

TABLE 27.—BASE TRANSCEIVER STATION (BTS) SECTOR CONFIGURATIONS AT NASA GLENN AND CLEVELAND HOPKINS INTERNATIONAL AIRPORT (CLE)

Base station	Location	Building	Sector[a]	Channel	Azimuth, deg	Tilt, deg	Height, m
1	Glenn	4	BTS1_1	F1	55	1	20
1	Glenn	4	BTS1_2	F5	200	1	20
2	CLE	ARFF[a]	BTS2_1	F2	45	1	10
2	CLE	ARFF[a]	BTS2_2	F4	185	1	10
2	CLE	ARFF[a]	BTS2_3	F3	295	1	10

[a]Aircraft Rescue and Firefighting building.

TABLE 28.—BASE STATION SECTOR CHANNEL-FREQUENCY ASSIGNMENTS FOR ANALYSIS

Channel	Frequency center, MHz
F1	5093.5
F2	5103.5
F3	5113.5
F4	5123.5
F5	5133.5

Figure 31 and Figure 32 show plots of DL (BS to SS direction) performance in the coverage area for 12-ft and 25-ft SS mounting heights, respectively. The eight SS locations are indicated by yellow circles. Sensitivities are based on a fade margin of 10 dB. The color scale references the highest order of IEEE 802.16e waveform modulation that can be supported for the signal level predicted to be present at each location.

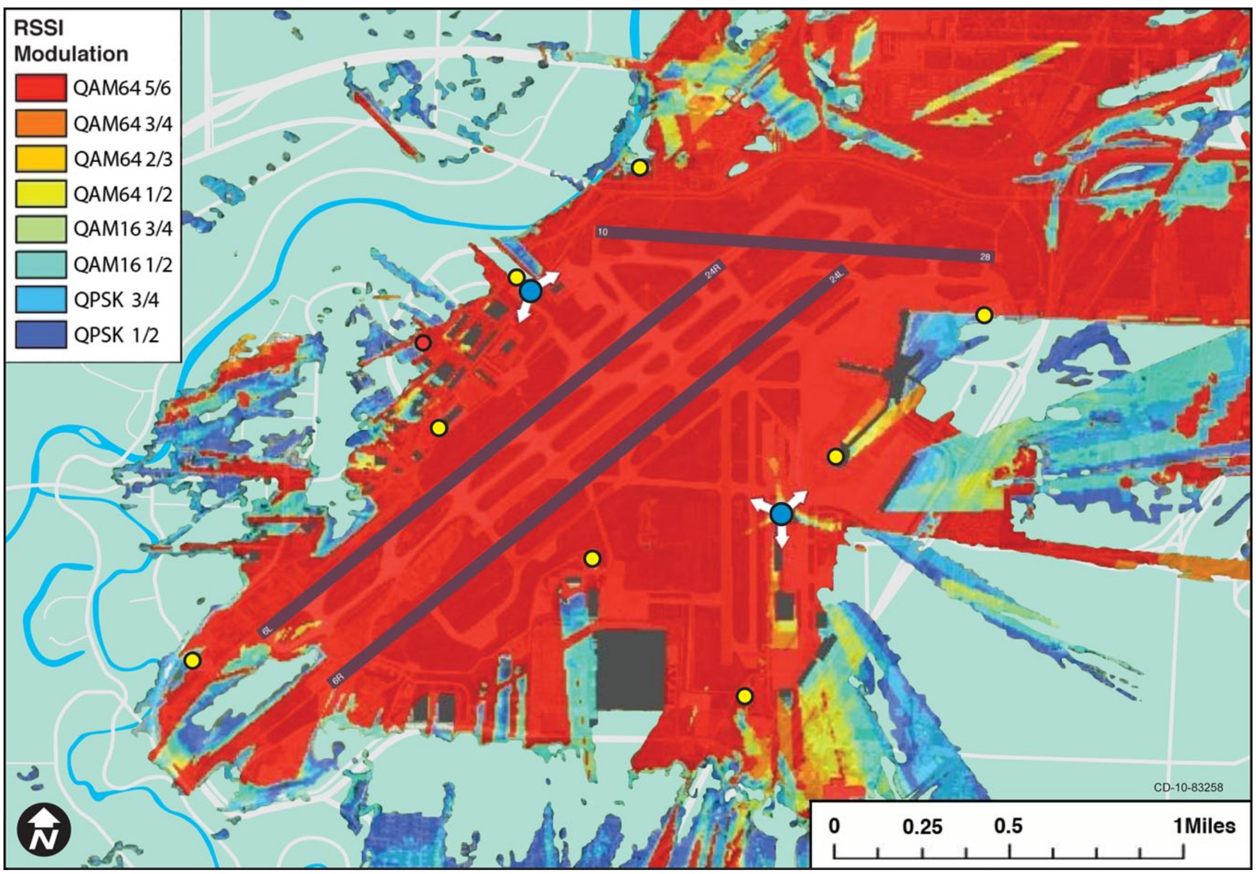

Figure 31.—Received signal strength indication (RSSI) plot for 17-dBi directional subscriber station mounted at 12 ft. Acronyms are defined in Appendix A.

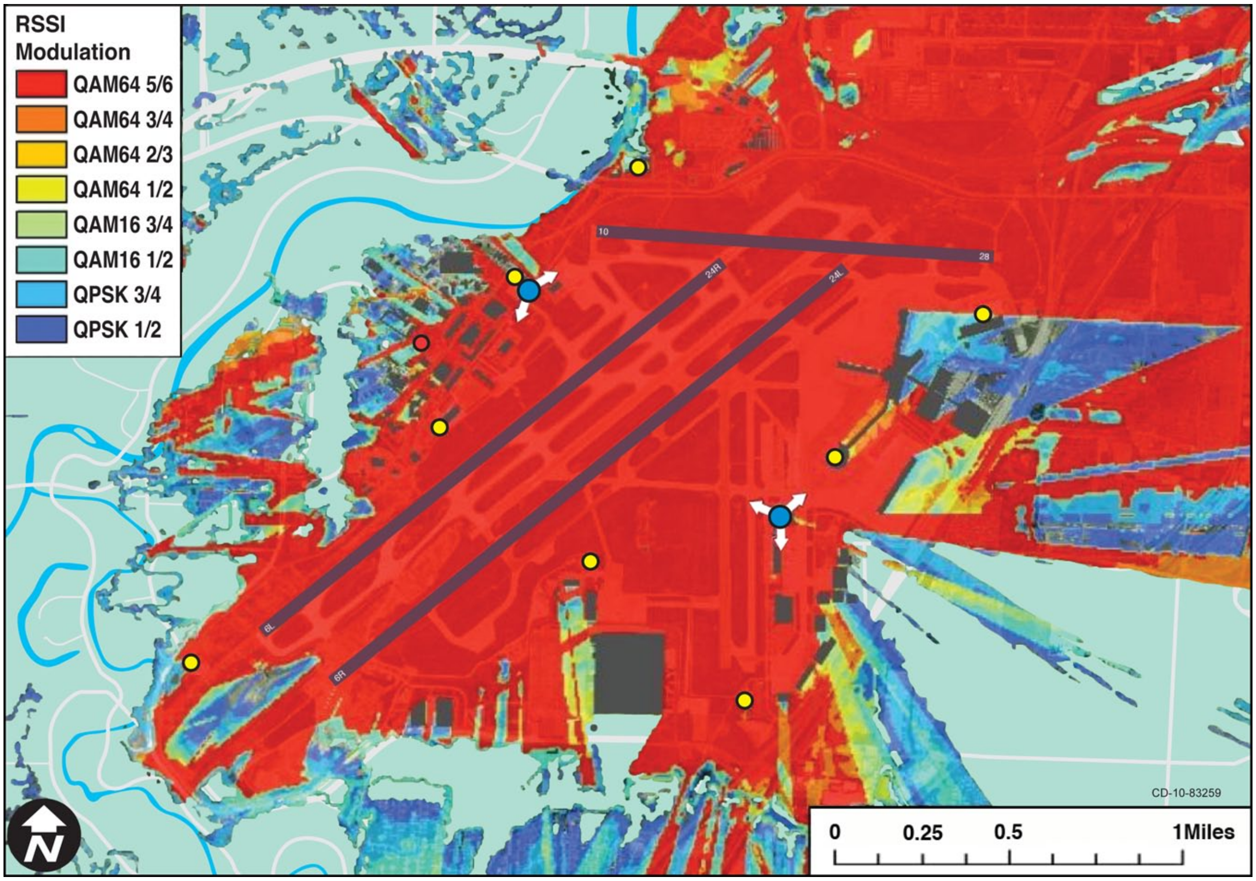

Figure 32.—Received signal strength indication (RSSI) plot for 17-dBi directional subscriber station mounted at 25 ft. Acronyms are defined in Appendix A.

As stated, this analysis and results are based on a fade margin of 10 dB. This value is commonly applied to fade margin for fixed LOS microwave links. However, the value for fade margin assigned for analysis will affect the reliability of the link. A recommended use of the test bed is to conduct link experiments to learn the correct value to apply for a broadband C-band system in the airport environment. Analyzing mobile links will require a different fade margin, which should also be validated with test bed tests.

A comparison of the plots in Figure 31 and Figure 32 reveals little difference in performance for the two SS mounting heights. 64–QAM with an FEC code rate of 5/6, which results in the highest data throughput rates, is achievable over the majority of the airport surface. Exceptions to the highest modulation rate occur in areas where both BSs are shadowed from the SS by buildings. Varying levels of modulation are predicted in these regions, ranging from lower orders of QAM and FEC coding, down through QPSK, with small regions with no link support. A region of shadowing is predicted to occur on the north side of the airport terminal buildings where LOS to both BSs is blocked by the buildings. In design of an operational AeroMACS network, the system designer may choose to locate the airport-side BS in a position that will provide more complete coverage in the terminal area, to include an additional BS for terminal coverage, or in the future, to make use of repeater stations as specified in the IEEE 802.16j amendment (Ref. 63) that is currently in development.

A best sector plot is shown in Figure 33. This plot indicates which BTS sector provides the best link sensitivity to a SS. The calculations demonstrate that each sector supports at least one SS. For comparison, Figure 34 illustrates the BTS sector that is closest to each SS location. The shadowing effects of building structures cause the closest sector to not necessarily be the optimal choice for link performance.

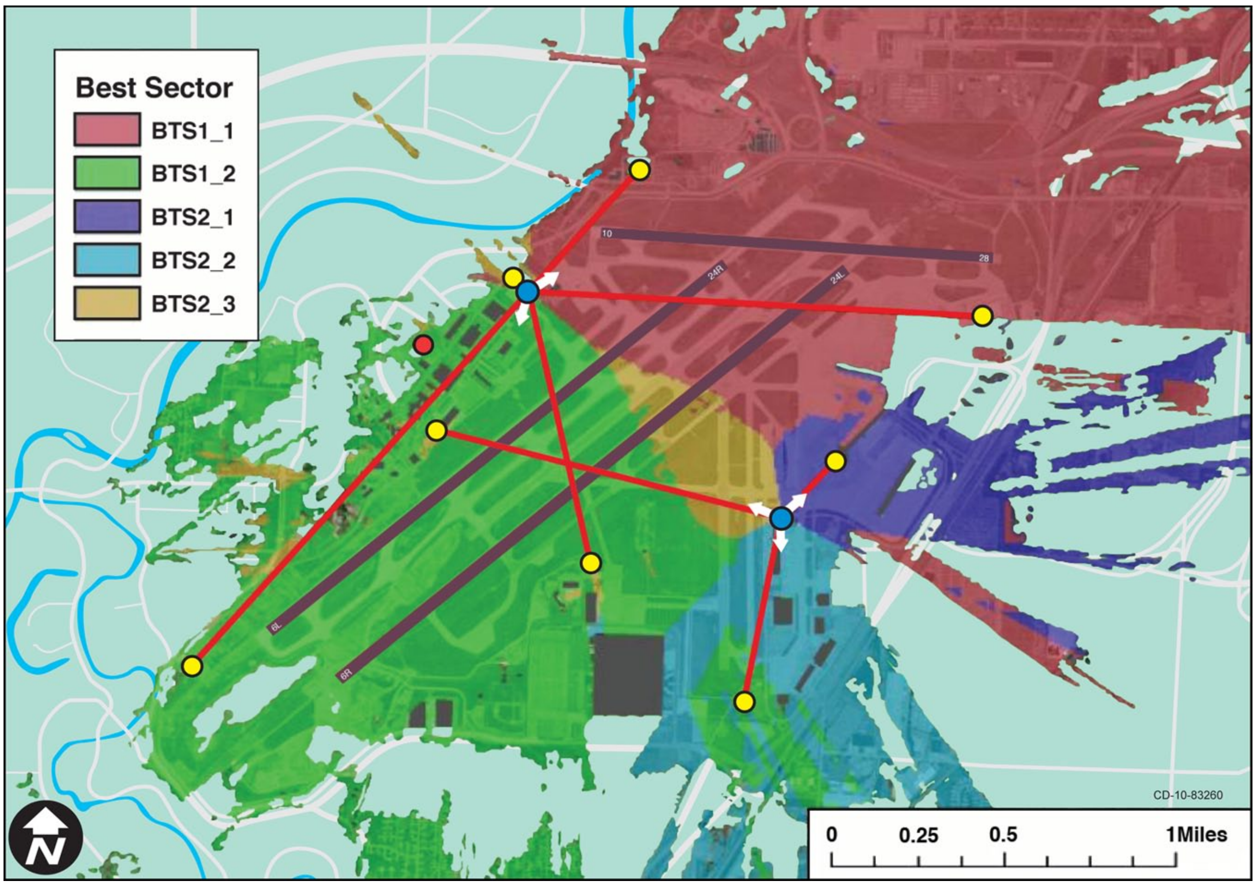

Figure 33.—Connection map for each subscriber station based on received signal strength indication (RSSI). Acronyms are defined in Appendix A.

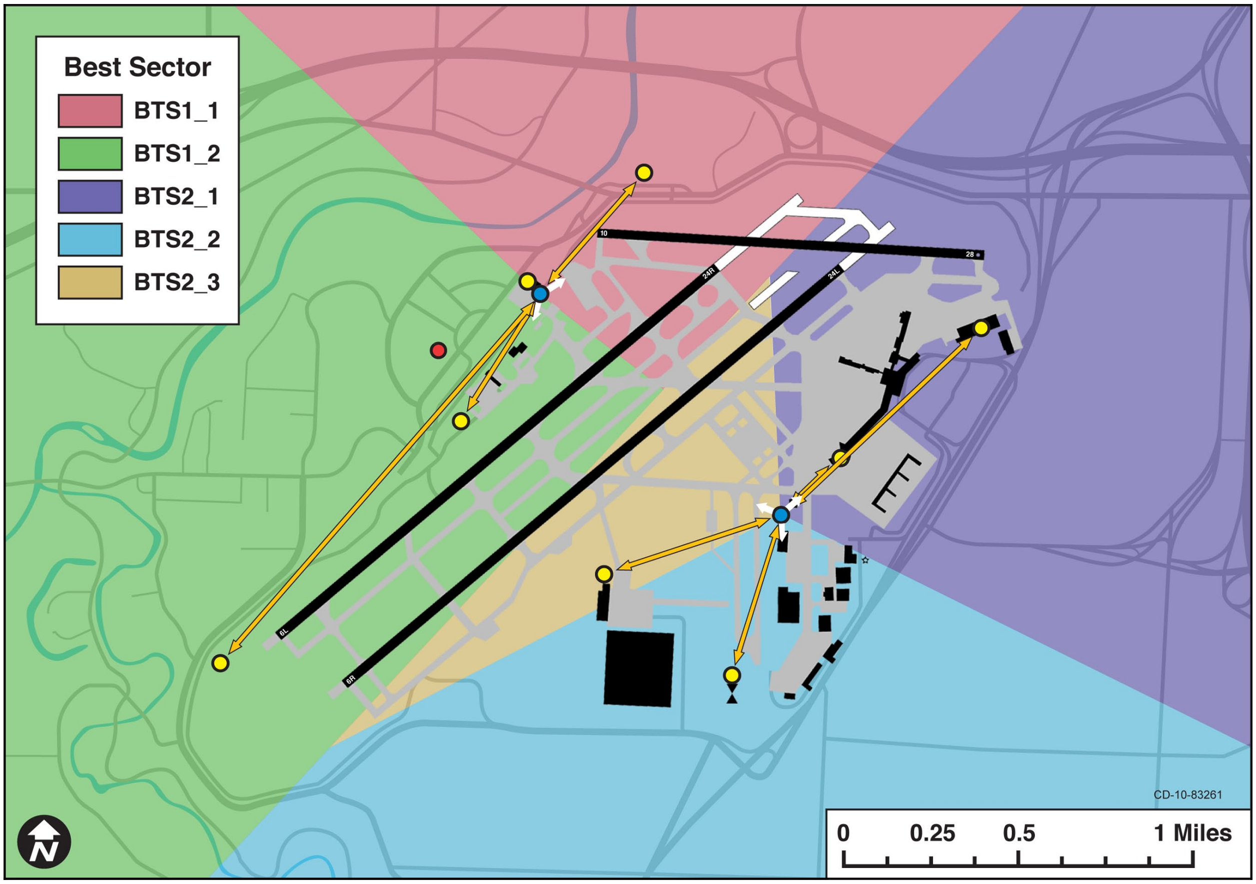

Figure 34.—Connection map for each subscriber station based on nearest base transceiver station (BTS) sector.

One SS location, the Aviation Services Hangar (ASH) on the CLE property, is on the edge of coverage from the BS at Glenn's Building 4 and is shadowed from the BS at CLE's ARFF building. However, because the SS at this location will be mounted 40 ft above the ground level, it will provide a clear LOS view over the airport terminal building to the BS at Glenn's Building 4.

6.2.2 Network Test and Evaluation Results

For the AeroMACS network, two BS locations were added to the NASA–CLE CNS Test Bed on opposite sides of the airport runways in order to provide wide coverage over the airport surface. Network operational redundancy results because each SS typically has both BSs within view and is able to link to either BS. An interruption of the established link, caused by blockages or obstructions, will cause the SS to use its mobility handoff capability to rapidly reestablish its data flow through the other BS. This capability may not be required, depending on the reliability requirements of applications, but it is available in the test bed for testing purposes.

