APPENDICES vol. 1

A-1 List of participants

Appended to the body of the report

A-2 CSMAC WG5 Objectives

The objectives of the study are to:

- Assess Electromagnetic Compatibility (EMC) between Aeronautical Mobile Telemetry (AMT) and LTE commercial wireless systems associated with possible sharing in the 1755-1850 MHz band
  - From LTE User Equipment (UE) handset environment to AMT receivers
  - From AMT aircraft transmitters to LTE base stations
- A collaborative/cooperative effort between DoD and commercial wireless interests
- Results will support development of CSMAC WG5 recommendations possible sharing configurations or alternative solutions

A-3 Characteristics of Aeronautical Mobile Telemetry Systems

AMT systems provide real-time AMT links critical to flight testing. These are required by law/regulation for aircraft development and certification. In particular, corrupted telemetry links or unavailability of spectrum introduces program delays and leads to increased costs.

There are more than 15 major test ranges across the US; hundreds of AMT antenna/receive locations in and around the major test ranges. This is not an "all inclusive" list, but major DoD test ranges include:

- Navy – China Lake, Pt. Mugu, Patuxent River/Atlantic Test Ranges (ATR)
- AF – Edwards, Eglin, Nellis, Atlantic Test Ranges (ATR)
- Army - Fort Irwin, Yuma Proving Grounds, White Sands Missile Range

AMT supports testing and evaluation of manned aircraft, and of unmanned aerial systems, missiles, and other payloads.

Flight test involves air vehicles other than manned aircraft, particularly at ranges such as NAWC-WD China Lake.

Flight test requires large, high-gain ground station antennas to track aircraft signals under noise-limited conditions. It provides real-time flight characteristics, video, flight research data, system status, and safety parameters.

AMT is essential to design and test of aircraft, missiles, and airborne payloads. It is heavily accessed by both federal and contractor users (all major defense companies and subsidiaries).

AMT operations normally involve:

- A flight which can operate in short links over multiple ranges with multiple "handovers" to different ground stations,
- A flight which could range up to 300 miles and at altitudes up to 100 Kft to a single ground receive station

Nominal AMT characteristics for this study are taken from ITU-R Recommendation M.1459, as agreed within CSMAC WG5:

- 10 Watt TX power
- 1 MHz, 5 MHz, 10 MHz and larger channels, with 5 MHz typical
- Aircraft antenna is omni-directional
- AMT ground stations have high gain (26 – 40 dBi, with 30 dBi typical) parabolic dish tracking antennas
    - Typical elevation angle above horizon during flight is 0 degrees, and ranges from -2 degrees to + 2 degrees for most of flight, with aircraft operating to 300 miles. At close range, AMT ground stations track from horizon to zenith
- Systems are noise limited, with typical system noise of 250K or less
    - Rec. M.1459 permits aggregate I/N of ~ -4 dB

Modeling and simulation has been performed based on data from multiple selected sites, including Pt. Mugu, Eglin AFB, Patuxent River/Atlantic Test Ranges (ATR). Detailed analytical descriptions of the geography and air space usage for each location are provided in the subsequent appendices to this report.

A-4 Characteristics of Long Term Evolution broadband wireless systems

The potential commercial wireless sharing partner is modeled as Long Term Evolution, i.e., 4G LTE. LTE is modeled in accordance with information approved by the LTE Technical Working Group established by Commerce Spectrum Management Advisory Committee Working Group (CSMAC) WG1, as provided in LTE Baseline document (*Baseline LTE Uplink Characteristics*, CSMAC LTE Characteristics Subgroup, 12 November 2012, Rev. 2)

Specifications and characteristics of LTE User Equipment (UE's):

- Antenna height of 1.5m
- Max EIRP of 20 dBm
- TX power modeled in simulation using an urban and rural cumulative distribution functions as in baseline document
- Geographic distribution of UE's around eNodeB base stations based on actual networks of major carriers – base station locations randomized at local level – approved and provided by industry
- 6 UEs, evenly distributed in frequency in a 10 MHz channel per base station per sector

