



Indoor positioning using FM radio signals

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Outline

- Introduction
- State of the art
- Proposed approach
- FM localization
 - With local transmitters (FM_L)
 - With broadcasting stations (FM_B)
- Conclusion



Indoor localization

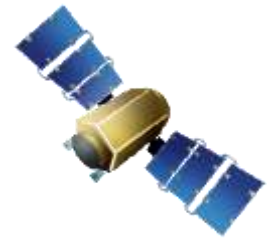
- Ambient intelligence
- Assisted daily living
- Activity recognition
- Behavior analysis
- Object tracking





Indoor localization

- GPS does not work indoors.
- Specialized systems are expensive.
- Systems based on cellular networks:
 - Good coverage
 - Low accuracy
- Wi-Fi is the de-facto standard, but
 - Limited coverage
 - High power consumption



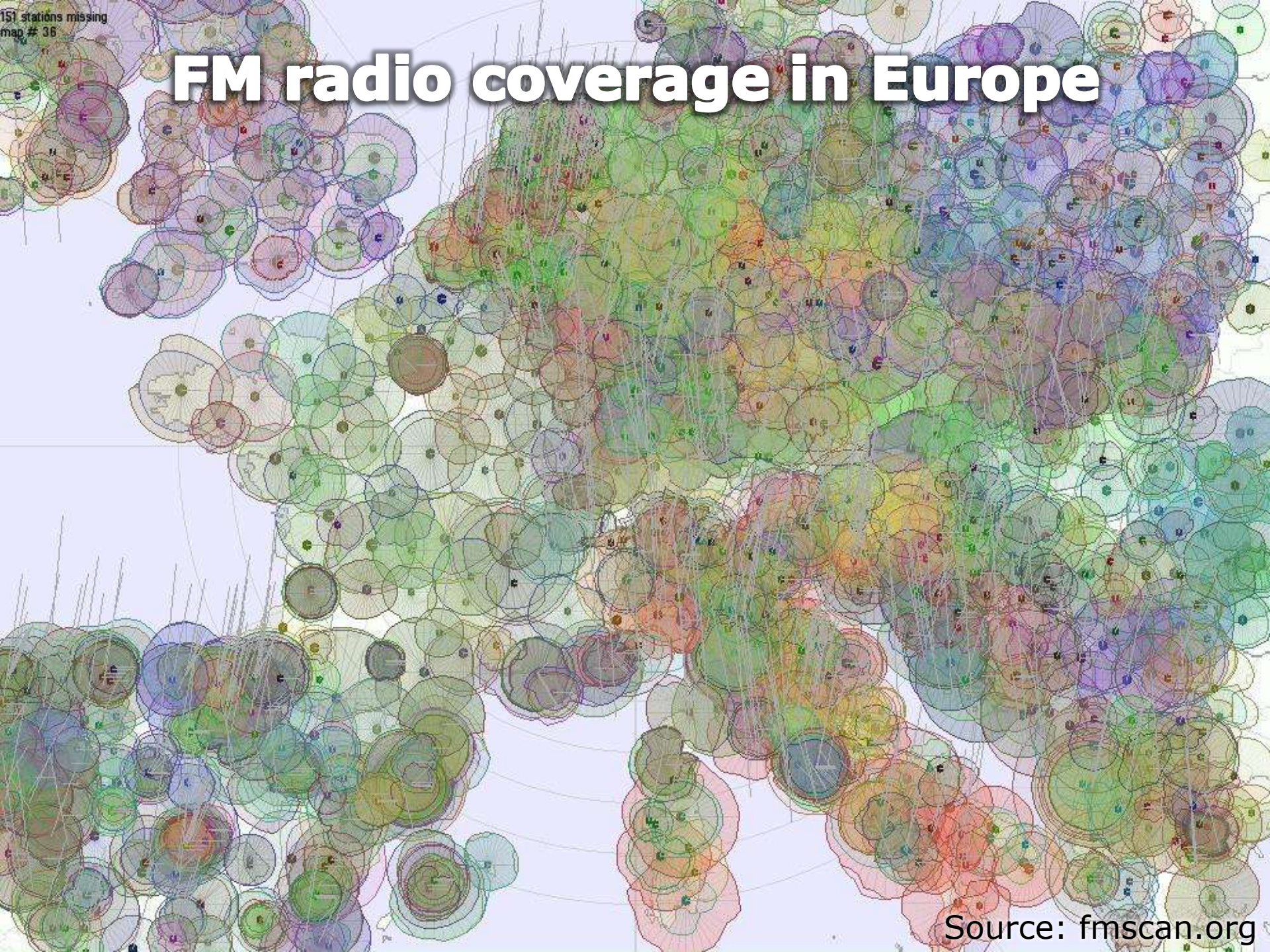


Indoor localization: FM radio

- FM radio addresses these issues, and provides:
 - High coverage
 - Long battery life
 - Good accuracy

151 stations missing
map # 36

FM radio coverage in Europe



Source: fmscan.org

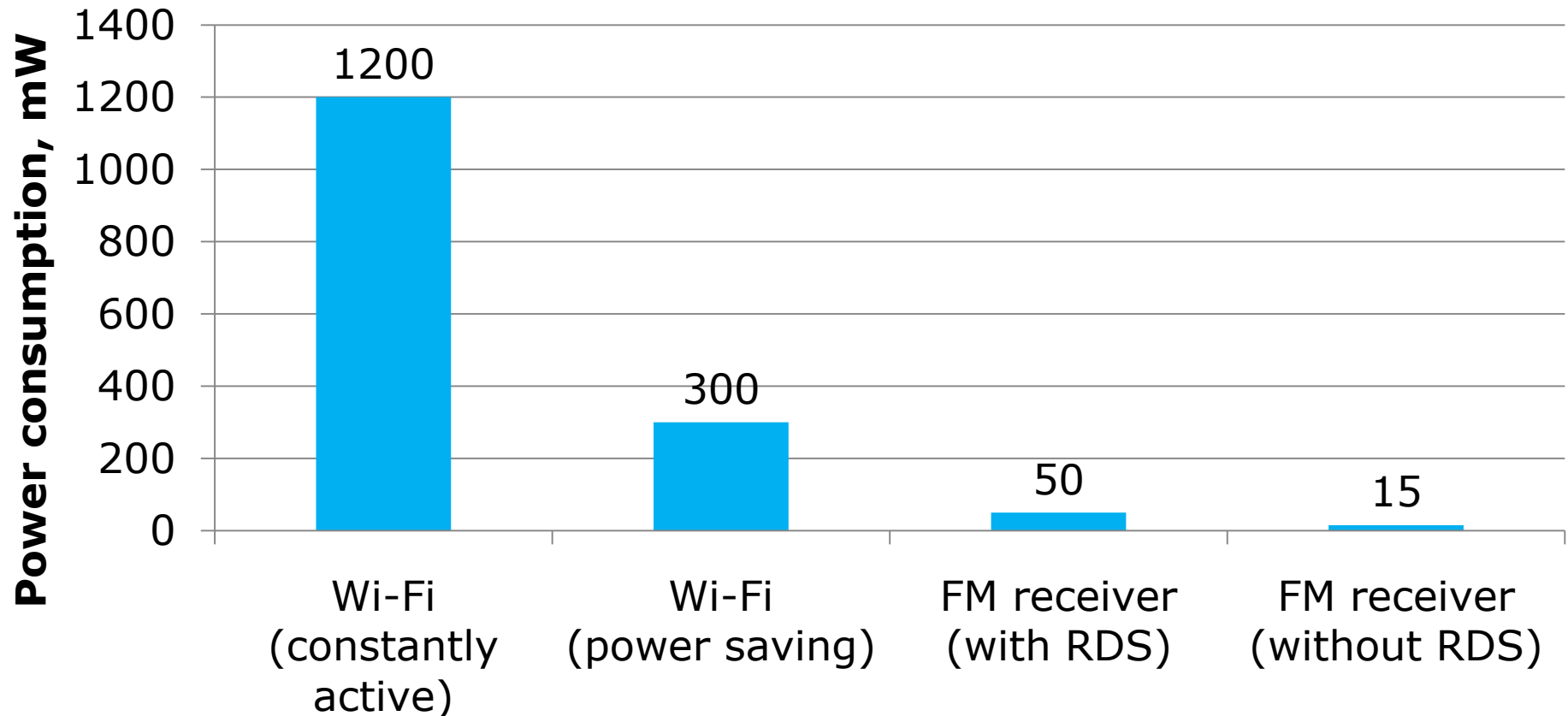


FM-enabled mobile devices





Power consumption





State of the art



State of the art: FM localization

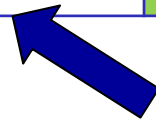
- There are few works on FM positioning.
- All of them consider only outdoor scenarios.
- Achieved accuracy:
 - 2005: 8 km with 50% probability (Krumm et al.)
 - 2009: 20 m with 67% probability (Fang et al.)

There are no results for *indoors*
performance of FM localization.



State of the art: Summary

Technology	Accuracy	Coverage	Battery life	System costs
Wi-Fi	Medium	Low	Low	Low
Cellular	Low	Medium	Low	Low
UWB	High	Low	High	High
FM (outdoor)	Low	High	High	Low
FM (indoor)	?			



The Gap



Localization methods

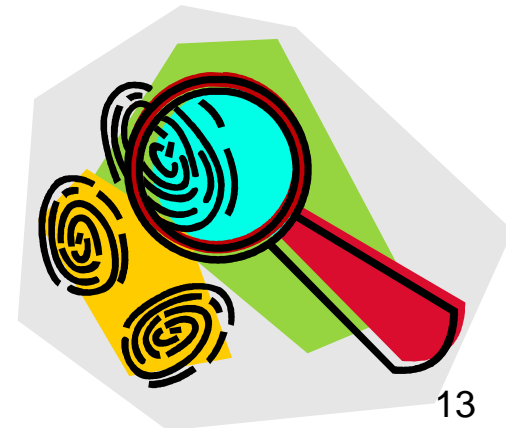
- Proximity-based
- Direction-based
- Time-based
- Based on signal properties
 - Propagation modeling
 - Fingerprinting ← Used in this work



Fingerprinting

Includes two phases:

- **Calibration:** creation of a database matching signal strength samples with the location.
- **Positioning:** comparing the observed signal properties to those in the database.

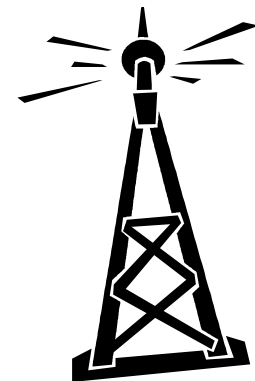




Proposed approach

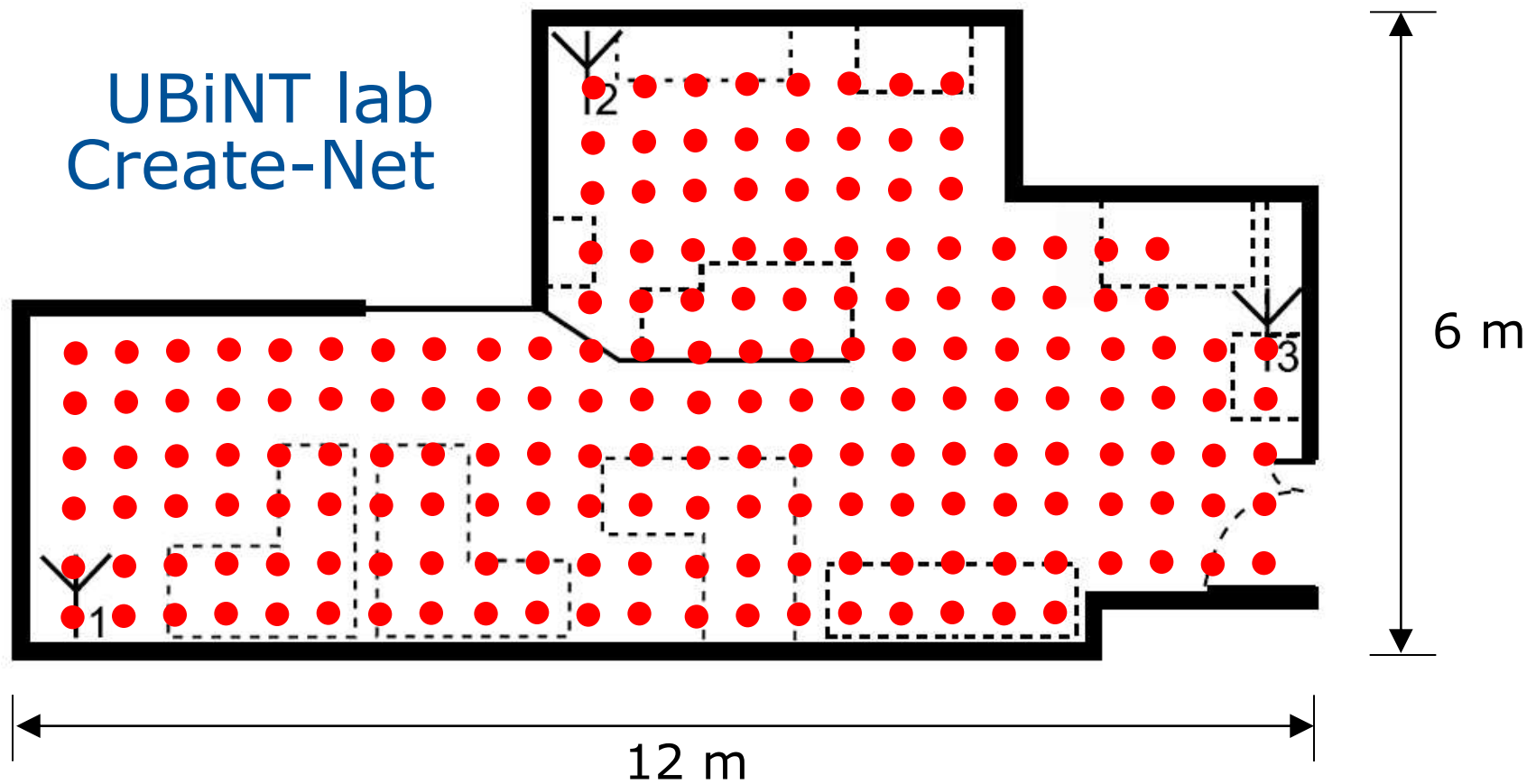
FM radio signal sources

- Short-range FM transmitters
 - Off-the-shelf devices
 - No licensing required
 - Can transmit arbitrary sound
- Broadcasting FM stations
 - Zero cost for localization
 - Worldwide coverage
- Both signal sources have been used in this thesis





