

WPI Precision Personnel Location System: Automatic Antenna Geometry Estimation

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The PPL Team

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Outline

- PPL System Overview
 - Background
 - System hardware
 - Transmitter location results
- Geometric Auto Configuration (GAC)
 - Ranging technique
 - Antenna geometry estimation
 - Results: outdoor, indoor, around bldg.

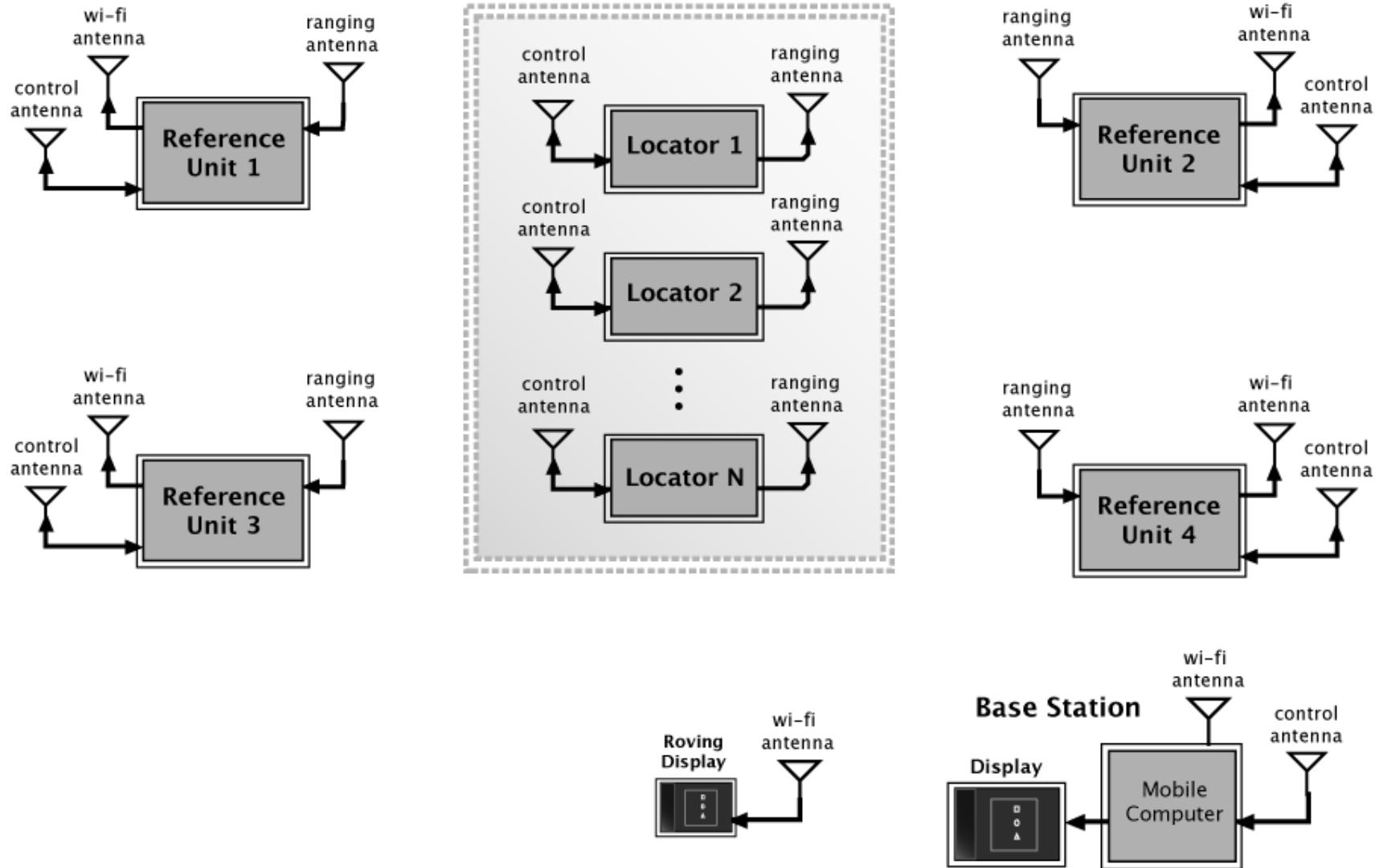
Position-Finding Technology for Emergency Personnel is a Critical Need

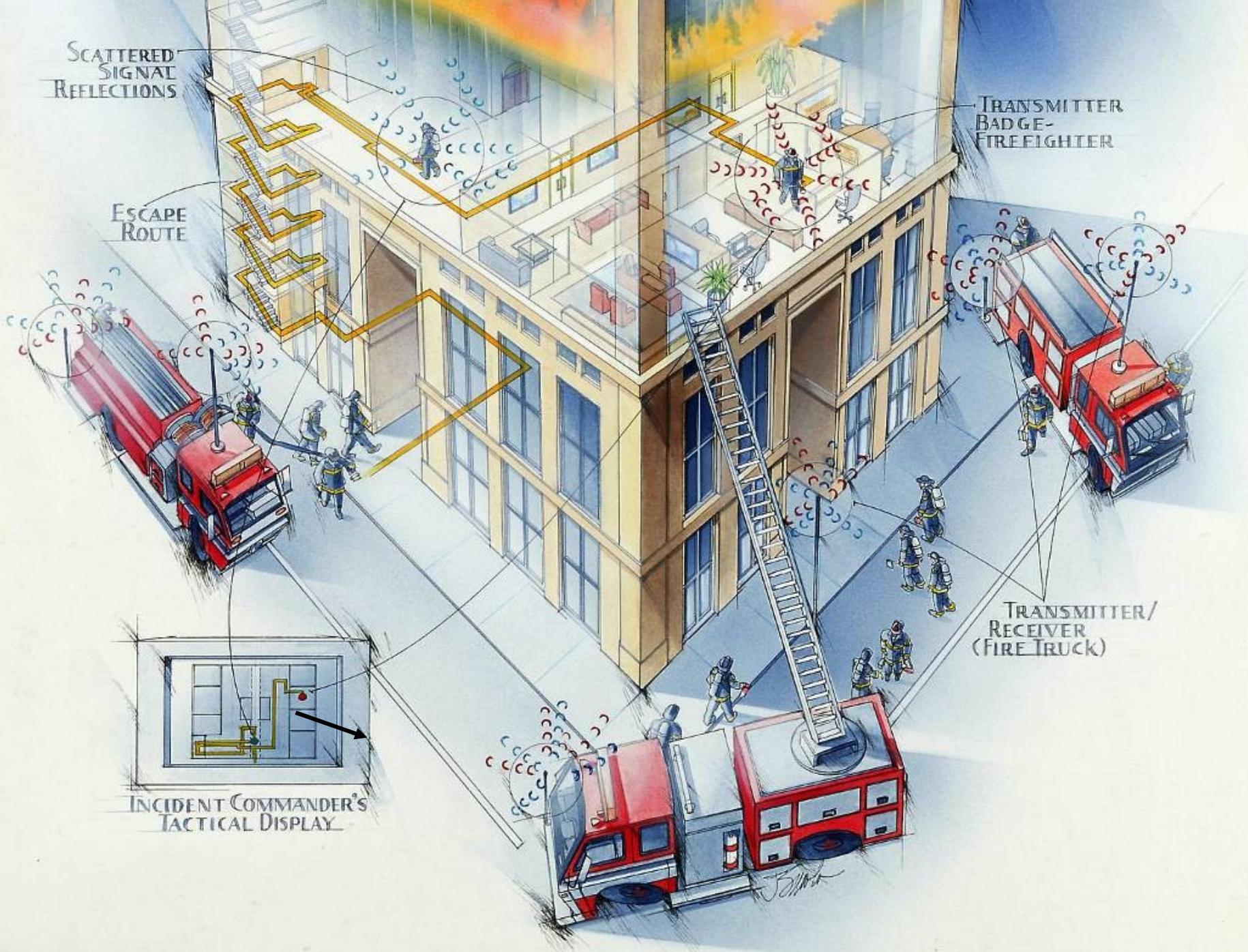
- 12/3/99: Six firefighters died in a warehouse fire literally within a few feet of safety in Worcester, MA.
- 9/11/01: A disaster of far greater magnitude, with some deaths in circumstances similar to the Worcester warehouse fire
- NFPA: lost/trapped 3rd ranking cause of fatalities
- Current emergency responder escape technology:
 - Audio alarms which sound upon lack of motion
 - Homing devices (Ultrasonic, RF) becoming available

WPI PPL Goal

- A location and tracking system which
 - displays locations, paths, and landmarks (exits, waypoints, etc.)
 - for multiple responders
 - in 3 dimensions,
 - requiring no pre-installed infrastructure
 - and minimal setup
- Must be transparent to users
- Solution: geometric auto configuration (GAC)

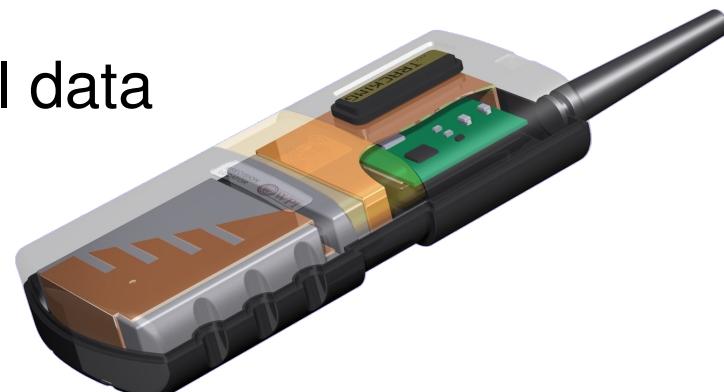
System Overview



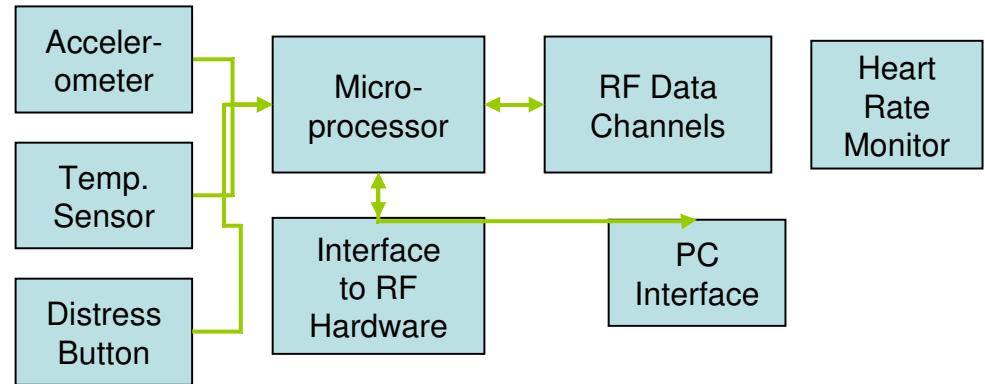


Locator Operational/Physical Specs

- Transmit ranging signal
 - Up to 150 MHz bandwidth
 - programmable waveform
 - Support 100 locators
 - Updates each second
- Low power, long battery life, automatic on/off
- Monitor and report environmental status data
 - Temperature, movement, diagnostics
- Provide distress button
- Small size, lightweight
- Provide support for Physiological data



