Sensor Network-Based Countersniper System

M.I.T. 6.S062, Mobile and Sensor Computing
Spring 2017

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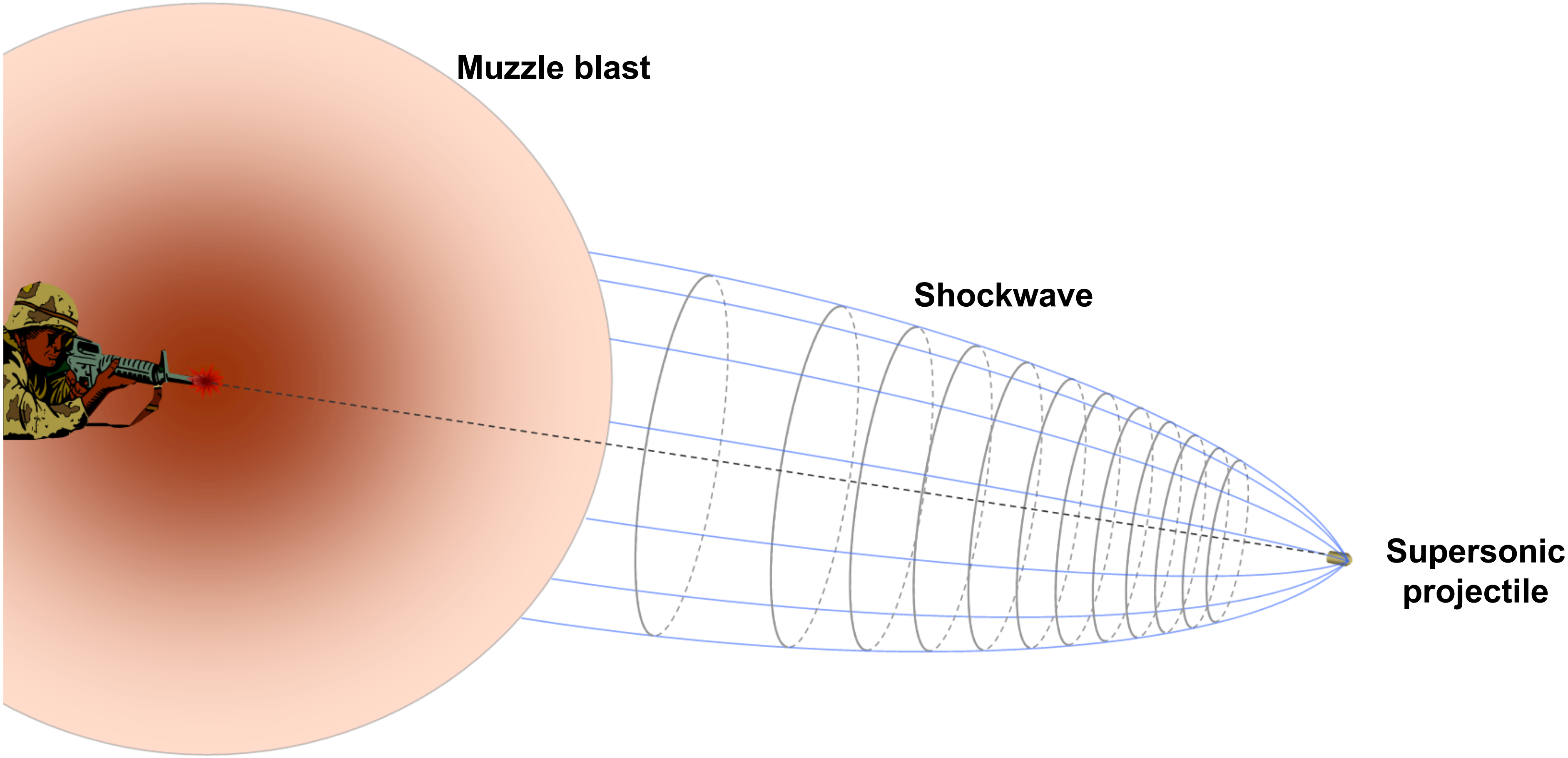
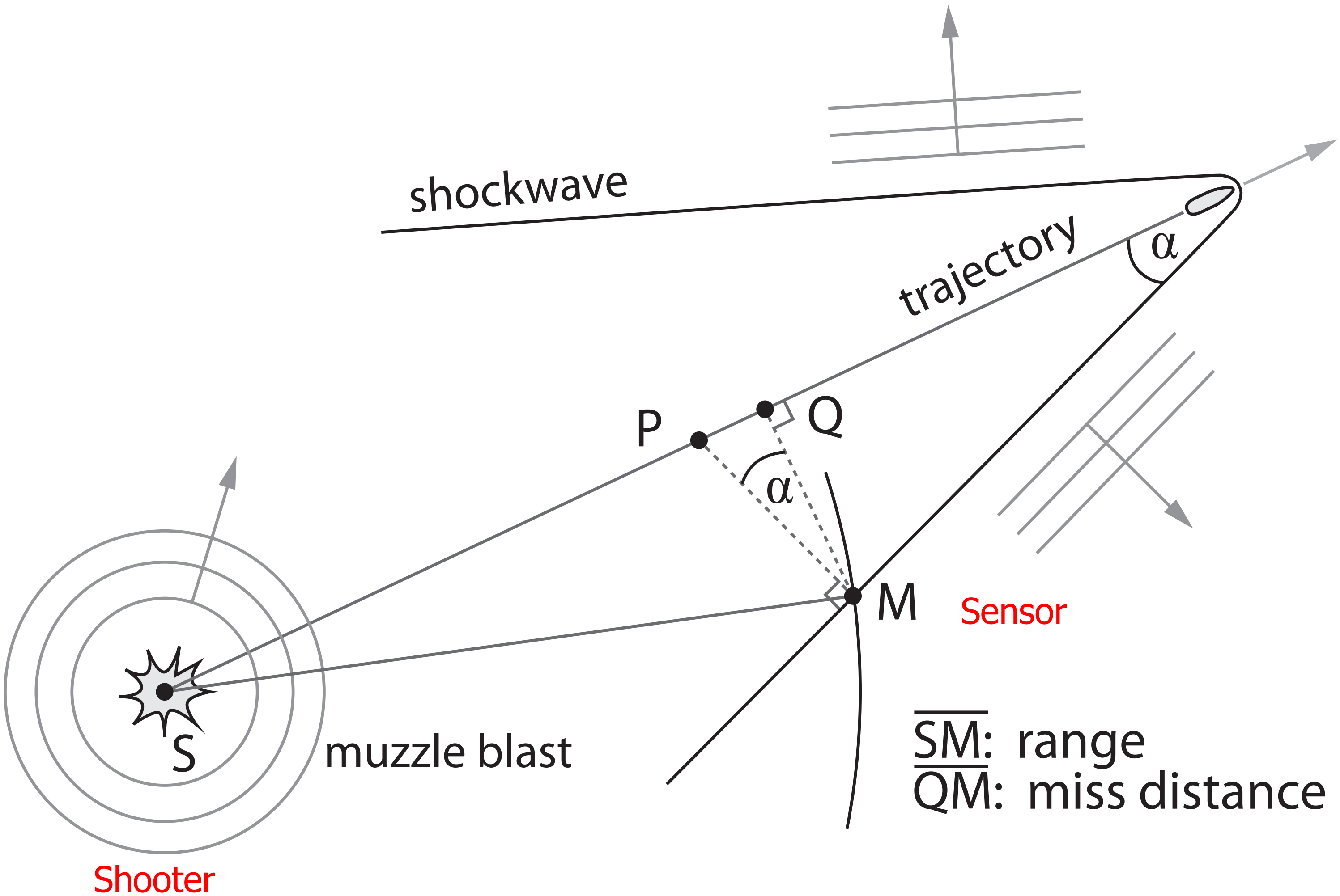
Slides from Akos Ledeczi, Vanderbilt

