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Communication Channel Propagation Model Based on a Combination of GTD and SBR

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The Remcom Communication Channel Propagation Model has been developed to a point where it is ready for commercialization. Remcom has used its own resources to continue development of the model past the end of the Phase II SBIR contract and to advertise it in print media and on the world wide web. Copies of the Remcom Communication Channel Propagation Model have been provided to several DoD and commercial customers Extensive testing and validation of the model has been performed by Remcom personnel and other users of the model.

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Abstract

Report developed under SBIR contract. The Remcom Communication Channel Propagation Model has been developed to a point where it is ready for commercialization. Remcom has used its own resources to continue development of the model past the end of the Phase II SBIR contract and to advertise it in print media and on the world wide web. Copies of the Remcom Communication Channel Propagation Model have been provided to several DoD and commercial customers Extensive testing and validation of the model has been performed by Remcom personnel and other users of the model.

1. Introduction

During this SBIR project a communication channel prediction model based on the shooting and bouncing ray method has been developed. The model consists of a graphical user interface and calculation engine. The model has been extensively tested for a variety of urban areas by both Remcom engineers and by other users, primarily at the Applied Research Laboratory of the Pennsylvania State University.

Since the end of the SBIR project, November 12, 2000, Remcom has continued to develop the model using internal funding. At this time the Remcom Communication Channel Propagation Model has been developed to a point where it is ready for commercialization. Copies of the Remcom Communication Channel Propagation Model have been provided to several DoD and commercial customers, including the Joint Spectrum Center, the United States Marine Corps Combat Development Command at Quantico, Virginia, The Pennsylvania State University Applied Research Laboratory, and a commercial joint venture between GE and Lubrizol.

The software is being commercialized under the name Wireless InSite^{TM}. An article about the model appeared in the March 2001 issue of *Microwave Journal.* Remcom has advertised the model in both print media and the world wide web. The capabilities of the software and several sets of example results are available at the Remcom web site at www.remcom.com.

Wireless InSite is a powerful electromagnetic modeling tool for predicting the effects of buildings and terrain on the propagation of electromagnetic waves. It predicts how the locations of the transmitters and receivers within an urban area affect the signal strength. Wireless InSite models the physical characteristics of the uneven terrain and urban building features, performs the electromagnetic calculations, and then evaluates the signal propagation characteristics.

The virtual building and terrain environment is constructed using InSite's editing tools, or can be imported from a number of popular formats such as DXF, DTED and USGS. Transmitter and receiver locations can be specified using InSite's powerful site-defining tools, or by importation from an external data file. Large areas of urban and terrain features may be specified. Separate calculations for portions of the overall area may be specified by defining Study Areas.

The calculations are made by shooting rays from the transmitters and propagating them through the defined environment. These rays interact with environmental features and make their way to receivers. Interactions can be a reflection off of the ground or the surface of a building face, diffraction off of an edge of a building, or transmission through a wall. Wireless InSite uses advanced high frequency electromagnetic methods to provide accurate results over a frequency range from approximately 30 MHz to 40 GHz. The effects of each interaction along a ray's path to the receiver are evaluated to determine the resulting signal level. At each receiver location the rays are combined and evaluated to determine signal characteristics such as path loss, delay, delay spread, direction of arrival, and impulse response. The user can specify incoherent or coherent combination of the rays, allowing calculation of fast fade characteristics if desired. The ray paths themselves can be displayed for each transmitter/receiver pair.

InSite presents results in a number of ways. It provides visual representation of some results, such as transmitter coverage areas and power distributions, placing these visually within the modeled environment. For other types of data, InSite provides an advanced plotting system. Overlays of data allow quick comparison to imported measurements, or even previous InSite calculations. All output files produced by InSite are in a readable ASCII format.

Technical information on the propagation models, graphical user interface (GUI) development, and validation and testing have been reported in quarterly progress reports. This information will not be repeated in this final report. Our first quarterly report [R99-200-001, February 1999] described conversion of the propagation model from Fortran 77 to Fortran 90, defining the file formats and organizing the GUI.

The second quarterly report [R99-200-002, May 1999] provided information on improvements made to the propagation model and initial GUI development. Propagation model improvements included changes in ray launching, faster triple diffraction ray tracing, and adding double and triple diffraction to the full 3D model. Validation vs other calculation results was also reported.

Quarterly progress report number three [R99-200-003, August 1999] described additional model improvements. These included adapting the full 3D model to the new file formats and further improvements in ray launching. Additional validation for the full 3D model when applied to irregular terrain was reported. The quasi-3D model was further developed and validated against the full 3D model and measurements. The GUI development was described including development of C++ code for data manipulation, menus, toolbars, and OpenGL drawing.

The fourth quarterly progress report [R99-200-004, November 1999] was an extensive review of the first year's progress. It reported improvements in the propagation models including further development of the irregular terrain model, reductions in memory and disk space requirements and reduced calculation time by saving ray paths. The three different models, full 3D, 2D, and quasi-3D, were described and contrasted. Validation results for a generic urban area and for irregular terrain were reported. GUI development including a toolkit for loading, saving, and displaying building and terrain data, another toolkit for managing the display, menu, and toolbars, and further development of OpenGL drawing routines were described.

The fifth quarterly progress report [R00-200-005, February 2000] reported new validation results for the model. These were for Fribourg, Switzerland at 1890 MHz. GUI development including addition of the menus to control the calculation parameters. The file formats were described in this report.

The sixth quarter progress report [R99-200-002, May 2000] included validation results for Bern, Switzerland. Improvements in the GUI including editing building geometries and defining wall materials were described. GUI capabilities were illustrated by using it for the Bern validation calculations and display of building features and calculation parameters and results including 3D display of ray paths.

Progress made in development of Wireless InSite since the last quarterly report are described here. This included additional validation and beta testing. A summary of Wireless InSite capabilities is included here as well. Discussion of sales and marketing activities as we endeavor to take Wireless InSite to full commercialization is also included in this report.

2. Recent Testing and Validation

An important part of the development of Wireless InSite is testing and validating the software. In previous SBIR progress reports validation results were reported for Bern, Switzerland, Fribourg, Switzerland, and Rosslyn, Virginia. The propagation model was also validated against full wave FDTD calculations. Since our last progress report other validation results have been obtained and are reported here.

2.1 Validation for Ottawa, Canada

The most recent validation exercise was for Ottawa, Canada. Measurements of propagation path loss at 910 MHz in Ottawa, Canada were reported in J. H. Whitteker, "Measurements of path loss at 910 Mhz for proposed microcell urban mobile systems," *IEEE Trans. Veh. Technol.*, vol. 37, no. 3, pp. 125-129, Aug. 1988. This is probably one of the better papers reporting path loss measurements in an urban environment with low transmitting and receiving antennas. The measurements were made within the 1000 m x 600 m area in Figure 1. The transmitters were at a height of 8.5 m and the mobile receiving antennas were at a height of 3.65 m. All antennas were vertically polarized. Figure 1 shows a map of the area in which the measurements were made. More information on the measurements can be found in the original paper.

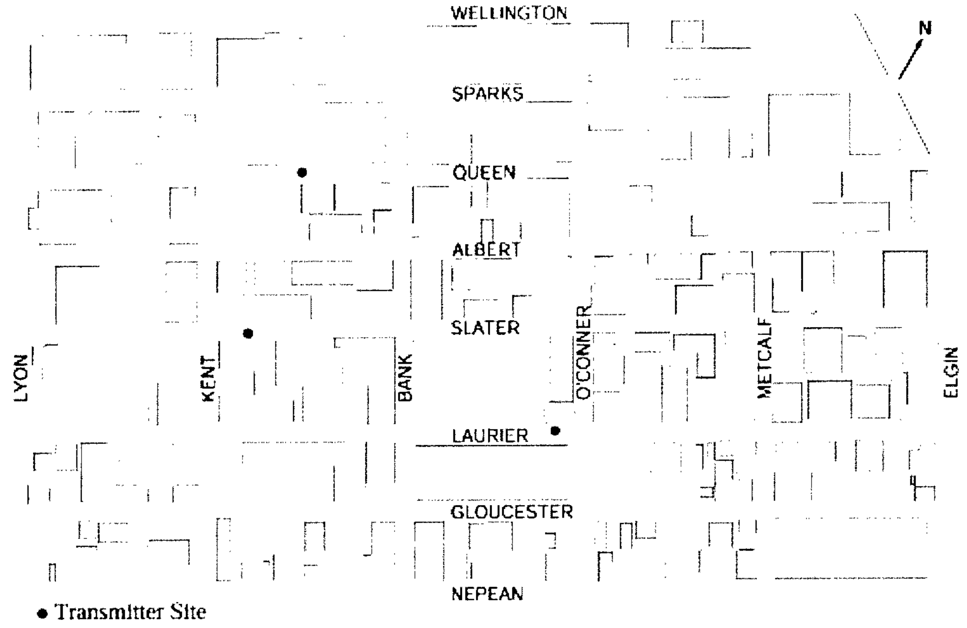


Figure 1 Map of Ottawa showing street names and transmitter locations

The building data for the calculations were obtained directly from the maps in the paper. These maps contained the footprints of the buildings. No specific information on building height was included, although the author's observation that the small buildings were typically three stories and the large buildings were many stories was used to create a more realistic looking building database. All calculations reported here were made using InSite's urban canyon model and no attempt was made to predict propagation over the buildings. No information about the terrain was included, and we have assumed a flat terrain in all our calculations.

