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Issues in RF Propagation Modeling in an Urban Environment using the Extended Air Defense Simulation (EADSIM) Mission Level Model

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Abstract

As military operations in urban environments become more numerous, the ability of combat units to communicate, jam enemy communications, or employ RF weapons within this environment must be evaluated. To perform this evaluation in a mission level model requires a capability to evaluate the contributions of both terrain and man-made structures (interior and exterior) to RF propagation. The present study is an analysis of the adequacy of a mission level model (EADSIM) to perform these RF propagation calculations in an urban environment.

Three basic environments must be assessed. The first environment consists entirely of terrain, with no man-made features impacting propagation values. The second environment includes terrain, but also includes the contribution of solid structures with abrupt edges, which may obstruct/influence LOS paths. The third environment includes not only terrain and structures, but also contains structures with interior features which must be evaluated to determine the propagation levels within and around these structures.

EADSIM was used as the model for evaluation in view of its suite of propagation tools which can be used for analysis of RF propagation between transmitters and receivers including terrain. To assess EADSIM's capability to perform in these environments, flat terrain maps with an obstruction were created to permit comparison of EADSIM's

propagation models with analytical calculations and with measurements. Calculations from the Terrain Integrated Rough Earth Model (TIREM) and the Spherical Earth Knife Edge (SEKE) propagation models included within EADSIM showed that the ability of the models to calculate knife-edge diffraction agreed favorably with analytical values. The representation of multipath effects was less encouraging. SEKE only models multipath when Fresnel clearance exists. TIREM models multipath, but the cyclical characteristics of multipath are not represented, and only subtractive path loss is considered. Multipath is only evaluated along a 2-D path in the vertical orientation. This precludes modeling propagation in the urban canyons of metropolitan areas, where horizontal paths are dominant. It also precludes modeling exterior to interior propagation.

In view of the apparent inadequacy of urban propagation within mission level models, as evidenced by EADSIM, the study also attempts to address possible solutions to the problem. Correction of the sparsing techniques in both TIREM and SEKE models is recommended. Both SEKE and TIREM are optimized for DTED level 1 data, sparsed at 3 arc seconds resolution. This led to significant errors when map data was sparsed at higher or lower resolution. TIREM's errors would be significantly reduced if the 999 point array limit was eliminated. This would permit using interval sizes equal to the map resolution for larger areas. This same problem could be fixed in SEKE by changing the interval spacing from a fixed 3 arc second resolution (~93 meters) to an interval which is set at the map resolution. Additionally, the cell elevation interpolation method which TIREM uses is inappropriate for the man-made structures encountered in urban environments. Turning this method of determining height off, or providing a selectable switch is desired.

In the near term, it appears that further research into ray-tracing models is appropriate. Codes such as RF-ProTEC, which can be dynamically linked to mission level models such as EADSIM, can provide the higher fidelity propagation calculations required, and still permit the dynamic interactions required of the mission level model. Additional research should also be conducted on the best methods of representing man-made structures to determine whether codes other than ray-trace can be used.

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1.0 Introduction

1.1 Problem

The present study is an analysis of the adequacy of mission level models to perform RF propagation calculations in an urban environment. As military operations in urban environments become more numerous, the ability of combat units to communicate, jam enemy communications, or employ RF weapons within this environment must be evaluated. To perform this evaluation in a mission level model requires a capability to evaluate the contributions of both terrain and man-made structures (interior and exterior) to RF propagation.

Three basic environments have been assumed for the study. The first environment consists entirely of terrain, with no external features impacting propagation values. This type of terrain is appropriate when the area to be considered is not influenced significantly by the proximity of man-made structures, and frequently is used when the scale of these structures is small when compared with the area under consideration. The second environment includes terrain, but also includes the contribution of solid structures with abrupt edges, which may obstruct/influence LOS paths. This area could be represented by downtown New York City, where the ability of a transmitter and a receiver to communicate in the urban canyons is in question. The third environment includes not only terrain and structures, but these structures contain interior features which must be evaluated to determine the propagation levels within and around these structures. This case would be critical when attempting to assess the ability of a small patrol to communicate with higher echelons when inside a large building.

To address these issues in a combat scenario, a mission level model is required. Attempting to determine the capability of current models to address these issues, or to determine requirements for a new or modified model was the goal. The Extended Air Defense Simulation (EADSIM) mission-level model was used for evaluation in view of its suite of propagation tools which can be used for analysis of RF propagation between transmitters and receivers including terrain. Other models would encounter similar issues.

