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Simulating Global AeroMACS Airport Ground Station Antenna Power Transmission Limits To Avoid Interference With Mobile Satellite Service Feeder Uplinks

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April 2013

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Summary

The Aeronautical Mobile Airport Communications System (AeroMACS), which is based upon the IEEE 802.16e mobile wireless standard, is expected to be implemented in the 5091 to 5150 MHz frequency band. As this band is also occupied by Mobile Satellite Service feeder uplinks, AeroMACS must be designed to avoid interference with this incumbent service. The aspects of AeroMACS operation that present potential interference are under analysis in order to enable the definition of standards that assure that such interference will be avoided. In this study, the cumulative interference power distribution at low Earth orbit from transmitters at global airports was simulated with the Visualyse Professional software. The dependence of the interference power on antenna distribution, gain patterns, duty cycle, and antenna tilt was simulated. As a function of these parameters, the simulation results are presented in terms of the limitations on transmitter power from global airports required to maintain the cumulative interference power under the established threshold.

Introduction

The Aeronautical Mobile Airport Communications System (AeroMACS), which is based upon the IEEE 802.16e mobile wireless standard, is envisioned as a wireless network covering all areas of the airport surface for next-generation air transportation (Ref. 1). The system would accommodate all mobile communications requirements including parked and taxiing aircraft, various types of ground vehicles, and personnel as well as connection to fixed assets related to airport safety requirements (such as surveillance and navigation aids, weather sensors, and communications stations).

AeroMACS is intended to operate in portions of the 5000 to 5150 MHz frequency band, in particular 5091 to 5150 MHz. It is essential that the AeroMACS service does not interfere with other users in this band. In particular, the allocation of the 5091 to 5150 MHz band to the Earth-to-space fixed-satellite service (FSS), limited to feeder links of nongeostationary satellite systems in the Mobile Satellite Service (MSS) and utilized by the Globalstar network, will restrict the power levels that will be allowed for the AeroMACS networks. This investigation is focused on helping to establish practical limits on AeroMACS transmissions from airports so that the threshold of interference into Globalstar feeder links is not exceeded. This threshold interference power level for Globalstar at low Earth orbit (LEO) has been established at –157.3 dBW corresponding to a 2 percent increase of the satellite receiver's noise temperature (Ref. 2).

Previously, the interference power distribution at LEO from the AeroMACS transmitters at the 497 largest airports in the contiguous United States was simulated with the Visualyse Professional software (Transfinite Systems Ltd.) (Ref. 3). The results were shown to correlate well with those of a previous study by MITRE–CAASD (Ref. 4). Both omnidirectional and sector antennas were modeled and 5- and 10-MHz channels were considered with a center frequency of 5100 MHz.

In Reference 5, the effect of the antenna-gain profile on interference power was investigated and the model accuracy was improved by including a profile based on measured data. It was assumed that the channel bandwidth was 5 MHz, centered at 5100 MHz. The effect of the inhomogeneous distribution of airports was examined by comparing the baseline case with a case where the airports were evenly distributed. Dependence of the interference power on the number of airport antenna beams and their directions was also simulated.

In this report, the airport database increased from 497 to 6207 airports including more sites from North America, Europe, and all other continents. Nineteen cases with variations in antenna distribution, antenna-gain pattern, and antenna tilt are examined. Based on the simulations, recommendations are provided for global airport ground station antenna power transmission limitations.

Analysis

Interference modeling was performed with Visualyse Professional Version 7 software from Transfinite Systems Limited (Ref. 6). Details for using this software are provided in (Ref. 7) with the modeling procedure summarized as follows:

1. Define antenna-gain dependence on azimuthal and elevation angles.
2. Locate stations (transmitters and receivers).
3. Specify carrier frequency and bandwidth.

4. Set up the propagation environment.
5. Set up the links between stations.
6. Define victim and interfering links.
7. Specify desired output, submit run, and analyze results.

Two different antenna-gain patterns were used in the simulations. The first was for an 80° beamwidth sector antenna and was based on the manufacturer's data for the antennas used in the Cleveland airport testbed experiments (Ref. 5). The second was for a 120° beamwidth sector antenna and was based on the recommendation of the International Telecommunication Union Radiocommunication Sector ITU–R F.1336–3 (Refs. 8 and 9). The model elevation and azimuthal-gain patterns for these two antennas are shown in Figures 1 and 2, respectively.

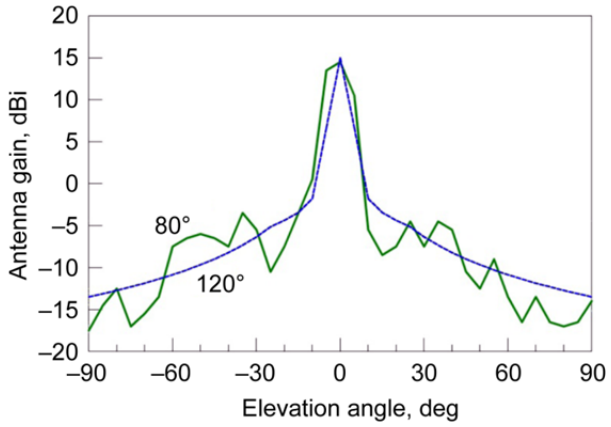

Figure 1.—Modeled gain versus elevation angle for 80° and 120° beamwidth sector antennas.

