CSMAC Working Group 5
Sub-Working Group 4 Report

Feasibility of DoD PGM and Miscellaneous Airborne Systems Sharing the 1755-1850 MHz Band with Commercial Long Term Evolution Systems

19 June 2013

DISTRIBUTION STATEMENT A.

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1 INTRODUCTION

This report concerns SWG-4.

1.1 BACKGROUND

The focus of work for SWG-4 is:

1). The determination of protection requirements for federal operations, and

2). The understanding of the periodic nature and the impact to commercial wireless systems of government airborne operations.

SWG-4 is responsible for the following deliverables:

- Briefing on Analysis Approach
- Briefing on Analysis Results
- The CSMAC WG-5 SWG-4 Report

1.2 EXECUTIVE SUMMARY OF FINDINGS

1.2.1 Analyses

The feasibility of LTE systems sharing the 1755-1850 MHz band with PGMs and other miscellaneous airborne systems was determined by performing analyses of potential electromagnetic interference (EMI) between LTE and the DoD system.

The following DoD systems were analyzed:

- PGMs
- TactiLink Eagle
- Joint Tactical Radio System (JTRS) Airborne and Maritime/Fixed (AMF) (Note: analysis of ground-ground communications between JTRS radios was accomplished in WG-4)
- Tactical Targeting Network Technology (TTNT), including systems used by the Navy, Army/USMC, and Air Force
- LITENING/Sniper targeting pods with Compact Multiband Data Link (CMDL)
- Dragoon
- Video ORiented Transceiver for EXchange of information (VORTEX)
- Remote Operations Video Enhanced Receiver (ROVER)

Two different types of analyses were performed for the systems listed above:

- the DoD system receiver as potential victim of EMI from LTE UEs
- the DoD system transmitter as potential source of EMI to LTE base stations.

The analyses were performed for several locations, such as DoD test and training ranges, for each DoD system. The analyses predicted required distances to protect a receiver from EMI.

1.2.2 Results

The estimated protection distances for the DoD systems assessed in the SWG-4 effort are summarized in Table 1-1. For a DoD system, a range of distances accounts for assessing the system at multiple sites.

Table 1-1. Summary of Estimated Protection Distances for All Assessed Systems

DoD System	Estimated Protection Distances[1] (km)	
	UEs to DoD Receiver	DoD Transmitter to LTE Base Station
PGM	290	43 - 423
TactiLink Eagle	Not applicable	145 - 230
JTRS AMF	130 - 165	180 - 245
Navy TTNT	330 - 360	291 - 440
Army/USMC TTNT	350 (air), 25 (gnd)	260 - 415
LITENING CMDL	80 - 300	40 - 280
Sniper CMDL	80 - 300	Not applicable
Dragoon	45 - 94	145 - 325
VORTEX	80 - 300	160 - 420
ROVER	5 - 30	Not modeled – characteristics similar to CMDL

[1] Distances are for the sites included in the assessment

Note: an Air Force system utilizing TTNT waveforms was identified very late in the task. Because of time constraints, this system was not analyzed.

Observations for the case of LTE UEs to a DoD receiver are as follows:

- UEs are predicted to cause EMI to DoD systems within the protection distances identified in Table 1-1.
- Predicted protection distances are the result of considerable line-of-sight distances from an aircraft that is operating at a high altitude and the assumption that the interference threshold for the victim receiver is an interference-noise (I/N) ratio of -6 dB.
- Protection distances depend on the number of UEs deployed in the vicinity of the DoD system due to aggregation of the received power from these sources. If the number of UE's increase over time, these distances could increase.

Observations for the case of a DoD transmitter to an LTE base station are as follows:

- DoD systems are predicted to cause EMI to LTE base stations within the protection distances identified in Table 1-1.
- Predicted protection distances are the result of:
  - Considerable line-of-sight distances from an aircraft that is operating at a high altitude and the assumption that the interference threshold for the victim receiver is an interference-noise (I/N) ratio of -6 dB.

        - Relatively high base station antenna gain for certain orientations relative to the aircraft

The actual protection distances will be less under most circumstances, depending on specific link budget parameters and actual propagation losses. But the impact of such considerations has not been determined.

1.2.3 Conclusion

Based on the results of the analyses, it is not feasible for LTE systems to share the 1755-1780 MHz band with DoD systems within the sites and protection distances provided unless technical and operational mitigation approaches are developed (see, for example, Paragraph 1.4.1).

Additional details relative to the results are provided in later sections.

1.3 SUMMARY OF RECOMMENDATIONS

This subsection lists the recommendations for the DoD systems assessed as part of the SWG-4 effort.

1.3.1 PGM

Based on the results of the analyses, the following is recommended for PGM:

- The following additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with PGM systems:
    - Time-Based Sharing – Due to the intermittent nature of the training and test periods associated with PGM systems, utilization of shared spectrum by LTE systems could occur for a large majority of the time. The benefit of this approach is offset by the loss of spectrum by LTE systems over extensive areas, inclusive of major urban areas in the Southwest, during the smaller time windows when the incumbent PGM system needs to use spectrum.
    - Frequency Off-Tuning – Utilizing the Time-Based Sharing approach above in concert with frequency off-tuning would allow a reduction in the size of the interference protection or exclusion areas.
    - Interference Thresholds – Since receivers in the LTE network are generally not noise-limited, a more realistic interference threshold or criterion may allow a reduction in the size of the interference protection or exclusion areas.
    - Possible Effects Of Clutter And Terrain – Current WG-5 analysis does not take into account the effects of clutter and terrain. Additional study of the impact that clutter and terrain have on propagation, particularly in air-to-ground analysis, may have the potential to significantly impact protection distances.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.2 TactiLink Eagle

Based on the results of the analyses, the following is recommended for TactiLink Eagle:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with TactiLink Eagle systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.3 JTRS AMF

Based on the results of the analyses, the following is recommended for JTRS AMF:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with JTRS AMF systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches,
    - Establish JTRS protection zones for the 1755-1850 MHz band at the following six highest-priority DoD training installations/locations to minimize impacts to operational training requirements: Fort Irwin, CA (NTC); Fort Polk, LA (JRTC); Fort Bliss, TX and WSMR, NM; Fort Hood, TX; Fort Bragg, NC (Includes Camp Mackall); Yuma Proving Ground (YPG), AZ
    - For all other DoD training installations/locations, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
    - If relocation is required, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.4 TTNT

Based on the results of the analyses, the following is recommended for Navy TTNT systems:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Navy TTNT systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches,
    - Establish protection zones for Navy TTNT and the Multifunctional Information Distribution System for JTRS (MIDS-J) for the 1755-1850 MHz band at the seven highest-priority DoD test and training installations/locations to minimize impacts to operational training requirements. The list of seven highest-priority DoD installations/locations can be provided.
    - For all other DoD installations/locations for test and training of Navy TTNT and MIDS-J, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
    - If relocation is required, relocate to an alternate frequency band that is

    - comparable to the 1755-1850 MHz band.

Based on the results of the analyses, the following is recommended for Army/USMC TTNT systems:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Army/USMC TTNT systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches,
    - establish protection zones for Army/USMC TTNT for the 1755-1850 MHz band at the six highest-priority DoD installations/locations for Army testing/training and the six highest-priority DoD installations/locations for USMC testing/training to minimize impacts to operational training requirements. The lists of six highest-priority Army/USMC installations/locations can be provided.
    - For all other DoD installations/locations for test and training of Army/USMC TTNT, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
    - If relocation is required, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

The following is recommended for Air Force TTNT systems:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Air Force TTNT systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches,
    - Establish protection zones for Air Force TTNT systems for the 1755-1850 MHz band at the six highest-priority DoD test and training installations/locations to minimize impacts to operational training requirements. The list of six highest-priority DoD installations/locations can be provided.
    - For all other DoD installations/locations for test and training of Air Force TTNT, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
    - If relocation is required, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.5 CMDL

Based on the results of the analyses, the following is recommended for CMDL:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with CMDL systems.

- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.6 Dragoon

Based on the results of the analyses, the following is recommended for Dragoon:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Dragoon systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.7 VORTEX

Based on the results of the analyses, the following is recommended for VORTEX:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with VORTEX systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

1.3.8 ROVER

Based on the results of the analyses, the following is recommended for ROVER:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with ROVER systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

A concern of the recommendations above is that COAs for the ROVER system are contingent on following any/all COAs related to SUAS.

1.4 PATH FORWARD

1.4.1 Promising Opportunities for Future Studies

The PGM-Miscellaneous Systems SWG determined there are other possible topics that may warrant additional study. The following list of possible topics is applicable to all the DoD systems that were assessed.

1. Time-Based Sharing – Commercial wireless industry presented information on innovative spectrum sharing techniques (e.g., time-based sharing or real time monitoring via Licensed Shared Access) that could exploit the dynamic nature of Government use of spectrum and the advanced features in the LTE standards. These mechanisms would enable commercial wireless

industry licensees to dynamically relinquish use of spectrum with minimal impact to users in areas and during times that government users are operating. The economic acceptability of such sharing will depend on the amount of time and the areas impacted. Accordingly, commercial wireless industry study should include mechanisms to minimize the amount of time and area when a channel would need to be cleared for government operations. DoD study should include the feasibility of the time-based sharing Licensed Shared Access technique. This study should also include the potential impact on government operations and the requirements for government inputs to the commercial wireless industry licensees via a database or some other secure means.

2. Frequency Off-Tuning – In certain areas, off-tuning between the channel assignments of LTE and government systems would avoid direct co-channel operation. However, there could still be non-co-channel interference between LTE and a government system because of leakage of energy from the adjacent LTE channels into the DoD receiver. The protection distances in non-co-channel operation are expected to be less than the ones generated in this report based on co-channel operation of LTE and each government system. The feasibility of such off-tuning between assignments and the magnitude of protection distance reduction would require further study. In addition, the DoD should determine requirements for coordination between government and industry.

3. Frequency Notching of LTE – Possible notches in wireless use of frequencies at locations with potential for EMI to DoD – Commercial wireless industry provided information on innovative spectrum sharing techniques that take advantage of advanced features in LTE technology to notch out a portion of an LTE channel at times and locations when government agencies are using the spectrum. This mechanism could be used to avoid co-channel operation with minimal impact on private sector users in cases where the government signals are narrow relative to an LTE channel. However, as indicated in item 2 above, there could still be non-co-channel interference between LTE and the government systems because of energy leakage from one system into another. The protection distances in non-co-channel operation are expected to be less than the ones generated in this report based on co-channel operation of LTE and each government system. The magnitude of this reduction would require further study. As with item 1 above, the economic acceptability of sharing via frequency notching will depend on the amount of time and the areas impacted and an effort would be needed to minimize the amount of time and area when an LTE channel would need to be notched to accommodate government operations. This could include real-time monitoring to limit impact to times when government systems are operating rather than scheduled. The DoD should investigate the technical approach and feasibility of this notching technique. The DoD should also determine requirements for coordination with commercial wireless industry and the requirements for government frequency usage inputs to commercial wireless industry.

4. Interference Thresholds – This topic considers different interference thresholds based on desired signal level rather than merely defining interference as a rise in the noise floor. Current WG-5 analysis uses long standing interference criteria established by the ITU. While there is no desire to modify this internationally accepted criteria, study of interference relative to a desired carrier taking into account actual system operations would be beneficial to understand how government and LTE systems would interact in a shared environment with close coordination between users and could significantly reduce any exclusion or protection zone required. DoD airborne systems are often at maximum range from their ground stations, and hence the receivers

are noise-limited. For DoD systems, therefore, the current -6 dB I/N interference threshold is appropriate. In the LTE Baseline document, industry defined the interference threshold as -6 dB I/N. Since receivers in the LTE network are generally not noise-limited, commercial wireless industry needs to propose a more realistic interference threshold or criterion if any follow-on work to refine the protection distances is required.

5. Possible Effects Of Clutter And Terrain – The ground-to-ground analyses conducted in WG-5 took into account terrain effects via the features included in the Irregular Terrain Model (ITM) in conjunction with a USGS terrain database. The air-to-ground analyses, using ITU-R Recommendation P.528, did not take into account terrain effects. As discussed and agreed at the outset of the work, clutter effects were not considered in any of the studies. Whether to do so, and how to do so, in future analyses remains under discussion. In particular, additional study of the impact that clutter and terrain have on propagation, particularly in air-to-ground analysis would provide greater confidence in the analysis and may have the potential to significantly impact protection distances. A proposal under consideration from the technical working group would be to compare measured data to the results of analysis. Commercial wireless industry has proposed defining a validated methodology for computing the effects of clutter for propagation paths that extend beyond the network laydown. The DoD should investigate the clutter methodology for validity and applicability.

6. UE Antenna Height – In the LTE Baseline document, commercial wireless industry defined the antenna height for UEs to be 1.5 meters above ground level and the WG-5 analyses were completed using this height. If terrain-dependent propagation loss and clutter loss are included in the analyses, a substantial number of UEs in urban and rural environments could be above the surrounding terrain and any clutter. For any follow-on work to refine the protection distances, the DoD and commercial wireless industry together should define and agree on a realistic range of antenna heights for urban and rural environments.

7. Frequency Assignment Information – The frequency assignment information for DoD systems could be prioritized to maximize access to markets that are important to commercial wireless industry. Prioritizing DoD assignments in a way that minimizes impact to markets prioritized by commercial wireless industry has the potential to improve the economic viability of sharing while continuing to meet government requirements.

2 SUB-WORKING GROUP 4 DETAILS

2.1 ORGANIZATION

SWG-4 is responsible for the analysis of the following DoD systems:

- PGMs
- TactiLink Eagle
- JTRS AMF, also referred to herein as Airborne JTRS
- TTNT, including systems used by the Navy, Army/USMC, and Air Force
- LITENING/Sniper targeting pods with CMDL
- Dragoon
- VORTEX
- ROVER

2.2 PARTICIPATION

Co-chairmen for SWG-4 are:

- Mark Johnson, Navy
- Prakash Moorut, Nokia Siemens Networks

Participation also included representatives from the following Federal agencies, DoD services, and supporting contractors:

- NTIA
- US Air Force
- US Army
- US Marine Corps
- US Navy
- Alion Science and Technology

2.3 WORK PLAN

The focus of work for SWG-4 is:

1). The determination of protection requirements for federal operations, and

2). The understanding of the periodic nature and the impact to commercial wireless systems of government airborne operations.

2.4 FUNCTIONING

Meetings and teleconferences were held regularly to discuss possible approaches and concerns.

2.5 ABSTRACT

The feasibility of LTE systems sharing the 1755-1850 MHz band with each DoD system listed in Section 1 was determined by performing analyses of potential EMI between LTE and the DoD system.

Specific sites in the United States for the analysis of each DoD system were selected based on the system's expected operational usage. In some cases, military test and training ranges were selected, and in other cases, locales where the system could be operated were selected. For each selected site, latitude/longitude points were selected to represent locations of the DoD system. Airborne systems were assumed to be at a specific altitude based on operational usage.

Two different types of analyses were performed: the DoD system receiver as potential victim of EMI, and the DoD system transmitter as potential source of EMI.

2.5.1 UE Transmitters to DoD Receiver

For the analysis of potential EMI from UEs to a DoD receiver, locations for urban/suburban and rural base stations were defined. For some analyses, the base station locations were in the form of a grid with separations according to the LTE baseline document. For other analyses, the locations were from a commercial wireless industry-provided realistic network.

At each base station location, UE transmitters were assumed to be positioned at the coordinates of the base station with an antenna height for each UE of 1.5 m AGL.

The undesired received power at the narrowest IF stage of the DoD receiver due to each UE was computed as a net sum of the following terms. A random value for the EIRP of each UE transmitter EIRP was determined from cumulative distribution function data in the LTE baseline document for all studies except for the PGM study where EIRP was modeled as fixed mean values: -3 dBm urban, 8 dBm rural (statistical output power not used). The propagation loss along the path between antennas was evaluated using an appropriate model: ITU-R 528-3[1] for ground-air paths or ITU-R 452-14[2] for ground-ground paths. Receiving system data was either based on measured data or was obtained from the DD Form 1494, Application for Equipment Frequency Allocation (also known as the J/F-12) for the system. The frequency dependent rejection (FDR) of the UE signal due to the bandwidth of the receiver IF stage was computed using the ratio of the transmitter and receiver bandwidths.

The analysis was many-on-one where the sources consisted of the collection of UE transmitters, and the level of aggregate undesired received power was calculated by summing the individual received power values in Watts, and then converting the value into dBm or dBW.

For each receiver, a threshold I/N of -6 dB was selected as the value for which operational impact to the receiver would be minimal. The aggregate I/N in dB was computed by subtracting the receiver system noise level from the aggregate undesired received power, both in dBm or dBW.

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[1] *Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands,* Recommendation ITU-R P.528-3, International Telecommunication Union, February 2012.

[2] *Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz,* Recommendation ITU-R P.452-14, International Telecommunication Union, October 2009.

The protection distance is the minimum distance between a DoD system receiver and the laydown of UEs at which EMI to the DoD receiver would not be expected to occur. For each location of the DoD system receiver, the protection distance between the receiver and the laydown of UEs was determined iteratively so that the predicted aggregate I/N was approximately equal to the threshold I/N. Plots of predicted results were generated where the urban/suburban and rural LTE locations were depicted along with the protection distance for each DoD receiver location.

2.5.2 DoD Transmitter to LTE Base Station Receiver

The analysis of potential EMI from a DoD system to an LTE base station receiver was essentially the same as that described above except that the analysis was one-on-one (i.e., the DoD system transmitter to one LTE base station receiver). The analyses used the same specific locations that were used in the analyses of UEs to the DoD receiver.

The undesired received power and the I/N for the LTE BS receiver due to each DoD system transmitter was computed in a fashion similar to that described previously, with the following differences. The EIRP for the DoD transmitter was set to the maximum. System loss at the transmitter (e.g., cable loss, insertion loss, etc.) was included where appropriate. The bandwidth for the LTE BS receiver was set at 10.0 MHz. Receiver system loss was 2 dB from the Baseline LTE document. The FDR of the DoD signal due to the bandwidth of the receiver IF stage was computed using the ratio of the transmitter and receiver bandwidths. The off-axis angle was defined as the difference between the azimuth angle for an antenna’s maximum gain and the azimuth angle for the transmitter-receiver path. The analyses were performed for several antenna off-axis gain values. Given parameters from the LTE Baseline document, off-axis gain values for the LTE base station sectoral antenna were obtained using a model of the antenna.[3]

A color-coded contour representing the transmitter-receiver distance at which the I/N at the LTE receiver is equal to the I/N threshold (e.g., -6 dB) was generated and plotted. This contour represents the protection distance within which EMI to LTE base station receivers would not be expected.

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[3] *Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz*, Recommendation ITU-R F.1336-3, International Telecommunication Union, March 2012.

3 WORK PLANS

3.1 PGMS

Potential EMI from LTE UE transmitters to the PGM receiver was analyzed. Potential EMI from a PGM transmitter (using parameters for both airborne and ground-based testing conditions) to LTE base station receivers was analyzed.

Air Force PGM systems were not included in the CSMAC assessments. Current Air Force planning calls for discontinuing the use of PGMs that have RF links in the 1755−1850 MHz frequency range.

3.2 TACTILINK EAGLE

Potential EMI from the TactiLink Eagle transmitter to LTE base station receivers was analyzed. The ground-based receiver receiving video from the airborne TactiLink was assumed to be a ROVER. Analysis of ROVER is discussed in a subsequent subsection.

3.3 JTRS AMF

Potential EMI from LTE UE transmitters to the JTRS AMF receiver was analyzed. Potential EMI from the JTRS AMF transmitter to LTE base station receivers was analyzed.

3.4 TTNT

Potential EMI from LTE UE transmitters to the Navy and Army/USMC TTNT receivers was analyzed. Potential EMI from the Navy and Army/USMC TTNT transmitters to LTE base station receivers was analyzed.

3.5 LITENING/SNIPER PODS WITH CMDL

Potential EMI from LTE UE transmitters to the airborne CMDL receiver on the LITENING pod was analyzed. Potential EMI from the airborne CMDL transmitter on the LITENING pod to LTE base station receivers was analyzed. The ground-based receiver receiving video from the airborne CMDL was assumed to be a ROVER. Analysis of ROVER is discussed in a subsequent subsection.

Potential EMI from LTE UE transmitters to the CMDL receiver on the Sniper pod was analyzed.

3.6 DRAGOON

Potential EMI from LTE UE transmitters to the Dragoon receiver was analyzed. Potential EMI from the Dragoon transmitter to LTE base station receivers was analyzed.

3.7 VORTEX

Potential EMI from LTE UE transmitters to the VORTEX receiver was analyzed. Potential EMI from the VORTEX transmitter to LTE base station receivers was analyzed.

3.8 ROVER

The ROVER is manufactured by the same company that builds VORTEX and CMDL. In addition, the characteristics for the ROVER transmitter are similar to those for the CMDL. For analysis purposes, the ROVER was assumed to be receive-only. Potential EMI from LTE UE transmitters to the ROVER receiving video from TactiLink Eagle and from LITENING CMDL was analyzed.

4 DETAILED APPROACHES AND FINDINGS

This section includes reports for the systems analyzed in SWG-4. Detailed approaches and findings for the systems are provided in the following subsections.

4.1 PGMS

4.1.1 EMI Analysis

4.1.1.1 Analysis Parameters

EMI analysis of LTE and PGM systems was performed using an Excel spreadsheet as described in Subsection 7.2.

For potential EMI from the LTE UE transmitters to the airborne PGM receiver, the airborne PGM receiver was analyzed at an altitude of 20,000 feet AGL.

For potential EMI from the PGM transmitter to the LTE BS receiver, the PGM transmitter was analyzed in two types of operation: ground testing at 5 feet above the ground, and flight testing at an altitude of 10,000 feet AGL. In addition, three base station antenna off-axis angles relative to the PGM antenna were analyzed: 0, 60, and 180 degrees. Simulated ground testing was analyzed in low-power mode. For simulated flights, only high-power mode was used.

Protection distances were computed for the above two cases. To provide a visual depiction of the Excel-predicted protection distances, three test and training ranges were selected based on high-density usage. The distance results were plotted at the following air spaces:

- NAS Jacksonville, FL airspace
- NAS Whidbey Island, WA airspace
- MCAS Kaneohe Bay, HI airspace

Representative analysis points were selected from the following specific warning areas:

- Jacksonville: Warning Areas W-133, W-157A, W-158A, and W-158E
- Whidbey Island: Warning Areas W-237A, W-237B, and W-237E
- Kaneohe Bay: W-189, W-194, and W-196

4.1.1.2 Results

The plotted protection distance results for NAS Jacksonville, FL, NAS Whidbey Island, WA and MCAS Kaneohe Bay, HI, sites are presented in Figure 4-2, Figure 4-3, and Figure 4-4. The key for these three figures is depicted in Figure 4-1. The green circles represent possible locations for the aircraft in the selected warning areas. The radius of all purple circles in the three figures was 290 km.

