Centaur: Locating Devices in an Office Environment

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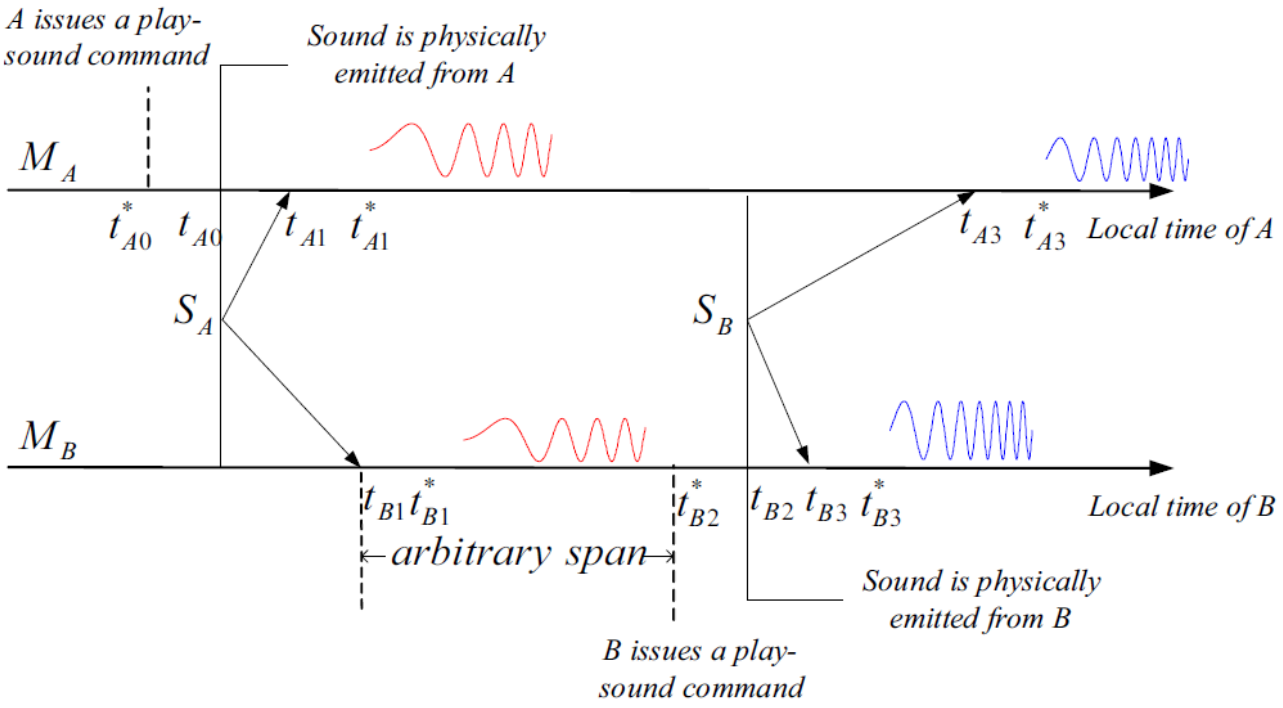
LOCALIZATION TECHNIQUES

	Radio Frequency (WiFi)	Acoustic Ranging (AR)
Based on	Variations of the RF signal strenght with distance	Speed of sound
Models	Fingerprint-based RF Model-based	«Thunder-and-lightening»
Located devices	Laptops, smartphones…	Desktop PCs, speakers
Problems	Location errors (meters)	Acoustic signal detection Precise time synchronization Software delays

- WiFi: Probability distribution of possible locations
- AR: Geometric constraints that relate the locations
  - IDC: Inter-device Distance Constraint
  - IDDC: Inter-device Distance Difference Constraint

BEEP-BEEP

- AR Localization for devices with Speakers+Microphone



$$\Delta t_{AB} = \frac{\Delta N}{F} = \frac{1}{2F}\left[(N_B^A - N_A^A) - (N_B^B - N_A^B)\right]$$

