



# 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



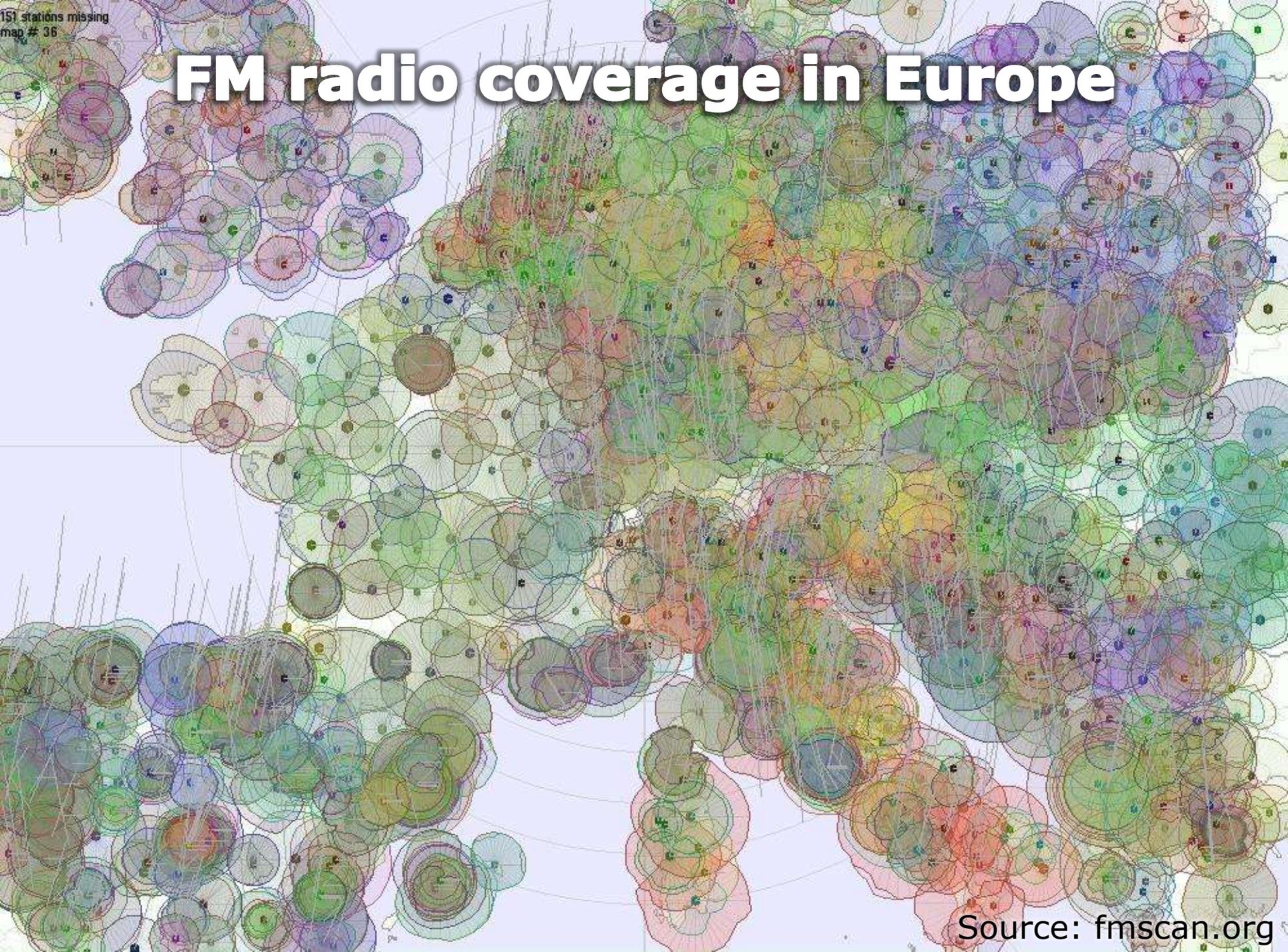


# Indoor localization: FM radio

- 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](http://fmscan.org)

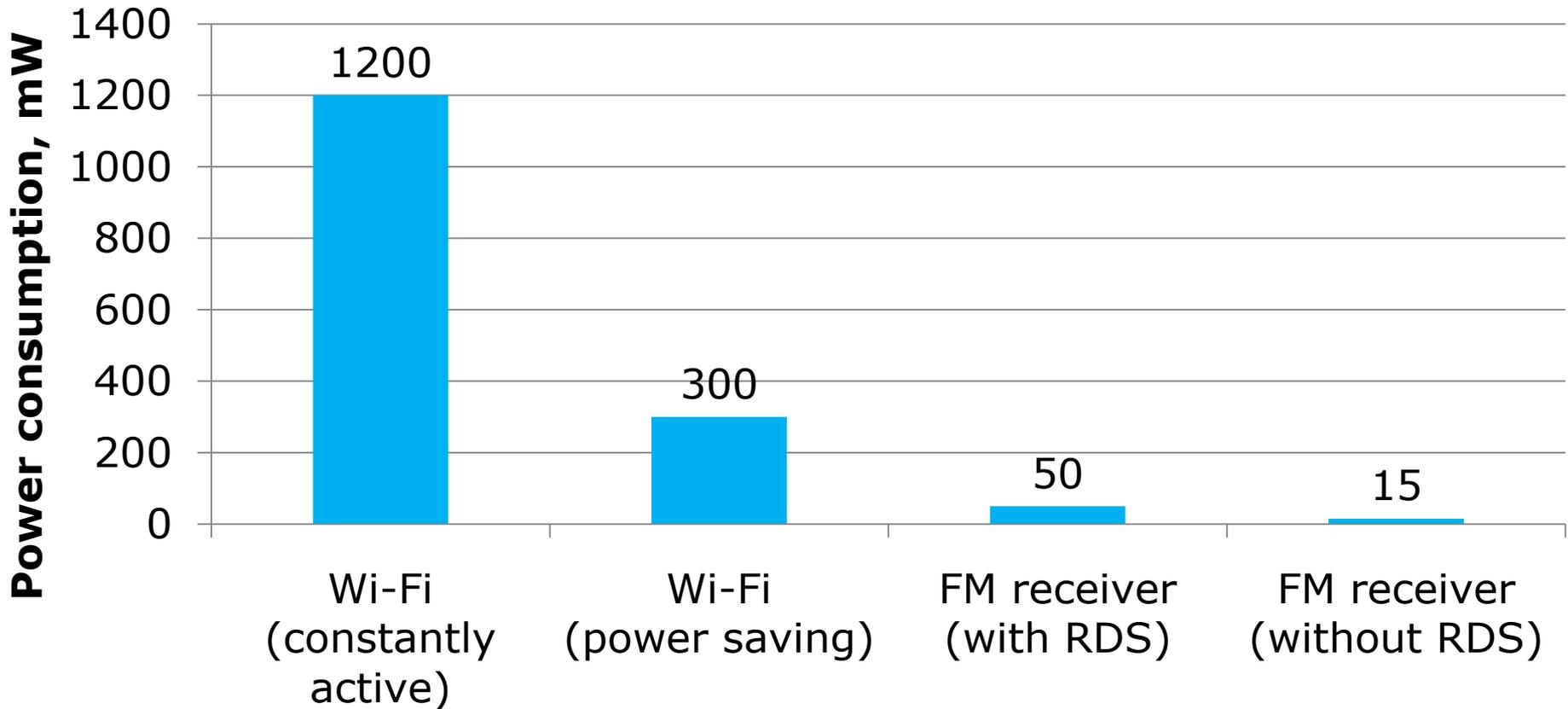


# FM-enabled mobile devices





# Power consumption





# State of the art



## State of the art: FM localization

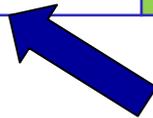
- There are few works on FM positioning.
- All of them consider only outdoor scenarios.
- Achieved accuracy:
  - 2005: 8 km with 50% probability (Krumm et al.)
  - 2009: 20 m with 67% probability (Fang et al.)

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)	?	High	High	Low



The Gap



# Localization methods

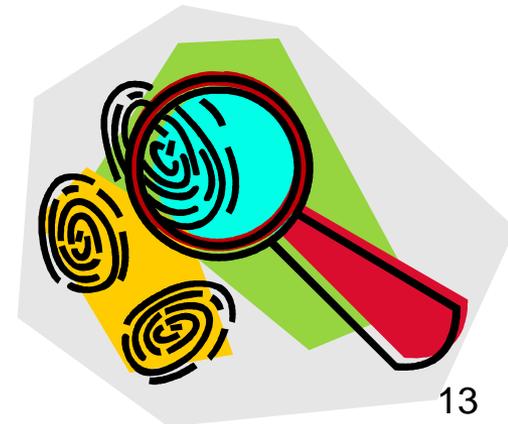
- Proximity-based
- Direction-based
- Time-based
- Based on signal properties
  - Propagation modeling
  - Fingerprinting ← Used in this work



