AeroMACS Deployment & Integration Analysis

Document information	
Project Title	Airport Surface Datalink
Project Number	15.02.07
Project Manager	Indra
Deliverable Name	AeroMACS Deployment & Integration Analysis
Deliverable ID	D04
Edition	00.02.00
Template Version	03.00.00
Task contributors	
AENA, Indra, Thales, Selex, Eurocontrol, DSNA, Airbus, NATMIG.	

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Abstract

This document as part of SESAR P15.2.7 provides general guidelines on how to deploy AeroMACS at the airport surface, taking into consideration several constraints we can find in order to make the deployment as easier and cheaper as possible, within the requirements to provide safety critical and regularity of flights services. Aspects such as cell planning, interference, integration with ATM network and interoperability will be addressed.

Authoring & Approval

Prepared By - *Authors of the document.*		
Name & Company	Position & Title	Date
[redacted] AENA	[redacted]	21/09/2012
[redacted] AENA		21/09/2012
[redacted] AENA		21/09/2012

Reviewed By - *Reviewers internal to the project.*		
Name & Company	Position & Title	Date
[redacted] INDRA	[redacted]	21/09/2012
[redacted] SELEX		21/09/2012
[redacted] THALES		21/09/2012
[redacted] NATMIG		21/09/2012
[redacted] AIRBUS		21/09/2012
[redacted] AENA		21/09/2012
[redacted] DSNA		21/09/2012
[redacted] EUROCONTROL		21/09/2012

Reviewed By - *Other SESAR projects, Airspace Users, staff association, military, Industrial Support, other organisations.*		
Name & Company	Position & Title	Date
[redacted] EUROCAE WG-82	[redacted]	21/09/2012

Approved for submission to the SJU By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
[redacted] INDRA	[redacted]	21/09/2012
[redacted] AENA		21/09/2012
[redacted] THALES		21/09/2012
[redacted] NATMIG		21/09/2012
[redacted] AIRBUS		21/09/2012
[redacted] SELEX		21/09/2012
[redacted] DSNA		21/09/2012
[redacted] EUROCONTROL		21/09/2012

Rejected By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date

Rational for rejection
None.

Document History

Edition	Date	Status	Author	Justification
00.00.01	17/01/2012	DRAFT	AENA	First edition

00.00.02	13/02/2012	DRAFT	AENA	Comments integrated
00.00.03	09/03/2012	DRAFT	AENA	Comments integrated
00.00.04	16/03/2012	DRAFT	AENA	Comments validated
00.00.05	10/04/2012	DRAFT	AENA	Comments validated
00.00.06	20/07/2012	DRAFT	AENA	Second edition
00.01.00	21/09/2012	FINAL	AENA	Final review
00.02.00	22/04/2014	FINAL	INDRA	Correction of IPR statement to "Deliverable consist of SJU foreground". No other changes with respect to version 00.01.00

Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

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Executive summary

SESAR P15.2.7 intends to develop a new system and certification profile for the specification of features to be implemented in future datalink for airport surface services. Such defined AeroMACS profile needs to address the support of each of these features based on the specification of the IEEE 802.16e-2005/802.16-2009 standards, as Eurocontrol and FAA have jointly recommended [AP17 Final Report and recommendations]. In order to be compliant with existing certification methodologies and processes, AeroMACS is derived from the system profile defined by WiMAX ForumTM, industry-led organization which aims interoperability and compatibility of IEEE802.16 based products.

Following the recent WRC2007 outcome, this new communication system should operate in dedicated aeronautical spectrum in the so called C –band. The considered spectrum is located between 5091 and 5150 MHz.

This specification is the result of simultaneously investigating the need for aviation to operate a high data rate link at airport surfaces as well as the requirement for delivering such a link in the most cost effective way (IEEE802.16-2009 based).

There are two projects in SESAR addressing AeroMACS's definition: project P15.2.7 and project P9.16. Project P15.2.7 addresses the overall system aspects and focuses on the ground component development whereas project P9.16 focuses on the mobile component.

This work will feed the EUROCAE group WG82 that has been formed to define the required aviation specifications.

An equivalent to the EUROCAE WG82 group has been set up in US by RTCA (SC223) and it has been agreed that a jointly developed profile will be drafted.

After both EUROCAE and RTCA have finalised the common AeroMACS profiles, further standardisation of AeroMACS is scheduled to take place under ICAO WG-S as well as the AeroMACS ad hoc working group created by the WMF, named Aviation Working Group (AWG).

This document is the deliverable of the WA4 "Deployment and Integration Analysis" within SESAR 15.2.7 Project and it covers guidelines on how to deploy AeroMACS at the airport surface, taking into consideration several constraints we can find in order to make the deployment as easier and cheaper as possible, within the requirements to provide safety critical and regularity of flights services.

1 Introduction

1.1 Purpose of the document

This document as part of SESAR P15.2.7 provides general guidelines on how to deploy AeroMACS at the airport surface and its integration with other ATM networks and systems, taking into consideration several constraints we can find in order to make the deployment as easier and cheaper as possible, within the requirements to provide safety critical and regularity of flights services. Aspects such as cell planning, interference, integration with ATM network and interoperability will be addressed.

Section 2 of the document, "Overview of AeroMACS Requirements", will review the main RF characteristics and requirements of the AeroMACS system and the major operational requirements that help to understand the rationale for system characteristics, operational goals, requirements and workout of AeroMACS datalink, in order to extract relevant information to develop the guidelines for the deployment of the system.

Section 3 of the document, "Deployment and Interference Analysis", will provide general rules and guidelines on how to deploy an AeroMACS system in an airport. The different sections will deal with several aspects to take into account, such as airport operational areas, airport layouts, sitting regulations, interference with other systems…, before conducting a capacity and coverage analysis. Rules and requirements for frequency planning, installation and acceptance of BS sites will also be given.

A complete AeroMACS deployment analysis for the particular cases in Barajas and Toulouse airports will be done, added as Case Study 1 and Case Study 2 in annexes A.1 and A.2.

The objective of Section 4, "Integration and Interoperability Analysis", is to derive guidelines on how to install AeroMACS in order to provide connectivity to the ATM network, Airport operator network and AOC servers.

One main task will be to identify the relevant use cases to be considered as it will have an implication on the implementation of the different functions. AeroMACS shall have the ability to mix vendor equipment in the network and be interoperable with legacy and future networks present in the system.

1.2 Intended readership

The AeroMACS Deployment and Integration Analysis document has been developed for technical people, engineers, ANSP and Airport owners interested and/or involved in the development of AeroMACS systems.

The document is also of interest to both ATC and AOC operational staff or other 3rd party entities, such as NSP, as it provides detailed information on the different services, functionalities and traffic patterns AeroMACS will be supporting.

1.3 Background

The following documents have been used as reference material

- SESAR 15.2.7 T1.1A **"System Analysis For AeroMACS Use"**
- SESAR 15.2.7 T1.1B **"AeroMACS System Requirements Document"**
- SESAR 15.2.7 T1.2/T1.3 "**AeroMACS Profile Analysis**"

- SESAR 15.2.7 T2.6 “**AeroMACS Traffic Modelling**”
- SESAR 15.2.7 T2.1 “**AeroMACS Channel Modelling**”
- SESAR 15.2.7 D2.3 “**Compatibility_FSS_AeroMACS**”
- SANDRA : http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&QUERY=0125500f5fe9:165e:0b338978&RCN=92885
- **SANDRA_R6.2.2: Report on Modeling and Performance Simulations (in work).**

1.4 Acronyms and Terminology

Term	Definition
AAA	Authorisation, Authentication and Accounting
AeroMACS	Aeronautical Mobile Airport Communication System
AK	Authorization Key
AMC	Adaptive Modulation and Coding
AMHS	Aeronautical Message Handling System
AMT	Aeronautical Mobile Telemetry
ANSP	Air Navigation Service Provider
ARB	Authoritative Representative Body
AOC	Airline Operational Communication
ARQ	Automatic Repeat Request
AS	Aeronautical Security
ASN-GW	Access Service Network-Gateway
ATM	Air Traffic Management
BB	Base Band
BE	Best Effort Service
BER	Bit Error Ratio
BS	Base Station
BW	Bandwidth
CFMU	Central Flow Management Unit

Term	Definition
CDM	Collaborative Decision Making
COCR	Communications Operational Concept and Requirements
COMT	Eurocontrol COM Team
CONOPS	Concept of Operations
COTS	Commercial of the shelf
DCL	Departure Clearance
DDS	Data Distribution Services
DL	Downlink
DoS	Denial of Service
D-TAXI	Departure Taxi
EAD	European AIS Database
EAP	Extensible Authentication Protocol
E-ATMS	European Air Traffic Management System
EIRP	Effective isotropic Radiated Power
EUROCAE	European Organisation for Civil Aviation Equipment
FAB	Functional Airspace Block
FCI	Future Communication Infrastructure
FFS	For Future Study
FMTP	Flight Message Transfer Protocol
FOQA	Fligt Operations Quality Assurance
H-ARQ	Hybrid Automatic Repeat Request
HMI	Human Machine Interface
IP	Internet Protocol
IPsec	Internet Protocol security
ITU-R	International Telecommunication Union – Radio Communications
KEK	Key encryption Key
LOS	Line of Sight

Term	Definition
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MLS	Microwave Landing System
MPLS	Multiprotocol Label Switching
MS	Mobile Station
MTOW	Maximun Takeoff Weight
NAP	Network Access Provider
NET	Network Management Service
NLOS	Non Line of Sight
NSP	Network Service Provider
PENS	Pan European Network Services
PKM	Privacy Key Management Protocol
QoS	Quality of Service
RF	Radio Frequency
rtPS	Real Time Polling Service
RX	Receiver
SA	Security Association
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SNR	Signal to Noise Ratio
SPR	Safety and Performance Requirements
SS	Subscriber Station
SWIM	System Wide Information Management
TEK	Traffic Encryption Key

Term	Definition
TMA	Terminal Control Area
TX	Transmit
UGS	Unsollicited Grant Service
UL	Uplink
VLAN	Virtual Local Aera Network (IEEE 802.1Q)
WA	Work Activity
WMF	WiMAX Forum

2 Overview of AeroMACS requirements

Most of AeroMACS requirements have already been defined in AeroMACS system requirements document [3] or in some of the other documents listed above. Some of these requirements will be repeated as they are considered relevant to AeroMACS deployment and integration (named implementation hereafter).
Whenever requirements are based on previous P15.2.7 or P9.16 deliverables no requirement numbering will be provided.
To facilitate reading, some existing requirements may also be combined as there is no need for further validation (requiring unique unambiguous requirement statements as input).

Most importantly this document will also deliver new AeroMACS requirements which are direct related to AeroMACS implementation issues.
All new requirements will be unique and will be foreseen from a new requirement number, allowing further validation – when deemed necessary during P15.2.7 WA6 V&V phase.

2.1 AeroMACS RF Requirements

2.1.1 AeroMACS general RF requirements

AeroMACS major RF requirements are summed hereafter:

AeroMACS shall:

1. Operate within the extended MLS band between 5091 and 5150 MHz.
2. Support 5 MHz (512 point FFT) channel BW.
3. Use a frequency grid covering the whole 5000-5150 MHz band with 250kHz step offsets.
4. Not operate on frequencies where AMT is operating (at airport level).
5. Not impact MLS operations.
6. Comply to ITU-R M.1827 limiting the total aggregated power flux density (pfd) at the satellite receiver to increasing the satellite receiver Noise temperature (ΔT/T) by no more than 3% at any orbit point and within the LEO satellite antenna's footprint.
7. Provide both ATC, AOC and NET services on the same AeroMACS channels (no split spectrum usage is foreseen in Europe).

2.1.2 AeroMACS RF Transmitter Requirements

AeroMACS transmitter characteristics shall comply at the requirements listed beneath:

AeroMACS transmitter shall:

1. Comply at the output power categories 1,2,3,4 as defined by WMF.
2. Comply at the AeroMACS transmit mask as defined in RTCA SC-223 Aero MACS profile.
3. Have an average maximum output power (RMS) within +/- 1dB of the value provided for in its power class.
4. Support single step sizes shall be 1dB (+/- 0,5), 2dB (+/- 1), 3dB (+/- 1,5) and between 4 and 10 dB(+/- 2).
5. Ensure that the absolute power difference in between adjacent AeroMACS active carriers shall not vary more than 0,4 dB.
6. Emit power at the DC offset sub carrier not exceeding – 15 dB relative to the total transmitted power.
7. Comply at CEPT/ERC/REC/74-01for unwanted emission in the spurious domain.

NOTE : FOR THE TIME BEING – AND BASED ON THE FSS-AEROMACS INTERFERENCE STUDY - IT IS ASSUMED THAT AEROMACS POWER AMPLIFIER OUTPUT POWER WILL

COMPLY TO WMF POWER CLASS 1 AND HENCE EMMIT AN OUTPUT POWER BETWEEN 20 AND 23 dBm WHENEVER A DIRECTIONAL ANTENNA WITH 15dBi ANTENNA GAIN IS DEPLOYED.

2.1.3 AeroMACS RF Receiver Requirements

AeroMACS minimum receiver sensitivity values shall comply to the values indicated in the table beneath. For these minimum receiver sensitivity values the BER after FEC shall be < 1.10-6.

The IEEE 802.16-2009 uses the following formula to specify AeroMACS receiver sensitivity:

$$RSS = -114 + SNR_{Rx} - 10 \times \log_{10}(R) + 10 \times \log_{10}\left(\frac{F_s \times N_{used} \times 10^6}{N_{FFT}}\right) + ImpLoss + NF$$

Where:

- -114: is the thermal noise power term in dBm, referred to 1 MHz Bandwidth and 300 K temperature
- SNR_{Rx}: is the receiver SNR , it can be defined as the SNR necessary , at the demodulator input, to get the desired BER for the given modulation and coding rate.
- R : is the repetition factor of the FEC encoder used
- Fs: is the sampling frequency in Hz
- NFFT: is the FFT size
- Nused: is the number of subcarrier used (FFT size – Number of guard band subcarriers – DC carrier)
- ImpLoss: is the implementation loss, which includes non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors, and phase noise.
- NF: is the receiver noise figure, referenced to the antenna port.

With SNRrx values provided in SRD Table 8 [3], Implementation loss of 5 dB, NF of 8dB, Nused=420, NFFT=512 and Fs=5.6 *10-6 the minimum receiver sensitivity is found to be as indicated in the table below:

Modulation scheme	Rep. Factor	Sensitivity
64 Qam ¾ CC	1	-74,37 dBm
64 Qam 2/3 CC	1	-76,37 dBm
64 Qam 1/2 CC	1	-78,37 dBm
16 Qam ¾ CC	1	-80,37 dBm
16 Qam ½ CC	1	-83,87 dBm
Qpsk ¾ CC	1	-86,37 dBm
Qpsk ½ CC	1	-89,37 dBm
Qpsk 1/2 CC with repetition 2	2	-92,37 dBm

Table 1: AeroMACS Receiver Sensitivities Rss

The values listed in table 1 will be at least 2 dB lower in case a CTC FEC is used.

Notes:

1. All receiver sensitivity values are obtained under Additive White Gaussian Noise (AWGN) conditions.
2. **<u>WMF uses for any data services/all types of service flows CTC for certified products. CC is only used for the transfer of one management message.</u>**

AeroMACS downlink and uplink receivers shall:

1. Keep full performance functioning with a maximum signal input level of – 30 dBm and shall withstand input powers of at least 0dBm without being destroyed.
2. Have a minimum dynamic range from -30 dBm down to the receiver's minimum sensitivity level.

2.1.4 Impact of Minimum Receiver Sensitivity on Coverage

Taking into account the different AeroMACS minimum receiver sensitivities in function of modulation scheme and FEC model, the following conclusions can be drawn on coverage when assuming that AeroMACS cell is operating under AWGN for all MS:

1. The operating range of QPSK ½ CC is 2 times larger than the operating range of 16 QAM ½ CC.

2. The operating range of 16 QAM ½ CC is 2 times larger than the operating range of 64 QAM ½ CC.

A graphical presentation of a theoretical coverage x (m) is presented below in figure 1.

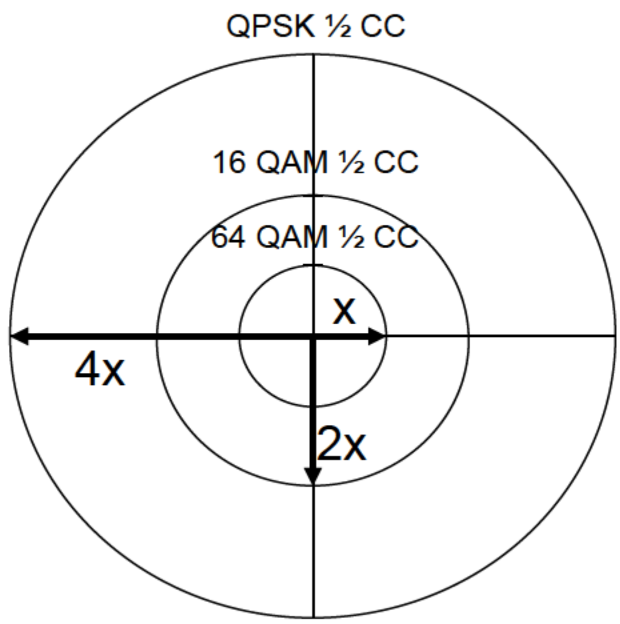


Figure 1: Cell coverage in function of modulation schemes

For free space LOS AWGN and NLOS (MUNICH) conditions and an emitted power of 23dBm using an antenna gain of 15 dBi, the value of x in the DL would be around:

X (m) for Downlink	QPSK 1/2CC	QPSK 1/2CTC	16QAM 1/2CC	16QAM 1/2CTC	64 QAM 1/2CC	64 QAM 1/2CTC
Free space LOS	11190	14250	5600	7400	3150	4060
NLOS MUNICH	1350	1640	770	970	490	600

Table 2: Free Space and NLOS MUNICH DL cell range estimations [25]

In the uplink direction a power emission of 21 dBm and omni-directional antenna of 6 dBi is assumed for coverage estimation:

X (m) for Uplink 24 carriers	QPSK 1/2CC	QPSK 1/2CTC	16QAM 1/2CC	16QAM 1/2CTC	64 QAM 1/2CC	64 QAM 1/2CTC
Near LOS (Matolak)	5400	6900	2800	3500	1500	1900
NLOS MUNICH	750	920	450	540	270	330

Table 3: Free Space and NLOS MUNICH UL cell range estimations (max sub-channelisation gain case) [25]

As can be seen, the UL coverage is only half of the DL coverage – under the condition that maximum subchannelisation gain is used (only 24 carriers used of 408 available) per MS attached to the BS.

Note: Both table 2 and table 3 cell range estimations are theoretical values which are obtained as a result of the spreadsheet calculations provided in table 18 and 19.

For lower sub-channelisation gains, coverage for UL will even decrease further in such a way that **without sub channelisation gain** (a MS consuming simultaneously all subcarriers for its own data needs), coverage would be roughly **only one fourth of the values provided in the table above.**

2.2 AeroMACS Major Operational Requirements

This section aims to gather worthwhile information that helps to understand the rationale for system characteristics, operational goals, requirements and workout of AeroMACS datalink.

A SESAR operational requirement is a statement of the operational attributes of a system needed for the effective and/or efficient provision of air traffic services to users. Those attributes include the process of ensuring that safety, performance, and interoperability objectives and requirements for the ATS and operating environment are maintained throughout operations [10].

AeroMACS as a radio datalink aimed for airports shall be an enabler to enhance the productivity and safety of ATS by optimizing the involvement of controllers, aircrew and airline operators through integrated data communications, improved forms of surveillance and automation.

AeroMACS SHALL support data services (NET, ATC and AOC).

AeroMACS SHOULD support voice services.

AeroMACS data link SHALL be able to support every single data transaction related to ATM services while the A/C is lower than 50 knots.

2.2.1 Operating Altitude

AeroMACS shall be available, exclusively, on the airport surface. Only the A/Cs on top of the ground will trigger services through AeroMACS.

2.2.2 Coverage

The foreseen playground for AeroMACS goes from terminals (RAMP area) to taxiing zones (GROUND and TOWER). AeroMACS operating coverage shall extend to full airport area. It's important to point out that coverage area is very related to specific deployment cases. In order to fully accomplish this statement, a specific deployment design shall be performed attending to different means such as:

- Capacity requirements.
- Number of BSs.
- Pathloss constraints.
- Clutter distribution within the airport area (forest, water, buildings…) etc.

R-OPS-CVG-01. AeroMACS SHALL guarantee full coverage for more stringent services (like NET and ATC) within the whole operational set of zones. Mainly those zones are RAMP area (operational turnaround zones) and taxiways.

AeroMACS SHALL use the minimum number of BSs in order to accomplish full coverage.

2.2.3 Min Max aircraft, vehicle speed

AeroMACS SHALL support only mobile services in Europe.

AeroMACS SHOULD properly acquire and track service link signals when aircrafts and vehicles are moving at a ground speed of up to 50 knots.

2.2.4 ATS and AOC support

In the future, AeroMACS SHALL be the primary means of communication for the supported services on the airport surface for AeroMACS equipped airports.

AeroMACS SHALL support all ATC data services related to safety and regularity of flight as encountered at airport surface level.

AeroMACS SHALL support all AOC data services related to safety and regularity of flight and as encountered at airport surface level.

AeroMACS SHALL support the necessary Network Management services (NET) as required by the supported safety of life and flight regularity services.

The list of all services AeroMACS is meant to support can be found on 3.3.

AeroMACS SHALL support airport vehicles services related to safety and regularity of flight.

AeroMACS SHOULD support VoIP services for airport operation.

Note: Currently, it is not intended to support VoIP for ATC applications in Europe.

AeroMACS SHALL provide traffic prioritization between ATC, AOC and NET services according to the next table:

Subscribers	Priority 1 (highest)	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6
Aircraft	NET services	ATS 1	ATS 2	ATS 3	AOC 1	AOC 2
Surface vehicles	NET services		ATS2	ATS 3	Surface operation	

Table 4: AeroMACS prioritization table [3]

2.2.5 Security Requirements

R-OPS-SCR-01. AeroMACS SHALL provide protection against unauthorized entry.

R-OPS-SCR-02. AeroMACS SHALL support security control mechanism in order to avoid unauthorized users to reach and get ATC/AOC/NET services and interact with other parts of the infrastructure.

R-OPS-SCR-03. AeroMACS SHALL perform device authentication. According to ARINC 842, aircraft identification SHALL be performed through tail numbering and optionally including ICAO 24-bit ID.

R-OPS-SCR-04. AeroMACS SHALL support mechanisms and procedures to ensure message integrity and the continuous verification of the sender of the message.

R-OPS-SCR-05. AeroMACS by means of Authorization and Authentication mechanisms SHALL deal with different types of access (USER/ADMIN). Nevertheless user authentication is out of the scope of AeroMACS and hence left to implementation.

R-OPS-SCR-06. AeroMACS, in order to provide secured communications within the air interface (MS/BS) SHALL implement security association with cryptographic suites. Moreover, two types of SA's SHALL be implemented: primary and static.

A Security Association will provide AeroMACS a set of security information by which a secured communication between the MS and the BS is established. The "primary" SA will enable secured management and data transport connections. The "static" SA are triggered by the MS when it intends to use a new service and therefore they are dynamically terminated when the data transfer in the service ends.

R-OPS-SCR-07. AeroMACS BS units SHALL handle and manage the security, and connection identifiers of each MS that is successfully authenticated.

R-OPS-SCR-08. AeroMACS SHALL provide transmission confidentiality.

R-OPS-SCR-09. AeroMACS SHALL support Advanced Encryption techniques.

R-OPS-SCR-10. AeroMACS SHALL implement an authentication client-server protocol for supporting AAA procedures. The use of a AAA server will ease other functions like the HA or the HA address in order to accomplish the registration of "foreign" aircrafts within the visited airport.

Special care should be paid to the previous identified vulnerable servers of AeroMACS architecture (revision on analysis done in WA8 will be made).

R-OPS-SCR-11. AeroMACS architecture SHALL give the means to correct billing of data traffic to the respective users (Accounting). Nevertheless the implementation of accounting in an AeroMACS deployment scenario will largely depend on the way airport infrastructure will be handled by airport operators.

R-OPS-SCR-12. AeroMACS SHALL support the exchange of public certificates between MS and the authorization entities.

R-OPS-SCR-13. AeroMACS SHALL support security association mechanisms between MS and BS. Therefore some control policy must be applied in order to give differentiated grade of service and accuracy to the same user.

2.2.6 Safety and Performance requirements based on WG78 draft deliverables

2.2.6.1 Refinement of SRD Requirements

Some requirements previously stated in the SRD [3] have been reviewed thanks to the simulations performed in this WA (further information and proper justification can be found in section 3.7.2). They're the one below listed:

R-AFR-PER-10.	Downlink one way data latency for NET and ATC services SHALL be < 20 ms.
R-AFR-PER-11.	Uplink one way data latency for NET and ATC services SHALL be < 80 ms.
R-AFR-HAN-01.	AeroMACS HO interruption time SHALL be < 200 ms.
R-AFR-SCA-02.	AeroMACS SHALL be able to scan through the 11 channels as defined within the preferred frequency set in less than 10 s.
R-AFR-SCA-03.	AeroMACS SHALL be able to scan the entire bandwidth using a step size of 250 kHz within 35 s (dwell time of 150ms and 236 possible channels).
R-SYN-S&T-02.	AeroMACS Synchronisation dwell times SHALL be <150 ms.
R-SYN-S&T-03.	AeroMACS dwell times SHALL be long enough to ensure that the probability of false synchronization would be < 0,1 %.
R-SYN-S&T-04.	AeroMACS SHALL keep the number of non existing preamble detections (false alarm case) sufficiently low in order not to affect the frequency scanning time.

2.2.6.2 Safety and Performace Requirements derived from WA08

The following section is based on 15.2.7 WA08 draft deliverable on safety and performance. The safety analysis done in WA08 is developed accordingly to the draft deliverables of the joint Eurocae/RTCA group WG78/SC214.

The following requirements come or are derived from draft version I of WG78/SC214 [43].

To get further information, the reader may refer to Appendix E, WG78/SC214 draft deliverable version I and 15.2.7 WA08 draft deliverable V0R13 [44].

Note: In this section, the use of the word "Shall" indicates a mandated criterion; i.e. compliance with the particular procedure or specification is mandatory and no alternative may be applied. The use of the word "Should" (and phrases such as "It is recommended that...", etc.) indicate that although the procedure or criterion is regarded as the preferred option, Alternative procedures, specifications or criteria may be applied, provided that the manufacturer, installer or tester can provide information or data to adequately support and justify the alternative.

In the following sub sections related to safety and performance requirements, only requirements coming from WG78/Sc214 and applicable to the ACSP domain are considered as “SHALL” requirements.

All other requirements are considered as “SHOULD” requirements since they are based more or less system design and/or maintenance organisation dependent.

R-OPS-S&P-01.	Prior implementing AeroMACS to support safety and regularity of flight critical services (e.g. CPDLC, D-TAXI…), a safety and performance analysis shall be performed.

2.2.6.2.1 Corruption of message

The following safety requirement applicable to the ACSP is identified:

R-OPS-S&P-02.	The likelihood that the ACSP corrupts a report shall be less than 2.8E-03/FH.

This requirement should disappear in the next update of working group 78/sc214 documents.

2.2.6.2.2 Availability requirement: HARDWARE allocation

2.2.6.2.2.1 Requirements applicable to the ACSP (CSN+ASN)

R-OPS-S&P-03.	The availability of the ACSP service shall be more than 99.95%.
R-OPS-S&P-04.	The likelihood that the ACSP service is unavailable shall be less than 4.3E-04/SOH.
R-OPS-S&P-05.	The maximum unplanned ACSP service outage duration shall be 6 minutes.
R-OPS-S&P-06.	The maximum number of unplanned ACSP service outage shall be 40 minutes.
R-OPS-S&P-07.	The maximum accumulated ACSP service unplanned outage time shall be 240 minutes/year.
R-OPS-S&P-08.	The maximum unplanned ACSP service outage notification delay shall be 5 minutes.

2.2.6.2.2.2 Requirements applicable to the CSN function

It is assumed that the failure of this function could have an impact at, at least, regional scale. Consequently, the operator will take necessary measures to ensure great availability and continuity of service for this function.

The CSN operator should implement redundant AAA function.

In case, the AAA infrastructure is connected to a certificate revocation server and if failure of this latter leads to incapacity for Mobile Subscribers to get access to the network or for connected mobiles to maintain their connection, this certificate revocation server function (server + connection to the AAA infrastructure) should be made redundant.

The CSN operator should implement redundant Mobile IP function (e.g. Home Agent…).

In case dynamic IP address assignment is implemented, the CSN operator should implement redundant DHCP function.

The CSN operator should make redundant all the level 2 (LAN infrastructure) and 3 (IP infrastructure) supporting the security, Mobile IP and Dynamic IP address assignment functions.

All the equipments should have a double attachment to the network.

All the equipments should be supplied by a redundant non interrupted power supply.

The CSN operator should target availability for the service greater than 99.9998%.

The CSN components should have the capability to be remotely monitored and controlled.

Human intervention to recover from a system failure should be possible 365 days a year.

While experiencing a single failure at CSN level, the interruption of service should not last more than 6 minutes.

The ATC centre should be notified in less than 5 minutes by the CSN operator in case of interruption of service.

In order to minimize the interruption of service while experiencing single failure at CSN function, the CSN operators should pay attention to the way redundancy is implemented. Notably single failure at CSN functions should not require human intervention to recover the service on the back-up system.

Depending on the way redundancy is implemented, the CSN function should implement strategy to enable automatic recovery of service in case of single failure at the various CSN sub functions (AAA, Mobile IP, DHCP…).

For instance, in case a mobile subscriber gets access to its Home CSN through a Visited CSN, the Visited CSN and Home CSN should implement AAA service recovery in case a single failure occurs at AAA proxy or server level and this failure being not transparent for the AAA counterpart (server or proxy).

In case, CSN function is implemented through several CSN operators for a given mobile subscriber (roaming operation):

- CSN operators (Visited and Home CSN) should comply with all requirements here above,
- Home and Visited CSN should be connected through redundant network access
- security gateways at CSN frontiers should be redundant,
- the availability target should apply to the whole CSN service,
- Home and Visited CSN should establish contractual arrangements to ensure that CSN requirements are met before putting the service into operation and are kept during continuous operation.

ANSP and Home CSN, in case these entities are different, should establish contractual arrangements to ensure that ACSP applicable requirements are met before putting the service into operation and are kept during continuous operation.

With regard to the implementation of redundancy, manufacturers may rather target implementation based on load balancing or context maintenance on both main and back-up machines in order to avoid complete reconnection of Mobile Subscribers in case of single failure.

Note: current safety and performance requirements related to availability of service do not require the need to implement redundancy through different manufacturers. However, if possible such approach should be preferred.

2.2.6.2.2.3 Requirements applicable to the ASN function

Note: According to the safety and performance requirements derived by joint RTCA/Eurocae SC214/WG78, only the requirement related to the maximum interruption of service duration requires redundancy at ASN function level (notably for the BS and ASN Gateway).

The ASN operator should implement redundant ASN gateway function.

The ASN operator should implement redundant Base Station function.

The ASN operator should make redundant all the level 2 (LAN infrastructure) and 3 (IP infrastructure) supporting the ASN function.

The Base Stations should have a double attachment to the network.

The ASN Gateways should have a double attachment to the network.

All the equipments should be supplied by a redundant non interrupted power supply.

Connection between ASN and CSN networks (if operated by different entities) should be made redundant. This includes access routers and security features such as firewall.

The ASN operator should target availability for the service greater than 99.9503%.

ASN Gateway manufacturers should target a MTBF about 90 000 hours (for a single machine).

Base Stations manufacturers should target a MTBF about 65 000 hours (for a single machine).

The ASN components should have the capability to be remotely monitored and controlled.

For large airport (e.g. Paris Charles De Gaulle, Madrid Barajas), Human intervention to recover from a system failure should be possible 365 days a year.

While experiencing a single failure at ASN level, the interruption of service should not last more than 6 minutes.

The local ATC centre should be notified in less than 5 minutes in case of interruption of service at ASN level.

Depending on the way redundancy is implemented, the ASN function should implement strategy to enable automatic recovery of service in case of single failure at the various CSN sub functions (Base Stations, ASN Gateways…).

In order to minimize the interruption of service while experiencing single failure at ASN function, the ASN operators should pay attention to the way redundancy is implemented. Notably single failure at ASN functions should not require human intervention to recover the service on the back-up system.

ASN and CSN operators (visited or home), in case these entities are different, should establish contractual arrangements to ensure that ACSP applicable requirements are met before putting the service into operation and are kept during continuous operation.

With regard to the implementation of redundancy, manufacturers may rather target implementation based on load balancing or context maintenance on main and back-up machine in order to avoid complete reconnection of Mobile Subscribers.

Note: current safety and performance requirements related to availability of service do not require the need to implement redundancy through different manufacturers. However, if possible such approach should be preferred.

2.2.6.2.2.4 Other requirements related to Sc214/WG78 ACSP availability requirements

The Mobile subscriber system should implement a procedure for service recovery while experiencing failure at ASN (Base Station and ASN Gateway) and CSN ground system level.

The service recovery procedure should be based on random mechanism to avoid avalanche of network access requests.

Unintended continuous transmission by the mobile subscriber system should be avoided.

2.2.6.2.3 Availability requirement: SOFTWARE allocation

2.2.6.2.3.1 Requirements applicable to the ACSP (CSN+ASN)

All ACSP components should be allocated a SWAL 4 which is equivalent to a Development Assurance Level equaled to AL5 according to ED-109 document.

2.2.6.2.4 Transaction Time requirements

2.2.6.2.4.1 Requirements applicable to the ACSP domain (ASN+CSN)

R-OPS-S&P-09.	The one way transaction time in ACSP shall be less than 9 seconds for 99.9% of the messages.
R-OPS-S&P-10.	The one way transaction time in ACSP shall be less than 4 seconds for 95% of the messages.

2.2.6.2.4.2 Requirements applicable to the CSN function

The various CSN components should be sufficiently sized to minimize the time to process data.

The CSN components should process data in less than 100 ms under all traffic conditions.

The CSN should be sufficiently sized to avoid congestion of the network.

The CSN operator should monitor the transit delay offered by its network and adapt its capacity to the demand.

The CSN components should have the capability to log exchanged traffic in order to derive statistics about network performance.

The transaction time in the CSN should be less than 2 seconds for 99,9% of applicative messages.

The transaction time in the CSN should be less than 0,8 seconds for 95% of applicative messages.

In case congestion of the network occurs, the CSN should carry ATC traffic with the maximum priority compared to other types of traffic (AOC, AAC, ground vehicle operation) apart from the Net services.

In case, CSN function is implemented through several CSN operators for a given mobile subscriber (roaming operation):

- CSN operators (Visited and Home CSN) should comply with all requirements here above,
- the transaction time target should apply to the whole CSN service,
- Home and Visited CSN should establish contractual arrangements to ensure that CSN requirements are met before putting the service into operation and are kept during continuous operation.

ANSP and Home CSN, in case these entities are different, should establish contractual arrangements to ensure that ACSP requirements are met before putting the service into operation and are kept during continuous operation.

2.2.6.2.4.3 Requirements applicable to the ASN function

The various ASN components should be sufficiently sized to minimize the time to process data.

The ASN components should process data in less than 50 ms under all traffic conditions.

The ASN should be sufficiently sized to avoid congestion of the network.

The ASN operator should monitor the transit delay offered by its network and adapt its capacity to the demand.

The ASN components should have the capability to log exchanged traffic in order to derive statistics about network performance.

The transaction time in the ASN should be less than 7 seconds for 99,9% of applicative messages.

The transaction time in the ASN should be less than 3,2 seconds for 95% of applicative messages.

The scheduler should be optimized to minimize the number of AeroMACS channels to cope with a given demand.

Coverage and capacity analysis to meet transaction time should be done per airport prior deploying Base Stations.

Base Station deployment should ensure seamless operation from user point of view while experiencing hand-over.

The transaction time in the ASN should be less than 3,2 seconds for applicative messages while experiencing hand-over procedure.

In case congestion of the network occurs, the ASN should carry ATC traffic with the maximum priority compared to other types of traffic (AOC, AAC, ground vehicle operation) apart from the Net services.

Note: Manufacturers and ASN operator may consider to use AeroMACS Base Station dynamic range (about 10 dB) to create redundancy. In case of Base Station failure, the transmitted power of other BS could be increased to extend their coverage in the sector of the failed BS. Such approach may result in reduction of available bandwidth for each given Mobile Subscriber in the extended coverage of the remaining Base Station. In addition, it may lead to unexpected spurious emission. Such approach to implement redundancy should be thus considered with attention during cell planning phase and would probably be declared to the local entity responsible for frequency license delivery.

2.2.6.2.5 Monitoring and Alert requirements

2.2.6.2.5.1 Requirements applicable to the ACSP domain (ASN+CSN)

The safety requirement regarding detection and alert in case of ACSP failures are:

R-OPS-S&P-11. The ground system shall be capable of detecting ground system failures and configuration changes that would cause the communication service to no longer meet the requirements for the intended function.

R-OPS-S&P-12. When the communication service no longer meets the requirements for the intended function, the ground system shall provide indication to the controller.

2.2.6.2.5.2 Requirements applicable to the CSN function

The CSN nodes should be capable of detecting CSN failures and configuration changes that would cause the communication service to no longer meet the requirements for the intended function.

When the CSN communication service no longer meets the requirements for the intended function, the CSN components should provide indication to the operator.

2.2.6.2.5.3 Requirements applicable to the ASN function

The ASN nodes should be capable of detecting ASN failures and configuration changes that would cause the communication service to no longer meet the requirements for the intended function.

When the ASN communication service no longer meets the requirements for the intended function, the ASN components should provide indication to the operator.

2.2.7 Registration procedure

R-OPS-REG-01. AeroMACS architecture might not provide the AAA logical entity of any user's DB. Besides, it SHALL act as the gateway to reach seamlessly the policy authority of the network, independently of where the server or the DB is hosted.

R-OPS-REG-02. AeroMACS SHALL give means to create, configure and delete accurately user profiles with different grades of service in the access network.

R-OPS-REG-03. Aircraft device SHALL automatically register and de-register from AeroMACS system without intervention of human agents.

2.2.8 Mobility and Handover

R-OPS-MOB-01. AeroMACS SHALL be capable to operate within the FCI multilink architecture and associated data links whenever these other FCI datalinks are available.

R-OPS-MOB-02. AeroMACS architecture SHALL support seamless HOs at up to minimum maximum vehicular speeds.

R-OPS-MOB-03. AeroMACS SHALL guarantee service availability for vehicles and home/visiting aircrafts within the airport.

R-OPS-MOB-04. AeroMACS SHALL meet availability and continuity figures stated on COCRv2 [1] for services for both vehicles and aircrafts.

R-OPS-MOB-05. AeroMACS SHALL be based on an all IP radio and ground Internet Protocol (IP) compliant infrastructure as defined in ICAO DOC 9896 [11]

Premise: any method used to assign aircraft addresses SHALL ensure efficient use of the entire address block that is allocated to that State. Network addressing is dependent on system deployment. Input on general aspects shall be covered within section 4.1.2 “Access Network aspects”.

R-OPS-MOB-06. AeroMACS SHALL support hard handover between BSs and sectors. The HO procedure shall be initiated by the BS.

R-OPS-MOB-07. AeroMACS handover SHALL be transparent for applications. Notably, it shall not jeopardize compliance with continuity of service requirements.

R-OPS-MOB-08. Service flows connections shall be kept and guarantee their continuity without service disruption from the user's point of view.

R-OPS-MOB-09. AeroMACS SHALL guarantee the context retrieval procedure, that is to say, the integrity and seamless transfer of AK contest from serving BS to target BS through ANS-GW.

R-OPS-MOB-10. AeroMACS SHALL guarantee the transfer of the authorization policy and the mapping of the SA's currently established of the MS triggering the HO.

2.2.9 Synchronization and Timing Requirements

R-OPS-SYN-01. AeroMACS MS SHALL be able to synchronies at the limit of the AeroMACS cell size.

R-OPS-SYN-02. AeroMACS synchronization dwell times SHALL be as short as possible.

R-OPS-SYN-03. All the BSs SHALL get synchronized using a unique time reference.

R-OPS-SYN-04. AeroMACS SHALL perform a resynchronization procedure of the MS after a signal loss.

R-OPS-SYN-05. AeroMACS handover interruption time SHALL be kept sufficiently low to guarantee no service disruption within the whole operational turnaround of the aircraft in the airport surface.

2.2.10 QoS Requirements

In a real deployment, a specific mapping of QoS levels SHALL be provided. Consequently, in section 3.7.2.3.4 is provided one example of IP QoS to AeroMACS QoS map. Indeed, this proposal has been used for capacity analysis simulations in order to address the mapping of different grade of services to AeroMACS QoS.

R-OPS-QOS-01. AeroMACS SHALL provide means to guarantee data integrity.

R-OPS-QOS-02. AeroMACS BSs SHALL be capable to establish different dynamic service flows (SF) to the MSs (with different parameters of throughput, jitter, delay, etc.)

R-OPS-QOS-03. AeroMACS SHALL guarantee the dynamic change of a SF attending to different traffic patterns and requisites.

R-OPS-QOS-04. AeroMACS SHALL implement different traffic schedule in order to accomplish differentiated class of service support.

R-OPS-QOS-05. All messages of each transaction SHALL be assigned to a common AeroMACS Class of Service (CoS)

2.2.11 Traffic Requirements

The required Throughput based on the simulation results1 (see capacity analysis on 3.7.2.3.6.2) should be:

- ATC: The overall (combined up and downlink) average data load supported by one cell/sector SHOULD be at least 0,6kbps (GROUND/TOWER) or 0,2kbps (RAMP).

[1] These figures have been yielded from a large airport case analysis (typically of 50A/Cs). Thus, figures for smaller airports would be likely more relaxed.

- AOC: The overall (combined up and downlink) average data load supported by one cell/sector SHOULD be at least 800kbps (GROUND/TOWER) or 1Mbps (RAMP).

R-OPS-S&P-13. Latency. The maximum time to complete a transaction using AeroMACS datalink. The rate at which a transaction expiration time can be exceeded is determined by the continuity parameter.

R-OPS-S&P-14. Transaction expiration time (defined in OSED [10]). AeroMACS SHALL provision the means to, given a maximum time for completing a transaction, start up an alternative procedure to accomplish the transaction. This is related to the continuity parameter.

R-OPS-S&P-15. Packet size (see capacity analysis on 3.7.2.3). AeroMACS average ATC message size is 190 Bytes. AeroMACS average AOC message size is 278 kBytes.

2.2.12 Performances monitoring

Monitoring includes data collection on a routine basis and as problems or abnormalities arise. System monitoring shall be performed by organizations which operate the AeroMACS system or components in order to:

- Monitor in real-time the status of the system (availability of the subcomponents, current number of connected mobiles, current channel load, security event alarms …). This information will enable the operators to trigger appropriate procedures to maintain the level of safety and then restore the service in case of abnormal event,
- Monitor off-line the performances and technical problems for proper trouble-shouting and capacity planning.
- Provide or use an ATS or are in control of or responsible for an element of the CNS/ATM system in operation and a data collection point resides within that element [10].

R-OPS-PMO-01. The monitoring capability of the AeroMACS SHALL NOT impede the working of the AeroMACS system.

2.2.13 System supervision

R-OPS-SPV-01. AeroMACS SHALL support VPN or VLAN in case it`s required for system supervision purposes. Please, be referred to security issues addressed on WA8 documentation.

R-OPS-SPV-02. The supervision capability of the AeroMACS SHALL NOT impede the working of the AeroMACS system.

AeroMACS SHOULD support SNMP protocol in order to give to the operator of the network the means to supervise the status and get problems reports of the elements of the AeroMACS system.

AeroMACS architecture SHOULD integrate a management information base (MIB).

AeroMACS BSs SHOULD implement SNMP agents in order to enable its management whereas MSs SHALL NOT include any agent.

Information concerning identified problems on AeroMACS data link SHOULD be disseminated to operators and ATS providers to raise awareness and facilitate problem resolution.

AeroMACS problem resolution SHOULD be easily traced back to the point at which the problem was encountered from the SNMP protocol.

3 Deployment & Interference Analysis

This section of the document will provide general rules and guidelines on how to deploy an AeroMACS system in an airport. The different sections will deal with several aspects to take into account, such as airport operational areas, airport layouts, siting regulations, interference with other systems…, before conducting a capacity and coverage analysis. Rules and requirements for frequency planning, installation and acceptance of BS sites will also be given.

Particular cases for AeroMACS deployment in Barajas and Toulouse airports will be studied.

3.1 Airport Operational Areas

An accurate RF design ensures that the deployed wireless network provides the necessary coverage, capacity, and reliability, with minimal interference, that satisfies the service requirements. Although it is possible to estimate 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 co-channel interference.

In order to achieve the goals described in the previous paragraph, we should firstly introduce some terms and definitions concerning the operational areas of an airport.

These terms, related to ATC concept of operations world, divide the airport into three different operational areas from an ATC point of view: RAMP, GROUND and TOWER. These operational areas match some of the physical areas within the boundaries of the airport (gates, taxiways, etc). These physical areas are described in section 3.2.

1. RAMP area: location at the airport where A/C is stationary and hooked on at the gate/stand. For instance, physical areas like gates belong to RAMP.

2. GROUND area: airport surface area used when A/C is pushed back and is moving most of the time – up to the end of the taxiing phase. Taxiways and parking/stand areas belong to GROUND.

3. TOWER area: airport surface where ground control is handed over to Tower until take-off phase. TOWER area is shortly before the runways. The GROUND controller hands over to the TOWER controller after the aircraft is on its way to the runway. On smaller airports the GROUND + TOWER could not be separated.

From the service point of view, it could be possible that an aircraft at the RAMP area has the same requirements as an aircraft at the parking area (considered as GROUND).

3.2 Airport Domain

3.2.1 Definitions.

The APT domain consists of an area 10 miles in diameter and up to 5000 ft consisting of the airport surface and immediate vicinity of the airport (COCR v2 definition).

Within the airport boundaries it can be found a lot of areas which definitions and description are as follows [12]:

Aerodrome. Any defined area of land or water intended or designed to be used either wholly or partly for the landing, departure, and surface movement of an aircraft; and includes any buildings, installations, and equipment on or adjacent to any such area used in connection with the aerodrome or its administration.

Aircraft stand. A designated area on an apron intended to be used for parking an aircraft.

Apron. A defined area, on a land aerodrome, intended to accommodate aircraft for purposes of loading or unloading passengers, mail or cargo, fuelling, parking or maintenance.

Clearway. A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height.

De-icing/anti-icing pad. An area comprising an inner area for the parking of an aeroplane to receive de-icing/anti-icing treatment and an outer area for the maneuvering of two or more mobile de-cing/anti-icing equipment.

Holding bay. A defined area where aircraft can be held, or bypassed, to facilitate efficient surface movement of aircraft.

Landing area. That part of a movement area intended for the landing or take-off of aircraft.

Maneuvering area. That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, excluding aprons.

Movement area. That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, consisting of the maneuvering area and the apron(s).

Primary runway(s). Runway(s) used in preference to others whenever conditions permit.

Road. An established surface route on the movement area meant for the exclusive use of vehicles.

Road-holding position. A designated position at which vehicles may be required to hold.

Runway. A defined rectangular area on a land aerodrome prepared for the landing and take-off of aircraft.

Runway end safety area (RESA). An area symmetrical about the extended runway center line and adjacent to the end of the strip primarily intended to reduce the risk of damage to an aeroplane undershooting or overrunning the runway.

Runway strip. A defined area including the runway and stopway, if provided, intended:

a) to reduce the risk of damage to aircraft running off a runway; and

b) to protect aircraft flying over it during take-off or landing operations.

Runway turn pad. A defined area on a land aerodrome adjacent to a runway for the purpose of completing a 180-degree turn on a runway.

Shoulder. An area adjacent to the edge of a pavement so prepared as to provide a transition between the pavement and the adjacent surface.

Signal area. An area on an aerodrome used for the display of ground signals.

Stopway. A defined rectangular area on the ground at the end of take-off run available prepared as a suitable area in which an aircraft can be stopped in the case of an abandoned take off.

Take-off runway. A runway intended for take-off only.

Taxiway. A defined path on a land aerodrome established for the taxiing of aircraft and intended to provide a link between one part of the aerodrome and another, including:

a) Aircraft stand taxi lane: A portion of an apron designated as a taxiway and intended to provide access to aircraft stands only.

b) Apron taxiway: A portion of a taxiway system located on an apron and intended to provide a taxi route across the apron.

c) Rapid exit taxiway: A taxiway connected to a runway at an acute angle and designed to allow landing aeroplanes to turn off at higher speeds than are achieved on other exit taxiways thereby minimizing runway occupancy times.

Taxiway intersection. A junction of two or more taxiways.

Taxiway strip. An area including a taxiway intended to protect an aircraft operating on the taxiway and to reduce the risk of damage to an aircraft accidentally running off the taxiway.

Threshold. The beginning of that portion of the runway usable for landing.

Touchdown zone. The portion of a runway, beyond the threshold, where it is intended for landing aeroplanes to first contact the runway.

These different areas can be grouped into two areas on the airport movement area, the main airport area where aircrafts and vehicles operate, although AeroMACS will be deployed over the whole airport to provide coverage to the surface vehicles:

- **Apron area (RAMP and GROUND Operational Areas):**
    - **Gate**: This is the area where aircrafts park, load and unload and it belongs to RAMP operational area.
    - **Parking areas**: These are the areas where aircrafts and surface vehicles defined above park (e.g. fire brigade station, snow trucks parking area ...). Parking areas are included in the GROUND operational area.
- **Maneuvering areas (GROUND and TOWER Operational Areas):**

- **Taxiway**: These are the areas used by aircraft to get to and from the ramp and the runway. Like the runways, taxiways are meant for aircraft use. Authorisation is required before someone could operate a vehicle on taxiway and runway. Taxiways belong to the GROUND operational area.

- **Runway**: Area used by aircraft for take-off and landing operations. Runways belong to the TOWER Operational area.

- <u>**Other areas**</u>: Access roads to air navigation installations for maintenance operations, access roads to maneuvering area, etc.. They are included in the GROUND operational area.

As stated previously all these areas must be covered by AeroMACS.

3.2.2 Airport Basic Terminal Layouts

Airport terminal layout can be differentiated into 7 different layouts [14]. These terminal layouts have mainly an impact on coverage issues and are not necessary related to AeroMACS capacity issues (assuming enough BS can be deployed under good site conditions). Gates are included in the different types of terminals.

A description of these airport terminal layouts is provided in order to have an idea on different AeroMACS deployment scenarios for RAMP operational area coverage.

3.2.2.1 Simple Terminal Configuration

This configuration consists of one building holding a common ticketing and waiting area with several exits leading to a small aircraft parking apron for boarding. This is used at mainly small aircraft airports and some older large airports.

It is applied at low traffic volume airport. Aircrafts are normally parked either angled nose-in or nose-out for self taxi-in or taxi-out. Apron expansion can be done incrementally in accordance with demands, causing little disruption of airport operation.

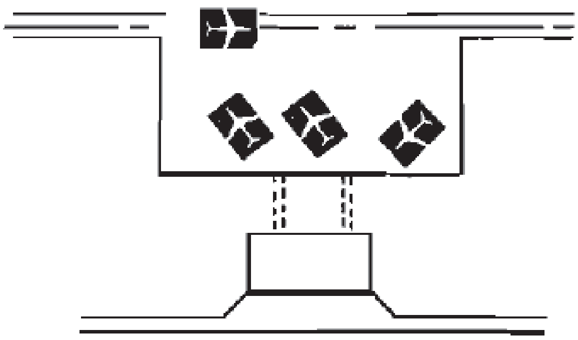


Figure 2: Simple Terminal

Simple terminal layouts do not provide any particular difficulties in AeroMACS BS site determination because most of these terminals belong to small airports.

3.2.2.2 Linear Terminal Configuration

This is simply an extension of the simple terminal concept providing more gates and more room within the terminal for ticketing and passenger processing.

Aircraft can be parked in an angled or parallel parking configuration. However, nose-in/push-out configuration with minimum clearance between apron edge and terminal becomes more common in this concept for more efficient utilisation of apron space and handling of aircrafts and passengers.

At busy traffic airports, it may be become necessary to provide double apron taxiways to reduce blocking of the taxiway by push-out operations. The corridor between the apron edge and terminal frontage can be used for circulation of apron traffic and the area around the nose of the parked aircraft can be used for ground service equipment parking slots.

The linear concept has as much flexibility and expansibility as the simple concept and almost as much as the open apron concept.

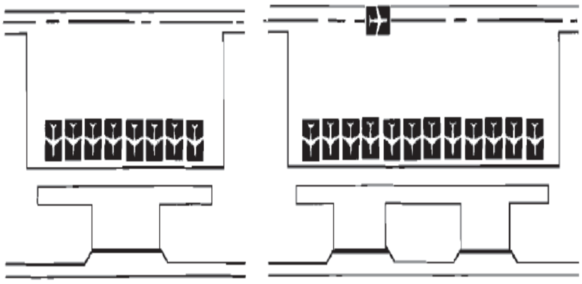


Figure 3: Linear Terminals

3.2.2.3 Curvilinear /Satellite Terminal Configuration

This is also a simply extension of the simple terminal concept providing more gates and more room within the terminal for ticketing and passenger processing. Sometimes curvilinear terminals are also called satellite terminals when they form a circular or near circular building.

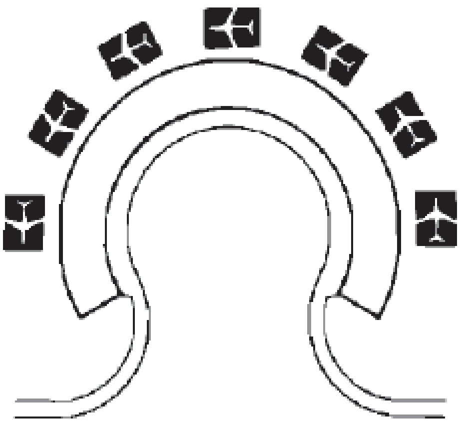


Figure 4: Curvilinear/Satellite Terminals

Curvy linear layouts may be a bit more challenging when deploying BSs compared to linear of small terminals types. These terminals are found very often at older airports and new constructions of this type are rare. A/C at gates could be served by attaching sectorized BS at lighting poles along the curve or on top of a tower when tower is in close vicinity of terminal.

Ideally a satellite terminal could be covered by a single omni or a 3 sector BS (in function of amount of gates served by the satellite) when the centre of the buildings allows the construction of a tower on top of the roof. Unfortunately chances that this is possible are slim. Other difficulties are encountered by roof diffraction on edges which scatters the radio waves creating possible the loss of LOS signals.

3.2.2.4 Pier Finger Terminal Configuration

This terminal configuration evolved during the 1950s when gate concourses were added to the simple terminal building designs. A concourse is actually defined as an open space where paths meet. Passengers are usually processed at the simple terminal location and then routed down a "pier" where aircraft are parked in the "finger" slots or gates for boarding.

Aircraft can be parked at gate positions on both sides of the pier, either angled, parallel or perpendicular (nose-in). When there are two or more piers, care must be taken to provide proper space between them. If each pier serves a large number of gates, it may be necessary to provide double taxiways between piers to avoid conflicts between aircrafts entering and leaving the gate positions.

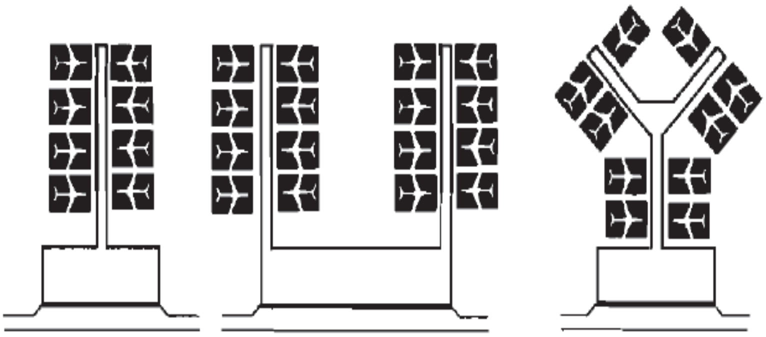


Figure 5: Pier Finger Terminals

Pier finger terminals may allow the easiest AeroMACS BS site deployment as often along the gates, light poles have been erected to illuminate gate areas. Furthermore a large part of the GROUND area runs along the pier´s length.

3.2.2.5 Satellite Terminal Configuration

The satellite concept consists of a satellite unit, surrounded by aircraft gate positions, and separated from the terminal. The passenger access to a satellite from the terminal is normally via an underground or elevated corridor to best utilize the apron space, but it could be on the surface. Depending on the shape of the satellite, the aircraft are park in radial, parallel or some other configuration around the terminal. When aircraft are parked radially, which used to be common, push-back operation is easy but requires larger apron space. If a wedge-shaped aircraft parking configuration is adopted, it not only requires unfavourable sharp turns taxiing to some of the gates positions but also creates traffic congestion of ground service equipment around the satellite.

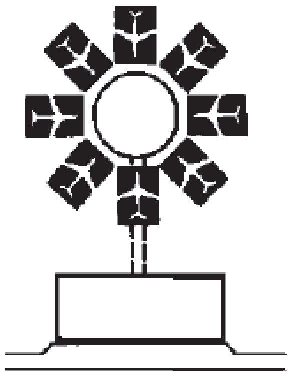


Figure 6: Satellite Terminal

3.2.2.6 Transporter Terminal Configuration

This concept may refer to as an open or remote apron concept. As aprons may be ideally located for aircraft close to the runways and remote from other structures, it would provide advantages for aircraft handling such as shorter over-all taxiing distance, simple self-manoeuvring, ample flexibility and expansibility of aprons, etc . However, as it requires transporting passengers, baggage and cargo for relatively longer distances by transporters (mobile lounges/buses) and carts to and from the terminal, it can create traffic congestion problems on the air side.

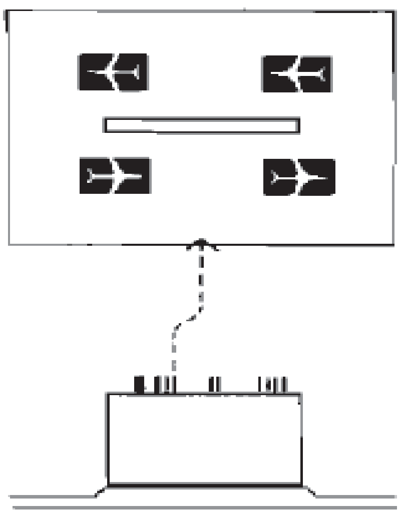


Figure 7: Transporter Terminal

Currently this configuration does not exist in Europe.

3.2.2.7 Hybrid Terminal Configuration

The hybrid concept means the combining of more than one of the above-mentioned concepts. It is fairly common to combine the transporter concept with one of the other concepts to cater to peak traffic. Aircraft stands located at remote areas from the terminal are often referred to as remote aprons or remote stands.

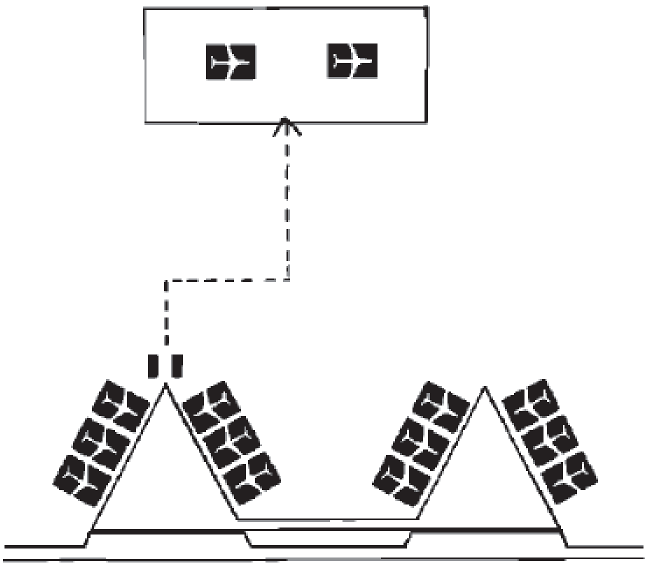


Figure 8: Hybrid Terminal

3.2.3 Airport Basic Parking Layouts

Aprons are interrelated with the terminal complex, and should be planned in connection with terminal buildings to achieve an optimum solution.

A description of different basic aircraft parking layouts is provided in order to have an idea on different AeroMACS deployment scenarios for GROUND area coverage [13].

This subject is related to the method by which the aircraft will enter and leave the aircraft stand under its own power (self maneuvering) or taxies in and is pushed out (tractor assisted). The different parking configurations are shown in the next figure.

As a general rule, nose-in parking configurations are common at high traffic airports where the tractor cost is justified by more efficient use of limited apron area. Other parking configurations are employed at low traffic airports where it is difficult to offset the tractor operation cost by savings in apron size.

As important as the different aircraft parking layout is the number of aircrafts that can be accommodated in every parking area. This data must be provided for the capacity analysis.

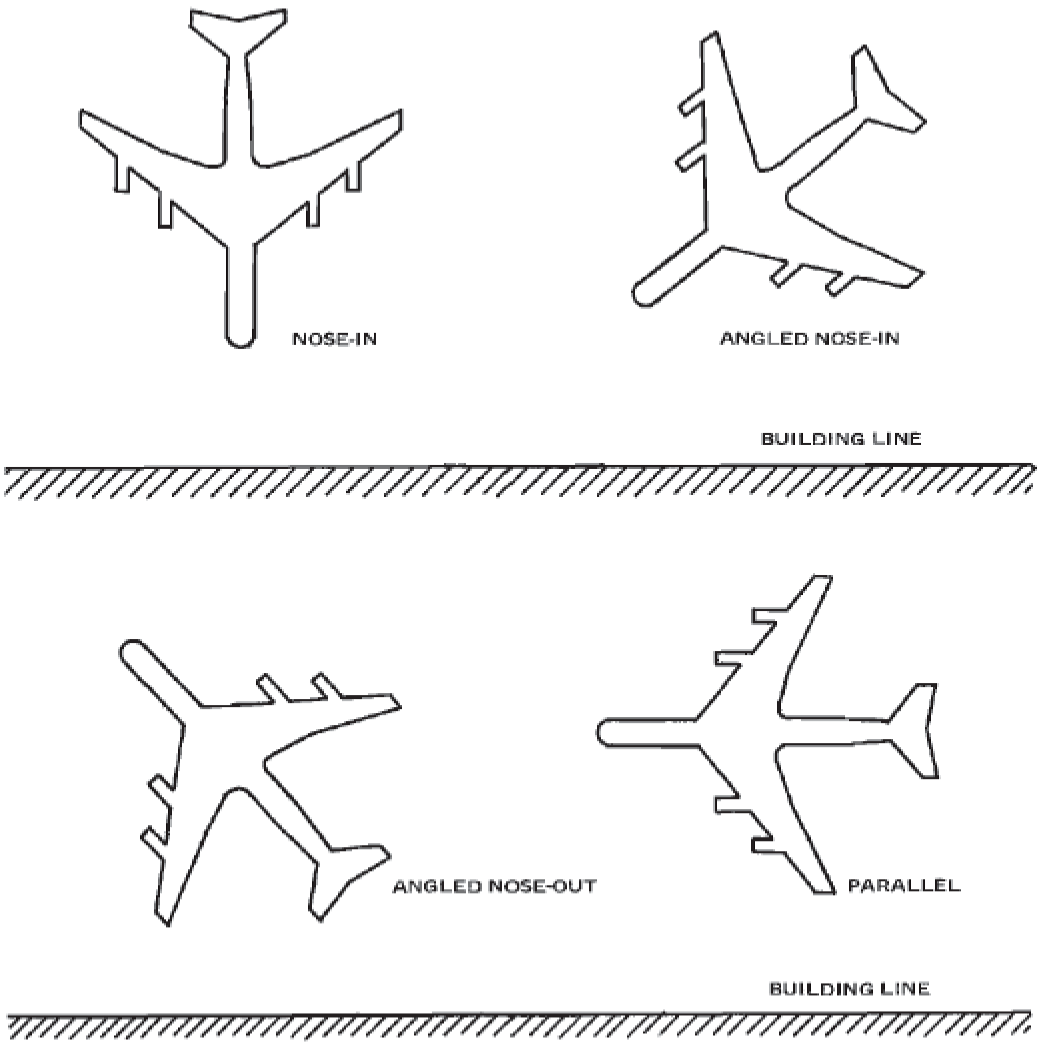


Figure 9: Parking Layouts

3.2.4 Airport Basic Runway Layouts

A description of four possible basic airport runway layouts is provided in order to have an idea on airport capacity as well as GROUND and TOWER coverage. **Airport capacity** or size is directly **linked to its runway layout** and configuration.

While obviously not every airport in Europe or US may have an exact layout complying to the descriptions beneath, all existing airport layouts are actually considered slight variations of these basic configurations.

Each of the presented configurations is associated with its respective estimated operational capacity (expressed in an amount of operations/hour).

When considering the expected airport coverage and capacity requirements linked to each of these basic layouts, the reader should be aware that – besides the category the airport belongs - the airport coverage/capacity is also determined by following factors :

1. A/C traffic mixes at the airport such as IFR/VFR flights, cargo / passenger flights, ..etc.
2. Airport Terminal Layout
3. Installed navigation aids at each runway end (GBAS, ILS – GLS, MLS,…etc)
4. Prevailing winds and wind directions limiting airport operational capacity for open V type runways as well as intersecting runway type.
5. Aircraft type: ranging from light to widebody A/C frames.

Although these configurations show only runways - and AeroMACS targets mainly taxiways under GROUND coverage – large parts of these taxiways are most of the time running in parallel with the runways.

3.2.4.1 Single Runway Configuration

This is the simplest of the 4 basic configurations. It is one runway optimally positioned for prevailing winds, noise, land use and other determining factors. During VFR (visual flight rules) conditions, this one runway should accommodate up to 99 light aircraft operations per hour. While **under IFR** (instrument flight rules) conditions, it would **accommodate between 42 to 53 operations per hour** depending on the mix of traffic and navigational aids available at that airport.

Figure 10: Single Runway

3.2.4.2 Parallel Runway Configuration

There are 4 types of parallel runways. These are named according to how closely they are placed next to each other. Operations per hour will vary depending on the total number of runways and the mix of aircraft. In IFR conditions for predominantly light aircraft, the number of operations would range between **64 and 128** per hour.

For predominantly **medium and heavy aircraft, the number of operations would be between 50 and 70 per hour, in function of the traffic mix**. Amount of operations will be determined by MTOW|MTOM class separation minima – see further in this document.

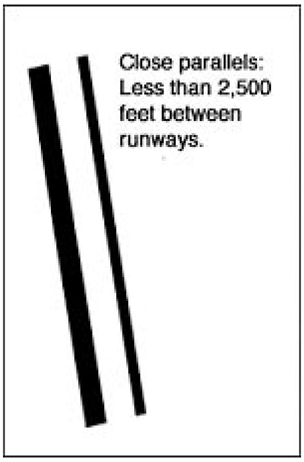


Figure 11: Close Parallel Runways

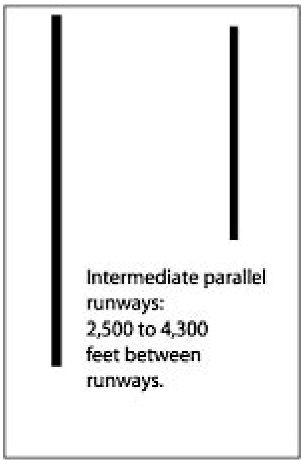


Figure 12: Intermediate Parallel Runways

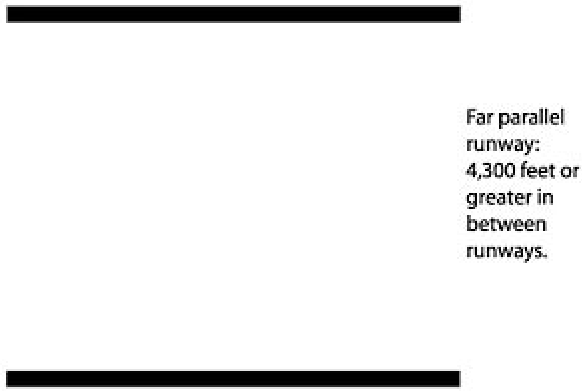


Figure 13: Far Parallel Runways

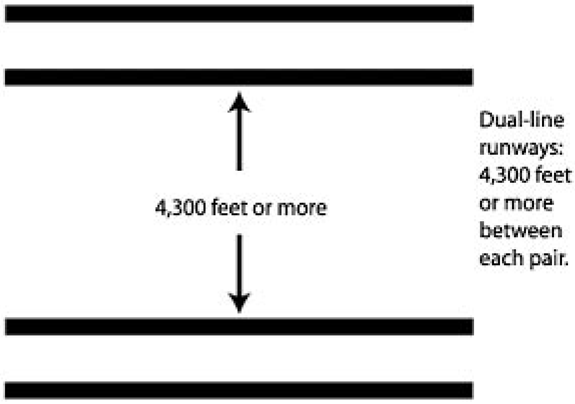


Figure 14: Dual Line Parallel Runways

With four parallel runways, expected airport capacity may be **larger than 100 operations** (all IFR / medium, heavy, super heavy) per hour and in function of navigation aids installed at these runways.