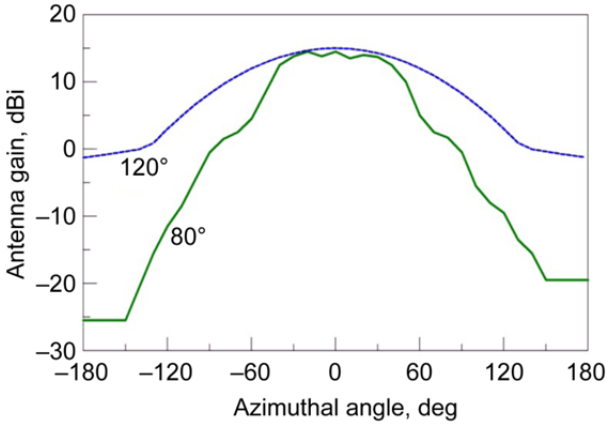

Figure 2.—Modeled gain versus azimuthal angle for 80° and 120° beamwidth sector antennas.

Antenna locations were selected from the OpenFlights database (Ref. 10), which includes the locations of 6207 global airports and are shown in Figure 3. Airports that did not have an International Civil Aviation Organization (ICAO) location identifier (a four-character alphanumeric code) were assumed to have minimal traffic and were not included. Transmission was centered at 5100 MHz with a 5 MHz bandwidth. The propagation model utilized basic transmission loss in free space, based on ITU–R Rec. P.525. Five runs were performed for each of the following cases with the antennas pointing in different random directions, except for case 2, which is pseudo-omnidirectional.

Case 1. This is the baseline case with 6207 worldwide airports, each with a single 80° beamwidth sector antenna. The airport locations are shown in Figure 3.

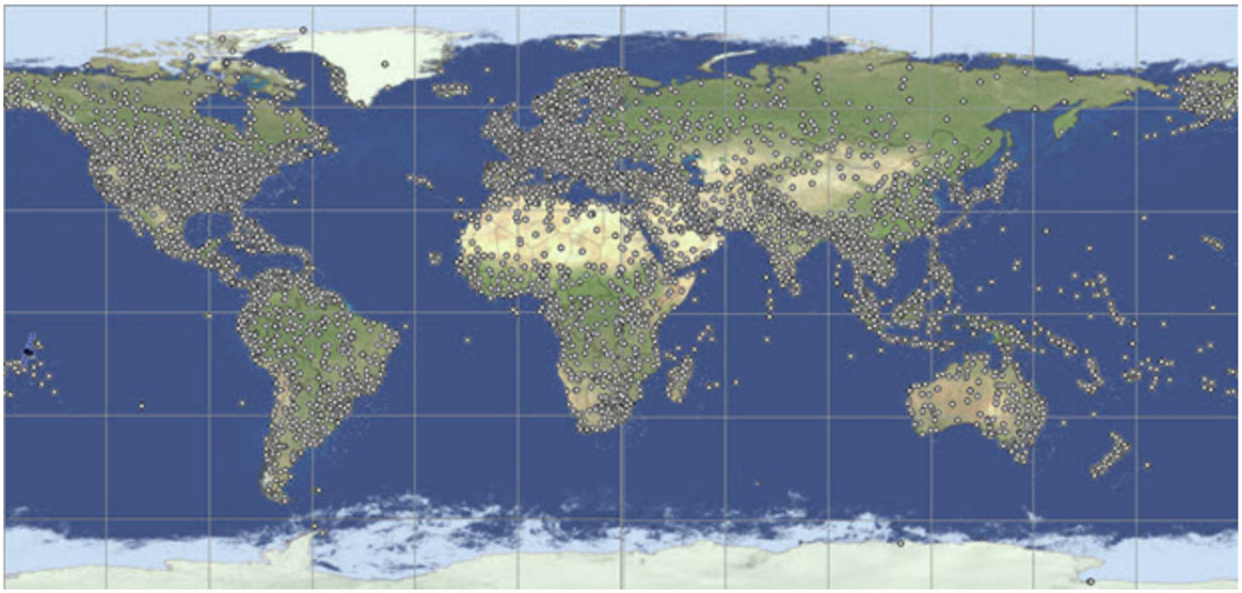

Figure 3.—Locations of the 6207 airports in the OpenFlights database.

Case 2. This case is pseudo-omnidirectional, with four 80° beamwidth sector antennas with directions separated by 90° at each of the 6207 airports (Fig. 3).

