Precision Indoor Personnel Location and Tracking for Emergency Responses

Technology Workshop, Aug 7-8, 2006

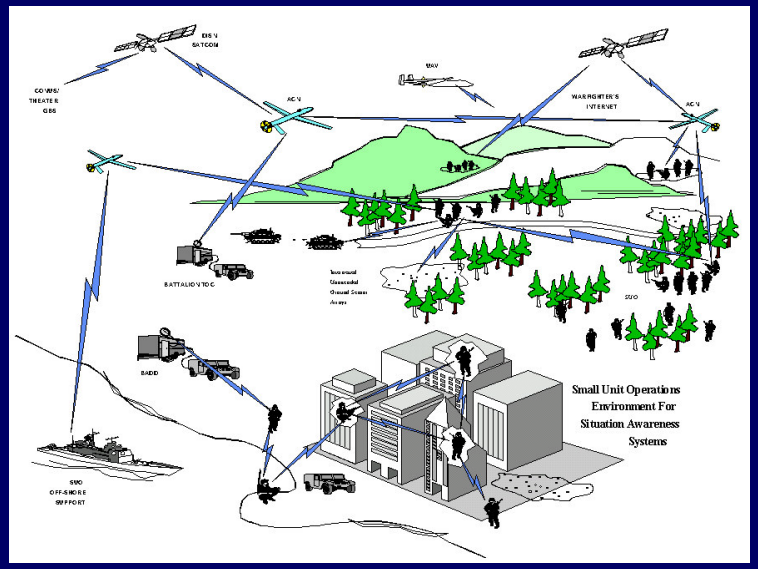
Multipath and Robust Precise Indoor Geolocation

Kaveh Pahlavan

August 8, 2006

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)

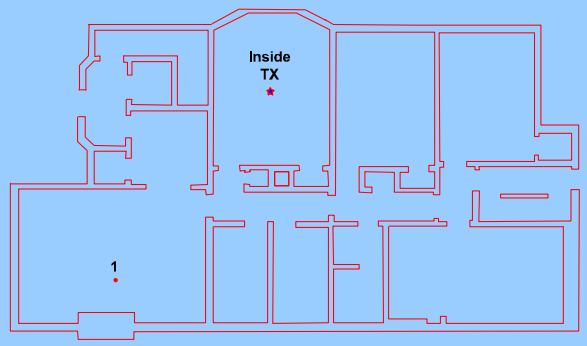
Source: DARPA web site

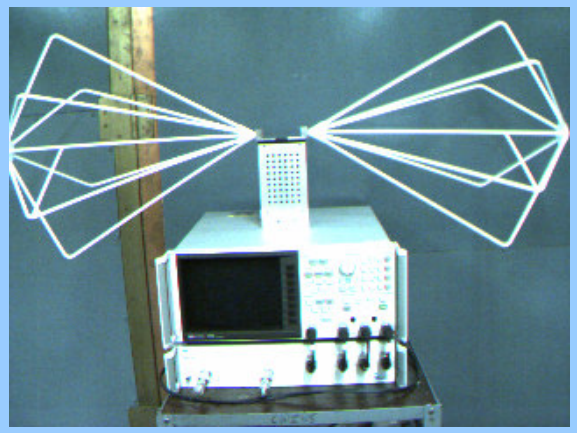
CWINS experiences

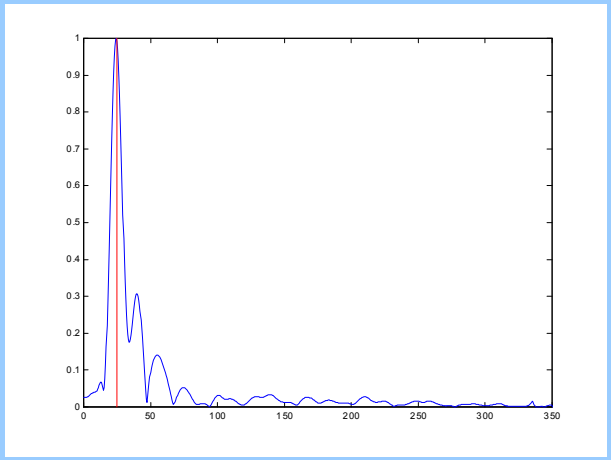
- Urban Geolocation System Analysis and Demonstrator with TASC/Litton (DARPA SUO/SAS) -1997
  - Measurement campaign in multiple buildings at 60, 90, 500 and 1000MHz
  - Observation of large errors caused by undetected direct path conditions
- Wireless Indoor Geolocation and Vo-IP-v6 with University 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

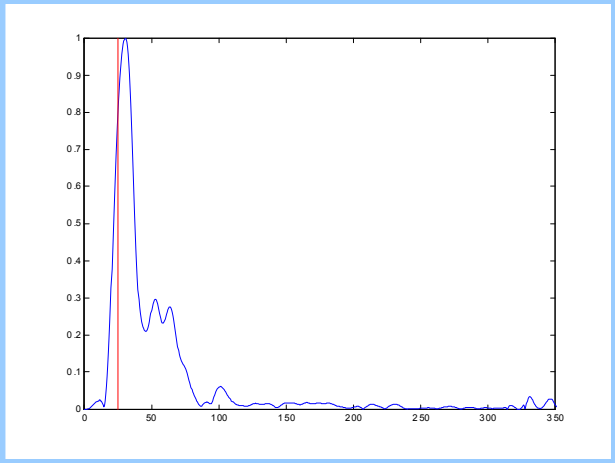
RF Propagation Measurements for SUO/SAS



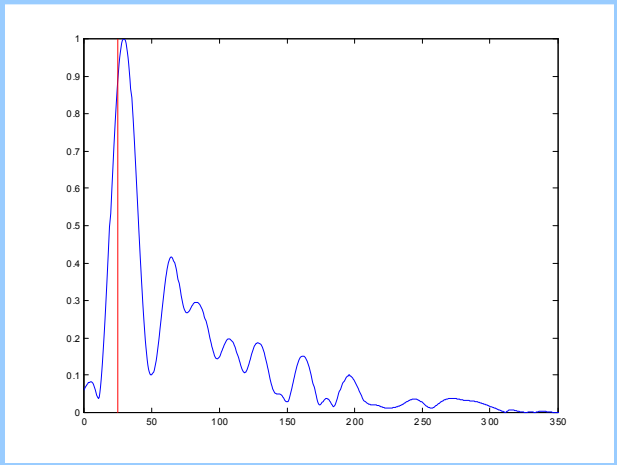




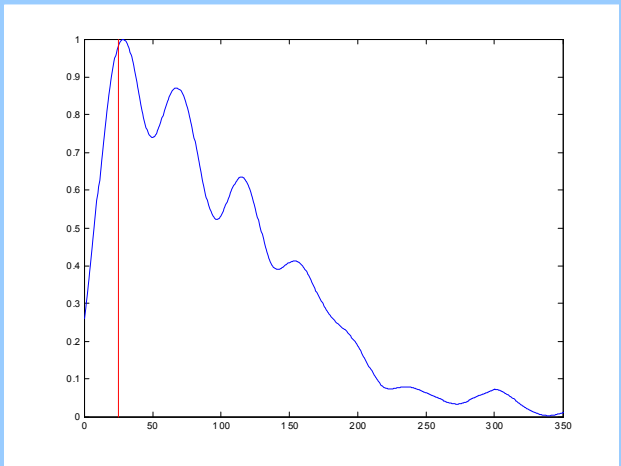
Fc = 1 GHz / BW = 200 MHz
Peak value = -59.9 dB



