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Initial considerations on 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

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REPORT ITU-R M.2168

Initial considerations on 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)

Scope

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 (RR) 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-Family" standards[1]. As noted in Report ITU-R M.2118, because of the mobility capabilities built into IEEE Std 802.16, it is expected that it will prove to be the most compliant with aviation requirements. As a result, the remainder of this analysis will reference that protocol. AM(R)S parameters used for the analysis are shown in Table 1, and Figs 1, 2 and 3, and due to the signal modulation utilized, it is expected that the signal will look noise-like to RNSS and RAS receivers.

TABLE 1

AM(R)S based on IEEE Std 802.16 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 Std 802.16) will reduce the power based on actual transmitted bandwidth (by a factor of 10 log (No. of 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 Std 802.16, 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

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1 While the system would be based on the IEEE 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 sensitivities, and sectorized antennas.

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 Std 802.16 are contained in Appendix A.

FIGURE 1

AM(R)S 802.16e base station antenna pattern

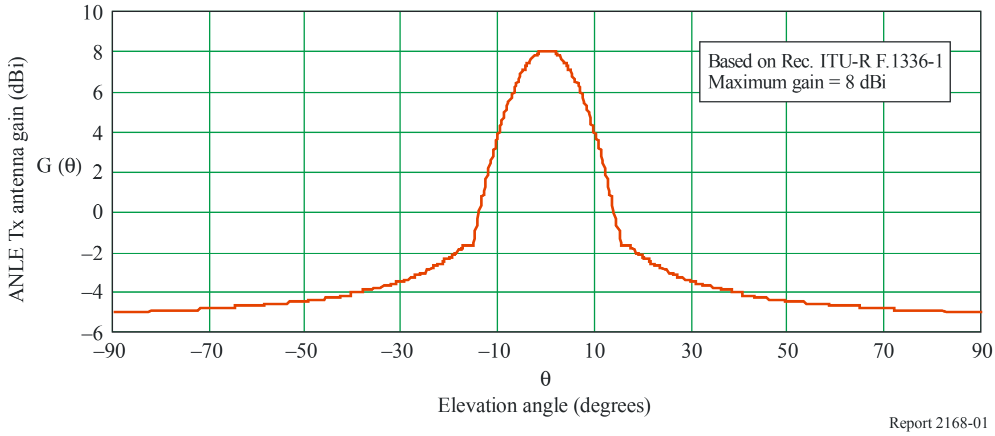


FIGURE 2

AM(R)S 802.16e subscriber unit antenna pattern
(Ref. Recommendation ITU-R F.1336-1)

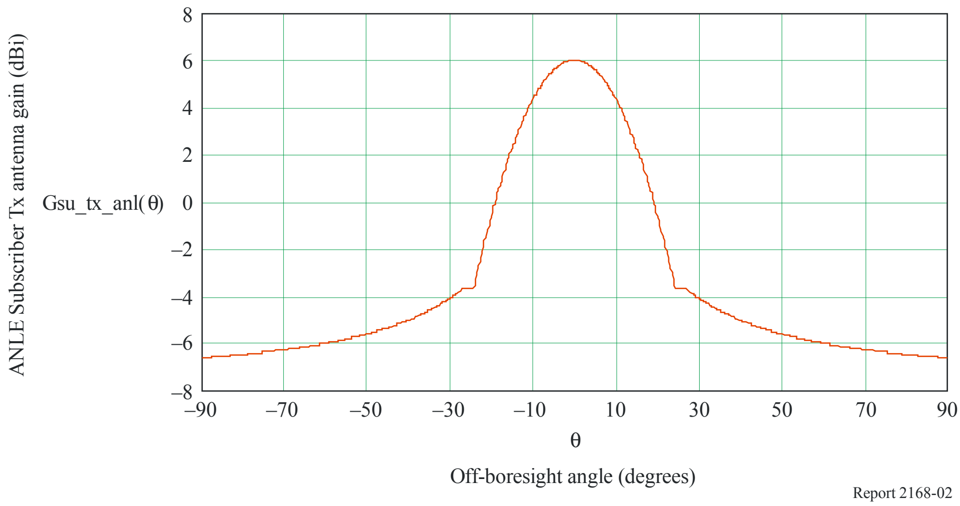
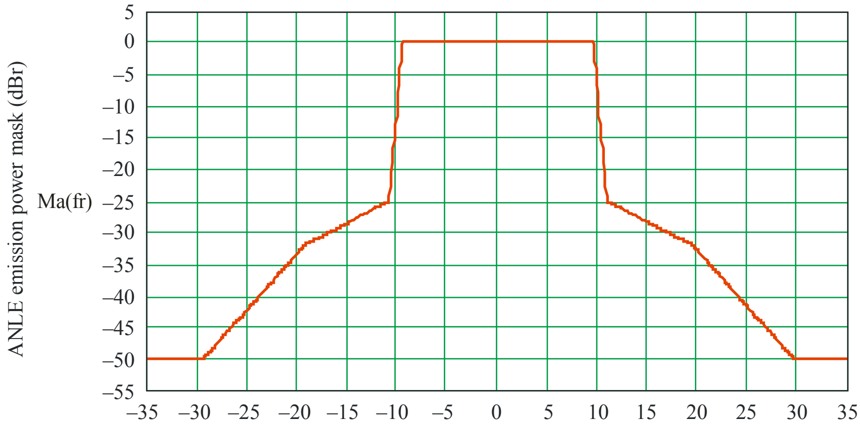


