Aeronautical Mobile Airport Communications System (AeroMACS) Development Status

NASA/James Budinger, ITT/Ward Hall, NASA/ Robert Dimond, Jeffrey Wilson, FAA/Rafael Apaza, Brent Phillips

ICAO ACP WGM-16
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Overview

• Modernization of airport surface operations requires enhanced, high bandwidth communications capabilities to handle expected services

• A portion of the C-Band AN(R)S band, 5091 to 5150 MHz, was co-allocated as AM(R)S for airport surface mobile communications

• Standards are under development in the U.S. RTCA for the Aeronautical Mobile Airport Communications System (AeroMACS)

• Concepts of Use (ConUse), System Requirements, and a recommended System Profile for the proposed C-Band AeroMACS are being developed by the ITT Corporation under contract with NASA Glenn Research Center via sponsorship and guidance of the FAA

• Presented here is a summary of both the status of ITT’s C-band research contract and NASA Glenn’s related research

• An official NASA Contractor Report (NASA/CR-2010-216324) for ITT’s research will be posted to the NASA Glenn Technical Reports Server http://gltrs.grc.nasa.gov/ during Q2 CY2010
Background

- Future Communications Study (AP-17), ICAO Aeronautical Communications Panel, Recommendation #1:
  - Develop a new system based on the IEEE 802.16e standard operating in the C-band and supporting the airport surface environment.
- FAA’s NextGen Implementation Plan to improve collaborative Air Traffic Management includes “New ATM Requirements: Future Communications”
  - Concepts of use, preliminary requirements, and architecture for C-band airport surface wireless communication system
  - Test bed infrastructure to enable validation of aviation profile
RTCA SC-223

- RTCA Program Management Council approved SC-223 in July 2009 for Airport Surface Wireless Communications standard development
  - Aeronautical mobile airport communications system (AeroMACS) profile based on IEEE 802.16-2009 standard
  - Co-Chairs: Honeywell/Aloke Roy and ITT/Ward Hall; Government Official; FAA/Brent Phillips; AeroMACS Profile Working Group Lead: Harris/Art Ahrens
  - Coordinating with EUROCAE WG-82
  - Initial AeroMACS profile to be defined by October 2010
Approach for Technical Parameter Profile

- System profiles define AeroMACS operation in the unique airport surface environment
- Profile based on IEEE 802.16e broadband mobility standard
- Leverages commercial mobile Worldwide Interoperability for Microwave Access (WiMAX) for profiles, hardware, software, and network architecture
- Test and analysis will assess whether application needs are met
- RTCA SC-223 is developing FAA profile recommendations; EUROCAE WG-82 is developing common profile for EUROCONTROL in parallel

<table>
<thead>
<tr>
<th>Profile Area</th>
<th>Key Parameter Selections</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RF/Radio parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Frequency band</td>
<td>5091 to 5150 MHz</td>
</tr>
<tr>
<td>Channel BWs</td>
<td>5, 10 MHz</td>
</tr>
<tr>
<td>Channel center frequencies</td>
<td>Center frequencies at 5 MHz increments</td>
</tr>
<tr>
<td><strong>Power class</strong></td>
<td></td>
</tr>
<tr>
<td>Max DL TX power</td>
<td>Unchanged from IEEE 802.16e</td>
</tr>
<tr>
<td>Max UL TX power</td>
<td></td>
</tr>
<tr>
<td><strong>Duplex Mode</strong></td>
<td>TDD</td>
</tr>
<tr>
<td><strong>Physical Layer</strong></td>
<td></td>
</tr>
<tr>
<td>M-ary QAM range</td>
<td>Performance profiles – Min. performance defined in 802.16e and sensitivity values scaled for frequency</td>
</tr>
<tr>
<td>Coding options</td>
<td></td>
</tr>
<tr>
<td>MIMO</td>
<td></td>
</tr>
<tr>
<td><strong>MAC Layer</strong></td>
<td></td>
</tr>
<tr>
<td>ARQ</td>
<td>Unchanged from IEEE 802.16e</td>
</tr>
<tr>
<td>Security protocols</td>
<td></td>
</tr>
<tr>
<td>Mobile protocols</td>
<td></td>
</tr>
<tr>
<td>QoS options</td>
<td></td>
</tr>
</tbody>
</table>
# Typical Communication Service Requirements