Specifications and characteristics of LTE Base Stations

- Antenna heights – 30m urban, 15-60m rural
- Sector coverage – pattern as described in ITU-R F.1336-3
- Downtilt – 3 degrees from the horizontal

A-5 Methodology for Interference Calculations and Simulations

Interference power at the AMT ground stations victim receiver is specified as a power flux density (pfd), measured at the aperture of the AMT ground station receive antenna. This protection value is elevation angle dependent. This takes into account that at high ground station antenna elevation angles, aircraft at maximum altitude are close to the ground station

The pfd protection level to be used is -180 dBW/m^2 per 4 kHz averaged over the AMT channel bandwidth

Aggregation computations are performed, as a function of AMT antenna azimuth pointing angle, using the composite antenna pattern in Rec. M.1459. Computations are done for -180 to +180 degree azimuths in 0.5 degree increments

As agreed by CSMAC WG5, interference power calculations are performed, by Alion Science engineers, using the Visualyse automated software tool implementing the Irregular Terrain Model (ITM)/Longley-Rice Propagation Model.

The model uses actual terrain data (30" USGS data) for ground/ground interactions, and takes into account antenna heights above local terrain.

Total aggregate interference over 360 degrees is computed for each possible antenna azimuth pointing angle, at 0.5 degree increments, in order to include aggregate signal power received in the AMT antenna sidelobes. Interference received in AMT ground station antenna sidelobes is converted to a single equivalent interference level into the ground station antenna mainlobe using an appropriate scaling factor of G(q)/Gmax, where G is the gain function for the composite antenna provided in Rec. M.1459

Sharing is possible only when the total aggregate interference is at or below the not-to-exceed pfd protection level defined in ITU-R Recommendation M.1459.

At many AMT ground station sites, there are multiple antennas 1 – 15 km apart. The Alion analyses considered one to four antennas per site. The operation of multiple antennas per site extends the protection distances

A-6 Additional simulation details and summary of analysis assumptions

For AMT ground stations as interference victim, the initial assessment was conducted for different antenna locations at 3 sites, Patuxent River/ATR, Pt. Mugu, and Eglin

UE transmit power was modeled using urban & rural cumulative distribution functions (CDF's). The UE geographic distribution is created according to "RANDOMIZED REAL NETWORK" data.

For modeling of AMT equipped aircraft as the interference source, the LTE victim system at an eNodeB base station was specified to be an LTE 10 MHz receive channel. The base station antennas are located at 30m and 60m heights, as appropriate, to provide an accurate model of the given locality.

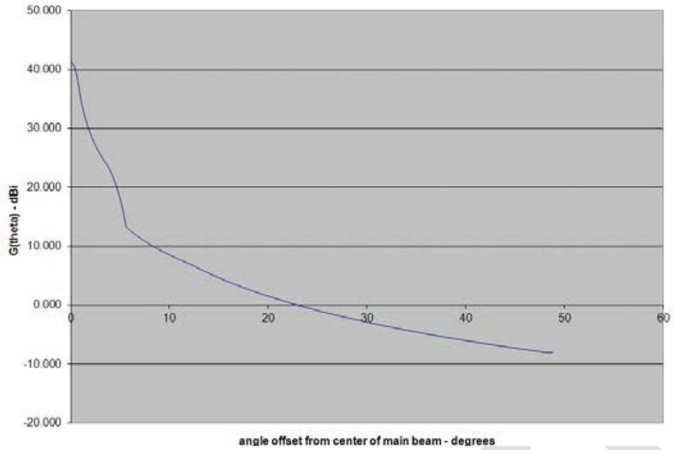
Interference to the eNodeB base station was assessed for the following eNodeB antenna orientations with respect to the AMT equipped aircraft: on-azimuth, 60^o off-axis, 180^o off-axis, and with a 3 degree down tilt.

