AeroMACS

Delivering Next Generation Communications to the Airport Surface

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Author's Note

Performance of wireless systems is highly dependent on the operating environment and deployment choices. Performance projections presented in this paper are based on simulations performed with specific multipath models, usage assumptions, and equipment parameters. In practice, actual performance may differ due to local propagation conditions, multipath, and hardware choices. The performance numbers presented should not be relied on as a substitute for equipment field trials and detailed RF analysis.

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List of Acronyms

A/C	Aircraft
AAA	Authentication Authorization Accounting
AAC	Airline Administrative Controls
ACARS	Aircraft Communications And Reporting System
ACSP	Air Communications Service Provider
AES	Advanced Encryption System
AeroMACS	Aeronautical Mobile Airport Communications System
AIS	Aeronautical Information Service
AMRS	Aeronautical Mobile Route Service
AMS	Aeronautical Mobile Service
AMT	Aeronautical Mobile Telemetry
ANSP	Air Navigation Service Provider
AOC	Aeronautical Operational Control
ARNS	Aeronautical Radio Navigational Services
AS	Aeronautical Security
ASDE-X	Airport Surface Detection Equipment - Model X
ASN	Access Service Network
ASP	Application Service Provider
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
BS	Base Station
BW	Bandwidth
CNS	Communications, Navigation, Surveillance
CoS	Class of Service
COCR	Communications Operating Concepts and Requirements
CPDLC	Controller Pilot Data Link Communications
CSN	Connectivity Services Network
D-LIGHTING	Digital Lighting Control (taxiways and runways)
D-OTIS	Data Link Operational Terminal Information System
D-SIG	Digital Link Surface Information and Guidance
DAUS	Data Link Aeronautical Update Services
DL	Down Link
DM	Device Management
EFB	Electronic Flight Bag
EIRP	Effective Isotropic Radiated Power
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FMS	Flight Management System
FOQA	Flight Operational Quality Assurance
GA	General Aviation

GHE	Ground Handling Equipment
GPS	Global Position Satellite
GSO	Geo-Synchronous Orbit
GTG	Graphical Turbulence Guidance
GW	Gate Way
HARQ	Hybrid Automatic Repeat Request
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ITU	International Telecommunications Union
LoS	Line of Sight
MASPS	Minimum Aviation System Performance Specifications
MCS	Modulation and Coding Scheme
MET	Meteorological (data services)
MIMO	Multiple-Input and Multiple-Output
MLAT	Multilateration
MLS	Microwave Landing System
MOPS	Minimal Operational Performance Standards
MSC	Modulation and Coding Scheme
MSS	Mobile Satellite Service
NMS	Network Management System
NOTAMs	Notices to Airmen
NRM	Network Reference Model
OFDMA	Orthogonal Frequency Division Multiple Access
OH	Overhead
OSS	Operations Support System
OTA	Over-the-Air
PDC	Pre-Departure Clearance
PHAK	Pilots Handbook of Aeronautical Knowledge
PHS	Payload Header Suppression
PUSC	Partially Used Sub-Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RF	Radio Frequency
RMM	Remote Maintenance and Monitoring
RP	Reference Point
RTCA	Radio Technical Commission for Aeronautics
RTR	Remote Transmit Receiver
RTW	Runway/Taxiway
SARPs	Standards and Recommended Practices
SE	Spectral Efficiency

SS	Subscriber Station
SWIM	System Wide Information Management
TCP	Transmission Control Protocol
TDD	Time Division Duplex
UDP	User Datagram Protocol
UL	Up Link
VHF	Very High Frequency
WGW	Working Group of the Whole
WOI	Weather Observation Improvement
WRC	World Radio Conference
4D-TRAD	4-Dimensional Trajectory Negotiations

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1.0 Introduction

It has been widely recognized that airport communications systems are greatly outdated. Major airports throughout the world lack the communications capacity to meet today's airport traffic demands and certainly will not be sufficient to address the requirements for improved weather information, better aircraft and ground-handling equipment traffic management, and the growing need for communications leading to improved safety and airport and aircraft security. Recently, wireless broadband capabilities have been considered to guarantee future safety and regularity of flight services at airports worldwide.

To this end, the Aeronautical Mobile Airport Communications System (AeroMACS) profile has been proposed in [1], [2], [3], and [4] to support such emerging and evolving airport surface communications needs. AeroMACS operates in the aeronautical spectrum in the 5 GHz band. A core allocation between 5091 MHz and 5150 MHz was designated on a worldwide basis by the International Telecommunication Union (ITU) at the World Radiocommunication Conference in 2007 (WRC-07 [5]). EUROCONTROL and FAA have jointly recommended that an IEEE 802.16-2009 [6] (Mobile WiMAX profile release 1.0 [7]) based system is considered for the provision of dedicated aeronautical communication services for the airport surface level [8]. The common short list of technologies recommended for further evaluation through prototype developments was approved by ICAO in April 2008 [9]. Gilbert et al. in [10] provides details regarding evaluation of IEEE Std 802.16-2009 for the airport surface.

This paper provides further details on how AeroMACS can meet the short- and long-term demands for improved airport surface communications and what it would take to facilitate a typical AeroMACS deployment in airports.

2.0 AeroMACS Network Reference Model

AeroMACS Bandplan

At the International Telecommunications Union World Radio-communication Conference held in late 2007 [5], agenda item 1.6 invited participants "to consider allocations for the aeronautical mobile route service (AM[R]S) in parts of the bands between 108 MHz to 6 GHz, and to study current frequency allocations that will support the modernization of civil aviation telecommunication systems." At the conclusion of WRC-07, a new AM(R)S co-primary allocation in the 5091 to 5150 MHz band was added to the International Table of Frequency Allocations (see Figure 1). The new allocation is limited to surface applications at airports. This allocation is in a region of the frequency spectrum commonly referred to as C-band.

