U.S. Army Research, Development and Engineering Command

Predicting RF Signal Attenuation in Urban Environments

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

- Introduction
- Motivation
- Challenges & Related Work
- Recent Achievements in Ray-Tracing
- Conclusion & Future Works

Introduction

Virtual Environment for MANET Hardware and Software Testing and Evaluation

Develop a set of real time RF propagation path loss applications using GPGPUs that can be used for MANET simulation, emulation and experimentation

Off-line RF Path Loss Computations are not realistic due to:

- Real-time constraints

- Unpredictability of events in the environment

Hi-Fidelity RF path loss modeling in urban environments

MANET (Mobile Ad-hoc NETwork) emulation integrated with real-time RF propagation computations

Support for 100's to 1000's of emulated radios

Introduction

Virtual Environment for McANET Hardware and Software Testing and Evaluation

Develop a set of real time RF propagation path loss applications using GPGPUs that can be used for MANET simulation, emulation and experimentation

GPGPU (General Purpose Graphical Processing Unit) versions of multiple path loss algorithms

1- ITM (Irregular Terrain Model or Longley-Rice)

2- TLM (Transmission Line Matrix)

3- Ray Tracing

Real-Time results injected into MANET Emulation

Motivation

Troop Deployments

Placing radios in the hands of individual soldiers creates a complex physical environment

External Sources of Interference include:

- Jamming equipment
- Channel contention from other soldiers
- Interference from other sources including sensors, civilian communications

Motivation

Troop Deployments

Large Scale modeling and Simulation requires an accurate representation of the frequency spectrum usage

Emulations of Battalion (300 – 1300 soldiers) or larger unit sizes will include 1000s of radios

Unit	No. Soldiers
Fireteam	4
Squad	8-13
Platoon	26-55
Company	80-225
Battalion	**300-1,300**
Brigade	3,000-5,000
Division	10,000-15,000
Corps	20,000-45,000
Field Army	80,000-200,000

Challenges & Related Work

Traditionally it has been impractical to accurately compute path loss in real time

- Mobility must be known a priori to allow for pre-computation of path loss tables
- Very large numbers of dedicated CPU cores were required to proved a sufficient FLOP rate
- Real time path loss calculations generally limited to free-space models
- Digital Terrain and Building data Availability and Fidelity

Challenges & Related Work

Traditionally it has been impractical to compute path loss in real time with accuracy

Non-GPGPU

- *V. Sridhara (2007) MODELS AND METHODOLOGIES FOR REALISTIC PROPAGATION SIMULATION FOR URBAN MESH NETWORKS, (Ph.D.), University of Delaware*
- *Many other historical CPU-based solvers for Longley-Rice, TLM, and Ray-Tracing*

GPGPU

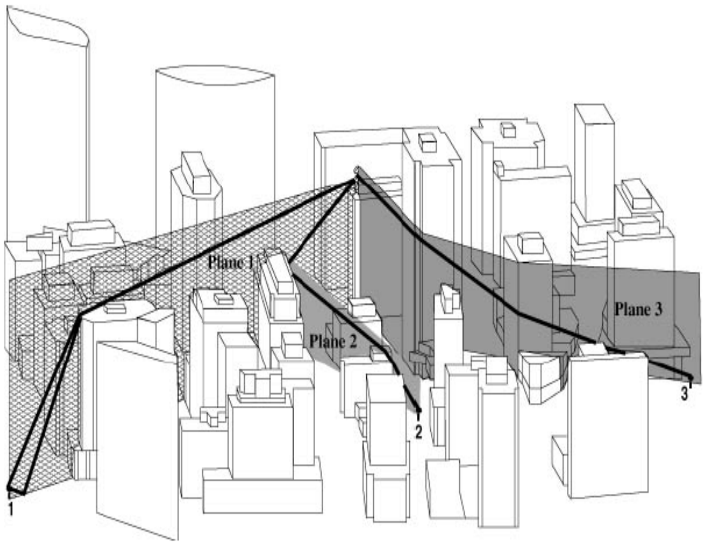
- *S. Bai (MITRE) and D.M. Nicol (U. of Ill. Urbana-Champaign) GPU Coprocessing for Wireless Network Simulation, 2011 Symposium on Application Accelerators in High Performance Computing (SAAHPC'11), July 19-21, 2011*
- *A.N. Cadavid (Icesi University) and D.G. Ibarra (Universidad Pontificia Bolivariana, Colombia) Using Game Engines in Ray Tracing Physics, 2010 IEEE Latin American Conference on Communications*
- *Efforts focused on mobile networks (i.e. cell phones, not ad-hoc)*

2D Vs 3D representation of environment

Real-Time Path Loss computation

How then, Can we efficiently model RF Signal Attenuation?