1.2 Scope and Limitations of the Study

The study attempted to understand the implementation of the Terrain Integrated Rough Earth Model (TIREM) and the Spherical Earth Knife Edge (SEKE) model in EADSIM. To accomplish this, we developed test cases which permitted a comparison of these two models with analytical calculations and actual measurements. Once the comparison was complete, a determination was made as to whether the model was usable in its present form, whether code modifications to the propagation code would need to be made to permit modeling the desired environment, or whether a different model, with requirements to be defined, was required.

To assess EADSIM's capability to perform in these environments, flat terrain maps in Digital Terrain Elevation Data (DTED) format were created at several levels of resolution with an obstruction placed normal to the propagation path extending the full width of the map. The height and depth of this obstruction could be varied to assess the diffraction and reflection calculations being performed within EADSIM. Calculations from the TIREM and SEKE propagation models included within EADSIM showed that the ability of the models to calculate knife-edge diffraction agreed favorably with calculated values. The representation of multipath effects was less encouraging. SEKE only models multipath when Fresnel clearance exists. TIREM models reflections, but the cyclical characteristics of multipath are not represented, and only subtractive path loss is considered. Reflections are only evaluated along a 2-D path in the vertical orientation. This precludes modeling propagation in the urban canyons of metropolitan areas, where horizontal paths are dominant. It also precludes modeling exterior to interior propagation. In view of the apparent inadequacy of urban propagation modeling within mission level models, as evidenced by EADSIM, the study also attempted to address possible solutions to the problem. While actual urban maps which include structures are limited, a map of downtown Washington, DC is available for assessing capabilities once the basic implementations are understood.

1.3 Overview of Report

Section 2 discusses the TIREM and SEKE models, the implementation of these codes within EADSIM, and the methods used to develop test maps for evaluating propagation modeling within EADSIM . Section 3 presents the analysis results, and recommended actions to permit successful implementation of urban operations within EADSIM.

2.0 Technical Approach

2.1 Terrain Integrated Rough Earth Model (TIREM)

TIREM, developed originally by DoD in the 1980's, predicts basic propagation loss over irregular terrain and seawater for ground-based and air-borne transmitters and receivers. It predicts median propagation loss for frequencies between 20 MHz and 20 GHz. The techniques used to calculate these losses include free-space spreading, reflection, diffraction, surface-wave, tropospheric-scatter, and atmospheric absorption. TIREM uses as input a terrain profile described by a number of discrete points, the position of which is specified by a distance from the transmitter and an elevation above mean sea level. Also required is information on the transmitter (antenna height, frequency, and antenna polarization), the receiver (antenna height), atmospheric constants (surface refractivity and humidity), and ground constants (relative permittivity and conductivity). TIREM, as implemented in EADSIM, is valid for antenna heights from 0.5 meters to 30,000 meters and for transmitter to receiver distances greater than 0.5 statute miles. TIREM version 2.2 is implemented in EADSIM. (This is not the current TIREM version.) For the areas of interest in this study, TIREM will calculate knife-edge diffraction with reflection or free-space path loss based on calculating a 2 dimensional path between the transmitter and receiver, determining whether line of sight exists, and whether that line of sight has fresnel clearance. Areas for analysis in this study were how TIREM samples the terrain data along the path, and how the diffraction and reflection values were calculated.

2.2 Spherical Earth Knife Edge (SEKE) Model

SEKE, developed originally by MIT Lincoln Laboratory, is included in EADSIM as part of the Advanced Low Altitude Radar Model (ALARM), where it calculates propagation loss for the radar models. EADSIM was modified several years ago to permit use of the SEKE module to calculate communications propagation loss as an alternative to TIREM. The advantage of SEKE in this role was primarily its ability to handle the constructive and destructive interference generated as a result of reflections when line of sight exists and its ability to consider antenna patterns with regard to multipath calculations. SEKE was developed as a site-specific propagation model for general terrain to compute multipath, spherical earth diffraction, and multiple knife-edge diffraction losses. The proper algorithm is selected based on terrain geometry, antenna heights, and frequency. For the areas of interest in this study, SEKE will calculate multipath loss when line of sight exists, and multiple knife-edge diffraction losses when line-of-sight does not exist. Areas for analysis in this study were how SEKE samples the terrain data along the path, and how the diffraction and reflection values were calculated.