Our method for manually extracting the building data from the published maps has led to a systematic enlargement of all buildings by a meter or so on each side. This has consequently led to slightly narrower street widths. This rather small error would not be a problem in many other urban areas, but due to the fairly narrow streets in this section of Ottawa, this may have been an additional source of error in the computations. This would not be an error source if we had computer files of the building features available for import into Wireless InSite.

No information on building materials was reported. Following the suggestion in S. Y. Tan and H. S. Tan, "Propagation model for microcellular communications applied to path loss measurements in Ottawa city streets," *IEEE Trans. Veh. Technol.*, vol. 44, no. 2, pp. 313-317, Aug. 1995, we set the relative permittivity of all the building walls to 7, and the conductivity to 0.2 S/m. A relative permittivity of 15 and a conductivity of 0.05 S/m were used for the ground.

Figures 2, 3 and 4 show the measured and calculated path loss along Laurier St., Albert St., and Queen St., respectively, with the transmitter at the Slater St. site. The route starts on Lyon and ends on Elgin. The free space path loss was included to demonstrate the large attenuation due to the buildings. The agreement is good considering the quality of the building data and the lack of information on building materials. It is worthwhile to comment on two of the more notable differences with the measurements.

First, the error at the beginning of Laurier St. is surprising because there is nearly a line-of-sight path from the transmitter. The predicted path loss is nearly at the free space value, while the measured path loss is 10 dB lower. One explanation is that there are some trees or other obstruction in the open area between Kent and Laurier.

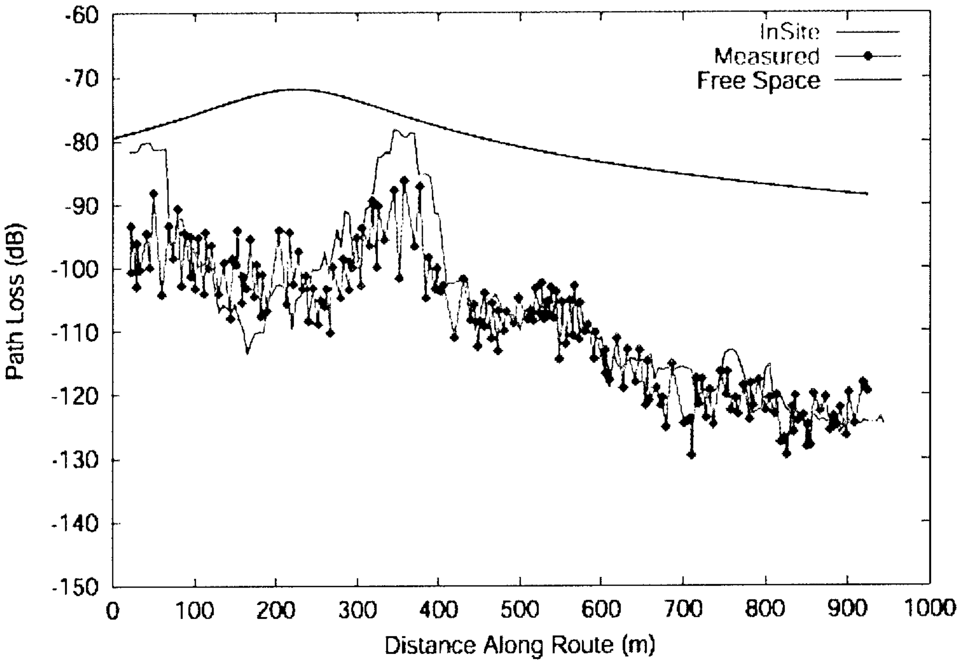


Figure 2 Path loss along Laurier St. with the transmitting antenna on Slater St.

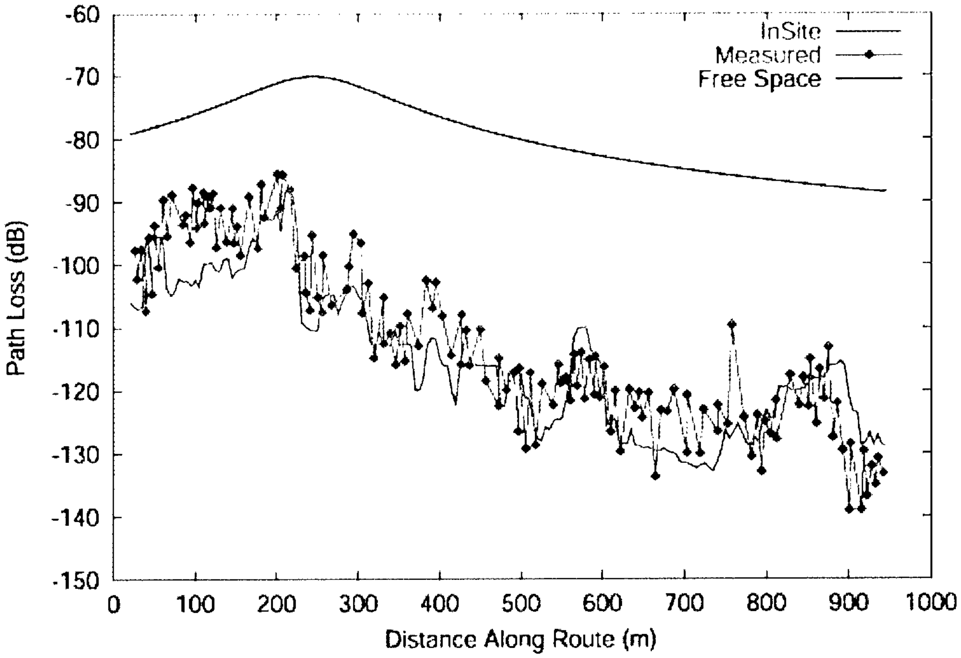


Figure 3 Path loss along Albert St. with the transmitting antenna on Slater St.

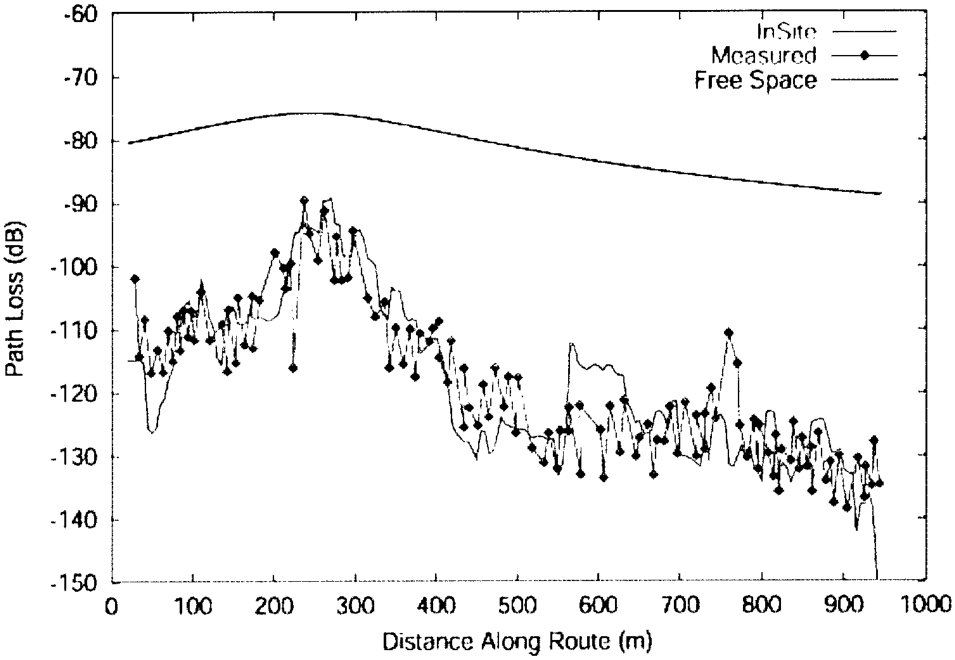


Figure 4 Path loss along Queen St. with the transmitting antenna on Slater St.

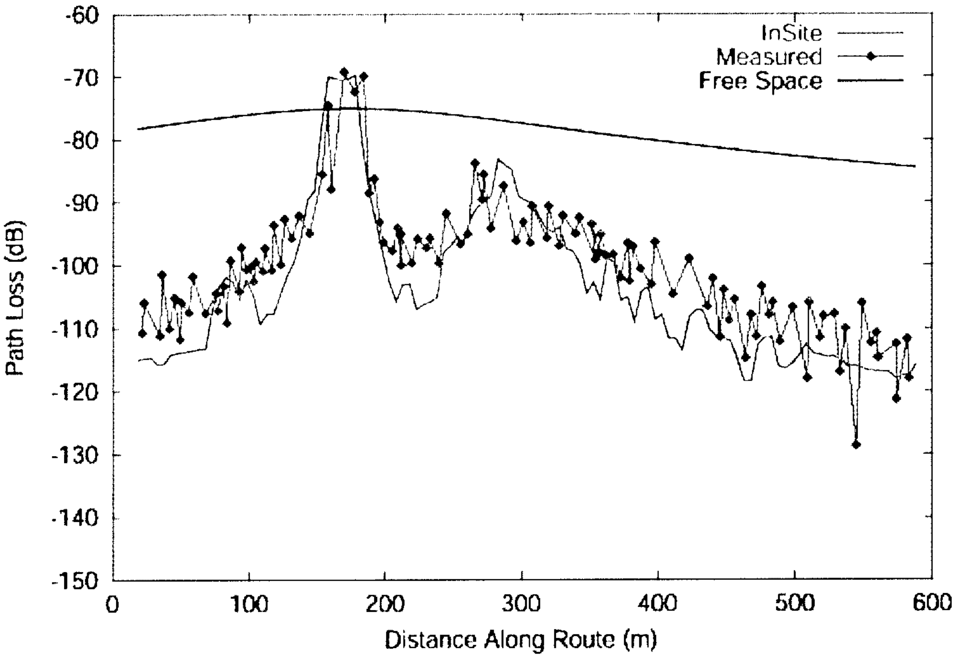


Figure 5 Path loss along Bank St. with the transmitting antenna on Laurier St.