Current Locator Hardware

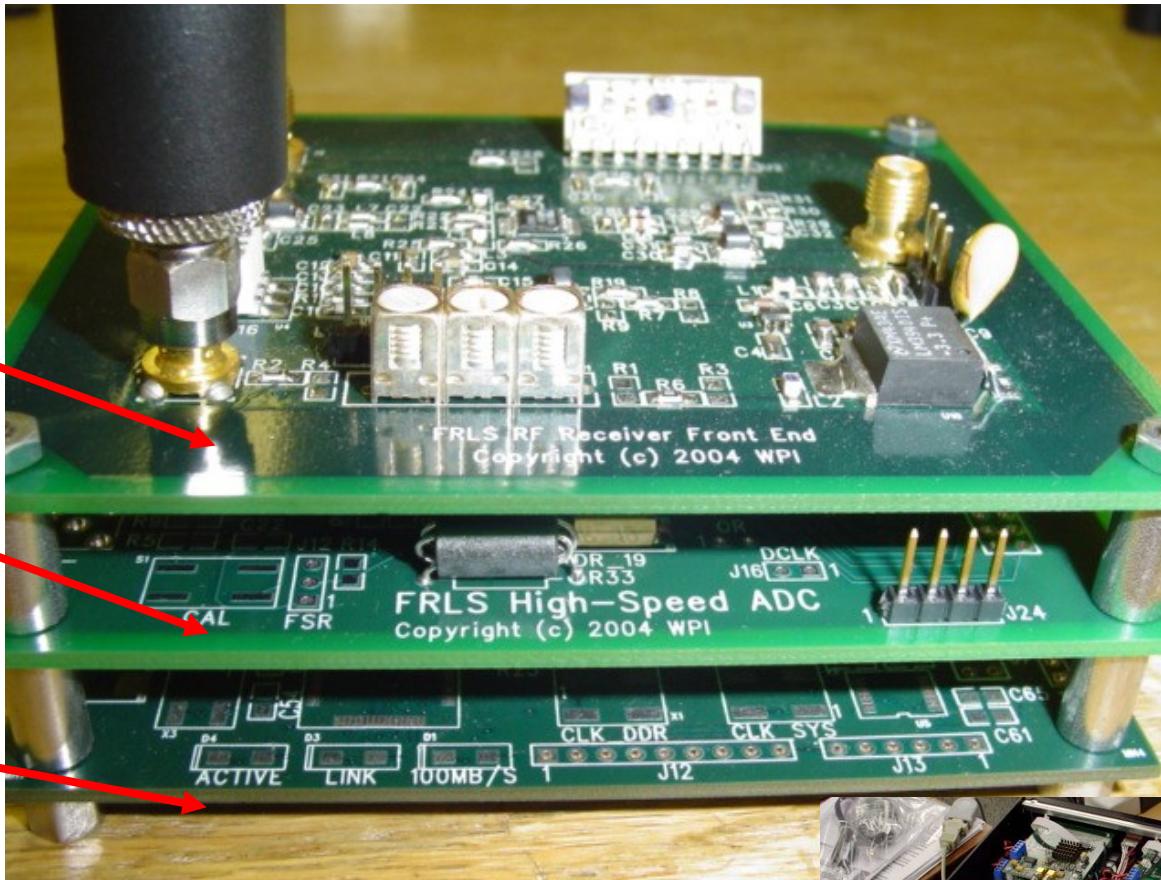


Custom FPGA based Software Radios

RF Front End
board

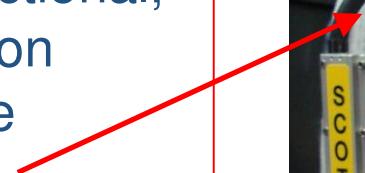
Analog to Digital
board

FPGA Digital
Controller board



Antenna Design and Testing

Several innovations have been introduced in small, wideband, near-omni directional, multi-polarization patch and base antennas

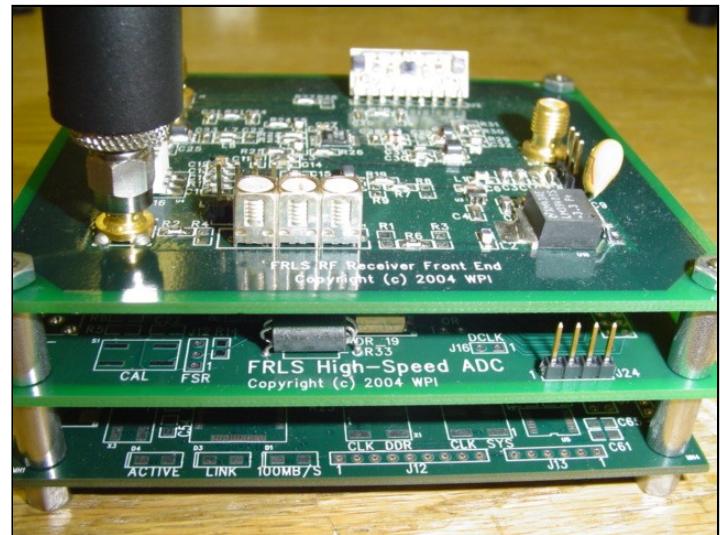


Antenna Concept for Fire Trucks



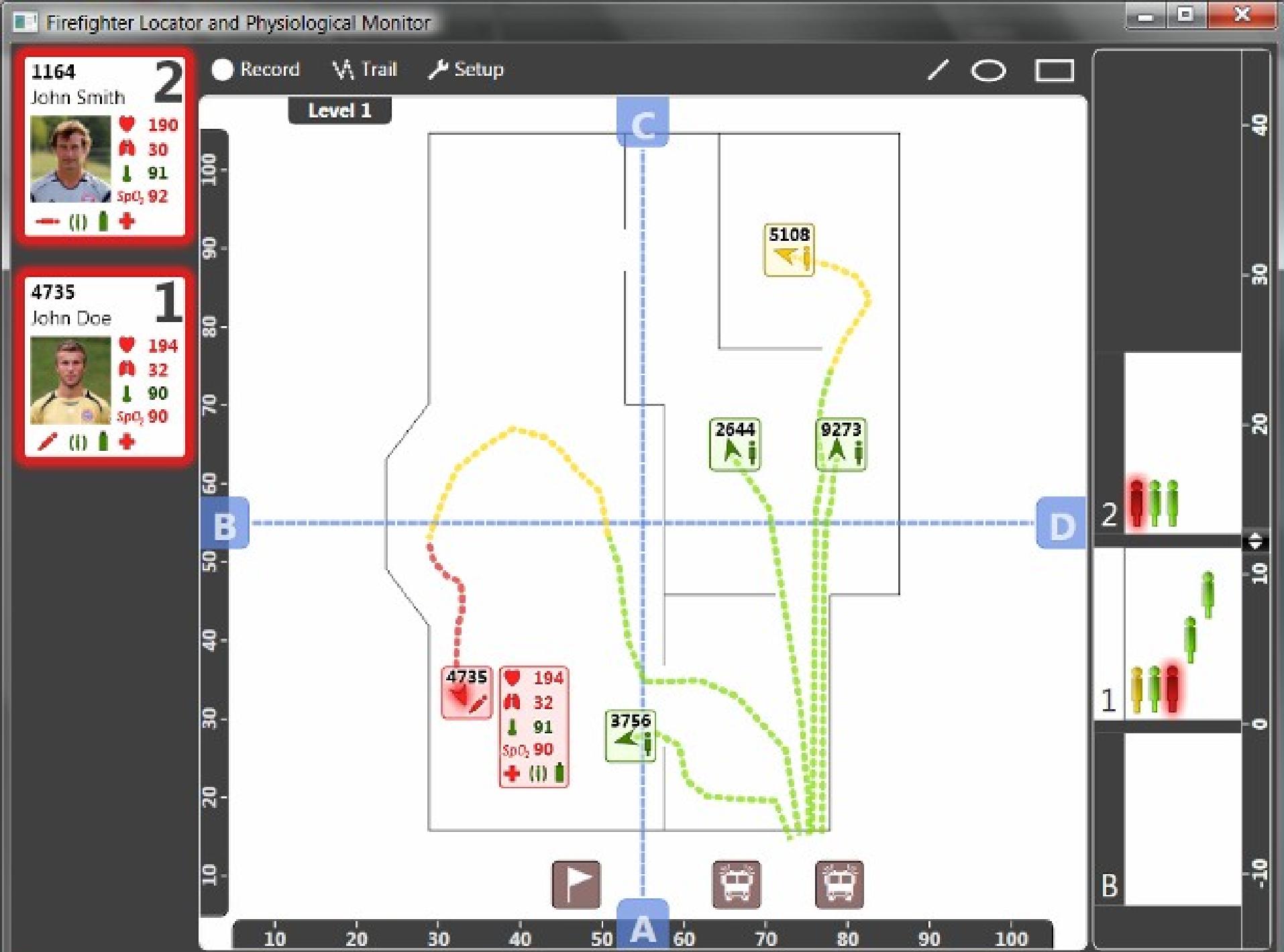
Patch
Antennas

System Hardware



Videos

- Live system operation
- Real-time tracking display
- New display integrating tracking and physiological status monitoring/reporting