Figure 4-1. Key for LTE UEs to PGM Figures

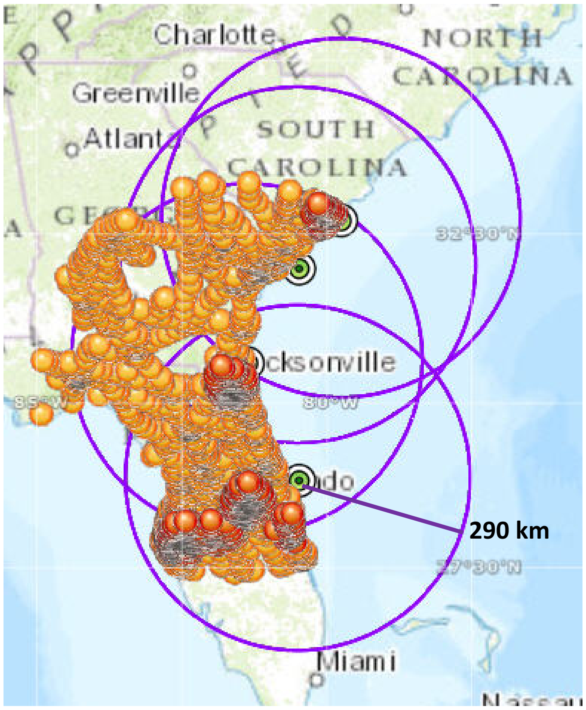


Figure 4-2. LTE UEs to PGM, NAS Jacksonville, FL

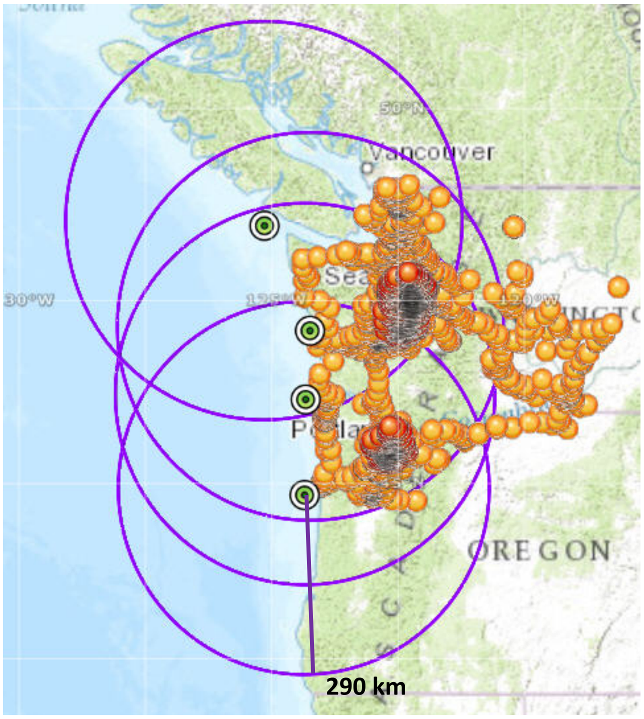


Figure 4-3. LTE UEs to PGM, NAS Whidbey Island, WA

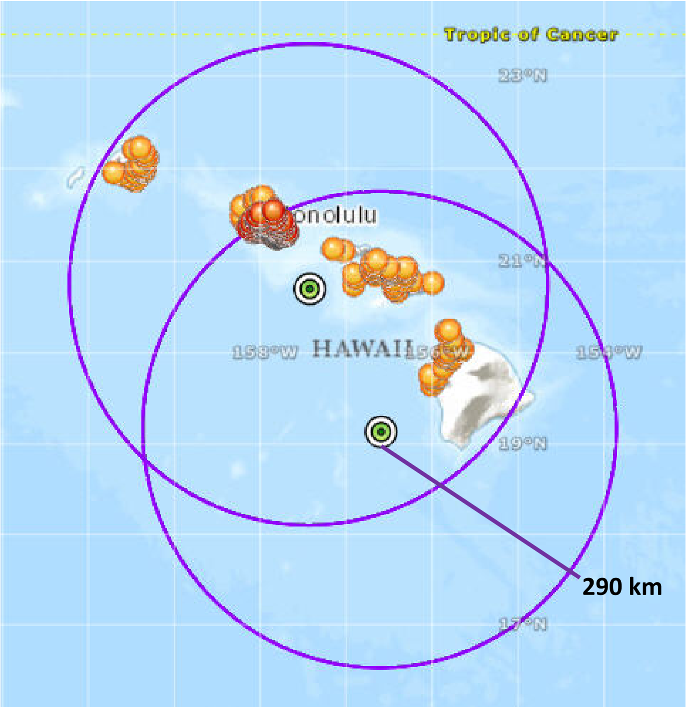


Figure 4-4. LTE UEs to PGM, MCAS Kaneohe Bay, HI

Protection distance results for the airborne PGM transmitter to the LTE BS receiver at the NAS Jacksonville, FL, NAS Whidbey Island, WA and MCAS Kaneohe Bay, HI, sites are presented in Figure 4-6, Figure 4-7, and Figure 4-8. The green circles represent possible locations for the aircraft in the selected warning areas. In each figure there are three circles centered on one of the possible aircraft locations. The key for the three circles is depicted in Figure 4-5, where the color-coding of a circle presents the orientation of the base station antenna relative to the PGM antenna (e.g., “Base antenna 60 deg off-axis” means that the angle between the base station antenna main lobe direction and the line from the PGM to the BS was 60 degrees) and the radius of the circle in km.

🟥 Base antenna on-axis, R = 423 km
🟦 Base antenna 60 deg off-axis, R = 375 km
🟩 Base antenna 180 deg off-axis, R = 43 km

Figure 4-5. Key for PGM to LTE Base Station Figures

Figure 4-6. PGM to LTE Base Stations, NAS Jacksonville, FL

Figure 4-7. PGM to LTE Base Stations, NAS Whidbey Island, WA

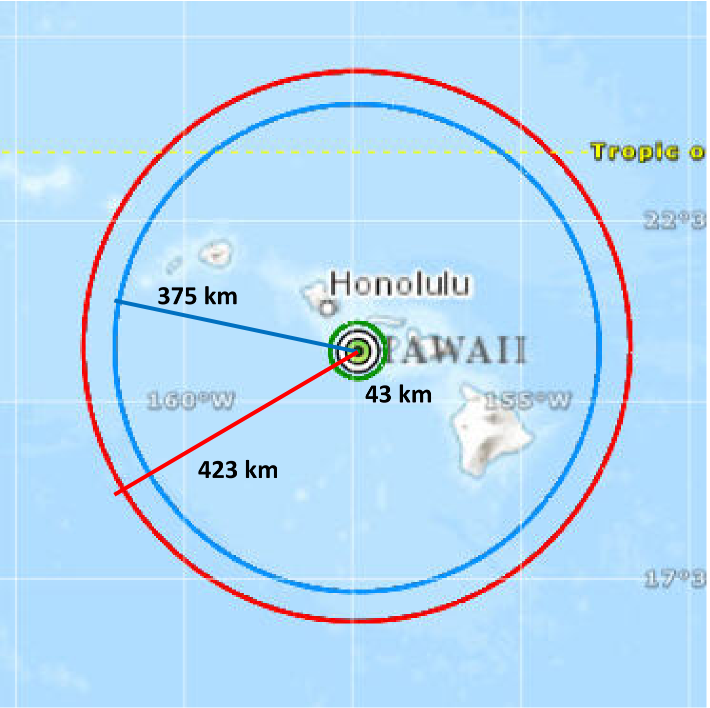


Figure 4-8. PGM to LTE Base Stations, MCAS Kaneohe Bay, HI

Protection distance results for the ground-based PGM transmitter (in low-power mode) are as follows:

- 311 km (0 degrees off-axis)
- 183 km (60 degrees off-axis)
- 13 km (180 degrees off-axis)

4.1.1.3 Summary

Protection distances for predicted interference between LTE and PGM for the NAS Jacksonville, FL, NAS Whidbey Island, WA and MCAS Kaneohe Bay, HI, sites are summarized in Table 4-1.

Table 4-1. Summary of Protection Distances - LTE Versus PGM

From UEs to PGM Receiver	**From PGM Transmitter to LTE Base Station Receiver**	
Excel Protection Distance (km)	Base Station Antenna Off-Axis Angle (deg)	Excel Protection Distance (km)
290	0	423
	60	375
	180	43

Based on the results of the analyses, it can be seen that PGM and LTE will interfere with each other unless protection distances are established. Therefore, it is not feasible for LTE to share the 1755-1780 MHz band with PGM systems within the sites and protection distances provided unless technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.1.1.4 Recommendations

Based on the results of the analyses, the following is recommended for PGM:

- The following additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with PGM systems:
    - Time-Based Sharing – Due to the intermittent nature of the training and test periods associated with PGM systems, utilization of shared spectrum by LTE systems could occur for a large majority of the time. The benefit of this approach is offset by the loss of spectrum by LTE systems over extensive areas, inclusive of major urban areas in the Southwest, during the smaller time windows when the incumbent PGM system needs to use spectrum.
    - Frequency Off-Tuning – Utilizing the Time-Based Sharing approach above in concert with frequency off-tuning would allow a reduction in the size of the interference protection or exclusion areas.
    - Interference Thresholds – Since receivers in the LTE network are generally not noise-limited, a more realistic interference threshold or criterion may allow a reduction in the size of the interference protection or exclusion areas.
    - Possible Effects Of Clutter And Terrain – Current WG-5 analysis does not take into account the effects of clutter and terrain. Additional study of the impact that clutter and terrain have on propagation, particularly in air-to-ground analysis, may

have the potential to significantly impact protection distances.

- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

4.2 TACTILINK EAGLE

4.2.1 EMI Analysis

4.2.1.1 Analysis Parameters

As indicated above, the TactiLink Eagle may be used anywhere in the lower 48 states of the U.S. Three missions were selected for the EMI analysis of LTE and TactiLink Eagle systems. The missions and a nearby city potentially causing/affected by EMI are as follows:

- Homeland Security mission (San Diego, CA)
- Oil spill in the Gulf of Mexico (New Orleans, LA)
- Atlantic superstorm (New York City, NY)

For each mission above, the helicopter carrying TactiLink was assumed to be flying in the following restricted airspaces and warning areas:

- Homeland Security mission: Kane E, W, S Military Operational Area (MOAs) east of San Diego
- Oil spill: Warning area W-453 in the Gulf of Mexico east of New Orleans
- Atlantic superstorm: warning areas W-106A, W-106B, W-107B, W-107C, in the Atlantic Ocean east of New York City and New Jersey

For each location, the analysis case involving the TactiLink Eagle transmitter to the LTE base station receiver is addressed in this subsection. The case of LTE UEs to the ground-based ROVER receiver is described in a subsequent subsection. The analyses were performed using Visualyse as described in Subsection 7.1.

In the analyses, the aircraft carrying TactiLink Eagle was simulated at 2000 feet altitude AGL.

4.2.1.2 Results

Protection distance results for the TactiLink Eagle transmitter to LTE base station receivers at the San Diego, New Orleans, and New York City areas are presented in Figure 4-9, Figure 4-10, and Figure 4-11. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively. The green spheres are the locations of the TactiLink Eagle transmitter, and the green star represents a center point for the locations.

Results for a ROVER receiving FMV from an airborne TactiLink Eagle are presented in Subsection 4.9.

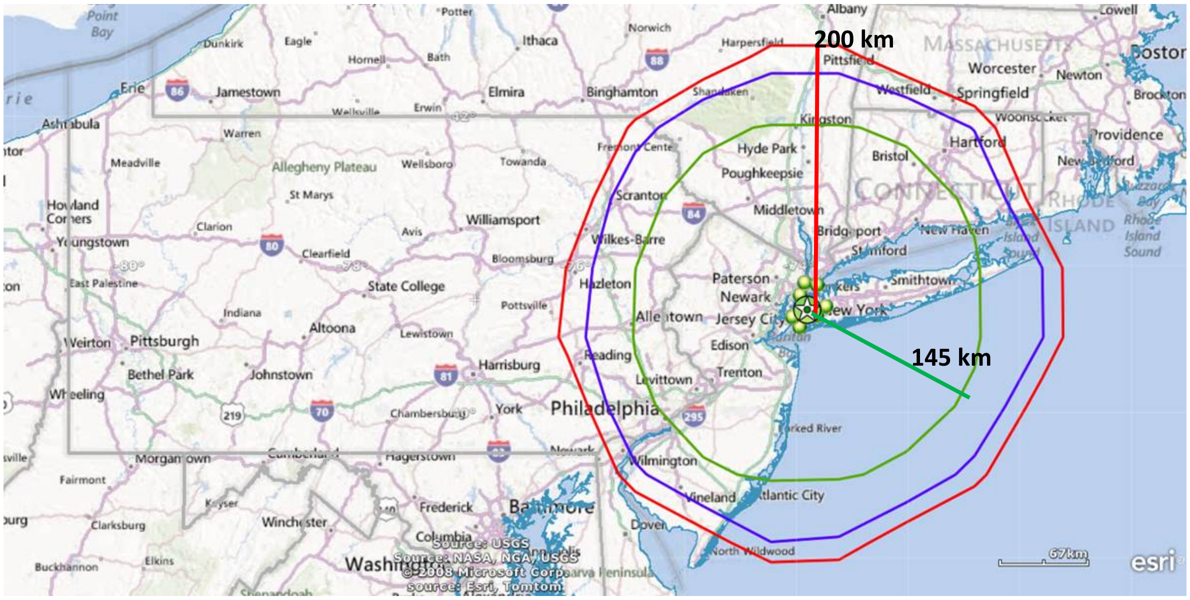


Figure 4-9. TactiLink Eagle to LTE Base Stations, New York City

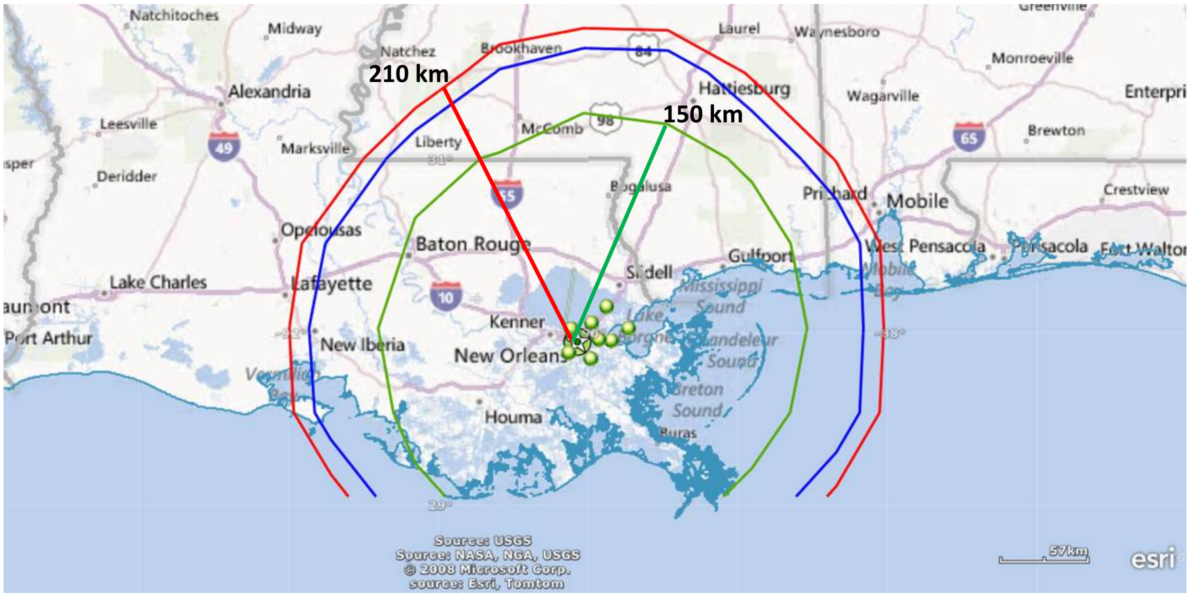


Figure 4-10. TactiLink Eagle to LTE Base Stations, New Orleans

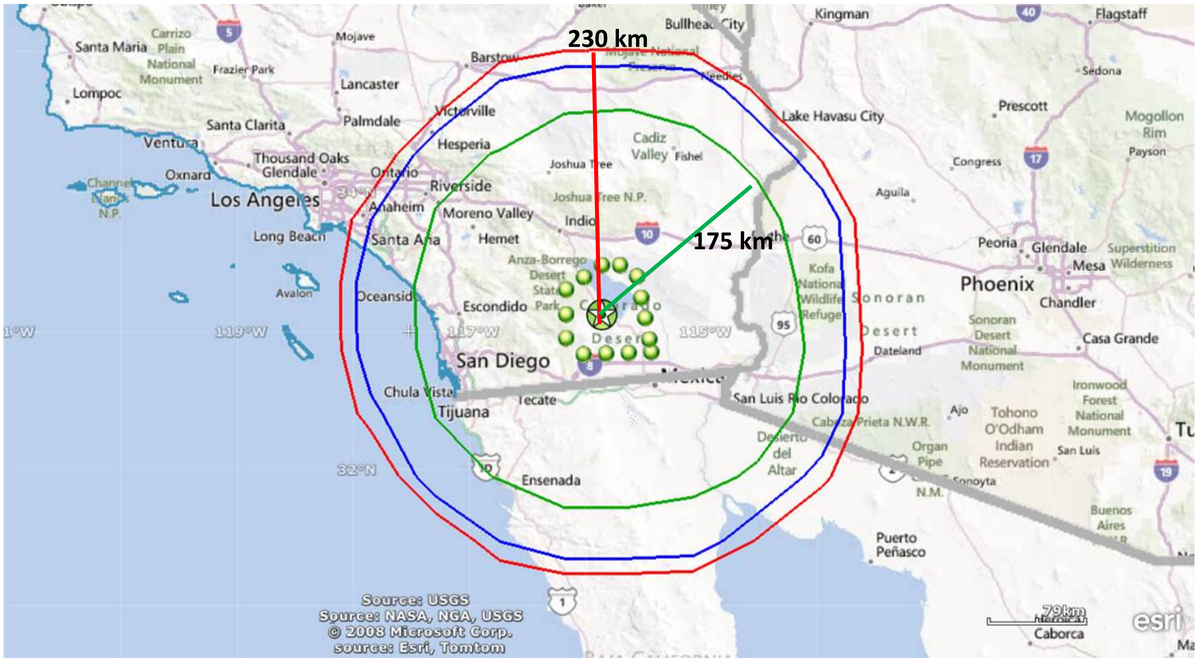


Figure 4-11. TactiLink Eagle to LTE Base Stations, San Diego

4.2.1.3 Summary

Protection distances for predicted interference between LTE and TactiLink Eagle for the New York City, New Orleans, and San Diego sites range are summarized in Table 4-2. The lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-2. Summary of Protection Distances - LTE Versus TactiLink Eagle

From TactiLink Eagle Transmitter to LTE Base Station Receiver	
TactiLink Eagle Site	Estimated Range of Protection Distances (km)
New York City	145 - 200
New Orleans	150 - 210
San Diego	175 - 230

Based on the results of the analyses for the three sites, it can be seen that TactiLink Eagle will interfere with LTE base stations unless protection distances are established. Therefore, it is not feasible for LTE to share the 1755-1780 MHz band with TactiLink Eagle systems within the sites and protection distances provided unless technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.2.1.4 Recommendations

Based on the results of the analyses, the following is recommended for TactiLink Eagle:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with TactiLink Eagle systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

4.3 JTRS AMF

4.3.1 EMI Analysis

4.3.1.1 Analysis Parameters

EMI analysis of LTE and JTRS AMF systems was performed for the following test and training ranges:

- Ft. Bragg, NC
- Ft. Hood, TX
- NTC, Ft. Irwin, CA

For each range above, the description of the area in which an aircraft carrying JTRS was assumed to be flying is as follows:

- Ft. Bragg: 75 km by 65 km area, center coordinate at 35°23'15"N, 116°37'00"W
- Ft. Hood: 40 km by 40 km area, center coordinate at 31°15'23"N, 97°44'49"W
- NTC: 40 km by 40 km area, center coordinate at 31°15'23"N, 97°44'49"W

For each location, two analysis cases were considered: LTE UE transmitters to the JTRS AMF receiver, and the JTRS AMF transmitter to the LTE base station. The analyses were performed using Visualyse as described in Section 8.1.

In the analyses, aircraft were simulated at 10,000 feet altitude AGL.

4.3.1.2 Results

Protection distance results for LTE UE transmitters to the JTRS AMF receiver at the Ft. Bragg, Ft. Hood, and NTC Ft. Irwin sites are presented in Figure 4-13, Figure 4-14, and Figure 4-15. The key for these three figures is depicted in Figure 4-12.

