Propagation Group
Research at Georgia Tech

by Prof. Gregory D. Durgin
17 November 2004
Personal History
My Most Influential VT Prof’s

Prof. David A. de Wolf
- Undergraduate Study
- Very mathematical

Prof. Gary S. Brown
- First-Principles teaching style
- Propagation Theory

Prof. Theodore S. Rappaport
- Advisor, “The Great Provider”
Post Doctoral Assignment

- Japanese Society for the Promotion of Science (JSPS)

University of Osaka
Kansai Region
Life in Morinaga Laboratory

Profs. Norihiko Morinaga and Seiichi Sampei

Book Title: *Space-Time Wireless Channels*

Space-Time Wireless Channels

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Propagation Group
What Does a Propagation Engineer Do?

- Everything
- Hardware
- Wave Propagation/Electromagnetic Theory
- Antenna/RF Design
- Field Measurements
- Robotics
- Software
- Random Processes and Statistical Analysis
- System Architecture
- Communication Link Design
- Personnel Management
RFID Team
in conjunction with Kippelin Lab
**Goal:** Characterize the Electromagnetic interactions of novel RFID tag designs.
RFID Applications

- Commercial inventory management
- Repetitive monitoring of medical conditions
- Airline luggage security and tracking tags
- “Instant Checkout” at the supermarket
- Sensor read-outs

Before any of this happens, we have to make cheaper, more reliable tags.
1. A continuous wave RF signal is transmitted by the interrogator.

2. The tag modulates and reflects the incident signal.

3. The modulated backscatter is received and processed by the interrogator ...

4. ... as well as large amounts of unmodulated backscatter from the immediate environment.
An RFID tag modulates backscatter by switching between matched and short-circuited loads.
Antenna Connected to Balun/Modulator Circuitry

- Example Antenna: folded dipole
- Test antennas have been manufactured with electroless copper or wet silver deposition
- Sub-optimal conductivity
- Plating is thin with respect to skin depth at 915 MHz
Open-Air Antenna Measurements on the Rooftop of Van Leer Building
Balun/Modulator Circuit Connected to Silver Wet Deposition Antenna

- Example below can be manufactured on an inexpensive sheet of plastic using an inkjet printer
- Silver folded dipole antenna
Current Work: Radio Assay Test

RF Signal Generator → Spectrum Analyzer

RFID tag structure

Object Block

Modulation from Signal Generator

Free space, styrofoam, wood block, plastic (PVC), book, salt solution, foil-coated block
E911 Cellular Location Team
sponsored by Polaris Wireless Inc. and Comarco Wireless Inc.
E-911 Cellular Radiolocation Group

Jian “Jet” Zhu

Anil Rohatgi

**Goal:** Use propagation modeling and measurement to find E911 calls made from a cellular phone.
Key Problem: How Can We Find a Cell Phone That Dials 911?

- Original FCC 911 mandate issued in 1996
- In 2004, most carriers are still having trouble meeting compliance specification
- Key Spec (in 2D):
  - 100m position error less than 67% of the time
  - 300m error less than 95% of the time
- Most solutions involve expensive hardware modifications at the base station and/or user handset.
The state-of-the-art solution for E911 is currently A-GPS. An A-GPS cellular phone will, under open-sky conditions, receive signals from 4 GPS satellites and calculate enough pseudo-ranges to calculate its longitude and latitude.

This information is fed back through the network where the calculation is completed.
Problems with A-GPS

- There will be many legacy handsets without GPS for quite some time
- Moderate overhead shadowing is enough to wipe out the ability to locate oneself
  - Cannot meet FCC safety requirements outdoors
  - A-GPS almost never works indoors
  - ~67% of all wireless calls now originate indoors
New Method: Received Signal Strength Measurement Made by a Cellular Handset

A phone located somewhere in the red “bin” makes a series of adjacent channel signal strengths.

