International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Report ITU-R M.2168-1
(11/2010)

Compatibility between a proposed new aeronautical mobile (R) service (AM(R)S) system and both radionavigation-satellite service (RNSS) operating in the 5 000-5 010 MHz band and radio astronomy in the adjacent band 4 990-5 000 MHz

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

<table>
<tr><td colspan="2" align="center">**Series of ITU-R Reports**</td></tr>
<tr><td colspan="2" align="center">(Also available online at http://www.itu.int/publ/R-REP/en)</td></tr>
<tr><td>**Series**</td><td align="center">**Title**</td></tr>
<tr><td>**BO**</td><td>Satellite delivery</td></tr>
<tr><td>**BR**</td><td>Recording for production, archival and play-out; film for television</td></tr>
<tr><td>**BS**</td><td>Broadcasting service (sound)</td></tr>
<tr><td>**BT**</td><td>Broadcasting service (television)</td></tr>
<tr><td>**F**</td><td>Fixed service</td></tr>
<tr><td>**M**</td><td>**Mobile, radiodetermination, amateur and related satellite services**</td></tr>
<tr><td>**P**</td><td>Radiowave propagation</td></tr>
<tr><td>**RA**</td><td>Radio astronomy</td></tr>
<tr><td>**RS**</td><td>Remote sensing systems</td></tr>
<tr><td>**S**</td><td>Fixed-satellite service</td></tr>
<tr><td>**SA**</td><td>Space applications and meteorology</td></tr>
<tr><td>**SF**</td><td>Frequency sharing and coordination between fixed-satellite and fixed service systems</td></tr>
<tr><td>**SM**</td><td>Spectrum management</td></tr>
</table>

Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.

Electronic Publication
Geneva, 2011

© ITU 2011

REPORT ITU-R M.2168-1

**Compatibility between a proposed new aeronautical mobile (R)
service (AM(R)S) system and both radionavigation-satellite service (RNSS)
operating in the 5 000-5 010 MHz band and radio astronomy
in the adjacent band 4 990-5 000 MHz***

(2009-2010)

TABLE OF CONTENTS

Page

---

*   This Report should be brought to the attention of Radiocommunication Study Groups 4 and 7.

Objective

This Report addresses the feasibility of an allocation for AM(R)S for surface applications at airports with particular emphasis on technical and operational issues relating to the protection of RNSS in the band 5 000 and 5 010 MHz and of the radio astronomy service in the band 4 990-5 000 MHz from AM(R)S.

1   Introduction

1.1   Studies within ITU-R have identified a number of AM(R)S applications for airport surfaces. These range from uploads of routing and electronic flight bag information, to scheduling de-icing facilities, and surface mapping to preclude runway incursion and aid in obstacle avoidance. In general those applications share the characteristics of short-range (a few kilometres maximum) and high bandwidth per airport. Limitation to ground transmission and the geographic separation of airports will likely facilitate airport-to-airport channel reuse.

1.2   To accommodate future growth in surface applications, the 5 000-5 010 MHz band has been selected for evaluation as potential additional spectrum for the airport surface local area network (LAN) currently being developed for operation in the 5 091-5 150 MHz band. The 5 000-5 010 MHz band currently has aeronautical radionavigation service (ARNS), aeronautical mobile-satellite (R) service (AMS(R)S, reference Radio Regulations No. 5.367), and radionavigation-satellite service (RNSS) Earth-to-space (E-s) allocations. Taking into account that a final determination on compatibility cannot be made until both the AM(R)S and RNSS systems are fully defined, this paper presents the results of initial considerations on compatibility between a proposed new AM(R)S system and RNSS (E-s) systems operating simultaneously in the 5 000-5 010 MHz band. In addition, considerations on compatibility of the proposed new AM(R)S system with the radio astronomy service (RAS) operating in the adjacent 4 990-5 000 MHz band are also examined.