Acoustic Shooter Localization



- The muzzle blast originates at the gun and propagates spherically away at the speed of sound.
- The shockwave is generated by the supersonic projectile as it slices through the air. The wavefront has a conical shape the angle of which is determined by the Mach number, the ratio of the speed of the bullet and the speed of sound.
- The miss distance is the perpendicular distance from the sensor to the trajectory. The shockwave length depends on it as well as on the caliber, and the Mach number.

Acoustic Events of a Typical Rifle Shot



P: origin of shockwave heard at M
SP: at the speed of bullet
PM: at the speed of sound
α: shockwave cone angle

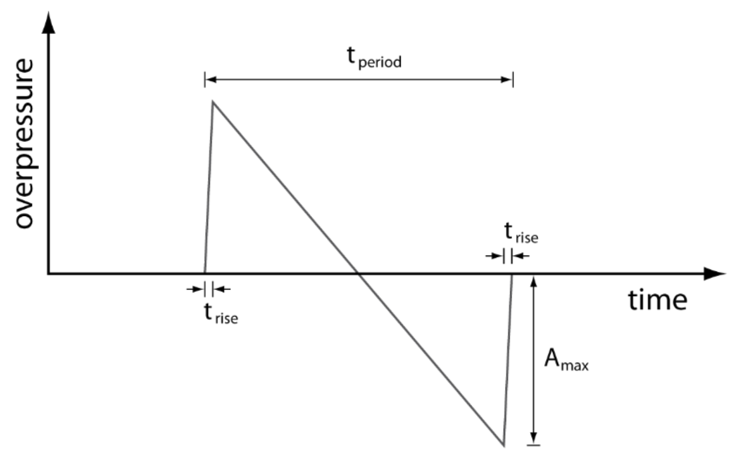
Prior Approaches: Centralized

- Obstacles prevent line-of-sight, causing errors

Boomerang by Raytheon BBN Technologies

Acoustic Shooter Localization

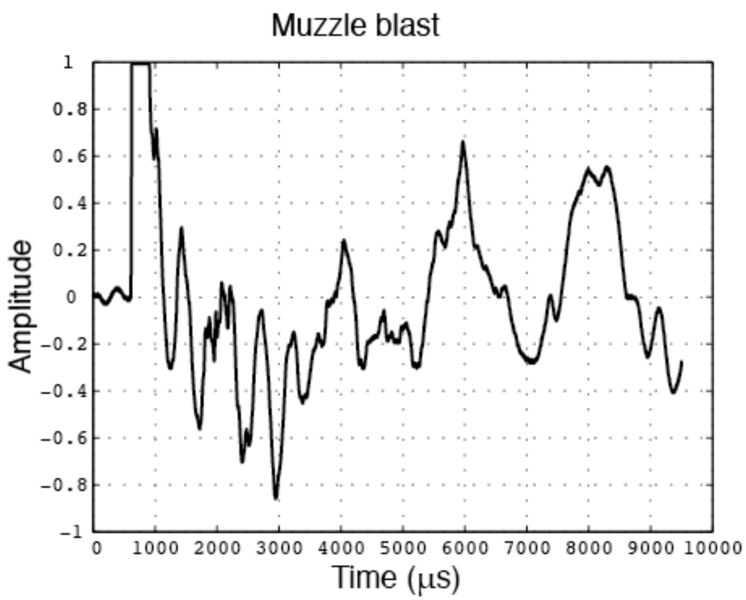
- Using shockwave times-of-arrival (TOAs) and muzzle blast TOA gives time-difference-of-arrival (TDOA) of both between pairs of microphones.
- On a microphone array, this gives angle-of-arrival (AOA) of muzzle blast (i.e. shooter) and AOA of shockwave.
- A simple analytical formula gives shooter position using the two AOAs and the TDOA of the shockwave and the muzzle blast (needs microphone array).
- Using distributed microphones, TDOA equations with muzzle blast TOAs at 3+ microphones can provide shooter location.
- However, location error of microphones and possible echoes due to non-LOS conditions make this approach very inaccurate.