This specific 59 MHz of spectrum is also referred to as the Microwave Landing System (MLS) extension band. MLS carries an aeronautical radio navigation services (ARNS) allocation. The WRC-07 decision on agenda item 1.6 essentially removed the prior limitation for support of ARNS only. Along with the existing MLS and new AeroMACS services, the other co-primary service allocations in this band include Earth-to-Space satellite feeder links for non-geostationary orbiting (GSO), mobile satellite service (MSS), and new co-allocations for aeronautical mobile telemetry (AMT) used with research aircraft during test flights and an aeronautical mobile service (AMS) limited to aeronautical security (AS). The AM(R)S communications are defined as safety communications requiring high integrity and rapid response. AeroMACS services can be provided to an aircraft anywhere on the airport surface, as long as wheels are in contact with the surface. AeroMACS can also be used for communications with a variety of service vehicles and airport infrastructure components that directly support safety and regularity of flight. The protected allocation for AM(R)S in this portion of C-band enabled ICAO to approve international standards for AeroMACS wireless mobile communications networks on the airport surface. Based on the expectation of high demand for AeroMACS services, additional allocation of AM(R)S spectrum within the 5000 to 5030 MHz band may be considered nationally (see Figure 1). According to the AeroMACS profile [1][2], channel bandwidth is 5 MHz.

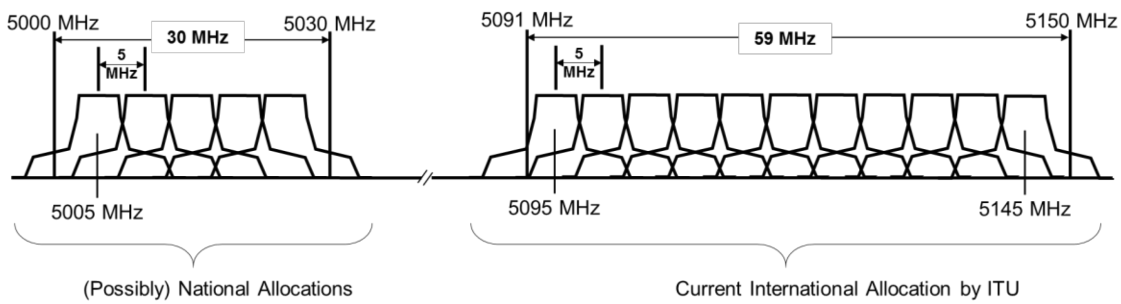


Figure 1: AeroMACS Channels Are Defined across 5000-5150 MHz of which 5091-5150 MHz Was Internationally Allocated by ITU in 2007

Network Architecture

To define the system performance requirements and outline possible implementation options (e.g. architectures and use cases) for AeroMACS, EUROCAE has released Minimum Aviation System Performance Specification (MASPS) [2], incorporating WiMAX Forum® inputs such as the Network Reference Model (NRM).

As shown in Figure 2, the NRM is a general, logical representation of the network architecture including AeroMACS based on Mobile WiMAX Release 1 [7]. The NRM identifies functional entities and reference points over which interoperability is achieved between functional entities. Each of the entities (i.e. SS, ASN, and CSN) represents a grouping of functional entities. Each of these functions may be realized in a single physical functional entity or may be distributed over multiple physical functional entities. While the grouping and distribution of functions into physical devices within the ASN is an implementation choice, the AeroMACS architecture specification defines one ASN interoperability profile. Figure 3 shows some details of ASN and CSN reference models.

The purpose of the NRM is to allow multiple implementation options for a given functional entity, and yet achieve interoperability among different realizations of functional entities. Interoperability is based on the definition of communication protocols and data plane treatment between functional entities to achieve an overall end-to-end function, for example, security or mobility management. Thus, the functional entities on either side of Reference Point (RP) represent a collection of control and bearer plane end-points. In this setting, interoperability will be verified based only on protocols exposed across an RP, which would depend on the end-to-end function or capability realized.