Second, the differences between the measurements and the calculations at the beginning and end of Kent St. and Queen St. may be due to the absence on the map of the buildings along the right and left-hand edges of the area. If present, these building may have scattered a significant amount of energy from Slater St. up Lyon and Elgin Streets. Figure 5 shows the path loss along Bank St. with the transmitter at the Laurier St. site. The route starts on Nepean and ends on Wellington.

2.2 Validation for Munich, Germany

Data files describing the buildings of Munich were obtained [http://www-ihe.etec.uni-karlsruhe.de/forschung/cost231/datseit2_inh.en.html] and converted into Remcom's facet based file format. A three dimensional layout of the city was generated using Wireless InSite and is shown in Figure 6.

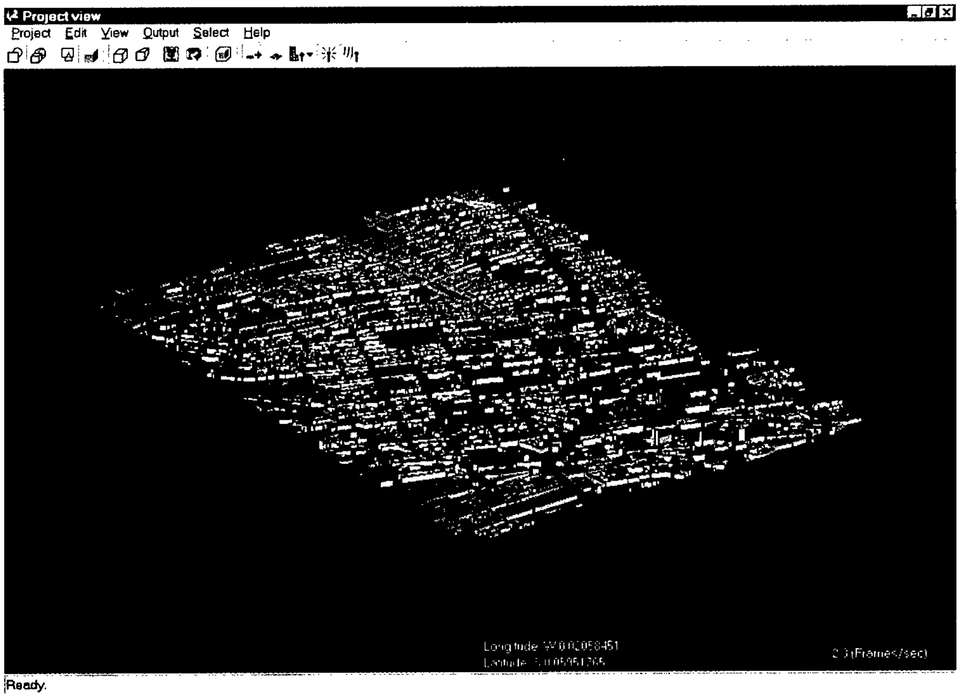


Figure 6 View of Munich city area used for validation of Wireless InSite.

Two receiver routes were set up throughout the city and predictions of received power were made by Wireless InSite's 2-D urban model.

A 1 km^2 area and a subset of the receiver sites were chosen to perform trial calculations. The x and y coordinates, in meters, of the chosen bounding box relative to an origin placed at one corner of the city are (800, 800), (1900, 800), (1900, 1881), (800, 1881). This region of the city and the transmitter and receiver sets chosen for model calculations are shown in Figure 7. It includes 265 buildings all of which are assumed to have flat roofs. All calculations involved only a single vertically polarized isotropic transmitter located at (1281.36, 1381.27, 13.0) which is approximately the center of the region chosen. All receivers for the two routes were located at a distance of 1.5 meters above the ground. Ground was assumed to be a flat reflecting plate. The 2-D urban canyon propagation model was used for all calculations performed. Since no material type was available for the buildings, a material type had to be chosen for model calculations. The values $\varepsilon_r = 6$, $\sigma = 0.05$ S/m were chosen as representative of the permittivity and conductivity of the material comprising buildings in Munich.

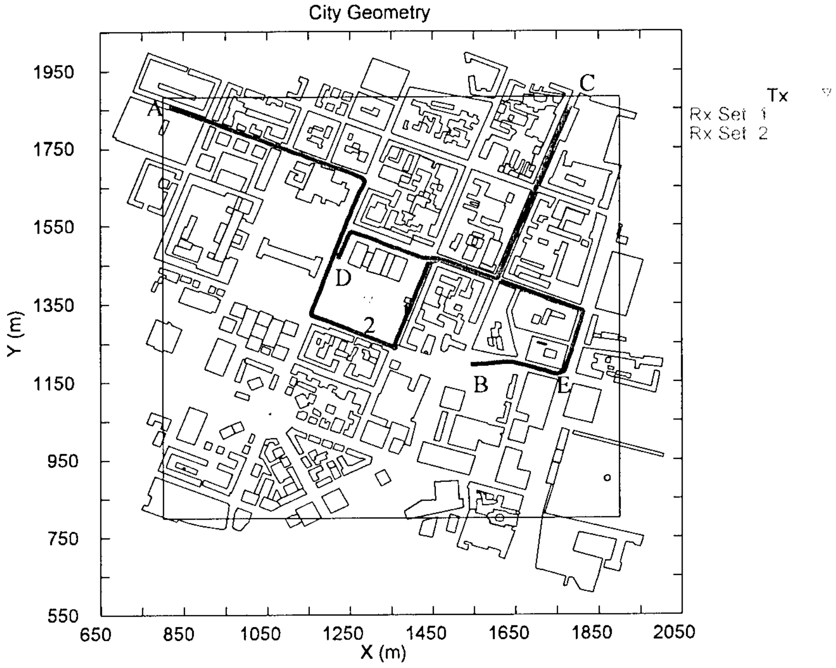


Figure 7 A 1 km^2 section of Munich and associated routes utilized in the validation calculations.

The segment of route 1 inside the boxed study area chosen comprises 167 receivers placed over a distance of 2141 meters. Two thousand equally spaced rays were traced from the transmitter and the path loss over the route was calculated. The rays were allowed up to 15 reflections and 2 diffractions with the reflections distributed equally into groups of 5 before, between, and after the diffractions. The path loss as a function of distance over the route is plotted in Figure 8. Agreement between the calculated and measured values is generally good with the exception of a short segment of the path located around 1845 meters. This corresponds to the receivers located near E in Figure 7. Changing the number of reflections and diffractions in the model calculations did not appreciably affect this discrepancy. Possibly, radiation is diffracting over rooftops or the material of one or more buildings is not correctly described by the constitutive parameters chosen in the calculations.

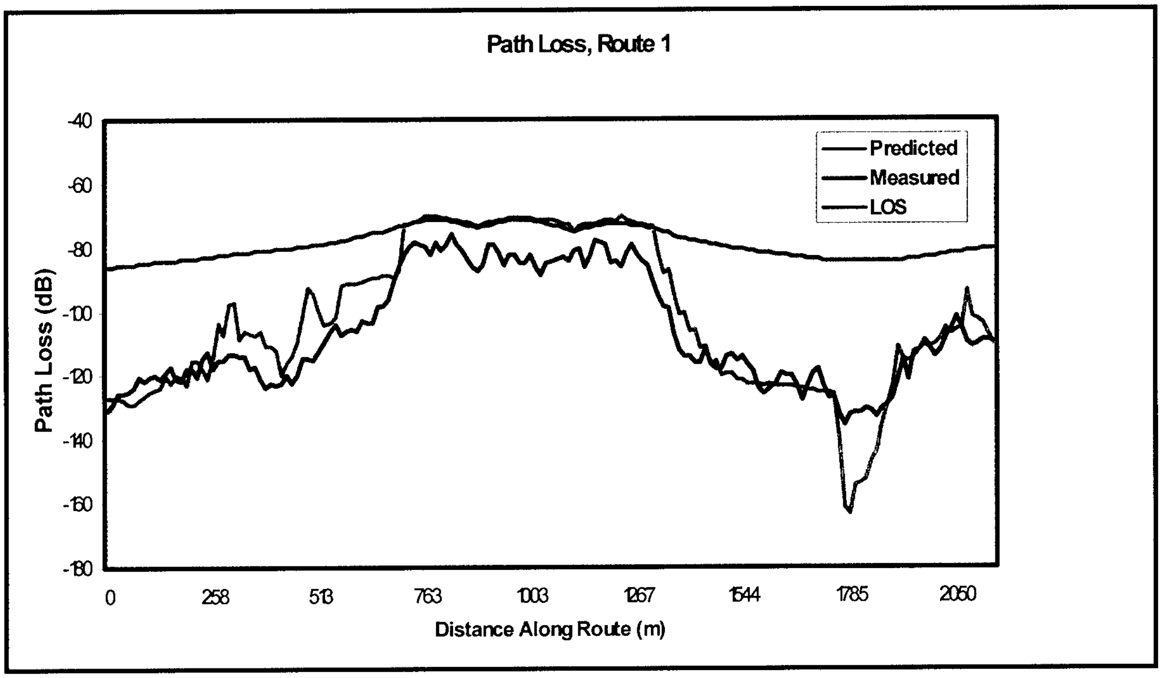


Figure 8 Path Loss as a function of distance along Route 1.