<table>
<thead>
<tr>
<th>Communication Service</th>
<th>Example Airport Application</th>
<th>Performance Parameters</th>
<th>Typical values</th>
<th>Supported by 802.16e</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point-to-Point Data</strong>&lt;br&gt;Link – (Low, Medium Speed, &lt; 200 kbps)</td>
<td>Backup for sensor cable link (weather sensor)</td>
<td>Data rate</td>
<td>100 kb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Packet Error Rate (PER)</td>
<td>$1.0 \times 10^{-3}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>1 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>100 msec</td>
<td></td>
</tr>
<tr>
<td><strong>Point-to-Point Data</strong>&lt;br&gt;Link – (High Speed)</td>
<td>Backbone linking BS, link to relay gateway node in remote area</td>
<td>Data rate</td>
<td>1 Mb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>$1.0 \times 10^{-3}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>100 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>100 nsec</td>
<td></td>
</tr>
<tr>
<td><strong>Point-to-Multipoint, Broadcast</strong></td>
<td>Scheduled broadcast of weather info, NOTAM</td>
<td>Data rate</td>
<td>200 kb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>$1.0 \times 10^{-3}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>1 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt; 1 ms</td>
<td></td>
</tr>
<tr>
<td><strong>Command &amp; Control</strong>&lt;br&gt;Point-to-Point data Link</td>
<td>Remote operation of ADS-B ground station</td>
<td>Data rate</td>
<td>200 kb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>$1.0 \times 10^{-6}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>100 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt; 1 ms</td>
<td></td>
</tr>
<tr>
<td><strong>Command &amp; Control</strong>&lt;br&gt;Network</td>
<td>Operation of surface devices at remote airport (e.g. Virtual tower)</td>
<td>Data rate</td>
<td>200 kb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>$1.0^{-4}$</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>200 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt; 10 ms</td>
<td></td>
</tr>
</tbody>
</table>
## Typical Communication Service Requirements

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<thead>
<tr>
<th>Communication Service</th>
<th>Example Airport Application</th>
<th>Performance Parameters</th>
<th>Typical values</th>
<th>Supported by 802.16e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Voice Network</td>
<td>Provide N circuits for ATC or AOC operations</td>
<td>Data rate</td>
<td>10 kb/s x N</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>1.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>100 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt;100 ms</td>
<td></td>
</tr>
<tr>
<td>Point-to-Point Video Link</td>
<td>Airport surveillance, Robotic vehicles</td>
<td>Data rate</td>
<td>600 kb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>1.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>200 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt;10 ms</td>
<td></td>
</tr>
<tr>
<td>Mobile – Basic</td>
<td>Handoff control for voice, data sessions-low speed</td>
<td>Data rate</td>
<td>200 kb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>1.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>200 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt;10 ms</td>
<td></td>
</tr>
<tr>
<td>Multi-media</td>
<td>Collaborative Decision Making</td>
<td>Data rate</td>
<td>1 Mb/s</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>1.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>100 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt;10 ms</td>
<td></td>
</tr>
<tr>
<td>Mobile – Enhanced</td>
<td>Handoff control for video, higher data rate applications – high speed (160 knots)</td>
<td>Data rate</td>
<td>1 Mb/s</td>
<td>Need not yet established</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>1.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>200 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt;10 ms</td>
<td></td>
</tr>
<tr>
<td>Relay/Gateway</td>
<td>Extend network coverage on the Airport surface, ad-hoc CDM</td>
<td>Data rate</td>
<td>1 Mb/s</td>
<td>Relay supported in future amendment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PER</td>
<td>1.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay</td>
<td>200 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter</td>
<td>&lt;10 ms</td>
<td></td>
</tr>
</tbody>
</table>
## Expected Range of Service Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum Expected Requirement</th>
<th>Maximum Expected Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>10 kb/s</td>
<td>1 Mb/s</td>
</tr>
<tr>
<td>Packet Error Rate (UDP)</td>
<td>$1.0 \times 10^{-4}$</td>
<td>$1.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>Delay</td>
<td>100 ms</td>
<td>1 s</td>
</tr>
<tr>
<td>Time Jitter</td>
<td>100 ns</td>
<td>10 ms</td>
</tr>
</tbody>
</table>
AeroMACS Additions to NASA-CLE CNS Test Bed

- CNS Test Bed at NASA Glenn and adjacent Cleveland Hopkins International Airport (CLE) already includes Sensis’ precision multilateration (MLAT) surveillance and unlicensed WiFi network
- ITT’s AeroMACS prototype implements features required to support mobile wideband communications for safety and regularity of flight services in an operational airport environment
- Full network installed, including user verification and security with Authentication, Authorization, and Accounting (AAA) server function
- AeroMACS hardware and network installation completed in October 2009 with two multi-sector base stations providing wide area coverage and redundancy (one on Glenn property, one on CLE) and eight subscriber stations (two on Glenn, six on CLE)
NASA-Cleveland Test Bed AeroMACS Network Layout

- **NASA Glenn Research Center**
- **Cleveland-Hopkins International Airport**
- **Core Server**
- **Subscriber Stations**
- **Base Stations**