2.3 Test Map Development

In view of the complexity of standard DTED maps, it was desired to develop a simple map to use for comparison with analytical calculations. An application was developed to permit building artificial DTED maps with flat terrain at any desired resolution, and single or multiple "fences" of desired height and width crossing the width of the map (figure 1). The fences have the same electrical properties as the rest of the terrain.

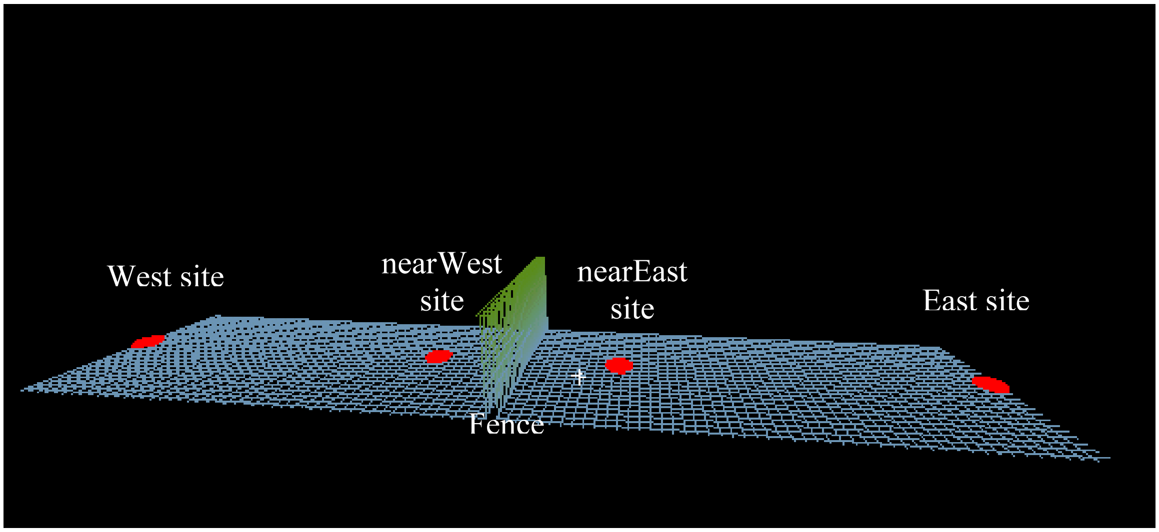

Figure 1. Terrain Map Layout

This permitted setting up simple test cases that could be verified with calculations. The maps were ~11 kilometers by ~2.5 kilometers in expanse, with resolutions of 1 meter x 1 meter, 10 meters x 10 meters, and 100 meters x 100 meters. Fences were constructed aligned north/south with a width of 20 meters, 100 meters, or 200 meters, and a height of 100 meters or 1000 meters. This permitted varying antenna heights to measure free space, diffraction and reflection losses. Two antenna pairs were deployed in the 11 kilometer map. The long range pair was separated by 11,078 meters, and the short range pair was separated by 2,398 meters.

3.0 Analysis and Simulation Results

3.1 Conduct of Analysis

To evaluate the capability of EADSIM to model propagation in an urban environment, communications networks were created for two pairs of transmitter/receiver pairings. One pairing was located 11,078 meters apart, centered on the RF fence, while the other pairing was located 2,398 meters apart, also centered on the RF fence. The EADSIM model was run to determine the path loss between the paired units. The model was run in TIREM and SEKE mode for each case. Additionally, the EADSIM Graphics User Interface (GUI) has a side profile visualization tool which can be used to display a graph of the terrain elevation versus ground range, line of sight, and the lower boundary of the first fresnel zone. This tool also displays path loss along the selected path calculated using TIREM, and the Free Space Path Loss (FSPL) along the same path (figure 2). Results from this "TIREM Tool" were also recorded for each run.