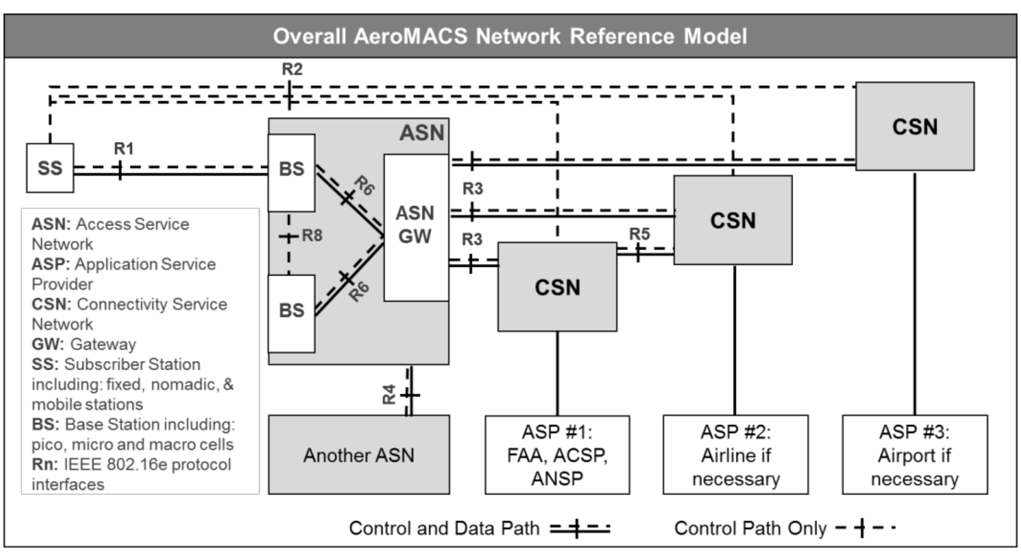


Figure 2: Overall Network Reference Model

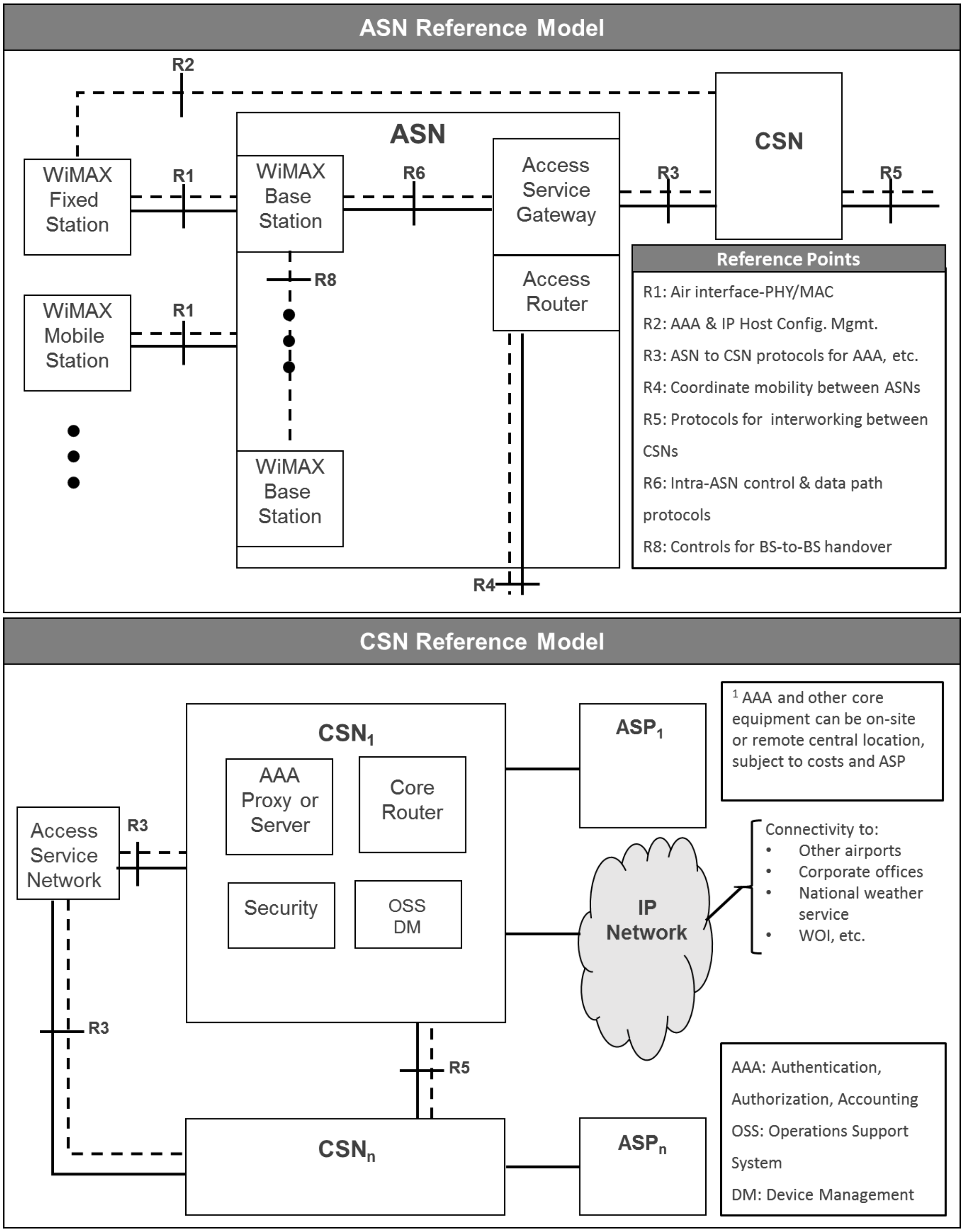


Figure 3: Detailed AeroMACS ASN and CSN Reference Model

AeroMACS Air Interface

The protocols and parameters associated with the R1 interface (air interface) are key to understanding and assessing the performance of the AeroMACS network based on WiMAX under the following conditions:

Channel BW	5 MHz
Duplex	Time Division Duplex (TDD)
Permutation	Partially Used Sub-Channel (PUSC), 360 Data sub-carriers in the DL and 272 Data sub-carriers in the UL
DL to UL Ratio	21 Symbols DL and 20 Symbols UL is assumed for this analysis[1]

Other considerations and factors impacting the link budget and channel capacity are:

Uplink

- Subscriber stations (SS) will be deployed with low gain omnidirectional antennas with anticipated gain of 6 dBi.
- Aggregate interference to non-GSO satellite uplinks must not exceed a threshold corresponding to a 2% increase in noise temperature at the satellite receiver. Aggregate interference takes into account the impact of AeroMACS transmissions from all SSs in view of the satellite receiver.
- EIRP limitations must be consistent with human safety exposure limitations (<1 mw/sq-cm).
- SS EIRP is limited to 30 dBm [2] in Runway and Taxiway areas and to 26 dBm in gate areas with single or multiple antennas.
- Per [2], AeroMACS requirements MCS 16QAM-3/4 to QPSK-1/2 with 2 repetitions.
- Multiple antennas (MIMO) are not always easy to implement with all SSs.

Downlink

- It can be assumed base stations (BS) will be pointing at or below the horizon. This is essential to ensure that the aggregate interference from AeroMACS BSs to non-GSO satellite uplinks does not exceed the noise threshold, as described above.
- Per [2], the maximum EIRP shall not exceed 39.4 dBm.
- 64QAM-3/4 to QPSK-1/2 with 2 repetitions.

The link budget in the DL and UL directions includes allowances for fade and interference margins to arrive at the maximum allowable path loss. The interference margin assumes a frequency reuse factor of 3. The corresponding link budgets for the two airport domains are summarized in Table 1.

