Multi-Carrier Technology for Precision Personnel Location in Indoor and other High Multipath Environments

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Motivation

- 12/3/99: On that day, six firefighters lost their lives in a tragic cold storage warehouse fire in Worcester, MA. Two fire fighters initially got lost and then two search teams became lost in the maze due to zero visibility from the dense smoke. Six people died literally within 100 feet of safety.
- 9/11/01: A disaster of far greater magnitude involving Firemen, Police, EMTs, etc., in which personnel location would have provided fast answers, vital command and control data and greatly enhanced search and rescue.

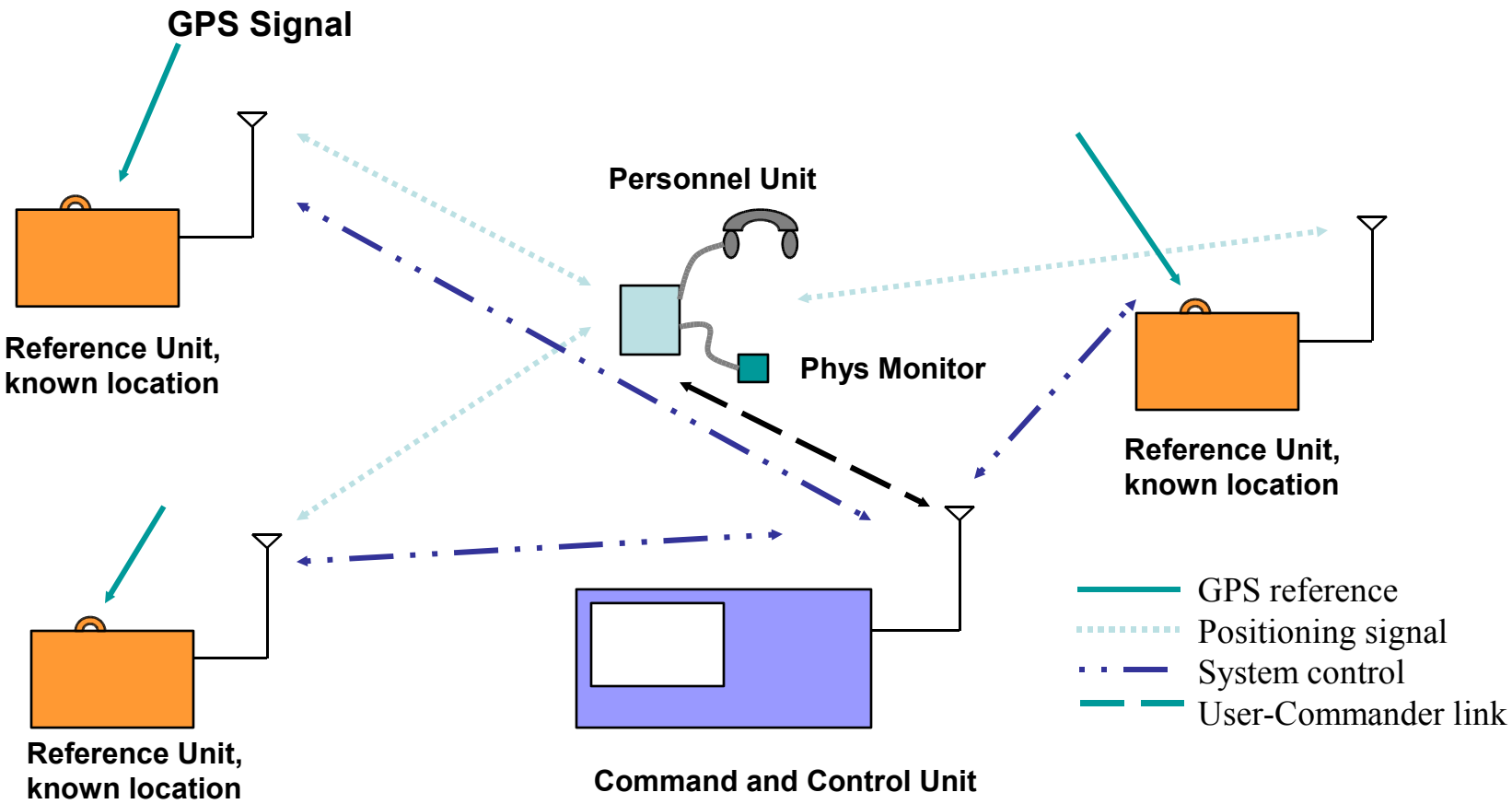
Our Goal

- The lives of First Responders, Corrections Staff and other Public Safety Personnel can depend upon precise location information.
- Our Goal: Create technology to aid and rescue those who put the mission of our safety before personal safety