Case 3. Here and in cases 4 and 5, the number of antennas is doubled in specific regions to determine each region's relative impact on the interference hot spot. In this scenario two 80° beamwidth sector antennas are positioned at each of the 1510 contiguous United States, Canadian, and Central American airports (ICAO sections K, C, and M). One sector antenna is positioned at each of the other 4697 airports (Fig. 3).

Case 4. Two 80° beamwidth sector antennas are positioned at each of the 1338 European airports (ICAO sections E and L). One sector antenna is positioned at each of the other 4869 airports (Fig. 3).

Case 5. Two 80° beamwidth sector antennas are positioned at each of the 3359 non-North American and non-European airports. One sector antenna is positioned at each of the 2848 North American and European airports (Fig. 3).

Case 6. In cases 1 to 5, it was assumed that all sector antennas transmitted 100 percent of the time. Here and in cases 7 and 8, the effects of different duty cycles are considered by randomly turning off some of the transmitters. This is the same as case 1, except that the transmitters are randomly turned off at 25 percent of the 6207 airports, leaving 4655 airports transmitting with one 80° beamwidth sector antenna each (Fig. 4).

Case 7. This is the same as case 1, except that the transmitters are randomly turned off at 50 percent of the 6207 airports, leaving 3104 airports transmitting with one 80° beamwidth sector antenna (Fig. 5).

Case 8. This is the same as case 1, except that the transmitters are randomly turned off at 75 percent of the 6207 airports, leaving 1552 airports transmitting with one 80° beamwidth sector antenna (Fig. 6).

Case 9. Here and in the remaining cases, the airport categories are divided into large, medium, and small sizes. The 35 Operational Evolution Partnership (OEP 35) airports in the United States (Ref. 11) are assigned as large airports and the next 123 airports with the most 2009 passenger boardings from the Federal Aviation Administration's (FAA's) Commercial Service Airports CY09 Passenger Boardings list (Ref. 12) are assigned as medium airports. The 50 largest European airports as listed by Wikipedia (Ref. 13) are assigned as large airports and the next 50 on the list are assigned as medium airports. The remaining 5949 airports in the United States, Europe, and the rest of world from the OpenFlights database (Ref. 10) are assigned to be small airports. The large airports have eight 80° beamwidth sector antennas each, medium airports have four 80° sector antennas each, and small airports have one 80° sector antenna each (Fig. 3).

Case 10. In a previous analysis (Ref. 9), European airport transmitters were modeled with 120° beamwidth sector antennas. Thus, in case 10 each of the 50 large European airports have six 120° beamwidth sector antennas; each of the 50 medium European airports have three 120° beamwidth sector antennas; and each small European airport has one 120° beamwidth sector antenna. Each of the 35 large U.S. airports has six 80° beamwidth sector antennas; each of the 123 medium U.S. airports has three 80° beamwidth sector antennas; and each small U.S. airport and the rest of the world has one 80° beamwidth sector antenna (Fig. 3).

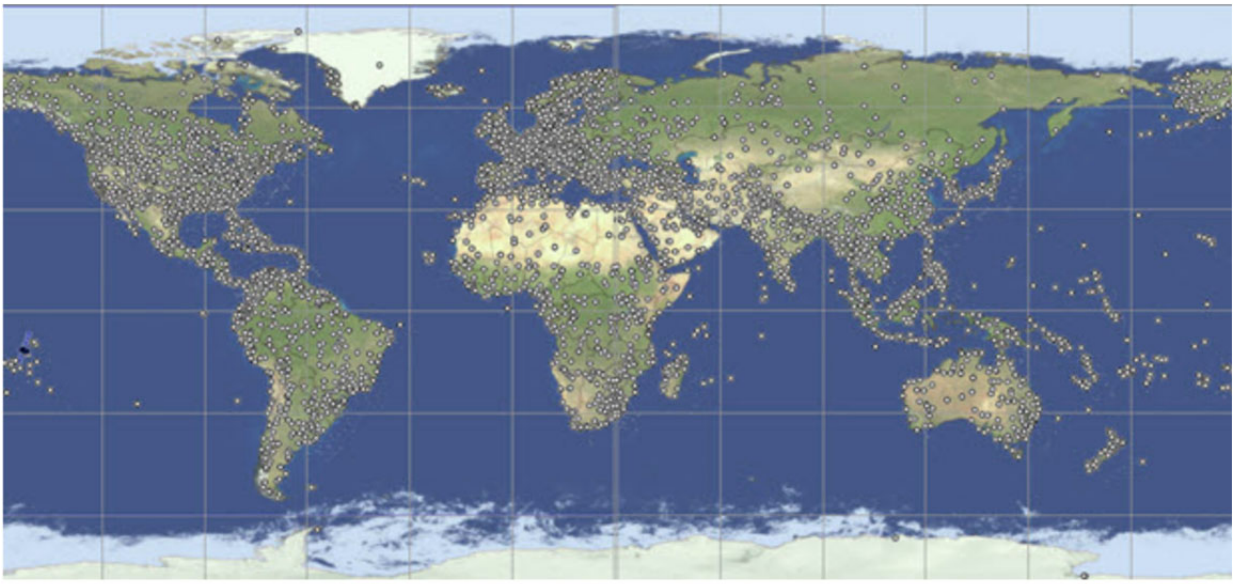

Figure 4.—Locations of 4655 transmitting airports in case 6.