Challenges & Related Work



Henry L. Bertoni. *Radio Propagation for Modern Wireless Systems*. Prentice Hall Professional Technical Reference, 1999.

Generate or obtain 3D digitized model of urban environment

Compute or collect real time radio mobility

Use ray-tracing to compute RF path loss and report back to MANET simulation/emulation

Compare these results directly with measured signal strength

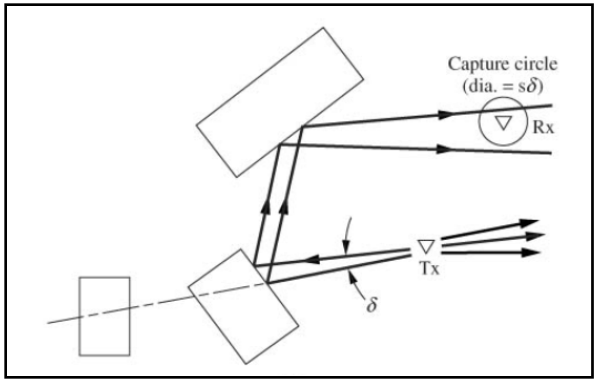
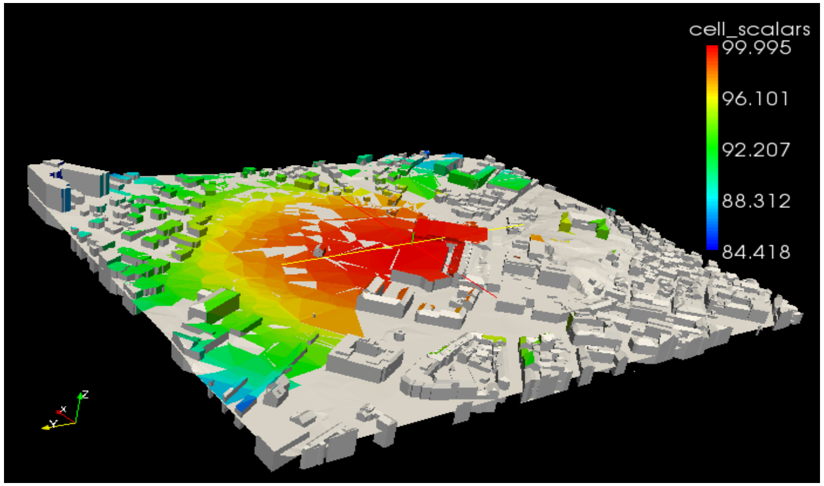


Illustration of the SBR method. Henry L. Bertoni. *Radio Propagation for Modern Wireless Systems*. Prentice Hall Professional Technical Reference, 1999.

Challenges & Related Work



Data parallel approach use ray tracing to compute Line of Sight (LOS)

- No Reflection/Diffraction
- Urban Environment

Processor	Execution Time (sec)
Simple CPU	323
Quadtree CPU (recursive)	38
Quadtree CPU (stack)	34
Radeon HD 4870 GPU	3.4

Timeline

Pre 2010	2011	2012 and Beyond
Free Space - Simple calculation on CPU - Does not require digital terrain data - Does not consider terrain - Inaccurate if ground is not flat	**ITM (Longley-Rice)** - Efficient GPGPU implementation (>10x faster than single core) - Considers terrain - Does not consider human made structures **TLM** - Very efficient GPGPU computation (60x faster than single core) - Typically used for pico-cell modeling - Scale as $O(n^3)$ with spatial discretization	**Ray-Tracing** - Perceived efficiency on GPGPUs - Capable of accurately predicting propagation in urban environment - Requires 3-D model of environment - Computationally expensive

ITM: Verification / Validation

ITM Implementation is based upon the open-source distribution available from the Department of Commerce