Initial Focus Area

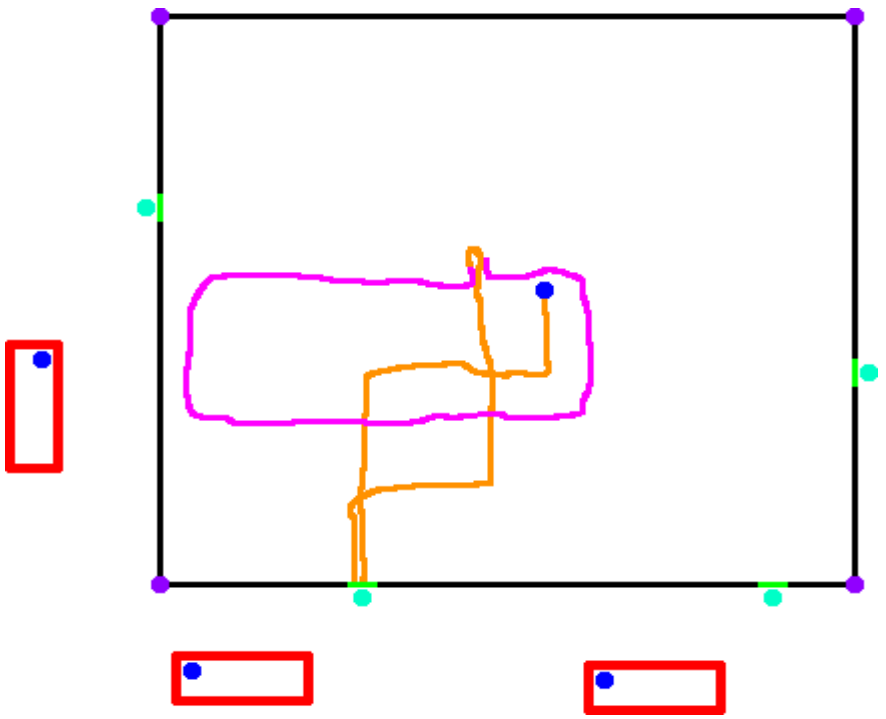
- Precision, ad hoc, positioning and associated exchange of data for situational awareness and command/control for
  - Firefighters
  - Law enforcement officers
  - First-responders
  - Corrections officers
  - Military

System Overview



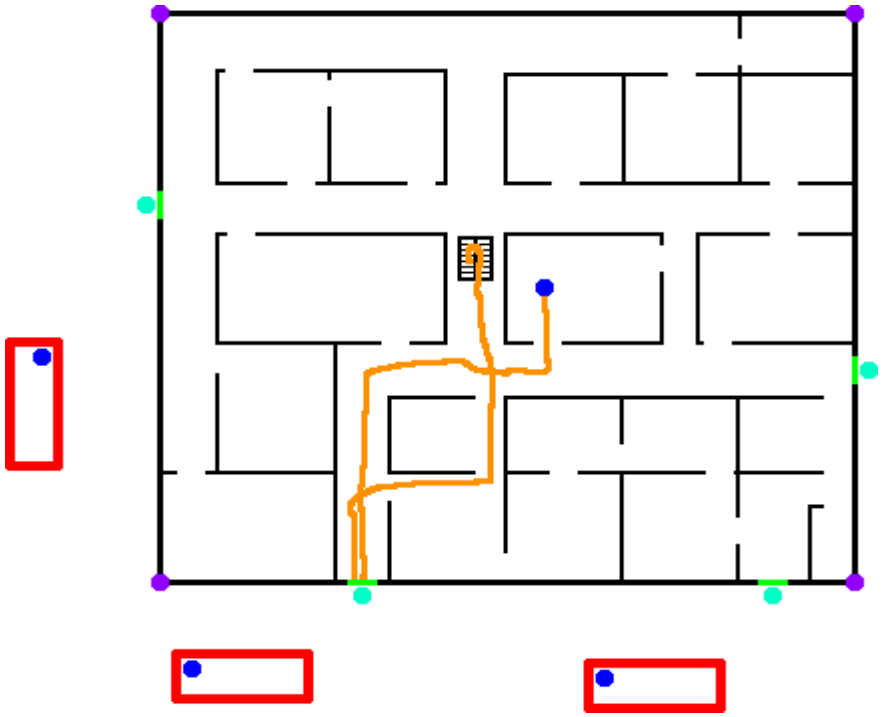
Real-Time Deployable Personnel Geolocation

Vehicles (red)
drive
up to a building
and
use reference units
(blue) to locate and
display tracks of
fire fighters. Exits
and other key
building features
may be “marked”
on the fly.



