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Radio Interferometric Positioning

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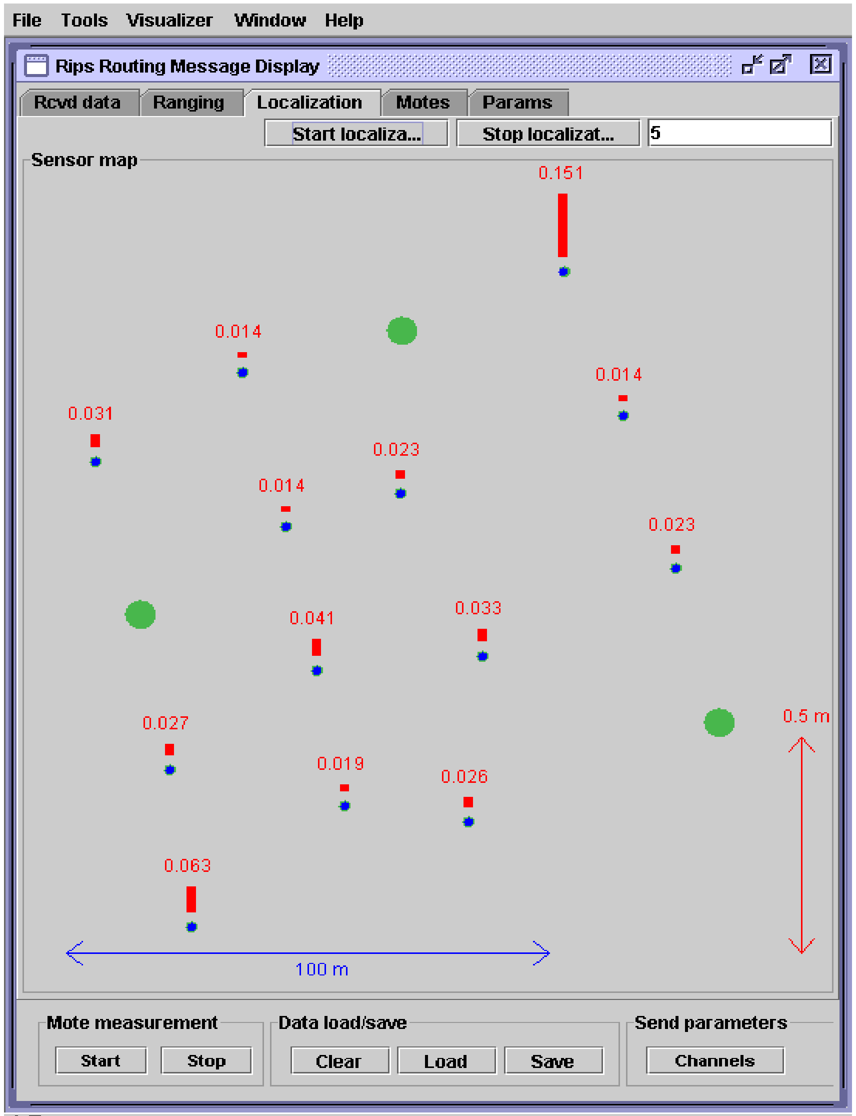
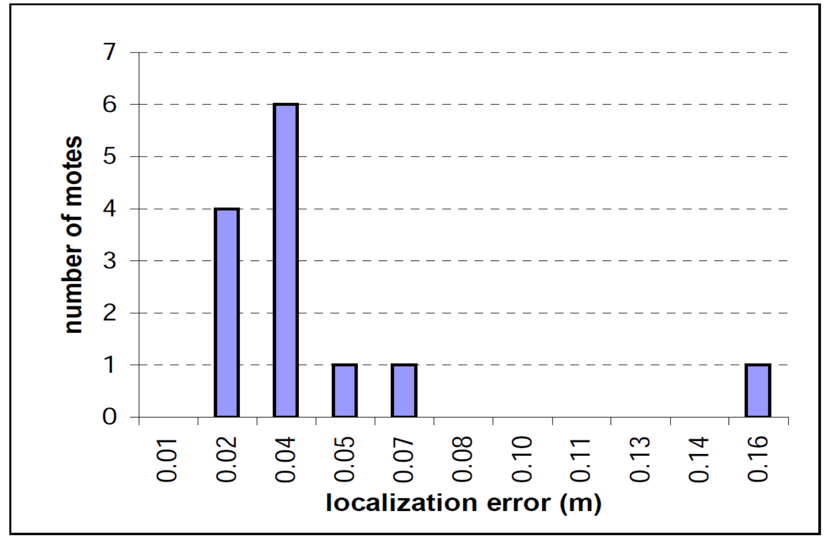
Ranging Techniques