Location System Performance Review

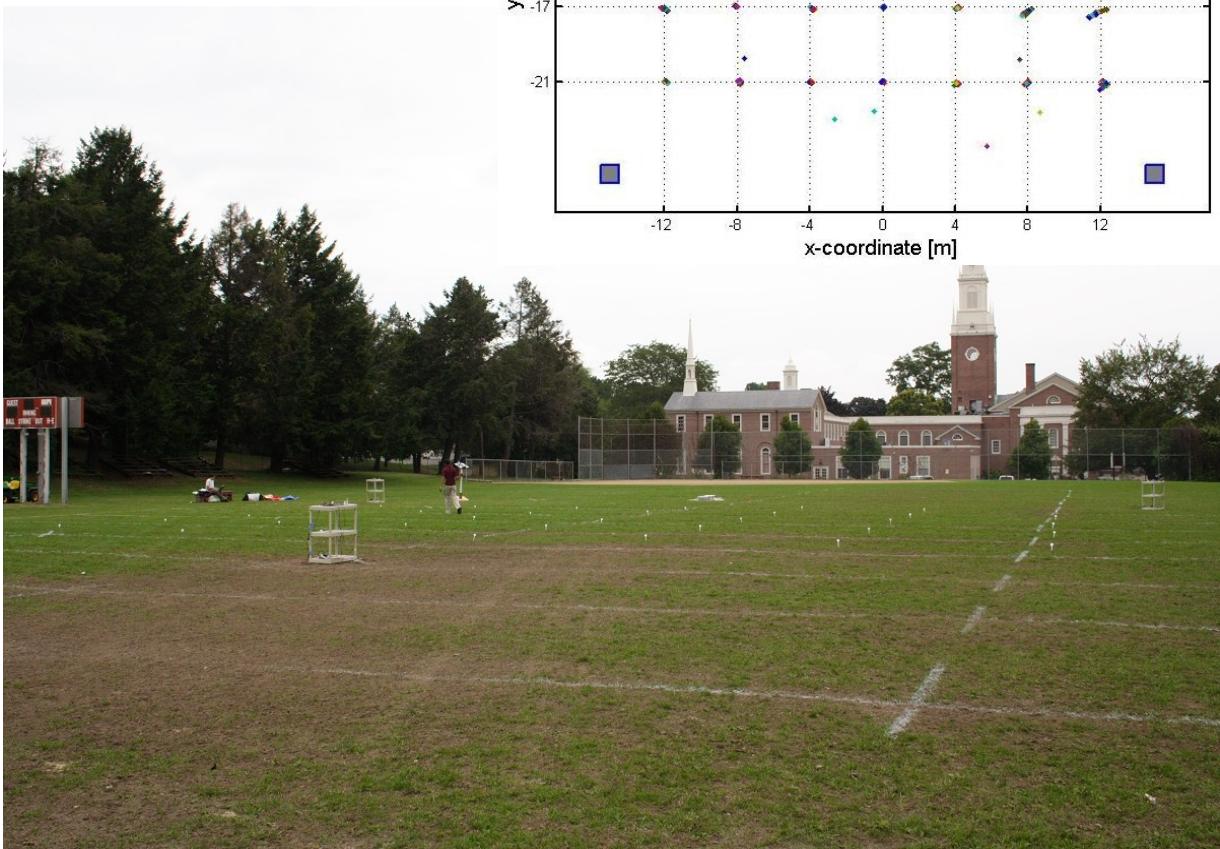
- Different Scenarios
 - Outdoor to Indoor
 - Indoor to Indoor
 - Around Building
- Our system has demonstrated sub-meter accuracy in location estimation in all these configurations
- The location performance sets the bar for the performance of GAC

2005: Outdoor 2D TDOA results

Our new multicarrier (MC) signal structure and processing approach theoretically provides high accuracy ranging data with low bandwidth and spectral flexibility

Outdoor tests proved that our approach could achieve high precision results with low bandwidth

Only classic radio location algorithms were applied to the new ranging data



New end-to-end method developed



- Previous papers document results from a new location method developed by WPI
- Location system does not use TDOA or other classic triangulation-inspired technique



Through-wall/High Multipath Demo

**Antennas on
3 sides WPI
Civil Eng.
Building –
poor
geometry**

**Antennas
facing
directly into
brick walls**

**No system
training
information
or pre-sited
devices**



Kaven Hall Geology lab test site

2006 Live Demo
site was WPI
Civil Eng.
Geology Lab.

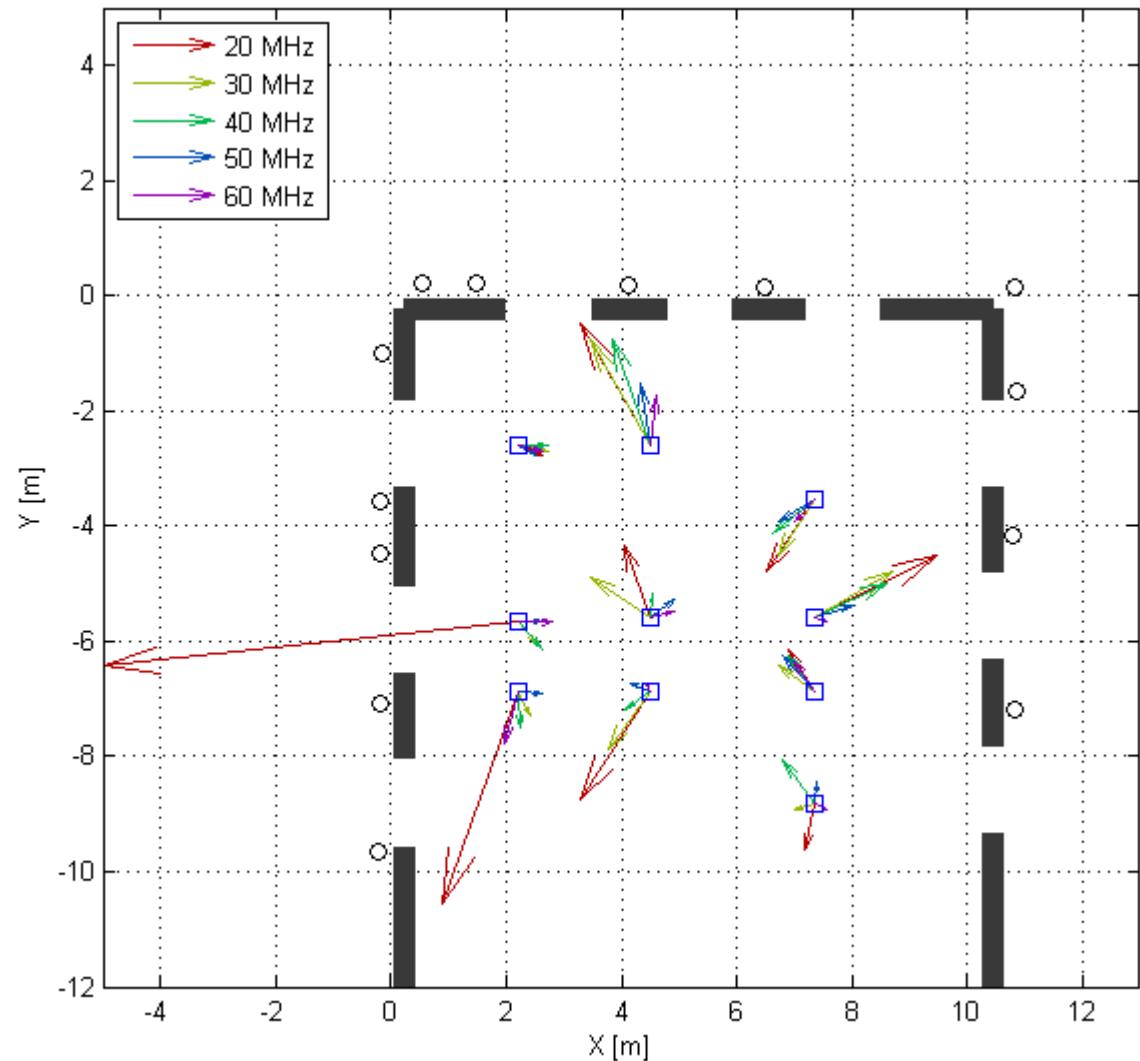
Steel Frame and
concrete block
construction
with heavy
equipment and
metal cabinets.

2006 test
achieved 1 m
average abs.
error using 30
MHz signal.



Effects of Increased Bandwidth

- 410-470MHz
 - Middle Slice
- Mean Error
 - 20MHz: 2.32m
 - 30MHz: 1.00m
 - 40MHz: 0.87m
 - 50MHz: 0.58m
 - 60MHz: 0.5m,
 - improved SP:
0.37m