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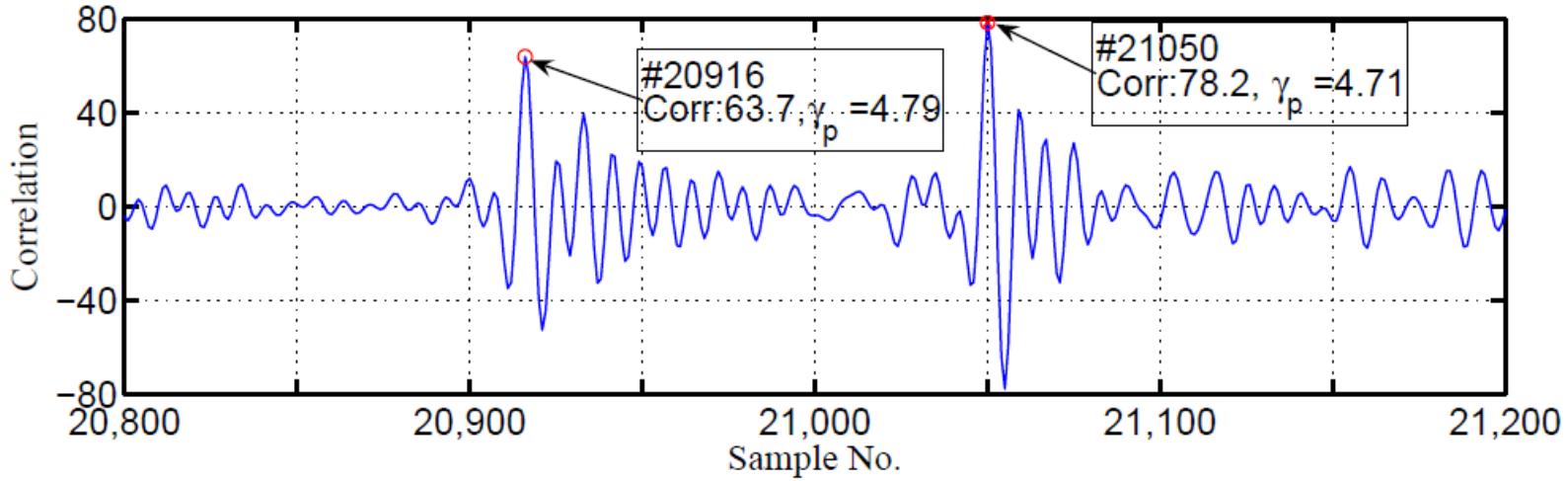
BEEP-BEEP

- Recorded data are correlated with the reference signal
- Maximum peak is located
- Signal detected when: $\frac{\text{Samples around the peak}}{\text{Maximum peak}} > 85\%$



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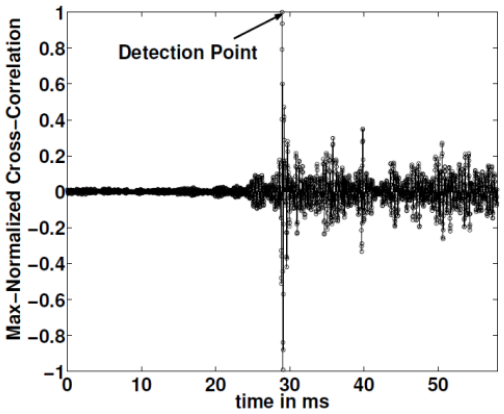
ECHOBEEP: Speaker + Microphone in NLoS scenarios

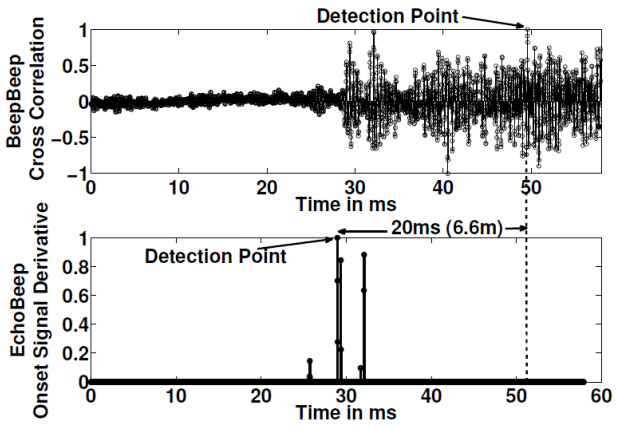
- Performance of additional processing
  - Onset signal: $O(n) = \max\left(C(k)\right) \forall n \geq k > n - W$
  - Derivative of O(n): $\Delta O(n) = O(n) - O(n-1)$