2   System characteristics

2.1   AM(R)S system

2.1.1   In order to address the mix of aviation applications intended for the airport surface, an airport safety service LAN is being developed for operation in the 5 091-5 150 MHz band. Based on projected spectrum requirements for such a system, its operation in the 5 000-5 010 MHz band is also under consideration. One candidate architecture is the airport network and location equipment (ANLE) system. ANLE is visualized as a high-integrity, safety communications, wireless LAN for the airport area, combined with an interconnected grid of multilateration sensors. Simple transmitters would be added to surface-moving vehicles, allowing for the development of a high-fidelity, complete picture of the airport surface environment. In order to speed development and reduce the cost of the ANLE, the system would be based on existing Institute of Electrical and Electronics Engineers (IEEE) "802 series" standards[1]. As noted in Report ITU-R M.2118, because of the "mobility" capabilities built into IEEE 802.16e, it is expected that it will prove to be compliant with aviation requirements. As a result, the remainder of this analysis will reference that protocol. Example AM(R)S parameters are shown in Table 1. Due to the signal modulation utilized, it is expected that the AM(R)S signal will look noise-like to RNSS and RAS receivers.

---

[1]   While the system would be based on the IEEE 802 series standards, it is expected that system elements would be tailored for the aviation application. Such tailoring might include bandpass filtering to facilitate sharing with adjacent band MLS, improved receiver sensitivies, and sectorized antennas.

TABLE 1

Example AM(R)S based on IEEE 802.16 e parameters

Parameter	ANLE
Operational bandwidth (MHz)	$20^{(1)}$
Receiver sensitivity R_{xs} (dBm)	$-83.4^{(2)}$
Base station antenna gain G_t (dBi)	8.0
Subscriber unit antenna gain G_r (dBi)	6.0
Assumed link margin (dB)	11
Path loss exponent	2.3
Free-space characteristic distance d_0 (m)	462
Transmitter power required P_t	32.2 dBm$^{(3)}$

[1]   Though this is larger than the band being examined (5 000-5 010 MHz), it results in the worst-case (i.e. highest) transmitter power requirements for the AM(R)S system. Since the maximum sub-carrier power and spacing remains constant (see Appendix A), the total power transmitted in the 5 000-5 010 MHz band would be 3 dB less.

[2]   This sensitivity is for a receiver using all the sub-carriers within a 20 MHz bandwidth. Receiver sensitivity varies versus sub-carrier/channel bandwidth, so a receiver using only all the sub-carriers in the 5 000-5 010 MHz band would be 3 dB more sensitive.

[3]   This is the power required to close the link to users at 3 km assuming worst-case receiver sensitivity. The scalable OFDMA implementation and power control (as described in the IEEE 802.16e standard) will reduce the power based on actual transmitted bandwidth (by a factor of 10 log (No. used subcarriers/total subcarriers)), and based on actual measured signal-to-noise (such that the minimum signal-to-noise is maintained for the selected modulation).

2.1.2   Regarding the time waveform of the AM(R)S signal, for a system based on IEEE 802.16e standards it is envisioned that there really will be no "basic" message duration, rather the parameters are selectable from a "menu" of options. This flexibility of the AM(R)S system is anticipated to exist both in channel bandwidth (i.e. the spectral domain), and message frame duration (i.e. the time domain). In general each frame consists of a forward link (FL; base-to-subscriber) and a reverse link (RL; subscriber-to-base) portion shared on a time division duplex manner where FL and RL transmissions occur on the same frequency channel, but in different (time) portions of the frame. A typical division might be 2/3 FL, and 1/3 RL. It is also envisioned that there will be a brief guard time between all FL and RL frames. Depending on the channel bandwidth during a message frame, a number of message symbols are transmitted. Those symbols are distributed in frequency across the sub-carriers for the selected channel bandwidth. Further details on IEEE 802.16e are contained in Appendix A.

2.2   RNSS systems

Details of the RNSS parameters used for this Report are provided below. The $\Delta T/T$ analysis presented in § 4 provides compatibility analysis results for all RNSS systems in the band 5 000-5 010 MHz. The resulting maximum allowable aggregate interference using the $\Delta T/T$ criterion is calculated.

2.2.1   The 5 000-5 010 MHz band is allocated to RNSS (E-s), and as such would be used for RNSS feeder links. System parameters used for the analysis are shown in Table 2.

2.2.2 The aggregate interference levels to RNSS systems operating in the band 5 000-5 010 MHz from all radio sources of primary services in the band other than in the RNSS should not exceed 6% (i.e. *I*/*N* of −12.2 dB) of the worst-case RNSS receiver system noise. Considering that ARNS and AMS(R)S already exist in this frequency band, 2% of the RNSS receiver system noise due to the aggregate AM(R)S interference should be applied.