- http://flattop.its.bldrdoc.gov/itm.html

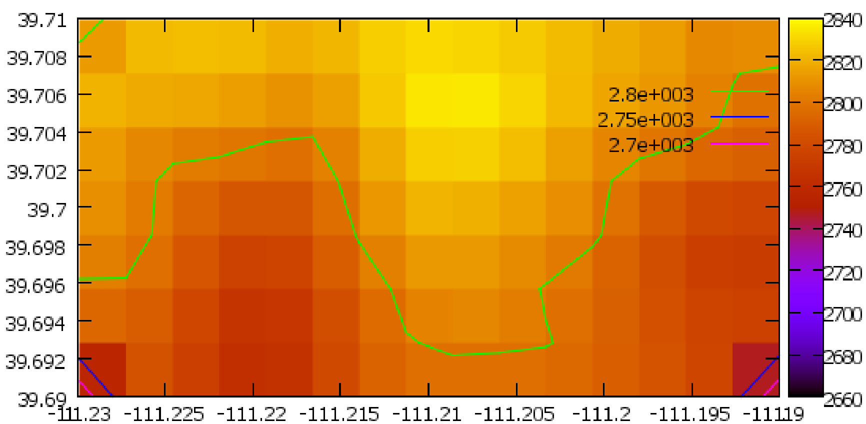
ITM results are valid for 20MHz to 20GHz

- JTRS was originally planned to use frequencies from 2MHz to 2GHz
- Specific waveforms of interest primarily fall within this range

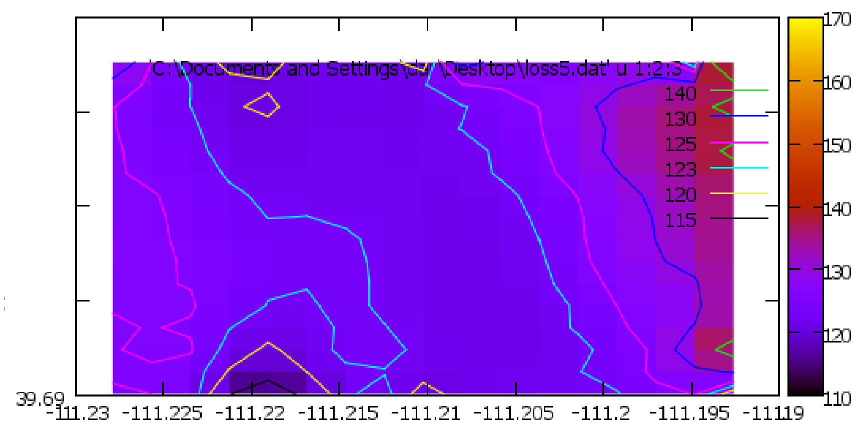
Current Development uses OpenCL for future portability

- Targets AMD/ATI CPU/GPU, NVIDIA GPU, and Intel CPU
- NVIDIA C2070 capable of computing >65K Point-to-Point calculations per ½ seconds or > 130K per seconds

Tx coordinate -111.2201, 39.6901



Terrain

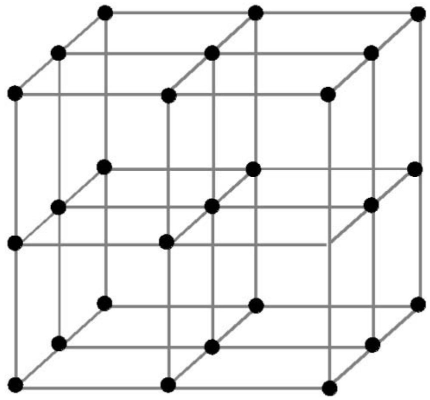


Pathloss

TLM (Transmission Line Matrix)

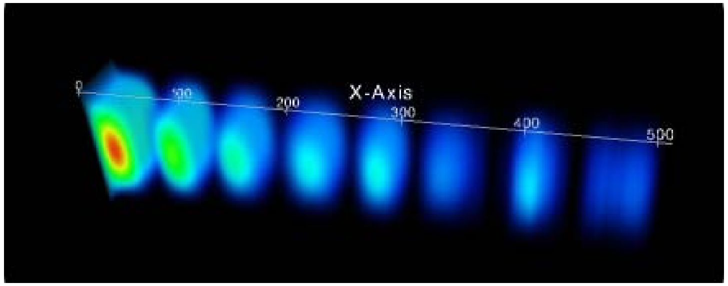
The TLM method has much higher fidelity than ITM