Assumption: Sound signal arriving via the shortest path is typically weaker than the reflections

Detection in Beep-Beep



Difference between the weak signal and noise is bigger than between the strongest signal and the weak



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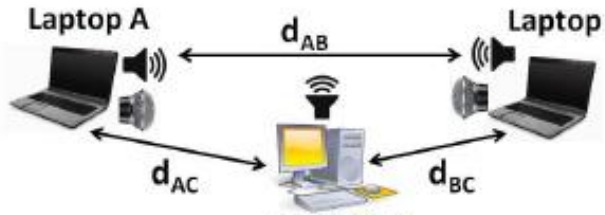
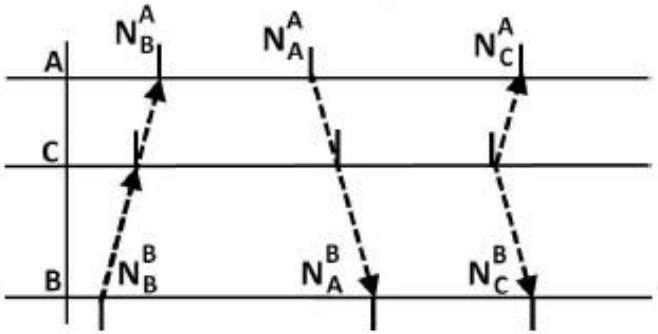
CONTRIBUTIONS OF THE PAPER

- DeafBeep
  - Unlocated devices only with speaker, not microphone
  - Difference in distances from two devices that have both a speaker and a microphone





$$\Delta^2_{ABC} = (\Delta t_{AC} - \Delta t_{BC}) = \frac{1}{F}\left[\begin{array}{c}(N_C^A - N_C^B) - \\ \frac{1}{2}\left[(N_B^A - N_B^B) + (N_A^A - N_A^B)\right]\end{array}\right]$$

$$\left[N_C^A - N_C^B\right] - \frac{1}{2}\left[\left(N_A^A - N_A^B\right) + \left(N_A^A - N_A^B\right)\right] = \frac{S}{V}\left[(d_{AC} - d_{BC}) + (d_{AA} - d_{BB})\right]$$

Result: Geometric constraint to estimate the location

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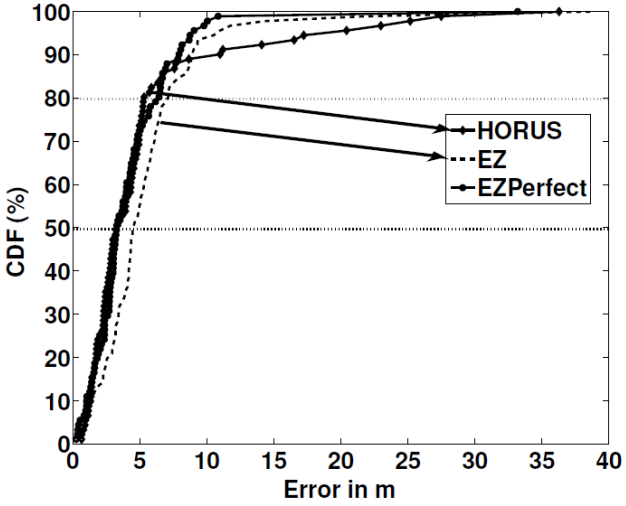
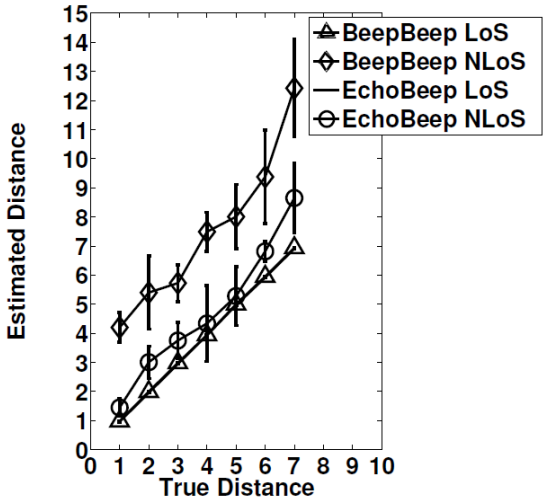
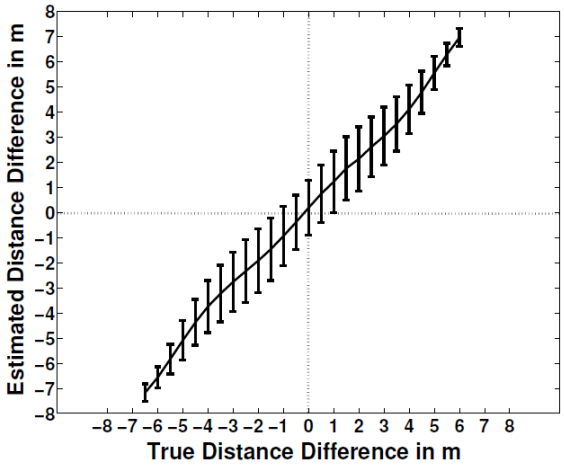
BENCHMARKS