Approaches	Pros	Cons
Acoustic ranging (time of flight)		extra HW (actuator, detector), line of sight
A. Sound	range (30m)	not stealthy, echoes
B. Ultrasound	accurate (9cm), stealthy	limited range, directionality
Radio signal strength (RSS)	no extra HW, stealthy	imprecise beyond few meters, extensive calibration
GPS	single node, global time	Extra HW, outdoors only, inaccurate
Differential GPS	very accurate (1cm)	extra HW, outdoors only, very expensive
Infrared light	inexpensive	extra HW, accuracy, direct line of sight, sunlight
Magnetic field	accuracy (1mm)	range (3m), metal interference
Radio Interferometric Ranging	accurate (5cm), stealthy, long range, no extra HW	multipath

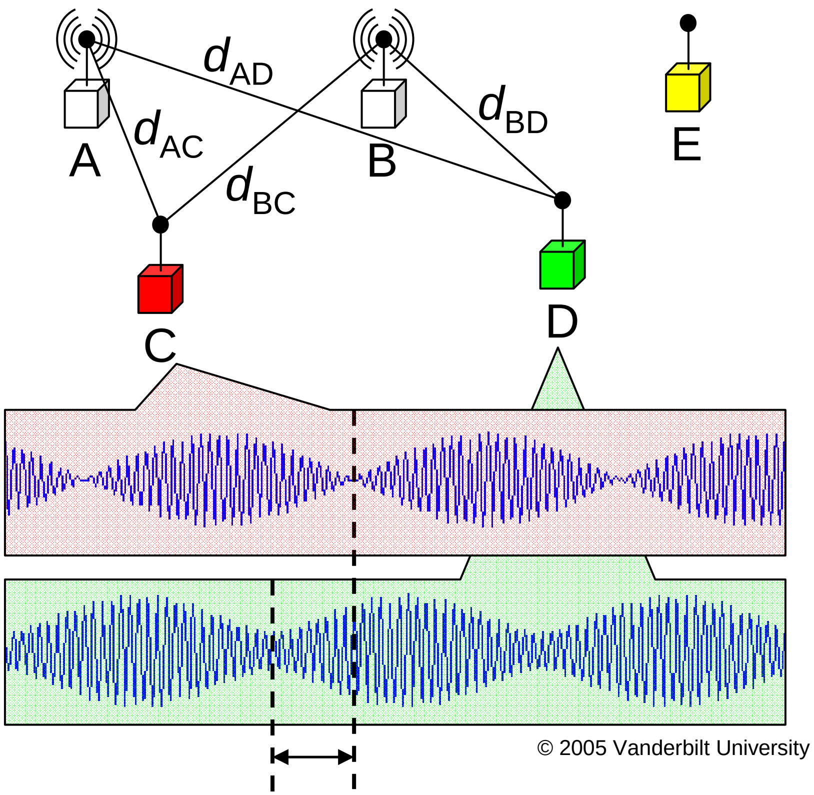
Large scale RIPS experiment





- 12000m^2 area
- 16 XSM motes on the ground
- Minimum node distance 25m
- 3 anchor nodes
- Took 50 minutes
- Average loc error < 4cm
- Maximum loc error 16cm
- Maximum “range” 170m

