High Fidelity Modeling of Spatio-Temporally Dense Multi-Radio Scenarios

Mendel D. Schmiedekamp [1], Adam J. Kuhlman [1], Ryan Ohs [1], and Scott Buscemi[2]

[1] Remcom, Inc.
State College, PA, 16801, USA

[2] Advanced Communications Technologies Lab
SPAWAR Systems Center Atlantic
Charleston, SC, USA

This paper was presented at ACES 2013, the annual conference of the Applied Computational Electromagnetics Society

Abstract: Heterogeneous, mobile wireless networks are becoming increasingly difficult to validate for operational use, depending on digital simulation of the wireless channels to properly predict behaviors in the field. The complexity of these simulation scenarios demands high fidelity modeling of the physical channels at very dense resolution of the trajectories of each moving radio in order to handle rapid changes and multi-path, a high performance computing problem of its own. Presented is an approach to reduce the run-time of these high fidelity simulations by constructing precise results based on adjacent ray-paths from a lower resolution simulation. Speed and accuracy trade-offs are presented for this approach in typical urban scenarios, demonstrating its effectiveness in meeting the growing needs of wireless channel emulation.

Keywords: Mobile Wireless Networks, Digital Wireless Channel Emulators (DWCE), Run-time Optimization, Shooting Bouncing Rays (SBR)

1. Introduction

As networking radios become increasingly complex with multiple communication protocols and operational modes, validating large, heterogeneous networks has become extremely difficult. Digital simulation of the wireless channels is an essential tool to evaluate and vet these networks. In order for these simulations to handle non-trivial operational scenarios, especially those involving multi-path and rapidly changing delay profiles, parameters describing the channels are needed. Remcom's Wireless InSite® software tools can generate these parameters using high fidelity models to capture the multi-path behavior. However, for scenarios with hundreds of channels among moving radios this computation can be prohibitively time consuming due to the number of time steps that must be modeled independently.

In order to provide this capability in a timelier manner, Remcom has developed an approach to faster high fidelity ray-tracing by generating correct paths for a dense collection of time steps using a much coarser resolution to perform the initial ray-tracing. In this approach an existing Wireless InSite model will generate results at a coarse resolution, and a post-processing algorithm will adjust the adjacent dominant paths to the locations of the intervening time steps, verifying and computing precise results for these new paths. Result presented of this subdivision of the problem of high-fidelity ray-tracing for fine resolution moving radios indicate that this strategy shows several orders of magnitude speed-ups over the brute force approach with little effect on accuracy.

2. Background

A. Digital Simulation of Wireless Channels

Networking radios and, in particular, military networking radios are very complex systems. Commercial products available today will typically use multiple processors running a distributed system with several different communication protocols and modes of operation. Moreover, all these components have their own software base that has been developed by multiple vendors. This makes the process of debugging the radios and ensuring capability for the warfighter an extremely challenging task. To make matters worse, many features of these radios cannot be examined without forming large networks of 30 or more radios in controlled situations. Presently, to create these networks, one needs to perform a field test where each radio is loaded onto a mobile platform filled with a plethora of supporting equipment which gather a range of performance data. These events take months to plan and execute, requiring a large supporting cast of technicians and engineers. If these radios could be set up and connected in a laboratory setting, using identical scenarios in the field could drastically reduce resources and time required to develop new radios. Specifically, a Wireless Channel Emulator (WCE) that faithfully recreates a realistic environment and supports a large number of radios would present a much better solution compared to field testing. While several WCE exist now, none can meet the scale, bandwidth, and accuracy requirements to vet current networking radios. For example, current analog WCE can meet the scaling requirement; however, they do not meet the accuracy requirements because they cannot provide channel effects such as Doppler and multipath. Commercial *Digital* Wireless Channel Emulators (DWCE) can create these effects but currently only support a maximum of 8 channels. While some academics have written papers detailing a method of scaling to larger number of channels, the approaches described are typically limited by the capacity of a single device.

The reason large scale DWCEs are not available today is because as the number of radios increases, the amount of computations required increases on the order of N^2. The problem is further compounded because each radio must send its signal to every other radio under tight latency constraints due to the real-time nature of the problem. This presents a unique challenge to any parallel architecture in that it needs a large number of computing units with a large network bandwidth that can meet a real-time low latency constraint. Such a simulation capability requires creating delay parameters for each channel at update frequencies as high as 1 KHz. This is a high-performance computational challenge in and of itself. To solve these issues Remcom has modified their Wireless In-Site software to provide high fidelity simulations for complex scenarios of moving radios at dense spatio-temporal resolutions.