# 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.



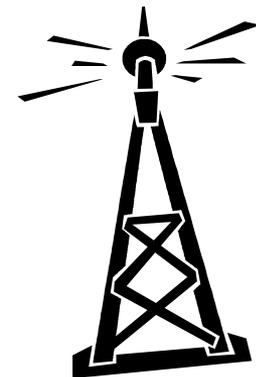


# Proposed approach



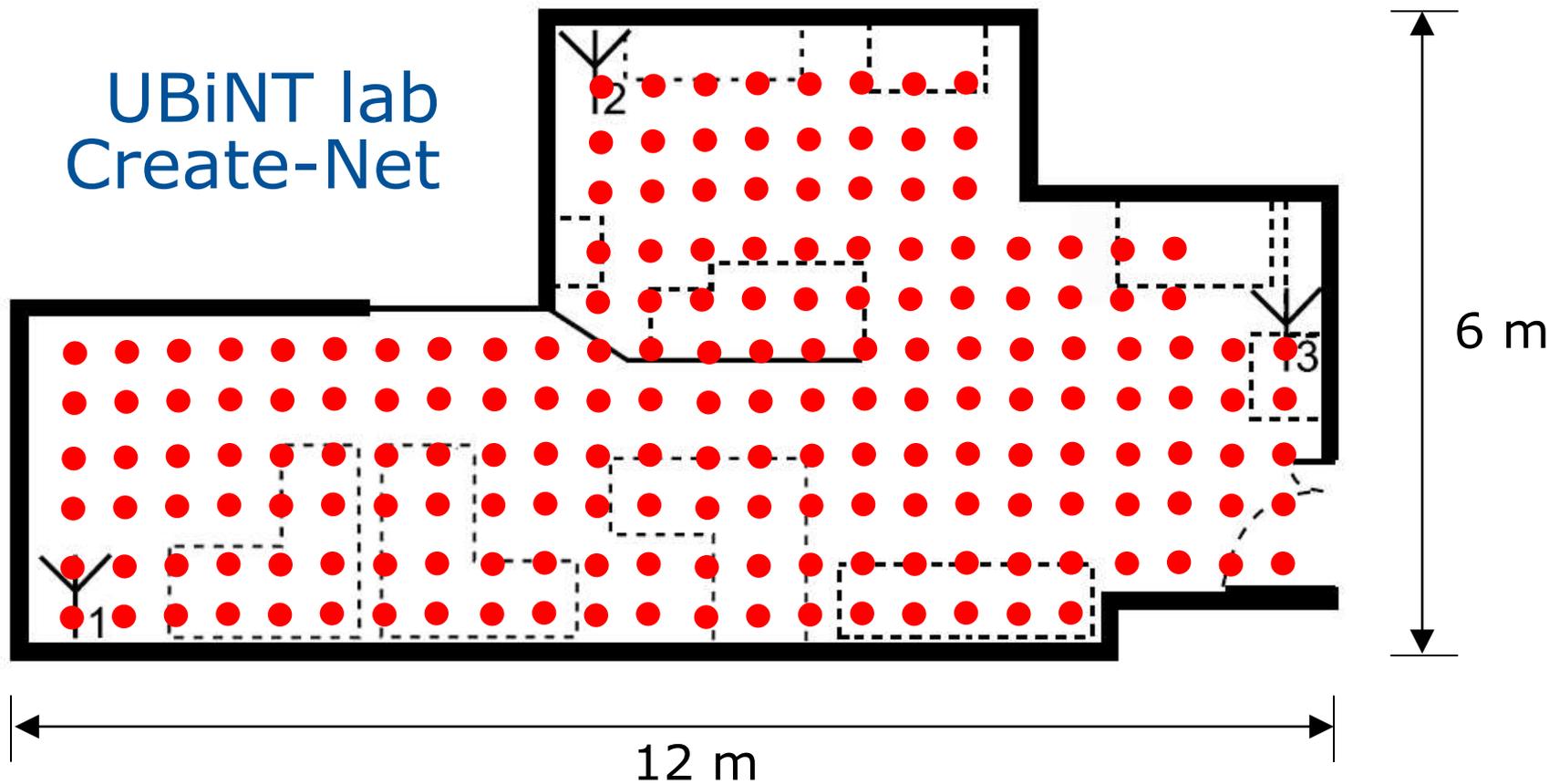
## FM radio signal sources

- 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

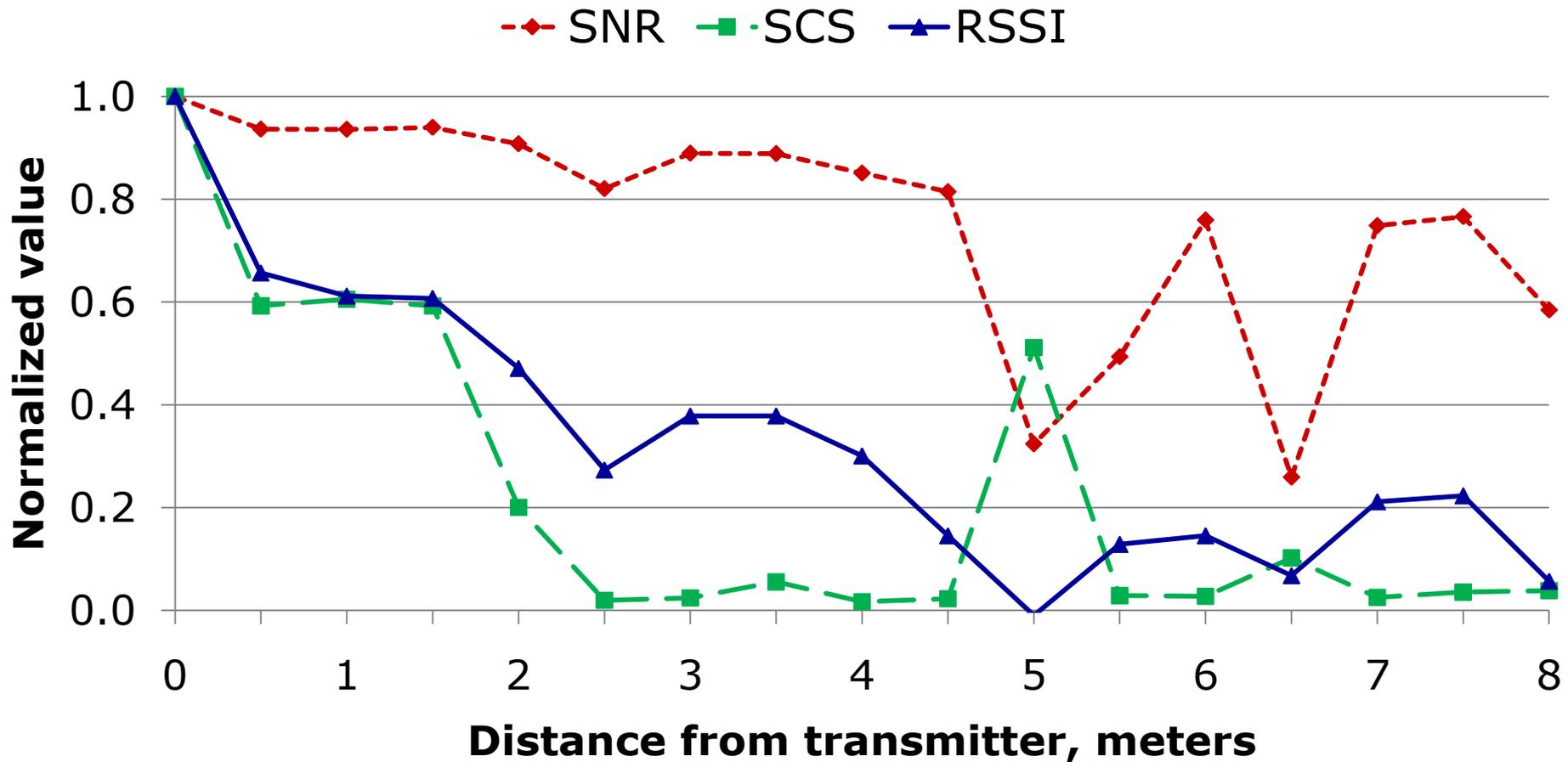


## FM<sub>L</sub> positioning

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

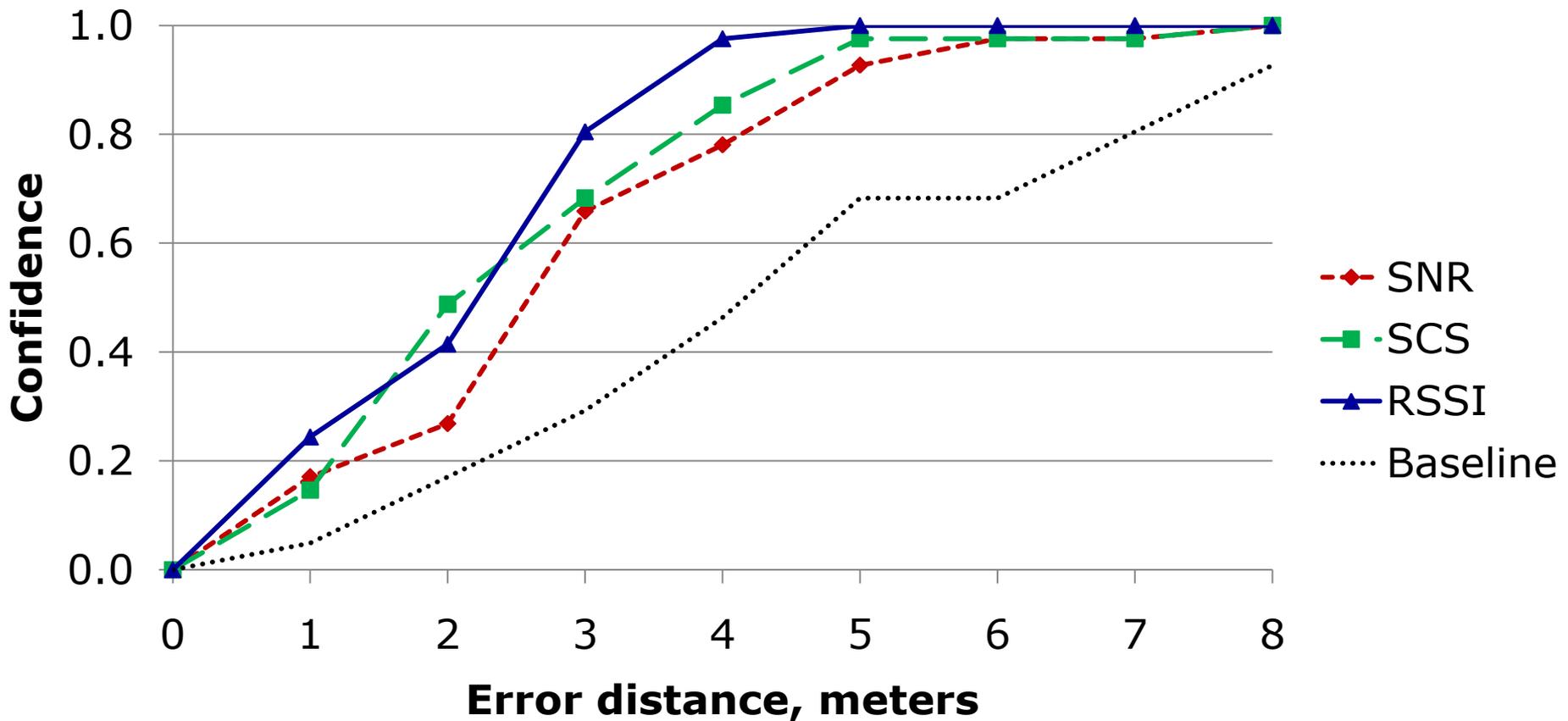


# Signal properties vs. distance





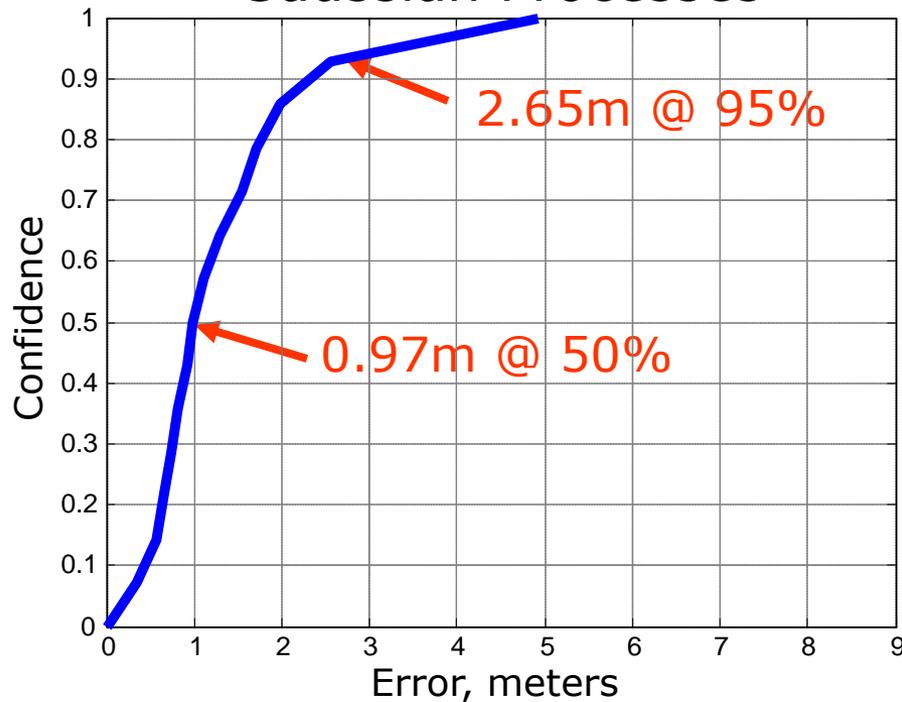
# FM<sub>L</sub> positioning performance



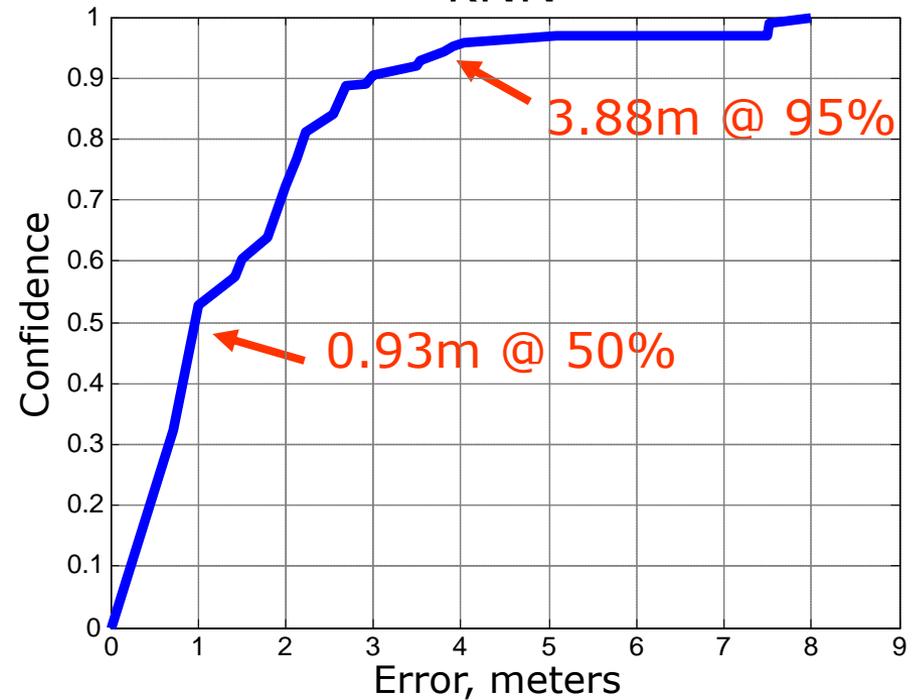


# FM<sub>L</sub> positioning accuracy (RSSI)

## Gaussian Processes



## kNN





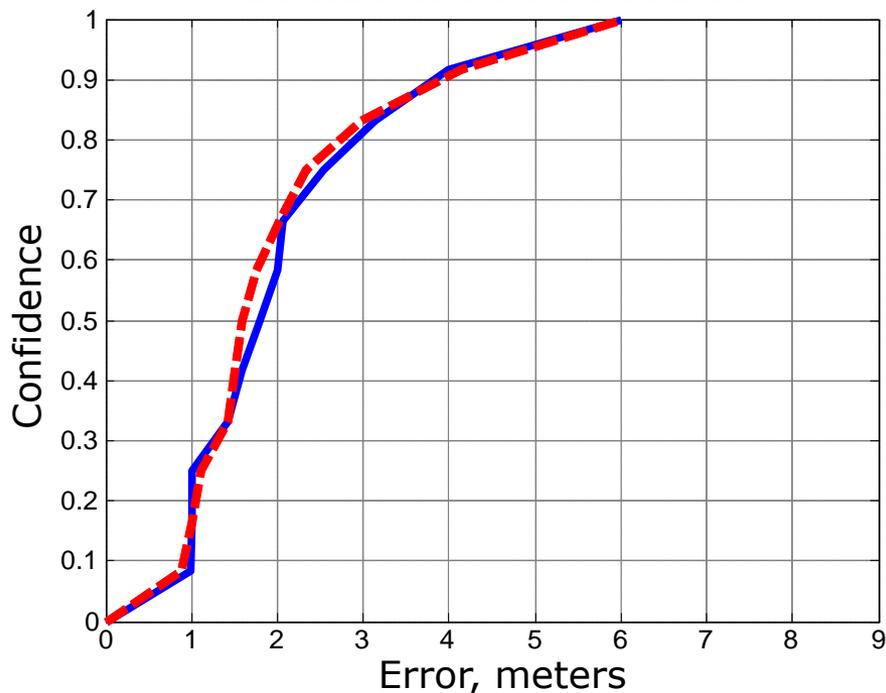
# FM<sub>L</sub>: positioning using local transmitters

- FM<sub>L</sub> positioning
- **FM<sub>L</sub> vs. Wi-Fi**
- Orientation analysis
- Accuracy degradation

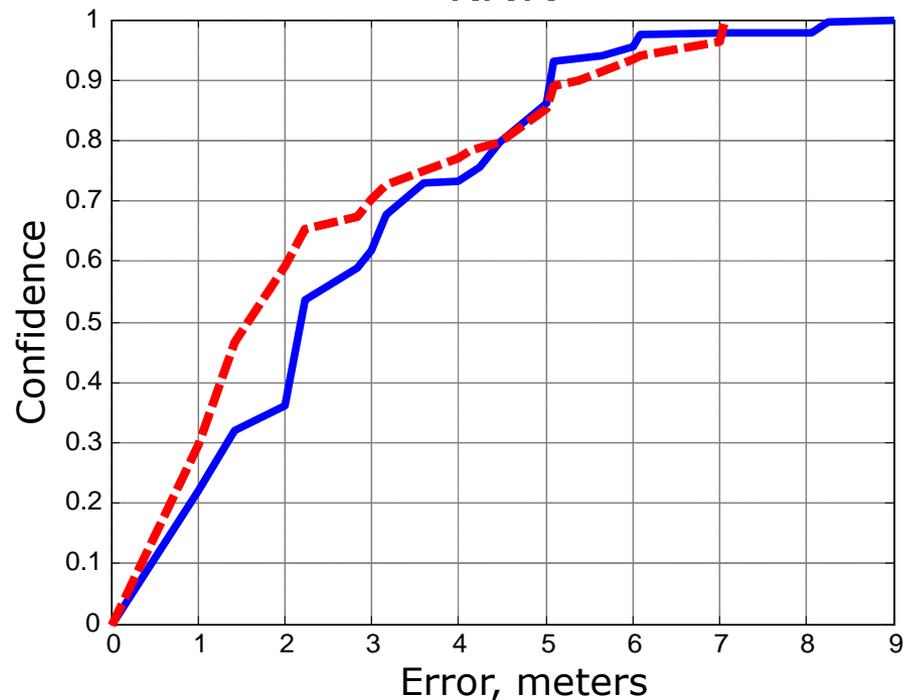


# FM<sub>L</sub> versus Wi-Fi

Gaussian Processes



kNN



--- FM      — Wi-Fi

Receiver: HTC Artemis; grid: 1 m.