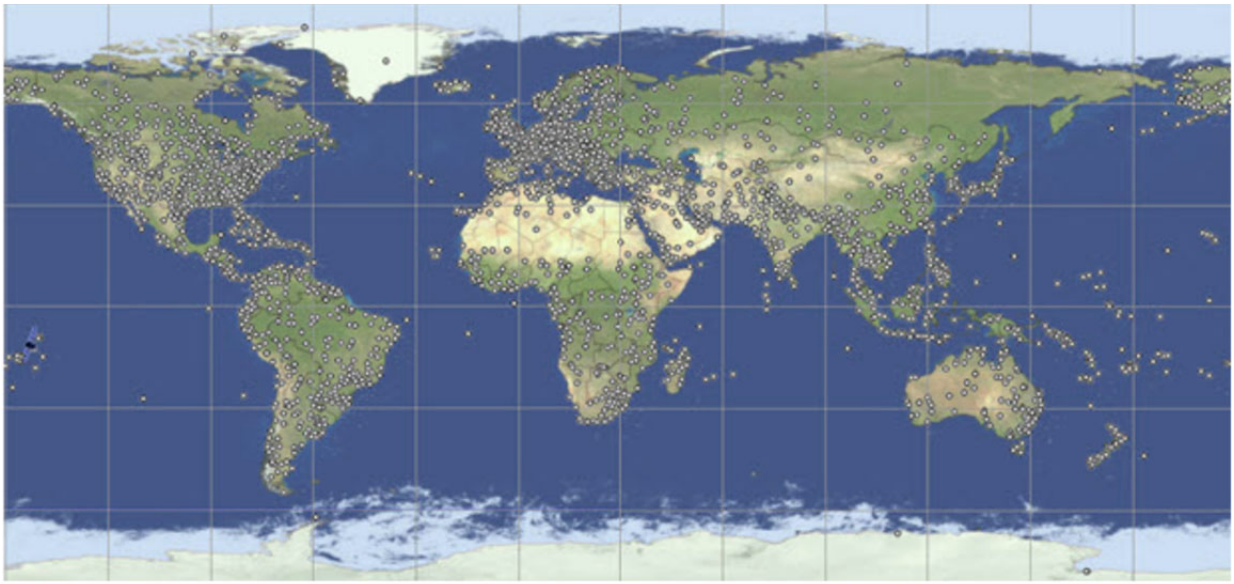

Figure 5.—Locations of 3104 transmitting airports in case 7.

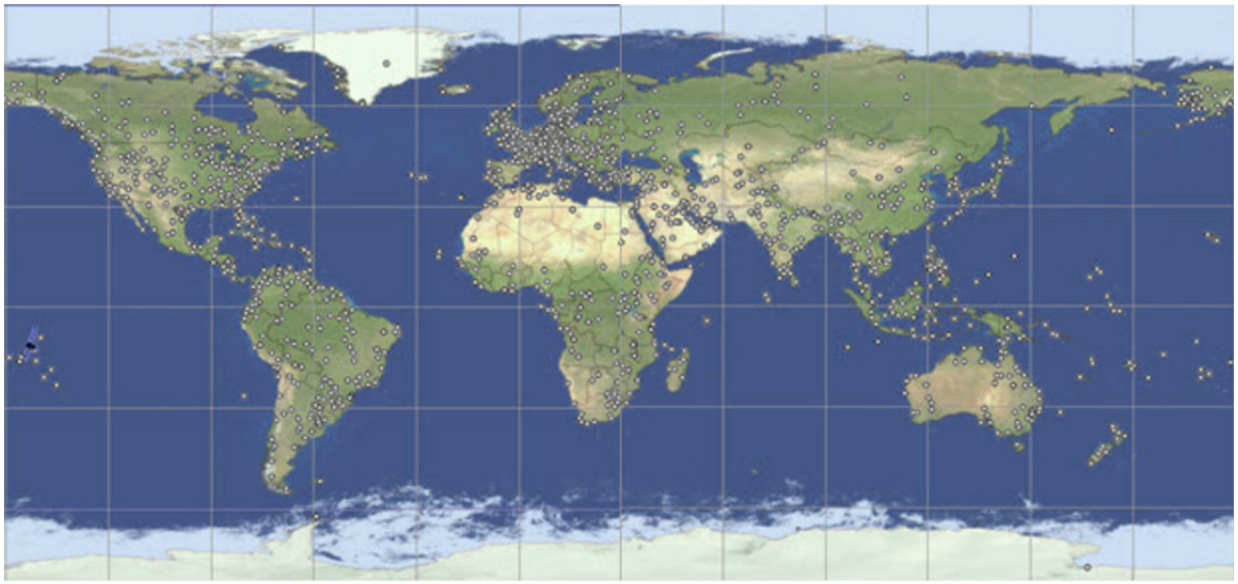

Figure 6.—Locations of 1552 transmitting airports in case 8.