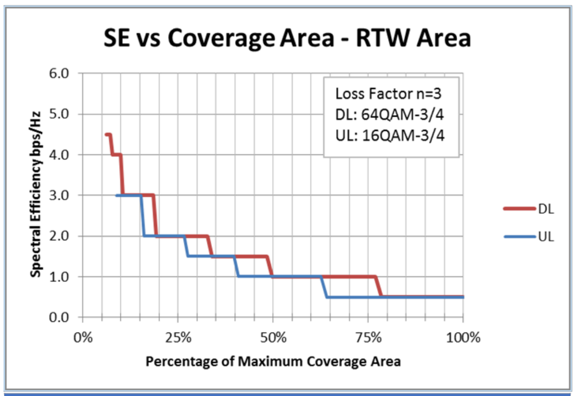
Table 1: Downlink and Uplink Link Budget

Airport Area	DL Link Budget	UL Link Budget
Runway/Taxiways	130.7 dB	129.5 dB
Gate/Ramp Areas	130.7 dB	125.5 dB

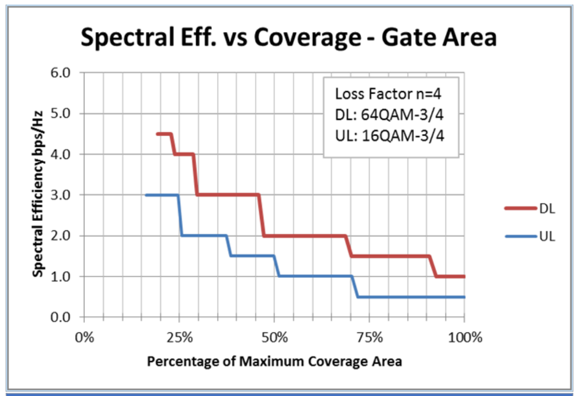
[1] AeroMACS supports variable DL to UL symbol ratios to accommodate asymmetric traffic which is expected to be more dominant in the DL direction.

It is important to note that the UL link budget does not consider authorized airport personnel with hand-held AeroMACS devices which would be equipped with a lower gain antenna and lower EIRP resulting in a 7 dB to 10 dB lower link budget. Although this is not considered a priority use case, it certainly can be expected to take place for data and voice communications from time to time. These devices will still have connectivity most of the time given the assumed fade margin and support for up to 6 HARQ repetitions. The ability to move for a better connection will also be an aid when a reliable connection is required.

Figure 4 illustrates the modulation and coding scheme (MCS) supported by AeroMACS as a function of the coverage area. The range and coverage area is determined by the UL link budget and since the link budget is higher in the DL direction, subscriber stations at the cell edge will experience a higher over-the-air (OTA) spectral efficiency (SE) or, as in the case of runway taxiway areas, a slightly higher margin. The asymmetric allocation of data sub-carriers with PUSC results in a DL to UL OTA rate of more than 2:1 in the gate areas and 1.75:1 in the runway and taxiway areas. The anticipated payload for AeroMACS, with the aircraft dominating the channel loading, is expected to be biased to the DL direction.



	Data Symbols	Sub-carriers	Peak OTA Rate	Average OTA Rate
DL	21	360	6.80 Mbps	2.46 Mbps
UL	20	272	3.26 Mbps	1.41 Mbps



	Data Symbols	Sub-carriers	Peak OTA Rate	Average OTA Rate
DL	21	360	6.80 Mbps	4.04 Mbps
UL	20	272	3.26 Mbps	1.67 Mbps

Figure 4: Spectral Efficiency and Over-the-Air Data Rate

3.0 Applications for AeroMACS

AeroMACS based on the Mobile WiMAX standard can potentially support a wide variety of voice, video, and data communications and information exchanges among fixed and mobile users at the airport. This wideband communications network can enable sharing of graphical data and near real-time video to significantly increase situational awareness, improve surface traffic movement to reduce congestion and delays, and help prevent runway incursions. AeroMACS can reduce the cost of connectivity in comparison to underground cabling. A broadband wireless communications system like AeroMACS can enhance collaborative decision-making, ease updating of large databases and loading of flight plans into flight management system (FMS) avionics, and enable aircraft access to system wide information management (SWIM) services for delivery of time-critical advisory information to the cockpit.

The services and applications provided by AeroMACS can be grouped into three major categories: aviation authority operations, airport and/or port authority operations, and airline carrier operations (see Figure 5). Within these broad categories, the data communications services and applications can be described as either fixed or mobile, based on the mobility of the end user.

Figure 5: Examples of AeroMACS Applications

Applications for Aviation Authorities

Some ATC/ATM mobile applications have been identified:

- Messages that are currently conveyed over the aircraft communications addressing and reporting system (ACARS) (e.g., pre-departure clearance [PDC]).
- Controller pilot data link communications (CPDLC) messages (e.g., 4-dimensional trajectory negotiations [4D-TRAD]).
- COCR services (e.g., surface information guidance [D-SIG]).
- Other safety-critical applications (e.g., activate runway lighting systems from the cockpit [D-LIGHTING]).

Potential fixed infrastructure applications include:

- Navigation (e.g., instrument landing system data for glide slope and visibility data for runway visual range)
- Surveillance (e.g., airport surface movement detection and airport surveillance radar [ASR]).

AeroMACS can also be used to convey electronic equipment performance data for remote maintenance and monitoring (RMM).

Applications for Airports and Port Authorities

The airport or port authority operations are dominated by video applications required for safety services (e.g., fixed surveillance cameras and in-vehicle and portable mobile cameras for live video feeds and voice communications with central control during snow removal, de-icing, security, fire, and rescue operations). AeroMACS can also help ensure compliance with regulations for safety self-inspection (e.g., reporting status of airport runway and taxiway lights and monitoring and maintenance of navigational aids and time critical airfield signage).

Many of these services and applications are currently provided to mobile users through a mix of VHF voice and data links, land mobile radio services, and commercial local area wireless networks. The fixed communications services and applications at airports are typically implemented via buried copper and fiber optic cables. AeroMACS offers the potential for integration of multiple services into a common broadband wireless network that also securely isolates the applications from each other. The first safety-critical application expected to migrate to AeroMACS in the U.S. is airport surface detection equipment model X (ASDE-X). For ASDE-X, AeroMACS provides wireless interconnection of multilateration (MLAT) sensors distributed across the airport surface. MLAT data is combined with surface movement radar data and aircraft transponder information to display detailed information about aircraft position. The deployment of AeroMACS infrastructure at an airport to enable the migration or augmentation of one of more existing services opens the potential for many additional services, especially those that require wider bandwidth, such as graphical information delivery and video services.

Applications for Airline Carriers

Mobile AIS/MET services have the potential to become significant drivers of AeroMACS design because of several high-volume data base synchronization services that would benefit from AeroMACS implementation. These include:

- The AIS baseline synchronization service (e.g., uploading flight plans to the FMS and updating terrain and global positioning satellite [GPS] navigational databases and aerodrome charts to electronic flight bag [EFB]).
- Data delivery to the cockpit (e.g. data link aeronautical update services (DAUS), and airport/runway configuration information [D-OTIS]).
- Convective weather information (e.g., graphical forecast meteorological information and graphical turbulence guidance [GTG] data and maps).