… with GIS (Geographic Info. Sys.) overlays.

If GIS information such as complete floor plans are available, they can be integrated with the track display to assist route planning and other time-critical decisions.



System Requirements Draft

- Fundamental capabilities:
  - 3-D location of each user relative to a chosen reference point
  - Relative locations among users
  - Graphical display at command/control station
  - Graphical path information on all users
  - Self rescue information to users (audio)
- Accuracy: +/- 1 ft
- Maximum range: 2000 ft
- Max number of simultaneous users: 100
- Enhancements:
  - Physiologic information telemetry
  - Integration with stored databases: geographic and structural

Technical Challenges

- Multipath: the indoor radio environment is much more problematic than the outdoor situation. Signal reflections pose a fundamental issue with respect to precision of location.
- Portability and quick set-up: The goal is for the response vehicles to drive to the incident site and be ready to go with the geolocation system. The most significant problem is reference initialization (site self-calibration).
- Size, cost: personnel devices must be small and very low cost to permit widespread deployment

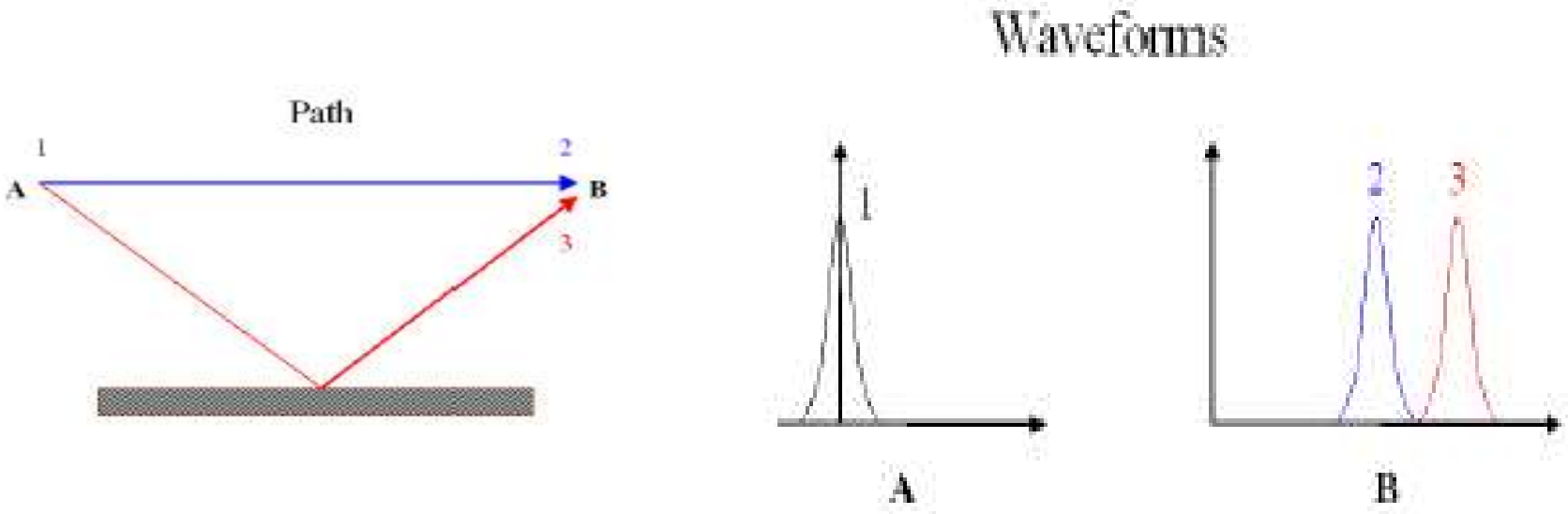
Differences from GPS

- Small operational area (< ~1km^2)
- Absolute geographic reference may not be needed
- User devices may be active
- Overall system cost must be kept low – especially the numerous user devices
- Entire system must be self-initializing, self-monitoring, self-repairing

Possible Approaches

- How do we achieve transportable (no infrastructure) precision location on the order of 20 cm accuracy indoors?
- GPS ?
  - Insufficient resolution
  - Insufficient signal strength inside buildings
  - Multi-path degraded
- What about Impulse UWB?