Measurement

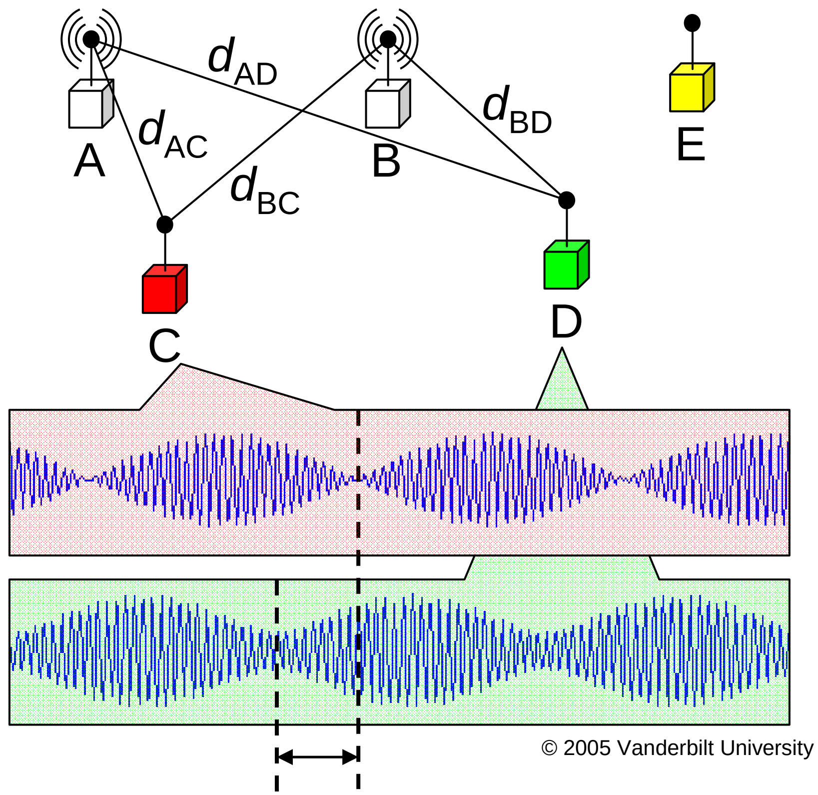


phase offset / 2π · λ

$$= (d_{AD} - d_{BD} + d_{BC} - d_{AC}) \bmod \lambda$$

- COTS radio chip (CC1000)
  - adjustable transmit frequency
  - RSSI output
- Two senders (A and B) transmit simultaneously
  - pure sinusoid waves
  - high transmit frequency (400–460 MHz)
  - wave length is λ (65–75 cm)
  - small frequency separation (100–800 Hz)