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



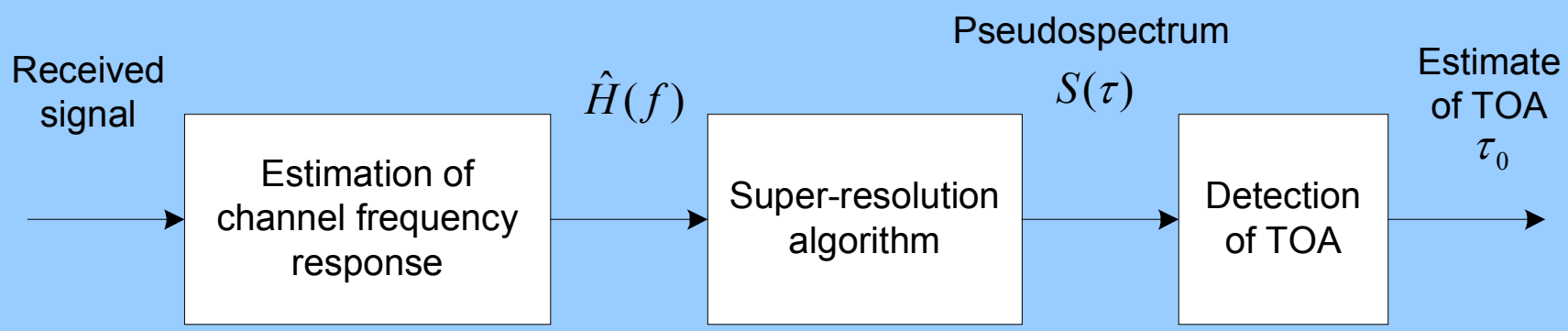
Fc = 90 MHz / BW = 100 MHz
Peak value = -34.5 dB



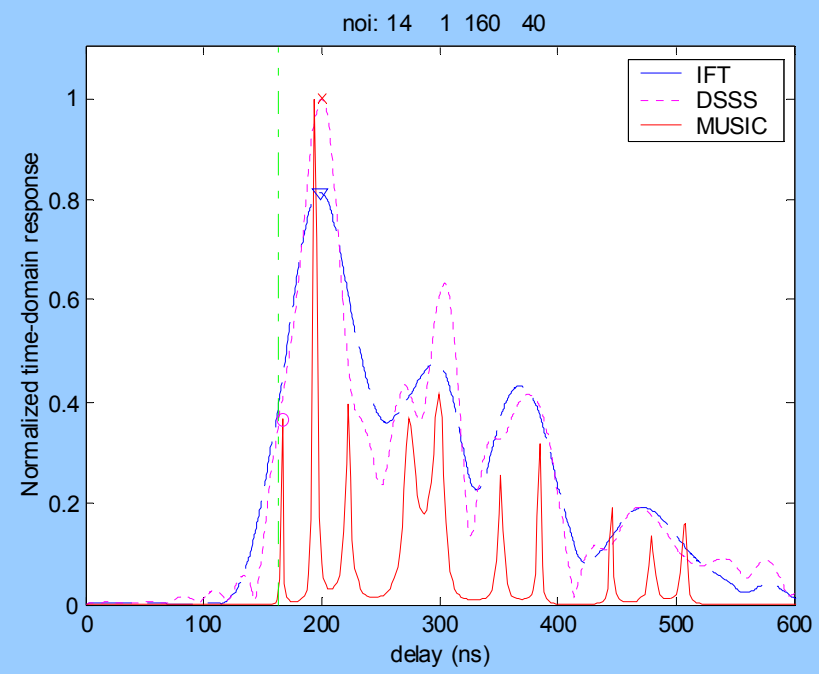
Fc = 60 MHz / BW = 50 MHz
Peak value = -31.3 dB

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



A sample result:



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

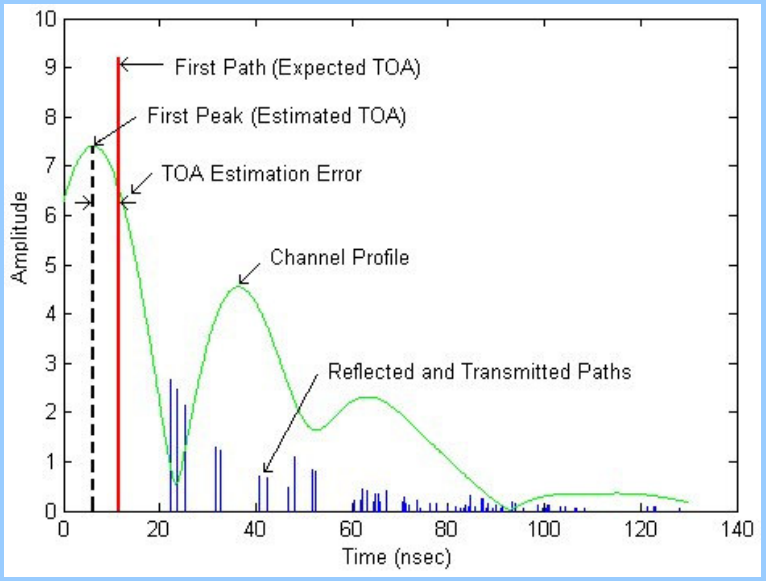
X. Li and K. Pahlavan, "Super-resolution TOA estimation with diversity for indoor geolocation", IEEE Trans on Wireless Comm. Dec. 2003

X. Li, " Super-resolution TOA Estimation with Diversity for Indoor Geolocation", PhD Dissertation, CWINS, WPI, 2003

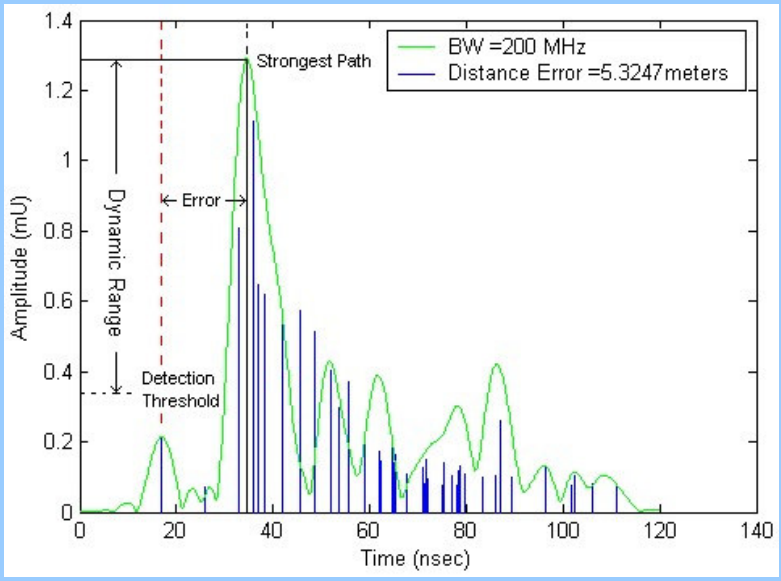
N. Alsindi, X. Li, K. Pahlavan, "Analysis of TOA estimation using wideband measurements of indoor radio propagations," accepted for publication in *IEEE Transactions on Instrumentation and Measurement*, 2006.