WiFi



EchoBeep



DeafBeep

- WiFi: The tail can be eliminated by using AR constraints
- Beep-Beep and EchoBeep are identical with LoS

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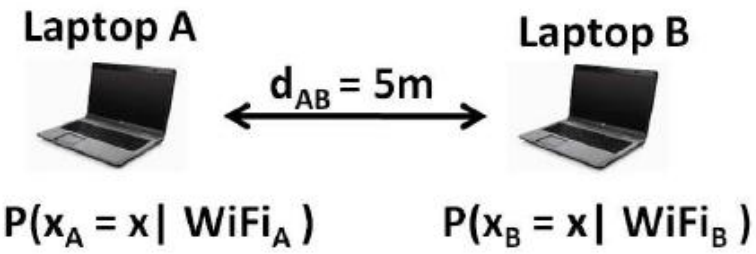
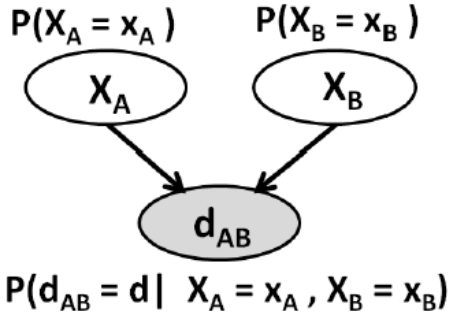
CENTAUR FRAMEWORK

- Anchors
  - Devices whose locations are known a priori
  - At least have a speaker to locate other devices
- Dual-mode devices
  - Speakers and microphones
  - WiFi interfaces (laptops, smartphones)
- Speaker-only devices
- Centaur only attempts to estimate the device locations (bayesian graphs)

BAYESIAN GRAPHS

- Random Variables are modeled as nodes
  - Non-evidence nodes
    - Probability distribution of variables without evidences
  - Evidence nodes (variables that can be measured)
    - WiFi, distance and distance differences
- Edges: Relationship between nodes (conditional probabilities)