B. Wireless InSite

Wireless InSite is a suite of electromagnetic modeling tools for predicting the effects of electromagnetic wave propagation due to buildings, terrain, and other structures. These models are each based on different propagation modeling theories such as Shooting Bouncing Ray (SBR) and Finite Difference Time Domain (FDTD). For the purposes of this paper, we used the X3D model, an SBR model with GPU acceleration. The SBR calculations are made by shooting rays from the transmitter and propagating them through the scene as described in [1] and [2]. The rays will interact with the environment as they make their way to the receivers. The interactions can be limited to consider reflections off feature faces, diffractions around edges, transmissions through features, etc. The effects of each interaction along the ray's path, from the transmitter to the receiver, are evaluated based on the Uniform Theory of Diffraction (UTD) [3-5]. At each receiver, the contributions from each arriving ray are combined and evaluated to determine quantities such as electric and magnetic field strength, received power, path loss, path gain, interference measures, delay spread, direction of arrival, impulse results, etc.

3. Approach

The X3D model in Wireless InSite applies an additional level of analysis beyond SBR ray-tracing, verifying the exact ray-paths between the transmitter and the receiver. Without this processing step, the resulting paths would be one of the ray-paths shot, which does not hit the receiver precisely. This algorithm constructs a distance minimization problem from the geometry of a ray-path's interactions and the exact positions of the transmitter and receiver, and then solves this problem using iterative convergence. Finally, the ray-path is verified to ensure that the ray does not encounter blocking objects or slide off the edge of a diffraction.

As part of an adaptive meta-model which breaks down the moving and stationary radios of the scenario into a number of jobs, Remcom has converted this capability to reprocess the ray-paths of a coarse selection of steps along a moving channel and then adjust and verify them for the entire channel at the desired density of simulation, called Adjacent Path Generation (APG). While the APG is multi-threaded in the same manner as its equivalent computation within the X3D model, the X3D model often must process thousands or tens of thousands of ray-paths per channel in order to generate the final dominant subset of those ray-paths. The APG need only process those dominant subsets for the adjacent channels of the coarse spacing. This generates a reliable speed-up based on the reduction of effort, but introduces a risk of prospective dominant paths for a fine resolution channel being missed by all adjacent coarse resolution channels.

4. Results and Discussion

Both the benefit and the risk of the APG are expected to be dependent on the specific scenario and the coarse spacing used for the initial X3D job. To evaluate these we constructed scenarios similar to the urban moving radio scenarios for which the X3D model will be used.

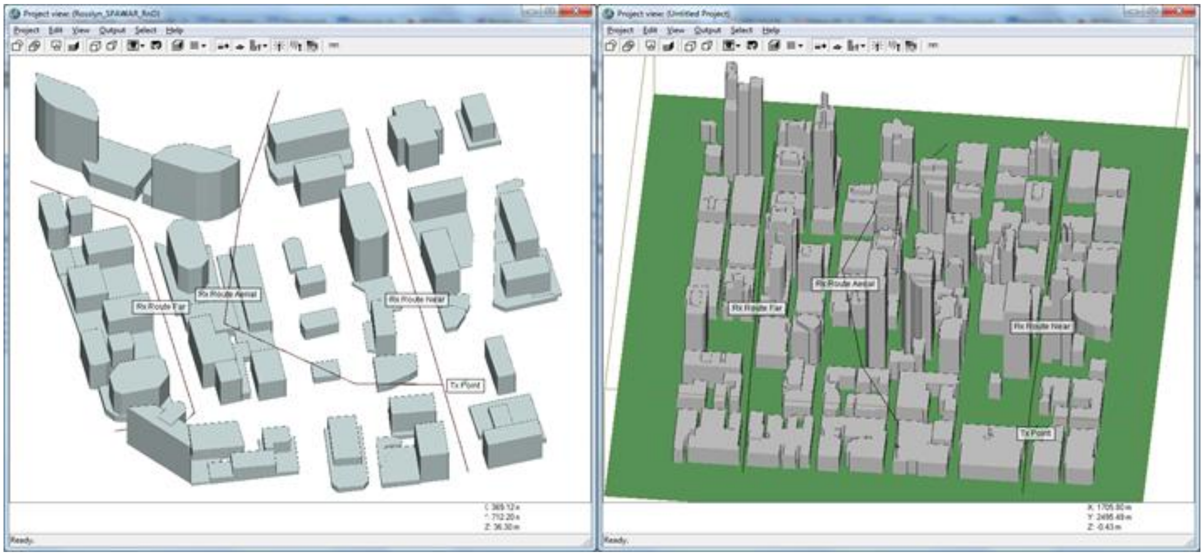

Fig. 1. Example scenarios used to evaluate adjacent path generation, Rosslyn and Chicago, respectively.