Summary of simulation parameters:

- Possible effects of clutter not considered for airborne transmissions
- UE physical distributions using a "randomized" real network
- UE urban and rural transmit power modeled w/ CDFs
- Single UE is 1.67 MHz, 6 UEs in a 10 MHz channel
- Base station receiver threshold taken as I/N value from baseline document
- Base stations modeled with sector antenna directionality as provided in baseline document
- AMT modeled using Spectrum Certification data and ITU-R Recommendation M.1459 internationally agreed to parameters
- AMT aircraft modeled at 23000 and 85000 feet
- AMT receiver interference threshold taken as -180 dBW/m^2 per 4 kHz averaged over the AMT channel bandwidth
- AMT transmit EIRP taken as 10 Watts
- Air-to-ground, ground-to-air propagation modeled using ITU-R P.528 for 50%
- Ground-to-ground propagation modeled using Longley Rice point-to-point, 50% reliability, 50% confidence

A-7 <u>The composite antenna pattern from ITU-R Recommendation M.1459</u>

Figure A3.1 shows the composite antenna pattern from Rec. M.1459 as a function of the off-axis angle of a hypothetical parabolic dish antenna. The antenna combines the main lobe of a 40 dBi antenna with the sidelobes of a 30 dBi antenna. The use of this pattern makes possible a single protection level for coordination purposes, thus eliminating the need to consider the manner in which multiple antennas are used interchangeably, sometimes during a single flight, at most flight test ranges.



A-8 The CDF functions for Urban and Rural UE's

Note: differencing of the CDF yields a normal distribution (i.e., a bell-shaped curve). This can be used to compute the percentage of UE's transmitting at a particular power level. Because of the logarithmic distribution of power levels, a small percentage of the active UE's radiate a significant amount of the aggregate power.

Rural CDF	Power dBm
0.00000	-40
0.00000	-37
0.00000	-34
0.00000	-31
0.00000	-28
0.00005	-25
0.00022	-22
0.00060	-19
0.00132	-16
0.00389	-13
0.00989	-10
0.02524	-7
0.05769	-4
0.11517	-1
0.20623	2
0.33072	5
0.48429	8
0.64477	11
0.79204	14
0.91232	17
1.00000	20

CDF Urban	Power dBm
0.00000	-40
0.00010	-37
0.00030	-34
0.00110	-31
0.00310	-28
0.00710	-25
0.01540	-22
0.03200	-19
0.06470	-16
0.11940	-13
0.20330	-10
0.31600	-7
0.45300	-4
0.59590	-1
0.72970	2
0.83900	5
0.91430	8
0.95940	11
0.98300	14
0.99360	17
1.00000	20

A-9 The conversion methodology used to convert the UE CDF value given in dBm for a 10 MHZ LTE channel to the Y axis of the graph represented as dbW/m^2 in 4 kHz

For each of 720 values of azimuth (-180 - 180 degrees in .5 degree increments), the antenna is pointed at a fixed value of azimuth at zero degrees elevation, and the composite pattern given in Rec. M.1459 is used for the interference analysis.

The signals from the UE's are processed according to the direction, relative the main beam of the antenna, from which they arrive. The effective area of the antenna in the direction of the UE's is taken into account, along with path loss including terrain and diffraction effects. The resulting signal is thus converted into an equivalent power measured at the terminals of the AMT receive antenna.

If, for example, the signal from a subset of UE's arrives in a side-lobe that has a gain of 10 dB, the effective area lambda^2 G/4pi is used with a G value of 10 dB for the aggregate signal coming from that particular direction.

The power received in each of 720 separate 0.5 degree wedges is then summed to compute the total aggregate received interference power from all directions. This is done again for each of 720 mainbeam pointing angles.

The aggregate power for each mainbeam pointing angle is then compared to the power at the terminals that a single interference source at -180 dBW/m^2 in 4 kHz would cause when received in the main-beam of the antenna. This provides a scale factor for converting total interference power measured at the AMT antenna's terminals to a single value of pfd. Note that the antenna pattern in Rec. M.1459 is used for this "reverse" computation that turns a power level into a pfd.