Measurement

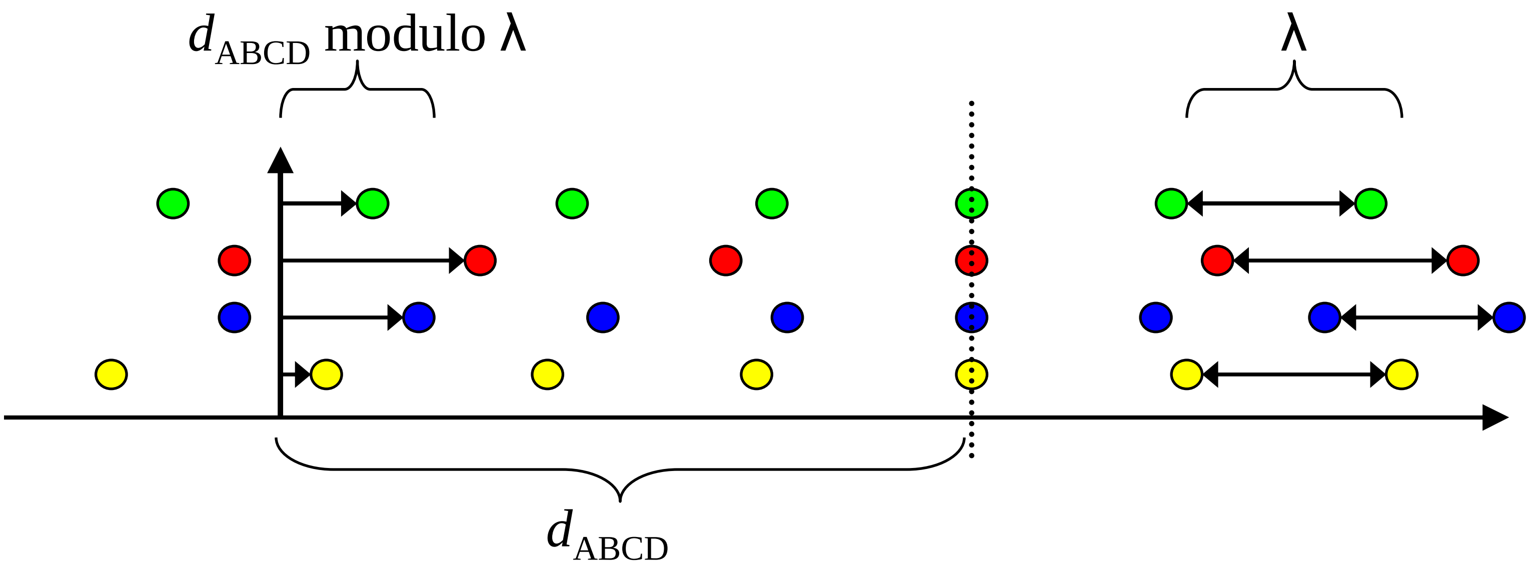


phase offset / 2π · λ

$= (d_{AD} - d_{BD} + d_{BC} - d_{AC}) \bmod \lambda$

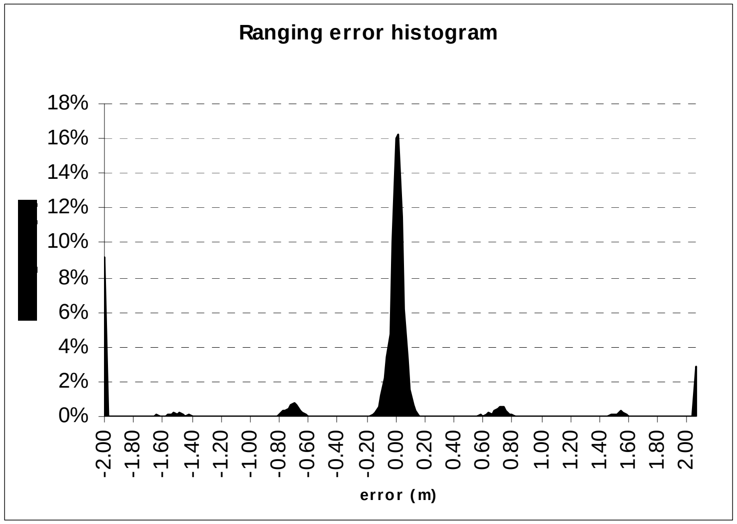
- Receivers (C, D and E) measure radio interference
  - sample RSSI (at 9 KHz)
  - find beat frequency (100–800 Hz)
  - time synchronization (1 μs precision)
  - measure phase offset of RSSI
- Relative phase offset between C and D is a function of the distances d_{AC}, d_{AD}, d_{BC}, d_{BD} and the wave length λ