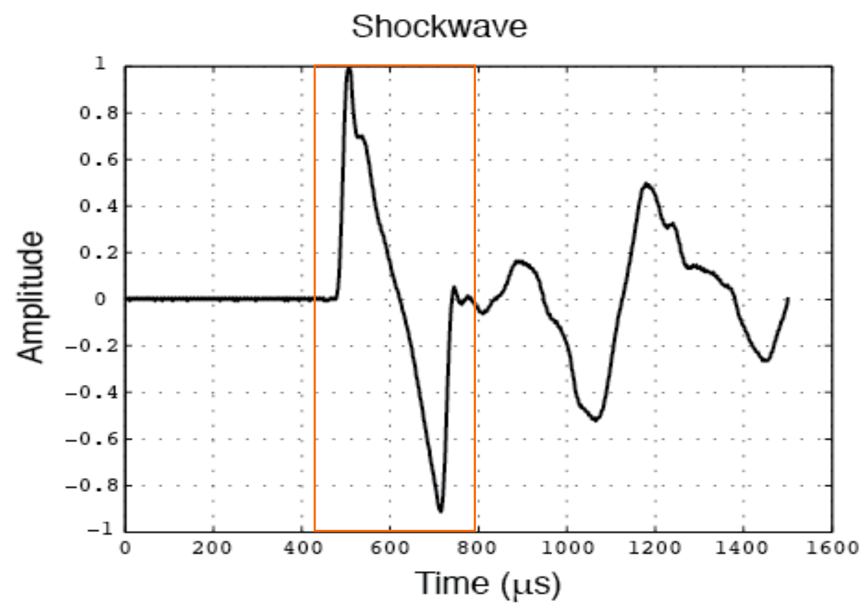


Shockwave signature

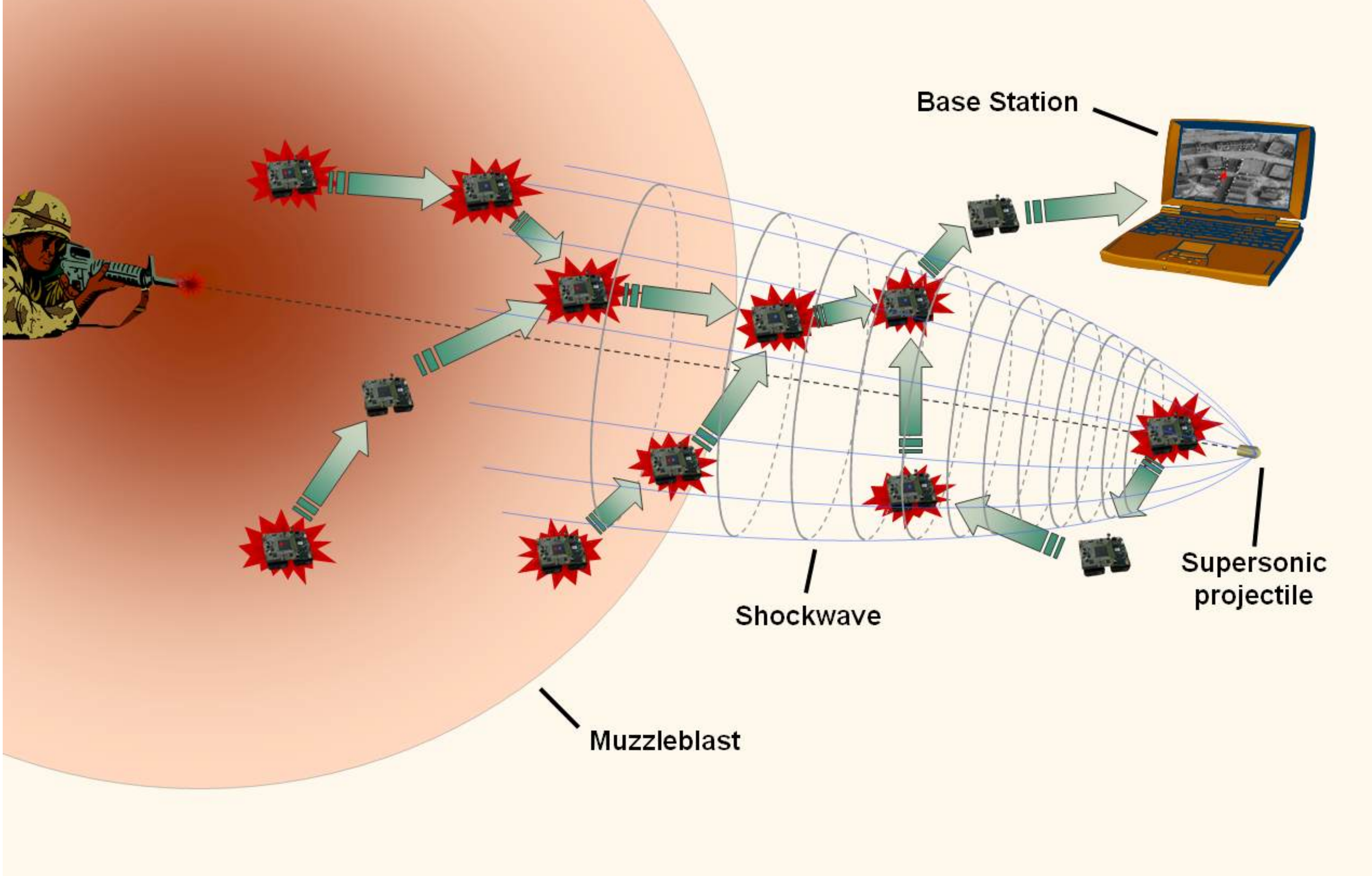
Boomerang by Raytheon BBN Technologies

Signal Shapes





Wireless Sensor Network-Based Countersniper System



System Components

- Accurate time synchronization
- Message routing
- Sensor localization
- Detection of shockwave / muzzle blast
- Sensor fusion

Accurate Time Sync

- Idea: multiple nodes timestamping a common event
- Challenge: variable delays at different layers of network stack
- Reference Broadcast Method
- Flooding Time Sync Protocol
  - Timestamp a single broadcast message multiple times after different byte offsets
  - In mesh network, sync to parent time

Message Routing Protocol

- Nodes organized as a rooted tree, with base station as root
- Application-specific goal: 1-second latency to receive message about potential gunshot at base station
- Challenge: correlated activity -- many nodes will detect gunshot signal at nearly the same time!
- Protocol must balance between latency, reliability, and overhead
- Each node xmits 0, 1, or up to 4 times (at most 3 rxmits)
- If node hears another node nearer to root in tree send data, then suppress, else send at different times (but all within 1 second of signal detection)

Sensor Localization

- RF + acoustic signal (similar to Cricket, different from Voxnet, which doesn't use RF)
- Proposed design uses 4 "anchor nodes" at known locations
- Built prototype (as described) uses hand-coded locations based on manual survey!
  - Localization in the real world is a hard problem – robustness isn't easy to achieve
- Multiple acoustic chirps in signal
  - Paper comments that adding chirps increases SNR – that sounds incorrect – both signal and noise will proportionally increase!