TABLE 2

RNSS parameters for compatibility analysis

Parameter	Galileo	GPS	QZSS
Coverage	global	global	Regional
Noise temperature (K)	580	590	400
Bandwidth (MHz)	10	1.1	0.4/channel
Feeder loss (LFeed, dB)	1	1	0[(1)]
Maximum RNSS antenna gain (Gr, dBi)	12.8	13.6	16.8[(1)]
Minimum satellite altitude (km)	23 222	20 200	31 600

[(1)]   For QZSS, feeder loss is included in the antenna gain value.

2.3   Radio astronomy

Details, parameters and approach for compatibility analyses with RAS are contained in relevant ITU-R RA-series Recommendations, in particular Recommendation ITU-R RA.769. Of particular note is that the RAS has a long history of compatible operation with adjacent band mobile applications, as reflected by the large number of frequency bands where such operations occur. Of particular note the 4 990-5 000 MHz and the adjacent 4 800-4 990 MHz band are both currently in use by some administrations, on a primary basis to the mobile (except aeronautical mobile) service. This is important because while the service being considered in this Report is aeronautical mobile (i.e. AM(R)S), restriction of that service to surface application at airports results in compatibility conditions similar to those for the "mobile (except for aeronautical mobile)" service.

3   Analysis methodology

3.1   Analysis parameters

For the analysis, the RNSS was assumed to have the characteristics of Table 2 and the resultant limits on the AM(R)S were derived. For Earth-to-space paths standard free-space propagation was assumed. Total path loss is then computed as the propagation path loss plus any polarization and cable losses.

3.2   Interference to AM(R)S

While sharing studies must take into account both directions, the assessment of RNSS-to-AM(R)S compatibility was relatively simple. In the 5 000-5 010 MHz band the RNSS transmissions come from a high-gain, well-focused dish antenna, generally geographically separated from major airports, so the RNSS transmissions would not cause unacceptable levels of interference to a ground-based airport AM(R)S receiver. In the case that an RNSS feeder-link earth station needs to be in close proximity to a major airport, it is expected that local coordination – up to and including

not using specific AM(R)S channels at that airport – can be employed to solve any remaining issues. While reducing the number of channels will reduce maximum useable AM(R)S data rates and may reduce overall efficiency at those airports, those excluded AM(R)S channels could potentially be used at other airports.

3.3 Interference to RNSS

Using the RNSS parameters in Table 2 and the methodology of Recommendation ITU-R M.1827 (which was developed in-part to facilitate compatibility between AM(R)S and fixed satellite service feeder links in the 5 091-5 150 MHz band), aggregate instantaneous power limits for the AM(R)S were determined. Those limits were based on not increasing the noise temperature of the RNSS satellite system receivers by more than 2%.

3.4 Interference to radio astronomy

As noted above, the AM(R)S system planned for the 5 000-5 010 MHz band is an airport surface LAN. The LAN will be used for a number of applications and limited to surface applications at major airports. Those characteristics will serve to help ensure protection of radio astronomy (RA) operating in the adjacent 4 990-5 000 MHz band since, in general, RA observatories are not located in close proximity to large airports due to the myriad of other radio-frequency signals present at those sites. As a result, in most cases geographic separation will suffice to ensure the compatibility of the planned AM(R)S systems with RA stations. In the few instances where RA observatories are in relative proximity of major airports (e.g. Arecibo observatory in the United States or Jodrell Bank in the United Kingdom), it is expected that local coordination can be employed to solve any remaining issues.

4 Compatibility study results and discussion

4.1 RNSS

The methodology in Recommendation ITU-R M.1827 is used to compute the allowed power flux density (pfd) limit for the AM(R)S based on the RNSS protection criteria ($\Delta T_s/T_s = 2\%$) and 250 in-view AM(R)S stations transmitting simultaneously at a given satellite in the 5 000-5 010 MHz[2] band. Assuming Table 2 characteristics for the RNSS, the maximum aggregate interference level acceptable at the receiver input is $I_{Agg\text{-}Rec}$:

$$I_{Agg-Rec} = KTB - 17 \text{ dB}$$

where:

K: Boltzmann's constant (1.38×10^{-23} J/K);

T: represents the receiver noise temperature (K);

B: receiver bandwidth (Hz).