- May include structures and building interiors
- e.g. Urban environments

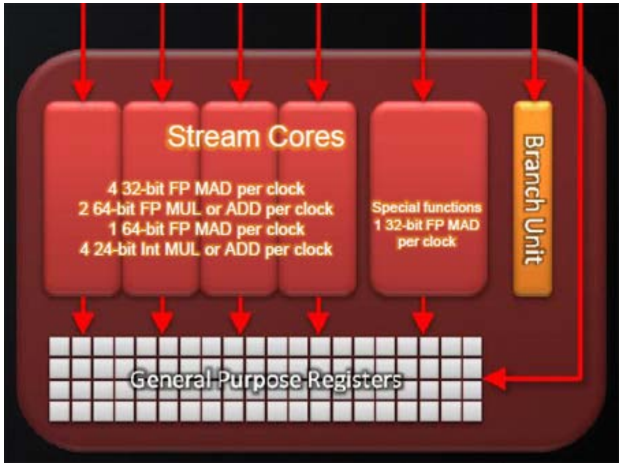


TLM is based on the finite difference method

- FDTD is a direct solution to Maxwell's Eqs., TLM is an approximation
- FDTD requires ~10 points per wavelength (fullwave), TLM does not
- TLM simulation models propagation of energy through space (the grid)
- Very efficient on GPGPUs (General Purpose Graphical Processing Units)
- Memory accesses are local in 3-D
- Calculations are basically MADDs (Multiply Adds)