3.2.4.3 Open –V Runway Configuration

Two runways that diverge from different directions but do NOT intersect form a shape that looks like an "open-V" are called open-V runways. This configuration is useful when there is little to no wind as it allows for both runways to be used at the same time. When the winds become strong in one direction, then only one runway will be used. When takeoffs and landings are made away from the two closer ends, the number of operations per hour significantly increases. When takeoffs and landings are made toward the two closer ends, the number of operations per hour can be reduced by 50%.

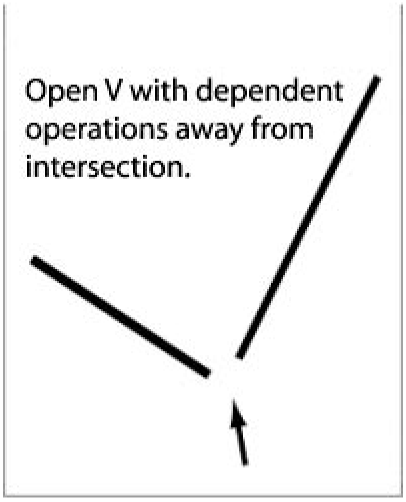


Figure 15: Open-V Runways

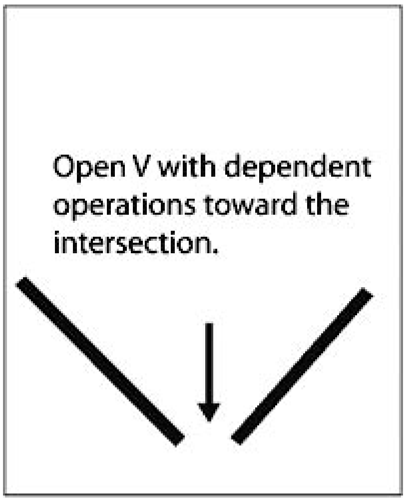


Figure 16: Open-V Runways mvts Towards Intersection

3.2.4.4 Intersecting Runway Configuration

Two or more runways that cross each other are classified as intersecting runways. This type of configuration is used when there are relatively strong prevailing winds from more than one direction during the year. When the winds are strong from one direction, operations will be limited to only one runway. With relatively light winds, both runways can be used simultaneously. The greatest capacity for operations is accomplished when the intersection is close to the takeoff end and the landing threshold as shown below.

The capacity for the number of operations varies greatly with this runway configuration. It really depends on the location of the intersection and the manner in which the runways are operated (IFR, VFR, aircraft mix). This type of configuration also has the potential to use a greater amount of land area than parallel runway configurations.

Because also for this type of runway, wind directions play an important role, no capacity estimation is provided so airport capacity should be determined for any such particular airport individually.

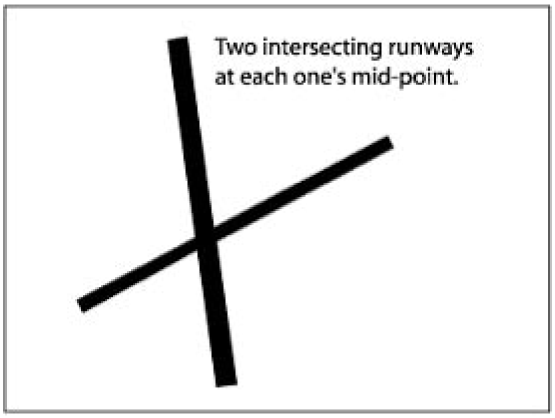


Figure 17: Intersecting Runways

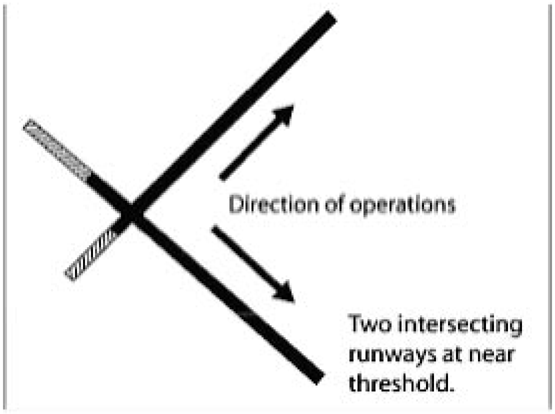


Figure 18: Intersecting Runways near Threshold

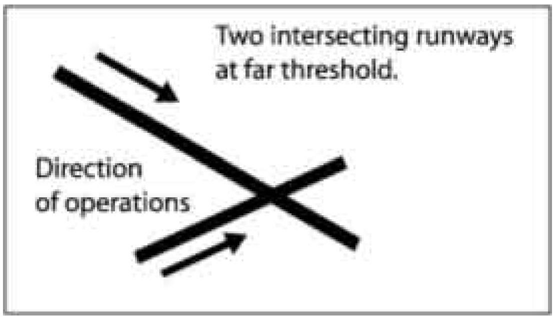


Figure 19: Intersecting Runways far Threshold

3.3 AeroMACS Services

This section covers the list of services to be supported by AeroMACS (a revision and a refinement on WA2 work has been carried out). Service instantiation deemed and description for an operational landing, turnaround and take off procedure is shown. The description will settle the basis for the ongoing simulations of AeroMACS deployment (see section 3.5). One step further, WA2 inputs for QoS figures, continuity, integrity and availability have been gathered in order to move on. A proposal of several QoS levels to support AeroMACS services is foreseen. In addition, the mapping between different levels of QoS (application, IP and AeroMACS) has been addressed.

3.3.1 Operational concept

This section aims to refine the Traffic Model for AeroMACS developed in [6] by describing the instantiation of the service sequence in time. This is done by defining the operational use of AeroMACS in the departure and arrival phases in airport surface and mapping the service list to the chronological description of these operations. Previous work carried out in [1][10][27] is taken as a reference and characterised for AeroMACS.

When an aircraft executes its complete operation cycle in an airport, both arrival and departure phases are completed. During a given period between these, the aircraft is in turn-around phase, but this is considered just as a physical status of the aircraft and not an operational phase here since it does not define a separation between arrival and departure.

Thus, arrival sequence finishes when all the related services are completed. Departure sequence will not start until the previous arrival is correctly finished. This will happen at an undetermined moment between door opening and closure. All the pre-departure sequence and related services are considered as departure.

The figure below depicts the time evolution of the operational phases and events considered in this analysis. Time events [46] establish the start and end of the operation periods. Operation periods are executed in specific operational domains (RAMP, GROUND, TOWER), which can be managed by different type of controllers and, as thus, define a different set of executed ATC/AOC/NET services.

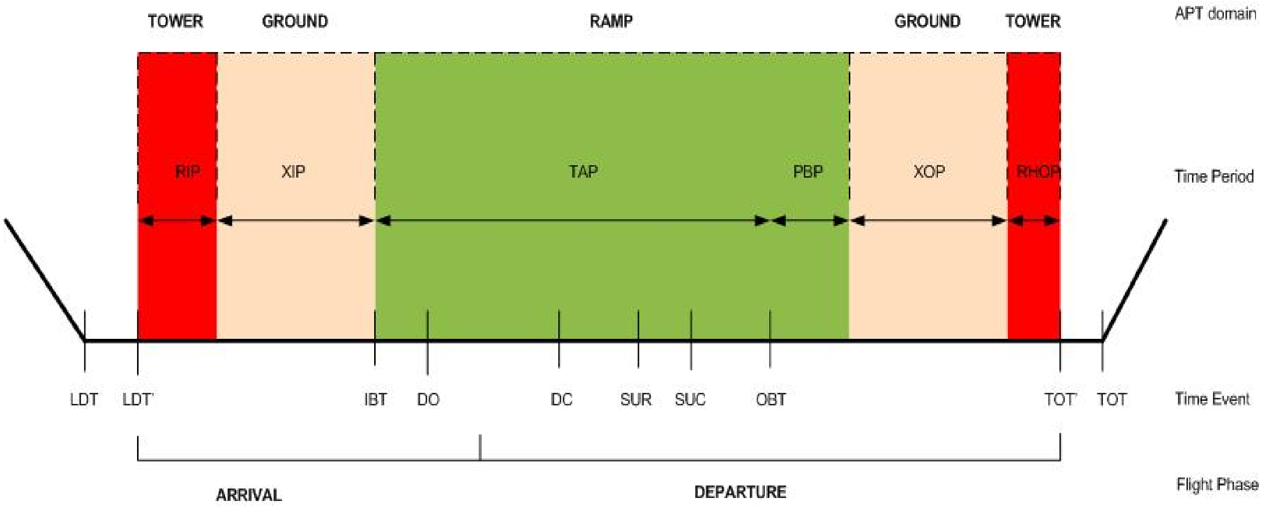


Figure 20: Flight phases and events in APT surface

Time events are explained below:

- LDT: Landing Time. Event at which the aircraft wheels touch down the runway.
- LDT': Landing Time for AeroMACS. It stands for the instant at which the aircraft moves below the maximum speed supported by AeroMACS (50 knots).
- IBT: In-Block Time. Event at which the aircraft stops moving at the stand.
- DO: Doors Open. Disembark can start, arrival phase can finish.
- DC: Doors Close. Departure phase has already started, boarding has finished.
- SUR: Start-up Request. Aircraft is ready to block off, waiting for ATSU permission.
- SUC: Start-up Clearance. ATSU permission delivered.
- OBT: Off-Block Time. Event at which the aircraft starts moving off the stand.
- TOT': Take Off Time for AeroMACS. It stands for the instant at which the aircraft is expected to move over the maximum speed supported by AeroMACS (50 knots)
- TOT: Take Off Time. Event at which the aircraft wheels off the runway.

Time periods are explained below:

- RIP: Runway-In Period. The aircraft moves within and out of the runway after landing.
- XIP: Unimpeded Taxiing-In Period. Aircraft moves by its own means from the landing runway to the assigned stand.
- TAP: Turn Around Period. The aircraft stays at the gate and is serviced for post-arrival and pre-departure operations.
- PBP: Push-Back Period. The aircraft is moved back by a tug from the stand to a position in which it can proceed to taxiing.
- XOP: Unimpeded Taxiing-Out Period. Aircraft moves by its own means from the stand to the assigned take-off runway.
- RHOP: Runway Holding and Out Period. It includes the likely Runway Holding (RHP) plus the runway out movement itself.

The services included in the study gather the subset of services from [6] deemed applicable in an operational scenario in airport surface that is covered by AeroMACS system. The service model has not been limited to those used to guarantee safety of life and regularity of flight, but also operational control services have been included in order to test the technology for the support of this traffic and facilitate the future aggregation of services in the same pipeline.

- Air Traffic Services (ATS) include Air Traffic Control, Flight Information services and Alerting service. These services are provided by Air Traffic Service Units (ATSUs) performing specific ATS services. Communications, navigation and surveillance on the ground and in the aircraft support these ATS services. The ATS categories applicable to airport surface are the following:
    - Data Communications Management Services (DCM). These involve Data Link Logon and ATC Communication Management.
    - Clearance / Instruction Services (CIS). These involve ATC Clearance, Departure Clearance, Data Link Taxi and Common Trajectory Coordination.

- Flight Information Services (FIS). These involve Data Link Operational Terminal Information Service, Significant Meteorological Information, Runway Visual Range and Surface Information and Guidance.

- Flight Position / Intent / Preferences Services (FPS). These involve Surveillance, Flight Plan Consistency and Intent, and Pilot Preferences Downlink.

- Emergency Information Sevices (EIS). This involves Data Link Alert.

According to WG78 naming [10], the services can be categorized in a different manner. These are explained below:

- Context Management (CM). The functions of CM are Contact, Logon and Update. CM ground systems can be configured to operate either in their domain of responsibility or for a facility outside their domain.

- Controller Pilot Data Link Communications (CPDLC). The CPDLC functions required are Controller-pilot message exchange function, transfer of data authority function and downstream clearance function.

- Automatic Dependent Surveillance (ADS-C). The functions of ADS-C include the following functions: demand, event, periodic, cancel contracts and operation in emergency/urgency mode. The ATSUs are capable of requesting different types of contracts, and the aircraft system elements are capable of providing ADS-C reports to support the contract requests.

- Digital Flight Information Services (D-FIS). Flight Information Services is an ATS application by which the flight crew can retrieve operational data from an ATSU System providing flight information services. These encompass meteorological and various other information which may affect the departure, approach and landing flight phases as well as surface operations.

- Aeronautical Operational Control (AOC) are services that involve data communication between the aircraft and the AOC centre, company or operational staff at an airport.

  - Legacy AOC (L-AOC). This category contains AOC data communication services that are expected to be in use during Phase 1 and Phase 2 and were listed in COCRv2 [1].

  - Electronic Flight Bag (EFB). This category includes the additional services other than UPLIB that were not part of the COCRv2. EFB is an electronic information management device that replaces current paper-based flight bag by including and updating electronic manuals and documents, automated calculation and navigation tools. The included services can be categorized as EFB hosted services in 2020, however other implementations of the same service on different platforms are also possible [1].

  - Sporadic (S) services. These are specific L-AOC or EFB services that have a limited instantiation, i.e. they are executed seldom in a departure/arrival phase (instance probability lower than 10% [6]). They involve software or chart update on the FMS system in the aircraft, action that is executed after a given number of flights, with a subsequent heavy load transfer. They will be included in a worst-case scenario in which an aircraft requires a complete update of the system.

- Network Management (NET). These services are used to establish and maintain connections between each pair of aircraft and ground systems.

Below the list of services executed in an orderly and categorized manner is proposed for the analysis in both phases of study (departure and arrival). This list is the basis to build the per-scenario service model defining the chronological execution. Categorization and chronology will also be used to drive the classification of service model applied to quality of service (QoS) politics.

Operational domain execution	Service		Category	Application FRS data services [1] [27]	Application WG78 ATS services [10]	Directionality
RAMP	NETCONN	Network connection	NET	NET	-	G ↔ A/C
	NETKEEP	Network keep-alive	NET	NET	-	G ↔ A/C
	DLL	Data Link Logon	ATC	DCM	CM [2]	G ↔ A/C
	AOCDLL	Airport Operational Center Data Link Logon	AOC	L-AOC	-	G ↔ A/C
	LOADSHT	Load Sheet Request/Transfer	AOC	L-AOC	-	G ↔ A/C
	E-CHARTS	e-Charts Update	AOC	EFB (S)	-	G → A/C
	UPLIB	Update Electronic Library	AOC	L-AOC (S)	-	G → A/C
	SWCONF	Software configuration management	AOC	EFB	-	G ↔ A/C
	SWLOAD25	Software Loading (Part 25)	AOC	EFB (S)	-	G → A/C
	SWLOAD	Software Loading	AOC	L-AOC (S)	-	G → A/C
	BRFCD	Aircraft Briefing Cards	AOC	EFB	-	G → A/C
	ACLOG	Aircraft Technical Log Rectification	AOC	EFB	-	G ↔ A/C
	TECHLOG	Technical Log Book Update	AOC	L-AOC	-	G ↔ A/C
	AIRWORTH	Airworthiness Statement	AOC	EFB	-	G → A/C
	WXTEXT	Textual Weather Report	AOC	L-AOC	-	G ↔ A/C
	PASSENGER	Passenger Information List/Manifest	AOC	EFB	-	G → A/C
	CREW-RPS	Crew rotation/planning/scheduling	AOC	EFB	-	G → A/C
	CREW-BUL	Crew Briefings/Bulletins	AOC	EFB	-	G → A/C
	CREW-REG	Flight Crew Recency Registration	AOC	EFB	-	G ← A/C
	FLTPLAN	Flight Plan Data	AOC	L-AOC	-	G ↔ A/C
	NOTAM	Company's Notice to Airmen	AOC	EFB	-	G → A/C

[2] This service is named Data Link Initiation (DLIC) in WG78 documentation [10]

Operational domain execution	Service		Category	Application FRS data services [1] [27]	Application WG78 ATS services [10]	Directionality
	COTRAC (interactive)	Common Trajectory Coordiantion	ATC	CIS	CPDLC	G ↔ A/C
	EFF	Electronic Flight Folder Exchange	AOC	EFB	-	G ↔ A/C
	WXGRAPH	Graphical Weather Information	AOC	L-AOC	-	G ↔ A/C
	CREW-L	Crew list	AOC	EFB	-	G → A/C
	HANDLING	Handling process Monitoring	AOC	EFB	-	G ← A/C
	CATERING	Catering inventory	AOC	EFB	-	G ← A/C
	BAGGAGE	Baggage Loading	AOC	EFB	-	G ↔ A/C
	NOTOC	Notice to Captain	AOC	EFB	-	G → A/C
	LOADDOC	Load documentation Acceptance	AOC	EFB	-	G ← A/C
	PREFLT-INS	Pre-Flight Inspection Signoff	AOC	EFB	-	G ← A/C
	D-OTIS	Data Link Operational Terminal Information Service	ATC	FIS	D-FIS	G ↔ A/C
	D-SIGMET	Data Link Significant Meteorological Information	ATC	FIS	D-FIS [3]	G ↔ A/C
	DOOR	Aircraft Door movements	AOC	EFB	-	G ← A/C
	DCL	Departure clearance	ATC	CIS	CPDLC	G ↔ A/C
	FLOWCON	Flow Control (CTOT & Routing)	AOC	EFB	-	G ↔ A/C
	FLIPCY	Flight Plan Consistency	ATC	FPS	-	G ↔ A/C
	FLIPINT	Flight Path Intent	ATC	FPS	-	G ↔ A/C
	D-RVR	Data Link Runway Visual Range	ATC	FIS	D-FIS	G ↔ A/C
	D-SIG	Data Link Surface Information and Guidance	ATC	FIS	-	G ↔ A/C
	EFFU	Electronic Flight Folder Update	AOC	EFB	-	G ↔ A/C
	TAKEOFF-CALC	Takeoff Performance Calculation	AOC	EFB	-	G ↔ A/C
	D-FLUP	Data Link Flight Update	ATC	AVS	-	G ↔ A/C
	PPD	Pilot preferences downlink	ATC	FPS	-	G ↔ A/C

[3] This service is included inside Hazardous Weather service (D-HZWX) in WG78 documentation [10]

Operational domain execution	Service		Category	Application FRS data services [1] [27]	Application WG78 ATS services [10]	Directionality
	D-TAXI	Data Link Taxi Clearance	ATC	CIS	CPDLC	G ↔ A/C
	OOOI	Out-Off-On-In	AOC	L-AOC	-	G ← A/C
GROUND	SURV	Air Traffic Control Surveillance	ATC	FPS	ADS-C [4]	G → A/C
	ACL	ATC clearance	ATC	CIS	CPDLC [5]	G ↔ A/C
	ACM	ATC Communication Management	ATC	DCM	CPDLC	G ↔ A/C
TOWER	WXRT	Real Time Weather Reports for Met Office	AOC	L-AOC	-	G ← A/C
	OOOI	Out-Off-On-In	AOC	L-AOC	-	G ← A/C
	ACM	ATC Communication Management	ATC	DCM	CPDLC	G ↔ A/C

Table 5: Services executed during departure phase

Operational domain execution	Service		Category	Application FRS data services [refCOCR] [refAOCstudy]	Application WG78 ATS services [refSPR]	Directionality
TOWER	OOOI	Out-Off-On-In	AOC	L-AOC	-	G ← A/C
	NETKEEP	Network keep-alive	NET	NET	-	G ↔ A/C
	AUTOLAND-REG	Autoland Registration	AOC	EFB	-	G ← A/C
	ACM	ATC Communication Management	ATC	DCM	CPDLC	G ↔ A/C
GROUND	SURV	Air Traffic Control Surveillance	ATC	FPS	ADS-C [6]	G → A/C
	ACL	ATC clearance	ATC	CIS	CPDLC	G ↔ A/C
	D-SIG	Data Link Surface Information and Guidance	ATC	FIS	-	G ↔ A/C
	D-TAXI	Data Link Taxi Clearance	ATC	CIS	CPDLC	G ↔ A/C
	EFFU	Electronic Flight Folder Update	AOC	EFB	-	G ↔ A/C
	FLT-JOURNAL	Flight Journal Documentation	AOC	EFB	-	G ← A/C
	TECHLOG	Technical Log Book Update	AOC	L-AOC	-	G ↔ A/C
	CREW-TIME	Flight Deck Duty Time Registration	AOC	EFB	-	G ← A/C
RAMP	OOOI	Out-Off-On-In	AOC	L-AOC	-	G ← A/C
	FOQA	Data Transfer (DFDR/QAR bulk data download)	AOC	EFB	-	G ← A/C
	FLTLOG	Flight Log Transfer	AOC	L-AOC	-	G ← A/C
	CABINLOG	Cabin Log	AOC	L-AOC	-	G ← A/C
	ETS-REPORT	Post flight report required for ETS (Emissions	AOC	EFB	-	G ← A/C

[4] Equivalent to Position Report (PR) in WG78 documentation [10]
[5] This service is named Clearence Request and Delivery (CRD) in WG78 documentation [10]
[6] Equivalent to Position Report (PR) in WG78 documentation [10]

Operational domain execution	Service		Category	Application FRS data services [refCOCR] [refAOCstudy]	Application WG78 ATS services [refSPR]	Directionality
		Trading Scheme)				
	REFUEL	Fuel ordering (Tickets) / Fuel Release	AOC	EFB	-	G ← A/C
	ACM	ATC Communication Management	ATC	DCM	CPDLC	G ↔ A/C

Table 6: Services executed during arrival phase

3.3.2 Service instantiation

Not all services in departure phase are executed in every operation. As it can be checked in [6], services such as E-CHARTS, UPLIB, SWLOAD and SWLOAD25 have a low instance probability and a very high load in channel, so different scenarios need to be simulated. In this previous description, a complete set of possible services is depicted.

During operations, some services may be executed simultaneously but others need to wait previous services to have finished thus a chronological order of implementation need to be defined. The latter are defined as sequential services that require a correct finalisation of previous services that represent previous necessary actions that involve the pilot and the ATC or AOC operator. This model is depicted in the figures below.

Note that surveillance (SURV) service has been included in this hypothetical sequence scenario. Although not a primary use of AeroMACS, the data link can be considered an enabler for message exchange between ground and aircraft that supports ADS-C and ADS-B services. As so, this service will be included and simulated in this analysis in order to test the ability of AeroMACS to provide it.

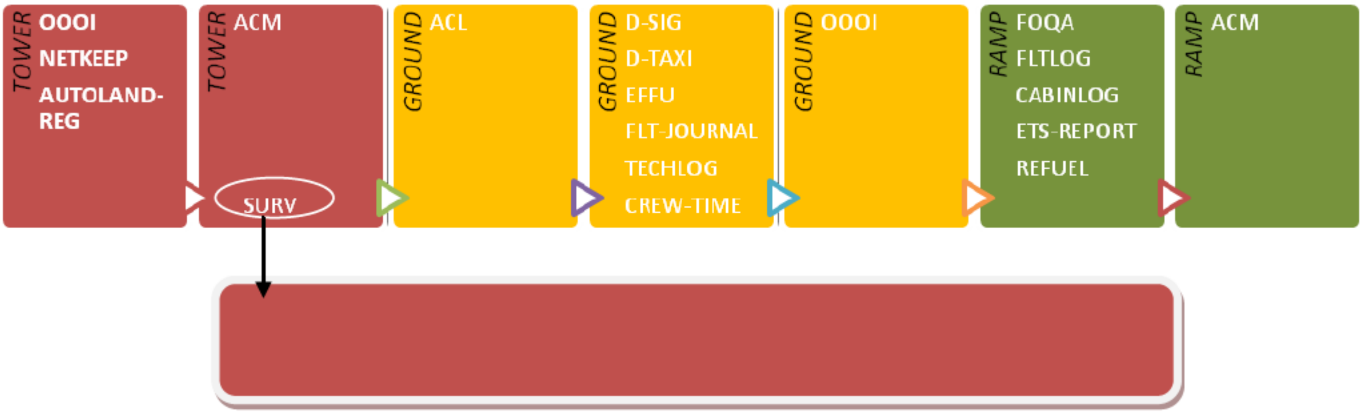


Figure 21: Sequential execution of services in arrival

Figure 22: Sequential execution of services in departure

3.3.3 QoS model

Every service needs to be mapped to a Class of Service (CoS). Each CoS will be treated differently per service flow by AeroMACS, by guaranteeing a maximum latency or minimum throughput. This leads to prioritization politics in AeroMACS transmission queues, by optimizing the packet sending rate that covers all the service class policy.

QoS model proposed in this analysis is based on the two existing references that are applicable to AeroMACS, namely:

1. ICAO 9896 [11] provides a recommendation to support legacy ATN applications over the IPS, mapping ATS services to proposed CoS (very High, High, Normal and Best Effort), shown below.

2. SESAR 15.2.7 System Requirements Document (SRD) [3]. The classification required for AeroMACS can be depicted in the table below. This service categorization has been extracted from COCRv2 and SJU AOC service studies.

Priority/Application Mapping			Traffic Identification (Ingress)		
Class (CoS Type)	Drop Precedence	ATN Priority	ATN Application	TCP/UDP Port	IP Address
Very High (EF)			Voice (VoIP)	RTP numbers 16384-32767	-
High (AF)	1	0	-	-	-
		1	-	-	-
		2	-	-	-
		3	ADS-C	TCP 5913 UDP 5913	The source or destination address will be part of a reserved address space assigned to mobile service providers
			CPDLC	TCP 5911 UDP 5911	
Normal (AF)	1	4	AIDC	TCP 8500[1]	
			FIS(ATIS)	TCP 5912 UDP 5912	The source or destination address will be part of a reserved address space assigned to mobile service providers
	2	5	METAR	-	-
	3	6	CM(DLIC)	TCP 5910 UDP 5910	The source or destination address will be part of a reserved address space assigned to mobile service providers
			ATSMHS	TCP 102	
		7			
Best Effort (Default)		8 - 14	-	-	

Table 7: ATN/IPS priority mapping into classes proposed by [11]

Subscribers	**Priority 1 (highest)**	**Priority 2**	**Priority 3**	**Priority 4**	**Priority 5**	**Priority 6**
Aircraft	NET services	ATS 1	ATS 2	ATS 3	AOC 1	AOC 2
Surface vehicles	NET services		ATS2	ATS 3	Surface operation	

Table 8: 15.2.7 SRD prioritization table [3]

The CoS classification used in this analysis can be seen below. It is based on the basic SRD classification, and ICAO recommendation is taken as guidance to define the mapping for ATS services. These have been classified in three categories according to the application they are part of. The link with SESAR 15.2.7 WA2 defined CoS [6] is shown.

Regarding AOC, they have been classified into the two existing categories according to the load/latency requirement ratio as well as the 15.2.7 WA2 CoS. Hence, a priority AOC category covers services that transmit a low amount of information in a reduced time normally related to clearances and reports. The lowest AOC category involves transfer of high amount of information (e.g. updates, files, etc) and is aimed to be executed in the background with the remaining free bandwidth.

CoS	Services included	Equivalent WA2 CoS
NET	NET services • NETKEEP, NETCONN	DG-A
ATS1	FPS by ADS-C • SURV	DB-D
ATS2	CIS (CPDLC) • ACL, COTRAC, DCL, D-TAXI FPS • FLIPCY, FLIPINT, PPD	DG-C DG-D
ATS3	DCM • DLL, ACM FIS • D-OTIS, D-SIGMET, D-RVR, D-SIG AVS • D-FLUP	DG-C DG-D DG-F
AOC1	• AOCDLL, CABINLOG, FLTLOG, FLTPLAN, LOADSHT, OOOI, TECHLOG, WXGRAPH, WXRT, WXTEXT, BRFCD, DOOR, ACLOG, AIRWORTH, AUTOLAND-REG, BAGGAGE, NOTAM, CATERING, CREW-L, CREW-RPS, CREW-BUL, CREW-REG, CREW-TIME, FLOWCON, REFUEL, HANDLING, LOADDOC, NOTOC, PASSENGER, PREFLT-INS, TAKEOFF-CALC	DG-J DG-K
AOC2	• SWLOAD, UPLIB, EFF, EFFU, E-CHARTS, FLTJOURNAL, FOQA, SWLOAD25, SWCONF	DG-K DG-L

Table 9: CoS classification for Airport Capacity Analysis

This model for CoS will be taken as hypothesis to develop the QoS configuration in Capacity Analysis study. Regarding the requirements set by each CoS, service flows and QoS parameters will be defined at the radio link to be compliant with the required figures.

3.4 AeroMACS BS Installation and Deployment Requirements

P15.2.7 SRD [3] defines that AeroMACS shall operate with aircraft moving with maximum speeds of up to 50 knots. However, AeroMACS may work at higher speed depending on manufacturer solution and operational conditions and provided it remains compatible with safety and performance requirements related to Datalink services.

Only these airport areas - where Doppler effects created on MS are corresponding to Doppler effects created by a MS moving either directly towards or directly away from the BS at speeds of up to 50 knots – shall be covered. Note: only the radial component of motion vis-à-vis the BS induces Doppler.

Attached is a list of general BS installation and deployment requirements.

R-INST-DEP-01. AeroMACS BS deployment locations shall comply to ICAO Annex 14, chapter 4.

R-INST-DEP-02. AeroMACS BS deployment locations shall comply to ICAO PANS-OPS 8168.

R-INST-DEP-03. AeroMACS BS shall be deployed in such a way that a maximum of A/C within a cell shall operate under Line of Sight (LOS) conditions.

R-INST-DEP-04. AeroMACS BS antenna mounting heights above metallic terminal roofs shall be avoided, especially these at close range. This to keep interference to Globalstar within limits.

R-INST-DEP-05. AeroMACS antenna installations (BS and MS) shall always use vertical antenna polarisation.

R-INST-DEP-06. Where possible and in order to decrease AeroMACS interference to Globalstar, AeroMACS BSs antenna shall be installed having a small downtilt (2 to 6 degrees) angle.

R-INST-DEP-07. In order to avoid polarisation losses the down tilt angle of the BS shall not be larger than 6 degrees.

R-INST-DEP-08. AeroMACS BS shall be mounted on existing airport infrastructure (buildings, towers, lighting infrastructure, ..etc) wherever feasible (while fulfilling both coverage and throughput requirements) to keep airport installation cost minimal.

R-INST-DEP-09. AeroMACS BS site deployment shall be such that there will be minimal cellular coverage overlap. (Note: In order to keep interference with Globalstar to a minimum, AeroMACS will not implement dual coverage during airport cell planning phases – hence both ATC and AOC traffic will use the same frequency).

R-INST-DEP-10. AeroMACS BS site deployment shall be such that overlap with adjacent BS – both operating under QPSK conditions is kept to a minimum at TOWER and GROUND areas which are further than 500 m away from Gates.

R-INST-DEP-11. AeroMACS BS site deployment shall be such that hand over under normal RF conditions is always possible.

R-INST-DEP-12. AeroMACS BS site deployment shall be optimised in such a way that LOS conditions prevail on most of BS cell coverage under normal (non blocking) airport operating conditions and this for every airport the BS is intended to serve (taking into account A/C heights at the gates / stands).

R-INST-DEP-13. AeroMACS BS site deployment shall ensure the largest data rate throughput at the RAMP area.

R-INST-DEP-14. AeroMACS BS site deployment at the airport´s RAMP area shall target 64 QAM operation for DL under all RF conditions with the exclusion of temporary RF blocking by large object movements. .

R-INST-DEP-15. AeroMACS BS site deployment at the airport´s RAMP area shall target 16 QAM operation for UL (if path loss conditions allow).

R-INST-DEP-16. AeroMACS medium data rate (16 QAM operation) throughput shall be made available at large part (close to gates) of the airport GROUND area.

R-INST-DEP-17. AeroMACS BS site deployment at the airport´s GROUND area shall ensure 16 QAM operations for both DL and UL under all RF conditions (except during RF blocking by e.g. A/C tail) and this within a range of 500 m around terminal buildings.

R-INST-DEP-18. AeroMACS lowest data rate throughput (QPSK) shall be made available at the airport´s TOWER area for both UL and DL.

R-INST-DEP-19. AeroMACS cell planning shall try to locate its BS's, covering GROUND area, in such a way that Doppler effects due to moving MS are minimised.

R-INST-DEP-20. AeroMACS cell planning shall be such that at remote GROUND and TOWER areas, the MS is able to synchronize under normal propagation conditions.

3.5 Airport Coverage and Capacity Requirements

3.5.1 Inputs to Coverage and Capacity Requirements

AeroMACS Coverage and Capacity requirements are function of many different parameters- listed below- and which will be addressed in succeeding paragraphs.

Airport Parameters to be considered are:

1. Airport Terminal Layout type (already described).
2. Airport Parking Layout type (already described).
3. Type of Basic Airport Runway Layout (already described).
4. Airport visiting A/C frame types and corresponding traffic mix (MTOW category: light – medium – heavy, mixed traffic, … etc).
5. Within each airport different areas exist which need to be covered by AeroMACS. However these areas have different capacity needs.
6. Aircraft (MS) antenna heights with respect to ground.

3.5.1.1 Amount of Gates and Stands

The total airport capacity is also determined by the amount of gates where A/C can be docked as well as the amount of A/C stands which are foreseen at the airport. Hence this factor will also determine the AeroMACS capacity needed at the airport.

3.5.1.2 Airport Areas Definitions

Under P15.2.7 WA2 D2.2a [6], a traffic model for airports has been developed. This document follows an identical airport area distribution as developed in [4], which every A/C passes through during either departure or arrival phase of flight. These areas are defined in section 3.1.

AeroMACS coverage requirements at an airport are also determined by the size of previously defined areas for this airport.

3.5.1.3 Airport visiting A/C frame types and airport traffic mix

Because runway capacity has the largest impact on overall airport capacity it is important to notice that for any particular airport considered – irrespective of the basic category it belongs to - its runway capacity is also determined by the type of traffic and /or traffic mix this airport is attracting.

An airport attracting many light aircraft will have a larger capacity compared to an identical airport attracting mainly heavy (commercial A/C – widebodies – 100+ passenger A/C) aircraft. This is because the WAKE VORTEX created by these large aircraft is so large that the interval times between landings (as well as for departures) depend on the A/C size and weight.

ICAO mandates separation minima based upon wake vortex categories that are, in turn, based upon the Maximum Take Off Mass (MTOW|MTOM) of the aircraft.

These minima are categorized as follows:

- Light – MTOW of 7,000 kilograms or less.
- Medium – MTOW of greater than 7,000 kilograms, but less than 136,000 kilograms.
- Heavy – MTOW of 136,000 kilograms or greater.

Note: a new category named SUPER is created by for very large heavy weight such as A380.

During take off phase the following rules are applicable:

-An aircraft of a lower wake vortex category must not be allowed to take off less than two minutes behind an aircraft of a higher wake vortex category.

- If the following aircraft does not start its take off roll from the same point as the preceding aircraft, this is increased to three minutes.

During landing phase the following separation minima shall be respected as indicated in the table below.

Preceding aircraft	Following aircraft	Minimum radar separation
Super	Super	4 NM
	Heavy	6 NM
	Medium	7 NM
	Light	8 NM
Heavy	Heavy	4 NM
	Medium	5 NM
	Light	5 NM
Medium	Light	4 NM

Table 10: A/C separation minima

3.5.1.4 Aircraft frame antenna heights from ground

In order to provide good coverage, it is important to know for some of the most popular commercial aircraft frames the AeroMACS antenna height with respect to the ground surface.

The following table provides a short overview of these heights:

AIRCRAFT FRAME TYPE	AeroMACS Antenna height (m)[7]
A 318	5,9
A 320	5,91
A 340-500	7,55
A 330-200	8,22
A 380	10,74
A 350-900	8,09
B 737-300/400/500	5,26
B 757	6,24 – 6,5
B 767	7,16 – 7,47
B 787	7,63 – 8,00
B 777	8,46 - 8,78
B 747	10,06

Table 11: Airframe heights with respect to ground

3.5.1.5 Traffic Modelling and Scenario Definition

TRAFFIC MODELLING: From previous Traffic Modelling [6] deliverable, a total estimation has been made for all NET, ATC and AOC services to be delivered on a complete airport. For this estimation, the airport had been divided in the three defined airport areas as specified in 3.1. For all these areas, different scenarios were provided in function of the amount of A/C at the airport.

SCENARIO DEFINITION: The number of A/Cs stated in each scenario is in "average" the number of A/Cs spread all over the airport in a given time "t" for the simulations. Such an average value however includes landing as well as departing A/Cs. Nevertheless, numbers depicted for data rates tables 5-1 and 5-2 in [6] apply to the specific zone indicated in the scenario description.

During a second simulation the average load for NET, ATC and AOC had been calculated for a single sector scenario. Once again different scenarios have been provided based on the total amount of A/C at an airport.

Important Notice: During WA2 traffic modelling FOQA had only been included in GROUND scenario (UL Traffic). For all other scenarios FOQA had not been included. Because this work is based on previous delivered simulation results, we have also excluded FOQA from all scenarios with the exception of the GROUND one.

SCENARIO – A/C DWELL TIME RELATIONSHIP: The reader of the traffic analysis should be aware that the number of A/C described in any scenario also has to take into account the average dwell time an A/C stays in the areas described within this document. These dwell times are gathered in the table beneath (see also COCR V2 for airport description).

Airport density and area	RAMP dwell time in min	GROUND dwell time in min	TOWER dwell time in min
HD Phase 2 Departure	30 m	12 m	4,5 m
HD Phase 2 Arrival	6 m	8 m	4,5 m

[7] Heights may fluctuate around 0,3 m depending on A/C load conditions.

LD Phase 2 Departure	15 m	6 m	2,5 m
LD Phase 2 Arrival	3 m	4 m	2,5 m

Table 12: A/C Dwell times vs A/C airport operation areas

Hence it is important to notice that the average amount of time an A/C is residing at an area - as described in the scenarios - is defined by the dwell time at these areas. Because airport capacity is determined in an amount of operations/movements per hour, the dwell times need to be converted or linked to operations per hour.

AIRPORT CAPACITY VERSUS SCENARIO INTERPOLATION: Within the SANDRA and SESAR P15.2.7 WA 2 tasks, several airport scenarios have been taken into account to make data load requirements estimation. For this several scenarios have been worked out but it is clear that they may not all fit exactly all possible existing European airport size. Hence there may be a need to perform some extrapolations in between scenarios to match a particular airport.

ASSUMPTIONS ON TRAFFIC MIX: Because runway capacity as well as data load requirements depend heavily on the airport traffic mix, it is assumed that the majority of traffic (>95%) visiting the airports belong mainly to ***commercial aircraft (medium and heavy MTOW)*** class with few business flights (light), all traffic operating ***under IFR rules***.

AeroMACS DL (BS) and UL (A/C or MS) supported Data loads: The following table provides an overview of AeroMACS data throughput capacity for a single cell or sector (DL/UL = 2/1). These figures were drawn beforehand simulations perform for this WA (see Appendix F).

MC scheme	Downlink [kbps]	Uplink [Kbps]
QPSK1/2	983.3	532.4
16QAM1/2	2153.52	1235.52
64QAM1/2	3595.04	1758.48

Table 13: AeroMACS expected throughputs vs modulation schemes

Available data rates are highly dependant on following factors:

1. Modulation scheme used (see table above).
2. FEC used.
3. RF channel conditions which are varying in time.
4. Distance between A/C (MS) and BS.
5. Actual service flow demand by BS/MS.

Hence it is clear that the actual data rate AeroMACS is able to support between BS and MS is difficult to establish. Therefore we assume that the data rates from the table above can be achieved.

These inputs on data load estimations will be used in combination with all other inputs (specially coming from [6]) as defined in the previous paragraph to obtain load and coverage requirements.

Single Sector data requirements: From Table 13combined with scenario which is providing the data requirements for 20 A/C [6] for the whole airport area in departure mode, up to 20 A/C could be served by a single cell.

Scenario		Average offered load ATC (Kbits/sec)	Average offered load AOC (Kbits/sec)
20 A/C, 4 VC	Overall	0,84	1867,43 (~1,8 MBitps)

RAMP departure **ATC, NET, AOC, EFF, UPLIB, E-CHARTS**	FL	0,34	1619,49
	RL	0,50	248,22

Table 14: Single Sector scenario – excluding FOQA

On scenario interpretation we could assume that 12 A/C may be in departure mode while 6 A/C would be in arriving and another 2 would be on Tower area.

European Airport database: In Appendix B an overview of all small, medium and large airports is provided including amount (not type) of runways, with for each case the amount of commercial movements.

COCR V2.0 HD and LD airports; COCR defines airport density in a different way and defines only low and high density volumes for the different airport areas and phases. See table 2-12 Airport Controller Position PIACs in COCR [1].

APT Position	Phase 1		Phase 2	
	HD	LD	HD	LD
Clearance/Ramp	134	4	194	7
Ground	48	3	70	4
Tower	18	5	26	8
Total	200	12	290	19

Table 15: Airport size categories according to COCR

For this document, the COCR differentiation was found not to be detailed enough. So by refining the airport model and to provide better estimations of airport surface data requirements, airports have been split up in small, medium, large and super large airports.

AIRPORT OPERATIONS/hr VS PASSENGER TRAFFIC: Airport size is in reality determined by the amount of passengers served on a yearly base and not on amount of operations handled per hour. However airport surface data throughputs are determined by the amount of operations per hour, therefore this last criterion prevails in this study. As can be seen from Appendix B, Europe´ s largest airport is passenger wise London Heathrow, however Amsterdam Schiphol will be in this study the largest airport needing the highest data throughputs. Hence it is obvious that London will be visited by larger MTOW A/C than Amsterdam which is confirmed by the fact that London is the major European hub for transatlantic flights.

3.5.2 SESAR 15.2.7 Airport Categorization

For this section, FL stands for "Forward Link" which operationally means data flowing from tower to the A/Cs and RL, "Reverse Link" that refers to packets going from A/Cs to the tower.

3.5.2.1 Small airports (<20mvts/hr) Single Runway- Simple Terminal

Small airports are complying with the basic single runway category. Very often these airports belong to the simple terminal category though it may also belong to the satellite or curvilinear category.

Because any airport needs to have at least a single runway, hence it is obvious that many airports exist in Europe having far less than 50 A/C operations per hour.

For the single runway airport some subcategories have been worked out – all belonging to the small airports category. These subcategories will be differentiated by indicating the amount of A/C operations per hour.

In Europe, airports such as KERKIRA, KOS, FUNCHAL, FUERTEVENTURA…etc, all match the requirements for small airports.

NOTE: It maybe very well possible that those airports having **less than 5 operations per hour will never be equipped with AeroMACS** either because it may not be economically viable or in order to preserve Globalstar interference limits.

3.5.2.1.1 Capacity Requirements for airports with 3 operations/hour

It is very likely that the Airport service provider cannot justify the installation/maintenance cost for deploying the AeroMACS infrastructure. From previous Globalstar interference studies, it is also not likely that all small European airports will be allowed by ICAO FMG to be equipped with AeroMACS – to be confirmed after development of COM AeroMACS tables and establishment of interference criteria rules.

In case of AeroMACS availability at such an airport it is obvious that any AeroMACS deployment will be able to serve any aircraft on the airport in a satisfactory manner, seen the small amount of A/C to be served.

The scenarios 19 and 20 [6] fulfil these data rate requirements for RAMP arrival and departure. Even though these scenarios cover only 1 A/C, the A/C dwell time foreseen is around 21 minutes per A/C. Even if all A/C would arrive at the same time – which is very unlikely for such small airports – any AeroMACS deployment will be able to deliver expected data loads under such scenario.

Scenarios 19, 20 are conform to such an airport data needs.

Scenario		Average offered load ATC (Kbits/sec)	Average offered load AOC (Kbits/sec)
Scenario 19 (1 A/C, 1 VC) RAMP arrival	**Overall**	**0,0**	**0,23**
	FL	0,0	022
	RL	0,0	0,01
Scenario 20 (1 A/C, 1 VC) RAMP departure/ ATC,NET,AOC,EFF,UPLIB,E-charts	**Overall**	**0,04**	**56,69**
	FL	0,02	47,64
	RL	0,02	9,35

Table 16: Airport capacity load for small airports (3 operations/hour)

According to the results drawn on WA3 [9], GROUND scenarios were raising problems due to the high load provoked by FOQA service. As stated on the conclusions, FOQA service was encouraged to be moved to RAMP area, where presumably, will be higher data rates due to the proximity to the BS. Therefore a recalculation of Table 16 values has to be done in order to introduce FOQA on the capacity analysis for RAMP area.

On the following lines are shown the main considerations taken in order to achieve the "movement" of FOQA service from GROUND arrival to RAMP arrival, knowing that simulations cannot be triggered again.

According to data yielded on [6] for scenario 9, table A.9-68. of the appendix, the relative volume of FOQA's packets generated to the rest of the services is 83,38%. On the other hand, table A.9-62 reflects overall data throughput for AOC services. The average data throughput for AOC services that are triggered on the RL is 42898,10kpbs. Hence, 42898,10*0,8338=35768,35kbps.

Nevertheless these figures yielded are for a scenario with 100A/Cs. There are no specific figures for a scenario of 1 A/C on GROUND. Therefore, as previously stated, an interpolation ought to be made. Paying attention to data for other scenarios, it is clearly appreciable that data estimations grow linear with the number of aircrafts. In conclusion, we can address it, without losing too much accuracy as a linear interpolation. The value deemed for FOQA service in a RAMP arrival scenario with 1 A/C is 35768,35*(1/100)=**357,68kbps**. As an immediate consequence of this, the average offered load for AOC traffic on the RL will be 0,23+357,68=357,91kbps.

Hereafter all data will be recalculated this way and consequently values from tables of WA2 properly amended.

Finally Table 16 will end up like this:

Scenario		Average offered load ATC (Kbits/sec)	Average offered load AOC (Kbits/sec)
Scenario 19 (1 A/C, 1 VC) RAMP arrival with FOQA	**Overall**	**0,0**	**357,91**
	FL	0,0	0,22
	RL	0,0	357,69
Scenario 20 (1 A/C, 1 VC) RAMP departure/ ATC,NET,AOC,EFF,UPLIB,E-charts	**Overall**	**0,04**	**56,69**
	FL	0,02	47,64
	RL	0,02	9,35

Table 17: Airport capacity load for small airports (3 operations/hour) considering FOQA as a RAMP service

3.5.2.1.2 Coverage Requirements for airports with 3 operations/hour

AeroMACS deployment at such an airport would be limited to **a single BS** using a sectorized antenna (allowing extended cell coverage). Antenna height is determined by airport AeroMACS equipped A/C type (light or medium). There is probably no need for antenna height above 10 m.
Existing airport infrastructure shall be used (building structure, tower, antenna towers or light poles) in such a way that all gates or stands are covered as well as all airport areas as defined in this document.

Cell sizes shall be of the **macro cell size** (large cells).

There is no need for special cell planning studies to determine BS site as terminal infrastructure is likely to be small.

Nevertheless – in case AeroMACS installation - the airport authority has to contact ICAO FMG and forward all information as specified under the frequency planning regulations as further established in this document.

3.5.2.1.3 Capacity Requirements for airports with 20 operations/hour

Such airport is likely to comply with scenarios 21 & 22 as provided by [6]. In this case data loads are provided assuming that the first half hour 10 A/C are arriving / departing and the next 10 A/C the next 30 minutes.

When comparing data needs from these scenarios and the table providing AeroMACS DL (BS) and UL (A/C or MS) supported Data loads, it is clear that also here a single sectorised BS will fulfil data requirements when no FOQA services condsidered at the airport. However when FOQA services over AeroMACS would be made available at such airport a second omnidirection cell will be needed operating on a different frequency in order to handle the 3 Mbps data load in UL.

Considerations previously made on FOQA service have been taken into account and the table values amended.

Scenario		Average offered load ATC (Kbits/sec)	Average offered load AOC (Kbits/sec)
Scenario 21 (10 A/C, 4 VC) RAMP arrival with FOQA	**Overall**	**0,14**	**3597,55**
	FL	0,06	18,32
	RL	0,08	3579,23
Scenario 22 (10 A/C, 4 VC) RAMP departure	**Overall**	**0,41**	**1039,82 (~1 MBit)**
	FL	0,16	902,07
	RL	0,24	139,24

Table 18: Airport capacity load for small airports (20 operations/hour)

3.5.2.1.4 Coverage Requirements for airports with 20 operations/hour

The same coverage requirements do exist as for the 3 operations per hour. This because **a single BS** data throughput can easily handle the required data loads as provided in the table above.

Also here **macro cell sizes** shall be deployed.

The BS installed shall be deployed in such a way that it will provide the highest data throughput at the RAMP area and hence operation under 64 QAM shall be strived for. It should be mentioned that 64QAM in UL is optional for implementation.

In case the terminal infrastructure is straight forward and not too complex there may be no need to rely on dedicated cell planning to optimize BS location. Application of RF rule of thumb, RF and installation requirements from this document as well as cell planning rules may be sufficient for AeroMACS deployment.

Nevertheless the airport authority has to contact ICAO FMG and forward all information as specified under the frequency planning regulations as further established in this document.

As an RF rule of thumb for establishing **LOS conditions** at several locations at the airport the 1^{st} **FRESNEL zone** can be calculated. This calculation will also allow the determination of BS antenna height. For good LOS conditions the maximum obstructions allowed into the beam is 20 to 40% of the first FRESNEL zone.

The general equation for calculating Fresnel zones radius at any point P in between the endpoints of the link is the following:

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

where,

F_n = the nth Fresnel Zone radius in meters

d_1 = the distance of P from one end in meters

d_2 = the distance of P from the other end in meters

λ = the wavelength of the transmitted signal in meters

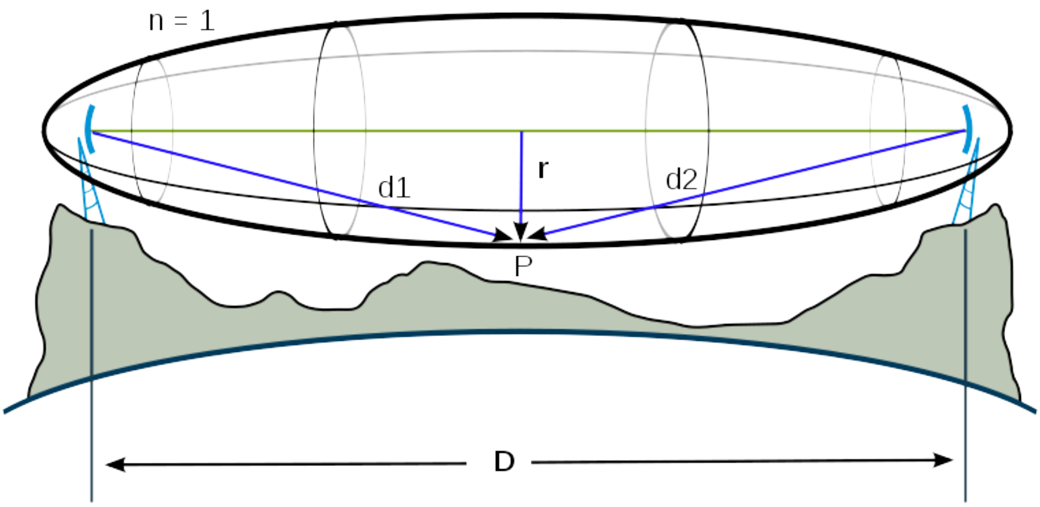


Figure 23: FRESNEL zone determination parameters

3.5.2.2 Medium airports (20- 60 mvts/hr) – Parallel or Open V Runways and Linear – Curvilinear Terminals

Medium airports may make use of either parallel or open V runway layouts or be based on a mixture of both types.

Medium airport is in Europe the **largest airport category** encountered.
Airports such as Geneva, Helsinki, Zagreb, Prague, Paris Le Bourget, Dusseldorf, Hamburg and many others belong to this category.

While it was not likely that many small airports will be equipped with AeroMACS, it is foreseen that the **medium airport category will be equipped**.

3.5.2.2.1 Capacity Requirements for airports with 50 operations/hour

Medium airports are likely to comply to scenarios 27, 28, 29, 30, 31, 32 as provided by [6].

Considerations previously made on FOQA service have been taken into account and the table values amended. Moreover, there was a mistaken found on simulations results for scenario 30. FOQA was introduced in that scenario and counted for the overall AOC traffic on the RL. That is completely wrong, and the service is only instantiated in GROUND arrival phase. Therefore it must be removed from the figures. As shown on table A.30-249 of [6], FOQA has a relative volume on the RL of 83,52%. Hence, 5737,92*(1-0,8352)=945,6kbps will be the total amount of traffic for AOC on the RL.

Scenario		Average offered load ATC (Kbits/sec)	Average offered load AOC (Kbits/sec)
Scenario 27 (25 A/C, 10 VC) RAMP arrival with FOQA	**Overall**	**0,47**	**9021,26(~9 MBit)**
	FL	0,19	69,42
	RL	0,28	8951,84
Scenario 28 (25 A/C, 10 VC) RAMP departure	**Overall**	**1,02**	**2317,97 (~2,3 MBit)**
	FL	0,41	1992,86
	RL	0,60	325,45
Scenario 29 (25 A/C, 10 VC) GROUND arrival without FOQA	**Overall**	**1,23**	**3321,19(~3 MBit)**
	FL	1,14	196,97
	RL	0,09	3124,22
Scenario 30 (25 A/C, 10 VC) GROUND departure (FOQA is not executed on departure)	**Overall**	**1,05**	**1041,2 (~1 MBit)**
	FL	0,98	95,58
	RL	0,07	945,6
Scenario 31 (25 A/C, 10 VC) TOWER arrival	**Overall**	**0,58**	**141,97**
	FL	0,57	0,0
	RL	0,02	141,97
Scenario 32 (25 A/C, 10 VC) TOWER departure	**Overall**	**0,44**	**287,38**

Table 19: Airport capacity load for medium airports (50 operations/hour)

3.5.2.2.2 Coverage Requirements for airports with 50 operations/hour

Most of the medium sized airports in Europe will likely be using AeroMACS for ATC and AOC operations.

As can be seen from the scenarios showed above, it is obvious that a single AeroMACS BS is not any longer able to sustain the needed data throughput.

Medium airports shall deploy multiple BSs to cover all airport areas.

Generally it is estimated that **3 BS with 3 sectors each** should be able to fulfil all AeroMACS data requirements. However there is not a fixed rule for establishing the amount of BS as deployment is highly depending on the terminal structure and rest of airport layout.

Cell sizes shall be considered **macro cells** although they will be much smaller than those used for small airports.

As the highest throughputs are needed at RAMP area, **1 or 2 BS shall be located close to the gates / stands**.

The exact location of the BS shall be determined by an airport cell planning study which will take into account the terminal and airport infrastructure availability for this particular airport.

Curvilinear – Satellite terminals may have special needs in case there is no possibility to install BS antenna on a small tower on the roof of such a terminal.
In case of small satellite terminals it may be useful to deploy an omni-directional antenna located at a tower installed on top of the roof (if structurally possible).
Tower height will be calculated in such a way that the A/C antenna for the A/C types handled at this airport can be reached by the BS antenna under LOS conditions trying to minimalize RF signal diffraction from roof edges. If it is not possible to install BSs on the roof, BSs may be installed on light poles around the terminal area.

Linear terminals do not have any particular deployment need and the most probably good installation conditions will be available on light infrastructure installed along the terminal or on a tower when these are within 200 meters of the gates.

Nevertheless for every European medium airport, the appropriate cell planning study shall be performed before any deployment can take place. AeroMACS frequency planning shall be co-ordinated with ICAO FMG.

3.5.2.3 Large airports (60-100mvts/hr) – 3 Runways - 4 Parallel Runways and Pier Finger – Linear - Curvilinear Terminals

Most of the large European airports belong to this airport category.

Airports such as Brussels, Copenhagen, Paris CDG, Paris ORLY, Frankfurt, Munich, Milan, Rome, Oslo, Stockholm, Zurich, London Heathrow belong to this category.

On the terminal site, most of these airports have mixed terminal layouts as most of them are constructed using extensions as part of a historical growth process as airports were not able to be relocated at a completely new site.

3.5.2.3.1 Capacity Requirements for airports with 100 operations/hour

Scenarios 3, 4, 5, 6 provided by [6], represent the data load requirements as met at these airports. Considerations previously made on FOQA service have been taken into account and the table values amended. RAMP scenarios data have been taken from **Table 57** and **Table 58**, which refine the original figures adding AOC data traffic

Scenario	Overall average offered load FL (Kbits/sec)	Overall average offered load RL (Kbits/sec)
50 A/C, 10 VC RAMP arrival	**137,53**	**17355,42**
50 A/C, 10 VC RAMP departure	**3106,42**	**496,42**
Scenario 03 (50 A/C, 10 VC) GROUND arrival without FOQA	**352,47**	**3418,44**
Scenario 04 (50 A/C, 10 VC) GROUND departure (FOQA is not executed on departure)	**180,93**	**1807,7**
Scenario 05 TOWER arrival	**1,08**	**279,21**
Scenario 06 (50 A/C, 10 VC) TOWER departure	**0,88**	**596,12**

Table 20: Airport capacity load for large airports (100 operations/hour)

3.5.2.3.2 Coverage Requirements for airports with 100 operations/hour

Even without the heavy AOC services included, it is obvious that multiple of sectorized BS's will need to be installed to handle data requirements.

At the RAMP area it is likely that AeroMACS will need to rely on **microcells (cell coverage in the order of 200 to 300m – 16 QAM).** As for any cellular system, AeroMACS data throughput can be increased by creating additional cells within the same coverage area. These microcells will emit less power compared macro cells – using lower gain antennas (e.g. 12 dBi), nevertheless the impact on Globalstar interference needs to be addressed properly.

Hence microcells will request a more **elaborated frequency planning** and establishing appropriate cluster and frequency re-use factors will be done during cell planning studies. Nevertheless the airport authority has to contact ICAO FMG and forward all information as specified under the frequency planning regulations as further established in this document.

Because the terminal area is often a mixed structure, every airport shall rely on a specific airport cell planning study to optimize BS placement so that all coverage requirements will be met.

3.5.2.4 Very Large airports(>100 mvts/hr) – 4 Parallel Runways and more, Pier Finger – Linear - Curvi-linear Terminals.

Today AMSTERDAM SCHIPHOL is the only airport in Europe handling more than 100 operations per hour handled over 5 runways.

3.5.2.4.1 Capacity Requirements for airports with more than 100 operations/hour

Very large airports are likely to comply to scenarios 7, 8, 9, 10, 11 and 12 as provided by [6]. Considerations previously made on FOQA service have been taken into account and the table values amended.

Scenario		Average offered load ATC (Kbits/sec)	Average offered load AOC (Kbits/sec)
Scenario 07 (100 A/C, 20 VC) RAMP arrival with FOQA	**Overall**	**1,91**	**36079,32 (~36 MBit)**
	FL	0,78	274,27
	RL	1,14	35805,05
Scenario 08 (100 A/C, 20 VC) RAMP departure service exempted[8]	**Overall**	**3,20**	**471,62**
	FL	1,29	408,09
	RL	1,91	63,53
Scenario 09 (100 A/C, 20 VC) GROUND arrival	**Overall**	**4,53**	**7840,33 (~8 MBit)**
	FL	4,19	710,03
	RL	0,34	7130,3
Scenario 10 (100 A/C, 20 VC) GROUND departure (FOQA is not executed on departure)	**Overall**	**3,52**	**3420,58 (~3,5 MBit)**
	FL	3,28	312,77
	RL	0,24	3107,81
Scenario 11 (100 A/C, 20 VC) TOWER arrival services exempted	**Overall**	**2,17**	**538,39**
	FL	2,11	0,0
	RL	0,06	538,39
Scenario 12 (100 A/C, 20 VC) TOWER departure	**Overall**	**1,55**	**1019,44 (~1 MBit)**

Table 21: Airport capacity load for very large airports (more than 100 operations/hour)

[8] Service exempted means that the really large AOC applications such as EFF, UPLIB, E-CHARTS have not been considered as AOC applications.

3.5.2.4.2 Coverage Requirements for airports with more than 100 operations/hour

Very large airports will have identical coverage requirements as large airports around terminal areas.

For GROUND and TOWER areas there may be a need to add one or two additional sectorized BSs to cover all 5 runways with accompanying taxiways.

3.6 BS Siting Analysis

3.6.1 Siting regulations: Airport and Government Aviation Authority

The main subjects on which coordination and cooperation with the customer (and possibly other relevant organisations) will be necessary for successful progress of equipment installation are the following:

- Coordination of frequency spectrum allocation with ICAO and utilisation with systems which share the 5 GHz band with AeroMACS;

- Interference studies to be presented to the Authorities. It shall be verified that the AeroMACS transmissions which will occur during test campaigns before the system enters into operation and in operation will not interfere with other communication systems.

- Aeronautical Easement studies to be presented to the Authorities [3.6.1.3];

- Provision of necessary technical documentation and drawings of the Airport and its infrastructure. This is a basic step in order to identify potential sites for the BS and the existing infrastructure;

- Definition of the architecture to be used for AeroMACS deployment;

- Provision of necessary permissions for access in such areas within the airport in which some parts of delivered equipment will be installed. As the AeroMACS deployment needs to occur in the Airport area, they will be submitted to have authorisations from relevant authority, according to the applicable rules. This includes for instance the capacity to drive cars into the airport areas;

- Provision of necessary permissions to install parts of the equipment on respective buildings, masts, towers, etc.;

- Deployment and interconnection of the base station with appropriate ground network(s);

- Provision of necessary support in any situation that may occur in course of equipment installation and trial operation;

- Management of authorizations for tests on the Airport surface, e.g. special driving license and associated training;

- Access of the vehicles (cars and Aircraft) to the appropriate Airport area for performing the tests;

3.6.1.1 ICAO Frequency Co-ordination and Registration Procedures

Co-ordination and registration procedures for frequency assignments are usually agreed between States under the rules of the ITU [15]. These procedures are agreed between States in order to assure mutual acknowledgement of (the status of) each other's frequency assignments and the corresponding rights and obligations under ITU rules. Within the aeronautical ICAO community in Europe, the Frequency Management Group (FMG) has established co-ordination procedures between States, which can be regarded as mirror procedures to the formal ITU versions. Although these procedures do not have the same formal status as the original ITU-ones, in practice they are treated by States concerned in much the same way. This document highlights the main parties involved in these procedures and their mutual relationship/responsibility.

Co-ordination of new or modified frequency assignments is required with all States concerned that in some way may be affected by the proposed assignment. In order to formalize the process of identification of States concerned, which have to be informed of new or modified assignments a “Table of Co-ordination Requirements” will be added.

In the European Region, civil aviation frequency matters are handled by the FMG of the EANPG. The main tasks of the FMG are;

a) to establish co-ordinated frequency assignment plans for the EUR aeronautical mobile services and the EUR radio navigation aids service, and to make recommendations, as necessary, concerning frequency aspects of their implementation;

b) to co-ordinate the frequency aspects of new requirements, as necessary;

c) to give advice to States on questions of frequency assignment, rated coverage, etc., as necessary;

d) to undertake specific tasks assigned to it by the EANPG;

e) to advise the EANPG on frequency spectrum issues covering all aeronautical radio services, including satellite based facilities; and

f) to work in liaison with international organizations, COMT, ARB, etc.

In most cases a Telecommunications Administration / Radio Authority within a State is the responsible superior authority for use of the radio spectrum. This includes the authority to co-ordinate new assignments with other States under the rules of the ITU and after successful co-ordination to register the new assignment with ITU.

In many States, some tasks may have been delegated to Civil Aviation who is taking care of the planning of frequency bands used exclusively or mainly by aviation. In this situation, Civil Aviation is handling proposals for new assignments, the necessary contacts with other national units as well as the co-ordination with other States. The basic aeronautical co-ordination procedure is depicted below.

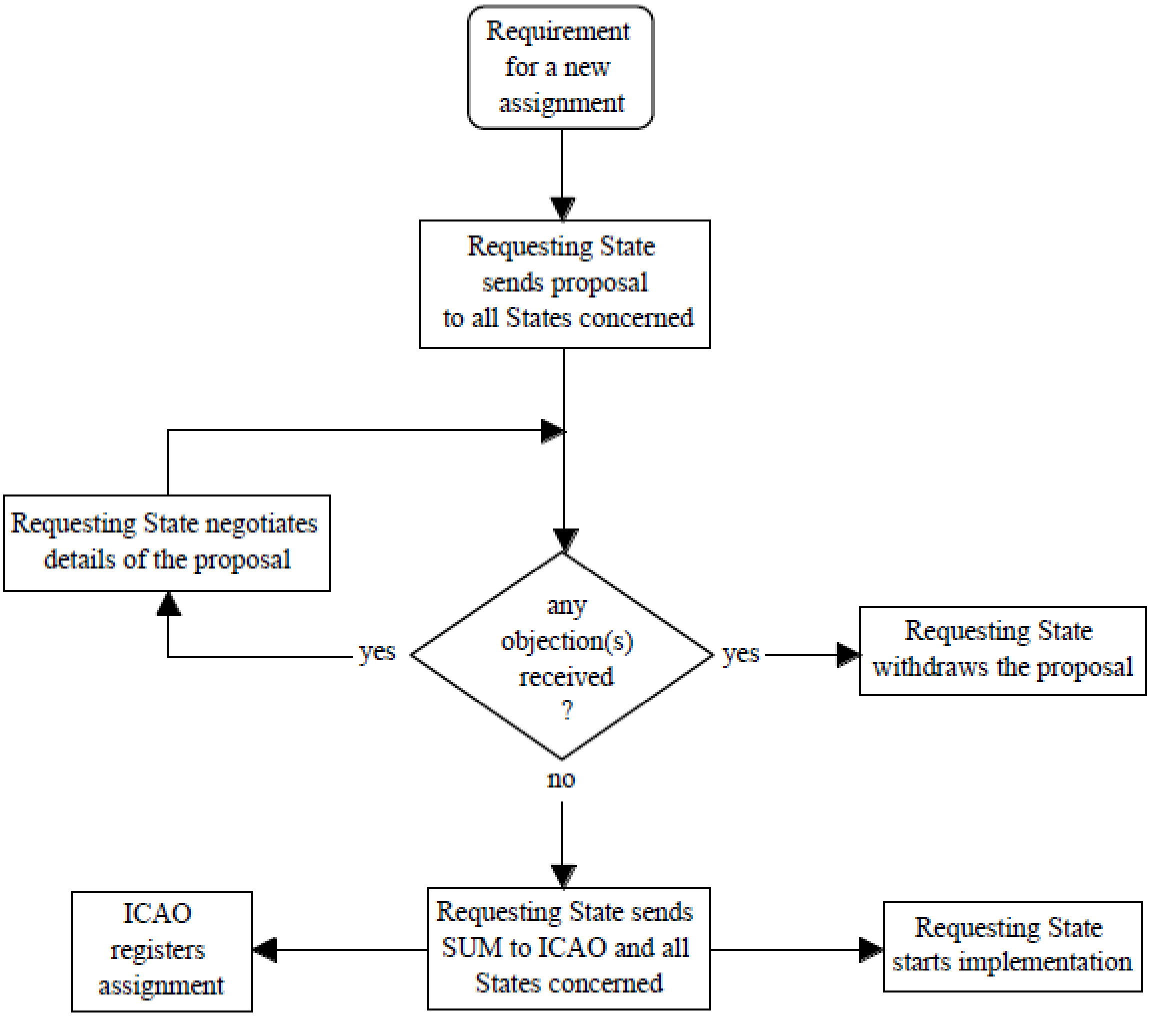


Figure 24: ICAO Frequency Co-ordination

In the co-ordination procedure, States who receive proposals have to respond within a 4 weeks period, according to an agreement by FMG. In case of special circumstances (e.g. interference on the presently used frequency) a shorter time limit may be necessary, but with some risk that an objection will be received shortly after the requested response date. No matter what time limit is used, an existing assignment, that has been properly coordinated and notified, always has the right to protection from new assignments.

Co-ordination must be made with all States that in some way may be affected by the proposed assignment. This should take into account the possibilities that an assignment already exists in another State which is not shown in the available aeronautical frequency assignment tables. Additionally some States may have an interest in being informed about changes, although not directly affecting them, in order to update national databases or for other purposes.

After successful co-ordination of a new or modified assignment, a Standard Updating Message (SUM) is sent to the ICAO Paris office, notifying the successful completion of the co-ordination and requesting the registration of the new or modified assignment in the appropriate frequency assignment table of the ICAO database.

3.6.1.2 Eurocontrol Frequency Planning and Deployment Rules on AeroMACS

So far ICAO FMG handles for Communications only the VHF frequencies. ICAO FMG is today not aware of AeroMACS - neither of the far more complex interference issues involved in AeroMACS deployment compared to VHF interference criteria. All previous studies done by MITRE – NASA and SESAR (P15.2.7 WA1) have been forwarded to ICAO FMG SG end of April 2012 and can be consulted on Eurocontrol's One Sky Team. Work is expected to start by ICAO FMG first week of June 2012. Once ICAO FMG SG has finalized their work on Globalstar and AeroMACS interference and a COM AeroMACS database has been created, all requirements below will be superseded by the approved ICAO FMG rules as published by them.

The next set of requirements could be applied before any AeroMACS deployment can take place in Europe according to Eurocontrol:

R-FMG-REG-01. AeroMACS centre frequencies shall be allocated by ICAO FMG.

R-FMG-REG-02. AeroMACS centre frequencies shall be allocated by Network Management.

R-FMG-REG-03. Before AeroMACS BS can be deployed at any airport in Europe, the local airport service provider or national ANSP shall inform relevant authority on their intentions for that particular airport.

R-FMG-REG-04. Before AeroMACS BS can be deployed at any airport in Europe, the local airport service provider or national ANSP shall also send an e-mail indicating their intentions for that particular airport to ' frequencies@eurocontrol.int'

R-FMG-REG-05. Intentions for AeroMACS deployment shall be communicated to ICAO FMG and EUROCONTROL at least one year in advance of scheduled deployment.

R-FMG-REG-06. The local airport service provider or national ANSP shall provide ICAO FMG all available information on MLS deployment at the airport- including intentions for future installations.