Experimental setup





FM_L: positioning using local transmitters



FM_L : positioning using local transmitters

➤ FM_L performance

- FM_L vs. Wi-Fi
- Orientation analysis
- Accuracy degradation

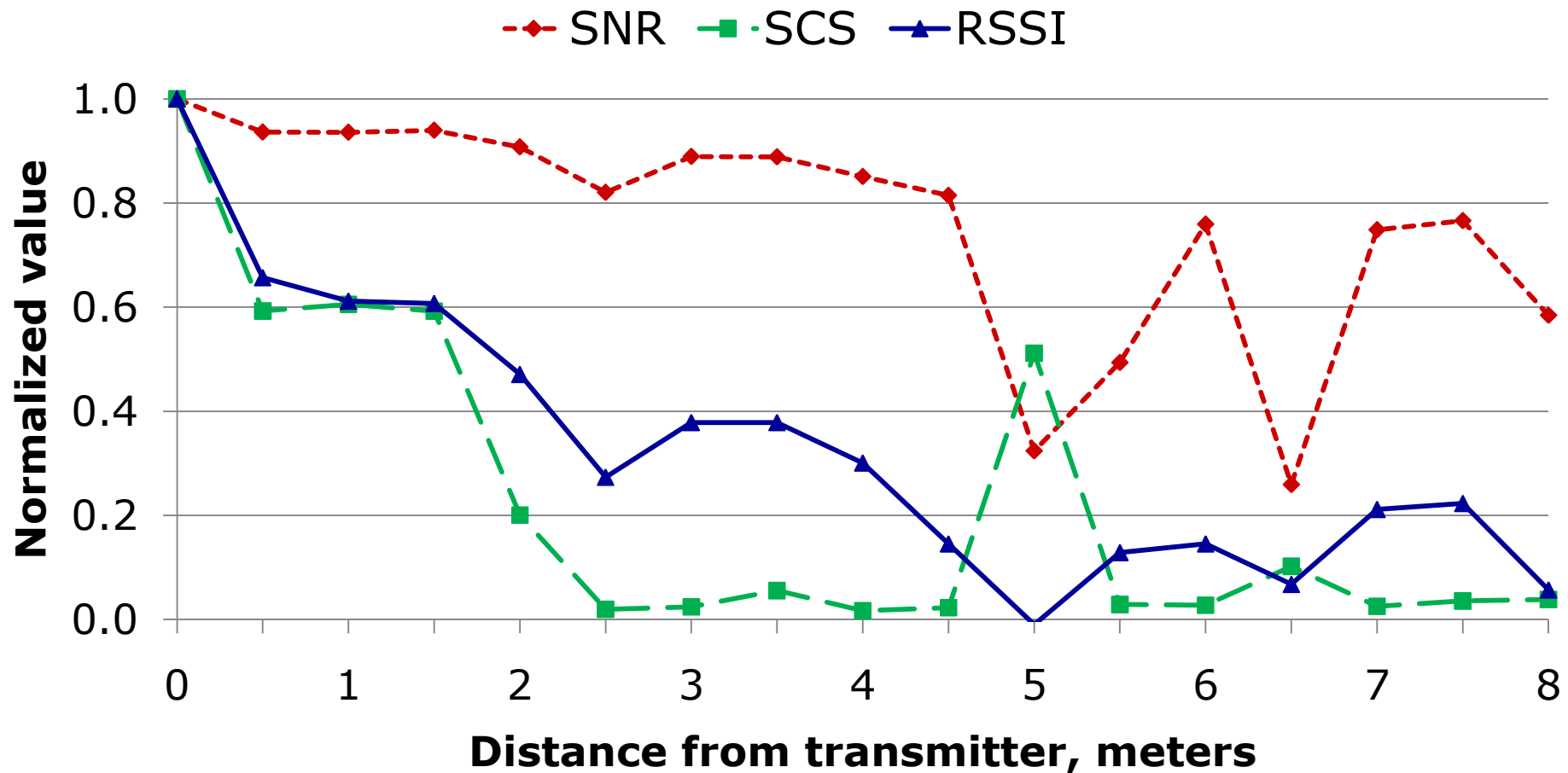


FM_L positioning

- Suitable signal features for fingerprinting:
 - Received signal strength (RSS)
 - Audio signal-to-noise ratio (SNR)
 - Stereo channel separation (SCS)

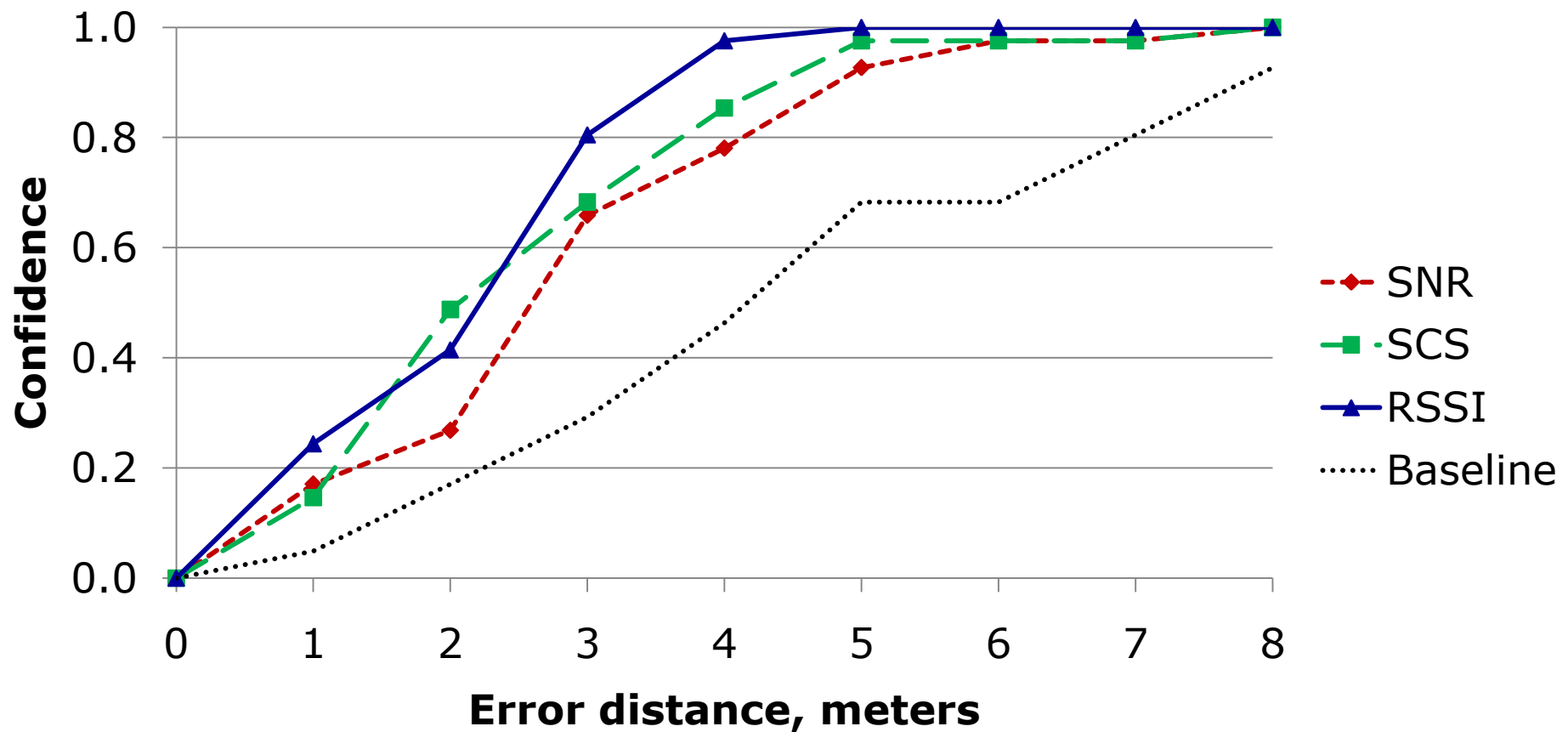


Signal properties vs. distance





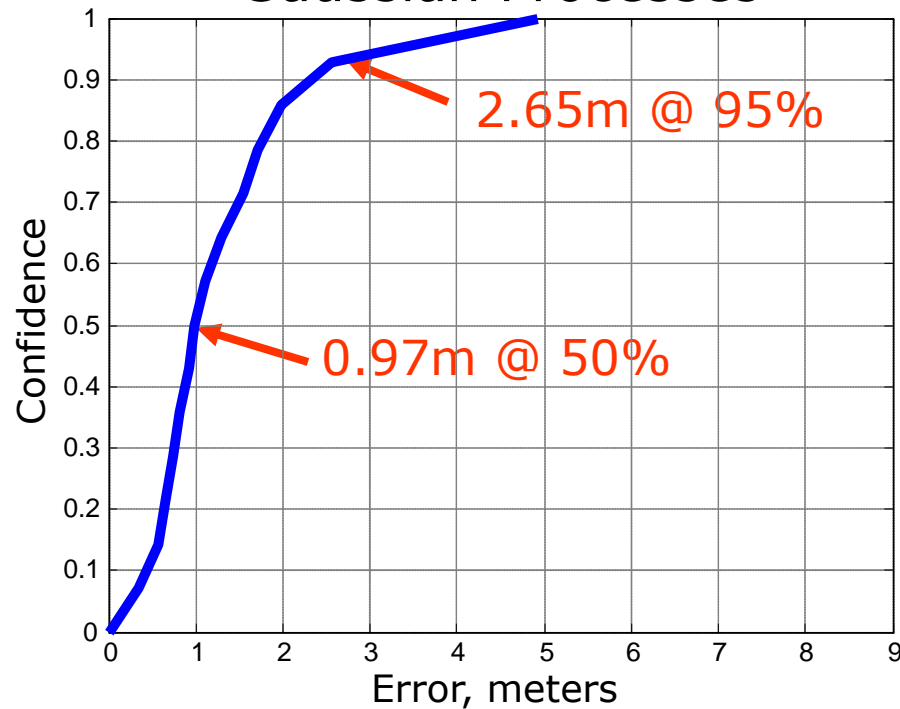
FM_L positioning performance



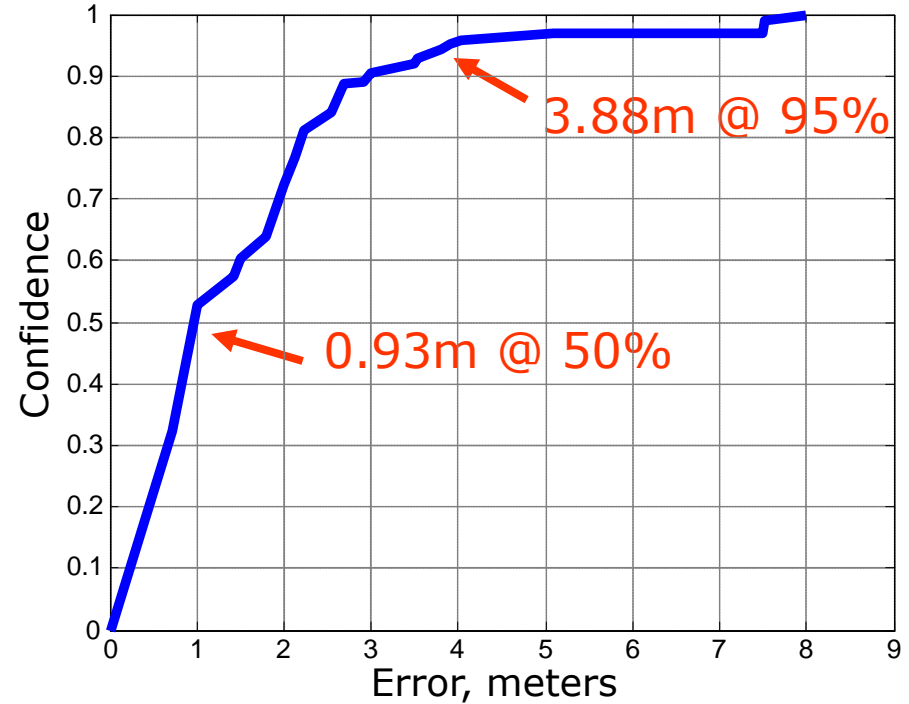


FM_L positioning accuracy (RSSI)

Gaussian Processes



kNN





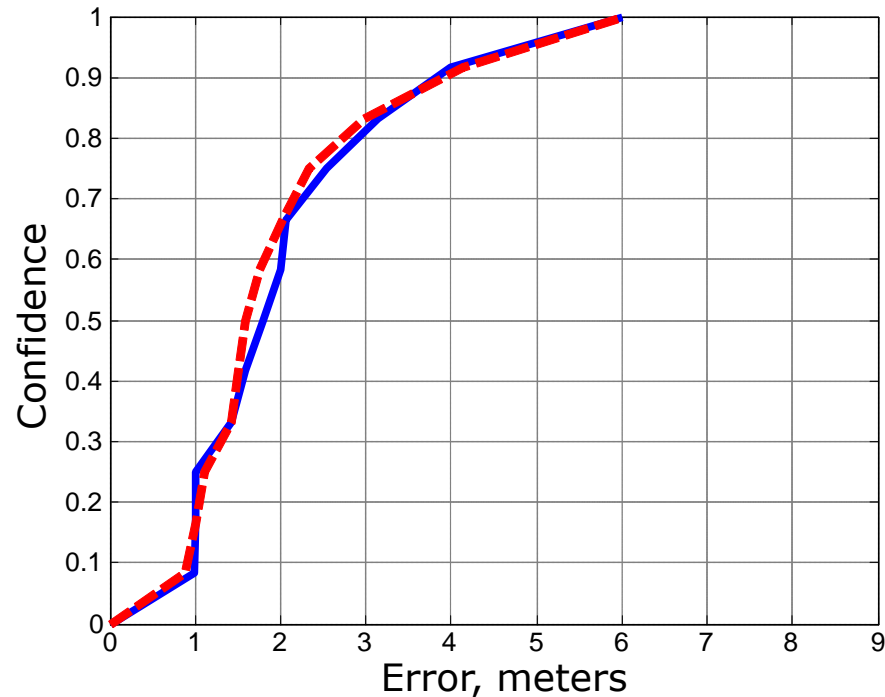
FM_L: positioning using local transmitters

- FM_L positioning
- **FM_L vs. Wi-Fi**
- Orientation analysis
- Accuracy degradation

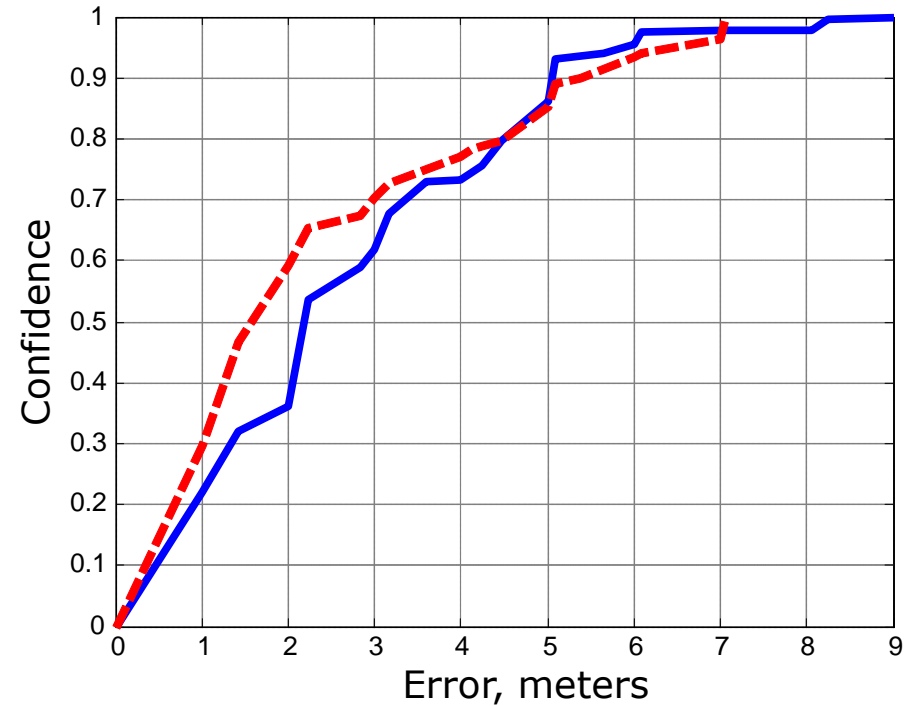


FM_L versus Wi-Fi

Gaussian Processes



kNN



--- FM

— Wi-Fi

Receiver: HTC Artemis; grid: 1 m.