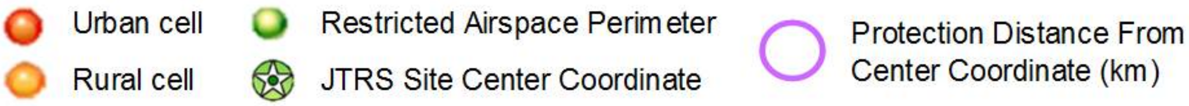
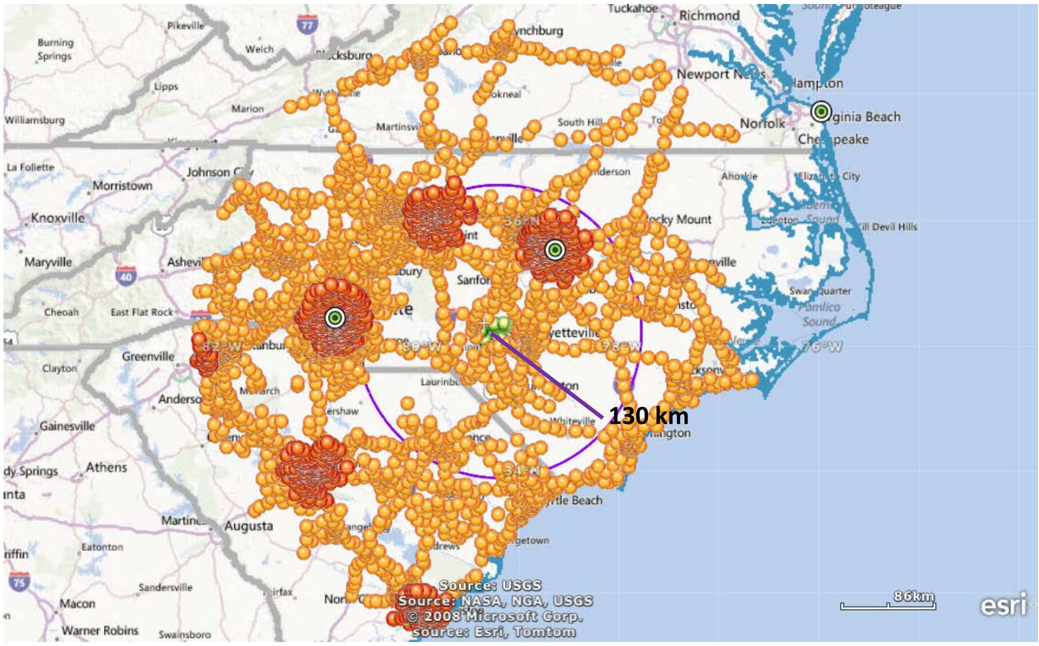
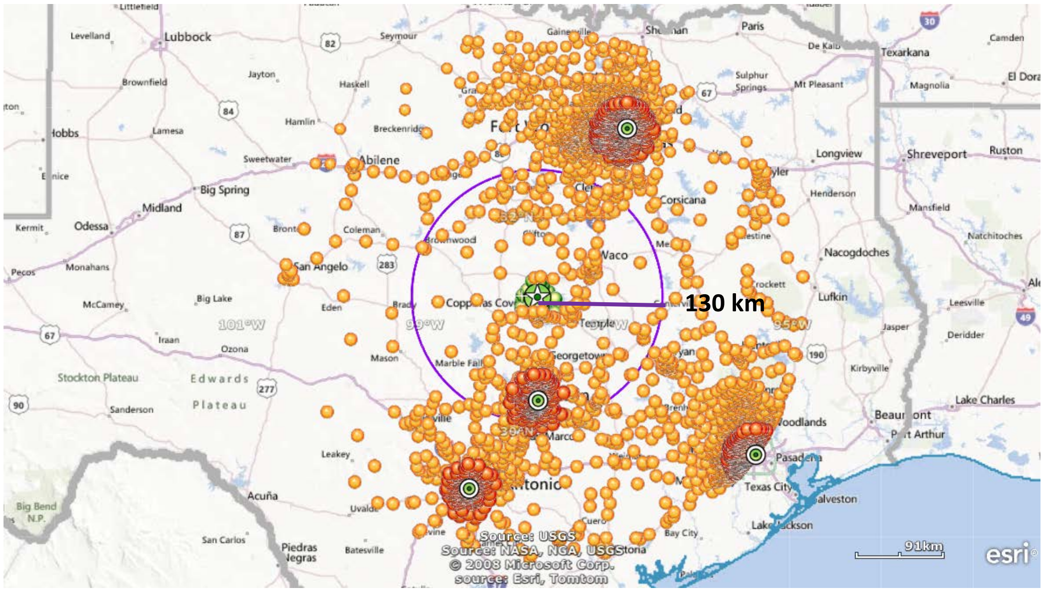


Figure 4-12. Key for LTE UEs to JTRS AMF Figures



Source: USGS
Source: NASA, NGA, USGS
© 2008 Microsoft Corp.
source: Esri, Tomtom

Figure 4-13. LTE UEs to JTRS AMF, Ft. Bragg, NC



Source: USGS
Source: NASA, NGA, USGS
© 2008 Microsoft Corp.
source: Esri, Tomtom

Figure 4-14. LTE UEs to JTRS AMF, Ft. Hood, TX

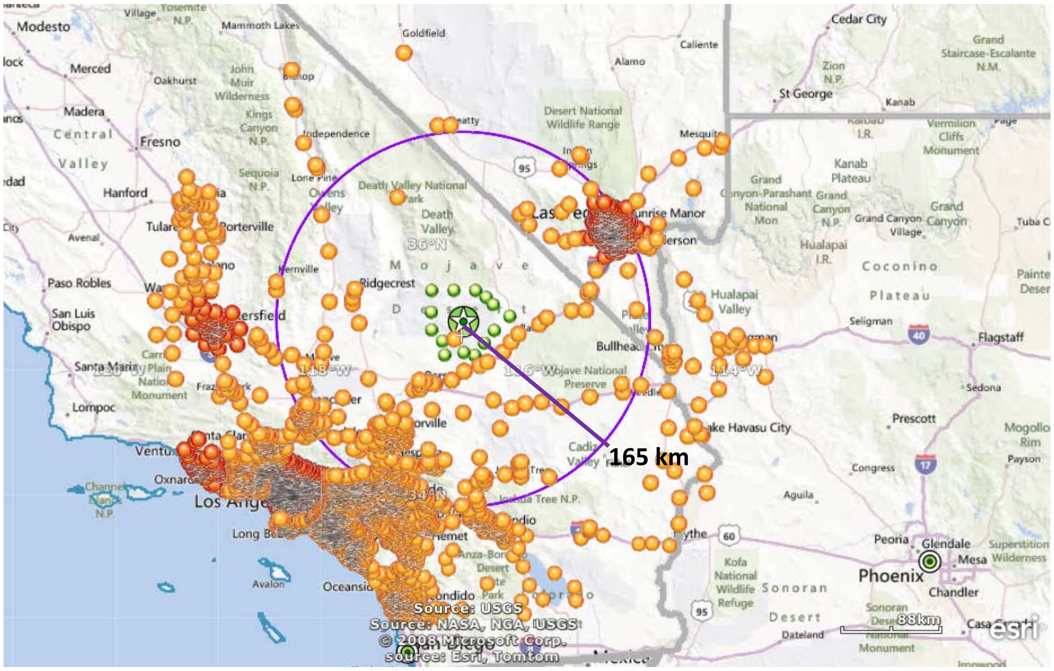


Figure 4-15. LTE UEs to JTRS AMF, NTC Ft. Irwin, CA

Protection distance results for the JTRS AMF transmitter to LTE base station receivers at the Ft. Bragg, Ft. Hood, and NTC Ft. Irwin sites are presented in Figure 4-16 through Figure 4-18. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively. The green spheres are the locations of the JTRS AMF transmitter.

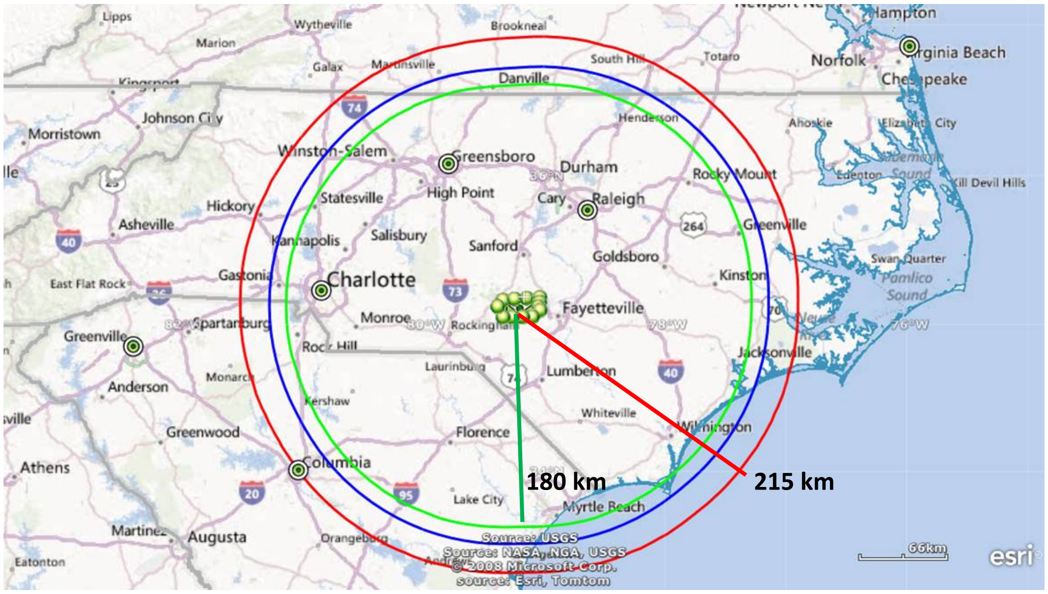


Figure 4-16. JTRS AMF to LTE Base Station, Ft. Bragg, NC

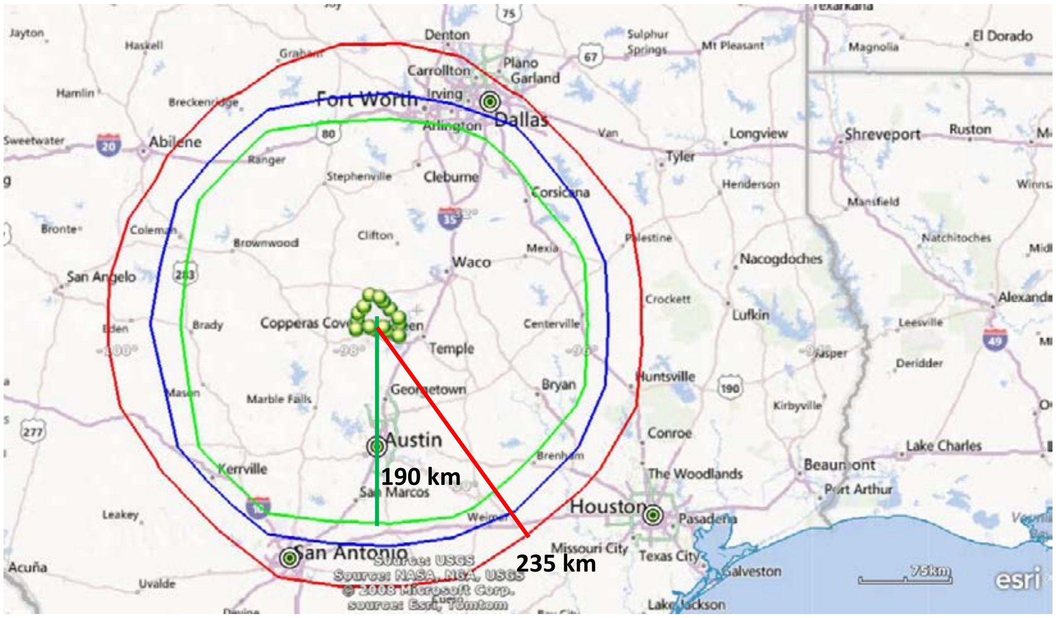


Figure 4-17. JTRS AMF to LTE Base Station, Ft. Hood, TX

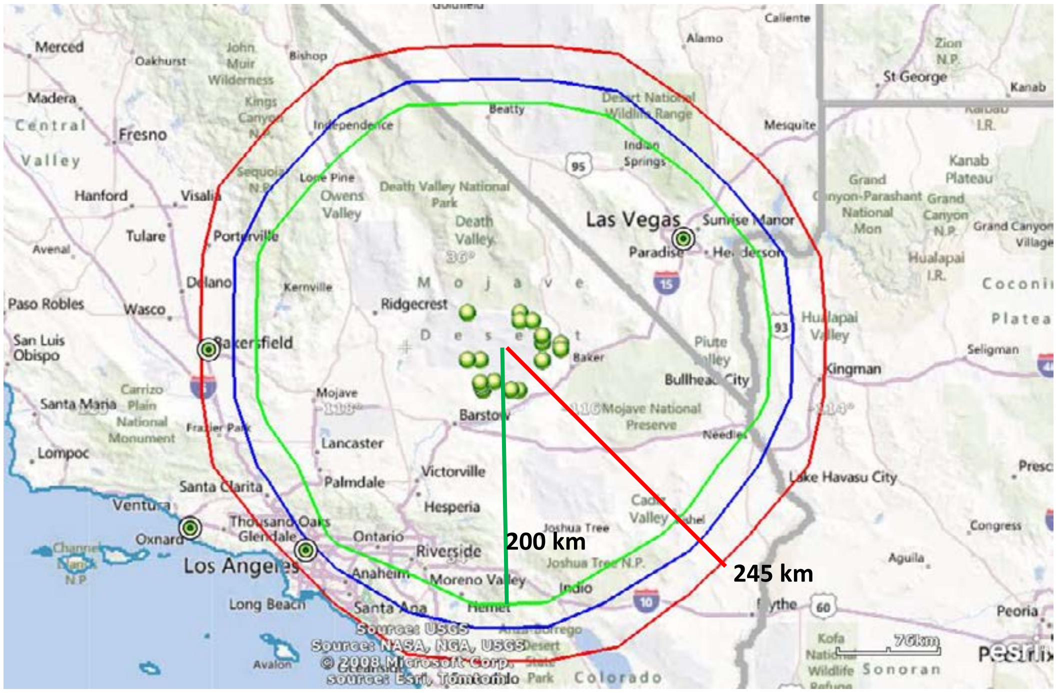


Figure 4-18. JTRS AMF to LTE Base Station, NTC Ft. Irwin, CA

4.3.1.3 Summary

Protection distances for predicted interference between LTE and JTRS AMF for the Ft. Bragg, NC, Ft. Hood, TX, and NTC Ft. Irwin, CA, sites range are summarized in Table 4-3. For JTRS

AMF transmitter to the LTE base station receiver, the lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-3. Summary of Protection Distances - LTE Versus JTRS AMF

From UEs to JTRS AMF Receiver		**From JTRS AMF Transmitter to LTE Base Station Receiver**	
JTRS AMF Site	Estimated Protection Distance (km)	JTRS AMF Site	Estimated Range of Protection Distances (km)
Ft. Bragg	130	Ft. Bragg	180 – 215
Ft. Hood	130	Ft. Hood	190 – 235
NTC Ft. Irwin	165	NTC Ft. Irwin	200 – 245

Based on the results of the analyses for the three sites, it can be seen that JTRS AMF and LTE will interfere with each other unless protection distances are established. Improved opportunities for LTE to share the 1755-1780 MHz band with JTRS AMF systems within the sites and protection distances provided are available if technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.3.1.4 Recommendations

Based on the results of the analyses, the following is recommended for JTRS AMF:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with JTRS AMF systems.
- If the protection distances as a result of additional studies are not sufficiently reduced, establish JTRS protection zones for the 1755-1850 MHz band at the following highest-priority DoD training installations/locations to minimize impacts to operational training requirements
    - Six locations were identified: Fort Irwin, CA (NTC); Fort Polk, LA (JRTC); Fort Bliss, TX and WSMR, NM; Fort Hood, TX; Fort Bragg, NC (Includes Camp Mackall); Yuma Proving Ground (YPG), AZ
- For all other DoD training installations/locations, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.

4.4 TTNT

4.4.1 EMI Analysis

4.4.1.1 Analysis Parameters

As indicated previously, the Navy, Army/USMC, and Air Force have systems employing TTNT waveforms.

EMI analysis of LTE and Navy TTNT was performed for the following assumed sites:

- Jacksonville NAS, FL airspace
- Patuxent River NAS, MD airspace

The assumed warning areas at each of the test and training ranges included:

- Jacksonville: three representative analysis points were chosen to cover all restricted airspaces in use at NAS Jacksonville
- Patuxent River:
  - Primary Operating Areas: Chesapeake Test Range restricted airspaces R-4002, 4005-8, 6609, Chessie A, Chessie B, and Chessie C
  - Offshore Operating Areas: Warning Areas W-386, W-387, and W-72

In the analyses of Navy TTNT, aircraft were simulated at an assumed 30,000 feet altitude AGL.

EMI analysis of LTE and Army/USMC TTNT was performed for the following assumed site:

- Yuma Proving Ground (YPG), AZ

In the analyses of Army/USMC TTNT, aircraft were simulated at 30,000 feet altitude AGL. The ground-based GCS antenna was modeled at 100 feet AGL.

As indicated previously, an Air Force system utilizing TTNT waveforms was identified very late in the task. Because of time constraints, this system was not analyzed.

For each location listed above, two analysis cases were considered: LTE UE transmitters to the airborne TTNT receiver, and the airborne TTNT transmitter to the LTE base station. The analyses were performed using Visualyse as described in Subsection 8.1.

4.4.1.2 Results

Protection distance results for the simulation of LTE UE transmitters to the airborne Navy TTNT receiver at the NAS Jacksonville, FL, and NAS Patuxent River, MD, sites are presented in Figure 4-19 and Figure 4-20. The outer edge of the red circle in each figure defines the protection distance for interference to TTNT from the selected UEs. For NAS Jacksonville, FL, the protection distance was determined from the border of all training areas. For NAS Patuxent River, the protection distance was determined from a single point at the center of the test range. The brown circle depicts the boundary of the area selected for LTE cells. The green star depicts the point at which the protection distance was determined.

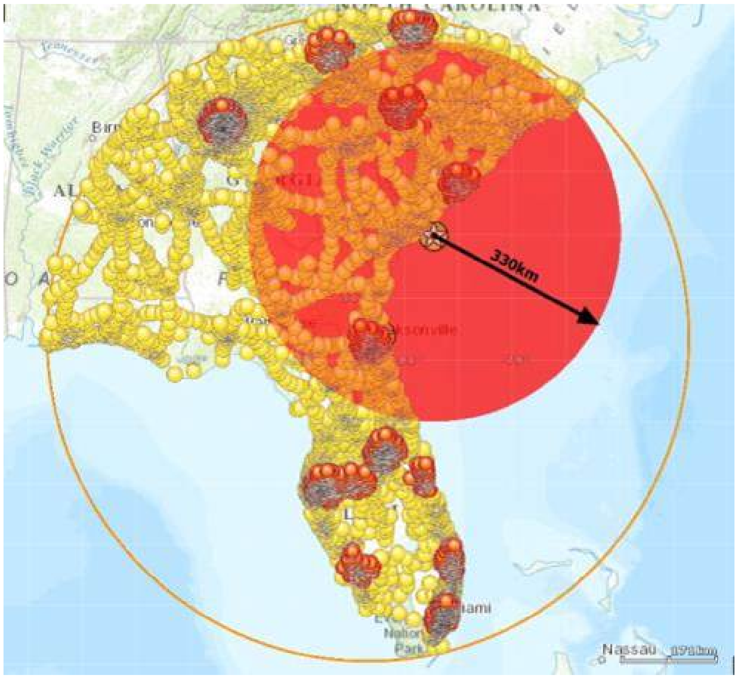


Figure 4-19. LTE UEs to Navy TTNT, NAS Jacksonville, FL

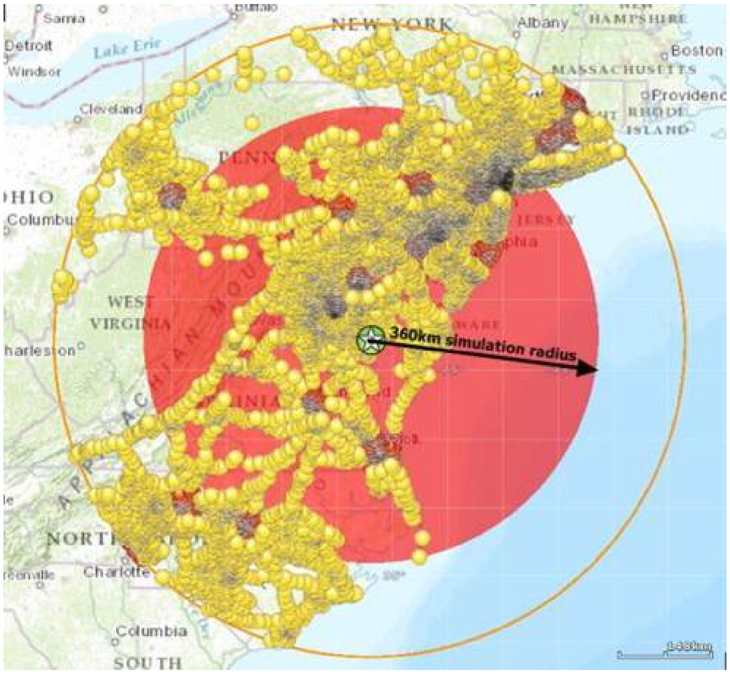


Figure 4-20. LTE UEs to Navy TTNT, NAS Patuxent River, MD

The simulated YPG environment is depicted in Figure 4-21. The green star in the figure depicts the location for the Army/USMC TTNT airborne and ground-based GCS.

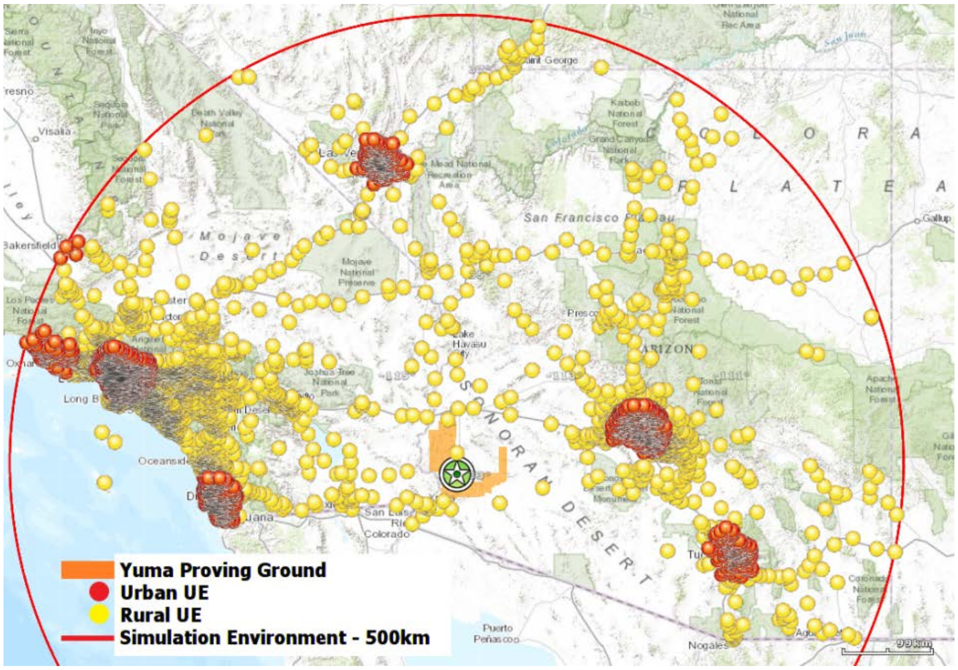


Figure 4-21. Yuma Proving Ground Environment

Protection distance results for LTE UE transmitters to the airborne Army/USMC TTNT receiver at YPG are presented in Figure 4-22. The horizontal red line marks the -6 I/N threshold. The light blue line indicates the aggregate I/N for the airborne Army/USMC TTNT receiver as a function of the candidate protection distance in km (horizontal axis). It can be seen that the light blue line drops below the -6 dB I/N threshold at a protection distance of 350 km. Similarly, the green line indicates the aggregate I/N for the ground-based Army/USMC TTNT receiver as a function of the candidate protection distance. It can be seen that the green line drops below the -6 dB I/N threshold at a protection distance of 25 km.