Impulse UWB



Ultra-narrow pulses enable simple isolation of direct paths from reflected paths

Impulse-UWB Problems

- Extremely narrow pulses imply large signal acquisition times, difficult tracking, huge bandwidth
- Pulse generation and time-windowing at receiver may require exotic, costly, circuitry
- Maintenance of pulse characteristics requires low distortion transmitter and receiver antennas over huge bandwidths

UWB Problems cont.

- Conflict with regulators:
  - UWB industry claims no spectral allocation needed
  - Other services and regulators worry about protecting existing services
- Conflicting claims by UWB industry:
  - High penetration capability enabled by low frequency components
  - High precision ranging enabled by high frequency components

What is the true benefit of I-UWB?

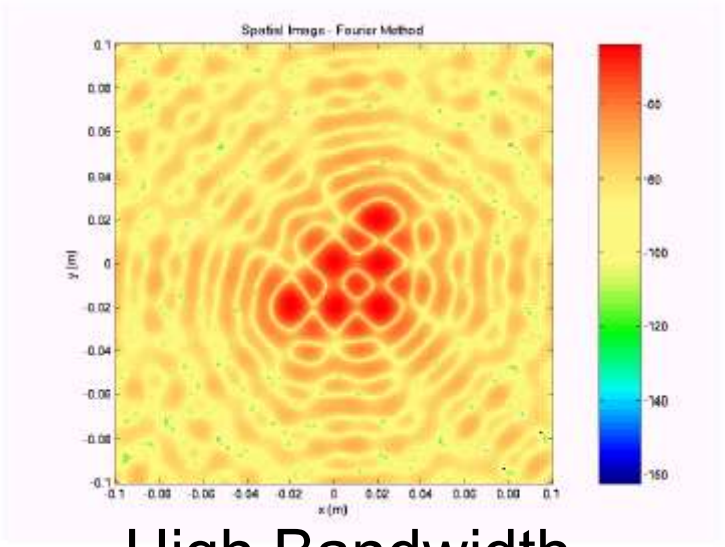
- **Marketing:**
  - The approach is immediately appealing because of the vivid transparency of its operation
  - Its short pulses on direct path transmission arrive before any reflections and hence allow multipath elimination and precise location.
- **The reality is:**
  - This compelling picture obscures the fact that short pulses are not needed for precision location

Multi-Carrier Ultra-Wideband

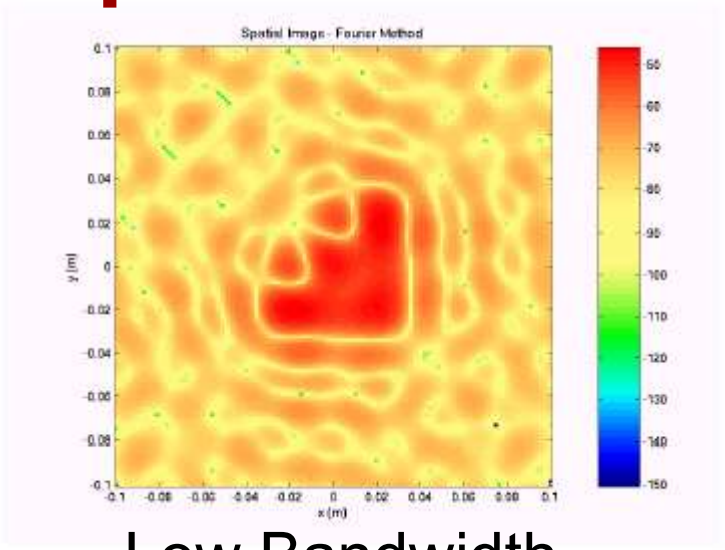
The solution appears to lie in a mix of two recent innovations:

- Super-resolution SAR/ISAR Radar
  - Enhances Radar resolution to centimeters and similarly improves angular resolution of SONAR systems.
- Orthogonal Frequency Division Multiplexing (OFDM)
  - Allows DSL transmission of many Mb/sec over existing subscriber loop twisted copper telephone pairs and provides new means to enhance fixed and mobile radio services in high multipath environments.

