FIDELITY AT HIGH SPEED: WIRELESS INSITE® REAL TIME MODULE™

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ABSTRACT

For predictions of vehicle to vehicle communications, convoy communications, and Improvised Electronic Device (IED) detection/defense operations, Remcom's Wireless InSite Real Time (RT) module provides a very rapid propagation prediction capability in urban environments. Previous models are either empirical and inaccurate but fast, or deterministic and high-fidelity but slow. The RT Module takes the best of both; it is deterministic and provides higher-fidelity results than empirical models and is much faster than full physics-based models, returning a point-to-point result in milliseconds. It is free of the spatial limits of empirical models. This paper will show how the Wireless InSite Real Time Module can be used to provide accurate communication and jamming predictions for mission planning tools in near real time. The RT module allows user-defined mobile objects to be placed into the urban scene and rapidly repositioned without expensive reloading of geometry. The C++ API permits developers to quickly integrate the RT capability into their Tactical Decision Aids (TDA's) and other graphical visualization tools.

INTRODUCTION

First, we will discuss three existing empirical urban models and their limitations. Then, we will discuss the high-fidelity full 3D model as implemented in Remcom's Wireless InSite product. Finally, we will discuss Wireless InSite's Real Time module in depth: how it works, how its results compare in accuracy and speed to the empirical and full 3D models, and how its features and advantages over these other models can be applied to urban military communications and jamming problems.

EMPIRICAL URBAN MODELS

Three commonly-used empirical urban models are Hata[1,2], COST-Hata[1,3], and Walfisch-Ikegami[1,3].

HATA

Okumura et al. [4] made extensive measurements of urban and suburban radio propagation losses in the city of Tokyo and based on that data published many empirical curves. However, the path losses for Japanese suburban areas do not match North American suburban areas very well. North American suburban areas are more like quasi-open areas in Japan. These empirical curves were then analyzed by Hata, who created a set of formulas known as the Hata model. This model is valid for frequencies of 150 - 1500 (MHz), link distances from 1 - 20 (km), base (transmitter) station heights from 30 - 200 (meters, AGL), mobile (receiver) antenna heights from 1 – 10 (meters, AGL). This model also uses a correction factor calculated from the type of city.

COST-HATA

For urban Personal Communications Systems (PCS) applications at 1.5-2 GHz, it was found by a European study committee (COST 231) that the Hata model consistently underestimates path loss, and an "extended Hata model" was developed to correct the situation by analyzing the Okumura curves in the upper frequency range. This model is valid for frequencies of 1500 - 2000 (MHz), link distances from 1 - 20 (km), base (transmitter) station heights from 30 - 200 (meters, AGL), mobile (receiver) antenna heights from 1 - 10 (meters, AGL). This model also uses the correction factor described above in the Hata Model.

WALFISCH-IKEGAMI

Walfisch-Ikegami is a deterministic empirical model useful in predictions where the dominant energy is contributed by over the rooftop diffractions. Buildings in the vertical plane between the transmitting and receiving antennas are used to seed the equations. This model is valid for frequencies of 800 - 2000 (MHz), link distances from 20 - 5000 meters, base (transmitter) station heights from 4 - 50 (meters,

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AGL), mobile (receiver) antenna heights from 1 - 3 (meters, AGL).

LIMITATIONS OF EMPIRICAL MODELS

Given the descriptions above, it is easy to see the limitations of these various models. Antenna heights (both transmitter and receiver), ranges (both minimum and maximum), and frequencies are all severely limited. In contrast, Wireless InSite's Real Time module has no limitation on transmitter and receiver height, allows ranges from 0 to 6 km, and is valid from 100 Mhz. Wireless InSite's Real Time module accounts for actual building geometry and moving objects in the scene, whereas empirical models employ heuristics based on statistical analysis of urban geometry.

The empirical methods mentioned above produce characteristic loss plots similar to Figure 1. To better illustrate these characteristics, the plot ignores the published limits of the Hata model. The transmitter is located in the lower, center part of the image.