R-FMG-REG-07. States deploying AMT or intending to deploy AMT shall inform ICAO FMG of their intended AMT frequency usage as soon as possible in order to enable proper AeroMACS frequency assignments at a very early stage.

R-FMG-REG-08. The local airport service provider or national ANSP shall provide ICAO FMG all available information on AMT deployment at the airport- including intentions for future installations.

R-FMG-REG-09. The local airport service provider or national ANSP shall provide ICAO FMG the cell planning study results for each airport where it intends to install AeroMACS.

R-FMG-REG-10. The local airport service provider or national ANSP shall ensure that the provider of the cell planning is aware of AeroMACS spectrum limitations as foreseen by ITU-R and ICAO FMG.

R-FMG-REG-11. For all European airports AeroMACS cell planning shall make sure that cell overlaps are kept to a strict minimum.

R-FMG-REG-12. AeroMACS cell planning shall not consider full dual coverage[9] in Europe.

R-FMG-REG-13. AeroMACS cell planning shall follow the advice on frequency re-use factor as provided by ICAO FMG for each airport willing to deploy AeroMACS.

R-FMG-REG-14. AeroMACS cell planning shall try to make maximum use of possible building blocking loss factors by selecting appropriate BS position locations.

R-FMG-REG-15. To limit AeroMACS inter-cell interference AeroMACS cell planning shall avoid the use of adjacent channel frequencies at the same airport when using small frequency re-use factors.

R-FMG-REG-16. The local airport service provider or national ANSP shall provide ICAO FMG with the amount of BSs to be deployed at each airport where it intends to install AeroMACS.

R-FMG-REG-17. The local airport service provider or national ANSP shall provide ICAO FMG with the exact geographical location of each airport where it intends to install AeroMACS.

R-FMG-REG-18. The local airport service provider or national ANSP shall provide ICAO FMG with the power amplifier emitted output power for each BS.

R-FMG-REG-19. The local airport service provider or national ANSP shall provide ICAO FMG with the cable loss for each cable installed between PA and BS antenna for each AeroMACS BS deployed.

R-FMG-REG-20. The local airport service provider or national ANSP shall provide ICAO FMG for each BS location the intended antenna type (omni or directional) it intends to deploy at each airport where AeroMACS will be installed.

R-FMG-REG-21. The local airport service provider or national ANSP shall provide ICAO FMG for each antenna its antenna gain pattern (elevation and azimuth over 360

[9] Dual coverage is obtained when at any particular cell area the MS sees 2 frequencies under same modulation conditions. It can be used for second operator or to increase capacity.

degrees) it intends to deploy at each airport where AeroMACS will be installed.

R-FMG-REG-22. The local airport service provider or national ANSP shall provide ICAO FMG for each directional antenna its intended pointing angle vis-à-vis North (values should be within 5 degrees accuracy).

R-FMG-REG-23. The local airport service provider or national ANSP shall provide ICAO FMG for each directional antenna its intended tilting angle vis-à-vis ground plane (values should be within 1 degree accuracy).

R-FMG-REG-24. The local airport service provider or national ANSP shall provide ICAO FMG an estimation of Building Blocking factor loss for each directional antenna it intends to deploy at each airport where AeroMACS will be installed. Note: Building blocking loss estimations can vary between 6 and 20 dB (see tables 20 and 21).

R-FMG-REG-25. During AeroMACS cell planning a conservative approach shall be taken with respect to building loss values as provided in tables 18 and 19 – hence the provided values shall be decreased with at least 3 dB for values up to 10 dB and with 6 dB for values between 10 and 20 dB.

R-FMG-REG-26. Whenever a building blocking factor loss value is used, the local airport service provider or national ANSP shall provide ICAO FMG - for this particular antenna position - with the installed antenna height.

R-FMG-REG-27. Whenever a building blocking factor loss value is used the local airport service provider or national ANSP shall provide ICAO FMG - for this particular antenna position - the building height this particular antenna points to.

R-FMG-REG-28. Whenever a building blocking factor loss value is used the local airport service provider or national ANSP shall provide ICAO FMG - for this particular antenna position – with the distance between this particular antenna location and the building façade this antenna points to.

Note: Under P15.2.7 and P9.16 WA6 Validation and testing all requirements linked to ICAO FMG are not applicable.

It should be noted that, in the 5091-5150 MHz band, airport surface communication networks, based on either Method A or Method B topologies, will need to protect NGSO-MSS feeder links operating in the band. Recommendation ITU-R M.1827 and Report ITU-R M.2118 are relevant to this protection.

3.6.1.3 Aeronautical Easements

Aeronautical Easements are areas and surfaces which size and slope are well defined, under which areas the vertical deployment or some activities are subject to a previous approval process, no matter whether they infringe the surfaces that conform those Aeronautical Easements or not [16].

Aeronautical Easements must be respected to ensure the safety of aircraft movements.

There are 3 types of Aeronautical Easements:

1. Airport Easements: They are defined as those surfaces defined to preserve the airport approaching areas, which must be kept free of obstacles[10] in order to carry out aircraft operations with safety. They are classified as:

    a. Inner horizontal surface

    b. Conic surface

    c. Approaching surface

    d. Transition surface

    e. Take-off rising surface

    f. Outer horizontal surface

2. Operational Easements: They are defined as those surfaces to guarantee the safety in the different phases of the instrumental approaching to an airport. They are made up by the areas where the different flight phases are carried out and the surfaces they form in plan by means of horizontal or slanted planes. They are classified as:

    a. Surface for ILS maneuvering

    b. Surface for NDB or VOR/NDB maneuvering

    c. Surface for Precision Approach Radar maneuvering

    d. Surface for Surveillance Radar maneuvering

    e. Surface for Visual Approach Slope Indicator System maneuvering

3. Radio electrical Easements: They are defined as those surfaces that guarantee the correct working order of the services provided by the radio electric installations which are of paramount importance for the regularity of flights. They are classified as:

    a. Communications

    b. Air Navigation Aids

Within these areas, the construction or installation of new elements or the modifying of existing elements that breaks the Aeronautical Easement will need, compulsorily, a study in which the effect of such as elements in the quality of these signals in the space of the Radio installations will be assessed, in order not to affect the performance or quality of the signals in the area of the Aeronautical Easement.

The quality of a signal emitted by a radio electrical installation will depend on the equipment characteristics itself and its operational environment. The presence of new obstacles in its vicinity, or the modifying of the existing ones, can strongly affect the signals emitted and can cause a degradation of its functionalities or even the outage of the service.

[10] Obstacles are defined as all fixed objects, or parts thereof that are located on an area intended for the surface movement of aircraft or that extend above a surface intended to protect an aircraft in flight.

R-INST-DEP-21. Airport Authority shall not permit to carry out any work/installation unless a thorough study on Aeronautical Easement has been performed.

To perform the Aeronautical Easement study, it will be needed to get the information of the analysed obstacles as precise as possible. The accuracy and validity of the results will depend on the quality of that information. In case of lack of enough information it will be needed to make estimate assumptions.

3.6.1.4 Equipment Siting

The next paragraph describes general restrictions about siting of equipment and installations on operational areas according to ICAO Annex 14 [12] and ICAO "Aerodrome Design Manual" Part 1 Runways.

In order to consider the worst case, it should be deemed that references to equipment for air navigation purposes in ICAO documents only include visual aids, so that more restrictions will apply to AeroMACS BS deployment.

This first general restriction (section 9.9.1 [12]), that is fully applicable to AeroMACS considering the previous assumption, is*;"Unless its function requires it to be there for air navigation purposes, no equipment or installation shall be:*

a) on a runway strip, a runway end safety area, a taxiway strip or within the distances specified in Table 3-1, column 11 of [12], if it would endanger an aircraft; or

b) on a clearway if it would endanger an aircraft in the air",

so **AeroMACS system SHOULD NOT be deployed in all these areas.**

The specific restrictions about equipment deployed on runway strips are the followings;

- Section 9.9.5 [12]. *"Unless its function requires it to be there for air navigation purposes, no equipment or installation shall be located within 240 m from the end of the strip"*
- Section 5.3.7 [26]. *"No fixed object, other than visual aids required for air navigation purposes and satisfying the relevant frangibility requirement in Chapter 5 [26], shall be permitted on a runway strip:*
    - *a) within 77.5 m of the runway centre line of a precision approach runway category I, II or III where the code number[11] is 4 and the code letter[12] is F; or*
    - *b) within 60 m of the runway centre line of a precision approach runway category I, II or III where the code number is 3 or 4; or*
    - *c) within 45 m of the runway centre line of a precision approach runway category I where the code number is 1 or 2."*

R-INST-DEP-22. AeroMACS system SHALL NOT be deployed in the runway areas defined in section 9.9.5 of ICAO Annex 14 "Aerodromes", Fourth Edition July 2004 and

[11] The code is not intended to be used for determining runway length or pavement strength requirements. The code is composed of two elements (number and letter) which are related to the aeroplane performance characteristics and dimensions. The code shall be determined by selecting the code number corresponding to the highest value of the aeroplane reference field lengths of the aeroplanes for which the runway is intended. Airplane code number is available in Annex 1 [26].

[12] Code letter available in Table 1.1 (section 3.1.9 [12]).

section 5.3.7 of ICAO “Aerodrome Design Manual” Part 1 Runways, Third Edition 2006.

Regarding siting of equipment and installations on taxiway strips, these areas should provide an area clear of objects which may endanger taxiing aeroplanes (section 3.11.3 [12]). The next distances should be taken into account;

Code letter	Taxiway, other than aircraft stand taxilane, centre line to object (metres)	Aircraft stand taxilane centre line to object (metres)
A	16.25	12
B	21.5	16.5
C	26	24.5
D	40.5	36
E	47.5	42.5
F	57.5	50.5

Table 22: Taxiway minimum separation distances (Table 3-1 [12])

By the way, it is important to consider the clearance distances ***on aircraft stands which define the*** minimum clearances between an aircraft using the stand and any adjacent building, aircraft on another stand and other objects like AeroMACS components.

Code letter	Clearances (meters)
A	3
B	3
C	4.5
D	7.5
E	7.5
F	7.5

Table 23: Clearence distances on aircraft stands (section 3.13.16 [12])

3.6.1.5 Frangibility

All information gathered in this section has been extracted from:

- ICAO Annex 14, Chapters 5 and 9 [12], and
- Aerodrome Design Manual (Doc 9157) Part 6 Frangibility [13].

Additional guidance can be found in the referred documents.

The first objective should be to site objects so that they are not obstacles. Nevertheless, certain airport equipment and installations, because of their function, must be located in an operational area near runways, taxiways and aprons, where they may present a hazard to aircraft in the event of accidental impact during landing, take-off or ground maneuvering.

ICAO Annex 14, Volume I, Chapter 9, specifies that any equipment or installation required for air navigation purposes which is an obstacle of operational significance should be frangible and mounted as low as possible. This frangibility is achieved by use of lightweight materials and/or the introduction of break-away or failure mechanisms that enable the object to break, distort or yield under impact.

In the next paragraphs, general rules on frangibility for the deployment and installation of structures and equipment in an airport are given. These recommendations shall also apply for the AeroMACS equipment when is installed in regulated areas defined hereinafter;

- Section 9.9.2 [12]. "*Any equipment or installation required for air navigation purposes which must be located:*
    - *on a runway end safety area, a taxiway strip or within the distances specified in Table 3-1* [12]*; or*
    - *on a clearway and which would endanger an aircraft in the air;*

  shall be frangible and mounted as low as possible."

- Section 9.9.4 [12]. *"Any equipment or installation required for air navigation purposes which must be located on the non-graded portion of a runway strip shall be regarded as an obstacle and shall be frangible and mounted as low as possible."*

- Section 9.9.8 [12]. "*Any equipment or installation required for air navigation purposes which is an obstacle of operational significance in accordance with 4.2.4, 4.2.11, 4.2.20 or 4.2.27 [12] should be frangible and mounted as low as possible.*

A review of relevant accident data reveals that a majority of the accidents in the overrun area occur within a distance of 300 m from the runway end. All equipment located within this area should, therefore, be of low mass and frangible. Where practicable, all equipment located beyond a distance of 300 m from the runway end should be of low mass and frangible. The available accident data also indicate that a majority of accidents occur where the airplane comes to rest within the graded portion of the runway strip. All equipment located within this portion of the strip should, therefore, be of low mass and frangible. Where practicable, all equipment located within the non-graded portion of the runway strip should be of low mass and frangible.

These distance requirements should also be valid for structures supporting the equipment and obstacles.

In some cases, and due to its heavy mass, the equipment housing for system installations cannot be made frangible. Therefore, when planning for the installation of a system, the location of the equipment housing should be carefully considered. In no instance should the equipment housing be located within the runway end safety area (or the extension thereof within a distance of 300 m from the runway end).

R-INST-DEP-23. AeroMACS BS shall support mounting on frangible structures (i.e. frangible masts) while fulfilling both coverage and throughput requirements.

3.6.1.6 Equipment Design

Equipment and enclosures shall be designed and constructed to withstand all forces within the operational and survival limits. Upon impact the equipment shall provide minimal impact resistance and absorb the least amount of energy. A sufficient number of break-away joints shall be used in equipment construction to enable it to break up into fragments of minimal size and mass. Equipment shall be fabricated from low density brittle materials where applicable.

The frangibility of the design should be proven either by means of full-scale tests, computer evaluations or by calculations based on comparison with similar already approved structures possibly supported by additional component tests.

Although required to be of a frangible design to minimize hazard to aircraft in the event of impact, the equipment must also be capable of withstanding the environmental conditions to which it may be exposed during normal service. Specifics on these as well as other conditions can be found in the pertinent documents of the authority having jurisdiction.

The purpose of the equipment shelter is to protect the equipment and personnel from the extremes of the environment, in particular from precipitation (rain, hail, and snow) and from wind or jet blast driven particles (dust, small stones, vegetation, and debris).

The enclosure shall be constructed of metal, plastic, wood, or other material, which meets the environmental requirements and regulations and the frangibility requirements mentioned above.

The construction of shelters must meet the overall frangibility requirements detailed in previous paragraphs. It is assumed that the equipment and the shelter can be regarded as separate physical entities. The overall frangibility of the equipment and the enclosure shall be considered.

3.6.1.7 System Installation

The installation should be conducted using accepted industry practices and in accordance with all local building and electrical codes and guidelines of the appropriate government aviation authority for installing and commissioning equipment.

The installation of the AeroMACS system equipment should comply with the obstacle limitation requirements of ICAO Annex 14 [12] and other relevant national guidelines.

The AeroMACS system installation should not interfere with existing equipment and operations.

Equipment installation shall be carried out according to aeronautical rules, leaving enough room where the equipment is going to be installed, for easy access in order to facilitate as much as possible maintenance tasks.

Interconnection cabling among the different units which form the system shall be labeled accordingly, this way any cable can be identified at any moment and be easily substituted if needed.

Signal and data interconnecting cables will be set and organized in the racks of the AeroMACS system, or through the existing paths in the technical room, and through new installations if they are required.

Power supply cables, console and extra rack units will be set on trays or on the false floor, or on the existing paths in the technical room, following different ways from the data cabling and shall be labeled accordingly.

Power supply of the AeroMACS equipment and associated systems shall be taken from the main power supply rack. These cables shall be set independently from the rest of the power lines.

Ground wire will be carried out by conductive copper of minimum 16mm2 of section. Ground wire will be connected to the one of the existing same-potential wire or to the available ground wire, and ground wire connection to the racks and systems will be provided through this ground wire.

As an example, AeroMACS BS could be installed on light poles dotted along pier sides. Care should be taken when using high gain sectorized antennas, the aperture of such antennas is often less than 10 degrees, creating N-LOS coverage at short (0-50m) range while at longer range NLOS may be encountered due to A/C frame shadowing from A/C lined up side to side. Most of the time vehicles will encounter NLOS conditions. A careful look on BS antenna height is also needed whenever gates for A/C wide bodies and medium bodies are mixed (see A/C frame heights) creating possible shadowing for A/C behind such a wide body. Recommended BS antenna installation height is between 10-12m when gates are mainly used for medium A/C frames. For wide body frames antenna heights should be between 12-15 m height.

BSs antennas should be aligned in such a way that sectors remain RF isolated between left and right pier sides while at the same time trying to cover as much as possible the surrounding GROUND area.

In case of metallic terminal roofs the site survey should try to keep BSs antenna heights below roof height to avoid too many reflections towards Globalstar.

Such configuration allows only those A/C close to the BS (100-400m, in function of channelization gain used and propagation conditions) to operate under 64 QAM. A/C located further away from BS should operate under 16QAM.

Another special case could be the BSs installation for inner area of dual parallel pier fingers. Whenever the distance between two piers is below 450-500 meter it could be investigated to install serving BSs to opposite sides of pier fingers - for those sides facing each other. This avoids smaller A/C to operate on NLOS conditions as consequence of RF blocking or shadowing by large bodies located at gates between BS attached and the smaller A/C. Such configuration allows all A/C to operate most of the time under LOS conditions and 64QAM mode when attached to the gate. NLOS conditions will also be met during most of the time vehicles are operating around the A/C. However NLOS conditions are encountered each time a large A/C tails moves in front of the serving BS RF beam when this A/C moves along GROUND area. It is also worthwhile to investigate the increase of BS antenna gain from 15 to 18-20 dBi to guarantee 64 QAM operation at all gates. Part of this increased signal strength will be blocked by the opposite building structure. This RF signal blocking may be an important factor to combat Globalstar interference and should be used wherever possible. Azimuth aperture angle of BSs antenna should be not too large in order to avoid the coverage by too many A/C within a single beam (at 500 m distance and an antenna aperture angle of 90 degrees the coverage at opposite pier would be around 1 km), hence the requirement for narrow (around 30 degrees) antenna azimuth apertures to be used in such case.

BS antenna height is not critical and could be between 9-12m.

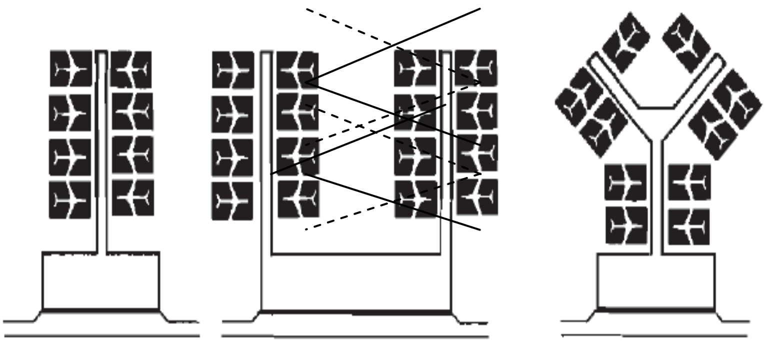


Figure 25: Example of possible BS deployment for parallel pier finger terminal layout.

3.6.1.8 Operational requirements

It is normal for a frangible structure to deflect when exposed to environmental loads. However, it is important that deflection of the structure remain within limits so as not to affect the signal quality of the system which the structure supports.

In those cases in which the design of the equipment to fulfill the frangibility requirements is not possible or the operational performance could be at risk, the equipment should be replaced in order not to be a danger for the aircrafts.

3.6.2 Inter-system Interference Analysis

In D01 –T1.5 [18], an assessment of potential coexistence problems between AeroMACS and other systems operating in the same or in adjacent frequency bands was made. The assessment included IEEE802.11a systems (i.e. Radio Local Access Networks - RLANs) operating in the 5150-5350 MHz band, BBDR (Broadband Disaster Relief) systems, MLS (Microwave Landing Systems) and AMT (Aeronautical Mobile services for Telemetry). The main conclusions from the assessment are that:

- MLS transmitters may cause harmful interference to AeroMACS receivers when installed at the same airport, even when the two systems are separated in frequency by several tens of MHz. AeroMACS transmitters may also prevent MLS operation.
- AMT transmissions from aircraft may cause harmful interference to AeroMACS receivers due to their high transmit powers.
- It is unlikely that other terrestrial systems will cause coexistence problems for AeroMACS.

Hence, coordination between the administrations operating AeroMACS, MLS and/or AMT systems is required.

3.6.2.1 Impact of Out of Band Interference on Deployment (MLS)

The MLS signal use Time Division Multiplexing (TDM) including azimuth and elevation signals. These signals are Continuous Wave (CW) with DPSK preambles with 3 dB bandwidth of 15.626 kHz. It is the preambles that may interfere with other systems and notably AeroMACS due to its low out-of-band attenuation.

3.6.2.1.1 Separation requirements

In [18], the minimum distance between a MLS transmitter and an AeroMACS receiver with antenna gain 4 dBi as function of frequency offset was estimated. The figure is included below for convenience.

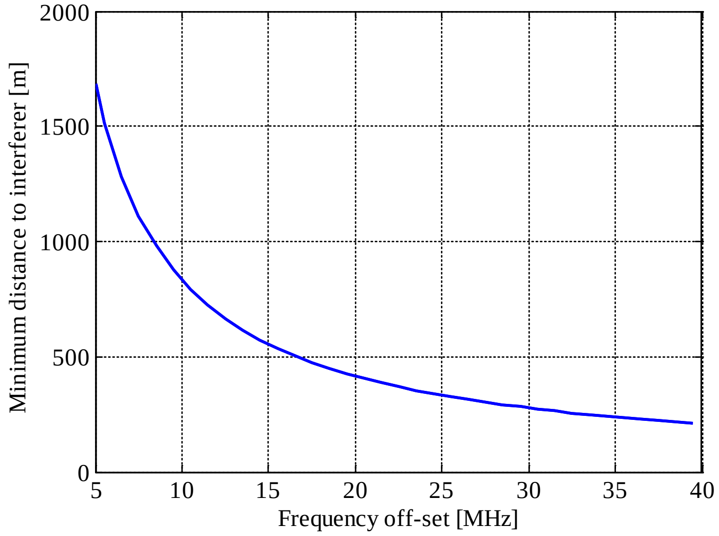


Figure 26: Minimum distance between MLS transmitter and AeroMACS receiver [18]

The minimum distance is reduced as the frequency offset increases. An offset of 10 MHz leads to a minimum distance of 800 meters, while an offset of 40 MHz leads to a minimum distance of 200-250 meters.

3.6.2.1.2 Impact on AeroMACS deployment

The impact of MLS on AeroMACS deployment will depend on the number of airports having operational MLS. In Europe, the future of MLS is still an open question.

In order to operate both MLS and AeroMACS at an airport, bilateral coordination between the two systems is necessary. This coordination must include:

- Use of frequency channels. Allocation of MLS frequency channels to European airports should facilitate operation of AeroMACS systems. Large airports, at which it is likely to deploy a multi-cell AeroMACS network, should if possible be allocated MLS channels low in the 5030-5091 MHz band. The AeroMACS system may be forced to avoid the frequency channels closest to the MLS channels.

- The cell planning of an AeroMACS network must take into account the location of MLS ground equipment, and perhaps also the approach routes so that a base station antenna is not directed directly towards approaching flights.

3.6.2.2 Impact of In Band Interference on Deployment (AMT)

3.6.2.2.1 Regulatory aspects

The AMT system is used for real-time analysis and visualization of data during flight tests. The 5091-5150 MHz band was allocated to AMT for transmission from aircraft to ground at WRC-07, and adds to a list of frequency bands allocated to AMT. In Table 14, the different frequency bands are listed [19]. In Area 1 (Europe + Africa) it is also possible to use the frequency band 5150-5250 MHz.

Frequency range [MHz]	Primary/secondary	Comments
1435-1525	Primary	
1525-1535	Secondary	Mobile satellite service (MSS) primary service
2200-2290	Co-primary	Co-primary service in USA
2310-2360	Secondary	Wireless Communication Service (WCS) and broadcasting-satellite (sound) service (BSS) primary
2360-2395	Primary	
4400-4940	-	Telemetry allowed under the mobile service allocation
5091-5150	-	Inclusion into NTIA Table of Frequency Allocation not yet completed.
5925-6700	-	Inclusion into NTIA Table of Frequency Allocation not yet completed.

Table 24: Telemetry frequency allocations (USA) [19]

The main challenge concerning AMT and AeroMACS is that AMT may interfere with AeroMACS. It is considered less safety critical that AeroMACS may interfere with AMT operations.

According to Annex 1 to Resolution 418 (WRC-07), certain conditions apply to the implementation of AMT:

- The operation of AMT systems shall be coordinated with administrations operating MLS systems within a certain defined distance from the AMT flight area.
- For the protection of FSS systems, the increase in equivalent noise temperature $\Delta T_s / T_s$ in the satellites due to AMT transmissions shall not exceed 1 %.
- For the protection of mobile services in the 5150-5250 MHz frequency band, the maximum power-flux-density at the Earth surface shall not exceed -79 dB(W/(m^2·20 MHz))-$G_r(\theta)$, where $G_r(\theta)$ represents the mobile service receiver antenna gain as function of elevation angle.
- For the protection of aeronautical mobile (R) service (AM(R)S) in the frequency band 5091-5150 MHz, maximum power flux density at the Earth surface produced by AMT emissions shall not exceed -89.4 dB(W/(m^2·20 MHz))-$G_r(\theta)$,(θ), where $G_r(\theta)$ represents the AeroMACS mobile receiver antenna gain as function of elevation angle. The maximum antenna gain is set to 6 dBi.

Hence, the last bullet point relates to AeroMACS and the protection of AeroMACS mobile receivers.

3.6.2.2.2 Utilisation of AMT on 5 GHz by Airbus

The Airbus telemetry department uses three downlink channels to transfer data from aircraft to ground stations. These channels allow monitoring directly the aircraft data from the ground.

A reason why the 5091-5150 MHz band was allocated to AMT at WRC-07 is jamming problems in the S-band. Currently, two frequency slots are available at S-band and C-band. From 2014 onwards, only the C-band will be used. According to AMT Airbus service, the following four 8 MHz channels have been allocated to AMT by the French telecom regulation authorities ANFR (centre frequencies):

- 5117 MHz
- 5126 MHz
- 5135 MHz
- 5144 MHz

The Airbus system is able to track three aircrafts on three different frequencies anywhere above France. Eight receiving antennas are placed at four strategic points to realise this coverage:

- 4 antennas in Toulouse
- 1 antenna in Martigues
- 2 antennas in Bordeaux
- 1 antenna in Saint-Nazaire

For the future programs, new antennas are planned to be mounted in Hamburg (Airbus factory), Tarbes, Perpignan, Clermont-Ferrand and Brest for covering the aircrafts during the first flights.

The figure below presents the coverage of the terrestrial AMT antennas in reception. The circles drawn in the figure give an idea of the optical coverage for each reception antenna. These circles do not take into account the S/N required in reception (15dB) and the power emitted by the aircraft antennas. The smallest circles represent an altitude of 3 km and the largest circles an altitude of 10 km.

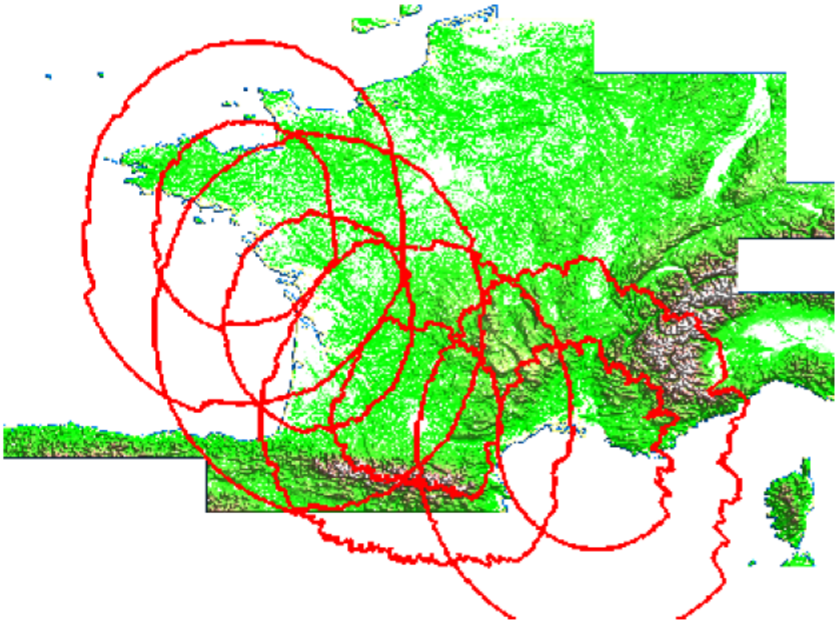


Figure 27: Reception antenna coverage

Several modulation types are defined for telemetry systems in [19]:

- Frequency Modulation (FM) and Phase Modulation (PM) – traditional methods
- Pulse Code Modulation/Frequency Modulation (PCM/FM) – most popular since the 1970s
- Feher Patented Quadrature Phase Shifting (FQPSK)
- Shaped Offset Quadrature Phase Modulation (SOQPSK)
- Advanced Range Telemetry (ARTM) Continuous Phase Modulation (PCM)

In the table below, characteristics of the Airbus AMT system are listed. These characteristics have been selected to obtain good operational conditions.

Channel bandwidth	4 x 8 Mhz
Modulation	Single Carrier-SOQPSK or COFDM-QPSK
Emitted Power	10 W
Aircraft antennas	One antenna on the bottom of the aircraft and another antenna on the top of the aircraft Gain: 0 dBi
Ground antenna	Steering Parabolic antenna 2.4 m diameter
Throughput expected	20 Mbps downlink
Deployment	Tests aircraft (16 to 25 aircraft for Airbus), but maximum 3 in flight at the same time
Coverage area	France

Table 25: AMT characteristics

To resolve jamming issues, COFDM adaptive modulation has been selected. The selected transmit power is 10 W, although 20 W is an option. The width of the channels allows conveying all the traffic with good performances.

3.6.2.2.3 Separation requirements

The maximum transmit power for AMT is 20 W per transmitter with 8 MHz bandwidth, and the typical number of transmitters on an aircraft is 2. As one antenna is located on top of the aircraft and the other one underneath the aircraft, it is assumed that only one of the two antennas will emit energy in the direction of an AeroMACS installation at any time. With 0 dBi AMT antennas, the maximum EIRP is then 43 dBm over 8 MHz or 41 dBm over 5 MHz.

The interference threshold for AeroMACS receivers is derived in [18]. Assuming noise factor $N_F = 8$ dB and setting the interference margin to 3 dB, the following is obtained:

- Thermal noise: $P_N = -174 + 10\log(B) = -107.4$ dBm (effective bandwidth $B = 4.89$ MHz)

- Interference threshold $I_{th} = P_N + 10\log(10^{0.8} - 1) = -100.1$ dBm

The AeroMACS base station antenna gain including cable loss is assumed to be 13 dBi. Hence, the attenuation of the AMT signal in the AeroMACS system's frequency channel due to separation in space and frequency should at least be in the order of 41-(-100.1-13) ≈ 154 dB, assuming the worst case that the AMT transmitter is located within the main beam of the AeroMACS antenna. The main beam of the AeroMACS BS antenna is generally close to horizontal to cover the airport surface. It is reasonable to assume that the distance to the AMT transmitter is shortest when the test aircraft is close to the ground. Hence, there is a risk that an interfering source will be within the main beam of the receive antenna when the distance is the shortest.

When the interfering signal's bandwidth is non-overlapping with the receive filters of the receiver, the total interference level depends on:

- The level of the interfering signal within the receiver filter's bandwidth
- The receive filter's attenuation within the interfering signal's bandwidth

First, the case where all interference is entering the receive bandwidth is considered. In Figure 28, the minimum spatial separation distance between an AMT transmitter and an AeroMACS base station and mobile station is illustrated as function of the spectral isolation.

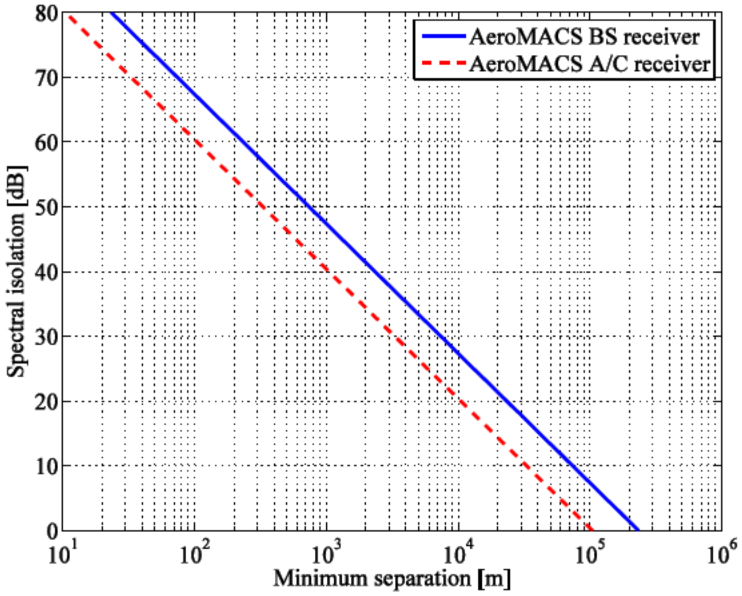


Figure 28: Minimum spatial separation as function of spectral isolation. Total isolation is 154 dB.

If the AMT transmitter operates on the same frequency as an AeroMACS receiver, there is no spectral isolation. In this case and assuming free space path loss, there should not be any AMT transmissions closer to an AeroMACS base station than 234 km. For AeroMACS A/C receivers, the minimum distance is 105 km.

Typical transmission masks of AMT signals are not available, but generally the spectral isolation will be between 50 dB and 80 dB at a distance from the centre frequency equal to or greater than the signal bandwidth. Assuming 50 dB spectral isolation, additional 104 dB attenuation can be obtained by about 740 meter spatial separation (assuming free space path loss). If however the spectral isolation can be increased to 80 dB, the additional 74 dB attenuation can be obtained by about 23 meter separation in space.

Considering the interference entering the receiver within the AMT bandwidth, the receive filters at radio frequencies (RF), intermediate frequencies (IF) and baseband together should assure that the interference level becomes well below the interference threshold. A similar analysis can be done as above for the case of interference level within the receive bandwidth. If the interference levels within both the AMT transmit band and the AeroMACS receive filters' band are of similar magnitude, it is important the sum of the two is below the interference threshold.

In this analysis, 3rd order inter-modulation products (IMP) is not included, as it is assumed that it will be of less importance. The same is the case for signal distortion due to saturation in the receive amplifier.

3.6.2.2.4 Impact on AeroMACS deployment

The calculations above indicate that AMT systems operating in the 5091-5150 MHz band may pose a problem for AeroMACS in Europe. Airbus currently operates three 8 MHz channels, which will overlap with at least 5 AeroMACS channels if they are all using the 5091-5150 MHz band. In particular large airports will probably have multiple AeroMACS cells occupying several or all of the eleven available 5 MHz channels. As the minimum separation distance for co-channel AMT transmitters and AeroMACS receivers is over 100 km, and the AMT coverage is the airspace over France, co-existence issues affecting all airports in France will arise. Coordination between AMT systems and AeroMACS systems will therefore be required.

It should be noted that the restrictions on AMT from WRC-07, keeping the power flux density P_D at the surface of the Earth where AeroMACS can be deployed lower than -89.4 dB (W/(m^2·20MHz)) with isotropic ground antenna, corresponds to an interference level of:

$$P_I = 10\log\left(\frac{P_D\lambda^2}{4\pi}\right) = -100.1 \text{ dBm},$$

assuming that two 8 MHz AMT channels are active simultaneously within the 20 MHz. Hence, the flux density requirement from WRC-07 corresponds to the interference threshold derived in this project. For an AMT transmitter with transmit power 10 W to comply with the requirements, the minimum altitude should be:

$$d_{min} = \frac{\lambda}{4\pi}\sqrt{P_I} = 46893 \text{ meters}$$

Hence, according to WRC-07, either AMT transmitters should be turned off in the vicinity of areas where AeroMACS is deployed, or the transmit power should be reduced.

3.6.2.3 Relevant agenda item 1.3 at WRC-12[13]

It is assumed that the use of Unmanned Aircraft Systems will increase significantly in the years to come and it may have an impact on AeroMACS deployments . Agenda Item 1.3 of WRC-12 concerns possible regulatory actions, and possibly frequency allocations, to support safe operation of UAS. It is estimated that the maximum amount of spectrum required for UAS are 34 MHz for the terrestrial component and 56 MHz for the satellite component.

Work is currently under way to develop standards for Control and Non-Payload Communications (CNPC). It is proposed that terrestrial CNPC is to use the following frequency bands [20]:

- Terrestrial (line-of-sight (LOS))
  - 960 - 1164 MHz
  - 5000 – 5150 MHz
  - 15.4-15.5 GHz
- Satellite (beyond line-of-sight (BLOS))
  - 1545 - 1555 MHz, 1610 - 1626.5 MHz, 1646.5 - 1656.5 MHz
  - 5030- 5091 MHz
  - 12/14 GHz
  - 20/30 GHz

If the band 5091-5150 MHz is allocated to CNPC, this will have an impact on AeroMACS deployment.

[13] Still under discussion

3.6.3 Preliminary Site Survey

The network design process begins with a physical site survey to gather information about the deployment location and suitable/potential sites for BSs. It is required to have maps and layouts of the airport with installations and cabling infrastructure. Site Surveys are needed to ensure the successful and efficient deployment of wireless networks. Before this, it is mandatory to contact with the customer (Airport Authority) to gather general Airport Authority´s constraints.

The objective of a site survey is to determine adequate coverage areas by verifying the number of BS required, as well as their most effective placement and configuration.

Without performing a site survey, you risk incurring performance degradation, cost overruns, security breaches, and potential gaps in coverage areas, ultimately affecting ATC and AOC service provision and administrative costs. In large deployments, a site survey can result in a reduced number of BS required to cover an area, improved user experience, and a better designed network. This is because the network is designed specifically for the customer applications and the usage requirements for which it was intended.

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 also provides input to the next three phases of the RF design process—coverage model, capacity analysis and cell planning.

This preliminary study should eliminate undesirable sites or determine the adequacy of an existing site before costly site inspections are undertaken.

When conducting a wireless site survey, the following points must be considered:

1. **Preparations**. The preparations start when the contract has been signed and include the following activities.

- ✓ Contact with the Airport Department in charge of designing the AeroMACS network to obtain the proposed nominal network design
- ✓ Obtain permission to visit the sites – Different permits and other arrangements are usually necessary because of security regulations must be requested through the appropriate party.
- ✓ Collection of all necessary information about the project
- ✓ Collection of all required equipment and documents
- ✓ Practical arrangements for traveling to the sites
- ✓ Obtain a map to mark the sites on

2. **Understand the wireless requirements**. In order to identify optimum locations for BS or mesh nodes, you must have a good understanding of specific requirements for the network that impacts signal coverage. For example, maximum range between a MS device and the BS decreases as data rate and resulting performance increases. Thus, you need to know the target data rates (and throughput) to correctly interpret survey results. Also, MS may have relatively low transmit power, which must be taken into consideration when using most site survey tools.

3. **Obtain an airport diagram**. Before getting too far with the site survey, locate a set of building blueprints or airport maps. If none are available, prepare a drawing that depicts the location of aprons, stands, runways etc. Site survey tools import diagrams in various image formats.

4. **Identify coverage areas**. On the airport map, indicate all areas where coverage is needed, such as gates, stands, parking areas, taxiways, runways and roads. Also, identifying where users will not have AeroMACS coverage is important to avoid wasting time surveying unnecessary areas. Keep in mind that you might get by with fewer BS's and lower equipment costs if you can limit the roaming areas.

5. **Visually inspect the airport**. Walk through the airport before performing any testing to verify the accuracy of the maps and diagrams. This is a good time to note any potential attenuation barriers that may affect the propagation of RF signals. For example, a visual inspection will uncover obstacles to signals such as metal racks and partitions, items that blueprints generally don't show. Also, note possible locations for mounting BS, such as above ceiling tiles or on pillars. You should also carefully assess the locations and availability of street lights and water towers for mounting BS and backhaul equipment. These actions will make the later testing efforts go much more smoothly.

   It is desirable to have LOS conditions as non-LOS conditions may lead to smaller service areas of each of the BS with lower capacity requirements per BS and as a result more BSs will potentially be required to provide coverage in non-LOS conditions.

6. **Assess existing network infrastructure**. Determine the capacity of any existing wired networks that can interface the BS nodes. Check on how much of the existing networks can be made available for supporting the AeroMACS network. This will aid designers later on in the deployment when defining the architecture and bill of materials for the wireless network.

7. **Preliminary site-survey report.**

   The preliminary site-survey report should stipulate the area where the BS candidates should be searched for.

   The report should provide detailed information of all factors necessary for a successful deployment, as a different individual could finally install the network.

   The report may contain more specific information such as the primary candidate for search and secondary candidates – thereby giving the site selection team more specific information on where to put their priorities. Also, this report should contain drawings, maps, and relevant information.

3.6.4 Site Pre-Selection

The site pre-selection is typically done by a service provider and/or the airport to find one or several suitable site candidates. The pre-selection may be done based on top level requirements. These include operational requirements (coverage volume), equipment requirements (like clearance zones, minimum separation distance between antennas, etc.) and other requirements like availability of power and communication lines with the ground infrastructure, site access and security. In addition the interference environment of the sites has to be checked. For the selected sites all necessary information (e.g. map, obstacles, power and telecommunication lines, frequencies, etc.) is gathered and documented. For the preparation of the final decision the future development plans of the airport should be taken into account.

1. **Determine preliminary BS locations**.

   This paragraph describes the main aspects to be taken into account when performing a site selection.

- ✓ **BS position relative to nominal grid**

The initial study for a cell system often results in a theoretical cell pattern with nominal positions for the site locations. The existing buildings must then be adapted in such a way that the real positions are established and replace the nominal positions. The visit to the site is to ensure the exact location (address/coordinates and ground level). It is also possible for more than one existing site to be used for a specific nominal position.

By considering the location of MS and range estimations, approximate the locations of BS that will provide adequate coverage throughout the airport areas. Plan for some propagation overlap (generally 25 percent) among adjacent BS, but bear in mind that channel assignments for BS will need to be far enough apart to avoid interference.

Be certain to consider mounting locations, which could be vertical posts or metal supports above ceiling tiles. Recognize suitable locations for installing the BS, antenna, and data/power cabling, paying attention to check if there is enough room to house the BS racks Also think about different antenna types, azimuth and downtilt when deciding where to position BS. A BS mounted near an outside wall, for example, could be a good location if you use a sector antenna with relatively high gain oriented within the airport.

- ✓ **Type and space for antennas**

The radio propagation predictions provide an indication on what type of antennas can be used on the base station and in what direction the antennas should be oriented.

The predicted antenna height should be used as a guideline when the on-site study starts. If space can be found within a deviation of a maximum of 15% from the predicted height, the original predictions can be used with sufficient accuracy.

If it is possible to install the antennas at a higher position than predicted, it must be ensured that there is no risk for co-channel interference. If the antennas are to be installed at a lower position than predicted, new predictions must be carried out based on this position.

It is not necessary that all antennas in one particular cell have the same height or direction. That is, it is possible to have cells on the same base station with different antenna heights. This can be the case if space is limited in some directions. There are also cell planning reasons for placing antennas at different heights, e.g. coverage, isolation, diversity, and/or interference.

- ✓ **Space for radio equipment**

Radio equipment should be placed as close as possible to the antennas in order to reduce the feeder loss and the cost for feeders. However, if these disadvantages can be accepted, other locations for the equipment can be considered. In addition sufficient space should be allotted for future expansions.

The preliminary site-survey should include a brief study with respect to this matter. A more detailed analysis takes place when the location is chosen to be included in the wireless network.

- ✓ **Power supply/battery backup**

The equipment power supply must be estimated and the possibility of obtaining this power must be checked. Power cables must be installed and a mains power source must be found in the vicinity of the site if mains power is not available at the site. For an indoor site, the BS equipment room must fulfill a number of requirements concerning mains power connection such as grounding, power outlet, and space for transport network interface products. Space for battery back-up may be required.

- ✓ **Transmission link**

The base station must be physically connected to the ASN-GW. This can be carried out via radio link, fiber cable, or copper cable. Detailed information on the existing infrastructure should be collected.

- ✓ **Service area study**

During the site-survey, it is important to study the intended service areas from the actual and alternate base station locations. Coverage predictions must be checked with respect to critical areas.

After listing all the potential sites considered worthy of further investigation, a thorough site inspection is required to provide a basis for assessment of the advantages and disadvantages of each site.

Potential BS sites should, if possible, be adjacent to power supplies, telephone lines etc… Availability of these services may eliminate the need to provide them specifically for the airport and so reduce costs.

At this stage, sufficient information should be available to reduce the number of BS to those meriting detailed consideration. At this point the planner should review the results of the office study and field investigation. Based on this review, sites which are unsuitable and which do not warrant further examination should be omitted.

2. Verify BS locations (site survey testing).

This is when the site survey testing begins. Most wireless LAN vendors provide wireless site survey software that identifies the associated BS, data rate, signal strength, and signal quality. You can load this software on a laptop and test the coverage of each preliminary BS location. Alternately, you can use a third party site survey tool available from several different companies, such as AirMagnet, Berkeley Varitronics Systems, and Ekahau.

Install a BS at each preliminary location, and monitor the site survey tool readings by walking varying distances away from the BS. There's no need to connect the BS to the distribution system because the survey tests merely ping the BS or read the beacon signal strength. Very important: Definitely consider the SNR range boundary and uplink signal strength when interpreting the results. To make the BS easy to move about the facility, you can mount it on a pole attached to a cart with a battery and DC/AC converter. Otherwise, you'll need to haul around an extension cord and always be looking for where to plug in for power (not recommended).

Take note of performance or signal readings at different points as you move to the outer bounds of the BS coverage. Keep in mind that a poor signal quality reading could indicate that RF interference is affecting the system. This would warrant the use of a spectrum analyzer to characterize the interference, especially if there are no other indications of its source. Based on the results of the testing, you might need to reconsider the location of some BS and redo testing for the affected locations.

3. Site pre-selection report.

Once you are satisfied that the location of the BS you have identified will provide adequate signal coverage, document your findings on the airport diagrams by depicting the location of each BS.

The report made after site selection should have more detailed information than the preliminary site-survey report. This may contain the height of the building/green-field, coordinates, antenna configuration (location, tilt, azimuth, etc.), maps, and a top view of the site with exact location of the base station and the antennas (both radio and transmission).

A comprehensive report supported by drawings etc…should be prepared. The report consists of two parts

- Site documents
- Site preparations

The site documents consist of:

- The result of the BS inspection and evaluation,
- Site data (Configuration data)
- A site layout drawing
- Antenna arrangement drawing
- Cabinet material list
- Ranking of sites in order of merit, supported by reasons for selection,
- Recommendations for further actions.

The site preparations document is a document that describes the scope of the civil engineering work needed on each site and who is responsible for them. As an example, it will define the following responsibilities:

- Antenna tower
- Concrete foundation
- Roof reinforcements
- Earthing system
- AC mains power
- Transport network
- Necessary permits

3.7 RF Cell Dimensioning

The scope we are willing to cover in this section and thus through the RF simulations is:

- Generic guidelines for simulations made with a RF tool.
- Description of the set up of the scenarios simulated.
- Designing considerations that will be addressed for the scenarios:
  - Determine cell density required for a desired level of service, performance, and coverage.
  - Illustrate the effect of frequency, power, terrain, clutter and CPE location on that coverage.
  - Determine expected point-to-point link performance using an analytical path loss model.
  - LOS and NLOS Maximum Allowable Path Loss (MAPL) based on system parameters.
  - Determine power settings and receiver sensitivities.
  - Channel bandwidth and frequency raster.
  - Deem antenna gains.
  - Fading model to be used.
  - Determine site selection criteria over Barajas and Toulouse layouts.

All the simulations of this section have been computed with HTZ Warfare tool (an ICS Telecom software based from ATDI Company). Maps from Toulouse and Barajas have been provided in order to perform simulations with the tool for the two airports. A description of the main parameters of the Radio planning tool can be found in Appendix A.0.

3.7.1 Coverage analysis

The objective of this section is to specify link budget for different airport areas to be used during radio planning, derived from WA2 channel models and allowed output power levels. In order to perform this activity, inputs from WA1 and WA2 (results from the measurement campaign carried out at Madrid Barajas and at Munich Airport), are needed, as well as a RF planning tool.

The objective of this sub-section is to appreciate the difference which may occur between statistical models and determinist models, which take into account real airport maps (DTM), environment (buildings), co-site situations (co-channel or interferences).

Thus LOS and NLOS propagation are differentiated in a real situation, taking into account multipath propagation as well. For this purpose, a deterministic model was used, combining ITU-R P.525 for LOS (Line Of Sight) loss, Deygout 94 method for diffraction loss (when the LOS is obstructed) and Standard for nLOS (near LOS) loss (when the 1st Fresnel zone is obstructed but that the LOS is clear). This propagation model takes also into account multipath effect.

The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. They require a 3-D map of the propagation environment: the more compatible the accuracy of the cartography with a certain technology to simulate, the better the coverage accuracy (for a given set of technical parameters for the Best Stations / Terminals / Mobile Stations). Typical examples are the ITU-R P.525/526 models, used with appropriate additional propagation effects (diffraction, sub-path attenuation, ray tracing). Attenuation associated to the signal strength received at each pixel will be attenuated based upon the selected diffraction model. A fully deterministic propagation model might be limited for technologies using high frequencies, where each above the ground feature can become a physical obstacle to the propagation of the signal (diffraction, absorption…).

3.7.1.1 Definition of propagation media

Propagation aspects can be divided in three different parts:

• LOS propagation (Line Of Sight): The transmitter and the receiver are in visibility one with each other.

The propagation in LOS is based upon clearly defined propagation methods, such as the ITU-R P.525 model. Note that in ICS Telecom, taking full advantage of the quality of the cartography loaded, deterministic propagation models, have proved to give the best correlation when correlated with on-field measurements. Of course, additional effects, such as attenuations due to the rain or gas are also considered.

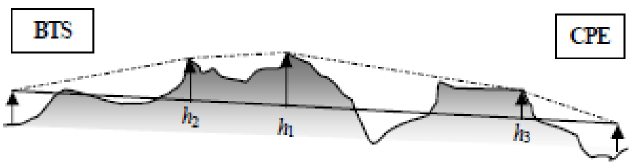
• NLOS propagation (NON Line Of Sight): The transmitter and the receiver are not in visibility one with each other. A typical example is a WiMAX BS located in Outdoor environment, when the MS is located inside a building. The signal between the BS and the MS is then diffracted, diffused, or both.

ICS telecom features a new cartographic layer, called the building file that describes the building height above ground level. In ICS telecom, the Digital Terrain Model is now separated from the above-the-ground features (buildings, trees…).

• nLOS propagation(near Line Of Sight): This case is a mix between the LOS and the NLOS case. The transmitter and the receiver can be for instance in visibility one with each other, but part of the Fresnel ellipsoid is obstructed. A transmitter and a receiver almost in visibility one with each other is all a possibility: the signal can then propagate using diffraction or multi-reflection on building sides.

3.7.1.2 Diffraction effect

The diffraction models in ICS telecom do quantify the losses due to obstacles between the BS and the MS, avoiding the two entities to be in Line of Sight one with each other.



3.7.1.3 Sub-path attenuation effect

The sub-path model in ICS telecom quantifies the losses due partial obstructions of the Fresnel zone. Such an attenuation term can be defined for partial obstruction in the Z axis only, or in full 3D.

3.7.1.4 Multi-reflection effect

This model calculates the field strength at all point of the simulation area according to reflected signals contribution, taking into account a reflection coefficient defined by the user.

3.7.1.5 AeroMACS Link Budget

A link budget provides a **static RF coverage calculation** taking into account all parameters which determine such a range, including modulation schemes and FEC.

LOS range estimations are based on **free space model and AWGN** conditions while **NLOS** ranges are based on **MUNICH NLOS** model [25].

Because in AeroMACS, the DL and UL operate with different amount of data carriers (sub-channels) under PUSC configuration, a short description is provided on sub-channelization. While in the DL all datacarriers are used simultaneously to download data to all MS attached to this particular BS in the UL the MS has only a limited amount of sub carriers available whenever a BS is serving multiple MSs at the same time.

3.7.1.5.1 Free space model

Both free space and NLOS MUNICH pathloss models have been calculated in the spreadsheet.

The mathematical formula for free space model and AWGN operating conditions corresponds to:

$$\mathbf{Lp = -32{,}4-20LOG(f\ (MHz))-20LOG(d\ (km))}$$

3.7.1.5.2 DLR Munich NLOS model

As kind of worst case scenario the cell coverage distance has also been calculated using the MUNICH NLOS model used within SANDRA [25].

The mathematical expression for this model corresponds to:

$$\mathbf{Lp = A + 10\mu log(d)\ with\ A = 49{,}3dB\ \ and\ \mu = 2{,}5}$$

3.7.1.5.3 Airport Model Comparison

Both of the models defined above have been used in the link budget as they present the best (freespace) as well as the worst channel model (DLR NLOS) from all airport channel models developed. The following models (the last 3 typical for airports) have been developed under various projects :

1. Free space model
2. MATOLAK(FAA / USA) or US(LOS)
3. D02.1 (Sesar P15.2.7 channel modelling) or BS1MR1 and BS2MR2
4. SANDRA MUNICH or DLR(NLOS)

A comparison can be found between all 4 models in D02.1 Figure 36 [6] and is repeated in Figure 29.

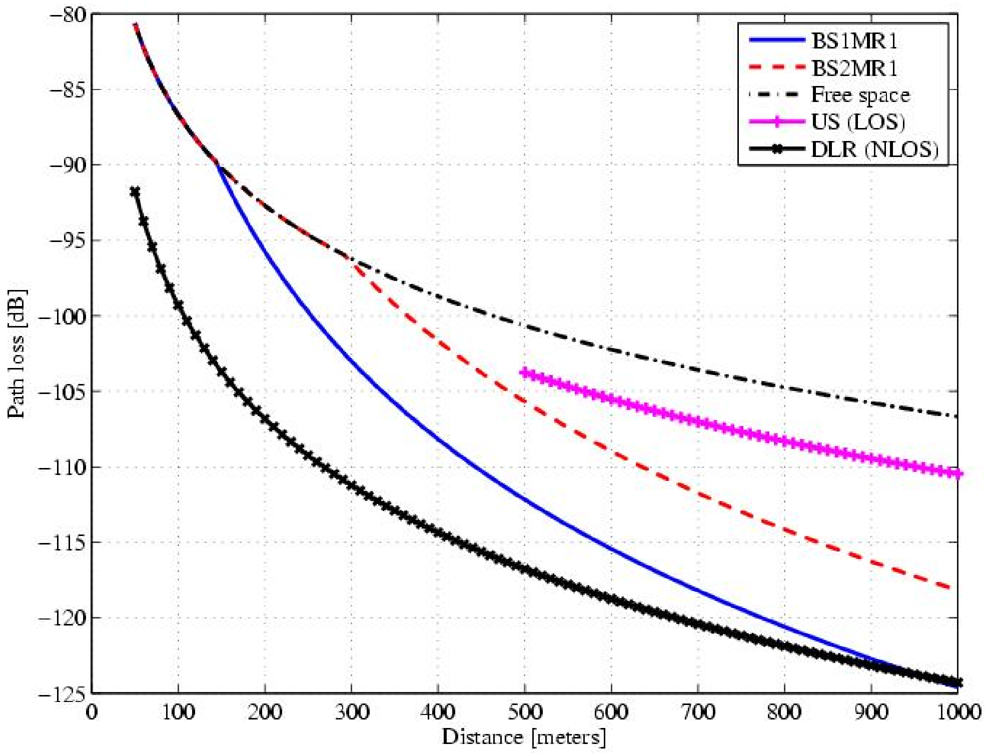


Figure 29: Comparison of airport pathloss models

Numerical values for free space and NLOS MUNICH coverage ranges can be found in the accompanying spreadsheet of the link budget.

3.7.1.5.4 Downlink PUSC

Downlink partial usage of sub-channels (DL PUSC)

Subcarriers are grouped into clusters of 14 contiguous sub-carriers per symbol. A sub-channel is a group of two clusters. A slot is one sub-channel over two OFDM symbols. The sub-channels in a DL PUSC zone can also be mapped into larger groups called segments. There can be up to three segments created from these larger sub-channel groupings.

WIMAX IEEE802.e LINKBUDGET FOR THE DOWNLINK (5 MHz Bandwidth)							
Modulation Scheme		QPSK 1/2		16QAM 1/2		64 QAM 1/2	
Link Direction		DL (CC)	DL (CTC)	DL (CC)	DL (CTC)	DL (CC)	DL (CTC)
TX Parameters	**Unit**						
# of antenna elements		1	1	1	1	1	1
TX Power per Antenna Element	dBm	23,00	23,00	23,00	23,00	23,00	23,00
Maximum TX Antenna Gain	dBi	15,00	15,00	15,00	15,00	15,00	15,00
Tx Cable loss	dB	3,00	3,00	3,00	3,00	3,00	3,00
TX EiRP	dBm	35,00	35,00	35,00	35,00	35,00	35,00
# of occupied sub-carriers		420	420	420	420	420	420
NFFT Window size		512	512	512	512	512	512
TX EIRP per sub-carrier	dBm	8,77	8,77	8,77	8,77	8,77	8,77
System Parameters							
Required SNR	dB	**5,00**	**2,90**	**11,00**	**8,60**	**16,00**	**13,80**
Bandwidth	MHz	5,00	5,00	5,00	5,00	5,00	5,00
sub-carrier spacing	kHz	10,94	10,94	10,94	10,94	10,94	10,94
Transmit upper Frequency	MHz	5120	5120	5120	5120	5120	5120
Margins							
Non-orthogonality Margin	dB	1	1	1	1	1	1
Inter-cell Interference Margin	dB	3	3	3	3	3	3
Implementation Margin	dB	3	3	3	3	3	3
Safety Margin	dB	0	0	0	0	0	0
Banking Loss Margin	dB	0	0	0	0	0	0
RX Antenna Diversity Gain	dB	0	0	0	0	0	0
RX Parameters							
Maximum RX Antenna Gain	dBi	6	6	6	6	6	6
Rx Cable loss	dB	1,8	1,8	1,8	1,8	1,8	1,8
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	-174
Receiver Noise Figure	dB	7	7	7	7	7	7
Composite Noise Figure	dB	8,8	8,8	8,8	8,8	8,8	8,8
RX Sensitivity (per sub-carrier)	dBm	-118,8	-120,9	-112,8	-115,2	-107,8	-110,0
RX Sensitivity (composite)	dBm	-92,6	-94,7	-86,6	-89,0	-81,6	-83,8
Maximum Allowable Path Loss	dB	127,6	129,7	121,6	124,0	116,6	118,8
free space LOS		11190,94	14251,70	5608,76	7393,78	3154,04	4063,19
NLOS MUNICH		1352,36	1640,94	778,20	970,72	491,01	601,30

Table 26: DL Link Budget

3.7.1.5.5 UPLINK PUSC

For UL PUSC zone type, four contiguous subcarriers are grouped over three symbols. This grouping is called a tile. Six tiles make a sub-channel. For the UL PUSC, the slot is defined as one sub-channel that occurs over the three symbols. Pilots are incorporated within the slot, their position changing with each symbol. Over the course of one tile, one in three subcarriers is a pilot.

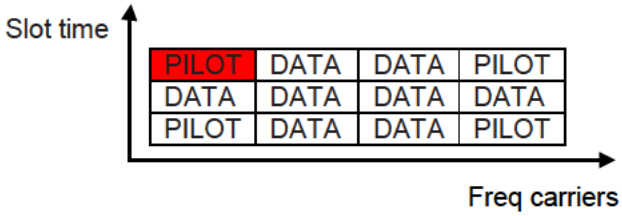


Figure 30: Graphical presentation of Tile in UL-PUSC zone ; Slot = 6 tiles over 3 Symbols

Mobile WiMAX implements “uplink sub-channelization” which allows the user to transmit over a limited number of sub-carriers (X * 24) thereby boosting the transmit power as the power spectral density is focused on a limited set of sub-carriers. While sub-channelization increases the cell coverage it decreases the data throughput for this user as the number of subcarriers assigned to him has been reduced.

WIMAX IEEE802.e LINKBUDGET FOR THE UPLINK (5 MHz Bandwidth)

Modulation Scheme		**QPSK 1/2**	**QPSK 1/2**	**16QAM 1/2**	**64QAM 1/2**	**64QAM 1/2**	**64QAM 1/2**
Link Direction		UL (CC)	UL (CTC)	UL (CC)	UL (CTC)	UL (CC)	UL (CTC)
TX Parameters	**Unit**						
# of antenna elements		1	1	1	1	1	1
TX Power per Antenna Element	dBm	21,00	21,00	21,00	21,00	21,00	21,00
Maximum TX Antenna Gain	dBi	6,00	6,00	6,00	6,00	6,00	6,00
Tx Cable loss	dB	1,80	1,80	1,80	1,80	1,80	1,80
TX EiRP	dBm	25,20	25,20	25,20	25,20	25,20	25,20
# of occupied sub-carriers		24	24	24	24	24	24
NusedsubCh UL		1	1	1	1	1	1
NSubChUL		17	17	17	17	17	17
NFTT Window size		512	512	512	512	512	512
TX EIRP per sub-carrier	dBm	11,40	11,40	11,40	11,40	11,40	11,40
System Parameters							
Required SNR	dB	**5,00**	**2,90**	**10,50**	**8,60**	**16,00**	**13,80**
Bandwidth	MHz	5,00	5,00	5,00	5,00	5,00	5,00
sub-carrier spacing	kHz	10,94	10,94	10,94	10,94	10,94	10,94
Uplink Sub-Channelization Gain	dB	12,3	12,3	12,3	12,3	12,3	12,3
Transmit upper Frequency	MHz	5120	5120	5120	5120	5120	5120
Margins							
Non-orthogonality Margin	dB	0	0	0	0	0	0
Implementation Margin	dB	5	5	5	5	5	5
Safety Margin	dB	0	0	0	0	0	0
Banking Loss Margin	dB	0	0	0	0	0	0
RX Antenna Diversity Gain	dB	0	0	0	0	0	0
RX Parameters							
Maximum RX Antenna Gain	dBi	15	15	15	15	15	15
Rx Cable loss	dB	3	3	3	3	3	3
Thermal Noise Density@290K	dBm/	-174	-174	-174	-174	-174	-174
Receiver Noise Figure	dB	8	8	8	8	8	8
Composite Noise Figure	dB	11	11	11	11	11	11
RX Sensitivity (per sub-carrier)	dBm	**-109,9**	**-112,0**	**-104,4**	**-106,3**	**-98,9**	**-101,1**
RX Sensitivity (per sub-carrier) without subcahnnelization gain	dBm	-97,6	-99,7	-92,1	-94,0	-86,6	-88,8
RX Sensitivity (composite)	dBm	-96,1	-98,2	-90,6	-92,5	-85,1	-87,3
Maximum Allowable Path Loss	dB	**121,3**	**123,4**	**115,8**	**117,7**	**110,3**	**112,5**
Maximum Allowable Path Loss without Sub-Channelization Gain	dB	109,01	111,11	103,51	105,41	98,01	100,21
free space LOS	m	5440,14	6928,04	2888,09	3594,27	1533,24	1975,20
NLOS MUNICH	m	**759**	**921**	**458**	**545**	**276**	**338**

Table 27: UL Link Budget

3.7.1.6 Building loss estimation (indoor communication)

In some cases (sector antenna radiating **perpendicular on buildings** and having beam elevation angle not radiating over the building) it may be possible to take into account building losses in order to decrease interference levels with Globalstar.

Note: The values provided have been obtained for indoor communication and may give an idea on generic value estimations for different materials. However for outdoor communication, values need to build in a safety factor of 3 to 6 dB.

Frequency GHz	Loss for Thin walls dB	Loss for Thick walls Concrete dB
2	3,3	10,9
3,5	3,4	11,4
5	3,4	11,8

Table 28: Wall attenuation values

Note: Because airport terminal very often include extremely large glass surfaces the attenuation loss for windows can be found in table beneath.

Frequency GHz	Glass/Window (not tinted) dB	Double-pane coated glass dB
2,4	2-3	13
5	6-8	20

Table 29: Window attenuation values

3.7.1.7 Radio Cell Planning Steps

Generally speaking, the radio cell planning is an iterative process, following several main steps summarized below.

Step 1: Consolidate customer expectations and local data
- Range, number of MS, expected data rates,
- Existing radio systems, power limitations

Step 2: Capacity study
- Derive number of devices
- Frequency planning

Step 3 – Coverage and Interference studies (linked to Step 2)
- Initial radio link budget (first cell dimensioning)
- Detailed Propagation model
- Antenna systems, choice of optimized localizations for BS and downtilts
- Detailed radio coverage analysis

Step 4 – Network optimization
- Interferers mitigation
- Tuning

This process is unique for each deployment and is common to all the wireless radio technologies.

3.7.2 Capacity analysis

3.7.2.1 Objectives

This section analyzes the capacity offered by an AeroMACS system against the requirements set by SRD. As a consequence, a refinement of both the requirements and the dimensioning of the system will be presented.

Capacity is considered as the ability of the system to fulfil a certain degree of accomplishment of requirements defined by the types of service that it enables. It is measured by means of throughput and delay parameters, which can be defined at different levels and scopes according to the boundaries of the system. For this analysis, AeroMACS capacity will be contrasted with the latency and throughput requirements that may be needed by the services identified in WA2 [6], considered the potential users of the data link. These metrics can be presented either per service or at MAC layer (i.e. independent on the specific service that runs over the radio medium).

Two possible scopes of study are defined: first, an analysis of the capacity offered per airport domain (i.e. RAMP, GROUND and TOWER) is performed. Then, a study of the overall capacity offered in a whole airport (Madrid Barajas) is presented.

3.7.2.2 Capacity analysis per operational domain

This section presents a preliminary AeroMACS system performance analysis obtained by means of simulation results. The aim of these system simulations is to investigate the AeroMACS profile in terms of average system performance (related to coverage, capacity, handover and channel impairments' robustness) in specific airport domains, such as the Ramp and Tower areas. Therefore these results will not be applicable to a whole airport domain but just to couples of adjacent cells and have a two-fold purpose: validate some of the requirements of AeroMACS SRD [3] and provide useful indications that could be exploited by the much more specific and airport-wide simulations that will be described in the next subchapters (the simulations of a complete AeroMACS network over Barajas and only coverage over Toulouse airports).

These simulations can be divided in three different types:

- Coverage estimation (in single cell scenarios)
- Handover validation (in two cells scenarios)
- System Performance (in two cells scenarios)

The first and second types focus on specific performance issues, such as coverage and handover, while the third one gives an overall evaluation of the system in the cited airport environments (Ramp & Tower). The simulations have been carried out considering the system profile defined in WA1 and WA3 [9] [5]. The PHY layer modelling refers to the results provided by SANDRA project [34] [35] and to the so-called Barajas' path loss models (in particular the BS2-MR1 & BS2-MR2 ones) [9]. Data traffic modeling refers to SESAR WA2 results [6].

3.7.2.2.1 Coverage analysis

The first set of simulations concerns with AeroMACS coverage capabilities. Taking into account the PHY performance (BER/PER curves) provided by SANDRA project and the Barajas' path loss model, the "maximum" possible coverage is evaluated. By maximum possible coverage here we mean the distance at which connections get dropped because throughput goes to zero; in fact at this distance the PER on the air-interface gets very high, greater than 10^{-2}, a condition in which communication is severely impacted. Therefore in following handover and system simulations much shorter distances will be considered as logical cell borders, corresponding to PER values not higher than 10^{-3}.

3.7.2.2.1.1 Hypotheses made in simulations

The simulations are carried out in a single "cell" where a single mobile terminal moves away from the BS position with uniform motion and low speed until the throughput goes to zero. The speed of the MS was set to 5m/s (18 km/h). We consider here hard constant bit rate (CBR)[14] traffic; MAC-level SDUs are splitted in one or more PHY-level PDUs that are then sent over the air-interface. We have considered three different cases:

Case 1: the amount of generated traffic is such that to saturate the available physical bandwidth (the link theoretical capacity). Bandwidth saturation represents a worst case from a channel propagation point of view too, because the packet dimension, i.e. the PDU dimension, is maximum and hence the packet error rate is maximum too. In this case MAC layer gets two SDUs in downlink transmission and one SDU in uplink transmission every 5 ms

Case 2: the amount of generated traffic is one fifth of the link theoretical capacity but all the available resources (the frame slots) can still be allocated to the MS. In this case the link is not fully loaded. MAC layer gets one SDU in downlink transmission and one SDU in uplink transmission every 5 ms.

Case 3: the amount of generated traffic is one fifth of the link theoretical capacity (as in case 2 above) but only one fourth of the available resources (1/4 of the frame slots) can be allocated to the MS. Here the situation is similar to case 1 with the difference that the available resources in the frame are less

Notice that the scheduler has the policy to use as wide as much PDUs to transmit data over the air interface; so this will generally happen in case 1 and case 2 but not in case 3 where resources are limited: in this last case smaller PDUs will be sent with higher frequency over the air interface for the same amount of offered traffic. In the table below the dimensions of the exchanged SDUs are shown:

SDU size	DL (Byte)	UL (Byte)
full load	1400 + 1100	674
1/5 full load	500	134

Table 30: Service Data Unit dimensioning (Bytes)

A traffic that saturates the available bandwidth is a traffic which at the physical layer is almost equal to the maximum link theoretical capacity; under the hypothesis of using 16QAM CC ½ and considering a fixed (1:2) UL/DL symbols ratio we get a traffic data rate of 4Mb/s in FL and 1.3Mb/s in RL.

The simulator is based on a simplified PHY model which takes into account the effects of propagation channel (i.e. power losses) on the received signal and the consequent packet errors.