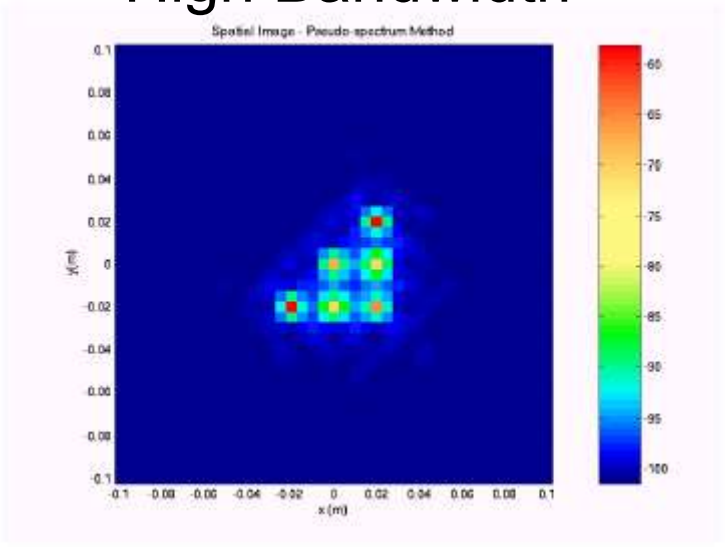
Fourier SAR versus Super-resolution

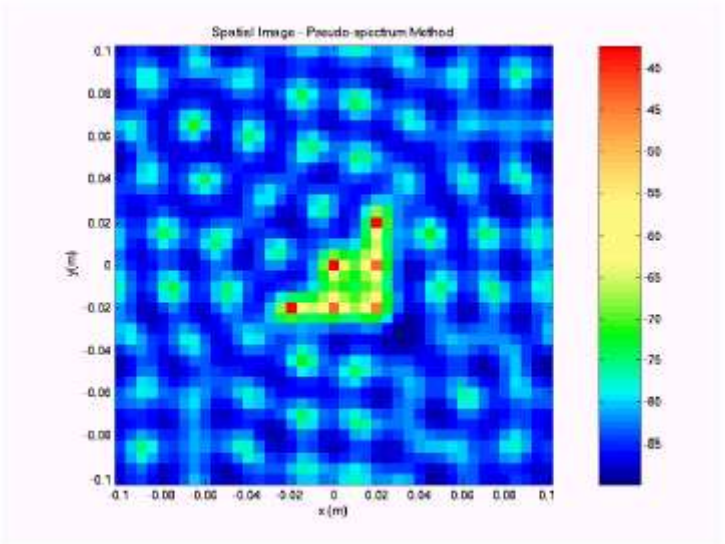


High Bandwidth

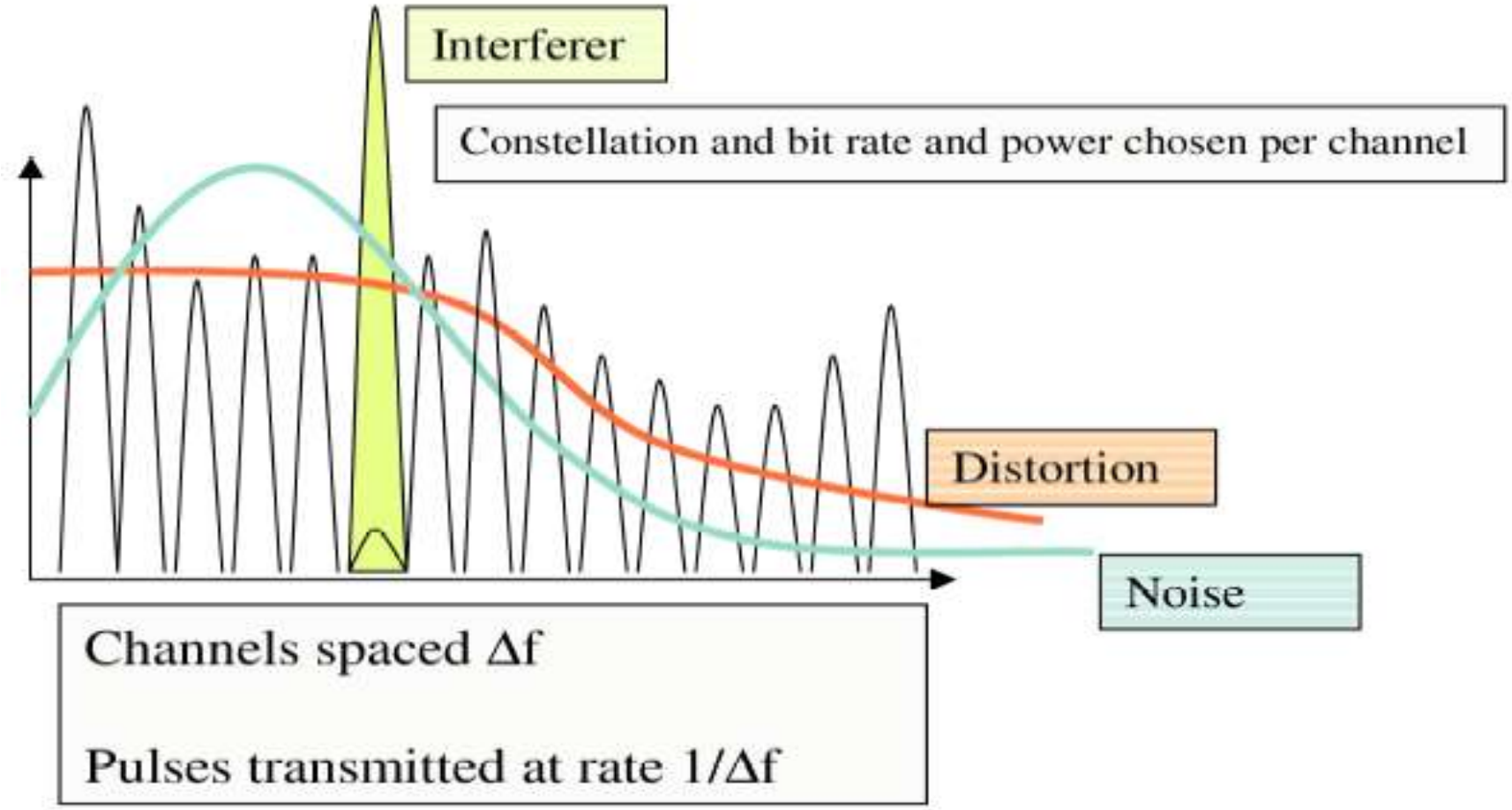


Low Bandwidth





The OFDM Concept



Lessons Learned from OFDM

High data rate transmission via multi-carrier modulation does not require a single wide band channel with:

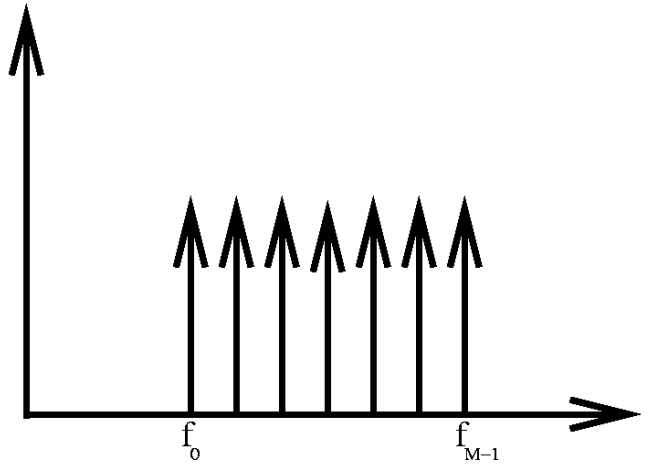
- Low distortion (in amplitude and/or phase response)
- Narrow pulses
- Uniform noise
- Absence of interferers
- Precise synchronization

MC-UWB

- Combining scatterer identification from super-resolution radar and multi-carrier modulation from OFDM we obtain:
  - Sub-wavelength precision location
  - Amelioration of multi-path by **imaging** the reflectors
  - Spectral compatibility with existing services
  - Dynamic response to interferers
  - Freedom from electronic and EM design constraints
  - Combined location and high bandwidth communication

MC-UWB Transmitted Signal

- The multi-carrier ultra-wideband signal consists of a comb of continuous carriers
- This signal effectively occupies zero spectrum and can fit between existing services
- Personnel tags can be cheap, simple and small