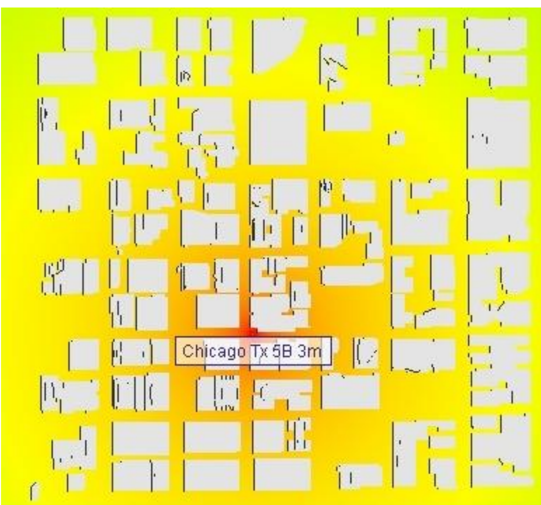

Figure 1. (U) Example of Hata statistical propagation loss calculated for Chicago, ignoring model limits.

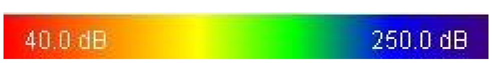

Figure 2. (U) Scale used for all path loss plots in this paper.

Only the macro-scale geometry is taken into account. Changing the geometry of individual buildings or moving objects around has no effect on the output. Individual cases of higher loss due to local geometry effects are ignored.

WIRELESS INSITE'S HIGH FIDELITY FULL 3D MODEL

Wireless InSite is an application that performs accurate analysis of the impact of the physical environment on the performance of wireless communication systems. The software provides a broad range of site-specific predictions of propagation and communication channel characteristics in complex urban, indoor, rural and mixed path environments. Most of these results are derived from accurate solutions to the underlying EM wave propagation problem determined by the Uniform Theory of Diffraction (UTD) and Finite Difference Time Domain FDTD methods.

Wireless InSite's Full 3D model is a deterministic model accounting for line-of-sight, reflection and diffraction in a complex urban scene. To do this, Wireless InSite employs a shooting-and-bouncing ray (SBR) tracing technique through the three dimensional building geometry. Rays are first traced from the source points with the rays reflecting specularly from the building walls and transmitting through the building walls with no change in direction. These SBR paths are also used to find diffraction points by searching for adjacent rays which have interacted differently with the building geometry and then locating a diffracting edge between them. Rays are then traced from all diffracting edges; this is repeated if higher order diffractions are requested. Rays that pass through receivers are noted, and used to construct ray paths from the transmitter to receiver.

InSite's 3D model produces very accurate results, but at the cost of extremely long run times. Run time is directly affected by the number of transmitters and receivers, and the number of faces in the building geometry. As the number of transmitters/receivers and building faces increases, run time increases.

WIRELESS INSITE REAL TIME

Remcom's Wireless InSite Real Time module (WI-RT or 'the RT module') is a deterministic path loss prediction solver made for ultra-fast computation times in urban environments. Wireless InSite Real Time is capable of modeling the effects of buildings and moving vehicles in the scene. The goal of Wireless InSite Real Time is to provide higher fidelity results than empirical models yet drastically reduce the calculation times below that of full physics based models such as Wireless InSite's Full 3D model. Loss results are returned in times ranging from well below a millisecond to perhaps a few milliseconds, depending upon the propagation model, the size and complexity of the urban environment, and the locations of the transmitter and receiver. The run time performance is achieved by rapid ray tracing techniques and efficient diffraction methods.

HOW WIRELESS INSITE'S REAL TIME MODULE WORKS

Wireless InSite Real Time contains the novel urban propagation models developed by Remcom. Unlike the conventional empirical models, Real Time's models use the exact profile of terrain and buildings and provide correspondingly more accurate results.

An additional limitation of conventional empirical models is that transmitters must be above roof level while receivers cannot be at roof level. This limitation does not occur in the Real Time module's models. Figure 3 compares results of Wireless InSite's full 3D model to the Real Time module. The run times for these simulations were seven hours for the full 3 dimensional ray tracing and forty seconds for the Real Time module.