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

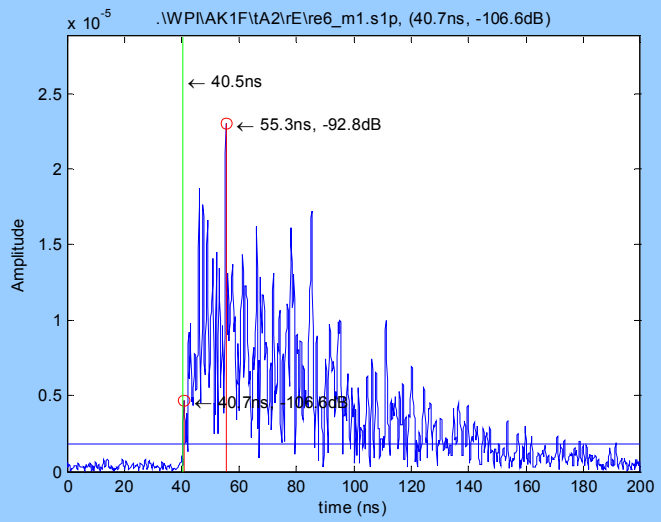


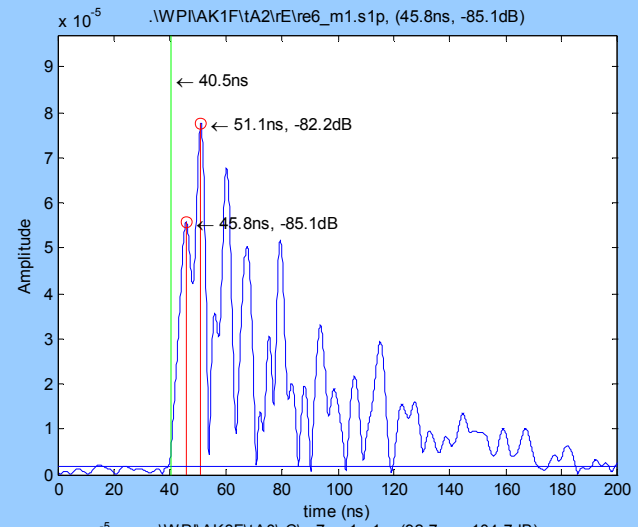
Undetected Direct Path

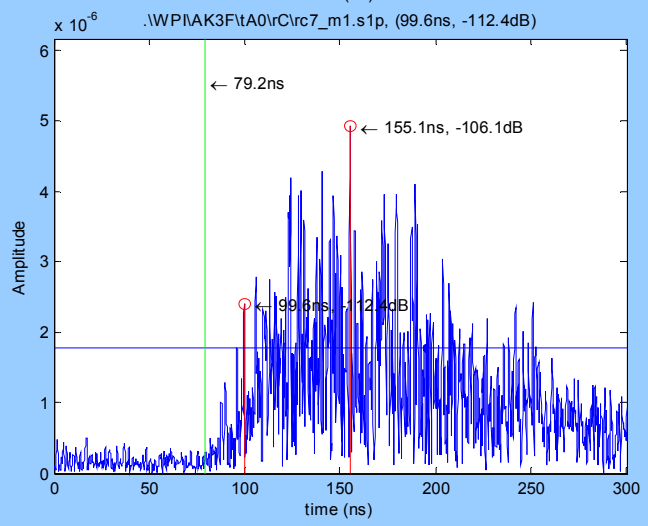
[Pah98] K. Pahlavan, P. Krishnamurthy and J. Beneat, "Wideband Radio Propagation Modeling for Indoor Geolocation Applications", IEEE Communications Magazine, April 1998.

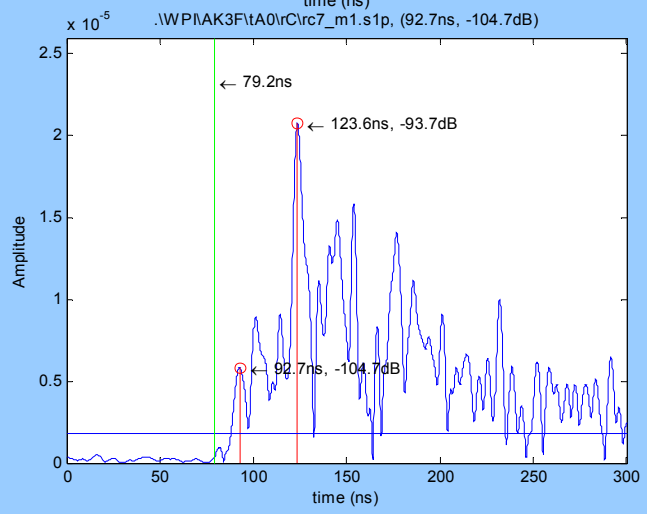
[Ala03] B. Alavi and K. Pahlavan, "Bandwidth Effect on Distance Error Modeling for Indoor Geolocation," 14th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC'03), Beijing, China, September 7-10, 2003.

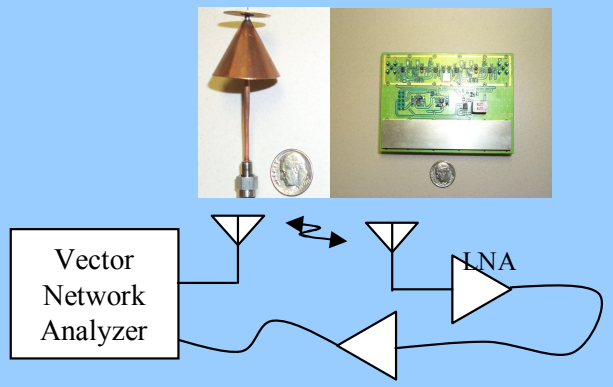
UWB Measurements for IWT/ARL











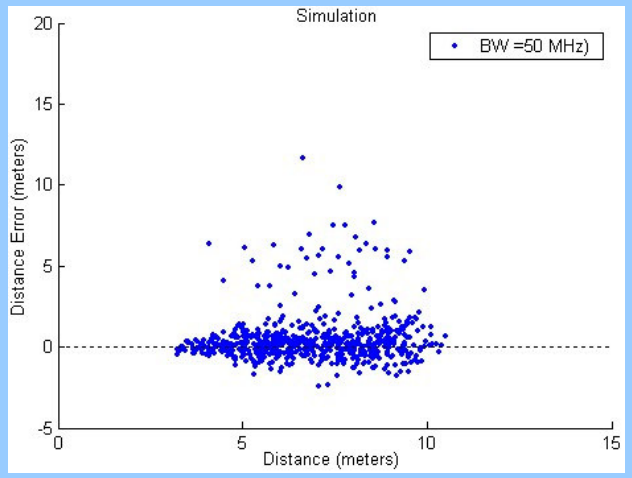
Bandwidth = 3GHz

Bandwidth = 500MHz

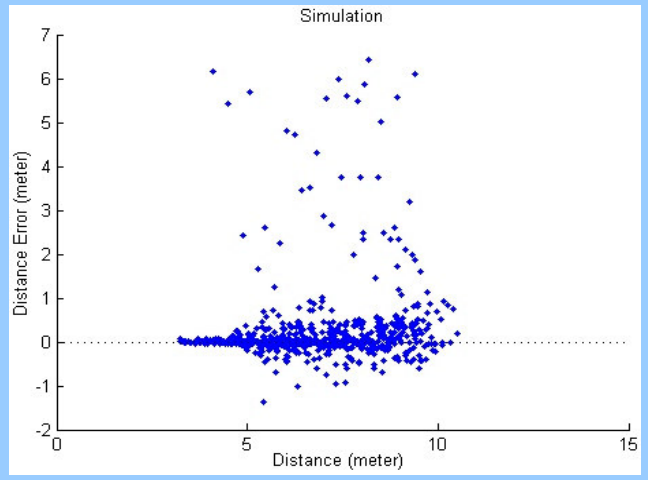
B. Alavi, N. Alsindi, K. Pahlavan, "UWB Channel Measurements for Accurate Indoor Localization," Military Communications Conference Proceedings, MILCOM 2006, Washington, DC, 23-25 October 2006.