FM RSSI granularity reduced to ensure a fair comparison.



# FM<sub>L</sub>: positioning using local transmitters

- FM<sub>L</sub> positioning
- FM<sub>L</sub> vs. Wi-Fi
- **Orientation analysis**
- Accuracy degradation



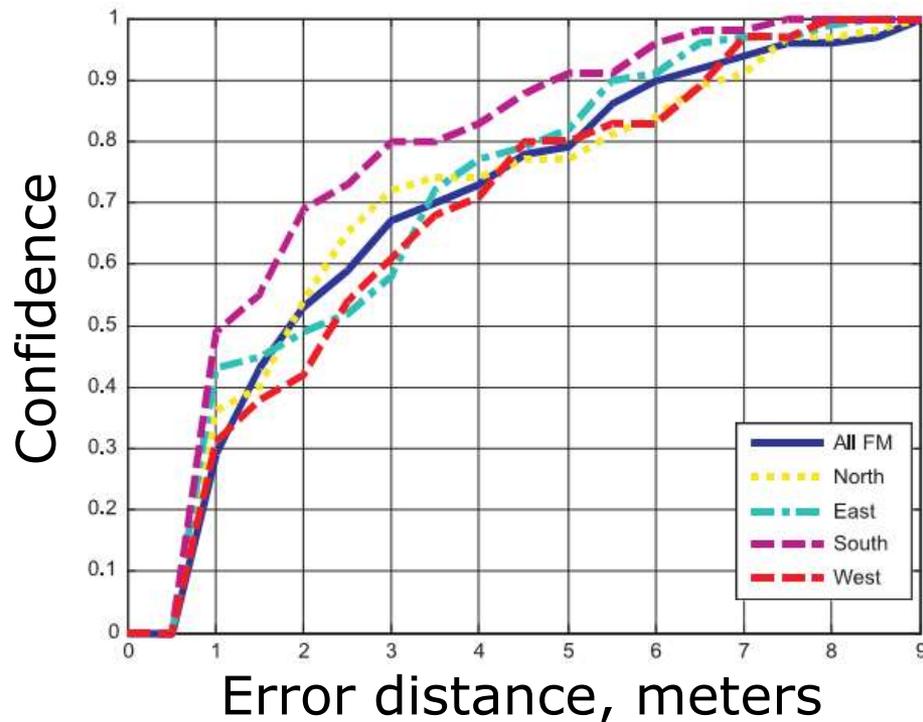
## Effect of orientation

- 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.



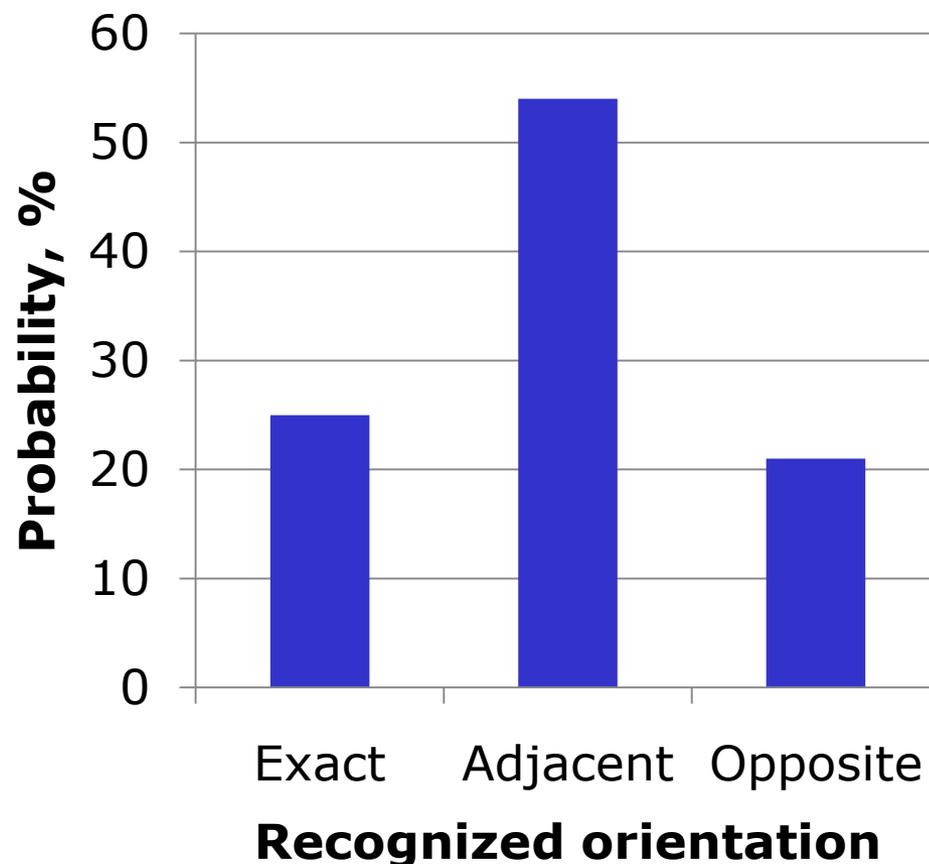
User direction has no significant effect on FM localization accuracy.



# Recognition of orientation

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

↪ **No, the result is random.**



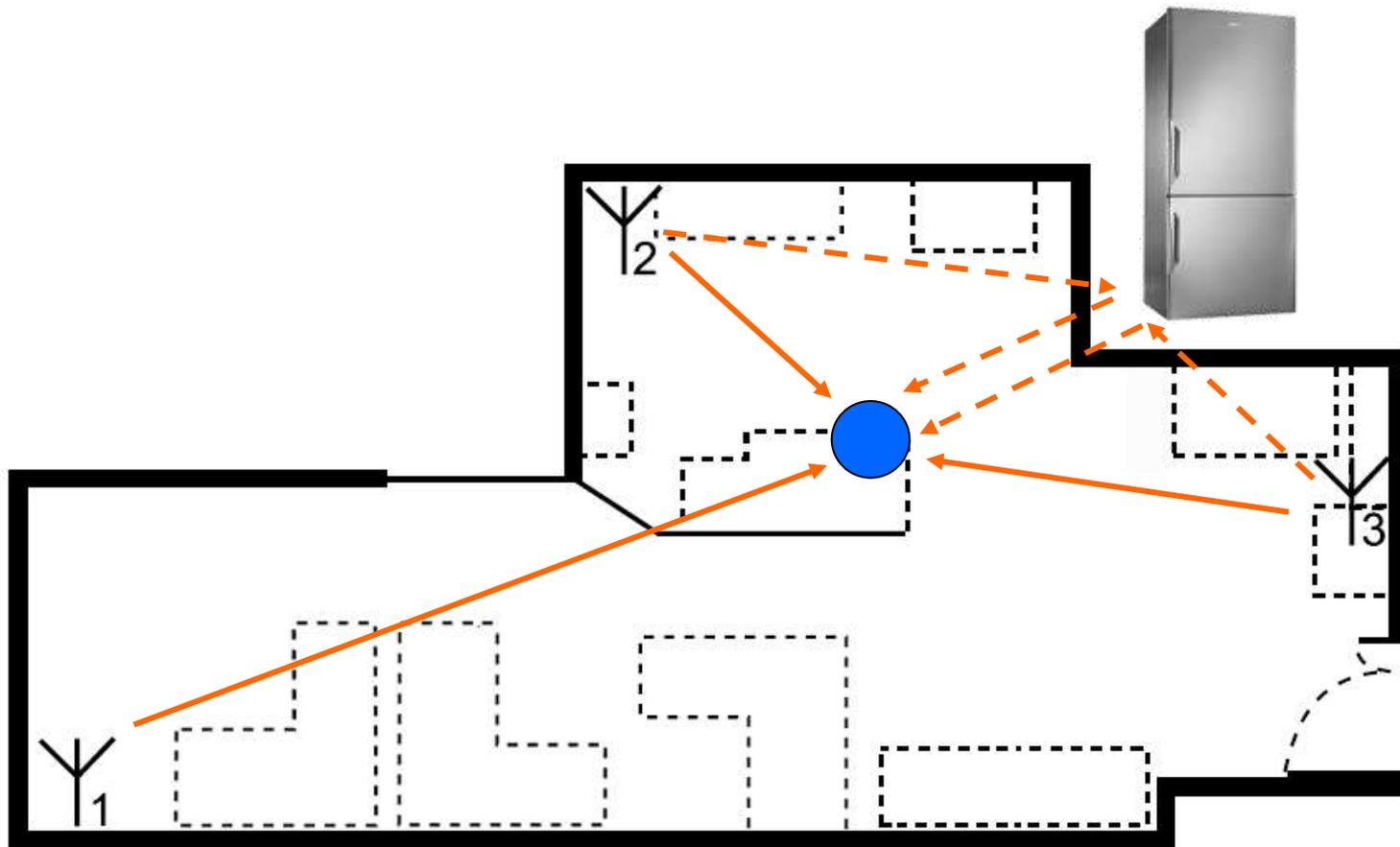


# FM<sub>L</sub>: positioning using local transmitters

- FM<sub>L</sub> positioning
- FM<sub>L</sub> vs. Wi-Fi
- Orientation analysis
- **Accuracy degradation**



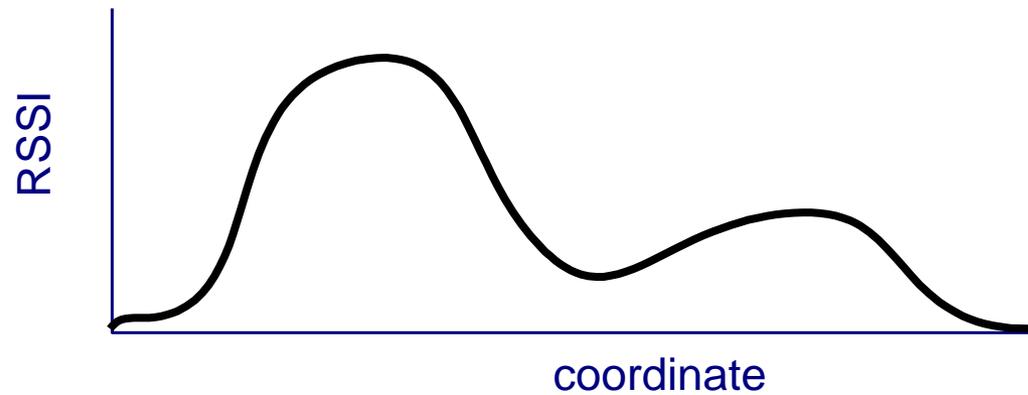
# What if...



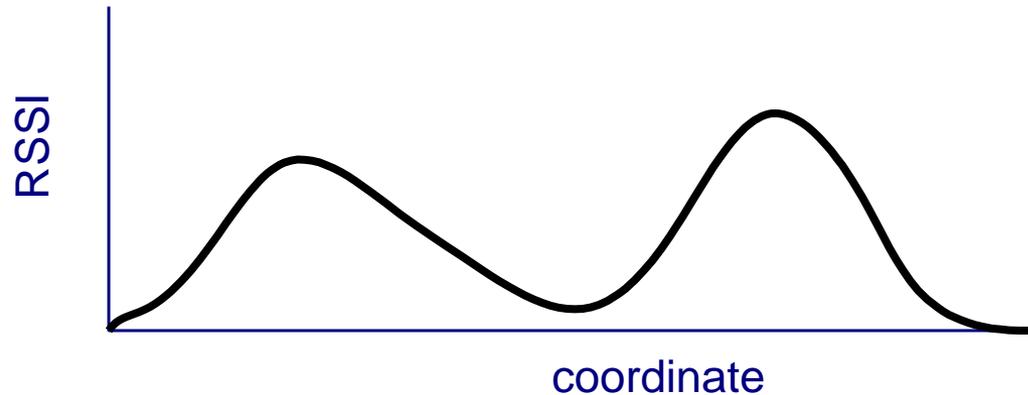


# Signal strength distribution

Before:



Now:





# Accuracy degradation

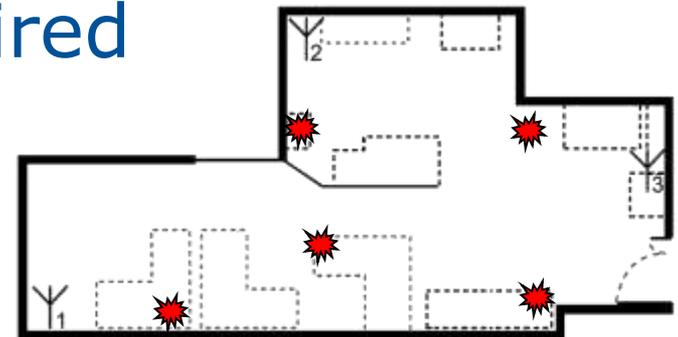
- Signal fingerprints change with time due to:
  - Furniture layout
  - Air temperature and humidity
  - Hardware temperature
- These fluctuations affect the accuracy.
- The **solution**: periodic recalibration
  - Requires personnel or additional hardware
  - Is tedious and expensive