For several practical reasons, SS locations were selected to match the sensor sites of the original Sensis Corporation MLAT surveillance test bed. These sites provide IP data streams from already installed data sensors, provide simplified installation, and have electrical power sources already available to power the SSs. In addition to the sensor data sources, a single-board computer is co-located at each SS site to provide known data streams for evaluating AeroMACS link performance.

All network hardware planned for initial test bed modifications has been installed at Glenn and CLE as described in the following list. Remote unit (RU) designators provided in the following descriptions correspond with the RU numbers assigned by Sensis Corp for their original MLAT surveillance test bed and can be referenced on the airport layout diagrams (Figure 25 and Figure 26).

Glenn Installation Sites

- Building 500 roof (RU08)
  - SS unit
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies
- Building 4 roof (RU07)
  - SS unit
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies
  - 11-GHz wideband microwave backhaul link outdoor unit to connect this BS to the core server in Building 110
- 80-ft radio tower adjacent to Building 4 (RU07)
  - BS with two BTS sectors mounted at 60 ft above the ground level
  - Two Global Positioning System (GPS) outdoor units mounted at 66 ft above the ground level to support the BTS outdoor units
- Building 4 copier room
  - Equipment rack with BTS power supplies, managed Ethernet switch, and microwave backhaul link indoor unit and power supply
- Building 110, Room 310
  - Equipment rack with the following CNS and data backhaul functions
    - Nortel 4134 secure router
    - Authentication, authorization, and accounting (AAA) server
    - Network Management System server
    - Data backhaul indoor units for links to Building 4 and ARFF building
    - Power supplies for servers and backhaul radios
    - Single-board-computer connected to 4134 secure router

Cleveland Hopkins Airport Installation Sites

- ARFF building roof (RU08)
  - BS with three BTS sectors mounted on a nonpenetrating roof-mount antenna mast
  - Three GPS outdoor units mounted on antenna mast above BTS outdoor units
  - 11-GHz wideband microwave backhaul link outdoor unit to connect this BS to the core server in Building 110 mounted on the antenna mast
- ARFF building inside observation desk
  - Equipment rack with BTS power supplies, managed Ethernet switch, microwave backhaul link indoor unit and power supply
- ASH roof (RU01)
  - SS mounted to roof-top support beams
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies mounted to roof-top support beams
- Terminal C roof (RU02)
  - SS mounted to Sensis equipment rack
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies mounted to Sensis equipment rack
- Glycol Tank support building (RU03)
  - SS mounted on external wall facing runways

  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies mounted on external-wall-facing glycol tanks
- Snow Barn building (RU04)
  - SS mounted near roof line
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies mounted inside of the building
- Approach lighting with sequenced flashing lights (ALSF) tower near ALSF building (RU05)
  - SS mounted on tower section
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies mounted on short tower
- Consolidated Maintenance Facility (building RU06)
  - SS mounted on roof edge near Sensis antennas
  - Support electronics enclosure for SS with a managed Ethernet switch, single-board computer, and power supplies mounted inside of building

Figure 35 to Figure 43 are photographs of AeroMACS hardware installations with key components highlighted. Figure 35 shows the BS and data backhaul radio outdoor unit at Glenn's Building 4 (hangar). Two BS outdoor units with built-in sector-coverage antennas are mounted 60 ft above the ground level on the radio tower that already existed beside Building 4. A GPS outdoor unit is mounted to the tower 6 ft above each BTS outdoor unit. GPS signals are used by the BTS outdoor units for precise timing and coordination of their transmit/receive operation.

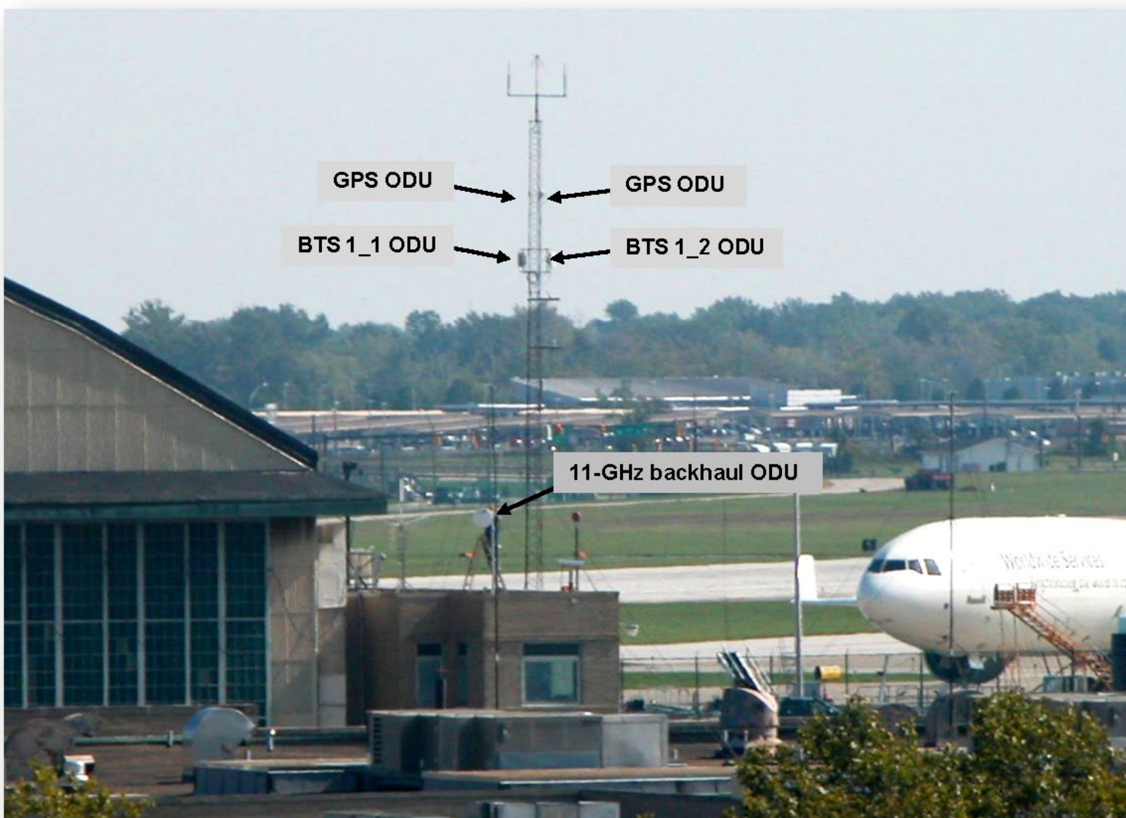

Figure 35.—Base transceiver station (BTS) sectors, Global Positioning System (GPS) receivers, and data backhaul installation at Glenn Building 4.

Figure 36 shows the BTS and data backhaul equipment rack that is located in the copier room on the second level of Building 4. The Lambda 48-Vdc supply powers the 11-GHz data backhaul indoor unit and outdoor unit. Two 55-Vdc power supplies running on 220 Vac are inside the rack that power the BTS sector radios through a Power-over-Ethernet (PoE) cable that also carries BS data traffic.

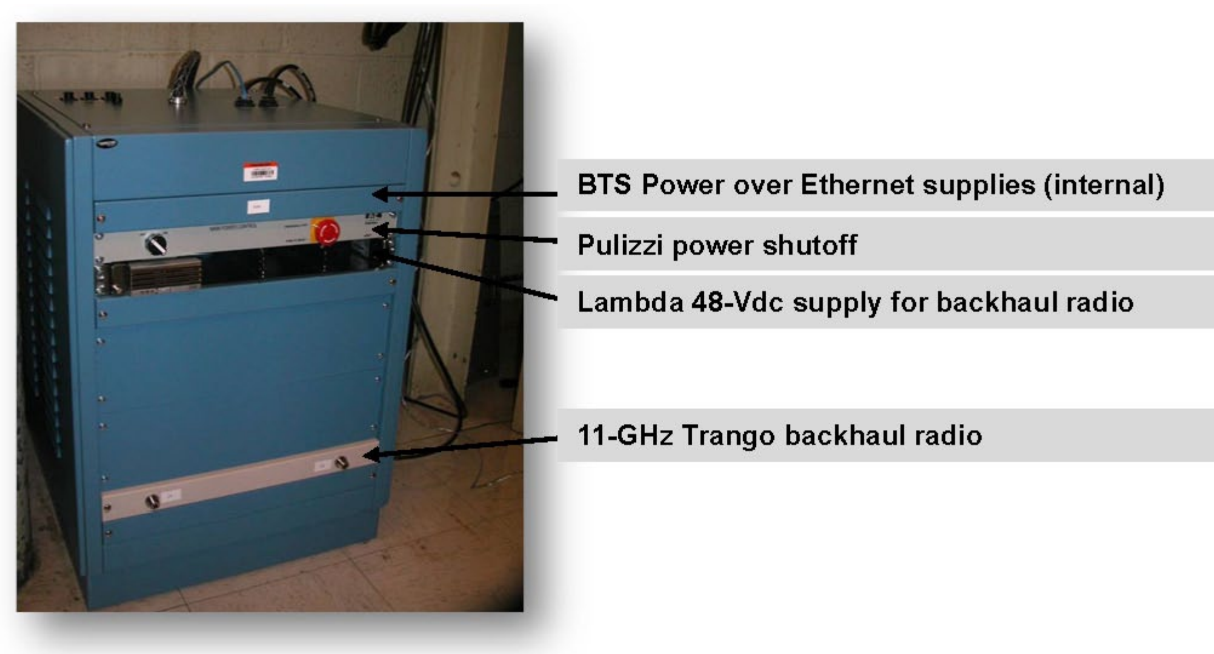

Figure 36.—Base transceiver station (BTS) and data backhaul equipment rack at Glenn’s Building 4.

Figure 37 shows an SS at Glenn’s Building 500. The SS radio and the SS electronics enclosure are mounted to the equipment rack that was installed by Sensis Corp. during the original test bed build. SS installations at Glenn’s building 4 and at CLE’s Concourse C are similar: the SS hardware is mounted to an existing equipment rack. The other five SS installations use varying methods of mounting SS equipment to existing structures.

Figure 37.—Subscriber station and enclosure at Glenn’s Building 500.

In Figure 37 the SS outdoor unit is pointed toward the BS near Glenn’s Building 4. The electronics enclosure is mounted on the opposite end of the equipment rack. The remaining enclosures are from the original installation and are not related to the AeroMACS network.

Figure 38 shows the internal components of an electronics enclosure during installation. Therefore, not all internal cabling is shown in this photograph. Identical electronics enclosures are installed at all SS installation sites.

Figure 38.—Internal electronics of subscriber station enclosure.

The SS power supply in the lower right-hand corner of the enclosure runs on 110 Vac and provides 48 Vdc as PoE. Above the SS power supply is an Ethernet input/output board with a single-board computer beneath it. The single-board computer uses a Linux operating system and hosts Chariot test software from Ixia. Chariot can be controlled through the network to generate and receive test data streams that are used to evaluate AeroMACS link performance. A lightning arrestor for PoE lines to the SS is shown in the upper left-hand corner.

The managed Ethernet switch in the upper left-hand corner provides connections for the SS, the single-board computer, and up to two other devices that have an IP-based Ethernet interface. Connection is with a standard RJ–45 connector. This will be the interface to the MLAT surveillance sensors.

The enclosure includes provisions for environmental control to protect the internal components. A fan is visible in Figure 38 that is on a temperature sensor and draws outside air into the enclosure above a set temperature. In addition, heating elements are mounted behind the aluminum mounting plate that are activated at a set low temperature.

Figure 39 shows the 11-GHz data backhaul radio outdoor unit located on the roof of Glenn's Building 4 during installation. This radio is part of the link that backhauls data with a similar radio on the roof of Glenn Building 110. Figure 40 shows the Glenn Building 110 end of this link and a second backhaul radio that supports the link to the BS located at CLE's ARFF building.

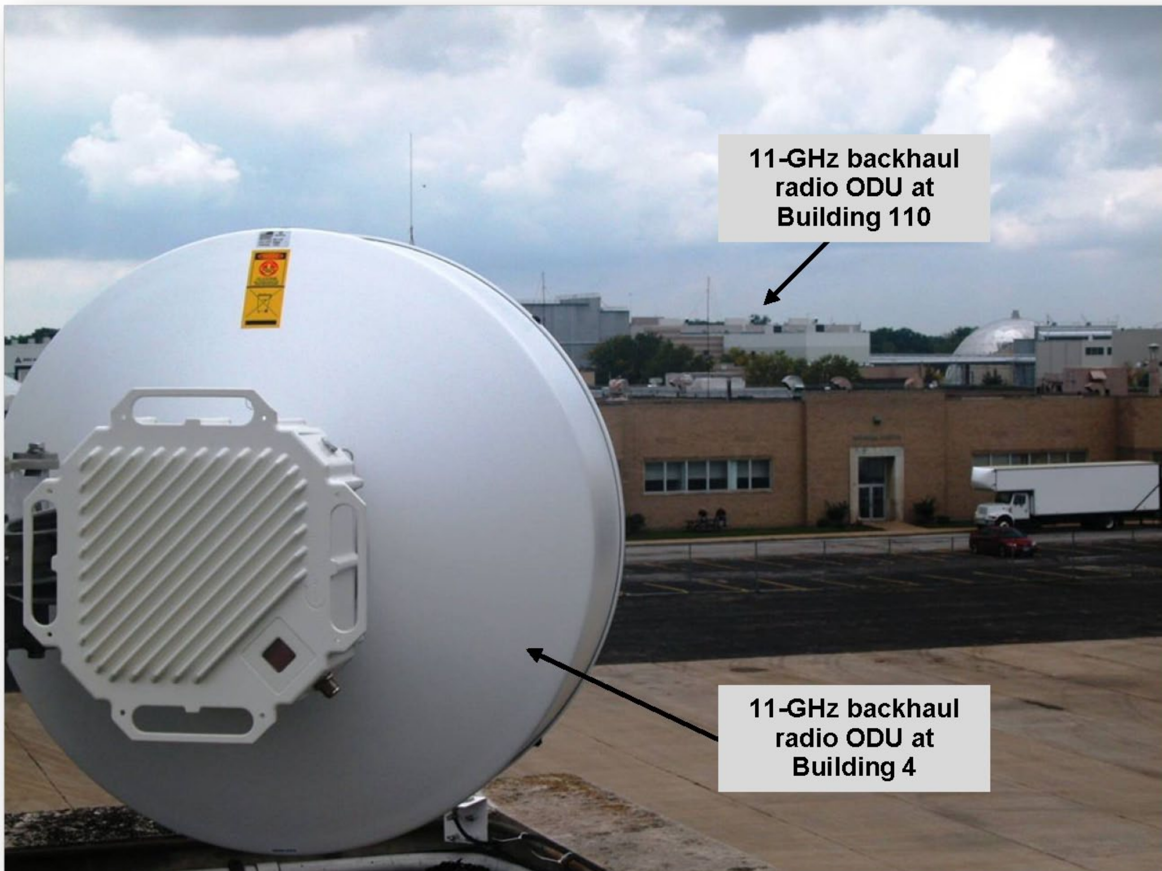

Figure 39.—11-GHz backhaul radio outdoor units at Glenn's Building 4 and Building 110.

Figure 40.—11-GHz backhaul radio outdoor units at Glenn Building 110 with links to Glenn Building 4 base station (BS) and to Cleveland Hopkins International Airport's (CLE) Airport Rescue and Firefighting (ARFF) building.

The airport-side BS is located on the roof of the ARFF building observation deck as shown in Figure 41 with a closeup view of the antenna mast and mounted components shown in Figure 42. The closeup view clearly shows the nonpenetrating roof-mount antenna mast that supports AeroMACS outdoor unit components and the 11-GHz backhaul radio that is pointed toward Glenn Building 110.

Figure 41.—Aircraft Rescue and Firefighting (ARFF) building base station on observation deck roof.

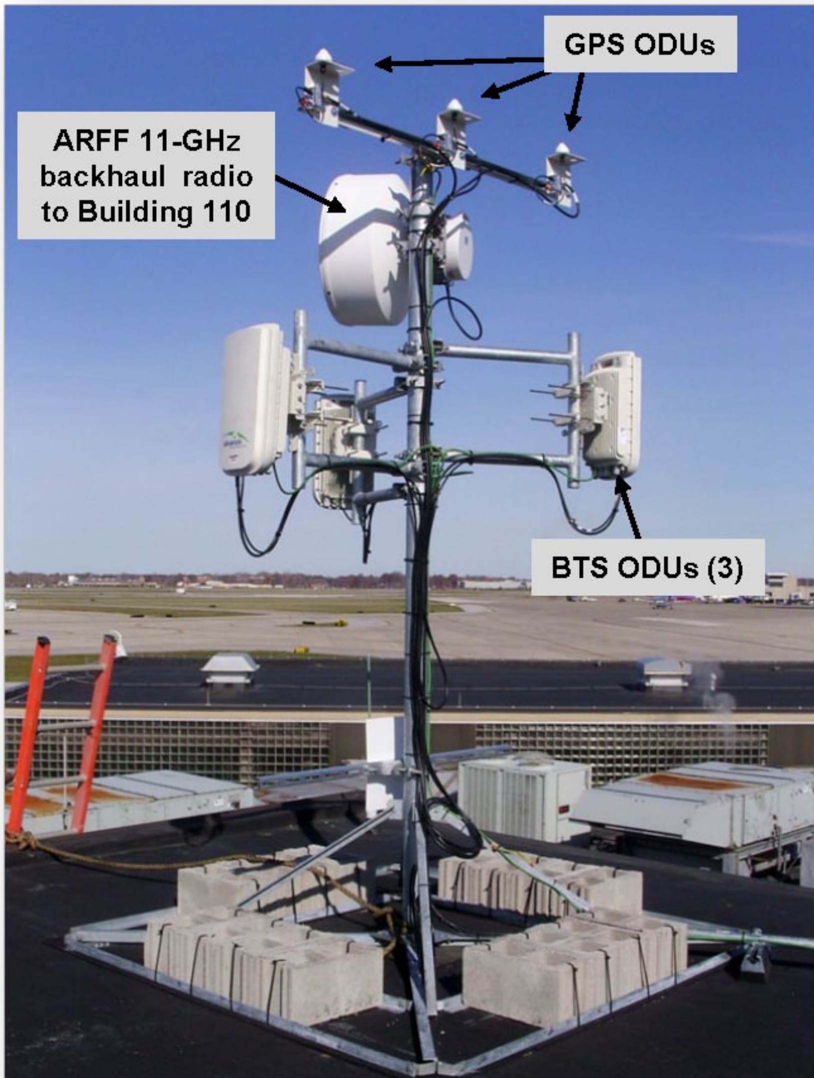

Figure 42.—Detailed view of base station at Aircraft Rescue and Firefighting (ARFF) building. Acronyms are defined in Appendix A.