Distance Measurement Error Modeling

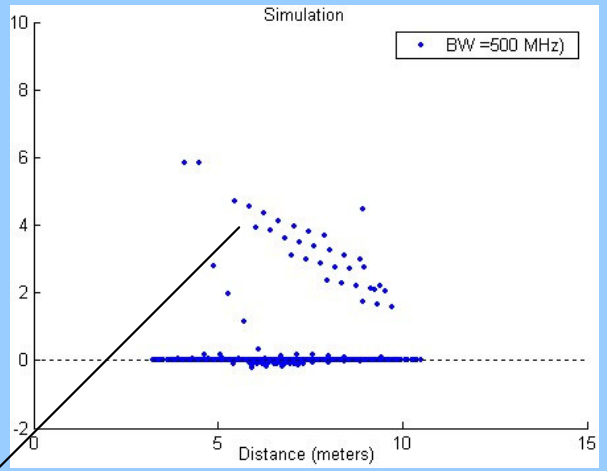
Scatter Plots of Distance Error for Different Bandwidths (OLOS)



Bandwidth = 50 MHz



Bandwidth = 100 MHz



Bandwidth = 500 MHz

UDP Cases (bandwidth independent)

Total 638 OLOS Points

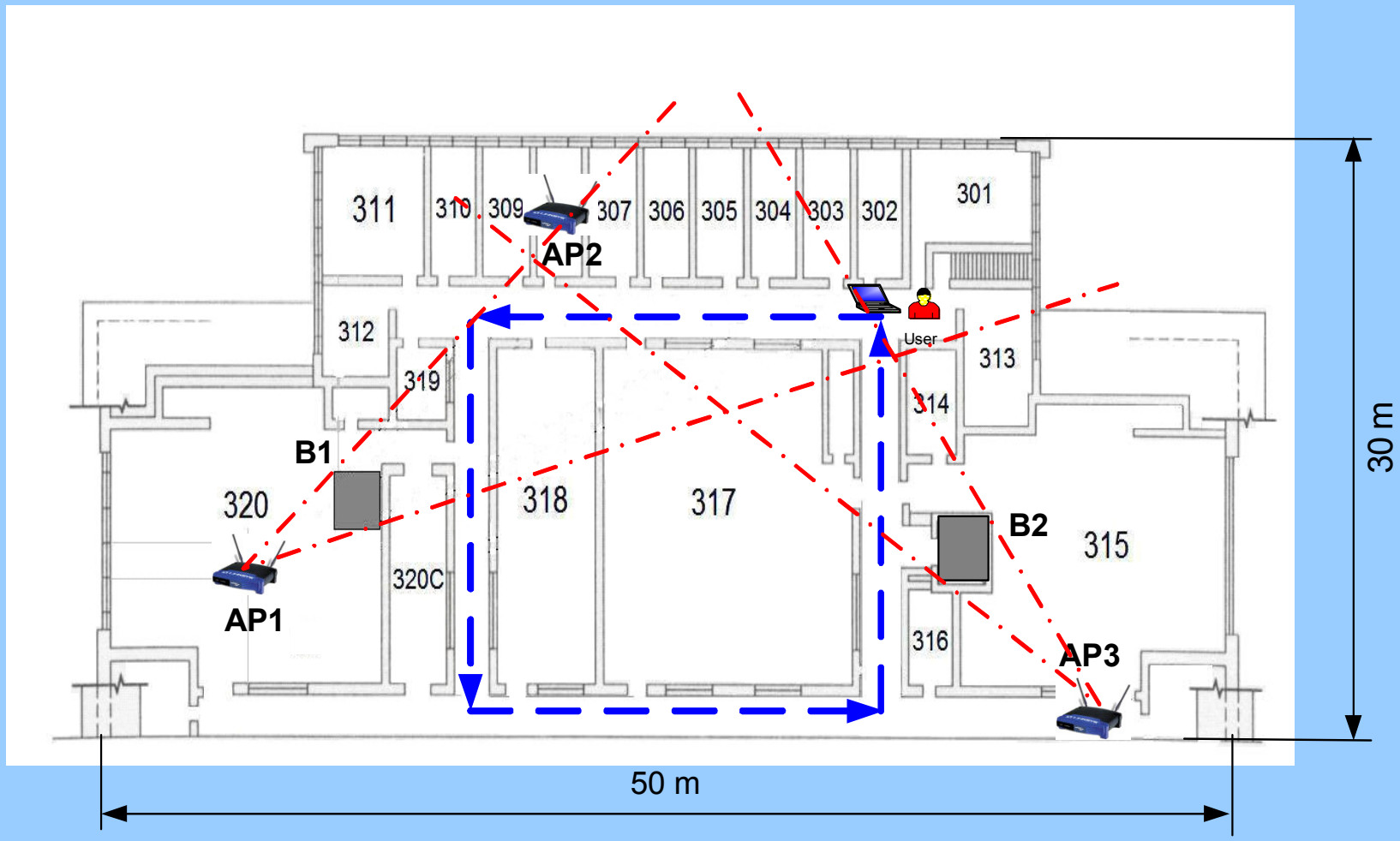
Bardia Alavi and Kaveh Pahlavan, "Modeling of the TOA based Distance Measurement Error Using UWB Indoor Radio Measurements" IEEE Communications Letters, April 2006.

Bardia Alavi, "Distance Measurement Error Modeling for Time-of-Arrival Based Indoor Geolocation", PhD Dissertation, CWINS, WPI, April 2006.

Performance Evaluation Laboratories

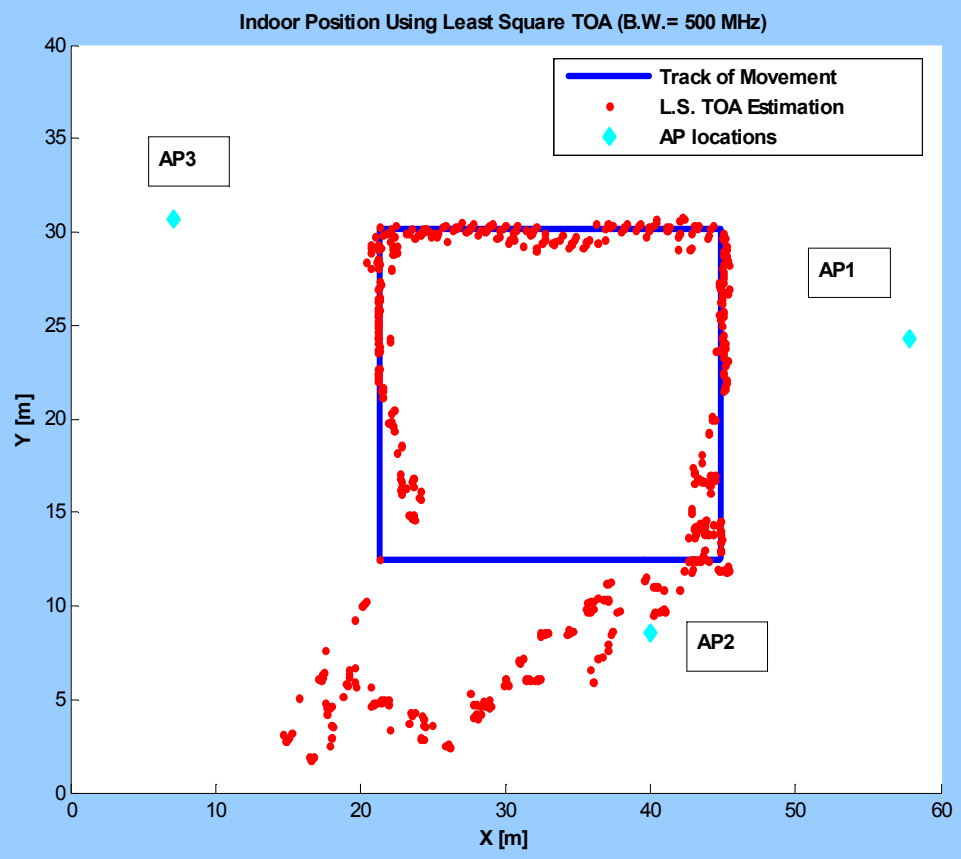
- Elements of an RF laboratory
  - Channel simulators or a defined route
  - Interface to products
  - Isolated environment
- Examples
  - Testbed using a defined path
  - Ekahau localization testbed using Elektrobit channel simulator
  - Azimuth isolated testbed