To test the accuracy and speed of the APG two city files where imported into the Wireless InSite project (Rosslyn, VA and Chicago, IL). Also added were three receiver routes for each city (Near Rx Route, Far Rx Route, and Aerial Rx Route). Chicago provides a large, crowded area that includes thousands of facets, whereas Rosslyn is a much smaller area and is not populated with near as many facets. The receiver routes were set up to include the entire scenario. The Near Rx Route, for each city, was chosen to maintain a best case, LOS scenario. The placement of the Aerial and Far Rx Routes were chosen to challenge the APG by requiring several reflections and diffractions in order to maintain accuracy. The cities and their perspective receiver routes are shown in Fig. 1 above.

Each route was simulated using the following AP distances, in meters: (0.2, 0.5, 1, 2, 5, 10, 20, and 50). An X3D simulation, using the same routes, but with a much more dense spacing was also simulated. The results of each AP distance simulation and for each receiver route were compared to establish a relationship for both accuracy and time.

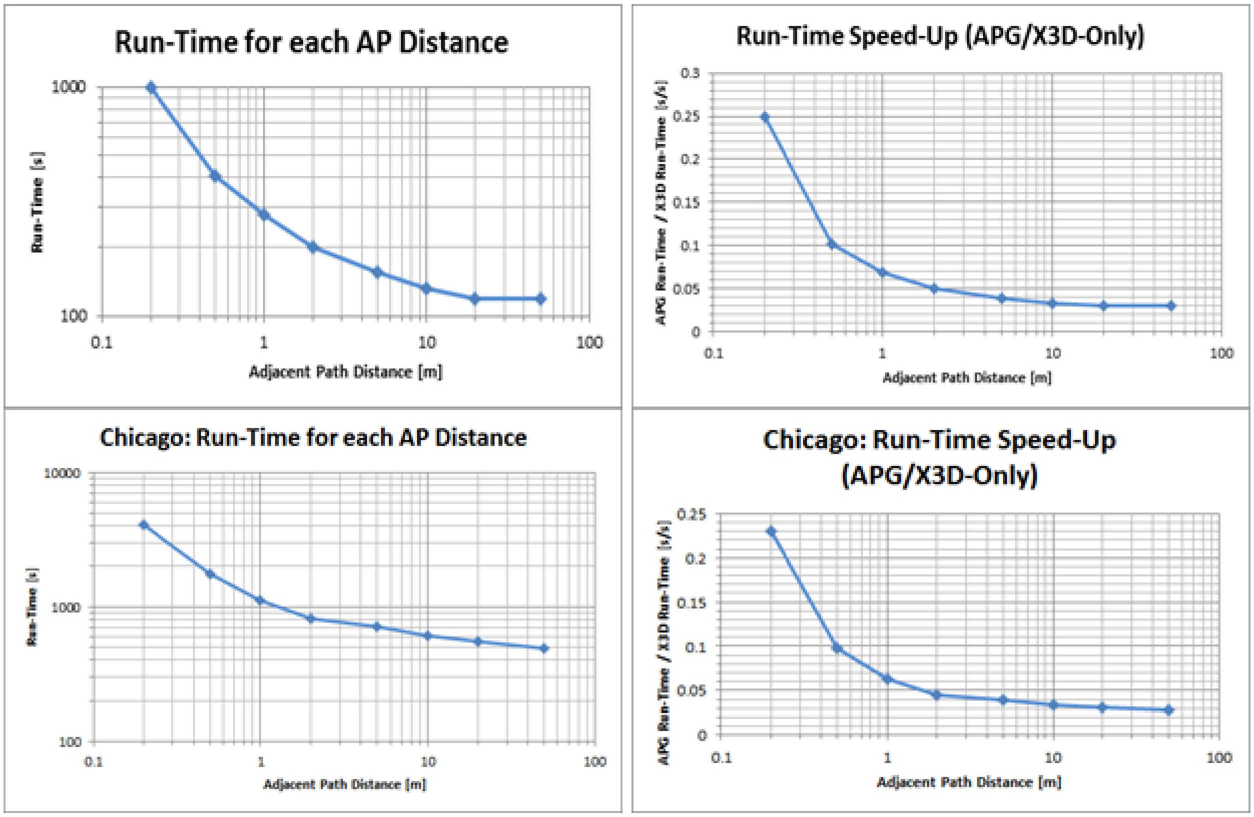

Fig. 2. Run-times for Rosslyn (top left) and Chicago (bottom left). Run-time Speed-up for Rosslyn (top right) and Chicago (bottom right). Notice the similar results for Run-time Speed-up between the two cities, even with the different in run-times.