Three IEEE-802.16e-compliant AeroMACS BS radios are mounted to the mast: each on a standoff arm. The separation of the standoff arms increases RF isolation between units and decreases the potential for in-band interference. The 11-GHz backhaul radio with its 2-ft-diameter dish antenna is mounted on the mast above the AeroMACS radios. Three GPS outdoor units are mounted on a bar above the backhaul radio at the top of the antenna mast. The GPS outdoor units support the three AeroMACS radios for precise timing with one GPS outdoor unit connected per radio.

The equipment shown in Figure 43 comprises the network core where data are aggregated from BSs and SSs and then disseminated to various data users. The equipment is a combination of power management breakers and switches, indoor units for the two data backhaul radios and their power supplies, computer servers to host the CNS functional software, and a secure Ethernet router.

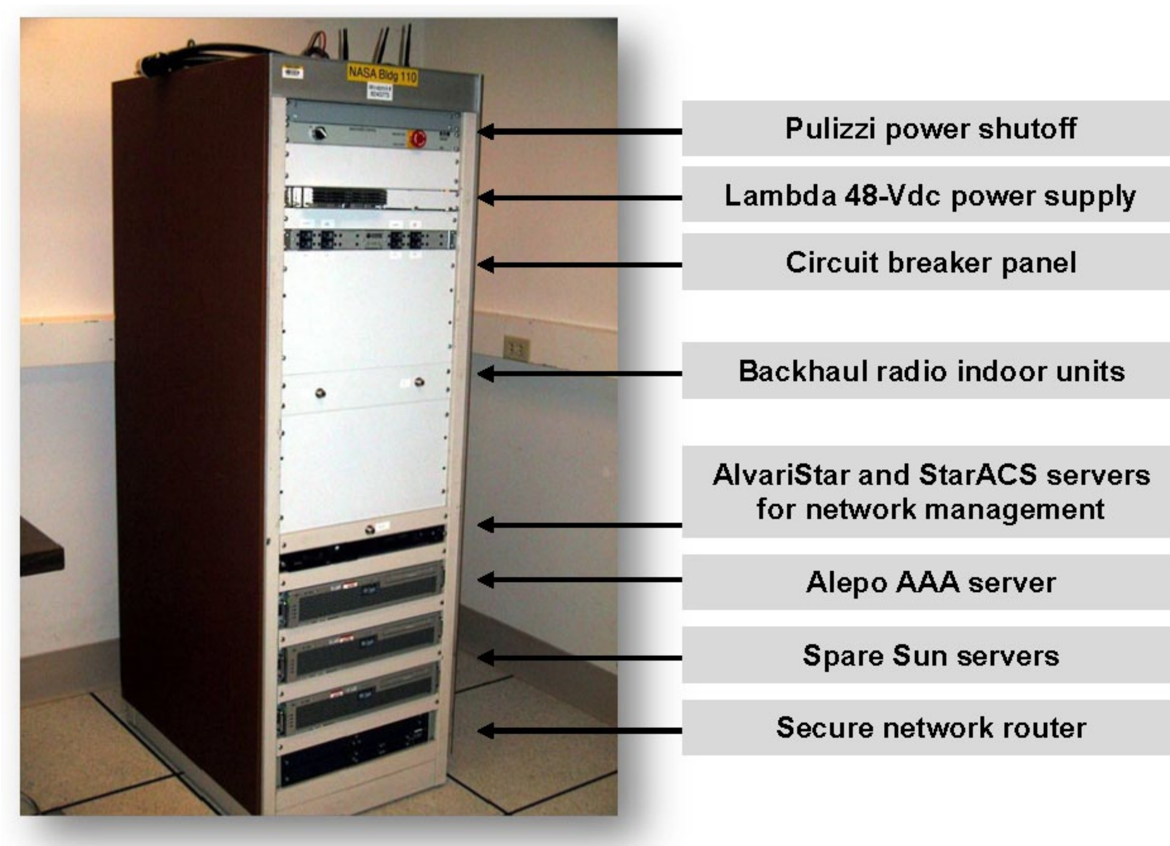

Figure 43.—Core server equipment in Glenn's Building 110, Room 310. Acronyms are defined in Appendix A.

The network architecture illustrated in Figure 44 can be used to understand the functions of the servers and secure router in the core network. The equipment rack (shown in Figure 43) includes one server more than is needed to host the CNS functions because one server was found to be able to host both the Network Management System (NMS) and the AAA functions. The major CNS functions and their corresponding programs are described in the following paragraphs.

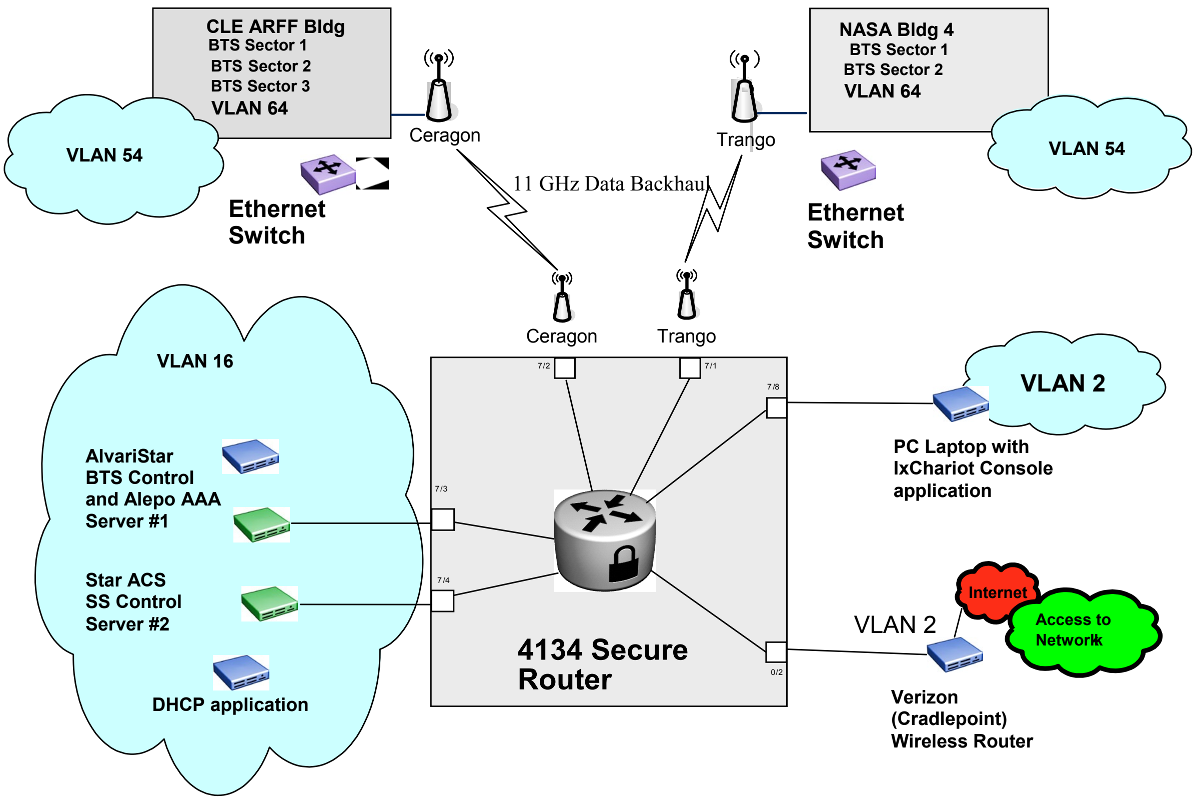

Figure 44.—IEEE 802.16e core network diagram. Acronyms are defined in Appendix A.

AlvariStar is a telecommunications-class NMS for managing commercial Mobile WiMAX BSs and supports the operation of AeroMACS network BSs without modification. AlvariStar supports common network management applications in compliance with telecom industry standards, providing comprehensive fault, configuration, performance and security management functionality. It provides network surveillance, maintenance, and fault-handling capabilities. AlvariStar is designed to support a variety of system architectures ranging from a single-airport size of network where AlvariStar resides on a single computer server, to a fully distributed system that would support multiple airports.

Alepo software provides AAA functions for commercial Mobile WiMAX networks and can be used to operate an AeroMACS network without modification. When an SS requests entry into the AeroMACS network, Alepo refers to a preprogrammed data base, validates the SS identity, and authorizes or rejects entry into the network. For SSs that are allowed entry, Alepo determines from its data base the level of QoS that the network should provide. Alepo is fully compliant with the IEEE 802.16e and WiMAX Network Working Group standards.

The Star Automatic Configuration Server (StarACS) provides a unified and standardized system for managing a variety of SSs. Developed for the commercial WiMAX industry, StarACS will support AeroMACS SSs without modification. It provides mass configuration updates, software upgrades, maintenance, and troubleshooting of SSs through the network, and integrates with higher-level NMSs.

Figure 44 identifies the interconnections between components of the AeroMACS network that was added to the NASA–CLE CNS Test Bed. At the center of the system is the Nortel 4134 secure router that enables secure virtual local area network (VLAN) data paths to be established through virtual private network (VPN) routes. With this capability, VLAN data channels can be established end-to-end through the AeroMACS network from an SS to an Ethernet port on the secure router that is kept private and secure from all other VLAN channels.

A data path between the SSs and a port on the 4134 secure router is established on VLAN 54 in order to connect the AeroMACS network to the laptop personal computer (PC) that hosts Ixia Chariot test software and controls network tests. Additional user IP ports at the secure router can be established for data-path connections through the AeroMACS network.

In addition to the data plane, a control plane is established on a separate VLAN through the 4134 secure router. In this manner, control traffic from the AlvariStar, Alepo AAA, and StarACS applications is segregated through the network on VLAN 16. In addition, VLAN 2 carries traffic over an Internet connection to the laptop PC for remote access to the PC. The Internet connection in Cleveland is provided by a Verizon modem. The Internet connection is isolated from the rest of the AeroMACS network though the use of a VLAN channel to the PC.

A private VLAN data channel will be established through the network to carry data between SSs connected to the Sensis Corp. MLAT sensor sites and a data port on the secure router. All MLAT system sensor data will be available for MLAT processing with the data transported to the processors over a suitable IP-based connection.

6.2.3 Network Evaluation Test Plan

The testing and evaluation of the IEEE 802.16e network can be grouped into two sets:

(1) Baseline performance tests within the project scope that will be reported in this document.
(2) A set of tests designed to support development of an aviation profile and evaluate the support of FAA applications

6.2.3.1 Baseline Performance Test Cases

Eleven network tests have been defined to establish the basic operating capability of the IEEE-802.16e-based capability that was added to the NASA–CLE CNS Test Bed. The tests establish operating capability in the following areas of network operation.

- Security with authentication and encryption
- Data throughput and channelization
- QoS data prioritization
- Mobility at motor vehicle speeds
- Reliability during extended operation

The 11 baseline test cases and their intended objectives follow:

Test case 1—Network entry with authentication and data transfer

The purpose of this test is to verify that a service flow is successfully created when an SS enters the network and that the service flow is removed completely when the SS exits the network. This test case also verifies that a valid user ID and/or password are required to successfully enter the network. Furthermore, this test case verifies that a bidirectional path (UL/DL) is successfully set up after network entry.

Test case 2—QPSK throughput, UL and DL

This test case verifies the baseline maximum throughput from LOS within the sector using QPSK 1/2 modulation. For this test case, LOS will also include near or partial LOS.

Test case 3—16-QAM throughput, UL and DL

This test case verifies the baseline maximum throughput from LOS within the sector using 16–QAM 1/2 modulation. For this test case, LOS will also include near or partial LOS.

Test case 4—64-QAM throughput, DL

The purpose of this test is to verify the baseline maximum throughput from LOS within the sector using 64–QAM 1/2 modulation on DL. For this test case, LOS will also include near or partial LOS.

Test case 5—Sector capacity with multiple SSs

This test demonstrates the operation of multiple SSs within a sector to test the maximum throughput capacity of a single sector and the capability of a sector to handle terminal "network entries" in congested conditions.

Test case 6—Multiple BTS throughput

This test demonstrates the operation of multiple SSs across multiple sectors to test the maximum throughput capacity of multiple BTSs and the capability of multiple sectors to handle terminal "network entries" in congested conditions.

Test case 7—QoS—DL non-real-time (nRT) prioritization over best effort with two terminals

This is a data prioritization test to verify the handling of data on the DL that has been classified as high priority. It will verify that an nRT protocol data stream is prioritized over a best-effort data stream when both data types are sent to the same SS.

Test case 8—QoS—UL nRT prioritization over best effort with two terminals

This is a data prioritization test to verify the handling of data on the UL that has been classified as high priority. It will verify that an nRT protocol data stream is prioritized over a best-effort data stream when both data types that are sent originate from the same SS.

Test case 9—Intrasector mobility with link adaptation

This tests the ability to maintain a User Datagram Protocol (UDP) traffic stream while mobile in a single BTS sector with link adaptation enabled. This test will demonstrate the network's ability to switch between QPSK, 16–QAM, and 64–QAM using adaptive modulation and coding.

Test case 10—Intersector mobility with link adaptation

This test evaluates BTS handover ability for a mobile SS that moves over multiple sectors and to maintain a UDP traffic stream while moving about multiple sectors with link adaptation enabled. This test will demonstrate the network's ability to switch between QPSK, 16–QAM, and 64–QAM using adaptive modulation and coding.

Test case 11—Long-term stability test

This is an extended-operation test to verify network stability by periodically sending and receiving data bursts.

6.2.3.2 Experiment and Test Plan to Validate Tradeoff Space and Application Support

The NASA–CLE CNS Test Bed, modified to include an AeroMACS communications network, will be used to evaluate various combinations of parameters within the IEEE 802.16 standard in order to validate the tradeoff space for an AeroMACS profile. The airport surface presents a unique combination of areas of open terrain around the runways, which have few obstacles to cause multipath and signal diffraction, and terminal and building areas, which have high levels of multipath dispersion and diffraction. Added to these contrasting propagation environments is the operation of AeroMACS at the upper end of the IEEE 802.16e frequency span of 2 to 6 GHz, where signal wavelengths are shorter and multipath effects are increased.

Table 29 presents a collection of test cases designed to evaluate AeroMACS parameters in the airport environment. The “Design tradeoff category” column defines broad parameter categories, whereas the “Parameters” column lists detailed parameters within the category. The “Evaluation test” column describes test conditions for exploring the tradeoff space of a category.

TABLE 29.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
Base station (BS)	Mounting placement	Analyze or simulate Verify analysis or simulation model Survey signal strength across airport surface Determine line of sight (LOS) and non line of sight (NLOS)
	Number of BSs and base transceiver station (BTS) sectors	Analyze, considering coverage area and composite throughput
	Multiple input, multiple output (MIMO) order	Test without MIMO Test with up to 2×2 MIMO Test with *N*×*N* MIMO Test with LOS and with NLOS or blockage
	Antenna polarization	Evaluate internal cross-polarization antennas versus external spatially separated antennas
	Maximum cell range	Extend with Media Access Control (MAC) changes within Institute of Electrical and Electronics Engineering (IEEE) 802.16e specification Evaluate IEEE 802.16m amendment
	Controlled-pattern antennas	Test with advanced BTS sector antennas Identify and evaluate steerable multibeam antennas
	Frequency band	Analyze minimum spectrum versus needed throughput
	Spectrum co-user interference (i.e., Globalstar satellite)	Analyze

TABLE 29.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
Subscriber station (SS)	Mounting height	Analyze
	MIMO order	Test without MIMO Test with up to 2×2 MIMO Test with $N \times N$ MIMO
	Antenna polarization	Evaluate internal cross-polarization antennas versus two external single-polarization antennas
	Maximum cell range	Extend with MAC changes within IEEE 802.16e specification Evaluate IEEE 802.16m amendment
	Frequency band	Analyze minimum spectrum versus needed throughput Test frequency reuse methods including $N = 1$ (all sectors on same center frequency)
	Spectrum co-user interference (i.e., Globalstar satellite)	Analyze on the basis of power class requirements and frequency reuse method
Channel bandwidth	Throughput rate	Test mixed mobile SS and fixed SS traffic including • Sources of highest expected data rate • Channel bandwidths of 5, 10, and 20 MHz
	Mobility performance	Test mobility throughput over speed range and cell radius including • Multiple mobile SS • Channel bandwidths of 5, 10, and 20 MHz
	Multipath performance	Evaluate performance in terminal area Evaluate mobile performance in building areas
	Efficient use of spectrum	Evaluate multiple mobile SS operation concurrent with fixed SS of differing data streams
	Hardware limitations	Test throughput versus expected at 20-MHz bandwidth
Modulation	Adaptive or fixed	Measure mobility throughput measurements across cell radius with fixed high and low modulation rates
	Modulation rates	Compare measured versus expected throughput versus modulation coding rate, including • Ranges from cell center to cell edge • LOS and NLOS
	Forward error correction (FEC) coding rate	Compare measured versus expected throughput versus error coding rate, including • Ranges from cell center to cell edge • LOS and NLOS
BTS power class	Fade margin allowance	Test long-term LOS throughput Conduct mobility tests in NLOS and high-multipath conditions
	Co-interference	Test throughput versus power between isolated sectors at the same center frequency in a frequency-reuse system
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Analyze interference on the basis of minimum power required to provide coverage across airport surface
	Range	Determine cell radius versus number of BSs
	Power amplifier power-output limitations	Analyze

TABLE 29.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
SS power class	Fade margin allowance	Test long-term LOS throughput Conduct mobility tests in NLOS and high-multipath conditions
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Analyze interference on the basis of minimum power required to provide coverage across the airport surface
	Range	Determine cell radius versus the number of BSs
	Power amplifier power-output limitations	Analyze
MAC layer and physical layer (PHY)	Maximum mobile speed	Conduct high-speed mobility tests for throughput and dropouts
	Repeater operation (IEEE 802.16j)	Test IEEE-802.16j-enabled BS when available for filling in poor coverage areas, including • Outside cell radius • NLOS regions
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	Analyze
Quality of service (QoS)	Time delay	Measure end-to-end time delay through AeroMACS network from SS input through communication, navigation, and surveillance (CNS) output port for all five QoS levels
	Time jitter	Measure end-to-end time jitter through AeroMACS network from SS input through CNS output port for all five QoS levels
	Message priority	Test high QoS and best-effort traffic Test until throughput overload Verify that high QoS priority is maintained
	Scheduling	Test high QoS and best-effort traffic Measure statistics of scheduling accuracy Measure scheduling performance as throughput is increased to overload
	Message integrity	Test high QoS and best-effort traffic Test continuous and burst traffic Verify packet error rate and that there are no dropped packets for high QoS traffic

6.2.4 Network Evaluation Test Results

At the time of this writing, the AeroMACS radio link between the SS on the roof of Glenn Building 500 and the two BTS sectors at Glenn Building 4 had been evaluated. The link to BTS1_1 sector is LOS with a distance of approximately 775 m. The SS is within the main lobe of the BTS1_1 sector antenna. For the second link, the SS is behind the BTS1_2 sector outdoor unit and in its antenna side lobes. However, the signal strength for the second link was still adequate to support the highest modulation level of the 64–QAM, 5/6 code rate.