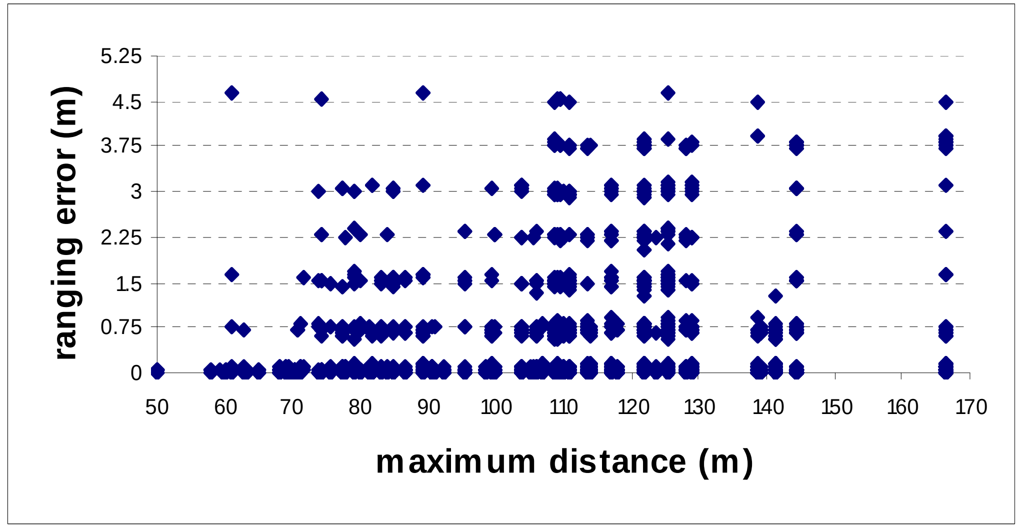
Ranging



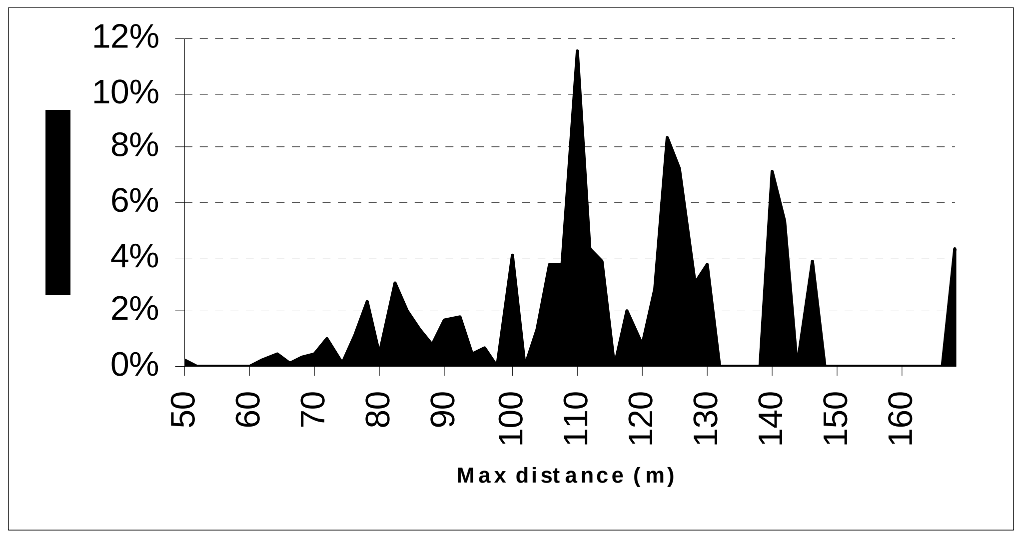
- Interferometric range: $d_{ABCD} = d_{AD} - d_{BD} + d_{BC} - d_{AC}$
- Phase offset measurements: d_{ABCD} modulo λ (65cm < λ < 75cm)
- Multiple measurements at different frequencies
- Wave length ambiguity