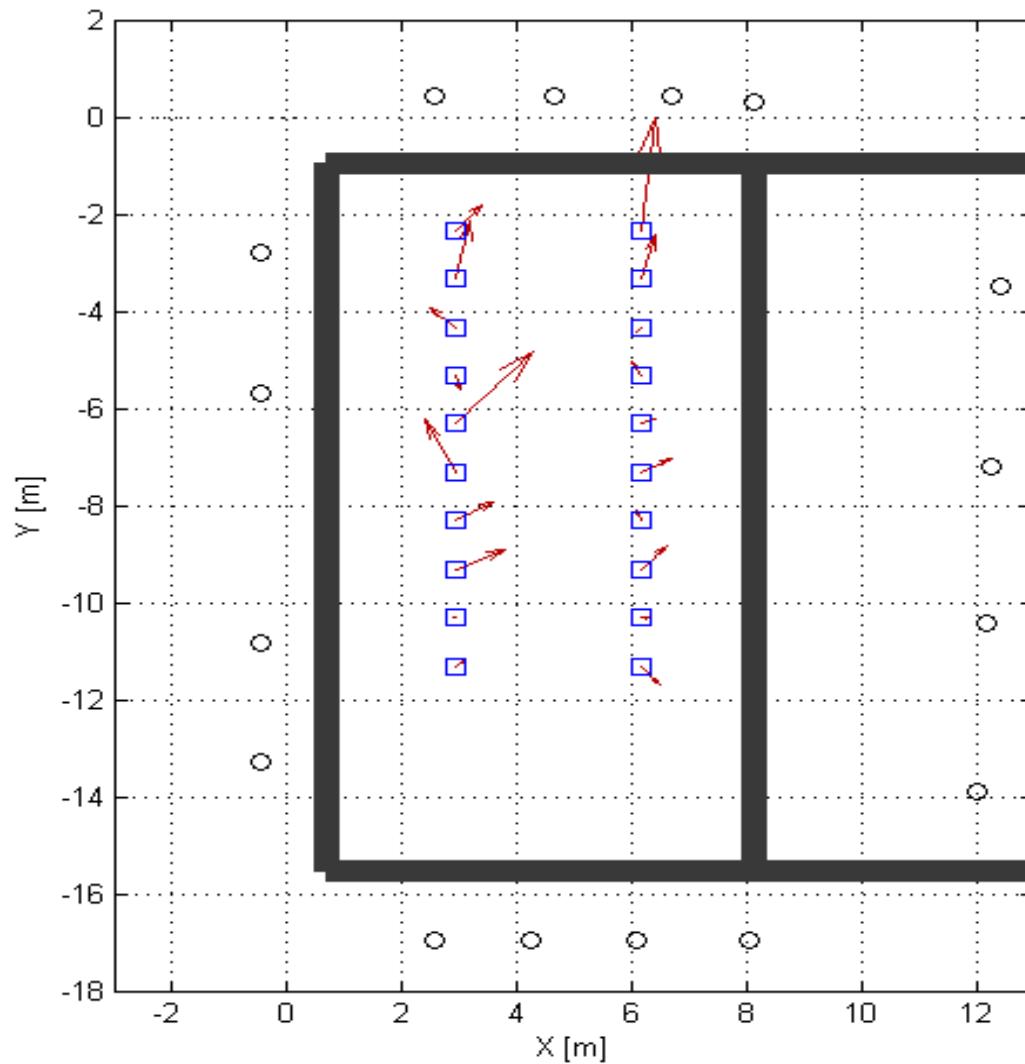
Another Building Test – AK-317 (Harsh Indoor RF Environment) !

- Metal ceiling
- Metal benches and cabinets
- Mesh Windows
- Metal backed black/white boards
- Fire Doors
- Metal studded walls – 16 inch spacing!



Building Test - Error Plots

- Approx 40ft by 50ft
- 60MHz BW
- Mean Error
 - 0.71m



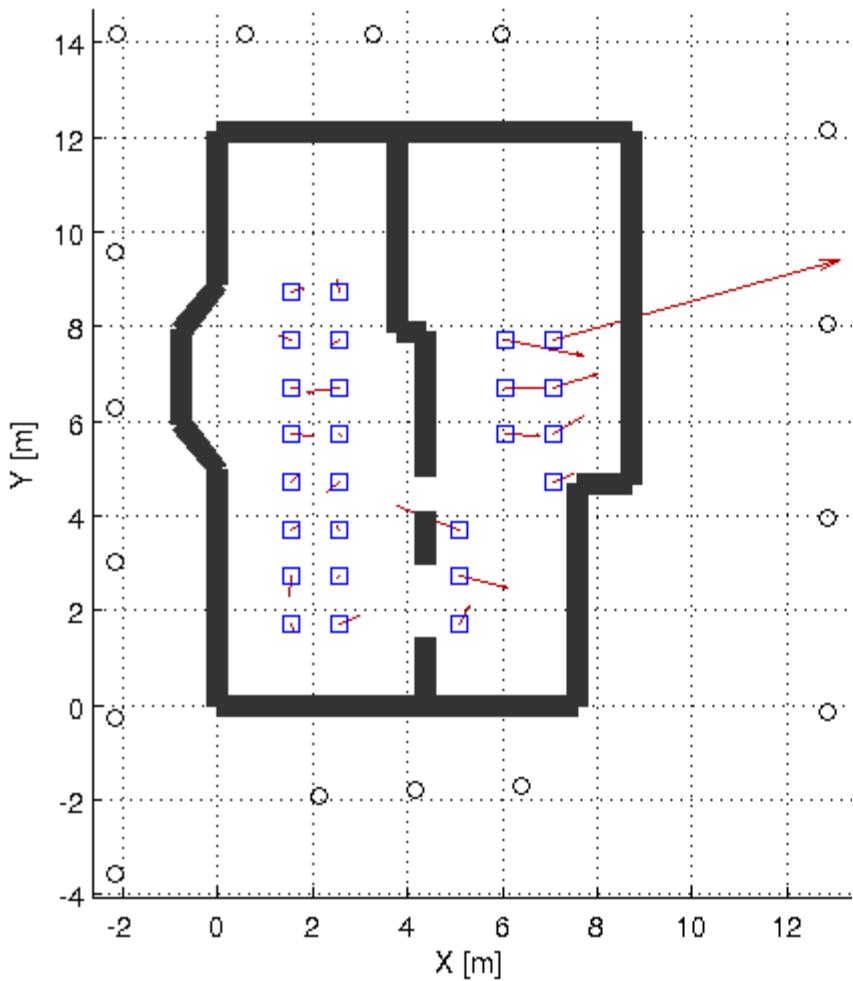
Residential Building - Tests

- 16 by 14 m coverage

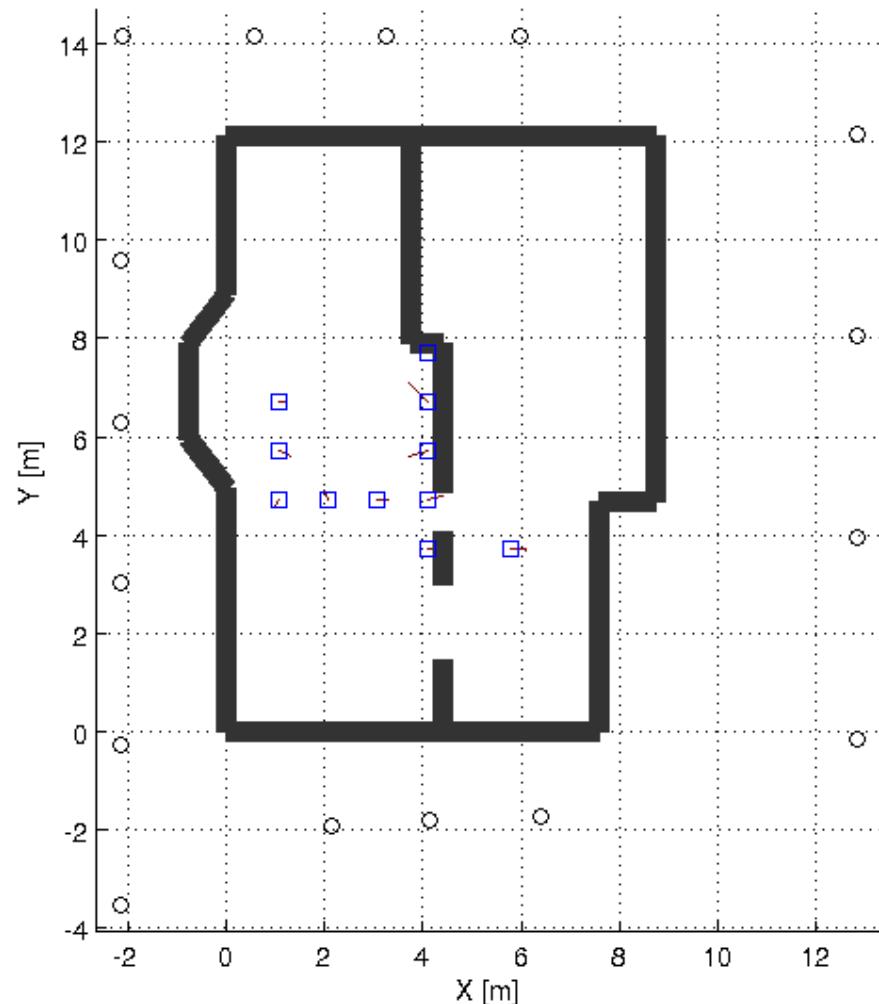


New TV band - 150 MHz/3D antennas

1st floor error: 0.72m



2nd floor error: 0.3m

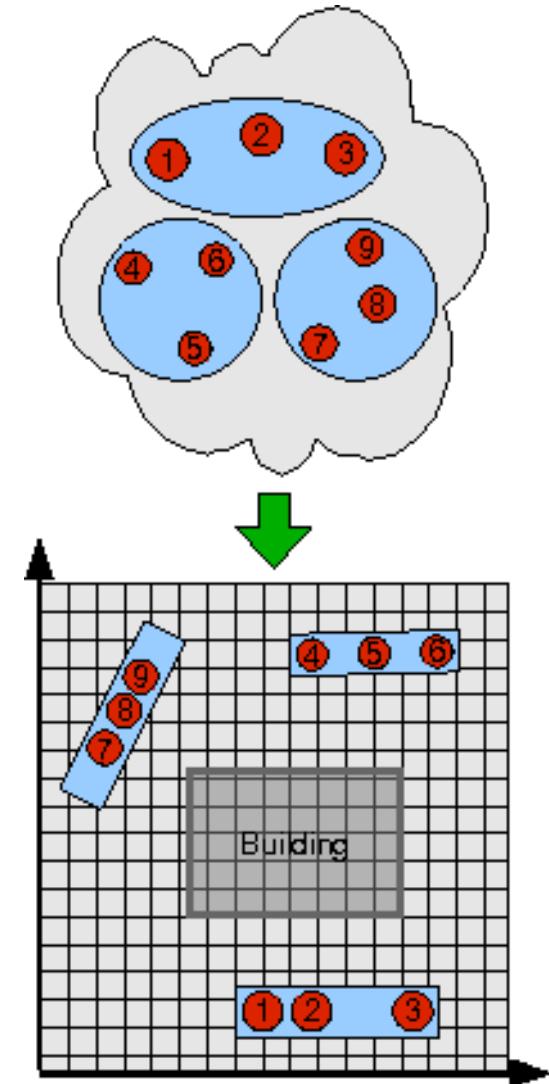


Results Summary

Test Location	Error	Bandwidth
Kaven Hall	0.37m	60 MHz
Atwater Kent, indoor	0.71m	60 MHz
Atwater Kent	1.08m	60 MHz
Campus Ministry 1st fl.	0.59m	60 MHz
Campus Ministry 2nd fl.	0.72m	60 MHz
Campus Ministry 1st fl.	0.72m*	150 MHz
Campus Ministry 2nd fl.	0.30m	150 MHz