Iperf network performance software was used in these tests to simulate traffic across the radio link. Iperf is an open-source application that generates Transmission Control Protocol (TCP) and UDP packets to measure network performance.

The following parameters were set for the link tests:

Service pipe for the SS

- Service type, Ethernet Layer 2
- QoS type, best effort
- Connection time, short
- Committed information rate, 7 Mbps

Test conditions

- Channel bandwidth, 5 MHz
- Received signal strength indication (RSSI), >–70 dBm
- Signal-to-noise ratio, >24 dB
- Modulation, 64–QAM 5/6
- MIMO, 2×2 at BTS sectors, 2×1 at SS
- Test computer hosting Iperf connected to the data interface on the BTS
- Test computer hosting Iperf connected to the SS Ethernet port
- TDD ratio, 60 percent (DL): 40 percent (UL)

Procedure

- Run the Iperf performance software server on the computer at the BTS.
- On the computer connected to the SS, execute a throughput test using the parameters in Table 30.

TCP test—This will simulate upstream and downstream traffic using the File Transfer Protocol (FTP).

- Server-side, Iperf –s –w64k –il
- Client-side, Iperf –c [Server IP Address] –t60 –w64K –i1 –P2

In total, the parameters listed in Table 30 affect the net data throughput that can be achieved (Ref. 64).

TABLE 30.—AeroMACS PARAMETER SETTINGS AFFECTING THROUGHPUT

BW	Nominal channel bandwidth, 5, 10, or 20 MHz
N_{used}	Number of subcarriers used (data and pilot subcarriers)
N_{data}	Number of data subcarriers
n	(Over-) Sampling factor, 8/7 or 28/25
G	Ratio of cyclic prefix (CP) time to useful time (default G = 1/8)
N_{FFT}	Fast Fourier transform size: smallest power of 2 greater than N_{used} (512 or 1024)
F_s	Sampling frequency, F_x = floor ($n \times BW$/8000) × 8000
Δf	Subcarrier spacing, $\Delta f = F_s/N_{\text{FFT}}$
T_b	OFDM symbol time, $T_b = 1/\Delta f$
T_g	Cyclic prefix (CP) time, $T_g = G \times T_b$
T_s	CP–OFDM symbol time transmitter, $(Tx) = T_b + T_g = (1 + G) \times T_b$
M	QAM modulation order, 2(QPSK), 4(16–QAM), or 6(64–QAM)
r_{FEC}	FEC coding rate, 1/2, 2/3, 3/4, or 5/6
r_{Rep}	Repetition code rate, 0, 2, 4, or 6

The expected throughput performance under the conditions listed in Table 30 and under other settable parameters is estimated by the equipment manufacturer to be 6.5 Mbps in the DL direction from BS to SS and to be 4.0 Mbps in the UL direction from SS to BS. The expected values and actual throughput test results are compared in Table 31. The measured throughput exceeded the manufacturer's estimated rates in all cases.

TABLE 31.—AeroMACS NASA–CLE TEST BED LINK TEST RESULTS

BTS sector	Measured DL throughput, Mbps	Expected DL throughput, Mbps	Measured UL throughput, Mbps	Expected UL throughput, Mbps
BTS1_1	6.82	6.5	5.4	4.0
BTS1_2	6.54	6.5	4.19	4.0

6.3 Initial Input to Aeronautical Mobile Specific IEEE 802.16 Design Specification

The IEEE 802.16 standard (Ref. 65) defines system profiles that list sets of features that apply to particular implementation cases. The IEEE 802.16e amendment (Ref. 18) adding mobility also amended the system profile. For this reason, the IEEE 802.16 standard and the IEEE 802.16e amendment must be used together to create the AeroMACS profile. In this report, the IEEE 802.16 standard plus the IEEE 802.16e amendment is referred to as IEEE 802.16(e).

6.3.1 AeroMACS Standard Profile

The IEEE 802.16 profiles to be evaluated here are limited in scope to functions of the MAC and PHY reference model layers. In addition to these, profiles defined by the WiMAX Forum include parameters from higher-level reference layers. These added parameters define network and security functions, for example.

Features listed in the IEEE 802.16 standard and the IEEE 802.16e amendment are listed as "mandatory" or "optional" for use. Profiles do not change the "mandatory" status of features listed as such in the standard. Features listed as "optional" in the standard may be listed as "required" or "conditionally required" in a profile. Any "optional" feature in the standard that does not appear in a certain profile is "optional" for the profile. For this reason, absence of a feature in a specific implementation does not affect conformance to the profile. Optional features will be implemented as specified in the standard (Ref. 65).

Four system profiles are used to define sets of features that are a subset of IEEE 802.16 according to these four classes:

(1) Wireless municipal area network, single carrier (WirelessMAN-SC, 10 to 66 GHz)
(2) WirelessMAN and wireless high-speed unlicensed metropolitan area networks, single carrier access (WirelessMAN-SCa and WirelessHUMAN-SCa)
(3) WirelessMAN and WirelessHUMAN, OFDM (WirelessMAN-OFDM and WirelessHUMAN-OFDM)
(4) WirelessMAN and WirelessHUMAN, OFDMA (WirelessMAN-OFDMA and WirelessHUMAN-OFDMA)

Table 32 examines the suitability of these four system profile feature sets for AeroMACS.

TABLE 32.—IEEE 802.16 STANDARD PROFILE FEATURE SETS

Profile set	Evaluation as basis for AeroMACS profile
1. WirelessMAN-SC (10 to 66 GHz)	Incorrect frequency range for AeroMACS operating in C-band
2. WirelessMAN-SCa and WirelessHUMAN-SCa	Lacks the support for mobility needed for AeroMACS
3. WirelessMAN-OFDM and WirelessHUMAN-OFDM	Lacks support for the mobility needed for AeroMACS (This is the profile for “Fixed WiMAX”.)
4. WirelessMAN-OFDMA and WirelessHUMAN-OFDMA	Correct profile to use as basis for an AeroMACS profile; supports C-band, mobility, and multiple-use access

The WirelessMAN-OFDMA and WirelessHUMAN-OFDMA (profile 4) defines a wireless system with support for mobility. These are the feature-sets used by the WiMAX Forum to define Mobile WiMAX wireless service profiles and will be the basis for an AeroMACS profile. This not only provides the desired mobility performance, it allows equipment vendors to adapt commercially available off-the shelf hardware with minimum modifications.

Note that in IEEE 802.16e, the WirelessMAN and WirelessHUMAN specification classes are contained in a common profile set. These specification classes are separated into separate profile sets in the IEEE 802.16-2009 standard. This report remains consistent as an analysis of the IEEE 802.16e standard and uses the combined class description.

6.3.2 System Profile Definition Method

The process for developing specification-level profile recommendations follows:

(1) Begin with system profiles defined in the IEEE 802.16-2004 standard and the IEEE 802.16e-2005 amendment.
(2) Identify parameters in the system profile that must change to support C-band AeroMACS operation. The center-frequency definition is an example.
(3) Compare the resulting C-band system profile to requirements flowed down from ConUse and system studies, and identify areas that are not supported, if any.
(4) Recommend additional changes to the system profile or recommend areas for further research into parameters that will better meet requirements while examining the cost of requiring additional hardware changes.

6.3.3 System Profile Definitions

This subsection defines recommended profiles for systems operating with AeroMACS air interfaces. Any feature not mandatory or conditionally mandatory for a profile is optional for the profile except where otherwise forbidden by the IEEE 802.16(e) standard. Optional features shall be implemented as specified in the standard. Design consideration comments are provided in each subsection to provide guidance for operation within the ranges of parameters that are offered within the profiles.

Table 33 defines four profiles for AeroMACS. AeroMACS_profM1 applies to all channel bandwidths. AeroMACS_profP1 to AeroMACS_profP3 apply to specific channel bandwidths.

TABLE 33.—AeroMACS PROFILE DEFINITIONS

Identifier	Description
AeroMACS_profM1	Basic packet point-to-multipoint Media Access Control (MAC) profile
AeroMACS_profP1	Basic physical layer (PHY) profile for 5-MHz channel
AeroMACS_profP2	Basic PHY profile for 10-MHz channel
AeroMACS_profP3	Basic PHY profile for 20-MHz channel

Note that 5-MHz channels are not included in the IEEE 802.16(e) standard but are included in the WiMAX Forum profile. These channels are incorporated in the AeroMACS standard recommendation because the 5-MHz channel is the lowest multiple of the center frequency f_c step and because it provides for more efficient use of the AeroMACS spectrum than wider channel bandwidths do. In addition, the 5-MHz center frequency f_c step size was chosen to be consistent with the IEEE 802.16e standard for 5000-MHz unlicensed bands. This will facilitate hardware reuse by vendors.

Although 5-MHz channel bandwidths will limit PHY and MAC performance in mobile and high-multipath environments and will limit the maximum data throughput available to each subscriber, the larger channel bandwidths will impair a system designer's ability to efficiently use the 5091- to 5150-MHz approved spectrum and the potential 5000- to 5030-MHz expansion band.

6.3.4 AeroMACS Power Class Profiles

The power class profiles recommended for AeroMACS correspond with those stated in Section 12.4.1 of the IEEE 802.16 standard. A power class profile contains the classes of SSs (fixed-position and mobile) used in a system. A power class profile may contain transmitters from more than one class, with the profile indicating the highest power class permitted. The recommended power classes are listed in Table 34.

TABLE 34.—AeroMACS POWER CLASSES

Class	Transmit power dBm
1	$17 \leq P_{Tx,\,\max} < 20$
2	$20 \leq P_{Tx,\,\max} < 23$
3	$23 \leq P_{Tx,\,\max} < 30$
4	$30 \leq P_{Tx,\,\max}$

The power ratings $P_{Tx,\,\max}$ associated with these classes are the maximum average output power ratings at which the appropriate transmitter requirements in Section 8.4.12 of IEEE 802.16(e) are met.

Network system designers should use the following design considerations to minimize AeroMACS inference with coexisting in-band services:

- For mobile SSs, select the number of BSs and their placement to enable low power class operation of MSs within their roaming area.
- For fixed-site SSs, specify the use of high-directivity, high-gain fixed-site antennas to minimize the SS power class.
- Use diversity propagation MIMO antenna systems for increased sensitivity with lower power class operation.

6.3.5 AeroMACS Media Access Control Profiles

The OFDMA_ProfM1 profile in Section 12.4.2 of the IEEE 802.16(e) standard is recommended for use in AeroMACS without modification. This MAC profile specifies mobile operation for WirelessMAN-OFDMA and WirelessHUMAN-OFDMA air interfaces. In particular,

- Using the OFDMA_ProfM1 profile without modification maximizes the reuse of commercial off-the-shelf hardware that is available for nearby licensed bands. Reuse of the profile gives system designers the flexibility to tailor performance for the airport environment with the parameter options that are available.

- MAC parameters provide for mobile operation. The maximum speed supported in commercial Mobile WiMAX is generally on the order of 120 km/hr. However, the actual maximum speed depends on many factors, including the frequency of operation. Greater maximum speeds are possible with changes in MAC parameters at the expense of performance in other areas such as data throughput. Future studies regarding adjustments to MAC parameters are needed to accommodate increased mobility speeds. Studies must include a cost/benefit analysis to weigh changes in other performance parameters against the benefit of operation at increased operating speed.
- The IEEE 802.16m amendment planned for future release will include MAC modifications that will increase the maximum operating speed above that of IEEE 802.16e.

6.3.6 AeroMACS System Physical Layer Profiles

This subsection defines PHY profiles for systems operating with the AeroMACS air interfaces. We recommend that IEEE 802.16(e) PHY profiles be used without modification for all features except for FDD PHYs. FDD transmissions require the use of two separate channels; one for UL and the other for DL. These channels require adequate frequency separation so that the transmitter does not desensitize the receiver, which needs to operate simultaneously. Practical FDD systems separate the transmit and receive channels by at least 3 percent (Ref. 66), which exceeds the C-band AM(R)S allocation of 59 MHz.

The following PHY profile definitions define the minimum performance required for each channel bandwidth. These requirements are in addition to the minimum performance requirements needed for all profiles, as defined in Table 413 of the IEEE 802.16(e) specification.

6.3.7 Basic Physical Layer (PHY) Profile for the AeroMACS 5-MHz Channel

A system implementing the AeroMACS_profP1 shall meet the minimum performance requirements listed in Table 35 (derived from the IEEE 802.16(e) specification).

TABLE 35.—BASIC PHY PROFILE FOR AeroMACS 5-MHz CHANNEL
[Acronyms are defined in Appendix A.]

Capability	Minimum performance
Channel bandwidth, MHz	5
Operation mode	Licensed AM(R)S C-band operation
Bit error rate (BER) performance threshold (BER = 10^{-6} if using all subchannels BS/SS)[a] QPSK 1/2, dBm QPSK 3/4, dBm 16−QAM 1/2, dBm 16−QAM 3/4, dBm 64−QAM 2/3 (if 64−QAM supported), dBm 64−QAM 3/4 (if 64−QAM supported), dBm	Greater than or equal to −85 −82 −78 −75 −71 −69
Reference frequency tolerance BS SS to BS synchronization tolerance, Hz	 $\leq \pm 2\times10^{-6}$ ≤22.5
Frame duration code set[b]	{2, 4, 5}

[a]Add to sensitivity $10\times\log^{10}$ (number of subchannels in the BS receiver).
[b]See Table 232 of the IEEE 802.16(e) standard (Ref. 18).

6.3.8 Basic Physical Layer (PHY) Profile for AeroMACS 10-MHz Channel

A system implementing AerMACS_profP2 shall meet the minimum performance requirements listed in Table 36 (derived from the IEEE 802.16(e) specification).

TABLE 36.—BASIC PHY PROFILE FOR AeroMACS 10-MHz CHANNEL
[Acronyms are defined in Appendix A.]

Capability	Minimum performance
Channel bandwidth, MHz	10
Operation mode	Licensed AM(R)S C-band operation
Bit error rate (BER) performance threshold (BER = 10^{-6} if using all subchannels BS/SS)[a]	Greater than or equal to
QPSK 1/2, dBm	–82
QPSK 3/4, dBm	–79
16–QAM 1/2, dBm	–75
16–QAM 3/4, dBm	–72
64–QAM 2/3 (if 64–QAM supported), dBm	–68
64–QAM 3/4 (if 64–QAM supported), dBm	–66
Reference frequency tolerance	
BS	$\leq \pm 2\times10^{-6}$
SS to BS synchronization tolerance, Hz	≤55
Frame duration code set[b]	{2, 4, 5}

[a]Add to sensitivity $10\times\log^{10}$ (number of subchannels in the BS receiver).
[b]See Table 232 of the IEEE 802.16(e) standard (Ref. 18).

6.3.9 Basic Physical Layer (PHY) Profile for AeroMACS 20-MHz Channel

A system implementing AeroMACS_profP3 shall meet the minimum performance requirements listed in Table 37 (derived from the IEEE 802.16(e) specification).

TABLE 37.—BASIC PHY PROFILE FOR AeroMACS 20-MHz CHANNEL
[Acronyms are defined in Appendix A.]

Capability	Minimum performance
Channel bandwidth, MHz	20
Operation mode	Licensed AM(R)S C-band operation
Bit error rate (BER) performance threshold (BER = 10^{-6} if using all subchannels BS/SS)[a]	Greater than or equal to
QPSK 1/2, dBm	–79
QPSK 3/4, dBm	–76
16–QAM 1/2, dBm	–72
16–QAM 3/4, dBm	–69
64–QAM 2/3 (if 64–QAM supported), dBm	–65
64–QAM 3/4 (if 64–QAM supported), dBm	–63
Reference frequency tolerance	
BS	$\leq \pm 2\times10^{-6}$
SS to BS synchronization tolerance, Hz	≤ 110
Frame duration code set[b]	{2, 4, 5}

[a]Add to sensitivity $10\times\log^{10}$ (number of subchannels in the BS receiver).
[b]See Table 232 of the IEEE 802.16(e) standard (Ref. 18).