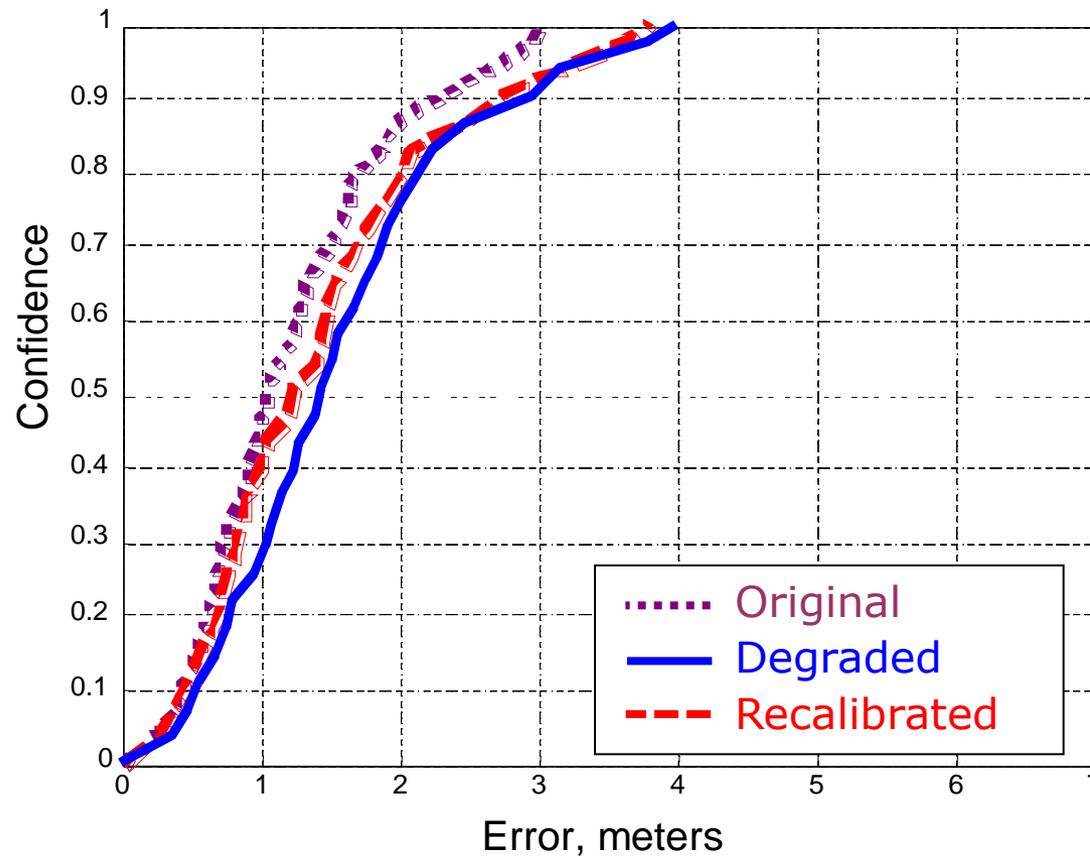
# Spontaneous recalibration

- 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

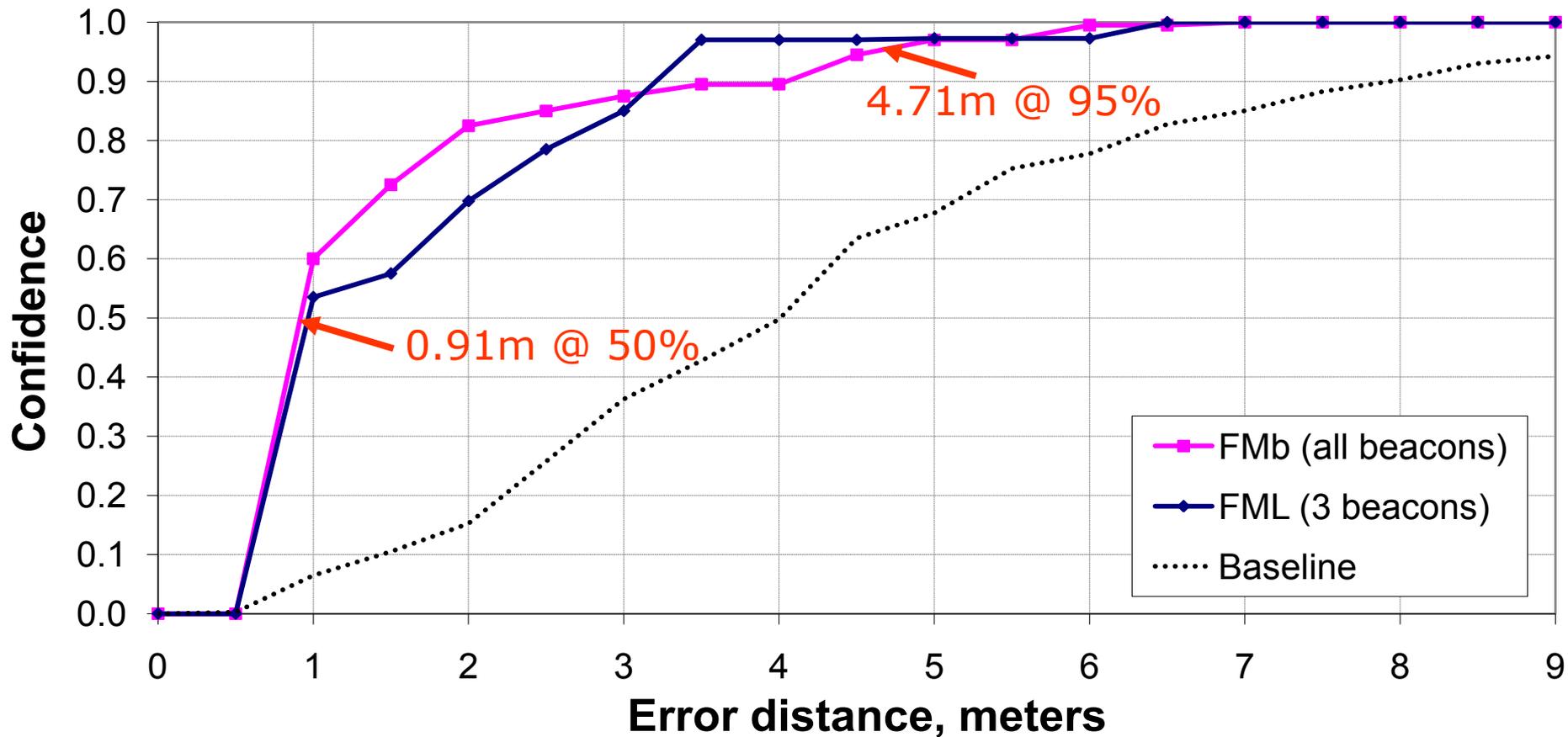


## FM<sub>B</sub> experiments

- 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<sub>B</sub> 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?