FM_L: positioning using local transmitters

- FM_L positioning
- FM_L vs. Wi-Fi
- **Orientation analysis**
 - Accuracy degradation



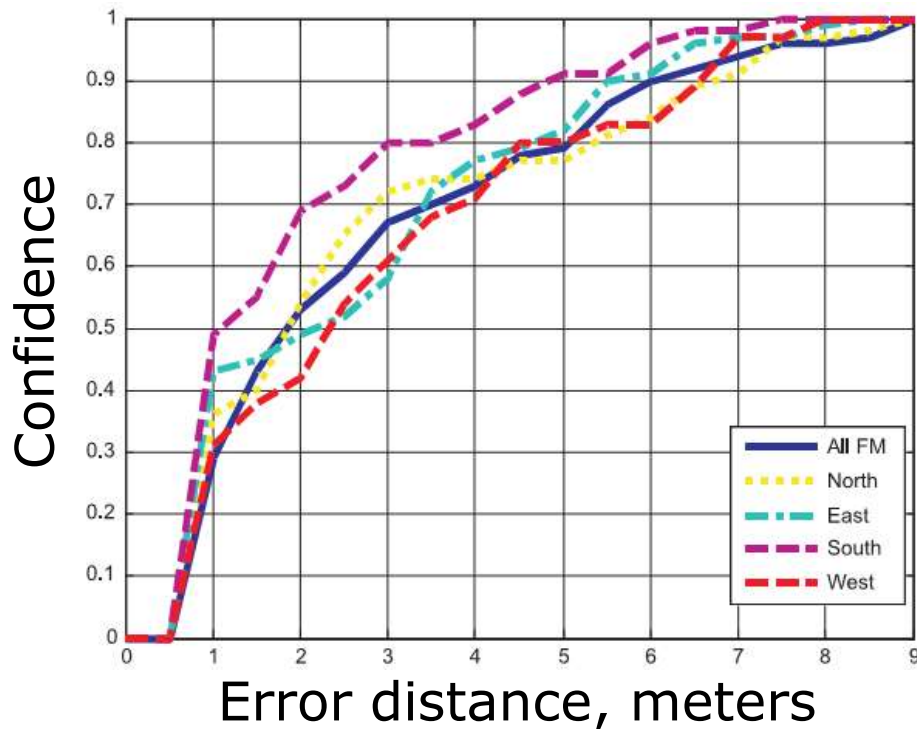
Effect of orientation

- Human body influences the signal distribution by reflecting and attenuating radio waves.
- This might impact the localization accuracy.
 - It does for Wi-Fi.
 - Does it for FM?





Effect of orientation



- Four datasets collected, one for each direction.
- “All FM” – accuracy when all four datasets are utilized.
- Other graphs - accuracy within each dataset.



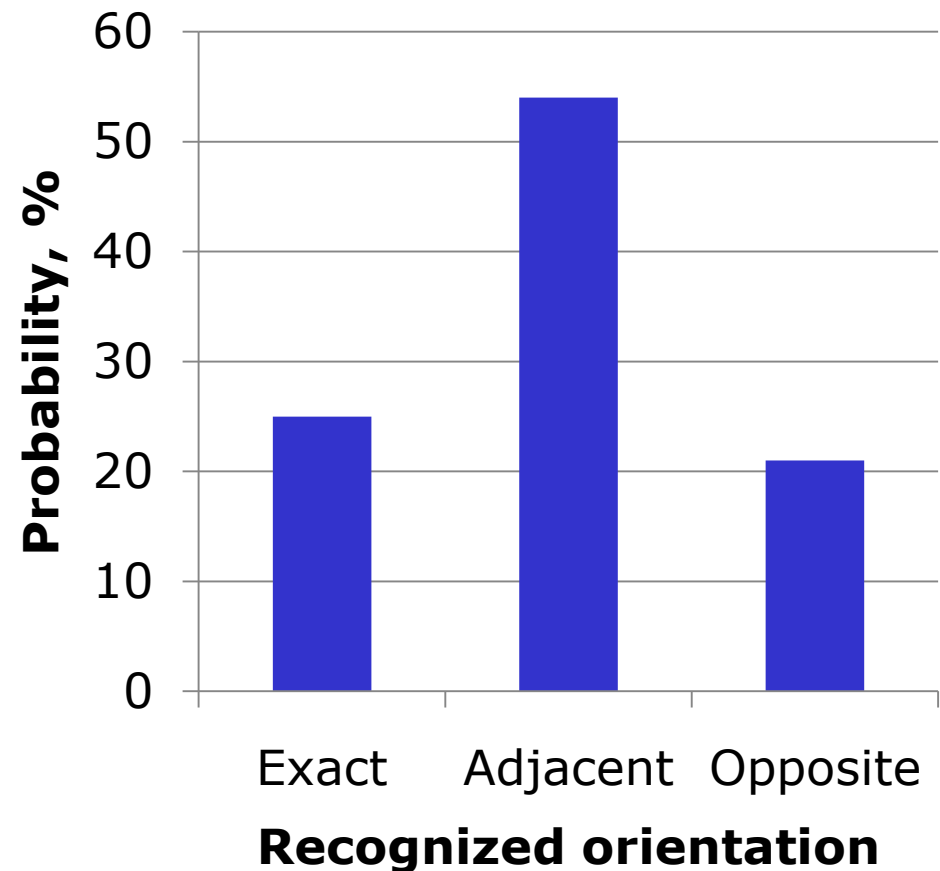
User direction has no significant effect on FM localization accuracy.



Recognition of orientation

- Is it possible to detect the orientation using FM RSS fingerprints?

↪ No, the result is random.



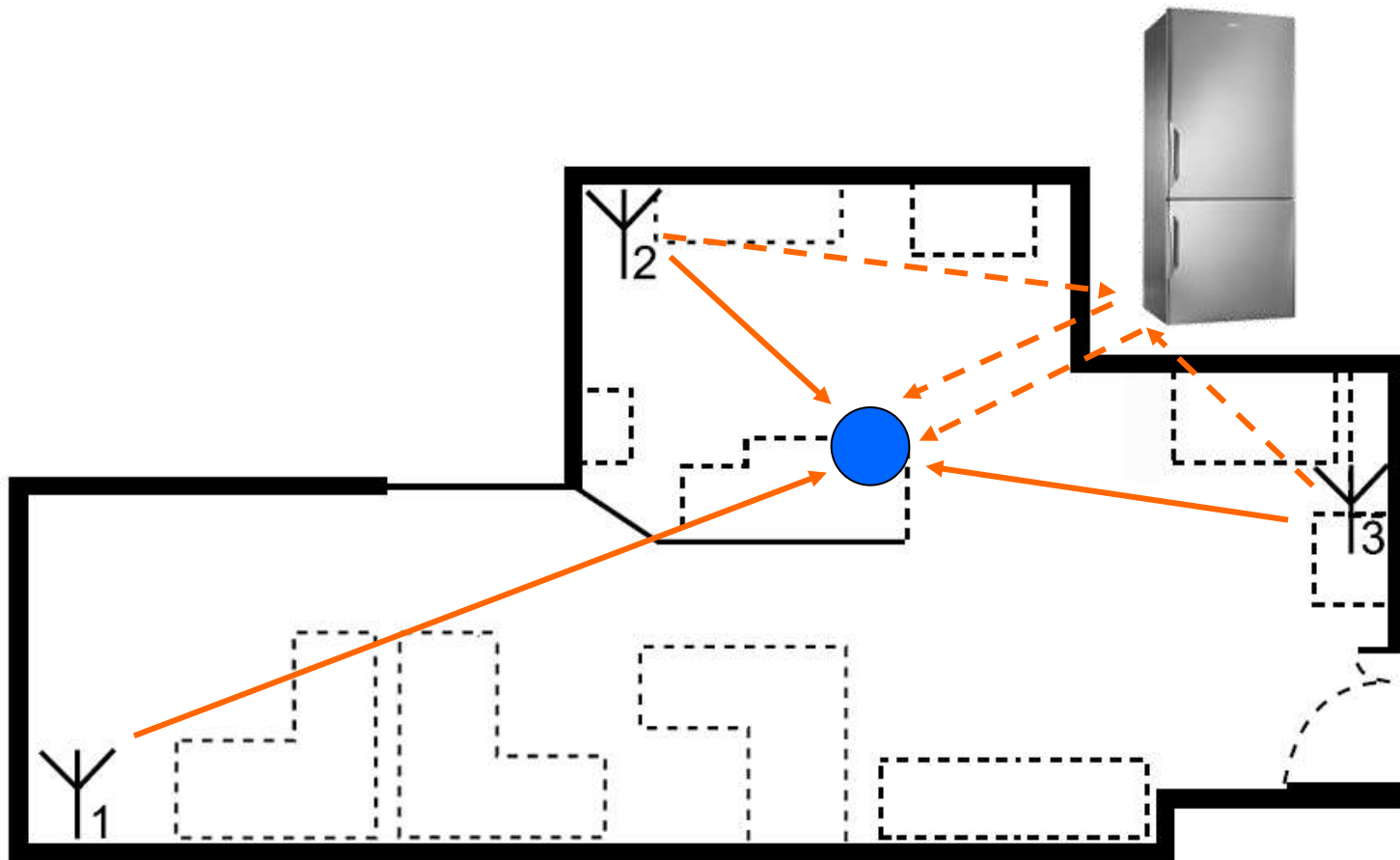


FM_L: positioning using local transmitters

- FM_L positioning
- FM_L vs. Wi-Fi
- Orientation analysis
- **Accuracy degradation**



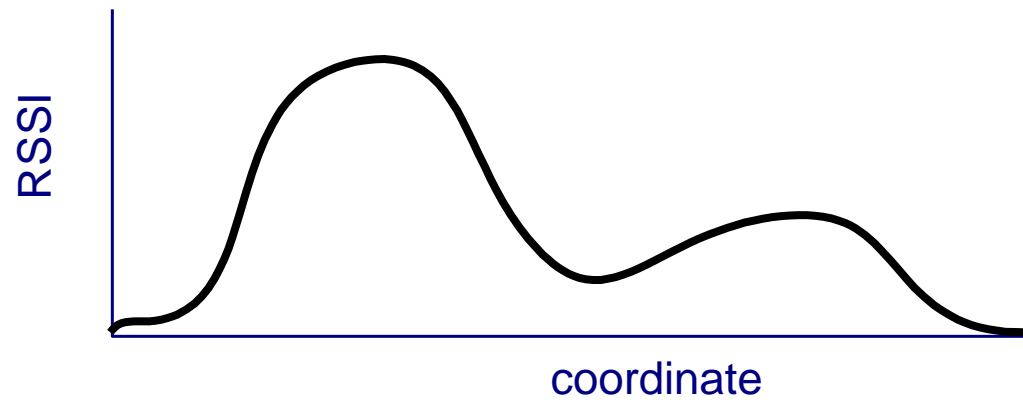
What if...



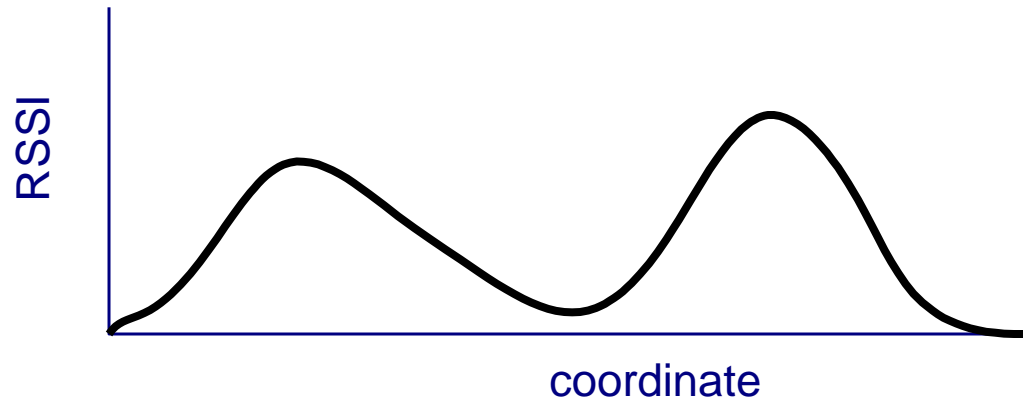


Signal strength distribution

Before:



Now:





Accuracy degradation

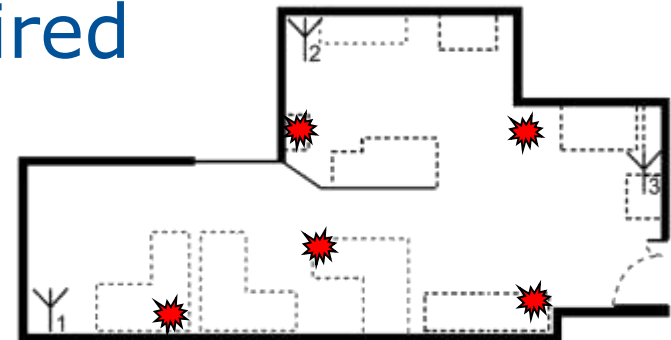
- Signal fingerprints change with time due to:
 - Furniture layout
 - Air temperature and humidity
 - Hardware temperature
- These fluctuations affect the accuracy.
- The **solution**: periodic recalibration
 - Requires personnel or additional hardware
 - Is tedious and expensive





