Simulating Radio Frequency Propagation via Ray Tracing

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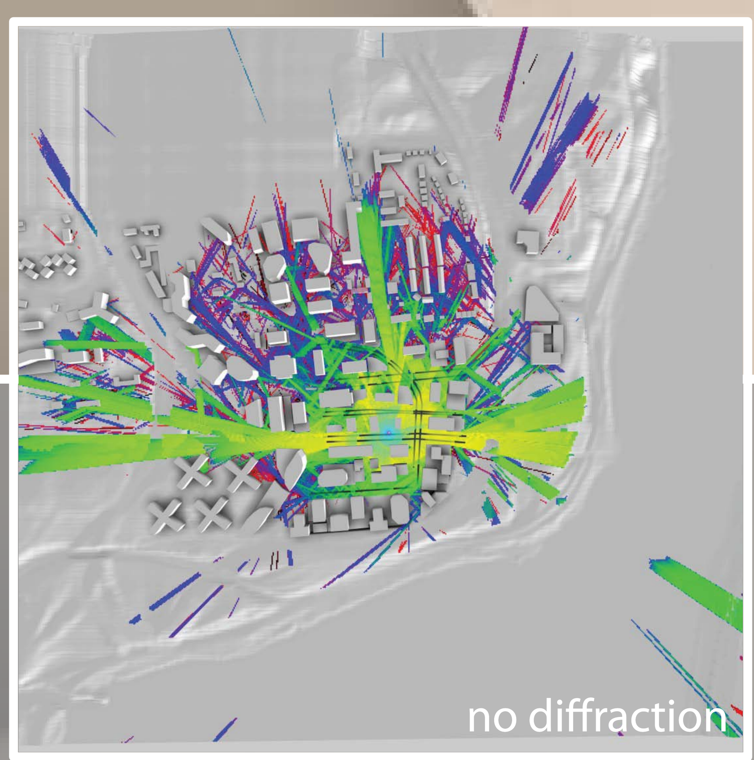
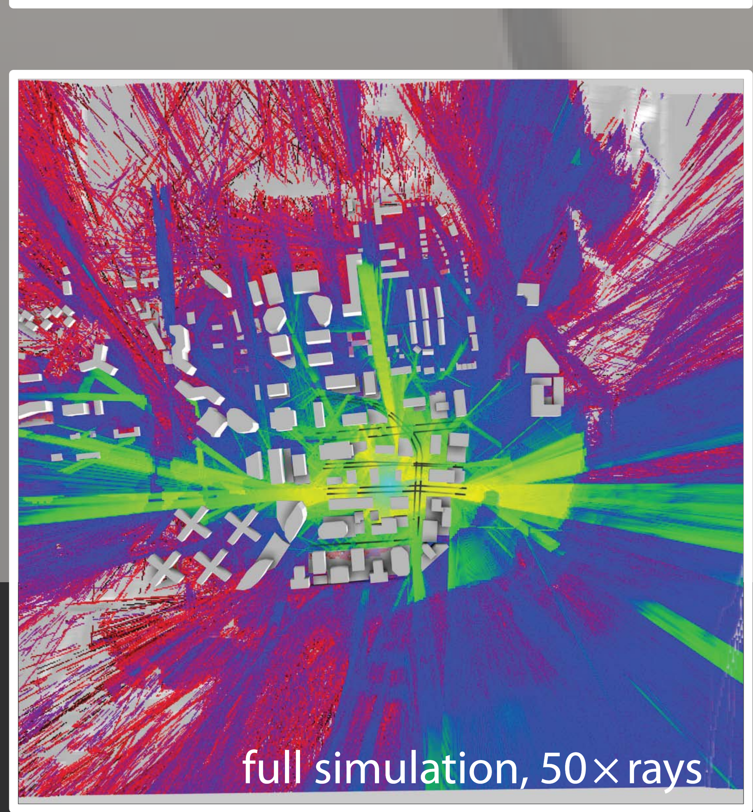
Overview

Prediction of radio frequency (RF) energy propagation in the presence of complex outdoor terrain features—urban environments, for example—is of great interest when planning, optimizing and analyzing wireless networks. A tool for fast prediction could improve network coverage, provide estimates of signal strength throughout the environment, estimate time delay of multipath signals, and provide data for power allocation in the deployed transmitters. Such a tool is essential when planning networks that need to be set up quickly for temporary purposes.