ATI RV870 shader core



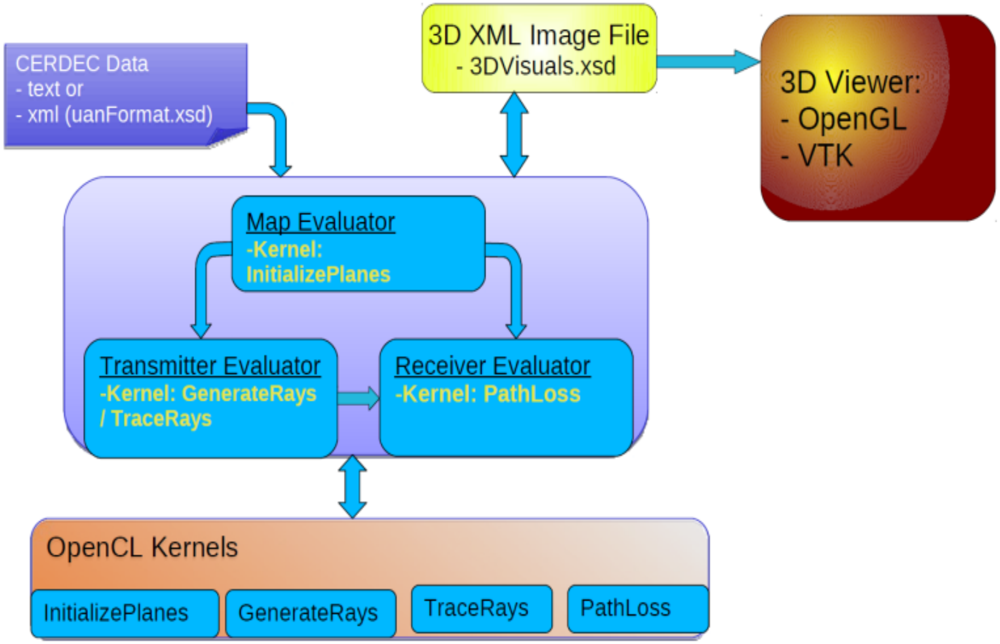
Ray-Tracing

For our quest, GPGPU devices are

- cost effective
- power efficient and
- improve space utilization

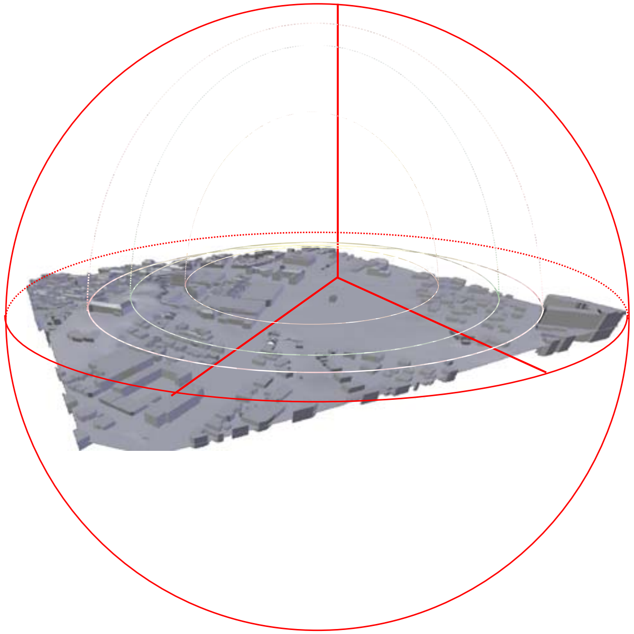
Use of OpenCL for portability

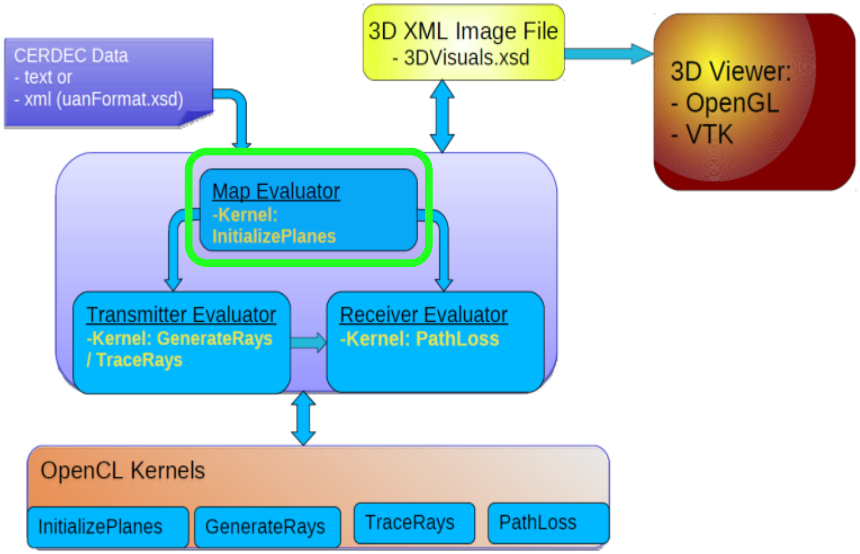
Execution Threads



Ray-Tracing

- 3D Environment is represented as a set of polygons
  - Generated offline
  - Used to Initialize planes
- Reducing the number of polygons consulted yields reduced computation time
  - Using Spherical Partitions
  - Preliminary results show a 23% reduction in number of polygons consulted