Description	**Symbol**	**Value**
Transmitted Power BS	$P_{TX,BS}$	23 dBm
Transmitted Power MS	$P_{TX,SS}$	20 dBm
Cable loss BS	L_{BS}	2 dB
Cable loss MS	L_{SS}	2 dB
Max antenna gain BS	G_{BS}	15 dBi

[14] Hard constant bit rate means a CBR traffic which has also tight restrictions on jitter and latency

Max antenna gain MS	G_{SS}	6 dBi
Sampling frequency	f_s	5.6 MHz
Carrier frequency	f_c	5.150 GHz
Noise figure	NF	8 dB
Implementation Loss	ImpLoss	5 dB
Used subcarriers	N_{used}	420(FL)/408(RL)
FFT dimension	N_{FFT}	512

Table 31: PHY Layer parameters

With reference to the parameters of Table 31 the received signal power and the SNR are calculated as:

$$P_{rx} = P_{tx} - L_{tx} - L_{rx} + G_{tx} + G_{rx} - L$$

$$SNR = P_{rx} - N$$

where L is the channel propagation loss and N is the noise term equal to:

$$N = -174 + 10\log_{10}\left(\frac{f_s}{N_{FFT}} N_{used}\right) + NF + \mathrm{ImpLoss}$$

The receiver evaluates the received signal level P_{rx}, if it is higher than the Noise power N the receiver considers the packet as received, calculates its SNR value and addresses a specific PER value in the pre-computed tables allowing further considerations (packet correctly received or packet corrupted). In particular, a random number uniformly distributed between 0 and 1 is drawn and if this value is greater than the PER, the packet is considered correctly received, viceversa the packet is discarded. PER tables are addressed referring to different parameters: SNR, modulation and coding schemes (MCS), channel type (LoS, NLoS). For PER tables[15] we refer to [34] [35]. Two different MCSs have been used, QPSK CC ½ and 16QAM CC ½, and two SNR threshold values have been set in FL/RL to switch between them. These thresholds, shown in Table 32 below, have been set in order to select the modulation and coding scheme that guarantees the maximum throughput at each SNR[16].

Adaptive MCS threshold (SNR in dB)		
	LoS	**NLoS**
UL	20.7	24.1
DL	24.9	28.7

Table 32: MCS switching thresholds

In the PHY model the propagation loss L experienced by the transmitted signal is comprised of two components, the Path Loss (PL), that is an increasing function of the distance *d*, and the Slow Fading (SF), that is a random fluctuation around the average value given by the path loss:

$$L=PL(d)+SF$$

Two different propagation models are simulated, mainly LoS and mainly NLoS, mixing them according to the type of node (aircraft/vehicle) and considered area (Ramp/Tower). The so-called Barajas' path loss models have been used in these simulations as propagation loss:

[15] We are interested in results in 5MHz bandwidth, 1 slot FEC, CP=1/8 and linear channel interpolation
[16] It is to be noted that these thresholds might be lower if using a CTC instead of a CC

$$L = \begin{cases} 32.44 + 20\log f_c + 20\log d + X_\sigma & d < d_{BP} \\ 32.44 + 20\log f_c + 20\log d_{BP} + 10\gamma\log\dfrac{d}{d_{BP}} + X_\sigma & d \geq d_{BP} \end{cases}$$

where:

- d_{BP} is the breakpoint distance
- X_σ is the slow fading term where σ is the slow fading standard deviation
- γ is the path loss exponent for distances above d_{BP}
- f_c is the carrier frequency in Ghz

Default values for the above parameters are shown in Table 33:

	Base Station height	**d_{BP}**	γ	σ
BS1-MR1	12m	144m	4.13	1.67
BS2-MR1	**38m**	**292m**	**4.15**	**2.80**
BS1-MR2	12m	52m	3.4	4.25
BS2-MR2	**38m**	**141m**	**3.15**	**3.96**

Table 33: Barajas Pathloss models' parameters

We considered the BS height equal to 38m, hence we used BS2-MR1 in NLoS propagation conditions and BS2-MR2 in LoS propagation conditions. As a rule we will consider Ramp areas as characterized by LoS (aircrafts) or NLoS (vehicles) propagation conditions respectively; Tower areas will always be characterized by LoS propagation conditions. In order to evaluate coverage worst case propagation condition should be considered, so in this case we applied BS2-MR1 *without slow fading* to get more deterministic results.

An ARQ scheme has been applied in simulations according to profile specifications. In particular in [9] two possible alternatives are suggested, ARQ type 1 and ARQ type 2. Both types have been considered in these simulations but results will only be presented for ARQ type 2 which showed to be more robust under medium-high BER conditions from a packet loss perspective (especially during MCS switching transients).

Main ARQ parameters are set as in Table 34:

Parameter	Value
ARQ Block Size [bytes]	64 UL / 256 DL
ARQ Window Size [ARQ blocks]	512
ARQ Block Lifetime [s]	6xRTI
ARQ Retry Timeout (Retransmission Time Interval-RTI) [s]	0,1

Table 34: Main ARQ parameters

Additional secondary-level parameters are set as in Table 35:

Parameter	ACK Type 1,2
In-Order SDU Delivery	enabled
Rearrangements	enabled
Feedback Time Interval	Every 16 ARQ blocks correctly received
Number of IE for each feedback message	1
Number of maps for each IE	1

Table 35: Secondary-level ARQ parameters

Regardless of the size, every PDU consists of an integer number of ARQ blocks. For example in the case of only one MS the composition of PDUs and ARQ blocks is shown in Table 36:

	UPLINK		DOWNLINK	
	Q-PSK 1/2	16-QAM 1/2	Q-PSK 1/2	16-QAM 1/2
Size of PDU (slots)	68	68	219	219
Size of slot (bytes)	6	12	6	12
# ARQ blocks in PDU	6	12	5	10
Size of ARQ block (bytes)	64	64	256	256

Table 36: Size of PDU and ARQ blocks

A description of the IP layer model can be found in [9].

3.7.2.2.1.2 Analysis of results

This section presents the coverage simulation results. In the simulated scenario there is only one node which starts to move after 10 seconds from BS position in radial direction with uniform motion and a speed equal to 5 m/s (18 km/h). The selected output metrics are:

- **Throughput**
- **Packet loss**

For the goal of these simulations, evaluating maximum coverage, packet delay has no relevance. As a matter of fact under a full traffic load condition high delays will occur when the terminal is far from the BS and will use QPSK modulation. The throughput values refer to the MAC SDUs reassembled at the receiver in each second. The transmitter sends through the MAC PDUs the different ARQ blocks of a SDU, that are actual numbered SDU fragments. When every ARQ block of a SDU is correctly received at the receiver, the SDU is reassembled and sent to the upper layer. When a received ARQ block in a SDU still contains an error after the maximum number of retransmissions has elapsed the whole SDU is rejected and counted in the statistics of packet loss. So packet loss can be defined as the number of packets that are discarded by the transmitter after a certain number of retransmissions have failed. So the retransmission of packets does not enter into the calculation of throughput and packet loss metrics. Furthermore the packets that are dropped because the transmission queue is full (i.e. packets that are not even scheduled for transmission) are not considered in the statistics, i.e. packet loss refers only to channel effects.

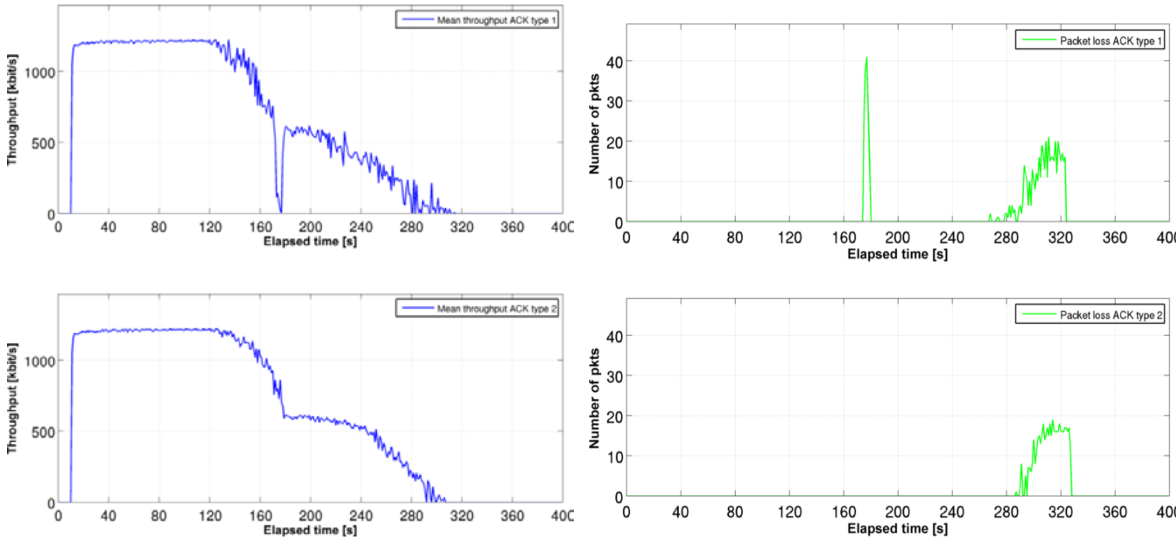


Figure 31: Throughput & Packet Loss with ARQ Type 1 and ARQ type 2 (UL)

Preliminary results provided here concern with a performance comparison of the two ARQ ACK types (1 and 2). We assume a traffic load almost equal to the theoretical link capacity and LoS propagation conditions. As Figure 31 shows ARQ type 2 assures better performance than ARQ type 1 in medium-high BER conditions since it manages retransmissions in a more efficient way.

At the beginning transmission is optimal and the channel causes very few errors which are managed by ARQ with negligible overhead. After about 120 seconds the propagation channel starts to insert more errors in the packets, leading to a throughput reduction due to a larger amount of retransmitted packets and a ripple effect in the throughput due to local delays in successfully delivered packets; still no packet loss is measured. At about 175 seconds the MCS is changed, switching from 16QAM to QPSK, to adapt to the worse channel conditions: throughput stabilizes to around ½ of the initial value and channel errors are reduced; during this transient phase some packets are lost if ARQ type 1 is used. After about 210 seconds the channel starts again to insert more and more errors in the packets, thus causing a gradual decrease in capacity due to retransmissions and a ripple in the throughput due to local delays. Packet loss remains null until around 265 s for type 1 and 285 s for type 2; afterwards channel conditions become so harsh that packet losses grow up very rapidly thus causing a rapid decrease in throughput too. After 310 s, corresponding to a distance of 1500 meters, throughput goes to zero, thus causing packet loss going to zero in turn, transmitter stops sending packets and the connection is virtually lost.

The performance behaviour of the downlink looks much like the uplink one. So ARQ type 2 seems to achieve better performance in terms of packet loss and throughput, especially during MCS switching and when channel conditions are harsh. *As a result of previous simulations all following results will be given for ARQ type 2 only.*

Afterwards simulations were carried out in different conditions of traffic load and available resources as described previously in Case 1, Case 2 and Case 3; results were analysed as function of Los/NLos propagation conditions and UL/DL directions. In the following figures throughput and packet losses will be shown, in Cases 1, 2, 3 respectively, for the downlink only, but pretty much equivalent results hold for the uplink too.

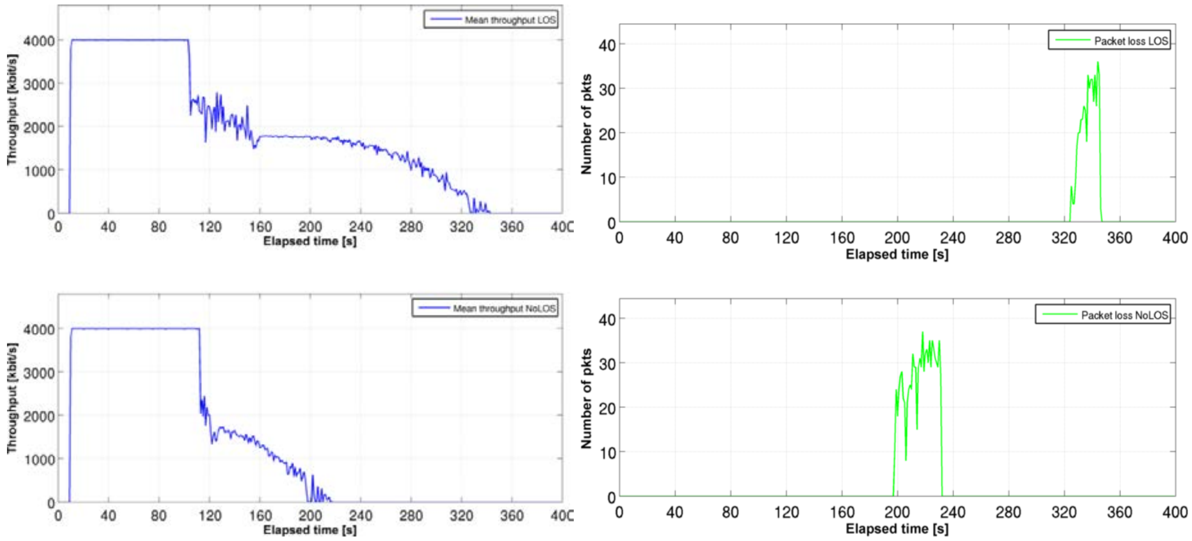


Figure 32: Case 1: Throughput & Packet Loss in Los/NLos (DL)

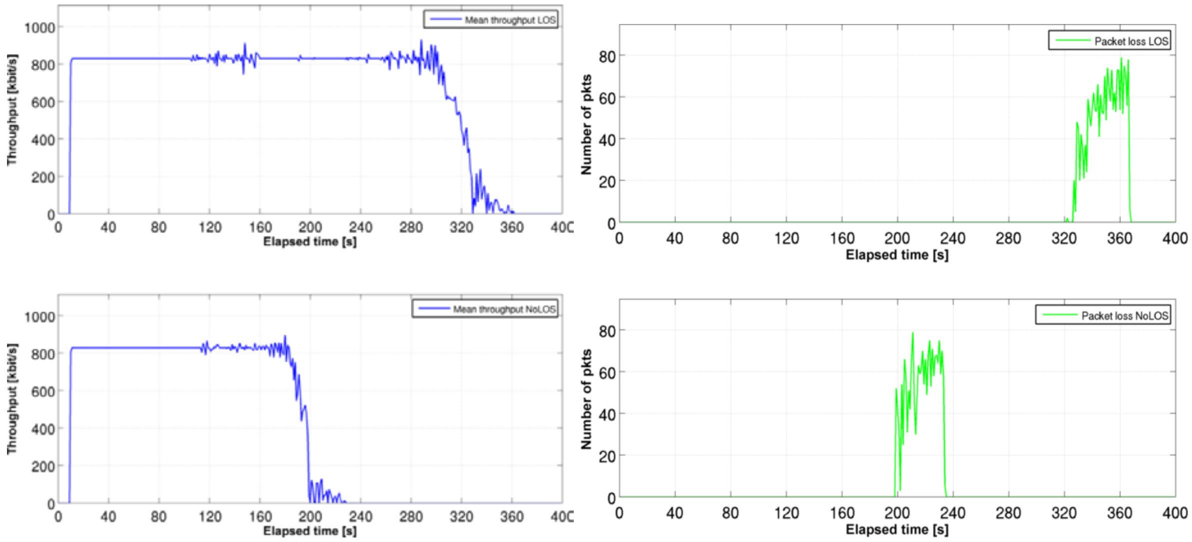


Figure 33: Case 2: Throughput & Packet Loss in Los/NLos (DL)

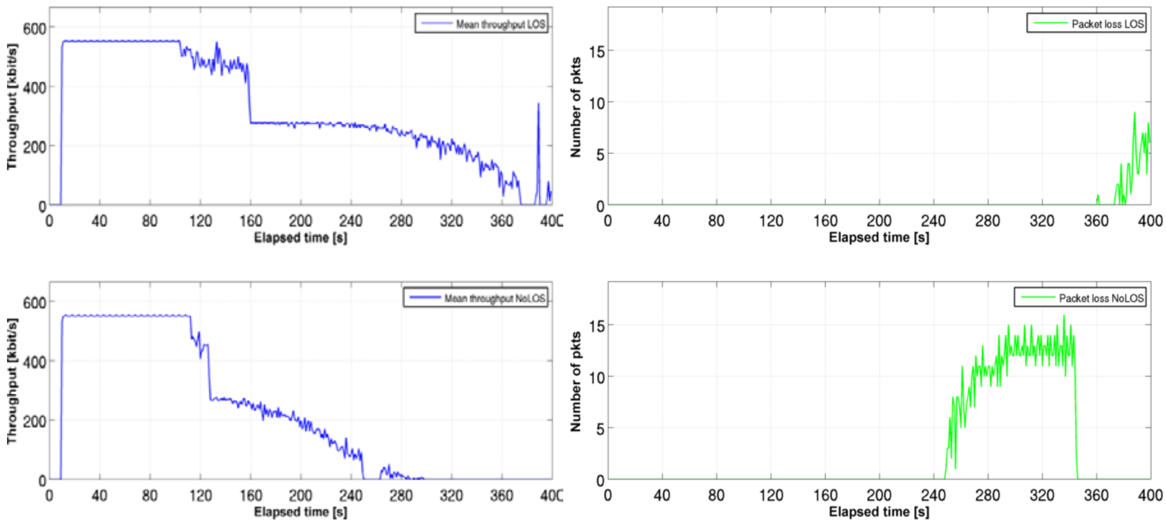


Figure 34: Case 3: Throughput & Packet Loss in Los/NLos (DL)

The general behaviour of the curves is the same as that observed in the ARQ type comparison: firstly 16QAM transmission is used, with degrading performance while channel impairments grow up, until a time in which a switch to QPSK occurs (at about 160 s in Los and 125 s in NLos conditions) which causes throughput to temporarily stabilize. After some further time performance degrades again until packets are lost, throughput nullifies and the connection is virtually stopped (the persistent ripple phenomena on the packet loss of Figure 34 - NLos case - are artefacts of the simulation which are not relevant for results).

From the figures it can be seen that i) the NLoS propagation condition causes a quicker degradation of performance and hence a smaller coverage ii) in Case 2 the change in modulation does not change the throughput because a lot of free resources are still available, where more than twice of the original resources can be used to sustain the source traffic rate iii) in Case 3 the range is a little bit increased with respect to Cases 1 and 2 (in fact the throughput goes to zero after a longer time period, at about 375 s in LoS and 250 s in NLoS). This last result, which might seem surprising, has an explanation; in Case 3 resources are limited, hence the scheduler will be forced to use shorter packets, transmitted of course with a higher frequency for the same amount of offered traffic. If the MAC PDUs are smaller the probability of error due to channel impairments decreases, assuring a better performance. Thus the BS scheduler could exploit smaller PDUs to transmit data to distant users with a more stable rate. *This clearly indicates how important the scheduling algorithm for the overall system performance is.*
Results for the uplink follow the trends of the downlink, hence the same considerations apply.

3.7.2.2.1.3 Conclusions

Simulation results show ARQ type 2 is more robust than ARQ type 1 in medium-high BER conditions, such as in MCS switching transients and every time channel conditions are harsh (for example when the distance between BS and MS is high). This means that ARQ type 2 should be preferred to ARQ type 1 to best manage these conditions.

Comparing the results obtained in the three considered simulation Cases it is possible to state that system performance is mainly influenced by two aspects, packet dimension and bandwidth saturation:

- if the packet dimension is reduced (Case 3) the probability of receiving wrong packets is lowered, the packet error rate decreases, the retransmissions' overhead is reduced, the throughput is higher and more stable for a given distance and the communication range increases
- when there is much available bandwidth MCS changes do not reduce the throughput, because more packets can be sent in parallel (Case 2). Conversely if the bandwidth is almost saturated an MCS change halves the throughput and retransmissions' overhead limits capacity (Cases 1 and 3) to an extent which depends on channel impairments and packets length; smaller packet lengths get a benefit from a lower error probability

Maximum coverage (mt)	DL	UL
Full load – LoS – ARQ ACK 1	1495	1365
Full load – LoS – ARQ ACK 2	1600	1420
Full load – NLoS – ARQ ACK 2	955	965
1/5 traffic- LoS – ARQ ACK 2	1605	1405
1/5 traffic- NLoS – ARQ ACK 2	960	985
1/4 resources LoS – ARQ ACK 2	1835	1685
1/4 resources NLoS – ARQ ACK 2	1210	1125

Table 37: Maximum coverage results

Defining here the maximum coverage as the distance at which the throughput goes to zero for the first time, under all the previously stated hypotheses, we get the results shown in Table 37. As expected NLoS propagation condition is characterized by lower coverage (faster throughput degradation). It can be added that, especially in the LoS case, the maximum coverage of the uplink is slightly more limited than the downlink, even if the PER curves in FL are worse than in RL for SNR greater than about 12.5 dB. This is due to the fact that at these distances we are working with signal to noise ratios which are close to that value and the MS has 3 dB less maximum power than the BS; considering a shorter cell border where SNRs are higher might yield the opposite conclusion, that the system is downlink limited in coverage, especially in the NLos case.

3.7.2.2.2 Handover analysis

The aim of these simulations is to evaluate handover performance both as a function of mobile speed and BS distance. In this case two properly dimensioned cells belonging to the Ramp or Tower areas will be considered. A realistic traffic scenario will also be simulated taking into account the models as provided by WA2 project.

3.7.2.2.2.1 Hypotheses made in simulations

We consider a two-cells environment (conceptually two 120° sectors) where a number of terminals are spread over the cells; among them a single mobile terminal moves linearly from BS_1 towards BS_2 with uniform motion and constant speed, the other MSs being in fixed positions. Specific assumptions of PHY layer modelling and data traffic modelling are detailed in the following.
In particular these simulations address two cases:

1) **RAMP area**: 2 cells in RAMP area, with
   - Traffic: scenario 27 from USBG simulations
   - Speed: intermediate value (30Km/h)
   - Type of connection: LoS (aircrafts) and NLoS (vehicles)
2) **TOWER area**: 2 cells in TOWER area, with
   - Traffic: scenario 31 from USBG simulations
   - Speed: maximum value (130Km/h)
   - Type of connection: LoS

In order to consider actual data traffic flows, the MAC layer simulator uses traffic models as provided by WA2 project. In particular reference statistical parameters (*Data message Inter-arrival time, Data message size*) to be used to regenerate traffic patterns have been derived from the following files [6]:

- *"Scenario_31_CELL_25_ARRIVAL_TOWER_XML.xml.gz.html"*
- *"Scenario_27_CELL_25_ARRIVAL_RAMP_XML xml.gz.html"*

The traffic scenarios parameters are summarized in Table 38.

		Mean Inter Arrival Time [ms]	Mean Data Message Size [bytes]	Source Throughput [kbps]	Mean # of aircrafts +vehicles	MS speed	Channel
Scenario 27 FL (RAMP)	ATC	18518,28	398	0,171	9+9	30Km/h	LoS/NLoS
Scenario 27 RL (RAMP)	ATC	15760,07	481	0,244	9+9	30Km/h	LoS/NLoS
Scenario 31 FL (TWR)	ATC	370,33	34	0,734	4+0	130Km/h	LoS
Scenario 31 RL (TWR)	ATC	60492,96	126	0,016	4+0	130Km/h	LoS

Table 38: Traffic scenarios parameters (ATC only)

In order to speed up simulation time and to obtain statistically reliable results (averaging is performed on multiple runs) we have considered ATC traffic (excluding AOC traffic). This is not harmful because handover performance basically depends on the probability of losing some control messages related to the handover procedure itself, and this is quite independent from the traffic payload. Considering AOC traffic too would only burden the simulation time without carrying any further useful information. Regarding the PHY layer model and the ARQ scheme (type 2) the reader can refer to §3.7.2.2.1.1.

Handover simulations were carried out with and without application of slow fading but results will be shown only for the former case which is the most interesting and closer to reality. When slow fading term is considered the MS involved in the handover is subject to a variable fading changing with the distance from the BS. Two independent slow fading realizations are considered for the two links with the "old" (serving) and the "new" (target) BS.

For what concerns the triggering threshold used to activate the HO, this is based on a maximum acceptable PER value. Once this value has been fixed, it is possible to derive a minimum acceptable SNR value below which the HO is started. The optimal cell radius is estimated through a link budget in which a correction margin is considered to take into account of the slow fading oscillations. This margin is related to the slow fading standard deviation; in particular we have assumed a conservative value of 3σ. Multipath fading effects are already considered in the provided BER/PER results for the LoS/NLoS cases respectively. An excerpt of the link budget is reported in Table 39:

LINK BUDGET	LoS			NLoS		
Threshold PER (QPSK - CC1/2 - RL)	1,0E-003	1,0E-002	1,0E-001	1,0E-003	1,0E-002	1,0E-001
SNR [dB]	13,79	10,76	7,57	17,91	14,35	10,02
Slow fading margin (3*σ) [dB]	12	12	12	8,5	8,5	8,5
Cell radius Rc [m]	460	574	725	487	593	754

Table 39: Link budget summary

In our simulations a maximum PER value of 10^{-3} (in red in the table) has been assumed, which is a value commonly considered in multipath fading environments to get good system performance, and the distance between BS_1 and BS_2 has been set to **d = 900 m** (for both LoS and NLoS scenarios).

The handover procedure depends on the following parameters:

- *Scanning Interval length*: number of frames used for the scanning (in a single scanning interval)
- *Scanning iterations*: number of scanning intervals
- *Interleaving interval*: period between two scanning intervals (in frames)

These handover parameters have been set according to the *fast handover profile* defined in [9] i.e.:

- *scanning iterations* = 3
- *interleaving interval* = 140
- *scanning interval length* = 5

The *neighbour advertisement frequency* parameter has been fixed because it has no impact on this kind of simulations (there are only two BSs). In addition *start frame*, the interval between the request to perform a scanning and the actual scanning start, has been fixed to 4 frames. We focus on Hard Handover and in particular the considered HO procedure is the following: the BS sends the scanning request to the MS when the received measurements from the MS show that its SNR has got below the triggering threshold value[17]. This request is sent in an *unsolicited* manner. The scanning request is performed by the BS sending a message MOB_SCN-RSP that contains all the parameters useful for the scanning (i.e. scanning interval, report mode, report period, first scanning frame etc.). The MS performs the scanning and then sends back to the BS the results of the scanning. The final decision to start the HO procedure is taken by the BS.

3.7.2.2.2.2 Analysis of results

This section presents the basic HO simulation results. The selected output metrics are:

- **Handover delay**: time between the reception of a scanning request message from the BS (in the form of an unsolicited MOB_SCN_RSP message) and the handover execution indication (HO_IND)

- **Interruption time**: time between the message indicating the start of the handover (HO_IND) and the message indicating the creation of the new service flow (DSA_ACK)

- **Probability of HO Failure**: this is defined as the probability to lose at least one control message during the HO procedure. This fact will always be accompanied by the aborting and restart of the HO procedure itself and may cause the drop of the communication when the MS is at cell edge. In order to distinguish these two facts two metrics have been defined:

1. The "*HO messages exchange failure*" indicates the percentage of cases in which at least one HO control message is lost during handover procedure
2. The "*HO Connection loss*" indicates the percentage of cases in which there is a loss of control messages which also leads to an actual connection loss; what typically occurs is that the MS which is far away from the serving BS loses its connection with the BS during the scanning period, it loses control packets necessary to complete the HO procedure towards the target BS and the connection breaks down. These cases, which are the most interesting ones from a planning point of view, are of course a subset of the cases of the previous metric

Output metrics have been averaged over 2000 independent runs (i.e. launched with different seeds of the random generators), hence probability values below 1% cannot be considered statistically reliable. The mean values of Handover Delay and Interruption Time are provided together with their estimated variance. The results are given in Table 40.

SCENARIO (d=900 m)	HO Delay [s]	HO Delay (Var)	Interruption time [s]	Interruption time (Var)	Messages exchange failure (%)	Connection loss (%)
RAMP LoS	1,54392	4,66E-02	0,150081	5,73E-05	2,5%	0.21%
RAMP NLoS	1,60032	1,31E-03	0,148979	2,01E-04	2,9%	0.75%
TOWER LoS	1,53098	3,02E-03	0,149081	7,35E-05	12,3%	3.76%

Table 40: Handover results

In accordance with the simulation results obtained in [9] the HO delay and interruption time values are strictly correlated to the HO parameters previously described (*scanning iterations, interleaving interval*, *scanning interval length*) and do not depend on the particular considered scenario.

In [9] the most critical results concerned the HO failure probability that in some cases was too high. For this reason we deeply investigated this aspect. The HO failure probability is highly dependent on the triggering threshold used to activate the HO, which also determines the cell range. In this new set of simulations a stricter PER threshold value has been selected with respect to what was done in [9] (PER_{th} = 0.001 instead of PER_{th} = 0.01). In addition in [9] we just considered all the cases of HO

[17] AeroMACS profile foresees the scanning is activated by the BS (i.e., *MS Requests Scanning Interval Allocations from BS* and *MS autonomous neighbor cell scanning* are disabled).

failures, being an "HO failure" defined as a case in which an HO control message is lost and HO aborted; however this does not necessarily imply that the communication is lost, therefore in this set of simulations we distinguished two different metrics:

- - the "*HO messages exchange failure"* that takes into account all the cases in which at least one HO control message is lost (it was the *HO failure* reported in [9])
- the "*HO connection loss*" that takes into account only the cases in which the MS is not actually able to establish a connection with the target BS and the connection drops down

From the simulation results we can notice that, under all stated hypotheses regarding the considered scenarios, the "*HO messages exchange failure*" has values less than 3% in Ramp area and close to 12% in Tower area, which is more critical due to the higher MS speed. Regarding the probability of an *actual connection drop* it always remains under 4%, and in most of the cases shows values under 1%.

Comparable (in Ramp area) or better (in Tower area) results were also obtained without slow fading.

3.7.2.2.2.3 Conclusions

These results clearly demonstrate that an optimized HO parameterization, together with an accurate cell planning, can yield a good performance for handover behaviour. Key factors are the choice of a proper triggering threshold for handover and the insertion of a proper fading margin in the link budget calculation (see [9]). It should also be remembered that the speed of the terminal in Tower area has been set to 130 km/h while the specification of the AeroMACS profile requires a maximum supported speed of 50 knots (92.6 km/h). So further performance improvements are expected in that area, at AeroMACS nominal operating conditions.

3.7.2.2.3 System analysis

The last set of simulations does not refer to the study of a specific procedure; the goal is rather to estimate the overall performance of the AeroMACS system in a generic scenario, still mainly from a physical layer point of view. Also in this case two properly dimensioned cells belonging to the Ramp or Tower areas will be considered. A realistic traffic scenario will also be simulated.

3.7.2.2.3.1 Hypotheses made in simulations

In these simulations two cells (i.e. two 120^{o} sectors) belonging to the Ramp area or to the Tower area are considered. In each cell a certain number of users are randomly distributed. The number of users is selected according to the specific traffic scenario. Users can be fixed or can move between the two cells, performing handover whenever they cross the cell boundary. Following [6], MSs are divided among aircrafts, always considered in LoS propagation conditions, and vehicles, considered in LoS or NLoS propagation conditions depending on the chosen area.
More in detail the two scenarios are the following:

1) RAMP Area:

- Two cells in RAMP Area
- BS distance 900mt
- Traffic: Scenario 27 USBG simulations [6]
- Propagation Conditions: mixed LoS and NLoS
- Mean number of terminals per cell: 9 aircrafts and 9 vehicles
  - 3 aircrafts are in movement with linear trajectories, all the others are fixed
  - all vehicles are in movement with random trajectories (random waypoint model)
  - the aircrafts/vehicles are in LoS/NLoS propagation conditions respectively
- Moving terminal speed: 30Km/h

2) TOWER Area:

- o Two cells in TOWER Area
- o BS distance 900mt
- o Traffic: Scenario 31 USBG simulations [6]
- o Propagation Conditions: LoS
- o Mean number of terminals per cell: 4 aircrafts
  - ▪ all aircrafts are in movement with linear trajectories
- o Moving terminal speed: 130Km/h.

In each scenario the two cells have same coverage, same traffic load and type. The results of these simulations depend on the particular considered configuration (i.e. number of MSs in movement or in fixed position, number of handover procedures activated during simulation, traffic exchanged during simulation, etc.). For this reason 1000 randomly generated configurations have been simulated and mean results are provided. Each simulation is a “snapshot” lasting 130 seconds. In each simulation the initial and the final positions of the MSs (vehicles and/or aircrafts) are randomly chosen within the cells, and the traffic is generated with a different random seed. In particular:

- when the simulation starts each BS has a number of MSs in its coverage range equal to the mean number indicated by the USBG model and specified above,

- the initial distance between the BS and each MS, allocated to it, is uniformly distributed in the interval [0 - 950] mt, where the maximum coverage range has been assumed equal to 950mt according to the previously shown NLoS maximum coverage simulation results,

- the final position of each MS is randomly chosen in the overall area covered by the two cells.

As an example, Figure 35 and Figure 36 show two particular cases of the possible configurations in Ramp and Tower areas respectively. Red and blue triangles represent the BSs, the “x” symbols indicate the starting position of the terminals (in blue those belonging to BS_1 and in red those belonging to BS_2) and the “+” symbols represent their final destination (if an aircraft is in fixed position the corresponding “+” symbol is not present). In the ramp area the symbols in bold refer to the vehicles, and the others to the aircrafts.

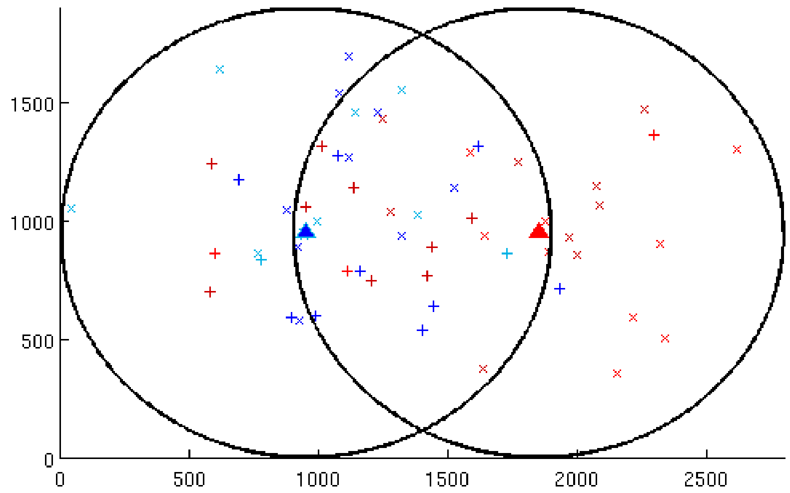


Figure 35: Snapshot of a simulation in RAMP area

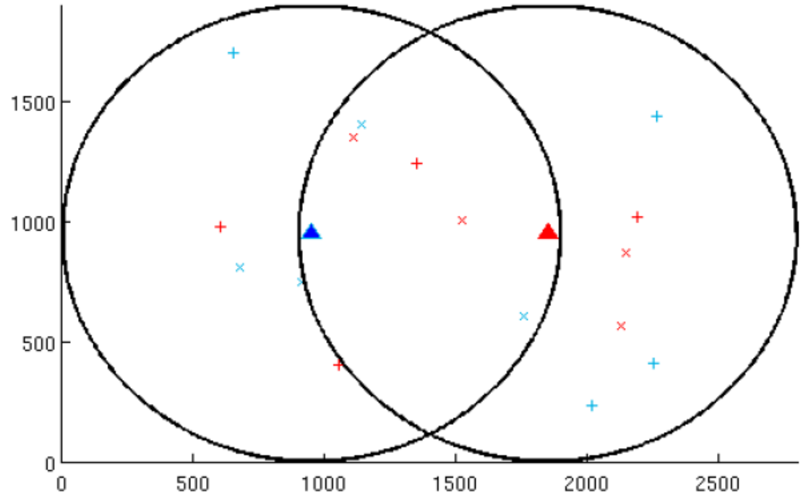


Figure 36: Snapshot of a simulation in TOWER area

Concerning the traffic model the reader can refer to §3.7.2.2.2.1. The considered scenarios are still n. 27 and n. 31 of [6]. In particular reference statistical parameters have been derived from the following files:

- *"Scenario_27_CELL_25_ARRIVAL_RAMP_XML xml.gz.html"*
- *"Scenario_31_CELL_25_ARRIVAL_TOWER_XML.xml.gz.html"*

In this case three different data flows are generated for three different aggregated classes: NET, ATC and AOC. For sake of simplicity the statistical scenario parameters have been reported in Table 41. The mapping between these aggregated classes and the AeroMACS quality of service is shown in Table 42.

		Mean Inter Arrival Time [ms]	Mean Data Message Size [bytes]	Source Throughput [kbps]	Mean # of aircrafts +vehicles	MS speed	Channel
Scenario 27 FL (RAMP)	ATC	18518,28	398	0,171	9+9	30Km/h	LoS/NLoS
	AOC	4258,89	33584	63,084	9+9	30Km/h	LoS/NLoS
	NET	-	-	-	9+9	30Km/h	LoS/NLoS
Scenario 27 RL (RAMP)	ATC	15760,07	481	0,244	9+9	30Km/h	LoS/NLoS
	AOC	292,57	372	10,171	9+9	30Km/h	LoS/NLoS
	NET	-	-	-	9+9	30Km/h	LoS/NLoS
Scenario 31 FL (TWR)	ATC	370,33	34	0,734	4+0	130Km/h	LoS
	AOC	-	-	-	4+0	130Km/h	LoS
	NET	-	-	-	4+0	130Km/h	LoS
Scenario 31 RL (TWR)	ATC	60492,96	126	0,016	4+0	130Km/h	LoS
	AOC	872,56	13686	125,479	4+0	130Km/h	LoS
	NET	-	-	-	4+0	130Km/h	LoS

Table 41: Scenarios' statistical parameters

Priority	Class of Service (CoS)	AeroMACS Quality of Service (QoS)	Notes[18]
HIGHEST	NET	rtPS	Max latency = 1s Min throughput UL=102.4 kbps

[18] Min throughput is *on-demand* and corresponds to a single ARQ block sent in a radio frame

			Min throughput DL=409.6 kbps
HIGH	ATC	rtPS	Max latency = 1s Min throughput UL=102.4 kbps Min throughput DL=409.6 kbps
LOW	AOC	BE	-

Table 42: Mapping between CoS and QoS

Regarding the PHY layer model, the ARQ scheme and the HO parameterization the reader can refer to §3.7.2.2.1.1 and 3.7.2.2.2.1 respectively. In this case slow fading is considered and characterized by different variance values for LoS and NLoS cases as reported in Barajas' path-loss models. The BSs distance is evaluated as explained in handover simulations and is equal to 900 mt, slightly less than the estimated maximum coverage range of 950 mt, as depicted in Figure 35 and Figure 36.

3.7.2.2.3.2 Analysis of results

This section presents the system simulation results. The selected output metrics are:

- **Mean system throughput** defined as the mean ratio between total amount of correctly received data in a cell and the observation time in each simulation
- **Mean delay** defined as the mean difference between the receiving time and the transmitting time of a SDU in each simulation. The receiving time refers to the moment in which a SDU is re-assembled from many ARQ blocks by the receiver MAC and sent to the upper layers, while the transmitting time refers to the moment in which a SDU arrives to the transmitter MAC from the upper layers
- **Mean packet loss** expressed as the mean percentage of packets lost in each simulation. This metric is differentiated in three sub-metrics, depending on the cause of the loss:
    - ARQ: the packet has been transmitted several times but it has always been received with errors introduced by the channel; when the number of retransmissions exceed the maximum allowed by ARQ, the packet is discarded by the transmitter
    - CID: the packet is discarded by the transmitter since there is not any active connection with a BS; this occurs during the interruption time of the handover process
    - CON: the packet is discarded when the connection with the serving BS ends or falls down and the relative queue must be cleared out.
- **Percentage of connections lost** during HO as defined in handover simulations

These metrics, apart from the last one, have been differentiated for traffic classes (ATC/AOC) and direction (FL/RL). The simulation results are shown in Table 43 and Table 44 for Ramp and Tower areas respectively.

RAMP area		Mean system throughput [kbit/s]	Mean Delay [ms]	Mean packet loss [%]		
				ARQ	CID	CON
ATC	FL	0.27	5.02	0.02	0.22	0
	RL	0.38	18.20	0	0.36	0.04
AOC	FL	106.35	1505.04	0.04	0.23	0.86

	RL	11.08	28.31	0.94	0.40	0.09

Table 43: System performance results (Ramp area)

The mean connection loss is **1.51%.**

TOWER area		Mean system throughput [kbit/s]	Mean Delay [ms]	Mean packet loss [%]		
				ARQ	CID	CON
ATC	FL	1.34	3.47	0.15	0.85	0.01
	RL	0.04	16.74	0.49	0.32	0.07
AOC	FL	N.A.	N.A.	N.A.	N.A.	N.A.
	RL	129.21	118.38	0.49	0.45	4.81

Table 44: System performance results (Tower area)

The mean connection loss is **3.13%.**

Results show that the system throughput always approaches the source throughput values, shown in Table 41, apart from the case of AOC/FL in Ramp area, where the occurrence of big packets whose size can reach 10^5 bytes causes the system throughput to appear locally higher. Since the ATC traffic has a higher priority than the AOC one, this reflects in the very low delays (<20 ms) of the ATC traffic class, while the high delays of the AOC traffic in FL in Ramp area (about 1.5 seconds) are due to the occurrence of said big packets. However the AOC class has relaxed latency constraints ([1]), so the result can be considered acceptable. This means that the system manages to dispatch the entire offered traffic load with relatively high delays on some very demanding AOC application services, which could probably be tolerated due to their relaxed latency constraints.

Packet loss strongly depends on the used traffic model and in particular on the size of the application packets and their mean inter-arrival times. However the number of lost SDUs in each simulation, in the stated hypotheses and scenarios, is always very limited, most of the time less than 1%.

Also the percentage of connection loss shows the good performance of the system: the average value never exceeds 4%. In particular in TOWER area, which is the worst case (3.13%), the speed of the mobile terminals has been set higher than what the AeroMACS is supposed to support (50 knots), so a further improvement in performance is expected in that area at AeroMACS nominal operating conditions.

3.7.2.2.3.3 Conclusions

The purpose of this final section was to evaluate the overall performance of the AeroMACS system in specific scenarios (Ramp and Tower operational domains), especially from the physical layer point of view; the simulation results showed the excellent behaviour of the system in both areas. Furthermore these results, compared with those previously obtained in WA3 task, clearly show that a planning activity should search the best trade-off between system efficiency and system performance; such an activity will be for example carried out in the use-case studies of Barajas and Tolouse airports.

3.7.2.3 Capacity analysis per airport

3.7.2.3.1 Operational concept

This section evaluates the performance in terms of capacity offered by an AeroMACS system by means of simulation in a modelled airport environment. The approach followed here is different to that used in the previous section, where the study is focused in specific airport domains. In this analysis, the system covers the whole airport area, while a single aircraft is the object of study throughout all the operational stages. For the sake of simplicity, configuration of trajectories and application demands is done by domain, as explained in the proper sections.

Capacity performance is evaluated through the study of metrics that affect the end-to-end availability levels of specific services or Classes of Service (CoS). In addition, specific metrics at MAC layer such as radio packet delay, frame occupation or handover delay deliver information about the performance of the radio link. Results are not given in terms of coverage, which is studied in other sections. This analysis considers instead that the system dimensioning (i.e. number of BSs deployed) is defined in terms of capacity requirements to cover the necessary availability and continuity figures for the services executed on surface.

In order to make the analysis as useful and close to reality as possible, a real case airport (Madrid Barajas) has been taken to define the environment. This airport is a particular case of most complex airport type due to the large number of served operations and the large size. The air traffic model and mobility model have been extracted from real figures that take into account the airport layout and empiric traffic figures. The results have been extracted, however, targeting evaluation metrics that can be considered generic enough to be applied to any airport. Specific cell planning for Barajas is not explained here, section A.1 should be checked for this purpose instead.

3.7.2.3.2 Propagation and PHY/MAC layer model

It should be noted that this analysis is focused on system level capacity, while effects of physical channel, propagation and PHY features (BLER and SNR calculation) are abstracted. The configuration at this level follows the same models as in WA3 simulations with OPNET Modeler [5]. This document should be checked for more detail on the physical layer configuration.

Briefly, the propagation channel configuration uses the analytical channel model for Barajas. HARQ is enabled and adaptive operation of every mandatory modulation and coding scheme (i.e. all except 64QAM in UL) are active.

The BS and MS have ARQ and HARQ configured as in [5]. The ARQ mode used in this scenario is Mode 2 “Cumulative and Selective ACK”.

3.7.2.3.3 Aircraft object of study

The A/C object of study is configured in a deterministic basis. It is considered that, for data generation purposes, it follows the application model explained in section 3.3. As it is indicated in the model description, the A/C executes a deterministic sequence of services that represent consecutive arrival and departure operations.

The A/C also follows a deterministic trajectory and speed according to the airport layout and following a reasonable track to complete the operations. Note that the trajectory strongly affects the execution of the service sequence, since the chronological execution depends on the instantaneous position of the A/C in the departure and arrival processes.

Airport zones have been split in four different zones, depending on the movements performed by the aircraft on surface, namely RAMP, GROUND and TOWER. In each zone the aircraft is configured with a different average speed, values are shown in table below:

Arrival	Speed [km/h]	Speed [knots]
TOWER	90	48.6
GROUND	40	21.6
RAMP	20	10.8

Table 45: Arrival speeds

Departure	Speed [km/h]	Speed [knots]
RAMP	10 (in push-back) 20 (in taxiing)	5.4 10.8
GROUND	40	21.6
TOWER	90	48.6

Table 46: Departure speeds

Due to the difference in trajectories followed by aircrafts in airport depending on a wide number of factors (atmospheric conditions, runway availability, assigned terminal position, airline operatives, etc), four different routes have been set in simulations, two in arrival phase, and two for departure phase.

Airport zones have been split in three different zones, depending on the movements performed by the aircraft on surface, namely RAMP, GROUND and TOWER. In each zone the aircraft is configured with a different average speed, values are shown in table below:

3.7.2.3.3.1.1 Scenario 1

This scenario assumes an AeroMACS equipped aircraft that completes the operational phases of arrival, turnaround and departure in a consecutive manner. This is the most stringent operational case since the aircraft needs to minimize the time in the airport in order to avoid flight delays caused by the departing or the previous arriving flight.

In this situation, the aircraft is assumed to land on the 33L runway (South). Then, it performs taxiing to Terminal 2 allocated slot for turnaround. The aircraft finally takes off on the 36L runway (North). This scenario tries to illustrate the context in which the aircraft performs long carrier or transoceanic flights. This kind of flights have long permitted turnaround times, which is normally operated by mainlines. It is assumed that the runways are closer to the terminal, thus yielding the taxiing time interval minimum. However, it should be noted that this is not always the pattern followed by mainlines in this airport.

3.7.2.3.3.1.1.1 Arrival

For arrival trajectory we estimate a speed of 90km/h about the half of the runway (yellow), then the A/C waits for authorization during a holding time of 5 minutes. After that the A/C cross the GROUND zone at an average speed of 40 km/h (blue) and arrives to the RAMP zone at a speed of 20 km/h (red) stopping finally at the terminal finger.

Figure 37: Scenario 1 arrival trajectory

This sequence assumes that the aircraft will start synchronization once it enters TOWER zone below 50 knots speed, which happens when it surpasses half the length of the runway. It is also assumed that the aircraft should be connected and operational at the runway exit (around 60 seconds after the start).

Total time for the arrival process (please note that time is the time between landing and the arrival to the airport terminal finger, it does not include disembarking) is 300 seconds, we show time in each zone in the **Table 47**. After the stop of the aircraft the process of disembarking starts, time during the A/C still stays executing service:

	TOWER	GROUND	RAMP	Post-arrival	Total arrival
Arrival [seconds]	63.87	186.44	48.6	1800	2098.912
Distance [meters]	1596.7	2071.6	270		
Speed [km/h]	90	40	20		

Table 47: Scenario 1 arrival trajectory times

According to the study of services description [1] some of those services may be executed in parallel or not, because it is not strictly necessary for them to wait for previous services to have finished. However other ones need to wait for previous services to have finished. So, services grouped in the following tables with the same background colour and labelled with the same number may be executed in parallel. Each service is started in one of the airport zones (RAMP, GROUND, TOWER) according to the coloured right column.

For example, OOOI messages must be sent when the A/C pass from Ground zone to Ramp independently of previous services ending and because of that it is classified as a “parallel service”.
The ACM service is executed when all the previous services have finished because in arrival phase and executed in the Ramp zone it finishes the communication.

	Aircraft->Base Station			Base Station->Aircraft	
t[seg]	Service	Execution order	ToS	Service	
0	OOOI	S1	AOC		
0	NETKEEP	S1->P	NET	NETKEEP	
0	AUTOLAND-REG	S1-P	AOC		TOWER
63	ACM	S2	ATC	ACM	
64		S2->P (periodic)	ATC	SURV	
65	ACL	S3	ATC	ACL	
69	D-SIG	S4	ATC	D-SIG	
69	D-TAXI	S4->P	ATC	D-TAXI	GROUND
69	EFFU	S4->P	AOC	EFFU	
69	FLT-JOURNAL	S4->P	AOC		
69	TECHLOG	S4->P	AOC	TECHLOG	
69	CREW-TIME	S4->P	AOC		
254	OOOI	S4->P	AOC		
254	FOQA	S4->P	AOC		
252	FLTLOG	S4->P	AOC		
252	CABINLOG	S4->P	AOC		RAMP
252	ETS-REPORT	S4->P	AOC		
252	REFUEL	S4->P	AOC		
When previous services have finished	ACM	S5	ATC	ACM	

Table 48: Chronological description of Scenario 1 arrival trajectory

3.7.2.3.3.1.1.2 Departure

In the Departure phase we have a previous time not considered here during which the A/C is executing services but it is not moving, for example during the boarding of passengers, baggage cargo, etc. The time while the A/C is moving starts with an initial pushback phase in the RAMP zone and finish about half of the runway where we exceed AEROMACS maximum speed supported. Please note the black line corresponds to the pushback procedure (10 km/h).

Figure 38: Scenario 1 departure trajectory

The departure time while the A/C is moving takes 868 seconds. The total time for the departure process showed (this time is taken since the A/C is towed when the Pushback starts until the A/C has gone over half of the runway) does not include boarding time and pre-departure times, time when the A/C is executing services. Time for each zone is showed in the table below.

	Pre-departure	Pushback RAMP	Taxiing RAMP	GROUND	Taxiing TOWER	Holding Time TOWER	Total departure
Departure [seconds]	1800	47.88	141.3	325.98	53.6	300	2668.76
Distance [meters]	0	133	785	3622	1340		
Speed [km/h]	0	10	20	40	90		

Table 49: Scenario 1 departure trajectory times

The main difference between arrival and departure phase is the critical timeout of services, because all services must have finished before A/C departure.

	Aircraft->Base Station			Base Station->Aircraft	
t[seconds]	Service	Execution order	ToS	Service	
0	NETCONN	S1	NET	NETCONN	RAMP
20	NETKEEP	S2	NET	NETKEEP	
20	DLL	S2->P	ATC	DLL	
25	AOCDLL	S3	AOC	AOCDLL	
25	LOADSHT	S4	AOC	LOADSHT	
25		S4->P	AOC	E-CHARTS	
25		S4->P	AOC	UPLIB	
25	SWCONF	S4->P	AOC	SWCONF	
25		S4->P	AOC	SWLOAD25	
25		S4->P	AOC	SWLOAD	
30		S5	AOC	BRFCD	
30	ACLOG	S5->P	AOC	ACLOG	
30	TECHLOG	S5->P	AOC	TECHLOG	
30		S5->P	AOC	AIRWORTH	
30	WXTEXT	S5->P	AOC	WXTEXT	
40		S5->P	AOC	PASSENGER	
40		S5->P	AOC	CREW-RPS	
40		S5->P	AOC	CREW-BUL	
40	CREW-REG	S5->P	AOC		
45	FLTPLAN	S5->P	AOC	FLTPLAN	
45		S5->P	AOC	NOTAM	
50	COTRAC (interactive)	S6	ATC	COTRAC (interactive)	
70	EFF/WXGRAPH/CREW-L	S7	AOC	EFF	
70	HANDLING	S7->P	AOC		
300	CATERING	S8	AOC		
310	BAGGAGE	S9	AOC	BAGGAGE	
400		S10	AOC	NOTOC	
410	LOADDOC	S11	AOC		
410	PREFLT-INS	S11->P	AOC		
410	D-OTIS	S11->P	ATC	D-OTIS	
410	D-SIGMET	S11->P	ATC	D-SIGMET	
900	DOOR	S11->P	AOC		
920	DCL	S12	ATC	DCL	
930	FLOWCON	S13	AOC	FLOWCON	
930	FLIPCY	S13->P	ATC	FLIPCY	
930	FLIPINT	S13->P	ATC	FLIPINT	
930	D-RVR	S13->P	ATC	D-RVR	
930	D-SIG	S13->P	ATC	D-SIG	
930	EFFU	S13->P	AOC	EFFU	
930	TAKEOFF-CALC	S13->P	AOC	TAKEOFF-CALC	
940	D-FLUP	S14	ATC	D-FLUP	
950	PPD	S15	ATC	PPD	
950	D-TAXI	S15->C	ATC	D-TAXI	
Pushback starts					
960	OOOI	S16	AOC		
1961		S16->C (periódico)	ATC	SURV (periódico)	GROUND
2008	ACL	S17	ATC	ACL	
2286	ACM	S18	ATC	ACM	
"+300 seconds of Holding Time"	Wainting for landing clearance and acceleration in runway.				TOWER
2580	WXRT	S19	AOC		
2585	OOOI	S19->C	AOC		
When previous services have finishe. Deadline=1042 seconds	ACM	S20	ATC	ACM	

Table 50: Chronological description of Scenario 1 departure trajectory

Taking this service sequence, the average generated ATC message size is 190 Bytes, and the average generated AOC message size is 278 kilobytes [6].

3.7.2.3.3.1.2 Scenario 2

In this situation, the aircraft is assumed to land on the 33R runway (South). Then, it performs taxiing to Terminal 2 allocated slot for turnaround. The aircraft finally takes off on the 36R runway (North). This scenario tries to illustrate the context in which the aircraft performs short regional flights. This kind of flights have short permitted turnaround times, which is normally operated by regional or low fare airlines. It is assumed that the runways are the furthest from the terminal, thus yielding the taxiing time interval maximum. However, it should be noted that this is not always the pattern followed by regional airlines in this airport.

3.7.2.3.3.1.2.1 Arrival

Exactly as happens in Scenario 1, we estimate a speed of 90km/h about the half of the runway (yellow) until the end of this, after this the A/C waits for authorization during a holding time of 5 minutes, then the A/C cross the GROUND zone at an average speed of 40 km/h (blue) and arrives to the RAMP zone at a speed of 20 km/h (red) stopping finally at the terminal finger.

Figure 39: Scenario 2 arrival trajectory

According to the description of arrival time given in 3.7.2.3.3.1.1.1, the total time while the A/C is moving is 540 seconds.

	TOWER	GROUND	RAMP	Post-arrival	Total arrival [sec]
Arrival [segs]	63.84	397.08	88.74	900	1449.66
meters	1596	4412	493		
km/h	90	40	20		

Table 51: Scenario 2 arrival trajectory times

This list of services and time between them are exactly the same that appears in 3.7.2.3.3.1.1.1 with the exception of the FOQA service whose size is now 10.000.000 Bytes..

	Aircraft->Base Station			Base Station->Aircraft	
t[seconds]	**Service**	**Execution order**	**ToS**	**Service**	
0	**OOOI**	*S1*	***AOC***		
0	**NETKEEP**	*S1->P*	***NET***	**NETKEEP**	
0	**AUTOLAND-REG**	*S1-P*	***AOC***		**TOWER**
63	**ACM**	*S2*	***ATC***	**ACM**	
64		*S2->P (periodic)*	***ATC***	**SURV**	
64	**ACL**	*S3*	***ATC***	**ACL**	
64	**D-SIG**	*S4*	***ATC***	**D-SIG**	
64	**D-TAXI**	*S4->P*	***ATC***	**D-TAXI**	**GROUND**
64	**EFFU**	*S4->P*	***AOC***	**EFFU**	
64	**FLT-JOURNAL**	*S4->P*	***AOC***		
64	**TECHLOG**	*S4->P*	***AOC***	**TECHLOG**	
64	**CREW-TIME**	*S4->P*	***AOC***		
461	**OOOI**	*S4->P*	***AOC***		
463	**FOQA**	*S4->P*	***AOC***		
463	**FLTLOG**	*S4->P*	***AOC***		
510	**CABINLOG**	*S4->P*	***AOC***		**RAMP**
510	**ETS-REPORT**	*S4->P*	***AOC***		
510	**REFUEL**	*S4->P*	***AOC***		
When previous services have finished	**ACM**	*S5*	***ATC***	**ACM**	

Table 52: Chronological description of Scenario 2 arrival trajectory.

3.7.2.3.3.1.2.2 Departure

According to the description of departure used in 3.7.2.3.3.1.1.2 the trajectory for departure followed by the A/C and the time it takes is shown below.

Figure 40: Scenario 2 departure trajectory

According to the description of arrival time given in 3.7.2.3.3.1.1.2 the total time while the line A/C is moving is 913 seconds.

	Pre-departure	Pushback RAMP	Taxiing RAMP	GROUND	Taxiing TOWER	Holding Time TOWER	Total Departure
Departure [segs]	900	39.6	70.74	450	53.6	300	1813.94
Distance [meters]	0	110	393	5000	1340		
Speed [km/h]	0	10	20	40	90		

Table 53: Scenario 2 departure trajectory times

This list of services and time between them are the same that appears in 3.7.2.3.3.1.1.2, with the exception of the following ones:

- E-CHARTS size is now 2.000.000 Bytes
- FOQA size is now 10.000.000 Bytes

This is due to the fact that short-range aircrafts exchange a much lower amount of data to update the electronic flight charts and upload the log of the flight events. Refer to SJU AOC study [27] for further details.

	Aircraft->Base Station			Base Station->Aircraft	
t[seconds]	Service	Execution order	ToS	Service	
0	NETCONN	S1	NET	NETCONN	RAMP
20	NETKEEP	S2	NET	NETKEEP	
20	DLL	S2->P	ATC	DLL	
25	AOCDLL	S3	AOC	AOCDLL	
25	LOADSHT	S4	AOC	LOADSHT	
25		S4->P	AOC	E-CHARTS	
25		S4->P	AOC	UPLIB	
25	SWCONF	S4->P	AOC	SWCONF	
25		S4->P	AOC	SWLOAD25	
25		S4->P	AOC	SWLOAD	
30		S5	AOC	BRFCD	
30	ACLOG	S5->P	AOC	ACLOG	
30	TECHLOG	S5->P	AOC	TECHLOG	
30		S5->P	AOC	AIRWORTH	
30	WXTEXT	S5->P	AOC	WXTEXT	
40		S5->P	AOC	PASSENGER	
40		S5->P	AOC	CREW-RPS	
40		S5->P	AOC	CREW-BUL	
40	CREW-REG	S5->P	AOC		
45	FLTPLAN	S5->P	AOC	FLTPLAN	
45		S5->P	AOC	NOTAM	
50	COTRAC (interactive)	S6	ATC	COTRAC (interactive)	
70	EFF/WXGRAPH/CREW-L	S7	AOC	EFF	
70	HANDLING	S7->P	AOC		
300	CATERING	S8	AOC		
310	BAGGAGE	S9	AOC	BAGGAGE	
400		S10	AOC	NOTOC	
410	LOADDOC	S11	AOC		
410	PREFLT-INS	S11->P	AOC		
410	D-OTIS	S11->P	ATC	D-OTIS	
410	D-SIGMET	S11->P	ATC	D-SIGMET	
900	DOOR	S11->P	AOC		
920	DCL	S12	ATC	DCL	
930	FLOWCON	S13	AOC	FLOWCON	
930	FLIPCY	S13->P	ATC	FLIPCY	
930	FLIPINT	S13->P	ATC	FLIPINT	
930	D-RVR	S13->P	ATC	D-RVR	
930	D-SIG	S13->P	ATC	D-SIG	
930	EFFU	S13->P	AOC	EFFU	
930	TAKEOFF-CALC	S13->P	AOC	TAKEOFF-CALC	
940	D-FLUP	S14	ATC	D-FLUP	
950	PPD	S15	ATC	PPD	
950	D-TAXI	S15->C	ATC	D-TAXI	
Pushback starts					
	OOOI	S16	AOC		
1027		S16->C (periódico)	ATC	SURV (periódico)	GROUND
1074	ACL	S17	ATC	ACL	
1352	ACM	S18	ATC	ACM	
"+300 seconds of Holding Time"	Waiting for landing clearance and acceleration in runway.				TOWER
1759	WXRT	S19	AOC		
1764	OOOI	S19->C	AOC		
When previous services have finishe. Deadline=1042 seconds	ACM	S20	ATC	ACM	

Table 54: Chronological description of Scenario 2 departure trajectory

Taking this service sequence, the average generated ATC message size is 190 Bytes, and the average generated AOC message size is 63 kilobytes [6].

3.7.2.3.4 QoS model

In order to configure a set of priority levels for the different applications executed over AeroMACS in the simulation, a refinement of the CoS classification from 3.3.3 is proposed here. For every Class of Service defined and applied at higher-layer messaging, a mapping is done to a specific QoS type applied by AeroMACS. Each QoS level defines the scheduling type, the estimated traffic reserved for the service type and the queuing algorithm. Note that AeroMACS, as based on the IEEE 802.16 standard series, does not imply hard priority between levels (i.e. packet by packet prioritization) but a QoS approach in which each level has been properly dimensioned to be able to guarantee a minimum throughput and maximum delay. Due to this, the QoS configuration in AeroMACS becomes complex and strongly depends on the specific operational concept. In this analysis, we will consider the configuration for the situation in which all the identified potential services are included, as previously explained.

The possible scheduling types admitted by the profile for data services [5] are the following:

- Non-real Time Polling Service (nrtPS) offers unicast polls on a regular basis, assuring a minimum reserved data rate even during network congestion. Bandwidth requests in queue are treated using the Modified Deficit Round Robin (MDRR) scheduling algorithm. Although the algorithm is implementation-dependent, for the sake of simulation a minimum polling rate is established.

- Real Time Polling Service (rtPS) offers real-time, periodic request opportunities that allow the subscriber to specify the size of the desired resources. Bandwidth requests in queue are treated using the Modified Deficit Round Robin (MDRR) scheduling algorithm. While rtPS requires more signalling overhead than nrtPS, it allows a periodic request interval of the order of milliseconds. It will be used for the most critical services that require a maximum delay per message of milliseconds, but should never be configured for heavy load services since it would have a strong impact on the allowed traffic for other messages.

- Best Effort (BE) guarantees no minimum throughput for the connection. It uses the remaining frame resources (if any) after the rest of connections have been allocated. In the simulation, the algorithm used to serve the queues is Round Robin (RR). The target of this scheduling type is heavy services that need to run in the background and are not delay sensitive.

The table below depicts the QoS level mapping proposed for every defined CoS at this analysis. For each QoS level, the relevant parameters used to define the polling rate are indicated.

CoS	Services included	Equivalent WA2 CoS	AeroMACS QoS
NET	NET services • NETKEEP, NETCONN	DG-A	rtPS Max latency = 1s Min throughput =32 kbps
ATS1	FPS by ADS-C • SURV	DB-D	rtPS Max latency = 1.5 s Min throughput = 32 kbps
ATS2	CIS (CPDLC) • ACL, COTRAC, DCL, D-TAXI FPS • FLIPCY, FLIPINT, PPD	DG-C DG-D	rtPS

ATS3	DCM • DLL, ACM FIS • D-OTIS, D-SIGMET, D-RVR, D-SIG AVS • D-FLUP	DG-C DG-D DG-F	nrtPS Min throughput =32 kbps
AOC1	• AOCDLL, CABINLOG, FLTLOG, FLTPLAN, LOADSHT, OOOI, TECHLOG, WXGRAPH, WXRT, WXTEXT, BRFCD, DOOR, ACLOG, AIRWORTH, AUTOLAND-REG, BAGGAGE, NOTAM, CATERING, CREW-L, CREW-RPS, CREW-BUL, CREW-REG, CREW-TIME, FLOWCON, REFUEL, HANDLING, LOADDOC, NOTOC, PASSENGER, PREFLT-INS, TAKEOFF-CALC	DG-J DG-K	nrtPS Min throughput =64 kbps (UL), 128 kbps (DL)
AOC2	• SWLOAD, UPLIB, EFF, EFFU, E-CHARTS, FLTJOURNAL, FOQA, SWLOAD25, SWCONF	DG-K DG-L	BE

Table 55: CoS classification for Airport Capacity Analysis

3.7.2.3.5 Handover configuration

The handover configuration is similar to that in WA3 3.3 and 2.3.2.3 sections [5].

Handover	
MS Handover Retransmission Timer [ms]	30
Maximum Handover Request Retransmissions	6
Handover Threshold Hysteresis [dB]	6
Maximum Handover Attempts per BS	10
Scan Duration (N) [Frames]	5
Interleaving Interval (P) [Frames]	140
Scan Iterations	3

Table 56: Handover parameters

- **MS Handover Retransmission Timer:** Time the Mobile Station will wait for a response after sending a MOB_MSHO-REQ message to the Serving Base Station. If no response (MOB_BSHO-RSP) is received within this time the Mobile Station will retransmit the MOB_MSHO-REQ message (until the maximum number of retransmissions is reached).

- **Maximum Handover Request Retransmissions:** Maximum number of retransmission attempts for the MOB_MSHO-REQ message. If set to 0 (zero) or "No Retransmissions", the Mobile Station will send the original MOB_MSHO-REQ and after expiration of "Handover Request Retransmission Interval" it will not retransmit the handover request. It will abandon the handover process instead.

- **Handover Threshold Hysteresis:** Specifies the minimum difference that a neighbor BS's CINR must be above the serving BS's CINR before triggering a handover decision to replace the serving BS with the neighbor BS.

- **Maximum Handover Attempts per BS:** Maximum number of attempts to handover to a specific target BS when the serving BS responds with a negative BSHO-RSP to the MS for that target BS. When Access Service Network is used by the serving BS to contact the target BS in advance (HO_Req), the target BS may indicate that it does not have enough resources to admit the MS. In this case the serving BS will indicate a rejection in its BSHO-RSP to the MS. This attribute prevents the MS from keep trying indefinitely to handover to a target BS with no resources. If set to "Disable", then the MS will ignore the BSHO-RSP and will continue with the handover process regardless of the capacity of the target BS.

- **Scan Duration:** Time (in frames) the Mobile Station scans/measures the neighbor BSs. Measurements are used to evaluate which BS is the best candidate to handover.

- **Interleaving Interval:** Duration (in frames) of normal operation intervals (interleaving intervals) during the scanning mode of a Mobile Station.

- **Scan Iterations:** Number of repetitions of scan interval and interleaving interval during the scanning mode of a Mobile Station.

3.7.2.3.6 Background traffic

The background traffic refers to all the data traffic generated by the rest of subscribers present in the airport surface that limit the radio resources usable by the A/C of study. In order to specify a representative model of the background traffic generation, a random model is used based on previous work from WA2 [6]. The relevant model for Barajas airport is extracted from those available in the study.

3.7.2.3.6.1 Air traffic figures in Madrid Barajas

Barajas as a large airport has roughly 1100 operations per day. If we consider 15 operational hours within a day, and assuming uniform air traffic distribution along the day, we get 73 op/h which turns into 0,0203 op/s. Checking the appendix in [6] it can be observed that this ratio is the one used for scenarios of 50 A/Cs.

Thus, it will be assumed from now on that Barajas has an average number of 50 A/C present on the airport surface. For sake of generality, it is considered that the A/Cs are uniformly distributed among the deployed cells.

3.7.2.3.6.2 Background traffic model

Background traffic will be configured per Base Station; A node acting as both generator and sink is present at every BS taking background traffic model from scenarios in [6] according to each zone (ramp, ground or tower) for an airport with 50 simultaneous ACs operating at the same time.

Some modifications have been made in order to suit the model with the concluding results from WA3, because of that FOQA service has been moved from GROUND zone to be initiated in RAMP zone, where the AC will stay long time in a static position. In consequence corresponding background traffic for the FOQA service has been extracted from GROUND zone and added to the RAMP zone. The following tables show the background traffic values for each operational zone according with the terms exposed.

50 A/C, 10 VC	Overall	Total [Kbps]

RAMP arrival	FL	137.53
	RL	17355.42

Table 57: RAMP Arrival Background traffic

50 A/C, 10 VC	Overall	Total [Kbps]
RAMP departure	FL	3106.42
	RL	496.42

Table 58: RAMP Departure Background traffic

(50 A/C, 10 VC)	Overall	Total [Kbps]
GROUND arrival	FL	352.47
	RL	3418.44

Table 59: GROUND arrival Background traffic

(50 A/C, 10 VC)	Overall	Total [Kbps]
GROUND departure	FL	180.93
	RL	1807.70438

Table 60: GROUND Departure Background traffic

(50 A/C, 10 VC)	Overall	Total [Kbps]
TOWER arrival	FL	1.08
	RL	279.21

Table 61: TOWER Arrival Background Traffic

(50 A/C, 10 VC)	Overall	Total [Kbps]
TOWER departure	FL	0.88
	RL	596.12

Table 62: TOWER Departure Background traffic

Cell planning has been made covering RAMP zone with 64QAM ½ in DL radius, and GROUND and TOWER covered with QPSK ½ radius, so BSs positioned to cover GROUND and TOWER areas were positioned the last ones. We consider these two zones as one in terms of background traffic. Taking this into account final total values for Background traffic for all airport are the following ones:

	RAMP	GROUND+TOWER	
Background Traffic	2.110E+04	6.637E+03	Kbps
DL	3.244E+03	5.354E+02	Kbps
UL	1.785E+04	6.101E+03	Kbps

Table 63: UL&DL Background Traffic

Note these values are the throughput generated at the whole airport. Since A/C are uniformly distributed per BS, it is straightforward to divide these figures by the number of BS taken in the scenario to obtain the background traffic present per BS.