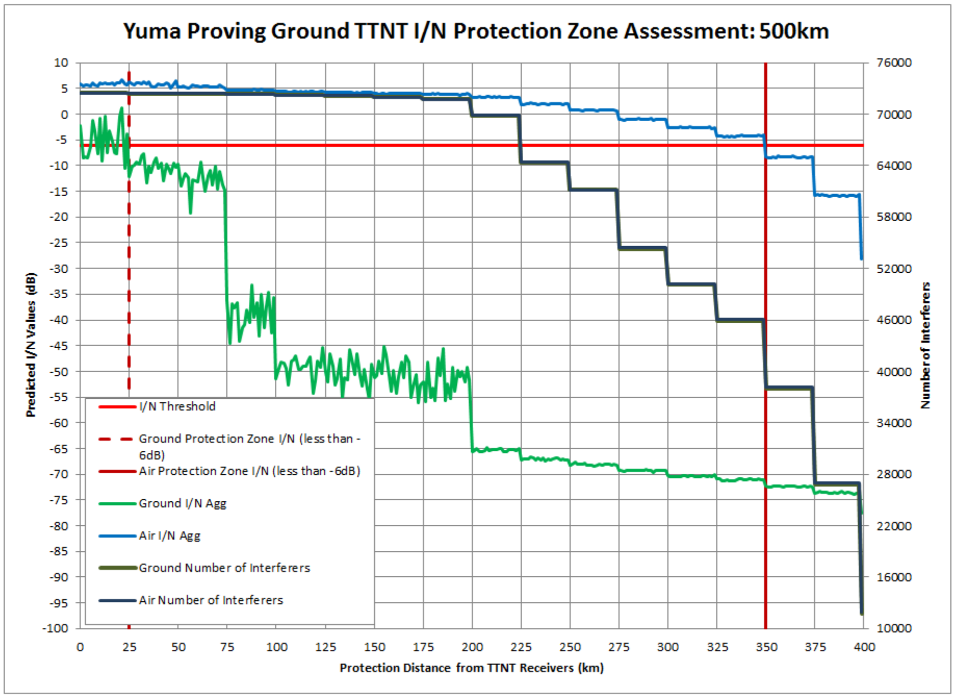


Figure 4-22. UEs to Army/USMC TTNT, Yuma Proving Ground

Protection distance results for the simulation of the Navy TTNT transmitter to LTE base station receivers at the NAS Jacksonville, FL, and NAS Patuxent River, MD, sites are presented in Figure 4-23 and Figure 4-24. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively. The green stars are the three representative analysis points for the TTNT transmitter.

Figure 4-23. Navy TTNT to LTE Base Stations, NAS Jacksonville, FL

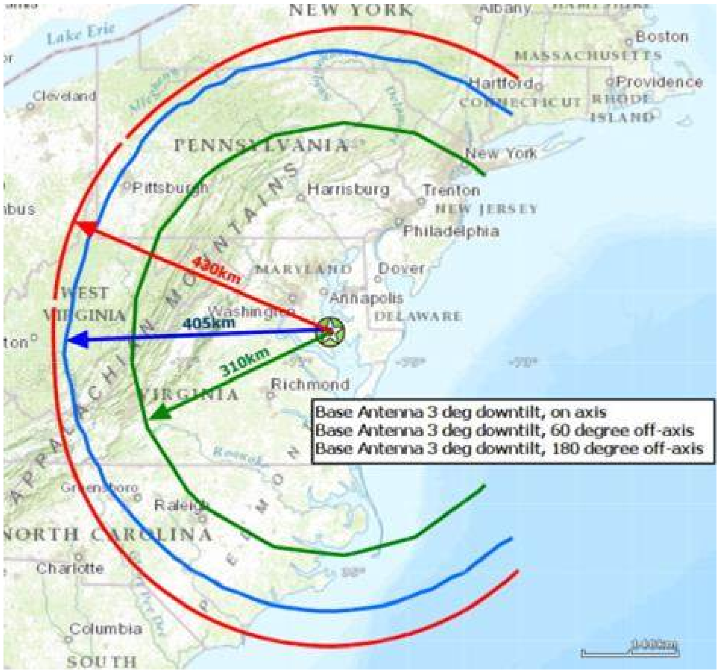


Figure 4-24. Navy TTNT to LTE Base Stations, NAS Patuxent River, MD

Protection distance results for the Army/USMC TTNT transmitter to LTE base station receivers at the analyzed site are presented in Figure 4-25. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively. The green star indicates the location for the Army/USMC TTNT transmitter.

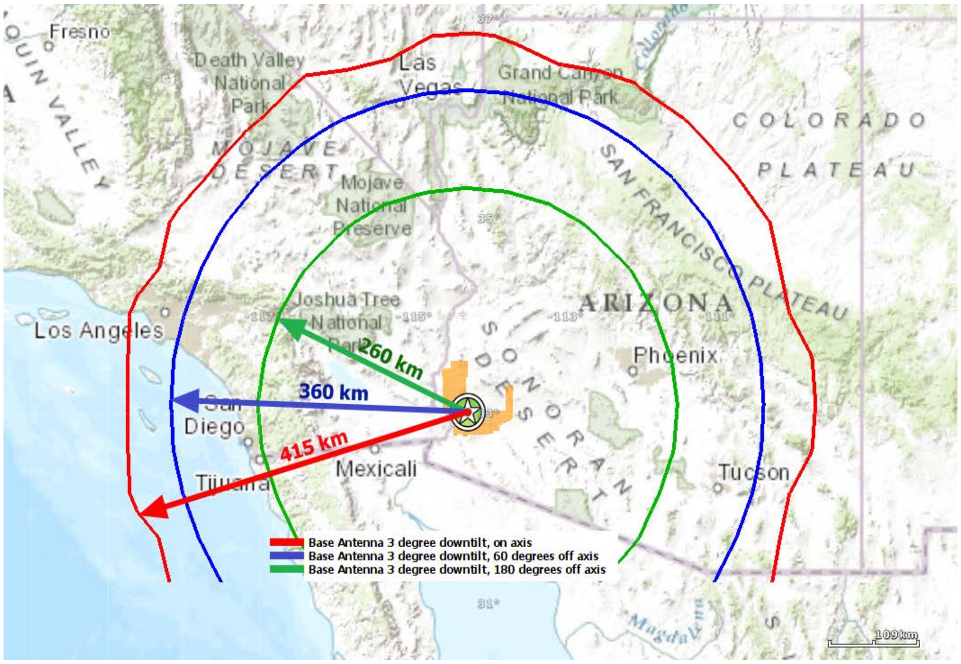


Figure 4-25. Army/USMC TTNT to LTE Base Stations, Yuma Proving Ground

4.4.1.3 Summary

Protection distances for predicted interference between LTE and Navy TTNT for the NAS Jacksonville, FL, and NAS Patuxent River, MD, sites range are summarized in Table 4-4. For the Navy TTNT transmitter to LTE base station receiver, the lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-4. Summary of Protection Distances - LTE Versus Navy TTNT

From UEs to Navy TTNT Receiver		**From Navy TTNT Transmitter to LTE Base Station Receiver**	
Analyzed Site	Estimated Protection Distance (km)	Analyzed Site	Estimated Range of Protection Distances (km)

NAS Jacksonville	330	NAS Jacksonville	291 - 440
NAS Patuxent River	360	NAS Patuxent River	310 - 430

Protection distances for predicted interference between LTE and Army/USMC TTNT for the analyzed site range are summarized in Table 4-5. For Army/USMC TTNT transmitter to LTE base station receiver, the lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-5. Summary of Protection Distances - LTE Versus Army/USMC TTNT

From UEs to Army/USMC TTNT Receiver			**From Army/USMC TTNT Transmitter to LTE Base Station Receiver**	
Army/USMC TTNT Site	Estimated Protection Distance (km), Airborne Receiver	Estimated Protection Distance (km), Ground Receiver	Army/USMC TTNT Site	Estimated Range of Protection Distances (km)
Yuma Proving Ground	350	25	Yuma Proving Ground	260 - 415

Based on the results of the analyses for the three sites, it can be seen that TTNT systems and LTE will interfere with each other unless protection distances are established. Improved opportunities for LTE to share the 1755-1780 MHz band with TTNT systems within the sites and protection distances provided are available if technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.4.1.4 Recommendations

Based on the results of the analyses, the following is recommended for Navy TTNT systems:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Navy TTNT systems.
- If the protection distances as a result of additional studies are not sufficiently reduced, establish protection zones for Navy TTNT and the Multifunctional Information Distribution System for JTRS (MIDS-J) for the 1755-1850 MHz band at the seven

highest-priority DoD test and training installations/locations to minimize impacts to operational training requirements. The list of seven highest-priority DoD installations/locations can be provided.

- For all other DoD installations/locations for test and training of Navy TTNT and MIDS-J, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
- If protection zones and truncation are not acceptable, update the cost and performance data related to the recommendation in the NTIA 1755-1850 MHz Report for relocation of Navy TTNT and MIDS-J to an alternate comparable spectrum band.

Based on the results of the analyses, the following is recommended for Army/USMC TTNT systems:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Army/USMC TTNT systems.
- If the protection distances as a result of additional studies are not sufficiently reduced, establish protection zones for Army/USMC TTNT for the 1755-1850 MHz band at the six highest-priority DoD installations/locations for Army testing/training and the six highest-priority DoD installations/locations for USMC testing/training to minimize impacts to operational training requirements. The lists of highest-priority Army/USMC installations/locations can be provided.
- For all other DoD installations/locations for test and training of Army/USMC TTNT, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
- If protection zones and truncation are not acceptable, evaluate the cost and performance data for relocation to an alternate comparable spectrum band.

The following is recommended for Air Force TTNT systems:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Air Force TTNT systems.
- If the protection distances as a result of additional studies are not sufficiently reduced, establish protection zones for Air Force TTNT systems for the 1755-1850 MHz band at the six highest-priority DoD test and training installations/locations to minimize impacts to operational training requirements. The list of six highest-priority DoD installations/locations can be provided.
- For all other DoD installations/locations for test and training of Air Force TTNT, truncate above 1780 MHz without requiring new spectrum assignments to replace the ones in the 1755-1780 MHz band.
- If relocation of Air Force TTNT is required, evaluate the cost and performance data for relocation to an alternate comparable spectrum band.

4.5 LITENING AND SNIPER CMDL

4.5.1 EMI Analysis

4.5.1.1 Analysis Parameters

EMI analysis of LTE and CMDL systems was performed for the following test and training ranges:

- Eglin Test Range (TR)
- Nevada Test and Training Range (TTR)
- Edwards AFB

In the simulation, the aircraft was assumed to be at points along the boundary defined by one or more restricted airspaces:

- Eglin TR: MOAs Eglin A (East and West), B, C, D, E, F
- Nevada TTR: restricted airspaces R-4806, R-4807
- Edwards AFB: restricted airspace complex R-2508

For CMDL on a LITENING pod, two analysis cases were considered for each simulated location: LTE UE transmitters to the CMDL receiver, and the CMDL transmitter to the LTE base station (the case of LTE UE transmitters to the ground-based ROVER receiving FMV from the CMDL is described in another subsection).

For CMDL on a Sniper pod, the only analysis case that was considered was LTE UE transmitters to the CMDL receiver.

All CMDL analyses were performed using Visualyse as described in Subsection 7.1.

In the analyses, the aircraft carrying CMDL was simulated at 30,000 ft altitude AGL.

4.5.1.2 Results

Protection distance results for LTE UE transmitters to the airborne LITENING CMDL receiver at the Eglin TR, Nevada TTR, and Edwards AFB sites are presented in Figure 4-27, Figure 4-28, and Figure 4-29. The outer edge of a red circle in each figure defines the individual protection distance for interference to CMDL from the selected UEs. An individual red circle was defined for each point along the boundary of the training area. The key for these three figures is depicted in Figure 4-26.

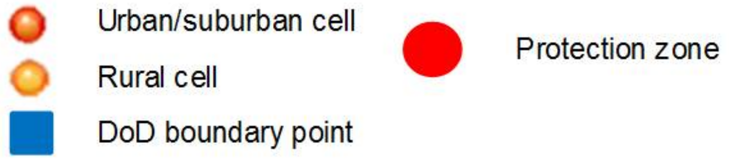


Figure 4-26. Key for LTE UEs to LITENING CMDL Figures

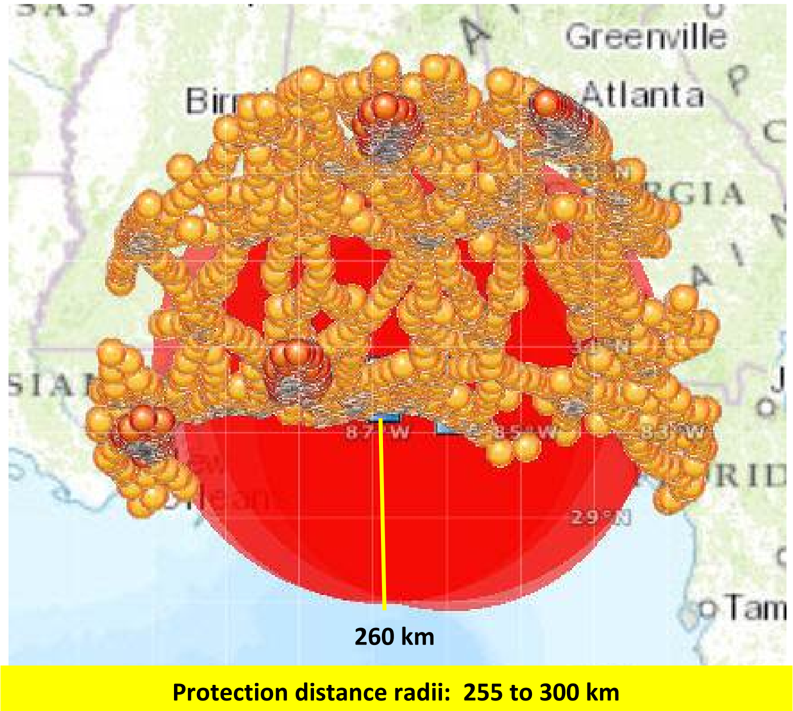


Figure 4-27. LTE UEs to LITENING CMDL, Eglin Test Range

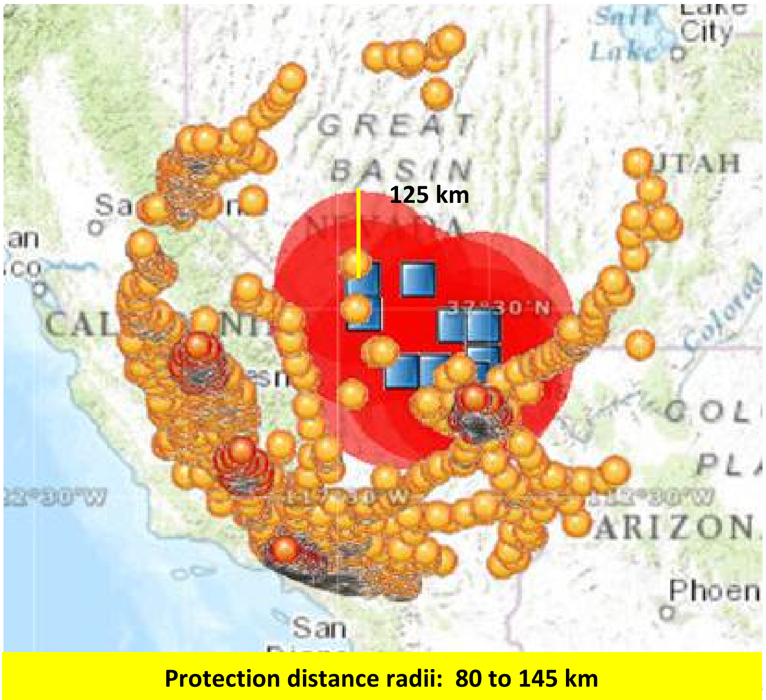


Figure 4-28. LTE UEs to LITENING CMDL, Nevada Test and Training Range

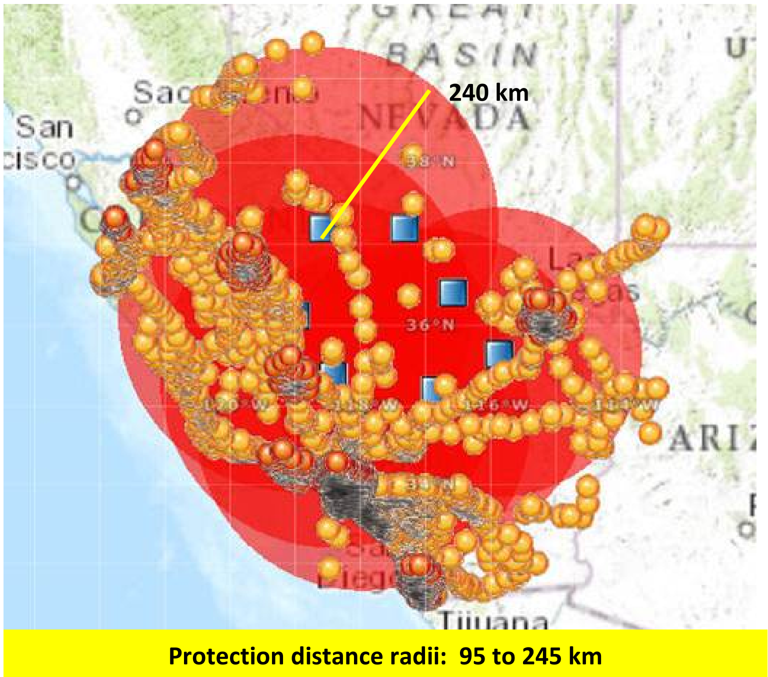


Figure 4-29. LTE UEs to LITENING CMDL, Edwards AFB

Protection distance results for the airborne LITENING CMDL transmitter to LTE base station receivers at the Eglin TR, Nevada TTR, and Edwards AFB sites are presented in Figure 4-30, Figure 4-31, and Figure 4-32. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively.

Figure 4-30. LITENING CMDL to LTE Base Stations, Eglin Test Range

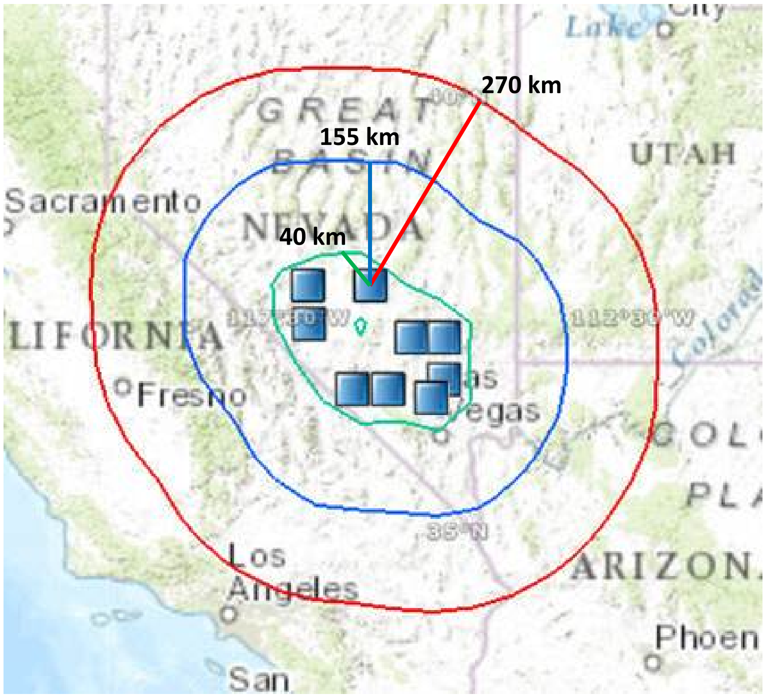


Figure 4-31. LITENING CMDL to LTE Base Stations, Nevada Test and Training Range

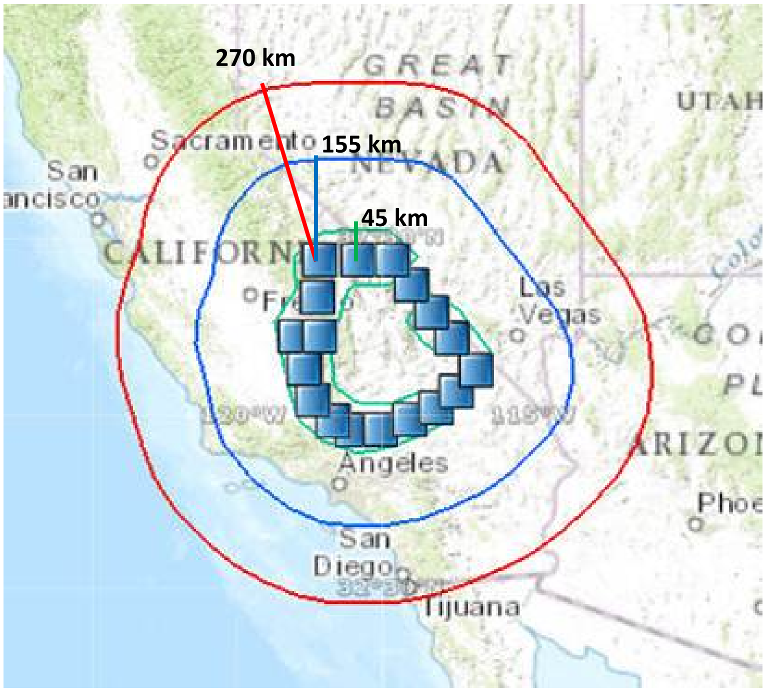


Figure 4-32. LITENING CMDL to LTE Base Stations, Edwards AFB

Protection distance results for LTE UE transmitters to Sniper CMDL receivers at the Eglin TR, Nevada TTR, and Edwards AFB sites are presented in Figure 4-34, Figure 4-35, and Figure 4-36.

The outer edge of each blue circle in a figure defines the individual protection distance for interference to CMDL from the selected UEs. An individual protection blue circle was defined for each point along the boundary of the training area. The key for these three figures is depicted in Figure 4-33.