FIGURE 3

AM(R)S emission mask (assumed 20 MHz channel)



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2.2 RNSS systems

Details of the RNSS parameters used for this report are provided below. This analysis focuses on the system which postulates the minimum transmitted e.i.r.p. while requiring the maximum effective carrier-to-noise ratio.

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. Since, as noted above, the RNSS parameters are still in flux, § 4 of this report will assess the impact of variations in those parameters compared to the values used for this analysis.

TABLE 2

RNSS parameters for compatibility analysis

Parameter	Feeder-link satellite	Feeder-link earth station
Tx effective isotropic radiated power (e.i.r.p.; dBW)	N/A	46
Tx antenna gain[(1)] (dBi)	N/A	39.40
Tx antenna pattern	N/A	2 m dish (Rec. ITU-R S.465)
Tx bandwidth (MHz)	N/A	1
Rx noise temperature (K)	300	N/A
Rx bandwidth[(2)] (MHz)	1	N/A
Rx antenna gain[(3)] (dBi)	30.90	N/A
Rx antenna pattern	0.75 m dish (Rec. ITU-R S.1528)	N/A
Earth station Rx antenna min. el. (degrees)	N/A	5
C/N_0 threshold (dB-Hz)	76	N/A

(1) Same as Rx

(2) Same as EsTx

(3) 0,75 m dish (Recommendation ITU-R S.1528)

2.3 Radio astronomy

Details, parameters and approach for compatibility analyses with RAS are contained in relevant Recommendations ITU-R RA. 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 AM(R)S was assumed to have the characteristics of Table 1, and the RNSS was assumed to have the characteristics of Table 2. 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