Geometric Auto Configuration

- Prerequisite to any location solutions
- Multicarrier range estimation
- Multidimensional scaling
- Experimental results
 - Outdoor
 - Indoor, unobstructed line of sight
 - Around-building

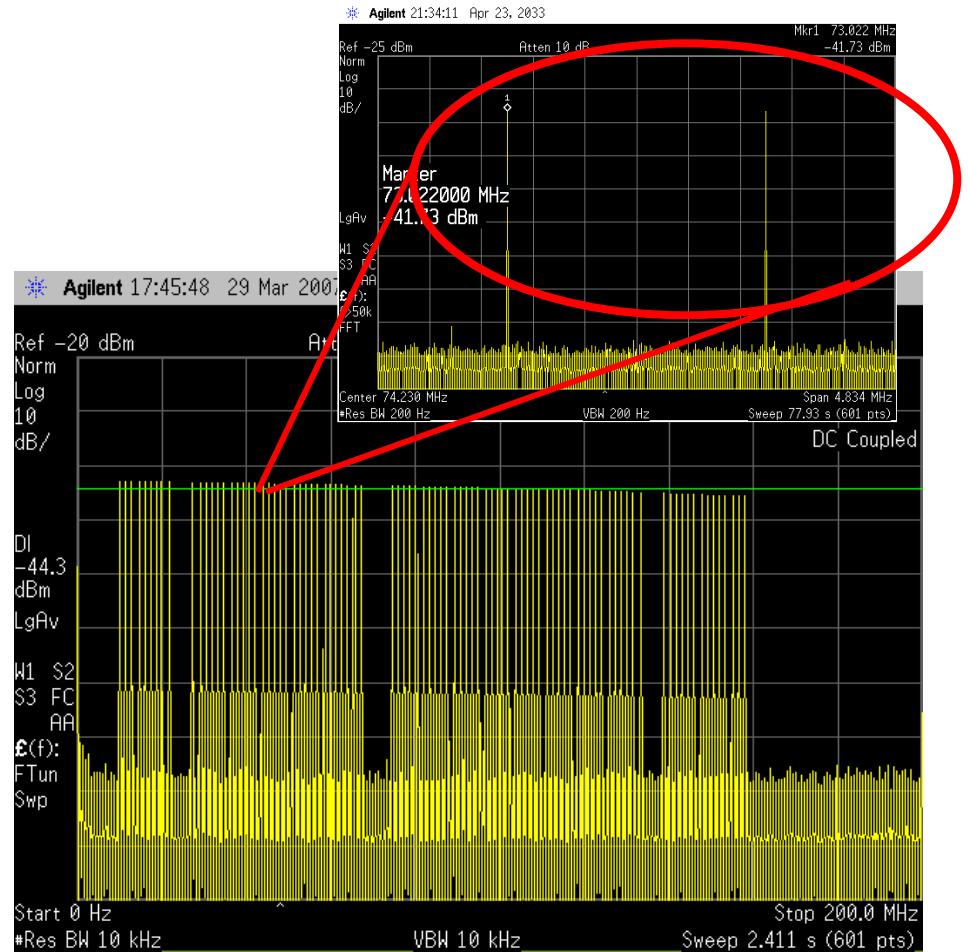


Ranging Signal

- Multi-carrier ranging signal
- Typically 50 carriers
- Bandwidths of about 25-150 MHz
- Multipath-resistant
- Processed by custom algorithms
- Generated digitally
- Spectrally friendly

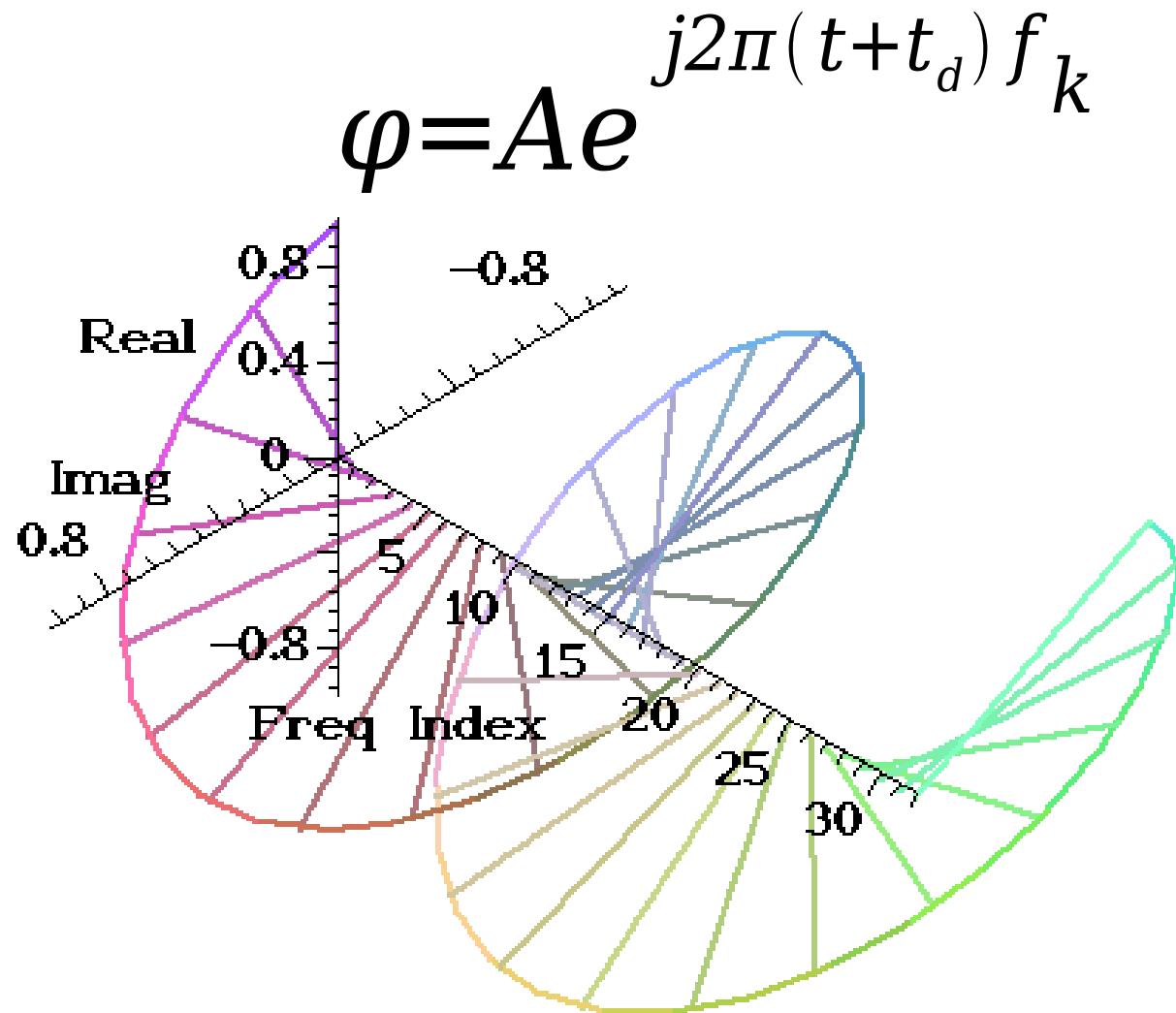
WPI Software Radio Capability

Band	Lower Freq. (MHz)	Upper Freq. (MHz)
1	410	470
2	512	608
3	614	698



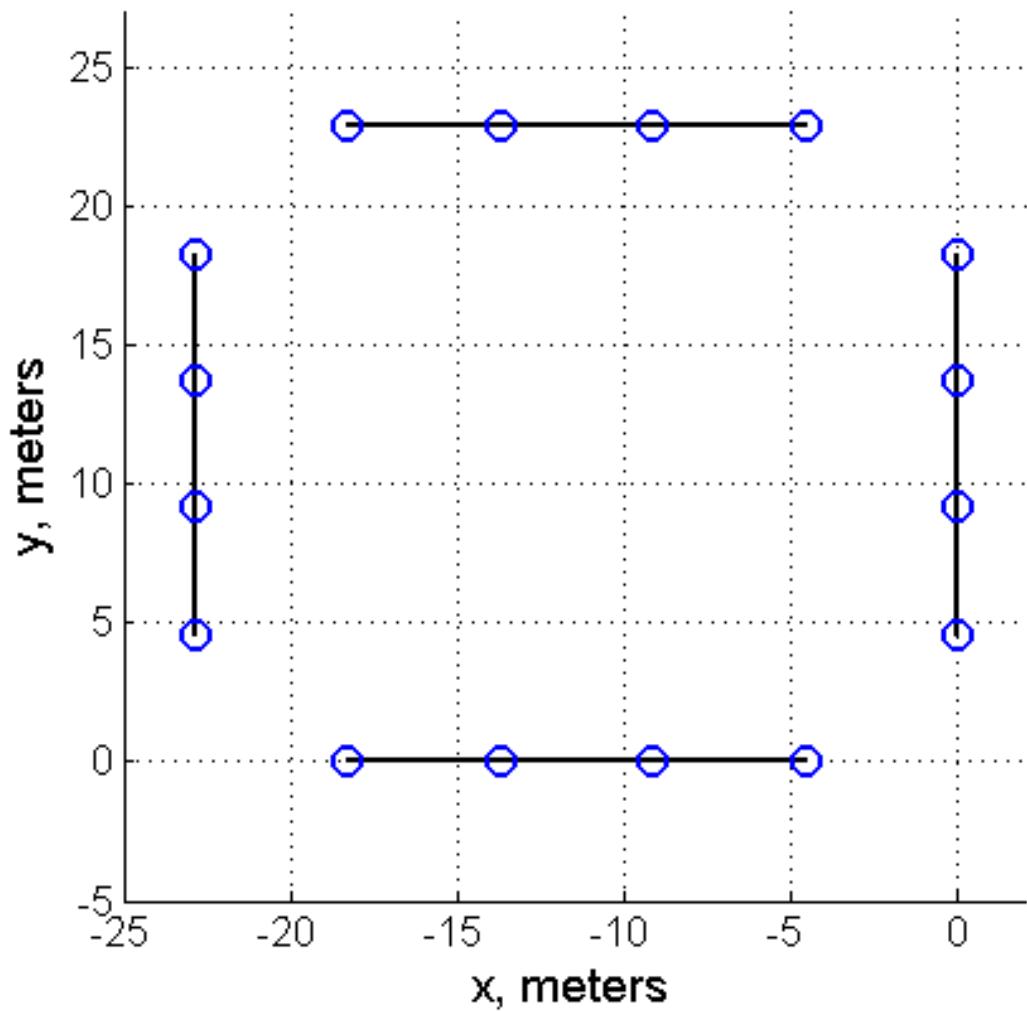
Range Estimation

- Every signal path contributes a sinusoid of a different period to the channel response
- Multipath easily separable
- Achieves the Cramer-Rao bound frequency est.