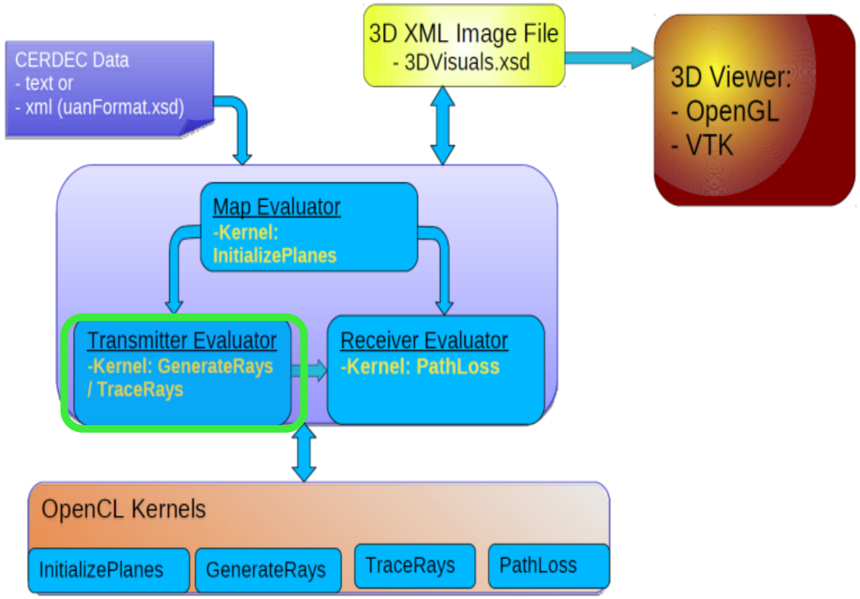


Ray-Tracing

Each GPU core traces one ray across the 3D environment

Support for parameterized number of reflections and diffractions

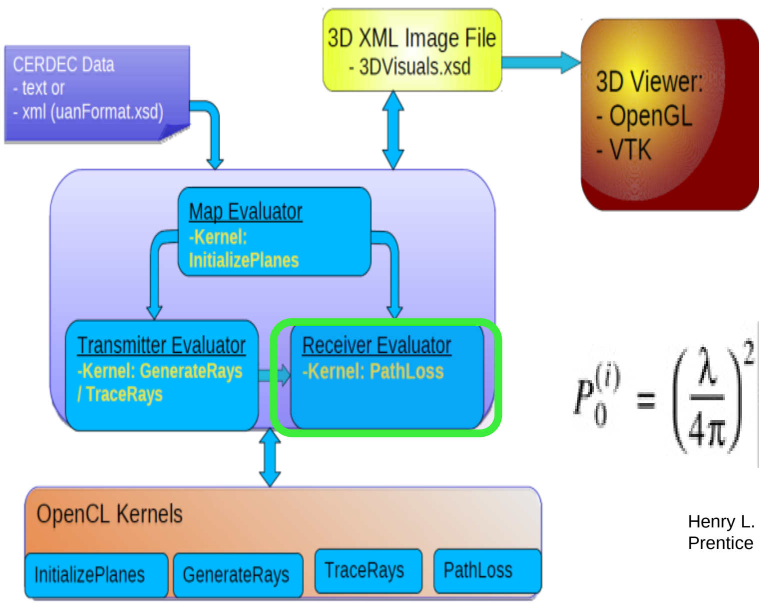
Ray Generation
Based on User specified values



Ray-Tracing

Path Loss due to reflection has been computed

Assuming Vertical Polarization of the antennas

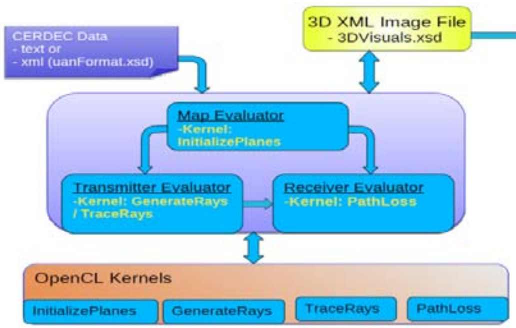


$$P_R^{(i)} = P_0^{(i)} \prod_j \left|\Gamma_E(\theta_j)\right|^2$$

$$P_0^{(i)} = \left(\frac{\lambda}{4\pi}\right)^2 \left|\frac{e^{-jks_{id}}}{s_{id}} + \Gamma_H \frac{e^{-jks_{ig}}}{s_{ig}}\right|^2 \approx \left(\frac{\lambda}{4\pi S_i}\right)^2 \left|e^{jkh_{BS}h_m/S_i} + \Gamma_H e^{-jkh_{BS}h_m/S_i}\right|^2$$