The expected traffic per cell can be derived by dividing the total traffic per airport zone by the number of cells deployed, obtaining aprox. 1 Mbps (RAMP) and 800 kbps (GND/TWR). Assuming nearly all traffic load is caused by AOC, these figures can be considered AOC traffic per cell. To derive ATC traffic share, the AOC/ATC ratio given by Table 21 for 100 A/C scenario can be assumed constant (6500 for RAMP and 1200 for GND/TWR), thus obtaining roughly 0,2 kbps (RAMP) and 0,6 kbps (GND/TWR).

3.7.2.3.6.3 Simulation Results

In this section, the following types of result are described to drive conclusions on the performance capacity and limits of AeroMACS deployments:

- End-to-end delay of all the data packets that are successfully received by the WiMAX MAC and forwarded to the higher layer. This statistic is extracted per CoS as an aggregate of the packets generated by all the services in that class. The aim of this figure is to measure the MAC layer (SDU level) capacity performance against the radio latency requirements from SRD [3].

- Service response time: This statistic exposes the time elapsed between the sending of the request from the source and the reception of the response at the source (if the service has respond messages).This is measured at application layer from the time the service starts with the first request at application layer until the response is received, or in case of unidirectional services, until the receiver receives the last packet sent by the sender. This statistic measures the effect of the radio throughput on the performance in service execution. Every service has a latency requeriment, so service must have been completed in a time lapse less or equal to the latency requeriment to be valid [3].

- Data burst usage: This metric records the portion of the UL and DL subframes allocated to service flow data (data bursts and polls). It excludes the size of preamble and MAPs, together with other signalling. It is a measure of the occupation of the radio medium available at a specific BS and give a figure on the saturation of the channel. This is useful to predict the availability for the channel to correctly serve further traffic requests.

- Handover delay, interruption time and failure probability: These statistics are similar to those used in handover analysis in WA3 [5]. They are used in the refinement of handover study presented here, to measure the performance of mobility in AeroMACS deployment.

The simulation has been split in two main aspects. First, scenarios where a deployment of a given number of BSs enabling the execution of an arriving and departing aircraft passing by all the airport domains are launched. The focus in this battery is to find out the number of BSs necessary to yield enough capacity to the system to cope with the packet and service delay requirements. The two presented scenarios (Scenario1 and Scenario2) are evaluated following the same approach.

This first battery of tests is performed in an iterative manner. The first iteration launched assumed a minimum configuration needed to cover the airport surface. It was then found that a second iteration with a more dense cell planning and a refined QoS configuration was needed to yield satisfactory results. While the comprehensive results are presented for the second iteration, a comparison is also presented in order to measure the effect of certain parameters into the performance figures.

Finally, a refinement of the cell planning at the GROUND and TOWER areas is performed taking into account the main limitation of handover performance at these airport domains [5]. This section is a refinement of the analysis performed in WA3 taking into account the realistic environment and trajectories, and is complemented by the analysis in section 3.7.2.2.3.The cell planning characteristics are summarized in the table below for both iterations. Note that cells have been split in two independent plans: RAMP area is composed of BS with a high overlap ratio in order to cover the area with 16QAM or 64QAM schemes. GROUND/TOWER area is composed of BS minimizing the overlap, since the required service load is low, QPSK can be used and thus the deployment is coverage limited in that domain.

Iteration		**# sites**	**# BS (sectors)**	**Reuse cluster size ***	**Tx power**	**Avg BS – BS distance**
Iter 1	RAMP	6	15	6	23 dBm	1300
	GND/TWR	3	8	5	23 dBm	2650
Iter 2	RAMP	10	20	6+1 **	23 dBm	1000
	GND/TWR	3	8	5	23 dBm	1300

Table 64: Cell planning features used in capacity simulations

*Reuse cluster size = Number of available channels without considering frequency reuse
**One channel from GND/TWR has been reused in a single segment in RAMP zone

3.7.2.3.6.3.1 Scenario 1 – Simulation Results

As result of the second iteration in Barajas airport and following AC's trajectory and speeds indicated in 3.7.2.3.3.1.1, the following metrics have been obtained for the different CoS and aeronautical services executed in the AC.

The packet (MAC SDU) delay for every CoS is indicated below. Downlink direction is effectively well under the required packet latency in SRD [3], while Uplink packets latency slightly surpasses the proposed draft requirement in SRD. This effect is caused by the ATC message being fragmented and transmitted in a number of consecutive frames due to its size, and it does not affect the service execution latency. Hence, the requirement for the uplink latency is refined according to the figures that can be provided by the data link.

It must be cleared out that packet latency requirements can only be targeted for critical ATS applications, AOC being out of this objective since these less prioritary applications must not be time limited and are thus considered delay tolerant.

E2E Delay [avg][ms]	**NET**	**ATC1**	**ATC2**	**ATC3**	**AOC1**	**AOC2**
UpLink	53	56.33333	59.5	66	167.5	75
DownLink	6.95	7.95	8.75	7.9	24.45	22

Table 65: End to end Delay per Class of Service

The service latency figures for each specific application executed during the arrival and departing operation are indicated in the tables below. Services are depicted following a per-CoS classification.

	NET Service	Response Time [s]	Latency Requeriment [s]
Arrival	**NETKEEP**	**0.91007**	20
Departure	**NETCONN**	**0.28186667**	20
	NETKEEP	**0.15653333**	20

Table 66: NET Services Response Time

	ATC1 Service	Response Time [s]	Latency Requeriment [s]
Arrival	**SURV**	**1.157**	1.2
Departure	**SURV**	**1.07415**	1.2

Table 67: ATC1 Services Response Time

	ATC2 Service	Response Time [s]	Latency Requeriment [s]
Arrival	**ACL**	**0.65025**	3
	D-TAXI	**0.2832**	5
Departure	**COTRAC (interactive)**	**0.6725**	5
	DCL	**0.324**	20
	FLIPCY	**0.194805**	5
	FLIPINT	**0.206125**	5
	PPD	**0.195625**	10
	D-TAXI	**0.32**	5
	ACL	**1.3826**	3

Table 68: ATC2 Services Response Time

	ATC3 Service	Response Time [s]	Latency Requeriment [s]
Arrival	**ACM**	**0.975**	3
	D-SIG	**0.71875**	10
	ACM	**0.194375**	3
Departure	**DLL**	**0.1990775**	3
	D-OTIS	**0.414375**	5
	D-SIGMET	**0.415**	5
	D-RVR	**0.59575**	3
	D-SIG	**0.611625**	10
	D-FLUP	**0.21125**	5

	ACM	**0.19125**	3
	ACM	**0.195625**	3

Table 69: ATC3 Services Response Time

	AOC1 Service	Response Time [s]	Latency Requeriment [s]
Arrival	**OOOI**	**4.604125**	30
	AUTOLAND-REG	**1.39156**	60
	TECHLOG	**0.393225**	60
	CREW-TIME	**1.105475**	60
	OOOI	**0.64645**	30
	FLTLOG	**0.432945**	60
	CABINLOG	**0.1747875**	60
	ETS-REPORT	**0.15505**	60
	REFUEL	**1.579625**	30
Departure	**AOCDLL**	**0.196125**	60
	LOADSHT	**0.34225**	10
	BRFCD	**0.830625**	30
	ACLOG	**2.6147875**	30
	TECHLOG	**0.1945**	60
	AIRWORTH	**0.241**	60
	WXTEXT	**0.33**	30
	PASSENGER	**0.9545**	60
	CREW-RPS	**0.228**	60
	CREW-BUL	**2.816625**	60
	CREW-REG	**0.645125**	60
	FLTPLAN	**0.367**	30
	NOTAM	**0.5255**	60
	HANDLING	**0.38725**	60
	CATERING	**0.830625**	60
	BAGGAGE	**7.536**	20
	NOTOC	**0.374375**	60
	LOADDOC	**0.40875**	20
	PREFLT-INS	**0.195**	120
	DOOR	**1.071**	30
	FLOWCON	**0.1955**	60
	TAKEOFF-CALC	**0.980625**	40
	OOOI	**9.519125**	30
	WXRT	**1.016**	30
	OOOI	**0.749**	30

Table 70: AOC1 Services Response Time

	AOC2 Service	Response Time [s]	Latency Requeriment [s]
Arrival	**EFFU**	**31.418**	30
	FLT-JOURNAL	**367.2365**	60
	FOQA	**1191.11875**	1200
Departure	**E-CHARTS**	**1064.785**	60
	UPLIB	**426.626875**	120
	SWCONF	**0.416125**	120
	SWLOAD25	**109.4075**	60
	SWLOAD	**26.429375**	120
	EFF/WXGRAPH/CREW-L	**262.08875**	60
	EFFU	**25.820625**	30

Table 71: AOC2 Services Response Time

As can be observed from the tables, the response time of all critical services (NET and ATC) is lower than the service latency requirements, most of the services spending less than 1 second in the total completion. In effect, although the proposed requirements for these services were relatively loose, it could be argued that, as critical applications, they should be however executed in the shortest possible delay. It is proven that AeroMACS can enable instantaneous transmission for safety critical ATC applications.

AOC services are in general well under the delay requirements, too. However, it can be observed that the requirements set for several heavy load services (all belonging to AOC2 Class of Service) are inconsistent with the features and needs set in [6] for these applications and should be disregarded. First, the latency figures required are irrealistic in terms of radio transmission. For instance, the execution of E-CHARTS in 60 seconds time would need a single subscriber to have 20 Mbps available for itself in the link. Besides, this level of stringency is unnecessary considering the operational needs of the application. These applications are completed during the turnaround phase that will take 20 minutes (2400 seg) at the very least, while AOC services can be executed in less than half that time. Thus, a review of the real needs for these services has to be undertaken by the involved airspace users to set a realistic figure that can drive a requirement.

The figures below depict the frame utilization by data traffic for one specific channel. The sector to which the A/C is connected during the turnaround phase has been chose, where the most heavy loaded services are executed. It can be observed that, even considering the very worst case in which all the heavy services are instantiated (each of which is actually executed only during 1% of the flights) the channel does not reach complete saturation and can cope with additional critical ATC services if required.

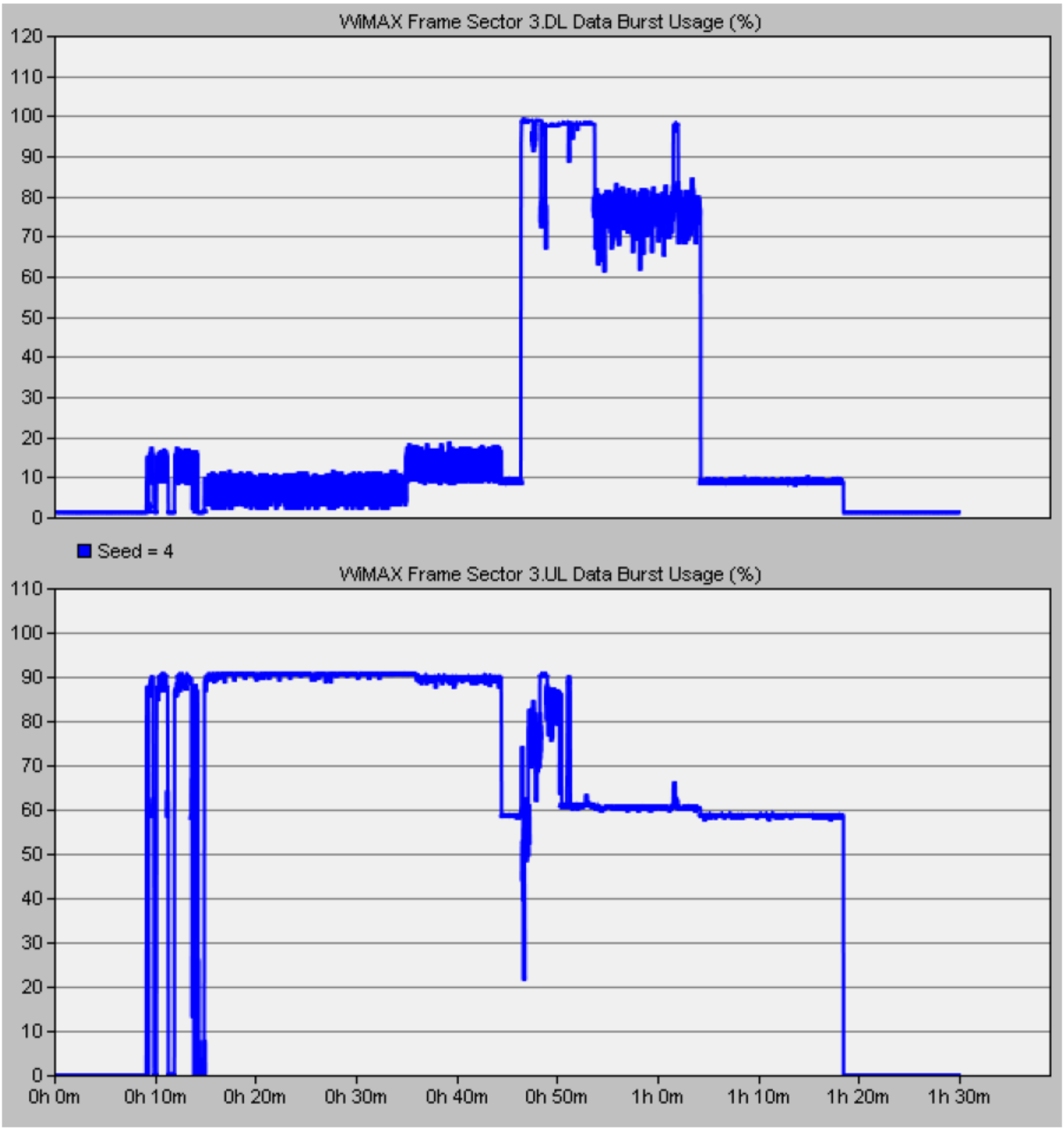


Figure 41: UL/DL WiMAX Frame. Data Burst Usage in %

3.7.2.3.6.3.2 Scenario 2– Simulation Results

Results are shown for the different CoS and aeronautical services executed in the AC in Scenario 2. The packet (MAC SDU) delay for every CoS is indicated below. It can be observed that both downlink and uplink figures are well under the packet latency requirements. Note that, in Scenario 2, heavy services are much minimised, by assuming the A/C is a short-range aircraft. RAMP services being the most stringent factor in this scenario, the traffic generated by these services does not affect the performance level.

E2E Delay [avg][ms]	NET	ATC1	ATC2	ATC3	AOC1	AOC2
UpLink	6.4	10.42625	9.9875	7.80625	24.4875	20.65
DownLink	6.45	9.764375	9.33125	8.289375	23.13125	20.125

Table 72: End to end delay per Class of Service

The service latency figures for each specific applications executed during the arrival and departing operation are indicated in the tables below. Services are depicted following a per-CoS classification.

	NET Service	Response Time [s]	Latency Requirement [s]
Arrival	**NETKEEP**	**0.2998**	20
Departure	**NETCONN**	**0.156**	20
	NETKEEP	**0.0494**	20

Table 73: NET Services Response Time

	ATC1 Service	Response Time [s]	Latency Requirement [s]
Arrival	**SURV**	**0.066**	1.2
Departure	**SURV**	**0.061033333**	1.2

Table 74: ATC1 Services Response Time

	ATC2 Service	Response Time [s]	Latency Requirement [s]
Arrival	**ACL**	**0.18**	3
	D-TAXI	**0.126**	5
Departure	**COTRAC (interactive)**	**0.46732**	5
	DCL	**0.815**	20
	FLIPCY	**0.63**	5
	FLIPINT	**0.2225**	5
	PPD	**0.25572**	10
	D-TAXI	**0.55875**	5
	ACL	**0.125**	3

Table 75: ATC2 Services Response

	ATC3 Service	Response Time [s]	Latency Requirement [s]
Arrival	**ACM**	**0.086**	3
	D-SIG	**0.372**	10
	ACM	**0.34**	3
Departure	**DLL**	**0.09575**	3
	D-OTIS	**0.292**	5
	D-SIGMET	**0.2278**	5
	D-RVR	**2.1146**	3
	D-SIG	**2.1132**	10

	D-FLUP	0.328	5
	ACM	0.095	3
	ACM	0.085	3

Table 76: ATC3 Services Response

	AOC1 Service	Response Time [s]	Latency Requirement [s]
Arrival	OOOI	0.76	30
	AUTOLAND-REG	0.1866	60
	TECHLOG	0.0506	60
	CREW-TIME	0.1196	60
	OOOI	0.229	30
	FLTLOG	0.294	60
	CABINLOG	0.197	60
	ETS-REPORT	0.187	60
	REFUEL	1.78	30
Departure	AOCDLL	0.190333333	60
	LOADSHT	2.544	10
	BRFCD	0.795	30
	ACLOG	3.368	30
	TECHLOG	0.198	60
	AIRWORTH	0.1876	60
	WXTEXT	0.3802	30
	PASSENGER	0.856	60
	CREW-RPS	0.1932	60
	CREW-BUL	2.508	60
	CREW-REG	0.443	60
	FLTPLAN	0.4356	30
	NOTAM	0.5218	60
	HANDLING	0.3574	60
	CATERING	1.1524	60
	BAGGAGE	10.232	20
	NOTOC	0.5328	60
	LOADDOC	0.5474	20
	PREFLT-INS	0.2352	120
	DOOR	1.4232	30
	FLOWCON	1.0894	60
	TAKEOFF-CALC	15.5668	40
	OOOI	0.566666667	30
	WXRT	0.751	30
	OOOI	0.75	30

Table 77: AOC1 Services Response Time

	AOC2 Service	Response Time [s]	Latency Requirement [s]
Arrival	**EFFU**	17.72	30
	FLT-JOURNAL	320	60
	FOQA	189.8	1200
Departure	**E-CHARTS**	205.4	60
	UPLIB	1060	120
	SWCONF	71.6	120
	SWLOAD25	110.464	60
	SWLOAD	163.3	120
	EFF/WXGRAPH/CREW-L	325.286	60
	EFFU	86.222	30

Table 78: AOC2 Services Response Time

It can be observed that, as in Scenario 1, the service latency requirements for ATC are fully accomplished. Note that this scenario is more stringent in terms of turnaround time. The same effect as in Scenario 1 is replicated here, although the heavy services are mitigated as they generate a smaller amount of traffic.

The figures below depict the frame utilization by data traffic for one specific channel. The sector to which the A/C is connected during the turnaround phase has been chosen, where the most heavy loaded services are executed. It can be observed that, even considering the very worst case in which all the heavy services are instantiated (each of which is actually executed only during 1% of the flights) the channel does not reach complete saturation and can cope with additional critical ATC services if required.

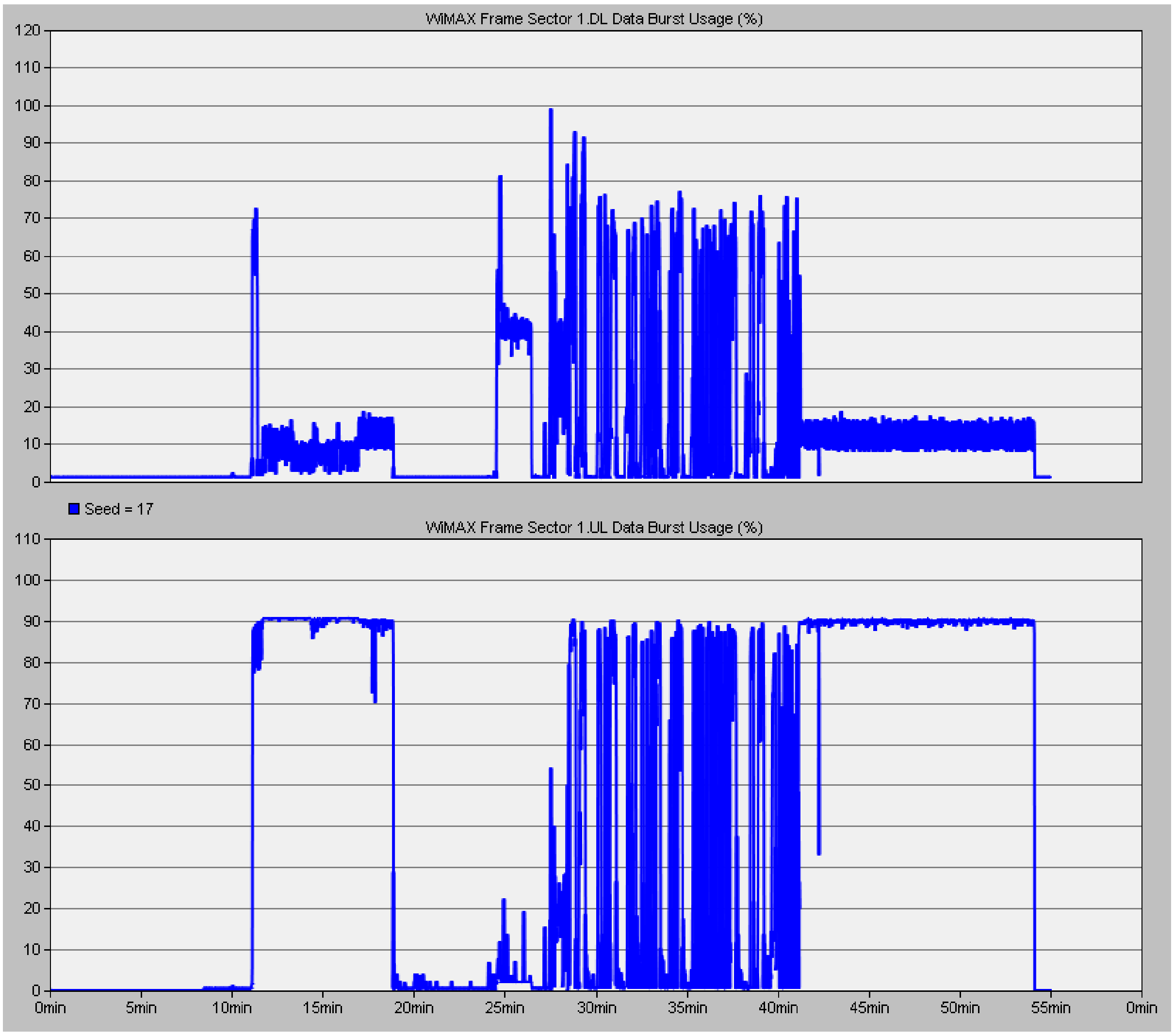


Figure 42: UL/DL WiMAX Frame. Data Burst Usage in %

3.7.2.3.6.3.3 Comparison between Iteration 1 and Iteration 2 for scenario 1.

In order to get convergence between services response time and required latency a pair of iterations increasing the number of base stations has been necessary. Scenario 1 is assumed for the sake of comparison. This paragraph show briefly main differences between the two iterations.

The table below summarises the number of BS configured per iteration, and the consequent amount of background traffic. It can be observed that, in iteration 2, the number of BS in the RAMP area were increased, while GROUND/TOWER kept the same planning. That is due to the fact that the services found to be operating near the limit of the system capacity, as shown in the results below, were executed in RAMP. Note that, assuming uniform background traffic distribution in the airport surface, this figure is inversely proportional to the number of BS. Refer to the first subsection in 3.7.2.3.6.3 for detail on the difference between cell planning in iteration 1 and iteration 2. In the latter, the background traffic that occupies a sector is around 1 Mbps.

		Iteration 1	Iteration 2
Number of BSs	RAMP	15	20
	GROUND&TOWER	8	8
Background traffic in	DL	216.263333	162.1975

RAMP [Kbps]	UL	1190.12267	892.592
Background traffic in GROUND&TOWER [kbps]	DL	66.92	66.92
	UL	762.684297	762.684297

Table 79: Summary of BS number and background traffic figures per iteration

Another major difference of iteration 1 is the QoS configuration. For polling services, the polling rate at which the BS sends periodic unsolicited poll requests has been underdimensioned in iteration 1. In addition, ATC3 CoS has been configured as nrtPS instead of rtPS as in iteration 2. As a consequence, a minimum periodic poll rate is not set up, and thus the maximum latency per packet is not controllable. The differences in QoS configuration is depicted in the table below. The polling rate is a figure extracted from the configured parameters Maximum or Minimum Traffic Rate. The algorithm to work out the polling rate (PR) is implementation dependent.

Class of Service	Iteration 1	Iteration 2
NET	rtPS PR = 1 ms	rtPS PR = 5 ms
ATC1	rtPS PR = 1 ms	rtPS PR = 7.813 ms
ATC2	rtPS PR = 1 ms	rtPS PR = 9.375 ms
ATC3	nrtPS PR = 1 ms	rtPS PR = 10.714 ms
AOC1	nrtPS PR = 1 ms	nrtPS PR = 23.475 ms
AOC2	BE	BE

Table 80: QoS configuration for iteration 1 and iteration 2

Differences on the results in terms of packet delay and execution latency for some relevant services is shown in the tables below. The first aspect to observe, is the apparently shocking result for iteration 1 in the tables below: although the polling rate is maximum for every CoS (1 ms) , there is a big deal of difference between the maximum delays caused per CoS, and those are not coherent with the priority level the CoS should have. That is explained by the fact that, in the de facto QoS configuration in iteration 1, there is no effective prioritization at all. By scheduling the same polling rate to all rtPS CoS, they are finally served in a FIFO manner. In this case, the packets that arrive at the queue will be dequeued at a lower delay than those arriving at peak traffic instants. On the other side, nrtPS services are always served with a lower priority, thus causing a significantly longer delay. That is why, in iteration 2, an affective prioritization is configured to serve each CoS in a gradual manner according to its level of priority.

E2E Delay [avg][ms]	NET		ATC1		ATC2		ATC3		AOC1		AOC2	
	I1	I2	I1	I2	I1	I2	I1	I2	I1	I2	I1	I2
UpLink	55.85	53	27.8	56.33333	22.75	59.5	480.5	66	179	167.5	80.5	75
DownLink	8.765	6.95	8.255	7.95	9.735	8.75	10.583	7.9	38.2	24.45	19.795	22

Table 81: Results on packet latency for iteration 1 and iteration 2. Scenario 1

	Service Name	Iter 1 Simulation Latency	Iter 2 Simulation Latency	Required Latency
GND Arr	ACL	4.475	0.65025	3
	EFFU	111.6	31.418	30
	FLT-JOURNAL	939	367.2365	60
RMP Arr	ACM	-	0.194375	3
RMP Dep	ECHARTS	933.14	1064.785	60
	UPLIB	375.66	426.626875	120
	SWLOAD	123.8	26.429375	60
	EFF	340.22	262.08875	60
GND Dep	ACM	-	0.19125	3
	ACL	-	1.3826	
TWR Dep	WXRT	-	1.016	30

Table 82: Capacity limitations in Iteration 1 solved in Iteration 2

A balanced latency target can be achieved through proper QoS configuration. Note that, in order to do this, dimensioning should not be equal per CoS, but rather a polling rate needs to be configured per CoS depending to the traffic generation rate and message size of the aggregated services in the specific class. Of course, an implementation-dependent algorithm could be active in the scheduler to adapt to the CoS varying data rate in an optimized manner. It can be observed that, with a well balanced QoS, the end-to-end delay of a packet is well below 80 ms, which is very valid for data, and even for real time and voice applications.

It is obvious that the QoS configuration mainly affects the Uplink in terms of delay. In effect, the Downlink does not require a polling delay since the BS generates traffic and directly forwards it to lower layers. Uplink, on the other side, has a delay of several frame due to polling negotiation. Besides, with the current symbol configuration, the downlink has more available resources than the Uplink, which could be optimized (within the limits of supported symbol configurations in [5]) although not strictly necessary.

Regarding service execution latency, it can be observed that iteration 2 deals better with it in general, especially for ATS. Some heavy services would still require a redefinition in terms of required latency to suit them better to the operational concept and milestones.

Finally, the graphs below depict the improvement in terms of frame occupation by data traffic achieved by the refined configuration in iteration 2. It can be observed that, in both Downlink and Uplink, iteration 1 led to a saturation of the channel in the BS in charge of the turn-around phase. This is due to the under-dimensioned cell planning but also to the non optimized QoS per class of service, which causes an overhead provoked by excessive polling delay. Iteration 2 solves both issues and avoids a saturation of the channel, thus allowing new service flows to be admitted in the sector if necessary.

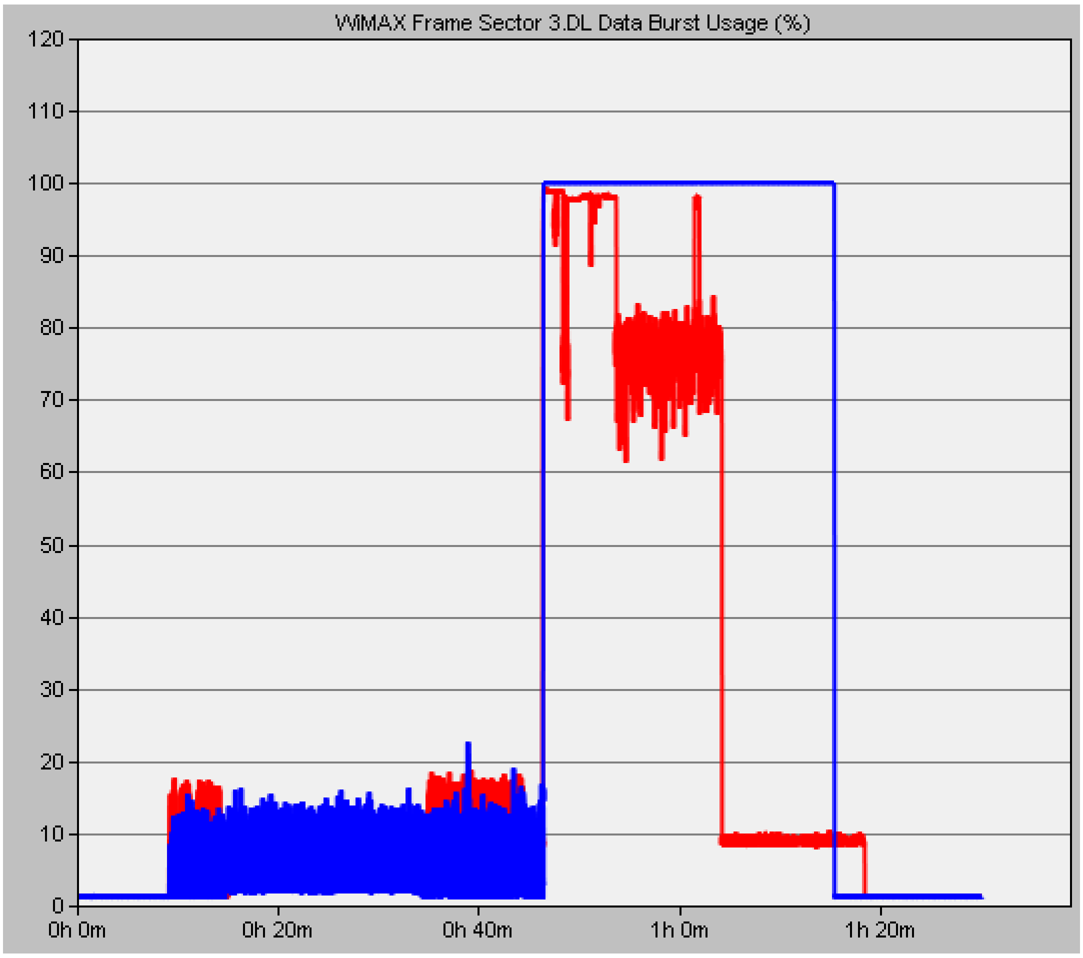


Figure 43: WiMAX DownLink Data Burst Usage. Red=Iteration2. Blue=Iteration1.

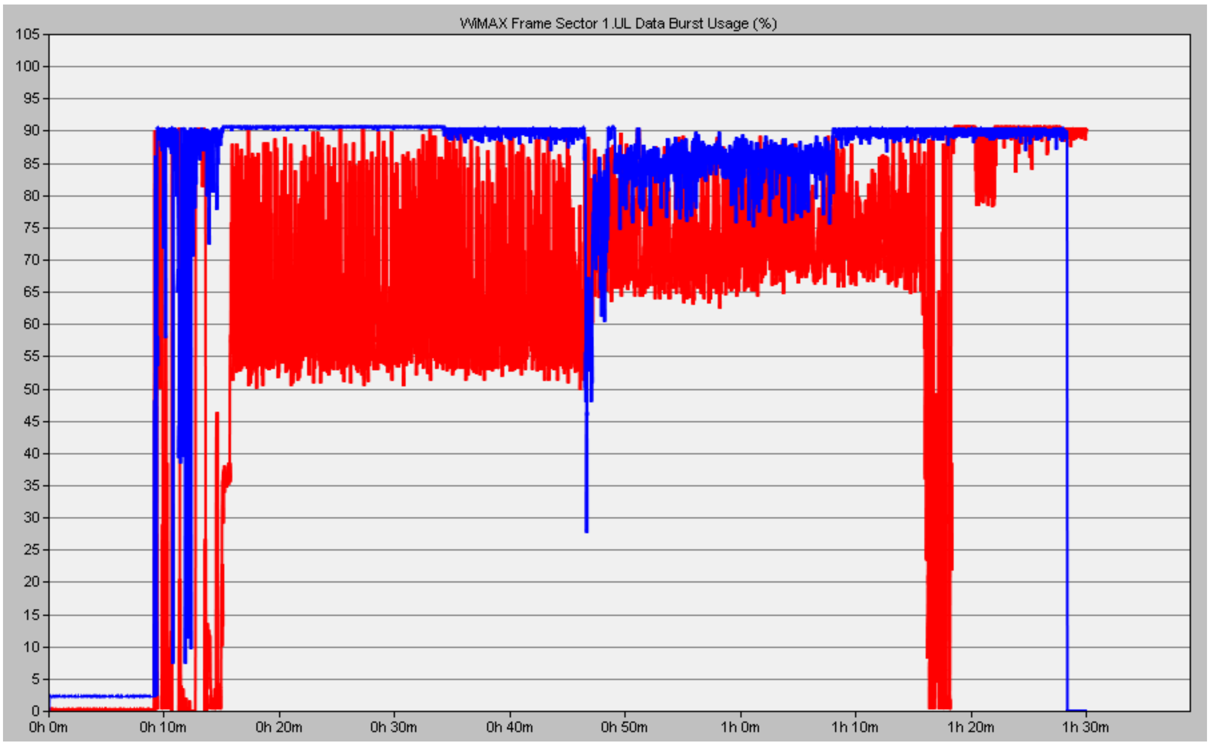


Figure 44: WiMAX UpLink Data Burst Usage. Red=Iteration2. Blue=Iteration1.

3.7.2.3.6.4 Handover results

The network dimensioning affects mainly the capacity levels of the system in terms of throughput and delay, which could be seen as parameters of “static” capacity (i.e. linked to the ratio BS vs aircrafts in the overall airport surface). However, capacity also includes the performance levels of the handover process (i.e. the smooth transition of an aircraft registered in a BS to a different one without session interruption), since it may affect the availability of services being executed at a specific moment. As this process is purely dynamic, handover figures depend largely on the aircraft movement on surface, BS placement and signal quality on the moment of handover.

This section is a refinement of the handover performance study started in WA3 [5]. According to these results, handover is not an issue at RAMP area, where BSs are dense and the subscriber is handed over at high signal to noise values. Besides, the aircraft is expected to move slowly, thus suffering low shadow fading effect. An optimization is needed in GROUND/TOWER areas, though, where BSs are more distant and the aircraft moves faster. This is a harsh situation that leads to a refinement of the cell planning to meet the requirements.

The scenario follows the arrival and departure trajectory defined in Scenario 2, starting from the cell planning proposed in iteration 2. The aircraft of study, in this scenario, executes services following the data rate in background traffic generation. This is configured in order to obtain a uniform traffic generation and study the effect of handover interruption over the services. In addition, shadow fading has been activated and considered for GROUND and TOWER zones in the same way as in [5].

MAC and PHY configuration is similar to that in WA3. Refer to [5] section 3.3 for further details about configuration.

For sake of comparison, statistics similar to study in [5] have been analysed here.

- **Handover delay:** Handover delay is computed from the time the Mobile Station sends a MOB_MSHO-REQ message starting the handoff process until initial ranging with the new Serving BS is succesfully completed.

- **Interruption Time:** time between the message indicating the start of the HO (HO_IND) and the creation of the new service flow (DSA_ACK), in other words, time lapse in which the MS is not able to communicate with any BS through a valid Service Flow.

- **Failure probability:** percentage of Handover Cancellations produced during simulation time over all the Handover realizations.

- **Dropped Packet Rate:** this new statistic has been gathered in this scenario in order to illustrate the effect from handover interruption and delay to the transmission of data packets. This statistic is extracted at PHY SDU level, in order not to take buffering effects into account.

Handover optimisation has been performed taking care of the cell range of contiguous BSs that participate in handover processes (not in all of them). In this sense, contiguous BSs inside GND/TWR or between RAMP and GND/TWR are taken into account (handover within RAMP zone is not part of this analysis). In order to do this, the deployer has to estimate the most likely movement patterns that an aircraft will follow, as has been done in this study.

First, the cell planning from iteration 2 is kept in the simulation, where consecutive BSs in an aircraft trajectory are distanced 2650 m in average. Then, consecutive cells that fall under a likely aircraft trajectory are brought closer to the distance necessary to target the recommended PER = 1E-03 from 3.7.2.2 at the cell edge. To meet this PER level at QPSK ½ an SNR = 17 dB is needed (see Figure 3-14 in Calibration simulations [5]), which corresponds to a cell range of 650 m (1300 m distance between BS) according to Figure 26 with propagation model BS1MS1, and considering Noise power = -107.4 dBm. See A.1 for details on the BS sitting.

Contiguous BS avg distance	**Avg HO delay [ms]**	**Avg interruption time [ms]**	**Probability of HO failure [%]**	**Dropped Packet Rate in UL [%]**	**Dropped Packet Rate in DL [%]**
2650 m (initial)	402,84	266,73	7,16	8,68	1,44
1300 m	322,54	194	3,6	7,77	0,84

Table 83: Results for HO performance. Consecutive BS distance = 2650 m / 1300 m

Results show that, in effect, a distance of 1300 m for the BS affected by handover guarantees the fullfilment of the requirement in terms of handover interruption time. It also yields an acceptable probability of handover failure below 4%. Even keeping the initial BS distance of 2650 m, the requirements from SRD are close to be fulfilled, since it should be noted that the packet dropping rate caused by handover interruption remains well under 10%. Note that dropping rate has been measured at PHY level, thus not taking retransmission into account. MAC takes charge of the dropped packets by retransmitting them in ARQ.

Note that, as previously indicated, only the distance between contiguous BSs that participate in the handover process has been taken into account, it is unnecessarily costly to increase the density of BS in areas that will not see a cell transfer. This is feasible since mobility patterns of aircrafts in the surface are predictable and limited to very specific runway and taxiway zones. It is recommended for a deployment to take care of this when planning the cell sitting in order to optimise handover performance without largely increasing the density of BS.

3.7.2.3.7 Conclusions

In this section, a capacity analysis of an AeroMACS deployment is carried out in an airport situation. An aircraft performing arrival and departure phases has been simulated in a large airport (Madrid Barajas) with a background traffic generated by present aircrafts on the surface. Two iterations have been launched in refining the cell planning to cope with the capacity required by the system in the hypothetical case all the potential identified NET/ATC/AOC services are active. Following this approach, the system has been challenged to its maximum possible capacity level (all possible current and future ATC and AOC services enabled through AeroMACS). A revision of the service list should be done by operational stakeholders at deployment stages.

It has been shown that AeroMACS can cover the necessary services in this demanding capacity situation if cell planning and QoS configuration are correctly dimensioned. For the services executed when the aircraft is operating in the GROUND and TOWER domains, the system is clearly dimensioned by coverage, however in RAMP more attention needs to be paid to the amount and type of traffic that aircrafts turning around will need to generate per sector. Consequently, sites in GND/TWR area may be spaced 2650 m out, while RAMP BSs should be closer (around 810 m).

Regarding QoS, AeroMACS permits a balance to be achieved by means of adjusting the assignation of specific services to real time and non-real time CoS, and assigning a periodic polling rate that guarantees a dedicated data rate depending on the amount of traffic and delay requirements of the aggregated CoS. AeroMACS deployers should consider the expected data rate for every configured class of service (CoS), in order to guarantee a traffic rate and maximum delay adapted to the requirements of the most stringent services present in each of them. If this aspect is covered, AeroMACS is able to fulfil high throughput (1 Mbps) respecting real time-like delay requirements (80 ms) for an aggregation of different classes of service.

Lastly, it has been shown that AeroMACS fulfils the capacity requirements in terms of handover in the more exigent GROUND and TOWER zones, if a distance between contiguous BS that participate in handover processes of 1300 m is respected. This demonstrates that an optimized configuration of the AeroMACS cell planning can cope with dynamic behaviours in stringent conditions of terminal speed and link budget with fading.

3.7.3 Initial Dimensioning of BS

The number of 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. 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.

An essential element in designing and deploying an AeroMACS network is a comprehensive RF design. Real-life deployments must take into account variables from the environment to achieve optimal performance and minimize coverage holes and RF co-channel interference.

As it was mentioned in section 3.6 the following aspects have to be checked as general rules to validate the initial BS placement used during simulations:

- Check that there are no coverage holes, the whole airport is covered and the modulation achieved in every area is the expected to accommodate the traffic generated in those areas.
- Check the interconnection of the base stations with appropriate ground networks for easy, cheap and fast deployment. Positioning of the BSs to achieve airport surface coverage may place them distant from existing access points and cabling infrastructure, making difficult and costly the connection with the ASN-GW.
- Check access to power supply.
- Verify that no BS's are placed in forbidden areas and/or do not break the aeronautical easements.
- Verify that the type, height and position of the antennas are correct for the intended purposes. Omni or directional antennas will typically be deployed, with directional antennas likely used when coverage has to be focused in a particular direction. Sectored BSs with directional antennas may also be deployed to support higher capacity demand.

If antennas are placed above the clutter (i.e., on the tallest building or on a tower), propagation would approach free-space characteristics and fewer sites may be needed. The number of BSs and the height above the surface and structures will be adjusted accordingly for each airport during the design phase.
Related to antennas, tilting is a decisive factor. Setting the antenna tilt angle too high causes interference in the downlink to other cells, and setting it too low reduces the propagation distance, potentially resulting in failed handovers or null spots.

- Verify that there is enough overlap to perform handover and guarantee enough coverage if one cell fails but not too much in order not to provide full dual coverage. Verify that the cell overlaps are kept to a minimum.

For the particular case of Barajas simulations, although the coverage and capacity results seems to be very good to cover the whole airport and fulfill the traffic demand, some refinement should be done, as some of the previous general rules have not been followed.

First of all, some BSs were placed in not feasible areas, either because they are placed in restricted areas or there is no communication/power infrastructure nearby. This is the list of sectors to be moved and a proposal of new placements:

Sector name	Original place (see Figure 68)	New Place Proposal
R10s3	Parking Areas T4	Buildings nearby at lower height
R5s1/R5s3	Parking Areas T4	Buildings nearby at lower height
G1s1/G1s2/G1s3	Between taxiways (no infrastructure)	Power Supply Buildings
G2s1/G2s2/G2s3	Forest between runways (no infrastructure)	Buildings nearby (Fire Brigade) at lower height
R2s1/R2s3	In T1	In T2 TWR S (a bit north the original place on the terminal building)
R7s1	Between taxiways (no infrastructure)	Iberia Cargo Area Buildings

Table 84: Alternative locations for BSs

Secondly, in G2s1/G2s2/G2s3 and G3s2/G3s sectors omnidirectional antennas could be a better option as the sites are in an open area and not much capacity is needed as their main function is to cover the runways. This way it could just use 1 sector with and omnidirectional antenna, using fewer channels and reducing the intra-system interference and the number of handovers. On the contrary, omnidirectional antennas could increase Globalstar satellite interferences as the radiation pattern is less controlled than using directional antennas.

Thirdly, all the simulations have been done with BSs antenna height above ground of 38 meters, which is not very realistic, and a down tilt of 3º was considered. Of course, this parameter has to be adjusted and cannot be taken as a rule for the other airports. It has to be reconsidered for each airport, because it is linked to infrastructure available (height of buildings), to coverage goals.

In RAMP area, operators would like to increase the BS antenna down tilt, in order to favor the power distributed close to the gates. On the other hand, if a maximum coverage has to be achieved, the BS antenna tilt would have to be moderate. Thus, a trade off will be necessary for each airport.

Further simulations should be made taking into account these issues to check and guarantee the coverage and capacity requirements.

A similar refinement analysis could apply for Toulouse airport, although in this case the deployment is much easier because of the small size of the airport.

3.8 RF Cell Planning

The purpose of this section is to identify and provide recommendations for AeroMACS cell planning and for intra and inter-system interference reducing. This will be done based on real example of deployments, on Barajas airport for frequency planning and intra-system interference, and on Toulouse airport for inter-system interference (MLS–AeroMACS) which will be studied in Appendix A Case Study 2.

3.8.1 Simulation of intra-system interference

3.8.1.1 Frequency reuse-plan among base stations deployed over the airport area

A frequency planning has been operated for Barajas' airport, with capacity hypothesis made previously. All the spectrum available in future AeroMACS standard has been used. Because of the number of activated BS's (24) and available frequencies (11), a frequency re-used has been used, operating a permutation of sectors on the airport area. The frequency permutation, as well as sectors deployed can be seen on the following table and figure.

A more detailed analysis of this process can be found in Appendix A Case Study 1.

Note: The calculation of central frequencies is done according to the SRD formula (5005 +n*5 (n=0..4 and 19..28)), which gives 11 contiguous channels.

Frequency planning & reuse for HTZ

5005 +n*5 (n=0..4 and 19..28) — **11 available contiguous freq for range 5091 to 5150 MHz**

n	0	1	2	3	4	18	19	20	21	22	23	24	25	26	27	28
Fi	5005	5010	5015	5020	5025	5095	5100	5105	5110	5115	5120	5125	5130	5135	5140	5145
n° Fi	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Freq nb in HTZ						1	2	3	4	5	6	7	8	9	10	11

freq. n°	
1	G1s1, G2s3
2	G1s3, G3s2
3	G1s2
4	G2s1
5	G2,s2, G3s3
6	R1s1, R3s3, R8s2
7	R1s3, R8s1, R10s3
8	R2s1, R4s1, R7s2
9	R2s3, R4s3
10	R3s1, R5s1, R6s3
11	R5s3, R7s1, R8s3
12	R6s2
13	R6s1, R9s2

Table 85: Frequency planning & reuse for intra-system interference analysis

Note that the tables above refer to physical and logical frequencies respectively. Among the logical frequencies, 1-5 are frequencies used in GROUND while 6-13 are frequencies used in RAMP. Frequencies 12 and 13 in RAMP are physically the same as frequencies 4 and 5 in GROUND, respectively. They have been re-used since they do not alter the frequency reuse scheme due to enough distance between emitting BS, thus avoiding intra-system interference limitations.

3.8.1.2 Simulation of intra-system interference (co-channel and adjacent channel interference)

The purpose of this sub-section is to evaluate the co-channel and adjacent channel interference that may occur during a real deployment on airport. We still consider Barajas airport for this simulation.

Interference is considered at BS level and calculation is performed according to C/I or IRF rules. Results will be presented and displayed on a map. A CINR analysis has been performed in order to check which modulation (i.e bit rate) will be lost according to the interference. For that, a C/(N+Sum(I)) has been calculated, based upon a noise floor N and the interference rejection factors (IRF) of the equipment.

Note: C/(N+Sum(I)) function computes the maximum C/(N+sum(I)) value on each point of the terrain according to the noise level value of the receiving point. C is the received wanted power coming from activated stations considered one by one and unwanted power is the power sum of the other stations. Moreover, because PUSC permutation mode is used, the received wanted power C is weighted according to the number of segmentation and the “PUSC sector loading” allocated to the station.

We considered the following IFR mask, in line with data given in AeroMACS’ SRD, and that is equivalent to the most strict value of ETSI mask.

- Co-channel (N=0): 0 dB
- Adjacent channel (N=1): 32 dB
- Alternate channel (N=2) : 50 dB

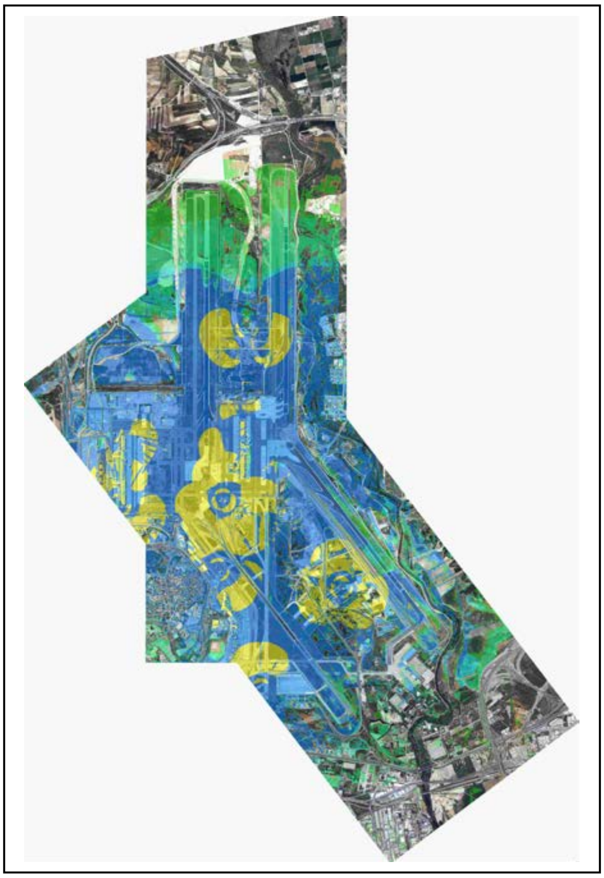


Figure 45: Map of C/I intra-system interference, based on DL coverage

C/I (>dB)	Received Power (>=dBm)	Modulation Scheme
5	-92	QPSK1/2
8	-86	QPSK3/4
11	-84	16QAM 1/2
14	-80	16QAM 3/4
16	-78	64QAM 1/2
19	-76	64QAM 2/3
20	-74	64QAM 3/4

Table 86: C/I versus Modulation Schemes[19]

In order to operate in a given modulation scheme, and thus access to a given data bit rate, a minimum C/I shall be respected. We observe on the C/I map that all the airport area have a C/I between 16 and 40dB, which means that, based on the frequency planning prepared, no interferences occur in the AeroMACS system for this deployment.

Because FFR (Fractional Frequency Re-use) won't be available in AeroMACS, if any interference appears during a cell planning, an optimization of either the frequency arrangement or BS localization will have to be done in an iterative process.

3.8.2 Optimization of cell planning

As result of this cell planning process the number of base stations could change. In this case, the planning tool should make an iterative process in order to provide the best solution for any airport and in particular for the deployment within Barajas or Toulouse airports.

Considering real cases:

- Barajas airport (large airport)

As no interference has been found on frequency allocation planned, no optimization has been processed. An optimization process could arise for other cases, where frequency availability would be very limited or where area to cover and capacity to achieve is high.

The radio coverage is sufficient at this step. A deeper optimization would be useful when real deployment will occur (it will be the case in WA6 work-package, for a limited number of BS).

- Toulouse airport (small airport)

Cell planning is basic, and focus has been done on inter-system interference analysis.

[19] See table 85 Item 6 in [42]

3.9 Test and acceptance of selected Sites and equipment

3.9.1 Installation and Acceptance of Base Stations

The installation of AeroMACS Base Stations will take place according to the deployment and installation plan, which is under responsibility of the ASN owner. In section 3.6.1 several recommendations for the installation are given (e.g. civil works completed, communication infrastructure availability, power supply cables…). A thorough site survey of the site is mandatory before starting installation.

After completion of a BS installation, the equipment will be commissioned. Commissioning includes software initialization, setting the node addresses, running the equipment self-check, activating the equipment and establishing the transmission connections with the ASN-GW. Basic functional test will be passed and all actions and results will be recorded in the commissioning protocol.

After installation and commissioning of the system elements themselves they have to be integrated in order to ensure a stable system operation and interoperability with other network devices. As AeroMACS system must be integrated in the Airport Network and/or connected to Air Navigation infrastructure a strong coordination between the different partners is a must.

As soon as a site is integrated in the network, the corresponding site will be ready for acceptance. ASN owner will verify the correct installation and functionality of the site and it will issue a list in case of any deficiencies found which will not meet the agreed specifications. These list entries will be rated according their severity and all critical points have to be eliminated within a time frame.

This process, along with the AeroMACS network and optimization test explained later, validates the end-to-end functioning of the network with respect to requirements and functional parameters of AeroMACS.

Finally, all documentation and reports generated during the implementation of the project must be stored in a cohesive and structured manner, preferably in electronic format on databases. A professional archiving of the very large number of documents produced during project implementation permits the efficient operation of the network as network enhancements or maintenance requires fast and easy access to the information. Among this documentation we can find:

- As-built site documents
- Equipment user and maintenance manuals
- Software release management documents
- Acceptance Documents

3.9.2 AeroMACS Network Verification and Optimization Tests

AeroMACS network verification tests take place after successful completion of site acceptance. It should be repeated before and after any major network hardware/software changes to verify their effect on the network performance. It can start during the network trial period and continues after opening the commercial service and during the network expansion.

The aim of this process is to evaluate and maximize the quality of service in the network with the corresponding set of quality criteria.

AeroMACS Verification and Validation objectives have been defined in WA6 and a test plan definition for every objective is being developed. The tests themselves will be carried out during the first half of 2013.

Basically, the network verification procedure consists of the following steps:

- Planning of the measurement resources (including tools), schedule and test route(s)
- Setting of the network performance objectives and quality criteria
- Measurement execution and analysis of the statistical results
- Reporting to the customer the results of analysis
- Agreement on possible corrective actions if the set quality criteria is not met

As an example, field strength measurements are needed for determination of coverage areas as well as for tuning the propagation model of network planning system. In some cases it will be needed to perform measurements before base station installation. To do this a test transmitter, which simulates the BS, should be placed at the final position of the planned BS. The selection of routes to be measured depends on the purpose of the measurements. For more details, a similar process can be found in [7] during Madrid measurement campaign in 2010.

AeroMACS network optimization is the last step of the network planning and deployment procedure. It can be defined as a continuous process of improving overall network quality.

It is almost impossible to achieve the exact performance of a network in the first time once it has been implemented, so it will be always necessary to make minor adjustment to the network.

Network performance optimization involves finely tuning the network after the configurations faults are eliminated by selecting appropriate network parameters to achieve the set QoS targets. The main focus of AeroMACS radio network optimization is expected to be on areas such as the channel allocation scheme and antennas tilting to reduce inter and intra-system interferences. The optimization process is initiated by collecting and analyzing network data from drive testing on selected routes and also data from core network nodes by using customized software.

4 Integration and Interoperability Analysis

The objective of this section is to derive guidelines on how to integrate AeroMACS in the ground network in order to provide connectivity to the ATM network, Airport operator network and AOC servers. One main task will be to identify the relevant use cases to be considered as it will have an implication on the implementation of the different functions.

AeroMACS shall have the ability to mix vendor equipment in the network and be interoperable with legacy and future networks present in the system.

This section is a very first analysis of the different issues. Detailed analysis should be performed in order to specify a system which could be implemented. This work will notably be done at ICAO level WG S and I and in SESAR P15.2.4 which addresses the End-To-End communication infrastructure build upon IP suite.

4.1 AeroMACS Ground Architecture and Network Topology

4.1.1 Functional Requirements

The Network infrastructure should enable provision of ATC services to all Aircrafts.

The Network infrastructure should enable provision of AOC and AAC services to Aircrafts depending on contractual arrangements between Airlines and AOC/AAC service providers.

The Network infrastructure should enable provision of Airport Operation related services (communication with the surface vehicles) depending on contractual arrangements between Airport operators and AeroMACS service providers.

All ASN and CSN operators should be able to support ATC services.

All ASN and CSN operators should be able to support ATC service provision to all aircraft independently from their AOC/AAC contracts. For instance, Airlines which do not subscribe any AOC/AAC contract over AeroMACS should be accepted on NAP and NSP networks for ATC only service provision.

All ASN and CSN operators should grant access to all aircraft for ATC only purposes provided airborne system is certified against aviation regulatory framework.

All ground networks should advertise to the mobile subscribers the types of service it can provide: ATC, AOC, AAC and airport operation. This information should be updated depending on real-time status of connectivity.

All Airborne Radios should not be locked to a given NAP or NSP. A certified radio should be capable of logging into any NAP or NSP seamlessly.

All the airborne system, ASN and CSN implementation should not preclude having different deployment and service provision models depending on the regions of the world.

All Airborne and Ground implementation should enable change of Home Network for the aircraft while moving from an airport to another, from one region of the world to another. Notably, depending on region of the world, ANSP or ACSP can act as Home-NSP to support both ATC and AOC service provision.

All NAP and NSP should have the same Authentication mechanism and logon process for aircraft.

All CSN and ASN operators should be able to handle traffic priorisation.

4.1.2 Access Network Aspects

The scope of this section is to address general aspects related to the access network that have impact on a hypothetically AeroMACS deployment. What would be needed in order to accomplish a reliable deployment of an AeroMACS network within an airport. That is to say, elements from the standardized architecture, and therefore out of the scope of the radio datalink, engaged to the AeroMACS deployment and integration with the overall airport system. Some figures of system procedures will be detailed in this section as well.

R-ARC-ASN-01. AeroMACS surface datalink is independent from any network technology on the backbone or ground side.

R-ARC-ASN-02. AeroMACS architecture SHALL give the means to avoid security risk propagation from vulnerable AeroMACS ASN elements (mainly ASN-Gateway) to the backbone of the Communication infrastructure.

R-ARC-ASN-03. During basic and primary connections, MAC management messages are sent in plain text leading a third party the reading of them. X.509 certificates give a potential solution and therefore AeroMACS SHALL support the Public Key Infrastructure utilizing X.509 certificates.

R-ARC-ASN-04. In order to give support to USER and DEVICE authentication, proper means shall be foreseen. Thus, MS and AAA server SHALL support EAP-TTLS framework.

R-ARC-ASN-05. During Hand-over procedure, ASN-GW shall update the AK from the MS to the new serving BS. Therefore the whole set of keys is transferred to the BS (TEK) through PKM protocol. Besides it shall command the BS to destroy current SF and trigger the new BS to create the new SF.

R-ARC-ASN-06. AeroMACS infrastructure SHALL support different Network addressing schemes in order to give support to network addressing for vehicles and home and visiting aircrafts without distinction.

R-ARC-ASN-07. Mobile IP shall be implemented in compliance with ICAO standard for communication with Aircraft

R-ARC-ASN-08. AeroMACS SHALL support IPv4 address in order to be interoperable with legacy systems and for vehicles on the airport domain.

R-ARC-ASN-09. An airport vehicle SHALL get a dynamic IPv4 address.

R-ARC-ASN-10. The vehicles which have been allocated the same address SHALL not operate on the same aerodrome.

R-ARC-ASN-11. AeroMACS SHALL support IPv6.

R-ARC-ASN-12. AeroMACS SHALL support multiple NSPs for provisioning ATC/AOC services over the same data link.

R-ARC-ASN-13. AeroMACS infrastructure SHALL provide the availability to the subscriber to select the preferred CSN/NSP.

R-ARC-ASN-14. ASN-GW SHALL support GRE tunnelling on R6 interface.

R-ARC-ASN-15. ASN routers SHALL support dual network layer stack for connecting IPv6 core networks to AeroMACS ASN core network which goes over IPv4 stack.

R-ARC-ASN-16. MSs SHALL support UDP/TCP transport connections.

R-ARC-ASN-17. All the BSs SHALL get synchronized using a unique time reference getting an error of the clocks of 1ppm at the most.

R-ARC-ASN-18. AeroMACS synchronization dwell times SHALL be as short as possible (<150ms). Some requirements can be extracted from ICAO's Annex 10

R-ARC-ASN-19. The maximum resynchronization time for the MS after signal loss SHALL be less than 10 s.

R-ARC-ASN-20. AeroMACS SHALL guarantee data transfer delays not exceed the values stated in section 2.2.6.

R-ARC-ASN-21. AeroMACS maximum network entry time for a MS SHALL be less than 60 s.

R-ARC-ASN-22. AeroMACS handover interruption time SHALL take no more than 200ms.

R-ARC-ASN-23. The maximum bit error rate that AeroMACS supports SHALL not exceed is 10-9 for undetected errors and 10-7 for detected errors.

R-ARC-ASN-24. AeroMACS SHALL enable advanced RRM by enabling the collection of reliable statistics over different timescales, including system (e.g., dropped call statistics, BS loading conditions, channel occupancy, RSSI), user (e.g., terminal capabilities, mobility statistics), flow, packet, etc.

R-ARC-ASN-25. AeroMACS architecture SHALL NOT preclude inter-technology HOs. This is FFS.

R-ARC-ASN-26. AeroMACS network architecture SHALL support IPv4 CS and IPv6 CS and MAY support ETH_CS

AeroMACS SHOULD endorse QoS interworking by the following mean: Differentiated services through IP DSCP field. Packets with DSCP different from 0x00 shall be uniquely matched to one of the five AeroMACS QoS.

4.1.3 Network Topology

This section aims to cover overall aspects of Intra ASN architecture to support AeroMACS and the connection and network topology that most likely is meant to be when AeroMACS Access Service Networks connects to backbone or IP core network. Nevertheless, as previously stated, the outcomes of this section are general lines and a functional description of the elements that should support AeroMACS Datalink when deployed on an airport.

Finally, it must be said that the aviation model may have a remarkable impact on some of the functional entities here depicted.

The Network Reference Model (NRM) addressed in AeroMACS FAD [4], and based on Wimax NWG outcomes, depicts the normative use of protocols, interfaces (commonly named as reference points) and functional entities to support interoperability between AeroMACS Datalink and the backbone and give the corresponding service support. The overall principles followed to provide this architecture for AeroMACS are:

- Functional decomposition. The architecture provided grants that required features are decomposed into functional entities. The reference points are means to provide multivendor interoperability. AeroMACS BS multivendor interoperability will be described in section 4.4.

- Modularity and flexibility. The modularity of the architecture proposed give means to adapt it to different AeroMACS deployments and the interconnection to the ground infrastructure. This way we are letting the interconnection of different CSN topologies with just one single access network. The architecture also eases the scalability of the network in case after initial deployment it's required the growth of the number of BSs installed within the airport in order to support more users.

- Decoupling the access and connectivity services. This architecture enables full mobility with end-to-end QoS and security support making the IP connectivity network agnostic from AeroMACS radio specification and full PHY/MAC standard. In consequence, this allows for unbundling of access infrastructure from IP connectivity services.

- Support to a variety of business models. As previously stated, this architecture supports the sharing of different aviation business models. The architecture allows a logical separation between the network access provider (NAP), the entity that owns and/or operates the access network, the network service provider (NSP) and the application service providers (ASP). The architecture SHALL NOT preclude the access networks being shared by multiple NSPs.

- As stated on requisite R-ARC-ASN-12 (section 4.1.2), the architecture supports the discovery and selection of one or more accessible NSPs by a subscriber.

The following pictures illustrate the NRM and the ASN models chosen for AeroMACS with the corresponding reference points and entities.

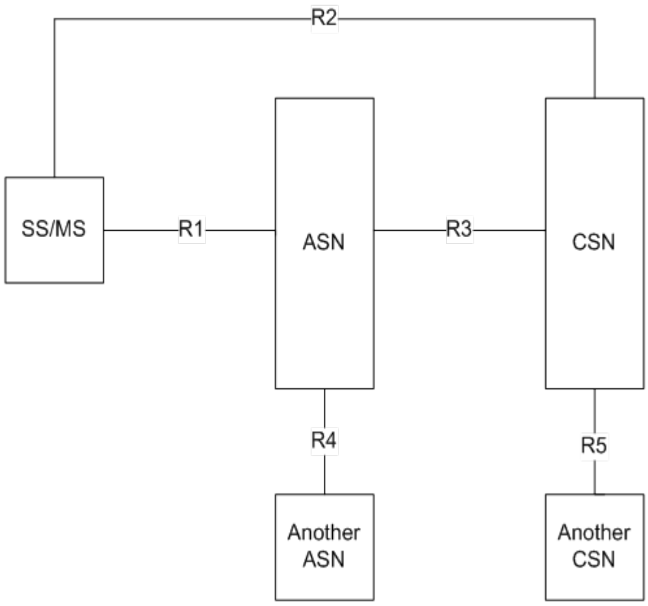


Figure 46: Network Reference Model (NRM)

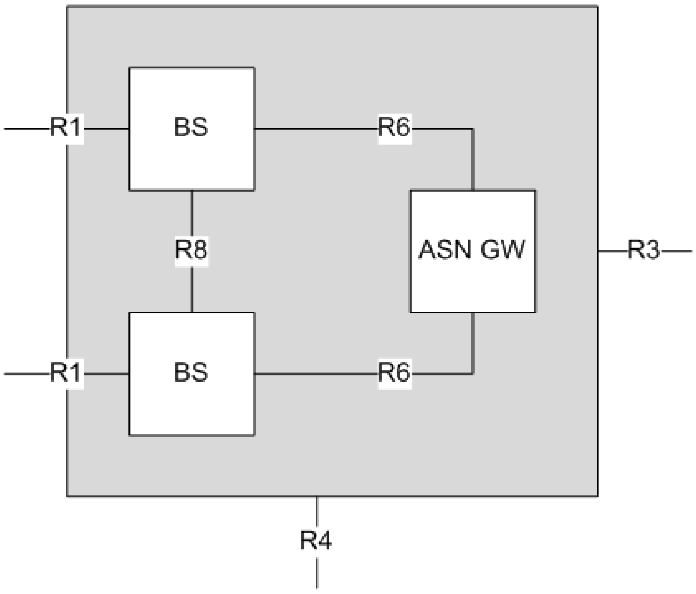


Figure 47: ASN Reference Model

These pictures match profile C from Wimax Forum reference architecture [21]. Profile C defines and sets a clear boundary for AeroMACS vendors (mainly focused on BSs manufacturing) and IP core service providers. This also eases the radio part to be agnostic from the rest of the IP pipe.

AeroMACS system shall be implemented according to profile C as defined by the Wimax Forum [3].

The main actor on the network topology is the ASN-GW, on which relays most of the management and control procedures to support the datalink and its interconnection with the backbone. Moreover, ASN-GW deals with interoperability between Wimax manufacturers as well. This will be achieved through third party equipment, since this element is out of the scope of SESAR 15.2.7 which focus on the radio side (MS and BS).The Reference points can represent a set of protocols to give control and provide management support on the bearer plane. On an overall hypothetic deployment, functional entities here depicted could be matched to more than one physical device.

Regarding the reference points, most of them are left opened. The architecture does not preclude different vendor implementations based on different decompositions or combinations of functional entities as long as the exposed interfaces comply with the procedures and protocols specified by NWG for the relevant reference points. Reference Point (RP) represents a conceptual link that connects different functions of different functional entities. RP are not necessarily a physical interface.

Those relevant points are:

- R1 (which has been taken on by the AeroMACS profile [5]) and deals with most of the interoperability issues to address for AeroMACS. It's related with the air interface and the protocols and procedures specified by IEEE 802.16e standard conveniently adapted and conformed to the avionics constraints.

- R6: a set of control and bearer plane protocols for communication between the BS and the ASN-GW. The bearer plane consists of intra-ASN data path or inter-ASN tunnels between the BS and the ASN-GW. The control plane includes protocols for mobility tunnel management. R6 also serves as a conduit for exchange of MAC states information between neighboring BSs. The main protocol used in this interface is and IP-in-IP tunnelling protocol, named GRE (Generic Encapsulation Protocol). This leads to the forwarding and transport of Ethernet packets coming from the ASN to CSN. Another mean to achieve that is the end-to-end VLAN services.

- R8: logical, not physical interface between BSs. This interface gathers a set of control plane message flows and bearer plane data flows between BSs to ease handover procedures. R8 are conveyed through ASN-GW.

- R3 supports AAA (In case AAA server is in the CSN) and encompasses the bearer plane methods (such as tunnelling) to transfer IP data between the ASN and the CSN. Policy enforcement and mobility management capabilities are part of this interface as well. Some of the protocols foreseen on this RP are RADIUS and DHCP.

R2 is only a logical interface and no protocol is foreseen. It represents MS to CSN connectivity for authentication, authorization and IP configuration management.

R4 open interface is not covered within this document since there’s no foreseen inter-ASN interoperability addressing on this document (R4).

R5 is not fully addressed in the present document even if implementation of Wimax roaming would be of interest for aviation. The complete specification of this Reference Point is out of scope of of SESAR 15.2.7. This is FFS.

For interoperability purposes, special care should be paid to the reference points R1 and R6 of the ASN reference model. Regarding the AeroMACS business model, it’s likely to have just one single ASN-GW deployed in the airport domain. Intra ASN mobility will imply full support of R6 control messages.

Aviation business model and hence contractual agreements between parties can have an impact on the network topology that supports AeroMACS service provision. The figure underneath depicts the overall contractual case and entities involved on behalf of provisioning services to the subscribers.