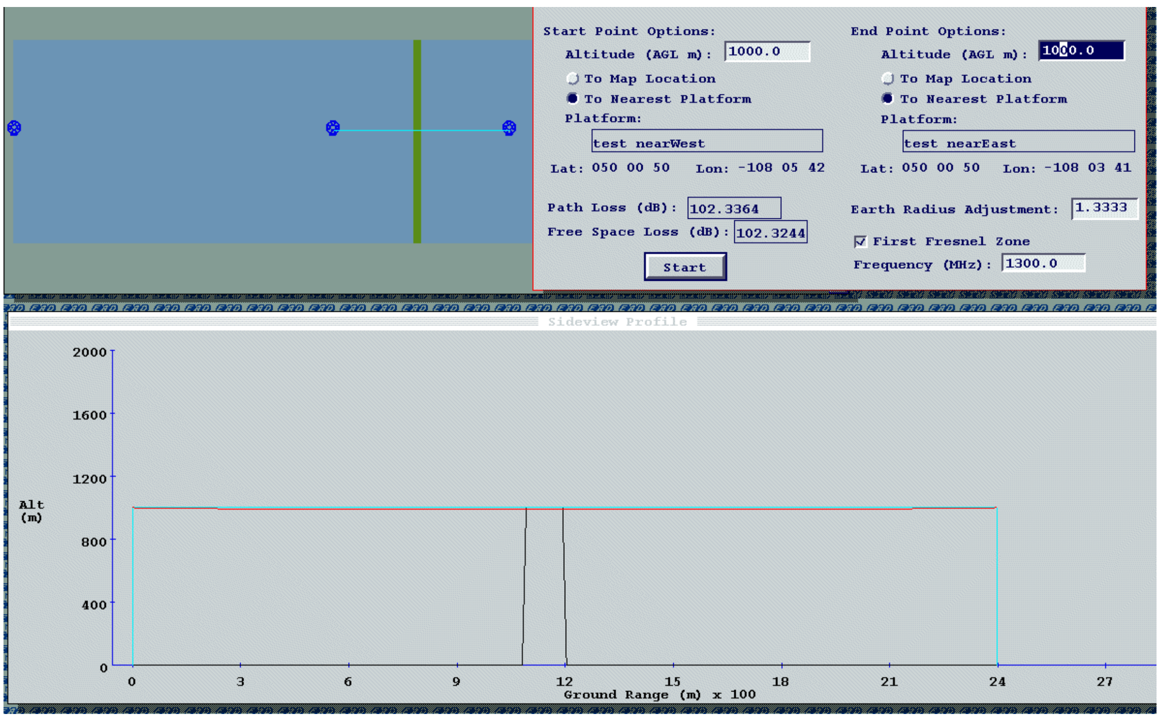

Figure 2. Side Profile Tool

All scenario runs were conducted using an 11 kilometer by 2.4 kilometer terrain grid. Initial runs utilized a 20 meter wide fence with a height of 100 meters for two of the map resolutions and, because the 100 x 100 meter grid resolution case could not support a 20 meter wide fence, a fence 200 meters was used in that case. Due to this inconsistency, a second set of runs was performed using a fence width of 100 meters for all three cases. This permitted a 100 block wide fence in the 1 meter x 1 meter case, a 10 block wide fence for the 10 meter x 10 meter case, and a one block wide fence for the 100 meter x 100 meter case. To eliminate ground bounce, and attempt to evaluate TIREM's ability to calculate diffraction alone, a third set of runs was conducted with a fence height of 1000 meters and a narrow field of view in elevation.

Path loss computed within EADSIM was compared with Free Space Path Loss and knife-edge diffraction calculations as well as calculations using a four-ray diffraction/reflection model. The results were then compared to understand how each propagation model was computing path loss, and compare that value to calculations. Once the runs were completed and path loss values were entered, runs which could not be explained were analyzed in more detail by debugging EADSIM's C++ code to determine precisely how the values were being derived.

3.1.1 TIREM Analysis

TIREM builds an array along the selected path using a cell array equal to the total distance divided by the approximate cell size, not to exceed 999. This 999 point limit was a Fortran fixed array size limit which was carried over to the C++ implementation within EADSIM. If the distance increment is greater than the block size, elevation values will be dropped. TIREM also assesses the position of the transmitter/receiver within a block, and interpolates the elevation based on position relative to the surrounding elevation blocks. When the constructed fence is narrower than the distance increment, it may be missed. If the resulting fence width is 1 or 2 blocks, the maximum fence height will be interpolated based on the elevation of the surrounding blocks, and a shortened fence will result. This may significantly impact path loss calculations. It was also determined during the analysis that TIREM does not consider Field of View or Antenna patterns during its calculations. This may significantly impact path loss due to reflections.