3.3.1 Compatibility of AM(R)S with RNSS feeder links in the 5 000-5 010 MHz band was addressed using the same methodology as was used for compatibility studies of AM(R)S with FSS feeder links in the 5 091-5 150 MHz band (see Report ITU-R M.2118). In particular, a computer model was developed in which a grid of satellite positions was assumed, and for each position the aggregate interference was calculated. Key to that calculation was the number of transmitters in view, transmitter power, and for each transmitter the transmitter antenna gain toward the satellite, transmitter-to-satellite path loss, and satellite antenna gain toward that transmitter (see § 2). The geometry associated with this methodology is depicted in Fig. 4. One additional complication over the FSS study is that the RNSS criterion is given in terms of C/N_0[2] rather than the change in equivalent noise temperature used for the FSS analysis. This makes the calculations more involved, since one now must determine not only the received interference power but also the power of the desired carrier at the input of the victim satellite's receiver. At each relevant satellite position, this desired carrier power depends on the specific location assumed for the earth station transmitter. To be conservative, a "many-to-one" approach (many AM(R)S transmitters vs. one satellite receiver) was used. For this analysis, an example RNSS system was modelled based on published parameters for the Global Positioning System (GPS) satellite constellation. The GPS space segment has a minimum of 24 satellites operating 20 200 km above mean sea level in six orbital planes having four satellites each. The planes are equally spaced 60° apart and are inclined 55° from the equatorial plane, so that every subsatellite point (i.e. every point lying directly beneath a satellite) lies between latitudes 55° N and 55° S. The master control station is assumed to be located in Colorado Springs (but relocatable). Some possible alternative locations include the current GPS monitoring station locations shown in Fig. 5. Of course, transportable RNSS earth stations could, if consistent with local requirements, potentially be located almost anywhere on the Earth. For the purpose of this analysis we assume the use of six control stations, at the locations shown in Table 3, which also shows atmospheric and rain losses that could be experienced by GPS uplink signals emanating from each location. In addition, to further "worst-case" the results, the desired signal was assumed attenuated by atmospheric loss (≈1 dB) and the worst-case rain loss (up to 5.57 dB), while the co-frequency ANLE interference was assumed not to be attenuated by either of those factors.

3.3.2 Interference from ANLE FL transmissions – The base station will use the same power to communicate with all of the subscriber units. Those subscriber units will adaptively use the modulation scheme appropriate to its received signal-to-noise ratio (SNR) (see Appendix A). Using the parameters in Table 1, it can be shown that the power per sub-channel needed to communicate

[2] C/N_0 is used to denote "carrier-to-system receiver noise ratio". When interference is added, the term C/N_{0eff} is used to denote "effective noise" as a noise-equivalent combination of N_0 and white noise interference.

with subscribers in each modulation region is 14.4 dBm. With a maximum of 60 subchannels in a 20 MHz channel, the total base station power is 14.4 + 10 log(60) = 32.2 dBm.

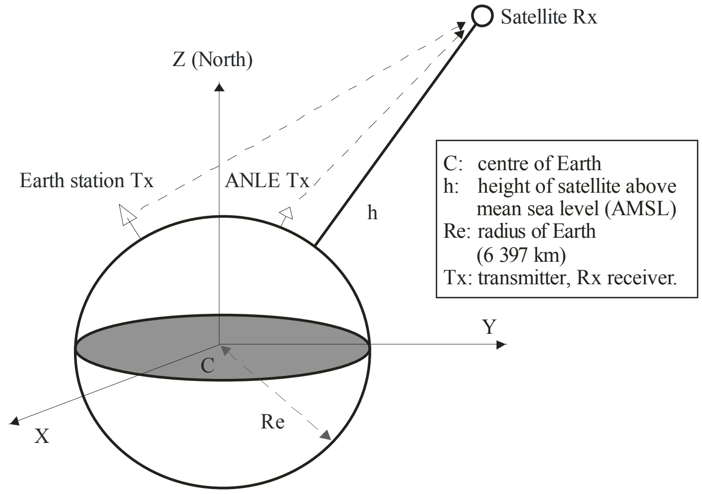
Note that, as mentioned above, in a 10 MHz channel there are a maximum of 30 sub-channels, so the total base station power would be 14.4 + 10 log(30) = 29.2 dBm.

3.3.3 Interference from ANLE RL transmissions – In practice, subscriber units will be distributed in range across the airport surface, and each can be allocated one or more sub-channels by the base station. Since the IEEE Std 802.16e implement power control on the RL, the aggregate RL power as seen by the RNSS satellites will vary depending on the actual distribution of subscriber units with respect to the base station. In order to simplify this analysis however, the assumption is made that all subscriber units are at the edge of coverage, and therefore, like for the FL, the aggregate power from all RL sub-channels (assuming all 70 are in use) is 32.2 dBm[3].

3.3.4 Antenna pattern considerations – Figures 1 and 2 depict the assumed ANLE antenna patterns for the base station and subscriber units respectively. It is evident from the figures that for some elevation angles, the base station gain is larger than that of the subscriber units, while for other elevations the situation is reversed. As a result, in order to determine worst-case aggregate ANLE power at all RNSS satellite positions both the FL and RL transmissions were analysed.