6.3.10 AeroMACS Radiofrequency Profiles

This subsection defines proposed RF profiles for the AeroMACS air interfaces. Table 38 defines the RF channels for informative purposes. The channels shall be calculated using Equation (2):

$$F_{\mathrm{start}} + n \bullet \Delta f_c \quad \text{for all } n \text{ in } N_{\mathrm{range}} \tag{2}$$

where

F_{start} start frequency for the specified band
Δf_c center frequency step
N_{range} range of values for the *n* parameter

TABLE 38.—RADIOFREQUENCY PROFILE LIST FOR AeroMACS C-BAND

Radiofrequency profile	Channel bandwidth, MHz	Center frequency step,[a] Δf_c, MHz	Uplink (UL) start frequency, F_{start}, MHz	Downlink (DL) start frequency,[b] F_{start}, MHz	Range of values for *n*, N_{range}
AeroMACS_ProfR1	5	5	5000	N/A	{19, 20, …, 37}
AeroMACS_ProfR2	10	5	5000	N/A	{20, 21, …, 36}
AeroMACS_ProfR3	20	5	5000	N/A	{21, 22, …, 35}
AeroMACS_ProfR4[c]	5	5	5000	N/A	{1, 2, …, 5}
AeroMACS_ProfR5[c]	10	5	5000	N/A	{1, 3, …, 5}
AeroMACS_ProfR6[c]	20	5	5000	N/A	{2, 3, … 4}

[a]The minimum center frequency step Δf_c is 5 MHz to match the IEEE 802.16(e) standard for the 5000-MHz frequency bands. The center frequency step Δf_c of 5 MHz requires that the minimum channel bandwidth be 5 MHz and that channel bandwidths increase in multiples of 5 MHz.
[b]DL F_{start} = UL F_{start} in a TDD system.
[c]Use of a profile is dependent on International Telecommunications Union (ITU) authorization.

7.0 Final Requirements and Specifications Recommendations for the C-Band System

7.1 Final Performance Requirements Recommendations

Table 39 relates AeroMACS technical parameters, requirement source for each parameter, and the profile parameter area that is directly impacted. When a technical parameter is indicated as only impacting airport system design, the parameter will be finalized during the system design process for a new airport installation. For example, the number of BTS sectors to be used at a specific airport will be determined in the system design process using the range of settings that are available within the AeroMACS profile parameters.

TABLE 39.—AeroMACS C-BAND RADIOFREQUENCY PROFILE LIST

Design tradeoff category	Technical parameters	Affected process					
		IEEE 802.16e profile parameter area					
		Airport system design	Radio-frequency/ radio	Power class	Duplex mode	Physical (PHY) design	Media Access Control (MAC) design
Base station	Placement/location/height	x					
	Number of base transceiver station (BTS) sectors	x					
	Multiple input, multiple output (MIMO) order	x	x	x		x	x
	Antenna polarization	x					
	Maximum cell range	x					x
	Controlled-pattern antennas	x					x
	Frequency band	x	x		x		
	Spectrum co-user interference (i.e., Globalstar satellite)	x					
Subscriber station	Mounting height	x					
	MIMO order	x				x	x
	Antenna polarization	x					
	Maximum cell range	x					x
	Frequency band		x		x		
	Spectrum co-user interference (i.e., Globalstar satellite)	x					
Channel bandwidth	Throughput rate	x					x
	Mobility performance	x					x
	Multipath performance	x					
	Efficient use of spectrum	x					
	Co-interference	x					
	Hardware limitations					x	
Modulation	Adaptive or fixed	x				x	
	Modulation rates	x				x	
	Forward error-correction (FEC) coding rate	x				x	

TABLE 39.—AeroMACS C-BAND RADIOFREQUENCY PROFILE LIST

Design tradeoff category	Technical parameters	Affected process					
		IEEE 802.16e profile parameter area					
		Airport system design	Radio-frequency/ radio	Power class	Duplex mode	Physical (PHY) design	Media Access Control (MAC) design
BTS power class	Fade margin	x					
	Co-interference	x					
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	x		x			
	Range	x					
	Line-of-sight (LOS) and non-line-of-sight (NLOS) operation	x				x	
	Mobile operation	x				x	
	Power amplifier power-output limitations			x		x	
SS power class	Fade margin	x					
	Co-interference	x					
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	x		x			
	Range	x					
	LOS and NLOS operation	x					
	Mobile operation	x					
	Power amplifier power-output limitations			x		x	
(MAC and PHY layers	Maximum mobile speed						x
	Repeater operation (IEEE 802.16j)	x					x
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode				x		
Quality of service (QoS)	Time delay	x			x		x
	Time jitter	x	x		x	x	x
	Message priority						x
	Scheduling						
	Message integrity	x	x	x		x	x

However, the number of BSs is not an AeroMACS profile parameter because it will be highly dependent on airport geographic size and the assessment of total data throughput for the network. Other parameters, such as frequency band, do impact the AeroMACS profile parameter area in the areas of RF radio design and duplex mode.

The PHY and MAC designs will accommodate the system design space to a degree with the range of parameter settings that are within the profile. If an application requires a level of performance that cannot be met with PHY and MAC parameters within the profile, a redesign will need to occur that will move the AeroMACS hardware further away from being a simple modification to a commercial off-the-shelf

WiMAX. For example, requiring greater mobile speeds than can be provided with commercial off-the-shelf WiMAX hardware will require a redesign of the PHY and MAC layers.

7.2 Final Input to Aviation-Specific IEEE 802.16 System Design Specifications

Table 40 summarizes the key parameter selections that are recommended for an AeroMACS standard profile. The five profile areas listed in Table 40 correspond with the five profile areas that distinguish mobile WiMAX profiles.

TABLE 40.—SUMMARY OF FINAL RECOMMENDATIONS FOR AeroMACS PROFILE

Profile area	Key parameter selections
Radiofrequency and radio parameters	
Frequency band, MHz	5091 to 5150
Channel bandwidths, MHz	5, 10, and 20
Channel center frequencies	See Table 38
Power class	
Maximum downlink transmitter (Tx) power	6.3.4 —Unchanged from IEEE 802.16(e)
Maximum uplink Tx power	6.3.4 —Unchanged from IEEE 802.16(e)
Duplex mode (time-division duplex (TDD) or frequency-division duplex (FDD))	TDD
Physical layer	Performance profiles—minimum performance defined in IEEE 802.16(e) and
M-ary quadrature amplitude modulation (QAM) range	Table 35 for 5-MHz channels
Coding options	Table 36 for 10-MHz channels
Multiple input, multiple output (MIMO)	Table 37 for 20-MHz channels
Media Access Control (MAC) layer	All parameters unchanged from IEEE 802.16(e)
Automatic repeat request	
Security protocols	
Mobile protocols	
Quality-of-service (QoS) options	
Mesh options	

Special committee SC–223 was established within the RTCA aviation industry consortium to establish standards for AeroMACS. The principal products of this special committee are a set of system profile recommendations to be delivered in September 2010 and a Minimum Operational Performance Standards (MOPS) document to be delivered in September 2011. EUROCONTROL established a similar work group, WG–82, that is chartered to develop an AeroMACS profile. SC–223 and WG–82 will work cooperatively to develop a common profile document that will be provided as recommendations for consideration by ICAO.

Appendix A.—Acronyms and Abbreviations

This appendix identifies acronyms and abbreviations used throughout this document.

A/A	air to air
A/C	aircraft
A/G	air to ground
AAA	authentication, authorization, and accounting
ACARS	Aircraft Communications Addressing and Reporting System
ACSTS	Aerospace Communication Systems Technical Support contract
ADAS	AWOS Data Acquisition System
ADDS	Aviation Digital Data Service
ADS–B	automatic dependent surveillance—broadcast
ADS–C	automatic dependent surveillance—contract
ADSx	automatic dependent surveillance—next generation
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Aircraft Communications System
AFB	Air Force base
AFSS	Automated Flight Service Station
A–G	air to ground
AIM	Aeronautical Information Management
AISR	Aeronautical Information System Replacement
ALS	airport lighting system
ALSF	approach lighting with sequenced flashing lights
AM(R)S	aeronautical mobile (route) service
AMS(R)S	aeronautical mobile satellite (route) service
ANSP	air navigation service provider
AOC	aeronautical operational control
AP–17, –30	Action Plan 17, 30
ARCTR	aeronautical center in Oklahoma City, Oklahoma
ARFF	Aircraft Rescue and Firefighting building (at Cleveland Hopkins International Airport)
ARINC	Aeronautical Radio Incorporated
ARSR	air route surveillance radar

ARTCC	air route traffic control center
ARTS	Automated Radar Terminal System
ASDE–X	Airport Surface Detection Equipment—Model X
ASH	Aviation Services Hangar
ASN	access service network
ASN–GW	access service network gateway
ASN–GW–DP	access service network gateway—decision point
ASN–GW–EP	access service network gateway—enforcement point
ASOS	automated surface observation systems
ASR	airport surveillance radar
ATC	air traffic control
ATCSCC	air traffic control system command center
ATCT	air traffic control tower
ATFCM	air traffic flow and capacity management
ATIS	Automatic Terminal Information Service
ATM	air traffic management
ATN	aeronautical telecommunications network
ATO	Air Traffic Organization
ATS	air traffic services
ATSP	air traffic service provider
ATSU	air traffic services unit
AWIPS	Advanced Weather Interactive Processing System
AWOS	Automated Weather Observing System
AZ	azimuth
BASOP	base operations
BER	bit error rate
BLOS	beyond line of sight
BS	base station
BTS	base transceiver station
BUEC	backup emergency communications
C&P	crossing and passing
CANRAD	Canadian Radars
CDA	Continuous Descent Arrivals or Continuous Descent Approach

CDM	collaborative decision making
CDTI	cockpit display of traffic information
CIWS	Corridor Integrated Weather System
CLE	Cleveland Hopkins International Airport, Cleveland, Ohio
CMF	Consolidated Maintenance Facility
CNS	communication, navigation, and surveillance
COCR	communications operating concept and requirements
COM	communications
ConOps	concepts of operation
ConUse	concepts of use
CP	cyclic prefix
CPDLC	controller pilot data link communications
CPE	customer premise equipment (same as subscriber station)
CSN	Connectivity Service Network
CTA	Controlled Time of Arrival
D/L	data link
dATIS (D–ATIS)	Digital Automatic Terminal Information Service
DC	data communications
DCG	data communications gateway
DCS	data communications system
DFU	display functional unit
DHCP	Dynamic Host Configuration Protocol
DHS	Department of Homeland Security
DINS	Defense Internet NOTAM (Notice to Airmen) services
DL	downlink—base station to subscriber station data-flow direction
DME	distance measuring equipment
DoD	Department of Defense
D–OTIS	data link operational terminal information service
D–RVR	data link runway visual range
D–SIG	data link surface information and guidance
D–SIGMET	data link significant meteorological information
DSB AM	double-sideband amplitude modulation
DSR	dynamic source routing

DSS	decision support system
D–TAXI (D-Taxi)	data link taxi clearance
DTS	Dedicated Telecom Services
DYNAV	dynamic route availability
EA	enterprise architecture
ECG	En Route Communications Gateway
ECS	emergency communications systems
ERAM	En Route Automation Modernization
ERIDS	En Route Information Display System
ERT–VR	extended real time—variable rate
ES	Extended Squitter
ETVS	Enhanced Terminal Voice Switch
EUR	Europe
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
F&F	flight and flow
FAA	Federal Aviation Administration
FANS–1/A+	Future Air Navigation System—1/A+ version
FBWTG	FAA Bulk Weather Telecommunications Gateway
FCI	future communications infrastructure
FCS	Future Communications Study
FDD	frequency-division duplex
FEC	forward error correction
FFT	fast Fourier transform
FLIPCY	flight plan consistency
FMS	flight management system
FOC	Flight Operations Center
FPR	Final Program Requirements
FRS	future radio system
FTP	File Transfer Protocol
FY	fiscal year
G/A	general aviation
G/G	ground to ground

GA	general aviation
GBT	ground-based transceiver
GI	general information
GIS	geographical information system
Glenn	Glenn Research Center
GPS	Global Positioning System
GS	ground station
GSC	ground station controller
GTWY	gateway
GW	gateway
HCS	host computer system
HF	high frequency
HPA	high-power amplifier
IAP	Internet Access Point
ICAO	International Civil Aviation Organization
ID	identification
IDS	Information Display System
IEEE	Institute of Electrical and Electronics Engineering
ILS	instrument landing system
IP	Internet Protocol
Iperf	network testing tool
ITP	In-Trail Procedure
ITU	International Telecommunications Union
ITWS	Integrated Terminal Weather System
JPDO	Joint Planning and Development Office
LCGS	low-cost ground surveillance
LINK 2K+	European SESAR (Single European Sky ATM Research) program
LLWAS	Low-Level Wind Shear Alert System
LOC	localizer
Loc	location
LOS	line of sight
LRR	long-range radar
M&S	merging and spacing

MAC	Media Access Control
M-ary	digital transmission of two or more bits at a time
MASPS	minimum aviation system performance standards
MIMO	multiple input, multiple output
MITRE CAASD	MITRE Corporation's Center for Advanced Aviation System Development
MLAT	multilateration
MM	middle marker
Mode S	Mode Select secondary surveillance Beacon System
MOPS	Minimum Operational Performance Standards
MS	mobile station
NADIN	National Airspace Data Interchange Network
NAS	National Airspace System
NASA–CLE	NASA Glenn Research Center and Cleveland Hopkins International Airport
NASAD	NAS architecture document
NASCR	NASA Common Reference System
NAS–SR	National Airspace System—System Requirements
NAV	navigation
NAVAIDS	navigation aids
NDB	nondirectional radio beacon
NEXCOM	Next Generation Air/Ground Communications
NEXRAD	Next Generation Radar
NextGen	Next Generation Air Transportation System
NFU	National Weather Service Filter Unit
NIPRNET	Nonclassified Internet Protocol Router Network
NIWS	NAS Integrated Web Services
NLOS	non line of sight
NMS	Network Management System
NNCC	National Network Control Centers
NNEW	NextGen Network Enabled Weather
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
nRT	non real time

nrtPS	non-real-time polling service
NWS	National Weather Service
O&M	operations and maintenance
OAS	Oceanic Automation System
ODU	outdoor unit
OFDM	orthogonal-frequency-division multiplexing
OFDMA	orthogonal-frequency-division multiple access
OI	operational improvement
OM	outer marker
Ops IP	operations IP
Ops	operations
OPUS	Online Positioning User Service
ORIS	operational en route information service
OSED	Operational Services and Environment Definition
OTIS	operational terminal information service
OV–1, OV–2	operational views
PAIRAPP	paired approach
PC	personal computer
PER	packet error rate
PHY	physical
PIREP	pilot report
PLA	project-level agreement
PoE	Power over Ethernet
PPD	pilot preferences downlink
PRM	Precision Runway Monitor
PSN	packet switched network
PV6	plan view 6
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase-shift keying
RAPCO	Radar Approach Control
RASP	Regional ADAS (Automated Weather Observation Station Data Acquisition System) Service Processor

RCAG	remote communications air to ground
RCE	radio control equipment
RCE–C	RCE at control site
RCE–R	RCE at remote (transmitter/receiver) site
RCO	remote communication outlet
RCP	required communication performance
RDVS	Rapid Deployment Voice Switch
RE&D	research, engineering and development
RF	radiofrequency
RRM	radio resource management
RSSI	received signal strength indication
RTCA	RTCA, Inc. (founded as Radio Technical Commission for Aeronautics)
rtPS	real-time polling service
RTR	remote transmitter/receiver
RU	remote unit
RUC	rapid update cycle
RVR	runway visual range
Rx	receiver
SAMS	Special Use Airspace Management System
SARPs	standards and recommended practices
SATCOM	satellite communications
SC	single carrier; special committee
SCa	single carrier access
SCS	Sensor Control Subsystem (ADAS, AWOS Data Acquisition System)
SE	system engineering
SEM	system engineering manual
SESAR	Single European Sky ATM Research
SIGMET	significant meteorological information
SITA	Société Internationale de Télécommunications Aéronautiques
SOA	service-oriented architecture
SOAMOM	service-oriented architecture messaging oriented middleware
SOC	Service Operations Center
SOCC	Security Operations Control Center

SONET	synchronous optical networking
SPR	safety and performance requirement
SR	system requirement
SRD	system requirements document
SRR	short-range radar
SS	subscriber station
SSR	secondary surveillance radar
StarACS	Star Automatic Configuration Server (for WiMAX (Worldwide Interoperability Microwave Access) networks)
STARS	Standard Terminal Automation Replacement System
surv	surveillance
SV–1, SV–2	system views
SWIM	System Wide Information Management
SYSCO	system-supported coordination
TACAN	tactical air navigation
TAP/CDA	Tailored Arrival Procedure/Continuous Descent Approach (Arrival)
TBO	trajectory-based operations
TCP	transmission control protocol
TDD	time-division duplex
TDLS	tower data link system
TDMA	time-division multiple access
TDWR	Terminal Doppler Weather Radar
TFDM	Tower Flight Data Manager
TFM	traffic flow management
TFR	temporary flight restrictions
THEVAN	Terrestrial Hybrid Environment for Verification of Aeronautical Networks
TIBA	Traffic Information Broadcast by Aircraft
TM	Traffic Management
TMA	terminal maneuvering area
TRACO	facility type for TRACON
TRACON	Terminal Radar Approach Control Facility
TVS	Terminal Voice Switch
TWIP	Terminal Weather Information for Pilots

Tx	transmitter
UAT	universal access transceiver
UDP	User Datagram Protocol
UGS	unsolicited grant service
UHF	ultra-high frequency
UL	uplink—subscriber station to base station data-flow direction
URCO	urgent contact
VCS	Voice Communications System
VDL	very high frequency digital link
VHF	very high frequency
VLAN	virtual local area network
VoIP	digital voice over Internet Protocol
VOLPE	John A. Volpe National Transportation Systems Center
VOR	very high frequency (VHF) omnidirectional range
VPN	virtual private network
VSCS	Voice Switching and Control System
WAAS	Wide Area Augmentation System
WAKE	wake vortex
WARC	World Administrative Radio Conference (now World Radiocommunication Conference)
WARP	Weather and Radar Processor
WiMAX	Worldwide Interoperability Microwave Access
WINS	Weather Information Network Server
WirelessHUMAN	wireless high-speed unlicensed municipal area network
WirelessMAN	wireless municipal area network
WJHTC	William J. Hughes Technical Center
WMD	wake mitigation departure
WMS	wide-area master station
WMSCR	Weather Message Switching Center Replacement
WRC	World Radiocommunication Conference
WRS	WAAS (wide-area augmentation system) reference stations
WTWD	Wake Turbulence Mitigation for Departures
Wx	weather

4–D	four dimensional (latitude, longitude, altitude, and time)
4DLINK	proposal for the next data link package that targets initial four-dimensional trajectories and airport services (This capability fits in Implementation Package 2 as identified by the Single European Sky ATM Research (SESAR) Master Plan.)
4DT	four-dimensional trajectory (latitude, longitude, altitude, and time)

Appendix B.—RTCA National Airspace System Concept of Operations Applicable to the Proposed Aeronautical Mobile Airport Communications System (AeroMACS)

AeroMACS could provide a communication link to transfer surveillance and weather information, facilitate flight and resource management, and enable exchange of aeronautical information in the future NAS. Table 41 to Table 45 document the select RTCA NAS ConOps (Ref. 13) found applicable to the proposed AeroMACS.