Diagram showing various locations and connections within the network layout.
Two-Sector Base Station Located at NASA Glenn Hangar Building 4
Three-Sector Base Station Located at CLE Airport Rescue and Firefighting (ARFF) Building

ARFF Building and Observation Deck

11 GHz Data Backhaul to B110

GPS ODUs

BS ODUs (3)
Subscriber Station Installation Example on Sensis MLAT Equipment at NASA Glenn Building 500
Predicted AeroMACS Link Performance
Initial Data Throughput Measurements Between Buildings 500 and 4

- Initial data throughput measurement results available for links between NASA Building 500 and two Base Station sectors at NASA Building 4
  - > 6.5 Mbps in Downlink direction (BS to SS)
  - > 4 Mbps in Uplink direction (SS to BS)

- Conditions
  - 5 MHz Channel bandwidth
  - TDD ratio 60% (DL), 40% (UL)
  - TCP data traffic

<table>
<thead>
<tr>
<th>BTS Sector</th>
<th>Measured Throughput DL, Mbps</th>
<th>Expected DL Throughput, Mbps</th>
<th>Measured Throughput UL, Mbps</th>
<th>Expected Throughput UL, Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTS1_1</td>
<td>6.82</td>
<td>6.5</td>
<td>5.40</td>
<td>4.0</td>
</tr>
<tr>
<td>BTS1_2</td>
<td>6.54</td>
<td>6.5</td>
<td>4.19</td>
<td>4.0</td>
</tr>
</tbody>
</table>
AeroMACS Parameter Evaluation Test Plans

- Measure data throughput and packet integrity for the following conditions:
  - 5 and 10 MHz channel bandwidths
  - Stationary and mobile subscriber stations at speeds of at least 40 knots
  - Line-Of-Sight (LOS) and Non-LOS (N-LOS) propagation links
  - Presence of adjacent channel activity

- Mobility tests with hand-off transition between base station coverage sectors and between base stations

- Determine transmit power required to maintain a minimum level of link performance:
  - Single subscriber station antenna
  - MIMO antenna diversity

- Characterize link performance when transferring sensor data from MLAT sensors in test bed
  - Mixture of data traffic streams
  - Traffic priority setting with Quality of Service (QoS) settings
AeroMACS Development Considerations

• Frequency Spectrum Use
  – Compliance with International Telecommunications Union Radiocommunications (ITU-R) Co-Allocation for Aeronautical Mobile Route Service [AM(R)S] in 5091-5150 MHz band
  – Assessment of AeroMACS interference within (Mobile Satellite Service feeder links, Aeronautical Mobile Telemetry, MLS) and adjacent bands
  – Channelization of allocated spectrum within commercial WiMAX Forum standard options

• Wireless Security Implications
  – Assess compliance with NIST Recommended Security Controls for Federal Information Systems and identify potential gaps

• Potential Services and Providers
  – Identify potential categories of AeroMACS services for airport users and options for implementation to enable multiple service providers
Spectrum Interference Initial Assessment

- Establish limits on aggregated AeroMACS transmissions to not exceed interference threshold for MSS feeder links
- Model based on Visualyse Professional 7 software from Transfinite Systems Limited
  - Includes: antennas, stations, carriers, links, and interference paths to determined signal, interference, and noise levels.
  - Preliminary model included all 703 US towered airports
  - Refined model benchmarks MITRE case for omni antennas at 497 major US towered airports
- Plan to increase complexity and realism of interference models:
  - Multi-sector antennas; multiple base and subscriber stations per airport; co-channel and adjacent band; proximity; frequency reuse; multipath signal propagation
Channelization Considerations

• Selection of standard channel BW depends on several factors:
  – Current 59 MHz and potential 30 MHz allocation
  – Guard bands to limit out-of-band transmitted power
  – Anticipated number of BS and SS for practical airport installation
  – Amount of frequency spectrum reuse at the largest airports
  – Bandwidth requirements of potential applications
  – Availability of equipment with WiMAX Forum channel masks
  – Number of independent AeroMACS infrastructure operators
Initial Channelization Methodology/Channel Plan

- Select common channel bandwidths of 5 MHz
- Equally spaced 5 MHz center frequency grid from 5005-5145 MHz
- Proposed channel plan consisting of 10 usable channels within the current AM(R)S allocation (5091-5150 MHz)
- Out-of-band (OOB) interference into adjacent aeronautical band (5030-5091 MHz) may be coordinated via ICAO for 11th channel
- 55 MHz of the total 59 MHz allocation may be usable with stringent channel mask
Initial Channelization Methodology/Channel Plan

• Methodology supports potential future AM(R)S allocation in 5000-5030 MHz

• Potential for channel plan consisting of 5 usable 5 MHz channels

• All 30 MHz of the potential allocation might be usable

• Need to investigate mechanisms to meet out-of-band interference requirement (-44 dBc; -27 dB/MHz at the band edges)
  – Guard bands, band edge filter, or more stringent channel mask
Wireless Security Initial Assessment

• WiMAX security functions meet the NIST SP800-53 controls for access, audit and accountability, and identification and authentication.
  – WiMAX PHY and MAC layer mechanisms assist in addressing NIST Control SC-5, Denial of Service (DOS) Protection.