Sensor Fusion Method

$$t_i(x,y,z,t) = t + \frac{\sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2}}{v}$$

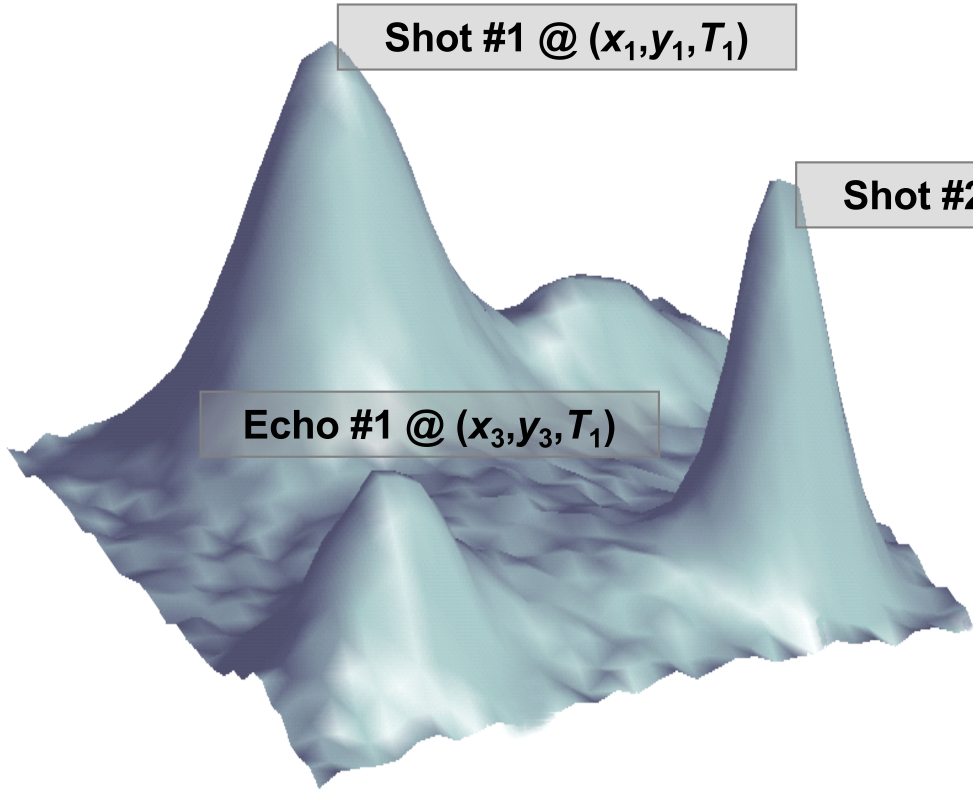
$$|t_i(x,y,z,t) - t_i| \le \tau$$

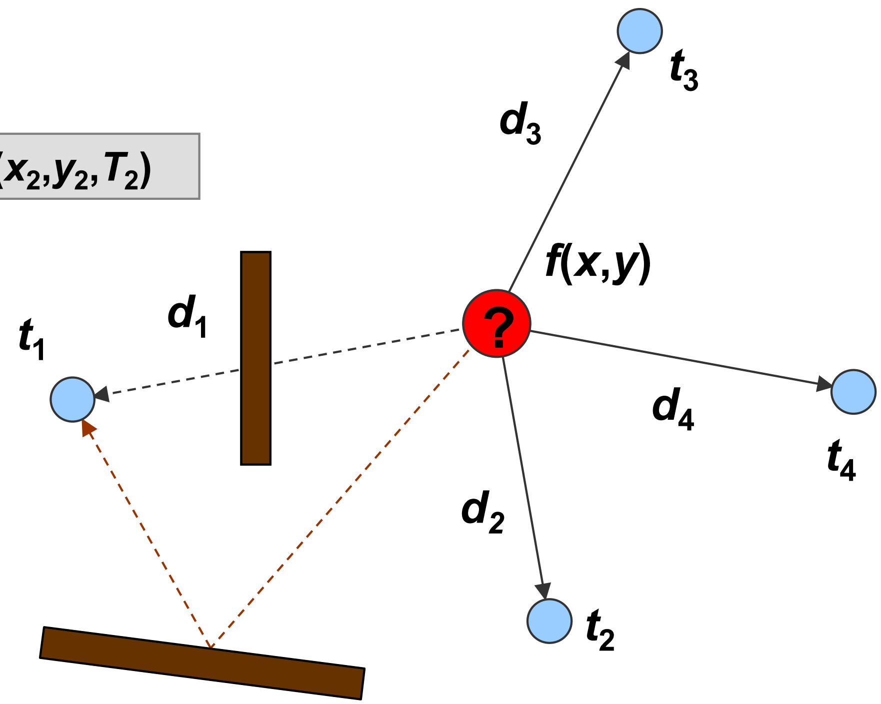
$$\tau = \delta_1 / v + \tau_2 + \tau_3$$