---

[2] Recommendation ITU-R M.1827 (Annex 1, Section II) assumes a maximum of 250 co-channel AM(R)S stations transmitting concurrently toward the FSS satellite, based on an assumption of 500 airports and a 50% duty cycle. 500 airports was based on the maximum number of existing towered airports in the United States. Because frequency assignment plans call for the 5 000-5 010 MHz to be used only at very large airport where the 5 091-5 150 MHz is not sufficient, this assumption can be used for an average value for medium earth orbit RNSS systems like GPS and Galileo. However, the appropriate assumption for RNSS systems with higher altitude like QZSS should be studied further using the RNSS parameters for those specific systems.

Table 3 provides the results of that calculation for each RNSS system.

TABLE 3

Maximum aggregate AM(R)S level tolerable at the RNSS receiver input

	Galileo	**GPS**	**QZSS**
$I_{Agg\text{-}Rec}$	−148 dBW/10 MHz	−157.5 dBW/1.1 MHz	−163.6 dBW/400 kHz

Therefore, at the satellite receiver antenna input, the allowed maximum power flux density (pfd) level in any given direction produced by the aggregate transmissions from all AM(R)S transmitters at any single airport is:

$$pfd_{max} = I_{Agg-Rec} - G_r + L_{Feed} + L_P - 10\log(250) + 10\log\left(\frac{4\pi}{\lambda^2}\right) - 10\log(B)$$

Assuming 1 dB polarization loss for each case, the result of that calculation for each RNSS satellite system is shown in Table 4.

TABLE 4

Maximum pfd level in any given direction produced by the aggregate transmissions from all AM(R)S transmitters at any single airport at the satellite receiver antenna input

	Galileo	**GPS**	**QZSS**
pfd_{max}(dBW/(m² · Hz))	−217.3	−218.0	−223.9

An alternative way to express the limit is to derive the equivalent isotropically radiated power (e.i.r.p.) density at the AM(R)S transmitters such that the pfd limits are preserved. Because the distance from the satellite differs depending on the geometry of the interaction (i.e., distance is smallest when the satellite is directly above the AM(R)S and maximized at the horizon), the acceptable radiated power varies. For circular orbits, the distance is smallest whenever the satellite is directly above the AM(R)S and maximized at the horizon, but this is not generally true for elliptical orbits (such as QZSS) for which the distance to the satellite is also a function of latitude and longitude of both the satellite and the AM(R)S transmitter.

The relation between the maximum acceptable received pfd power, from all AM(R)S transmitters at any single airport, and the maximum acceptable e.i.r.p. (dBm) is given by:

$$eirp_{max} = pfd_{max} + 10\log\left(4\pi R^2 B_{Tx}\right) + 30$$

where:

R: distance (m) between the transmit and satellite antennas;

B_{Tx}:   bandwidth (Hz) of the AM(R)S transmission; e.g., 10 MHz.

