Predicting RF Signal Attenuation in Urban Environments

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07 Nov 2012
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

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

<table>
<thead>
<tr>
<th>Unit</th>
<th>No. Soldiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fireteam</td>
<td>4</td>
</tr>
<tr>
<td>Squad</td>
<td>8-13</td>
</tr>
<tr>
<td>Platoon</td>
<td>26-55</td>
</tr>
<tr>
<td>Company</td>
<td>80-225</td>
</tr>
<tr>
<td>Battalion</td>
<td>300-1,300</td>
</tr>
<tr>
<td>Brigade</td>
<td>3,000-5,000</td>
</tr>
<tr>
<td>Division</td>
<td>10,000-15,000</td>
</tr>
<tr>
<td>Corps</td>
<td>20,000-45,000</td>
</tr>
<tr>
<td>Field Army</td>
<td>80,000-200,000</td>
</tr>
</tbody>
</table>

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

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

Challenges & Related Work

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

- No Reflection/Diffration
- Urban Environment

<table>
<thead>
<tr>
<th>Processor</th>
<th>Execution Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple CPU</td>
<td>323</td>
</tr>
<tr>
<td>Quadtree CPU (recursive)</td>
<td>38</td>
</tr>
<tr>
<td>Quadtree CPU (stack)</td>
<td>34</td>
</tr>
<tr>
<td>Radeon HD 4870 GPU</td>
<td>3.4</td>
</tr>
</tbody>
</table>
### Timeline

<table>
<thead>
<tr>
<th>Pre 2010</th>
<th>2011</th>
<th>2012 and Beyond</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Free Space</strong></td>
<td><strong>ITM (Longley-Rice)</strong></td>
<td><strong>Ray-Tracing</strong></td>
</tr>
<tr>
<td>- Simple calculation on CPU</td>
<td>- Efficient GPGPU implementation (&gt;10x faster than single core)</td>
<td>- Perceived efficiency on GPGPUs</td>
</tr>
<tr>
<td>- Does not require digital terrain data</td>
<td>- Considers terrain</td>
<td>- Capable of accurately predicting propagation in urban environment</td>
</tr>
<tr>
<td>- Does not consider terrain</td>
<td>- Does not consider human made structures</td>
<td>- Requires 3-D model of environment</td>
</tr>
<tr>
<td>- Inaccurate if ground is not flat</td>
<td></td>
<td>- Computationally expensive</td>
</tr>
</tbody>
</table>

**TLM**
- Very efficient GPGPU computation (60x faster than single core)
- Typically used for pico-cell modeling
- Scale as $O(n^3)$ with spatial discretization
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](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

\[
P_R^{(i)} = P_0^{(i)} \prod_j |\Gamma_E(\theta_j)|^2
\]

\[
P_0^{(i)} = \left(\frac{\lambda}{4\pi}\right)^2 \left| e^{-jks_{id}} + \Gamma_H e^{-jks_{ig}} \right|^2 \approx \left(\frac{\lambda}{4\pi S_i}\right)^2 e^{jkh_{BS}h_{m}\frac{S}{S_i}} + \Gamma_H e^{-jkh_{BS}h_{m}/S_i}^2
\]

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

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!!