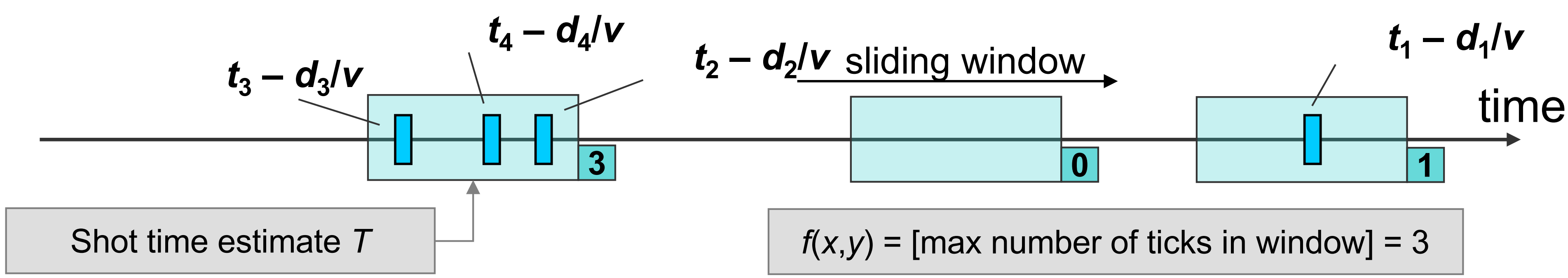
- Tau is max positioning error caused by error in localization (first term), max time sync error (second), and max signal detection uncertainty (third term)
- Approach: maximize consistency function and search for (x,y,z,t) corresponding to max of function

$$C_\tau(x,y,z,t) = \underset{i=1,\ldots,N}{\text{count}} \left(\left| t_i(x,y,z,t) - t_i \right| \le \tau \right)$$