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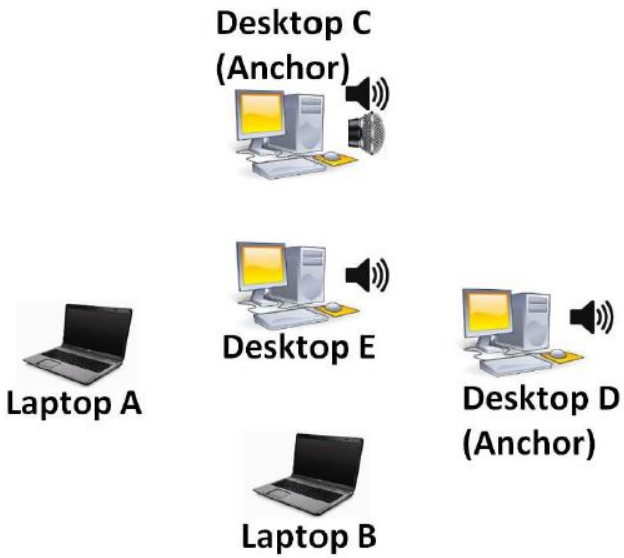
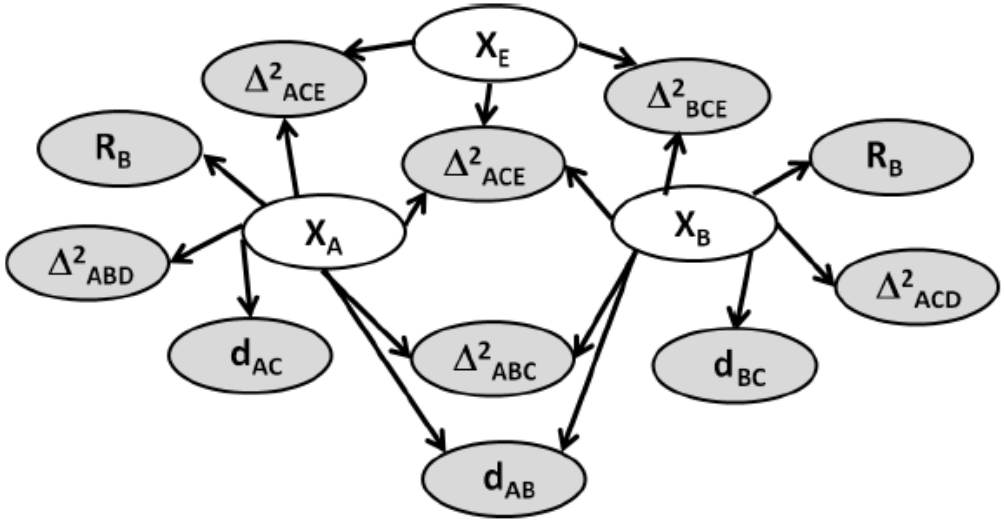
BAYESIAN GRAPHS: Inferences



$$\mathbf{G} = (\mathbf{X}, \mathbf{\Phi}, \mathbf{E})$$
$$P(\mathbf{X}_i = \mathbf{x}_i | \mathbf{\Phi})$$



What is the best approach to approximate inferences to determine the posterior probability?

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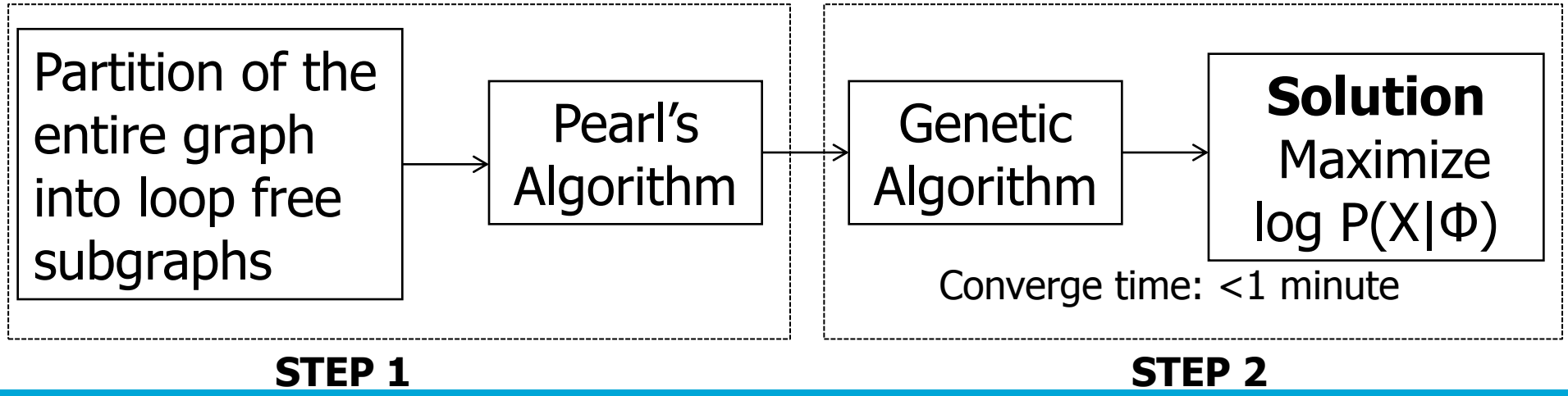
BAYESIAN GRAPHS: Approaches