A-10 Patuxent River/Atlantic Test Ranges Technical Parameters and Simulation Results

Characteristics and Assumptions specific to the Patuxent River/Atlantic Test Ranges (ATR)

20 fixed Automatic Tracking Telemetry Antenna Systems (ATTAS)
Primary Operating Areas:
  Chesapeake Test Range
  Restricted Areas R-4002, 4005-8, 6609, Chessie A, B, C
  Altitude: Surface to 85,000 feet
Offshore Operating Areas:
  Warning Areas W-386, W-387, W-72
  Altitude: Surface to Unlimited

Hangar 101: 15 ft. Aperture
Hangar 2805: 8 ft. Aperture
Westover: 4 ft. Aperture
Point Lookout: 4 ft. Aperture

The “Protection Distance” for interference to AMT from UE was determined assuming all stations in the ATR network are in use. For example, the protection distance for Hangar 101 was found assuming the protection distance for Point Lookout was in effect, etc.

Figure A-10.1 Maps of the relevant Atlantic Test Range flight areas

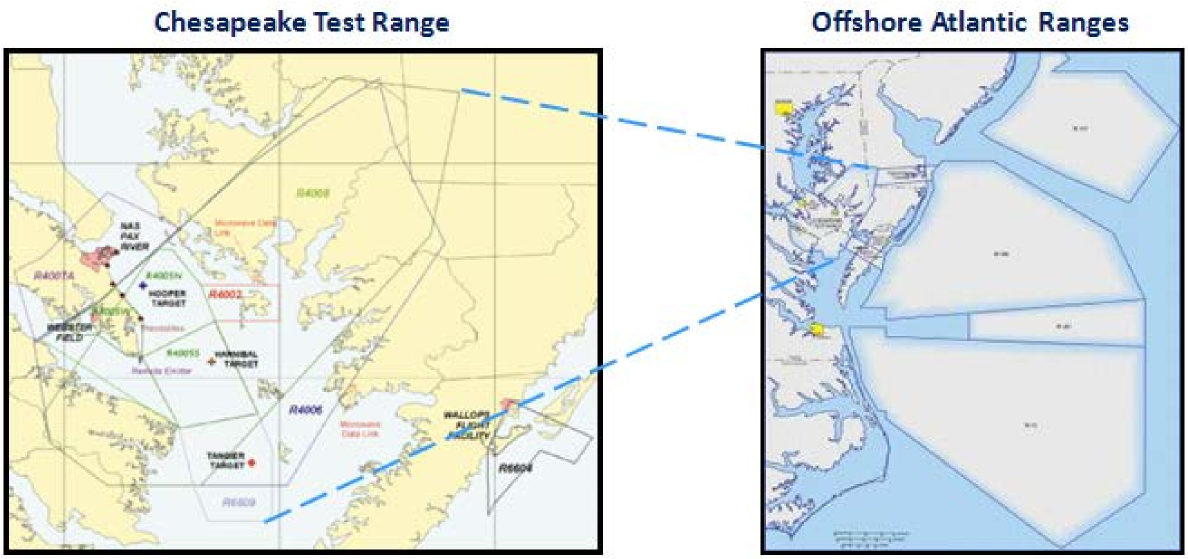


Figure A-10.2 The Randomized-Real Data layout of User Equipment. Red circles represent urban deployment; the yellow represent rural deployment.

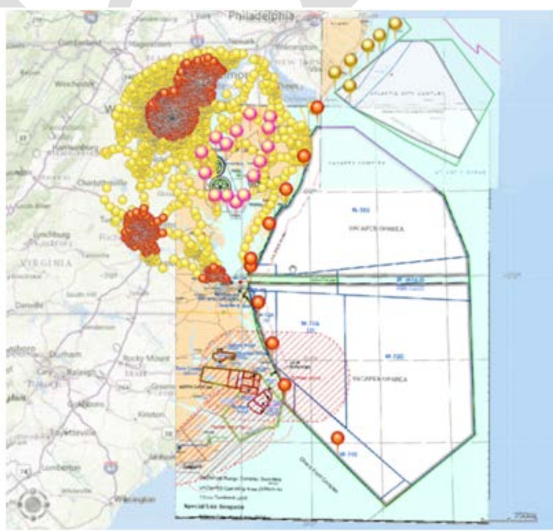


Figure A-10.3 Interference results for Patuxent River Hangar 101.