Run times and disk space requirements for several scenarios involving reflections and diffractions inside the 265 building area along Route 1 are presented in Table 1. All calculations were performed using an HP J5000 UNIX work station. Two thousand equally spaced rays were broadcast from the transmitter inside the city area designated in Figure 7. It is clear that as the number of reflections and diffractions are increased, the run times and disk space requirements increase substantially. The last row indicates the actual set of values utilized in the model calculations.

Table 1. Run Time and Disk Space Requirements for Route 1

Case	Reflections	Diffractions	Transmissions	Run Time (mm:ss)	Temporary Disk Space (MB)	Path Files (MB)
1	6	0	0	4:72	139	6
2	6	1	0	8:33	215	48
3	6	2	0	23:33	271	77
4	15	2	0	58:44	480	169

Route 2 comprised 77 receivers placed as shown in Figure 7. Calculated and measured values of path loss as a function of distance along the route is presented in Figure 9. The calculated results agreed very well with measured values for receivers over the first 530 meters of the route. The agreement was less precise for receivers along the last several hundred meters.

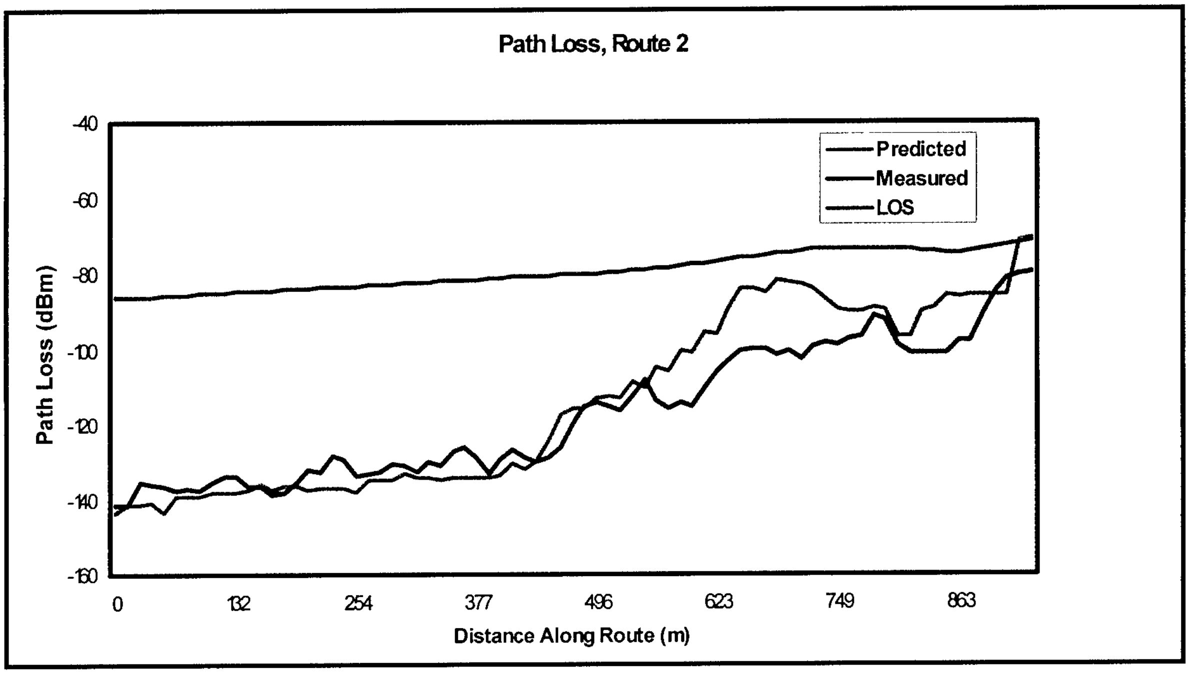


Figure 9 Path loss as a function of distance along Route 2.

No building material data was available for the calculations performed and a single reasonable choice of building material was made for all buildings. We decided to utilize the Wireless InSite feature allowing individual buildings and even individual faces to have their own material type. Changing the material type to that of glass (ε_r=2.4, σ=0) on just two building faces which are located at positions 1 and 2 in Figure 7 produced the results given in Figure 10. These results show remarkably improved agreement between model calculations and measured values. This clearly indicates the need for correct material specifications of buildings in urban propagation models in addition to the need for models which can manipulate material properties at the sub-building level. These features are provided and easy to use in Remcom's Wireless InSite urban propagation model.

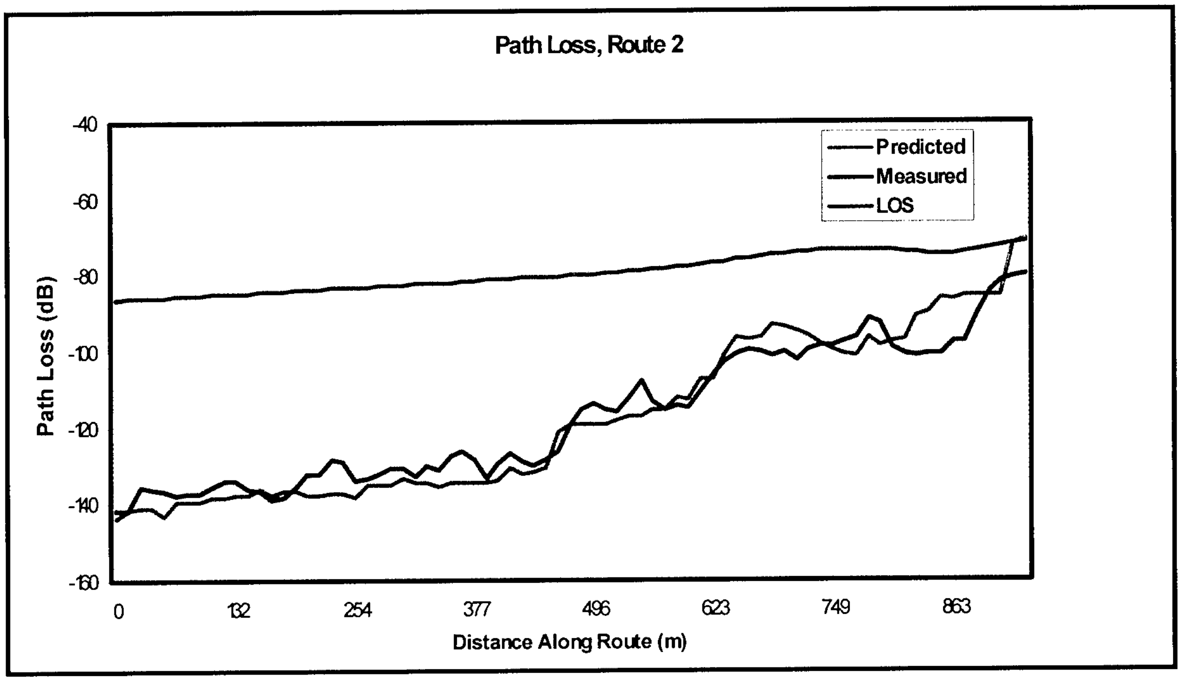


Figure 10 Path loss as a function of distance along Route 2 when the permittivities of two faces have been changed from the average chosen values.

The run times and disk space required to run calculations for Route 2 are shown in Table 2. Again, the amount of disk space and the run times increased with the number of reflections and diffractions chosen.

Table 2. Run Time and Disk Space Requirements for Route 2

Case	Reflections	Diffractions	Transmissions	Run Time (mm:ss)	Temporary Disk Space (MB)	Path Files (MB)
1	6	0	0	4:42	129	8
2	6	1	0	6:53	145	9
3	6	2	0	11:34	150	13
4	10	2	0	33:36	167	20

2.3 Testing by Pennsylvania State University Applied Research Laboratory

The United States Marine Corps Combat Development Command at Quantico, Virginia is in the process of specifying frequencies for urban communication. As a part of this process they desired to investigate the effects of frequency on outdoor urban propagation. They turned to the Applied Research Laboratory at the Pennsylvania State University (PSU) for support in this investigation. The university in turn subcontracted to Remcom Inc. for an urban propagation modeling tool, in particular Wireless InSite. Over the six month duration of the study Remcom

Inc and PSU personnel worked together. The PSU researchers used Wireless InSite to make the urban path loss predictions for the USMC. Remcom engineers supported this effort, in part by improving the performance of Wireless InSite in response to suggestions made by PSU. The result of this effort was both the information needed by the USMC and an improved and tested version of Wireless InSite.

Some of the urban geometries chosen for study were "generic" cities composed of regular buildings arranged on a regular grid. This provided general results rather than results for a specific urban area. It also tested Wireless InSite since many of the transmitter/receiver pairs required a large number of diffracted/reflected rays for accurate results. An example of this is shown in Figure 11.