• WiMAX standard meets all NIST Systems and Communication Protection Controls with regards to user data

• WiMAX mechanisms that minimize impact of DOS and signal attenuation or interference from contending RF sources include:
  – OFDM/OFDMA reduces interference by breaking signal into subcarriers
  – Adaptive Antenna Systems (AAS) focus transmission and reduce unintentional interference
  – Dynamic Frequency Selection (DFS) can change frequency if interference is detected
Potential WiMAX Security Vulnerabilities

• Some MAC messages generated by a BS do not use encryption to ensure messages received by a SS are authentic and unaltered. Intentionally forged MAC information could cause service disruption.

• Potential vulnerabilities include:
  – **DOS by forging “Mobile Neighbor Advertisement” messages:** Malicious generation of BS lists can omit or falsify important information causing loss of SS connection during handoffs
  – **DOS by spoofing “Downlink Burst Profile Change Request” messages:** A forged BS message can cause a SS to change to the wrong modulation method resulting in temporary loss of communication
  – **Battery Drain by spoofing “Mobile Traffic Indicated” messages:** Repeated forging of these messages may defeat power conservation mechanisms of battery-powered SSs by responding to forged traffic IDs

• NASA Glenn plans to verify the impact of these vulnerabilities via the Test Bed
Potential AeroMACS Service Categories in U.S.

- **Air Traffic**
  - Mobile: Air Traffic Control, Advisory Services
  - Fixed: Surface CNS Services

- **Airline**
  - Mobile: AOC Services, AAC Services, Advisory Services
  - Fixed: TBD

- **Airport**
  - Mobile: Port Authority Ops Safety Services
  - Fixed: Port Authority Ops Security Services

- **Other Organizations**
  - FAA, FTI, Others?
  - ARINC, SITA, Airlines, Others?
  - Port Authority, Commercial?
# AeroMACS Service Examples and Provision Options

## Air Traffic Services

<table>
<thead>
<tr>
<th>Service Examples</th>
<th>Provision Options</th>
</tr>
</thead>
</table>
| ● Air traffic control commands beyond Data Comm Segment 3  
● Surface communications, navigation, and surveillance (CNS) fixed assets | ● Government-owned (licensed)/Government-operated (GO/GO)  
● Government-owned (licensed)/Commercially-operated (GO/CO)  
● Non-competed service extension via FAA Telecommunications Infrastructure (FTI)  
● Open commercial competition by FAA |

## Airline Services

<table>
<thead>
<tr>
<th>Service Examples</th>
<th>Provision Options</th>
</tr>
</thead>
</table>
| ● Airline Operational Control (AOC)  
● Airline Administrative Communications (AAC)  
● Advisory information  
● System Wide Information Management (SWIM)  
● Aeronautical Information Management (AIM)  
● Meteorological (MET) data services | ● Commercially-owned (licensed)/Commercially-operated (CO/CO)  
● Non-competed service extension via exiting AOC service providers  
● Airline service provision internally  
● Open commercial competition by airlines |

## Airport Operator/Port Authority Services

<table>
<thead>
<tr>
<th>Service Examples</th>
<th>Provision Options</th>
</tr>
</thead>
</table>
| ● Security video  
● Routine and emergency operations  
● De-icing/snow removal | ● Local Government-owned (licensed)/Commercially-operated (GO/CO)  
● Commercially-owned (licensed)/Commercially-operated (CO/CO)  
● Open commercial competition by Operator/Port Authority |
Airport Surface Experiments and Demos

- FY10 Experiments
  - Network performance, mobile sector handoffs, blockage/outage recovery, signal propagation
  - QoS data prioritization, data throughput, channelization
  - Security with authentication and encryption

- Potential Demos
  - Communication of MLAT surveillance data via AeroMACS
  - Loading graphical weather products into cockpit
  - Precision monitoring of 4D surface trajectories
Conclusion

• Initial Concepts of Use, requirements, and service examples are established for an AeroMACS system

• An initial set of specification-level system profile parameters are recommended with detailed analysis continuing

• The NASA-CLE CNS Test Bed is modified with a functional prototype AeroMACS network and will be used to:
  – establish performance capability
  – validate AeroMACS profile parameter recommendations
  – verify spectrum compliance and security vulnerabilities
  – evaluate selected service applications
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