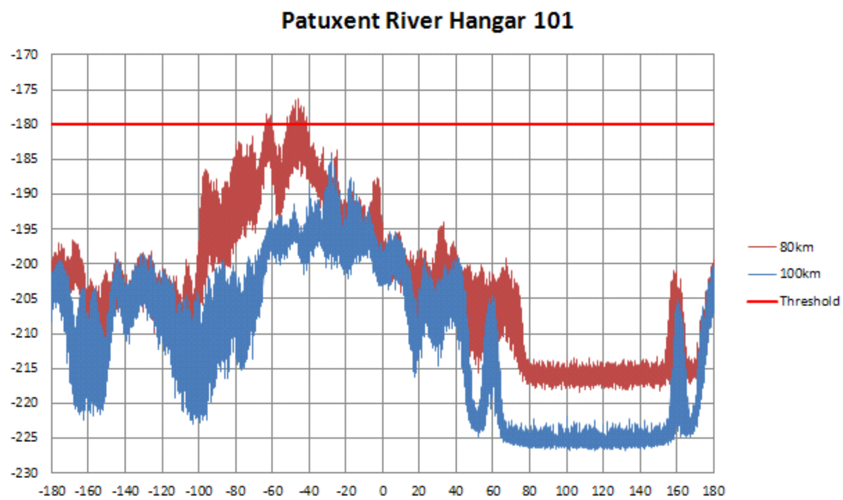


Figure A-10.4 Interference results for Patuxent River Hangar 2805.

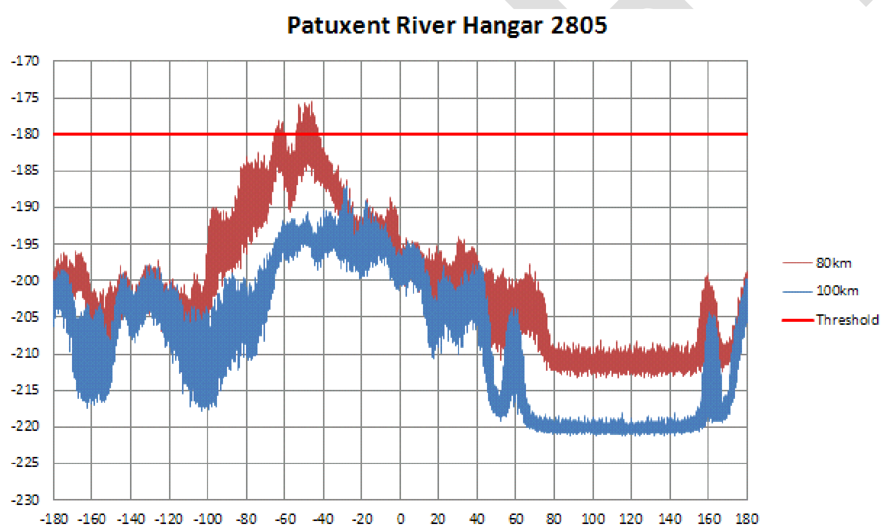


Figure A-10.5 Interference results for Patuxent River Westover Site.