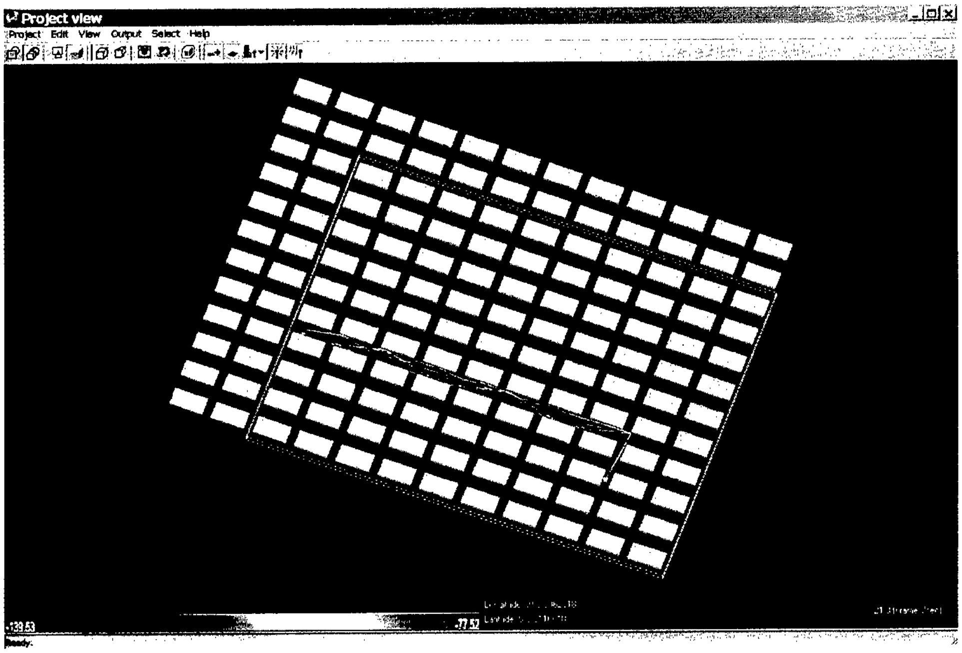


Figure 11 Generic urban area showing the large number of rays needed to describe the electromagnetic energy propagation mechanisms for the USMC study performed by PSU/ARL.

3. Wireless InSite Capabilities

This section describes the current state of the Wireless InSite propagation prediction tool. We anticipate further improvements in this interface with this improvement funded by Remcom internal funds.

3.1 Data Import

Wireless InSite can import urban building features data from various sources provided that the files are in the widely used AutoCAD dxf format. Remcom Inc has worked with Vexcel, Spot

Image, and Harris to determine that they can provide urban features data in file formats compatible with Wireless InSite. Remcom has negotiated a contract to be a value-added reseller of Vexcel data, and is in negotiations with Spot Image and Harris.

An example of importing a dxf file into Wireless InSite is shown in Figure 12. This is a section of Denver provided by Vexcel for testing purposes. Wireless InSite can then be used to specify the building wall materials, and also has the capability to pre-process the dxf files before the propagation calculations are made. For example, buildings that do not touch the ground can be extruded automatically, wall normals can be automatically set to point outward (as required by WI for ray shooting), and small building features that are not important for accuracy can be removed automatically. These changes are controlled by parameters that can be set by the user.

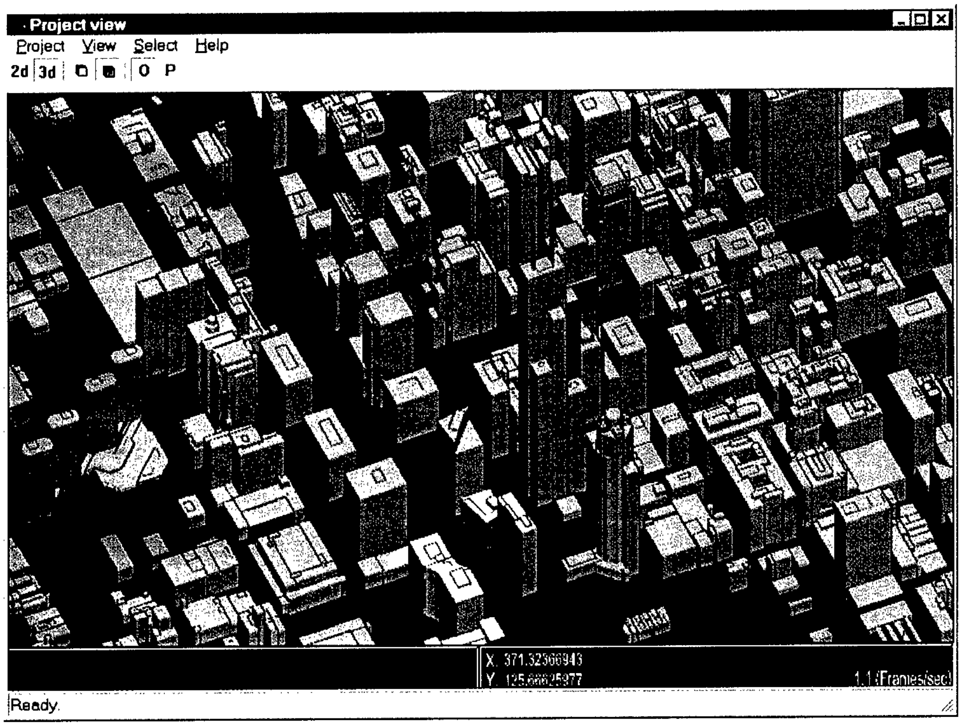
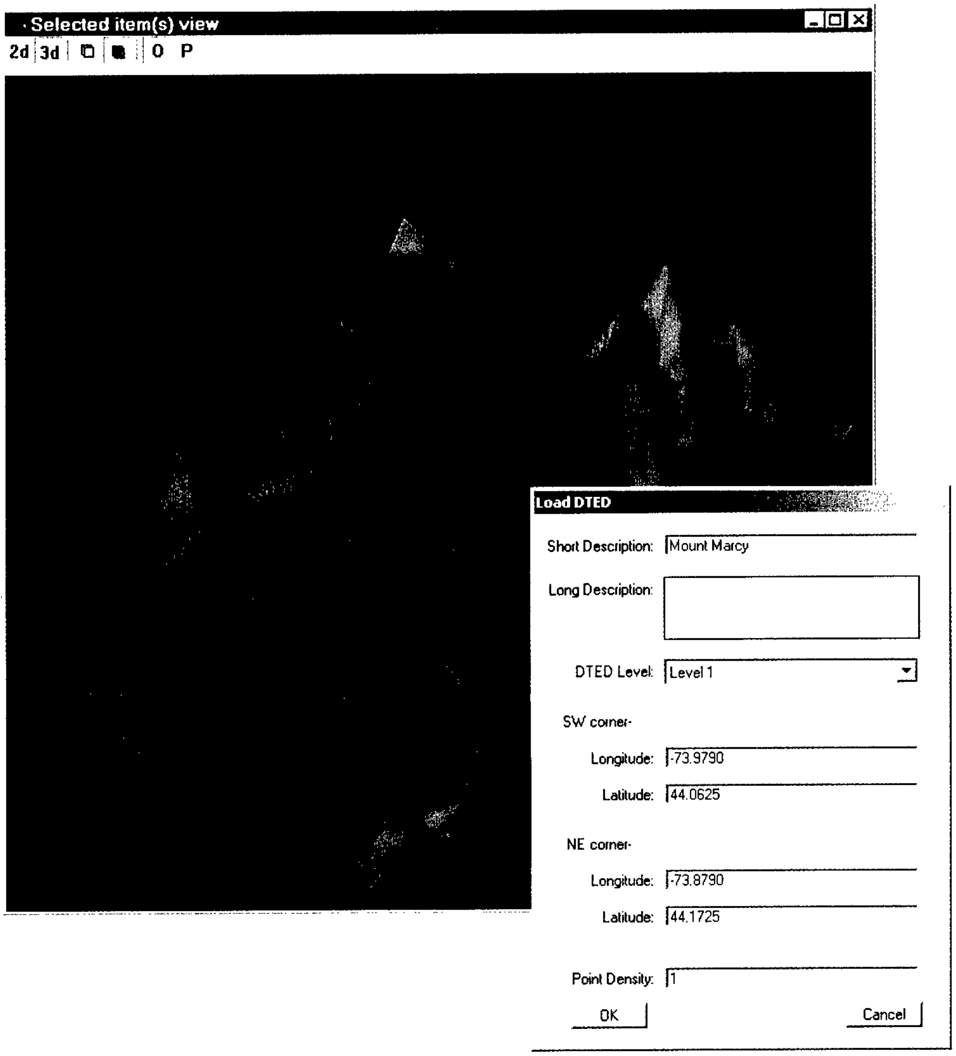


Figure 12 Wireless InSite view of a complex urban area imported as a dxf urban features file.

Wireless InSite can also import DTED and USGS terrain features. An example is shown in Figure 13. Wireless InSite automatically searches through the data files and imports the specified area.

However, additional improvements need to be added to Wireless InSite before large areas of terrain can be modeled efficiently. The reason is that large areas of terrain involve very large numbers of facets for accurate description, and the drawing time of Wireless InSite is too slow. Remcom is currently working on reducing this drawing time. This is not a problem for terrain under urban neighborhoods since in this latter situation the area covered is much smaller and the number of terrain facets is fewer, allowing for quick response of the software.