no diffraction

full simulation



full simulation, 50× rays

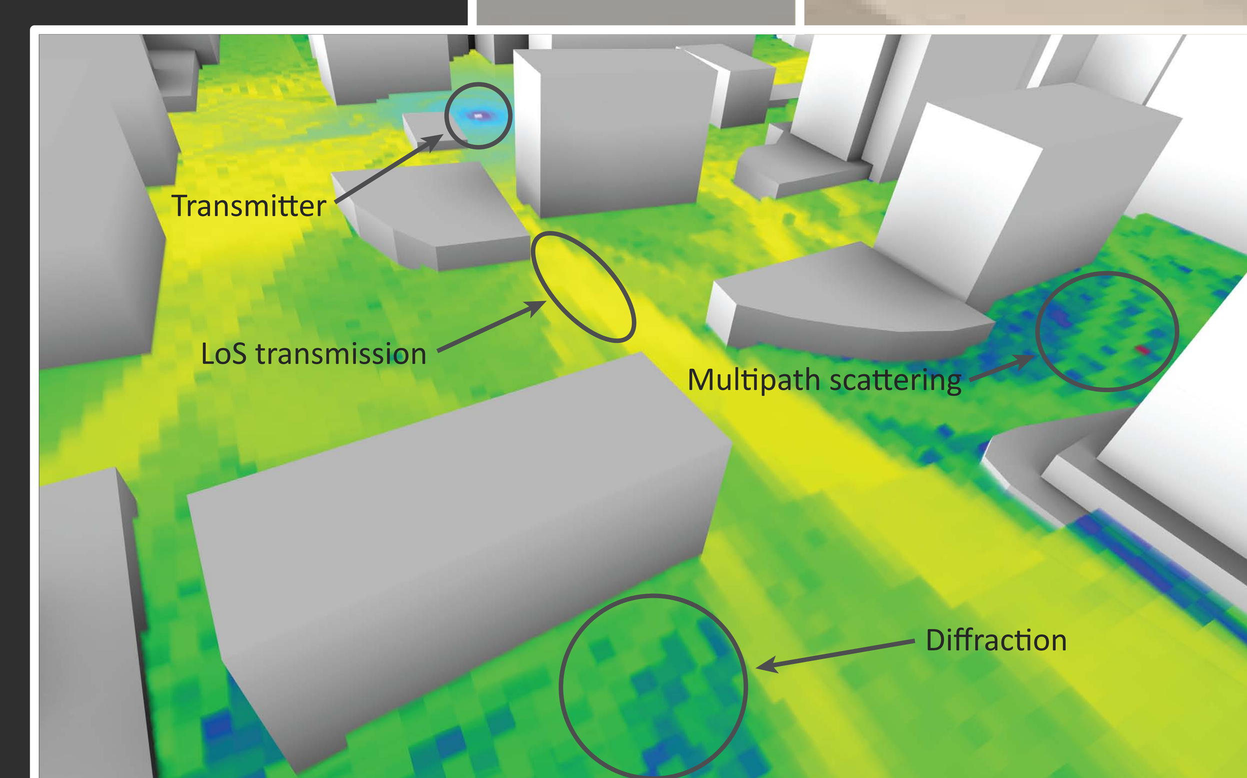
Ray tracing for RF simulation

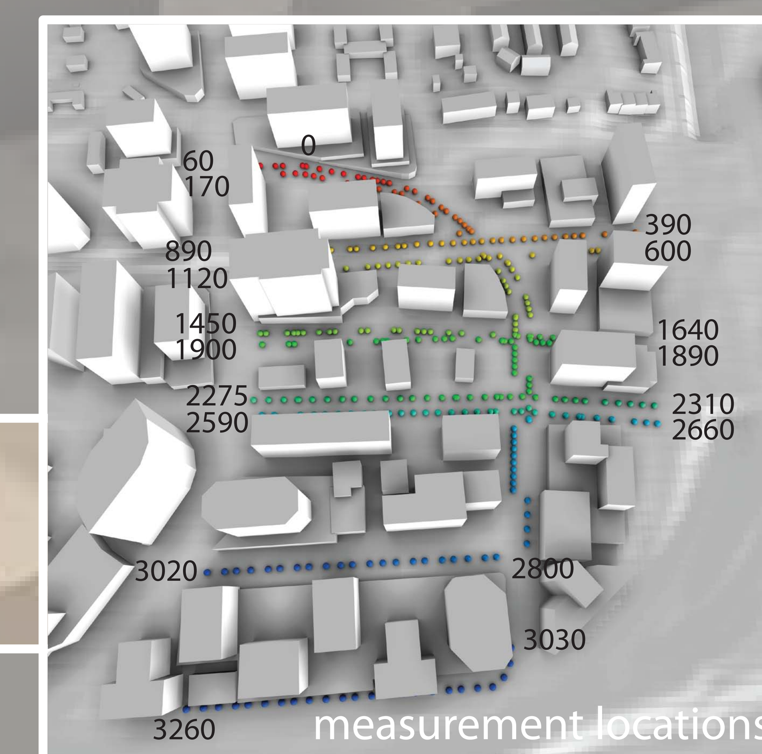
Optical ray tracing simulates the propagation of visible light in complex 3D environments and also elegantly handles important effects such as direct line-of-sight, reflection, and diffraction. We observe that RF energy is also a form of electromagnetic energy, albeit at a very different frequency than light; thus, ray tracing exhibits potential for simulating physical phenomena in the RF domain. We thus build on optical ray tracing to simulate RF energy propagation in complex urban environments.