Target antenna geometry scenario

- Antenna spatial diversity primarily in two dimensions
- 30x30 meter area
- Assume knowledge of antennas on the same firetruck





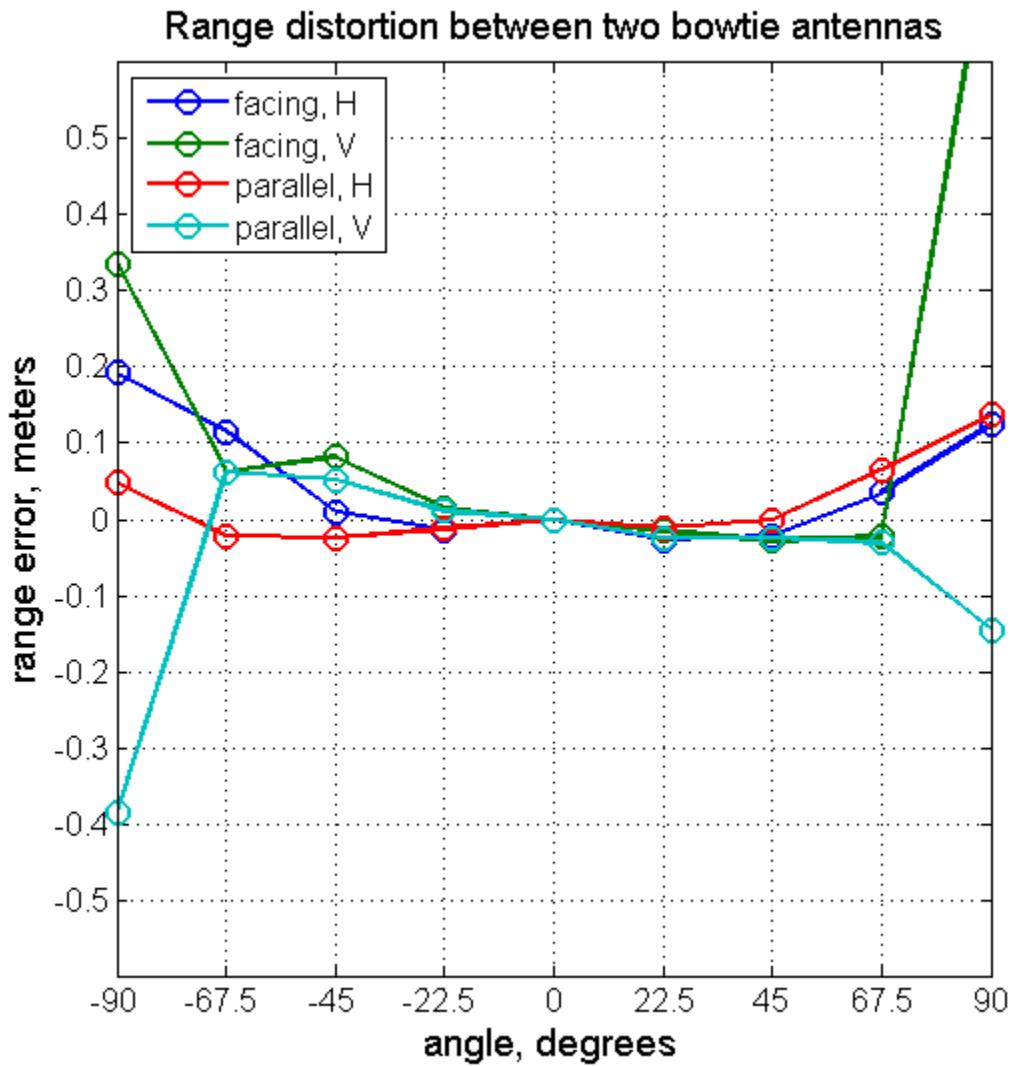
Range distortion

- Antenna transfer function angle dependence causes distortion of range estimates
- Measured in two configurations for UHF Antennas:
 - Bowtie (wideband dipole)
 - Conformal Patch suited for firetrucks



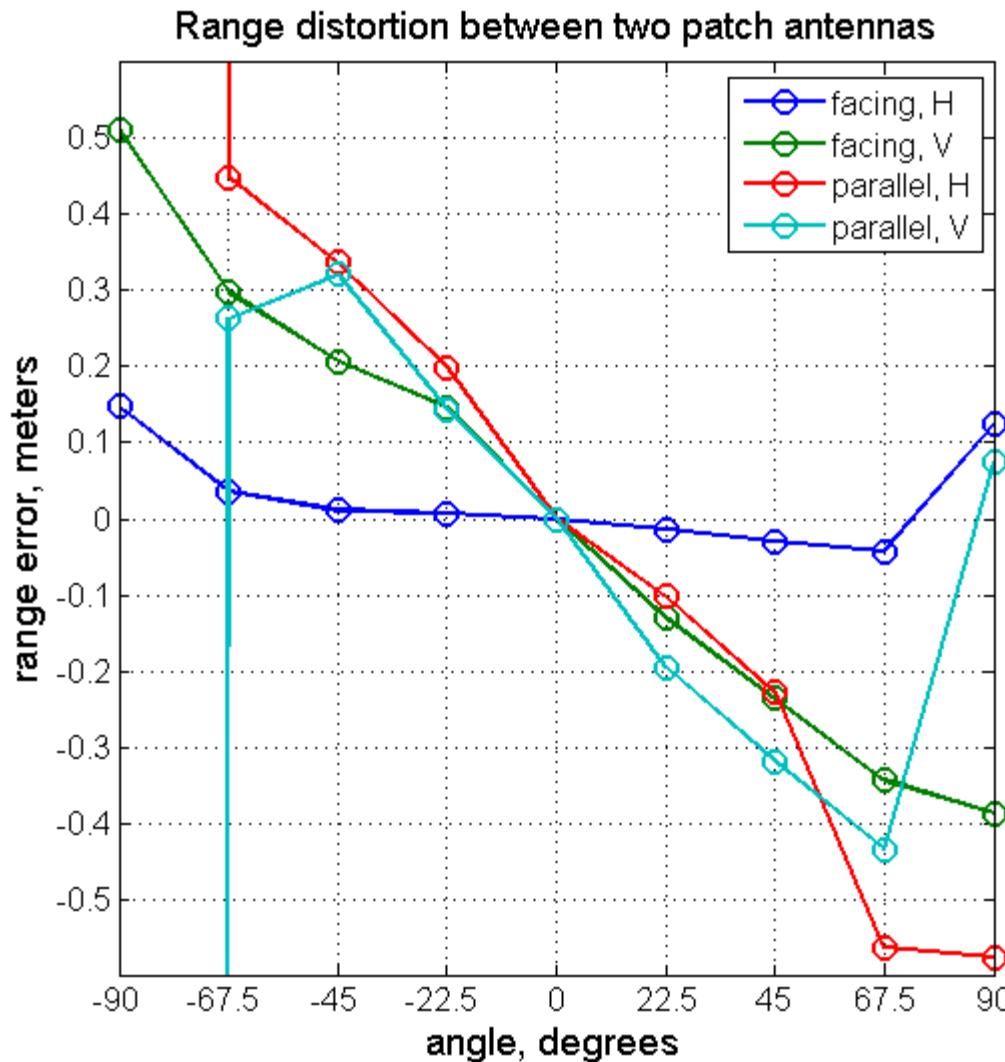
Bowtie Range Distortion

- Bowtie antennas show very little range distortion for a wide variety of angles
- Not conformal



Patch Range Distortion

- First-order effects of antenna pattern distortion
- Likely contributing source of error for range estimation with patch antennas
- SNR drop at extreme angles make results there less trustworthy



Multidimensional Scaling (MDS)

- Used to reduce dimensionality of data while preserving original relationships
- Classic example: Distances between cities
- Direct MDS relates the inner product of the true coordinates to the centered square of the distance matrix via an eigen- (or singular-) value decomposition:

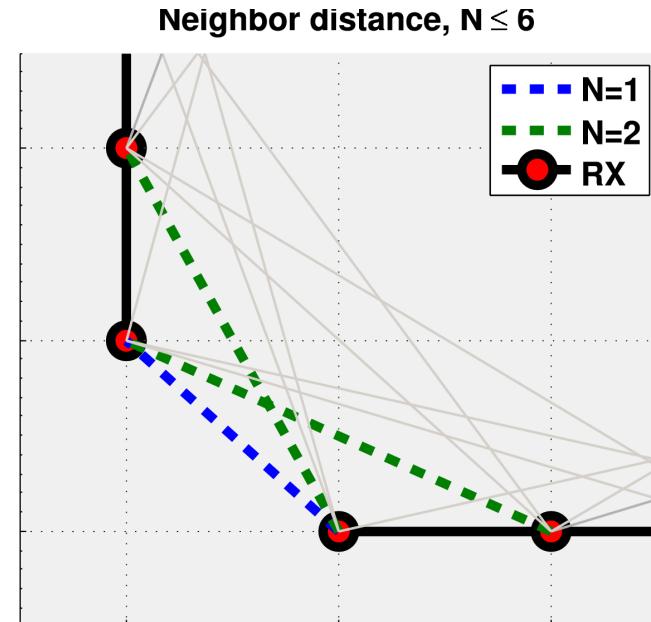
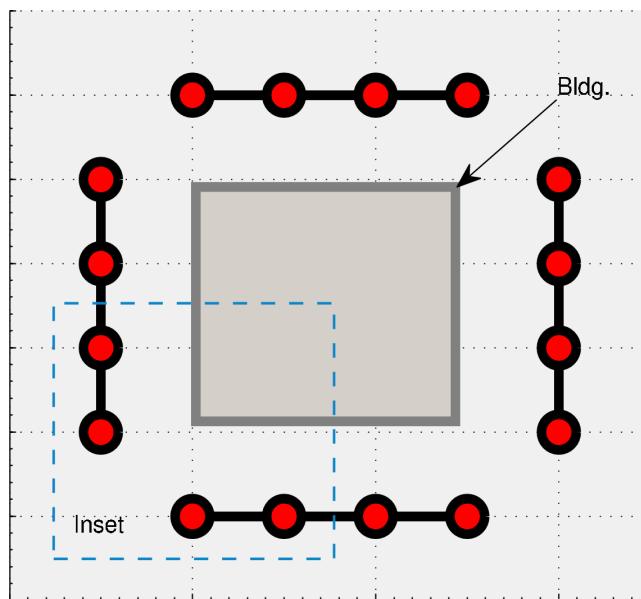
$$X^T X = -\frac{1}{2}CD^2C = V\Lambda V^T$$