Case 11. This is the same as case 10, except that all airports use 120° sector antennas. The 35 large U.S. and 50 large European airports have six 120° sector antennas each; the 123 medium U.S. and 50 medium European airports have three 120° sector antennas each; and the remaining 5949 airports in North America, Europe, and the rest of world have one 120° sector antenna each (Fig. 3).

Case 12. This is the same as case 11, except that transmitters for 25 percent of the small airports are turned off.

Case 13. This is the same as case 11, except that transmitters for 50 percent of the small airports are turned off.

Case 14. This is the same as case 11, except that transmitters for 75 percent of the small airports are turned off.

Case 15. All previous cases assumed that all airports operate on the same channel. In a more realistic scenario, medium and small airports will not need to use all of the 11 channels. Case 15 assumes that large airports will use all 11 channels, medium airports will use 6 channels, and small airports will use just 1 channel. Thus 5 out of 11 medium airport transmitters and 10 out of 11 small airport transmitters are turned off to model the results for a single channel (Fig. 7).

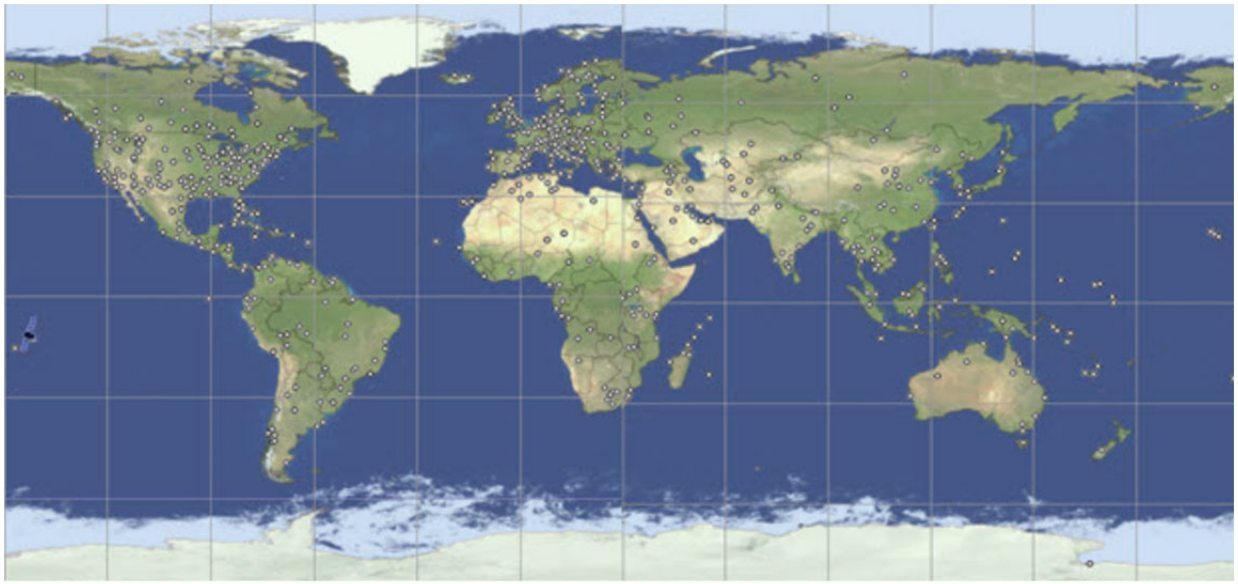

Figure 7.—Locations of 1286 transmitting airports in case 15.