Specifically, we have created the Manta-RF system, which is based on the open source interactive ray tracing framework Manta [Bigler et al. 2006]. To enable RF prediction, we have made a number of enhancements:

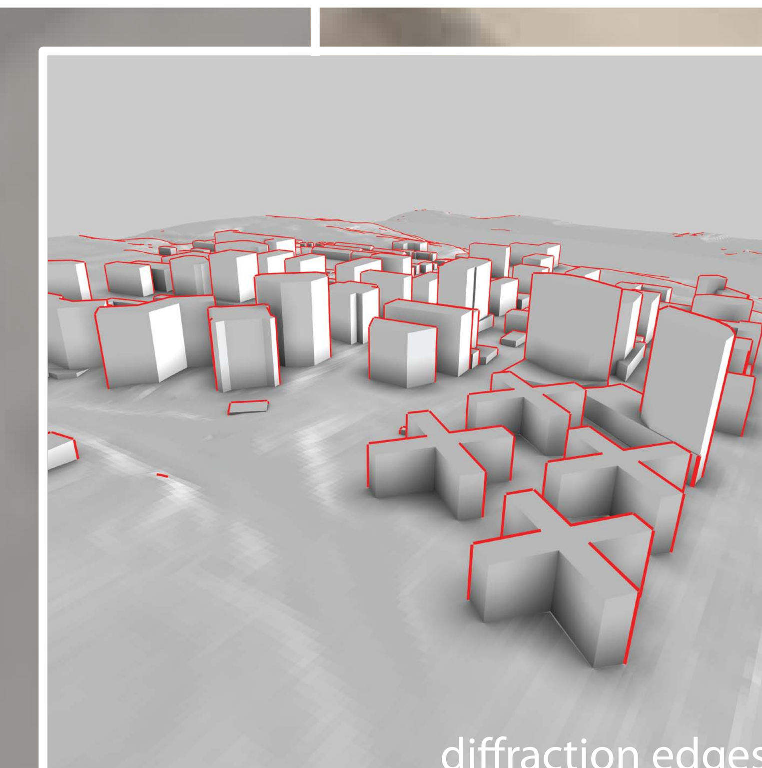
- a technique for simulating and capturing RF energy information in each volume grid point,
- a technique for measuring the arrival time of energy at volume grid points in a manner that accounts for wave-based interference,
- an algorithm for finding all edges in the geometry that could cause diffraction, and
- a simple but reasonably accurate diffraction model for RF propagation.

Validation against several measured datasets, including Rosslyn, VA [Seong-Cheol et al. 1999] and Munich, Germany [Damosso 1998], shows that ray-based simulation offers a high fidelity approach for RF prediction. Importantly, a ray-based solution also offers high performance: simulations involving $O(10^8)$ rays complete in less than 10 minutes on a modern laptop. Moreover, these simulations scale gracefully: for a machine with more processors, either similar quality results are computed in less time or higher fidelity results are computed in similar time.