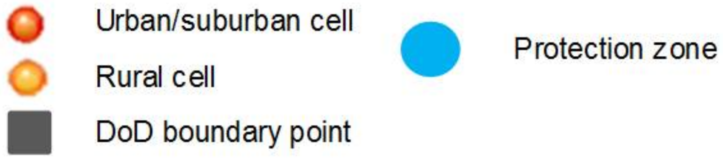


Figure 4-33. Key for LTE UEs to Sniper CMDL Figures

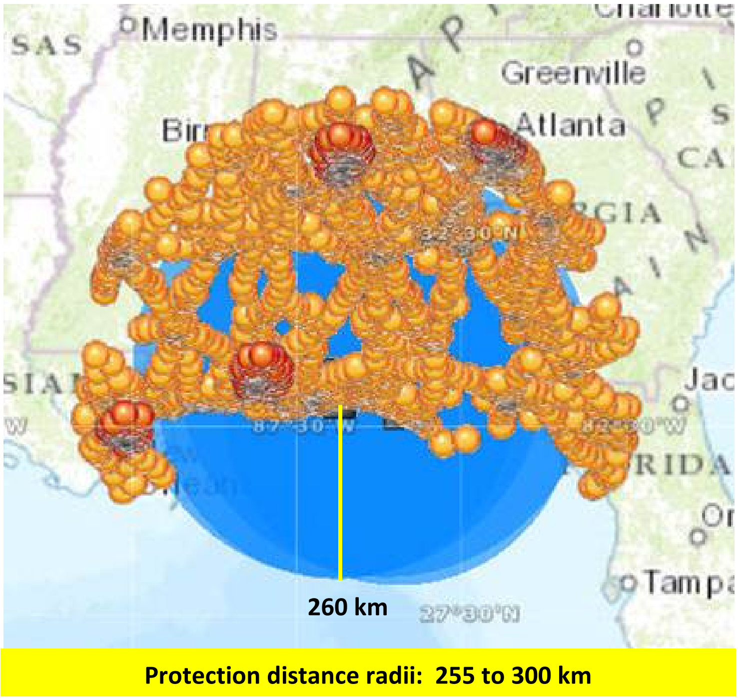
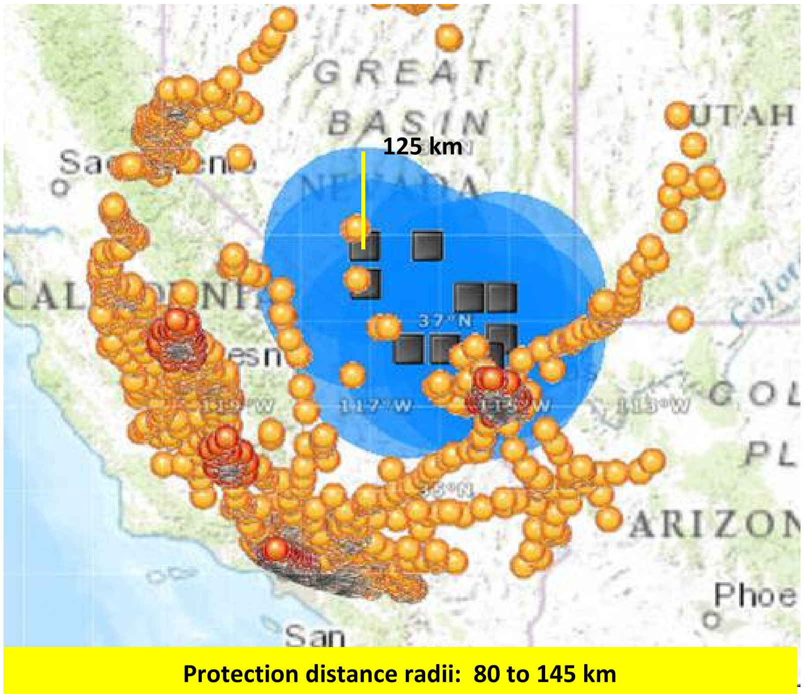
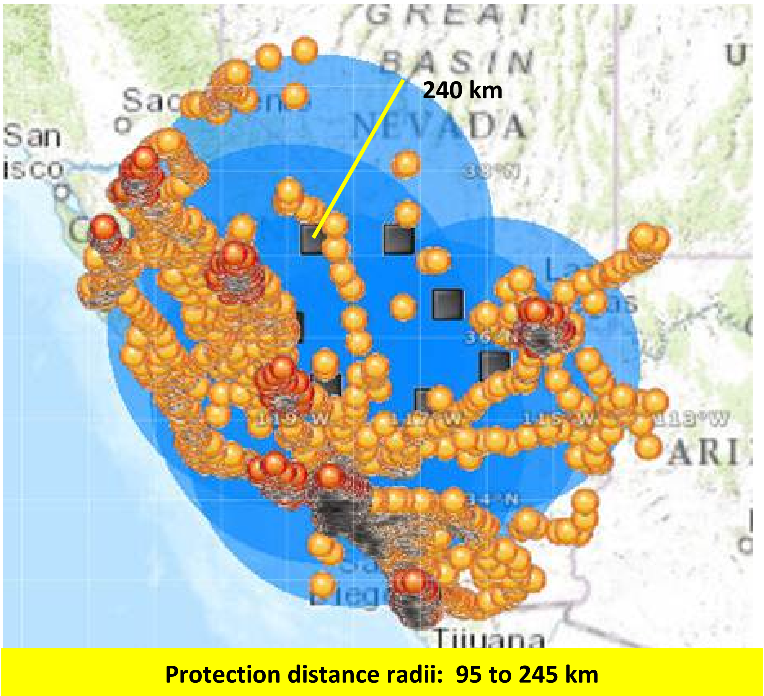


Figure 4-34. LTE UEs to Sniper CMDL, Eglin Test Range



Protection distance radii: 80 to 145 km

Figure 4-35. LTE UEs to Sniper CMDL, Nevada Test and Training Range



Protection distance radii: 95 to 245 km

Figure 4-36. LTE UEs to Sniper CMDL, Edwards AFB

4.5.1.3 Summary

Protection distances for predicted interference between LTE and CMDL for the Eglin TR, Nevada TTR, and Edwards AFB sites range are summarized in Table 4-6. For CMDL transmitter to LTE base station receiver, the lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-6. Summary of Protection Distances - LTE Versus CMDL

From UEs to CMDL Receiver		**From CMDL Transmitter to LTE Base Station Receiver**	
LITENING CMDL Site	Estimated Range of Protection Distances (km)	LITENING CMDL Site	Estimated Range of Protection Distances (km)
Eglin Test Range	255 - 300	Eglin Test Range	55 - 280
Nevada Test and Training Range	80 - 145	Nevada Test and Training Range	40 - 270
Edwards AFB	95 - 245	Edwards AFB	45 - 270
Sniper CMDL Site	Estimated Protection Distance (km)	Sniper CMDL Site	Estimated Maximum Distance (km)
Eglin Test Range	255 - 300	Eglin Test Range	Not applicable
Nevada Test and Training Range	80 - 145	Nevada Test and Training Range	Not applicable
Edwards AFB	95 - 245	Edwards AFB	Not applicable

Based on the results of the analyses for the three sites, it can be seen that CMDL systems and LTE will interfere with each other unless protection distances are established. Therefore, it is not feasible for LTE to share the 1755-1780 MHz band with CMDL systems within the sites and protection distances provided unless technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.5.1.4 Recommendations

Based on the results of the analyses, the following is recommended for CMDL:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with CMDL systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

4.6 DRAGOON

4.6.1 EMI Analysis

4.6.1.1 Analysis Parameters

As indicated, the Dragoon may be used anywhere in the continental U.S. Three missions were selected for the EMI analysis of LTE and Dragoon systems. The missions and a nearby city potentially causing/affected by EMI are as follows:

- Homeland Security mission (San Diego, CA)
- Oil spill in the Gulf of Mexico (New Orleans, LA)
- Atlantic superstorm (New York City, NY)

For each mission above, the aircraft carrying Dragoon was assumed to be flying in the following restricted airspaces and warning areas:

- Homeland Security mission: Kane E, W, S MOAs east of San Diego
- Oil spill: Warning area W-453 in the Gulf of Mexico east of New Orleans
- Atlantic superstorm: warning areas W-106A, W-106B, W-107B, W-107C, in the Atlantic Ocean east of New York City and New Jersey

For each mission above, Dragoon VMR was assumed to be on the ground at the following locations:

- Homeland Security mission: east of San Diego, near the U.S.-Mexico border
- Oil spill: east of the city of New Orleans
- Atlantic superstorm: at Newark International Airport

For each location, two analysis cases were considered: LTE UE transmitters to the ground-based VMR, and the airborne Dragoon transmitter to the LTE base stations. The analyses were performed using Visualyse as described in Subsection 7.1. For the ground-based VMR, ITU P.452-14 was used for ground-ground propagation losses. For the airborne Dragoon transmitter, ITU P.528-3 was used for air-ground propagation losses.

In the analyses, the aircraft carrying Dragoon was simulated at 15,000 feet altitude AGL.

4.6.1.2 Results

Protection distance results for LTE UE transmitters to the ground-based Dragoon VMR at the New York City, New Orleans, LA, and NY San Diego, CA, sites are presented in Figure 4-38, Figure 4-39, and Figure 4-40. The key for these three figures is depicted in Figure 4-37.

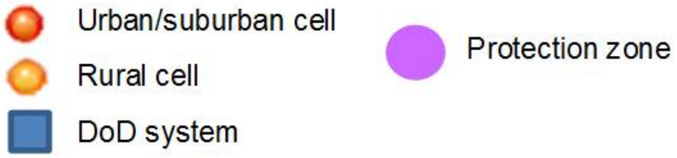


Figure 4-37. Key for LTE UEs to Dragoon Figures

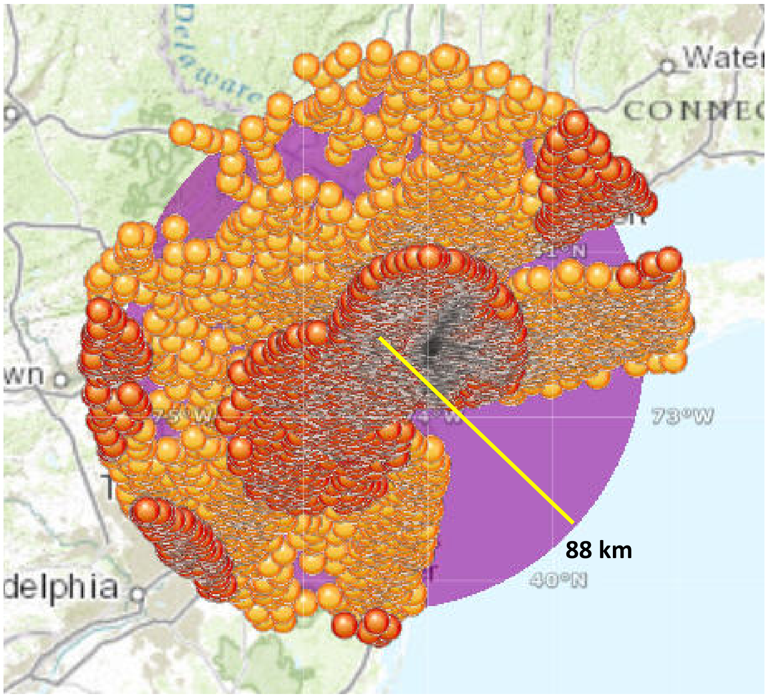


Figure 4-38. LTE UEs to Dragoon VMR, New York City, NY

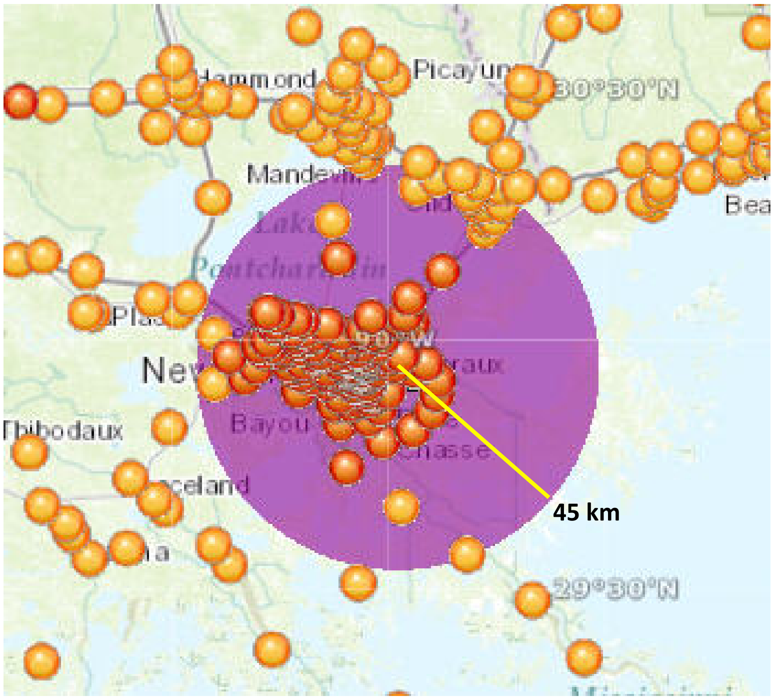


Figure 4-39. LTE UEs to Dragoon VMR, New Orleans, LA

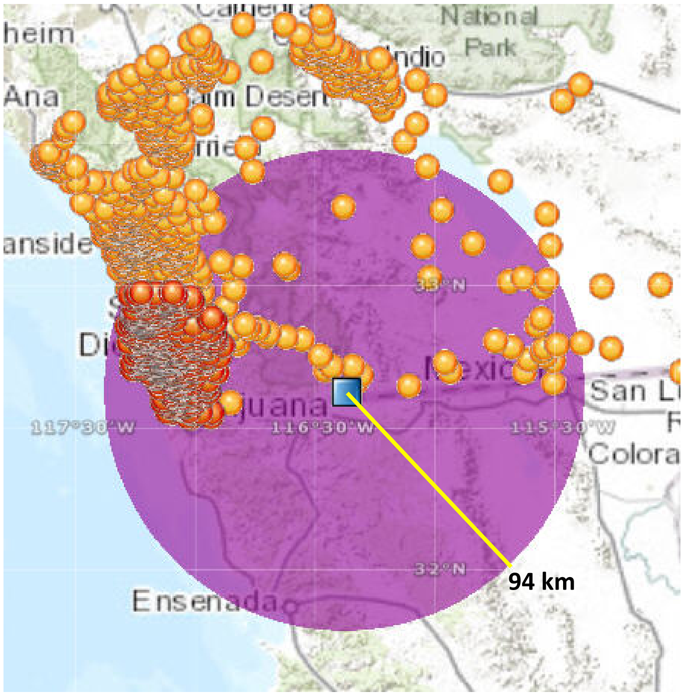


Figure 4-40. LTE UEs to Dragoon VMR, San Diego, CA

Protection distance results for the airborne Dragoon transmitter to LTE base station receivers at the New York City, New Orleans, LA, and NY San Diego, CA, sites are presented in Figure 4-41, Figure 4-42, and Figure 4-43. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively.

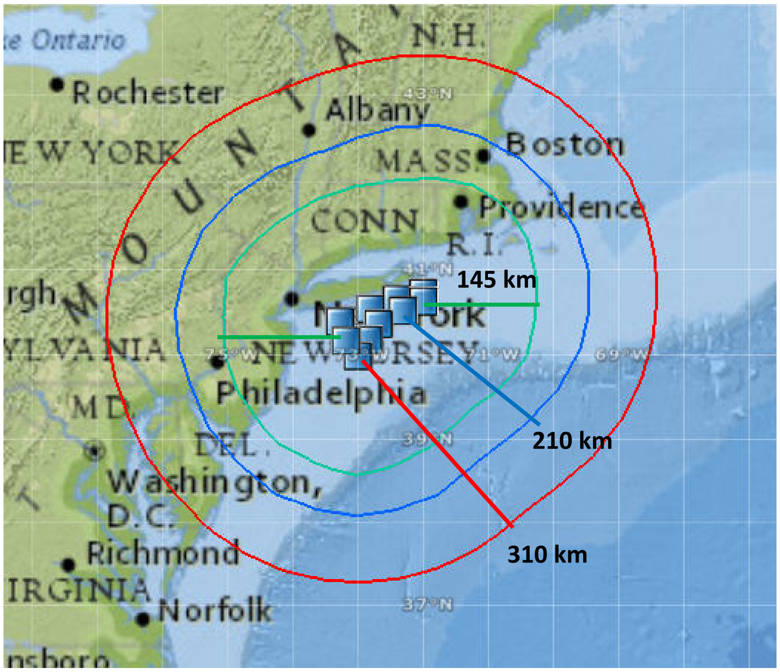


Figure 4-41. Dragoon to LTE Base Stations, New York City, NY

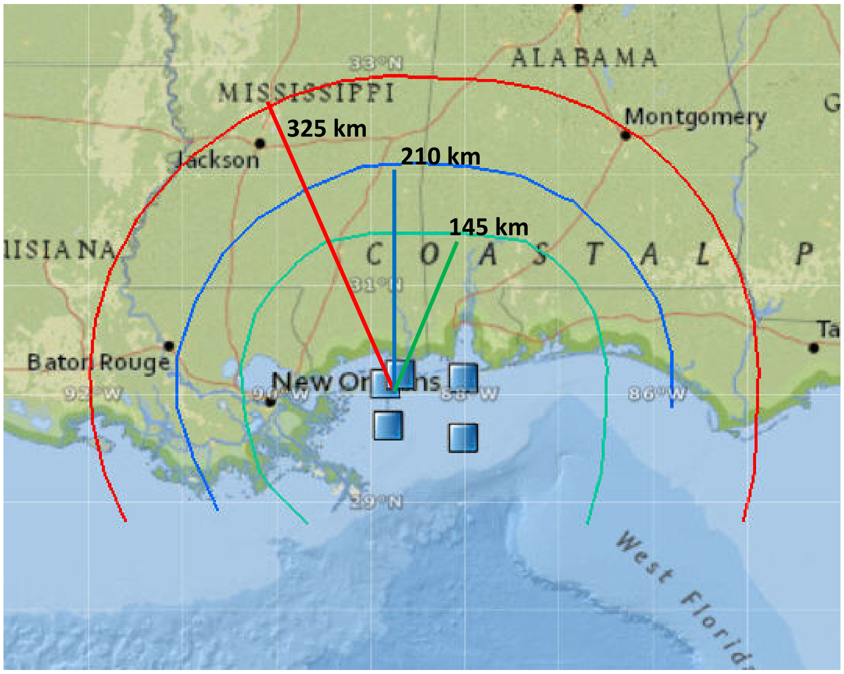


Figure 4-42. Dragoon to LTE Base Stations, New Orleans, LA

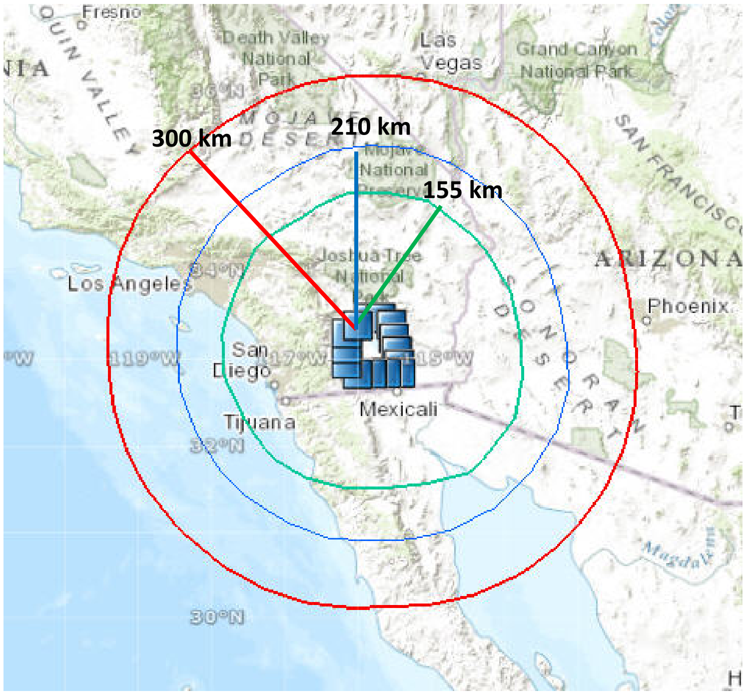


Figure 4-43. Dragoon to LTE Base Stations, San Diego, CA

4.6.1.3 Summary

Protection distances for predicted interference between LTE and Dragoon for the New York City, New Orleans, LA, and NY San Diego, CA, sites are summarized in Table 4-7. For Dragoon transmitter to LTE base station receiver, the lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-7. Summary of Protection Distances - LTE Versus Dragoon

From UEs to Dragoon VMR		**From Dragoon Transmitter to LTE Base Station Receiver**	
Dragoon Site	Estimated Maximum Protection Distance (km)	Dragoon Site	Estimated Range of Protection Distances (km)
New York City, NY	88	New York City, NY	145 - 310
New Orleans, LA	45	New Orleans, LA	145 - 325

San Diego, CA	94	San Diego, CA	155 - 300

Based on the results of the analyses for the three sites, it can be seen that Dragoon and LTE will interfere with each other unless protection distances are established. Therefore, it is not feasible for LTE to share the 1755-1780 MHz band with Dragoon within the sites and protection distances provided unless technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.6.1.4 Recommendations

Based on the results of the analyses, the following is recommended for Dragoon:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with Dragoon systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

4.7 VORTEX

4.7.1 EMI Analysis

4.7.1.1 Analysis Parameters

EMI analysis of LTE and VORTEX systems was performed for the following test and training ranges:

- Eglin TR
- Nevada TTR
- Edwards AFB

In the simulation, the aircraft was assumed to be at points along the boundary defined by one or more restricted airspaces:

- Eglin TR: MOAs Eglin A (East and West), B, C, D, E, F
- Nevada TTR: restricted airspaces R-4806, R-4807
- Edwards AFB: restricted airspace complex R-2508

For each location, two analysis cases were considered: LTE UE transmitters to the VORTEX airborne receiver, and the airborne VORTEX transmitter to the LTE base station. The analyses were performed using Visualyse as described in Subsection 7.1.

In the analyses, the aircraft carrying VORTEX was simulated at 30,000 feet altitude AGL.

4.7.1.2 Results

Protection distance results for LTE UE transmitters to the airborne VORTEX receiver at the Eglin TR, Nevada TTR, and Edwards AFB sites are presented in Figure 4-45, Figure 4-46, and Figure 4-47. The outer edge of a purple circle in each figure defines the individual protection distance for interference to VORTEX from the selected UEs. An individual protection purple circle was defined for each point along the boundary of the training area. The key for these three figures is depicted in Figure 4-44.