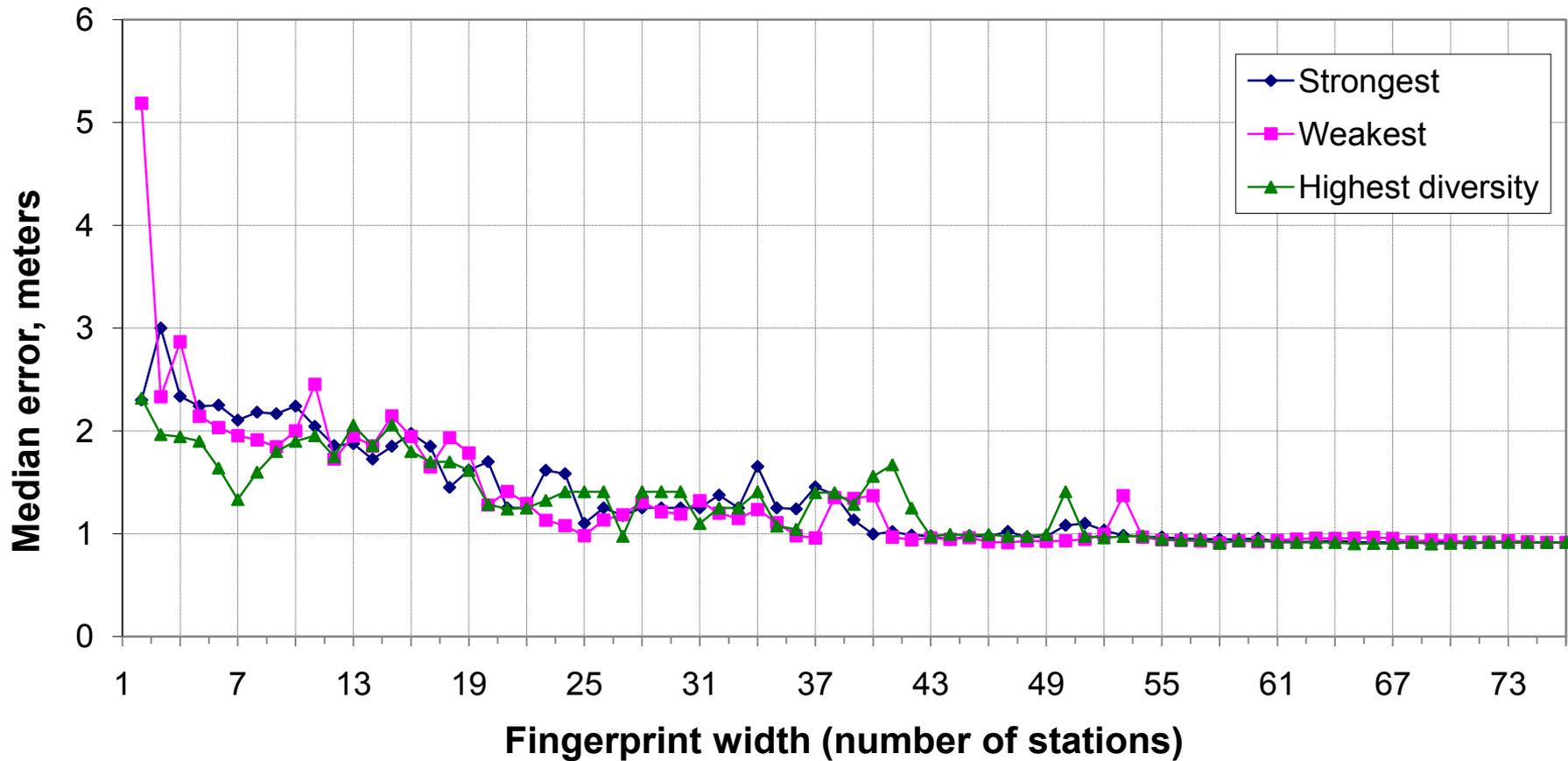


## Station selection methods

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

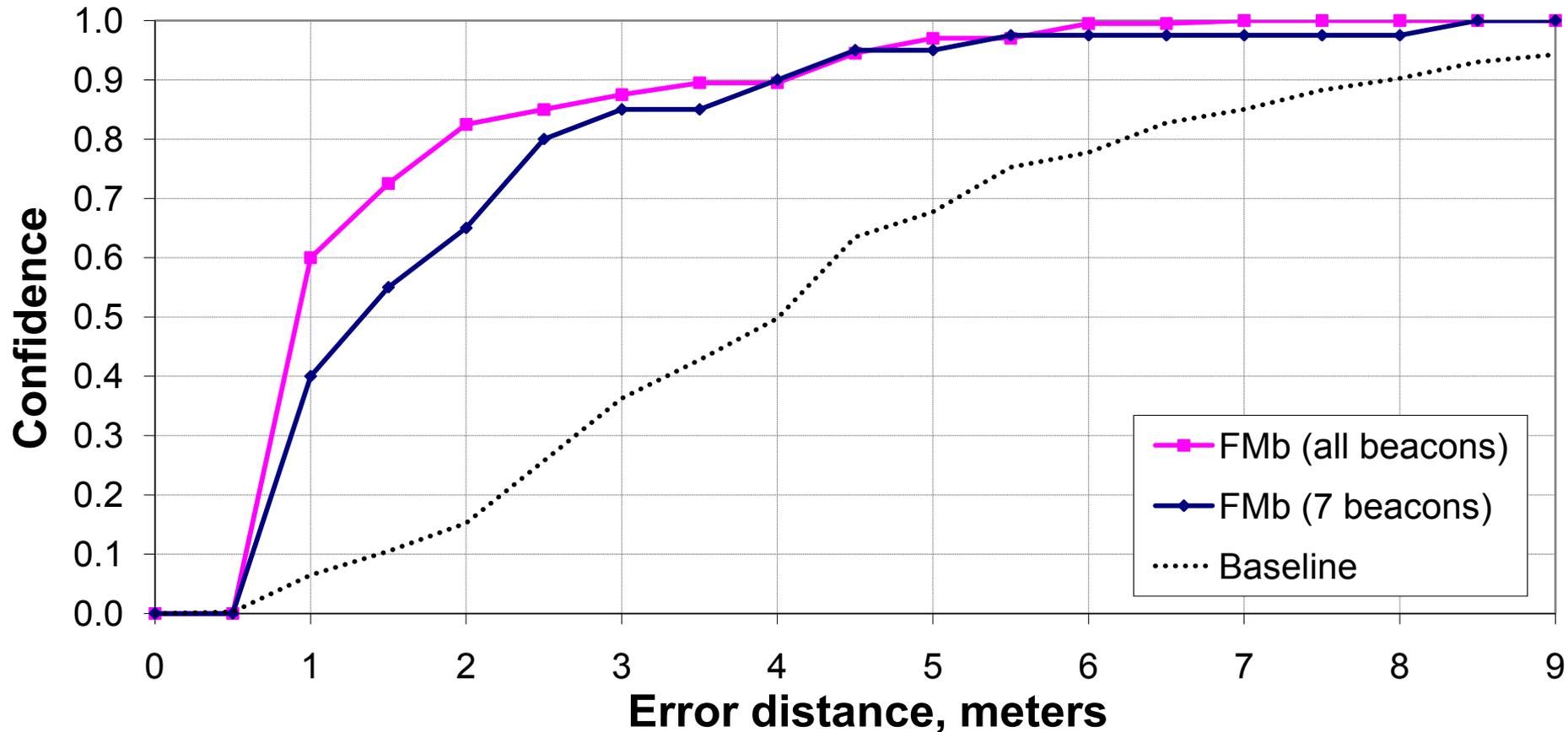


# Station selection methods





# FM<sub>B</sub> with 10% of stations



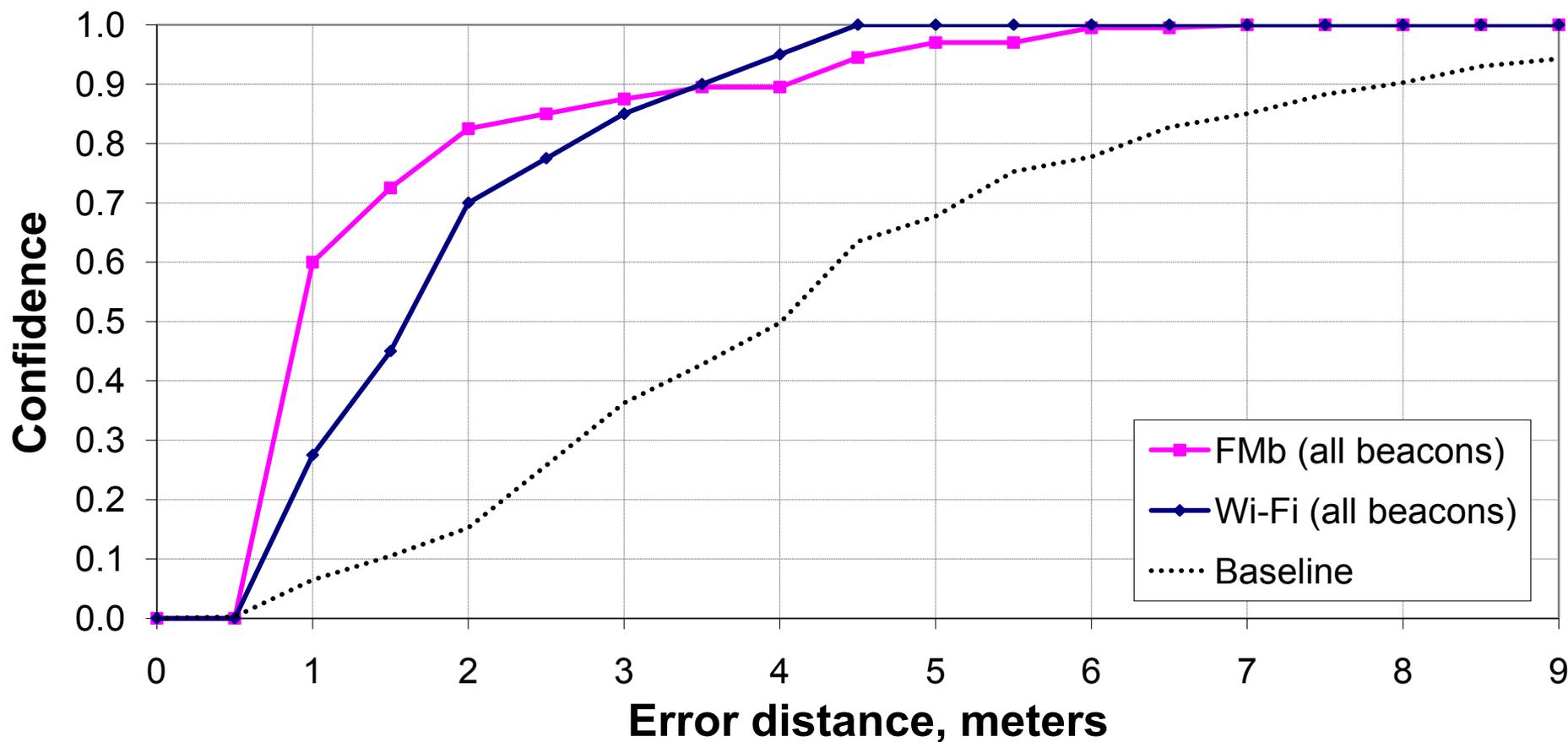


# FM<sub>B</sub>: positioning using broadcasting FM stations

- FM<sub>B</sub> performance
- **FM<sub>B</sub> vs. Wi-Fi and GSM**
- Signal stability and people's presence
- Power consumption

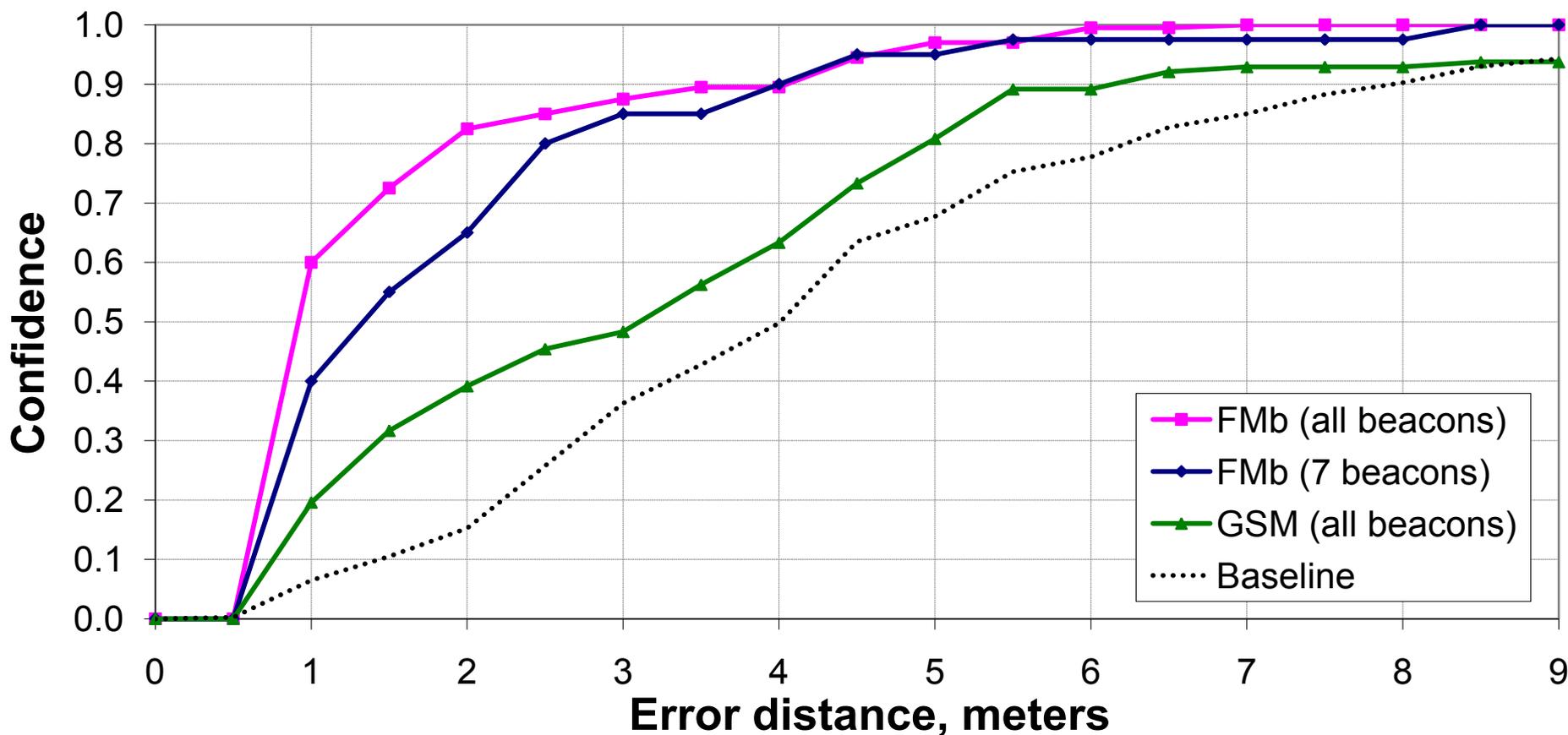


# FM<sub>B</sub> versus Wi-Fi





# FM<sub>B</sub> versus GSM





# FM<sub>B</sub> localization: Summary

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

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



# FM<sub>B</sub>: positioning using broadcasting FM stations

- FM<sub>B</sub> performance
- FM<sub>B</sub> 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.



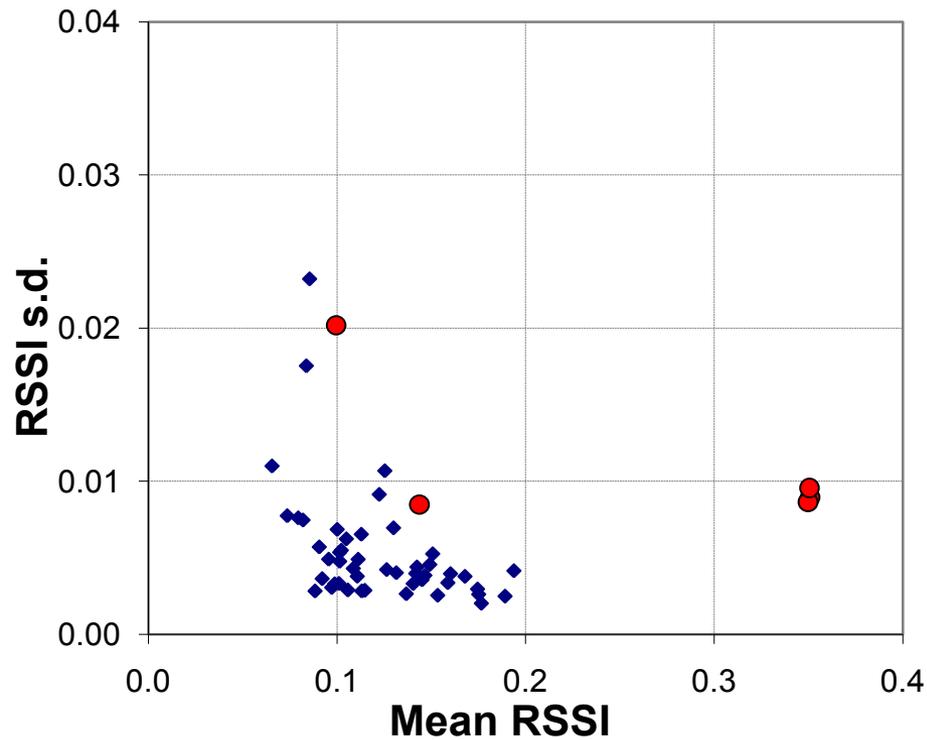
# Signal stability: Experiment 1

- 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.