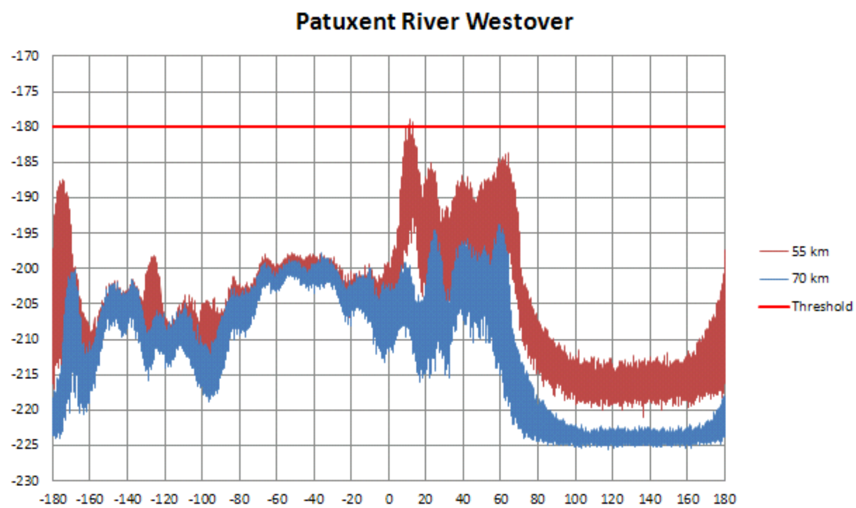


Figure A-10.6 Patuxent River/Atlantic Test Ranges (ATR) Summary of Analyses for the Randomized Real UE Deployment: Protection Distance

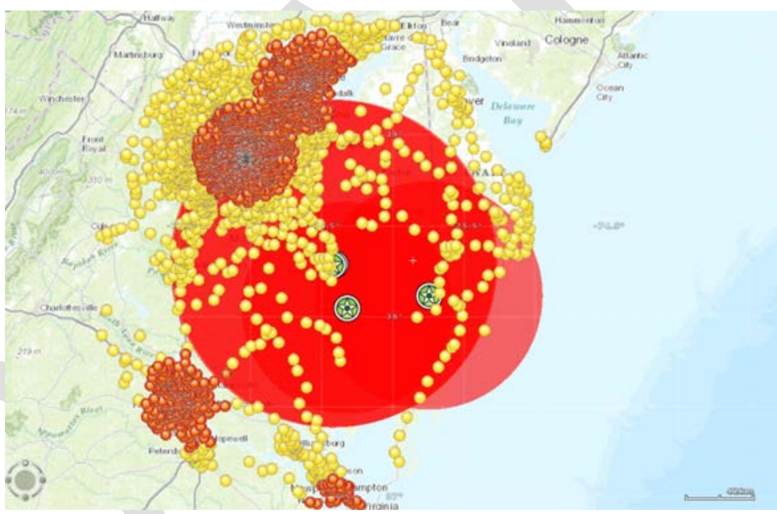


Figure A-10.7 Patuxent River/Atlantic Test Ranges (ATR) Summary of Analyses for interference from flight test aircraft telemetry transmitters to LTE eNodeB base stations for AMT Transmit to Base Station Receive : AMT Altitude=7km (23,000 ft.)

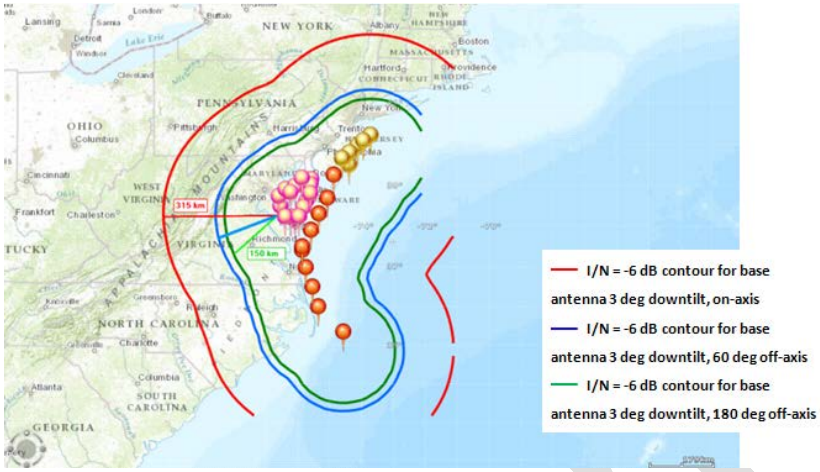


Figure A-10.8 Patuxent River/Atlantic Test Ranges (ATR) Summary of Analyses for interference from flight test aircraft telemetry transmitters to LTE eNodeB base stations for AMT Transmit to Base Station Receive : AMT Altitude= 26km (85,000 ft.)