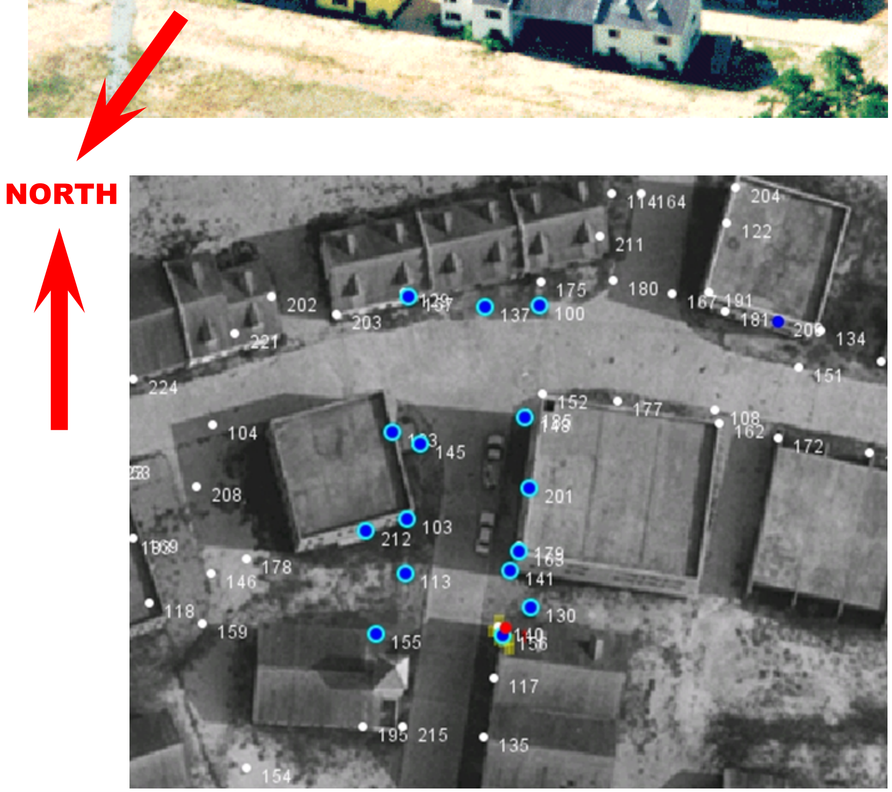
Sensor Fusion







Experiments at McKenna MOUT site at Ft. Benning



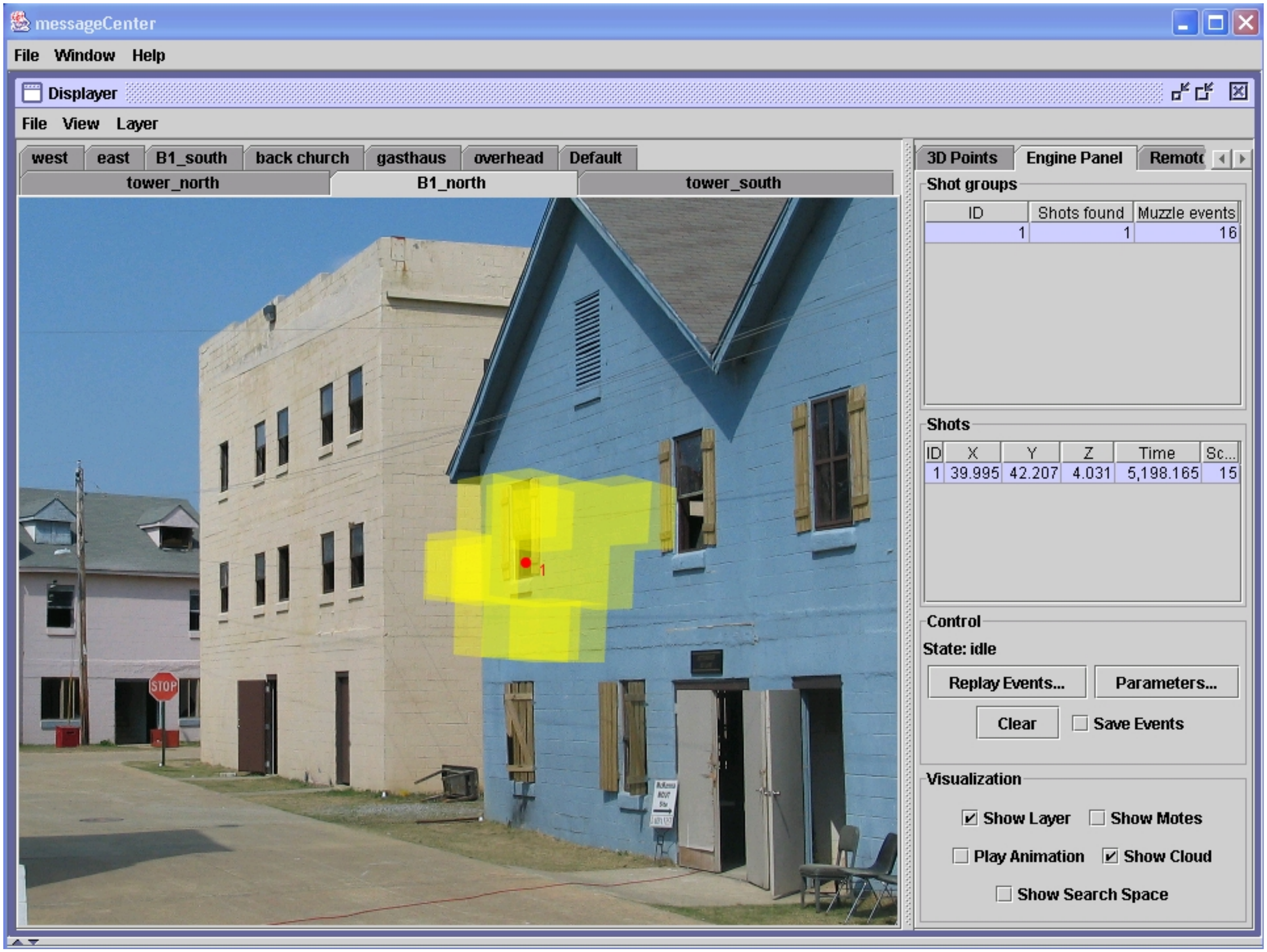
- **Sep 2003: Baseline system**
- **Apr 2004: Multishot resolution**

- **60 motes covered a 100x40m area**
- **Network diameter: ~7 hops**
- **Used blanks and Short Range Training Ammunition (SRTA)**
- **Hundreds of shots fired from ~40 different locations**
- **Single shooter, operating in semiautomatic and burst mode in 2003**
- **Up to four shooters and up to 10 shots per second in 2004**
- **M-16, M-4, no sniper rifle**
- **Variety of shooter locations (bell tower, inside buildings/windows, behind mailbox, behind car, …) chosen to absorb acoustic energy, have limited line of sight on sensor networks**