To determine the speed-up, it was necessary to consider the total calculation time for each AP distance. Dividing the overall run-time of each AP distance simulation by the overall run-time of the X3D simulation, provides the speed-up time for each APG simulation. Although the expected run-times of the Chicago scenarios far exceeded those of the Rosslyn scenarios, it was very promising to find that their speed-up time agreed almost exactly. The X3D simulation times for Chicago and Rosslyn were 17911s and 3992s, respectively. Fig. 2 and 3 show the run-times and run-time speed up for each AP distance. For AP distances greater than 2m both cities show that the APG runs faster than 5% of the dense X3D simulation.

This run-time speed-up improves with the AP distance, but it was noticed that the speed-up was slightly more obvious in the Chicago scenario for AP distances greater than 2m. There does not seem to be much improvement in run-time speed-up for AP distances greater than 10m for the Rosslyn scenario. This suggests that a speed vs. accuracy trade-off could be optimized using a 10m AP distance for smaller area scenarios or scenarios with fewer facets.

One measure of accuracy for the APG was determined by the number of common paths found between each AP distance simulation and the X3D simulation. This value is referred to as the Probability of Path Detection (PPD) for the remainder of this paper and it is described as the number of paths from an AP distance simulation that are found in the X3D simulation divided by the number of paths in the X3D simulation. As is shown in Fig. 2, the overall probability of path detection was considerably high for most of the adjacent path distances considered.

One interesting outcome of the PPD study suggested a higher probability of finding a higher percentage of the paths in Chicago than Rosslyn. After visually inspecting the paths it was clear that this method could, in fact, be more accurate for larger, densely faceted cities than for those that are spread out and not as large, such as Rosslyn. These PPD plots provide the user with a certain comfort level to select an accuracy threshold. An AP distance value of 10m would, most likely, serve as a reasonable default value.

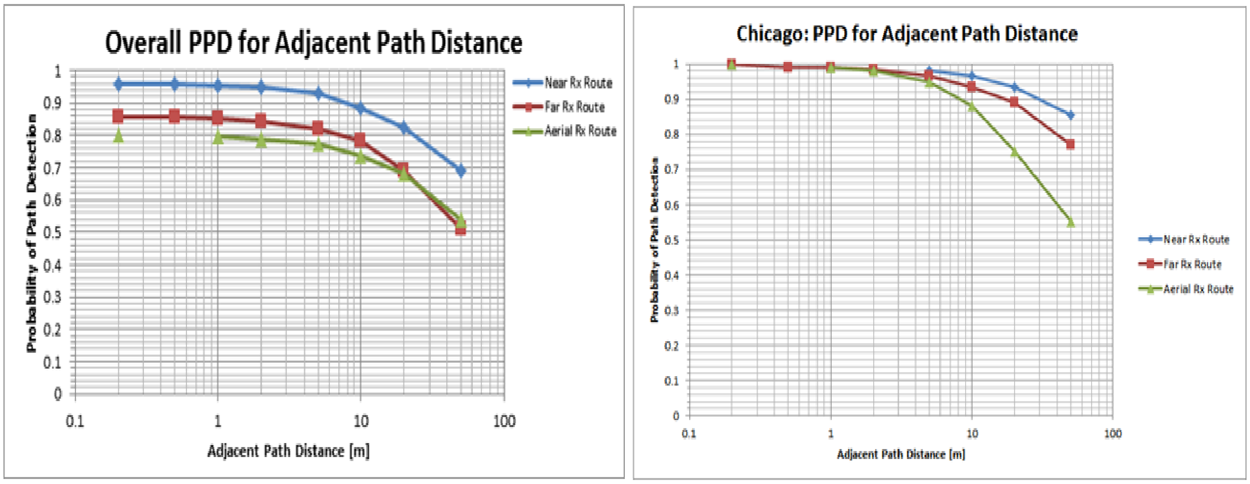

Fig. 3. Probability of matching the paths from an APG simulation with those of an X3D simulation for Rosslyn (left) and Chicago (right).