FIGURE 4

Earth-to-space link geometry



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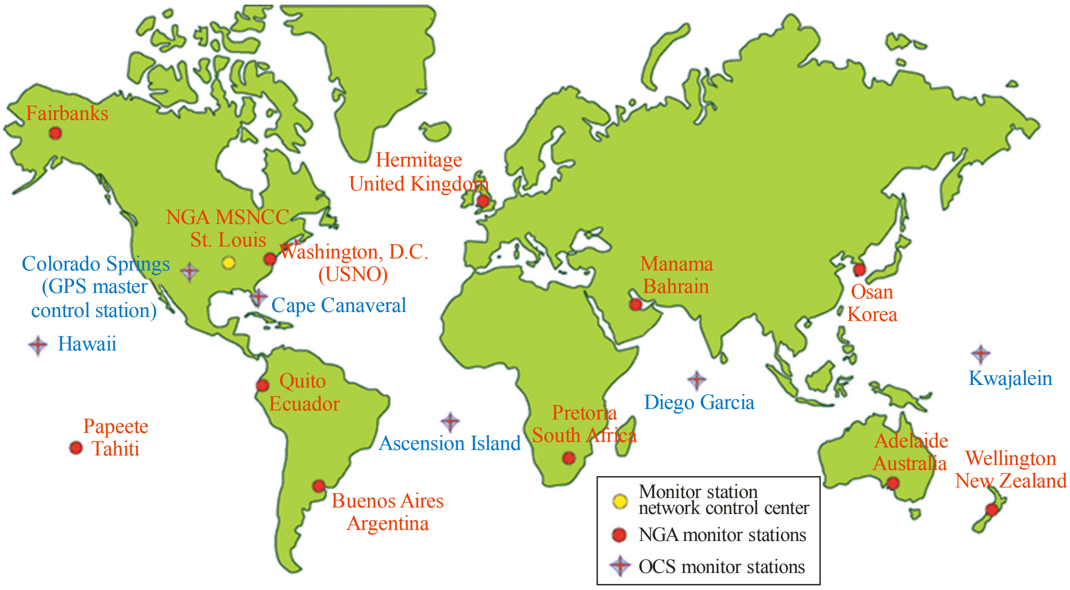
[3] It should be noted that this assumption of worst-case RL power introduces margin in the analysis. Alternatively, if the assumption was made that the subscriber units were uniformly distributed across the airport surface, the calculated total RL power would be 30.9 dBm.

FIGURE 5

GPS monitoring stations



Source: [GPS world, 2006]

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TABLE 3

Rain and atmospheric losses in GPS uplink

Assumed control-station location	Maximum atmospheric attenuation (dB)	Maximum rain attenuation (dB) exceeded 0.001% of the time
Colorado Springs	0.69	1.80
Diego Garcia	1.07	5.18
Ascension Island	0.98	1.18
Kwajalein	1.07	5.57
Hawaii	1.02	2.93
Fairbanks	0.84	0.82

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

4.1.1 As shown in Figs 6 and 7, even in the presence of AM(R)S interference the C/N_0 threshold in Table 2 at the satellite receiver can be met with margin for every possible satellite location above 5° with respect to the earth station. Results where potential satellite earth stations were added for this analysis in order to provide continuous earth coverage were equally successful. In fact, for all locations in the combined coverage area of the six assumed feeder-link earth stations, the minimum C/N_{0eff} value was 77.6 dB-Hz.

4.1.2 As noted above, parameters used for the RNSS systems still need to be confirmed by ITU-R, and at the time when this report was developed, ITU-R was working on the development of RNSS Recommendations giving the parameters of 5 GHz RNSS systems. In particular some of the parameters for the most-susceptible (i.e. minimum e.i.r.p., maximum required C/N_0) have changed from those in Table 2. Table 4 catalogues the pertinent differences.