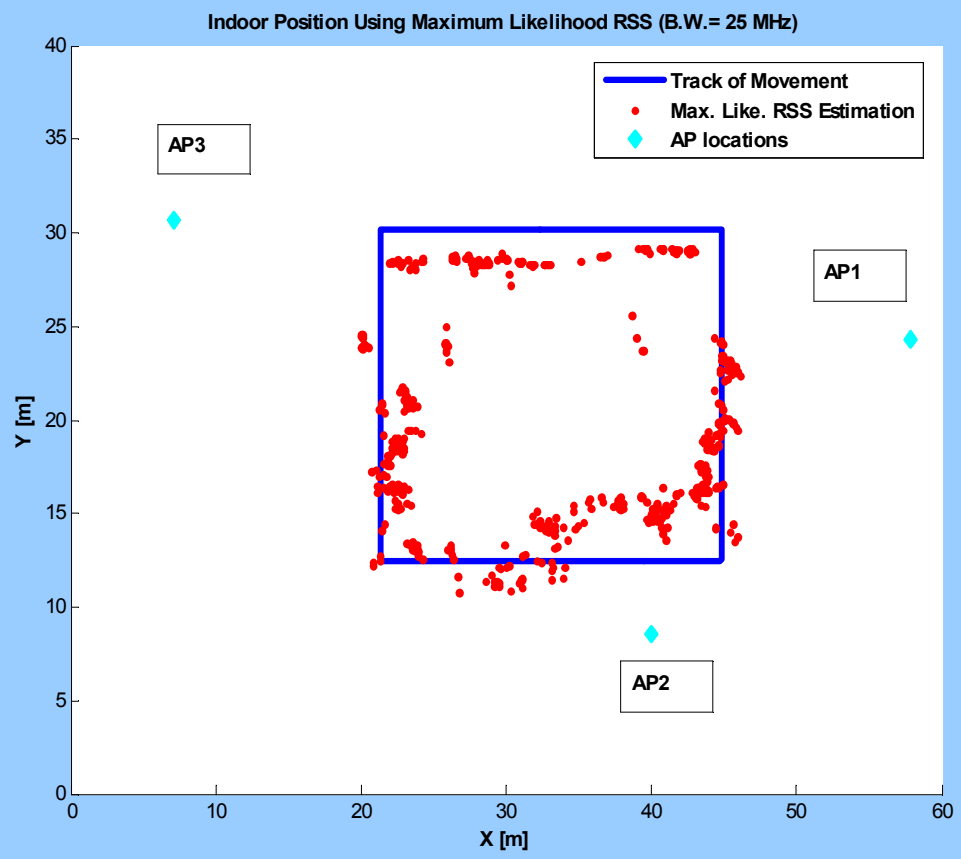
Example: Comparisons Using a Specific Route



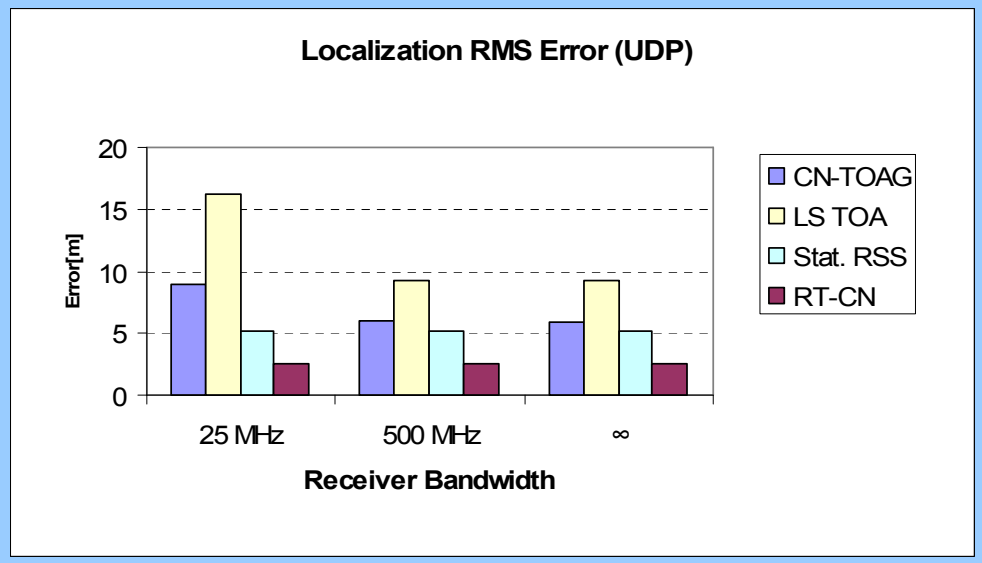
A. Hatami, and Kaveh Pahlavan, " Comparative statistical analysis of indoor positioning using empirical data and indoor radio channel models," *Consumer communications and networking conference*, 2006