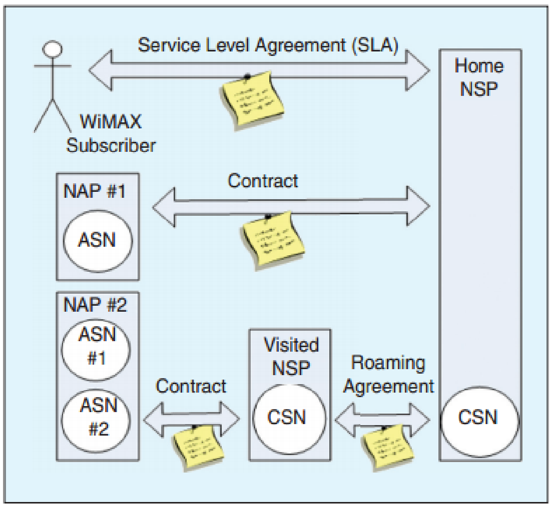


Figure 48: Overall Wimax relations between parties

The NAP is the entity that owns and operates the access network providing the radio access infrastructure to one or more NSPs. Correspondingly; the NSP is the entity that owns the subscriber and provides it with IP connectivity and services by using the ASN infrastructure provided by one or more NAPs. A NSP can be attributed as home or visited from the subscriber’s point of view. A home NSP maintains service level agreements (SLA), authenticates, authorizes, and charges subscribers. A home NSP may settle roaming agreements with other NSPs, which are called visited NSPs and are responsible to provide some or all subscribed services to the roaming users.

The previous description has been taken as a basis. Within the aeronautical environment, the following actors have been identified in the overall architecture and could make use of AeroMACS:

- NAP
  - Commercial DSP (Data Service Providers such as ARINC, SITA, AVICOM,….)
  - FBO (Fixed Based Operator)
  - SASO (Specialized Aviation Service Operator)
  - ANSP (Aeronautical Service Providers such as AENA, DSNA, DFS, …)
- V-NSP
  - Commercial DSP (ARINC, SITA, AVICOM,….)
  - ANSP (AENA, DSNA, DFS, …)
  - FBO (Fixed Based Operator)
  - SASO (Specialized Aviation Service Operator)
- H-NSP
  - Commercial DSP (ARINC, SITA, AVICOM
  - ANSP (AENA, DSNA, DFS....,….)
  - Others

The functional foreseeable entities within AeroMACS of Home Network and Visited network haven't been addressed yet. These concepts are more in line with telecom network, aviation business model and associated roaming contractual concepts. Moreover, the main actors involved are out of the scope of SESAR 15.2.7, even though this has direct impact on AeroMACS integration to the backbone of the network. This issue will be left as FFS.

As previously stated, WMF has depicted the overall architecture that could support AeroMACS ASN [21]. Despite all, this is very generic and there are open issues not addressed in the literature related mainly with the AAA server and the network layer connectivity.

One of the main roles of AAA server is gathering the information of all AeroMACS users. The most foreseeable scenario is one AAA proxy from the airport operator that sends queries and requests to a global database with all the aircrafts hosted remotely.

In the same line, we would find the DHCP server. IP allocation hasn't been addressed yet. We could think on a hypothetical scenario where one single IP is uniquely assigned to one single aircraft., This way, there won't be no extra cost investment on deployment brand new infrastructure elements (such as HA and FA server) since they are not needed. As a drawback, the simplest scenario does not preclude the need to establish contractual arrangements between the ANSP and the H NSP, between the H-NSP and the V-NSP and between the V-NSP and the NAP. Besides, in future deployments, it's likely that AeroMACS might connect to a ground network that is built on IPv4 and nowadays and it's well known the lack of IPv4 addresses.
As previously stated, the support of dynamic IP allocation (DHCP) and therefore the commitment of supporting roaming capabilities for an aircraft arises contractual issues between ANSPs and the addition of new entities to the CSN architecture. In this sense, a Home Agent (HA) SHALL be required in order to store local addresses and a Foreign Agent (FA) SHALL be add to the architecture of the ASN as well. FA stores information of aircrafts visiting the network, gives a local IP to the visiting aircrafts and advertises the so called "care of address" to the HA in order to allow re-enroute AeroMACs datagrams addressed to the MS to the Access Network where it's currently attached.

The redirection of an incoming packet to the home network to the visited network where the aircraft is currently in is done through a tunnel established between HA and FA. The procedures that implies are related to the specification of R5 interface (CSN interconnection) which is actually out of the scope of the project.

MIP suffers from several drawbacks. The main concern would be the big delay that tunnelling between HA and FA introduces. Only sensitive applications, such as real time ones, would be affected by this.

According to SITA's use cases and deployment scenarios workout presented in the frame of EUROCAE WG-82, HA location could vary in a real scenario from V-NSP to H-NSP and be centralized or decentralized. On the opposite, AAA is expected to act as a proxy only in the V-NSP.

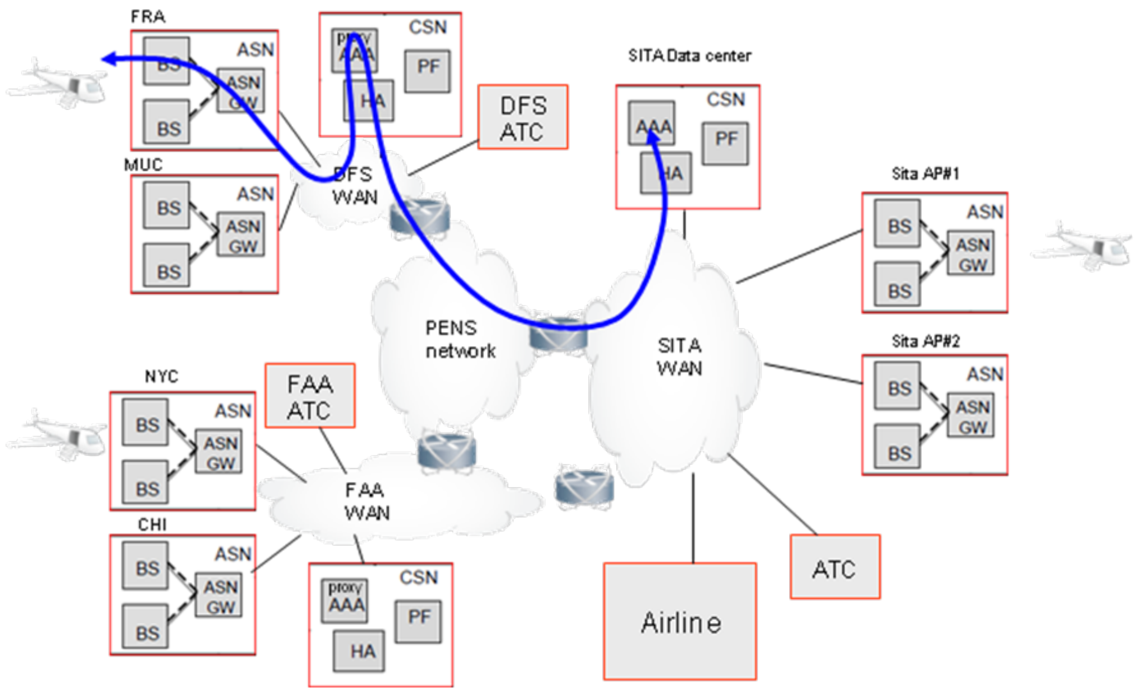


Figure 49: AeroMACS Deployment Scenario

In any case, the issues here prompted, are state as FFS. Most of them are out of the boundaries of AeroMACS specification.

Finally the IP allocation for surface vehicles can be done through a local IP pool in order to give dynamically IPs to them.

4.1.3.1 AeroMACS ASN-GW

According to AeroMACS Network Architecture Reference Model specified in [4], a generic ASN-GW covers the features/functionalities here drawn.

- AeroMACS layer 2 (L2) connectivity with MS.
- Relay functionality for establishing IP connectivity between the MS and the CSN.
- Network discovery and selection of the AeroMACS subscriber's preferred NSP. Manual or automatic selection is left as an open issue.
    - NAP discovery. This procedure will give means to the MS, after scanning and decoding the "operator ID" element for DL_MAP, to select which BS of a particular operator to connect. Such approach should be avoided in order to limit interference on other systems (e.g. Global star) and ensure a more efficient use of the spectrum.
    - NSP discovery. This item is mandatory in the profile. The MS will dynamically discover all NSPs in the airport during the Network entry procedure. In order to accomplish that, the MS will be listening to the broadcast message with the NSP IDs sent by the BSs (SII-ADV MAC message advertisement). Previously it SHOULD have a list of NSPs loaded in its configuration.

- IP address allocation for the A/Cs. Relay functionality for establishing layer 3 (L3) connectivity with a MS. Thus, querying the DHCP server for network establishment and DHCP DISCOVER messages forwarding. This issue is left FFS.
- IP forwarding to the backhaul is guaranteed by means of the ASN-GW. In case of supporting, IPv6, the ASN-GW SHALL implement an AR (Access Router) functionality. Nevertheless, for most likely AeroMACS scenarios there's no need for ASN-GW to implement a specific routing module.
- MIP. ASN-GW SHALL act as a MIP foreign agent.
- Connection Admission Control support to ensure service quality and different grades of service commitment and provision.
- Authentication and authorization. AAA proxy/client. The CSN of the home NSP SHALL distribute the subscriber's profile to the NAP directly or via the visited NSP. As a direct consequence, AeroMACS ASN-GW SHALL trigger the exchange of susceptible subscriber information and transfer AAA messages of AeroMACS subscriber's Visited NSP for authentication, authorization and accounting to the Home NSP. Nevertheless, this is related to AeroMACS business model and therefore FFS.
- Context management. Transfer of device, user and service credentials (it can store user's profiles or just cache them). Consequently, key distribution between entities.
- User profile management. After the authorization phase and key exchange the user profile is handled in order to create corresponding SFs.
- CID mapping for control messages.
- GRE tunnelling SHALL be set to the BSs. ASN-GW creates one data path per SF. Every SF has each different GRE key value.
- Data Path establishment and Service Flow Authorization (SFA)
- Mobility management and control for HOs.
- Accounting relay.
- Authentication relay.

  Some of the most commonly functions that can be found on a COTS ASN-GW have no applicability for AeroMACS. These, are listed below:
- Radio Resource Management (RRM) is left optional and therefore opened to specific implementations in the future.
- No paging needed as stated in the profile [5].
- No load balancing policy.
- No Multicast/Broadcast Control Module.
- Location registration. This is left opened to AeroMACS deployments and future implementations.

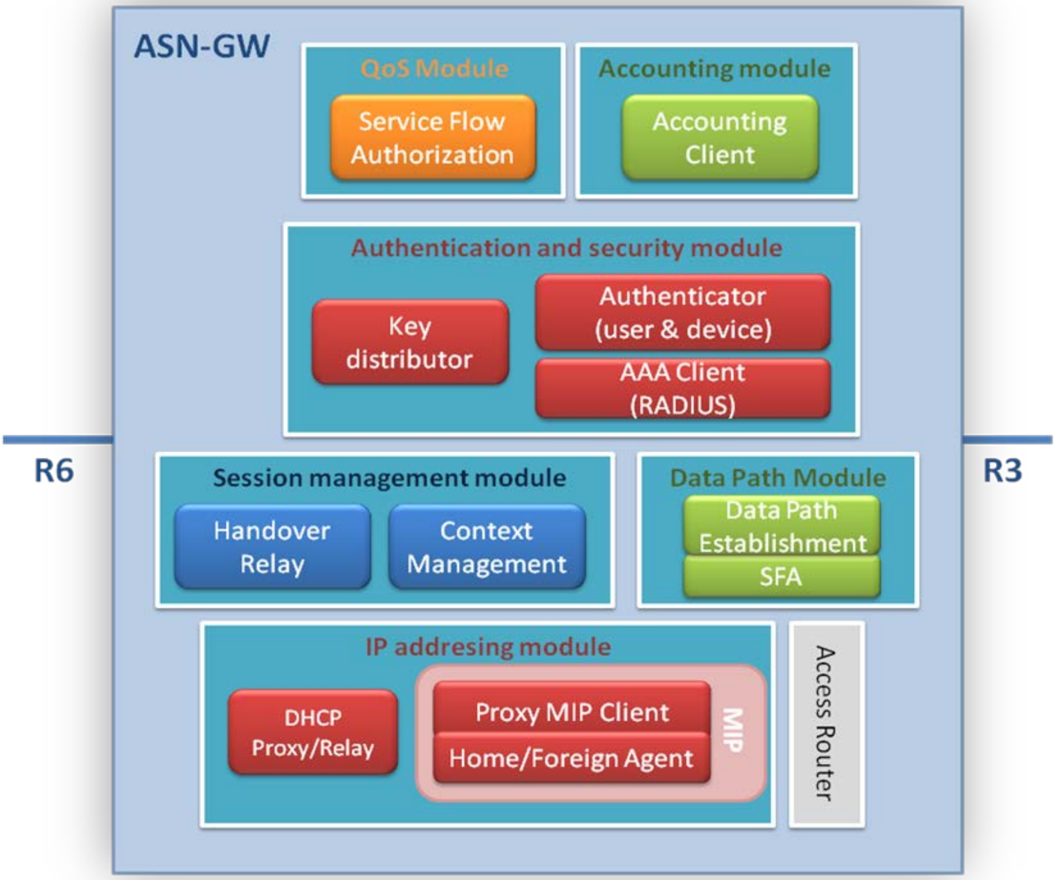


Figure 50: Main Functionalities of AeroMACS ASN-GW

As depicted, main interfaces for the ASN-GW are R6 which connects it to the BSs and R3 which deals with the interconnection to the CSN.

Finally it's likely foreseen the deployment of just one ASN-GW per airport.

4.1.3.2 AeroMACS Core Integration

Several guidelines have been drawn on the previous sections in order to address the interconnection of AeroMACS ASN to the IP backbone network that relies behind. In addition to this, it has been presented the main actor that undertakes this interconnection (ASN-GW) and its major functionalities.

On the other hand, there's still one issue to address which is how incoming IP packets to AeroMACS from the backbone are managed. Despite, one way to achieve this has been already pointed out on the capacity analysis 3.7.2.3. IP packets coming from ATS applications SHALL make use of the IP header field "Type of Service" (DSCP byte in IPv4 or Traffic Class in IPv6).

Either ASN-GW or the Access Router SHALL not drop IP packets with a ToS field distinct from zero. In contrast they SHALL be queued in case of congestion and accordingly to the different priorities gathered in RFC 4594. This entity will then read the field and map it to a user profile and hence with a GRE tunnel and a SF to convey the packet to the MS.

Within the work carried out in WA8, a generic architecture for integrating AeroMACS to the core infrastructure was presented. Hence a foreseeablee overall core integration is depicted underneath:

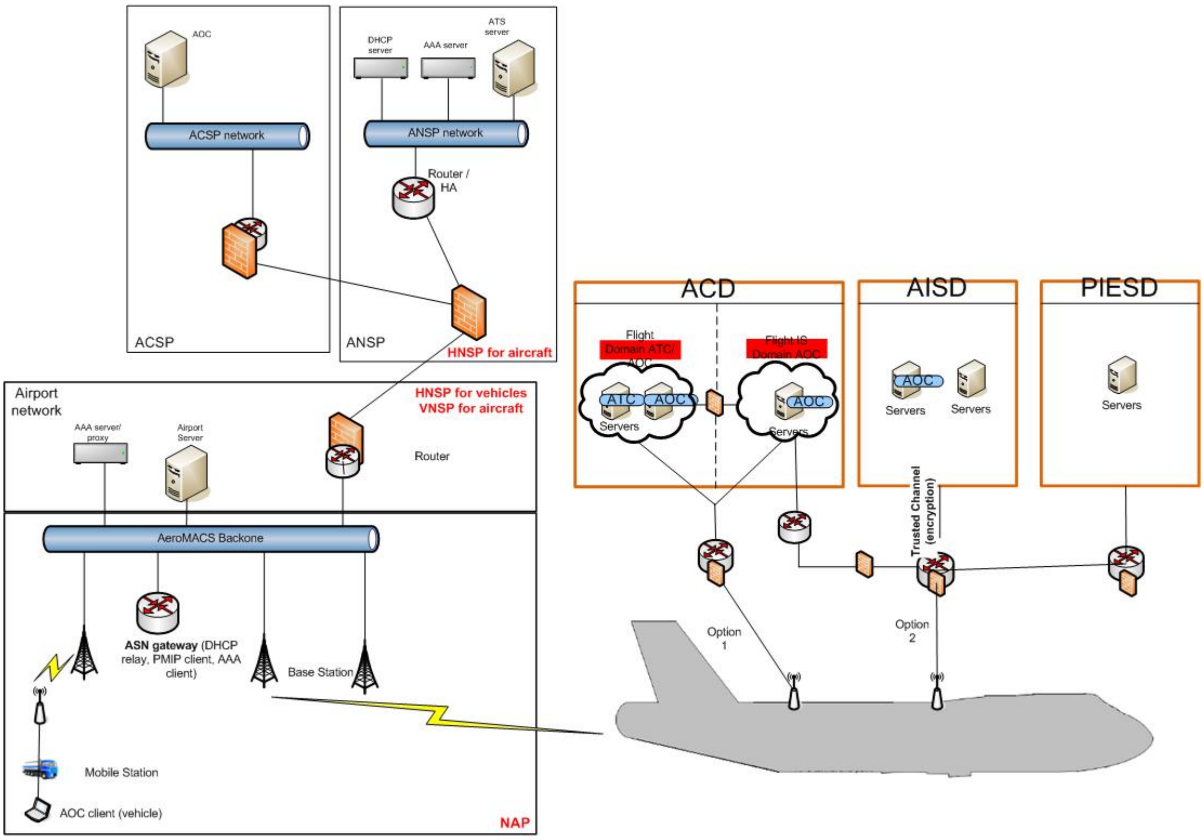


Figure 51: AeroMACS Core Integration Use Cases

The first half of the picture depicts the network connection of AeroMACS ASN to the ground network infrastructure of the airport. Main actors are the ASN-GW, the AAA server and DHCP server.

IP address assignment will be done after the MS has performed full network entry. The IP address allocated to a MS may be public or private, and may either be a point-of-attachment IP address or an inner-tunnel IP address, according to WMF specification [21]. As addressed in the picture, a tunnel between ASN-GW to the ANSP HA SHALL be required.

For the basic-connectivity IP service, the IP address is assigned by the CSN. In the picture, this is performed in the ANSP infrastructure. For IP services accessible over an inner-tunnel, the network that terminates the tunnel allocates the IP addresses.

AeroMACS security has been previously addressed within a specific project activity (WA8) and is being currently addressed with other partners and stakeholders of the avionic world. In this sense, there's a security framework proposed by RTCA working group SC-223.

An AAA server in the topology can act as a AAA proxy if the user that proceeds with registration belongs to a different domain, in a roaming context, since the two servers are placed in different entities.

By default, the IETF RADIUS protocol is assumed to be supported as the main protocol for AAA purposes. This is an application level protocol, client/server specifically. Therefore, MS should support and implement a client RADIUS. In the meanwhile, BSs are transparent.

PKMv2 will relay on the fact of whether in AeroMACS user/device authentication is needed. For the time being it's stated that only user authentication is mandatory. Terminal on board of the aircraft won't require to be authenticated. In consequence, the use of RSA is dismissed. According to what was stated in WA8, EAP-TLS framework is the most suitable suite to give support to user authentication.

Besides, basic and primary connections, which carry management messages, do not cipher, nor authenticate messages. Transport connections can be handled independently and be assigned security associations (SA). SA associates key material and connection, i.e. every CID is mapped to a SAID if it supports security. Every MS must be able to support at least 2 transport SAs according to WiMAX. SAID is updated in the MS by the target BS during handover.

Every MS establishes a primary SA with the BS. The rest of SAs are static as they are provisioned by the BS. If a pair BS/MS has no authorization policy, there is no related SA.

From the Access Service Network side, the ASN-GW acts as the extreme of the authentication communication flow. Thus is to say, the ASN-GW plays the role of the AeroMACS authenticator if it is actually the user data base. In the case it isn't, it works as a relay, as an AAA client that forwards queries to the AAA server or the user data base.

As previously said ASN-GW makes use of RADIUS protocol to support EAP for either user authentication or service authorization. AAA server is also in charge of checking the QoS policy for a given MS and consequently creating a Service Flow Authorization (SFA) as a response to a service flow initiation request from the MS.

Overall, AAA servers will depend on the core network of the airport operator. Data bases could belong to the Access Service Network of each airport; they could belong to the same virtual segment of network as AeroMACS or in worst case, be held remotely in other facility of the operator and therefore in other network. There could be another foreseeable special case, where the connection to the remote AAA server was set through the public internet. In such case, special attention must be paid in order to not compromise the security. IPsec support for the transport of all connections is envisaged. Moreover, the use of VPN tunnelling is encouraged to secure all the connections to the remote elements of the backbone of the network.

4.1.3.2.1 Roaming

Roaming is the capability of wireless networks via which a wireless subscriber obtains network services using a "visited network" operator's coverage area. At the most basic level, roaming typically requires the ability to reuse authentication credentials provided/provisioned by the home operator in the visited network, successful user/MS authentication by the home operator, and a mechanism for billing reconciliation and optionally access to services available over the Internet services.

In a roaming scenario, thus is an aircraft landing on an airport which is not its home airport, the local AAA server can act as an AAA proxy when the network entry process of AeroMACS is triggered.

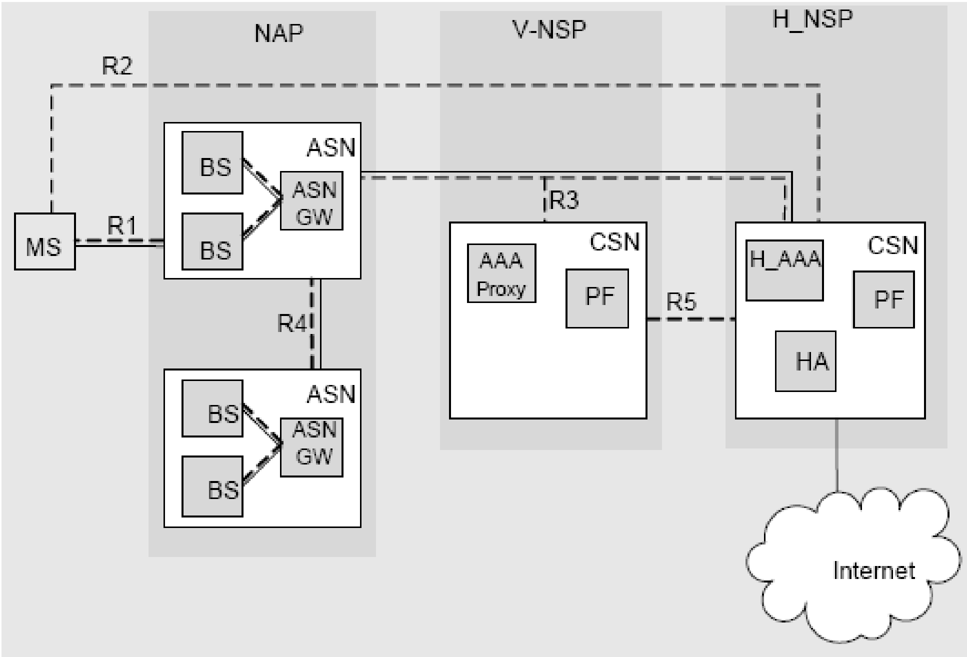


Figure 52: AeroMACS roaming architecture

An AeroMACS roaming subscriber aircraft will request access to a visited NAP when landing on a different airport from its home one. A visited NSP may have roaming contractual relationship with the subscriber's home NSP. Therefore, the visited NSP SHALL provide AAA traffic routing to the home AAA server with means to guarantee the confidentiality and safety of the procedure.

This architecture SHALL not preclude roaming between NSPs. The architecture SHOULD allow a single NAP to serve multiple MSs using different private and public IP domains owned by different NSPs.

The second scenario foreseeable is the use of one single AAA server shared by all the NAPs and out of the H-NSPs. As a consequence, no roaming scenario will occur, whereas the risk of failure and the probability of not completing the network entry and the creation of the data path increase.

This has been covered within WA8, security analysis [22].

IP connectivity establishment comes afterwards. Each AeroMACS MS SHOULD own a univocal IP address or get dynamically one. Thus, one scenario will consider one DHCP server reachable from different NAPs and the other would be a Mobile IP scenario with new entities as part of the architecture such as the HA and the FA. In any case, the ASN-GW will play the role of a proxy/relay forwarding queries to the NSP side.

The case where v-NSP operates the HA and application data will go through v-NSP instead of H-NSP is shown in 4.1.4.4

Finally, to sum up, the issues previously stated are far from the scope of 15.2.7 but have impact on the successful consecution of a hypothetical AeroMACS deployment. Most of these issues are FFS.

4.1.4 Deployment models

The Wimax Forum has identified various service provision models (see [30]).

The following ones are deemed relevant for aviation purposes and should be supported by ground and airborne implementation.

Further analysis should be performed to identity precise use cases applicable to aviation taking into account the different entities which could be involved in the network service provision to support ATC, AOC and surface operation services and potential technical limitations.

4.1.4.1 NAP sharing by multiple NSP

This deployment model should be preferred by NSP and NAP in order to rationalize infrastructure, ease cell planning at a given airport, and minimize interference on legacy systems (e.g. Global Star) with probably less Base Stations due to a more efficient use of the spectrum.

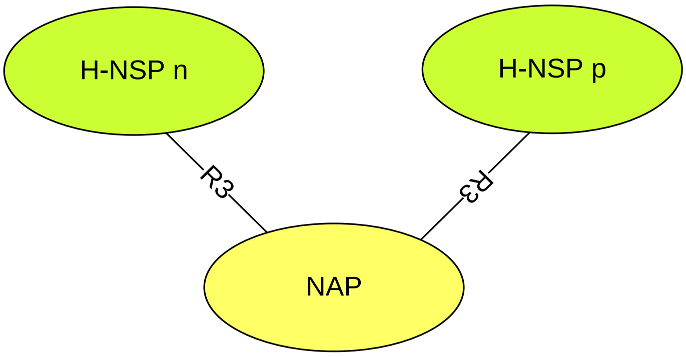


Figure 53: Single NAP - Multiple NSP

Several ASNs might be connected to a single CSN and vice-versa i.e., several CSNs might share the same ASN. The most common deployment that there'll be is one single ASN within the airport and multiple operators (CSNs) connected. Hence, this is the most likely business scenario that could be spotted for AeroMACS.

Airport telecom operator deploys and provides services to ARINC, SITA, NAVICOM, etc. playing the role of H-NSP who manages the relationship with airports on behalf of the airlines. Some airlines could have contractual agreements to H-NSP and other airlines could keep contracts with other H-NSP.

In this scenario, ASN-GW will advertise for incoming new MSs on the Access Network that there are different NSPs (see requisite R-ARC-ASN-12), enabling the MS to establish data communication to its NSPs through AeroMACS ASN and leading them to reach final airline operator.

4.1.4.2 Single NSP Providing Access through Multiple NAPs

This deployment model should be foreseen by NSP to extend its coverage at regional scale in relying on local NAP.

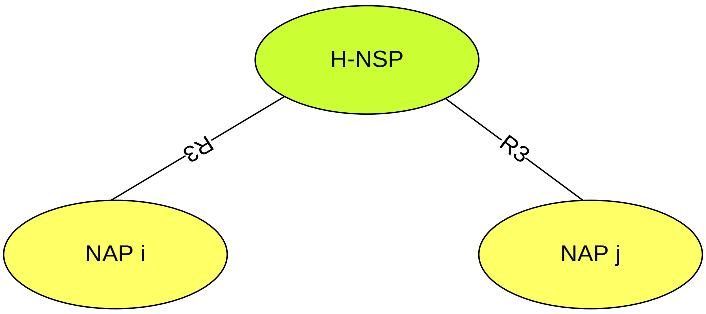


Figure 54: Multiple NAP - Single NSP

This would be a feasible topology in order to give AeroMACS ATS service support and core integration to the backbone. The cost of integration will be set to the minimum due to the NSP is just a single operator and it's isolated to each airport domain. Thus is to say, SITA, ARINC, NAVICOM… could be deploying itself on the airport ground network side acting as the same entity for the NAP and NSP on the business model.

As a hypothesis, all the services would be provided by components inside the airport network managed by a single network/service operator. In consequence, all the sensitive servers needed (mainly AAA and DHCP) would be set and placed locally. Besides, servers to be reached for provisioning data sessions would be found physically within the airport facilities. Therefore, there's no need to enable VPN end to end connectivity, packet forwarding or relay functions. In addition, there won't be time delay constraints on the service provisioning since this model behaves as standalone.

As a drawback of this standalone scenario, the routing tables in the network routers must be updated efficiently to reflect the pathway to reach the mobile node from the backbone network to the Access Network.

4.1.4.3 Greenfield WiMAX NAP+NSP

These deployment models should be foreseen by manufacturers and operator since they let flexibility to NSP to act or not as NAP depending on local issue.

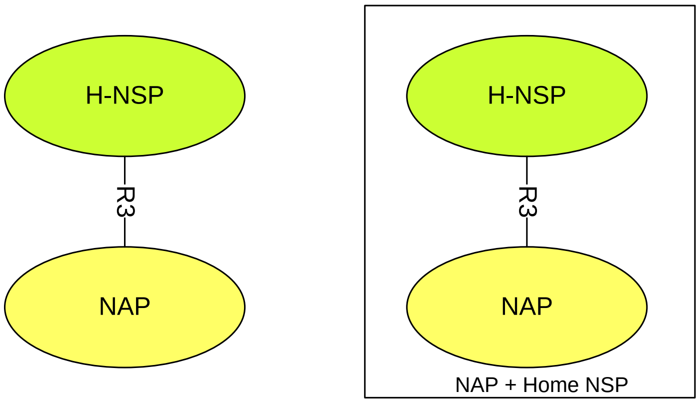


Figure 55: Greenfield NAP-NSP

4.1.4.4 WiMAX Roaming scenarios

The following cases are deemed relevant for aviation purposes;

- Data access via visited NSP: This deployment model should be foreseen by NSP to let the opportunity for the V-NSP to operate the Home Agent.

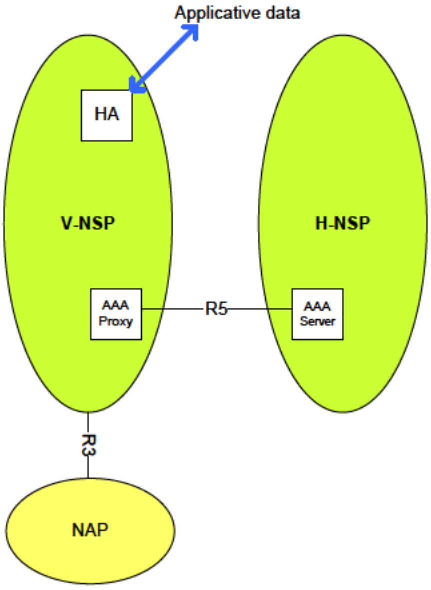


Figure 56: Roaming scenario 1

- Data access via home NSP

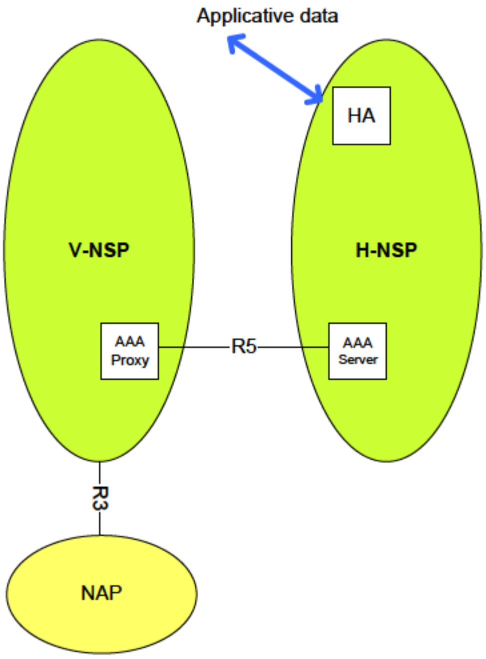


Figure 57: Roaming scenario 2

4.2 Airport Ground Infrastructure

AeroMACS system has to be connected to ATC and AOC network:

1. From a general point of view, ATC airport network is a combination of several LANs dedicated to data (radar, supervision) and voice (VoIP) which are interconnected via one or more redundant routers. ATC airport network is usually interconnected to ANSP national network.

2. AOC network is usually accessible through a CSN.

The next sub-sections provide a general description of the network architecture available at airports included in this working package for trials (e.g. Barajas). The way AeroMACS network shall be integrated within airport network depends on the deployment solution.

4.2.1 Barajas airport network topology

First of all, a general overview of Barajas airport is shown below, in which we can find four terminals; T1, T2, T3, T4 and one satellite terminal; T4S. In order to have and overall idea of Barajas airport dimensions, distances between terminals are included. The most relevant control buildings are also shown; Airport Operation Control Centre, West and North Control Towers located at Terminal 4 and Satellite Terminal 4, and also the South Tower located at Terminal 2.

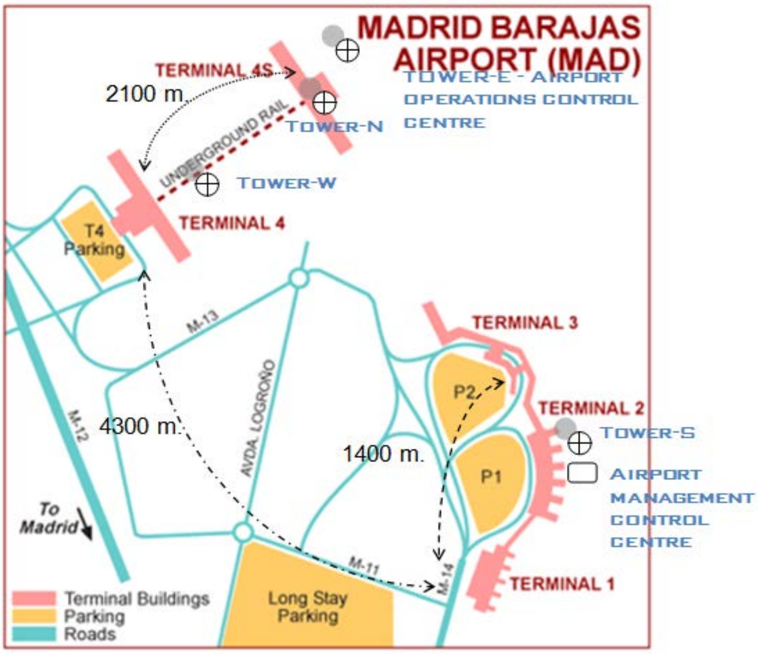


Figure 58: Barajas terminal map overview

The next paragraphs describe a general overview of the networks deployed at Barajas airport which could provide the necessary means for the integration of AeroMACS network. Although this subsection is focused only on Barajas airport, general guidelines are listed. Nevertheless, each deployment will need a particular study for the integration solution.

- <u>Multiservice Airport Network (MAN)</u>

The multiservice airport network offers more than 50000 access ports and network access equipment is deployed all over the airport. It is composed of three main nets extending over the terminals (T1-T2-T3, T4 and T4-S) and one more covering the Airport Data Process Centre. All these networks are integrated through a MPLS Core which could manage 40GB. The multiservice airport network supports the connectivity with traditional DSP (e.g. SITA, ARINC ...). The coverage of the MAN has been extended through 802.11 wifi stations deployed at terminals T1-T2-T3 and T4-S and nowadays a Wimax system is being tested in the airport network in order to manage the video signals collected from airport vehicles.

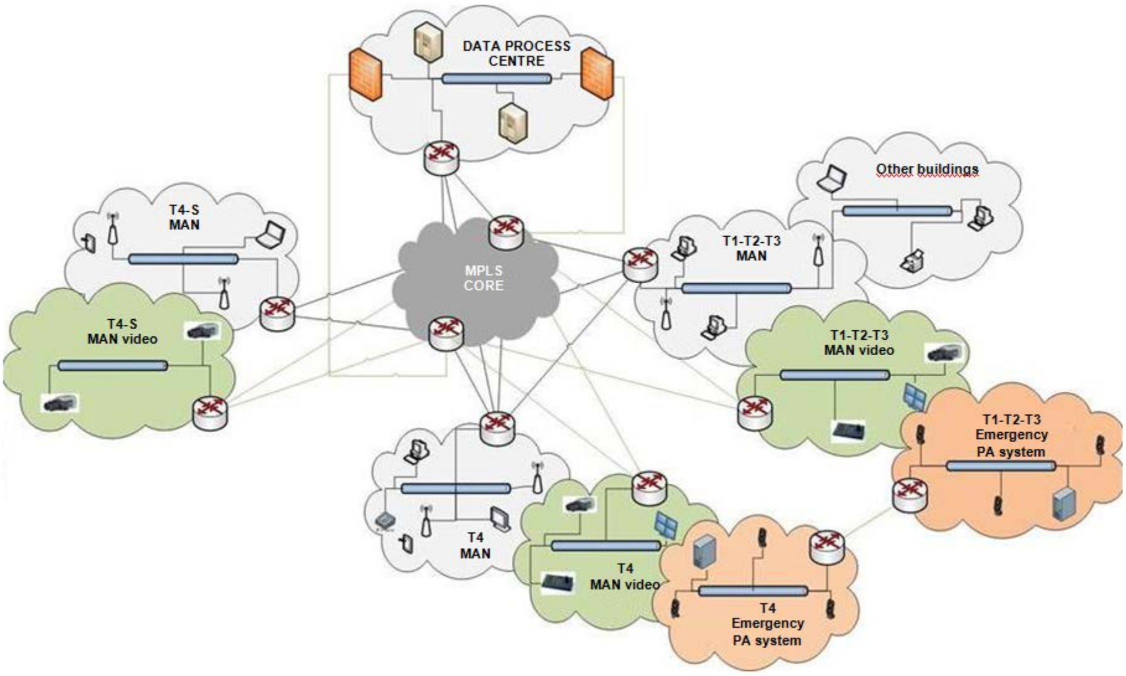


Figure 59: Barajas Multiservice Airport Network Topology

The infrastructure provided by the multiservice airport network supplies logical and physical redundancy (network access equipment duplicated) just in Control Towers and Data Process Centre due to its high relevance. Network access equipment supports the integration of AeroMACS system (ASN-GW, BS …) in accordance with Ethernet Standards supporting data services up to 100Mbps with UTP cabling.

The network access locations are situated mainly near airport terminals, but nevertheless it would be necessary a site survey to confirm the infrastructure available near the BS locations derived from the cell planning. It is assumed that some BSs could be deployed just in airport facilities with network access equipment but in the other hand and especially for BSs deployed near runways it is likely that no equipment is available so it would be necessary to make a study in order to reach the network access equipment through e.g. optical fiber infrastructure situated near the BS location.

- Air Navigation Data Network (ANDN)

Barajas ANDN consists of a primary node located at Tower-N which provides connectivity to all air navigation elements. Secondary nodes, which are connected to the primary one, are located in Tower-S and Tower-N, and outside the airport there is another access point at Aena headquarters (situated few kilometers away from the airport) which could be used during trials. The Air Navigation Data Network supports the connectivity with traditional DSP (e.g. SITA, ARINC ...).

In order to achieve the integration of AeroMACS system in ANDN, apart from the airport infrastructure, there are two main cabling infrastructure deployed at Barajas airport by the Air Navigation Service Provider;

1. The first one is comprised of two optical fiber rings deployed around the four runways which connect the radio navigation aids to the ANDN nodes at Tower-S and Tower-N. Although Tower-W is also connected to the ring through twisted pair and optical fiber cabling. The next figure depicts it;

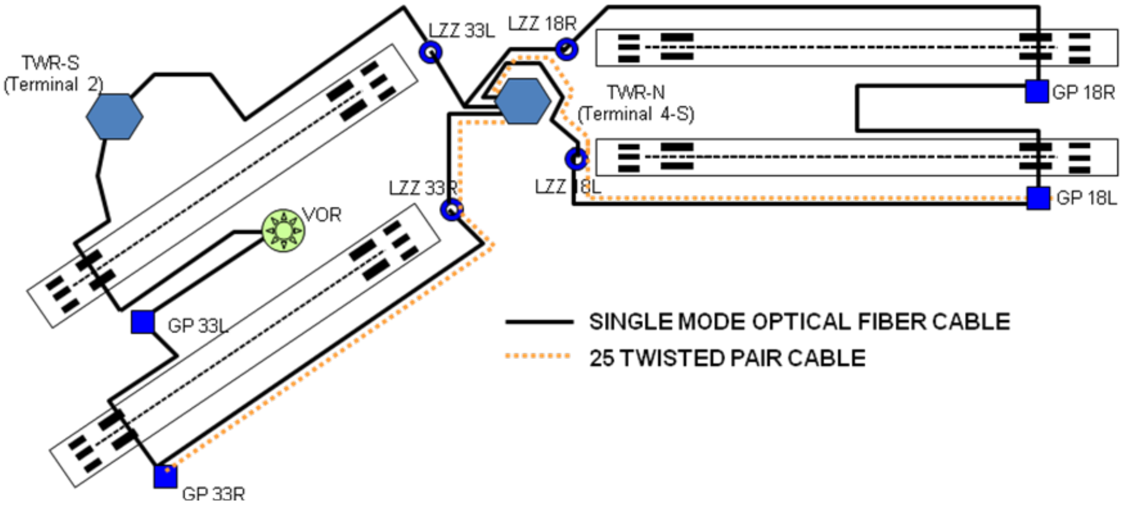


Figure 60: Barajas radio navigation aids cabling infrastructure

Circles and squares represent radio navigation aids locations with infrastructure available (optical fiber or twisted pair cable) to connect BSs to air navigation data network nodes. As we can see in the figure above, the number of sites is limited so in many cases, where the BS is far from this infrastructure access points, it will be necessary to deploy the physical communication means between the BS and the connectivity access point. Once the BS reaches the access point (e.g. GP 18L) it could be integrated in the ANDN (E1, E2 … interface) or it could make use just of the available cabling (e.g. free pairs of optical fiber) or in the last case it could be necessary to install proper physical communication means.

2. The second one consists of four optical fiber rings deployed around the airport for the multilateration system (MLAT). As we can appreciate in the figure below (circles represent MLAT stations), the deployment of MLAT system offers;

   - o High density of sites with infrastructure available to install BSs near terminals (RAMP area).

   - o Medium density of sites with infrastructure available to install BSs near runways (GROUND and TOWER areas).

Due to the high number of MLAT sites deployed, it is likely that BSs could be located in these locations, so it would not be necessary to deploy proper communication means between the BS and the access point to the infrastructure. In the case of MLAT network, AeroMACS system could take advantage just from infrastructure (cabling) and it is not likely that AeroMACS system will be integrated in MLAT network. This point should be discussed during the site survey.

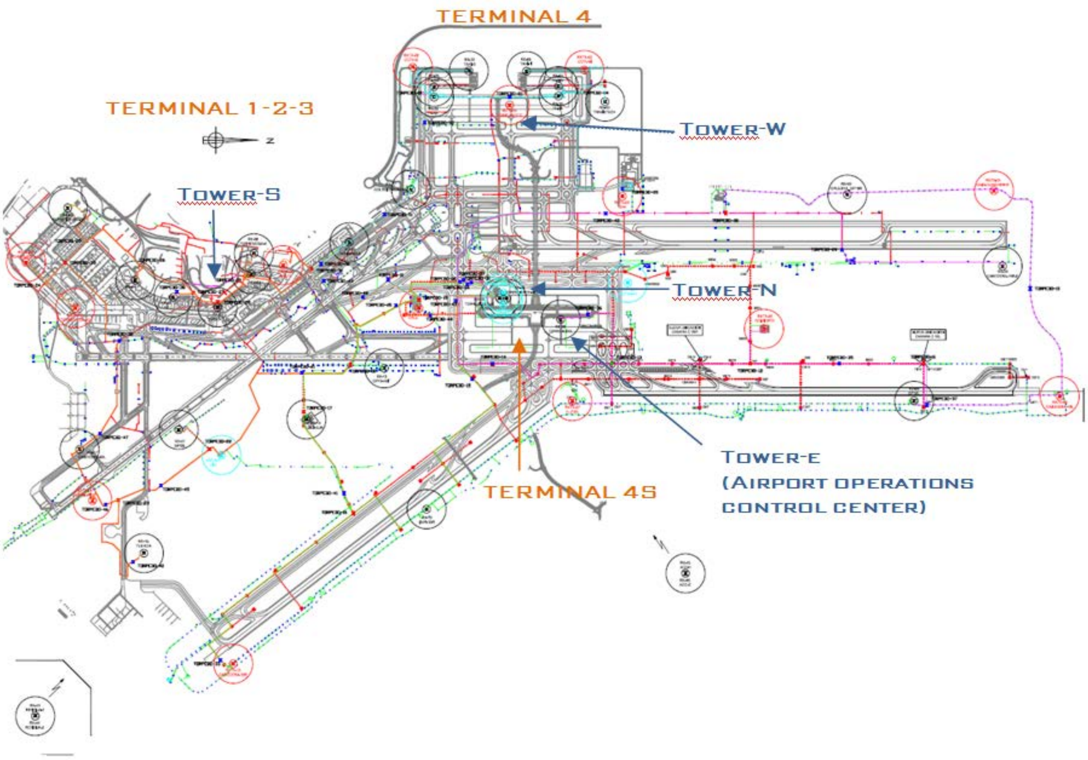


Figure 61: Barajas MLAT system cabling infrastructure

4.2.2 Conclusions

Based on the information showed above, general guidelines can be extracted in order to integrate AeroMACS system in the airport ground infrastructure;

1. Clear definition of AeroMACS arquitecture and the airport network infrastructure available for the integration of the AeroMACS system (BS, ASN-GW, AAA, DHCP …). This point will depend on the network arquitecture of each airport and the business model.

2. The current infrastructure deployed at the airport should be used as much as possible. Therefore, during the site survey it would be important to take advantage of infrastructure deployed such as MLAT system and define which sites provide cabling infrastructure available and also power supply for the integration of BSs. The same for access points related to the Airport Multiservice Network and the Air Navigation Data Network.

3. Once BS cabling gets into a network access point, three different scenarios could be possible;

   a. Take advantage just from the cabling infrastructure (e.g. free pairs of optical fiber). In this case it could be necessary to deploy switches/converters (e.g. ethernet to fiber converter) at these sites in order to adapt the BS Ethernet interface if necessary.

   b. Integration of BSs which reach the network access point in the network selected. In this case it is necessary to study if the network could support bandwitdth requirements of AeroMACS system. It is likely that only the Airport Multiservice Network could support high bandwidth requirements. For example, optical fiber rings related to radio navigation aids at Barajas (see Figure 60) provide currently E1 interface (2 Mbps).

   c. New installation of cabling infrastructure.

4. ASN-GW could be installed in Control Towers near primary nodes of the selected network with access to AOC Network and PENS in the future.

In conclusion, it seems that the most likely scenario in the short term could be;

- BSs mounting in existing infrastructure if possible, especially taking advantage of systems deployed such as MLAT.
- Use of cabling infrastructure from Air Navigation Data Network if possible.
- BSs integration in Airport Multiservice Network.
- ASN-GW integration in Airport Multiservice Network or Air Navigation Data Network. Both networks can be interconnected taking into consideration security aspects (e.g. firewalls).

In all the cases, the final solution will be compliant with Safety and Performance Requirements and Recommendations described in section 2.2.6 (e.g. redundancy).

4.3 Integration with PENS

4.3.1 PENS Vision

PENS (Pan European Network Service) is a joint EUROCONTROL-ANSPs led initiative to provide a common IP based managed network service across the European region to cover data and G/G voice communications. PENS shall be a cost-effective common infrastructure to support critical aeronautical data information flows between users in a seamless and integrated way.

The objective of PENS is threefold. First of all, it aims to fulfil the needs for inter-ANSP information exchange. Its second focus is to meet existing and future ATM communication requirements. Last and not least, it strives to enable the System-Wide Information Management (SWIM) developed in the context of the SESAR programme, following ICAO standards and SES Regulations.

Reference [32] has been the main source of information to write this section. Note that "shall" sentences refered to PENS have not been numbered as these statements are requirements for PENS not for AeroMACS.

4.3.2 PENS Current Situation

Current PENS solution is a result of a common procurement process between ANSPs and Eurocontrol for deployment of an initial Pan-European managed IP-based network to provide G/G communications services to the following users:

- CFMU
- EAD
- ANSPs (AMHS, FMTP, Surveillance data)

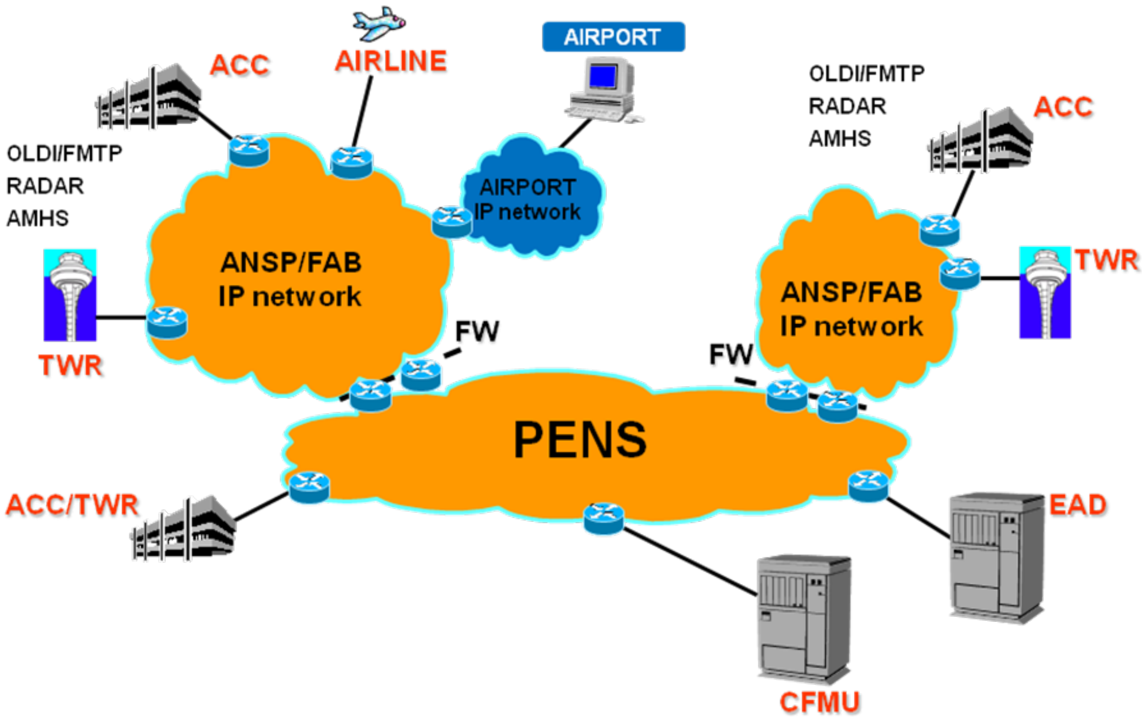


Figure 62: Current situation of PENS

From the strategic point of view it would be important to facilitate the access to new PENS Users, taking into account that presently the process to become a PENS User, it would need some changes. PENS future evolution is further explained.

4.3.2.1 Technical Aspects

PENS is based on an integrated concept and it leads to a relative cost-efficient solution for the operation of planned infrastructures.

PENS in the future will be the physical backbone of SWIM infrastructure and will offer the opportunity to use a common network environment for all ATM services: ATC, Airport applications, surveillance, navigation and communication.

PENS will be the fundamental technical enabler for SESAR new concept like data sharing through SWIM and CDM associated processes. Performances of such network is a key issue that needs to be assessed in order to further define the performance allocation to the various network elements.

PENS evolution will inherit the characteristic of a standard network, made by standard devices and standard protocols, and as such the quality of services (QoS) evaluated by measuring key parameters such as bandwidth, latency, jitter, packet loss etc.These key parameters must be continually monitored for performance end-to-end measures.
These requirements and parameters will be processed in service level agreement (SLA) with the Telecom providers.

Generally Voice and Data services shall be separated, either physically or logically, but the path such data do follow must be deterministic or identifiable at any time. In the same idea, Radio and Telephone data flows shall be separated, either physically or logically. A separation of Safety-critical / Business-critical / Non-critical applications shall be implemented, either physically or logically. Possibility to segregate or modularize customers segments shall be possible (in case of unbundling or reorganizations).Such segregation or separation shall prevent any contamination or intrusion between domains or application or customers.

PENS shall provide a reliable network with the necessary means to for contingency, disaster recovery and emergency situations.

Last but not least, PENS shall be SESAR compliant and IP standard compliant and should not be based on a proprietary technology (requirements could be put at "should" instead of "shall").

Basic Protocols and Interfaces

PENS shall support IPv4 and IPv6 (Unicast and Multicast).
PENS shall support MPLS protocol and allow to create VLAN with QoS.
PENS shall provide Layer 3 Routing for IPv4 and IPv6.
PENS shall support IPsec.

Interoperability

PENS shall be able to interconnect to other networks via gateway facilities (including security elements) supporting both IPv4 and IPv6. Border Gateway Protocol Version 4+ (BGP4+) and static/default routing shall be supported by the PENS entry point in order to properly route traffic between and/or within FABs. Data and Voice networks shall be separated logically (e.g. VLAN technology) or physically.

Class of Service (CoS) and Quality of Service (QoS)

PENS shall offer priorization (traffic shaping, scheduling, congestion avoidance) mechanism. PENS infrastructure and chosen technologies **shall** provide a CoS schema (end-to-end classification: CoS, TOS, Diffserv) that suits the needs of all expected applications.

PENS shall provide smooth delivery of voice and data packets to the end systems. To support this, voice and data traffic are expected to be prioritized differently on the network, to accommodate the extra sensitivity of voice traffic to latency and because voice is a continuous streaming that should not be interrupted. In addition, factors such as jitter and packet loss can affect the quality of communication services, and need to be handled by the PENS infrastructure.
These and other issues are to be addressed by the following requirements:

- Classification: PENS shall provide methods of categorizing traffic into different classes, also called Class of Service (CoS), and applying QoS parameters to those classes.
- PENS shall be able to reapply CoS and QoS parameters to the packets sourced by different systems in the network, in order to ensure the proper functionality.
- Prioritization: PENS shall provide methods of prioritizing traffic based on Class of Service.
- PENS shall be compliant with the following criteria to fulfill IP-Service communication needs: max. Latency, max. Jitter, max. Packet Loss Rate, max. Network Convergence and max. Recovery Time of Service of different applications.

Availability

Availability depends on the overall system architecture and usage of redundancy and backup-features and last resorts/emergency systems. These and other issues are to be addressed by the following requirements:

- PENS shall achieve the required availability of the different applications.
- The strongest requirement for Availability is: **99.99999%**

Security, Safety and Protection Mechanisms

It is needed that Safety and Security standards of the new infrastructure has to be compliant without any ambiguity to ones already defined, accepted and adopted by ANSPs.
In the future one of most important problems to be developed will be a security policy compatible with the most critical and demanding ATM services over PENS.
The primary requirement for security in PENS is to prevent unlawful interference with the provision of services, as widely depicted in Security Policy documentation. This assumes that Security protection is never perfect, and so, on basis of regulation 2096/2005, requires that security management systems make provision to detect security breaches, restore operation, and mitigate root causes.

4.3.3 PENS Future Evolution

PENS was initially thought to deliver services within areas including countries belonging to Eurocontrol and, in general, to EU countries; nature of these services is purely operational (ATS), therefore the originally expected users are only service providers of ATM environment (ANSP).
Nevertheless, in the last times, tendency is being changed and now is being aimed to extend PENS infrastructures to other users that, even if they are in certain way interconnected with ATM, they are not strictly involved in interchange of operational data: as reference, Air Companies, Aerodrome Societies, Military Organizations, and so on.

4.3.3.1 Identification of potential PENS Users

General principles that apply to the PENS Evolution are:

- PENS will provide connectivity to ANSPs users among them for all existing and forthcoming ATM services (FMTP, surveillance, AMHS, VoIP, datalink, …).
- PENS will provide connectivity to ANSPs users with European centralized applications (CFMU, EAD) and other forthcoming ones.

- PENS must be the SWIM backbone infrastructure, supporting all SESAR development. Future PENS shall be able to provide end-to-end services for future SESAR developments.
- Privacy of FABs and of ANSP's must be guaranteed. However, some ANSPs trusted zones might be created, depending on the future needs, however they shall be interconnected to external communities via gateways.
- Airlines IP Network will be connected directly to PENS Network using appropriate security measures for implementation of CDM concept. That is to say, the connectivity between ANSPs/Eurocontrol users with airline ones will be achieved by performing an interconnection of networks.
- Possibility to connect Airports IP Networks directly to PENS Network or through local connections with ANSP/FAB IP Networks using appropriate security measures for implementation of CDM concept.
- Military IP Network has to be connected to PENS Network directly or through local connections with ANSP/FAB IP Networks using appropriate security measures for implementation of CDM concept.
- PENS will be able to provide communications to the premises belonging to an ANSP (ANSPs that decide to outsource ATM communications).
- Other commercial oriented Aeronautical Applications (EGNOS, GALILEO, SATCOM, …) could be connected directly to PENS Network.
- PENS shall be able to interconnect non-European regions (EXPANSION of PENS), especially our European neighbours. Coordination with ICAO.
- Potential connectivity with industry for remote maintenance.
- It is desirable that Pan-European Communications Services could be provided by a Certified ATC Communications Service Provider. This would facilitate the operation of PENS since ANSPs would not be mandated to perform the Conformity Declaration.

Taking into account the general principles identified in this section as potential PENS users, the envisaged PENS evolution is depicted in the following figure:

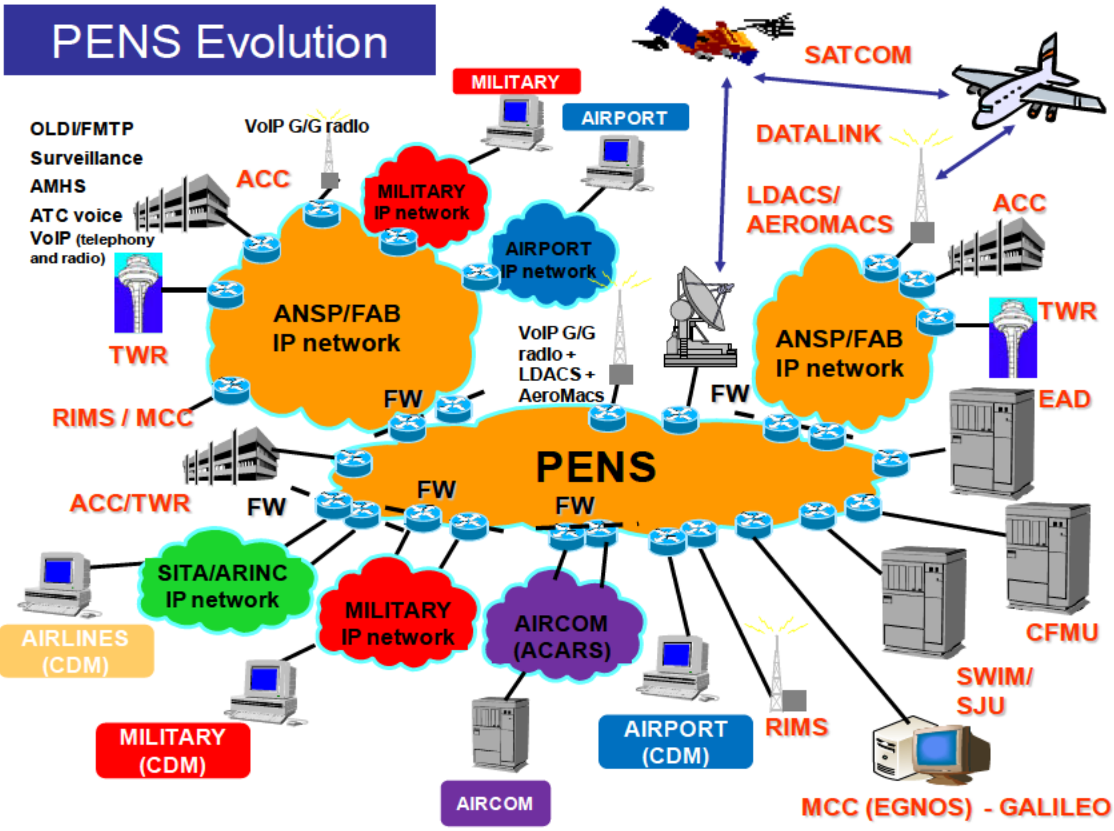


Figure 63: Vision for PENS evolution

VoIP technology will be another important service that will be available in next future over PENS, this service based upon standards developed by EUROCAE WG-67 will be verified in the PENS environment framework during SESAR activities. To achieve the desired level of performance for ATM VoIP communications, the QoS, which is a major issue in VOIP implementations, has to be addressed.

4.3.3.2 Access Infrastructure Requirements

PENS access infrastructure shall be comprised of all the network components between PENS user networks and the core VAN nodes.

PENS shall provide a Core VAN infrastructure, that allows to carry all the data flows and volumes that PENS users may require with the performances targets.

PENS shall be capable to cope with the estimated growth on a per site as well as on an overall basis.

The upgrade path for future growth shall be clearly described and will be with minimal impact for the PENS users.

The design proposed for PENS shall offer a fully resilient and redundant solution without any single point of failure between any particular main and remote site, with dual, diversified tail links. “Fully redundant solution” shall mean physically, geographically/topographic and logical separate paths.

The circuits shall be engineered and implemented providing a maximum of physical and geographical diversification (e.g. separate cables, power supply, ducts, etc.).

The connectivity requirements for PENS sites to the PENS core Infrastructure shall be provided via dual, redundant links. The main link and backup link for a remote site shall be fully diversified.

The SLA targets shall be applicable on main and backup links, regardless of the access technology chosen.

COS requirements shall be satisfied on main and backup links regardless of the access technology chosen.

Bandwidth requirements for PENS sites vary between 64 Kb to 4 Mb for remote sites and ANSP BB sites, and 2 Mb to 120 Mb for CFMU main sites, EAD main sites and OP centers.

PENS shall commit to adapt the bandwidth in relation with the evolution of the PENS traffic while keeping performances targets unaffected.

4.3.3.3 AeroMACS Connectivity Requirements

As we can see in Figure 62, in current PENS situation the Airport IP network where AeroMACS belongs to is connected to the ANSP/FAB IP network. This ANSP/FAB backbone already enforces some requirements to PENS. In this context, the ANSP/FAB backbone shall be able to accommodate AeroMACS requirements to be supported within PENS and if it is not able, the ANSP/FAB backbone shall impose new requirements to PENS or modify the existing ones.

According to PENS evolution description in Figure 63, Airports IP Networks could be directly connected to PENS Network. In this case, PENS shall guarantee the following AeroMACS requirements:

- An availability figure for service provision of .9995.
- An availability figure for service use of .999.
- A continuity figure for service use of .999.
- An integrity figure for service use of 10-5.
- An end-to-end downlink data latency < 20 ms.
- An end-to-end uplink data latency < 40 ms.
- Data Rate: depends on each airport.
- QoS: at least two different traffic segregated pipes shall be granted in order to handle properly specific ATC and NET services.

The following table, extracted from [3], provides an overview of the theoretical data throughput capacity for a single cell or sector which AeroMACS could provide for different modulations schemes.

Channel bandwidth: 5 MHz																	
Mod & coding rate	Data carriers	Symbol Period [us]	bits per symbol	Coding rate	Data symbols used per frame	OFDM symbols per frame	Achievable Data rate [Mb/s]		Mod & coding rate	Data carriers	Symbol Period [us]	bits per symbol	Coding rate	Data symbols used per frame	OFDM symbols per frame	Achievable Data rate [Mb/s]	
64QAM 5/6	360	102,9	6	5/6	25	48	9,1	Downlink	64QAM 5/6	272	102,9	6	5/6	12	48	3,3	Uplink
64QAM 3/4	360	102,9	6	3/4	25	48	8,2	Downlink	64QAM 3/4	272	102,9	6	3/4	12	48	3,0	Uplink
64QAM 2/3	360	102,9	6	2/3	25	48	7,3	Downlink	64QAM 2/3	272	102,9	6	2/3	12	48	2,6	Uplink
64QAM 1/2	360	102,9	6	1/2	25	48	5,5	Downlink	64QAM 1/2	272	102,9	6	1/2	12	48	2,0	Uplink
16QAM 3/4	360	102,9	4	3/4	25	48	5,5	Downlink	16QAM 3/4	272	102,9	4	3/4	12	48	2,0	Uplink
16QAM 1/2	360	102,9	4	1/2	25	48	3,6	Downlink	16QAM 1/2	272	102,9	4	1/2	12	48	1,3	Uplink
QPSK 3/4	360	102,9	2	3/4	25	48	2,7	Downlink	QPSK 3/4	272	102,9	2	3/4	12	48	1,0	Uplink
QPSK 1/2	360	102,9	2	1/2	25	48	1,8	Downlink	QPSK 1/2	272	102,9	2	1/2	12	48	0,7	Uplink

Table 87: Theoretical AeroMACS Downlink and Uplink raw data throughputs

In section 3.5.2 different types of airports are described and a rough number of BS is given. However this number is highly dependent on the many factors and it is difficult to provide exact figures. For instance, in Barajas 28 sector will be deployed for a full coverage, which amount to a sum of 229 Mbps, for a 64QAM 3/4 modulation scheme. However, it is expected that just ATC traffic could be shared and distributed over PENS whereas most AOC traffic would remain local to the airport. So a deeper analysis should be carried out individually in a real deployment environment. In any case, PENS shall provide the technical means to accommodate the traffic.

4.4 Multi-vendor Interoperability

The network reference model aimed to support AeroMACS access network and its interconnection to the backbone has been previously depicted on section 4.1.3.

Sticking to profile C of Wimax Architecture, AeroMACS BSs interoperability SHALL be guaranteed through R6 interface.

Beforehand, we'd like to highlight and remark something that is stated on WMF IOT documentation [29]:
"The term BS shall be interpreted as a logical unit consisting of BS, ASN-GW functionality and AAA server functionality. The reasons are missing standardization and conformance tests of the interfaces between these network elements".

In other words, WMF only focus on R1 interface to guarantee interoperability. Infrastructure interoperability has been left over for the moment. Therefore R6 is not likely to be on the frame of WMF certification engagement. Having said this, it can be found on AeroMACS FAD [4] the following statement:

The architecture SHOULD support interoperability between equipment from different manufacturers within an ASN and across ASNs. Such interoperability SHALL include:

- BS and backhaul equipment within an ASN.

R-INT-VIOT-01. The architecture SHALL support common functionalities according to what is currently stated down below as requirements between BSs and between BS and ASN-GW from different manufacturers.

As noted, these are not addressed issues and for the time being they're not going to be addressed.

The BS SHALL offer an interoperable interface with an ASN-GW. Besides, all interfaces to core equipment SHALL be performed through R3 interface (as stated on section 4.1.3). Protocols and procedures for R3 as well as R6 are drawn in [31].

As mandated on this WiMAX Forum document, GRE SHALL be used as the tunneling protocol for the data plane over R6. GRE is an IP-in-IP tunnel. The granularity of this tunnel SHALL be one tunnel per SF. It's important to get straight with the granularity issue in order to solve out interoperability. This is left to implementation. In this case, all control resides in the ASN-GW.

Packet forwarding in the downlink:

ASN-GW has to map incoming traffic from the backbone to a corresponding data path. The protocol has a KEY option that should be applied for provisioning Data Path ID of the tunnel. When a packet destined for an MS arrives, it looks at the IPv4/IPv6 packet header and/or flow ID to determine the service flow ID (SFID) that this packet needs to be mapped on to. The SFID maps to a data path ID. The ASN-GW uses the GRE key associated with the data path ID to forward the IP packet via the GRE tunnel to the BS. IP packets are extracted in the BS out of the GRE packet and forwarded over R1 to the MS.

Packet forwarding in the uplink:

The way back is equivalent to the one described previously. IP datagrams going upstream over R1 are encapsulated in the BS as user payload in GRE packets and transferred over R6 to the ASN-GW.

GRE is not so much meaningful in terms of security because all of R6 bearer message can be attracted without any protection due to GRE protocol but rather is used to differentiate each SF between ASN-GW and BS using a unique GRE key value. Every SF has each different GRE key value. This should be the main concern when validating multivendor interoperability, BS implementation of GRE protocol.

One advantage of GRE encapsulation is that it allows multiple IP hops to be encapsulated without any need for routing. All packets are decapsulated at ASN-GW and layer-2 communication is established between CPE and ASN-GW.

Another issue is that there's no backward compatibility for R6 messages. There should be an agreement in advance between vendors regarding the WMF release (1.0, 1.2, 1.5 and 2.0) that should implement the equipment.

Main concerns and focus shall be paid to a set of the whole batch of control messages and procedures on R6 in order to support interoperability [30]:

On the BS side:

R-INT-VIOT-02. AeroMACS BS SHALL support Data path registration ***type1***

Data_Path info IE*:*

Data Path Encapsulation Type: ***GRE***

Data Path ID: ***GRE Key***

Data Path Type: ***type 1***

Operation ID IE*:* ***Data Path registration***

R-INT-VIOT-03. AeroMACS BS SHALL support Data path deregistration for triggering MS network exit.

Operation ID IE*:* ***Data Path De-registration***

R-INT-VIOT-04. AeroMACS BS SHALL support HO preparation

Trigger source IE*:* ***16e function entity*** *(RRC and NRM dismissed)*

HO optimization IE: ***enabled or disabled?*** It's a flag that may skip some phases of network re entry during HO process. i.e SBC REQ/RSP, REG REQ/RSP PKM-TEK. In case of enabling it, it's important to define what phases we are willing to skip.