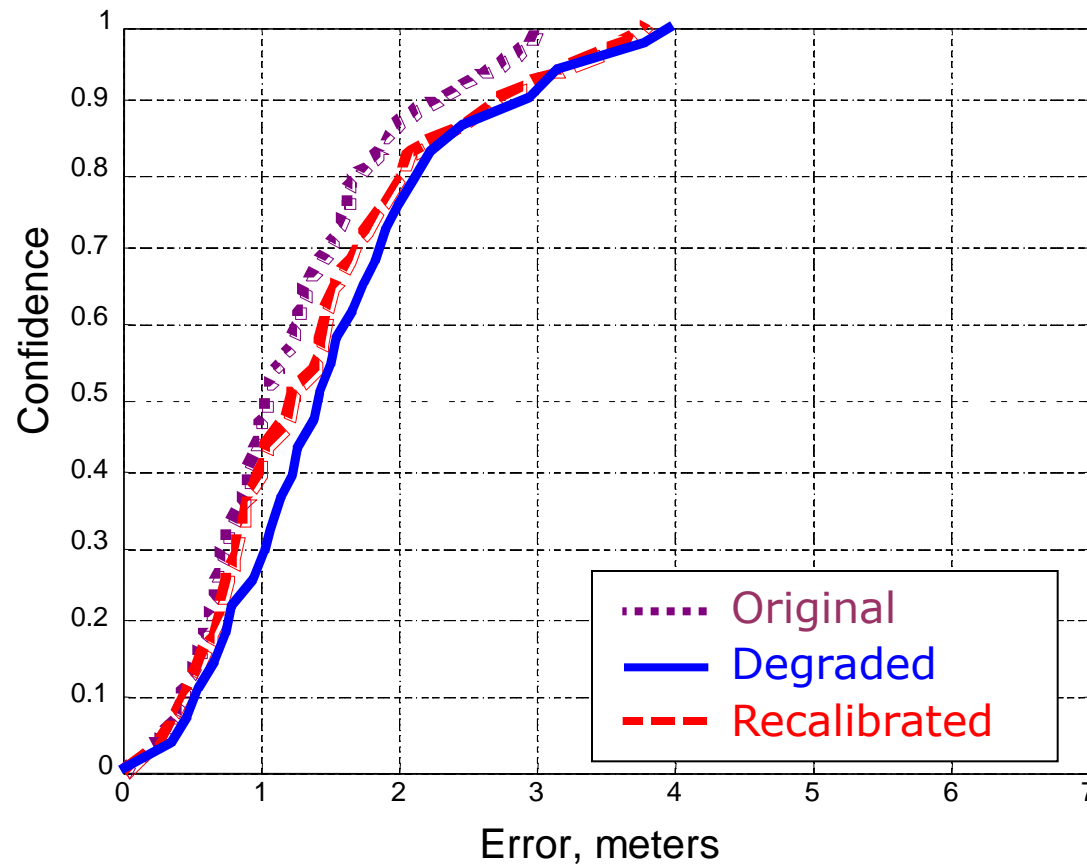
Spontaneous recalibration

- Recalibration performed automatically when the device position is known:
 - In a cradle
 - On a nightstand
 - Connected to a wall charger
- No additional hardware required
- Transparent for the user





Effect of recalibration





FM_B: positioning using broadcasting FM stations



FM_B : positioning using broadcasting FM stations

➤ FM_B performance

- FM_B vs. Wi-Fi and GSM
- Signal stability and people's presence
- Power consumption

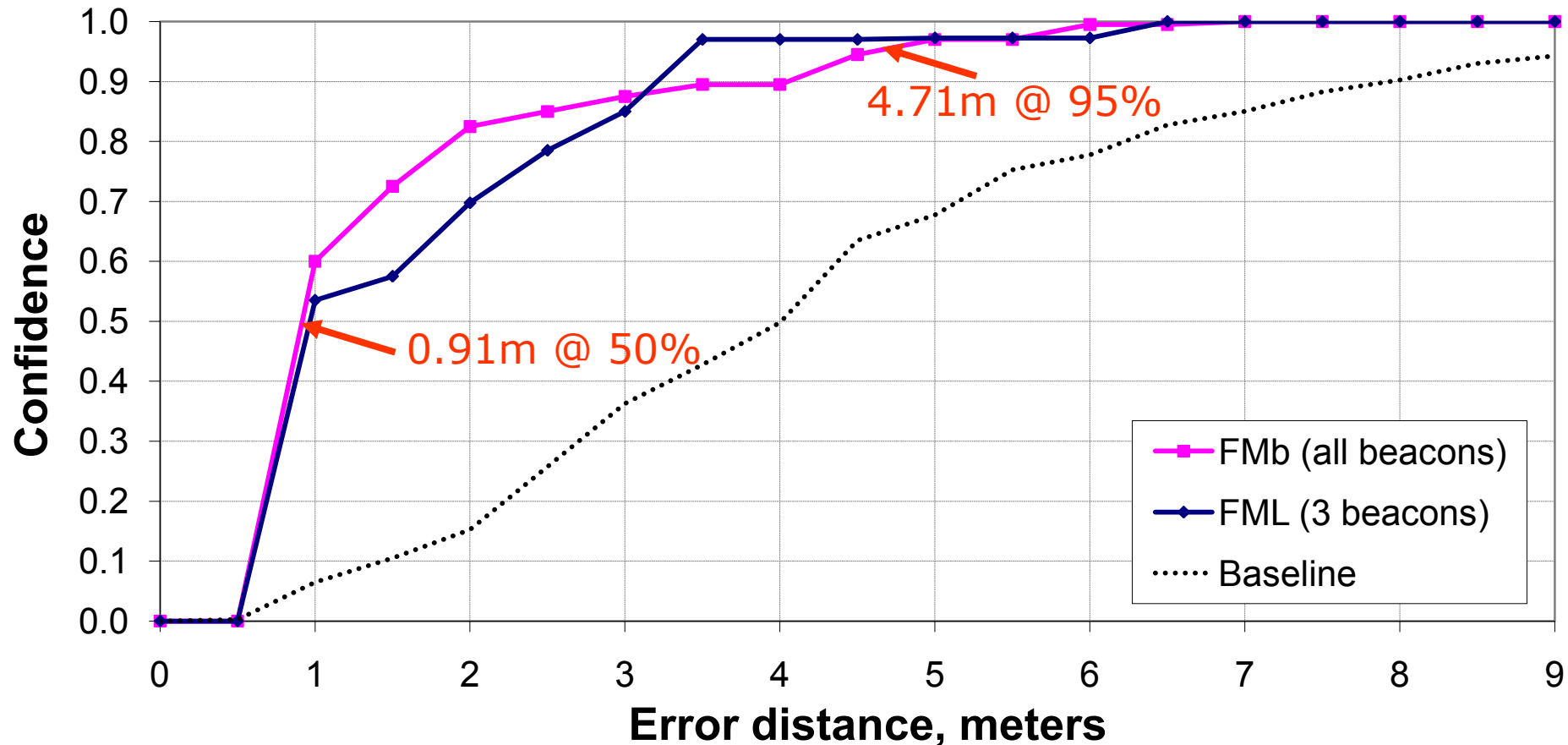


FM_B experiments

- Performed in the same 12x6 m testbed (with slightly changed layout).
- 76 active FM stations detected.
- 3 local FM transmitters for comparison.
- KNN classifier, leave-one-out evaluation.



FM_B localization performance





FM station selection

- More stations in fingerprint result in:
 - More accurate localization, but
 - Higher computational load
 - Longer scanning times
- Do all the stations contribute equally?
- Is there a trade-off between the number of stations and localization performance?

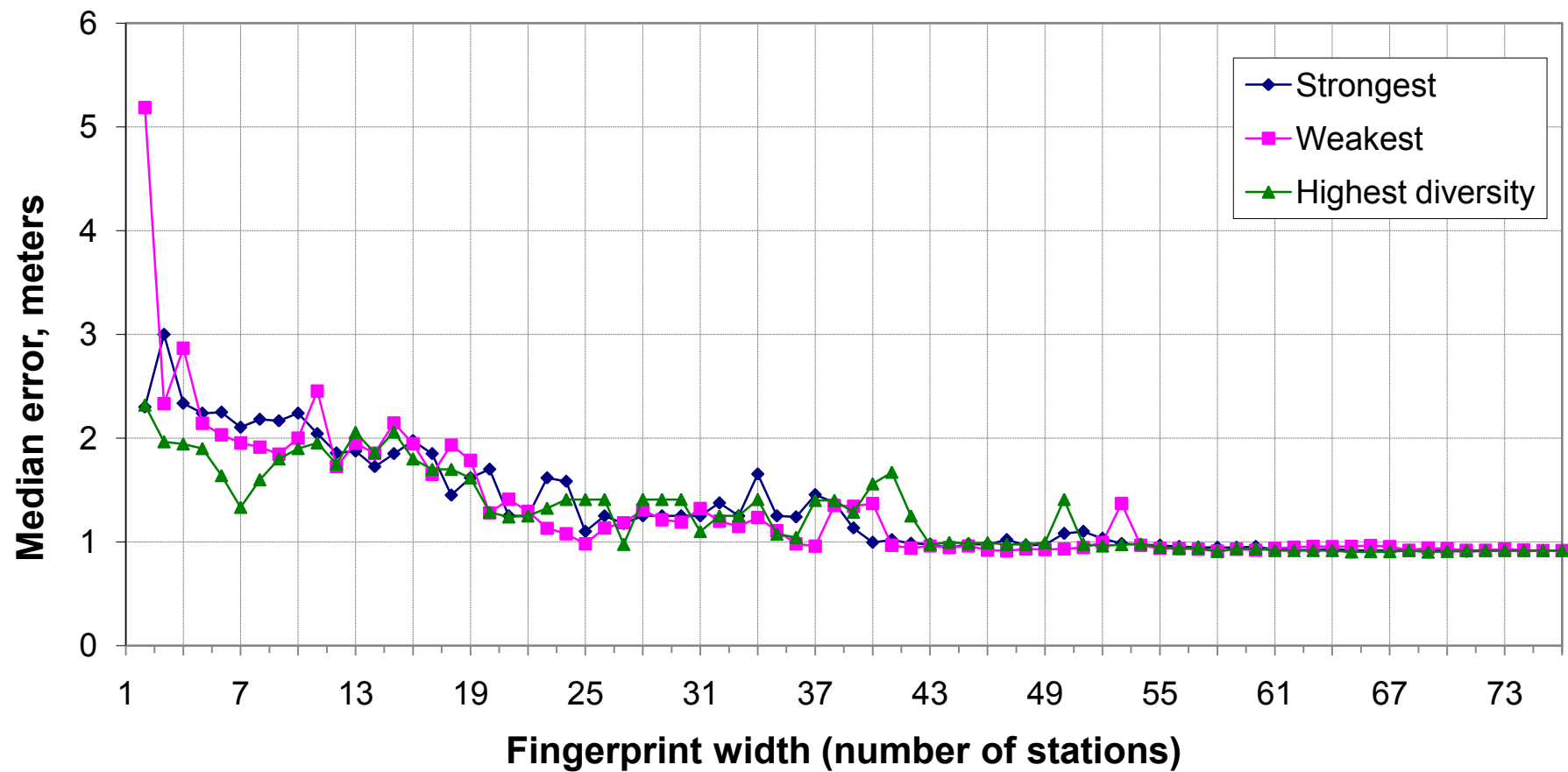


Station selection methods

- Naïve approach: select stations with
 - strongest signals;
 - weakest signals.
- Alternative approach: select the stations which vary the most across the test points.