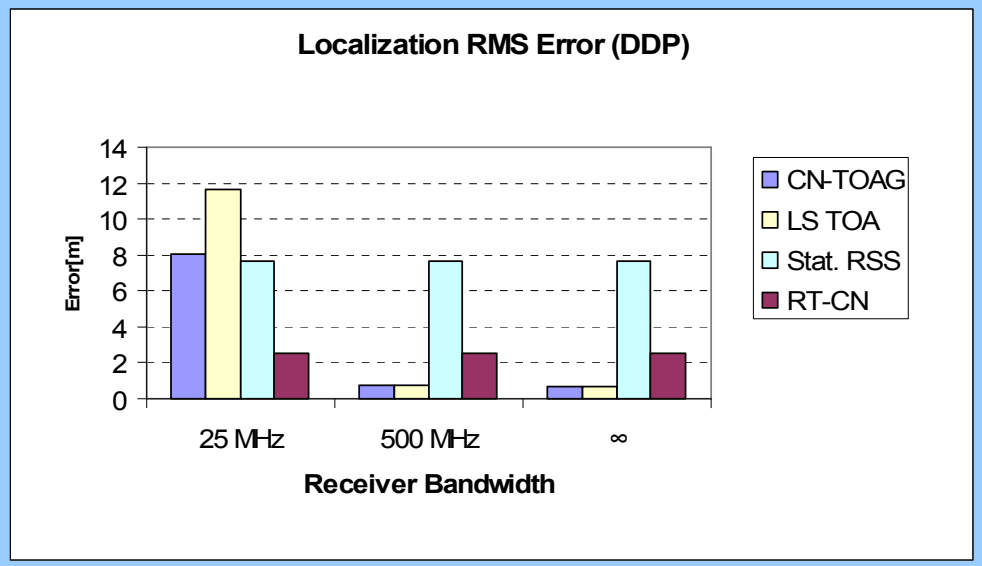
TOA vs RSS





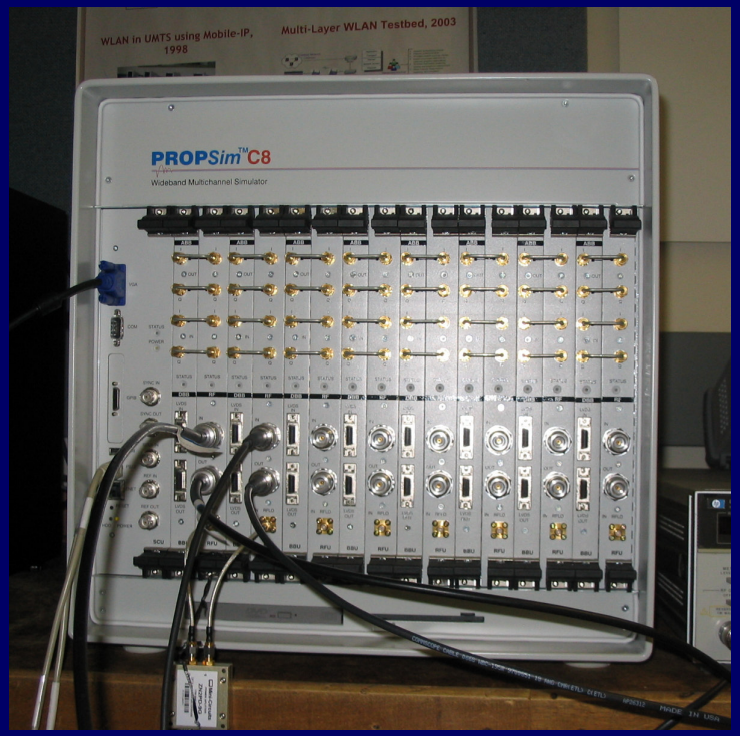
WiFi vs UWB





Real-Time Channel Simulator

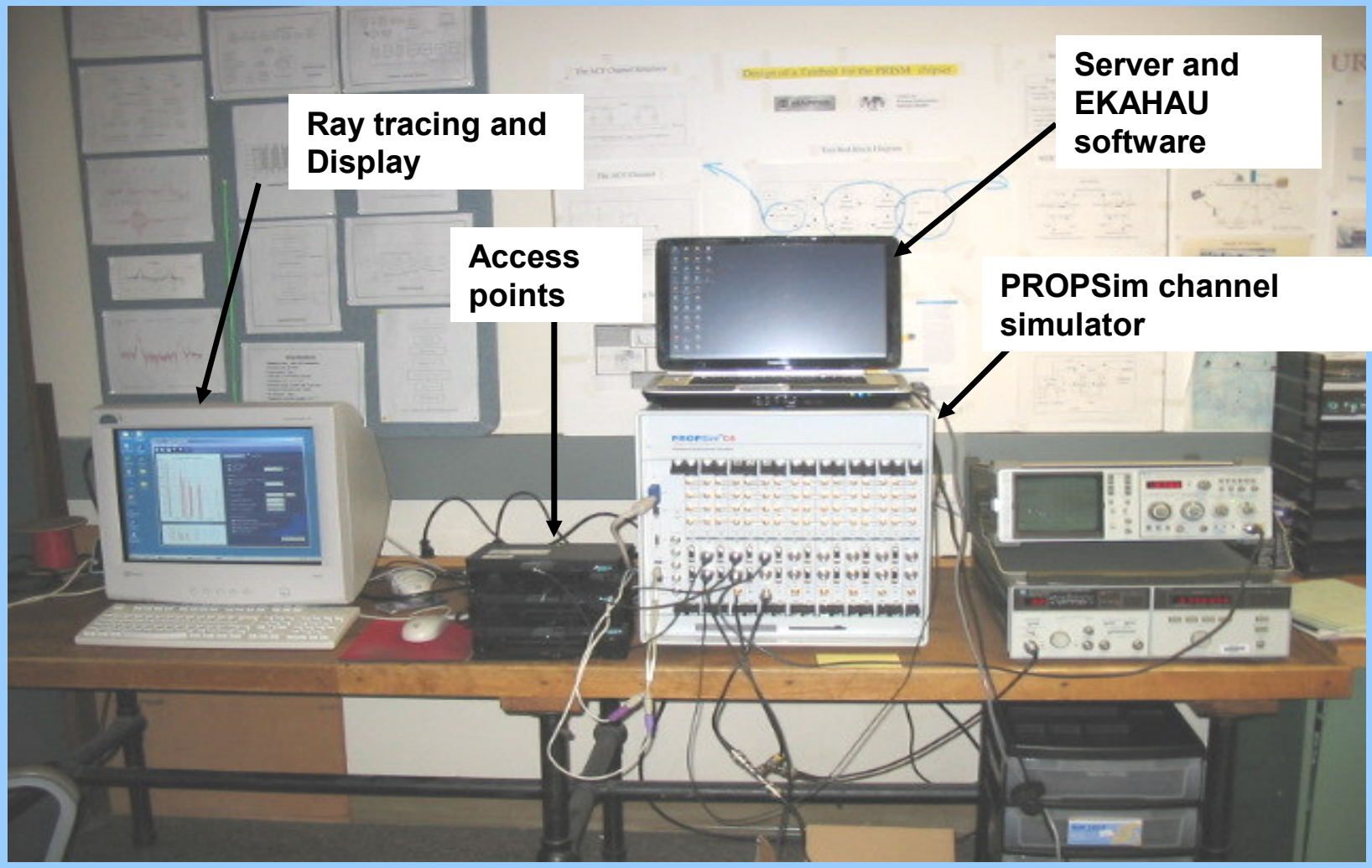
- Active channel simulator
- Provides simulation of up to 8 unidirectional channels
- Simulates multipath behavior using a tapped delay line
- Can be utilized for a wide range of wireless devices (e.g. cellular, WLAN, sensors, RFIDs, etc.)
- Frequency specifications:
  - Bandwidth of 70 MHz
  - Frequency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



(Elektrobit PROPSim C8)