In addition to the relevant section number, the "Relevant text" column presents the specific text from the NAS ConOps document pertaining to the identified type of information being exchanged and/or service provided. The "Relevant text" in these tables is copyrighted by RTCA, Inc., and is being used with permission.[16]

TABLE 41.—THE ROLE OF SURVEILLANCE INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
S-1	1.5.2	Traffic information collected by surveillance systems is transmitted to properly equipped aircraft. Thus equipped users have position information of appropriate aircraft available to support flight deck decisions.
S-2	1.5.3 2nd bullet	Enhanced CNS [communications, navigation, and surveillance] systems and automation in aircraft complement automation aids on the ground permitting more autonomous operations. This improved autonomy combined with greater ability to share information permits workload to be distributed between service provider and operator in a balance appropriate for the operations being conducted.
S-3	4.1.3	Accurate airport environmental information, including traffic, permits appropriately equipped aircraft to navigate on the airport surface with almost no forward visibility.
S-4	4.2.2	The proliferation of CDTI [cockpit display of traffic information] avionics and supporting ground infrastructure takes place in this time frame. The ground system that receives aircraft position reports also broadcasts traffic information and a complete set of graphical and text weather products … Safety is enhanced by situation displays that depict airborne and surface traffic as well as aerodrome information.
S-5	4.3.2 1st paragraph	… In addition, ground-based surveillance data is shared with users as a safety enhancement for preventing incursions.
S-6	5.1.3 2nd paragraph	Virtually all aircraft are equipped to provide position and intent information, and to receive position and intent data from other aircraft.

[16]The complete RTCA NAS ConOps (and other RTCA documents) may be purchased from RTCA, Inc., 1828 L St., N.W., Suite 805, Washington, DC 20036 (202–833–9339, http://www.rtca.org).

TABLE 42.—THE ROLE OF WEATHER INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
W-1	1.4 2nd bullet	In addition to this pool of common information, SWIM [System Wide Information Management] provides context-sensitive information to NAS elements that require the information. (This includes flight deck access to the information, such as weather and resource status.)
W-2	1.5.2 9th bullet	A SWIM system is developed by the service provider to distribute timely and consistent information across the NAS for both user and service provider planning … The system serves as an avenue for greater exchange of electronic data and information between users and service providers including… - Dynamic information including but not limited to current and forecast weather, radar summaries, hazardous condition warnings, information on updated airport and airspace capacity constraints Temporary Flight Restrictions (TFR), and Special Use Airspace (SUA).
W-3	1.5.3 6th bullet	There are continued advancements in the scope and accuracy of the weather information available to the service provider and use throughout the NAS, including automatic simultaneous broadcast of hazardous weather alerts for wind shear, turbulence, microburst, gust fronts; and areas of precipitation, lightning, icing, and low cloud ceilings and visibility. SWIM provides access to this information to all service providers and to participating aircraft via data link. Improved weather information integrated into DSSs and disseminated via data link reduces encounters with hazardous weather.
W-4	2.1.1	TFM [traffic flow management] service providers monitor traffic, weather, and infrastructure. … Improved information exchange among users and service providers enables shared insight about weather, demand, and capacity constraints which enhances the users understanding of NAS status and TFM initiatives.
W-5	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information including airport status and acceptance rate, composite weather information developed collaboratively by the FAA and users to assure a common projection of future weather.
W-6	3.1.2 1st paragraph	A common Geographical Information System (GIS) format is used to store all NAS information including terrain, obstacle, weather, and navigation, surveillance and communication coverage information. This information is available via SWIM to all service providers and users.
W-7	3.2.1 4th paragraph	Data link-equipped users load the flight plan directly into the Flight Management System (FMS). The user obtains a complete weather briefing for the proposed route via the FOC [Flight Operations Center] computer. In addition, system-wide information is obtained via the FOC SWIM interface.
W-8	3.2.3 3rd paragraph	Greater use of electronic flight planning, navigation database updates and weather briefing services via SWIM results in the routine transfer of preflight planning data to the flight deck. Dynamic safety-critical (e.g. turbulence, icing) and other flight plan is data linked directly to aircraft for use during flight.
W-9	4.1.1 2nd paragraph	The introduction of data-linked meteorological information improves overall situational awareness. Properly equipped aircraft receive graphical weather information via data link, including current observations, pilot reports, hazardous phenomena in both graphic and text format, and winds aloft information.
W-10	4.1.2 3rd paragraph	Clearances, airport information, and weather conditions (e.g., current, forecast, hazardous) are provided over data link to more users at more airports.
W-11	4.1.2 4th paragraph	The system provides access to airport environmental information, arrival, departure, and taxi schedules, airborne and surface surveillance information, flight information, ATIS [Automatic Terminal Information System] and other weather information, and TFM initiatives.
W-12	4.1.3 1st paragraph	Hazardous weather alerts are automatically and simultaneously broadcast to aircraft via data link and service providers via SWIM.
W-13	4.2.1 1st paragraph	Many users continue to use Aircraft Communications Addressing and Reporting System (ACARS) as a source of data linked information. ATIS and other weather information are received via data link or by voice.
W-14	4.2.2 3rd paragraph	The ground system that receives aircraft position reports also broadcasts traffic information and a complete suite of graphical and text products, including precipitation/lightning, icing, low ceiling/visibility maps, surface hazards, and wind shear and turbulence information, as well as site-specific weather reports and forecasts. Safety is enhanced through the use of situation displays that depict airborne and surface traffic as well as aerodrome information.

TABLE 42.—THE ROLE OF WEATHER INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
W-15	4.3.1 1st paragraph	SWIM and ACARS enhance the service provider’s ability to provide data products such as NOTAMs [Notices to Airmen] and meteorological information to the airport vicinity. Although weather information and advisories continue to be available via traditional means, there is increased use of automation to collect and package the information and increased use of data link to disseminate routine and hazardous weather and traffic information.
W-16	4.3.2 1st paragraph	SWIM provides access to weather and information via data link to flight crews, allowing them to develop near-real-time picture of the surrounding environment. SWIM and data link also expedite the service provider’s task of providing data products such as NOTAMs and meteorological information for the airport vicinity when changed or needed [b]y the user.

TABLE 43.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
FM-1	1.5.2 9th bullet	A SWIM [System Wide Information Management] system is developed to distribute timely and consistent information….[Including]: - Flight information on each flight, including the filed flight profile and all amendments, first movement of the aircraft, wheels-up, position data in flight, touchdown time, gate or parking assignment, and engine shutdown.
FM-2	1.5.2 13th bullet	The flight planning system accommodates all uses of the airspace as the flight profile evolves to include real time SUA [Special Use Airspace] operations scheduling information.
FM-3	1.5.2 14th bullet	By integrating all airspace management systems, the NAS achieves the technical goal of providing in a timely manner the airspace necessary to execute the flight profile. The ATM [air traffic management] system manages airspace based on each user's needs, including proximity to the user’s base of operations. As a result, more airspace, including special use, is made available to more users with increased efficiency.
FM-4	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information, including airport status and acceptance rate and composite weather information developed collaboratively by the FAA [Federal Aviation Administration] and users to ensure a common projection of future weather. Improved individual support capabilities use investigative operations and develop individual strategies to mitigate demand-capacity imbalances and their effect on the individual user fleets. Sharing strategies with the ATCSCC [air traffic control system command center] allows service providers to evaluate conditions based on user intention rather than published schedules.
FM-5	2.2.2 1st paragraph	With the increasing ability to maintain common situation awareness, users plan flight profiles that consider known constraints and provide the best advantage to their operations.
FM-6	2.2.2 2nd paragraph	… In addition, the flight planning system expands to offer users the opportunity to provide alternative profiles for flights. These alternative profiles are tested on a continuing basis as trial plans that are selected if conditions do not develop as foreseen.
FM-7	2.2.3 1st paragraph	…Within that constraint and allocation, the NAS has the ability to conduct a SYSCO [system-supported coordination] auto-negotiation of the flight profile to best meet the user's need within that user’s NAS resource allocation. The systems interactively re-plan each flight against both current constraints and any ancillary problems that arise through the execution of the initiative.
FM-8	3 1st bullet	Elements of SWIM are used to obtain and distribute flight-specific data and aeronautical information, including international coordination of planned flight trajectory.
FM-9	3 6th bullet	Real-time trajectory updates reflect more realistic departure times, resulting in more accurate traffic load predictions, and increased flexibility due to the imposition of fewer restrictions.
FM-10	3 2nd bullet	As the information available through SWIM increases, a more collaborative role for users evolves based on the access to accurate real-time NAS information for improved flight planning. Examples of this information include current and predicted SUA status, infrastructure status, traffic density, and prevailing TFM [traffic flow management] initiatives.

TABLE 43.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
FM-11	3 3rd bullet	Decision support suites are available for both interactive preflight planning with the service provider as well as changes by the pilot and/or dispatcher during the course of the flight.
FM-12	3.1.1 3rd paragraph	There is real-time sharing of system demand and the virtual ATM information, enabling service providers to collaboratively interact with the user and to mutually develop solutions to problems.
FM-12	3.1.2 2nd paragraph	Flight plan information is incorporated into the flight profile. This profile can be as simple as the user's preferred path or as detailed as a time-based trajectory that includes the user's preferred path and preferred climb and descent profiles. The climb and descent profiles may include extended periods of continuous change. This is similar in nature to a discretionary clearance (climb or descent) but is part of the flight planning process and, ultimately, the approved flight profile. This negotiated profile is available both to the user and to service providers across the NAS.
FM-13	3.1.2 4th paragraph	At the completion of the planning process, the user supplies the service provider with both the flight profile that best balances the NAS constraints and the user's preferred flight profile. This information, including any subsequent changes, is available electronically to all service providers until the termination of the flight.
FM-14	3.1.3 1st and 2nd paragraph	Interactive flight planning capabilities with immediate access to real-time data are fully implemented and are available throughout the flight to the flight deck, FOC [Flight Operations Center], and service provider. User-preferred routing is available to all properly equipped aircraft for both domestic and international flights. Controlled Times of Arrival (CTA) are the primary method for regulating flows in the planning, tactical, and strategic timeframes. The flight profile evolves with changes to operations to allow greater flexibility in user preferences, including the planning and filing of parabolic flight profiles.
FM-15	3.2.1 2nd paragraph	The TFM information network enables a two-way exchange of real-time information. Using flight plan information, flow managers determine when either airport or airspace demand is predicted to exceed capacity, thereby warranting some type of flow management initiative. NAS users receive information about projected areas of concern and revise their plans on a real-time basis.
FM-16	3.2.1 4th paragraph	Data link-equipped users load the flight plan directly into the aircraft Flight Management System (FMS). The user obtains a complete weather briefing for the proposed route via the FOC computer. In addition, system-wide information is obtained through the FOC SWIM interface.
FM-17	3.2.2 1st paragraph	SWIM ensures a continuously updated information base of NAS items, including service constraints and infrastructure status. The flight planner uses this data to prepare a flight profile by performing a probe for the user-preferred route against the known system constraints. User DSSs [decision support systems] using information available via SWIM analyze the route that most closely balances user preferences and constraints. The use of CTAs [Controlled Times of Arrival] continues to expand across NAS resources. As conditions change during the planning phase or during the flight, the user is notified, and he/she is able to interactively determine the impact of the changes on the flight and modify the flight profile as desired.
FM-18	3.2.2 2nd paragraph	The status of active and proposed flights, as well as real-time updates to reflect more realistic departure times (e.g., the latest planned departure times) are available to users. …. SWIM and SYSCO [system-supported coordination] facilitate more effective CDM [collaborative decision making] between the FOC and service provider. …
FM-19	3.2.2 4th paragraph	Users without an FOC capability access the same flight data used by all other system users and service providers via appropriate devices. They are able to enter a command and be transferred to a service provider for clarification of the information. Depending on the user's equipment, this dialog is by voice or through electronic messaging. For users equipped with data link, the capability exists to load a flight profile directly into the aircraft FMS [flight management system]. Other users can store the flight profile information on disk and upload it into the aircraft's avionics for use.
FM-20	3.2.2 9th paragraph	… SWIM enables domestic and international users and service providers to access flight profiles and associated SUA data.
FM-21	3.2.3 1st paragraph	SWIM and Omni-SYSCO support an interactive flight planning capability for all properly equipped users to aid in filing user-preferred departure-to-destination flight profiles. …

TABLE 43.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
FM-22	3.3.2 1st and 2nd paragraphs	SWIM information improves the user's ability to create a flight profile, which facilitates the automatic generation of a flight profile containing either the user's preferred flight path or a more detailed time-based trajectory within the known ATM system constraints. Potential problems are automatically displayed to the planner for reconciliation. Upon filing, the flight profile is updated, as necessary, along with all affected projections of NAS demand. As conditions change, SWIM (in concert with SYSCO) allows the planner to access information used to determine the impact of the changes on the flight. Intelligent agents are introduced in this period to identify the best alternatives in light of ATM system changes and user preferences. SWIM information is available to all users and service providers until the termination of the flight. Information such as runway preferences and aircraft weight or information to support flight following can be added during the planning phase or during flight.
FM-23	4.1.2 3rd paragraph	Clearances, airport information, and weather conditions (e.g. current, forecast, hazardous) are provided over data link to more users at more airports. Taxi routes and positions of other aircraft are data linked and displayed in appropriately equipped aircraft. The receipt of taxi routes over data link relieves communication frequency congestion. Pilot situational awareness and safety are enhanced with an integrated display of the aircraft's position, taxi route, and hazards.
FM-24	4.1.2 4th paragraph	Access to real-time data for surface movement DSSs makes for an increasingly integrated NAS. …. The system provides access to airport environmental information; arrival, departure, and taxi schedules; airborne and surface surveillance information; flight information; ATIS [Automatic Terminal Information System] and other weather information; and TFM initiatives. …
FM-25	4.1.2 5th paragraph	On taxi out, the flight's time-based trajectory is updated in SWIM, and projections are made based on prevailing traffic conditions.
FM-26	4.3.1 4th paragraph	…the service provider's ability to plan surface movement improves as timely traffic information becomes available. …. Both the initial values and subsequent adjustments are incorporated into the surface management information system to ensure consistency and an integrated approach across systems

TABLE 44.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
A-1	1.5.2 9th bullet	A SWIM [System Wide Information Management] system is developed by the service provider to distribute timely and consistent information across the NAS …including… Static data, such as electronic navigation data, maps, charts, airport facility guides, and published Notices to Airmen (NOTAMs) is available directly from the Internet as well as various intranets… Dynamic information, including, but not limited to, current and forecast weather, radar summaries, hazardous condition warnings, information on updated airport and airspace capacity constraints, Temporary Flight Restrictions (TFR), and Special Use Airspace (SUA) schedules. Flight information… Schedule information…
A-2	1.5.2 12th bullet	Traffic information collected by surveillance systems is transmitted to properly equipped aircraft…to support flight deck decisions.
A-3	1.5.3 2nd bullet	Enhanced CNS [communication, navigation, and surveillance] systems and automation in aircraft complement automation aids on the ground, permitting more autonomous operations. This improved autonomy, combined with greater ability to share information, permits the workload to be distributed between the service provider and user in a balance appropriate for the operations being conducted.

TABLE 44.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
A-4	1.5.3 4th bullet	Seamless communications and coordination, coupled with information accessible through SWIM, allow real-time reassignment of airspace between facilities to meet contingencies such as equipment outages.
A-5	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information including airport status and acceptance rate, …
A-6	3 1st bullet	Elements of SW[I]M are used to obtain and distribute flight-specific data and aeronautical information, including international coordination of flight trajectory.
A-7	3.1.1 3rd paragraph	There is real time sharing of system demand and the virtual ATM [air traffic management] information… User flight planning systems account for system constraints such as flow restrictions, hazardous weather, SUA and infrastructure outages.
A-8	3.1.2 1st paragraph	A NASCR [NAS Common Reference System] and index that incorporates a common Geographical Information System (GIS) format is used to store all NAS information including terrain, obstacle, weather, and navigation, surveillance and communication coverage information. This information is available via SWIM to all service providers and users.
A-9	3.1.2 3rd paragraph	To generate the flight profile, users access current and predicted weather, traffic density, restrictions, and SUA status information …
A-10	3.2.2 9th paragraph	SWIM enables domestic and international users and service providers to access flight profiles and associated SUA data.
A-11	4.1.2 4th paragraph	Access to real-time data for surface movement DSSs [decision support systems] makes for an increasingly integrated NAS. The surface management information system facilitates coordination between decision makers at all levels of the airport operation—service provider, flight crews, FOC [Flight Operations Center], ramp, airport operator, and airport emergency centers. The system provides access to airport environmental information; arrival, departure, and taxi schedules; airborne and surface surveillance information; flight information; ATIS [Automatic Terminal Information Service] and other weather information; and TFM [traffic flow management] initiatives. This data sharing allows service providers to coordinate local operations with airline ramp and airport operators, thus improving overall airport operations.
A-12	4.1.3 1st paragraph	…. Using data link, pilots receive ATIS-type messages with Runway Visual Range (RVR), braking action and surface condition reports, current precipitation, runway availability, and wake turbulence and wind shear advisories. Hazardous weather alerts are automatically and simultaneously broadcast to aircraft via data link and service providers via SWIM.
A-13	4.2.1 2nd paragraph	Airport maps are electronically available to properly equipped users
A-14	4.2.2 3rd paragraph	The proliferation of CDTI [cockpit display of traffic information] avionics and supporting ground infrastructure takes place in this time frame. The ground system that receives aircraft position reports also broadcasts radar-derived traffic information and a complete set of graphical and text products … Safety is enhanced by situation displays that depict airborne and surface traffic as well aerodrome information.
A-15	4.3.1 1st paragraph	SWIM and ACARS [Aircraft Communications Addressing and Reporting System] enhance the service provider's ability to provide data products such as NOTAMs [Notices to Airmen] and meteorological information for the airport vicinity. Although weather information and advisories continue to be available via traditional means, there is increased use of automation to collect and package the information and increased use of data link to disseminate routine and hazardous weather and traffic information.