3.1.1.1 100 meter high x 20 meter thick (200 meter thick in 100 meter x 100 meter resolution) Fence

TIREM runs were first assessed in the 20 meter/200 meter wide case. For the Far case, when the map blocks were 1 meter x 1 meter, TIREM sparsed the selected path from 11,000 terrain points to 999, spaced 11 meters apart. The 10 meter x 10 meter case had 998 points, each 11 meters apart, and the 100 meter x 100 meter case had 100 points, spaced 111 meters apart. With antenna heights of 100 meters and a fence height of 100 meters, TIREM calculated path loss in excess of FSPL at 6.73 to 12.11 dB (figure 3). Diffraction alone at this grazing angle should account for 6 dB of excess path loss. TIREM values agreed for the 10 meter x 10 meter resolution and 100 meter x 100 meter resolution cases. In the 1 meter x 1 meter resolution case, the fence was sparsed to two 100 meter points, while in the other cases it sparsed to one 100 meter point and two intermediate elevations. The additional path loss is assumed to be due to reflections, with the 12 dB loss treated as 2 knife-edge diffractions by TIREM . The same effect is seen in the 50 meter antenna elevation case.

In the Near case, the 1 meter x 1 meter resolution case fence was sparsed to nine 100 meter points and one intermediate elevation, while the 10 meter x 10 meter resolution and 100 meter x 100 meter resolution cases were sparsed to one 100 meter point and two intermediate elevations. This caused the difference between the 1 meter x 1 meter resolution and other cases. Additionally, because the 100 meter antenna elevation was treated as elevation Above Ground Level (AGL), in the 100 meter x 100 meter resolution case the 1 meter delta between the 101 meter antenna elevation and the 100 meter fence caused TIREM to use a Longley-Reasoner algorithm rather than the Knife-edge diffraction algorithm since LOS existed.

3.1.1.2 100 meter x 100 meter Fence

These runs were performed to permit use of a constant fence width for all three resolutions. Sparsing of the terrain was identical to paragraph 3.1.1.1. Sparsing of the fence provided an unexpected result. For the 100 meter x 100 meter case, the single cell width fence was interpolated as two cells with each cell clipped to ~500 meters height. This caused the 100 meter antenna height cases to have minimal excess loss, and the 50 meter antenna height case to have less excess loss than would have been expected due to a combination of diffraction and reflection in a near-grazing case. The differences in the 1 meter x 1 meter resolution and 10 meter x 10 meter resolution cases appear to be caused by a combination of fence sparsing (10 full height points for the 1 meter x 1 meter resolution case, and 9 full height and 2 intermediate elevations for the 10 meter x 10 meter resolution case) and the 100 meter AGL antenna elevation causing the code to use the Longley-Reasoner calculations.

In the near case, much the same results were seen, with the exception that both the 1 meter x 1 meter and 10 meter x 10 meter resolution cases had multiple full height points in the fence with an intermediate height point at each edge.

3.1.1.3 1000 meter x 100 meter Fence

These runs were performed to permit use of a constant width fence for all three resolutions at a great enough height to negate ground reflection with a narrow beam antenna. This was to limit excess path loss to diffraction alone, permitting comparison with the SEKE calculations. After running the cases and seeing little difference from the 100 meter x 100 meter fence cases, it was determined that TIREM does not consider antenna patterns when it calculates path loss. This is potentially significant since it increases the impact of multipath reflections in the simulation compared with the actual multipath reflections from a high gain antenna.

3.1.2 TIREM Tool Analysis

The TIREM Tool differs from the basic TIREM implementation in EADSIM in its treatment of elevations within a cell. While TIREM assesses the position of the antenna within a block, and interpolates the elevation based on position relative to the surrounding elevation blocks, the TIREM Tool uses a quick calculation where elevations are not interpolated based on position. This means that heights used for calculations will be the full cell height, rather than an interpolated value. This difference proved very significant in the cases where TIREM was sparsing a fence down to 1 or 2 cells, and then interpolating the values of those two cells. The TIREM Tool uses the actual elevation data of the sparsed cells and this ensures the fence is assessed at its full height.

3.1.2.1 100 meter x 20 meter (200 meter in 100 meter x 100 meter resolution) Fence

TIREM Tool values were equivalent to the TIREM run-time values when the fence profile was seen as full height cells in TIREM (1 meter x 1 meter resolution). In those cases where the TIREM run-time calculations interpolated the first and last cell heights of the fence profile, calculated values differed from TIREM Tool values due to reflection and diffraction variations caused by the differences in the fence shape.