Comparing the received power between the APG and X3D simulation was another important way for us to confirm our model's accuracy. To do so, the RMS error was calculated for the received power for the entire set (N receivers). The following equation was used to determine the RMS error for each Adjacent Path Distance and receiver route in Rosslyn and Chicago.

$$Prec_{RMS} = \sqrt{\frac{1}{N}\sum_{1}^{j}\left(Prec_{X3D,j} - Prec_{APG,j}\right)^{2}} \qquad (1)$$

Figure 3 displays the results of the RMS error analysis for each city. Most of the RMS error was kept below 5 or 6 dBm. The RMS error for all simulations with AP distances as high as 10m are either barely above 4dBm, or are below 4 dBm. The plots in Fig. 3 allow the user to determine their own accuracy threshold. For example, if a user wishes to consider aerial transceivers in a larger city, it may be best to stick to 5 m or 10 m AP distances. However, if a user is fairly close to the transceiver, or is in line-of-site, a 50 m AP distance may be acceptable.

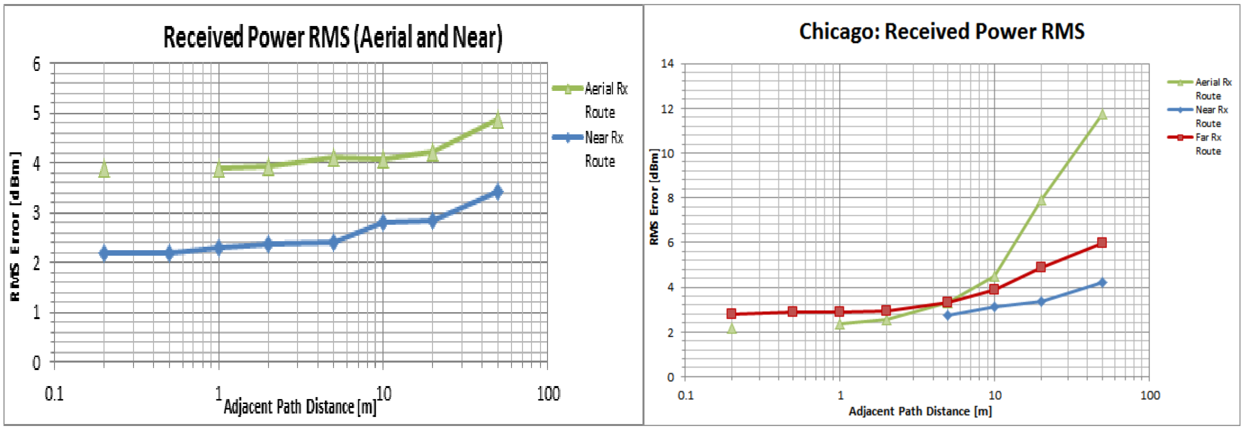

Fig. 4. RMS error of Received Power data for Rosslyn (left) and Chicago (right).

5. Conclusion

For urban scenarios likely to require high-fidelity multi-path simulation, the APG method for run-time optimization presents an attractive option. Even only considering the speed-ups from moving receiver sets, the run-time improvements are significant, lying between one and two orders of magnitude, and the majority of those improvements happen at distances before the accuracy losses begin to grow significantly. This supports the conclusion that the APG method will typically provide sizable run-time savings in exchange for a relatively small accuracy loss.

The capabilities of APG offer even more promise when applied to cases where both the transmitter and the receiver of a given channel are mobile. In these cases, the shifting transmitter requires a completely new ray-trace to generate results at consecutive time steps. By using the APG the number of these which must be performed can be reduced by several orders of magnitude.

At present, the APG is developed as a part of a high-fidelity multi-radio job which subdivides a scenario and runs multiple models as requested or needed to analyze the scenario. The APG was built to work directly with X3D, since both use the same path verification strategy. However, it may be possible that other Wireless InSite models can be made to work with the APG, such as the Urban Canyon 2D ray-tracing model.

References

[1] J. Schuster and R. Luebbers, “Hybrid sbr/gtd radio propagation model for site specific predictions in an urban environment,” *12th Annual Rev. of Progress in Applied Computational Electromagnetics*, vol. 1, pp. 84–92, 1996.

[2] J. Schuster and R. Luebbers, “Comparison of site-specific radio propagation path loss predictions to measurements in an urban area,” *IEEE AP-S International Symposium and URSI Radio Science Meeting*, vol. 1, pp. 1210–1213, July 1996.

[3] Balanis, C.A., *Advanced Engineering Electromagnetics*. Wiley, New York, pp. 782-790, 1989.

[4] R. Luebbers, “Finite Conductivity Uniform GTD Versus Knife Edge Diffraction in Prediction of Propagation Path Loss,” *IEEE Trans. Antennas Propag.*, vol. AP-32, pp. 70-76, 1984.

[5] R. Luebbers, “A Heuristic UTD Slope Diffraction Coefficient for Rough Lossy Wedges,” *IEEE Trans. Antennas Propag.*, vol. 37, pp. 206-211, February 1989.