Table 5 presents the results of that derivation for elevations of ninety degrees (directly above the AM(R)S) and 0° (horizon).
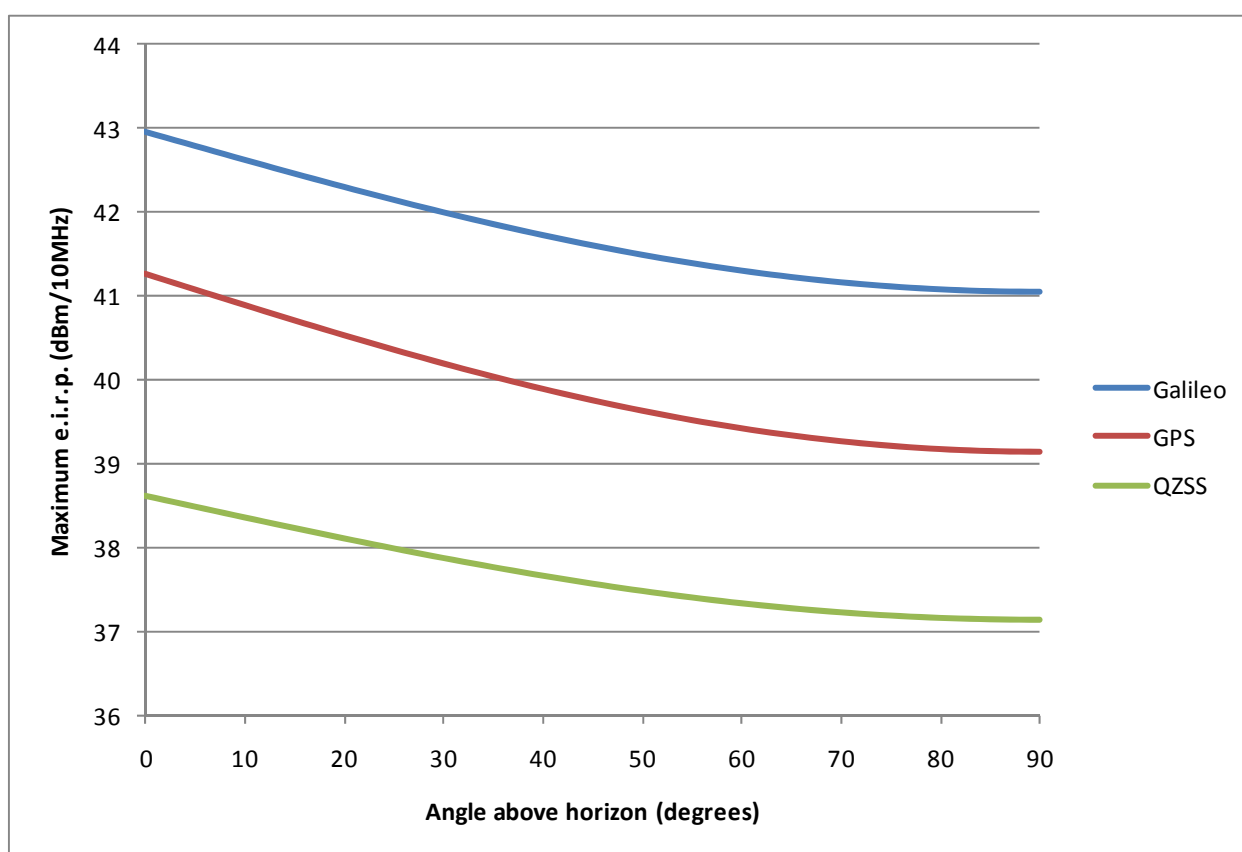
TABLE 5

**Elevation angle dependence of maximum acceptable AM(R)S e.i.r.p. density
to ensure levels in Table 4**

Elevation (degrees)	Maximum AM(R)S e.i.r.p. (dBm/10 MHz)		
	Galileo	**GPS**	**QZSS**
90	41	39.1	37.1
5	42.7	41.0	38.4
0	42.9	41.2	38.5

Figure 1 shows the function of Maximum AM(R)S e.i.r.p. (dBm/10 MHz) vs elevation angle (angle above the horizon).

FIGURE 1

Maximum AM(R)S e.i.r.p. (dBm/10 MHz) vs elevation angle

In order to take a more realistic approach, it would be possible to take into account averaged RNSS satellite antenna gain over range of angles to visible Earth's surface. Table 6 shows the results of the above pfd_{max} equation using this averaged RNSS satellite antenna gain for AM(R)S elevation angles of 0 to 5° (nearly the edge of visible Earth's surface from RNSS satellite) (see notes below Table 6 and Fig. 2).

TABLE 6

Elevation angle dependence of maximum acceptable AM(R)S e.i.r.p. density to ensure RNSS ΔT/T protection criterion of 2% with the use of RNSS satellite Rx antenna gain averaged over the range of angles to the visible Earth's surface

	Galileo	**GPS**	**QZSS**
Satellite Rx antenna gain (dBi) averaged over the range of angles to visible Earth's surface (dBi)	11.9	13.0	14.6
pfd_{max}(dBW/(m^2 · Hz)) with the averaged RNSS satellite antenna gain shown in the above row	−216.4	−217.4	−221.7
Maximum AM(R)S e.i.r.p. (dBm/10 MHz) at 5° elevation	43.6	41.6	40.6
Maximum AM(R)S e.i.r.p. (dBm/10 MHz) at 0° elevation	43.8	41.8	40.8

NOTE 1 – Further study is required to determine the appropriateness of the use of averaged RNSS satellite antenna gain for AM(R)S elevation angles exceeding 5° while ensuring protection of the RNSS satellites.