Additional applications that can be implemented over AeroMACS include:

- Ground operations and services (e.g., coordination of refueling and deicing operations).
- Sharing of maintenance information (e.g., offload of flight operational quality assurance [FOQA] data).
- Aircraft and company operations (e.g., updates to flight operations manuals and weight and balance information required for takeoff).

4.0 Airport Deployment Considerations

From the perspective of an airport operator, an important consideration is what will it take to deploy an AeroMACS network; that is: how many bases stations or base station sectors are needed to achieve ubiquitous coverage over the airport surface and how many channels are needed to meet the capacity requirements? An airport can cover a fairly wide geographical area, and over the entire area there will be varied propagation characteristics and varied capacity requirements. In general, one can expect cells comprised of 1, 2, or 3 sectors and a combination of: macro-cells where coverage is a key driver, micro-cells where capacity is the primary objective, and pico-cells to provide coverage in areas that are heavily shadowed. Nomadic vehicular-installed base stations can also play an important role in the event of an emergency or a base station equipment outage.

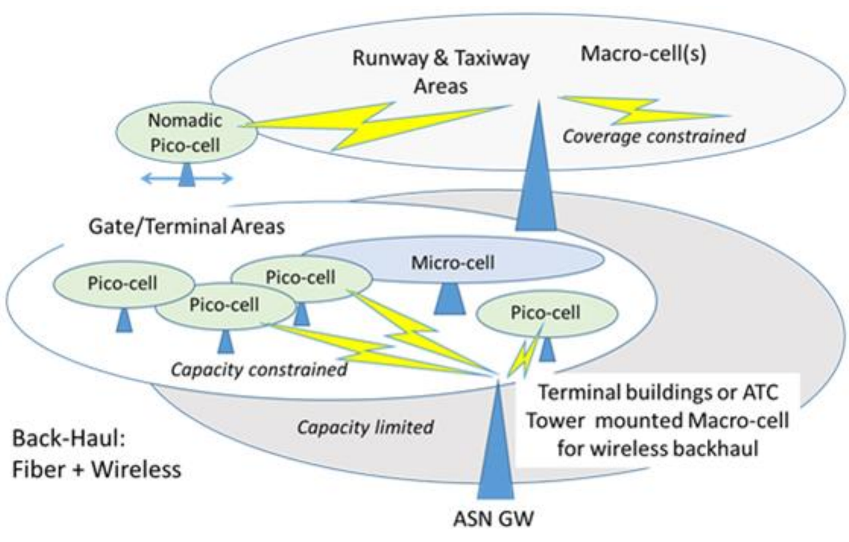


Figure 6: A large airport has varied BS requirements for coverage and capacity

Runways and Taxiways

Every airport has one or more runways that must be long enough to handle the largest aircraft flying into or out of that airport. The airport also has taxiways connecting the runway to the gate or ramp area where passengers board and un-board the aircraft. Large or small runways and taxiway areas generally dominate the total airport area. Runways and taxiways are generally wide open areas with the only objects being the aircraft and some ground-handling equipment (GHE). It is safe to say that from a wireless perspective these areas are "propagation-friendly." The primary difference between airports classified as large hubs versus those classified as small hubs would be the number of aircrafts in the taxiways at any given time. The busiest hubs handle more than 50 takeoffs plus landings per hour resulting in the presence of several aircrafts navigating the taxiways at any given time. Traffic at a small rural airport, on the other hand, may be no more than one or two arriving or departing aircrafts per hour.

Another consideration for a wireless access deployment is base station antenna heights and base station locations. Runway/taxiway areas will not accommodate high cellular-like towers, and base station locations will be limited to areas that will not obstruct aircraft. A further consideration is the fact the aircraft are in motion. This, in many cases, results in fast fading due to multipath variations, and the moving aircraft will undergo base station to base station handoffs between the runway, taxiway, and the gate areas.

Gate and Ramp Areas

Airport gate areas present a more challenging environment from a propagation perspective. The presence of terminal buildings, airport offices, and a higher density of aircraft, jet-ways, and GHE create considerable propagation obstacles. Fortunately, the terminals themselves will serve as a reasonably high location for mounting base station equipment. Once an aircraft has arrived at the gate, it is stationary so BS to BS handoffs are not an issue.

Based on these general characteristics, we can arrive at some propagation models to provide pre-deployment estimates for range and coverage in order to gain a perspective as to what a deployment might look like for any given airport. Obviously more detailed RF planning and site surveys will be necessary for a more detailed analysis, but the following can provide a reasonable, close projection.

Range, Coverage, and Capacity Estimates

In designing the network, we are concerned with both coverage and capacity requirements. The goal for coverage is to ensure that an aircraft or ground vehicle servicing the aircraft has the ability to connect to the AeroMACS network wherever it is located on the airport surface. The gate areas will be more congested with closely spaced aircrafts and GHE so capacity will generally be the key driver for channel requirements.

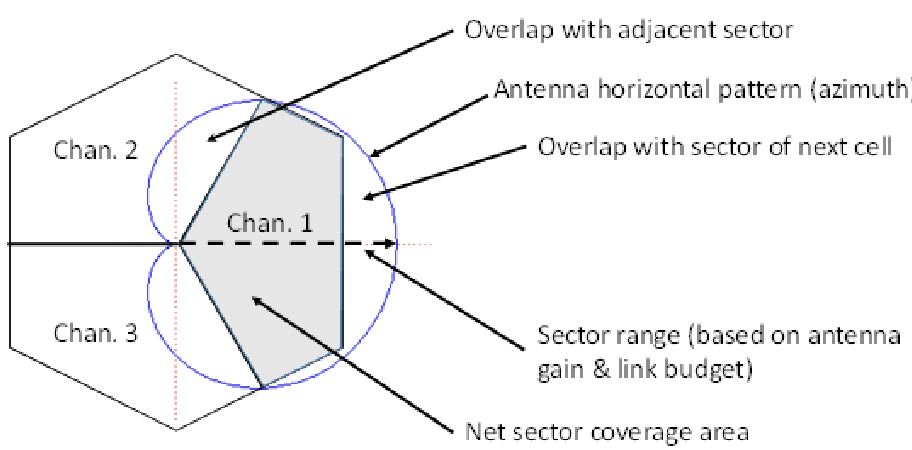


Figure 7: Sector or Channel Coverage for 15 dBi BS Sector Antenna

Figure 7 shows the relationships between range and channel coverage for a typical sector antenna pattern. The overlap between sectors of the same cell and sectors in adjacent cells ensures SSs at the sector-edge or cell-edge have access to an alternate channel in the event of a deep fade with its primary channel.