Short Description: Mount Marcy

Long Description:

DTED Level: Level 1

SW corner-

Longitude: -73.9790

Latitude: 44.0625

NE corner-

Longitude: -73.8790

Latitude: 44.1725

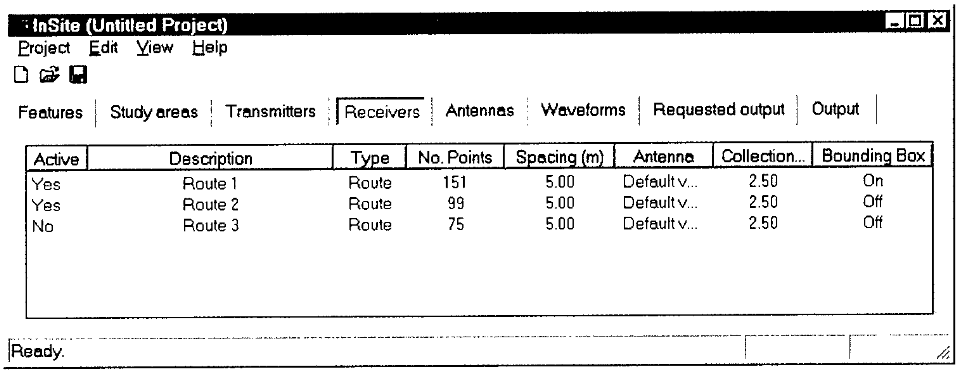
Point Density: 1

Figure 13 Example of DTED terrain data after importation into Wireless InSite. The menu used to specify the input area is also shown.

3.2 Controlling Calculation Parameters

Wireless InSite's features are specifically aimed at applying physics-based propagation models to site-specific predictions in rural, urban and indoor environments, and to viewing and analyzing the predictions. With only a few steps it is possible to import building and terrain data, define the antennas, specify the transmitter and receiver locations, select the desired output, and run the calculations.

Wireless InSite provides full menu control of calculation parameters. The parameters are divided into different classes and organized along with the output file tree in a separate window as shown in Figure 14. This window allows display and modification of all items, and addition of new items, by clicking the mouse in the appropriate section. Clicking on the tabs brings the selected information, such as Receivers, Transmitters, Urban/Terrain Features, etc., to the front.



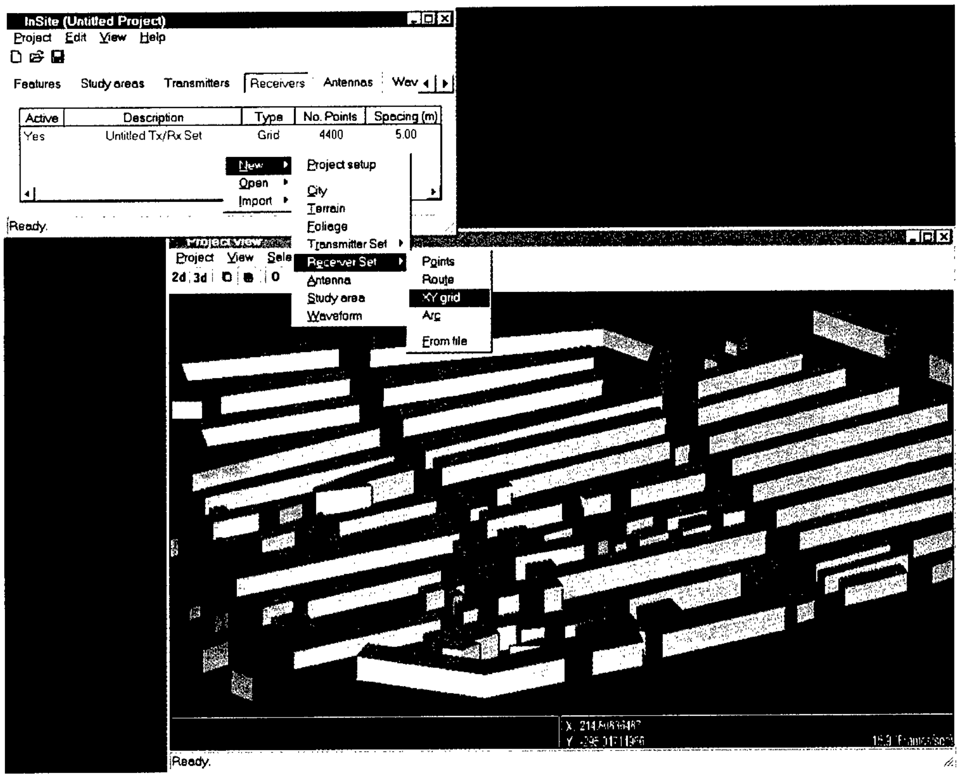
Active	Description	Type	No. Points	Spacing (m)	Antenna	Collection...	Bounding Box
Yes	Route 1	Route	151	5.00	Default v...	2.50	On
Yes	Route 2	Route	99	5.00	Default v...	2.50	Off
No	Route 3	Route	75	5.00	Default v...	2.50	Off

Figure 14 Main Window of Wireless InSite showing organization of calculation parameters and output

For example, successive mouse clicks result in the menus shown in Figure 15 for addition of a grid of receiver locations. Placing receiver sites along routes is a computationally efficient way of analyzing the coverage in urban areas. InSite routes can consist of one or more line segments and can be as simple as a straight line or they can be piecewise linear approximations to a curving route. Any number of routes can be defined. The user sets the spacing of points along the route. Once the routes are created, the Rx/Tx editing tools can be used to modify the location and elevation of the route. The ability to place receiver points on routes also facilitates comparisons to measurements made along a street.

InSite offers several ways to specify the radiation pattern and polarization of an antenna. Several simple, but often useful, pattern types are pre-programmed – isotropic, omnidirectional, ideal dipole, straight wire dipole, and directional pattern constructed from the half-power and first null beam widths. The direction of the main beam and the rotation about the main beam can also be specified. In addition, the gain, noise figure, VSWR, and a cable loss factor can be specified.

Similar menu sets are available to control all aspects of a calculation.



Active	Description	Type	No. Points	Spacing (m)
Yes	Untitled Tx/Rx Set	Grid	4400	5.00

Figure 15 Wireless InSite menus for addition of a receiver grid

3.3 Propagation Models

The various propagation models that have been developed under this effort have been described in detail in previously submitted quarterly reports. These ray-based propagation models aimed at different environments have been incorporated into Wireless InSite. All the propagation models are based a hybrid SBR/GTD approach developed by Remcom. The Shooting and Bouncing Ray (SBR) is employed at the start of the calculation to determine the geometrical ray paths through the building and terrain geometry. The SBR method has been implemented with robust ray tracing techniques that impose few limitations on the complexity of the building or terrain features. Once the propagation paths have been found, the amplitudes are evaluated using the Geometrical Theory of Diffraction (GTD). Available SBR models are Two-Dimensional, fully Three-Dimensional including vector fields, and a fast Quasi-Three-dimensional model. These are selected from menus and the pertinent parameters may be left to the default values or adjusted by the user.

3.4 Available Results

InSite produces a large number of point-to-multipoint predictions, including received power, path loss, time of arrival, direction of arrival, impulse response, SNR, and delay spread. These results can be view as color-coded displays overlaid on the feature data, or using InSite's line plotting tools. All predictions are made with full frequency, polarization and antenna pattern data taken into account. Data for multiple transmitters is also available, including C/I, C/I+N, and strongest base station to receiver. Figure 16 shows the color-coded signal strength results produced by Wireless InSite for a grid of receiver locations. This display quickly shows the areas with a given level of signal.

Figure 16 Coverage area display illustrating the Point-to-Multipoint capability of Wireless InSite.

InSite's physics-based propagation models are able to predict the paths by which energy travels from the transmitting to the receiving antenna. The graphical interface makes it easy to view and interpret these results. These include direction-of-arrival and impulse response for each transmitter-receiver link. Figure 17 shows the impulse response display produced by Wireless InSite. This information can be calculated and plotted for each transmitter/receiver pair in the project.

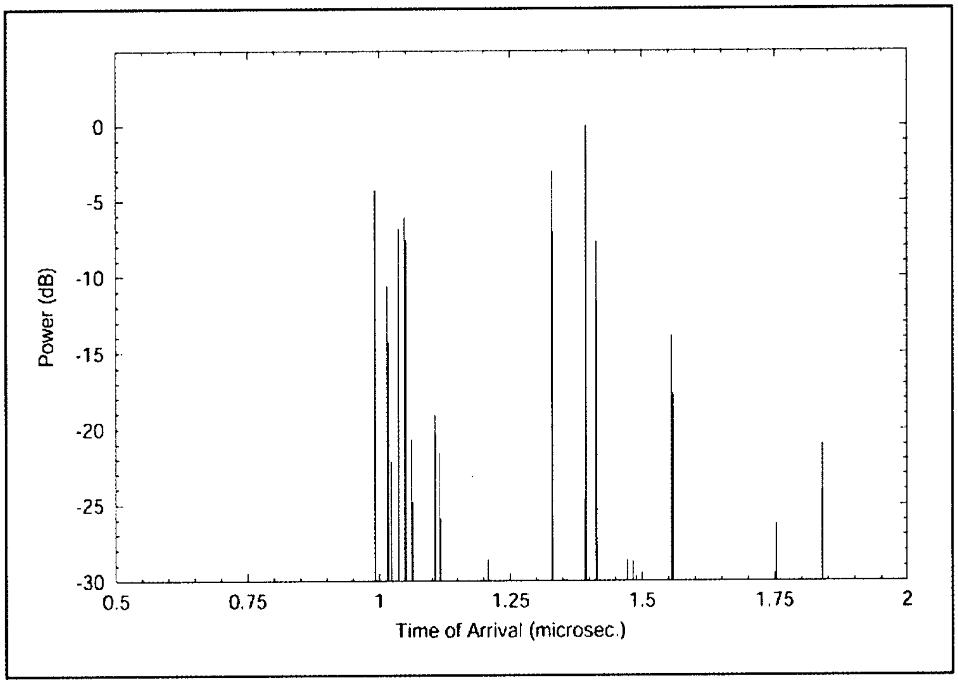


Figure 17 Wireless InSite display of impulse response for a specific transmitter-receiver pair.