Figure 2 shows the function of maximum AM(R)S e.i.r.p. (dBm/10 MHz) vs elevation angle (angle above the horizon) with the use of the RNSS satellite Rx antenna gain averaged over the range of angles to the visible Earth's surface.

FIGURE 2

Maximum AM(R)S e.i.r.p. (dBm/10 MHz) vs elevation angle (with the use of the RNSS satellite Rx antenna gain averaged over the range of angles to the visible Earth's surface)
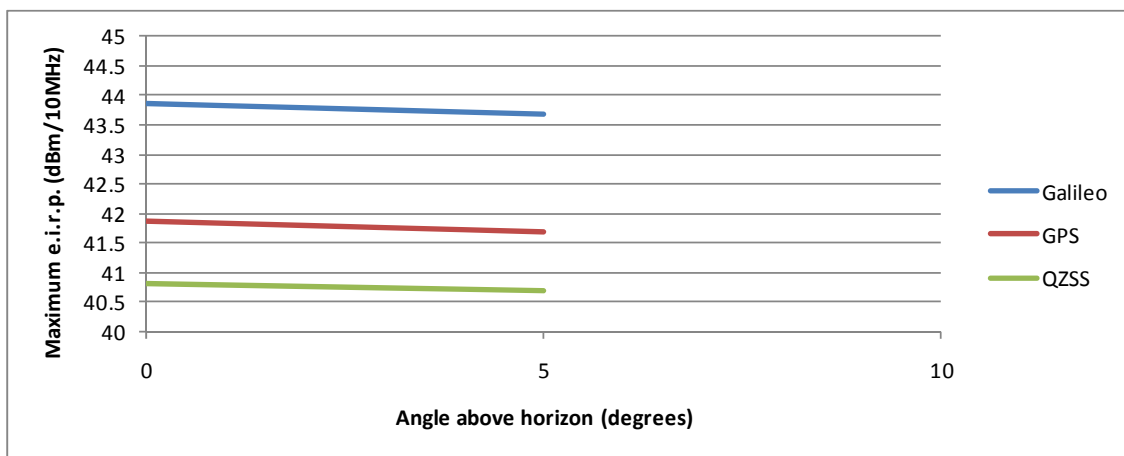
Note 1 – Further study is required to determine the appropriateness of the use of averaged RNSS satellite antenna gain for AM(R)S elevation angles exceeding 5° while ensuring protection of the RNSS satellites.

4.2   Radio astronomy results

For coexistence with the RAS operating in the band 4 990-5 000 MHz, restriction of the AM(R)S to surface applications at airports results in compatibility conditions with the RAS similar to that service with the mobile (except aeronautical mobile) service, and, as such, compatibility can usually be assured through geographic separation. When RAS observatories are in especially close proximity to an airport, local frequency management should be used to resolve any issues. The operation of AM(R)S applications for airport surface in the band 5 000-5 010 MHz would require separation distances in order to protect the RAS in the band 4 990-5 000 MHz. For separation distances less than 150 km, site-specific compatibility studies including local conditions should be performed to ensure that RAS is protected.

5 Conclusions

5.1 Initial analyses, assuming 500 airports operating the AM(R)S system at a 50% duty cycle, have shown that proposed aeronautical IEEE Std 802.16e-based LAN transmitters (operating in the AM(R)S) will not interfere with RNSS (E-s) feeder-link receivers in the 5 000-5 010 MHz band , as long as the AM(R)S aggregate instantaneous e.i.r.p. in any given direction from a single airport is limited as shown in Figs 1 and 2.

5.2 In the 5 000-5 010 MHz band the RNSS transmissions come from a high-gain, well-focused dish antenna generally geographically separated from major airports, so the RNSS transmissions would not cause unacceptable levels of interference to a ground-based airport AM(R)S receiver. In the case that an RNSS feeder-link earth station needs to be in close proximity to a major airport, it is expected that local coordination – up to and including precluding use of specific channels by AM(R)S transmitters at that airport – can be employed to solve any remaining issues.