- **1 meter average 3D accuracy (0.6m in 2D)**

- **Hand placed motes on surveyed points (sensor localization accuracy: ~ 0.3m)**

2.5D Display, Single shot



Red circle:
→ **Shooter position**

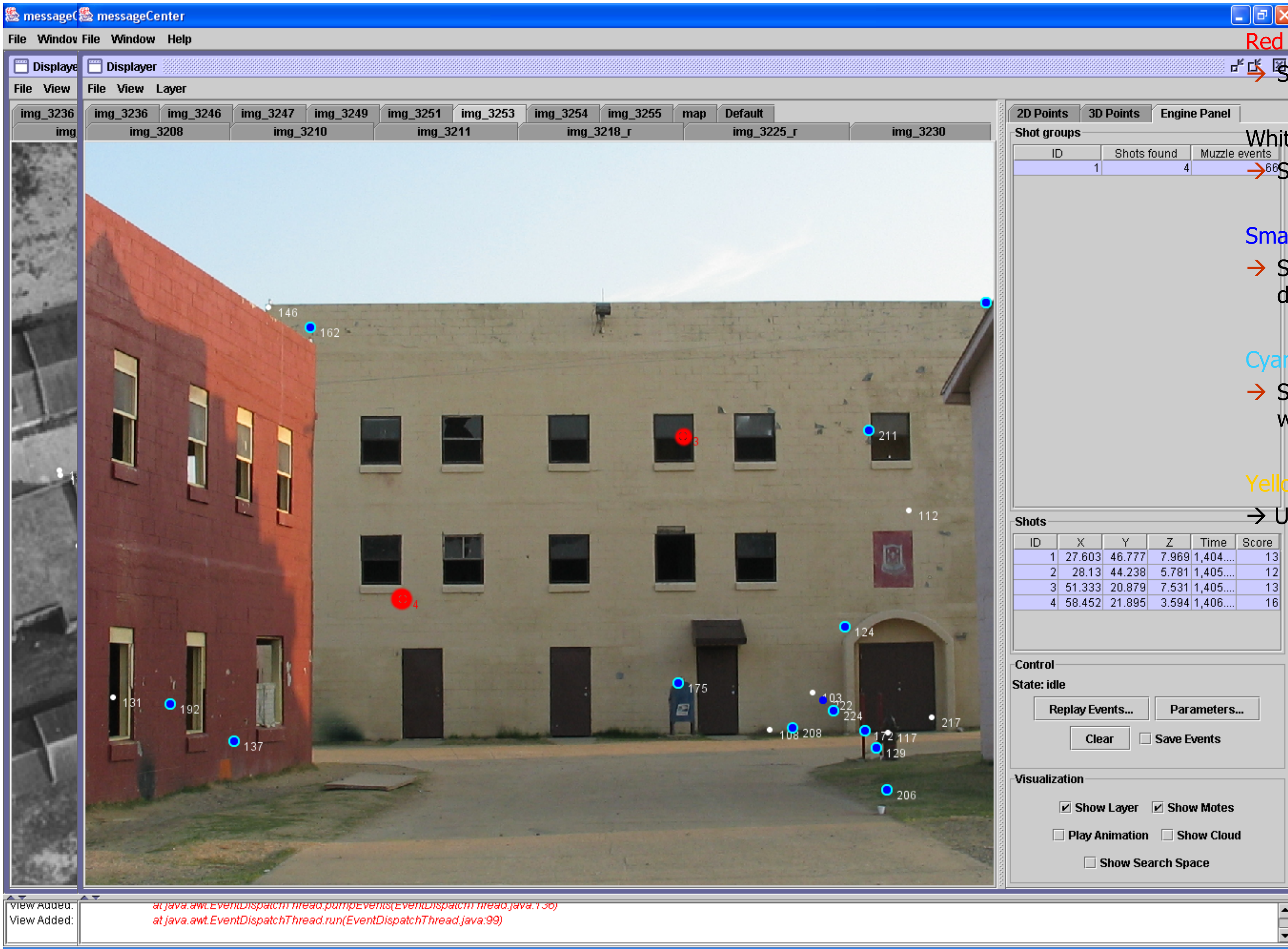
White dot:
→ **Sensor node**

Small blue dot:
→ **Sensor Node that detected current shot**

Cyan circle:
→ **Sensor Node whose data was used in localization**

Yellow Area:
→ **Uncertainty**

2.5D Display, Multiple Shots



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