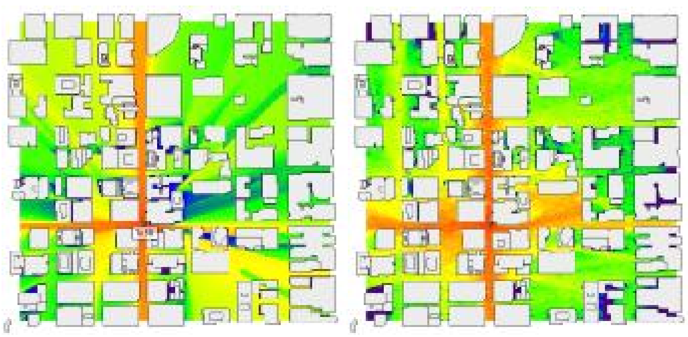

Figure 3. (U) Comparison of Wireless InSite Full 3D (left) and Real Time (right) in Chicago

The Wireless InSite Real Time models are so computationally effective because they use efficient and fast implementations of the physics and an optimized ray engine that allows the relevant geometric objects along the path to be identified and their geometric characteristics computed extremely quickly.

REMCOM'S OPTIMIZED RAY ENGINE (ORE)

The Wireless InSite Real Time models are based on Remcom's Optimized Ray Engine, ORE. Ray tracing is an advanced technique developed originally by the computer graphics community for adding realism to an image by including variations in shade, color intensity, and shadows that would be produced by having one or more light sources in a rendered scene. Ray tracing algorithms work by simulating the path of a single light ray as it would be absorbed or reflected by various objects in the scene. More generally, ray tracing utilizes the particle like behavior of high frequency electromagnetic energy, light in the classical case, to simulate the propagation of a wave through a virtual environment using linear approximations to the wave front. Typically when one speaks of ray tracing they are referring to a classical graphical ray tracer, however ray tracing applicability goes well beyond this and has been proven as a tool that is useful for investigating a wide variety of problems. Within the past two decades we have seen an explosion in interest in ray tracing techniques as more and more fields utilize the power of computer generated effects (games, motion pictures, art, and medicine are just a few). It is no surprise that ray tracing is also being heavily employed in the study and simulation of electromagnetic propagation as it pertains to communications and detection systems. This is the basis of Remcom's own Wireless InSite, which has applied the concepts of ray tracing to such diverse problems as RF propagation in full 3D urban environments, over irregular terrain, inside buildings and even in an anechoic chamber.

The most basic task of an electromagnetic ray tracer is to find the intersection of the simulated wave front with scene geometry as it propagates from the source. As data gathering techniques and computer technology advance, the requirements of simulation software move ever closer to reality with realistic models and environments. In today's most advanced ray tracers, it is not uncommon for there to be millions of geometric entities. If the ray tracing algorithm is implemented without consideration for the complexity and size of the task being handled by the ray tracer, it quickly becomes unusable due to high computation time and memory limitations of computer hardware.

A naïve search through complex geometry would make the system slow for simple scenes and unusable for more complex or realistic scenes. To alleviate this problem Remcom has employed a technique known as spatial partitioning. Spatial partitioning serves as an optimization of the intersection search problem by grouping large portions of geometry together into one bounding space. Therefore, a simple check of the bounding space can eliminate many significantly complex intersection tests of scene geometry. A property of such spatial partitioning is that the scene is hierarchically arranged so that each level of the hierarchy offers the same optimization. Common examples of such mechanisms are Binary Space Partition trees, kd-trees, and Octrees. Remcom's Optimized Ray Engine (ORE) utilizes an Octree data structure, because it offers a balance between configurable memory footprint and efficient tree traversal.