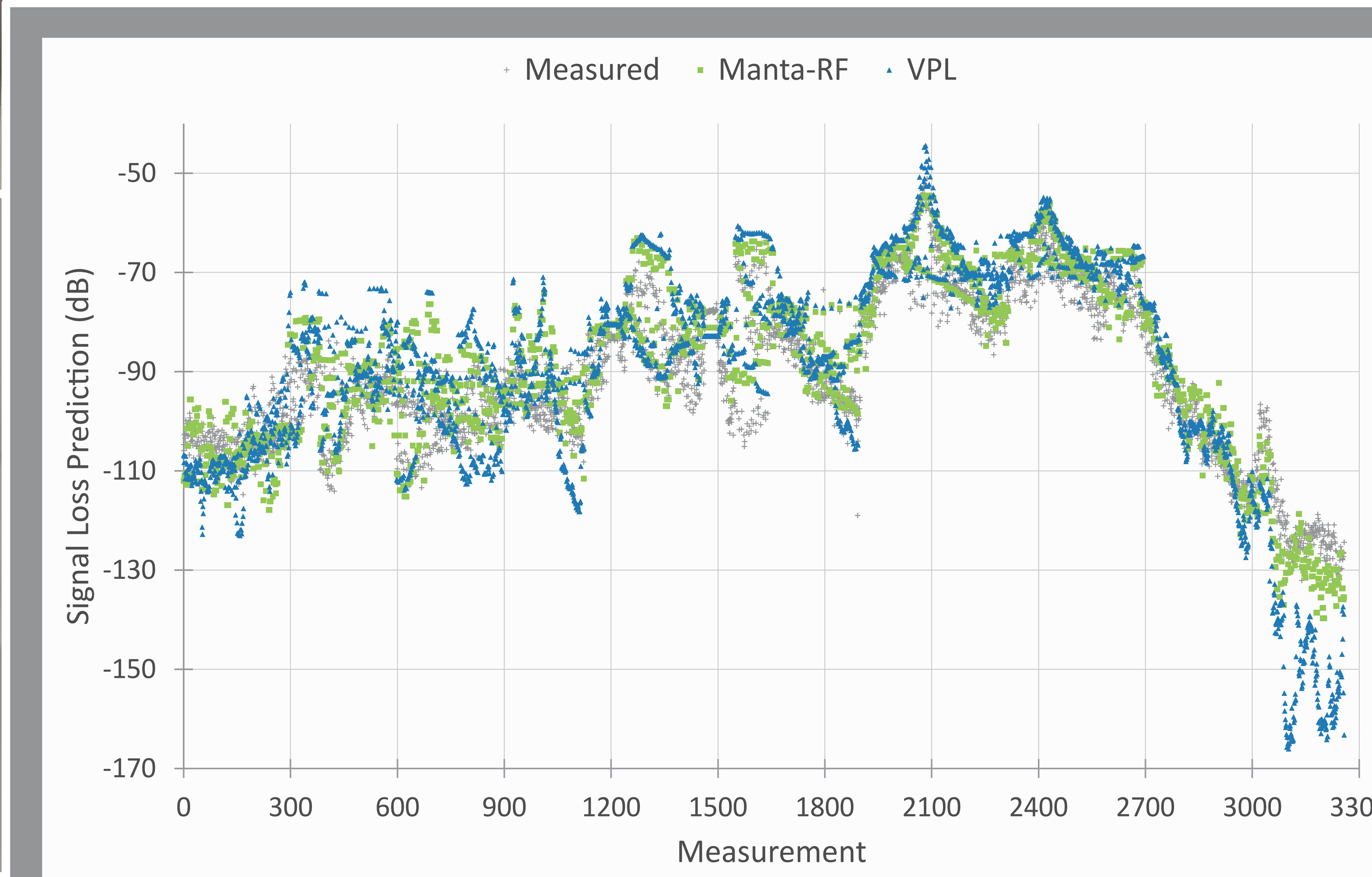




measurement locations



diffraction edges



Comparison of signal loss predictions using Manta-RF and VPL [Liang & Bertoni 1997] against measured data from the Rosslyn, VA dataset (measurement locations shown at left).

Next steps

We are actively migrating the Manta-RF implementation to the massively parallel computational environment provided by modern GPUs generally, and NVIDA's CUDA architecture specifically. Ray tracing scales well with core count, so GPU computing is particularly well-suited to this task.

In addition to significantly higher performance, GPU ray tracing with CUDA will facilitate combined simulation and real-time visualization. By fusing these components into a single computational pipeline, GPU ray tracing will allow users to explore numerous what-if scenarios in the time normally required for a single simulation run. However, it also enables a fundamental shift in the analysis process: users can now interact with a visual representation of not just the results, but also of the mechanisms of computation as a simulation proceeds. This approach actively drives understanding—understanding that will allow analysts to direct and refine their simulations more quickly and effectively.

References

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