Ranging

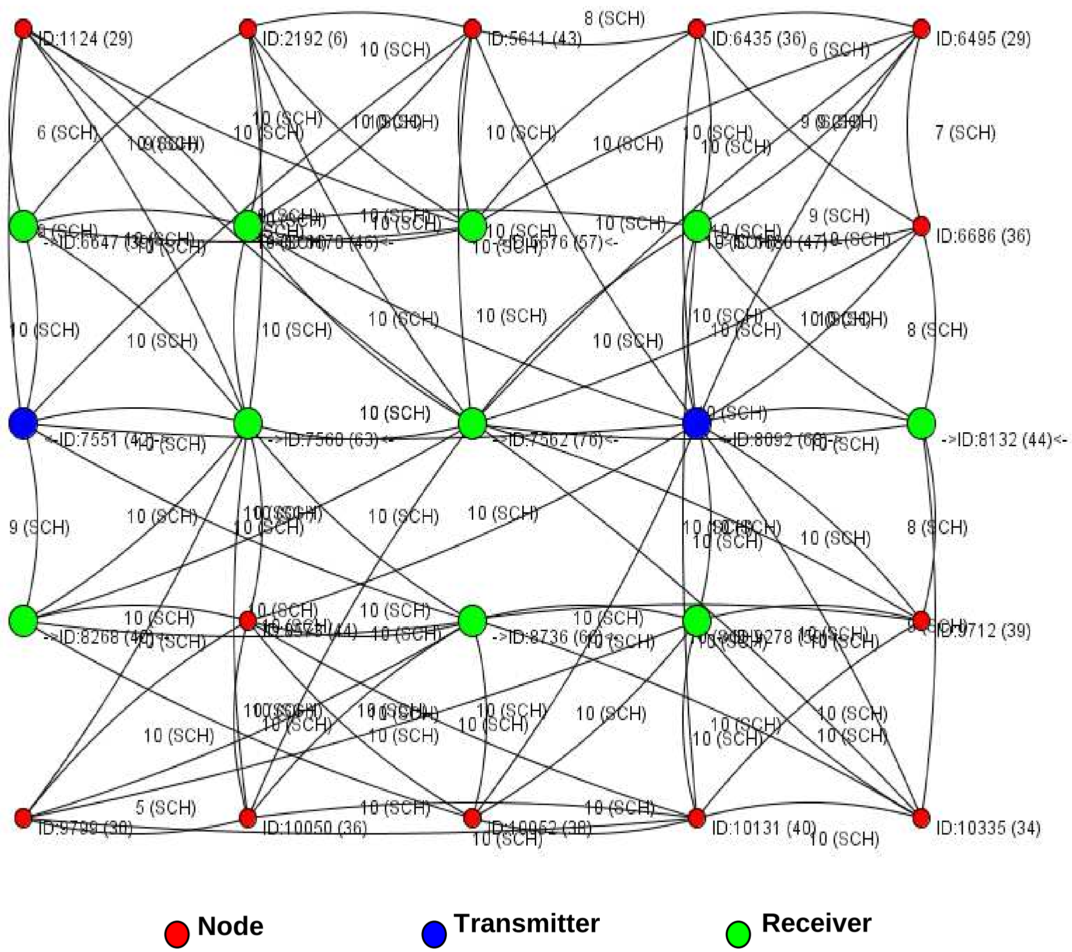




- Full wavelength errors
- Interferometric ranging error is independent of pairwise distances
- Maximum range is 3-4 times the communication range



Centralized Localization



Measurement schedule

Measurement scheduling

- Base station selects pairs of transmitters and corresponding groups of receivers
- Transmitters are calibrated
- Transmit at 55 different frequencies
- Absolute phase offsets are routed to base station

Ranging

- Measurements are filtered based on beat frequency and amplitude
- Relative phase offsets and ranges are computed