Although a spatial partitioning scheme used in association with a ray tracer can offer significant computational savings over a generic exhaustive search of the model space, it must be noted that these structures can grow quite large, causing unnecessary memory overhead, as well as degrading performance optimization due to structure traversal. ORE has addressed each of these potential problems. Memory usage is addressed in a preprocessing step that takes the geometry and breaks it down into elementary triangular facets. All geometry can be represented by triangular facets to a chosen degree of accuracy and it also allows for highly optimized intersection code. Once the geometry has been triangulated it is then condensed into a simple topological structure known as a triangle mesh. This mesh eliminates the need to store redundant information in memory which, when dealing with large scenes that are already in a triangular representation, can amount to a very significant portion of total memory usage; up to 60% reductions in geometry memory footprint have been seen. This condensing of information into the topological mesh also allows for fast spatial queries as well as a level of cache coherence, an important side effect as the gap between processor and memory speed continues to grow.

ORE also provides the ability to customize the construction of the Octree by providing build strategies. These strategies are interface level entry points that allow the developer of an application to customize construction to account for the tradeoffs between memory and computation time for a particular scenario. Traversal of the data structure as stated before is as important as the storage and Remcom's ORE takes full advantage of the coherency provided by the Octree data structure. Instead of a simple full recursive search of the Octree that will require visiting unnecessary nodes in the tree and performing a sort at the end of the intersection testing phase, we utilize an optimized parametric traversal algorithm.[5] By knowing the dividing planes at each level of the Octree, we can quickly and easily determine those nodes intersected by the ray and the order in which they were intersected. Using this parametric traversal algorithm in ORE has shown on average 10 times speed up over previous traversal strategies.

RESULTS – ACCURACY

Propagation loss results of the Real Time Module compare very favorably with results of Wireless InSite's high-fidelity Full 3D model. Figure 4 – Figure 7 show results for Rosslyn, Milan, and Ramadi at 908 MHz. The Full 3D results were obtained using 10 reflections and 2 diffractions.