TABLE 45.—IDENTIFICATION OF THE ROLE OF RESOURCE MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 13)
RM-1	1.5.2 16th bullet	By taking advantage of advanced information and communications capabilities, airspace design and underlying sector configurations are no longer constrained by the current geographic boundaries, particularly in high altitude. Tools and procedures are in place for frequent evaluation (up to several times a day) of the airspace structure and anticipated traffic flows, with adjustments made accordingly. This increased flexibility permits changes to the configuration of air traffic facilities.
RM-2	1.5.3 2nd bullet	Enhanced CNS [communications, navigation, and surveillance] systems and automation in aircraft complement automation aids on the ground permitting more autonomous operations. This improved autonomy combined with greater ability to share information permits the workload to be distributed between service provider and user in a balance appropriate for the operations being conducted.
RM-3	1.5.3 4th bullet	Seamless communications and coordination, coupled with information accessible through SWIM [System Wide Information Management], allow real-time reassignment of airspace between facilities to meet contingencies such as equipment outages.
RM-4	1.5.3 7th bullet	There are continued improvements in the collection and processing of NAS infrastructure data. These data are used to prioritize and schedule NAS infrastructure activities
RM-5	1.5.3 8th bullet	NAS infrastructure assets (e.g., radars, communications, etc.) are assigned/reassigned dynamically to mitigate infrastructure problems as well as in response to changes in sectorization and airspace assignment. All NAS resources are registered in the NAS Common Reference System (NASCR), and monitored and managed through SWIM.
RM-6	2.5.3	… NAS infrastructure assets are assigned/reassigned dynamically to mitigate infrastructure problems as well as to respond to changes to in sectorization and airspace assignment. SWIM provides access to all NAS management and resource information. The redundancy in the NAS is applied expeditiously to maintain flow and reduce operational impact
RM-7	3.1.1 3rd paragraph	There is real-time sharing of system demand and the virtual ATM information, enabling service providers to collaboratively interact with the user and to mutually develop solutions to problems. … User flight planning systems account for system constraints such as flow restrictions, hazardous weather, SUA and infrastructure outages.
RM-8	5.3.2 7th paragraph	Data from SWIM allows service providers to monitor traffic demand, NAS infrastructure status, and other conditions in order to allocate resources, including changes in staffing. Service providers also update the NAS about the available capacity of airport and surrounding airspace resources and the current status of SUA. This facilitates more effective collaboration with FOCs [Flight Operations Center] and improved formulation of TFM [traffic flow management] agreements.

Appendix C.—Hierarchical Diagrams of Functional Requirements

This appendix contains the functional analysis of the AeroMACS C-band communication system presented as a series of hierarchical diagrams (Figure 45 to Figure 60). The "C" preceding all of the numerical functional levels represents "C-band."

The analysis and diagrams were adapted from the National Airspace System Communications System Safety Hazard Analysis and Security Threat Analysis document (Ref. 67).

Solid blocks in the diagrams represent system functions that are part of the C-band system scope assumptions, and background blocks show NAS functions that are not currently part of the C-band functionality.

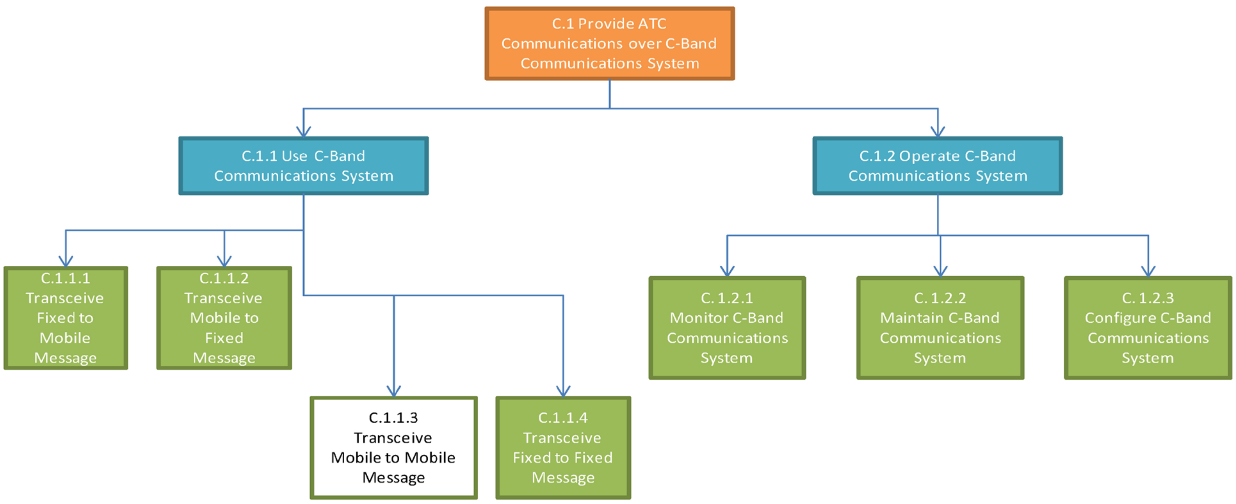

Figure 45.—High-level view of C-band communications system (adapted from Ref. 67).

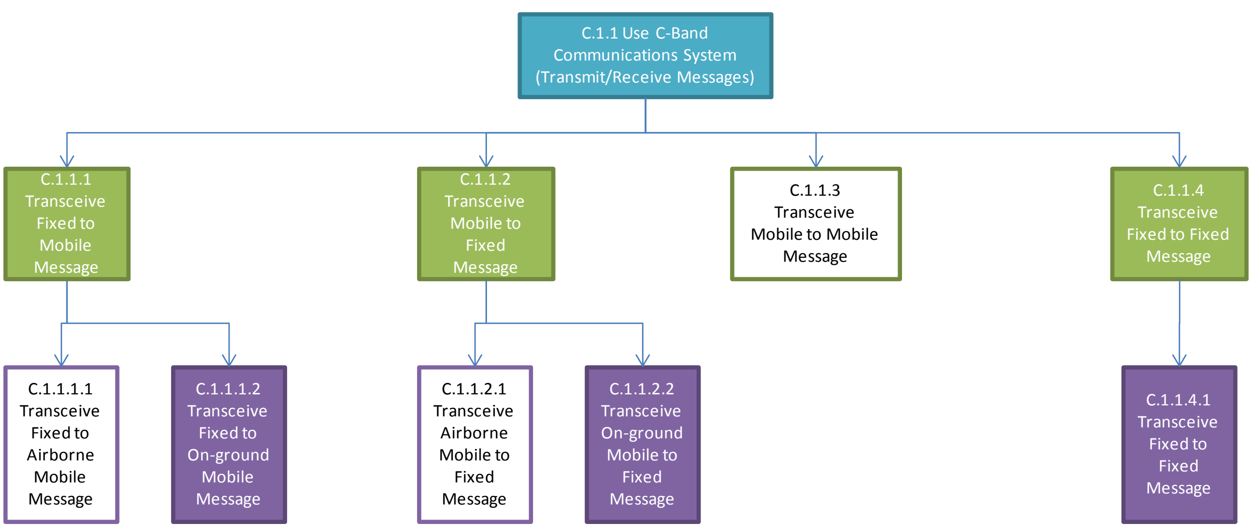

Figure 46.—Decomposition of use of C-band communications system to transmit/receive messages (adapted from Ref. 67).

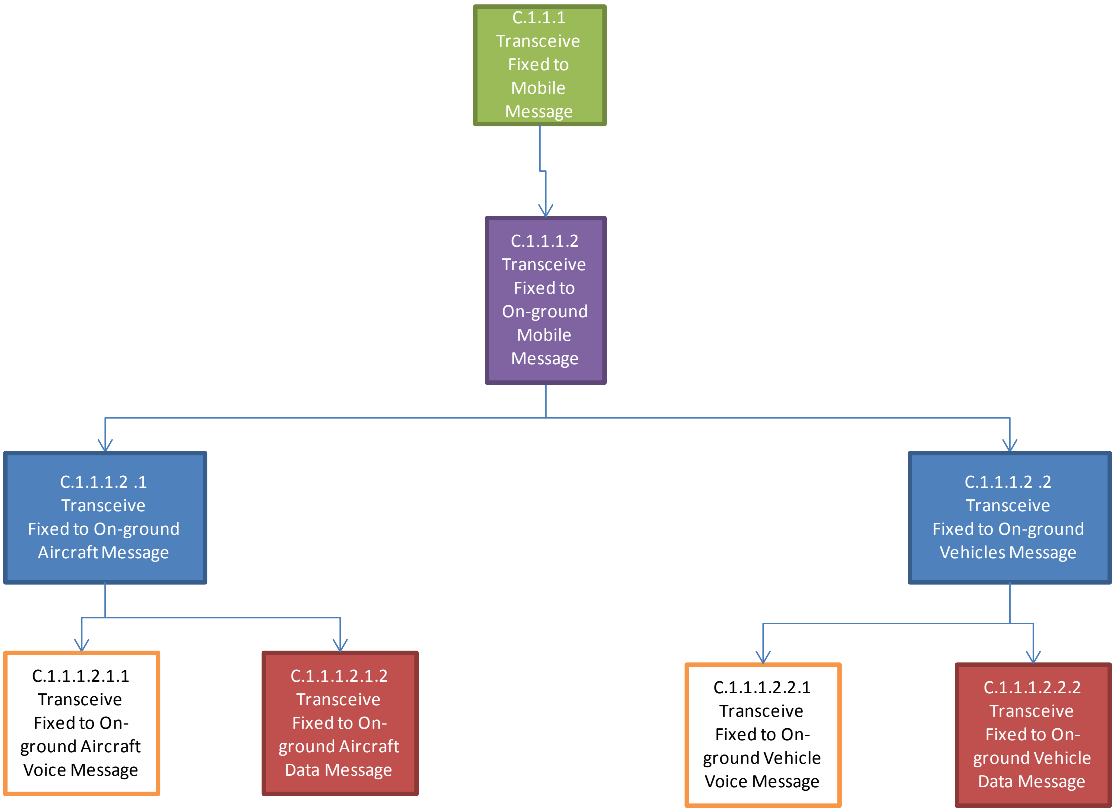

Figure 47.—Decomposition of transceive fixed-to-mobile message (adapted from Ref. 67).

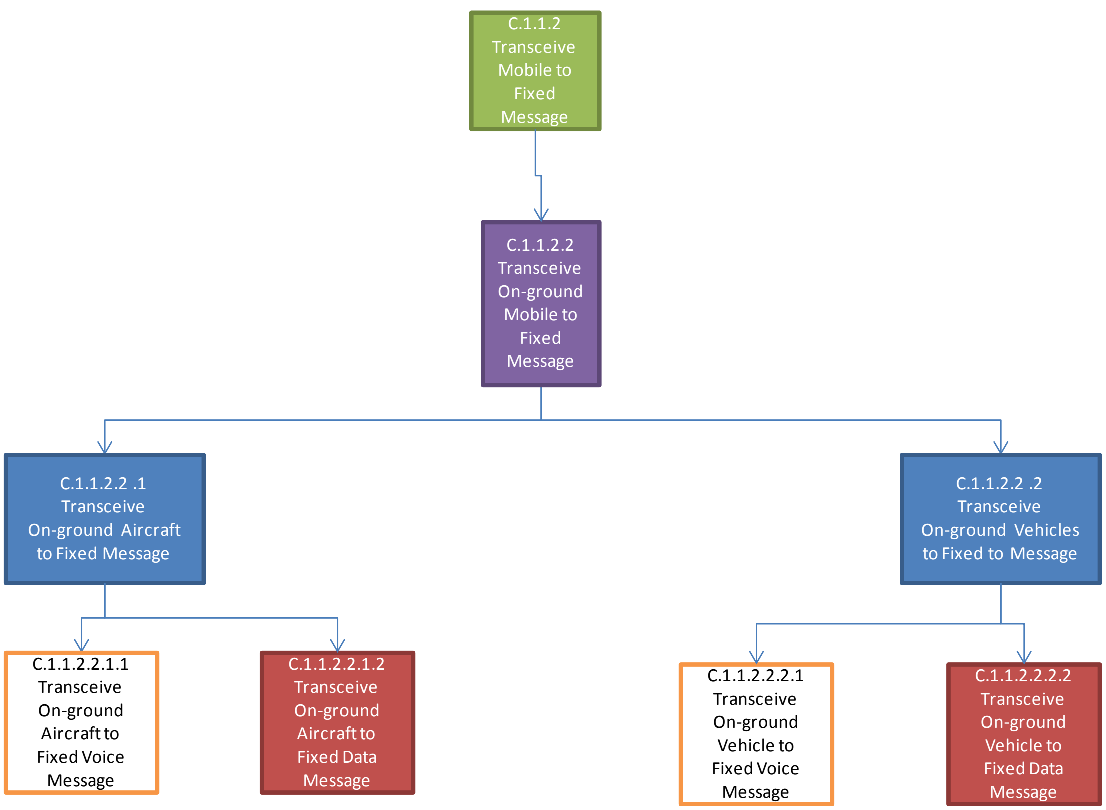

Figure 48.—Decomposition of transceive mobile-to-fixed message (adapted from Ref. 67).

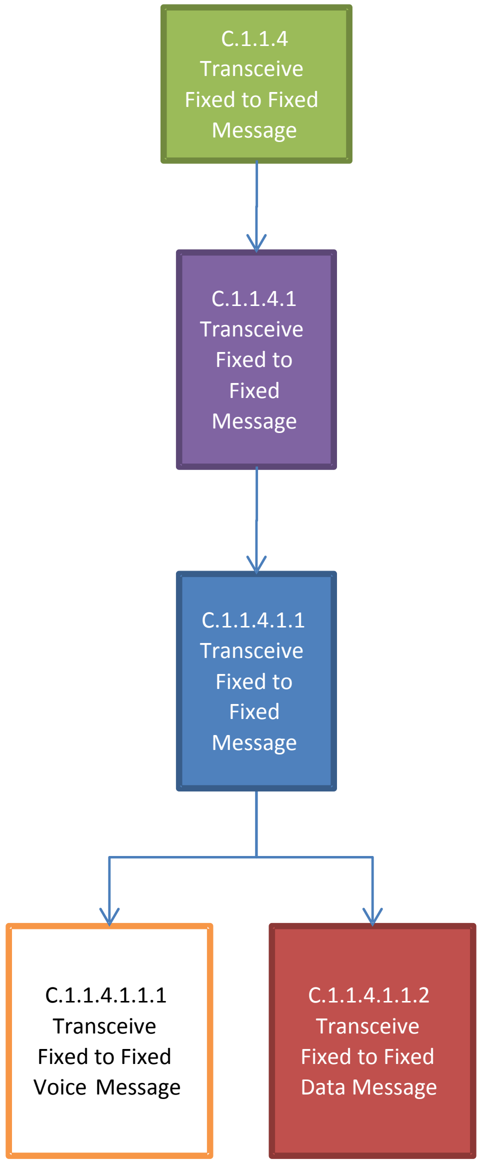

Figure 49.—Decomposition of transceive fixed-to-fixed message (adapted from Ref. 67).

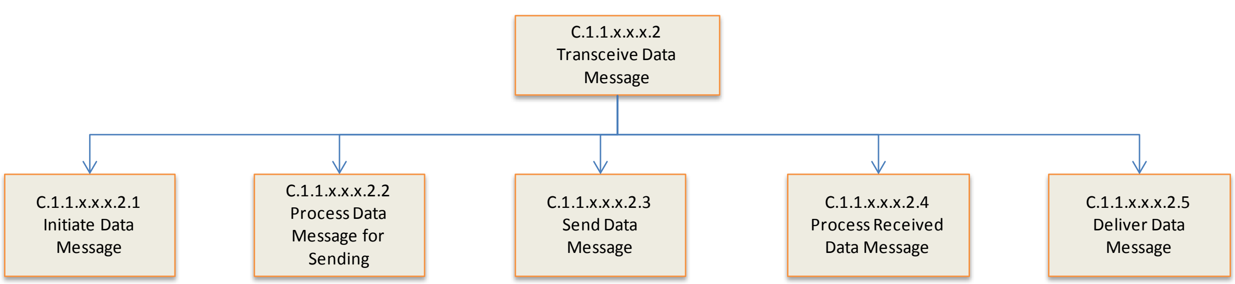

Figure 50.—Generic decomposition of transceive data message (adapted from Ref. 67).