Our Implementation of MDS

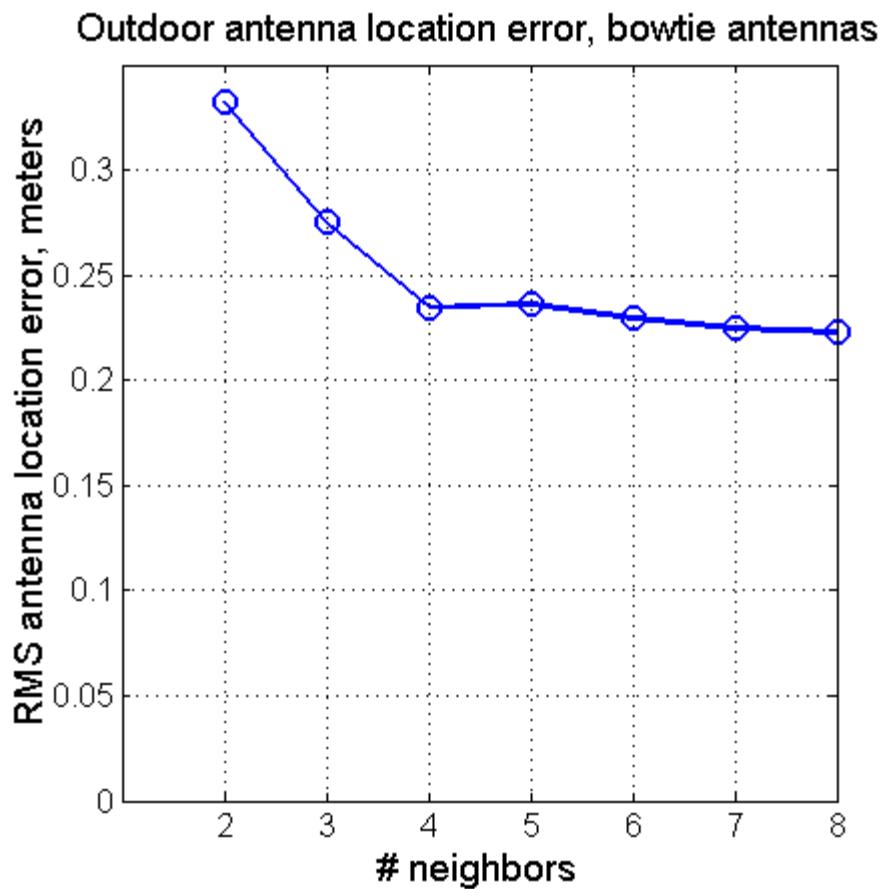
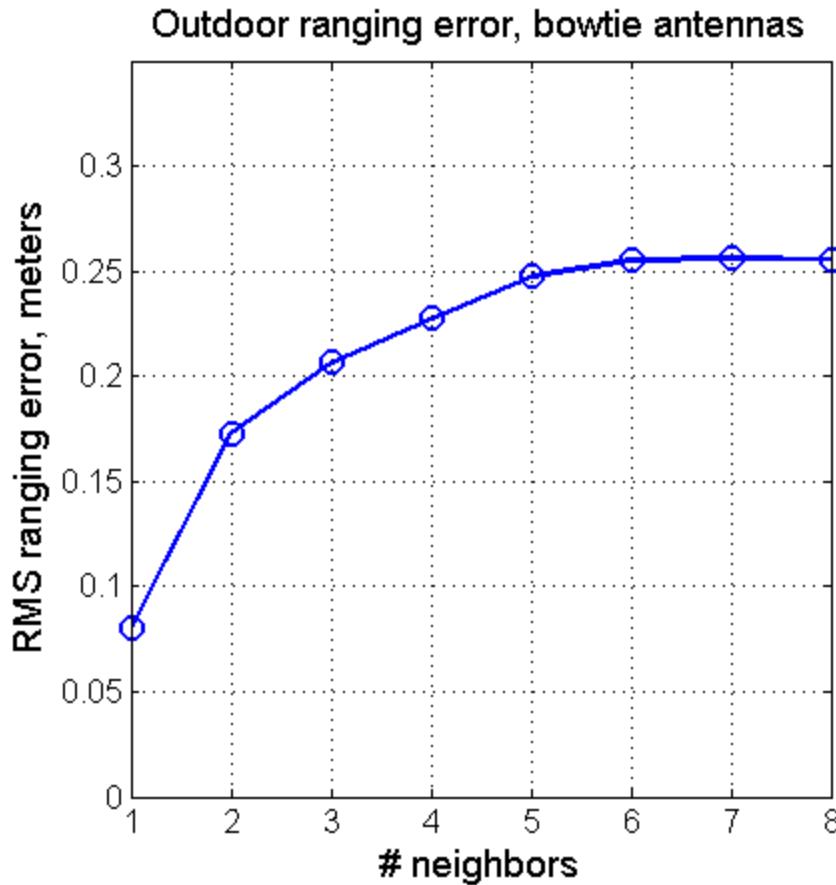
- MATLAB's `mdscale()` routine implements an iterative MDS solver
- Allows weighting and missing data
- Specification of initial solution guess
- Convergence to a solution may occur with as little as 26% of data available
- Ability for missing data convergence allows plotting errors with respect to a “difficulty factor”

GAC Performance Measurement

- Antennas placed along perimeter of area of operations, some hard to range to
- Evaluate performance wrt ranging difficulty



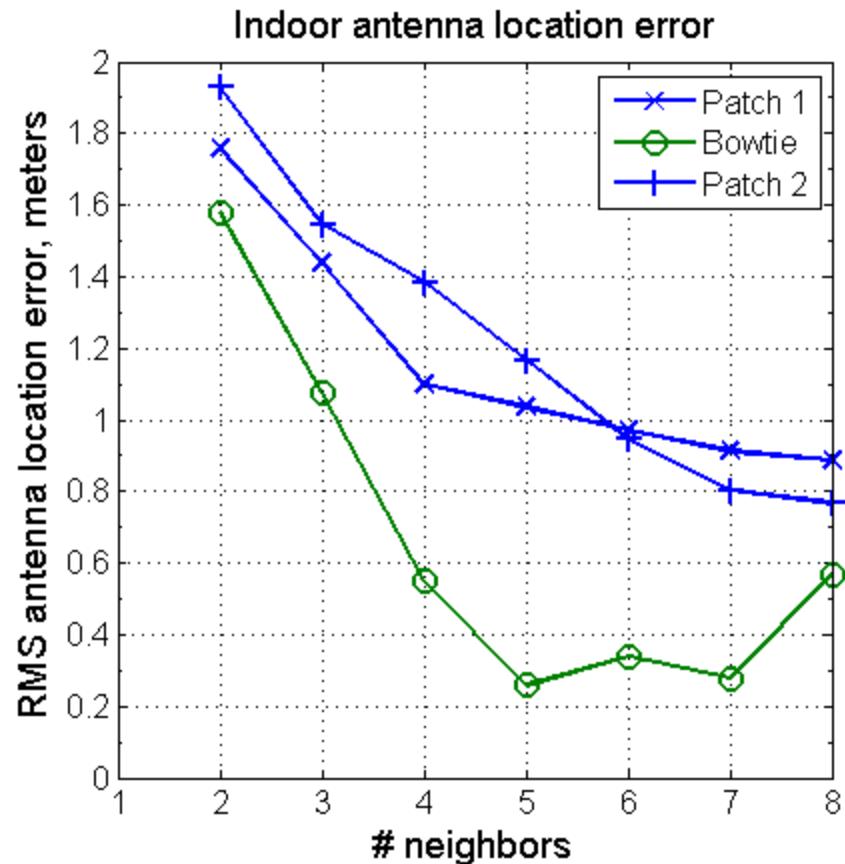
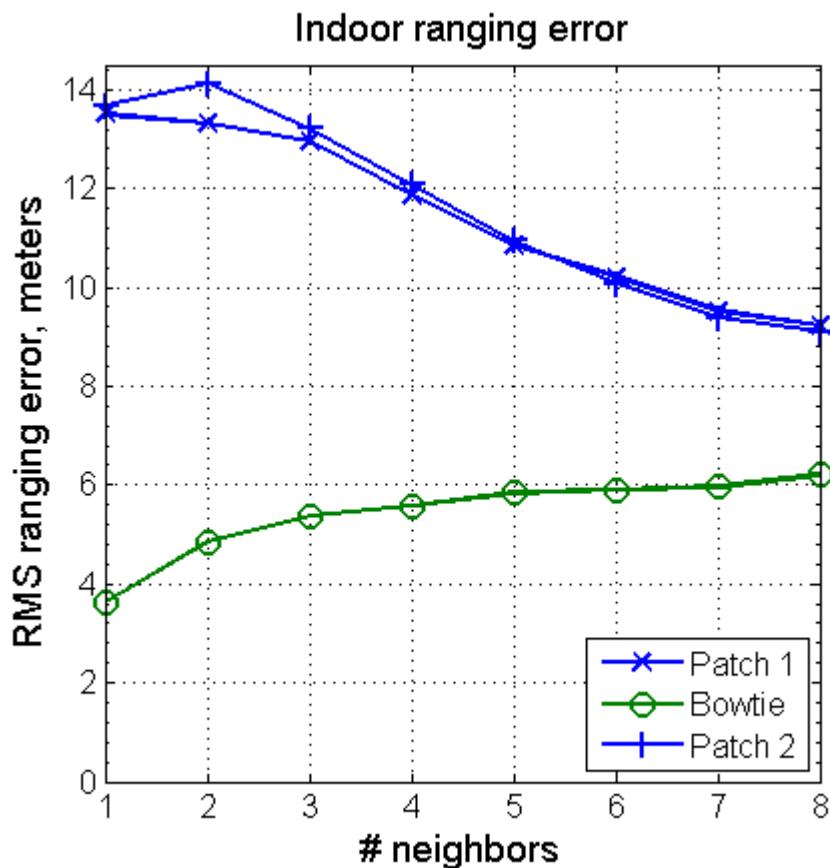
Outdoor Testing without multipath