3.1.2.2 100 meter x 100 meter Fence

Sparsing of the fence in the TIREM Tool did not result in the clipping of the fence seen in the 100 meter x 100 meter resolution case in the TIREM analysis. Calculated values for the Far 1 meter x 1 meter resolution cases were in agreement since cell heights in both models were full height. There were small differences between the TIREM and TIREM Tool cases in the Near 1 meter x 1 meter resolution cases and both Near and Far 10 meter x 10 meter resolution cases due to the change in shape of the fence profile when TIREM interpolated the first and last cell heights. Calculations were more consistent across map resolutions in the TIREM Tool cases than in the run-time TIREM analysis.

3.1.2.3 1000 meter x 100 meter Fence

As in the TIREM analysis, these runs were performed to permit use of a constant width fence for all three resolutions at a great enough height to negate ground reflection with a narrow beam antenna. Similar results to those seen in the 100 meter x 100 meter fence cases were seen here.

3.1.3 SEKE Analysis

SEKE also builds an array along the selected path. It uses a cell array sparsed to the DTED level 1 resolution of 3 arc seconds, or ~94 meters. If finer resolution terrain is used, SEKE will sparse terrain to the 94 meter cell size. SEKE determines the method of propagation calculation on the amount of fresnel clearance for the direct path. When the direct path provides line of sight, and terrain clearance is equal to or greater than the fresnel radius, multipath calculations are used. If clearance is less than the fresnel radius and greater than 1/2 fresnel radius, a weighted average of multipath and knife-edge diffraction losses is used. When clearance is less than 1/2 fresnel radius, a decision is made between a multiple knife-edge loss calculation and a spherical earth loss. In this case, the height of the highest terrain mask relative to the fresnel radius is used to determine loss methodology. If the highest mask value is greater than 1/2 the fresnel radius, multiple knife-edge diffraction is used. If greater than 1/4 the radius, and less than 1/2, a weighted average of knife-edge diffraction and spherical earth diffraction losses are used, and when the highest mask value is less than 1/4 the fresnel radius, spherical earth losses are used. Although this range of propagation calculations is useful when line of sight exists, it is rather limiting when no LOS exists because only knife-edge diffraction is available. Reflections from the ground are only considered when significant fresnel clearance (greater than 1/2 fresnel radius) exists.

3.1.3.1 100 meter x 20 meter (200 meter in 100 meter x 100 meter resolution) Fence

SEKE runs were first assessed in the 20 meter/200 meter wide case. When the 20 meter fence was used (1 meter x 1 meter resolution and 10 meter x 10 meter resolution cases), the calculated losses were equal to FSPL. It was determined that this was because the sparsing of the map to ~94 meter blocks eliminated the blocks the fence was located in. It was found that by repositioning the antenna locations, it was possible to find locations where sparsing did include the fence. In the 100 meter x 100 meter resolution cases, calculated path loss was equivalent to predicted knife edge diffraction losses using analytical calculations.

3.1.3.2 100 meter x 100 meter Fence

As in the TIREM runs, these runs were performed to permit use of a constant fence width for all three resolutions. In these cases, SEKE path loss calculations always were in agreement with analytical diffraction calculations.

3.1.3.3 1000 meter x 100 meter Fence

These runs were performed to permit comparison with TIREM's 1000 meter height fence cases. Since SEKE only considers diffraction when LOS does not exist, results were identical to the 100 meter height cases.

3.2 Interpretation of Results

The assessment of EADSIM's capability to model propagation in an urban environment required a detailed understanding of the propagation models and an understanding of how those models would represent the expected environments. Although both TIREM and SEKE have robust capabilities to model propagation in terrain, the areas where they are weak are those same areas most critical to urban propagation. The inability of either model to calculate diffraction or reflections in the horizontal is critical when transmitter and or receiver locations are at or near ground level, and intervening man-made structures are multiple stories in height. In scenarios where the environment is more residential, the horizontal paths are not as dominant, but the inability of SEKE to calculate multipath effects unless Line of Sight exists significantly limits the effects which are considered. TIREM is able to calculate multipath and diffraction, but the version of TIREM implemented in EADSIM only looks at the destructive interference (losses) due to reflections, it does not consider the constructive interference which also occurs. This results in a pessimistic prediction of path loss where the effects of reflection are significant. It should be noted that the current version of TIREM (version 3.15) no longer uses the Longley-Rice/Longley-Reasoner calculations, and that reflections in the transition zone now show the expected oscillations in reflective losses.