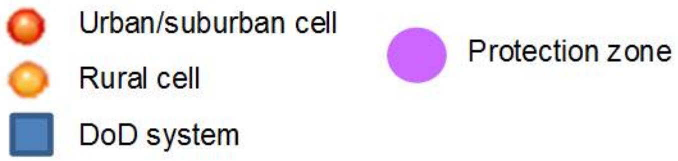
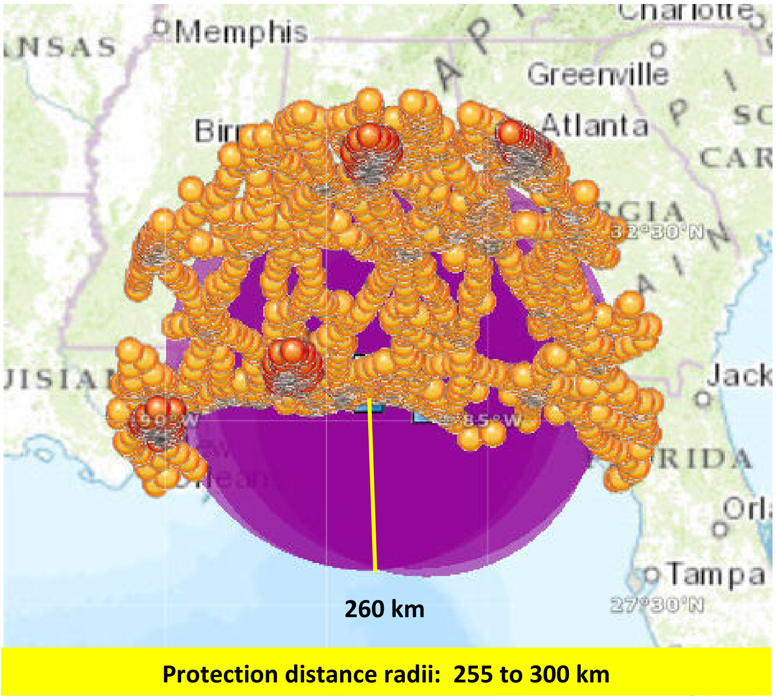
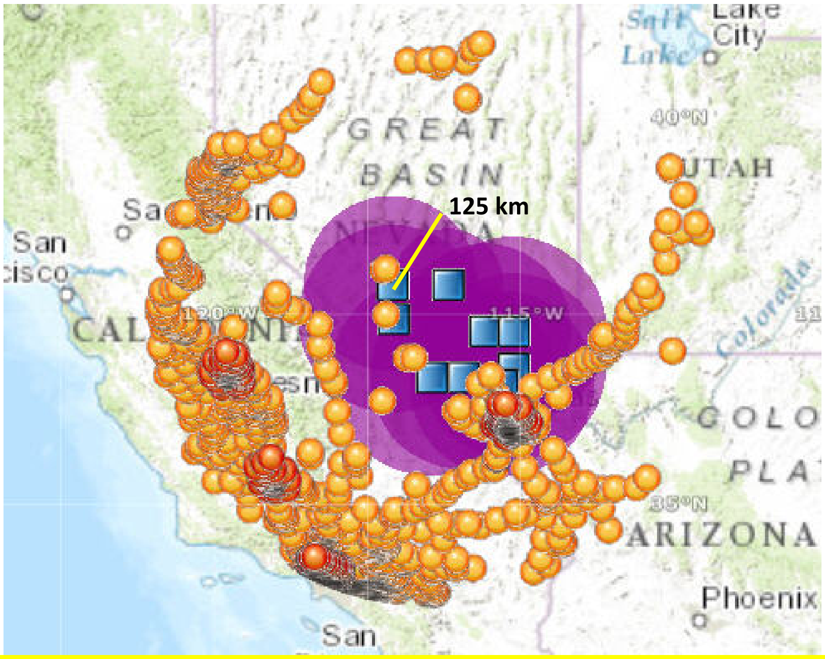


Figure 4-44. Key for LTE UEs to VORTEX Figures



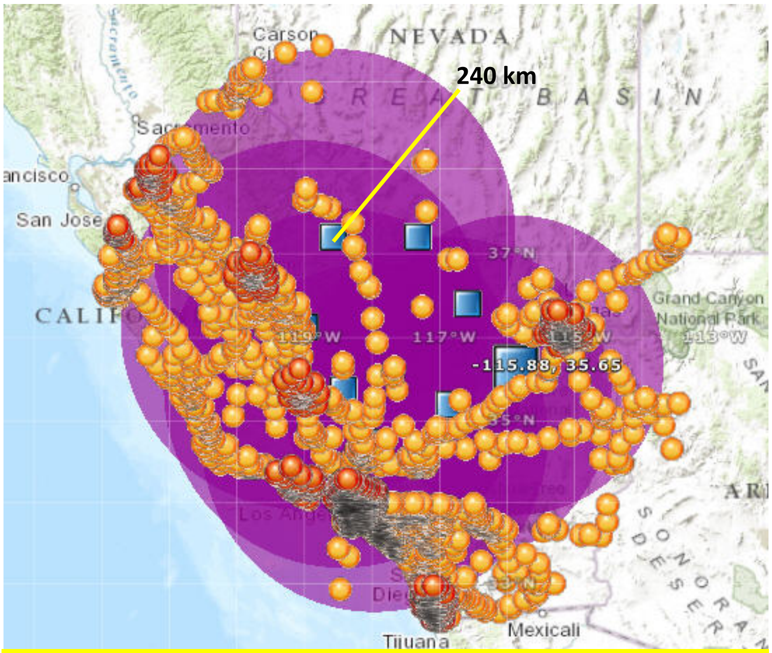
Protection distance radii: 255 to 300 km

Figure 4-45. LTE UEs to VORTEX, Eglin Test Range



Protection distance radii: 80 to 145 km

Figure 4-46. LTE UEs to VORTEX, Nevada Test and Training Range



Protection distance radii: 95 to 245 km

Figure 4-47. LTE UEs to VORTEX, Edwards AFB

Protection distance results for the airborne VORTEX transmitter to LTE base station receivers at the Eglin TR, Nevada TTR, and Edwards AFB sites are presented in Figure 4-48, Figure 4-49, and Figure 4-50. The red, blue, and green contours represent the protection distances for 0, 60, and 180 degree off-axis angles, respectively.

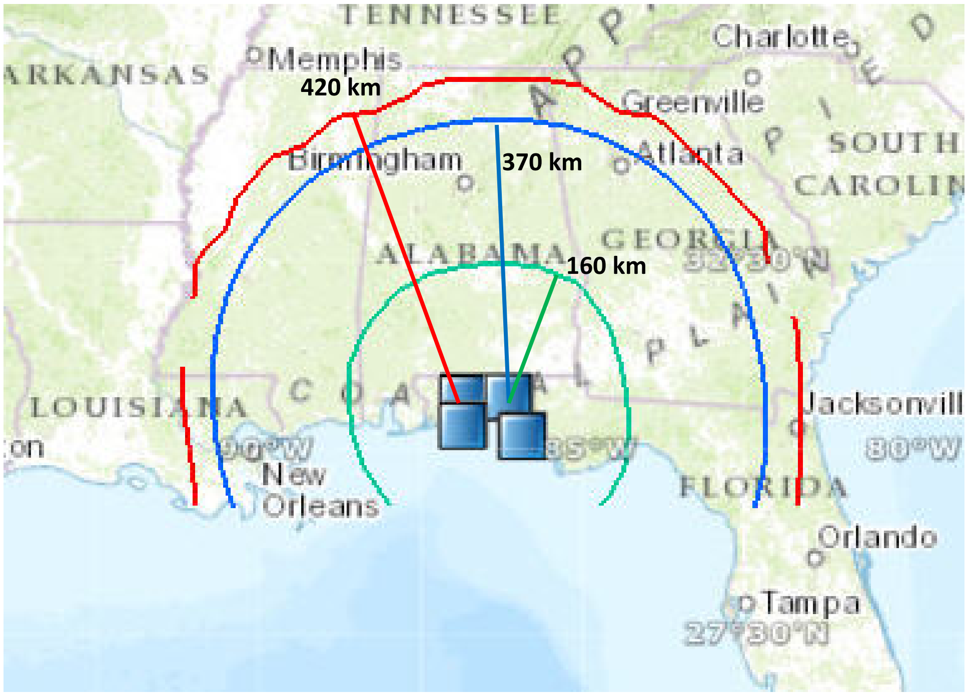


Figure 4-48. VORTEX to LTE Base Stations, Eglin Test Range

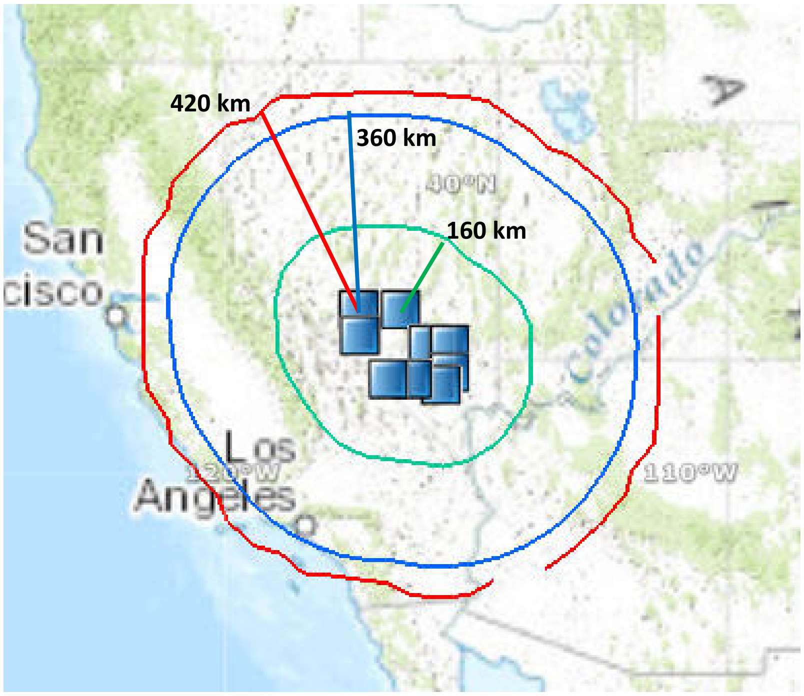


Figure 4-49. VORTEX to LTE Base Stations, Nevada Test and Training Range

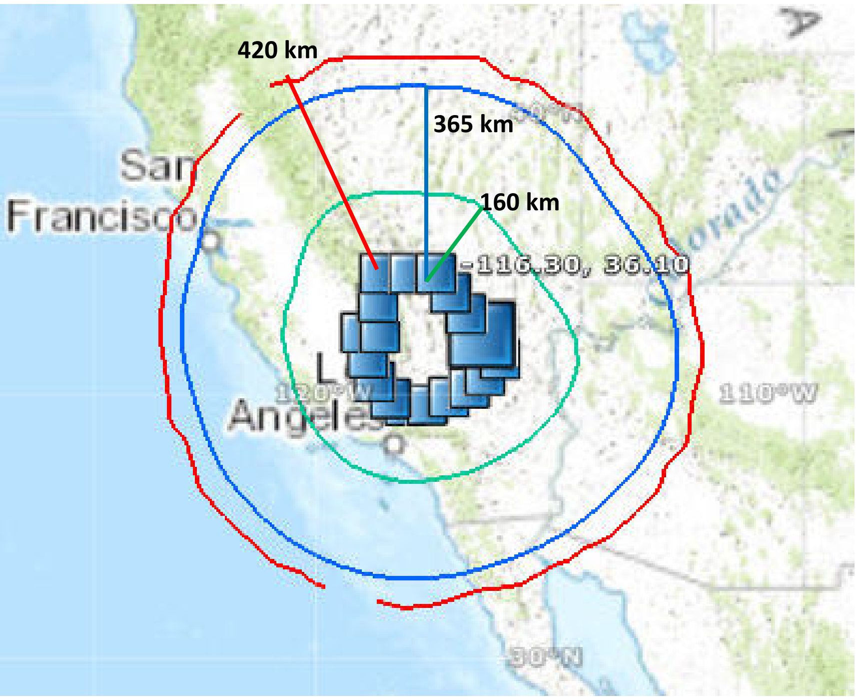


Figure 4-50. VORTEX to LTE Base Stations, Edwards AFB

4.7.1.3 Summary

Protection distances for predicted interference between LTE and airborne VORTEX for the Eglin TR, Nevada TTR, and Edwards AFB sites range are summarized in Table 4-8. For VORTEX transmitter to LTE base station receiver, the lower and upper values are for base station antenna off-axis angles of 180 and 0 degrees, respectively.

Table 4-8. Summary of Protection Distances - LTE Versus VORTEX

From UEs to VORTEX Receiver		**From VORTEX Transmitter to LTE Base Station Receiver**	
VORTEX Site	Estimated Range of Protection Distances (km)	VORTEX Site	Estimated Range of Protection Distances (km)
Eglin Test Range	255 - 300	Eglin Test Range	160 - 420
Nevada Test and Training Range	80 - 145	Nevada Test and Training Range	160 - 420
Edwards AFB	95 - 245	Edwards AFB	160 - 420

Based on the results of the analyses for the three sites, it can be seen that VORTEX and LTE will interfere with each other unless protection distances are established. Therefore, it is not feasible for LTE to share the 1755-1780 MHz band with VORTEX within the sites and protection distances provided unless technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.7.1.4 Recommendations

Based on the results of the analyses, the following is recommended for VORTEX:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with VORTEX systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

4.8 ROVER

4.8.1 EMI Analysis

4.8.1.1 Analysis Parameters

EMI analysis of LTE and ROVER systems was performed for the following locations:

- Eglin TR
- Nevada TTR
- Edwards AFB
- San Diego
- New Orleans
- New York City

The characteristics for the ROVER 5 transmitter are similar to those for CMDL (both systems are manufactured by L-3 Communications Systems-West). Consequently, the protection distances for an airborne ROVER 5 would be similar to those for CMDL and the case of ROVER 5 transmitter to the LTE base station was not modeled.

To capture a ground-ground EMI case, the ROVER was assumed to be on the ground and in receive mode only. For each location, only the case of LTE UE transmitters to the ROVER receiver was considered. The analyses were performed using Visualyse as described in Subsection 7.1. For the ground-based ROVER, ITU P.452-14 was used for ground-ground propagation losses. In the analyses, the ROVER antenna was simulated at 2 meters AGL.

4.8.1.2 Results

Protection distance results for LTE UE transmitters to ground-based ROVERs receiving FMV from TactiLink Eagle at the New York City, NY, New Orleans, LA, and NY San Diego, CA, sites are presented in Figure 4-52 through Figure 4-55. The key for these four figures is depicted in Figure 4-51.

Figure 4-51. Key for LTE UEs to ROVER Figures

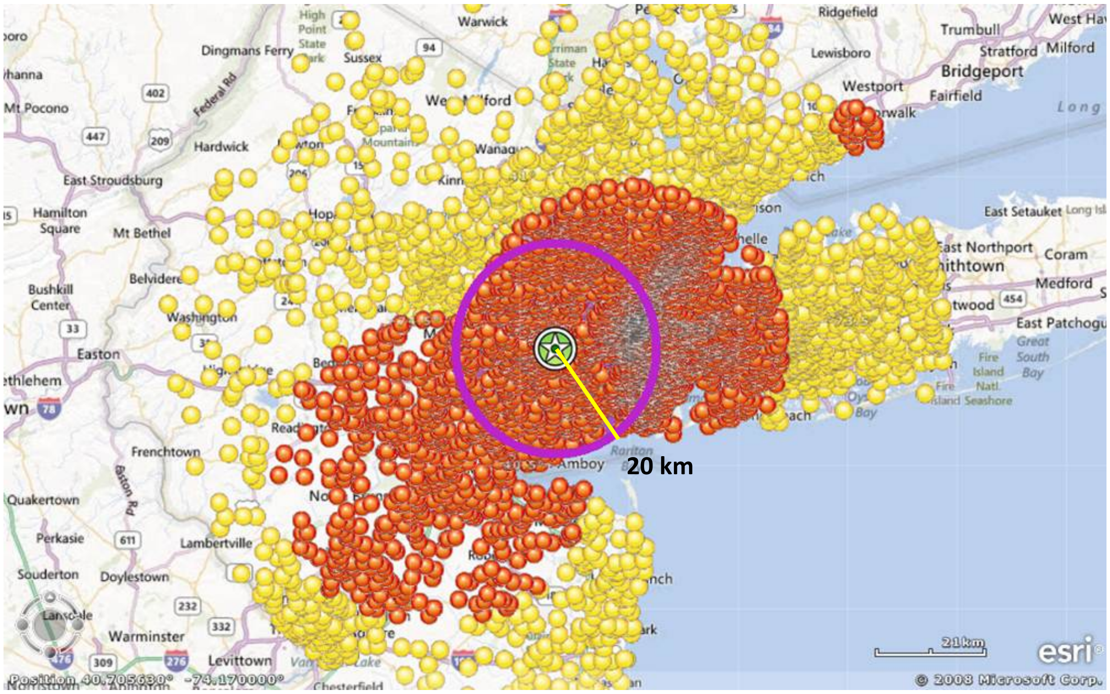


Figure 4-52. LTE UEs to ROVER, New York City, NY

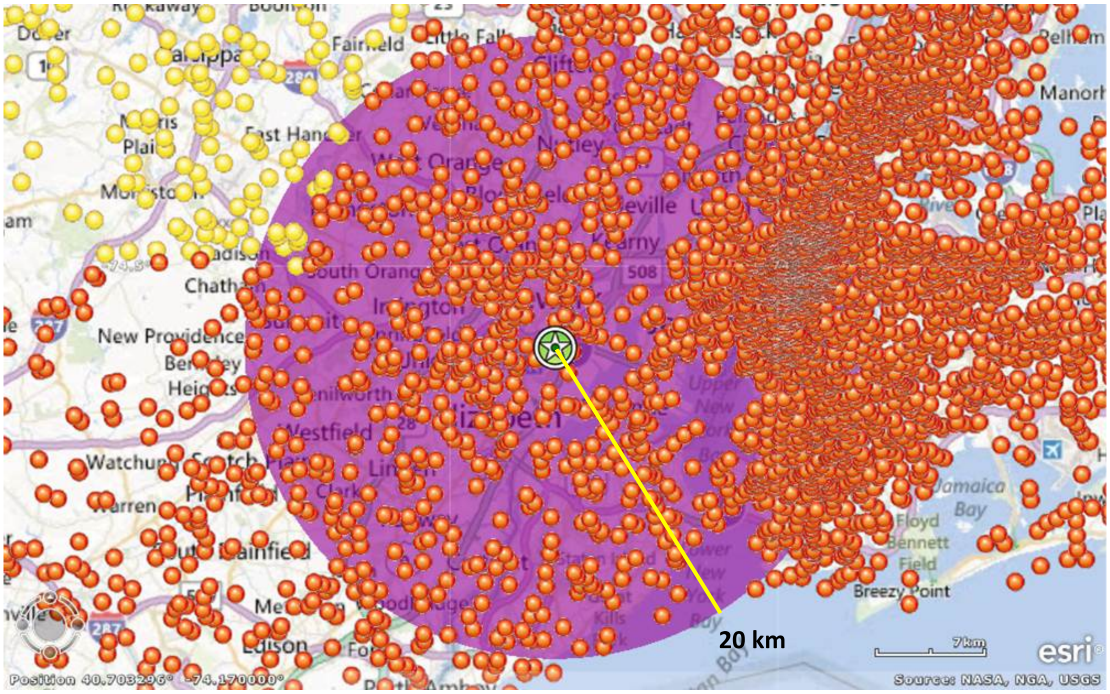


Figure 4-53. LTE UEs to ROVER, New York City, NY (Expanded View)

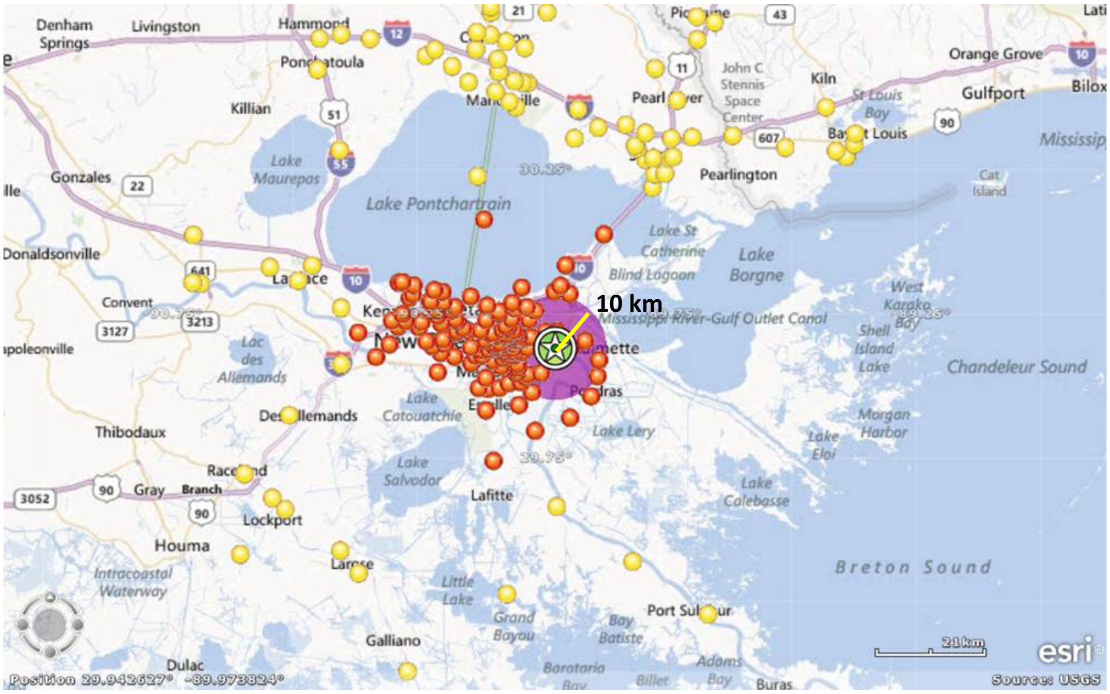


Figure 4-54. LTE UEs to ROVER, New Orleans, LA

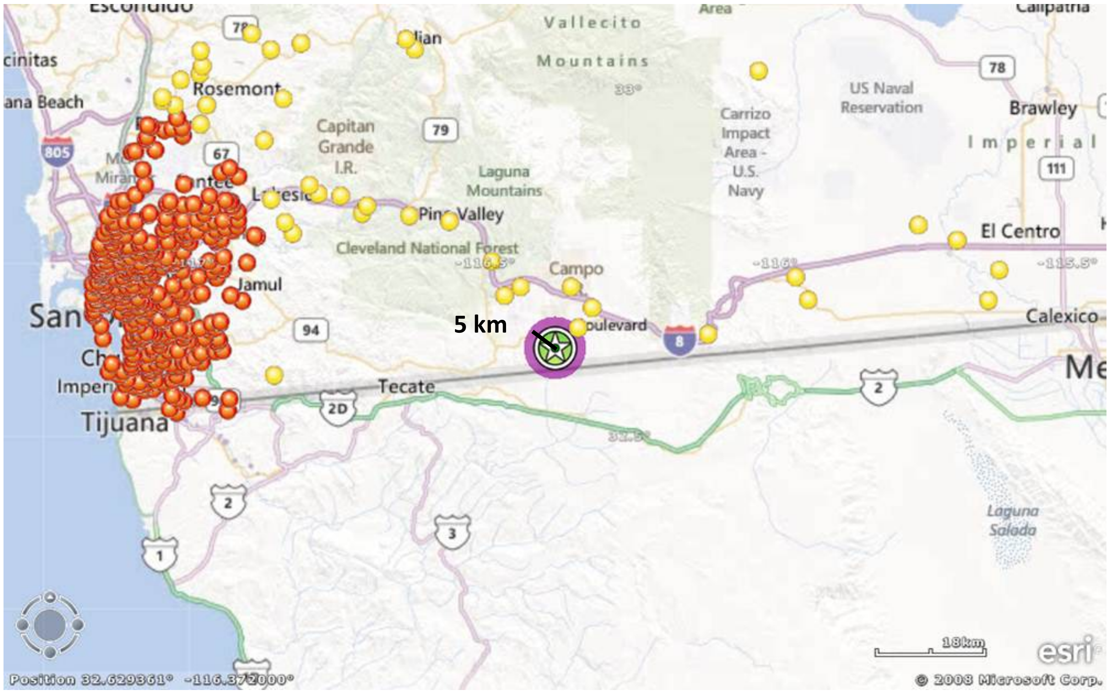


Figure 4-55. LTE UEs to ROVER, San Diego, CA

Protection distance results for LTE UE transmitters to ground-based ROVERs receiving FMV from LITENING CMDL at the Eglin TR, Nevada TTR, and Edwards AFB sites are presented in

Figure 4-56, Figure 4-57, and Figure 4-58. The key for these three figures is depicted in Figure 4-51.