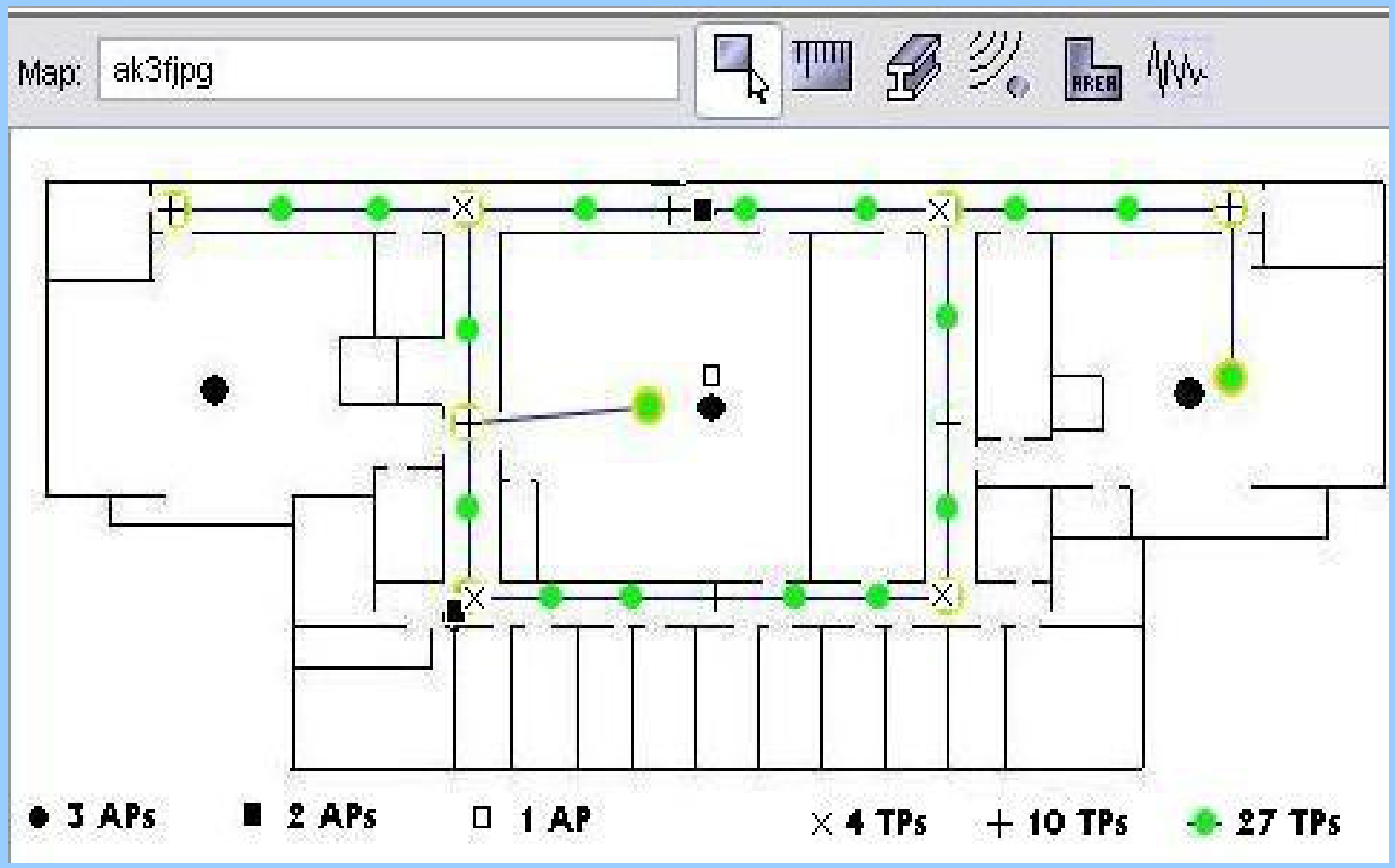
Purchased with DoD grant

Example: Testbed for Ekahau Deployment

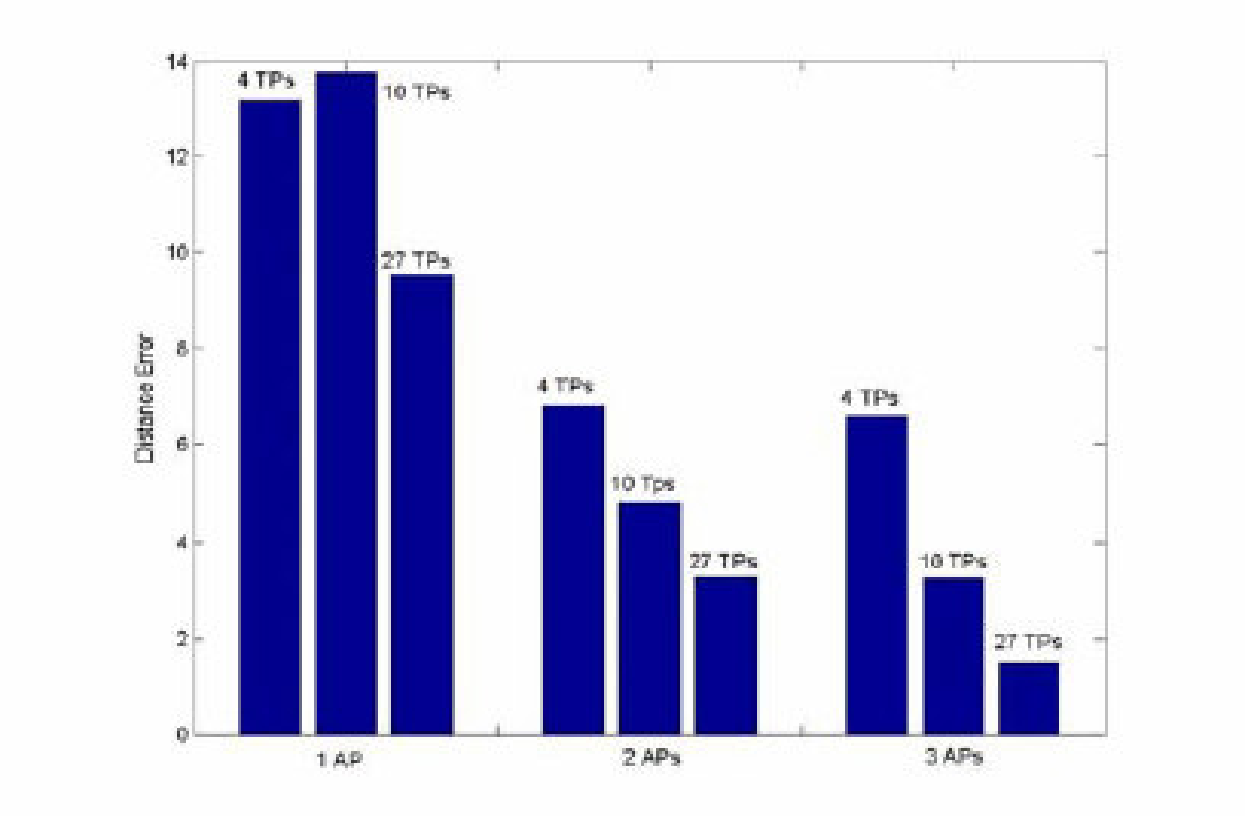


M. Heidari and K. Pahlavan, Performance Evaluation of Indoor Geolocation Systems Using PROPSim Hardware and Ray Tracing Software, IWWAN'04, Oulu, Finland, May 2004.