Cell Sparsing (# cells x cell size in meters)	Grid (meters x meters)	Ant Height (meters)	Fence	Range (meters)	FSPL	Diffraction calculations Excess Path Loss	Tirem Tool	Tirem Tool Excess Path Loss	TIREM	Tirem Excess Path Loss	SEKE	SEKE Excess Path Loss
	100 x 20 or 200 barricade											
	Far											
999x11	1 x 1	100 m	100m x 20m	11078	115.62	6.02	127.73	12.11	127.73	12.11	115.62	0.00
998x11	10 x 10	100 m	100m x 20m	""	115.62	6.02	127.73	12.11	122.35	6.73	115.62	0.00
100x111	100 x 100	100 m	100m x 200m	""	115.62	6.02	127.79	12.17	122.35	6.73	122.16	6.54
999x11	1 x 1	50 m	100m x 20m	""	115.62	21.90	129.34	13.72	129.34	13.72	115.62	0.00
998x11	10 x 10	50 m	100m x 20m	""	115.62	21.90	129.34	13.72	137.80	22.18	115.62	0.00
100x111	100 x 100	50 m	100m x 200m	""	115.62	21.90	132.65	17.03	137.80	22.18	137.68	22.06
	Near											
999x2.4	1 x 1	100 m	100m x 20m	2398	102.32	6.02	111.27	8.95	111.25	8.93	107.56	5.24
216x11	10 x 10	100 m	100m x 20m	""	102.32	6.02	111.27	8.95	111.27	8.95	107.56	5.24
22x114	100 x 100	100 m	100m x 200m	""	102.32	6.02	111.27	8.95	104.10	1.78	107.56	5.24
999x2.4	1 x 1	50 m	100m x 20m	""	102.32	28.54	126.74	24.42	126.74	24.42	130.68	28.36
216x11	10 x 10	50 m	100m x 20m	""	102.32	28.54	121.14	18.82	130.72	28.40	130.68	28.36
22x114	100 x 100	50 m	100m x 200m	""	102.32	28.54	131.99	29.67	130.73	28.41	130.70	28.38
	100 x 100 barricade											
	Far											
999x11	1 x 1	100 m	100m x 100m	11078	115.62	6.02	127.78	12.16	127.78	12.16	122.16	6.54
998x11	10 x 10	100 m	100m x 100m	11078	115.62	6.02	127.78	12.16	133.64	18.02	122.16	6.54
100x111	100 x 100	100 m	100m x 100m	11078	115.62	6.02	122.11	6.49	115.69	0.07	122.16	6.54
999x11	1 x 1	50 m	100m x 100m	11078	115.62	21.90	132.39	16.77	132.39	16.77	137.68	22.06
998x11	10 x 10	50 m	100m x 100m	11078	115.62	21.90	132.39	16.77	136.96	21.34	137.68	22.06
100x111	100 x 100	50 m	100m x 100m	11078	115.62	21.90	137.72	22.10	122.85	7.23	137.68	22.06
	Near											
999x2.4	1 x 1	100 m	100m x 100m	2398	102.32	6.02	110.87	8.55	110.75/110.96	8.54	107.56	5.24
216x11	10 x 10	100 m	100m x 100m	2398	102.32	6.02	110.87	8.55	110.86/110.81	8.52	107.56	5.24
22x114	100 x 100	100 m	100m x 100m	2398	102.32	6.02	110.88	8.56	102.34	0.02	107.56	5.24
999x2.4	1 x 1	50 m	100m x 100m	2398	102.32	28.50	131.68	29.36	131.69/131.68	29.37	130.70/130.68	28.37
216x11	10 x 10	50 m	100m x 100m	2398	102.32	28.50	131.24	28.92	132.98	30.66	130.70/130.68	28.37
22x114	100 x 100	50 m	100m x 100m	2398	102.32	28.50	130.73	28.41	114.53	12.21	130.70/130.68	28.37

(yellow) within one dB of diffraction calcs
(cyan) 100x100 clips the obstacle height to 2 ~500m cells
Getting FSPL
XXX / XXX Values differ East to West vs West to East