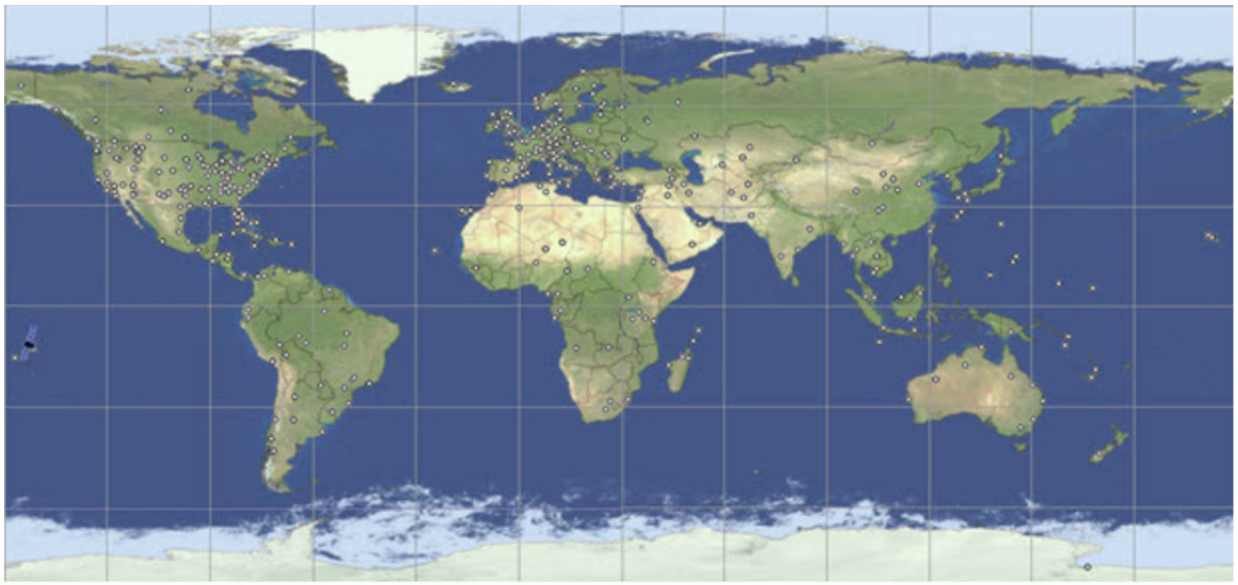

Figure 8.—Locations of 1016 transmitting airports in case 16.

Case 16. This is the same as case 15 except that the small airports are only allowed to transmit half as much power per sector as the medium and large airports. This was modeled by turning off half of the small airport transmitters in case 15 (Fig. 8).

Case 17. To establish limits on transmitter power as a function of elevation angle, each sector antenna from case 15 was set to a 1° upward tilt (Fig. 3).

Case 18. To establish limits on transmitter power as a function of elevation angle, each sector antenna from case 15 has a 2° upward tilt (Fig. 3).

Case 19. To establish limits on transmitter power as a function of elevation angle, each sector antenna from case 15 has a 4° upward tilt (Fig. 3).

The antenna distributions for these cases are summarized in Table I.

TABLE I.—NUMBER AND BEAMWIDTH OF SECTOR ANTENNAS FOR EACH AIRPORT CATEGORY

Case	Large U.S. (35)	Large European (50)	Medium U.S. (123)	Medium European (50°)	Small North American (1352)	Small European (1238)	Small Other (3359)	Notes
1	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	Baseline
2	4 at 80°	4 at 80°	4 at 80°	4 at 80°	4 at 80°	4 at 80°	4 at 80°	Pseudo-omnidirectional
3	2 at 80°	1 at 80°	2 at 80°	1 at 80°	2 at 80°	1 at 80°	1 at 80°	North American emphasis
4	1 at 80°	2 at 80°	1 at 80°	2 at 80°	1 at 80°	2 at 80°	1 at 80°	European emphasis
5	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	2 at 80°	Other emphasis
6	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	25% reduced
7	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	50% reduced
8	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	1 at 80°	75% reduced
9	8 at 80°	8 at 80°	4 at 80°	4 at 80°	1 at 80°	1 at 80°	1 at 80°	Size effects
10	6 at 80°	6 at 120°	3 at 80°	3 at 120°	1 at 80°	1 at 120°	1 at 80°	Mixed antennas
11	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	All 120°
12	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	25% small airports off
13	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	50% small airports off
14	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	75% small airports off
15	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	Channel reduction
16	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	Small airports half power
17	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	1° upward tilt
18	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	2° upward tilt
19	6 at 120°	6 at 120°	3 at 120°	3 at 120°	1 at 120°	1 at 120°	1 at 120°	4° upward tilt

Results

In all scenarios except for case 2, five runs were made for each with different random antenna pointing directions. Figure 9 shows a typical resulting cumulative, interference power pattern at LEO. The maximum interference power is at the hot spot over the northern Atlantic Ocean. To obtain the allowable transmitted power for each run, the power transmitted per antenna is adjusted so that the hot spot power is at the threshold value of –157.3 dBW. Table II shows the results for the allowable power per sector antenna for each run and the average value.

Case 1 is the baseline scenario with a randomly directed 80° sector antenna at each of the 6207 airports and an average allowable transmitted power per antenna of 100.9 mW. In case 2, each airport has four 80° beamwidth sector antennas with directions separated by 90° to approximate an omnidirectional antenna. Since this is virtually omnidirectional, only one run was necessary in this case. The resulting allowable power for each of the four antennas was 25.6 mW, which is equivalent to 102.4 mW per airport and is comparable to the allowable transmitted power per airport in case 1.