TABLE 4

Comparison of revised RNSS parameters with those used in Table 2

Parameter	Analysis value	New value
Assumed antenna	2 m dish (earth station Tx) 0.75 m dish (satellite Rx)	5 m dish (earth station Tx) 0.15 m dish (satellite Rx)
Transmit bandwidth (MHz)	1	1.1
Transmit EIRP (dBW)	46	66.6
Rx system noise temperature (K)	300	590
Rx noise PSD, N_0 (dBW/Hz)	−203.83	−200.9
Required $C/N_{0,eff}$ (dB-Hz)	76	69.4
C/N_0 (dB-Hz)	79.26	80.7
Apportionment factor (dB)	0	12.2
Calculated max interference allowable for the AM(R)S to meet required C/N_{0eff} (dBW/Hz)	−203.34	−202.1

NOTE 1 – The initial study in the table above is using 6% of the total link margin as apportionment factor. However, it was noted that the use of a RNSS receiver protection criterion ($\Delta T/T$) of 6% for allowable aggregate interference from potential AM(R)S needs to be further studied.

4.1.3 The analysis was performed under worst-case assumptions, including worst-case distribution of subscriber units[4] and 100% duty cycle for ANLE transmitters. In actual practice more realistic values for these parameters will result in reduced interference to RNSS satellite receivers.

4.1.4 If the parameters for the satellite receiver antenna of 0.15 m dish are used (see Table 4) then the receive gain toward the interference will be reduced by 17.1 dB (from 30.9 dBi to 13.8 dBi); however such changes will also broaden the beam, hence more sources of interference are potentially visible. In order to start quantifying the potential impact of such a change, an example case was analysed where the satellite was directly over a feeder-link station in the center of

[4] For each satellite location, for each airport, the AM(R)S was assumed to be either RL or FL depending on which link resulted in maximum interference power presented to the satellite.

the United States of America. This minimizes the number of AM(R)S stations that fall within the satellite beam (i.e. within the satellite "footprint"). With the old satellite antenna (narrower beam), approximately 40% of the total AM(R)S stations were visible. As a result, increasing the satellite receive antenna beam such that the footprint encompasses all of the AM(R)S stations would increase the aggregate interference by about 4 dB for this case. It is important to note however that the aggregate power of the original (40% of the total) AM(R)S would be reduced by 17.1 dB reflecting the reduced RNSS receiver gain. Therefore the total interference seen by the RNSS satellite, even under the condition of a larger footprint/more interfering AM(R)S stations, would still be less than that calculated in the analysis. Additional margin is introduced by the increased allowable contribution from AM(R)S systems (1.2 dB over the previous value as shown in Table 4) that could be tolerated without exceeding the new C/N_{0eff} threshold.

4.1.5 The available margin however is offset in part by a change in the assumed "apportionment factor", i.e. how much of the available performance margin can be allocated to the AM(R)S. It was noted that the use of an RNSS receiver protection criterion ($\Delta T/T$) of 6% for allowable aggregate interference from potential AM(R)S needs to be further studied.

4.2 Radio astronomy results

Due to the operational characteristics of the planned AM(R)S (surface transmitters at airports), in most cases geographic separation will suffice to ensure the compatibility of that system with RA stations. In the rare condition that RAS observatories are in close proximity to an airport, local coordination can be used to resolve any remaining issues.

5 Conclusions

5.1 Initial analyses have shown that proposed aeronautical IEEE Std 802.16-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 under worst-case conditions. This needs to be confirmed as RNSS parameters are further defined, however the margins remaining even under worst-case analysis offer considerable flexibility in accommodating future changes.

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 not using specific AM(R)S channels at that airport – can be employed to solve any remaining issues.

5.3 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 be assured through geographic separation. In the rare condition that RAS observatories are in close proximity to an airport, local coordination can be used to resolve any remaining issues.

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 RR allowing AM(R)S in that band should provide necessary measures to protect RNSS.