Figure (3). Path loss for 100 meter high fence

Cell Sparsing (# cells x cell size in meters)	Grid (meters x meters)	Ant Height (meters)	Fence	Range (meters)	FSPL	Diffraction calculations Excess Path Loss	Tirem Tool	Tirem Tool Excess Path Loss	TIREM	Tirem Excess Path Loss	SEKE	SEKE Excess Path Loss
	1000 x 100 barricade											
	Far											
999x11	1 x 1	1000 m	1000m x 100m	11078	115.62	6.02	120.61	4.99	120.57	4.95	122.16	6.54
998x11	10 x 10	1000 m	1000m x 100m	11078	115.62	6.02	120.60	4.98	120.78	5.16	122.16	6.54
100x111	100 x 100	1000 m	1000m x 100m	11078	115.62	6.02	120.60	4.98	115.68	0.06	122.16	6.54
999x11	1 x 1	500 m	1000m x 100m	11078	115.62	41.90	158.56	42.94	158.56	42.94	157.52	41.90
998x11	10 x 10	500 m	1000m x 100m	11078	115.62	41.90	158.57	42.95	154.96	39.34	157.52	41.90
100x111	100 x 100	500 m	1000m x 100m	11078	115.62	41.90	157.60	41.98	126.37/124.7	9.92	157.52	41.90
999x11	1 x 1	950 m	1000m x 100m	11078	115.62	21.90	132.39	16.77	132.39	16.77	137.69	22.07
998x11	10 x 10	950 m	1000m x 100m	11078	115.62	21.90	132.39	16.77	136.95	21.33	137.69	22.07
100x111	100 x 100	950 m	1000m x 100m	11078	115.62	21.90	137.72	22.10	115.68	0.06	137.69	22.07
	Near											
999x2.4	1 x 1	1000 m	1000m x 100m	2398	102.32	6.02	102.34	0.02	102.34	0.02	107.57/107.56	5.25
216x11	10 x 10	1000 m	1000m x 100m	2398	102.32	6.02	102.34	0.02	102.34	0.02	107.57/107.56	5.25
22x114	100 x 100	1000 m	1000m x 100m	2398	102.32	6.02	102.34	0.02	102.34	0.02	107.57/107.56	5.25
999x2.4	1 x 1	500 m	1000m x 100m	2398	102.32	48.50	171.69	69.37	171.69	69.37	150.87/150.84	48.54
216x11	10 x 10	500 m	1000m x 100m	2398	102.32	48.50	171.04	68.72	170.30	67.98	150.87/150.84	48.54
22x114	100 x 100	500 m	1000m x 100m	2398	102.32	48.50	151.13	48.81	115.55/113.27	12.09	150.87/150.84	48.54
999x2.4	1 x 1	950 m	1000m x 100m	2398	102.32	28.50	131.68	29.36	131.68	29.36	130.70	28.38
216x11	10 x 10	950 m	1000m x 100m	2398	102.32	28.50	131.24	28.92	132.99	30.67	130.70	28.38
22x114	100 x 100	950 m	1000m x 100m	2398	102.32	28.50	130.73	28.41	102.34	0.02	130.70	28.38

(yellow) within one dB of diffraction calcs
(cyan) 100x100 clips the obstacle height to 2 ~500m cells
Getting FSPL
XXX / XXX Values differ East to West vs West to East

Figure (4). Path loss for 1000 meter high fence

4.0 Implications of the Study and Suggestions for Further Work

Original plans were to conduct a second phase of the study which would construct more detailed maps containing elevation blocks representing multiple-story structures. This would have permitted evaluation of propagation capabilities in an "urban canyon" environment. Given the limitations of the current propagation models, it appears that further work modeling urban canyons is not appropriate. Correction of the sparsing techniques in both models is recommended. Both SEKE and TIREM are optimized for DTED level 1 data, sparsed at 3 arc seconds resolution. This led to significant errors when map data was sparsed at higher or lower resolution. TIREM's errors would be significantly reduced if the 999 point array limit was eliminated. This would permit using interval sizes equal to the map resolution for larger areas. This same problem could be fixed in SEKE by changing the interval spacing from a fixed 3 arc second resolution (~93 meters) to an interval which is set at the map resolution. Additionally, the cell elevation interpolation method which TIREM uses is inappropriate for the man-made structures encountered in urban environments. Turning this method of determining height off, or providing a selectable switch is desired. In the near term, it appears that further research into ray-tracing models is appropriate. Codes such as RF-ProTEC, which can be dynamically linked to mission level models such as EADSIM, can provide the higher fidelity propagation calculations required, and still permit the dynamic interactions required of the mission level model. Additional research should also be conducted on the best methods of representing man-made structures to determine whether codes other than ray-trace can be used.

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