The impact of different regions on the hot spot is investigated next. In cases 3, 4, and 5 the resulting average allowable transmitted power is 77.4, 59.5, and 89.2 mW, respectively, with the number of antennas doubled in North America, Europe, and other regions of the world. The hot spot is the most sensitive to the European airports because their geographic density is higher than that of North America and the other regions. North American airports still have a significant impact and the rest of the world has only a small impact. All previous cases assumed that all sector antennas transmitted 100 percent of the time on a specific channel. In cases 6, 7, and 8, the antenna distribution is the same as case 1 except that 25, 50, and 75 percent of the transmitters are turned off, respectively. This allows significantly more power to be transmitted at 134.9 mW with 25 percent of the transmitters off; 193.1 mW with 50 percent off; and 379.0 mW with 75 percent off.

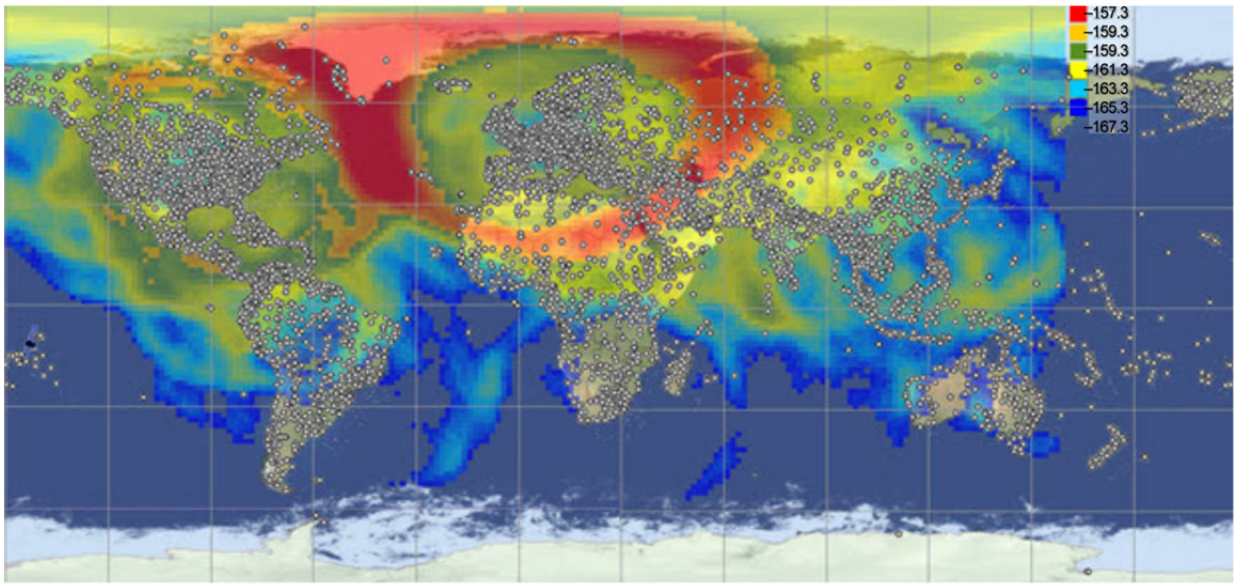

Figure 9.—Typical cumulative interference power pattern at low Earth orbit. The maximum interference power is at the hot spot over the North Atlantic Ocean.

TABLE II.—TOTAL NUMBER OF SECTOR ANTENNAS, ALLOWABLE POWER PER ANTENNA FOR RUNS WITH RANDOM ANTENNA DIRECTIONS, AND AVERAGE ALLOWABLE POWER

Case	Total sector antennas	Power per sector: Run 1, mW	Power per sector: Run 2, mW	Power per sector: Run 3, mW	Power per sector: Run 4, mW	Power per sector: Run 5, mW	Power per sector: Avg., mW
1	6 207	100.1	97.6	101.7	99.8	105.4	100.9
2	24 828	25.6	N/A	N/A	N/A	N/A	25.6
3	7 717	78.5	75.3	74.9	77.5	80.6	77.4
4	7 545	57.4	63.5	59.3	59.3	57.8	59.5
5	9 566	88.8	90.7	90.1	85.5	90.7	89.2
6	4 655	133.7	134.5	134.4	133.0	138.8	134.9
7	3 104	197.2	190.9	195.5	193.3	188.5	193.1
8	1 552	405.6	387.2	341.5	377.5	383.1	379.0
9	7 321	75.5	74.7	71.7	76.4	73.9	74.4
10	6 978	85.4	85.0	79.9	77.5	77.3	81.0
11	6 978	82.9	82.6	79.7	80.5	78.8	80.9
12	5 491	104.6	103.7	102.5	103.2	101.3	103.1
13	4 004	126.7	128.4	128.9	131.9	124.4	128.1
14	2 517	177.1	177.9	174.6	182.1	173.6	177.1
15	1 324	279.5	283.8	288.9	275.8	298.7	285.3
16	1 057	303.9	313.3	317.2	312.8	301.2	309.7
17	1 324	231.1	260.6	238.8	246.2	258.3	247.0
18	1 324	218.2	213.0	211.3	217.9	204.1	212.9
19	1 324	205.3	187.8	201.2	201.3	192.1	197.5

Since there is such a disparity in the traffic volume at airports, cases 9 to 19 distinguish between large, medium, and small airports. In each of these cases, the models assume 35 large U.S. airports, 50 large European airports, 123 medium U.S. airports, and 50 medium European airports. The remaining airports are assumed to be small. In case 9, large airports have eight 80° beamwidth sector antennas each, medium airports have four each, and small airports have one each. Since the average allowable transmitted power per antenna is 74.4 mW, large airports can transmit at 595.2 mW and medium airports can transmit at 297.6 mW.