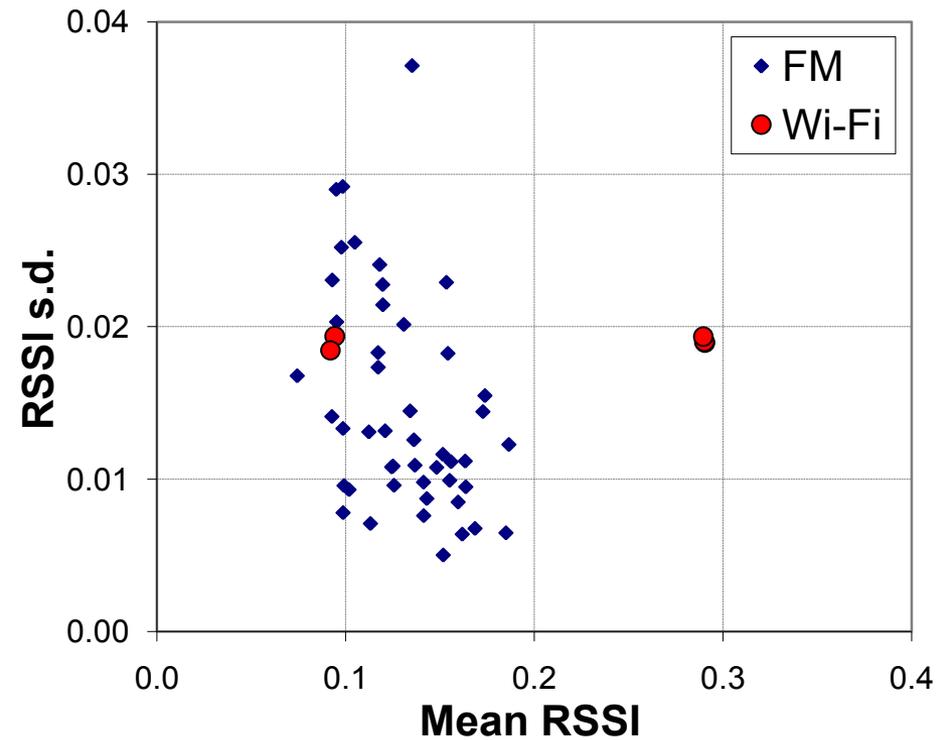


# Signal stability: Experiment 1

## Empty



## Crowded





## Signal stability: Experiment 2

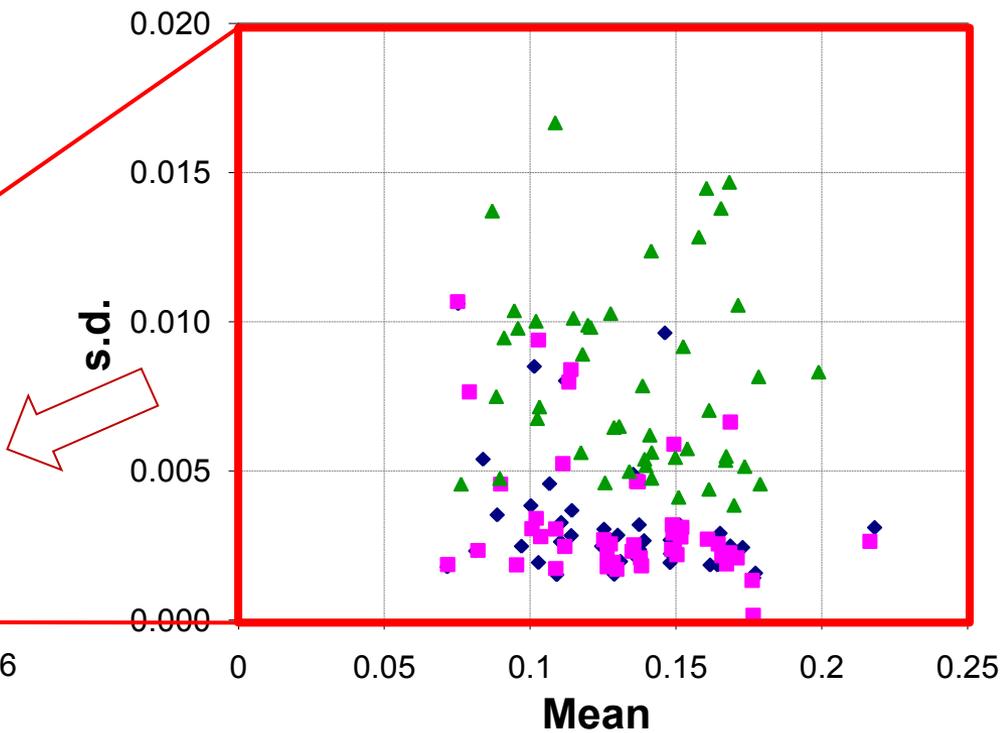
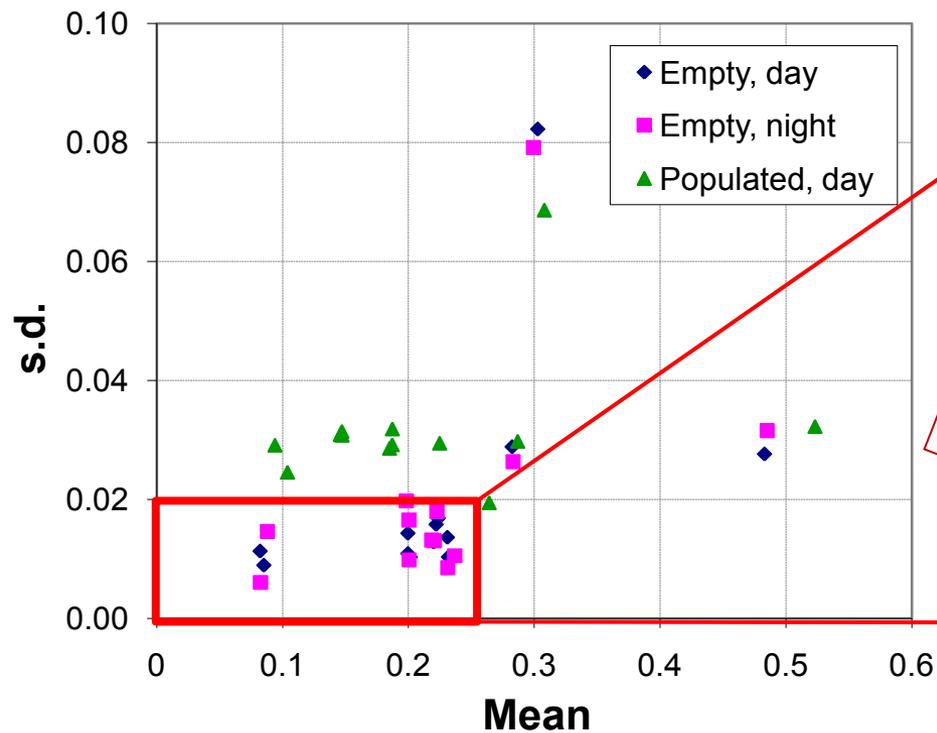
- An office environment:
  - Empty, daytime
  - Empty, nighttime
  - Populated
- 6 hours duration; 592 fingerprints
  - 23 FM stations
  - 13 Wi-Fi access points
- RSS normalized as in the previous experiment.



# Signal stability: Experiment 2

## Wi-Fi

## FM





# FM<sub>B</sub>: positioning using broadcasting FM stations

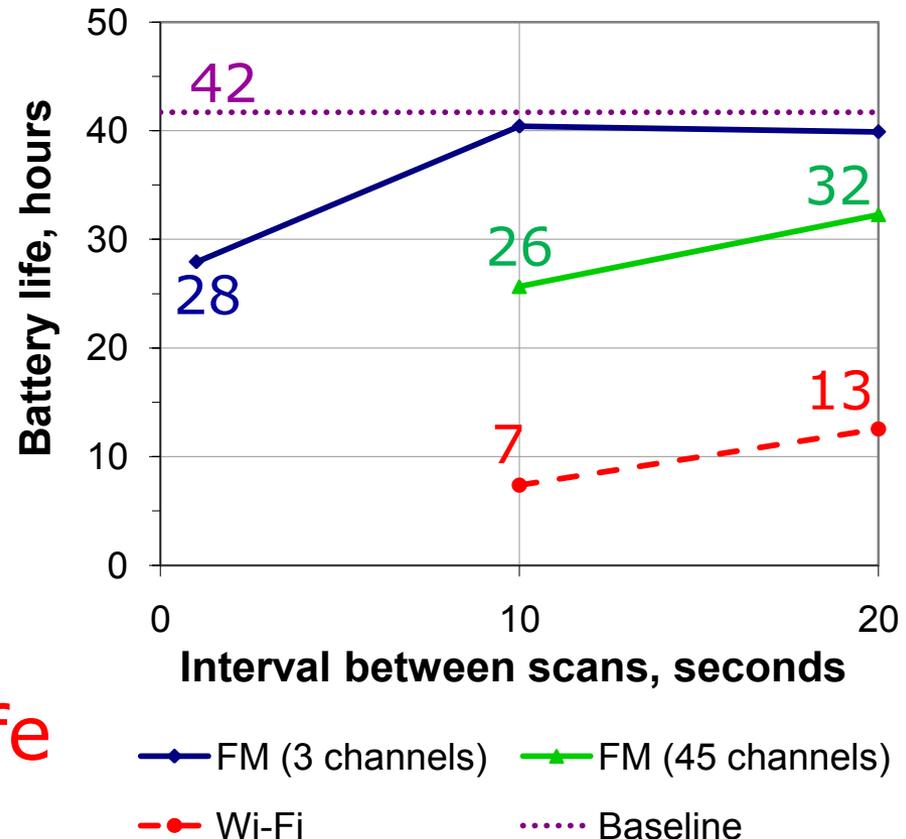
- FM<sub>B</sub> performance
- FM<sub>B</sub> vs. Wi-Fi and GSM
- Signal stability and people's presence
- **Power consumption**



# 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.

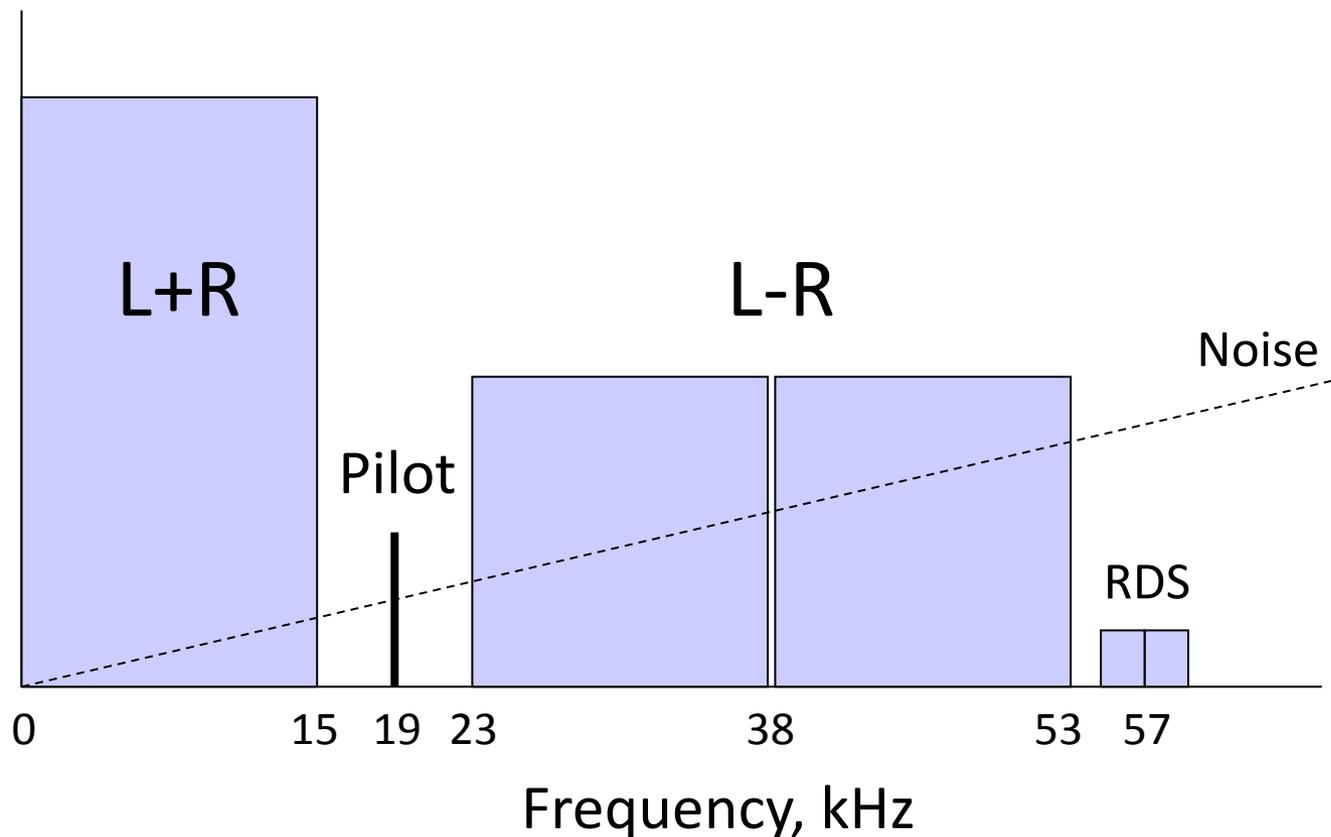


**Thank you**





# FM stereo signal encoding





# Signal strength representation

<b>FM</b>	<b>Wi-Fi</b>	<b>Unified (dB)</b>
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

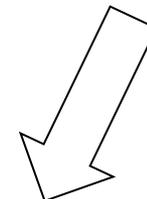
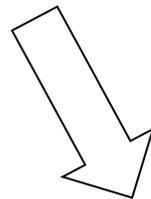


# FM with Wi-Fi

FM fingerprint



Wi-Fi fingerprint

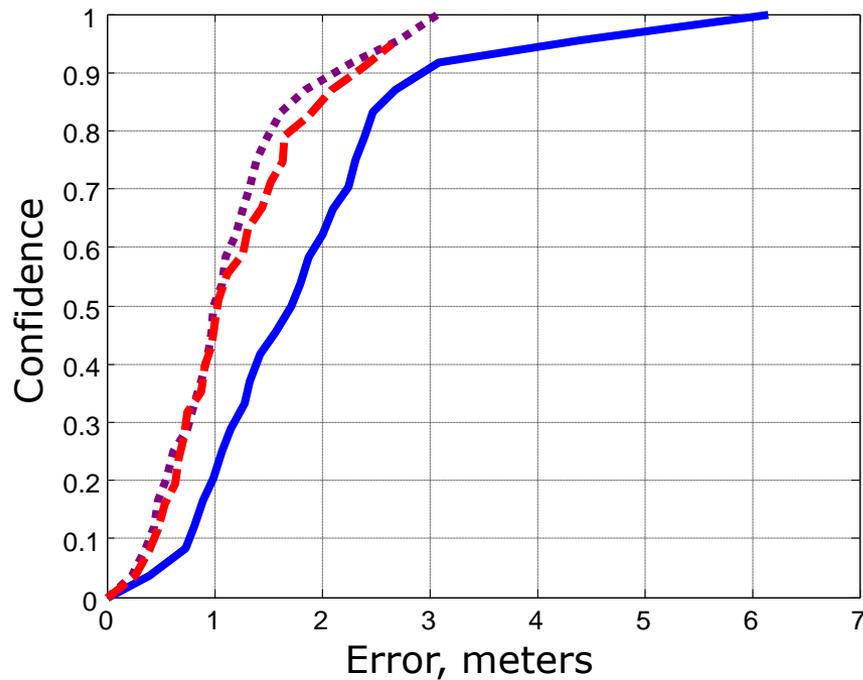


Combined wide fingerprint

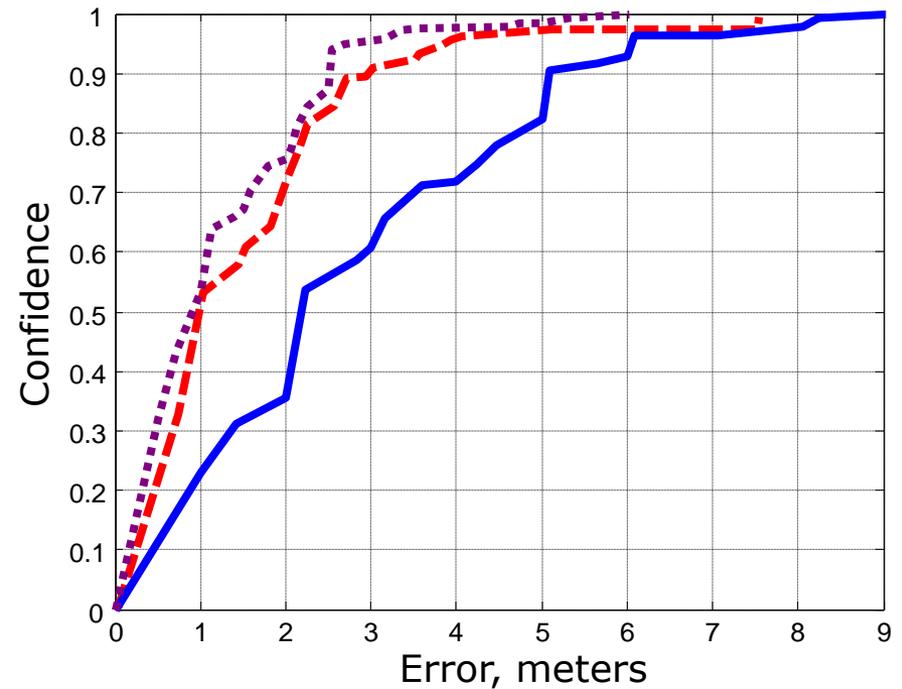


# FM<sub>L</sub> combined with Wi-Fi

Gaussian Processes



kNN



--- FM      — Wi-Fi      ..... Combined



## FM with Wi-Fi

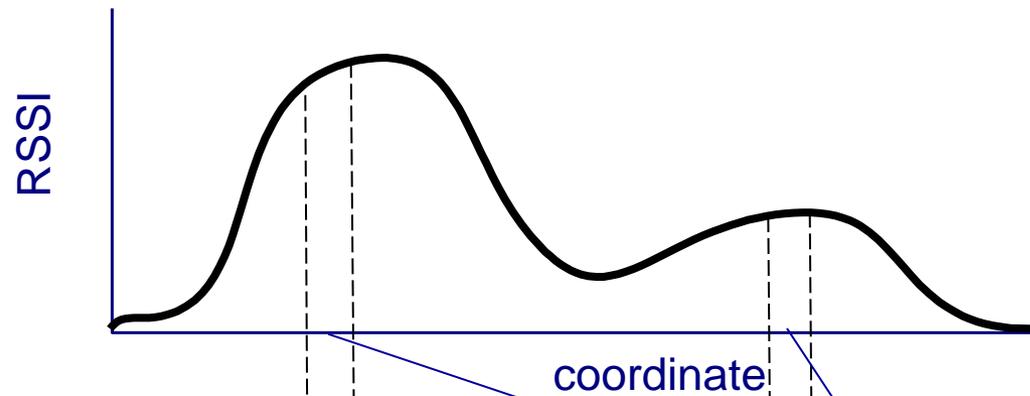
- Combined coverage
- Longer battery life
- Improved accuracy (by up to 22%)