Based on general airport characteristics, we propose a simplistic path loss model to account for propagation loss in the excess of free space loss, which is 20 dB per decade. The proposed path loss for the airport environment is described by the following equation:

$$PL = 20Log\left(\frac{4\pi d}{\lambda}\right) + 10nLog(D/d)$$

Where:

λ is the wavelength at 5150 MHz = 0.058 m

d is selected to be 100 m (this implies that subscriber stations within 100 meters of the base station are Line of Sight (LoS)

D is the path length $>d$ and

n is a value >2 defining the excess path loss at path lengths >100 m

In practice, the value of n will be a function of relative antenna heights for the SS and BS and the density of obstacles between the BS and the SS that are in a position to impede the signal.

The following table summarizes the expected range and sector coverage for the link budgets shown in Section 3 and the projected propagation loss, value of n, for the different airport areas. For the gate areas, rather than use coverage area, we use the number of gates that a sector will cover based on an average gate spacing of 80 to 120 meters. This is a more meaningful metric for gate area coverage since we are most interested on capacity for the gate areas.

Table 2: Estimated Range and Coverage

Airport	Propagation Loss	Expected Range	Sector Coverage
Large Airport's Runway/Taxiways	~30 dB/decade	~2.5 km	~5.4 sq-km (540 ha) *Assume ~500 ha to account for sub-optimal site location
Large Airport's Gate/Ramp Areas	~40 dB/decade	~0.95 km	7-9 gates/sector
Small Airport's Runway/Taxiways	Between 20 and 30 dB/decade	~3 km	~7.8 sq-km (~780 ha) *Assume ~700 ha to account for sub-optimal site location
Small Airport's Gate/Ramp Areas	Between 30 and 40 dB/decade	~1.5 km	10-12 gates/sector

The DL and UL over-the-air (OTA) rate is shown in Figure 4 in Section 3. To determine the net payload or goodput that can be delivered per channel, it is necessary to take into account the higher layer overhead. This is a function of payload size, the transport layer format, and IP version as shown below. These estimates include neither the benefit of payload header suppression (PHS), which is a required feature for AeroMACS, nor added OH due to encryption. In this regard, AES-128 is required for AeroMACS.

Table 3: MAC and Higher Layer Overhead

Payload	UDP/IPv4	UDP/IPv6	TCP/IPv4	TCP/IPv6
190 Bytes	13.3 %	20.7 %	17.9 %	24.5 %
1900 Bytes	1.94 %	2.95 %	2.55 %	3.55 %

Table 4: Average Goodput per Channel (Sector)

Airport Area	Characteristics	Time for Data Transfer	Net Avg. Payload per Channel over the duration of the transfer period	
			DL	UL
Runway/Taxiways	Only a few aircraft per channel 190 Byte avg. payload [2]	3-5 min	>44 MB	>25 MB
Gates/Ramp Areas	Up to 8 aircraft + GHE per channel 1900 Byte payload [2]	30 min or more	>880 MB >110 MB/Gate	>365 MB >45 MB/Gate

5.0 Phased Infrastructure Deployment for AeroMACS

It is important to note that several airport test beds and trials that have been underway have clearly demonstrated the viability of AeroMACS based on WiMAX technology. That said, we believe that AeroMACS is clearly ready to begin commercial deployment in selected venues. Many factors ranging from economic to regulatory will enter into the timing for an AeroMACS deployment that will differ from airport to airport, case by case, and country by country. For our purposes, we define three specific deployment phases[2] as described in Figure 8.

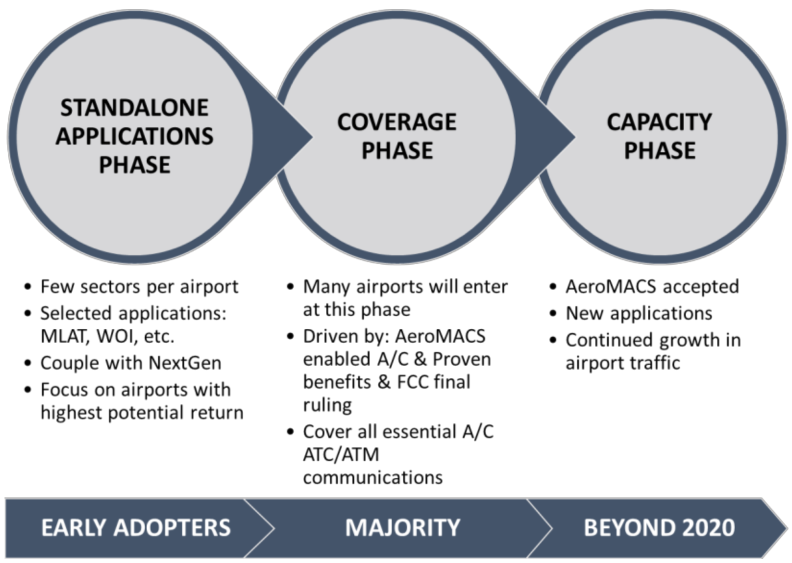


Figure 8: Phased deployment

Standalone Applications Phase

This phase describes a limited AeroMACS base station deployment at select airports driven by communication requirements necessary for the implementation of specific applications identified as having an immediate benefit to air transportation at that particular airport.

[2] This concept is similar to that encountered with any new technology adoption model or lifecycle, which begins with "innovators" and "early adopters," followed by the "early and late majority," and finally, the "laggards."