5.3 For coexistence with the (RAS) operating in the band 4 990-5 000 MHz, restriction of the AM(R)S to surface applications at airports results in compatibility conditions with the RAS similar to that service with the mobile (except aeronautical mobile) service, and, as such, compatibility can usually be assured through geographic separation. When RAS observatories are in especially close proximity to an airport, local frequency management should be used to resolve any issues. The operation of AM(R)S applications for airport surface in the band 5 000-5 010 MHz would require separation distances in order to protect the RAS in the band 4 990-5 000 MHz. For separation distances less than 150 km, site-specific compatibility studies including local conditions should be performed to ensure that the RAS is protected.

5.4 To reduce the risk of possible future conflicts between RNSS and AM(R)S in the 5 000-5 010 MHz band, any modification to the Radio Regulations allowing AM(R)S in that band should provide necessary measures to protect RNSS.

Appendix A

IEEE 802.16e

As discussed above, Table 7, and Figs 3, 4 and 5 illustrate the general orthogonal frequency-division multiple access (OFDMA) characteristics of the IEEE 802.16e standard used in this analysis.

As discussed in detail in the IEEE 802.16 standard, in the frequency domain, an OFDM symbol contains a number of sub-carriers equal to the size of the fast Fourier transform. The types of sub-carriers are data sub-carriers used for data transmission, pilot sub-carriers used for estimation purposes, and null (inactive) sub-carriers used for guard band and the DC sub-carrier.

In OFDMA, the data sub-carriers are divided into subsets, each of which is identified as a sub-channel. This allows for simultaneous transmissions by multiple users (i.e. multiple subscriber units) to a given base station on the reverse link; each user might be allocated one or more sub-channels. This can be seen in Fig. 4, which shows an example with data sub-carriers divided in three sub-channels.

TABLE 7

Scalable OFDMA channelization parameters

Parameters	Values			
Channel bandwidth (BW) (MHz)	1.25	5	10	20
Sampling frequency (F_s) (MHz)	1.4	5.6	11.2	22.4
FFT size (N_{FFT})	128	512	1 024	2 048
Subcarrier frequency spacing Δf (kHz)	10.94			
Useful symbol time (T_b) (µs)	91.4			
Guard time ($T_g = 1/8*T_b$) (µs)	11.4			
OFDMA symbol duration (T_s) (µs)	102.9			

FIGURE 3

Symbol time structure

FIGURE 4

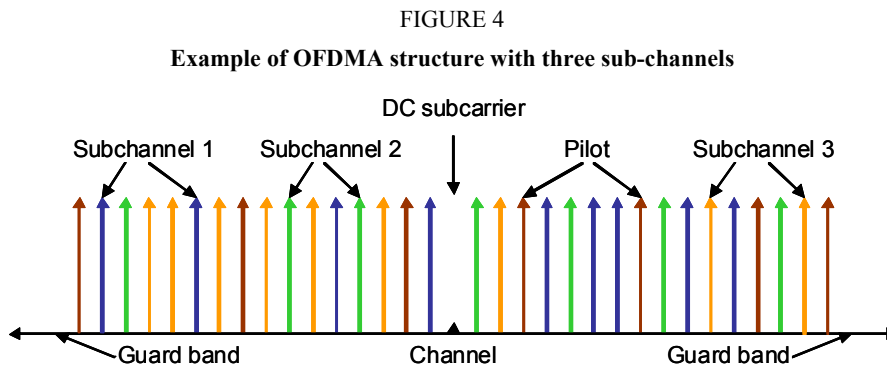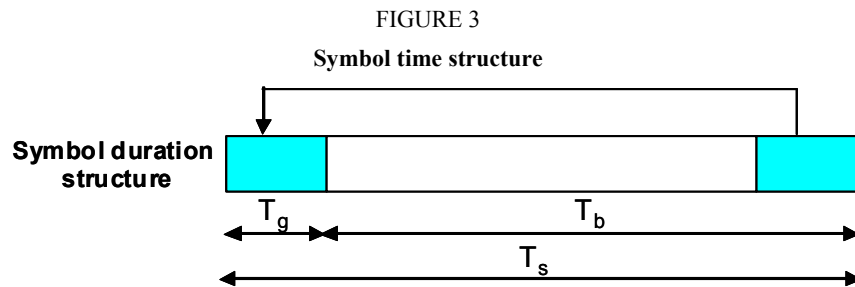**Example of OFDMA structure with three sub-channels**

Figure 5 shows an illustration of the OFDMA TDD frame structure. The term "forward link" describes the link from the base station to the subscriber unit, and it can be used interchangeably with the term "downlink" (DL) used in the standard. The term "reverse link" describes the link from the subscriber unit to the base station, and can be used interchangeably with the term "uplink" (UL) used in the standard. The terms forward link and reverse link are used throughout the remainder of this Report.