Deployment Analysis

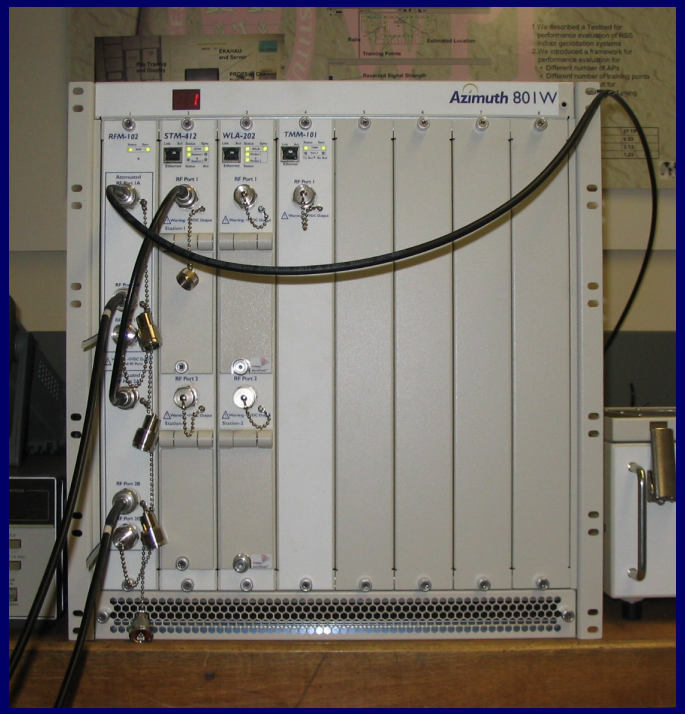


Performance Results



RF Isolated Environment

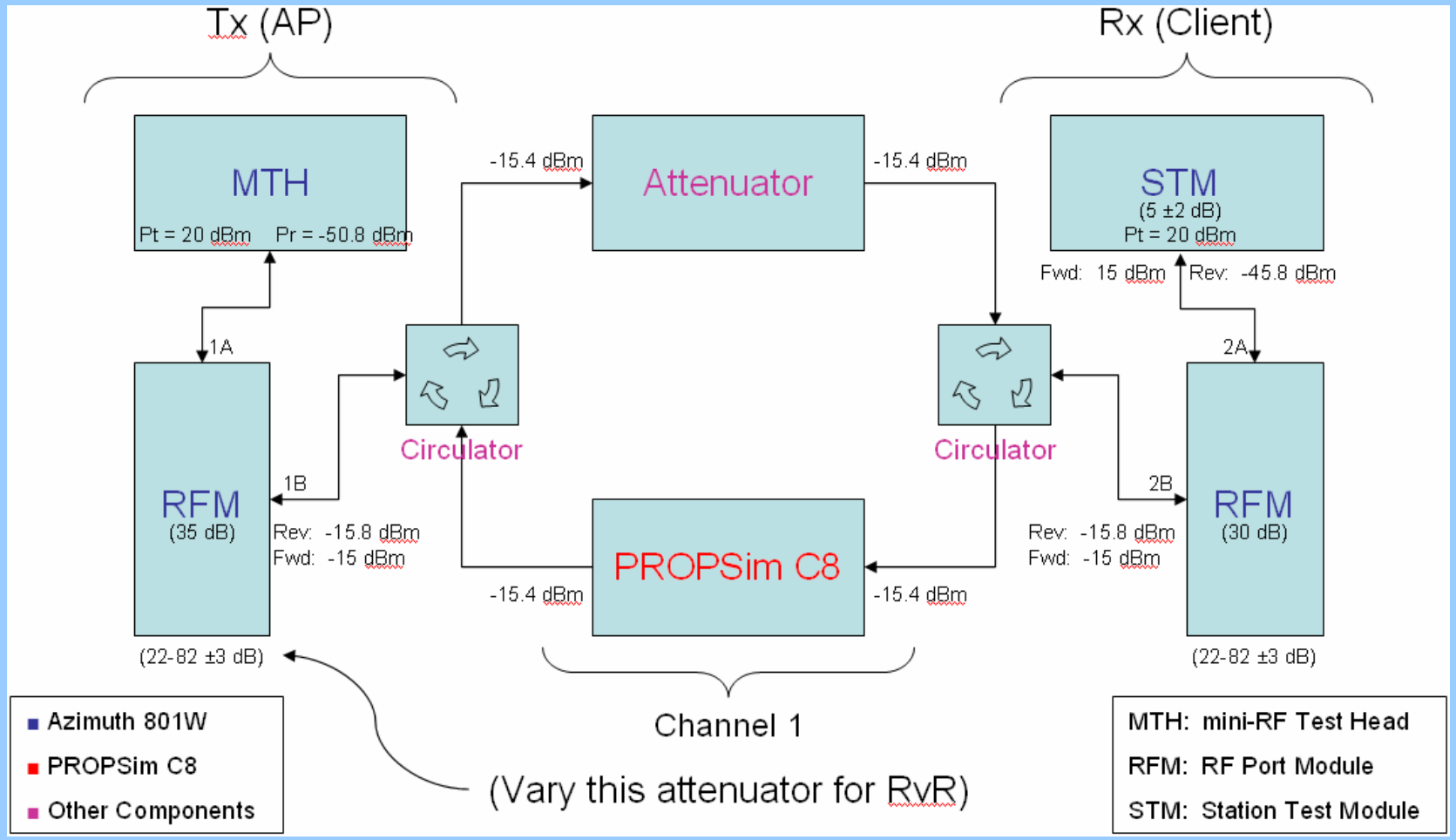
- Cabled WLAN test solution
- Provides high levels of isolation from the surrounding environment
- Allows for repeatability
- Full automation and remote access capability
- Various test setups possible including range, roaming, and VoIP



(Azimuth Systems 801W)

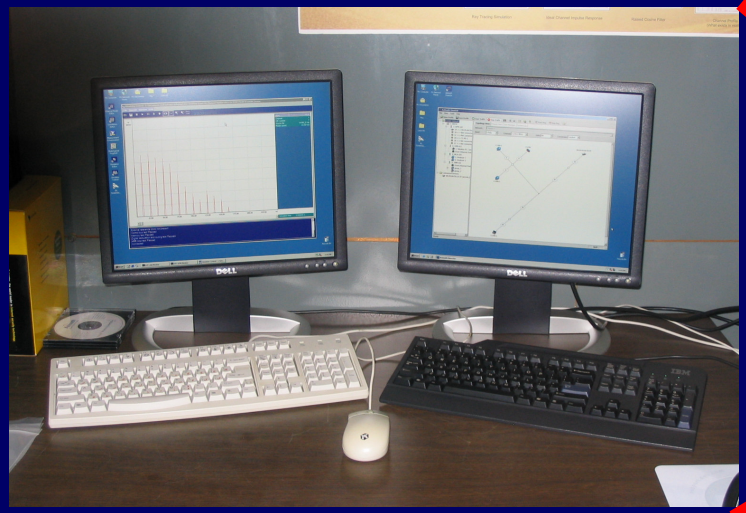
Purchased with NSF grant

Example: Testbed for WiFi Coverage

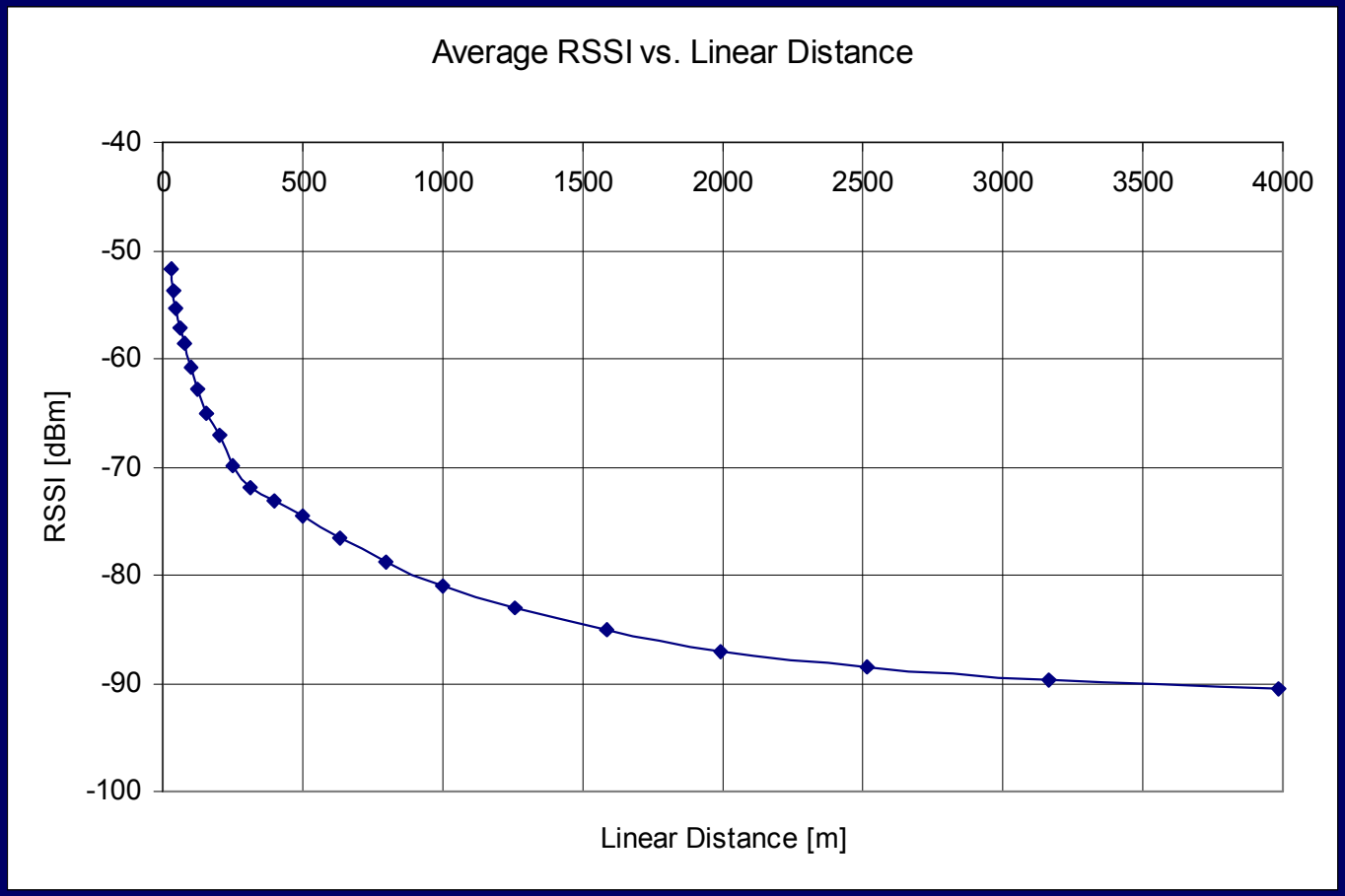


L.T. Metreaud and K. Pahlavan, "RF Isolated Real-Time Multipath Testbed for Performance Analysis of WLANs," presented at the 40th Annual Conference on Information Sciences and Systems, Princeton, NJ, 2006.

Testbed Equipment for Coverage



Sample RSSI of WiFi



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