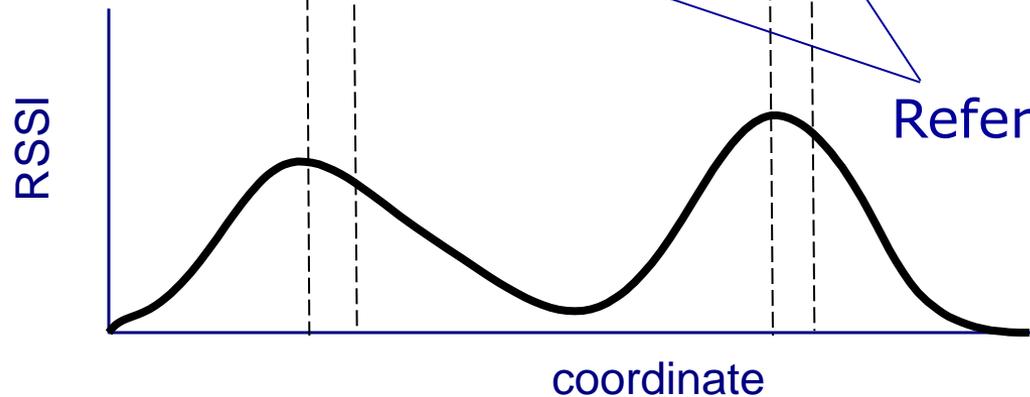


# Spontaneous recalibration

Before:

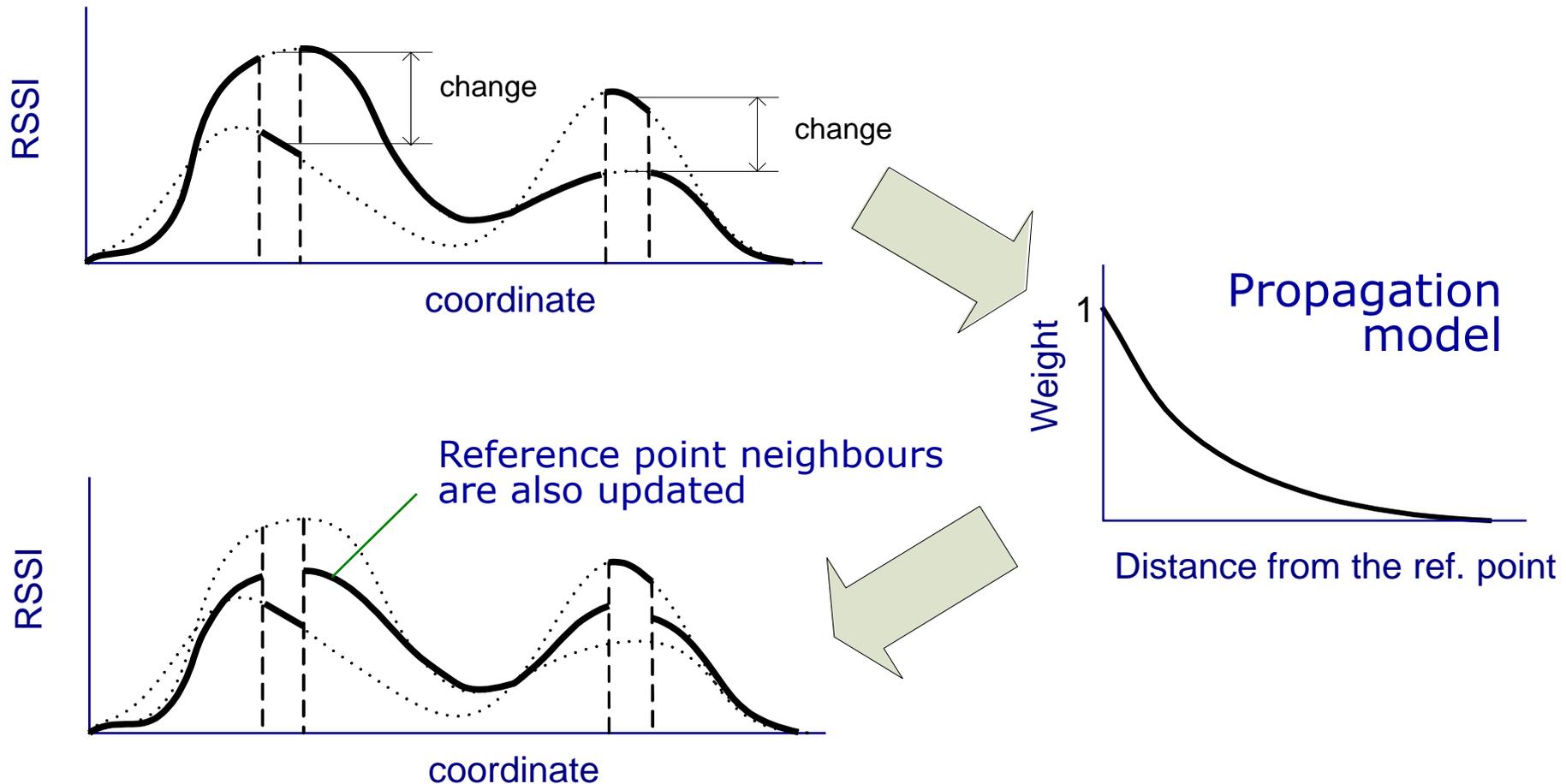


Now:



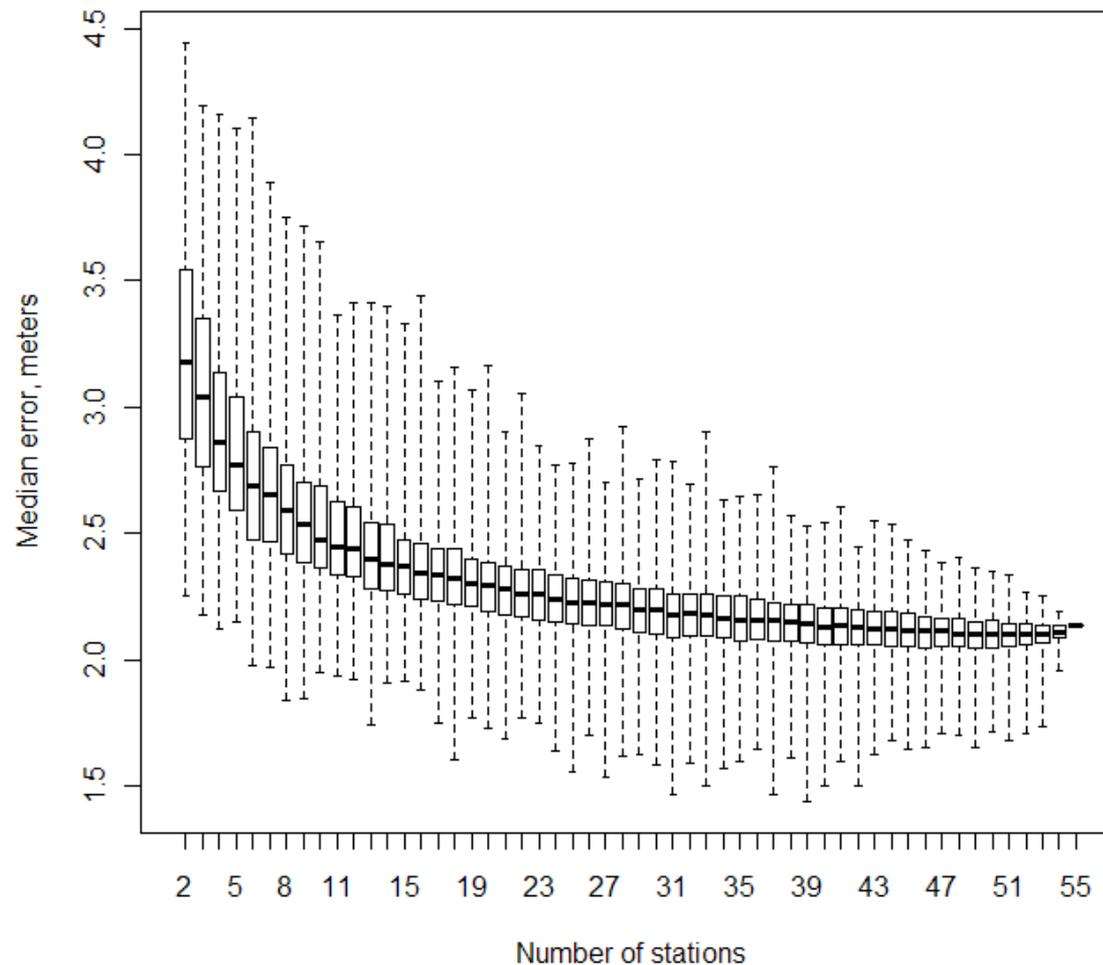


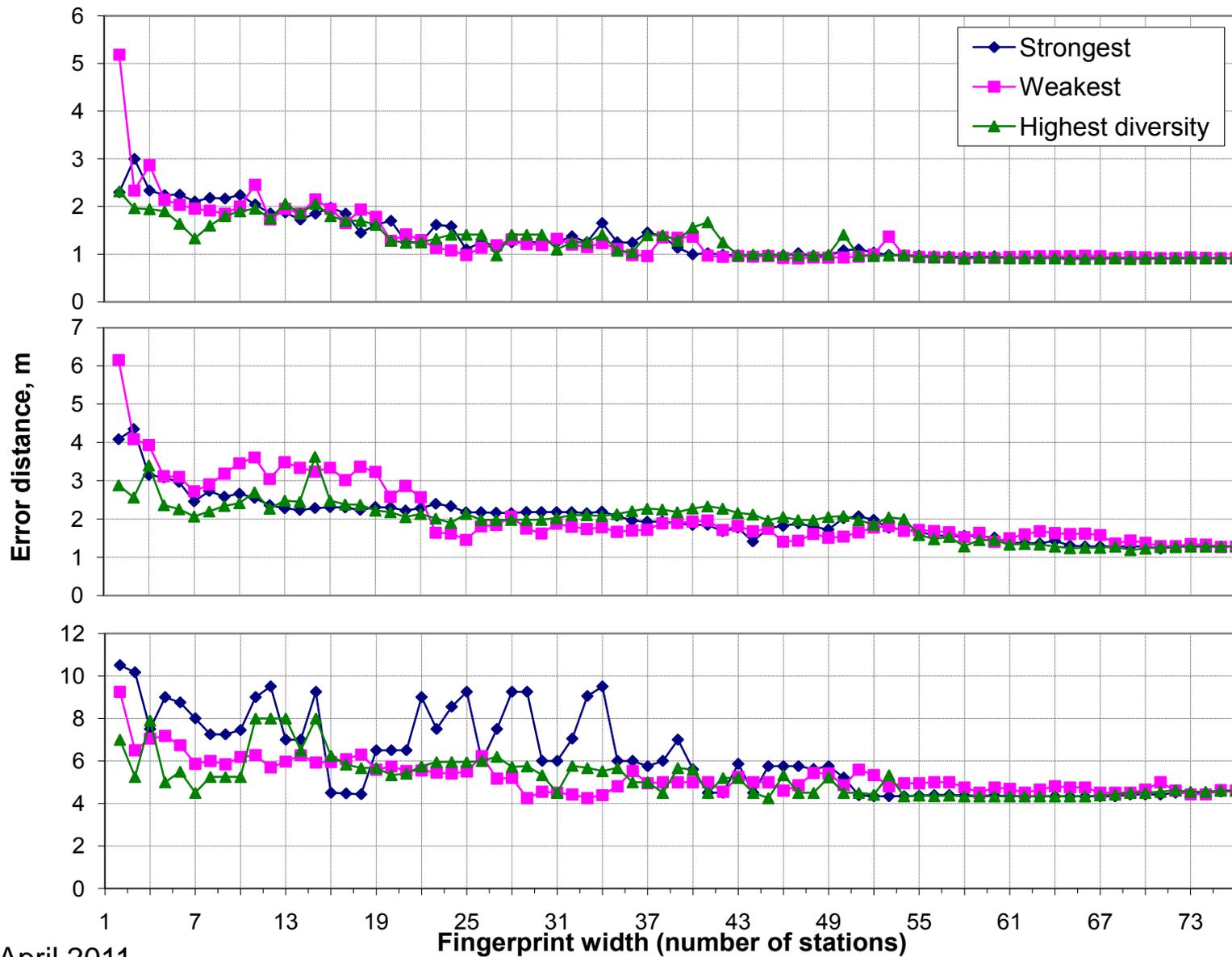
# Spontaneous recalibration





# FM<sub>B</sub> accuracy vs. number of stations





50%

67%

95%

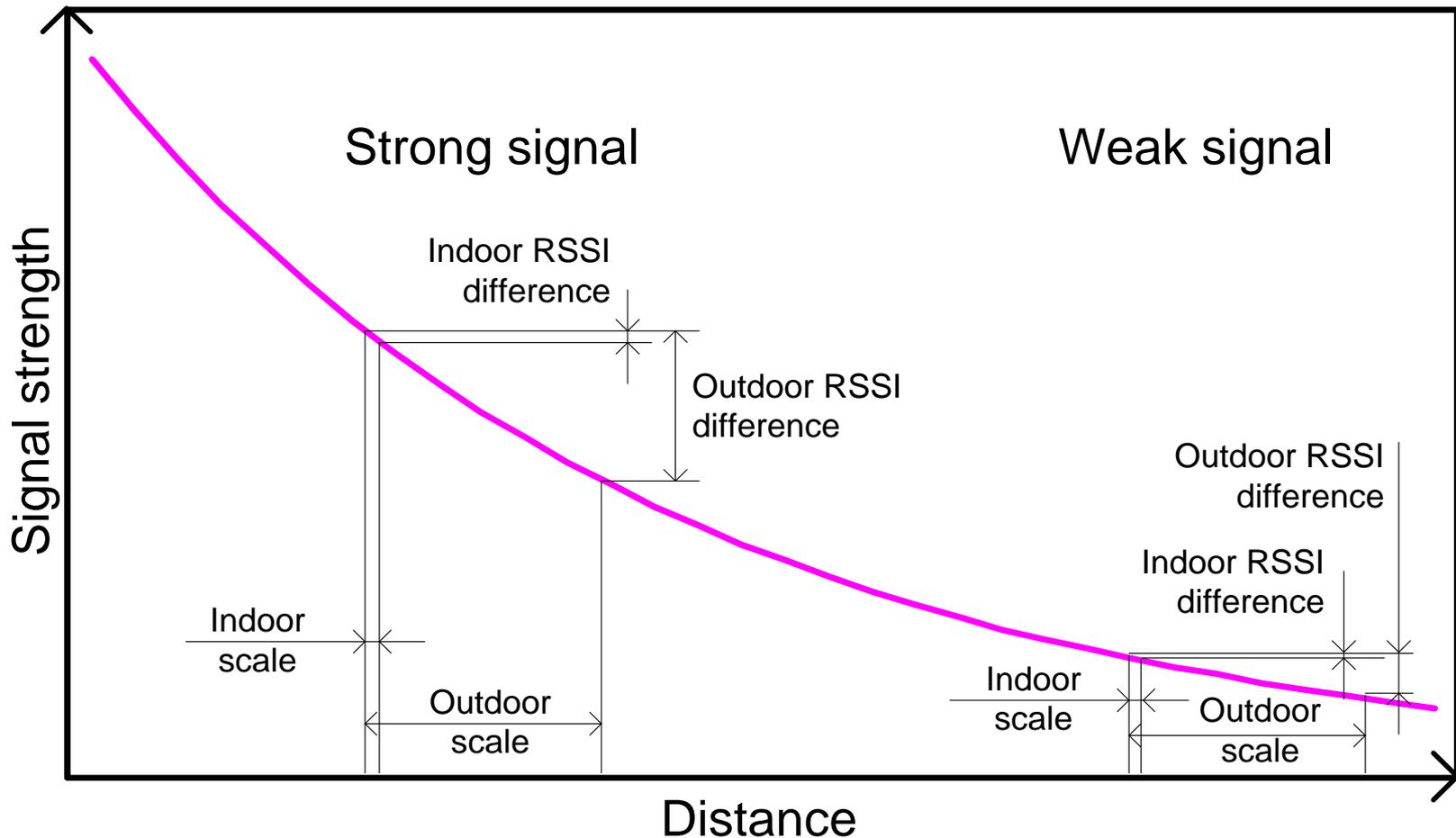


## Station selection methods

- 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.

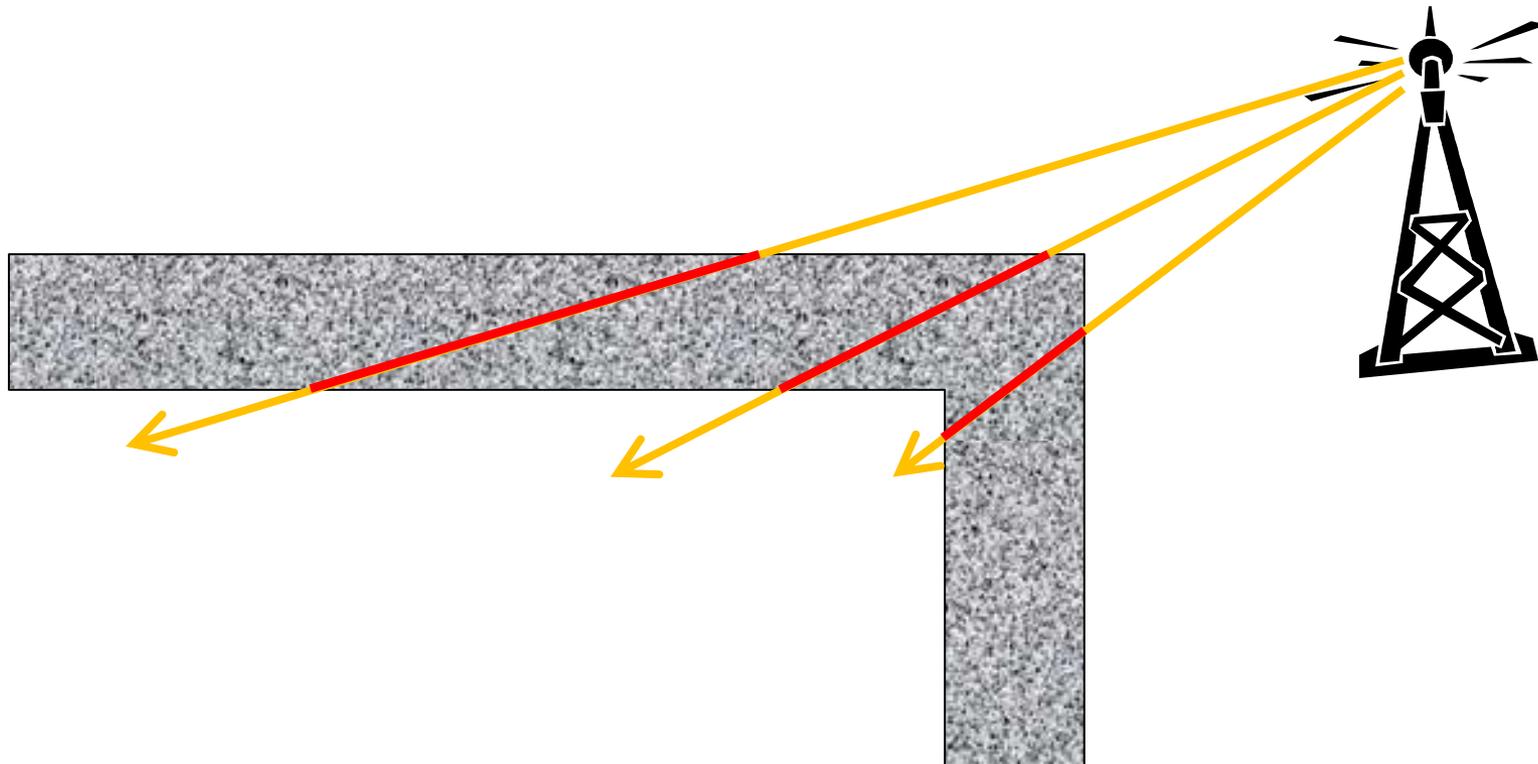


# Outdoors vs. indoors



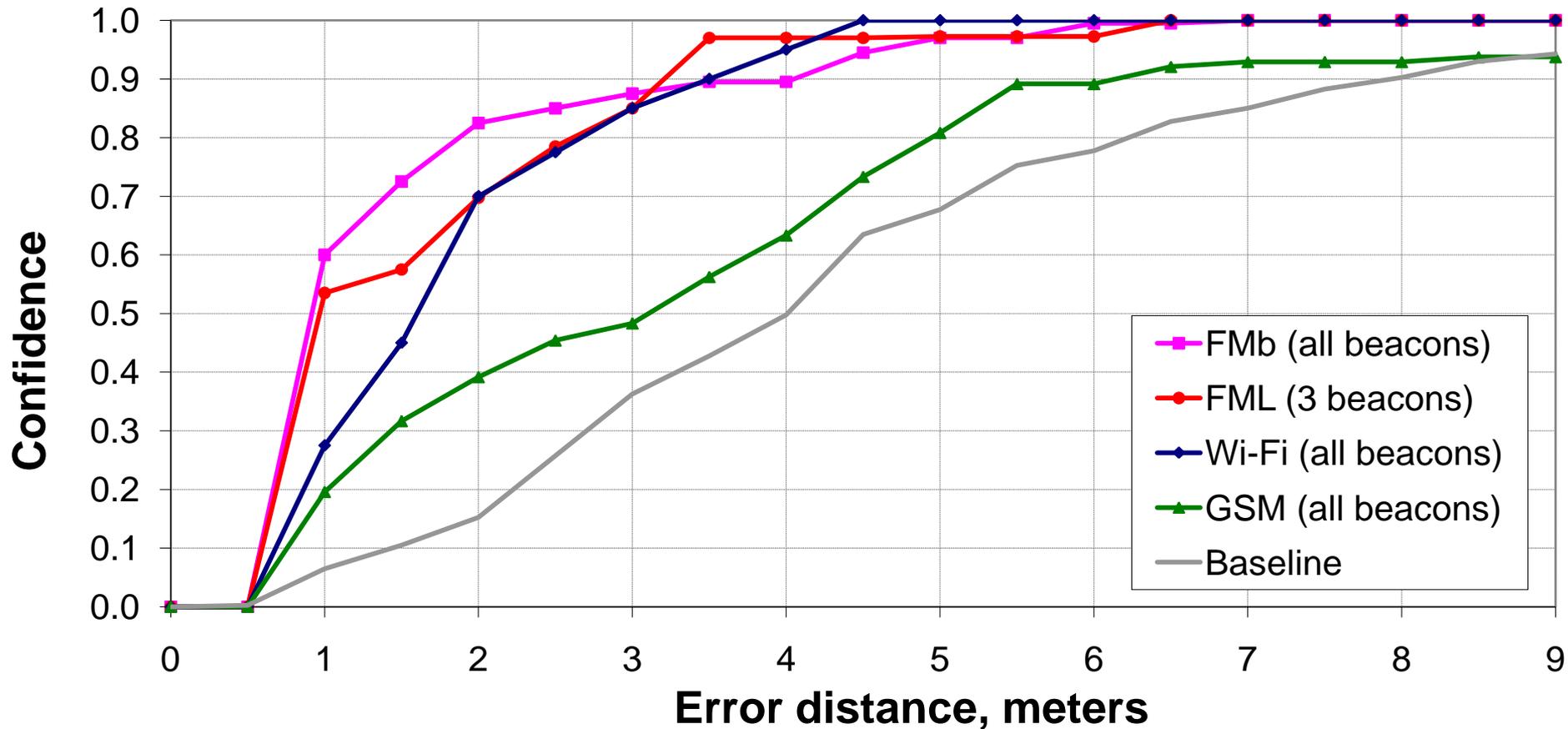


# Indoor obstacles



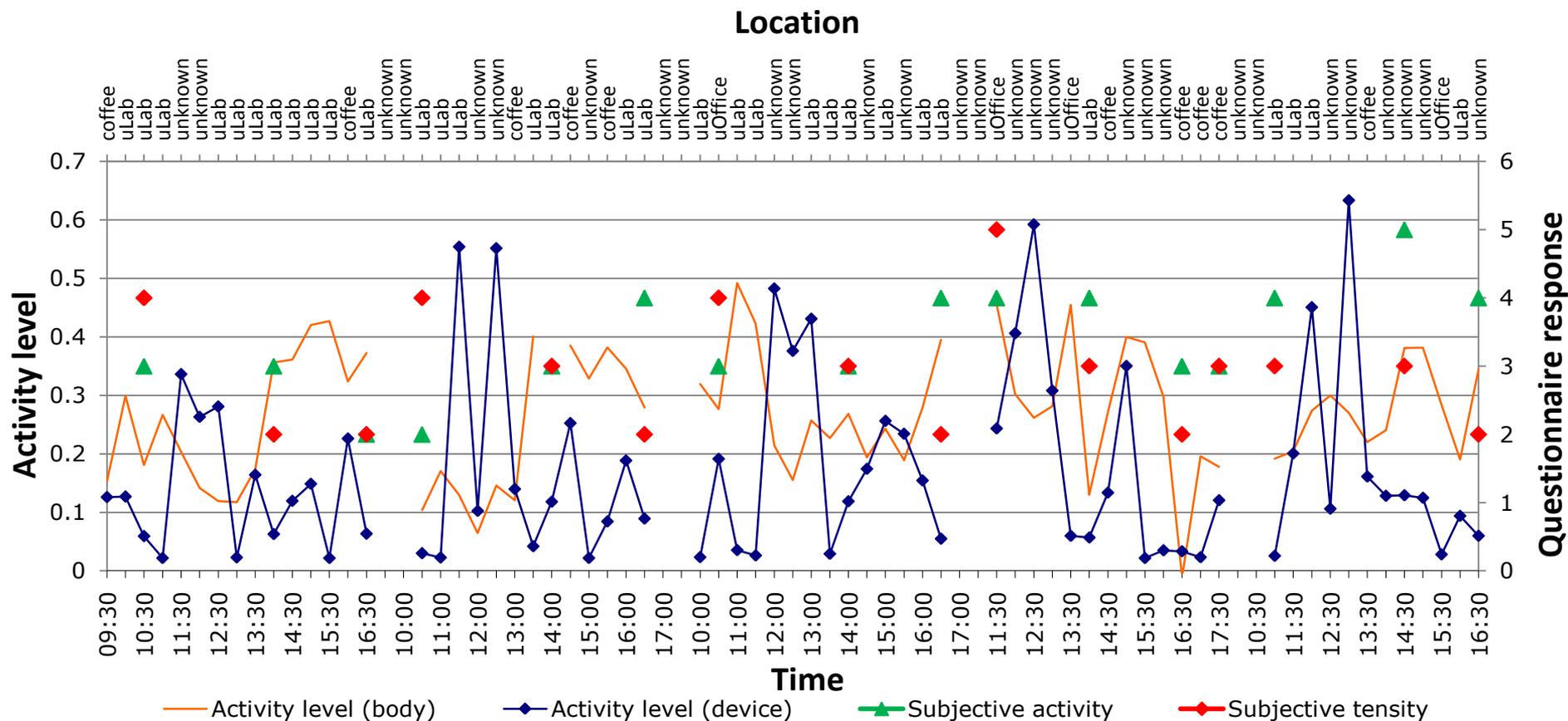


# Localization performance





# Application scenario





# Application scenario