FIGURE 5

OFDMA TDD frame structure
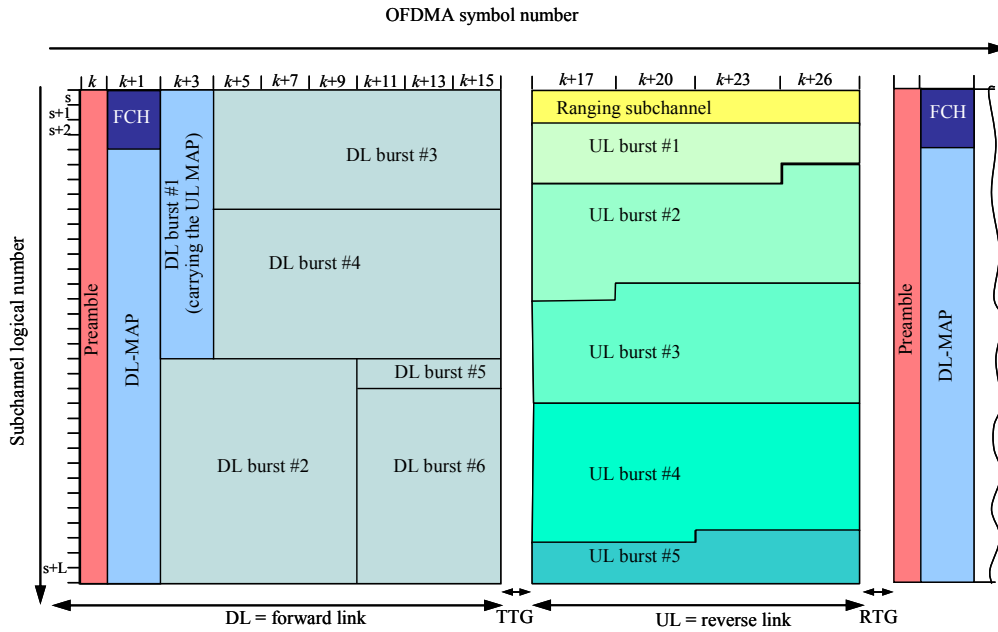
Adaptive modulation and coding allows a network to adjust the signal modulation scheme on the basis of the received signal-to-noise ratio (SNR). Higher-order modulation schemes are used for subscriber units close to the base station (i.e. higher SNR).

Table 8 shows the modulation and coding pairs as discussed in the IEEE 802.16 standard, from quadrature phase-shift keying (QPSK) with a coding rate of 1/2, to 64-quadrature amplitude modulation (64-QAM) with a coding rate of 3/4. The corresponding required SNR values for the various modulation and coding schemes are also presented in the table.

For the analysis presented in this section, it is assumed that at the edge of the coverage area (shown notionally as a circle of radius d_1), the minimum SNR is met for decoding QPSK 1/2. This minimum SNR is denoted as SNR_1. At distance d_i, the SNR value is SNR_i, as illustrated in Fig. 6. If noise power is assumed constant throughout the coverage area, then:

$$d_i = d_1 10^{\frac{-\Delta SNR(i)}{10n}} \tag{1}$$

where:

d_1:   distance to the edge of the coverage area

$$\Delta SNR(i) = SNR_i - SNR_1 \tag{2}$$

n: path loss exponent (assumed to be 2.3).

TABLE 8

Adaptive modulation results

Modulation	Coding rate	Modulation type (i)	Rx SNR (dB)	Calculated distance ratio d_i/d_1
QPSK	1/2	1	5	1
	3/4	2	8	0.74
16-QAM	1/2	3	10.5	0.58
	3/4	4	14	0.41
64-QAM	1/2	5	16	0.33
	2/3	6	18	0.27
	3/4	7	20	0.22

FIGURE 6

Adaptive modulation illustration

BS = base station

d_1 = distance from BS to the edge of the coverage area