Multipath and Robust Precise Indoor Geolocation

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Lessons from the past

- In the second half of the 1990’s DARPA started the SUO/SAS project for Urban and Indoor location aware networking, VC funded a few start up companies such as PinPoint, and indoor geolocation research started.

- In 2000 indoor WiFi localization
  - Commercial: Newbury Networks and Ekahau
- In 2003 UWB localization for WPANs
  - Commercial: IEEE 802.15.3
  - ARL: SBIR won by MSSI and IWT
- In 2004 localization for sensor networks
- In 2005 outdoor localization with GPS alternatives
  - Commerce: WiFi positioning in outdoor areas (Skyhook)
  - Military: Signals of opportunity for disaster recovery (DARPA, Rosum)

Source: DARPA web site
CWINS experiences

- **Urban Geolocation System Analysis and Demonstrator with TASC/Litton (DARPA SUO/SAS) -1997**
  - Measurement campaign in multiple buildings at 60, 90, 500 and 1000MHz
  - Observation of large errors caused by undetected direct path conditions

- **Wireless Indoor Geolocation and Vo-IP-v6 with University of Oulu, Finland (Nokia, Sonera, TEKES, Finland) – 1999**
  - TOA localization using HIPERLAN-2 OFDM WLAN signals

- **Indoor Geolocation Science for 4G Wireless Networks (NSF) – 2001**
  - Developed a framework for modeling the distance measurement error for traditional algorithms
  - Discovered the effectiveness of the super-resolution algorithms for TOA estimation

- **Innovative Methods for Geolocation and Communication with UWB Mobile Radio Networks, with IWT (ARL SBIR) - 2004**
  - UWB measurements and modeling for indoor geolocation in different buildings
  - Performance evaluation of traditional algorithms using these models

- **Innovative Indoor Geolocation Using RF Multipath Diversity – with Draper Laboratory – 2005**
  - Robust navigation in the absence of direct path
  - Channel modeling for dynamic behavior of channel

In addition, CWINS has had continual interactions with PinPoint, InTrak, Ekahau, PanGo and Skyhook
RF Propagation Measurements for SUO/SAS

Fc = 1 GHz / BW = 200 MHz
Peak value = -59.9 dB

Fc = 500 MHz / BW = 200 MHz
Peak value = -59.0 dB

Fc = 90 MHz / BW = 100 MHz
Peak value = -34.5 dB

Fc = 60 MHz / BW = 50 MHz
Peak value = -31.3 dB

J. Beneat, K. Pahlavan, and P. Krishnamurthy, "Radio Channel Characterization for Geolocation at 1 GHz, 500MHz, 90 MHZ, and 60 MHZ In SUO/SAS", MILCOM99, Atlantic City, NJ, November 1999
Super Resolution Techniques for TOA Estimation

Received signal → Estimation of channel frequency response → $\hat{H}(f)$ → Super-resolution algorithm → Pseudospectrum $S(\tau)$ → Detection of TOA $\tau_0$

A sample result:

Note:
IFT: uses Hanning window
DSSS: uses raised cosine pulses

Two Sources of Error

- The first path is not detectable by measurement system - Undetected Direct Path (UDP) [Pah98]
- Measurement bandwidth is not wide enough to distinguish the first few paths from each other [Ala03]

Limitations on Bandwidth

Undetected Direct Path

UWB Measurements for IWT/ARL

Bandwidth = 3GHz

Bandwidth = 500MHz

Distance Measurement Error Modeling

Scatter Plots of Distance Error for Different Bandwidths (OLOS)

Bandwidth = 50 MHz

Bandwidth = 100 MHz

Bandwidth = 500 MHz

UDP Cases (bandwidth independent)

Total 638 OLOS Points


Performance Evaluation Laboratories

- **Elements of an RF laboratory**
  - Channel simulators or a defined route
  - Interface to products
  - Isolated environment

- **Examples**
  - Testbed using a defined path
  - Ekahau localization testbed using Elektrobit channel simulator
  - Azimuth isolated testbed
Example: Comparisons Using a Specific Route

Indoor Position Using Least Square TOA (B.W. = 500 MHz)

Track of Movement
L.S. TOA Estimation
AP locations

Indoor Position Using Maximum Likelihood RSS (B.W. = 25 MHz)

Track of Movement
Max. Like. RSS Estimation
AP locations
WiFi vs UWB

Localization RMS Error (UDP)

Localization RMS Error (DDP)
Real-Time Channel Simulator

- Active channel simulator
- Provides simulation of up to 8 unidirectional channels
- Simulates multipath behavior using a tapped delay line
- Can be utilized for a wide range of wireless devices (e.g. cellular, WLAN, sensors, RFIDs, etc.)
- Frequency specifications:
  - Bandwidth of 70 MHz
  - Frequency range from 350MHz to 6 GHz

(Elektrobit PROPSim C8)

Purchased with DoD grant
Example: Testbed for Ekahau Deployment

Deployment Analysis
Performance Results
RF Isolated Environment

- Cabled WLAN test solution
- Provides high levels of isolation from the surrounding environment
- Allows for repeatability
- Full automation and remote access capability
- Various test setups possible including range, roaming, and VoIP

(Azimuth Systems 801W)

Purchased with NSF grant
Example: Testbed for WiFi Coverage

Testbed Equipment for Coverage
Sample RSSI of WiFi

Average RSSI vs. Linear Distance

<table>
<thead>
<tr>
<th>RSSI [dBm]</th>
<th>Linear Distance [m]</th>
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<tbody>
<tr>
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<tr>
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<tr>
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Conclusions

- Multipath poses a serious challenge to design of robust indoor geolocation systems.
- There are a number of candid technologies, we need testbeds to compare their performances.
- Channel measurement and modeling is essential for understanding of the behavior of the channel to implement meaningful testbeds for performance evaluation.
For details of our projects and publications see:

www.cwins.wpi.edu