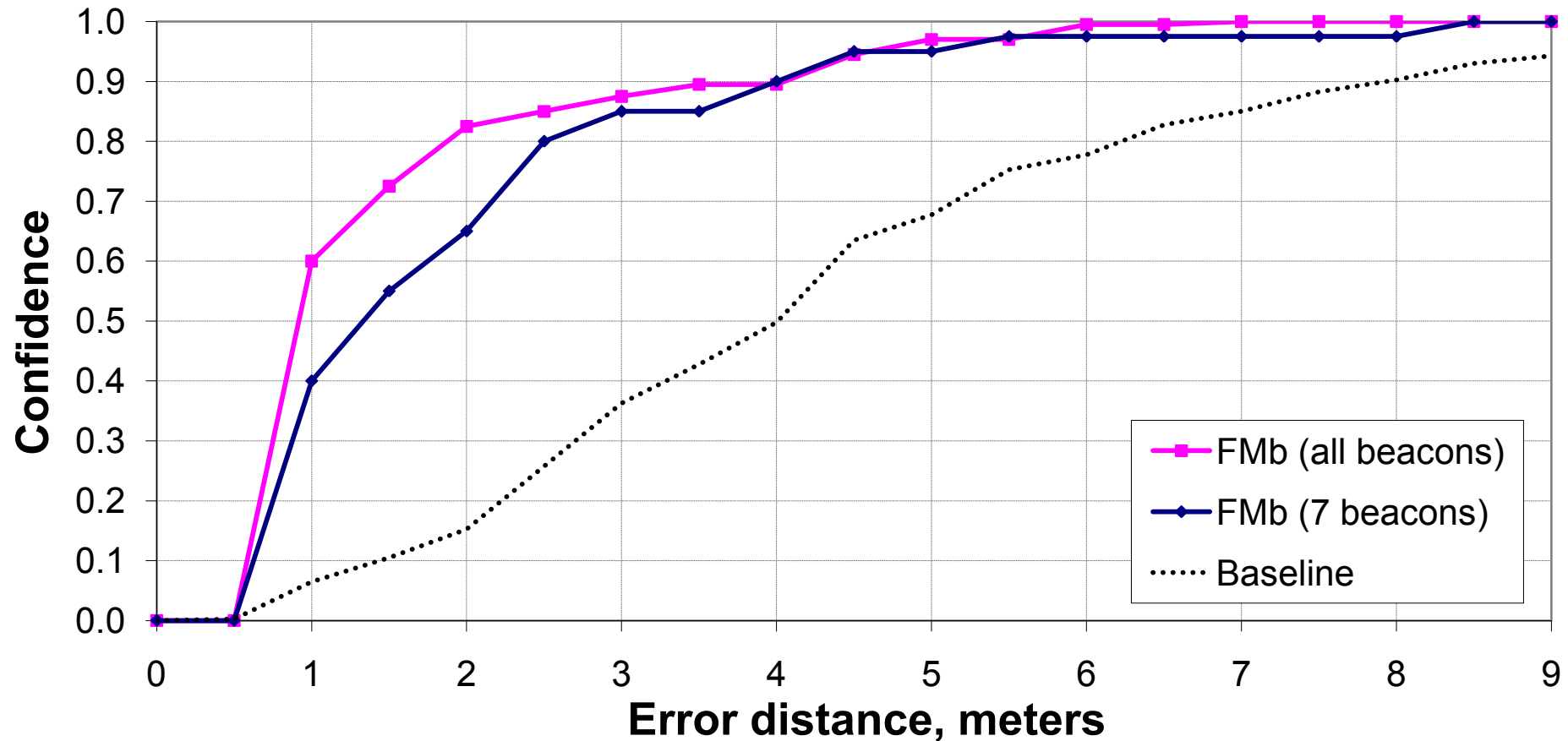


Station selection methods





FM_B with 10% of stations



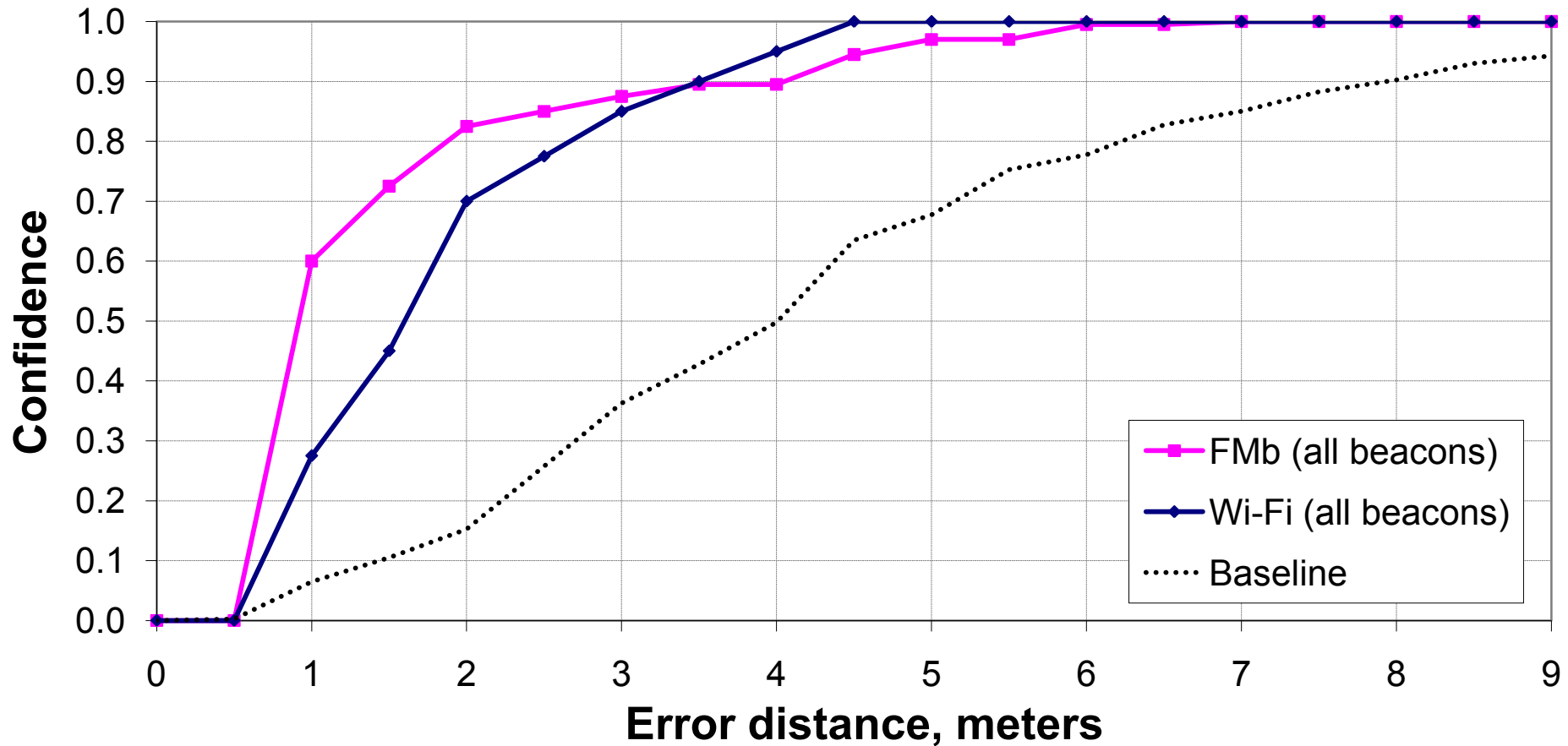


FM_B : positioning using broadcasting FM stations

- FM_B performance
- **FM_B vs. Wi-Fi and GSM**
- Signal stability and people's presence
- Power consumption

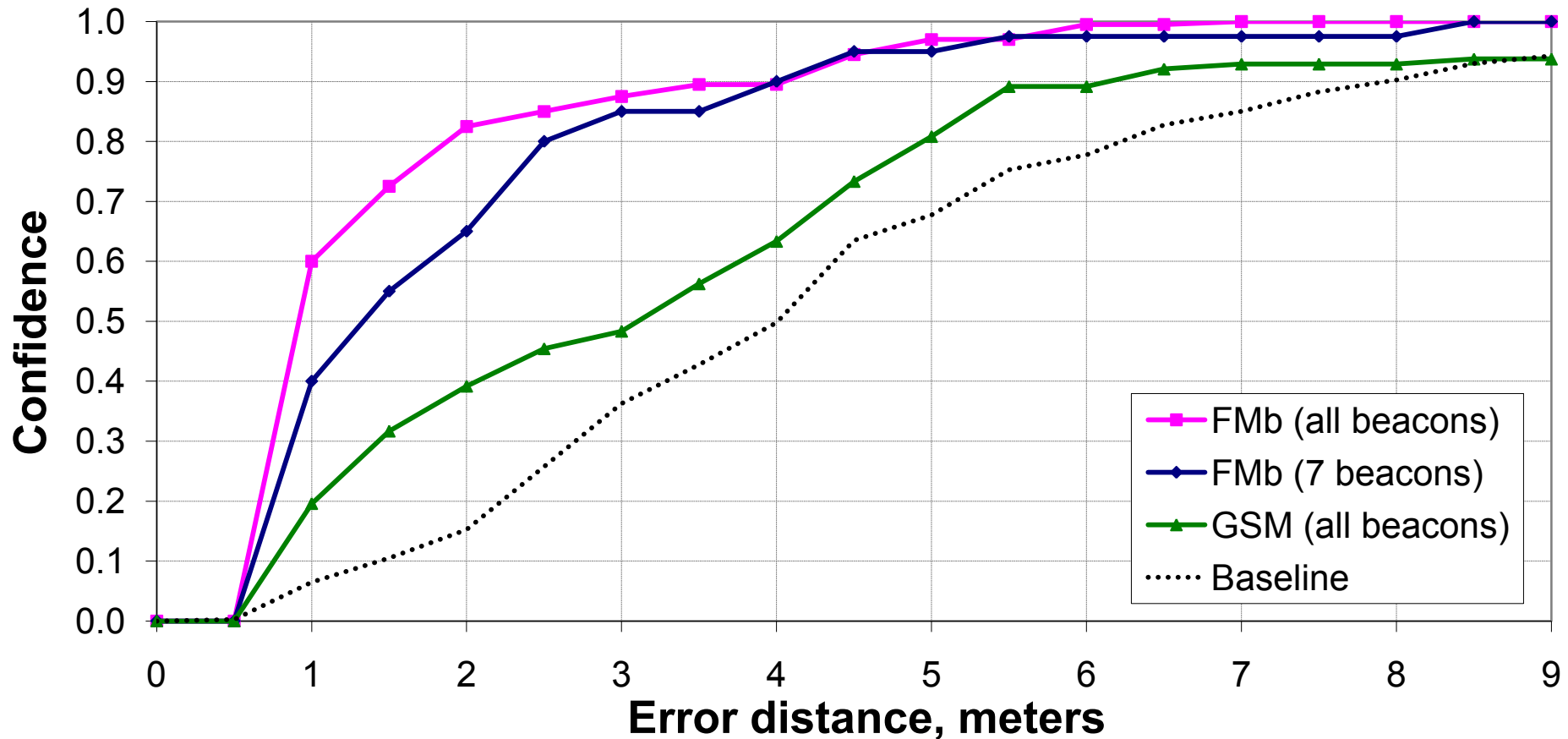


FM_B versus Wi-Fi





FM_B versus GSM





FM_B localization: Summary

Localization accuracy for different technologies (in meters)
measured in the same conditions.

Confidence	FM _B	Wi-Fi	GSM	FM _B (7 stations)
50%	0.9	1.6	3.1	1.3
67%	1.3	1.9	4.2	2.1
90%	3.4	3.5	6.2	4.0
95%	4.7	4.0	9.1	4.9



FM_B : positioning using broadcasting FM stations

- FM_B performance
- FM_B vs. Wi-Fi and GSM
- **Signal stability and people's presence**
- Power consumption



Signal stability analysis

- Human bodies interact with radio waves.
- Thus, people are an unpredictable factor that influences signal distribution and thus localization performance.
- FM radio waves are longer than Wi-Fi waves – this leads to differences in signal propagation.



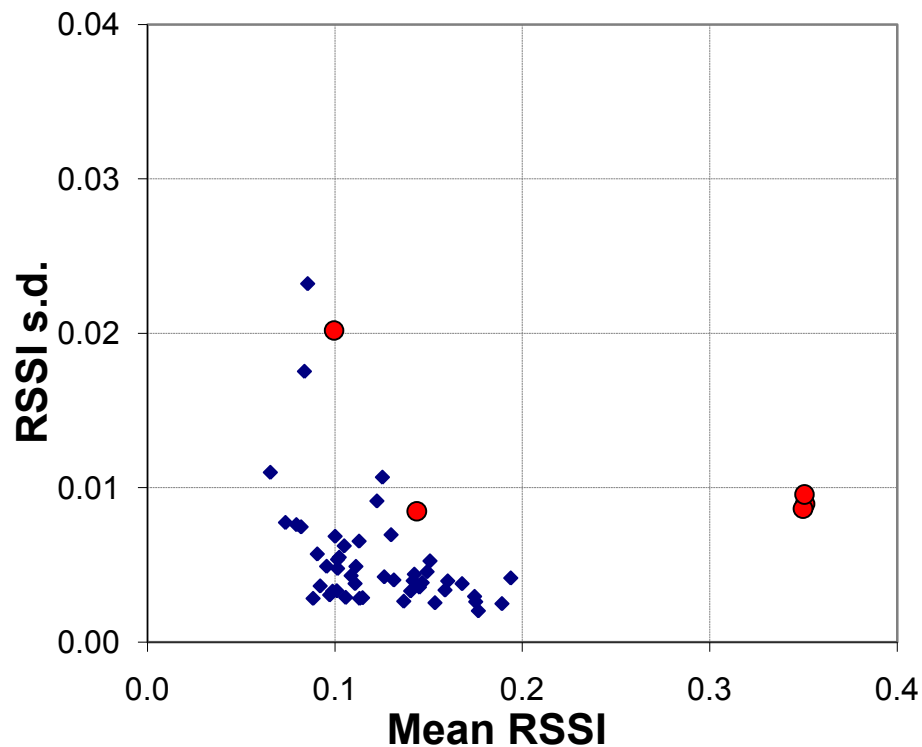
Signal stability: Experiment 1

- Environment: a student mensa
 - Lunch time (crowded)
 - Evening (empty)
- 50 minutes duration; 84 fingerprints
 - 26 FM stations
 - 5 Wi-Fi access points
- RSS samples normalized according to device's minimum and maximum values.

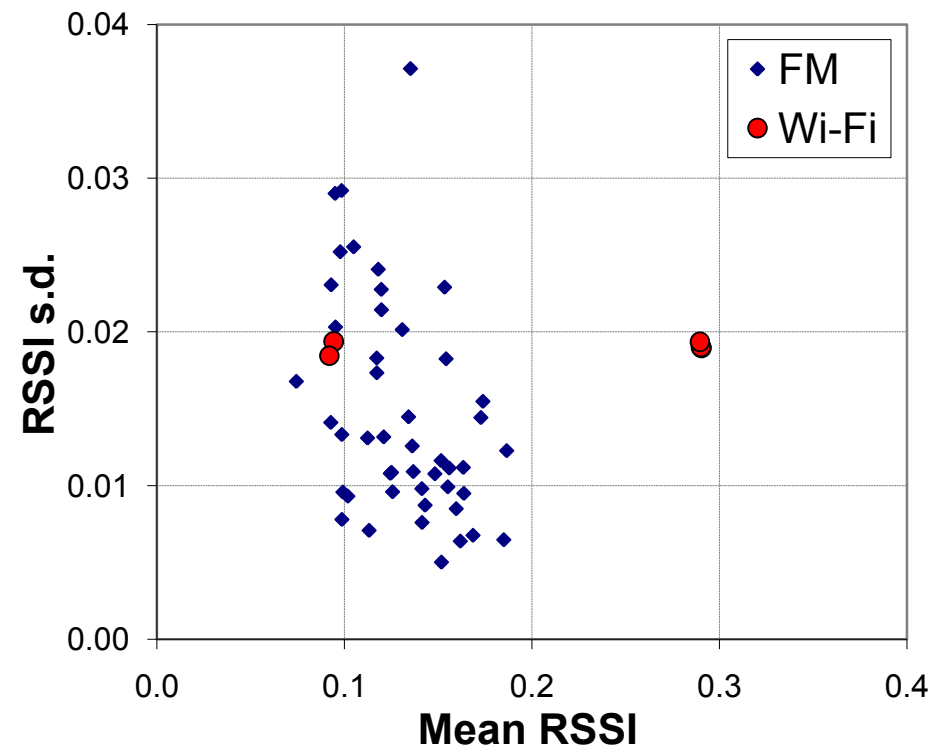


Signal stability: Experiment 1

Empty



Crowded





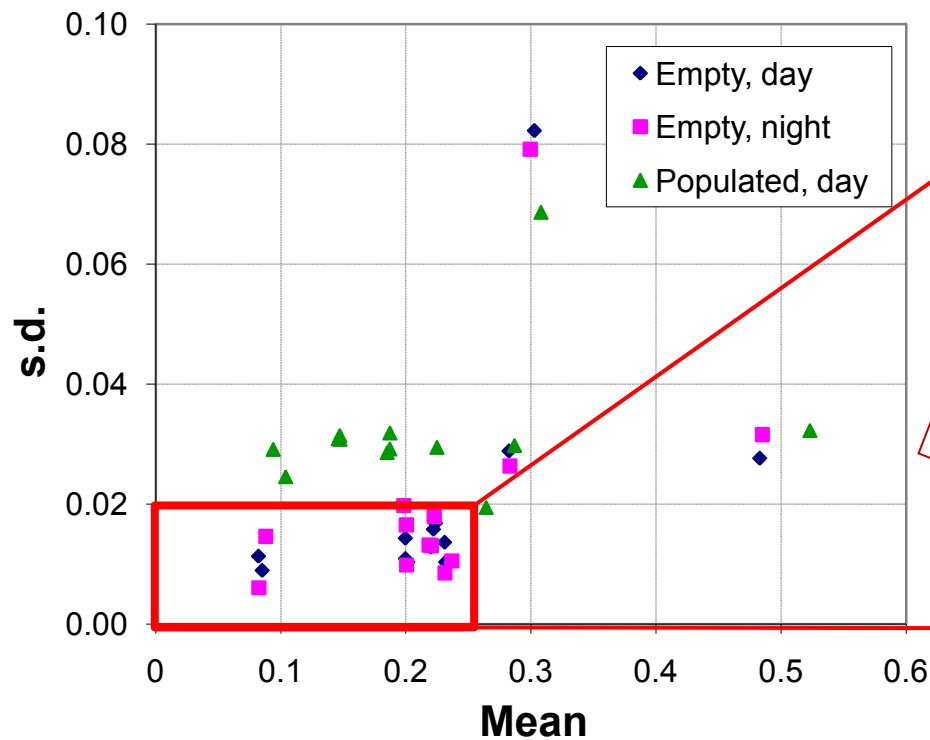
Signal stability: Experiment 2

- An office environment:
 - Empty, daytime
 - Empty, nighttime
 - Populated
- 6 hours duration; 592 fingerprints
 - 23 FM stations
 - 13 Wi-Fi access points
- RSS normalized as in the previous experiment.