All digital phones have this capability to allow for mobile-assisted handoffs.
Signal Strength Measurements are Cross-Referenced to the Database of RF Maps

RF Map Database

Raster Array of Predicted Signal Database (PSD)

Corresponding Cell ID

RSSI for a Single PSD Entry (values in dBm)

-57 10013
-109 22921
-88 10012
-78 34103
-92 34101
-99 43952
-102 10011

Georgia Institute of Technology

The Propagation Group

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www.propagation.gatech.edu
Location Trial on Georgia Tech Campus

Satellite photograph of the Georgia Tech campus. Red Xs mark buildings that are measured for the experiment.

Used an 850 MHz TDMA network with macrocells and microcells.
RF Maps with Modeling and Measurement

Example of one RSS map on GT Campus

Received Signal Strength (dBm)

Y-Position (units of 10m)

X-Position (units of 10m)
Results: Handset Collections with Relative Signal Strength Algorithm

Relative RSS Location:
– Mean is removed from Both NMR and each raster point in RF map data base

1) Database Measurements With dB-mean Removed

\[ P_{RSSr_{xy,i}} = P_{RSSr_{xy,j}} - \frac{1}{N} \sum_{j=1}^{N} P_{RSSr_{xy,j}} \]

2) Handset Measurement With dB-mean Removed

\[ N_{RSSr_i} = N_{RSSr_i} - \frac{1}{N} \sum_{j=1}^{N} N_{RSSr_j} \]

3) Chose Euclidean Minimum

\[ M(x,y) = \sqrt{\sum_{i=1}^{N} (P_{RSSr_{xy,i}} - N_{RSSr_i})^2} \]

<table>
<thead>
<tr>
<th>PSD level</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error statistics</td>
<td>&lt;100m</td>
<td>54%</td>
<td>54%</td>
</tr>
<tr>
<td>statistics</td>
<td>&lt;300m</td>
<td>94%</td>
<td>94%</td>
</tr>
</tbody>
</table>

*Table based on 1000 handset trials
Results: Average a Sequence of 10 NMRs

- NMR measurement from handset repeats every second
- Averaging a sequence of 10 NMRs cleans up small-scale fading, noise, interference, and other detrimental effects
- Some of these results exceed the FCC safety requirements

Location Error Statistics

<table>
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<tr>
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<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error</td>
<td>&lt;100m</td>
<td>61%</td>
<td>64%</td>
</tr>
<tr>
<td>statistics</td>
<td>&lt;300m</td>
<td>97%</td>
<td>98%</td>
</tr>
</tbody>
</table>

*Table based on 1000 handset trials*
Distribution of RSSA for Indoor vs. Outdoor Handsets

We find that the Received Signal Strength Aggregate (RSSA) – the dB-average of the strongest measured signals – follow Gaussian distributions whose means are 12.3 dB apart.

Even with modest amounts of handset variability, this property could be used to discriminate between indoor and outdoor handset users.
### Results: Discriminating Between Indoor and Outdoor Handsets

- Below are the discrimination rates for indoor and outdoor users based on RSSA (10 NMR average case)
- Incorrect detections account for fewer than 10% of the cases

<table>
<thead>
<tr>
<th>PSD level</th>
<th>Level 1 Outdoor Meas.</th>
<th>Level 2 Indoor Model</th>
<th>Level 3 Indoor/Outdoor Meas.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decision</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor</td>
<td>Indoor: 637, Outdoor:53</td>
<td>Indoor: 642, Outdoor:48</td>
<td>Indoor: 641, Outdoor:49</td>
</tr>
</tbody>
</table>

**Correct Rate:** 92%, 92%, 91%

*Table based on 1000 handset trials*
Conclusions

- First scientific validation of a cellular location technique
- New hybrid location method with ability to discriminate between indoor/outdoor handsets
- Current Research
  – Design an accompanying propagation engine
  – Live trial of Georgia Tech algorithm in a live city network
- Check out the GT Cellular Location Simulator on the Web at www.propagation.gatech.edu