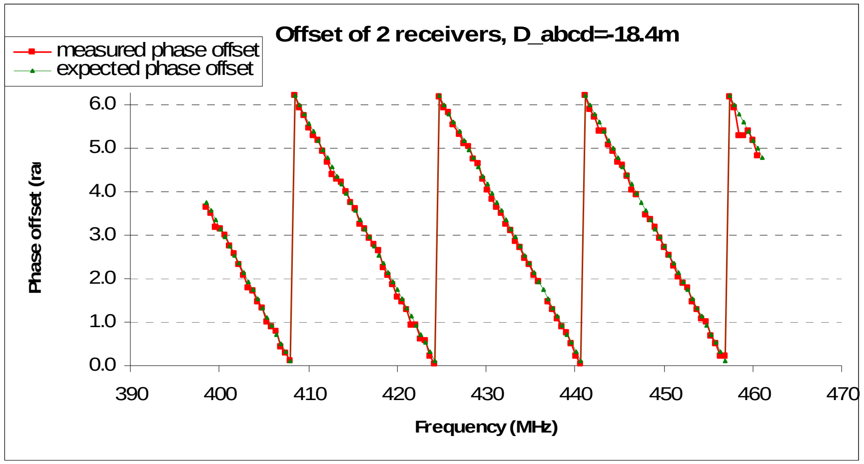
Localization

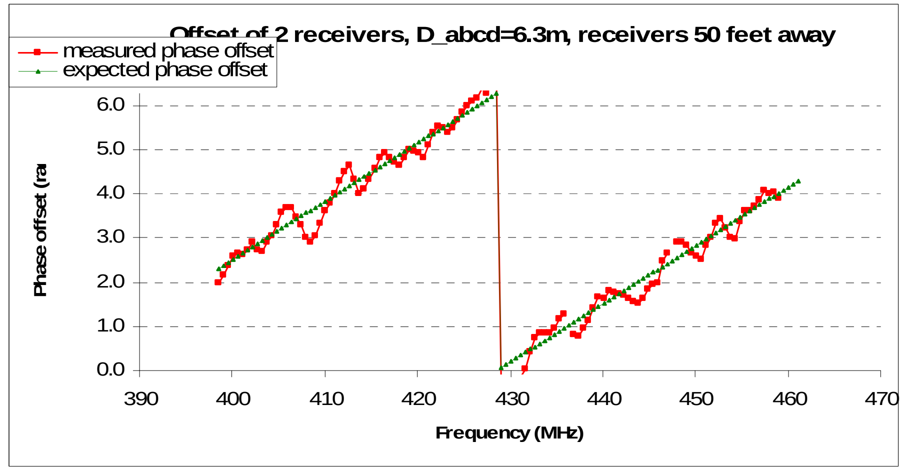
- Existing algorithms do not work with d_{ABCD} ranges
- Error function based on calculated and measured ranges
- Genetic algorithm based optimization and filtering

Design tradeoffs

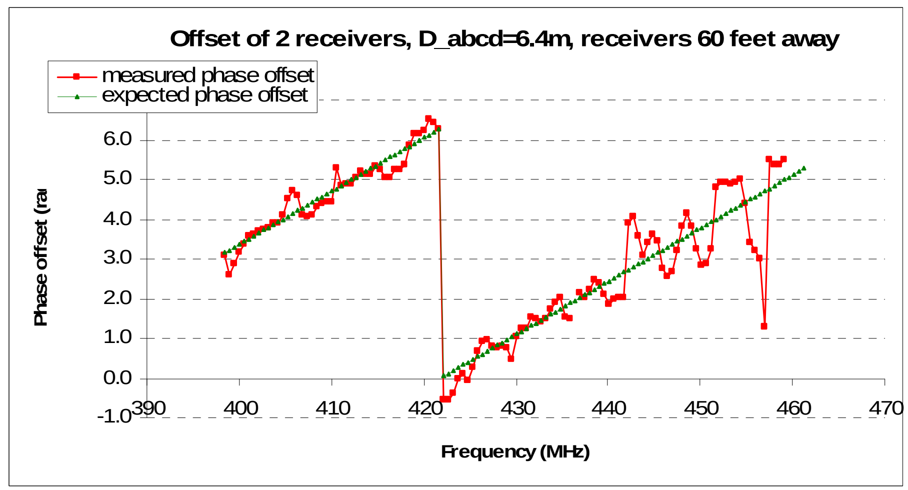
- Increase length of phase measurement
  - \+ allows more sophisticated DSP algorithm
  - \+ more precise phase measurement
  - – slows down ranging
  - – requires better time synchronization
- Increase frequency separation
  - \+ more beats in same amount of time
  - – less samples per beats
  - – requires better time synchronization
- Increase the number of frequencies
  - \+ eliminates the ambiguates in ranges
  - \+ improves ranging precision
  - – slows down ranging
- Increase the number of transmitter pairs
  - \+ improves localization precision
  - – slows down ranging
- Low frequency RSSI signal
  - \+ low precision hardware
  - \+ low precision time synchronization
  - \+ signal processing in real time
  - – slows down ranging
- High frequency RF signal
  - \+ high precision ranging
  - – modulo wave length ambiguities
- Increase frequency band
  - \+ eliminates the ambiguities in ranges
  - – interference with other devices
  - – requires hardware support