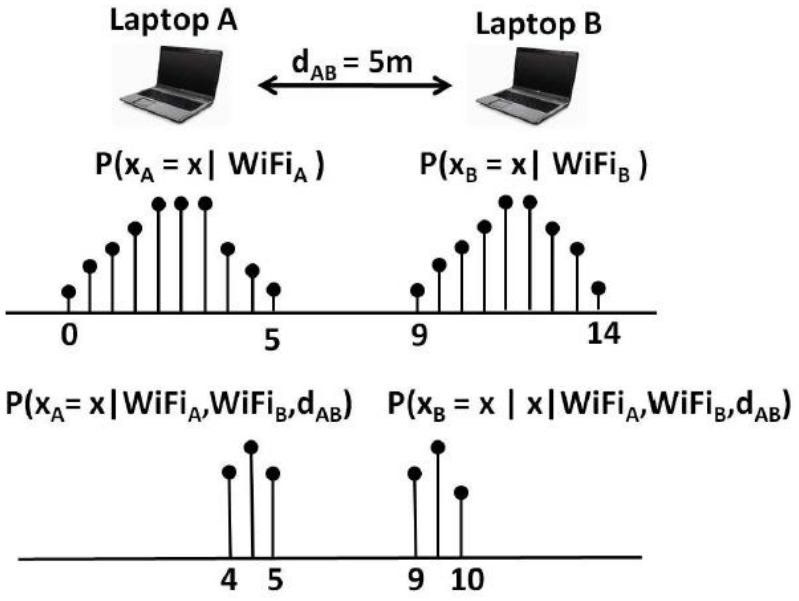
- Typical problems of popular approaches
  - Long time to converge to a solution
  - Limitations because of geometric constratints
  - Non-Gaussian distributions of some RSS measurements
- Centaur proposes a two-step approach

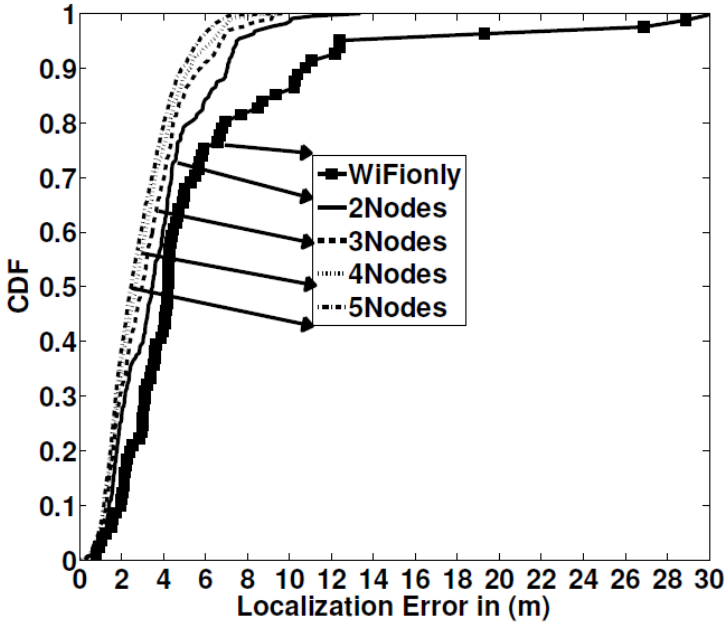


IMPLEMENTATION

- Centaur software = Server + Client
  - Clients (laptops, PCs…) report interfaces to the server
  - The anchors report their known locations to the server
- Clients: RSS, chirp sequences, record of ambient sound
- Server: Computation (EchoBeep and DeafBeep)
- Construction the Bayesian graph and use of the hybrid algorithm