Figure 4. (U) Full 3D Path Loss, Rosslyn, VA

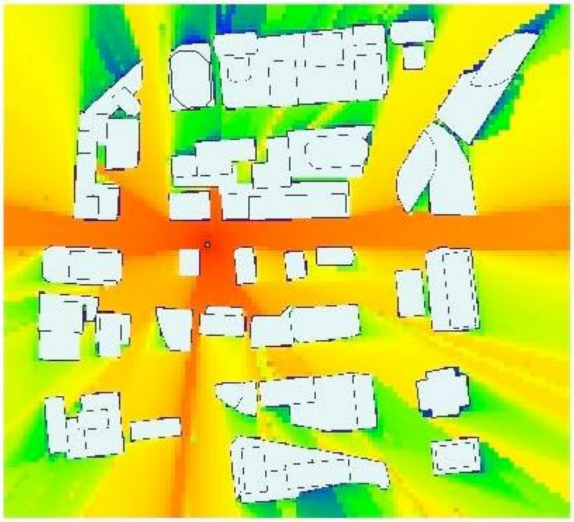

Figure 5. (U) Real Time Path Loss, Rosslyn, VA

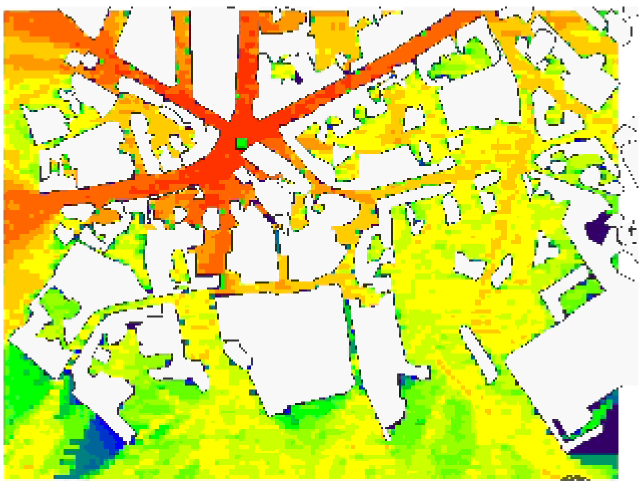

Figure 6. (U) Full 3D Path Loss, Milan, Italy

Figure 7. (U) Real Time Path Loss, Milan, Italy

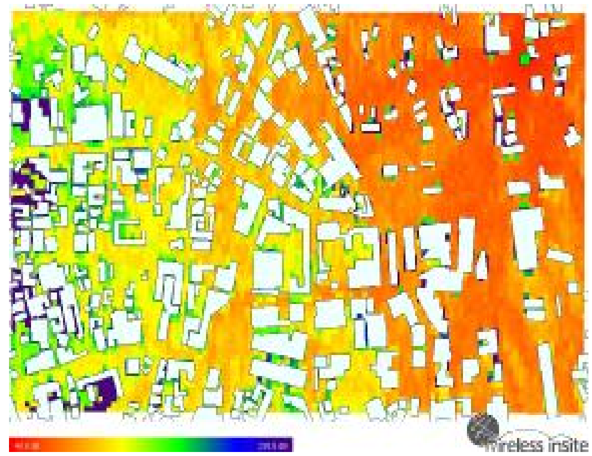

Figure 8. (U) Full 3D Path Loss, Ramadi, Iraq

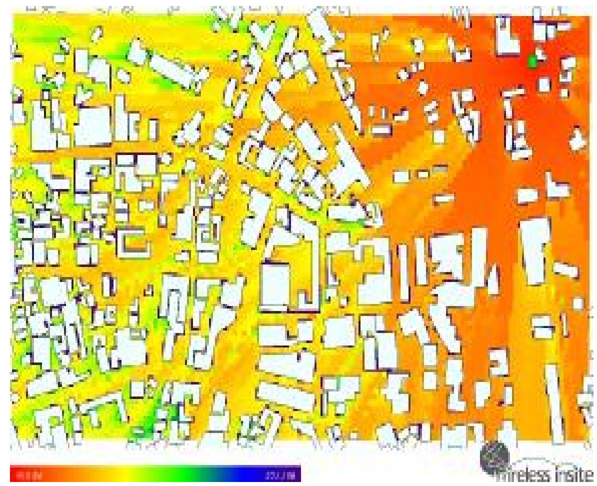

Figure 9. (U) Real Time Path Loss, Ramadi, Iraq

The small square represents the transmitter.

RESULTS – SPEED

Compared to the Wireless InSite Full 3D model running 10 reflections and 2 diffractions, the following speedups were recorded when using the Real Time module:

Urban Scene	Figure	Calculation Time with Real Time Module	Calculation Time with Full 3D SBR	Speed-Up
Rosslyn	3, 4	00:00:22	2:52:00	470 x
Milan	5, 6	00:01:20	3:44:00	166 x
Ramadi	7, 8	00:00:20	3:10:00	571 x

FEATURES OF WIRELESS INSITE REAL TIME

The Real Time module has an extensive C++ API that allows users to import geometry directly from DTED, shapefiles, Wireless InSite geometry files, STL and as individual facets. Geometry can be exported directly to Wireless InSite, STL or as individual facet elements.

MOVING OBJECTS

The Real Time module includes a moving object interface that permits a user to define vehicles and other objects that can be placed and moved around the scene without expensive reloading of geometry. Objects can be placed automatically upon terrain or placed given a specific position, bearing, pitch and roll. To simplify their use with moving objects, antennas are specified as a component of the platform and the specified pattern includes platform effects.

REAL TIME MODULE IN WIRELESS INSITE

The Real Time Module is available as an option in Wireless InSite. The full complement of real time models is available and the Wireless InSite geometry is exported automatically for use by the models.

ORE IN WIRELESS INSITE

ORE, the real time ray tracing engine, has been integrated into Wireless InSite to improve full 3D ray tracing times. The run-time comparisons in this paper are prior to this speed enhancement.

APPLICATIONS FOR MILITARY COMMS

Here we show two applications of the Real Time Module: Point-to-Point Convoy Communications and Convoy Coverage.

EXAMPLE 1: POINT-TO-POINT CONVOY COMMUNICATIONS

Here, only the ability of convoy elements to communicate is addressed. The example shows the relative signal loss from the lead element to the other vehicles. The total run time for this example was 47.7 ms.