The Next Generation Air Transportation System [11], known as NextGen in the US, is a key congressionally-supported FAA program aimed at improving air transportation by increasing capacity and reliability, improving safety and security, and minimizing environmental impact. AeroMACS will be a key component for NextGen in managing the traffic on the airport surface.

Installing AeroMACS cells at specific airports to provide communication links to airport multilateration sites and weather observation improvement sites are two important standalone applications that can drive early AeroMACS deployments and ties into the NextGen program. The NextGen program will focus on 40-50 of the busiest airports for MLAT applications and probably more than 1,000 airports for WOI. Additionally, specific airports may have other applications for improved airport operational efficiencies that may be enabled with AeroMACS.

While it does not necessarily provide coverage over the entire airport surface, it is prudent during this phase to do a complete site survey and RF planning exercise to ensure base stations deployed during this phase are installed in locations closely aligned with what will be necessary for the next phase, which is designed to provide total coverage.

Coverage Phase

The goal in this phase is to deploy sufficient base stations to ensure that an AeroMACS-equipped aircraft or ground vehicle would have a viable network connection anywhere on the airport surface.

As aircrafts and GHE become AeroMACS-enabled and present-day communications system get more congested, there will be increased motivation to deploy base station infrastructure at more and more airports with ubiquitous coverage. The goal is to enable an aircraft upon landing at an airport and slowed to 50 nmi per hour[3] to gain connectivity to the AeroMACS network and continue connectivity anywhere it may be located on the airport surface, including the gate area to the time when it has reached 50 nmi per hour prior to takeoff. At a minimum, AeroMACS in this phase would provide connectivity for all Air Traffic Control (ATC) and Aeronautical Operational Control (AOC) data, data that is now handled by the current Aircraft Communications and Addressing Reporting Systems (ACARS). The majority of the communications will take place when the aircraft is positioned at the gate, as shown in Figure 9[4]. Additional applications during this phase may also include:

- Moving map (video) display of airport with runway incursion alert
- D-Taxi
- Graphical weather
- Navigational database & flight chart to aircraft (UL)
- Engine performance & FOQA (flight recorder data) (DL)
- NOTAMs (both textual & graphical)
- PDC & Digital ATIS

[3] 1 nautical mile (nmi) is equal to 1.15 statute miles, therefore 50 nmi/hr = 57.5 mi/hr

[4] Source of image in Figure 9, Lufthansa

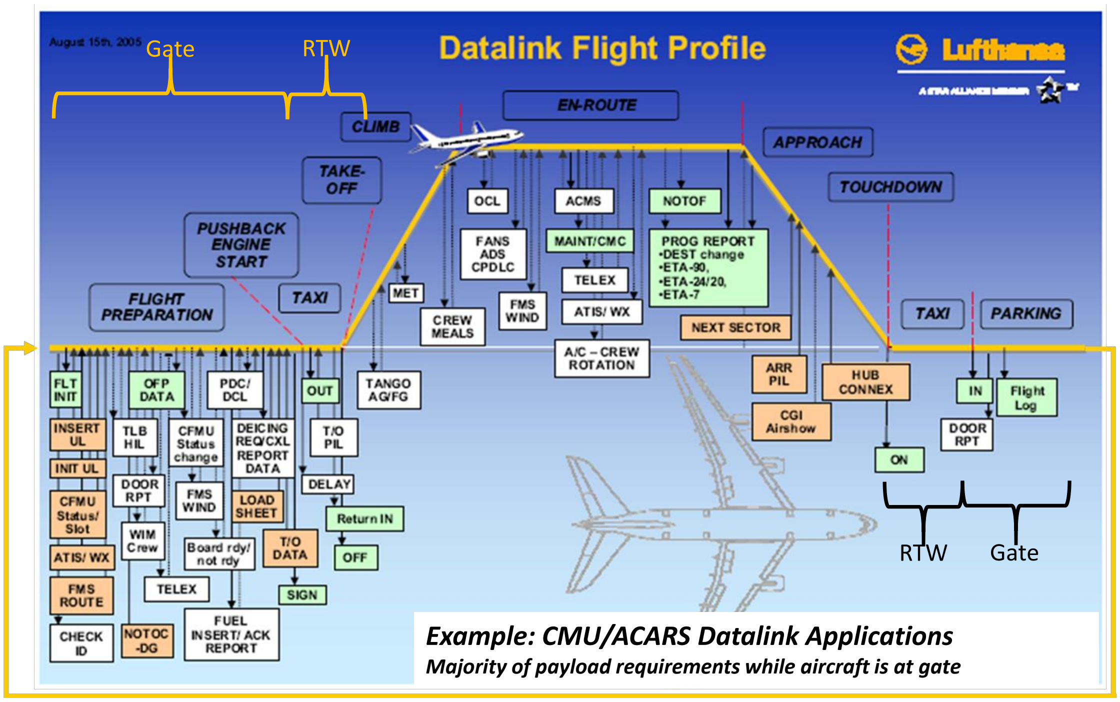


Figure 9: ACARS Datalink Applications

With no more than 8 gates per channel, there will likely be sufficient capacity for several years. We do expect, however, the many new applications will emerge. These new applications along with increases in air transportation traffic may, in the future, necessitate added capacity.

Capacity Phase

The "Capacity Phase" describes an on-going phase to add network capacity as driven by continued growth in air traffic and growth in new applications that can be supported by AeroMACS. When it is necessary to increase network capacity, it will most likely be in the gate area rather than in runway/taxiway areas. One of two approaches can be adopted for increasing capacity when needed. One approach is to simply add channels to existing base stations in the gate areas. The channel addition drops the number of gates per channel from 8 to 4 thus doubling the available goodput per gate in both the DL and UL directions.

The second approach is to deploy additional base stations between the existing terminal-mounted base stations. As with the first approach, this will also reduce the gate count per channel by a factor of two. Reducing the base station transmit power helps mitigate potential cell to cell co-channel interference with the more closely spaced base stations. If the subscriber station power is maintained at about the same level, this approach will lead to a greater goodput increase in the UL than in the DL.