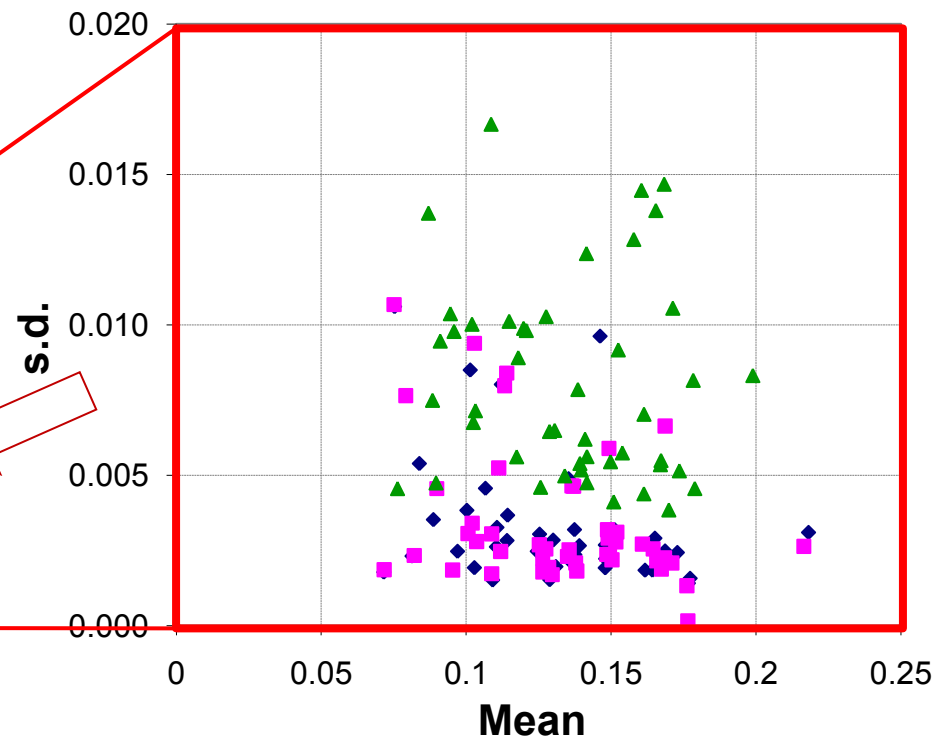


Signal stability: Experiment 2

Wi-Fi



FM





FM_B : positioning using broadcasting FM stations

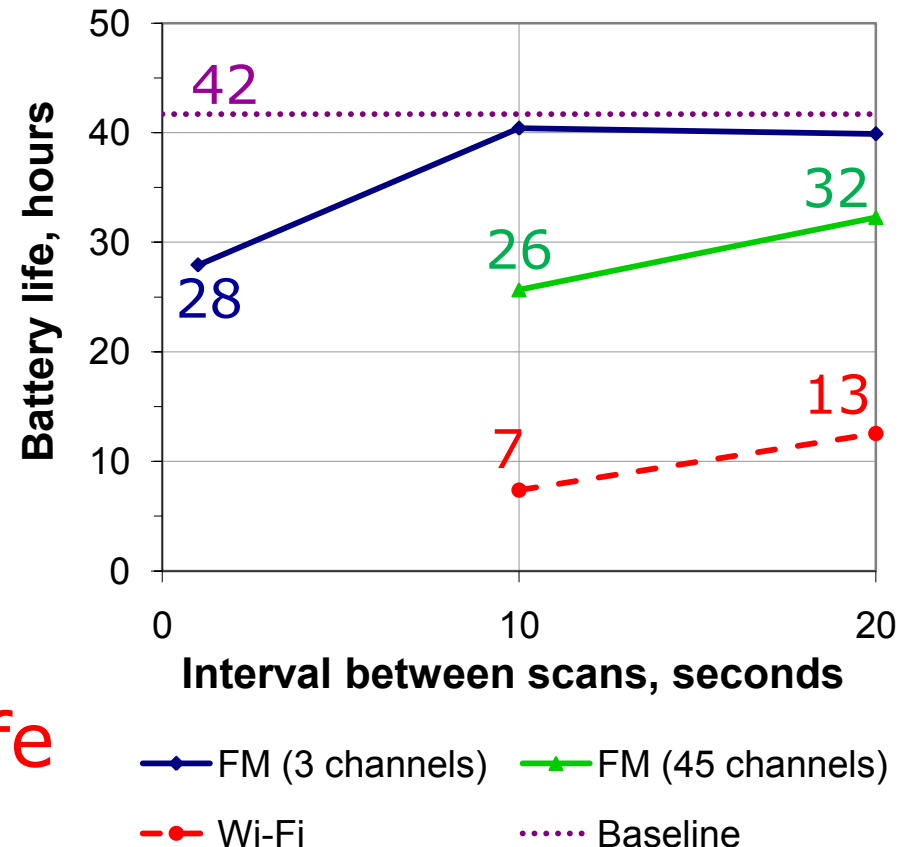
- FM_B performance
- FM_B vs. Wi-Fi and GSM
- Signal stability and people's presence
- **Power consumption**



Power consumption results

- Battery life: the time for a completely charged device to switch off.
- Unused modules were turned off.

⇒ FM provides 2.6 to 5.5 times longer battery life than Wi-Fi.





Conclusion



Summary

- FM radio:
 - provides a good localization accuracy;
 - can be used in sensitive environments;
 - provides longer battery life than Wi-Fi;
 - is more robust to people's presence;
 - is readily available.



Contributions (1/2)

- Demonstration of feasibility of indoor localization using FM radio signals from:
 - Short-range FM transmitters
 - Accuracy comparable to Wi-Fi.
 - Broadcasting FM stations
 - Accuracy superior than GSM;
 - Accuracy superior than Wi-Fi (for confidence levels up to 90%).



Contributions (2/2)

- Quantitative evaluation of influence of human presence on FM and Wi-Fi RSS characteristics.
- A method to counter accuracy degradation of fingerprinting-based systems.



Publications

- A.Papliatseyeu, V.Osmani and O.Mayora. Indoor Positioning Using FM Radio. *International Journal of Handheld Computing Research*, 3(2010). PP. 19–31.
- A.Matic, A.Popleteev, V.Osmani, and O.Mayora-Ibarra. FM Radio for Indoor Localisation with Spontaneous Recalibration. *Journal of Pervasive and Mobile Computing*, 6(2010). PP. 642–656.
- A.Papliatseyeu, A.Matic, V.Osmani, and O.Mayora-Ibarra. Indoor Positioning Using off-the-shelf FM Radio Devices. *Abs. volume IPIN-2010*. PP. 41–42.
- A.Matic, A.Papliatseyeu, V.Osmani, and O.Mayora-Ibarra. Tuning to Your Position: FM-radio based Indoor Localization with Spontaneous Recalibration. *Proc. PerCom-2010*. PP. 153–161.
- A.Papliatseyeu, N.Kotilainen, O.Mayora-Ibarra, and V.Osmani. FINDR: Low-cost indoor positioning using FM radio. *Proc. MobilWare-2009*. PP. 15–26.

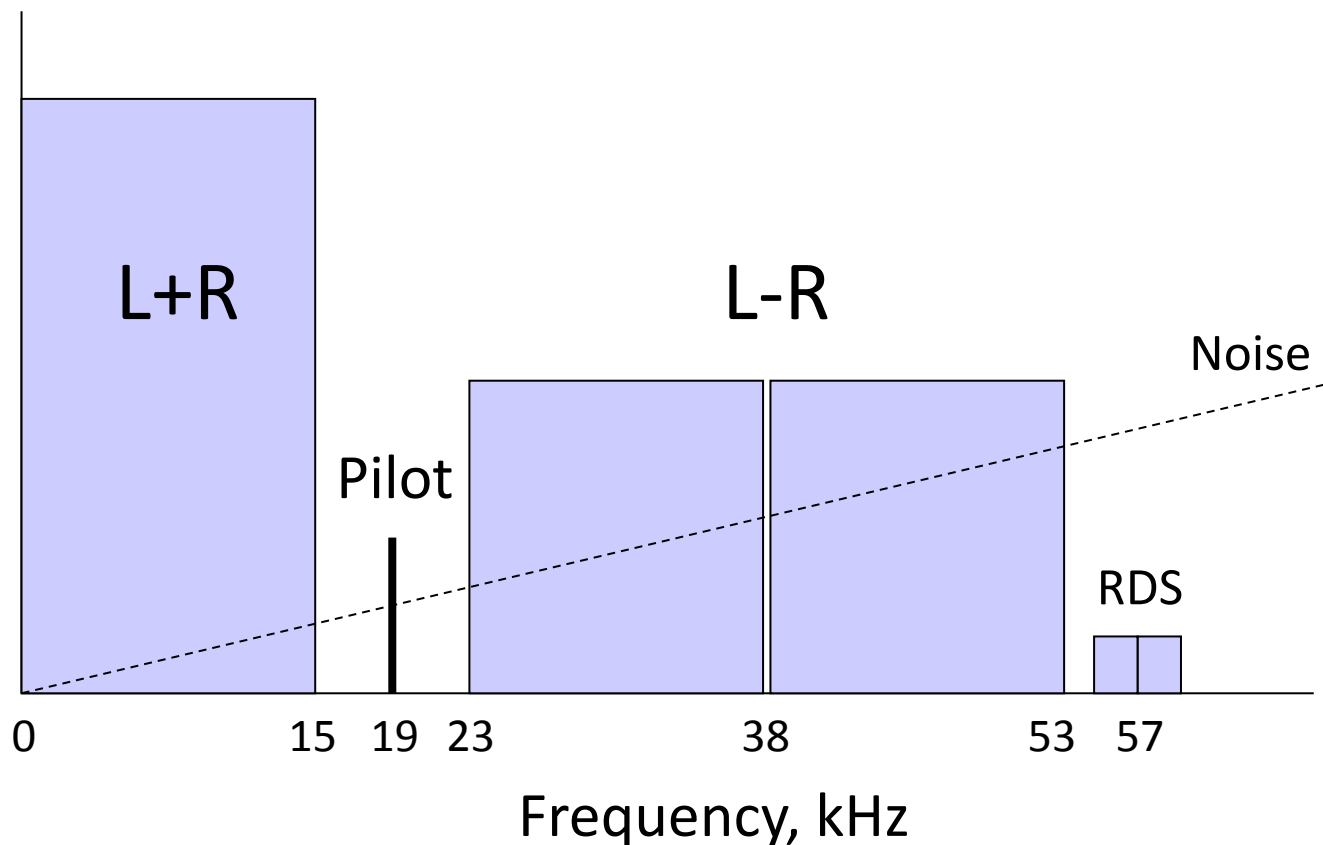


Thank you





FM stereo signal encoding





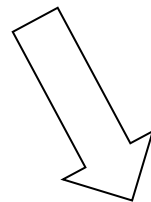
Signal strength representation

FM	Wi-Fi	Unified (dB)
40..50	"Excellent"	-50
30..39	"Very good"	-60
20..29	"Good"	-70
10..19	"Low"	-80
1..9	"Very low"	-90
0	"No signal"	0

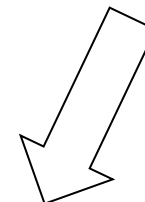
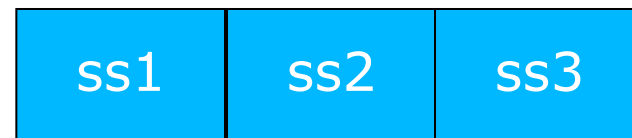


FM with Wi-Fi

FM fingerprint



Wi-Fi fingerprint

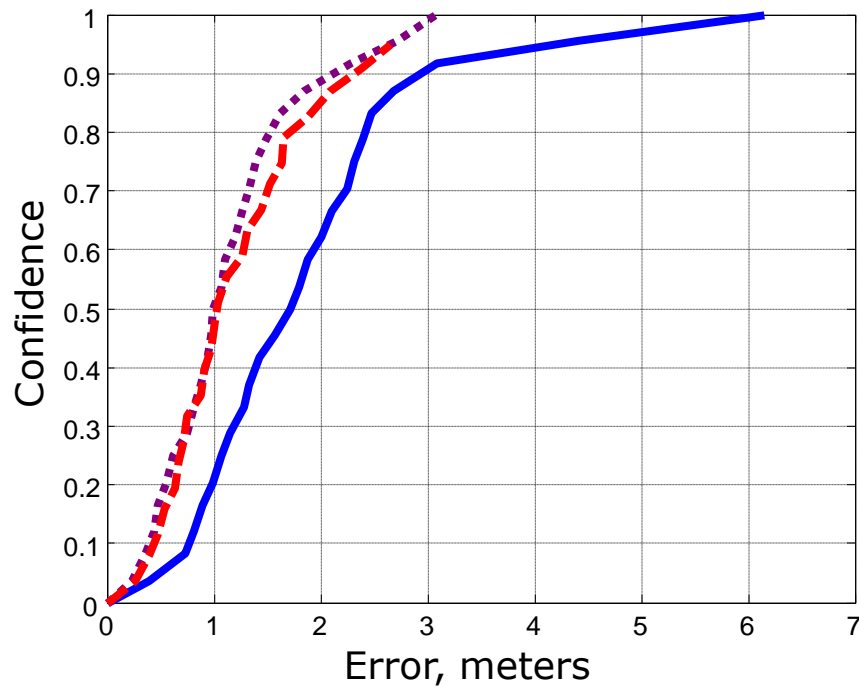


Combined wide fingerprint

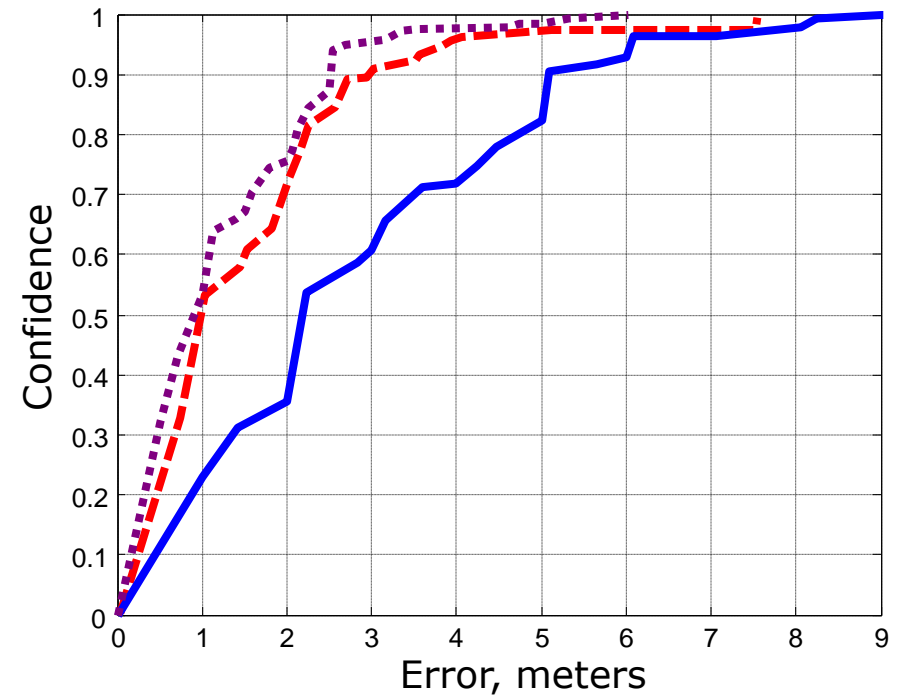


FM_L combined with Wi-Fi

Gaussian Processes



kNN



--- FM — Wi-Fi Combined



FM with Wi-Fi

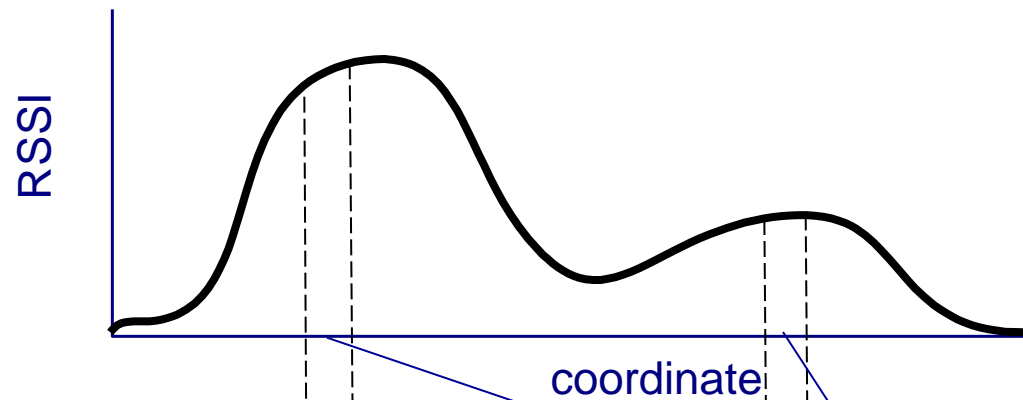
- Combined coverage
- Longer battery life
- Improved accuracy (by up to 22%)