M carriers

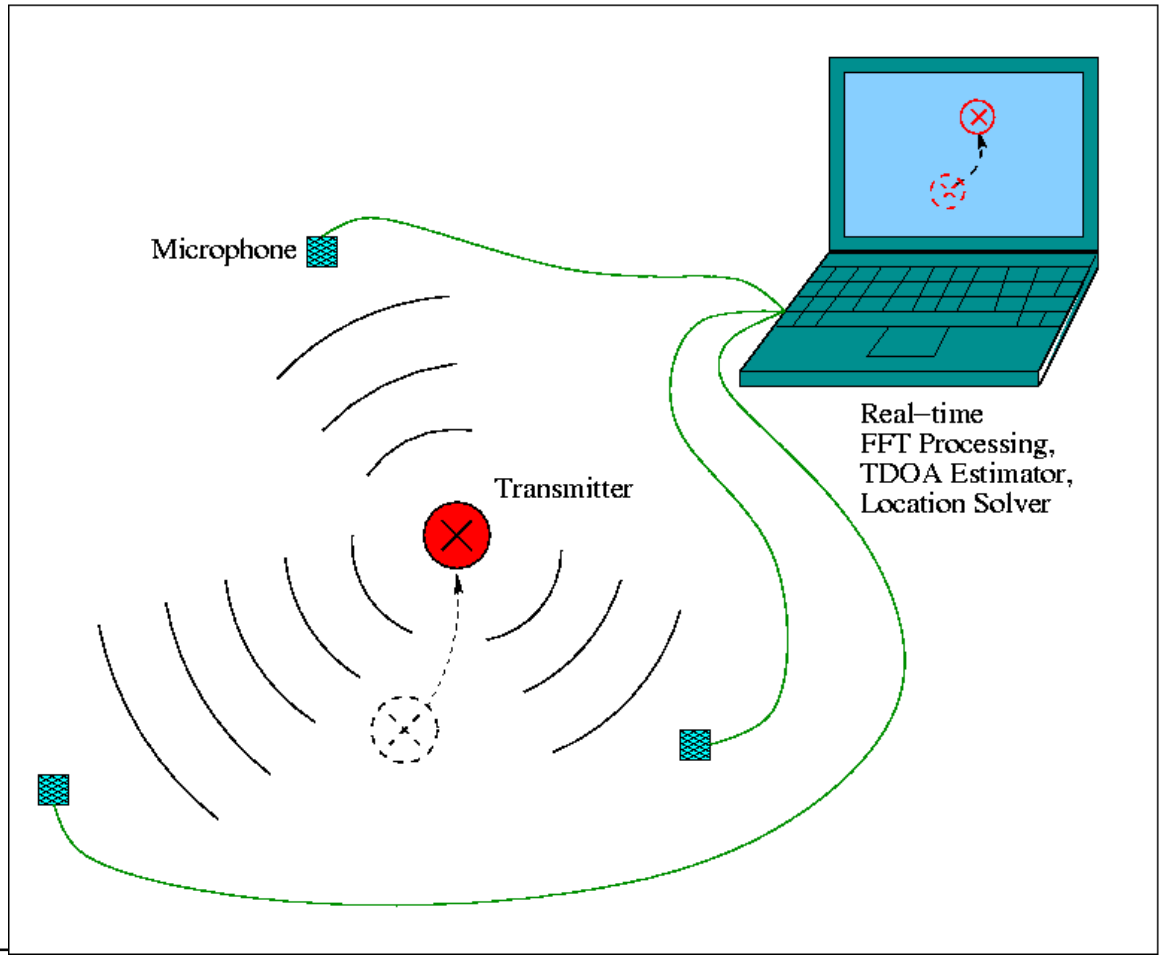
Carrier spacing = Δf

Each carrier has arbitrary phase Φ_m

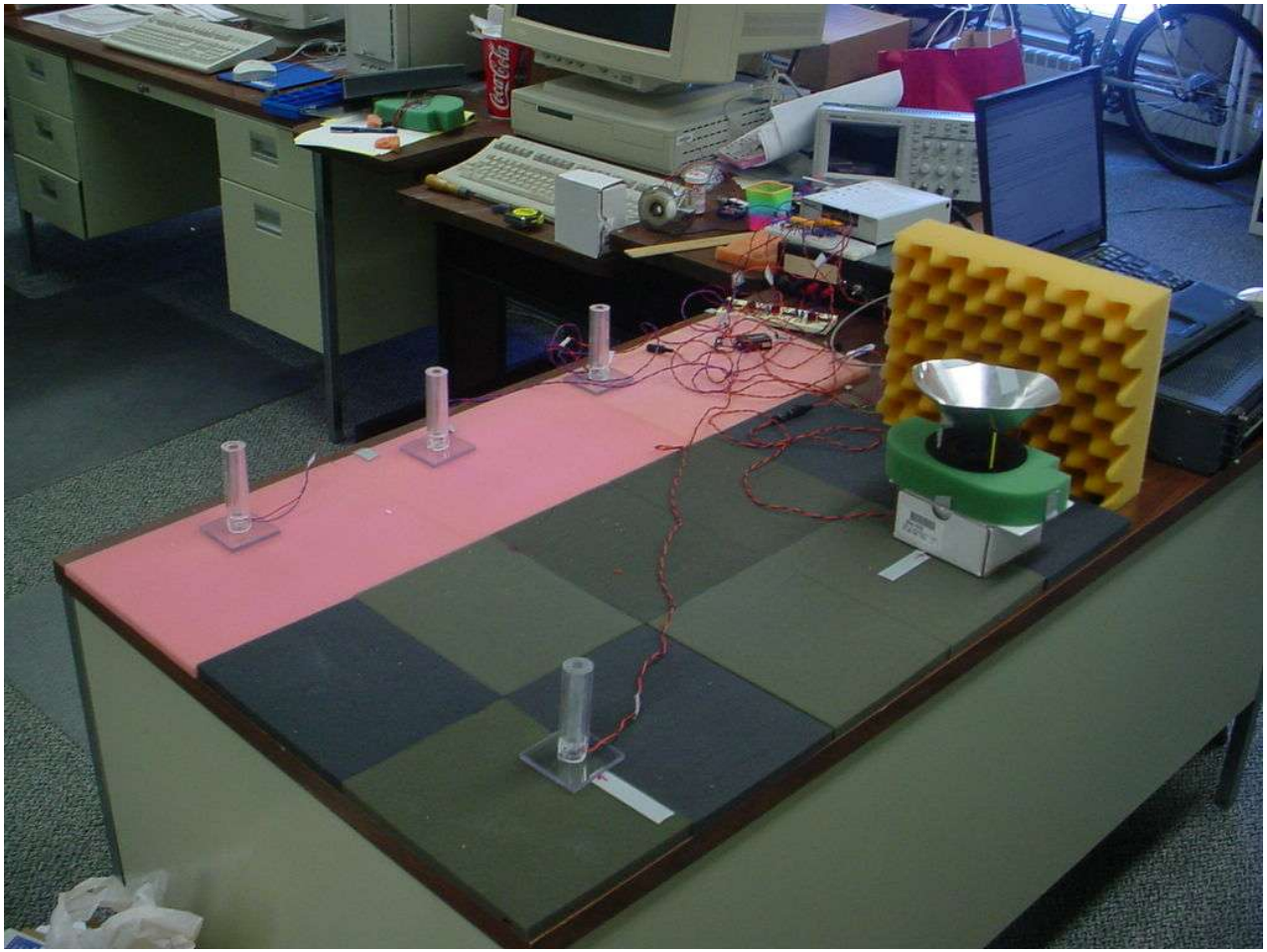
Proof of Concept Demonstration

- Uses audio, not RF - greatly eased prototyping
- Top audio frequency has wavelength in air of 4.5”
- 1:1 scale behavior with RF bandwidth 2.625 GHz
- Demo of real-time location system on laptop cpu
- Off the shelf microphone/speaker components could be used thanks to the OFDM like signal
- Displays true location solution and multipath solutions

Proof-of-Concept Demonstrator



Current Demo Setup



Video of Demonstration

Conclusions

- MC-UWB signal structure and solution techniques appear well-suited to the indoor positioning problem
- Initial analytic and proof-of-concept experimental work has been accomplished
- System optimization, Performance analysis and RF demonstration system design/construction are now underway
- Proposal being reviewed by DOJ/NIJ

Related WPI Research Centers

- **Convergent Technology Center**
  - Radar/Sonar signal processing and Automatic Target Recognition
  - Networking, Distributed computing and fault tolerance
- **Satellite Navigation Lab**
  - Global positioning systems
- **Center for Untethered Health Care**
  - Wireless physiological monitoring for military and commercial applications
- **NECAMSID: The New England Center for Analog and Mixed Signal Integrated Circuit Design**
  - RF/Microwave analog design
- **Center for Wireless Information Network Studies**
  - Mobile communications and geo-location