Indoor test, unobstructed line-of-sight

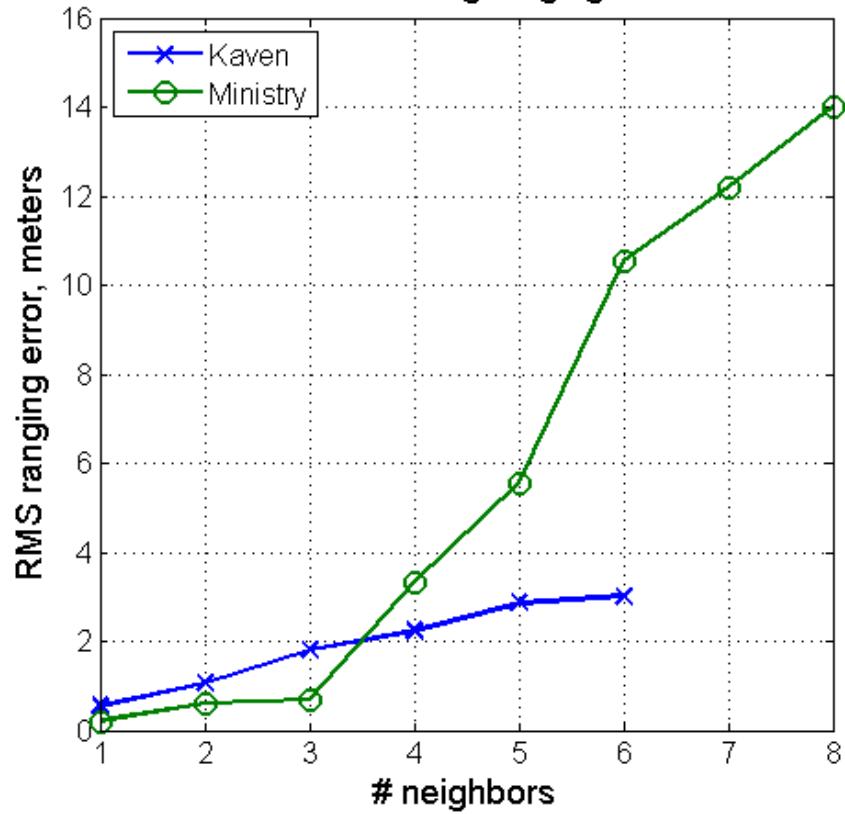


Indoor, unobstructed line-of-sight

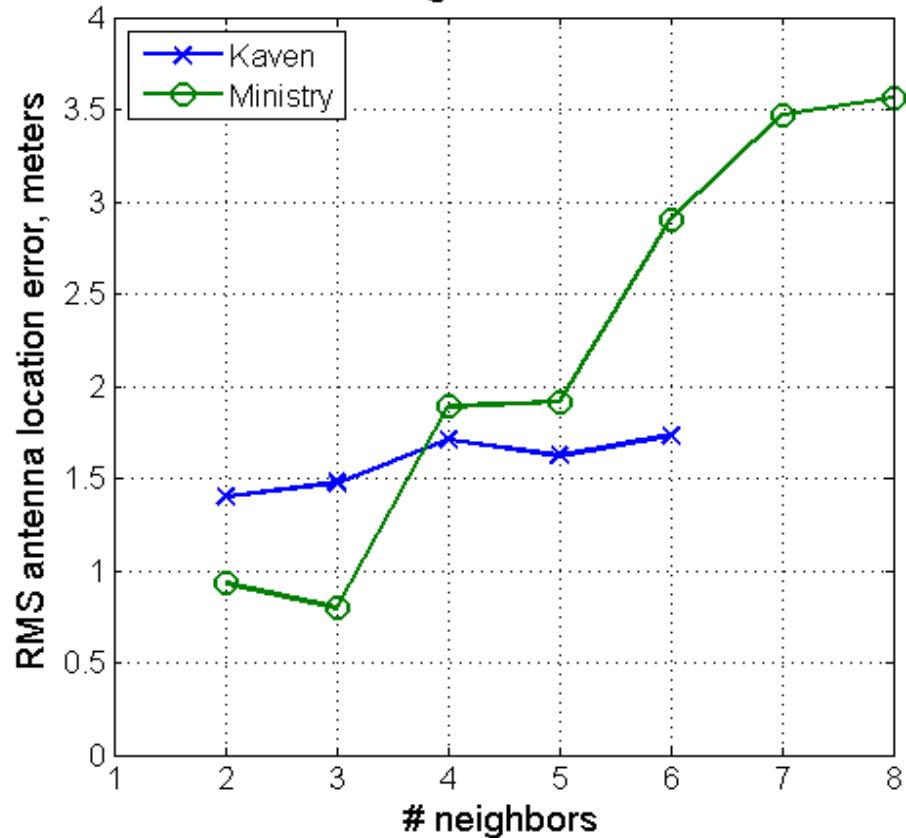


Around Building Test

Around building ranging error



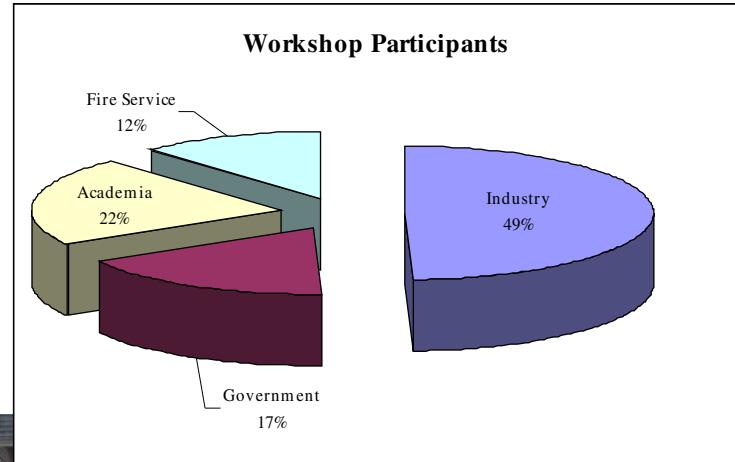
Around building antenna location error



Coming Soon...

- Paper documenting our new approach to precision location
- Different approaches to GAC
 - Manual: 0.13m, novel GAC: 0.41m
- WPI hosting 3rd annual workshop on *Precision Indoor Personnel Location and Tracking for Emergency Responders* in August 2008 in Worcester, Mass.

WPI Workshop - 2007



- Over 100 attendees
- Presentations, demos, working sessions
- **2008 – workshop**
 - August 4,5

WPI PPL Website

WPI Precision Personnel Locator Project: Precision Indoor/Outdoor Personnel Location Project - Mozilla Firefox

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Precision Personnel Locator PROJECT

Precision Indoor/Outdoor Personnel Location Project

The overall goal of this project is to protect the lives of emergency responders and to enhance their ability to accomplish their missions through research and development of systems for personnel location and tracking, physiological status monitoring, and command and control.

News & Events

- NEW! Pages on [Integrated Firefighter Locating and Physiological Monitoring](#) established
- NEW! [New presentations](#) and [paper](#) available from ION NTM 2008 and IEEE CCNC (Jan 2008)
- NEW! New [news article](#) available
- NEW! [Advance Announcement](#) available for 3rd Annual Workshop "Precision Indoor Personnel Location and Tracking for Emergency Responders" - August 4-5, 2008

Background and Context

This project brings together diverse technical capabilities from other centers and laboratories at WPI to address important problems for emergency responders, the most critical of which is precise location knowledge for each person. The two primary centers involved in the current work are the [Center for Advanced Integrated Radio Navigation \(CAIRN\)](#) and the Convergent Technology Center (CTC). CAIRN provides expertise in RF and software radio design, as well as extensive background in geolocation, while the Convergent Technology Center contributes expertise in advanced signal and image processing, information fusion, algorithm design, communication and computer networks.

Another important aspect of this work is that, as an academic enterprise, this project involves graduate students as research assistants, and undergraduate students as summer interns. The opportunity for research and development at the state of the art in communications, computation, and positioning, is an unparalleled experience for our students.

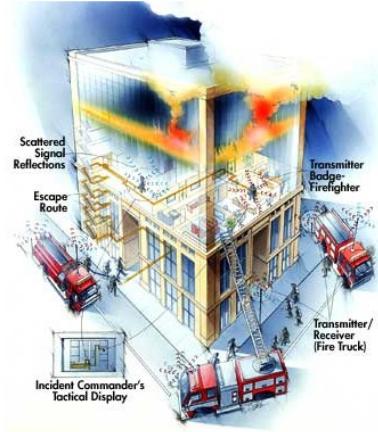
Current Work

Funded by the [National Institute for Justice](#) of the US Department of Justice, work on development of a prototype Precision Indoor/Outdoor Positioning System for use by firefighters, law enforcement, and corrections personnel is underway.

A new grant from the U.S. Department of Homeland Security, FEMA in cooperation with the U.S. Fire Administration, Fire Prevention and Safety Program for "Integrated Firefighter Locator and Physiological Monitoring" has been received. This new program integrates, for the first time, a unique 3-D location system and 'wear and forget' physiological stress monitoring system for the fire service. Results of this work can be seen on the "[Integrated Firefighter Locator and Physiological Monitor](#)" pages.

Detailed information is available through these pages.

Scattered Signal Reflections
Escape Route
Transmitter Badge- Firefighter
Transmitter/ Receiver (Fire Truck)
Incident Commander's Tactical Display



Done

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Done

WPI Precision Personnel Locator

➤ Acknowledgments

- The rest of the WPI team
- Worcester Fire Department
- The support of the National Institute of Justice of DOJ

➤ Thank you!

- Benjamin Woodacre, benw@wpi.edu
- www.ece.wpi.edu/Research/PPL