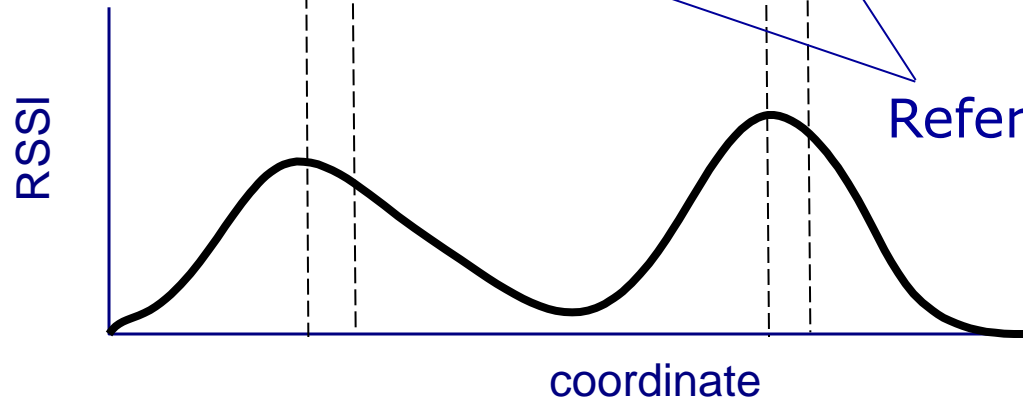


Spontaneous recalibration

Before:

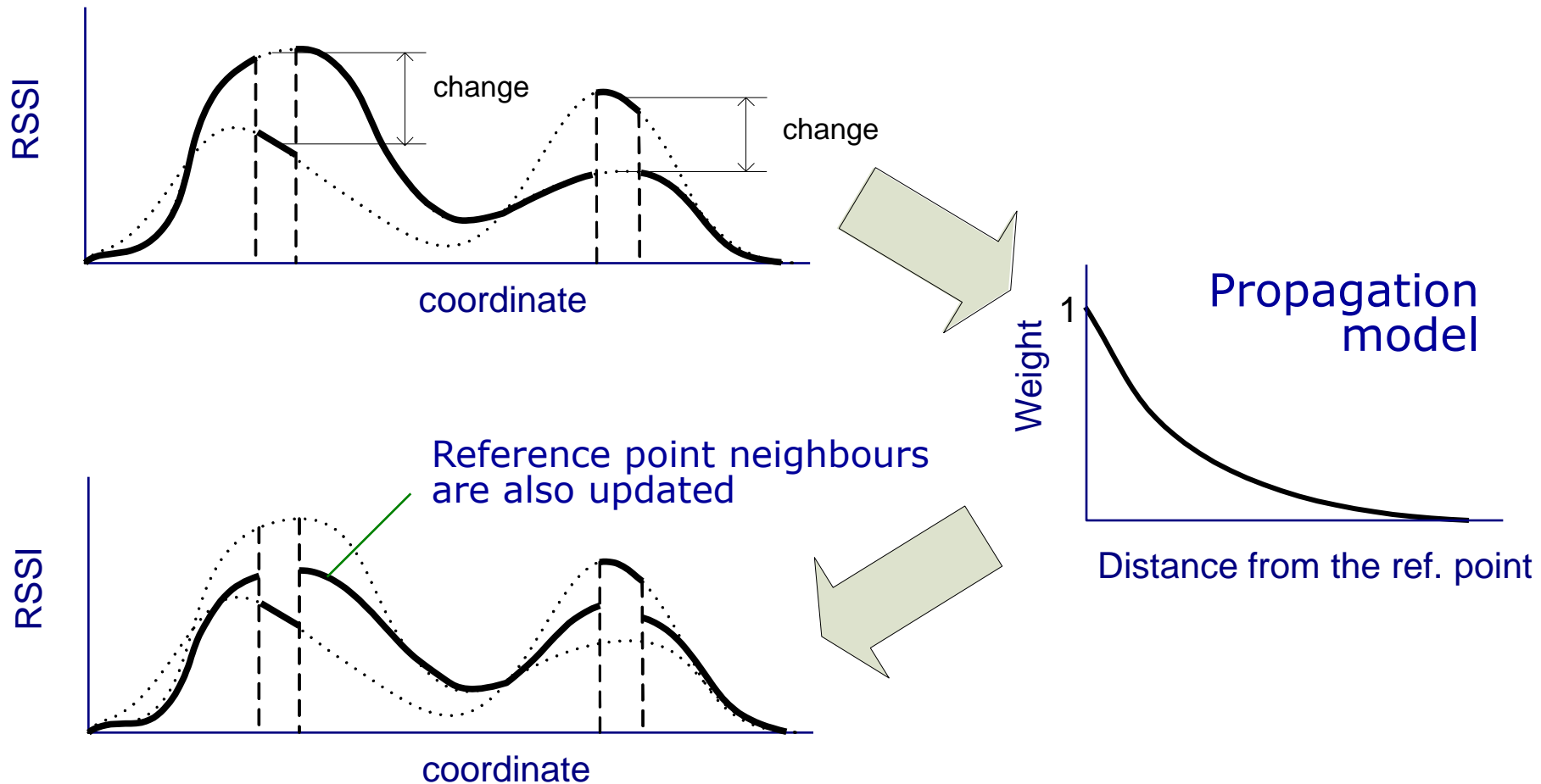


Now:



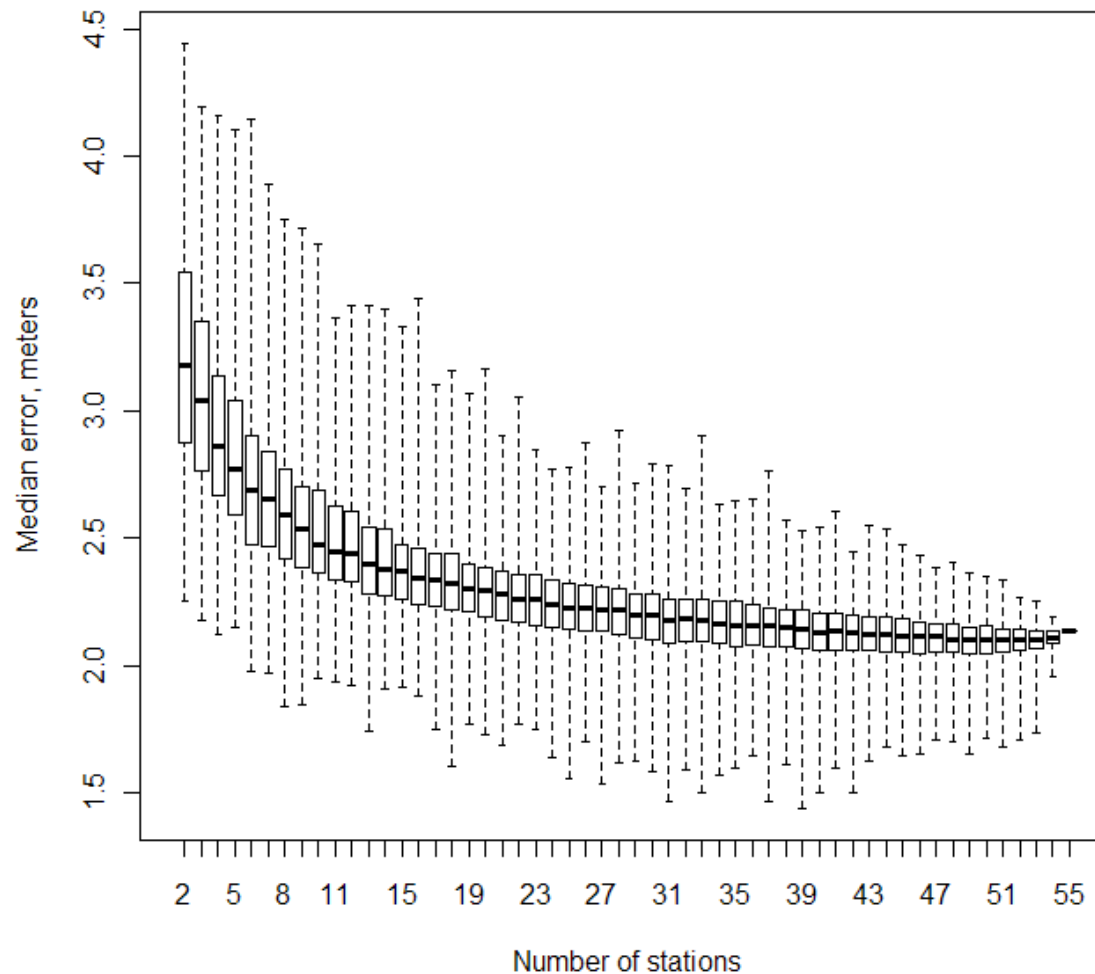


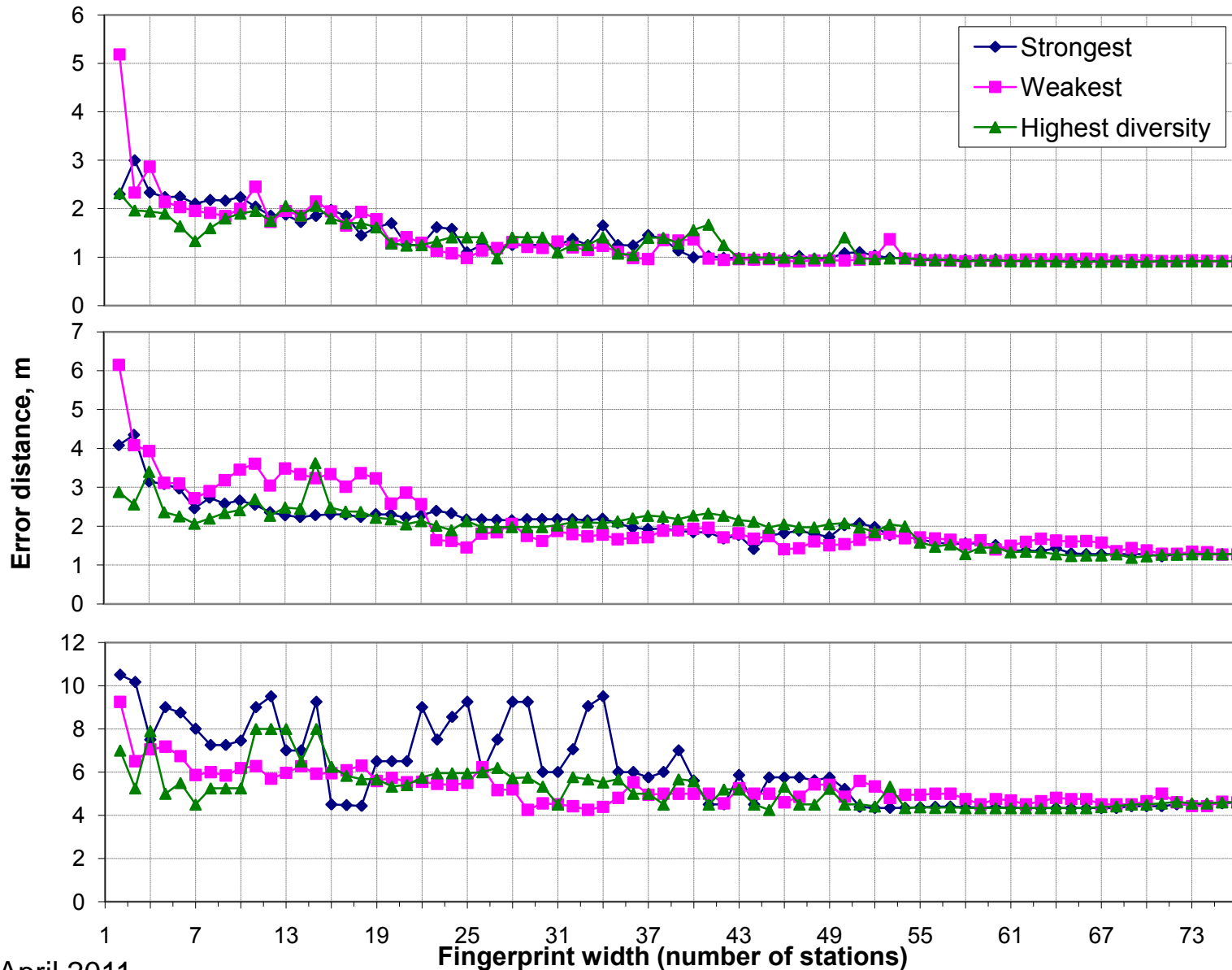
Spontaneous recalibration





FM_B accuracy vs. number of stations





50%

67%

95%

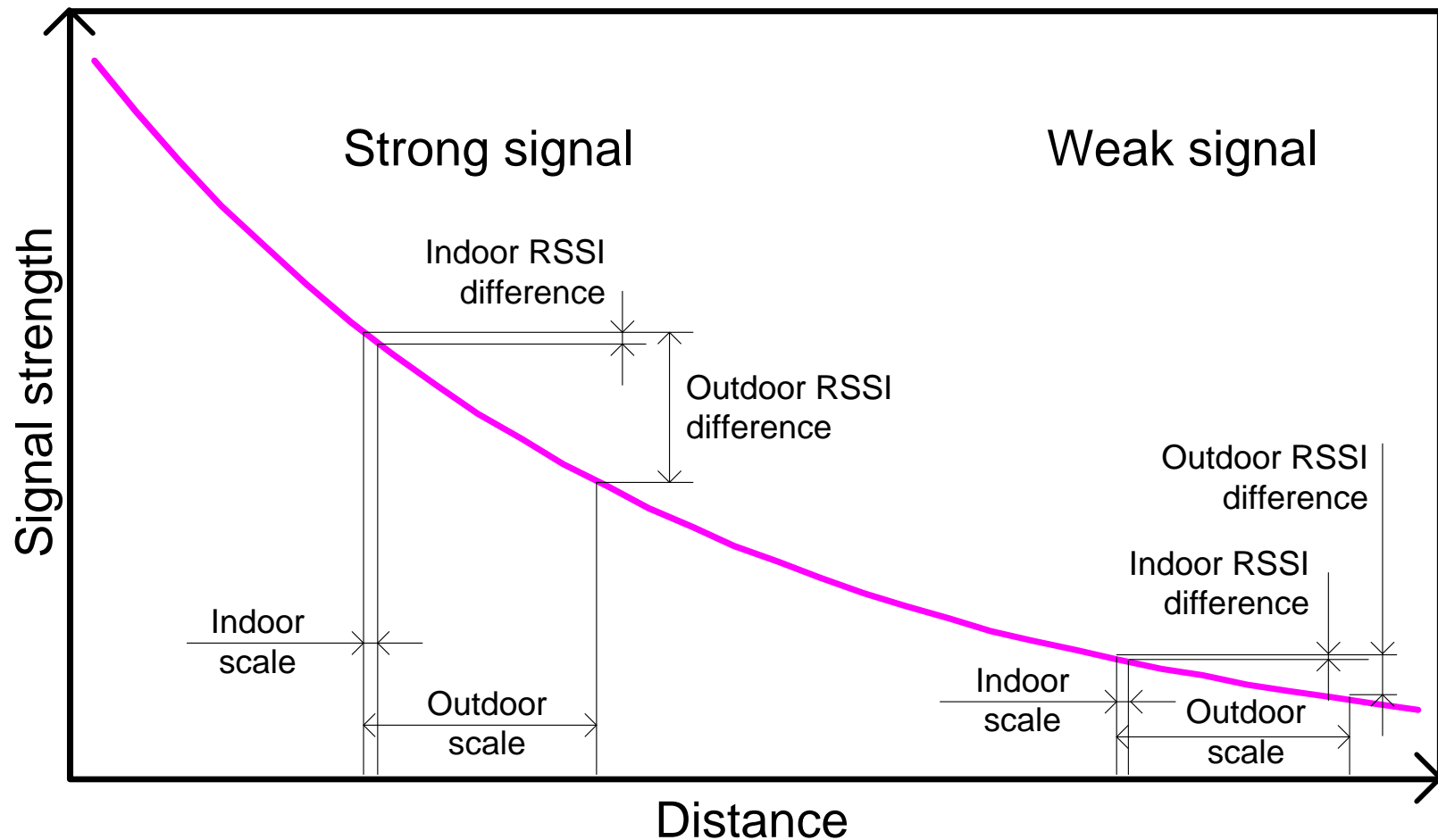


Station selection methods

- Highest diversity approach shows best results.
- Stronger stations perform similarly to weaker stations.
- In previous works, stronger FM stations provided better median accuracy.
- The contradiction is due to the difference between indoor and outdoor signal changes.

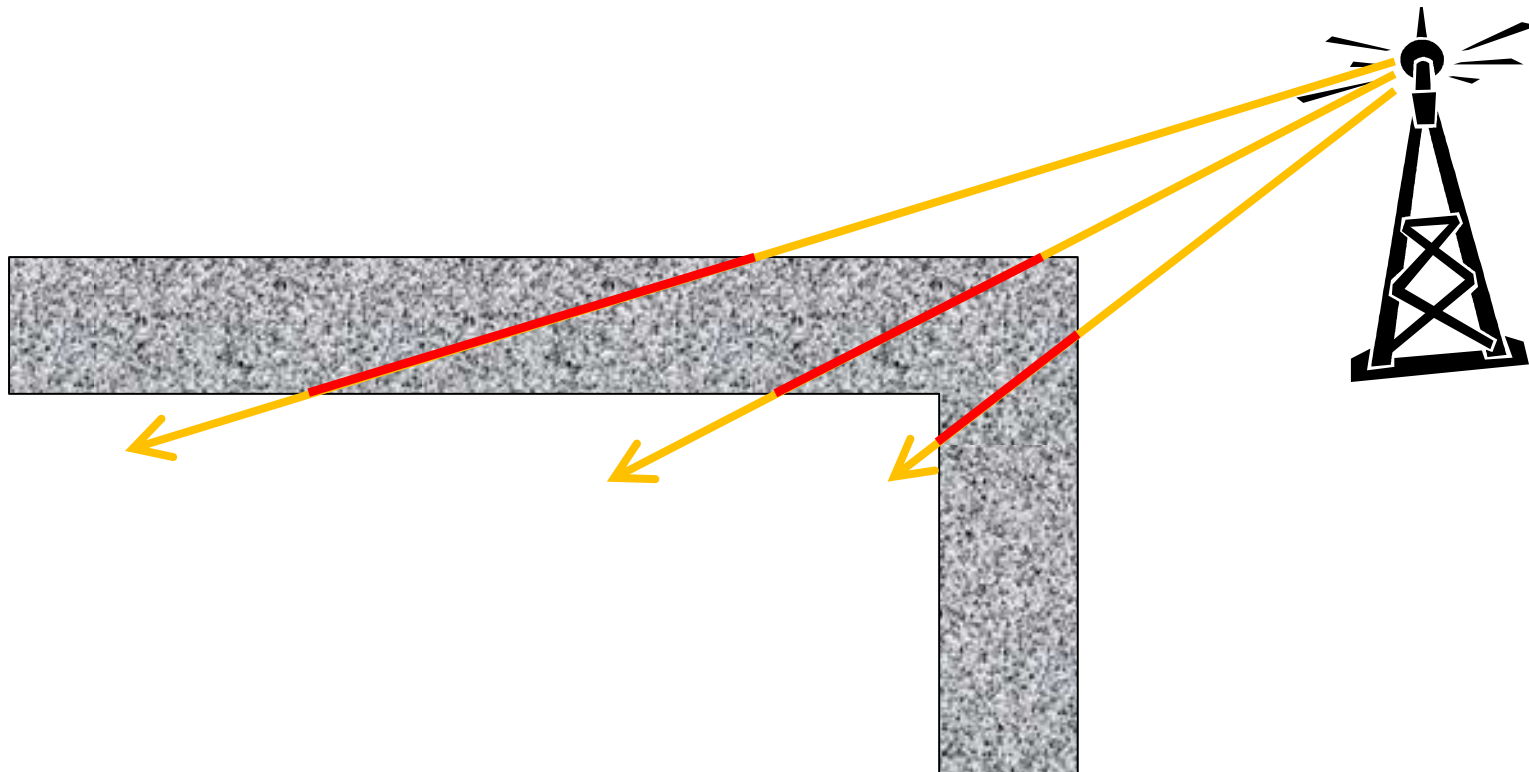


Outdoors vs. indoors



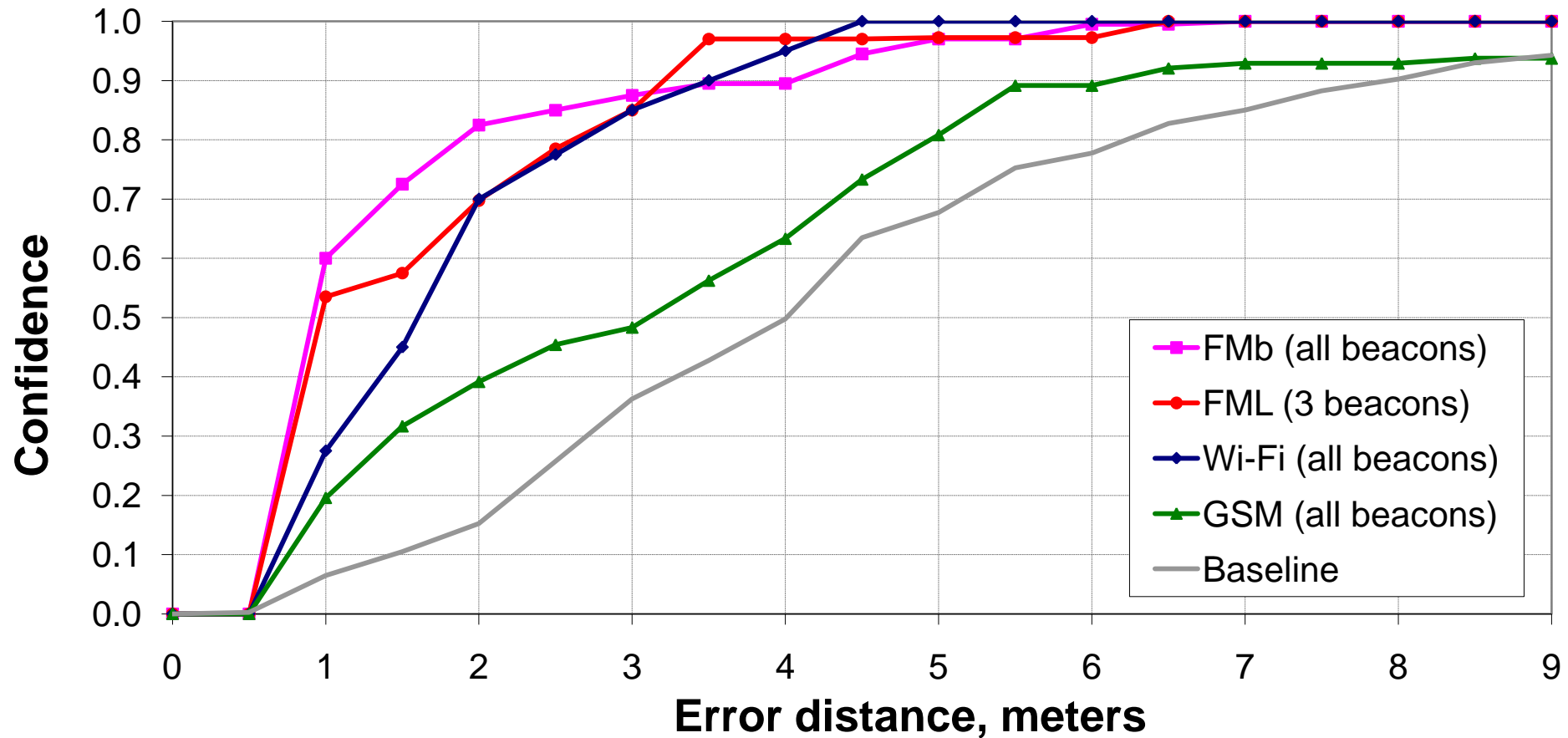


Indoor obstacles



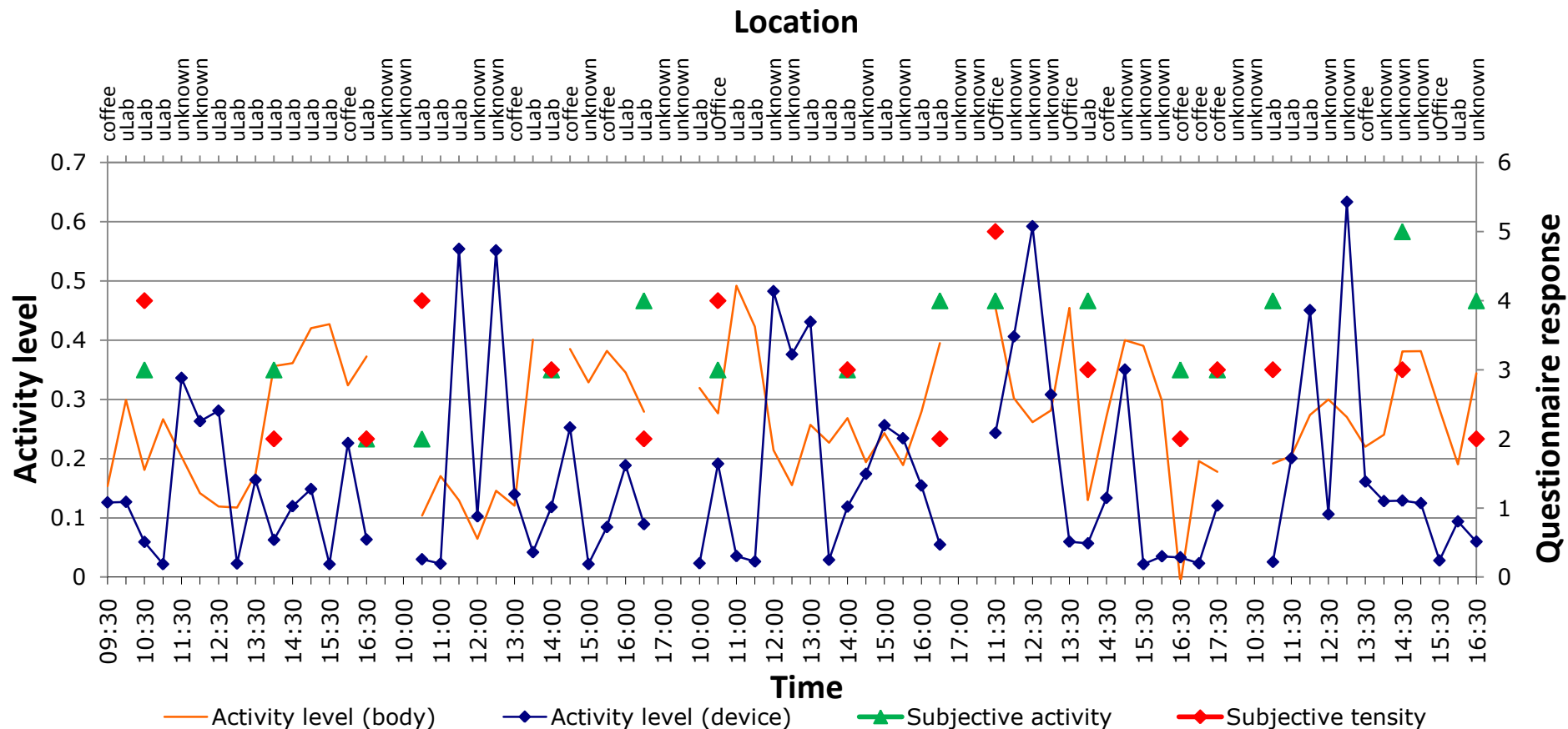


Localization performance





Application scenario





Application scenario