R-INT-VIOT-05. AeroMACS BS SHALL support HO action.

R-INT-VIOT-06. AeroMACS BS SHALL support HO cancellation.

R-INT-VIOT-07. AeroMACS BS SHALL support HO rejection.

R-INT-VIOT-08. AeroMACS BS SHALL perform Authentication Relay.

BS SHALL forward EAP messages over R6 to the ASN-GW Authenticator with the ASN control data plane protocol.

R-INT-VIOT-09. AeroMACS BS SHALL support AK transfer primitives and key reception.

R-INT-VIOT-10. AeroMACS BS SHALL support NSP id list.

R-INT-VIOT-11. AeroMACS BS SHALL implement the Context functionality.

On the ASN-GW side:

R-INT-VIOT-12. AeroMACS ASN-GW SHALL perform Authentication and key distribution

ASN-GW SHALL forward EAP messages over R3 to the AAA server with the RADIUS protocol

R-INT-VIOT-13. AeroMACS ASN-GW SHALL support Network Entry signalling

R-INT-VIOT-14. AeroMACS ASN-GW SHALL support Proxy MIPv4 Client

R-INT-VIOT-15. AeroMACS ASN-GW SHALL support MIP registration revocation

R-INT-VIOT-16. AeroMACS ASN-GW SHALL support DHCPv4 Proxy/Relay

R-INT-VIOT-17. AeroMACS ASN-GW SHALL support Service Flow Authorization.

Policies are pulled from external AAA. Therefore AeroMACS ASN-GW SHALL implement an AAA client.

R-INT-VIOT-18. AeroMACS ASN-GW SHALL support Data path registration ***type1***.

R-INT-VIOT-19. AeroMACS ASN-GW SHALL support Data path deregistration for triggering MS network exit.

R-INT-VIOT-20. AeroMACS ASN-GW SHALL support HO preparation.

SBC context IE in case the field HO_optimization is enabled. Thus no new capabilities are negotiated with the target BS and the ASN-GW has to forward the ones of the serving BS.

AK context retrieval to the target BS.

R-INT-VIOT-21. AeroMACS ASN-GW SHALL support HO action.

R-INT-VIOT-22. AeroMACS ASN-GW SHALL support HO cancellation.

R-INT-VIOT-23. AeroMACS ASN-GW SHALL support HO rejection.

R-INT-VIOT-24. AeroMACS ASN-GW SHALL support Context transfer.

This is related to the notification to the ASN-GW of security policy that is foreseeable to be used by the MS entering the network.

R-INT-VIOT-25. AeroMACS ASN-GW SHALL support CMAC key count update.

AeroMACS ASN-GW SHOULD support MIPv6 Access Router

Upon successful completion of Authentication, the Authenticator (in our case the AAA server) sets the count for the MS to 1.

4.5 Open issues

The following issues, which detailed analysis is out of scope of P15.2.7, shall be addressed to deploy AeroMACS system serving both ATC, AOC/AAC and surface operation purposes:

Deployment models applicable to aviation: this is a main driver to specify and implement the End-to-End communication infrastructure.

Logon procedure: notably the rules to advertise NAP and NSP identifiers and the NAP and NSP selection rules for the airborne system will have to be addressed.

Certificate Authorities and Hierarchy: the way credentials are delivered should be addressed.

IP address assignment: static or dynamic IP address assignment can be considered. And the detailed specification shall be developed for both Aircraft and vehicles.

Mobile IP: Mobile IP can be implemented through different approach (e.g. PMIP, CMIP). This shall be specified in order to guarantee Air/Ground interoperability.

ATC security needs vs AOC security needs: Authorisation to use NAP and NSP network for AOC purposes shall be granted according to Airlines AOC contract. While ATC services shall be provided to all aircraft independently from their AOC contract. Contractual arrangements for AOC purposes (or absence of contract) shall not preclude any aircraft from using any NAP and NSP to get ATC services. The technical details to address this issue should be addressed.

AAA node: WMF mentions Radius or Diameter as system to perform AAA functions. Radius is addressed extensively in the WMF documentation. Further analysis is needed.

In order for the NAP and NSP to be different entities, R3 reference point standardization should be further considered

In order to implement WIMAX roaming, R5 reference point standardization should be further considered.

5 References

[1] EUROCONTROL COCR v2.0, “Communications Operating Concept and Requirements for the Future Radio System”

[2] Deliverable T1.1A “System Analysis For AeroMACS Use”

[3] Deliverable T1.1B “AeroMACS System Requeriments Document”

[4] Deliverable T1.4 “AeroMACS Functional Architecture Definition v1.0”

[5] Deliverable T3.1-T3.3: D3.2 “AeroMACS Profile Definition v00.01.00”

[6] Deliverable T2.6 “AeroMACS Traffic Modelling”

[7] Deliverable T2.1 “AeroMACS Channel Modelling”

[8] Deliverable D2.3 “Compatibility_FSS_AeroMACS”

[9] Deliverable D3.1 “AeroMACS profile validation v0.2.0”

[10] EUROCAE ED78A, “Guidelines for approval of the provision and use of air traffic services supported by data communications”

[11] ICAO 9896 “Manual for the ATN using IPS Standards and Protocols”

[12] ICAO Annex 14 “Aerodromes”, Fourth Edition July 2004

[13] ICAO “Aerodrome Design Manual” Part 6 Frangibility, First Edition 2006

[14] ICAO “Airport Planning Manual” Part 1 Master Planning, Second Edition 1987

[15] ICAO “EUR Frequency Management Manual” EUR Doc 11, Edition 2010

[16] “Procedimiento Interno para Tramitación y Coordinación de Informes por Servidumbres Aeronaúticas” AENA, 2010

[17] “C-Band Airport Surface Communications System Standards and Development” Phase II Final Report, Volume 1: Concepts of Use, Initial System Requirements, Architecture, and AeroMACS Design Considerations, NASA, 2011

[18] SJU 15.2.7 D01-T1.5, Spectrum investigations, Ed. 1.0.

[19] IRIG 106, DOCUMENT 106-11 PART I: TELEMETRY STANDARDS, (APRIL 2011)

[20] ITU, 2nd Session of the Conference Preparatory Meeting (CPM) for WRC-12, 12-25 February 2011.

[21] WMF-T32-002-R010v04-Stage2 “Network Architecture: Architecture tenets, Reference Model and Reference Points”

[22] WMF-T33-001-R010v05-Stage3_”Network Architecture: Detailed Protocols and Procedures”

[23] WMF-T33-003-R010v4-Stage3 “R6 R8 ASN Anchored Mobility Scenarios”

[24] SESAR 15.2.7. WA8 “Security Analysis and Network topology”

[25] SANDRA_R6.2.2: Report on Modeling and Performance Simulations (in work).

[26] ICAO “Aerodrome Design Manual” Part 1 Runways, Third Edition 2006

[27] AOC Datalink Dimensioning Executive Summary, SESAR.

[28] ICAO PANS-OPS 8168

[29] NWG-T25-003-R010v07-IOT, “Mobile interoperability test”

[30] WMF-T32-002-R010v04-Stage2 “Network Architecture: Architecture tenets, Reference Model and Reference Points”

[31] WMF-T33-001-R010v05-Stage3_”Network Architecture: Detailed Protocols and Procedures”

[32] PENS Evolution Concept, version 0.4, 2011

[33] SANDRA Project, http://www.sandra.aero

[34] SANDRA WP6.2.3 Technical Document on PHY Layer Performance V0.2, 23/09/2010, Draft

[35] SANDRA Project, DLR, “PHY_Results_v4.xls”

[36] SANDRA Project, DLR, Set_Of_Parameters_rev9_selex.xls

[37] SANDRA WP6.2.4 “Discussion paper on MAC simulations”, September 2011

[38] WA3 IEEE802.16e/aero Profile evaluation and validation. Preliminary plan

[39] WiMAX Forum Application Working Group “The WiMAX Forum System Level Simulator NS-2”, Release 2.6, March 2009.

[40] RFC 791 – “Internet Protocol” (September 1981)

[41] IEEE802.16-2009, “Part 16: Air Interface for Broadband Wireless Access Systems”

[42] WiMAX Forum Mobile System Profile Specification: Release 1.5 Common Part WMF-T23-001-R015v01, (2009-08-03)

[43] Draft deliverables version I of joint Eurocae/RTCA working group WG78/SC214.

[44] Draft deliverable V0R13 of P15.2.7 WA08 on safety.

[45] AOC Datalink dimensioning study, Edition 01.00.00, Ed date Nov 16th, 2010.

[46] Leonardo 2nd Workshop, "Common terminology", EC DG-TREN Transport Programme, June 2004

Appendix A Case studies

A.0 PREAMBLE: Radio Planning Tool and Parameters

HTZ is a commercial tool, based on ICS Telecom tool, and dedicated to military application. It brings few additive functionalities dealing with jammers and interference stations.

Environmental Models

HTZ is a deterministic tool taking into account the real environment cartography, the **Digital Elevation Model**, whenever all details are available.

The choice of the cartography to use depends on the type of WiMAX radio-planning to perform:

- Large scale WiMAX networks would require Medium Resolution cartography
- Close range WiMAX network analysis would require High resolution cartography.

The DEM is a digital terrain model describing ground heights and a buildings elevation model combined. It describes the maximum or canopy height at any point on the ground. It is described generally by a matrix of points in the x and y or Eastings and Northings directions with the axes aligned to a chosen coordinates system. The matrix has a given resolution. For planning mobile systems and for microwave systems where every path will be surveyed a resolution giving a height point every 50 metres is usable. For PMP networks at 5 GHz, we need to achieve a resolution of nearer 5 meters to position nodes and subscribers more precisely.

In the z direction we need to specify a height. Given a Fresnel zone radius of 2.7 meters it would seem excessive if we had a resolution of 10 centimeters and provided that we have captured the maximum height at any point within the 1 meter matrix, a 1 meter z resolution is adequate. Of critical importance is the degree of error in positioning the matrix in the x and y directions and in specifying the height at each point. This error is a function of the way in which the data has been captured and processed to yield the DEM. Most high resolutions are developed from aerial survey either using downward looking radar or laser or the interpretation of stereo photographs. The methods are really beyond the scope of a brief presentation but the key issue is simply this. However produced, the planning engineer must have a specification of the DEM showing both resolution and error.

For the two airports considered within SESAR 15.2.7 WP WA4, we considered high resolution data, with the following:

- DTM (Digital Terrain Model) + clutters for Toulouse'map
- DEM (Digital Elevation Model) for Barajas' map (buildings merged with ground)
- Resolution: 5m

Propagation models

The global propagation model is a combination of the following models:

- Free space: ITU-R P.525 model
- Diffraction geometry: Deygout 94 method
- Sub-path attenuation: Standard model
- Reflection coefficient: clutter dependant

Parameters considered for simulations

<u>General 802.16e parameters</u>

- Signal TDD 5MHz
- PUSC segmentation 8

Note: Reflection is considered in the simulations if clutter data are available.

Base Stations & Mobile stations

- General radio parameters found in section 2.1.4 Table 2 and Table 3.
  Cable and implementation losses, Noise Factors, sub-channelization gain, …
- Sensitivity at receiver (from Table 1 – AeroMACS Receiver Sensitivity):
  QPSK ½ (-92.4 dBm) for coverage threshold in DL
- Sensitivity at transmitter: QPSK ½ (-96dBm), for Rx threshold in UL
- Specific parameters for coverage analysis:
  BS sectorized antenna 15dBi : 110° Azimuth ; 7° Elevation, Downtilt = 4.5°
  BS antenna height above ground = 38m
  MS omnidirectionnal dipole antenna 6dBi
  MS antenna height above ground = 10m (for A/C) and 2m (for vehicules)
- Specific parameters for interference simulations
  RAMP Stations: Req (C/N)+I = 14dB (UL) and 15dB (DL)
  GROUND & TOWER Stations: Req (C/N)+I = 5dB (UL) and 4.5dB (DL)

Antenna diagram for BS:

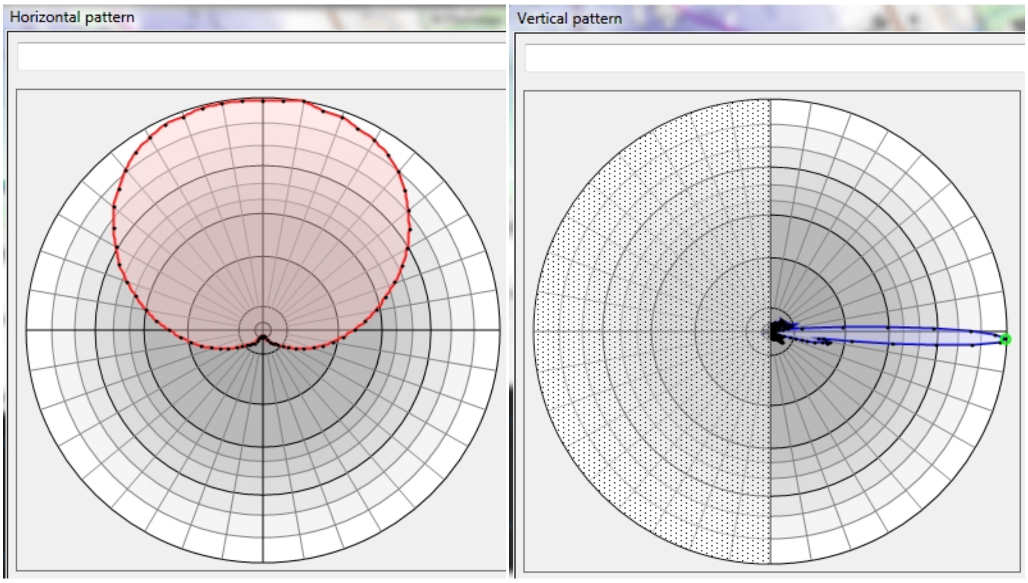


Figure 64: Horizontal and Vertical pattern for Base Stations
(H: 3dB beamwidth = 110°; V: 3dB beamwidth = 12° (tbc))

A.1 Case study 1: AeroMACS Deployment at Barajas Airport

This appendix deals with the special case of AeroMACS deployment in the airport of Madrid Barajas as a specific example that can serve as a guideline. While many generic results and statistics shown in 3.7.1 and 3.7.2.3 have been extracted by modelling scenarios in this airport (to have a real base for results), the specific cell planning proposed for the airport surface is shown in this section.

First, a review is done on the BS site features and limitations applicable to Barajas. Second, cells are distributed in line with the capacity needs in the respective operational domains. Then, it is verified that the coverage from all the BS sites is acceptable in terms of received signal quality in the whole airport surface.

Madrid Barajas is a large airport with four runways placed in two far dual parallel configurations (North-South axis 36L/18R 36R/18L – Northwest-Southeast axis 15L/33R 15R/33L). The estimated air traffic operating on the surface at a given moment is 50 A/C. Terminal layouts comprise the usual configurations for busy airports (linear and circular), plus a linear satellite terminal (T4S). Few transport areas are present in the surface.

Terminal zones are mixed with taxiing and runway zones in a complex manner leaving the two runway domains separated. Due to this, GND/TWR domain has been covered separately for the North and South taxi and runway zones. In both domains, BS have been planned to cover the airport surface, while RAMP has been planned taking into account the placement of the served aircrafts close to the terminal when doing turn-around. The central axe, together with the taxiing between Terminal 4 and Terminal 4S can be covered with the RAMP sectors.

Care has been taken to place the BS respecting the distances from runway and taxiways specified in [12], while no BS has been placed to point to terminal roofs in order to avoid reflections towards Globalstar. Antennas are 120º sectorized, in order to provide enough sectorization gain but avoid losses due to blocking small apertures.

No MLS system operates in the airport.

			Decimal values		Hex values		Sectors			
			Latitude	*Longitude*	Latitude	Longitude	Sectors	s1	s2	s3
RAMP	BS1	R1	*40,476480*	*-3,572308*	**40° 28' 35.33"**	**-3° 34' 20.31"**	2	0°	120°	240°
	BS2	R2	*40,466718*	*-3,569294*	**40° 28' 0.18"**	**-3° 34' 9.46"**	2	0°	120°	240°
	BS3	R3	*40,455423*	*-3,577383*	**40º 27' 19.5228"**	**-3º 34' 38.5788"**	2	0°	120°	240°
	BS4	R4	*40,492297*	*-3,590215*	**40º 29' 32.2692"**	**-3º 35' 24.774"**	2	0°	120°	240°
	BS5	R5	*40,48609*	*-3,591489*	**40º 29' 9.9234"**	**-3º 35' 29.3604"**	2	0°	120°	240°
	BS6	R6	*40,491917*	*-3,569112*	**40º 29' 30.9012"**	**-3º 34' 8.8032"**	3	0°	120°	240°
	BS7	R7	*40,458611*	*-3,563703*	**40º 27' 30.999"**	**-3º 33' 49.3302"**	2	0°	120°	240°
	BS8	R8	*40,496012*	*-3,566917*	**40º 29' 45.6432"**	**-3º 34' 0.9012"**	3	0°	120°	240°
	BS9	R9	*40,462429*	*-3,571356*	**40º 27' 44.7444"**	**-3º 34' 16.8816"**	1	0°	165º	240°
	BS10	R10	*40,497028*	*-3,593169*	**40º 29' 49.3008"**	**-3º 35' 35.4084"**	1	0°	120°	240°
								s1	s2	s3
GND TWR	BS1	G1	*40.486958°*	*- 3.571404°*	**40° 29' 13,05''**	**-3° 34' 17,05''**	3	0°	120°	240°
	BS2	G2		-	**40° 28'**	**-3° 32'**	3	0°	120°	240°

			40.473978°	3.548213°	26,32"	53,57"				
	BS3	G3	40.512807°	- 3.566953°	40° 30' 46.11"	- 3° 34' 1.03"	2	0°	120°	240°

Table 88: BS coordinates proposed for Madrid Barajas planning

gray	1	G1s1, G2s3
green	2	G1s3, G3s2
pink	3	G1s2
red	4	G2s1
black	5	G2,s2, G3s3

white	6	R1s1, R3s3, R8s2
pink 2	7	R1s3, R8s1, R10s3
orange	8	R2s1, R4s1, R7s2
green 2	9	R2s3, R4s3
yellow	10	R3s1, R5s1, R6s3
blue	11	R5s3, R7s1, R8s3
black	12	R6s2
red	13	R6s1, R9s2

Table 89: Frequency re-use planning proposal

Note that the tables above refer to physical and logical frequencies respectively. Among the logical frequencies, 1-5 are frequencies used in GROUND while 6-13 are frequencies used in RAMP. Frequencies 12 and 13 in RAMP are physically the same as frequencies 4 and 5 in GROUND, respectively. They have been re-used since they do not alter the frequency reuse scheme due to enough distance between emitting BS, thus avoiding intra-system interference limitations.

The tables above and the figure below depict the cell planning proposed for Madrid Barajas, which matches the network used to evaluate the AeroMACS Capacity in 3.7.2.3. In the picture, the use of each of the 11 available channels is illustrated per colour. The sector size corresponds to the maximum range attainable considering the pathloss model from WA2 in Barajas [7]. Note that sectors in RAMP have a transmission power of 23 dBm similar to GROUND and TOWER, but sizes of the coverage at 64QAM in the DL and 16QAM in the UL are depicted to illustrate the conformance to the high capacity requirements stated in [1].

It can be observed that a new sector could be activated in the Tower1 BS if the northern runway area is deemed necessary to cover (e.g. for surface vehicle applications). Otherwise, it is estimated that it is not used by aircraft services, and thus inactive in order to minimize interference with Globalstar.

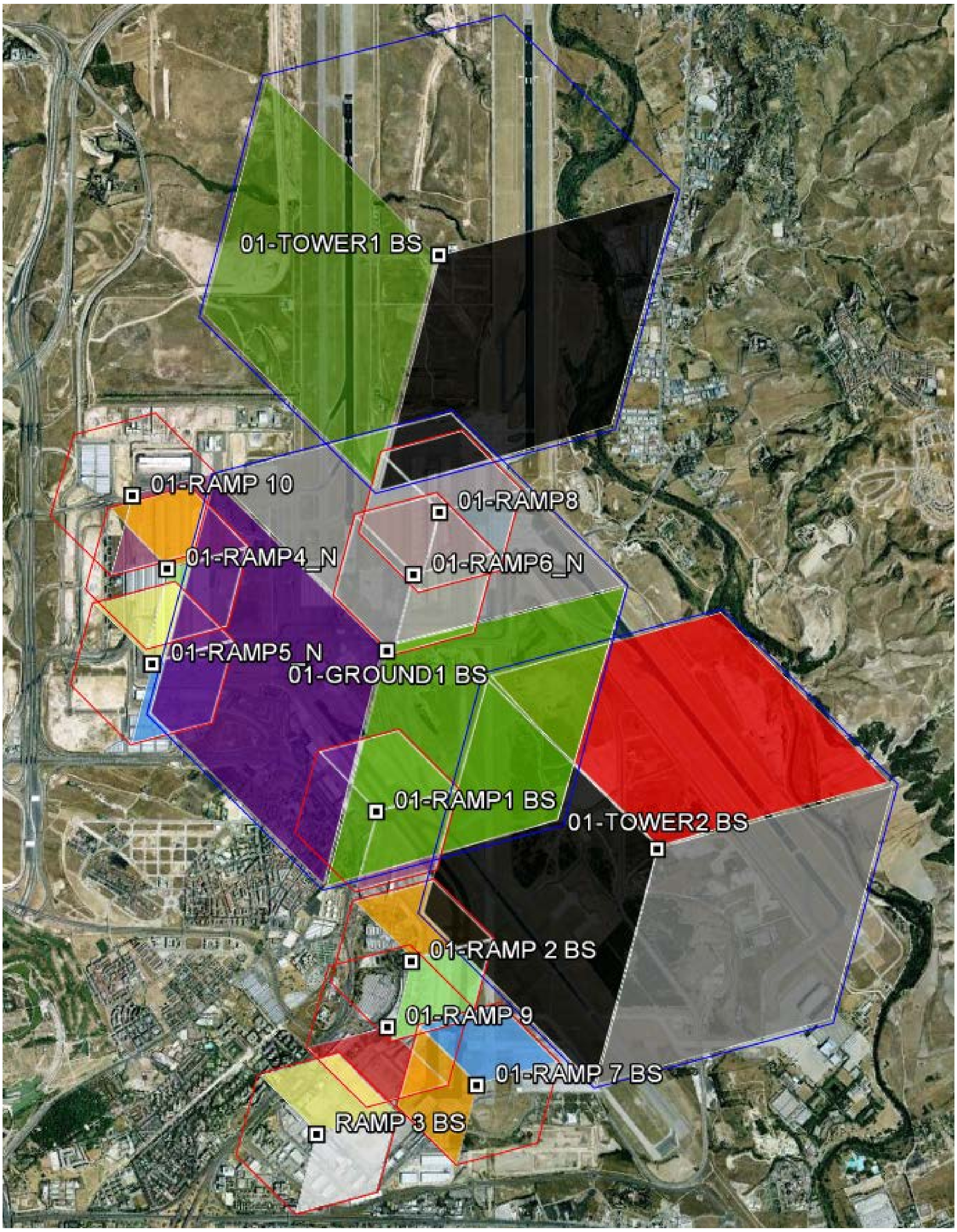


Figure 65: Proposed cell planning in Madrid Barajas

Below the optional cell planning proposed in 3.7.2.3.6.4 for handover optimisation is shown. Note that, in this configuration, the number of sectors remains the same, however the BS's have been moved and a new site exists, in order to increase the signal quality at the cell edge between BS participating in handover processes.

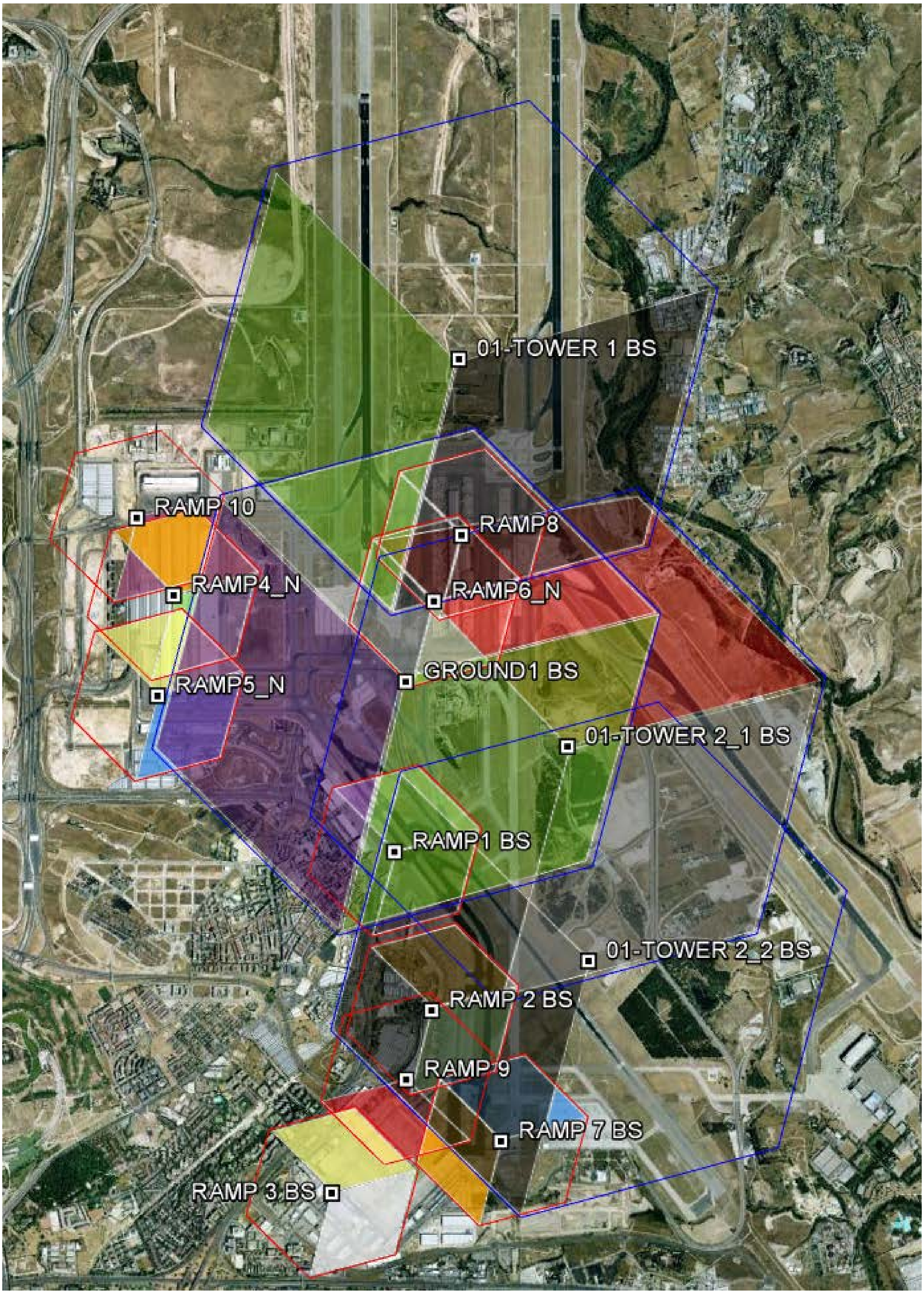


Figure 66: Proposed cell planning in Madrid Barajas – Closer distance between BS in handover

Below the cell planning showing only RAMP cells is depicted. Note that RAMP cell edges show the maximum range using 16QAM so, as it was indicated; RAMP cells in North terminals (T4 and T4S) are enough to cover the taxi ways between them by covering them with QPSK. As it can be seen, the sites to cover RAMP zone have been placed on towers and in the edge of buildings in order to cover the line where aircrafts are likely to stay when performing turn-around.

Figure 67: Proposed cell planning in Madrid Barajas – RAMP only

With the proposed cell planning, the following aspects regarding sector layout and capacity distribution of the AeroMACS deployment can be extracted. The data rate interval has been obtained by multiplying the number of sectors by the possible data rate offered per sector (which yields an interval depending on which modulation scheme is used for the subscriber, QPSK – 64QAM in downlink, QPSK – 16QAM in uplink).

Zone	**# sites**	**# BS (sectors)**	**# channels**	**Data rate per domain**	**Avg BS distance**	**Tx power**
RAMP	10	20	6+2 *	19.6 – 71.9 Mbps (DL) 10.6 – 24.7 Mbps (UL)	810	23 dBm
GND/TWR	3	8	5	7.9 – 28.8 Mbps (DL) 4.3 – 9.9 Mbps (UL)	2650 **	

Table 90: Capacity planning figures in Madrid Barajas

* RAMP uses two channels also used in GND/TWR

** This average distance is reduced if the optional cell planning to optimize handover is deployed

Finally, the coverage of the airport surface considering the proposed cell planning has been verified with a coverage simulation tool. In these simulations, a free space propagation model added to a fading value caused by the reflections on buildings and aircrafts distributed on Barajas surface has been used to calculate the signal level received at every point of the map. DTM maps have been applied together with information on the clutter and the refraction values of the buildings, instead of applying a generic fading model as was done in the tool for Capacity Analyisis. In this case, Free Space propagation mode ITU-R P.525 with Deygout 94 method for diffraction geometry have been applied to obtain the tracing model per point.

A.1.1 Global radio coverage in Barajas airport (DL)

Barajas' airport is taken as an example in order to estimate range and intra-system interference in case of frequency re-use using all the frequency slots available in the AeroMACS band.

The radio coverage is a DL estimation of the maximum range mainly driven by the BS transmitted power, BS antenna gain, MS antenna gain and MS sensitivity. It is driven by hypothesis made on capacity (see section 3.7.2) which led to 28 sectorized BS. Because of limitation of map area available, few BS are not activated in the simulation. Thus 24 BS are activated for coverage analysis, whose names are given in the following Figure. All BS are positioned at 38m height relative to ground.

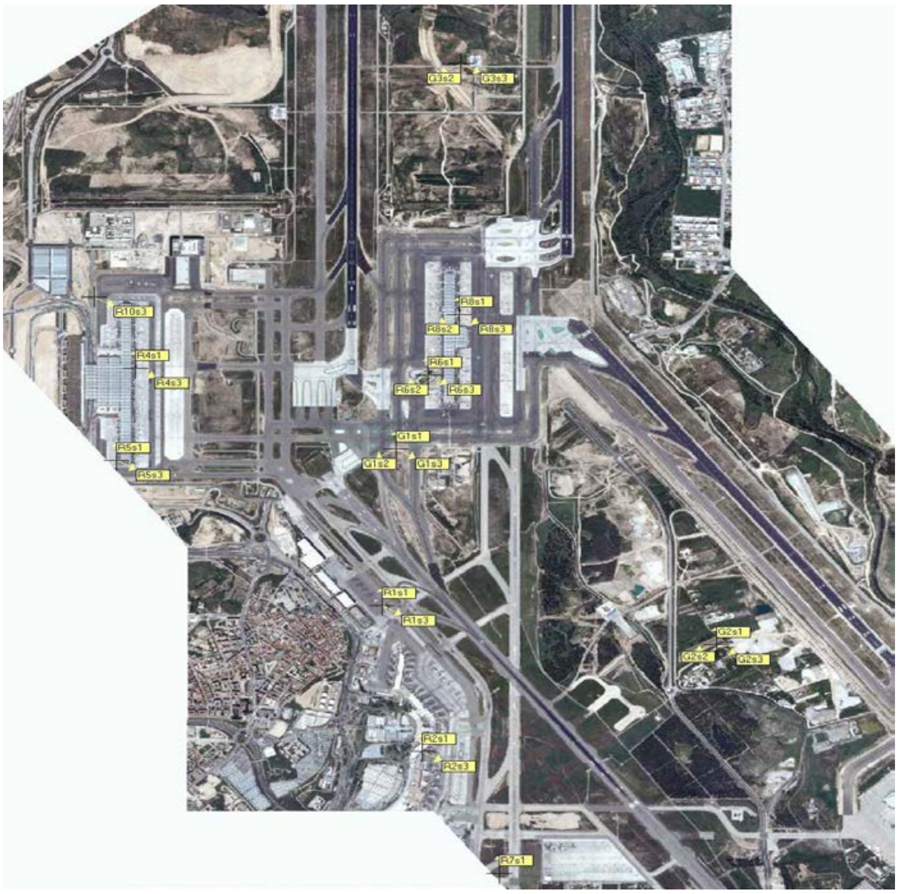


Figure 68: Focus on BS position and label on Barajas' airport

The global DL, in a composite server display, has been computed and its coverage map is given below for two MS types, aircrafts (with Hant = 10m) and vehicules (with Hant=2m).

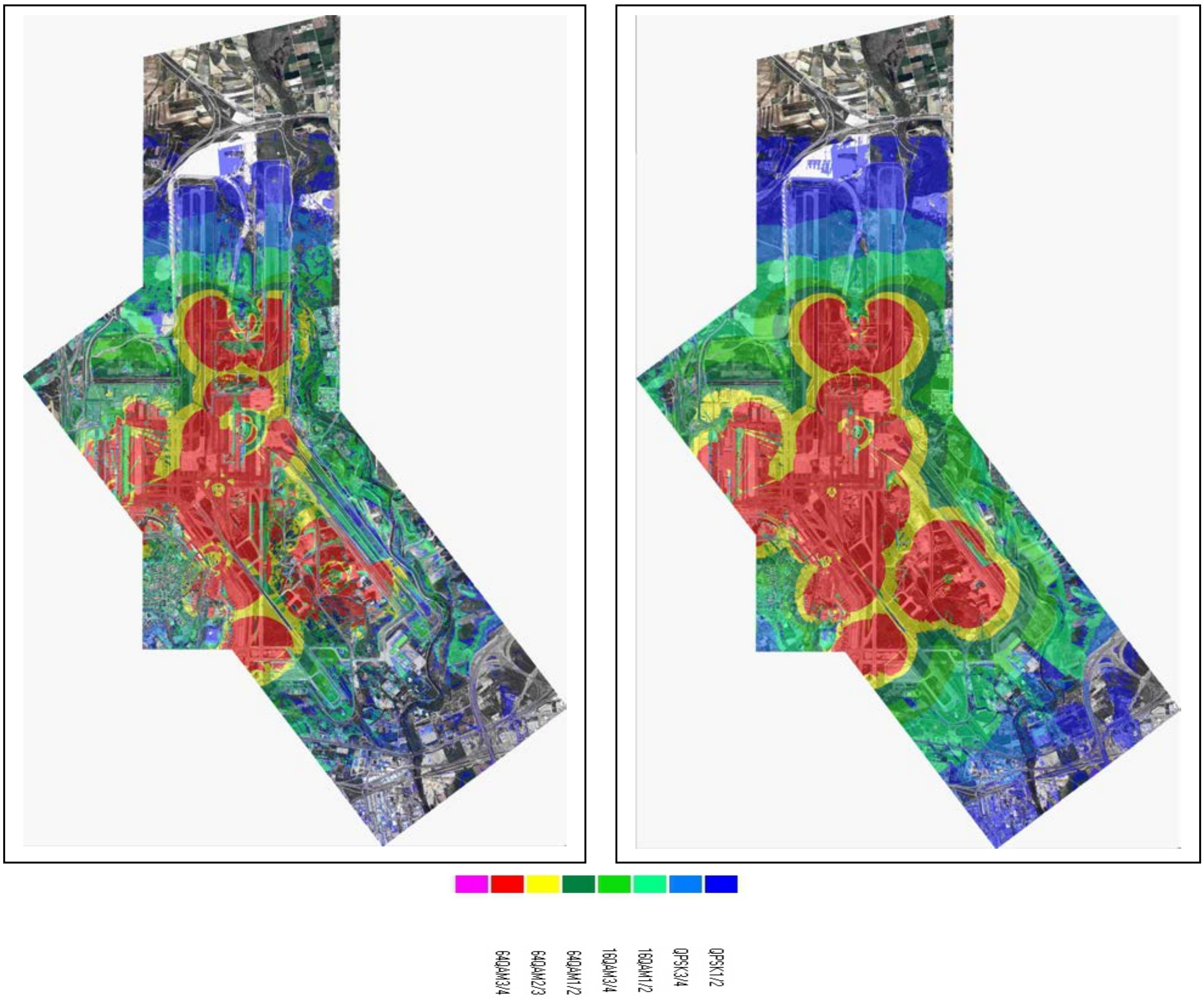


Figure 69: Global coverage (DL) in composite server display: Vehicules with Hant=2m(left) – Aircrafts with Hant=10m (right)

We first note that the Barajas' airport is fully covered by the 24 BS activated in the simulation software. The color legend shows the modulation scheme available at different location on the map, starting from the more efficient modulation scheme (in red) to the less efficient one (in dark blue).

Then, we can observe the difference in power collected by the MS in both cases. To be more specific in range values, we are going to focus in the next sub-section on one of the BS installed in the RAMP area.

MS category (antenna height/ground)	64QAM 3/4	64QAM 2/3	64QAM 1/2	16QAM 3/4	16QAM 1/2	QPSK 3/4	QPSK 1/2
Vehicules (h=2m)	1000	1260	1560	1950	2940	3600	5000
Aircrafts (h=10m)	1000	1260	1560	1950	2940	3600	6000

Table 91: Calculation of cell range (DL in m) for each modulation scheme and MS category (based on R1s1 coverage, near LOS direction)

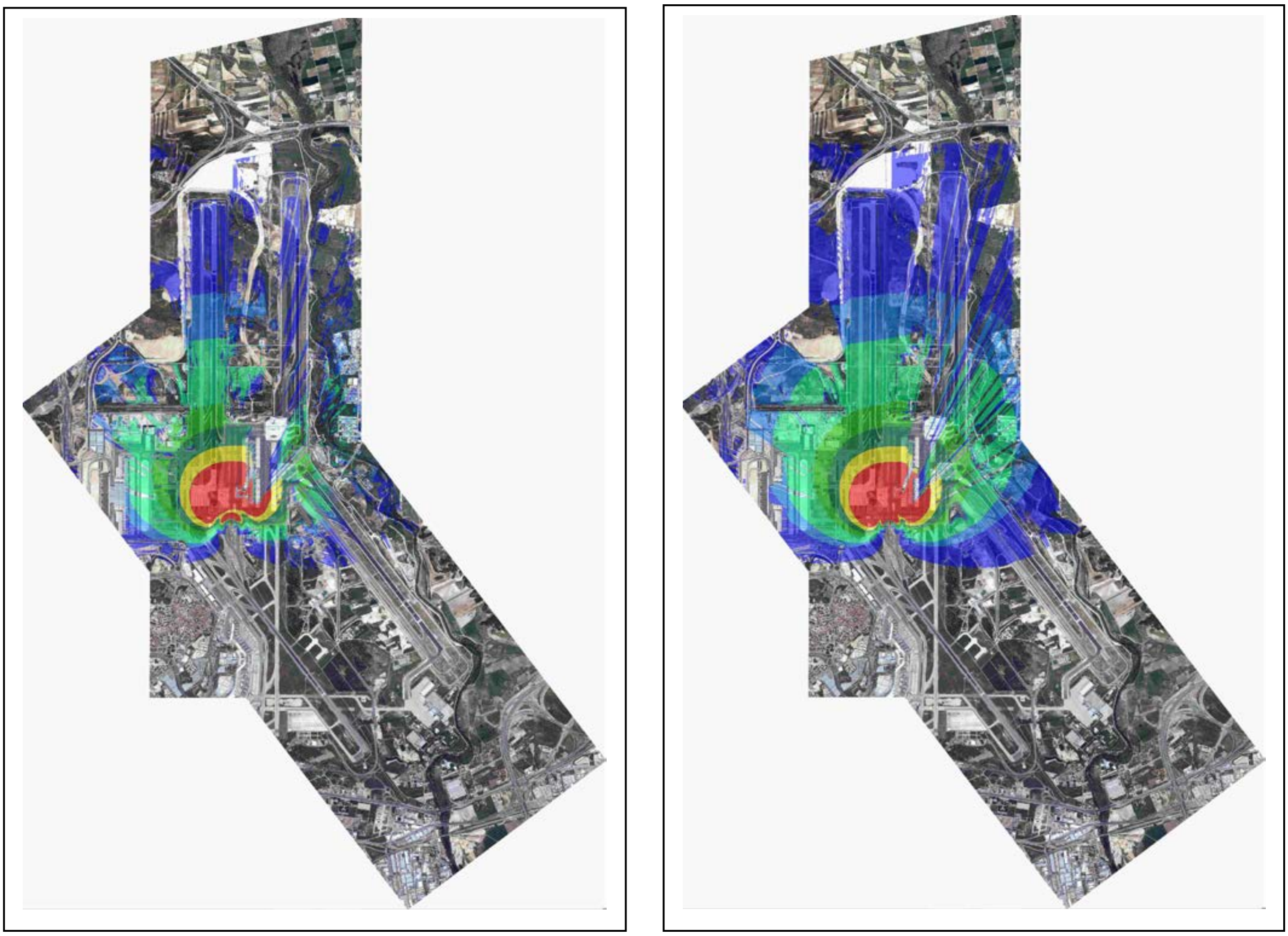


Figure 70: R1s1 coverage for Hant=2m(left) and Hant=10m (right)

The main range difference is visible on the;

- Last modulation scheme (QPSK 1/2) for the range (6 Km instead of 5 Km), where aircrafts take benefits of a better radio range.
- Better homogeneity of the power received at all positions, especially for 16QAM and QPSK modulations (light greens and blue color in Figure).

The aircrafts (Hant=10m) will collect more signal than the vehicule (Hant=2m), operating with a better C/N value, and will of course keep the AeroMACS connection further on the airport. The focus on one BS is mainly interesting for range estimation and visualization of directions where occur direct obstruction to LOS. The aim of the next table is to estimate the reachable range for NLOS directions.

MS category (antenna height/ground)	64QAM 3/4	64QAM 2/3	64QAM 1/2	16QAM 3/4	16QAM 1/2	QPSK 3/4	QPSK 1/2
Vehicules (h=2m)	600			700	1800	*	*
Aircrafts (h=10m)	800			1500	1800	**	**

Table 92: Calculation of cell range (DL in m) for each modulation scheme and MS category (based on R1s1 coverage, NLOS direction)

Note *: Not really appreciable due to other main obstructions to signal
Note **: Depending on the location of the antenna system on the A/C, mask can occur some of the time, compensated by the visibility of other BS on the airport where the AeroMACS system is deployed.

Generally speaking, if we focus on specific area of the composite radio coverage, we observe inhomogeneous colors, thus inhomogeneous modulation and data bit rates. This is either due to masked area (below BS that are installed at the top of high towers or buildings), or area where interference due to reflections occurs, leading to fading events, and thus to less effective modulation scheme.

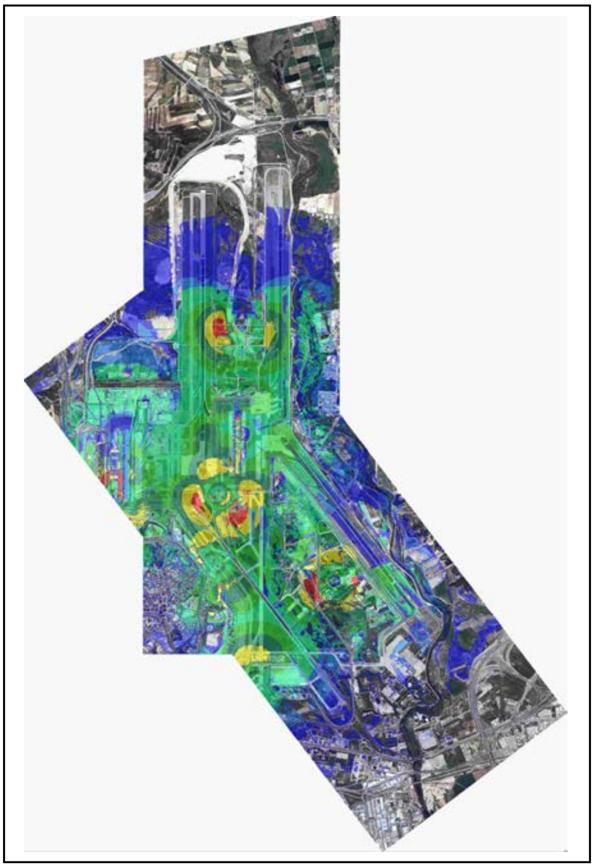
A.1.2 Radio coverage limited by the Uplink (UL)

Radio coverage is always in DL, but may appreciate limitation of the coverage by the MS ability to communicate with BS. We could use the “reverse radio coverage” terminology, or “radio coverage limited by the UL”.

Comparison between radio range (DL) and radio reverse range

The radio coverage that gives the area in which a connection may be established between a MS and a BS is mainly driven by the MS antenna gain, MS transmitted power, UL sub-channelization gain, BS antenna gain and BS sensitivity. This range is often different from the DL radio coverage because of an unbalance between the two DL and UL budget link (Cf. budget link tables).

This budget link unbalanced is around 6dB, considering the simulation hypothesis taken. If we consider this unbalanced in the simulation tool, we get the following figures for the global radio coverage.



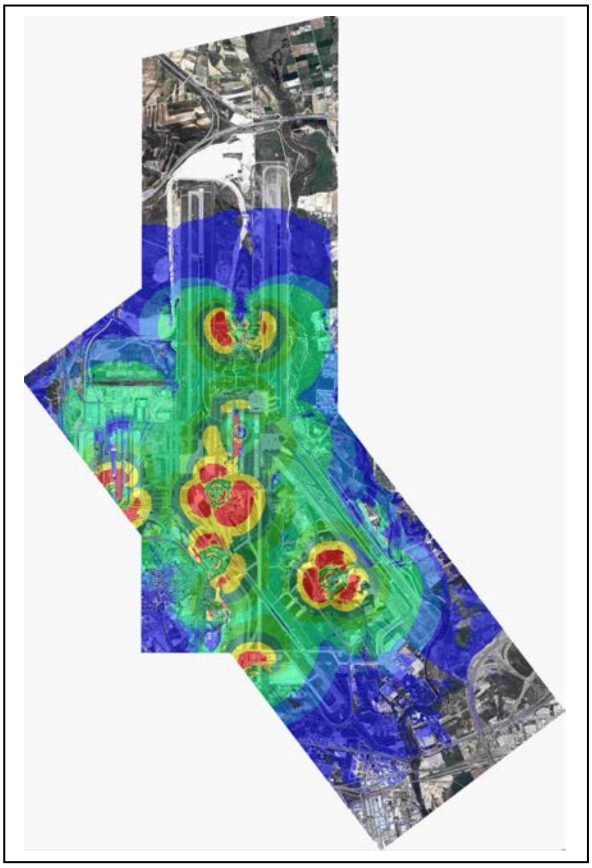


Figure 71: Global coverage (limited by UL) in composite server display: Vehicules with Hant=2m (left) – Aircrafts with Hant=10m (right)

The airport is still covered, but It can be observed that the

- highest modulation scheme are less available than in normal DL coverage, especially the 64QAM3/4 for MS on vehicules,
- radio coverage % of the airport is reduced in the BS configuration chosen (head of two take-off runways are no longer covered).

Full coverage is still accessible if positions of BS are modified (radio planning has been made in order to optimize the capacity).

Note: Hypothesis made in DL & UL Link Budget Tables can also be reviewed

Focus on R1s1 case, Hant=10m

The radio coverage is shown below

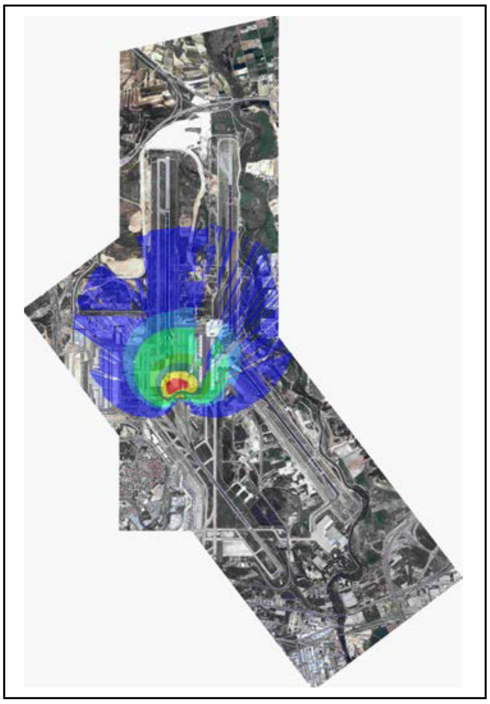


Figure 72: R1s1 radio coverage (limited by UL), Aircrafts with Hant=10m

Coverage convention	64QAM 3/4	64QAM 2/3	64QAM 1/2	16QAM 3/4	16QAM 1/2	QPSK 3/4	QPSK 1/2
DL (from previous tab)	1000	1260	1560	1950	2940	3600	6000
DL limited by the UL (current case)	500	630	800	1000	1500	1900	3600

Table 93: DL coverage and reverse coverage

Processing a radio coverage limited by the UL leads to a factor 2 degradation in range, as it was predictable by the physics law. These data can be compared to data in section 3.7.1.5.3 (NLOS

Munich, NLOS Barajas range estimation). Note that we are more in "near LOS case" than in a rigorous NLOS case.

A.1.3 Conclusions and recommendation

Radio coverage depends on radio parameters, directly linked to AeroMACS device, but also to the position of such equipment and especially;

- *Position of BS device on building (height over ground) = h1*. The highest the building or available infrastructure, the longer the reachable range

- *Position of antenna on BS device = h2 (h3 = h1 + h2 = height of antenna over ground) and relatively to local environment*. In order to optimize the performances and use the full device capacity, the antenna must be installed in a clear environment, away from any obstacle (LOS situation).

- *Antenna tilting for BS device*. After initial simulations for the Barajas case, a – 3° was considered . Of course, this parameter has to be adjusted and cannot be taken as a rule for the other airports. It has to be reconsidered for each airport, because it is linked to infrastructure availability (height of buildings), and to coverage goals.

In RAMP area, operators would like to increase the BS antenna downtilt, in order to favor the power distributed close to the gates. On the other hand, if a maximum coverage has to be achieved, the BS antenna tilt would have to be moderate. Thus, a trade off will be necessary for each airport.

As a result of this Barajas study and as is stated in 3.5.2.4, we can assume that very large airports will have similar coverage requirements as large airports around terminal areas.

For GROUND and TOWER areas there may be a need to add one or two additional sectorized BSs to cover all 5 runways with accompanying taxiways.

A.2 Case study 2: AeroMACS Deployment at Toulouse Airport

A.2.1 Global radio coverage in Toulouse airport

For this small airport, a limited number of BS's has been considered , leading to deployment of 3 sectors, covering the gates and the runways.

BSs1; 5100 MHz; GPS = 43° 38' 22.5" N / 1° 22' 40" E; Hant = 45 m
BSs2; 5110 MHz; GPS = 43° 38' 22.5" N / 1° 22' 40" E; Hant = 45 m
BSr1; 5130 MHz; GPS = 43° 37' 22.5" N / 1° 22' 48" E; Hant = 35 m

The radio coverage is a DL estimation of the maximum range mainly driven by the BS transmitted power, BS antenna gain, MS antenna gain and MS sensitivity. The computed figures (taking into account waves reflection) are shown below.

DL coverage

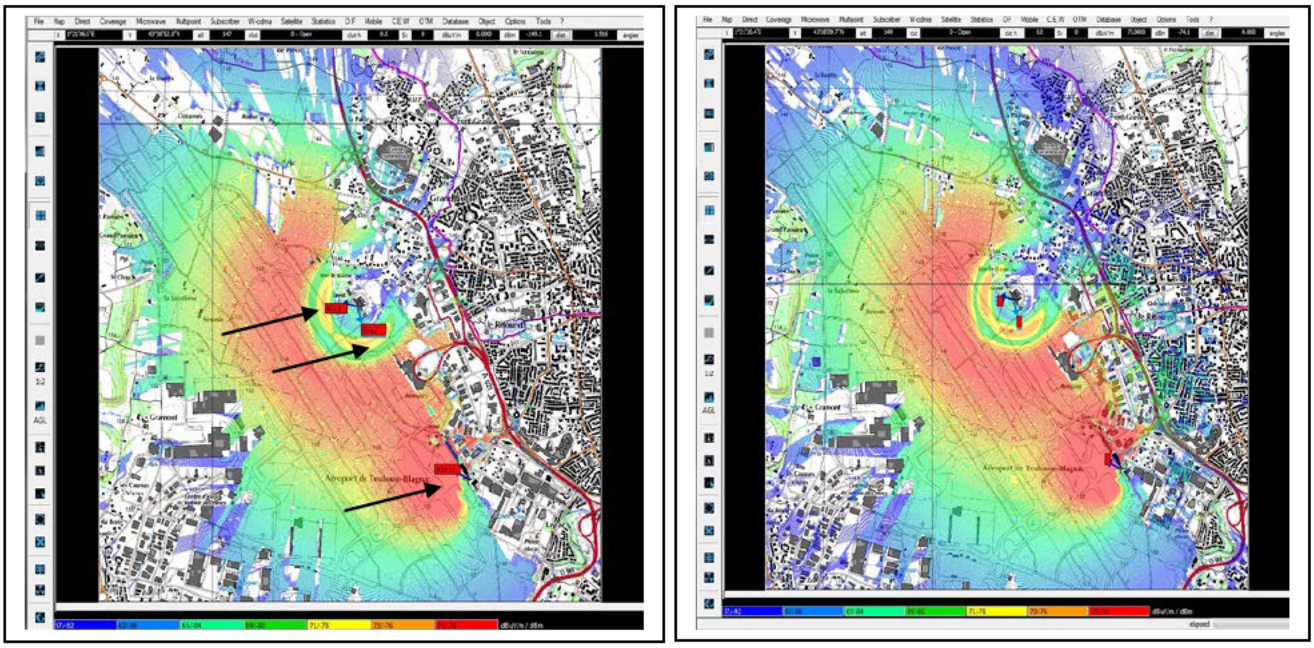


Figure 73: Global coverage (DL) in composite server display:
Vehicules with Hant=2m(left) – Aircrafts with Hant=10m (right)

We observe few differences, with a better coverage for aircrafts, mainly in specific areas (see arrows)

DL coverage limited by UL

Let's consider now a coverage limited by the UL:

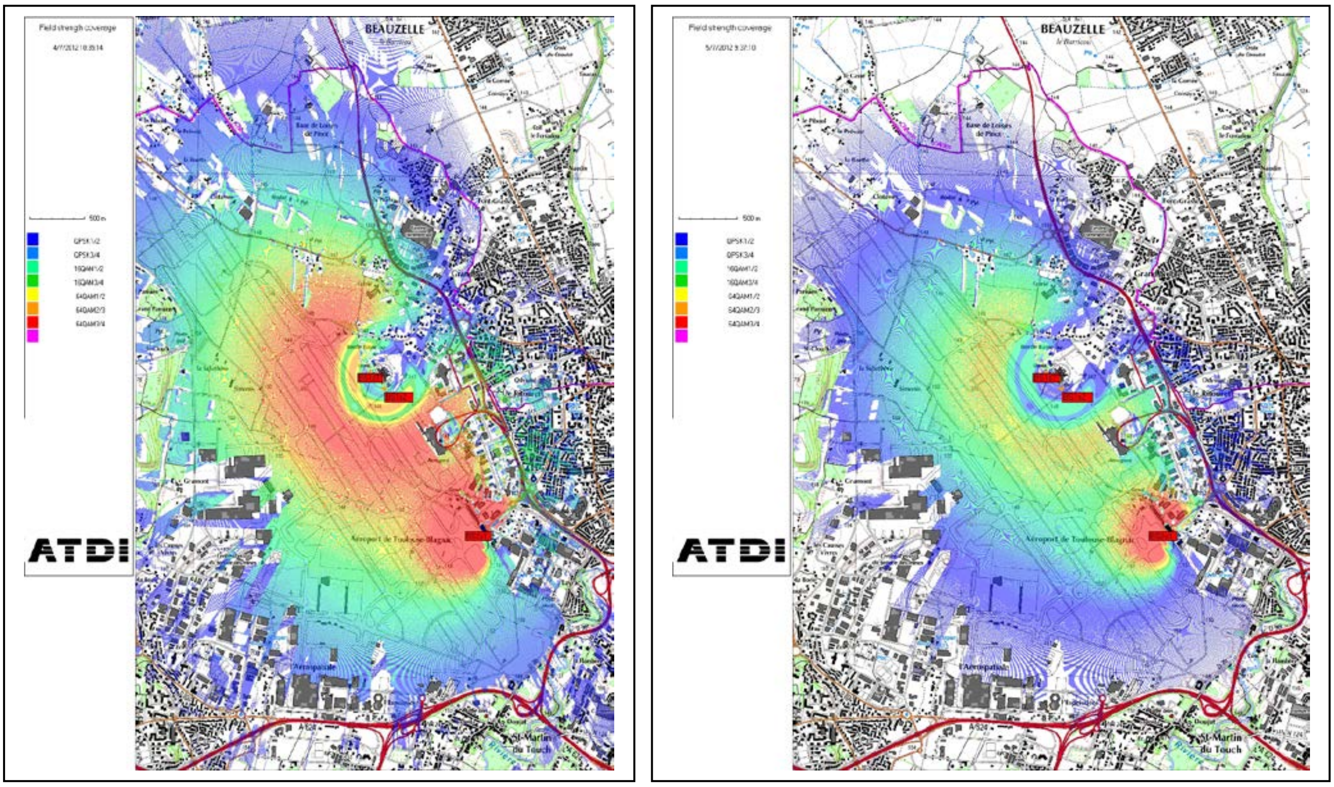


Figure 74: Global coverage for aircrafts (Hant = 10m) in composite server display:
DL coverage(left) – DL coverage limited by UL (right)

We observe that the covering is achieved on the airport area in both case, but the highest modulation (64QAM ¾) is not available for BS1 (sectors 1 and 2) because of the antennas heights and low downtilt selected. If we increase the latter, we should increase the capacity available close to BS1 (see next figure), but reduce range .

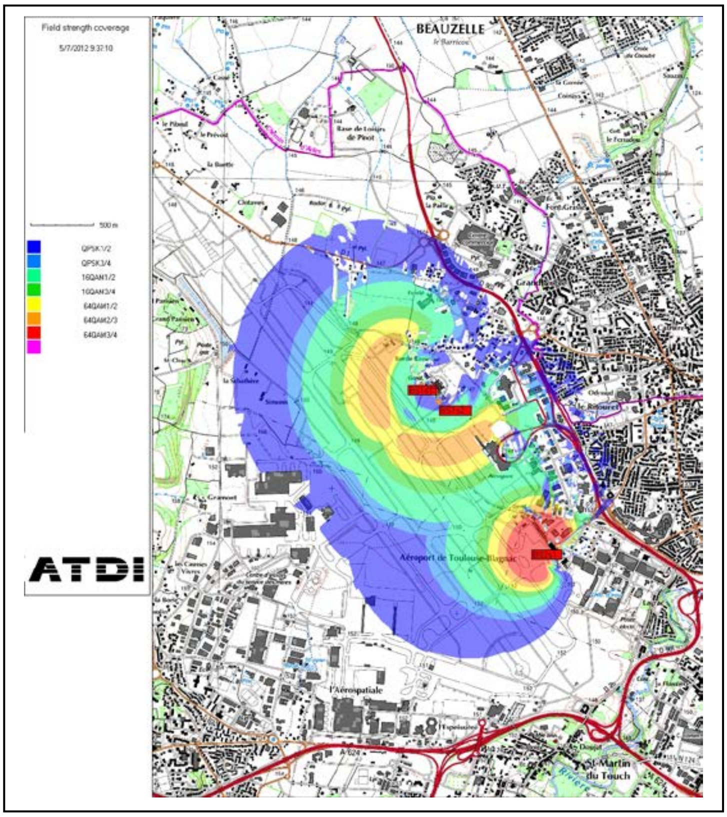


Figure 75: Global coverage for aircrafts (Hant = 10m) in composite server display: DL coverage limited, no reflections considered Downtilt for BS1 (s1 & s2) has been increased from 5 to 7°

Ranges

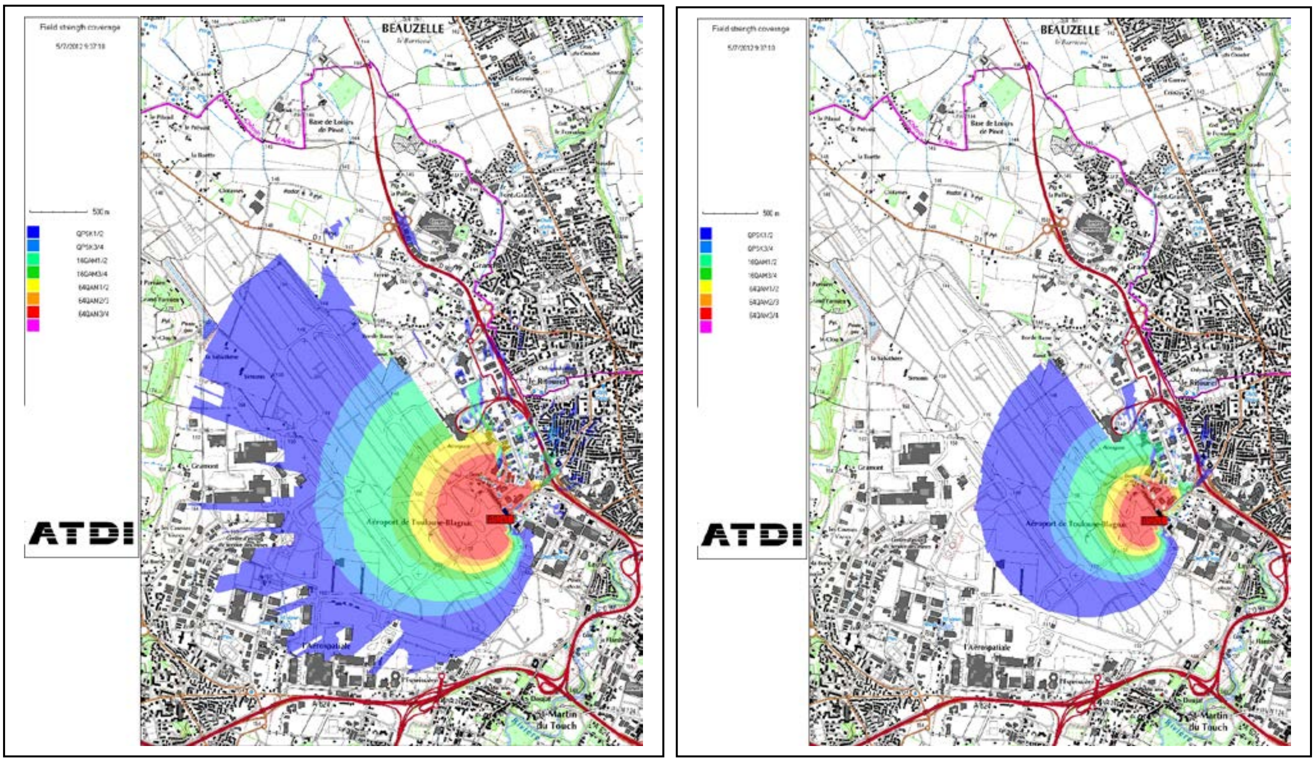


Figure 76: BS2 coverage - Aircrafts with Hant=10m, no reflections considered

DL (left) - DL limited by UL (right)

Coverage convention	64QAM 3/4	64QAM 2/3	64QAM 1/2	16QAM 3/4	16QAM 1/2	QPSK 3/4	QPSK 1/2
DL	600	750	900	1000	1500	1800	3000
DL limited by the UL	410	480	560	650	910	1000	1750

Table 94: BS2 Range for DL and DL limited by UL

A.2.2 Simulation of inter-system interferences in Toulouse

Purpose of the study

The purpose of this study is the compatibility analysis between two different telecommunication systems; an existing MLS system and an AeroMACS deployment, operating in the same band and in the same area (around the Toulouse-Blagnac airport in France). In order to derive general rules, we will consider the worst case, and then make recommendations.

More particularly, the calculations performed here will take care of :

- interference due to AeroMACS transmitters (3 stations) on MLS receivers (2 stations);
- interference due to MLS transmitters (2 stations) on AeroMACS Base stations (Uplink on 3 stations);
- interference due to MLS transmitters (2 stations) on AeroMACS receivers (Downlink for mobiles).

Figure 77: Localization of AeroMACS BS (in red, BS Tower with 2 sectors BSs1 and BSs2) and Tx MLS Stations (MLS AZ and MLS El in yellow) and Rx MLS Stations (Rx Az and Rx El in magenta)

Cartographic database

The different cartographic layers used in this study are described as follows :

- a digital terrain model with 5m resolution providing the altitude of the terrain on any point;
- an image with 2.5m resolution used in the background;
- a building layer describing the height and the shape of each building in the area;
- a clutter layer with 5m resolution containing four classes describing the nature of the ground: open area, building, water and vegetation.

Propagation model

The following propagation model has been chosen :

- free space losses according to the ITU-R P.525 recommendation,
- diffraction according to the Deygout 1994 model,
- and "standard integration" model for the sub-path attenuation.

Network and Simulation parameters

MLS transmitting station Tx

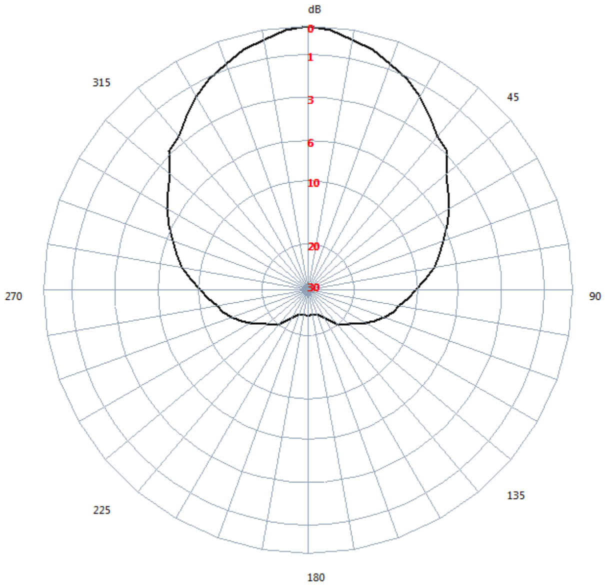
The MLS transmitting radio station parameters as well as the radiation patterns of the antennas connected are described below.

Name	Azimuth Ground
Coordinates	43°36' 56.7725"N / 1°22' 31.5807"E
Nominal Power	30W
Frequency (Bandwidth)	**5038.8MHz** (CW for beam scanning) / (**300kHz** for DPSK)
Antenna Gain	**27dBi** (scanning) / 12.5 dBi (DPSK)
Antenna 3dB Beam width (az)	1.65° (scanning) / **+/- 50°** (DPSK)
Antenna 3dB Beam width (el)	0-20°
Height above the Ground	1.5 m
Azimuth / North	310°
Tilt (>0 Uptilt)	0°

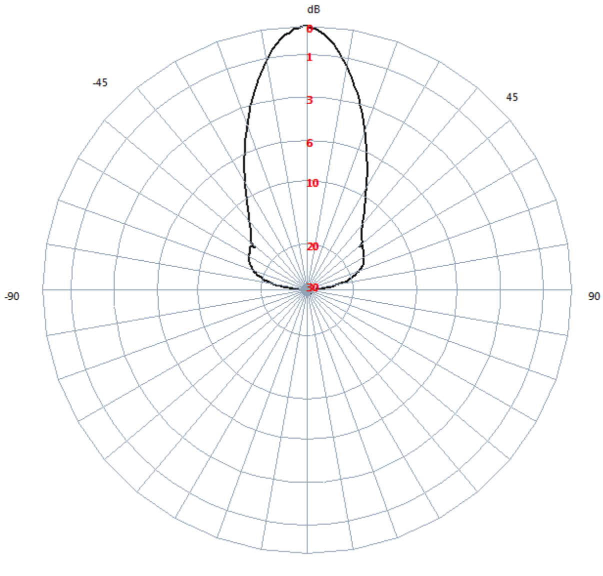
Name	Elevation Ground
Coordinates	43°38' 33.1581"N / 1°20' 57.0729"E
Nominal Power	30W
Frequency (Bandwidth)	**5038.8MHz** (CW for beam scanning) / (**300kHz** for DPSK)
Antenna Gain	**22dBi** (scanning) / 12.5 dBi (DPSK)
Antenna 3dB Beam width (az)	1.3° (scanning) / **+/- 50°** (DPSK)
Antenna 3dB Beam width (el)	0-20°
Height above the Ground	2.5 m
Azimuth / North	310.00
Tilt (>0 Uptilt)	0°

Table 95: Azimut and Elevation Tx MLS Station parameters

Note : The simulations have been done for the worst case, i.e. the gain of the scanning signal has been considered for the calculations, as for the bandwidth and the horizontal aperture of the DPSK signal.