FIGURE 6

C/N_{0eff} at satellite points visible above 5° elevation from six assumed ground stations
(ANLE FL)

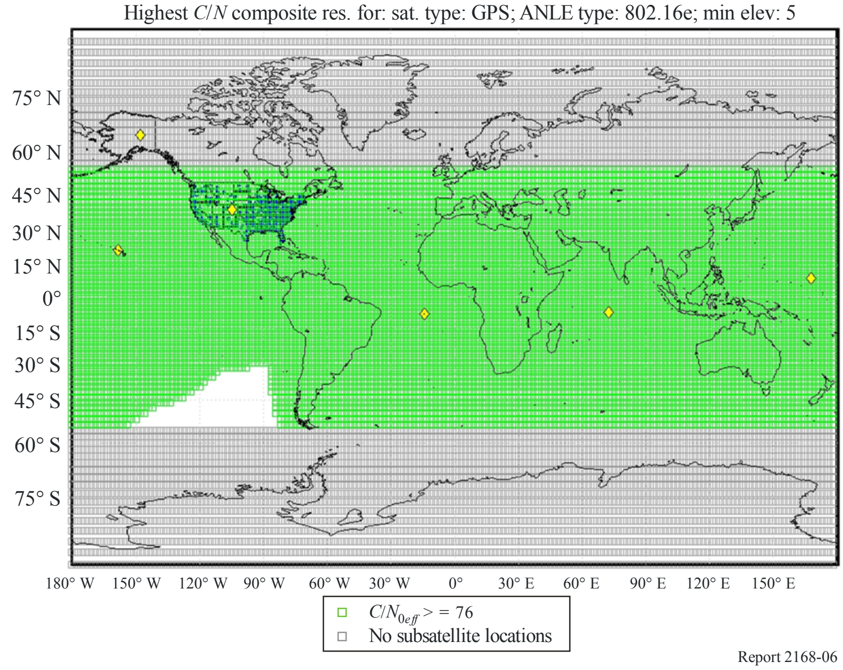

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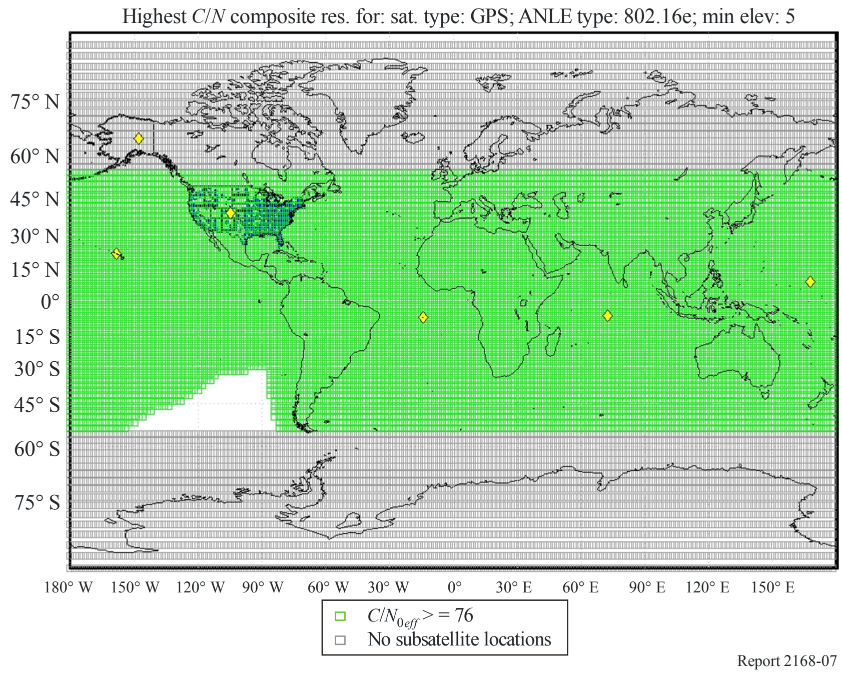
FIGURE 7

C/N_{0eff} at satellite points visible above 5° elevation from six assumed ground stations
(ANLE RL, subscriber units at worst-case locations)



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Appendix A

IEEE Std 802.16

As discussed above, Table 5, and Figs 8, 9 and 10 illustrate the general orthogonal frequency division multiple access (OFDMA) characteristics of the IEEE Std 802.16 used in this analysis.