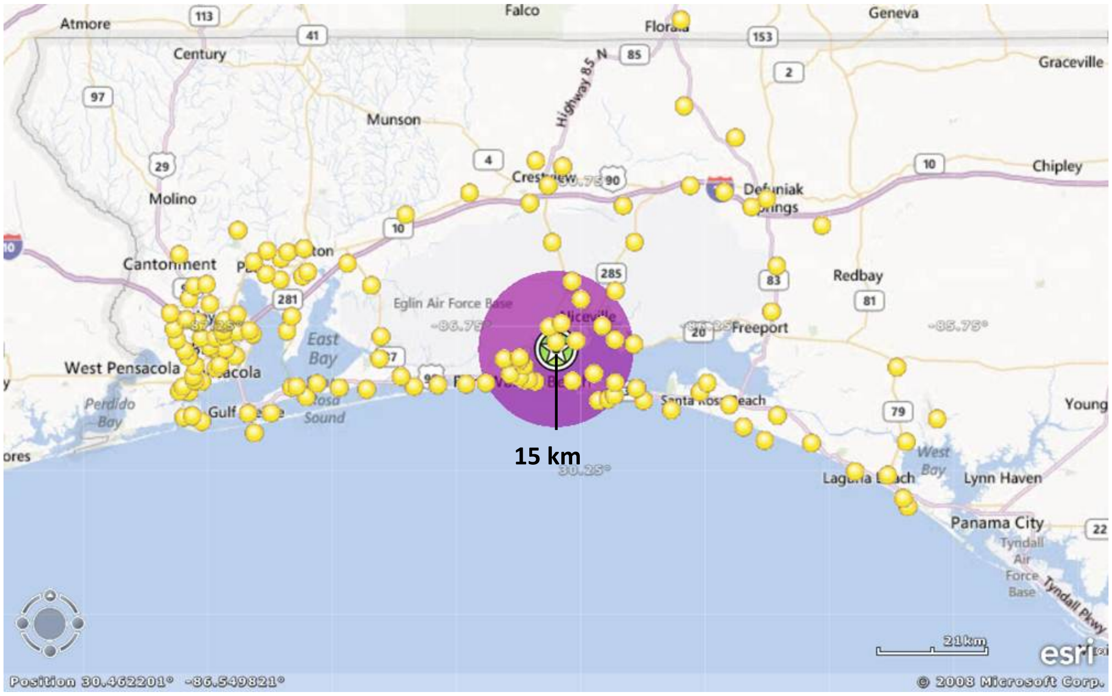


Figure 4-56. LTE UEs to ROVER, Eglin Test Range

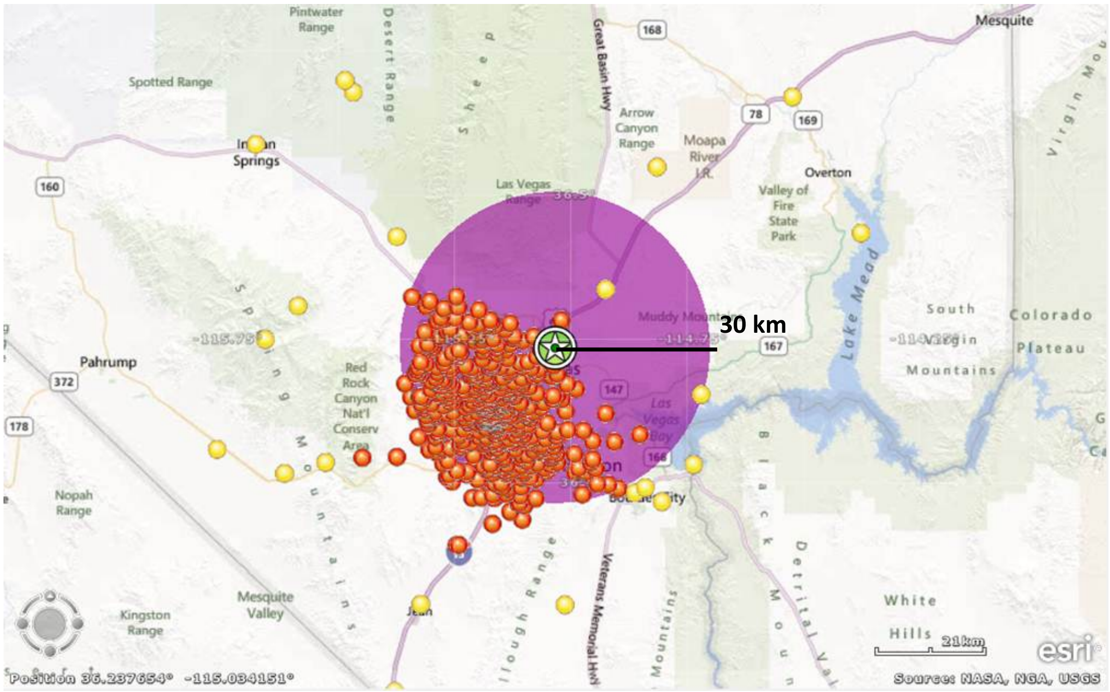


Figure 4-57. LTE UEs to ROVER, Nevada Test and Training Range

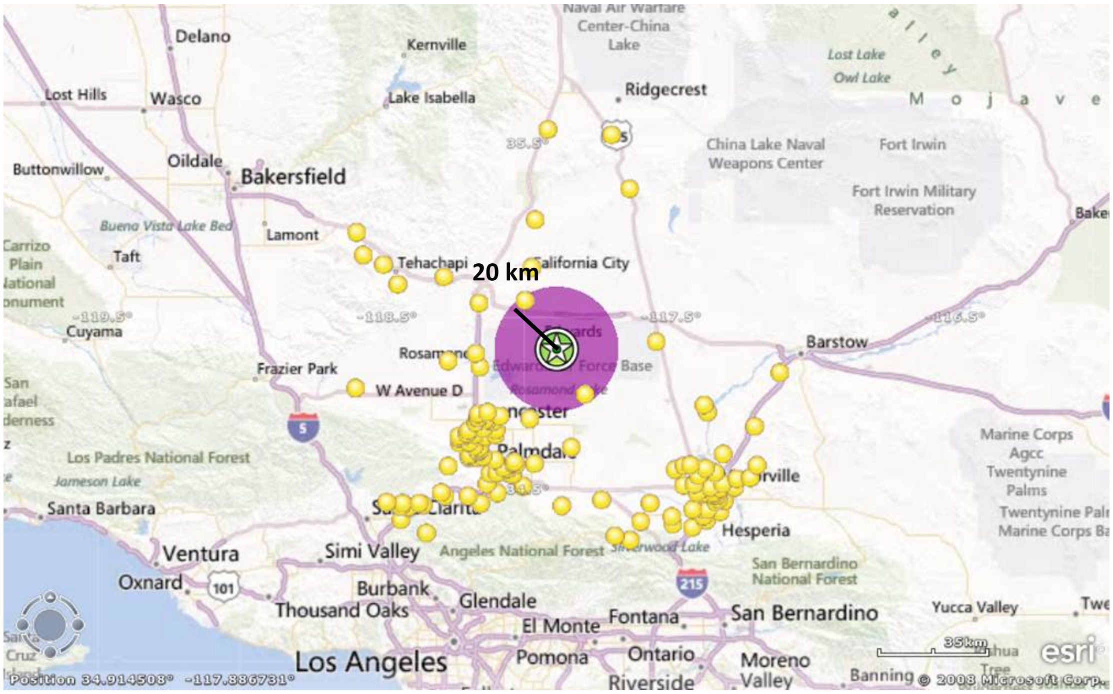


Figure 4-58. LTE UEs to ROVER, Edwards AFB

4.8.1.3 Summary

Protection distances for predicted interference between LTE and ground-based ROVER for the selected sites range are summarized in Table 4-9.

Table 4-9. Summary of Protection Distances - LTE Versus ROVER

From UEs to ROVER	
ROVER Site	Estimated Maximum Protection Distance (km)
New York City, NY	20
New Orleans, LA	10
San Diego, CA	5

Eglin TR	15
Nevada TTR	30
Edwards AFB	20

Based on the results of the analyses for the six sites, it can be seen that LTE will interfere with ROVER unless protection distances are established. Therefore, it is not feasible for LTE to share the 1755-1780 MHz band with ROVER within the sites and protection distances provided unless technical and operational mitigation approaches, such as those described in Section 1.4.1, are developed.

4.8.1.4 Recommendations

Based on the results of the analyses, the following is recommended for ROVER:

- The additional studies/mitigation approaches outlined in Paragraph 1.4.1 should be investigated to further quantify the feasibility of LTE sharing spectrum with ROVER systems.
- If band sharing is still not feasible after the investigation of possible mitigation approaches, relocate to an alternate frequency band that is comparable to the 1755-1850 MHz band.

A concern of the recommendations above is that course of action (COAs) for the ROVER system are contingent on following any/all COAs related to SUAS.

5 DESCRIPTIONS OF FEDERAL SYSTEMS

This section includes descriptions of the systems analyzed in SWG-4.

In general, nominal technical characteristics for each system were taken from the DD Form 1494, Application for Equipment Frequency Allocation (also known as the J/F-12). Additional parameters on the following topics were obtained from program subject matter experts:

- System function
- System operation
- Operational locations (installations, bases)
- Aircraft altitude

5.1 PGMS

5.1.1 System Description

PGMs can be used to attack single targets with one aircraft or one standoff weapon. PGMs increase aircrew survivability by allowing the launch of weapons outside of any enemy anti-air system threat envelope. PGMs require regular testing and training by operational units to maintain operational readiness. Regular testing is also required for developmental activities as the PGM are updated for new missions, threats, and capabilities.

Current PGMs affected by the reallocation of spectrum are used by the Air Force and the Navy. PGM control links previously operating within the 1710-1850 MHz band were compressed so they could operate in the 1755−1850 MHz band.

Current Air Force planning calls for discontinuing the use of PGMs that have RF links in the 1755−1850 MHz frequency range. A band sharing assessment is therefore not required.

The Navy PGM is an air-to-surface guided missile designed to provide the delivery platform with a range capability of 150 nautical miles against a variety of land and sea targets. Aircraft-missile communication is via RF data links. The data link transmitter on a pod carried by the aircraft provides steering commands to the missile, allowing the weapon to be directed remotely to a target by the launch aircraft or a remotely stationed controlling aircraft. The data link receiver on the pod also processes real-time video from the weapon and outputs the video in a format compatible with the aircraft cockpit display. There is also a data link system on the missile that receives and processes steering commands and transmits video back to the aircraft.

5.1.2 Operation

Navy PGM usage within the US&P is limited to testing and training. Typical altitudes for aircraft operating PGMs range up to 20,000 feet AGL.

5.2 TACTILINK EAGLE

5.2.1 System Description

The TactiLink Eagle is a legacy analog data link system installed on UH-72A Lakota light utility helicopters and on Bell OH-58 Kiowa light helicopters as part of the Security and Support (S&S)

Mission Equipment Package (MEP).[4,5]

The TactiLink Eagle is a transmit-only system, relaying FMV and data to a receiver on the ground (assumed to be a ROVER). The system does not have an airborne receiver.

5.2.2 Operation

The airborne platforms are Army National Guard assets and therefore can be utilized anywhere within the state of issue. They can also be used in other states in support of Homeland Security, law enforcement, disaster-relief, and protection of large-venue (e.g., Superbowl) missions. Therefore, the airborne platform and the ground-based receiver can be anywhere in the US, not necessarily in a training area.

Airborne platform altitudes are typically 500−5000 feet AGL.

5.3 JTRS AMF

5.3.1 System Description

JTRS AMF represents a family of multi-band/multi-mode software-defined radios, with planned capabilities for providing communications within the 1200 MHz to 2 GHz frequency range. The system will also have capabilities in the 225-960 MHz range. JTRS is intended to operate with new advanced waveforms that have enhanced performance capabilities in both military and civilian frequency bands, including the 1755–1850 MHz frequency band. Radios include the Small Airborne Link 16 Terminal (SALT) and the Small Airborne Networking Radio (SANR) operating the Soldier Radio Waveform (SRW) and the Wideband Networking Waveform (WNW). JTRS AMF is in the design phase and is not currently operational.

Aircraft to be installed with JTRS AMF include AH-64E Apache, UH-60M/L Black Hawk, HH-60M/L Black Hawk MEDEVAC, CH-47F Chinook, OH-58F Kiowa Warrior, MH-6 Little Bird, and MQ-1C Gray Eagle UA.

The JTRS Small Airborne (SA) system, AN/ZRC-2, with the SRW was analyzed.

5.3.2 Operation

JTRS AMF functions include air-to-air and air-to-ground voice and data for ground combat support. Major use is planned at a number of range and test facility bases: NTC at Ft. Irwin, CA; Ft. Hood, TX; WSMR, NM; Ft. Bragg, NC; Ft. Polk, LA; NAWCWD China Lake, CA; YPG, AZ; and Dugway Proving Ground (DPG), UT. Helicopter altitudes are 10,000 feet AGL and below.

JTRS AMF operation is also planned at the associated ranges and designated MOAs of Ft. Bragg, NC; Ft. Bliss, TX; Ft. Campbell, KY; Ft. Rucker, AL; Ft. Drum, NY; Ft. Carson, CO; Ft. Lewis, WA; Ft. Wainwright, AK; and Schofield Barracks, HI.

5.4 TTNT

5.4.1 System Description

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[4] *UH-72A S&S MEP Datalink*. Powerpoint presentation. Utility Helicopters Project Office. Undated.

[5] Online source: *Lakota UH-72A MEP Upgrade Underway*. http://ngbcounterdrug.ng.mil/News/Pages/LakotaMEPUpgradeUnderway.aspx. 2009.

TTNT is a “modular, open, networking system that provides wireless connections, and the underlying network management, to enable dynamic, machine-to-machine collaboration across platforms.”[6] TTNT will “permit 200 platforms or more separated by up to 100 nautical miles to transfer sensor and other data (not voice) at a total TTNT system rate of at least 10 Mbps, with a single platform having available up to a 2 Mbps rate, with ‘zero/very low’ latency define the desired performance goal.”

Navy TTNT is designed for airborne platforms and involves air-to-air networking. Navy TTNT systems are currently under development. From the DoD 2011 Report, the Navy plans to use the MIDS-J radio in their combat aircraft as the host for the TTNT waveform.

The Army/USMC TTNT system includes airborne and ground-based elements, and is used for air-air, air-ground, and ground-ground networking. The 1755-1850 MHz band is used for air-air and air-ground networking; ground-ground operations only occur on UHF. The system is currently in the experimental phase.

The Air Force TTNT system includes airborne elements, and is used for air-air networking. The system is currently undergoing fly-off testing with the competitors.

5.4.2 Operation

Currently, the Navy TTNT network permits a maximum number of platforms with additional numbers to be added in future years.

Army/USMC/Air Force TTNT systems are new systems currently under development and operations details are not available.

Testing and training of TTNT systems will be accomplished at a number of ranges and sites throughout the US&P.

5.5 LITENING AND SNIPER CMDL

5.5.1 System Description

Northrop Grumman’s AN/AAQ-28(V) LITENING targeting pod and Lockheed Martin’s Sniper targeting pod are used for long-range detection, identification, and tracking of targets.[7,8,9] Aircraft employing these targeting pods include F-16 Block 30, F-16 Block 40, A-10C, F-15E, B-52H, and B-1B. Both pods include L-3’s CMDL system for relay of video/data.

Implementation of CMDL on the two targeting pods is essentially the same, but with the following differences in function:

- The LITENING CMDL is both transmit and receive: the downlink includes FMV/still images to a ground unit, and the uplink includes still images extracted from inputs to the ground unit.

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[6] *Tactical Targeting Network Technology, TTNT “101” Brief*. Powerpoint presentation. USN Chief of Naval Operations. Distribution Statement A. Undated.

[7] *Sniper® Pod*. Product data sheet. Lockheed Martin Corporation. 2011.

[8] *AN/AAQ-28(V) LITENING*. Product data sheet. Northrop Grumman Corporation. 2012.

[9] *Sniper/LITENING ATPs & ATP-SE Spectrum Management Working Group*. US Air Force Aeronautical Systems Center. 12 Oct 2012 [FOUO].

- The Sniper CMDL is receive-only: the uplink is a relatively narrowband still image.

Still images are relatively narrowband compared to the FMV. The ground unit is typically a ROVER 3, 4, 5, or 6.

5.5.2 Operation

Typical altitudes for aircraft operating CMDL data links range from 20,000 feet AGL and above.

There are a number of locations in the US where Air Force, Navy, and Marine Corps units operate LITENING and Sniper CMDL data links. These include Air Force Bases (AFBs), Air National Guard (ANG) bases, Marine Expeditionary Units (MEUs), Marine Corps Air Stations (MCAS), Naval Air Stations (NAS), Naval Air Weapons Station (NAWS), and International Airports (IAPs).

5.6 DRAGOON

5.6.1 System Description

The Dragoon is a legacy data link system installed on Air National Guard RC-26B aircraft. Dragoon is a transmit-only system, relaying FMV and data to a receiver on the ground. The system does not have an airborne receiver. There are two types of ground-based receivers: Messenger Smart Receiver is a fixed station, Veta Monitor Receiver (VMR) is a mobile station.

5.6.2 Operation

The system function is used mostly for homeland security missions, but has also been used for law enforcement (local authorities up to and including federal authorities) and aerial surveillance in the event of disasters. Information from the Dragoon POC indicates that the system may be used anywhere in the continental U.S. Typical altitudes for RC-26 aircraft operating the Dragoon data link are between 3,000 and 15,000 feet AGL.

5.7 VORTEX

5.7.1 System Description

L-3's VORTEX data link system has functionalities similar to those for the CMDL: relay of video/data on the downlink, video/data on the uplink. Airborne platforms employing VORTEX include strike aircraft, Intelligence, Surveillance, and Reconnaissance aircraft, UAs, C-12, C-26, OH-58, and Blue Devil reconnaissance airship.

5.7.2 Operation

Typical altitudes for aircraft operating VORTEX data links are less than 30,000 feet AGL. The ground station is typically a ROVER 5 or 6. Operation is air-ground-air and air-air.

VORTEX can operate in L-band, S-band, C-band, and Ku-band. Only certain platforms (e.g., small UAs, OH-58, and C-26) downlink video/data on L-band frequencies. Uplink of data from a ROVER ground station is typically on L-band or S-band.

5.8 ROVER

5.8.1 System Description

As indicated previously, some airborne data link systems transmit FMV to ground-based units that receive the FMV using a ROVER Remote Video Terminal (RVT). Older ROVERs, such as ROVER III and ROVER 4, are receive-only. Newer ROVERs, such as ROVER 5 and ROVER 6, have transmitting capabilities. The ROVER 6 transceiver includes the DDL Raven waveform.

5.8.2 Operation

As indicated previously, the ground station receiving FMV from Tactilink Eagle, CMDL, and VORTEX was assumed to be a ROVER 5. ROVER systems are also used on airborne units such as helicopters.

6 DESCRIPTION OF LTE SYSTEM

6.1 NETWORK

This section provides details on the proposed LTE cellular network as obtained from documents presented to the CSMAC WG-5.[10,11,12]

The LTE system is the newest implementation for mobile broadband service based on standards from the 3rd Generation Partnership Project (3GPP). For proposed sharing, the uplink frequency band from mobile hand-held user equipment (UE) to a base station (BS) is 1755–1780 MHz, and the paired frequency division duplex (FDD) frequency band for downlink from the BS to the UEs is 2155–2180 MHz.

The LTE cellular network is based on a coverage-centric solution rather than a capacity-centric solution. Every base station in the network uses the same frequency, a concept referred to as universal frequency reuse. Each cell is divided into three angular sectors for coverage over 360 degrees in azimuth. Directional sector antennas at a BS provide azimuthal coverage, and the main lobe of radiation is directed below the horizon using a mechanical or electrical downtilt. For a 10-MHz channel, the maximum number of simultaneously transmitting UEs is six per sector or eighteen per BS.

Initial plans for deployment of LTE [11] involved cells installed within two concentric circles centered on a city or town. The inner circle (referred to as an urban/suburban area) consisted of a dense laydown of cells where the proposed inter-site distance between base stations was 1.732 km. The outer circle (for a rural area) had a less-dense laydown of cells with an inter-site distance of 7 km.

Commercial wireless industry representatives subsequently made available a more-realistic geographic laydown of cells. This laydown was based on an actual commercial wireless industry network of base station locations for urban/suburban and rural environments in the U.S., but with the locations slightly randomized.