The impact of replacing 80° beamwidth sector antennas with 120° beamwidth sector antennas is investigated in cases 10 and 11. Case 10 has 120° beamwidth sector antennas in Europe and 80° beamwidth sector antennas everywhere else; case 11 has 120° beamwidth sector antennas everywhere. The difference in average allowable transmitted power for cases 10 and 11 is only 0.1 mW suggesting that differences in beamwidth of the sector antennas has a minimal impact on the interference power hot spot.

In all the following cases, only 120° beamwidth sector antennas were used. The impact of duty cycle is investigated by turning the transmitters off at 25, 50, and 75 percent of the airports in cases 12, 13, and 14, respectively. This enabled significant increases in the average allowable transmitted power per antenna to 103.1, 128.1, and 177.1 mW, respectively.

Case 15 is the most realistic scenario since it assumes that medium and small airports will not use all 11 available channels. With an average allowable transmitted power per antenna of 285.3 mW, large airports can transmit 6×285.3 = 1711.8 mW on each of the 11 channels; medium airports can transmit 3×285.3 = 855.9 mW on each of 6 channels; and small airports can transmit 285.3 mW on 1 channel.

Case 16 is the same as case 15, except that small airport antennas can transmit only half the power of large and medium airport antennas. With this restriction, large airports can transmit 6×309.7 = 1858.2 mW on each of the 11 channels; medium airports can transmit 3×309.7 = 929.1 mW on 6 channels; and small airports can transmit 0.5×309.7 = 154.8 mW on 1 channel. Cases 17, 18, and 19 are the same as case 15, except that each antenna has an upward tilt of 1°, 2°, and 4°, respectively. These tilts reduce the allowable transmitted power by 13.4, 25.4, and 30.8 percent, respectively. It is expected that a downward tilt would increase the allowable transmitted power; however, these simulations were not undertaken because of a lack of a model for simulating reflected power from the Earth.

Conclusions

To establish power limits for the Airport Communications System (AeroMACS) base station transmitters to avoid interference with Globalstar uplinks, base stations with sector antenna transmitters at 6207 airports in the United States, Europe, and the rest of the world were modeled with Visualyse Professional software. Nineteen scenarios were simulated and in every case, except the one with pseudo-omnidirectional antennas, five different runs were generated with the antennas pointing in different random directions. The maximum simulated cumulative interference power hot spot at low Earth orbit for these runs was used to establish transmitter power limits.

The simulations indicated that the hot spot is most sensitive to the power transmitted from European airports because their geographic density is higher than that of North America and other regions. North American airports still have a significant impact, and the rest of the world has only a small impact. Simulations also showed that the allowable transmitted power significantly increases as the duty cycle is decreased and that the azimuthal beamwidth of the transmitting antennas does not have a significant effect.

In the most realistic scenario, case 15, 85 large airports in the United States and Europe can transmit up to 1650 mW on each of 11 available channels before the interference threshold is reached; 173 medium airports in the United States and Europe can transmit up to 825 mW on each of 6 channels; and the 5951 small worldwide airports can transmit up to 275 mW on 1 channel. In case 16, the allowable power was reduced for small airports resulting in a modest increase in allowable power for large and medium airports. However, it should not be necessary to provide this restriction on small airports since the allowable power levels in case 15 are more than adequate.

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Cleveland, Ohio, April 30, 2013.

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14. ABSTRACT
The Aeronautical Mobile Airport Communications System (AeroMACS), which is based upon the IEEE 802.16e mobile wireless standard, is expected to be implemented in the 5091 to 5150 MHz frequency band. As this band is also occupied by Mobile Satellite Service feeder uplinks, AeroMACS must be designed to avoid interference with this incumbent service. The aspects of AeroMACS operation that present potential interference are under analysis in order to enable the definition of standards that assure that such interference will be avoided. In this study, the cumulative interference power distribution at low Earth orbit from transmitters at global airports was simulated with the Visualyse Professional software. The dependence of the interference power on antenna distribution, gain patterns, duty cycle, and antenna tilt was simulated. As a function of these parameters, the simulation results are presented in terms of the limitations on transmitter power from global airports required to maintain the cumulative interference power under the established threshold.

15. SUBJECT TERMS
Airports; Antenna gain; Antenna radiation pattern

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