WiFi + AR among non-anchors





Acoustic distance measurements reduce WiFi error

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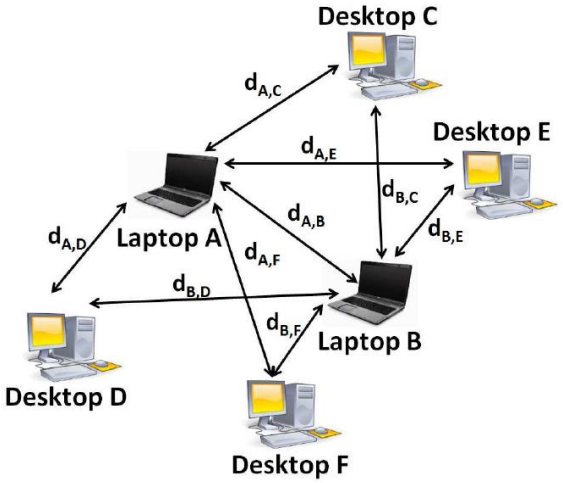
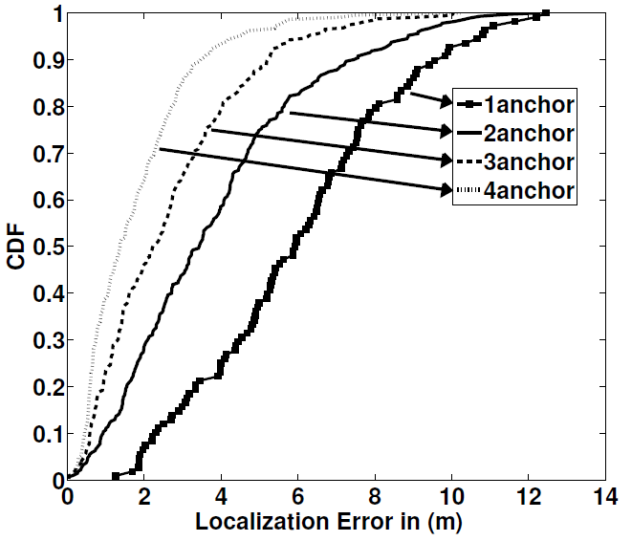
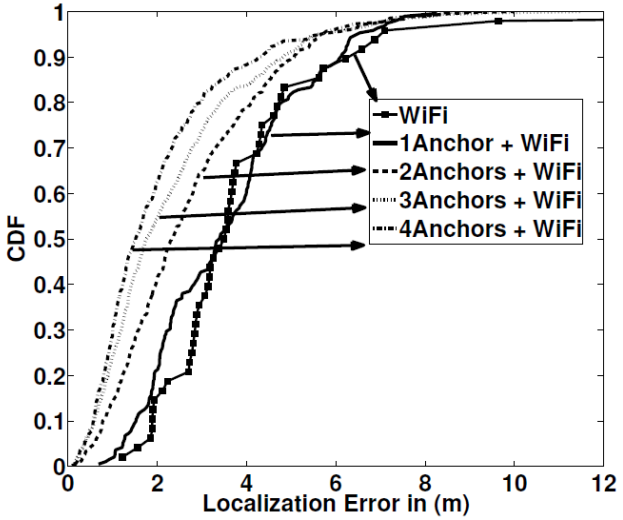
WiFi + AR to speaker-only anchors