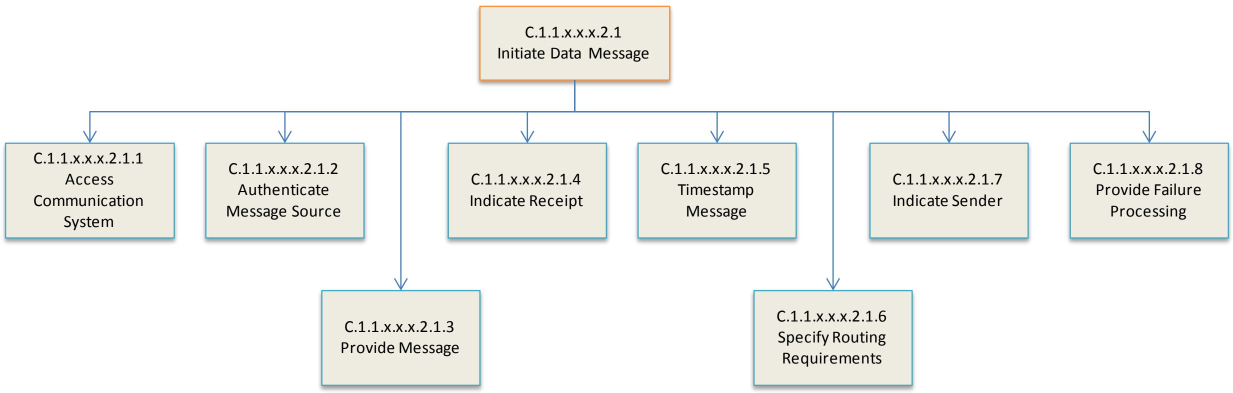

Figure 51.—Generic decomposition of initiate data message (adapted from Ref. 67).

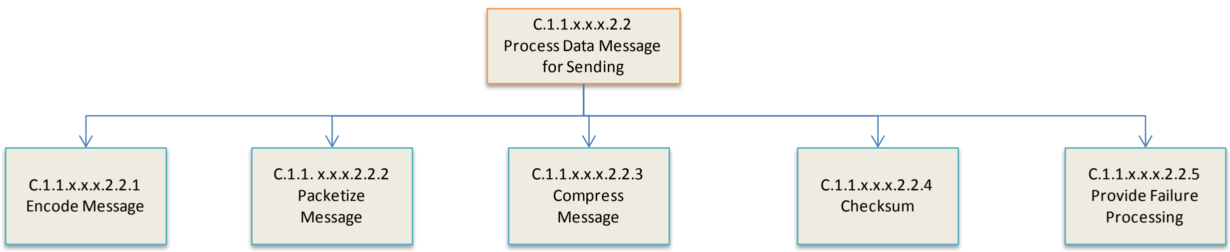

Figure 52.—Generic decomposition of process data message for sending (adapted from Ref. 67).

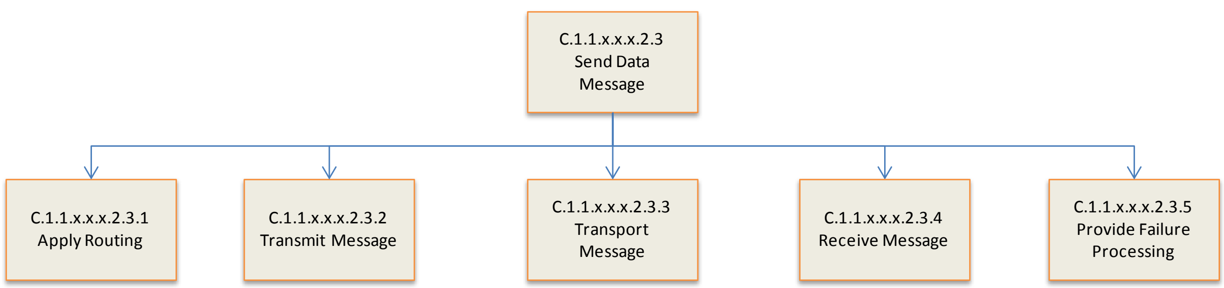

Figure 53.—Generic decomposition of send data message (adapted from Ref. 67).

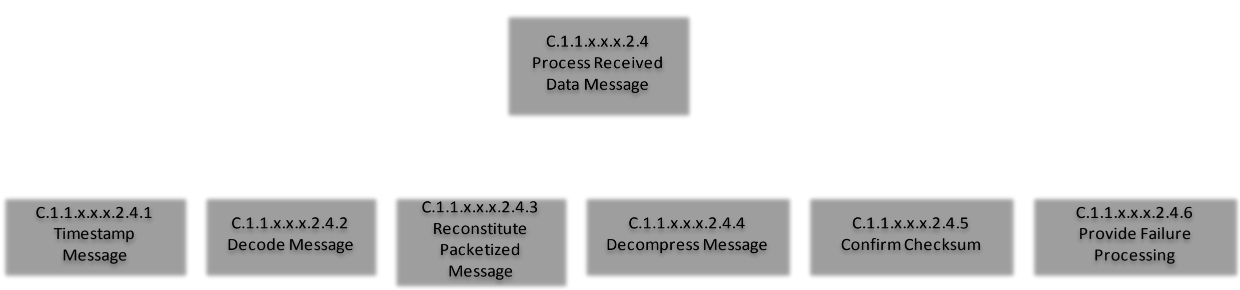

Figure 54.—Generic decomposition of process received data message (adapted from Ref. 67).

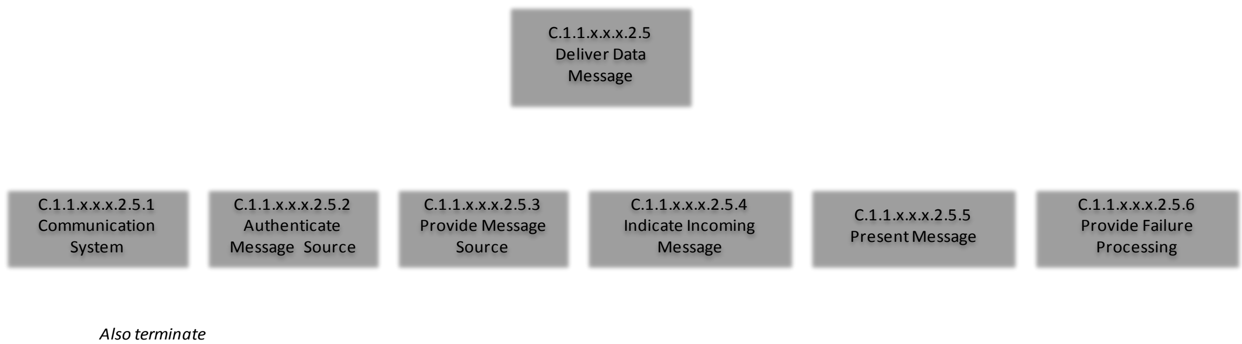

Figure 55.—Generic decomposition of deliver data message (adapted from Ref. 67).

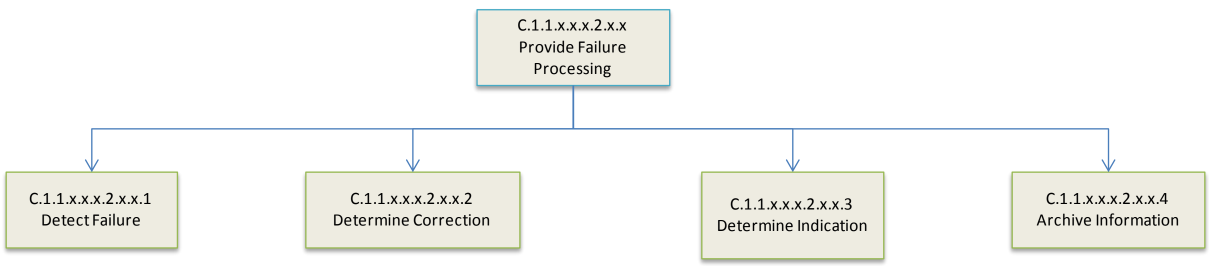

Figure 56.—Generic decomposition of provide failure processing (adapted from Ref. 67).

Failure-detection subfunctions

- Authentication failures
- Function unavailability
- Message unintelligible or garbled
- Message inaudible
- Message or message components missing or faulty
- Invalid or incorrect message components
- Checksum failures
- Invalid recipient

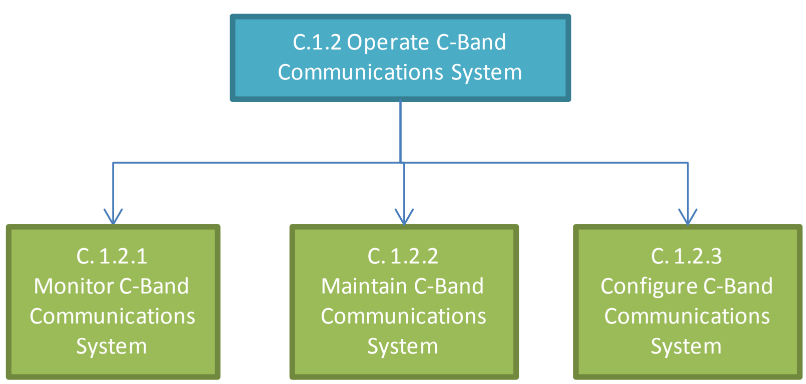

Figure 57.—Decomposition of operate C-band communications system (adapted from Ref. 67).

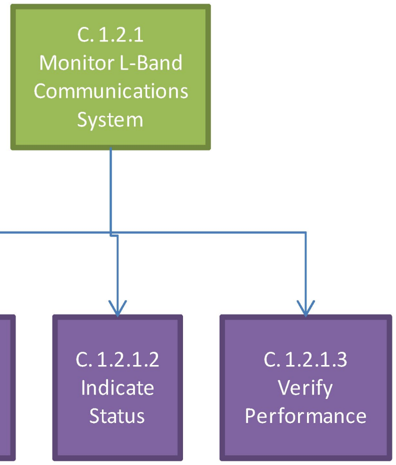

Figure 58.—Decomposition of monitor C-band communications system (adapted from Ref. 67).

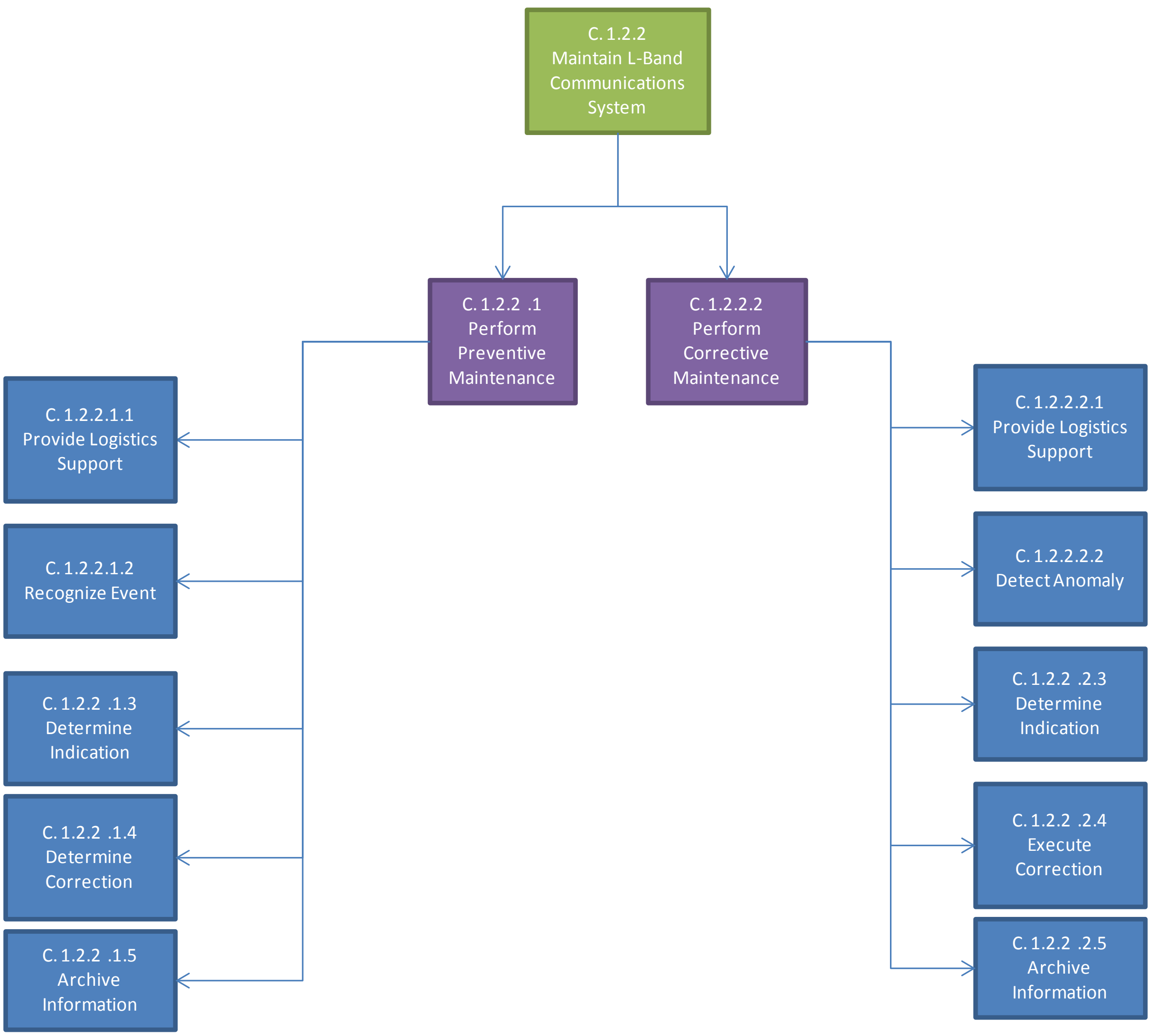

Figure 59.—Decomposition of maintain C-band communications system (adapted from Ref. 67).

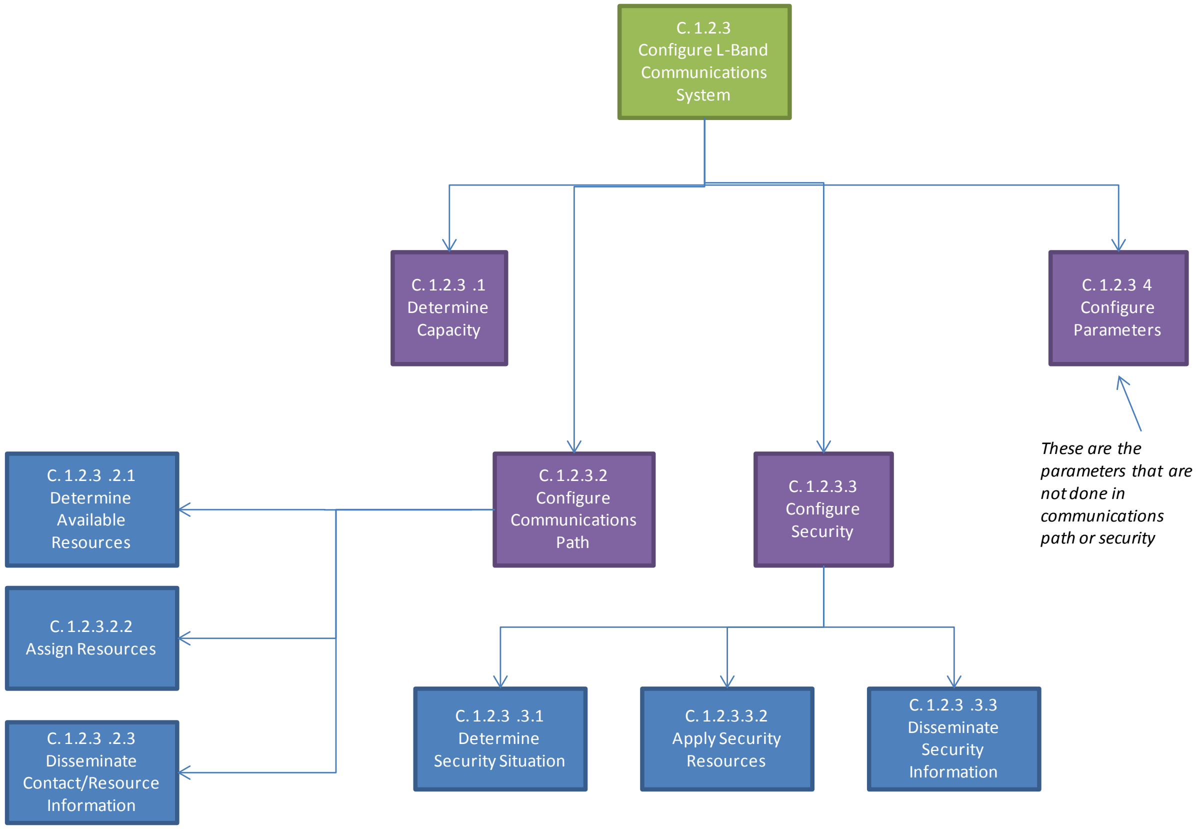

Figure 60.—Decomposition of configure C-band communications system (adapted from Ref. 67).

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14. ABSTRACT
This document is being provided as part of ITT's NASA Glenn Research Center Aerospace Communication Systems Technical Support (ACSTS) contract NNC05CA85C, Task 7: "New ATM Requirements--Future Communications, C-Band and L-Band Communications Standard Development." The proposed future C-band (5091- to 5150-MHz) airport surface communication system, referred to as the Aeronautical Mobile Airport Communications System (AeroMACS), is anticipated to increase overall air-to-ground data communications systems capacity by using a new spectrum (i.e., not very high frequency (VHF)). Although some critical services could be supported, AeroMACS will also target noncritical services, such as weather advisory and aeronautical information services as part of an airborne System Wide Information Management (SWIM) program. AeroMACS is to be designed and implemented in a manner that will not disrupt other services operating in the C-band. This report defines the AeroMACS concepts of use, high-level system requirements, and architecture; the performance of supporting system analyses; the development of AeroMACS test and demonstration plans; and the establishment of an operational AeroMACS capability in support of C-band aeronautical data communications standards to be advanced in both international (International Civil Aviation Organization, ICAO) and national (RTCA) forums. This includes the development of system parameter profile recommendations for AeroMACS based on existing Institute of Electrical and Electronics Engineering (IEEE) 802.16e-2009 standards.

15. SUBJECT TERMS
Aircraft communication; Wireless communications; Airports; Air traffic control

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