Figure 18 shows the rays propagating from one transmitter to a specific receiver location. Not only are the ray paths displayed, but the rays are color-coded by intensity.

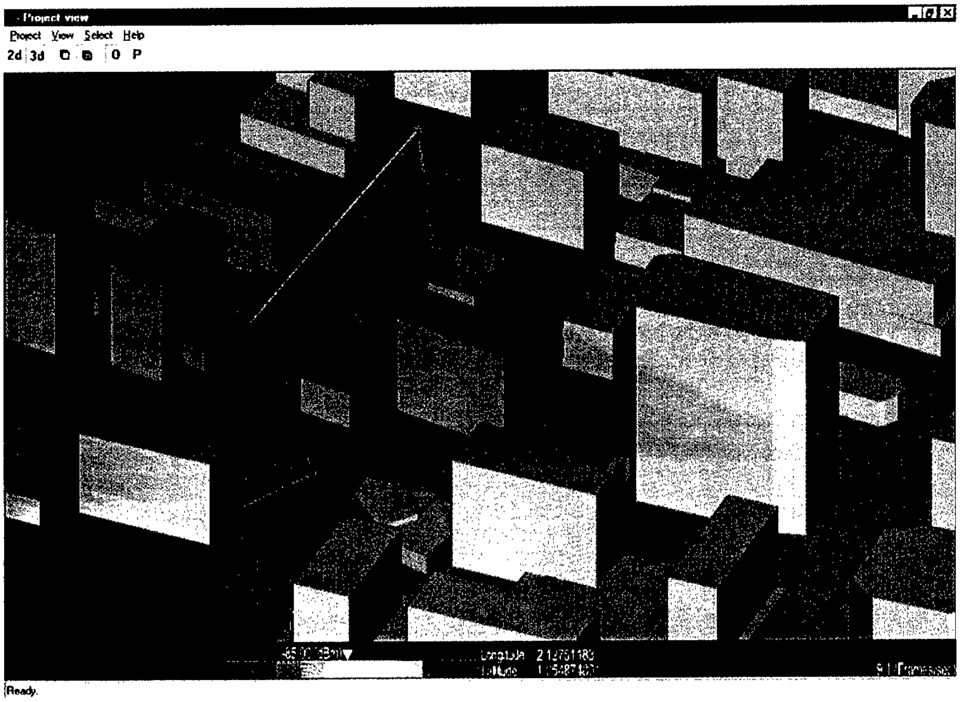


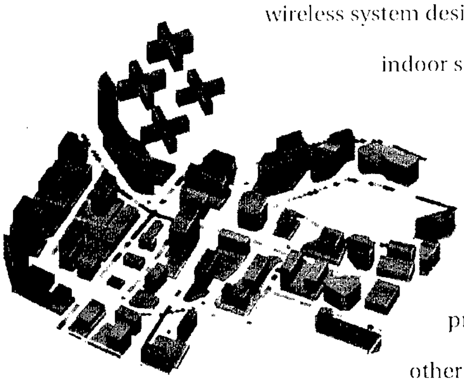
Figure 18 Wireless InSite 3D perspective view of the rays propagating from the transmitter location (green dot) to the receiver location (red dot).

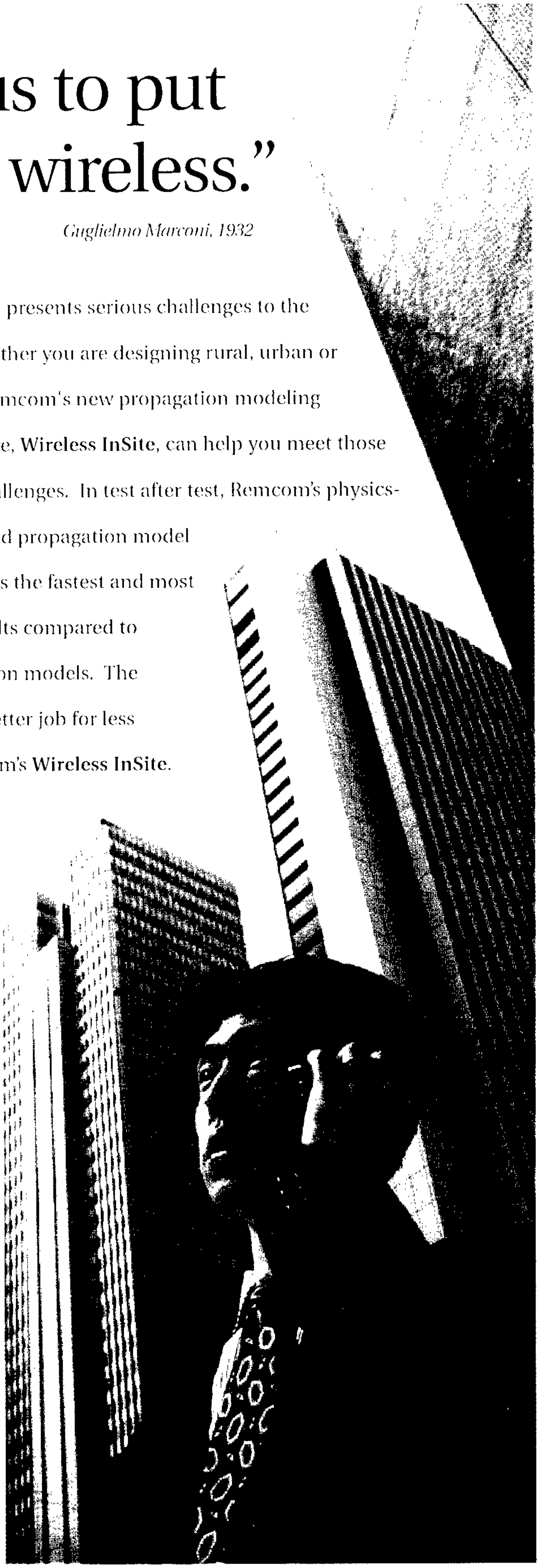
4. Advertising and Marketing

In the SBIR Phase II Proposal Remcom committed to spending corporate funds to advertise and market the proposed wireless propagation model. Remcom has pursued three different advertising routes. No SBIR funds were utilized in any of these activities.

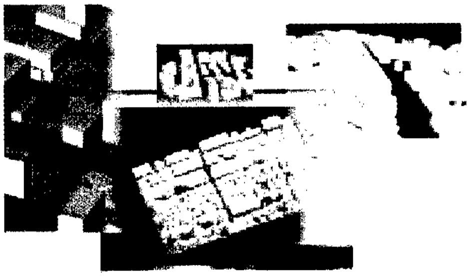
The first was development of a high quality web presence. This includes product description, validation results, and a software feature tour with graphics. It can be seen at http://www.remcom.com by clicking on the left graphic for Wireless InSite.

The second was the design and placement of print advertising. The advertising layout is shown on the following page. This ad has run in the *Institute of Electrical and Electronic Engineers (IEEE) Antennas and Propagation Society Magazine* issues since January of 2000. Placement has been at the premium position of full page on the inside front cover of the magazine. The advertisement has also been run as a full page in the *IEEE Communications Society Magazine* January and March issues.





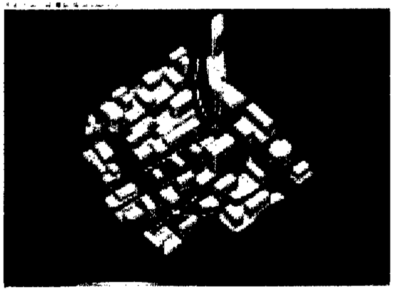
In addition to internet and print advertising, Remcom has supported a person half time to market Wireless InSite. The has produced a number of prospective customers and we are pursuing these. Another result of this marketing effort is placement of a product feature for Wireless InSite in *Microwave Journal*. This product feature is reproduced on the following pages of this report.



A NEW APPROACH TO WIRELESS PROPAGATION PREDICTION

A software tool has been developed that provides accurate, site-specific radio signal predictions for urban locations with many different receiver and transmitter antennas. The tool provides results very quickly, and is adept at providing new results for changes in transmitter and/or receiver antenna locations, and building geometries. The Wireless InSite propagation prediction tool combines techniques from several different disciplines, including computer graphics and asymptotic electromagnetic theory, to reduce the calculation time without compromising accuracy. Using computer graphics rendering techniques, the time necessary for shooting the rays through the urban geometry is greatly reduced. The tool also reuses rays, so that when transmitter and/or receiver antenna locations are added only a few additional rays must be shot. Parameters that do not involve geometrical changes, such as frequency, antenna pattern and building materials (that affect the reflection and diffraction) can be investigated quickly since the same ray set is reused.