Horizontal pattern



Vertical pattern

Figure 78: Radiation patterns attached to each MLS transmitting station

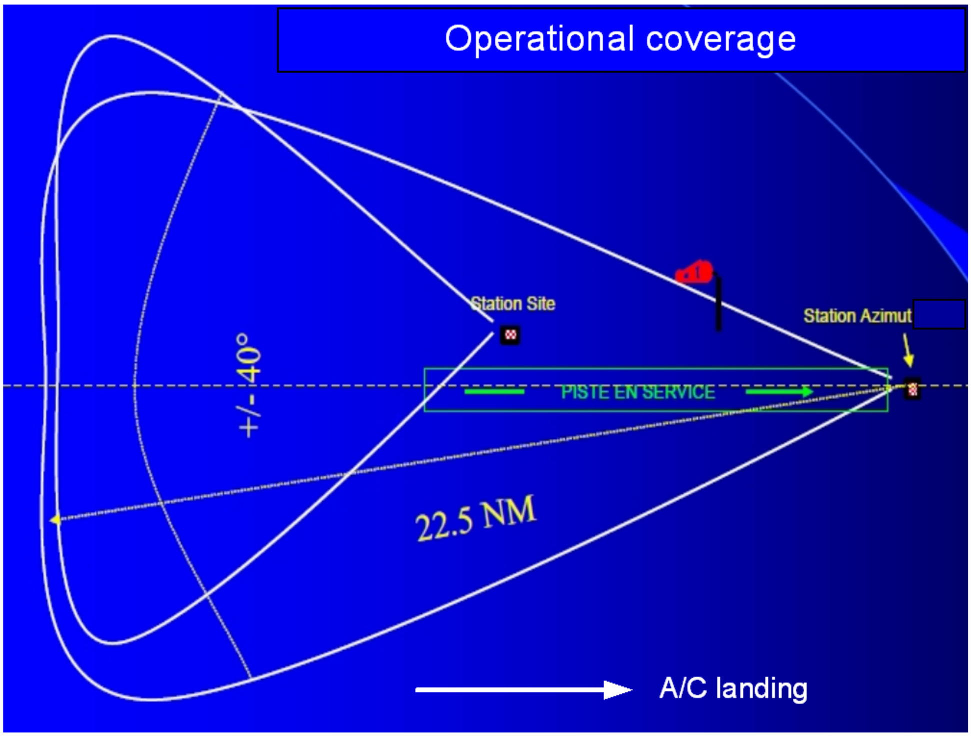


Figure 79: Schematic representation of Tx MLS stations H patterns over Toulouse airport

MLS receiving station Rx

The MLS receiving radio station parameters as well as the radiation patterns of the antennas connected are described below.

Name	Monitor angle Azimut
Location	30m in front of AZ Tx station
Coordinates	43°36'57.5"N / 1°22'30.7"E
Frequency (Bandwidth)	5038.8MHz (60 MHz) no selectivity
Antenna Gain	10dBi
Antenna 3dB Beam width (az)	+/- 50°
Antenna 3dB Beam width (el)	12°
Noise factor	11 dB
KTBF	-108dBm
Height above the Ground	2m
Azimuth / North	310°
Tilt (>0 Uptilt)	0°

Name	Monitor angle Site
Location	30m in front of EL Tx station
Coordinates	43°38'32.3"N / 1°20'57.7"E
Frequency (Bandwidth)	5038.8MHz (300kHz)
Antenna Gain	10dBi
Antenna 3dB Beam width (az)	+/- 50°
Antenna 3dB Beam width (el)	12°
Noise factor	11 dB
KTBF	-108dBm

Height above the Ground	2m
Azimuth / North	310°
Tilt (>0 Uptilt)	0°

Table 96: Azimut and Elevation Rx MLS station parameters

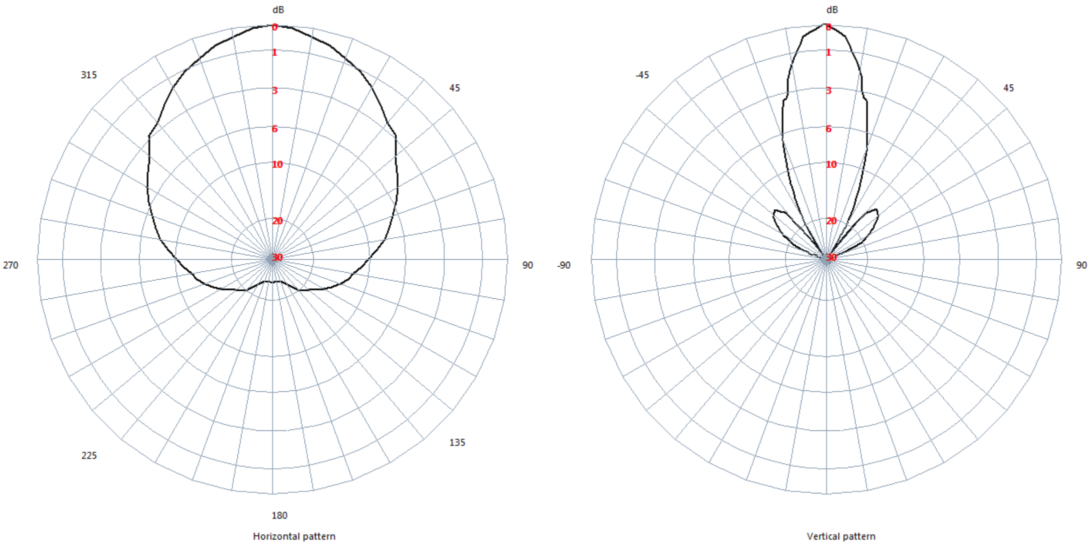


Figure 80: Radiation patterns attached to each MLS receiving stations

AeroMACS transmitting stations

The main parameters for AeroMACS radio transmitters and their antennas are described below.

Site	Name	Longitude (DMS)	Latitude (DMS)	Nom. Power (W)	Tx Ant. Gain (dBi)	Tx/Rx Losses (dB)	Rad. Power (W)
Tower	BSs1	1.2204	43.38062	0.2	15	8	0.61098
Tower	BSs2	1.2204	43.38062	0.2	15	8	0.61098
VHF	BSrs1	1.2248	43.37225	0.2	15	8	0.61098

Site	Name	Azimuth (°)	Tilt (°)	Antenna (m)	Frequency (MHz)	Bandwidth (kHz)	KTBF (dBm)
Tower	BSs1	280	-3	45	5038.8	5000	-96
Tower	BSs2	170	-3	45	5038.8	5000	-96
VHF	BSrs1	300	-3	30	5038.8	5000	-96

Table 97: Parameters of AeroMACS stations

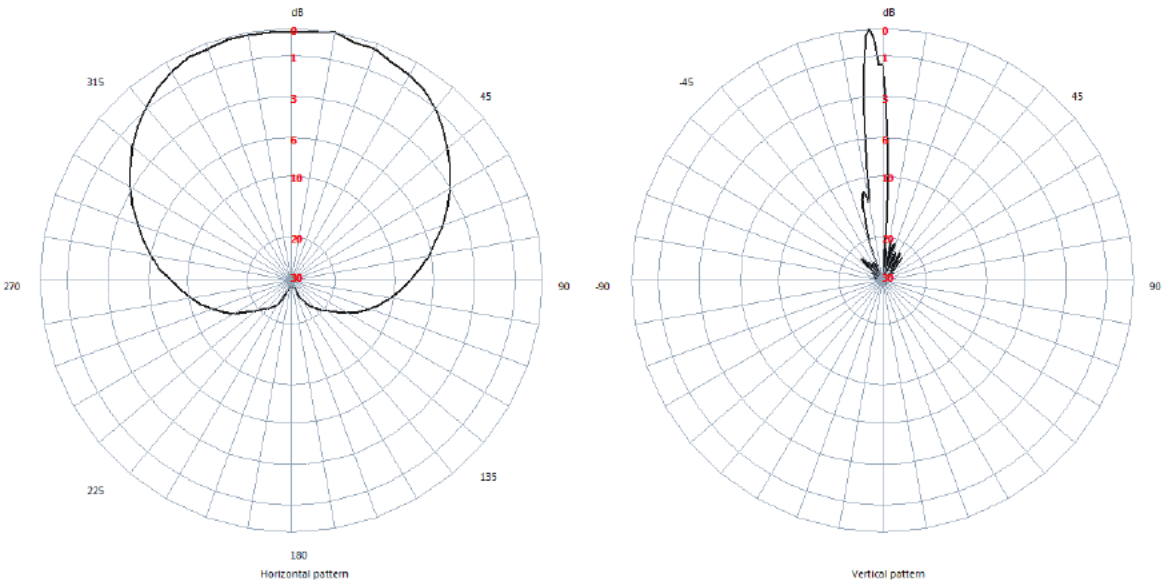


Figure 81: Radiation patterns of antennas attached to AeroMACS stations

AeroMACS receiving stations

For receiving Mobile Stations, an omnidirectional antenna has been considered, 2m over ground, taking into account a minimum coverage threshold of -92dBm, with a KTBF value of -98dBm.

Interference parameters

In the whole study, all transmitters are supposed to be operating at the same frequency and no rejection on the interfering signals (except the power diffusion effect) has been considered. In case of a AeroMACS signal with 5MHz bandwidth is interfering a MLS signal with 300kHz bandwidth at the same frequency, the power diffusion effect will reduce the interfering power of

- 10*log(300/5000) = -12.2dB

The interference levels are considered as the sum of all interferers and are expressed in terms of Threshold Degradation (TD in dB) defined by :

- TD (dB) = 10*log((Sum(I)+KTBF)/KTBF)

A common value used for the maximum TD value to consider that there is no significant interference is between 1 and 3dB.

Results

Interference on MLS receiving stations

According to the above assumptions, the TD is computed on the 2 MLS receiving stations with the 3 AeroMACS base stations considered as interferers. The results are given below.

Wanted station (Rx)	Rx KTBF (dBm)	Interferer (Tx)	Unwanted Power (dBm)	TD (dB)	Cumulated TD (dB)	Rejection (dB)	Tx BW (kHz)	Rx BW (kHz)	Distance Tx-Rx (m)

Rx Az MLS	-108	AeroMACS Tx BSs1	-103.58	5.76	5.76	12	5000	300	2205.3
Rx Az MLS	-108	AeroMACS Tx BSs2	-95.44	12.79	13.38	12	5000	300	2205.3
Rx Az MLS	-108	AeroMACS Tx BSrs1	-95.58	12.67	15.94	12	5000	300	863.69
Rx El MLS	-108	AeroMACS Tx BSs1	-114.03	0.97	0.97	12	5000	300	1694.96
Rx El MLS	-108	AeroMACS Tx BSs2	-128.92	0.03	1	12	5000	300	1694.96
Rx El MLS	-108	AeroMACS Tx BSrs1	-122.95	0.14	1.1	12	5000	300	3286.27

Table 98: TD calculation for Interference on MLS receiving stations

In order to avoid interference from AeroMACS stations on MLS receivers, an additional rejection of **16dB** would be required. This rejection might be provided by a combination of receiving filters and frequency separation between the 2 systems. Using adjacent frequencies might be enough, but this has to be confirmed by a further analysis requiring more detailed information about the MLS receivers (rejections).

Interference on AeroMACS base stations

According to the above assumptions, the TD is computed on the 3 AeroMACS stations (Uplink) with the 2 MLS transmitting stations considered as interferers. The results are given below.

Wanted station (Rx)	Rx KTBF (dBm)	Interferer (Tx)	Unwanted Power (dBm)	TD (dB)	Cumulated TD (dB)	Rejection (dB)	Tx BW (kHz)	Rx BW (kHz)	Distance Tx-Rx (m)
AeroMACS Rx BSs1	-96	Tx Az MLS	-56.99	39.01	39.01	0	300	5000	2234.67
AeroMACS Rx BSs1	-96	Tx El MLS	-81.96	14.21	39.03	0	300	5000	1720.27
AeroMACS Rx BSs2	-96	Tx Az MLS	-48.71	47.29	47.29	0	300	5000	2234.67
AeroMACS Rx BSs2	-96	Tx El MLS	-96.85	2.61	47.29	0	300	5000	1720.27
AeroMACS Rx BSrs1	-96	Tx Az MLS	-48.94	47.06	47.06	0	300	5000	877.1
AeroMACS Rx BSrs1	-96	Tx El MLS	-90.89	6.28	47.06	0	300	5000	3314.11

Table 99: TD calculation for Interference on AeroMACS base stations

In order to avoid interference from MLS transmitters on AeroMACS base station receivers, an additional rejection of **48dB** would be required. This rejection might be provided by a combination of receiving filters and frequency separation between the 2 systems. Using a frequency separation of 2 channels (N+/-2) might be enough, but this has to be confirmed by a further analysis requiring more detailed information about the AeroMACS receivers (out of band rejection).

Interference on AeroMACS receiving stations

According to the above assumptions, the TD is computed over the AeroMACS downlink coverage (where the AeroMACS mobile receivers are) with the 2 MLS transmitting stations considered as interferers. The results are given in the following maps :

- On a first simulation, Threshold degradation map on AeroMACS DL coverage interfered by Tx MLS stations have been computed, **without any rejection** applied.

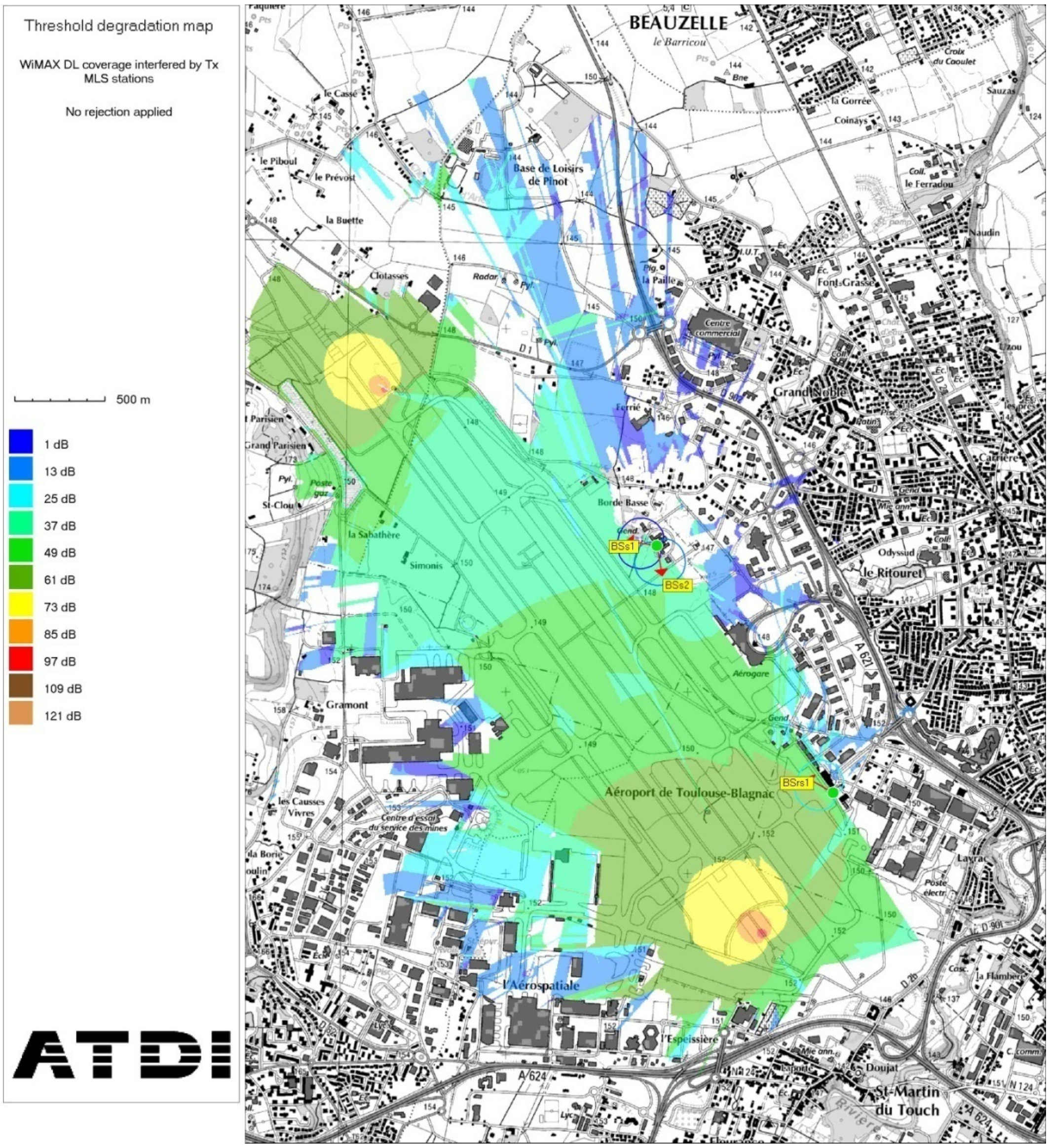


Figure 82 : Threshold Degradation map for Tx MLS vs. AeroMACS DL coverage - No rejection

- On a second simulation, Threshold degradation map on AeroMACS DL coverage interfered by Tx MLS stations have been computed, with a **rejection of 70dB** applied on each interferer

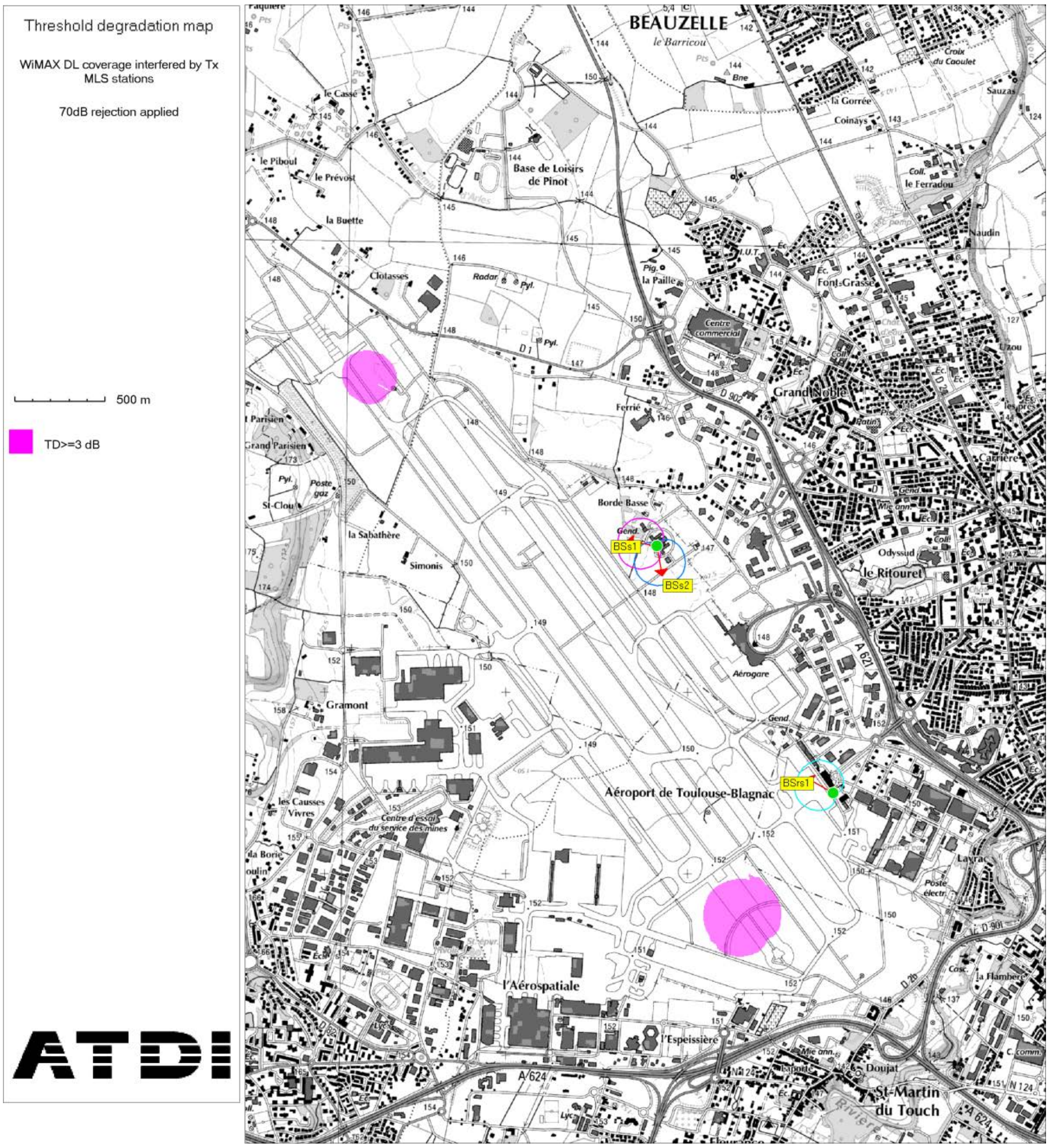


Figure 83 : Threshold Degradation map for Tx MLS vs. AeroMACS DL coverage – 70 dB rejection

In order to have a limited interfered area from MLS transmitters on AeroMACS mobile receivers, an additional rejection of **70dB** would be required. In that case, only areas very close to the MLS transmitters (in magenta) will be interfered. This rejection might be provided by a combination of receiving filters and frequency separation between the 2 systems. Using a frequency separation of 3 channels (N+/-3) might be enough, but this has to be confirmed by a further analysis requiring more detailed information about the AeroMACS receivers (out of band characteristics).

Conclusion

In order to be able to share the same band between the MLS service and the AeroMACS service, a rejection of 70dB in the worst case should be applied on interferers. This rejection might be provided by a combination of receiving filters and frequency separation between the 2 systems. Using a frequency separation of 3 channels (N+/-3) might be enough, especially with the pessimistic approach used in this study, but this has to be confirmed by a further analysis requiring more detailed information about the MLS and AeroMACS receivers.

In case of Toulouse airport, the MLS center frequency (5038,8 MHz) is separated from 52 MHz from the lower AeroMACS frequency (5091 MHz), which means a frequency separation of more than 10 channels. Thus we can conclude than no interference would occur between already deployed MLS and future AeroMACS prototypes to deploy on Toulouse airport.

Appendix B Overview of European Airports

Pls double click on the object file embedded to see the complete list of airports. (three pages)

Although data is collected in 1998 the data is still valid for most airports which has been verified with Eurocontrol`s airports division. Today these updated data is available (and approved by every airport operator) in separate documents for every single airport.

Note : The table provides an overview of commercial movements only.

1998 EUROPEAN AIRPORTS DATABASE - EXECUTIVE SUMMARY

AIRPORT	COUNTRY	YEAR		RUNWAYS		CAPACITY[1]		STANDS		TRAFFIC[2]		PASSENGERS[3]		COMMENTS
		Current	Future	Current	Future	Current	Future	Current	Future	Current	Future	Current	Future	
Salzburg Airport W.A. Mozart	Austria	1998	2016	1		20	20	35	46	25 280	36 100	1 139 892		
Vienna International Airport	Austria	1998	2010	2	3	54	66	61	92	165 242	280 000	10 636 055	19 800 000	New runway (2010). Terminal extension (2005)
Brussels - National	Belgium	1998	2000	3		68	72	107	130	300 000	326 000	1 850 000	2 300 000	
Sofia Airport	Bulgaria	1998	2010	1	2	24	24	32	36	21 447	31 421	1 141 000	2 166 000	New runway (2010). New terminal bulding (2002).
Zagreb Airport	Croatia	1998	2006	1		29	34	23	36	32 800	39 000	1 160 000	1 960 000	New passenger terminal (2005).
Larnaca International Airport	Cyprus	1998	2006	1		25	30	21	46	36 000	40 000	4 000 000	6 000 000	New terminal (2005). Runway extension (1999).
Prague - Ruzyne	Czech Republic	1998	2010	3	4	45	76	46		82 000		4 600 000		New parallel Runway (2010).
Billund	Denmark	1998	2001	1		50	60	22	66	58 000	70 000	2 130 084	4 000 000	New terminal (2001).
Copenhagen Airport	Denmark	1998	2000	3		81	91							New terminal (1998).
Tallinn	Estonia	1998	1999	1		22	22	32	33	24 951	26 672	563 946	612 273	Reconstruction of passenger terminal (1998-1999)
Helsinki - Vantaa	Finland	1998	2003	2	3	48	72	75	80	166 600	206 000	9 300 000	13 600 000	New runway (2003)
Alaccio Campo dell' oro	France	1998		2				14		15 800		950 000		
Euralrport Bale-Mulhouse	France	1998	2002	2		30	45	51	66	100 000	130 000	3 000 000	5 000 000	New Terminal (2002)
Bordeaux - Merignac	France	1998	2000	2		35	35	36	36	47 608	64 000	2 731 392	3 000 000	Third runway (2005)
Clermont-Ferrand/Auvergne	France	1998	2016	1		30		18		28 616	36 000	728 026	1 600 000	
Lille-Lesquin	France	1998	2010	2		30	30	22	27	21 065		854 903		Terminal extension (2010)
Lyon - Satolas	France	1998	2016	2	3	50	90	65	86	103 000	200 000	5 261 000	10 000 000	New runway (2015)
Marseille - Provence	France	1998	2016	2		30	60	23	40	86 899	140 000	5 647 768	10 000 000	Extension Runway 2 (2015)
Montpellier Mediterranee	France	1998	2016	2	3	25		42		103 526		1 523 719	6 000 000	New Runway (2015)
Nantes Atlantique	France	1998		1		16		39		68 659		1 683 267		
Nice Cote d'Azur	France	1998	2006	2		49	49	71	80	135 000		8 000 000	11 900 000	
Paris - Charles De Gaulle	France	1998	1999	3	4	84		153		429 691		38 669 169		First new runway 1999, second new runway 2001
Paris - Le Bourget	France	1998		3		45		125		48 725		58 283		
Paris - Orly	France	1998		3		70		90		246 240		24 957 451		
Rennes St Jacques	France	1998		2				20		63 624		334 226		
Strasbourg Entzheim	France	1998		1		20		31		49 026		2 114 341		
Toulouse - Blagnac	France	1998	2010	2		42		34	47	97 304		4 564 263		
Berlin Tegel	Germany	1998		2		40		42		120 132		8 881 771		
Berlin Tempelhof	Germany	1998		2		30		22		55 013		934 761		
Berlin-Schonefeld	Germany	1998	2007	2		32		41		44 759		1 947 623		Planned extension to form new Berlin Airport
Bremen Airport	Germany	1998		1				14		48 413		1 690 472		
Dresden	Germany	1998	2001	1		28		21		42 117	56 600	1 648 742	2 400 000	New terminal (2001).
Dusseldorf International	Germany	1998	2010	2		36		67	72	186 759	209 600	15 800 000	20 100 000	
Erfurt	Germany	1998	1999	1		18	18	23	27	17 237	26 269	343 779	420 000	Runway up to 2600m/CAT IIIb (1999)
Frankfurt am Main	Germany	1998	2000	3		76	80	186	186	416 300	442 600	42 700 000	47 700 000	
Hamburg-Fuhlsbuettel	Germany	1998	2006	2		42	54	42	56	124 458	163 000	9 126 000	11 750 000	New terminal (2005)
Hannover	Germany	1998		3		50		33		70 815		4 829 147		New terminal (1998)
Koln/Bonn	Germany	1998	2010	3		52	78	117	160	154 000		5 400 000	16 000 000	Terminal 2 (2000),Terminal 3 (2010)
Flughafen Leipzig - Halle	Germany	1998	2000	1	2	30	45	24	24	43 800	46 100	2 140 000	2 600 000	New runway North (2000). New terminal North (2010)
Munich Franz- Josef Straub	Germany	1998	2002	2		82		89	93	255 000	280 000	19 300 000	21 600 000	New terminal planned 2002/2009
Flughafen Numberg	Germany	1998	2006	1		30	30	24	26	84 000	93 000	2 500 000	3 600 000	Terminal extension (2005)
Stuttgart Airport	Germany	1998	2006	1		35	38	37	40	140 000	160 000	7 200 000	10 000 000	New terminal 3 (2005)

Appendix C Example of BS OMNI Antenna Characteristics

WiMo

Aufsteckantenne 5 GHz SMA
Best.Nr. 18720.11

WiMo

ELECTRICAL SPECIFICATIONS

ANTENNA TYPE :	RUBBER ANTENNA
MODEL NO.:	18720.11
REQUENCY RANGE:	5.1~5.5MHz
V.S.W.R:	<2.0
IMPEDANCE :	50 Ù ± 5 Ù
GAIN:	5dBi
WITH STANDING POWER:	MAX 5W
RADIATION:	OMNI
POLARIZATION:	VERTICAL
WEIGHT:	25g ± 2g
CONNECT TYPE:	SMA MALE
ELECTRICAL WAVE	1/2 ë
COLOR:	BLACK

WiMo Antennen und Elektronik GmbH
Am Gäxwald 14, D-76863 Herxheim Tel. (07276) 96680 FAX 6978
http://www.wimo.com e-mail: info@wimo.com

Appendix D Example of BS Sectorized Antenna Characteristics

ZDA COMMUNICATIONS US LLC.
wireless antenna solutions

Website: http://www.zdacomm.com
Email: sales@zdacomm.com
Tel:803-419-4702

5150-5850 MHz Sector Antenna ABS Radome

Frequency:5150-5850 MHz, gain:18dBi 17dBi 15dBi, It is a professional quality "cell site" antenna designed suitable for operate from 5.1 GHz to 5.9 GHz (5100-5900 MHz). The Wideband design of this antenna eliminates the need to purchase different antennas for each frequency.
This antenna features a heavy-duty plastic radome for all-weather operation. The mounting system adjusts from 0 to 15 degrees down-tilt.
This antenna is an ideal choice for "cell" sites since the cell size can be easily determined by adjusting the down-tilt angle.

5150-5850MHz 60deg18dBi - ZDADJ5159-18-60
5150-5850MHz 90deg17dBi - ZDADJ5159-17-90
5150-5850MHz 120deg 15dBi - ZDADJ5159-15-120

Features:
- 60,90,120 deg beam-width
- 15 deg Down-Tilt Mounting Bracket
- All weather operation
- Integral N-Female Connector
- Includes Mast Mounting Hardware

Applications :
- 5.3 GHz, 5.4 GHz and 5.8 GHz Band Applications
- IEEE 802.11a Wireless LAN
- 5.8GHz UNII and ISM Applications
- Unlicensed European 5.4 GHz Band Applications
- WIMAX Technology
- WIFI Systems
- 5.8 GHz Wireless Video Systems

ZDA COMMUNICATIONS US LLC
Website: http://www.zdacomm.com
Email: sales@zdacomm.com
Tel:803-419-4702

Appendix E Safety and Performance requirements applicable to the ACSP domain

WG78/SC214 requirements

The following section is based on 15.2.7 WA08 draft deliverable on safety and performance. The safety analysis done in WA08 is developed accordingly to the draft deliverables of the joint Eurocae/RTCA group WG78/SC214.

The following requirements come or are derived from draft version I of WG78/SC214 [43].

To get further information, the reader may refer to WG78/SC214 draft deliverable version I and 15.2.7 WA08 draft deliverable V0R13 [44].

Accordingly with WG78/Sc214, the following set of safety critical application is considered for AeroMACS:

Application		Services considered in safety analysis		Used in APT domain	Covered by WG78	Addressed in present section
CM	Context Management	DLIC	DataLink Initiation	X	X	X
CPDLC	Controller Pilot DataLink Communication	ACM	ATC Communication Management	X	X	X
		CRD	Clearance Request and Delivery	X	X	X
		AMC	ATC Microphone Check	X	X	X
		DCL	Departure Clearance	X	X	X
		D-TAXI	DataLink Taxi	X	X	X
		4DTRAD	4-Dimensional Trajectory Data Link	X		X
		IER	Information Exchange and Reporting	X	X	X
		PR	Position Reporting		X	
		IM	Interval Management		X	
		OCL	Oceanic Clearance		X	
ADS-C	Automatic Dependent Surveillance	4DTRAD	4-Dimensional Trajectory Data Link	X		X
		IER	Information Exchange and Reporting	X	X	X
		PR	Position Reporting			
		IM	Interval Management			
FIS	Flight Information Service	D-OTIS	DataLink Operational Terminal Information	X	X	X
		D-RVR	DataLink Runway Visual Range	X		
		D-HZWX	Data Link Hazardous Weather	X		

Table 100: WG78/Sc214 Safety critical applications selected for AeroMACS

In case, different services or applications would be considered to be supported by AeroMACS, safety and performance requirements should be refined accordingly.

In addition to the ATC services, the AeroMACS system should be able to support the following types of services:

- AOC/AAC communication between Aircraft and Airlines operation centers
- Communication between Airport operator and Ground vehicles to optimize surface operation.

Requirements related to AOC and AAC services and communication with ground vehicles are not addressed in this section for the following reasons:

- It is assumed that Safety (if any) and Performance requirements related to AOC and AAC services are less stringent than those related to ATC Datalink services. This assumption seems to be validated with regards to the result of the AOC Communication Study done in the frame of SESAR [45].

For communication with ground vehicles, there is no clear operation concept at this moment in time, it is thus very difficult to derive any Safety and Performance requirements related to such type of services.

The following table presents the safety and performance requirements applicable to the Aeronautical Communication Service Provider Domain based on the Version I of draft deliverables of joint WG78/Sc214 group.

Note: According to the definition of the ACSP domain presented in the WG78/SC214 documents, the ACSP encompasses the ASN and the CSN functions as defined WMF documentation.

WG78/SC214 Requirement list					
Ref	**Part**	**Parameter**	**Value**	**Title**	**Source**
PR_CP_01	ACSP	Transaction Time 99,9 % (in seconds)	9 s	The transaction time (one way) in ACSP shall be less than 9 seconds for 99.9% of the messages	Performance analysis ADS-C - RSP 95
PR_CP_02	ACSP	Transaction Time 95 % (in seconds)	4 s	The transaction time (one way) in ACSP shall be less than 4 seconds for 95% of the messages	Performance analysis ADS-C - RSP 95
PR_CP_03	ACSP	Availability (in percent)	99,95%	The availability of the ACSP shall be more than 99.95%	Performance analysis CPDLC - RCP 120 CPDLC - RCP 400 ADS-C - RSP 95 ADS-C - RSP 120
PR_CP_04	ACSP	Availability	-	The ground system shall be capable of detecting ground system failures and configuration changes that would cause the communication service to no longer meet the requirements for the intended function.	Performance analysis
PR_CP_05	ACSP	Availability	-	When the communication service no longer meets the requirements for the intended function, the ground system shall provide indication to the controller.	Performance analysis
SR_CP_01	ACSP	Corruption of message (per flight hour)	2,80E-03	The likelihood that the ACSP corrupts a report shall be less than 2.8E-03/FH	OH_WG78_FIS_3u (severity 3)
SR_CP_02	ACSP	Availability (per flight hour)	7,60E-06	The likelihood that the ACSP is unavailable shall be less than 7.6E-06/FH	OH_WG78_ADSC_02 (severity 4) OH_WG78_CPDLC_02 (severity 4) OH_NEW_ALL_02 (severity 4)

Table 101: Selected ACSP requirements

In addition, WG78/Sc214 has proposed the following additional requirements precising the availability requirement:

List of Availibility Performance Requirements								
Application	**RCP Type**	**Function**	**Part**	**Availability (in percent)**	**Unplanned service outage duration (min)**	**Maximum number of service unplanned outages**	**Maximum accumulated service unplanned outage time(min/yr)**	**Unplanned service outage notification delay (min)**
CPDLC	RCP 120	*Taxi Clearance; ATC Comm;*	ATSU	99,95%	6	40	240	5
			ACSP	99,95%	6	40	240	5
			AC	99,40%	-	-	-	-
	RCP400	*Departure Clearance*	ATSU	99,95%	6	40	240	5
			ACSP	99,95%	6	40	240	5
			AC	99,40%	-	-	-	-
ADS-C	RSP95	*4DTBO, ATC Comm periodic/even*	ATSU	99,95%	6	40	240	5
			ACSP	99,95%	6	40	240	5
			AC	99,40%	-	-	-	-
	RSP120	*4DTBO; ATC Comm single/1st*	ATSU	99,95%	6	40	240	5
			ACSP	99,95%	6	40	240	5
			AC	99,40%	-	-	-	-
D-FIS	RIP180	*ATIS, NOTAM, VOLMET, HZWX, RVR*	ATSU	99,90%	6	40	240	5
			ACSP	99,90%	10	48	520	5
			AC	99,90%	-	-	-	-

Table 102: Additional availability requirements proposed by WG78/Sc214

Note: The 6 minutes maximum service outage is based on the current Transport layer timer for the connection maintenance. Nowadays, in case no Transport message has been received for 6 minutes from the other commutating system, the Transport layer connection is down (event "Provider abort") and there is a need to re-establish the whole connection for the Avionics system. Such re-establishment can need a human action. It is thus desirable to limit as much as possible such disconnection.

Prior implementing AeroMACS to support safety and regularity of flight critical services (e.g. CPDLC, D-TAXI…), a safety and performance analysis shall be performed.

This safety and performance analysis will be led by the local ANSP with the support of the manufacturers supplying notably AeroMACS components and the local communication service provider, operating the AeroMACS system, if different from the ANSP.

Definitions related to performance requirements

Availability. WG78/Sc214 Performance Analysis defines end-to-end availability requirements, for each data link application. These availability requirements are expressed in terms of "availability of use" and "availability of provision".

WG78 Performance Analysis then derives these end-to-end availability requirements on the different CNS/ATM components (Aircraft, ACSP and ATSU) using the following formula:

$$A_{ACSP} = A_{ATSU} = \sqrt{A_{Provision}}, \text{ and}$$

$$A_{Aircraft} = \frac{A_{Use}}{A_{ACSP} * A_{ATSU}}$$

Availability is defined for each ATM component as the following ratio $A = \frac{MTSO}{MTSO+MTSR}$, expressed in percentage with MTSO: Mean Time to Service Outage and MTSR: Mean Time to Service Restoral.

Transaction Time (TT): Sc214/WG78 Performance Analysis defines end-to-end timing requirements, for each data link application. These timing requirements are expressed in terms of:

Normal Transaction time (TT95): it defines the time at which 95 percent of all transactions, that are initiated, are completed

Transaction Time at 99.9% (TT99.9): it defines the time at which 99.9 percent of all transactions, that are initiated, are completed. This duration is closely linked to the continuity requirement (cf. below)

Timing requirement are defined for each function of each application: a RCP-Type (Required Communication Performance) is defined for each function with a specific end-to-end timing requirement, expressed in seconds.

Sc214/WG78 Performance Analysis then derives these end-to-ends timing requirements on the different CNS/ATM components (Composition by the pilot, recognition by the controller, Aircraft, ACSP and ATSU), using statistical allocation. This allocation methodology leads to larger duration on the different components than the classical arithmetic allocation.

Continuity: Sc214/WG78 Performance Analysis defines end-to-end continuity requirements, for each data link application. Continuity is associated with the required level of efficiency or usability of the data communications system. It is defined as the probability that a transaction completes within the expiration time. Consequently, continuity is closely linked to transaction time.

WG78 Performance Analysis then derives these end to end continuity requirements on the different CNS/ATM components (Aircraft, ACSP and ATSU). In this allocation, continuity remains fixed over all ATM components: the allocation is made purely by the transaction time, allocated to each component.

Availability requirement: SOFTWARE allocation

The allocation of software assurance level has been performed using the SWAL allocation process of ED-153. The following table presents the SWAL allocation matrix:

Effect Severity Class / Likelihood of generating such an effect (Pe x Ph)	1	2	3	4
Very Possible	SWAL1	SWAL2	SWAL3	SWAL4
Possible	SWAL2	SWAL3	SWAL3	SWAL4
Very Unlikely	SWAL3	SWAL3	SWAL4	SWAL4
Extremely Unlikely	SWAL4	SWAL4	SWAL4	SWAL4

Table 103: ED-153 SWAL Allocation matrix

According to the safety analysis performed in 15.2.7 WA08, it is “Possible” that an ACSP software failure generates hazards with a severity of 4.

Allocation of Transaction Time requirements

Non compliance with the transaction time figure can be due to:

- The ASN including :

  - Base Station: processing time + time to access to the media + “low” bit rate RF link
  - ASN Gate Way : processing time
  - Airport Local network : processing time
  - Network access : processing time + bit rate of leased line

- The CSN: processing time + bit rate of leased line

Transaction time has been allocated on these different components using arithmetic allocations. Arithmetic allocations result in shorter individual allocation on each element than statistical allocations. However statistical allocation approach relies on the assumption that element delays are independent which cannot be verified in ACSP.

Based on the considerations presented here above, following rules have been applied for the apportionment of the safety and performance requirements:

- CSN : 20% of ACSP transaction time,
- ASN : 80% of ACSP transaction time.

Appendix F One Cell AeroMACS capacity simulation

The next excel tables show the methodology followed to extract the figures from Table 13. These simulations were done in a very first approach of this document.

Hoja de cálculo de
Microsoft Office Exce

Spreadsheet: CALCULATIONS

	QPSK 1/2 DL	QPSK 1/2 UL	16QAM 1/2 DL	16QAM 1/2 UL	64QAM DL	64QAM UL
MAC Throughput [Bytes/s]	2567,05	275,65	2178,75	271,425	2402,85	282,675
App Throughput [Bytes/s]	2470,62	212,2	2094	213,588	2308	218,125
% Frame Ocuppation	2,01	0,31884	0,7779	0,1383	0,5136	0,099234
MAC Overhead [symbols]	2,34	0,5206	0,58194	0,22128	0,33685	0,1475
MAC capacity per cell [bps]	**1021711,443**	**691632,1666**	**2240647,898**	**1570065,076**	**3742757,01**	**2278856,04**
App capacity per cell [bps]	**983331,3433**	**532430,059**	**2153490,166**	**1235505,423**	**3595015,58**	**1758469,88**
range per modulation [m]	2400	2400	1800	1800	600	600
area per modulation [m^2]	7912800	7912800	9043200	9043200	1130400	1130400
% area in macrocell	43,75	43,75	50	50	6,25	6,25
TOTAL AREA [m^2]	18086400	18086400	18086400	18086400	18086400	18086400
MAC capacity in macrocell [bps]	446998,7562	302589,0729	1120323,949	785032,538	233922,313	142428,502
App capacity in macrocell [bps]	430207,4627	232938,1508	1076745,083	617752,7115	224688,474	109904,367
DL MAC capacity in macrocell [bps]	**1801245,018**					
UL MAC capacity in macrocell [bps]	**1230050,113**					
DL App capacity in macrocell [bps]	**1731641,019**					
UL App capacity in macrocell [bps]	**960595,2297**					

Spreadsheet: QPSK

				Base Station UL
QPSK 1/2 DL	MAC Throughput	App Throughput	%Data Frame Occupattion	MAC Overhead [symbols]
300	18000	2157	1,79	2,07
13	24700	2979,1	2,372	2,77
2	20652	2486	2,02	2,35
501	18400	2211	1,824	2,13
173	20930	2520	2,044	2,38
Average	20536,4	2470,62	2,01	2,34
	bits/s	Bytes/s	%	symbols
QPSK 1/2 UL	MAC Throughput	App Throughput	%Data Frame Occupattion	MAC Overhead [symbols]
300	2155	210	0,304	0,486
13	2296	216	0,342	0,578
2	2219	214	0,324	0,525
501	2178	213	0,3142	0,494
173	2178	208	0,31	0,52
Average	2205,2	212,2	0,31884	0,5206
	bits/s	Bytes/s	%	symbols

Spreadsheet: 16QAM

16QAM1/2 DL	MAC Throughput	App Throughput	%Frame Occupattion	MAC Overhead [symbols]
300	14886	1784,5	0,6835	0,5177
13	21890	2636,5	0,945	0,694
2	18754	2255	0,828	0,615
501	14128	1692	0,655	0,503
173	17492	2102	0,778	0,58
Average	17430	2094	0,7779	0,58194
	bits/s	Bytes/s	%	symbols
16QAM 1/2 UL	MAC Throughput	App Throughput	%Frame Occupattion	MAC Overhead [symbols]
300	2147	214,86	0,136	0,2091
13	2250	215,68	0,1455	0,245
2	2185,5	213	0,139	0,2279
501	2136	214,7	0,135	0,205
173	2138,5	209,7	0,136	0,2194
Average	2171,4	213,588	0,1383	0,22128
	bits/s	Bytes/s	%	symbols

Spreadsheet: 64QAM

64QAM1/2 DL	MAC Throughput	App Throughput	%Frame Occupattion	MAC Overhead [symbols]
300	22500	2706	0,586	0,3925
13	17632	2116	0,4777	0,3078
2	21050	2529	0,555	0,368
501	19903	2391	0,5307	0,3487
173	15029	1798	0,4186	0,26725
Average	19222,8	2308	0,5136	0,33685
	bits/s	Bytes/s	%	symbols
64QAM1/2 UL	MAC Throughput	App Throughput	%Frame Occupattion	MAC Overhead [symbols]
300	2303	218,4	0,1033	0,159
13	2196	213,7	0,095	0,14
2	2334	222,5	0,1034	0,155
501	2289	220,8	0,0998	0,15
173	2185	215,5	0,09467	0,1335
Average	2261,4	218,125	0,099234	0,1475

Spreadsheet: RESULTS

Hypothesis
One cell using all the available 5 MHz channel, and DL:UL scheme = 2:1
Three MC types considered: QPSK1/2, 16QAM1/2, 64QAM1/2
MAC overhead active: MAP, ARQ, CRC, symbol wastage
ATC/AOC traffic generation following P15.2.7 Scenario21bis model over TCP/IP
No packet drops or retransmissions
Maximum coverage calculated per MC type in previous LOS environment simulation
- QPSK 1/2: 2400 m
- 16QAM 1/2: 1800 m
- 64QAM1/2: 600 m

Results are given for obtained datarate at two different levels:
- MAC layer: includes IP and TCP overhead
- App layer: Pure user application

Capacity with all the MSs using the same MC scheme

MAC datarate [Mbps]

MC scheme	Downlink	Uplink
QPSK1/2	1,02	0,69
16QAM1/2	2,24	1,57
64QAM1/2	3,74	2,28

App datarate [Mbps]

MC scheme	Downlink	Uplink
QPSK1/2	0,98	0,53
16QAM1/2	2,15	1,24
64QAM1/2	3,60	1,76

App datarate [kbytes per second]

MC scheme	Downlink	Uplink
QPSK1/2	122,92	66,55
16QAM1/2	269,19	154,44
64QAM1/2	449,38	219,81

Capacity in a microcell/macrocell
We consider a microcell placed in RMP area with a coverage of 500m
- Consequently all the MSs are using 64QAM1/2

We consider a macrocell covering GND/TWR areas with a coverage of 2400m
- The MSs are static placed and use MC according to their distance to BS
- MS are uniformly distributed in the area

MAC datarate [Mbps]

Cell type	Downlink	Uplink
Micro	3,74	2,28
Macro	1,80	1,23

App datarate [Mbps]

Cell type	Downlink	Uplink
Micro	3,60	1,76
Macro	1,73	0,96

App datarate [kbytes per second]

Cell type	Downlink	Uplink
Micro	449,38	219,81
Macro	216,46	120,07

Appendix G Requirements Summary

SRD Requirements list refined	
Ref.	Title
R-AFR-PER-10	Downlink one way data latency for NET and ATC services SHALL be < 20 ms.
R-AFR-PER-11	Uplink one way data latency for NET and ATC services SHALL be < 80 ms.
R-AFR-HAN-01	AeroMACS HO interruption time SHALL be < 200 ms.
R-AFR-SCA-02	AeroMACS SHALL be able to scan through the 11 channels as defined within the preferred frequency set in less than 10 s.
R-AFR-SCA-03	AeroMACS SHALL be able to scan the entire bandwidth using a step size of 250 kHz within 35 s (dwell time of 150ms and 236 possible channels).
R-SYN-S&T-02	AeroMACS Synchronisation dwell times SHALL be <150 ms.
R-SYN-S&T-03	AeroMACS dwell times SHALL be long enough to ensure that the probability of false synchronization would be < 0,1 %.
R-SYN-S&T-04	AeroMACS SHALL keep the number of non existing preamble detections (false alarm case) sufficiently low in order not to affect the frequency scanning time.

NEW Requirements list	
Ref.	Title
R-OPS-CVG-01	AeroMACS SHALL guarantee full coverage for more stringent services (like NET and ATC) within the whole operational set of zones. Mainly those zones are RAMP area (operational turnaround zones) and taxiways.
R-OPS-SCR-01	AeroMACS SHALL provide protection against unauthorized entry.
R-OPS-SCR-02	AeroMACS SHALL support security control mechanism in order to avoid unauthorized users to reach and get ATC/AOC/NET services and interact with other parts of the infrastructure.
R-OPS-SCR-03	AeroMACS SHALL perform device authentication. According to ARINC 842, aircraft identification SHALL be performed through tail numbering and optionally including ICAO 24-bit ID.
R-OPS-SCR-04	AeroMACS SHALL support mechanisms and procedures to ensure message integrity and the continuous verification of the sender of the message.
R-OPS-SCR-05	AeroMACS by means of Authorization and Authentication mechanisms SHALL deal with different types of access (USER/ADMIN). Nevertheless user authentication is out of the scope of AeroMACS and hence left to implementation.
R-OPS-SCR-06	AeroMACS, in order to provide secured communications within the air interface (MS/BS) SHALL implement security association with cryptographic suites. Moreover, two types of SA's SHALL be implemented: primary and static.
R-OPS-SCR-07	AeroMACS BS units SHALL handle and manage the security, and connection identifiers of each MS that is successfully authenticated.
R-OPS-SCR-08	AeroMACS SHALL provide transmission confidentiality.

R-OPS-SCR-09	AeroMACS SHALL support Advanced Encryption techniques.
R-OPS-SCR-10	AeroMACS SHALL implement an authentication client-server protocol for supporting AAA procedures. The use of a AAA server will ease other functions like the HA or the HA address in order to accomplish the registration of “foreign” aircrafts within the visited airport.
R-OPS-SCR-11	AeroMACS architecture SHALL give the means to correct billing of data traffic to the respective users (Accounting). Nevertheless the implementation of accounting in an AeroMACS deployment scenario will largely depend on the way airport infrastructure will be handled by airport operators.
R-OPS-SCR-12	AeroMACS SHALL support the exchange of public certificates between MS and the authorization entities.
R-OPS-SCR-13	AeroMACS SHALL support security association mechanisms between MS and BS. Therefore some control policy must be applied in order to give differentiated grade of service and accuracy to the same user.
R-OPS-S&P-01	Prior implementing AeroMACS to support safety and regularity of flight critical services (e.g. CPDLC, D-TAXI…), a safety and performance analysis shall be performed.
R-OPS-S&P-02	The likelihood that the ACSP corrupts a report shall be less than 2.8E-03/FH.
R-OPS-S&P-03	The availability of the ACSP service shall be more than 99.95%.
R-OPS-S&P-04	The likelihood that the ACSP service is unavailable shall be less than 4.3E-04/SOH.
R-OPS-S&P-05	The maximum unplanned ACSP service outage duration shall be 6 minutes.
R-OPS-S&P-06	The maximum number of unplanned ACSP service outage shall be 40 minutes.
R-OPS-S&P-07	The maximum accumulated ACSP service unplanned outage time shall be 240 minutes/year.
R-OPS-S&P-08	The maximum unplanned ACSP service outage notification delay shall be 5 minutes.
R-OPS-S&P-09	The one way transaction time in ACSP shall be less than 9 seconds for 99.9% of the messages.
R-OPS-S&P-10	The one way transaction time in ACSP shall be less than 4 seconds for 95% of the messages.
R-OPS-S&P-11	The ground system shall be capable of detecting ground system failures and configuration changes that would cause the communication service to no longer meet the requirements for the intended function.
R-OPS-S&P-12	When the communication service no longer meets the requirements for the intended function, the ground system shall provide indication to the controller.
R-OPS-S&P-13	Latency. The maximum time to complete a transaction using AeroMACS datalink. The rate at which a transaction expiration time can be exceeded is determined by the continuity parameter.
R-OPS-S&P-14	Transaction expiration time (defined in OSED [10]). AeroMACS SHALL provision the means to, given a maximum time for completing a transaction, start up an alternative procedure to accomplish the transaction. This is related to the continuity parameter.
R-OPS-S&P-15	Packet size (see capacity analysis on 3.7.2.3). AeroMACS average ATC message size is 190 Bytes. AeroMACS average AOC message size is 278 kBytes.
R-OPS-REG-01	AeroMACS architecture might not provide the AAA logical entity of any user’s DB. Besides, it SHALL act as the gateway to reach seamlessly the policy authority of the network, independently of where the server or the DB is hosted.
R-OPS-REG-02	AeroMACS SHALL give means to create, configure and delete accurately user profiles with different grades of service in the access network.
R-OPS-REG-03	Aircraft device SHALL automatically register and de-register from AeroMACS system without intervention of human agents.

R-OPS-MOB-01	AeroMACS SHALL be capable to operate within the FCI multilink architecture and associated data links whenever these other FCI datalinks are available.
R-OPS-MOB-02	AeroMACS architecture SHALL support seamless HOs at up to minimum maximum vehicular speeds.
R-OPS-MOB-03	AeroMACS SHALL guarantee service availability for vehicles and home/visiting aircrafts within the airport.
R-OPS-MOB-04	AeroMACS SHALL meet availability and continuity figures stated on COCRv2 [1] for services for both vehicles and aircrafts.
R-OPS-MOB-05	AeroMACS SHALL be based on an all IP radio and ground Internet Protocol (IP) compliant infrastructure as defined in ICAO DOC 9896 [11]
R-OPS-MOB-06	AeroMACS SHALL support hard handover between BSs and sectors. The HO procedure shall be initiated by the BS.
R-OPS-MOB-07	AeroMACS handover SHALL be transparent for applications. Notably, it shall not jeopardize compliance with continuity of service requirements.
R-OPS-MOB-08	Service flows connections shall be kept and guarantee their continuity without service disruption from the user's point of view.
R-OPS-MOB-09	AeroMACS SHALL guarantee the context retrieval procedure, that is to say, the integrity and seamless transfer of AK contest from serving BS to target BS through ANS-GW.
R-OPS-MOB-10	AeroMACS SHALL guarantee the transfer of the authorization policy and the mapping of the SA's currently established of the MS triggering the HO.
R-OPS-SYN-01	AeroMACS MS SHALL be able to synchronies at the limit of the AeroMACS cell size.
R-OPS-SYN-02	AeroMACS synchronization dwell times SHALL be as short as possible.
R-OPS-SYN-03	All the BSs SHALL get synchronized using a unique time reference.
R-OPS-SYN-04	AeroMACS SHALL perform a resynchronization procedure of the MS after a signal loss.
R-OPS-SYN-05	AeroMACS handover interruption time SHALL be kept sufficiently low to guarantee no service disruption within the whole operational turnaround of the aircraft in the airport surface.
R-OPS-QOS-01	AeroMACS SHALL provide means to guarantee data integrity.
R-OPS-QOS-02	AeroMACS BSs SHALL be capable to establish different dynamic service flows (SF) to the MSs (with different parameters of throughput, jitter, delay, etc.)
R-OPS-QOS-03	AeroMACS SHALL guarantee the dynamic change of a SF attending to different traffic patterns and requisites.
R-OPS-QOS-04	AeroMACS SHALL implement different traffic schedule in order to accomplish differentiated class of service support.
R-OPS-QOS-05	All messages of each transaction SHALL be assigned to a common AeroMACS Class of Service (CoS)
R-OPS-PMO-01	The monitoring capability of the AeroMACS SHALL NOT impede the working of the AeroMACS system.
R-OPS-SPV-01	AeroMACS SHALL support VPN or VLAN in case it`s required for system supervision purposes. Please, be referred to security issues addressed on WA8 documentation.
R-OPS-SPV-02	The supervision capability of the AeroMACS SHALL NOT impede the working of the AeroMACS system.

R-INST-DEP-01	AeroMACS BS deployment locations shall comply to ICAO Annex 14, chapter 4.
R-INST-DEP-02	AeroMACS BS deployment locations shall comply to ICAO PANS-OPS 8168.
R-INST-DEP-03	AeroMACS BS shall be deployed in such a way that a maximum of A/C within a cell shall operate under Line of Sight (LOS) conditions.
R-INST-DEP-04	AeroMACS BS antenna mounting heights above metallic terminal roofs shall be avoided, especially these at close range. This to keep interference to Globalstar within limits.
R-INST-DEP-05	AeroMACS antenna installations (BS and MS) shall always use vertical antenna polarisation.
R-INST-DEP-06	Where possible and in order to decrease AeroMACS interference to Globalstar, AeroMACS BSs antenna shall be installed having a small downtilt (2 to 6 degrees) angle.
R-INST-DEP-07	In order to avoid polarisation losses the down tilt angle of the BS shall not be larger than 6 degrees.
R-INST-DEP-08	AeroMACS BS shall be mounted on existing airport infrastructure (buildings, towers, lighting infrastructure, ..etc) wherever feasible (while fulfilling both coverage and throughput requirements) to keep airport installation cost minimal.
R-INST-DEP-09	AeroMACS BS site deployment shall be such that there will be minimal cellular coverage overlap. (Note: In order to keep interference with Globalstar to a minimum, AeroMACS will not implement dual coverage during airport cell planning phases – hence both ATC and AOC traffic will use the same frequency).
R-INST-DEP-10	AeroMACS BS site deployment shall be such that overlap with adjacent BS – both operating under QPSK conditions is kept to a minimum at TOWER and GROUND areas which are further than 500 m away from Gates.
R-INST-DEP-11	AeroMACS BS site deployment shall be such that hand over under normal RF conditions is always possible.
R-INST-DEP-12	AeroMACS BS site deployment shall be optimised in such a way that LOS conditions prevail on most of BS cell coverage under normal (non blocking) airport operating conditions and this for every airport the BS is intended to serve (taking into account A/C heights at the gates / stands).
R-INST-DEP-13	AeroMACS BS site deployment shall ensure the largest data rate throughput at the RAMP area.
R-INST-DEP-14	AeroMACS BS site deployment at the airport´s RAMP area shall target 64 QAM operation for DL under all RF conditions with the exclusion of temporary RF blocking by large object movements. .
R-INST-DEP-15	AeroMACS BS site deployment at the airport´s RAMP area shall target 16 QAM operation for UL (if path loss conditions allow).
R-INST-DEP-16	AeroMACS medium data rate (16 QAM operation) throughput shall be made available at large part (close to gates) of the airport GROUND area.
R-INST-DEP-17	AeroMACS BS site deployment at the airport´s GROUND area shall ensure 16 QAM operations for both DL and UL under all RF conditions (except during RF blocking by e.g. A/C tail) and this within a range of 500 m around terminal buildings.
R-INST-DEP-18	AeroMACS lowest data rate throughput (QPSK) shall be made available at the airport´s TOWER area for both UL and DL.
R-INST-DEP-19	AeroMACS cell planning shall try to locate its BS's, covering GROUND area, in such a way that Doppler effects due to moving MS are minimised.
R-INST-DEP-20	AeroMACS cell planning shall be such that at remote GROUND and TOWER areas, the MS is able to synchronize under normal propagation conditions.
R-INST-DEP-21	Airport Authority shall not permit to carry out any work/installation unless a thorough study on Aeronautical Easement has been performed.

R-INST-DEP-22	AeroMACS system SHALL NOT be deployed in the runway areas defined in section 9.9.5 of ICAO Annex 14 “Aerodromes”, Fourth Edition July 2004 and section 5.3.7 of ICAO “Aerodrome Design Manual” Part 1 Runways, Third Edition 2006.
R-INST-DEP-23	AeroMACS BS shall support mounting on frangible structures (i.e. frangible masts) while fulfilling both coverage and throughput requirements.
R-FMG-REG-01	AeroMACS centre frequencies shall be allocated by ICAO FMG.
R-FMG-REG-02	AeroMACS centre frequencies shall be allocated by Network Management.
R-FMG-REG-03	Before AeroMACS BS can be deployed at any airport in Europe, the local airport service provider or national ANSP shall inform relevant authority on their intentions for that particular airport.
R-FMG-REG-04	Before AeroMACS BS can be deployed at any airport in Europe, the local airport service provider or national ANSP shall also send an e-mail indicating their intentions for that particular airport to ‘ frequencies@eurocontrol.int’
R-FMG-REG-05	Intentions for AeroMACS deployment shall be communicated to ICAO FMG and EUROCONTROL at least one year in advance of scheduled deployment.
R-FMG-REG-06	The local airport service provider or national ANSP shall provide ICAO FMG all available information on MLS deployment at the airport- including intentions for future installations.
R-FMG-REG-07	States deploying AMT or intending to deploy AMT shall inform ICAO FMG of their intended AMT frequency usage as soon as poss ble in order to enable proper AeroMACS frequency assignments at a very early stage.
R-FMG-REG-08	The local airport service provider or national ANSP shall provide ICAO FMG all available information on AMT deployment at the airport- including intentions for future installations.
R-FMG-REG-09	The local airport service provider or national ANSP shall provide ICAO FMG the cell planning study results for each airport where it intends to install AeroMACS.
R-FMG-REG-10	The local airport service provider or national ANSP shall ensure that the provider of the cell planning is aware of AeroMACS spectrum limitations as foreseen by ITU-R and ICAO FMG.
R-FMG-REG-11	For all European airports AeroMACS cell planning shall make sure that cell overlaps are kept to a strict minimum.
R-FMG-REG-12	AeroMACS cell planning shall not consider full dual coverage in Europe.
R-FMG-REG-13	AeroMACS cell planning shall follow the advice on frequency re-use factor as provided by ICAO FMG for each airport willing to deploy AeroMACS.
R-FMG-REG-14	AeroMACS cell planning shall try to make maximum use of possible building blocking loss factors by selecting appropriate BS position locations.
R-FMG-REG-15	To limit AeroMACS inter-cell interference AeroMACS cell planning shall avoid the use of adjacent channel frequencies at the same airport when using small frequency re-use factors.
R-FMG-REG-16	The local airport service provider or national ANSP shall provide ICAO FMG with the amount of BSs to be deployed at each airport where it intends to install AeroMACS.
R-FMG-REG-17	The local airport service provider or national ANSP shall provide ICAO FMG with the exact geographical location of each airport where it intends to install AeroMACS.
R-FMG-REG-18	The local airport service provider or national ANSP shall provide ICAO FMG with the power amplifier emitted output power for each BS.
R-FMG-REG-19	The local airport service provider or national ANSP shall provide ICAO FMG with the cable loss for each cable installed between PA and BS antenna for each AeroMACS BS deployed.
R-FMG-REG-20	The local airport service provider or national ANSP shall provide ICAO FMG for each BS location the intended antenna type (omni or directional) it intends to deploy at each airport where AeroMACS will

	be installed.
R-FMG-REG-21	The local airport service provider or national ANSP shall provide ICAO FMG for each antenna its antenna gain pattern (elevation and azimuth over 360 degrees) it intends to deploy at each airport where AeroMACS will be installed.
R-FMG-REG-22	The local airport service provider or national ANSP shall provide ICAO FMG for each directional antenna its intended pointing angle vis-à-vis North (values should be within 5 degrees accuracy).
R-FMG-REG-23	The local airport service provider or national ANSP shall provide ICAO FMG for each directional antenna its intended tilting angle vis-à-vis ground plane (values should be within 1 degree accuracy).
R-FMG-REG-24	The local airport service provider or national ANSP shall provide ICAO FMG an estimation of Building Blocking factor loss for each directional antenna it intends to deploy at each airport where AeroMACS will be installed. Note: Building blocking loss estimations can vary between 6 and 20 dB (see tables 20 and 21).
R-FMG-REG-25	During AeroMACS cell planning a conservative approach shall be taken with respect to building loss values as provided in tables 18 and 19 – hence the provided values shall be decreased with at least 3 dB for values up to 10 dB and with 6 dB for values between 10 and 20 dB.
R-FMG-REG-26	Whenever a building blocking factor loss value is used, the local airport service provider or national ANSP shall provide ICAO FMG - for this particular antenna position - with the installed antenna height.
R-FMG-REG-27	Whenever a building blocking factor loss value is used the local airport service provider or national ANSP shall provide ICAO FMG - for this particular antenna position - the building height this particular antenna points to.
R-FMG-REG-28	Whenever a building blocking factor loss value is used the local airport service provider or national ANSP shall provide ICAO FMG - for this particular antenna position – with the distance between this particular antenna location and the building façade this antenna points to.
R-ARC-ASN-01	AeroMACS surface datalink is independent from any network technology on the backbone or ground side.
R-ARC-ASN-02	AeroMACS architecture SHALL give the means to avoid security risk propagation from vulnerable AeroMACS ASN elements (mainly ASN-Gateway) to the backbone of the Communication infrastructure.
R-ARC-ASN-03	During basic and primary connections, MAC management messages are sent in plain text leading a third party the reading of them. X.509 certificates give a potential solution and therefore AeroMACS SHALL support the Public Key Infrastructure utilizing X.509 certificates.
R-ARC-ASN-04	In order to give support to USER and DEVICE authentication, proper means shall be foreseen. Thus, MS and AAA server SHALL support EAP-TTLS framework.
R-ARC-ASN-05	During Hand-over procedure, ASN-GW shall update the AK from the MS to the new serving BS. Therefore the whole set of keys is transferred to the BS (TEK) through PKM protocol. Besides it shall command the BS to destroy current SF and trigger the new BS to create the new SF.
R-ARC-ASN-06	AeroMACS infrastructure SHALL support different Network addressing schemes in order to give support to network addressing for vehicles and home and visiting aircrafts without distinction. Mobile IP shall be implemented in compliance with ICAO standard for communication with Aircraft
R-ARC-ASN-07	Mobile IP shall be implemented in compliance with ICAO standard for communication with Aircraft
R-ARC-ASN-08	AeroMACS SHALL support IPv4 address in order to be interoperable with legacy systems and for vehicles on the airport domain.
R-ARC-ASN-09	An airport vehicle SHALL get a dynamic IPv4 address.
R-ARC-ASN-10	The vehicles which have been allocated the same address SHALL not operate on the same aerodrome.
R-ARC-ASN-11	AeroMACS SHALL support IPv6.

R-ARC-ASN-12	AeroMACS SHALL support multiple NSPs for provisioning ATC/AOC services over the same data link. AeroMACS infrastructure SHALL provide the availability to the subscriber to select the preferred CSN/NSP.
R-ARC-ASN-13	AeroMACS infrastructure SHALL provide the availability to the subscriber to select the preferred CSN/NSP.
R-ARC-ASN-14	ASN-GW SHALL support GRE tunnelling on R6 interface.
R-ARC-ASN-15	ASN routers SHALL support dual network layer stack for connecting IPv6 core networks to AeroMACS ASN core network which goes over IPv4 stack.
R-ARC-ASN-16	MSs SHALL support UDP/TCP transport connections.
R-ARC-ASN-17	All the BSs SHALL get synchronized using a unique time reference getting an error of the clocks of 1ppm at the most.
R-ARC-ASN-18	AeroMACS synchronization dwell times SHALL be as short as possible (<150ms). Some requirements can be extracted from ICAO's Annex 10
R-ARC-ASN-19	The maximum resynchronization time for the MS after signal loss SHALL be less than 10 s.
R-ARC-ASN-20	AeroMACS SHALL guarantee data transfer delays not exceed the values stated in section 2.2.6.
R-ARC-ASN-21	AeroMACS maximum network entry time for a MS SHALL be less than 60 s.
R-ARC-ASN-22	AeroMACS handover interruption time SHALL take no more than 200ms.
R-ARC-ASN-23	The maximum bit error rate that AeroMACS supports SHALL not exceed is 10-9 for undetected errors and 10-7 for detected errors.
R-ARC-ASN-24	AeroMACS SHALL enable advanced RRM by enabling the collection of reliable statistics over different timescales, including system (e.g., dropped call statistics, BS loading conditions, channel occupancy, RSSI), user (e.g., terminal capabilities, mobility statistics), flow, packet, etc.
R-ARC-ASN-25	AeroMACS architecture SHALL NOT preclude inter-technology HOs. This is FFS.
R-ARC-ASN-26	AeroMACS network architecture SHALL support IPv4 CS and IPv6 CS and MAY support ETH_CS
R-INT-VIOT-01	The architecture SHALL support common functionalities according to what is currently stated down below as requirements between BSs and between BS and ASN-GW from different manufacturers.
R-INT-VIOT-02	AeroMACS BS SHALL support Data path registration ***type1***
R-INT-VIOT-03	AeroMACS BS SHALL support Data path deregistration for triggering MS network exit.
R-INT-VIOT-04	AeroMACS BS SHALL support HO preparation
R-INT-VIOT-05	AeroMACS BS SHALL support HO action.
R-INT-VIOT-06	AeroMACS BS SHALL support HO cancellation.
R-INT-VIOT-07	AeroMACS BS SHALL support HO rejection.
R-INT-VIOT-08	AeroMACS BS SHALL perform Authentication Relay.
R-INT-VIOT-09	AeroMACS BS SHALL support AK transfer primitives and key reception.
R-INT-VIOT-10	AeroMACS BS SHALL support NSP id list.
R-INT-VIOT-11	AeroMACS BS SHALL implement the Context functionality.

R-INT-VIOT-12	AeroMACS ASN-GW SHALL perform Authentication and key distribution
R-INT-VIOT-13	AeroMACS ASN-GW SHALL support Network Entry signalling
R-INT-VIOT-14	AeroMACS ASN-GW SHALL support Proxy MIPv4 Client
R-INT-VIOT-15	AeroMACS ASN-GW SHALL support MIP registration revocation
R-INT-VIOT-16	AeroMACS ASN-GW SHALL support DHCPv4 Proxy/Relay
R-INT-VIOT-17	AeroMACS ASN-GW SHALL support Service Flow Authorization.
R-INT-VIOT-18	AeroMACS ASN-GW SHALL support Data path registration ***type1.***
R-INT-VIOT-19	AeroMACS ASN-GW SHALL support Data path deregistration for triggering MS network exit.
R-INT-VIOT-20	AeroMACS ASN-GW SHALL support HO preparation.
R-INT-VIOT-21	AeroMACS ASN-GW SHALL support HO action.
R-INT-VIOT-22	AeroMACS ASN-GW SHALL support HO cancellation.
R-INT-VIOT-23	AeroMACS ASN-GW SHALL support HO rejection.
R-INT-VIOT-24	AeroMACS ASN-GW SHALL support Context transfer.
R-INT-VIOT-25	AeroMACS ASN-GW SHALL support CMAC key count update.

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