Multipath effects





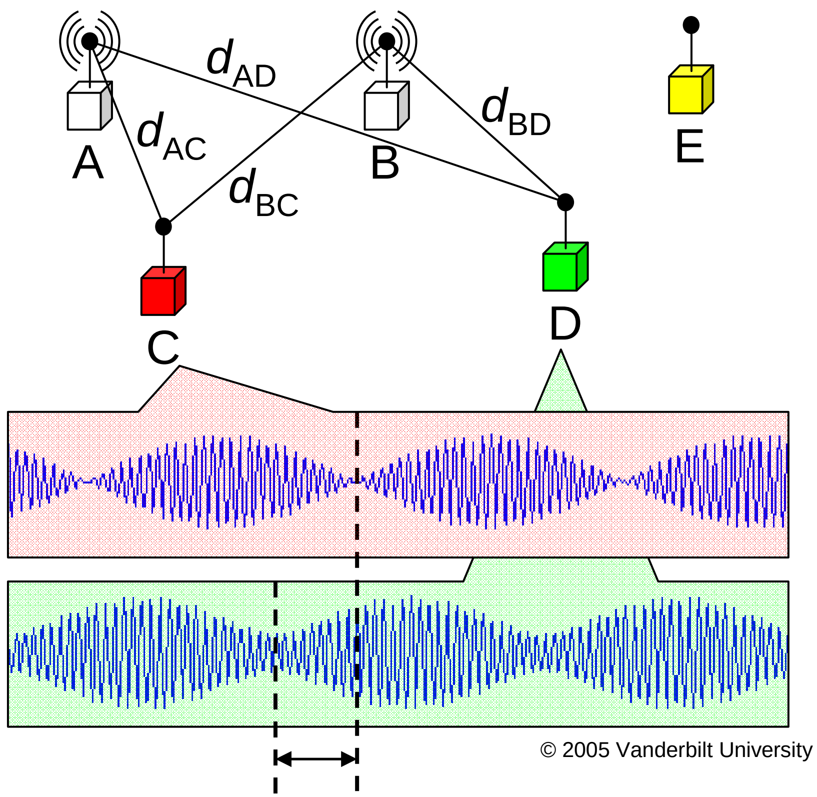
- Ideal phase offset measurement at 120 channels between 400 and 460 MHz (above)
- Multipath distorted measurements outdoors near buildings using different setups (right)
- Line fitting still works most of the time but the error incrases



Sources of errors

- Carrier frequency inaccuracy
- Carrier frequency drift and phase noise
- Multipath effects
- Antenna orientation
- RSSI delay and jitter
- RSSI signal to noise ratio
- Signal processing error
- Time synchronization error

Summary



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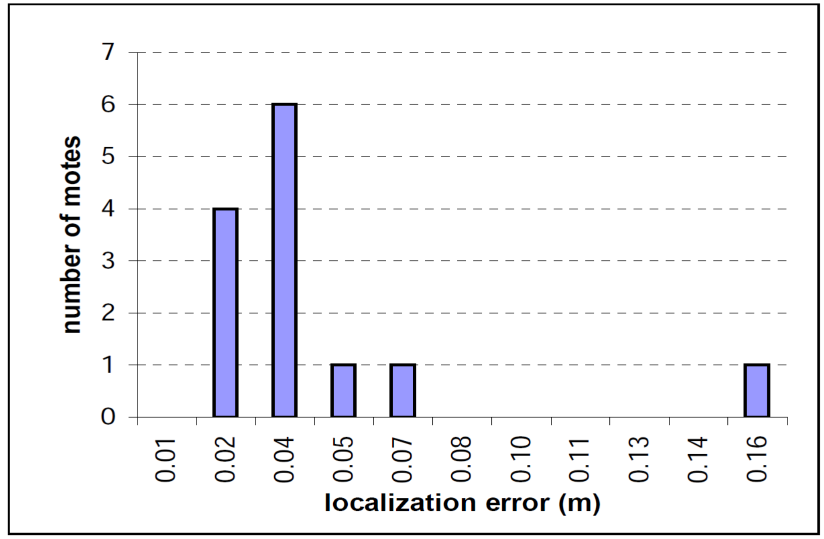

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