From [10], the uplink transmission scheme is single-carrier frequency-division multiple access (SC-FDMA). Advantages to this scheme are higher uplink throughput, improved coverage and cell-edge performance, lower terminal cost, and improved battery life. The time-domain structure is 10-millisecond frames consisting of ten subframes, each one millisecond in duration. Each subframe consists of two slots of length 0.5 millisecond, where each slot includes seven orthogonal frequency-division multiplexing symbols.

A physical resource block (PRB) consists of twelve 15-kHz subcarriers during one slot, for a total of 180 kHz. The LTE specification supports any bandwidth in the range of six PRBs (1.08 MHz) to 100 RBs (18.0 MHz) in steps of one PRB. However, 3GPP has adopted specific channel bandwidths, and a 10-MHz LTE channel bandwidth (50 PRBs for a transmission bandwidth of 9 MHz) has been proposed for the sharing study.

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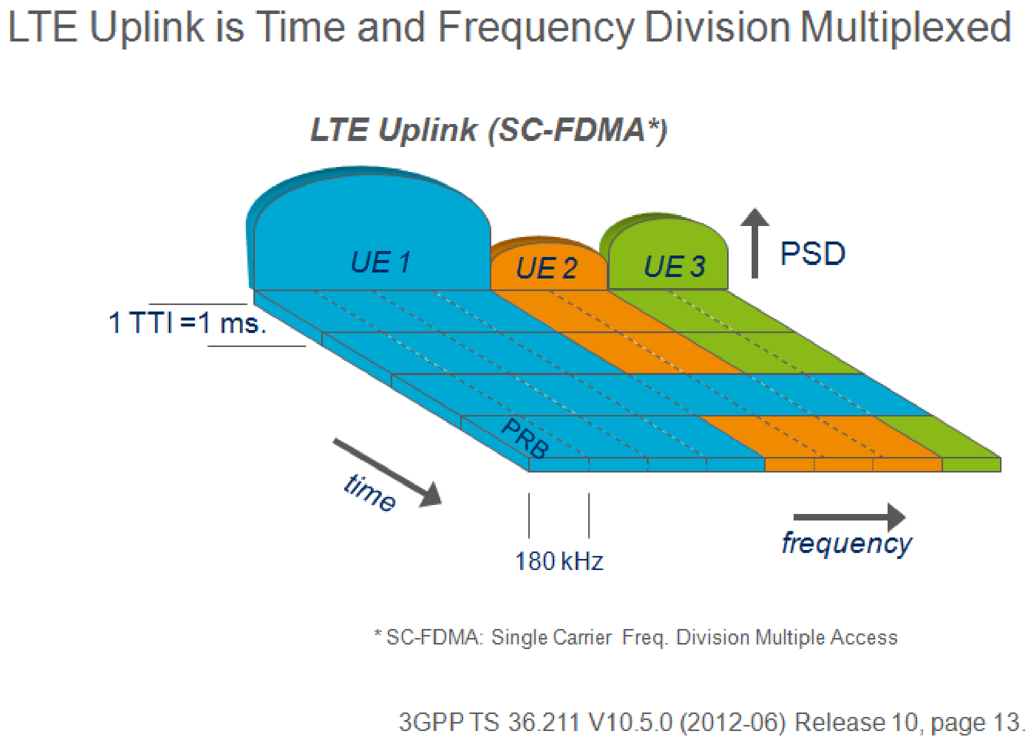
[10] *LTE Introduction*, Presentation to CSMAC WG-5 August 2-3, 2012.

[11] *Baseline LTE Uplink Characteristics*, CSMAC Working Groups – LTE Characteristics Subgroup, 12 November 2012.

[12] *Uplink Transmit Power Analysis for LTE*, 27 August 2012.

From [12], LTE is a packet-switched network that dynamically allocates PRBs to UEs in each 1-millisecond transmit time interval (TTI). The UE transmitter power, and the resultant power spectral density (PSD) at a point in space, are also controlled. The maximum number of UEs that can transmit at a given instant is limited and not all UEs in a sector can transmit at the same time. The LTE uplink multiplexing scheme is depicted in Figure 6-1.



LTE Uplink is Time and Frequency Division Multiplexed

* SC-FDMA: Single Carrier Freq. Division Multiple Access

3GPP TS 36.211 V10.5.0 (2012-06) Release 10, page 13.

From [12]

Figure 6-1. LTE Uplink Multiplexing Scheme

For analysis purposes, the network is assumed to be 100% loaded, where all PRBs are occupied at all times.

6.2 BASELINE CHARACTERISTICS

UE power control is a technique used in LTE to mitigate for the large variation in the propagation loss across the sector as well as to reduce the amount of interference to other cells. In general, UEs at the edge of the cell are controlled to transmit at higher power than UEs closer to the center. UE transmitter power ranges from -40 dBm to +23 dBm. Since the UE maximum antenna gain is -3 dBi, the effective isotropic radiated power (EIRP) ranges from -37 dBm to +20 dBm. The LTE Baseline document [11] provides cumulative distribution function (CDF) plots of the total EIRP for a UE in urban/suburban and rural environments.

The LTE Baseline document also includes the following data:

- UE transmitter emission spectrum masks for various channel bandwidths. For each bandwidth, the mask data consists of emission limits (i.e., maximum emission levels) for various difference frequencies (Δf's). The emission limit values are in terms of dBm and are relative to the maximum transmitter power of 23 dBm. The Δf's are defined with respect to the edge of the occupied bandwidth.

- BS receiver specification data such as reference sensitivity data for various channel bandwidths, the noise figure, and an adjacent-channel selectivity value. The selectivity value is in terms of the interfering signal mean power relative to the desired signal mean power, both in dBm.
- Specification data for the BS sector antenna. The data include the maximum gain, -3 dB beamwidths in the azimuth and elevation planes, downtilt angle in the elevation plane, polarization, antenna height above ground level (AGL), and miscellaneous system loss (cable, insertion, etc.).
- The reference to the ITU document that may be used to model the pattern of the BS sector antenna and obtain gains at off-axis angles in the azimuth and elevation planes.

7 ANALYSIS METHODOLOGIES

This section includes descriptions of the methodologies used in the analyses for WG-5 DoD systems.

7.1 VISUALYSE

7.1.1 Introduction

A commercially available software analysis tool called “Visualyse”[13] was used for sharing analyses of a number of DoD systems. Two different types of analyses were performed: the DoD system receiver as potential victim of EMI, and the DoD system transmitter as potential source of EMI. These two types are described below.

7.1.2 DoD Systems as Victim of EMI

For the analysis of a DoD system as a potential victim of EMI, specific locations in the United States were selected for analysis. The selection of the specific locations was based on the expected operational usage of the system. In some cases, military test and training ranges were selected, and in other cases, locales where the aircraft could be flown were selected. For each location, the aircraft was assumed to be operational within a specific area, and points along the boundary of the area were selected to represent locations of the DoD system receiver. The aircraft was also assumed to be operational at a specific altitude. In Visualyse, the receiving system was located at each of these points.

For the analyses, commercial wireless industry made available a realistic network of base station locations for urban/suburban and rural environments in the U.S. For each range to be analyzed, urban/suburban and rural base station locations in the vicinity of the DoD receiver site were selected. The radius for the select was based on the distance to the radio horizon from the aircraft at its operational altitude.

At each base station location, UE transmitters were assumed to be positioned on the ground at the coordinates of the base station tower, where the antenna height of each UE was 1.5 m AGL.

For each location of the DoD system receiver, the undesired received power and the I/N due to each UE was computed in the following way. UE transmitters were sequentially selected for analysis. Co-channel conditions were assumed for the transmitter and receiver frequencies (i.e., both were assumed to be tuned to the same frequency). A random value of the EIRP for the UE was evaluated using data provided in the LTE baseline document. The bandwidth for the UE transmitter was set at 1.67 MHz. Visualyse computed the propagation path and distance between the points representing the UE and the receiving antenna. The propagation loss along this path was evaluated using an appropriate model (ITU-R 528-3 for ground-air paths or ITU-R 452-14 for ground-ground paths). Since the receiving antennas of interest are simple types (e.g., monopoles and dipoles), the gain for these types of antennas was evaluated using an approximate model.[14] Receiver system loss (e.g., cable loss, insertion loss, etc.) was assumed to be 2 dB. The frequency dependent rejection (FDR) of the UE signal due to the receiver’s IF stage

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[13] *Visualyse Professional - make life easier, improve your output*. http://www.transfinite.com/content/professional.html. 2013.

[14] J. Kraus, *Antennas*, 2nd edition, McGraw-Hill.

bandwidth was computed. For cases where the transmitter emission bandwidth was wider than the receiver's IF bandwidth, the FDR was non-zero. The undesired received power in dBW at the narrowest IF stage of the receiver was computed. The I/N was computed by subtracting the receiver system noise level from the undesired received power, both in dBW.

The Visualyse analysis was many-on-one (i.e., the analysis consisted of the potential EMI from the collection of UE transmitters to a receiver), so the level of aggregate undesired received power was calculated by summing the individual received power values in Watts.

Because of the large number of UEs in the vicinity of the victim receiver, Visualyse run-time for some environments was very large. To reduce run-time, the number of UEs per cell that could contribute to the aggregate received power was adjusted based on the bandwidth of the receiver. For example, for a receiver bandwidth of 3 MHz, the receiver would accept power from two UEs (each of which is 1.67 MHz) per sector.

The protection distance is the minimum distance between a DoD system receiver and the laydown of UEs at which EMI to the DoD receiver would not be expected to occur. For each location of the DoD system receiver, the protection distance between the receiver and the laydown of UEs was evaluated as follows. Visualyse permits the user to set an exclusion radius value where UEs at distances smaller than the input radius are not included in the I/N calculations. Visualyse also has a capability for sequentially repeating an analysis for a series of time samples. Since UE transmitter power is a random variable, the aggregate undesired received power, and the I/N, will vary over the time samples. The aggregate I/N was computed for a series of time samples and collected in a file saved by Visualyse. From this file, the average aggregate I/N was then computed and compared to the receiver I/N interference threshold. Based on the comparison, the exclusion radius was iteratively varied until the average aggregate I/N was equal to the I/N threshold. The protection distance was set to the exclusion radius.

Plots of protection distance results were generated by using ArcGIS Explorer. The urban/suburban and rural locations, along with the DoD receiver locations, were imported into ArcGIS Explorer. The protection distance for each DoD receiver location was plotted as a color-coded circle.

7.1.3 DoD System as Source of EMI

The analysis of a DoD system as a potential source of EMI was essentially the same as that described in the previous subsection. A major difference was that the analysis was one-on-one (i.e., the DoD system transmitter to one LTE base station receiver).

For these analyses, the pattern for the LTE base station sectoral antenna with a downtilt angle of 3 degrees in the elevation plane was modeled using equations from ITU-R F.1336-3. An elevation plane cut through the main lobe (azimuth angle equal to 0 degrees) was obtained by computing the gain for elevation angles ranging from -90 to 90 degrees. A 3D pattern was created in Visualyse by entering this elevation plane cut at four azimuth angles, 0, 90, 180, and 270 degrees. Therefore, for any propagation path azimuth and elevation angles, Visualyse would compute the gain based on the elevation plane cut. Elevation plane cuts for off-axis azimuth angles equal to 60 and 180 degrees were similarly obtained.

DoD transmitting systems were modeled in Visualyse at points along the boundary of each analyzed military range or area.

For these analyses, Visualyse has a capability called Area Analysis, where the user defines a rectangular area over a geographic region that includes the set of transmitting system locations. The user also selects a value for the I/N threshold (*e.g.*, -6 dB). For each transmitter location, a receiver (in this case, the LTE base station receiver) is incrementally positioned at points within the area. The realistic network of base station locations was not employed in the Area Analysis. At each point for the receiver, Visualyse computes the undesired received power and the I/N. When all points have been analyzed, Visualyse plots a contour representing the distance from the transmitters at which the I/N is equal to the I/N threshold. This contour represents the protection distance within which EMI to LTE base station receivers would not be expected. The distance from the transmitter location to a point on the contour was determined using a Visualyse feature.

For each location of the LTE BS receiver, the undesired received power and the I/N due to each DoD system transmitter was computed in a fashion similar to that described in the previous subsection, with differences as follows. The transmitter power and antenna gain for the DoD transmitter were both set to the maximum. System loss at the transmitter (e.g., cable loss, insertion loss, etc.) was included where appropriate. The bandwidth for the LTE BS receiver was set at 10.0 MHz. Visualyse computed the propagation path between the points representing the DoD transmitting system and the LTE base station antenna, and the air-ground propagation loss along this path was evaluated using the ITU-R 528-3 propagation model. Visualyse also computed the azimuth and elevation angles from the transmitting antenna to the BS sectoral antenna. For the LTE base station receiving antenna gain, three cases based on the azimuth angle of the main lobe relative to the azimuth angle in the direction of a transmitter were analyzed. The three cases are: 0 degrees (main lobe azimuth in the direction of a transmitter), 60 degrees (main lobe at 60-degree offset), and 180 degrees (back lobe in the direction of a transmitter). In all three cases, the main lobe is tilted downward by three degrees in the elevation plane, so the main lobe doesn’t actually point toward the DoD transmitting antenna. Receiver system loss was assumed to be 2 dB [11]. FDR was computed and the value was not zero when the DoD system emission bandwidth was greater than the bandwidth of the LTE BS receiver.

Plots of protection distance results were generated as follows using a multi-step process. The Visualyse-generated data for a contour was written to a kml file which was imported into Google Earth. Using Google Earth, the contour data was subsequently written to a Google Earth kmz file which was imported into ArcGIS Explorer along with the urban/suburban and rural LTE locations. Three color-coded protection distance contours for 0, 60, and 180-degree base station off-axis angles were plotted using ArcGIS Explorer.

7.2 Excel

7.2.1 Introduction

The methodologies employed by Boeing and Raytheon for the analysis of PGMs are described in this subsection.

7.2.2 PGM System as Victim of EMI

The Raytheon analysis of potential EMI to the PGM receiver was similar to the analysis of the other DoD system receivers as described above. Differences are noted in the following paragraphs.

The many-on-one analysis was accomplished using an Excel spreadsheet, where the locations of urban/suburban and rural base stations were spaced at increments of 1.732 km for an urban/suburban deployment and increments of 7 km for a rural deployment as defined in the LTE baseline document for a grid laydown. Eighteen UE transmitters were positioned at each base station location. The antenna height for all UEs was 1.5 meters AGL.

The PGM system receiver was assumed to be at an altitude of 20,000 feet AGL.

The center frequency for each UE transmitter and the receiver were assumed to be the same. The median UE EIRP was +8 dBm for the rural emitters and -3 dBm for the urban emitters as determined from the LTE baseline document. The propagation loss between the UE transmitter and the PGM receiver was evaluated using ITU-R 528-3. An I/N of -6 dB was employed as the PGM receiver threshold. Additional system losses were assumed to be 2 dB. The received power in dBm due to each UE transmitter was computed, and the aggregate received power due to the collection of UEs was computed by summing the individual received power values in Watts and converting to dBm. The protection distance was iteratively calculated using the power level required at the PGM receiver to avoid interference based on the I/N ratio and using the ITU-R-528-3 propagation loss tables. The number of base stations and aggregate UE transmitters were also adjusted based on the protection distance determined during the iterative process. The number of cell towers was reduced to compensate where a portion of the aircraft/PGM operational mission was occurring over a large body of water.

7.2.3 PGM System as Source of EMI

The Boeing analysis of potential EMI to LTE base stations by the PGM transmitter was similar to the analysis of the other DoD system transmitters as described above. Differences are noted in the following paragraphs.

Several cases were analyzed for the PGM system transmitter. For ground testing, the transmitter was assumed to be located at 5 feet AGL and for test or training flights the transmitter was assumed to be located at an altitude of 10000 feet AGL. For simulated ground testing, low-power mode was used for the transmitter. For simulated flights, high-power mode was used. Three base station antenna off-axis angles were simulated: 0, 60, and 180 degrees.

The one-on-one analysis was accomplished using an Excel spreadsheet. The transmitter and receiver were both assumed to be tuned to the same frequency. The level of received power at the LTE base station was calculated using the maximum EIRP for the PGM system transmitter, 15 dBi receive antenna gain (includes 3-degree down-tilt pattern effects), and transmitter-receiver propagation loss evaluated using ITU-R 528-3. The I/N was computed by subtracting the receiver system noise level from the undesired received power, both in dBm.

The protection distance was determined by iteratively adjusting the transmitter-receiver distance in the spreadsheet until the I/N was equal to the I/N threshold (-6 dB).

7.3 RECEIVED POWER

The undesired received power, I, was computed using the following equation:

$$I = P_T - L_T + G_T - L_P + G_R - L_R - L_{misc} - FDR \qquad \text{(Eqn 7-1)}$$

where

I = undesired received power, in dBm

P_T = transmitter power of the undesired source, in dBm

L_T = loss at the transmitter (e.g., system, cable), in dB

G_T = transmit antenna gain of the undesired source, in dBi. G_T is the gain in the direction of the propagation ray path.

L_P = propagation loss, in dB. L_P is evaluated at the receive frequency, and includes any additional losses (diffraction, reflection, etc.) along the ray path.

G_R = receive antenna gain, in dBi. G_R is the gain in the direction of the propagation ray path.

L_R = loss at the receiver (e.g., system, cable), in dB

L_{misc} = total of any miscellaneous loss, in dB

FDR = frequency dependent rejection, in dB

7.4 AGGREGATE RECEIVED POWER

Aggregate received power due to multiple UEs was calculated using the following equation:

$$I_{agg} = 30 + 10\log_{10}\sum_{j=1}^{M} I_j \qquad \text{(Eqn 7-2)}$$

where

I_{agg} = aggregate received power, in dBm

M = number of UEs

I_j = undesired received power from a single UE, Watts

7.5 RECEIVER EFFECTIVE NOISE

The receiver’s thermal noise power is given by:

$$n_r = kTB \qquad \text{(Eqn 7-3)}$$

where

n_r = the receiver’s thermal noise power, in watts

k = Boltzmann’s constant, which is 1.38 x 10-23 J/K

T = the absolute temperature, in degrees Kelvin. The standard value of 290 K (62.3 degrees Fahrenheit) was used for T

B = the receiver’s bandwidth, in Hertz

Man-made, atmospheric, and galactic noise levels were assumed to be negligible at L-band frequencies. The effective receiver input noise power was computed as follows:

$$n = n_r f_n \qquad \text{(Eqn 7-4)}$$

where

n = the receiver's effective input noise power, in watts

f_n = the receiver's noise factor, unitless

The effective receiver input noise power, N, in dBm was computed as follows:

$$N = 30 + 10 \log n \qquad \text{(Eqn 7-5)}$$

7.6 RECEIVER THRESHOLD

The receiver threshold, i.e., the maximum allowed undesired received power, I_T in dBm, is given by:

$$I_T = N - 6 \qquad \text{(Eqn 7-6)}$$

In general, the interference threshold was based on a criterion of 6 dB below the receiver noise level although some SWGs may use a different value for the threshold.

7.7 FREQUENCY DEPENDENT REJECTION

Given the tuned frequencies of the transmitter and the receiver, FDR is the rejection provided by the receiver's IF stage to an undesired, possibly off-tuned, signal. The transmitter emission spectrum data and the receiver IF-stage selectivity data are inputs to the calculation of the FDR. For co-channel conditions, if the transmitter emission spectrum -3 dB bandwidth is narrower than the receiver IF-stage -3 dB bandwidth, the receiver accepts all the power of the transmitted signal. On the other hand, if the transmitter emission spectrum bandwidth is wider than the receiver IF-stage bandwidth, the transmitted signal is attenuated and the FDR is given by the following:

$$- \quad FDR = 10 \log_{10} \frac{BW_{Tx}}{BW_{Rx}} \qquad \text{(Eqn 7-7)}$$

8 REFERENCES

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9 ACRONYMS

3GPP	3rd Generation Partnership Project
ACMI	Air Combat Maneuvering Instrumentation
ACTS	Air Combat Training System
AFB	Air Force Base
AGL	Above Ground Level
AMF	Airborne and Maritime/Fixed
AMT	Aeronautical Mobile Telemetry
ANG	Air National Guard
ARNG	Army National Guard
BS	Base Station
C2	Command and Control
CDF	Cumulative Distribution Function
CMDL	Compact Multiband Data Link
COA	Course Of Action
CSMAC	Commerce Spectrum Management Advisory Committee
CTS	Combat Training System
dB	Decibel
dBi	Decibel above Isotropic
dBm	Decibel relative to 1 milliwatt (10^-3 W)
DDL	Digital Data Link
DOC	Department of Commerce
DoD	Department of Defense
EIRP	Effective Isotropic Radiated Power
EMI	Electromagnetic Interference
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDR	Frequency-Dependent Rejection
FMV	Full Motion Video
FOUO	For Official Use Only
GCS	Ground Control Station
HRV	High-Resolution Video

Hz	Cycles per second
I/N	Interference to Noise Ratio
IAP	International Airport
IF	Intermediate Frequency
ITU	International Telecommunications Union
ITU-R	International Telecommunication Union Radiocommunication Sector
JTRS	Joint Tactical Radio System
kHz	Kilohertz (10^3 Hertz)
LTE	Long Term Evolution
Mbps	Megabits per second (10^6 bits per second)
MCAS	Marine Corps Air Station
MEP	Mission Equipment Package
MEU	Marine Expeditionary Unit
MHz	Megahertz (10^6 Hertz)
MIDS	Multifunctional Information Distribution System
MOA	Military Operational Area
mW	Milliwatt (10^-3 Watts)
NACTS	Nellis Air Combat Training System
NAS	Naval Air Station
NAWS	Naval Air Weapons Station
NTC	National Training Center
NTIA	National Telecommunications and Information Administration
P5 CTS	P5 Combat Training System
PGM	Precision Guided Munition
PPSG	Policy and Plans Steering Group
PRB	Physical Resource Block
PSD	Power Spectral Density
RF	Radio Frequency
ROVER	Remote Operations Video Enhanced Receiver
RVT	Remote Video Terminal
S&S	Security and Support
SA	Small Airborne
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
SRW	Soldier Radio Waveform

SUAS	Small Unmanned Aerial System
SWG	Sub-Working Group
TACTS	Tactical Aircrew Combat Training System
TCTS	Tactical Combat Training System
TM	Telemetry
TR	Test Range
TTI	Transmit Time Interval
TTR	Test and Training Range
TTNT	Tactical Targeting Network Technology
UA	Unmanned Aircraft
UAS	Unmanned Aerial System
UE	User Equipment
USMC	United States Marine Corps
US&P	United States and its Possessions
VMR	Veta Monitor Receiver
VORTEX	Video ORiented Transceiver for EXchange of information
W	Watts
WG	Working Group
WSMR	White Sands Missile Range