Localization with speaker-only anchors



Speaker-only anchors + WiFi

WiFi does not improve significantly the AR

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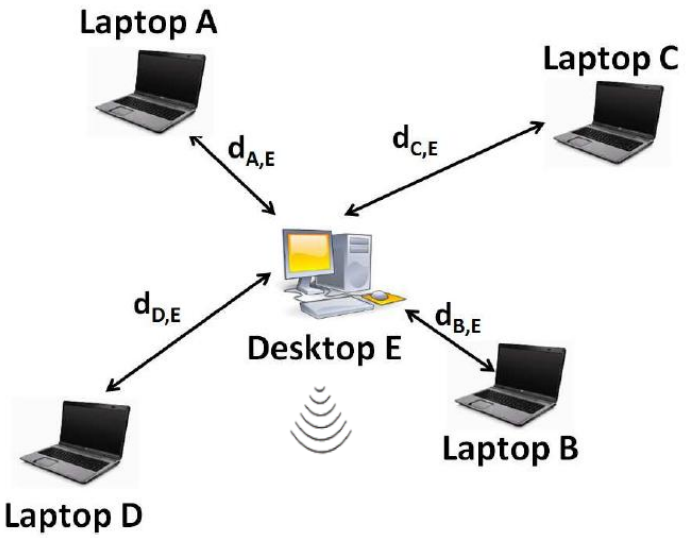
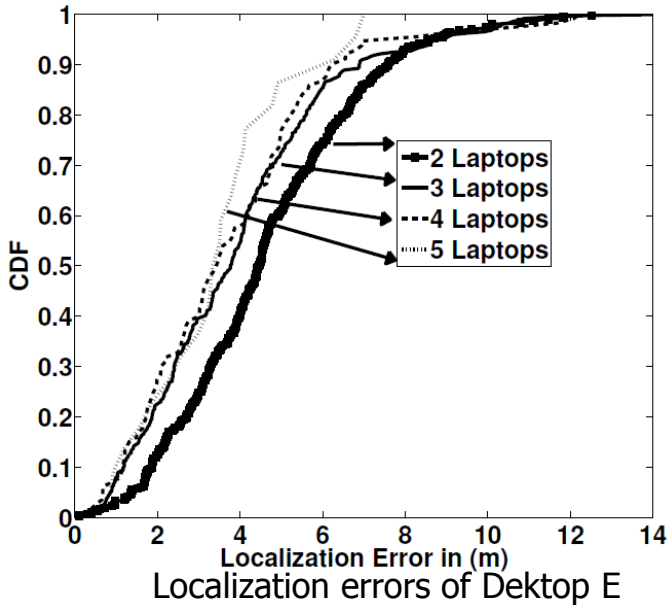
Locating speaker-only devices without any anchors





Localization errors of Dektop E

50%ile errors → 2 m
80%ile errors → 4 m

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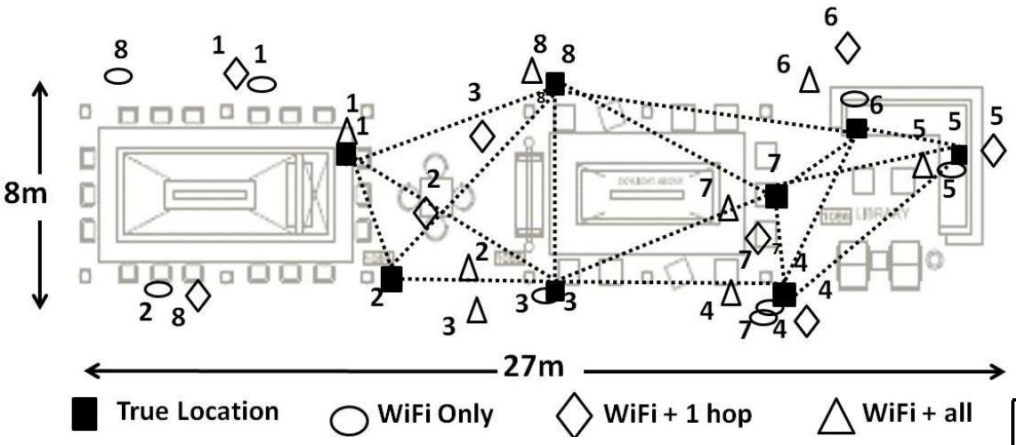
Locating several dual-mode devices simultaneously



Device	Error in m		
	WiFi Only	WiFi + 1 Hop	WiFi + All
1	4.5	4.0	0.7
2	6.3	2.1	2.9
3	0.7	4.9	3.5
4	0.7	1.1	2.4
5	0.7	1.2	1.6
6	1.3	3.5	2.4
7	4.1	1.5	2.8
8	13.2	10.7	1.4

Best results are obtained with WiFi + AR

CONCLUSIONS

- Two new and effective acoustic techniques
  - **EchoBeep**: non-line-of-sight settings (multipath)
  - **DeafBeep**: locating speaker-only devices

- **Centaur** takes the ubiquity of Radio Frequency with the low error rate of Acoustic Ranging
- **Centaur** estimates the most likely locations of all devices in the office without any additional infrastructure

QUESTIONS