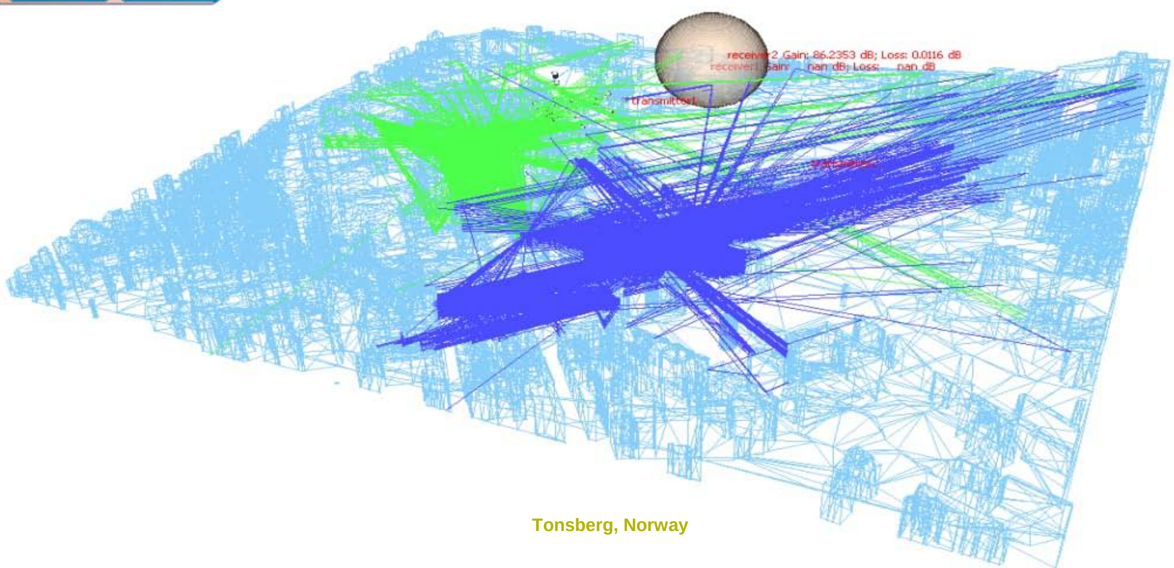
Henry L. Bertoni. *Radio Propagation for Modern Wireless Systems*. Prentice Hall Professional Technical Reference, 1999.

Ray-Tracing



Ray-Tracing using 3D representation of Tonsberg, Norway

Parameterized number of reflections : 6



Conclusion & Future Works

Accounting for Knife-Edge Diffraction and associated path loss

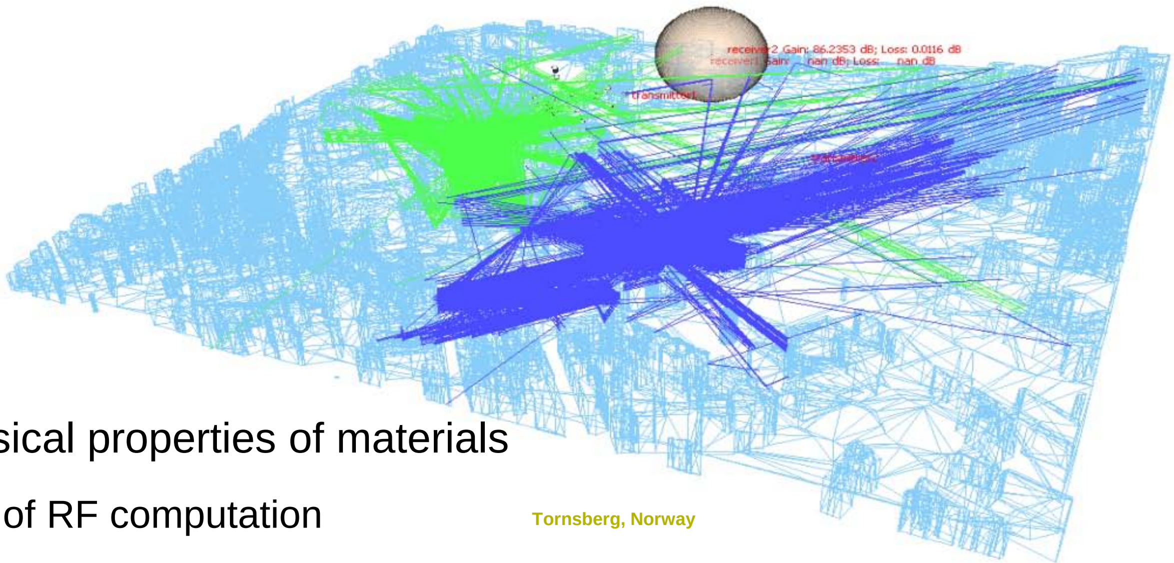
Modularity: Integrate CERDEC antenna characteristics

Reflective Path Loss needs to account for the following Antenna polarizations:

Horizontal

Circular

Elliptical



Tornsberg, Norway

Support for physical properties of materials

Increased fidelity of RF computation

Conclusion & Future Works

Study System Performance and Fidelity of results as implemented on GPGPU

Improve and further study the spherical partitions

- Minimize number of polygons consulted per ray

Large Scale modeling of JTRS waveforms

- MANET simulation using EMANE

Study interference patterns of RF Signals

Thank You!!