With the eleven 5 MHz channels available in the primary AeroMACS frequency band and five additional channels potentially available in the 5000-5030 MHz band, there is a sufficient number of channels to maintain a conservative frequency reuse for interference management while increasing capacity 2 times and even 4 times.

Coverage Requirements for a Range of US Airports

It is of interest to look at what the base station or sector requirements would be for some representative US airports to achieve the required coverage. The size and US rank in Table 5 refer to the number of passengers annually based on 2011 data. It is important to remind the reader that these are simply estimates based on what is felt to be a conservative propagation model for a typical airport environment.

Sectors, equivalent to channels, are used as the key infrastructure metric since not all base station sites will be deployed with the same number of sectors. The areas quoted in the following table come from different sources and may not always be consistent in what the area represents. Minimal AeroMACS requirements require runways, taxiways, and gate areas to be covered, whereas the quoted geographical areas may include airport areas where coverage is not required. The number of runways are included in the table as a point of reference and it is safe to assume that at least one sector per runway would be necessary for coverage. The gate numbers should be quite accurate and as can be seen with the busiest airports the sector requirements for the gate areas, at 8 gates per sector, dominate.

Table 5: Estimated Airport Deployment Requirements

Airport	Size-US Rank	Number of Gates	Number of Runways	Area	Estimated Sectors
ATL	LH-1	207	5	1902 ha	26 + 5 = 31
DFW	LH-4	160	7	4360 ha	20 + 7 = 27
IAD	LH-23	131	4	2255 ha	17 + 5 = 22
PDX	MH-30	59	2	~1500 ha	8 + 4 = 12
SAT	MH-45	24	2	1050 ha	3 + 3 = 6
OKC	SH-63	17	3	<1200 ha	2 + 3 = 5
AMA	SH-138	6	2	<1500 ha	1 + 4 = 5

6.0 AeroMACS Benefits

In addition to the obvious cost savings in not having to support and supplement today's out-of-date airport communications systems, there will be significant long-term benefits arising from the implementation of the next generation communications system for the airport surface, AeroMACS.

Airport Traffic Management

With continual growth in aircraft traffic, there will be increasing challenges in managing the flow of aircrafts and GHE on the airport surface to minimize the potential for flight delays, maintain safety standards, and minimize the time an aircraft spends on taxiways waiting for takeoff clearance or for a gate to clear.

Traffic management requires communications that are reliable, are accurate, and ensure the right message is delivered to the right aircraft in a timely fashion. In the previous sections, we have shown that AeroMACS will have considerable channel payload capacity. In addition to capacity, AeroMACS supports Quality of Service (QoS) and Class of Service (CoS), two additional attributes necessary to reliably meet future airport surface communications requirements.

QoS enables packet prioritization to ensure that mission-critical, latency-sensitive messages gain priority access to the communications channel over lower priority messages. With aircraft and GHE maneuvering taxiways at relatively high speeds with BS to BS hand-offs, QoS is essential to ensure reliable data link connectivity. CoS ensures the aviation authority, the airport operator, and the airline carrier all have access to sufficient capacity to meet their individual priority application requirements.

AeroMACS will also provide a greater reliance on data, graphic, and video communications to screen displays on the flight deck with less dependency on voice communications as is prevalent today. Over the long-term with AeroMACS, voice communication will be "only by exception" rather than the rule.

With more accurate and timely messaging, AeroMACS can play a key role in enhancing airport traffic management to reduce "Taxi-out Times[5]" thus reducing runway/taxiway congestion and significantly reducing the number of flight delays.

[5] 'Taxi-Out Time' is defined as the time duration between aircraft gate departure and aircraft takeoff.

Airport Safety and Security

With the channel capacity provided by AeroMACS, video surveillance can be expected to play an ever-increasing role for safety enhancements and for added support to airport security measures. Video surveillance information linked with accurate surface location data for GHE and aircrafts on the airport surface will be essential for avoiding mishaps as airport traffic congestion increases.

For example, runway incursions are occurring at an alarming rate. PHAK (Pilots Handbook of Aeronautical Knowledge) Appendix 1 [12] states:

> *"Runway incursions are a serious safety concern and have involved air carrier aircraft, military aircraft, general aviation (GA), and pedestrian vehicles", it goes on to say, "Approximately three runway incursions occur each day at towered airports within the United States."*

With the ability to provide the pilot and air traffic controllers with a clear visual display of runway conditions and a reliable communications link to traffic that might be in the wrong place at the wrong time, AeroMACS can play an important role in reducing runway incursions and more importantly eliminate the potential for these incursions that result in a serious and possibly fatal outcome.

Finally, we must also be mindful of the continued threat of unauthorized personnel or vehicles on the airport surface, whether they are there by accident, intending no harm, or are there for more destructive purposes, they must be detected and dealt with accordingly. Video surveillance is supported by AeroMACS and will be an important capability leading to enhancements to airport safety and security.

7.0 Summary

Much work has been done over the past several years to define the requirements for a new airport surface communications system. AeroMACS, based on IEEE Std. 802.16-2009 [6] and Mobile WiMAX profile release 1.0 [7], operating in the 5 GHz band has been identified as a solution that meets those requirements.

The applications envisioned for AeroMACS are extensive and cover the essential requirements for:

- Aviation Authorities (FAA, EUROCONTROL, etc.)
- Airports (airport operator, port authority, TSA, etc.)
- Airline Carriers (passenger and cargo)

In this paper, we have described what a typical airport configuration might look like from a network point of view. And, with a focus on the air interface, we have provided details on projected range, coverage, and channel capacity for the different airport domains:

- Runway/taxiway areas
- Gate/ramp areas

These two domains have different propagation characteristics and different requirements and hence require different considerations for an AeroMACS deployment.

A phased deployment approach has been discussed that could serve as a cost-effective implementation framework for AeroMACS at many airports. While many short-term benefits can be realized in the Standalone Applications Phase, the full complement of benefits will only be realized as airports complete the Coverage Phase, which ensures aircrafts and GHE have connectivity anywhere they may be located on the airport service.

The long-term benefits of AeroMACS will greatly enhance airport traffic management and airport safety and security.

8.0 References

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