Fig. 1 Three-dimensional orthographic view of downtown Rosslyn, VA showing transmitter antenna locations and field strength along the receiver routes. ▼



APPLICATION SPEED

In order to assess the relative calculation speed of Wireless InSite, some comparisons were made with an established propagation prediction tool. Comparison calculations were made for Rosslyn, VA. This is a complex urban area shown in ***Figure 1*** as displayed in 3D by the software package. The calculations were made for 36 buildings of various shapes, multiple transmitter antenna locations and numerous receiver paths. The 2D ray tracing model included with the comparison software was employed and compared with a 2D Wireless InSite calculation. A maximum of five reflections and one diffraction were allowed, and both models used the same building feature descriptions and made calculations for the same number of receiver antenna routes, each about 400 evenly spaced antenna locations along several city blocks. Two different street-level transmitter antenna locations designated A and B were considered, as shown in the diagram as green circles along with the predicted field intensity along the receiver routes for transmitting antenna A.

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TABLE I

PROCESSING SPEED COMPARISON

	Comparison Package		Wireless InSite	
Transmitter	**A**	**B**	**A**	**B**
N. Nash/E. 19th	6:14	7:21	0:16	0:17
Fort Myer Dr.	3:55	4:27	0:08	0:10
Moore St.	4:52	6:05	0:10	0:16
Lynn St.	5:00	4:02	0:09	0:15
Kent St.	3:20	3:40	0:11	0:07

Times are in mm:ss. All simulations were performed on a Pentium III 600, 128 MB RAM, Windows 2000 Professional.

▲ *Fig. 2 Three-dimensional orthographic view of Ottawa with false-color area signal strength prediction.*

By monitoring the computer time during the study, the times were recorded and are listed in ***Table 1***.

While the comparison package allows only one route to be calculated at a time, Wireless InSite permits the user to easily make the computation for all the routes simultaneously. When this is done the Wireless InSite run times for all receiver positions are 0:40 for transmitter location A and 0:49 for transmitter location B compared with total times of 23:21 and 25:35, respectively, for the other tool. While these tests were made by a Remcom engineer more familiar with Wireless InSite than with the other package, they indicate a calculation time for Wireless InSite of about 6 percent of that of the other simulator.

How can Wireless InSite be so much faster? First, the computer time required for shooting the rays is reduced by application of computer graphics techniques used for shooting rays at objects to determine highlight and shadow regions for visual rendering. Secondly, Wireless InSite saves and reuses ray path information. For example, a ray may travel from transmitter A to receiver point number 245 by traveling from the transmitter antenna via reflection from building 23 face 1, diffraction from building 17 corner 4, and so on until reaching the receiver location. A ray path from transmitter A to a different receiver location may also include a reflection from building 23, and a diffraction from building 17 corner 4. For other ray-based propagation tools these two receiver locations would require two independent ray shots, while Wireless InSite remembers the ray paths from the first shoot. This is the typical tradeoff between processor time and memory, and the developers of Wireless InSite have developed a procedure to save the ray paths that efficiently uses both memory and CPU cycles to reduce calculation time significantly.

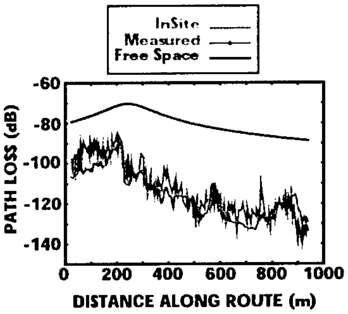
ACCURACY

The calculation engine used in Wireless InSite has been extensively tested and validated by comparison with measured data for a variety of cities. Since Rosslyn, VA is a complex urban area with buildings of different shapes, heights and setbacks, the initial validations of Wireless InSite in Rosslyn had the fortunate effect of encouraging a robust ray tracing method that was not confined to urban areas with rectangular buildings of nearly uniform height. Another effect of the initial Rosslyn validation was the development of a fully three-dimensional (3D) ray model that accommodates arbitrarily oriented building and terrain faces and provides results with full vector fields and, if desired, rays combined with full phase information. This model also allows the user to combine rays with no coherence, partial coherence or full coherence. Partial coherence is also a new development. With this mode rays are sorted to determine if they are interacting with the same building or terrain face. For example, there could be three rays, one that reflects from a building face and two that diffract from two corners of that same face. Wireless InSite will automatically combine these rays coherently. This results in greater accuracy and also removes a theoretical limit on the size of building faces that exists for other ray-tracing propagation tools.

This full 3D version is extremely accurate and general, but relatively slow compared with a two-dimensional (2D) model. An important development was a hybrid 2D/3D model that uses fast 2D ray tracing but then includes vertical building information which allows it to function as a 3D model. In numerous tests the Wireless InSite hybrid Fast 3D model provided nearly identical results with those of the full 3D model, but with much less calculation time. As a result, the program includes four different ray-based propagation models. For urban calculations with low antennas, where over-roof-top propagation is not important, the 2D canyon model is preferred due to its blinding speed. For urban situations where receiver and/or transmitter antennas can be located at elevations such that over-roof-top propagation is important, or when low buildings are involved, the Fast 3D model is used. For situations where full 3D ray tracing is needed, including full vector field with cross-polarization effects, the 3D model is available. For predictions of the effects of uneven terrain on propagation, the terrain model is the correct choice.

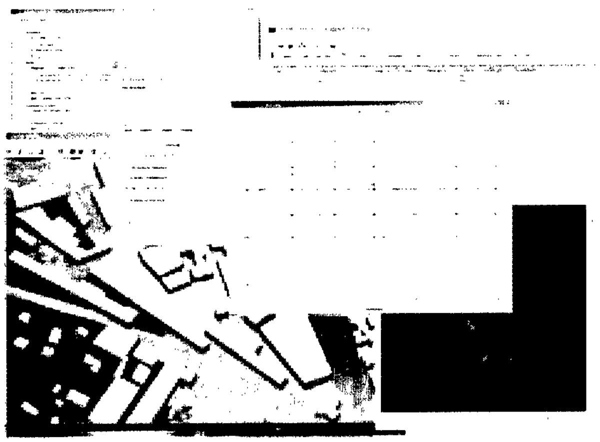
In some situations ray-based models are not applicable. This can occur when many blocks of buildings are interposed between transmitter and receiver antennas. For this situation Wireless InSite includes statistical models such as Hata, COST-Hata and COST-Walfisch-Ikegami.

A typical validation exercise for Wireless InSite was performed for Ottawa. The building layout is shown in gray in ***Figure 2***, along with color intensity indicating street coverage predictions. Comparisons with measured



▲ *Fig. 3 Comparison of measured and predicted path loss along Albert St. with the transmitting antenna on Slater St. in Ottawa.*

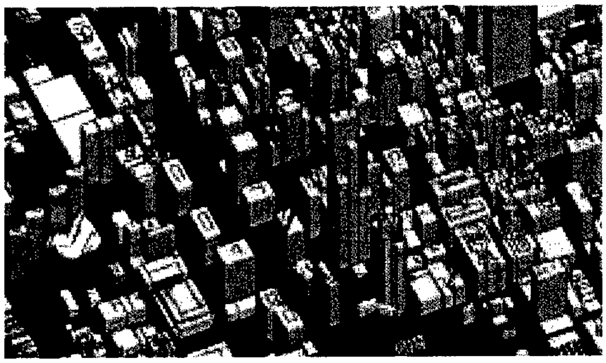
▼ *Fig. 4 Object-oriented GUI.*



data[1] are shown in ***Figure 3***. This level of accuracy is representative of the results that can be obtained with Wireless InSite, given accurate building and terrain features data.

EASE OF USE

Regardless of how fast and accurate a computer model is, it must also be easy to use. The Wireless InSite graphical user interface (GUI) has been in development for over two years. It is designed for Windows operation and its object-oriented organization is clear from the functional layout shown in ***Figure 4***. Wireless InSite is configured to read a variety of urban features data and terrain data formats and to display them. A portion of the city of Denver is shown in ***Figure 5*** after import from a commercially available urban-features CAD file. Building shapes can be edited and new buildings added with the Wireless InSite GUI. Building wall materials can be specified for an entire area, for individual buildings, or even for individual building walls. Receiver and transmitter antenna locations can be added in different ways, and results can be displayed graphically or with color coding. Propagation paths for specific transmitter/receiver antenna pairs are available, along with a wide variety of results including path loss, signal level, delay and delay spread, direction of arrival and many others. Wireless InSite also allows for straightforward organization of study areas so that variations due to antenna placement, frequency, or antenna patterns can be organized and compared.



▲ *Fig. 5 Orthographic view of Denver illustrating the program's capacity for loading CAD files of complex urban areas.*

CONCLUSION

After years of development involving asymptotic electromagnetics and computer graphics technology, a new approach to ray-based urban radio propagation prediction has been implemented. Coupled with a Windows GUI designed specifically for propagation analysis, the result is a powerful software tool for wireless system planners to utilize for accurate prediction of point-to-point and area coverage in urban and rural environments.

Reference

1. J.H. Whitteker, "Measurements of Path Loss at 910 MHz for Proposed Microcell Urban Mobile Systems," *IEEE Trans. Veh. Technol.*, Vol. 37, No. 3, August 1988, pp. 125–129.

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5. Goals for the Future

During the next several month Remcom plans to continue to advertise and market Wireless InSite to both DoD and commercial customers. The success or failure of this effort will determine the future development of Wireless InSite. If customers for Wireless InSite are found, the income from these sales will be used to for enhancements. Planned improvements to Wireless InSite include improving the terrain modeling capabilities and adding additional propagation mechanisms such as foliage and rough surfaces.