Element	Propagation Loss
2	57 dB
3	102 dB
4	148 dB
5	143 dB
6	124 dB

EXAMPLE 2: CONVOY COVERAGE

In this example, we examine the coverage of the lead vehicle over the scene as the convoy proceeds. At a resolution of 1 meter, covering an area of 200 square meters, the total runtime per frame for this example was 65 seconds. Figure 10 and Figure 11 are representative frames from this example.

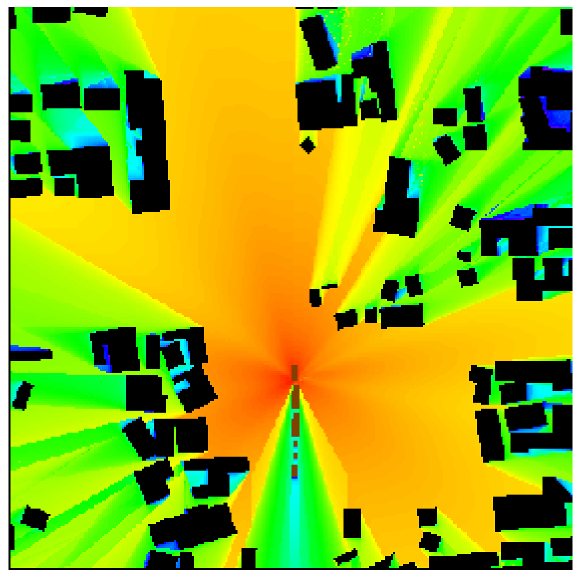

Figure 10. (U) Representative frame from example 2

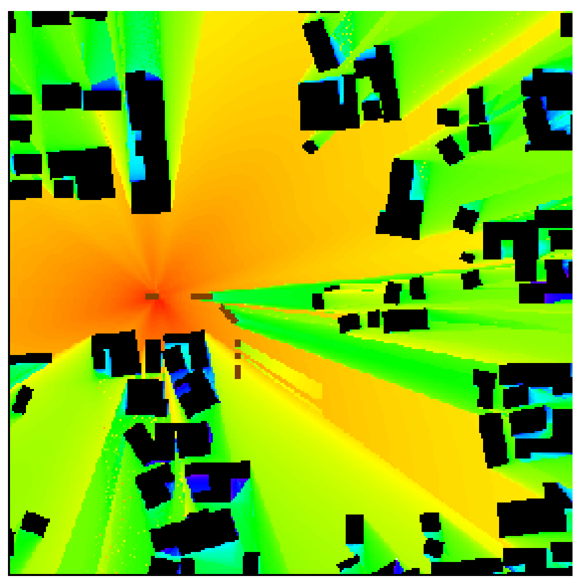

Figure 11. (U) Representative frame from example 2

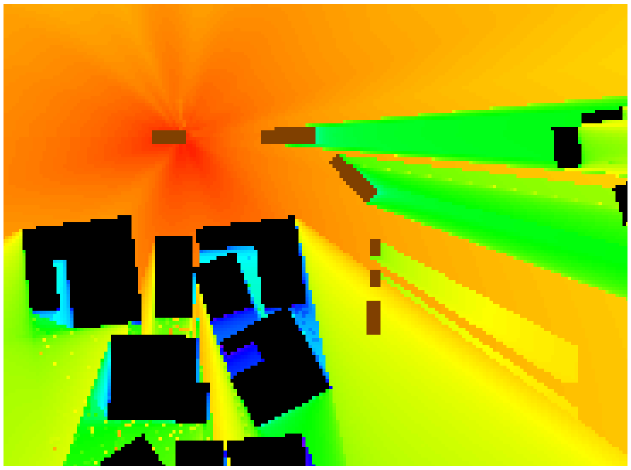

Figure 12. (U) Close-up of the convoy making the turn

CONCLUSIONS

The Wireless InSite Real Time module provides a fast, accurate and deterministic means of predicting RF propagation in urban environments. It has no limitations on transmitter and receiver locations. The results are comparable to results obtained from full 3D shooting and bouncing of rays and are returned in near real time.

These features make Wireless InSite Real Time well-suited for rapid-turnaround in urban mission planning and simulations of high fidelity communication and jamming.

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