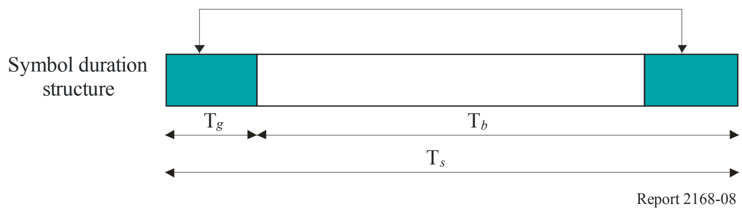
TABLE 5

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 8

Symbol time structure



As discussed in detail in the IEEE Std 802.16, 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 (RL); each user might be allocated one or more sub-channels. This can be seen in Fig. 9, which shows an example with data sub-carriers divided in three sub-channels.

FIGURE 9

Example of OFDMA structure with three sub-channels

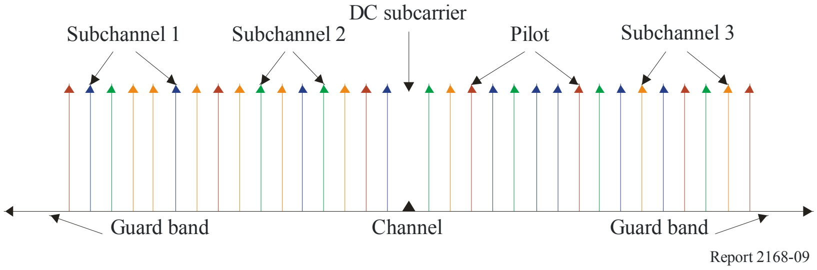
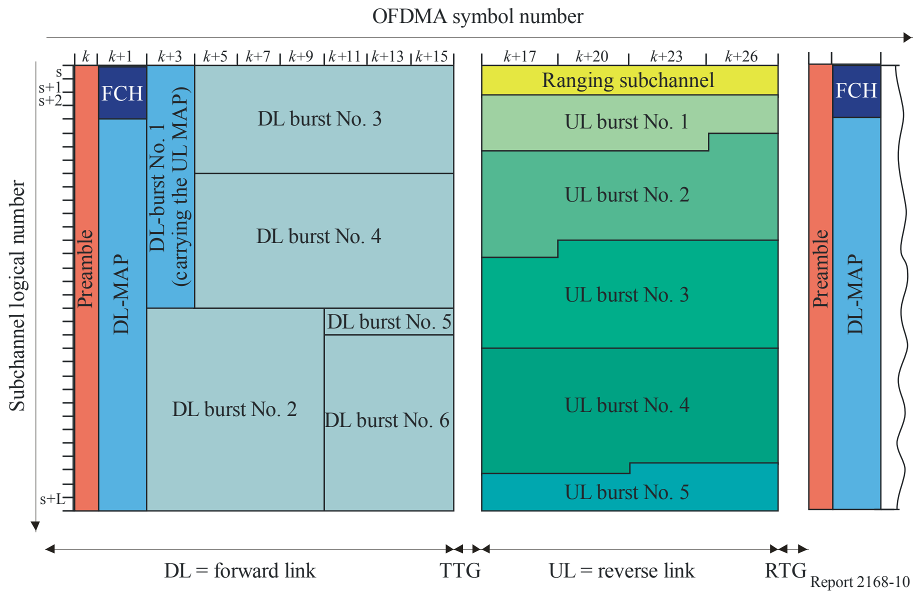


Figure 10 shows an illustration of the OFDMA TDD frame structure. The term "forward link" describes the link from the base station to the subscriber unit, and it can be used interchangeably with the term "downlink" (DL) used in the standard. The term "reverse link" describes the link from the subscriber unit to the base station, and can be used interchangeably with the term "uplink" (UL) used in the standard. The terms forward link (FL) and reverse link (RL) are used throughout the remainder of this report.

FIGURE 10

OFDMA TDD frame structure



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

Table 9 shows the modulation and coding pairs as discussed in the IEEE Std 802.16, from quadrature phase-shift keying (QPSK) with a coding rate of 1/2, to 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. 11. 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 6

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 11

Adaptive modulation illustration