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Robust Positioning in Indoor Environments

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Why Indoor Positioning?

People spend 87% time indoor:
- Office
- Shopping malls
- Hospitals
- Metros

Location Based Service:
- Security Management
- Intelligent Guidance
- Fire Rescue
- Robot Navigation
- Health care system

What is Robust Positioning?

"The ideal indoor-location technology, then, would be one that required no additional hardware to be installed in buildings or added to mobile phones." *The Economist*

...anywhere, anytime, infrastructure free, global, standardised….

Provide GNSS-like performance in indoor environments.

Positioning Metrics

- Accuracy is a measure of the error, or the deviation of the estimated position from the unknown true position.
- Integrity relates to the level of trust that can be placed in a navigation system. Here, “trust” refers to reliance that gross errors (errors much larger than the accuracy of the system) can be avoided.
- Continuity concerns the reliability of the position outputs of a navigation system. Continuity risk is the probability that the system will stop providing navigation outputs of the specified quality during a given operation or time interval.
- Availability expresses the likelihood that the other three performance parameters previously defined meet the requirements of a particular application.

http://insidegnss.com/auto/sepoct08-gnsssolutions.pdf

Indoor Positioning Technologies

Infrared mobile reader	Audible sound active	Bluetooth	Cellular
Infrared badge	Audible sound passive	ZigBee	TV, FM
Laser (passive)	Audible sound ambient	UWB	Air pressure
Ultrasound passive	Tomographic (water resonance)	Magnetic generated	Inertial
Ultrasound active	Cameras infrastructure	Magnetic ambient	Ambient light
RFID mobile tag	Cameras (portable)	Indoor AGPS, pseudolites	Artificial light (no encoding)
RFID mobile reader	Floor tiles	Wi-Fi	Artificial light (encoded)

Ramon F. Brena, Juan Pablo García-Vázquez, Carlos E. Galván-Tejada, David Muñoz-Rodriguez, Cesar Vargas-Rosales, and James Fangmeyer, Jr., "Evolution of Indoor Positioning Technologies: A Survey," Journal of Sensors, vol. 2017, Article ID 2630413, 21 pages, 2017.

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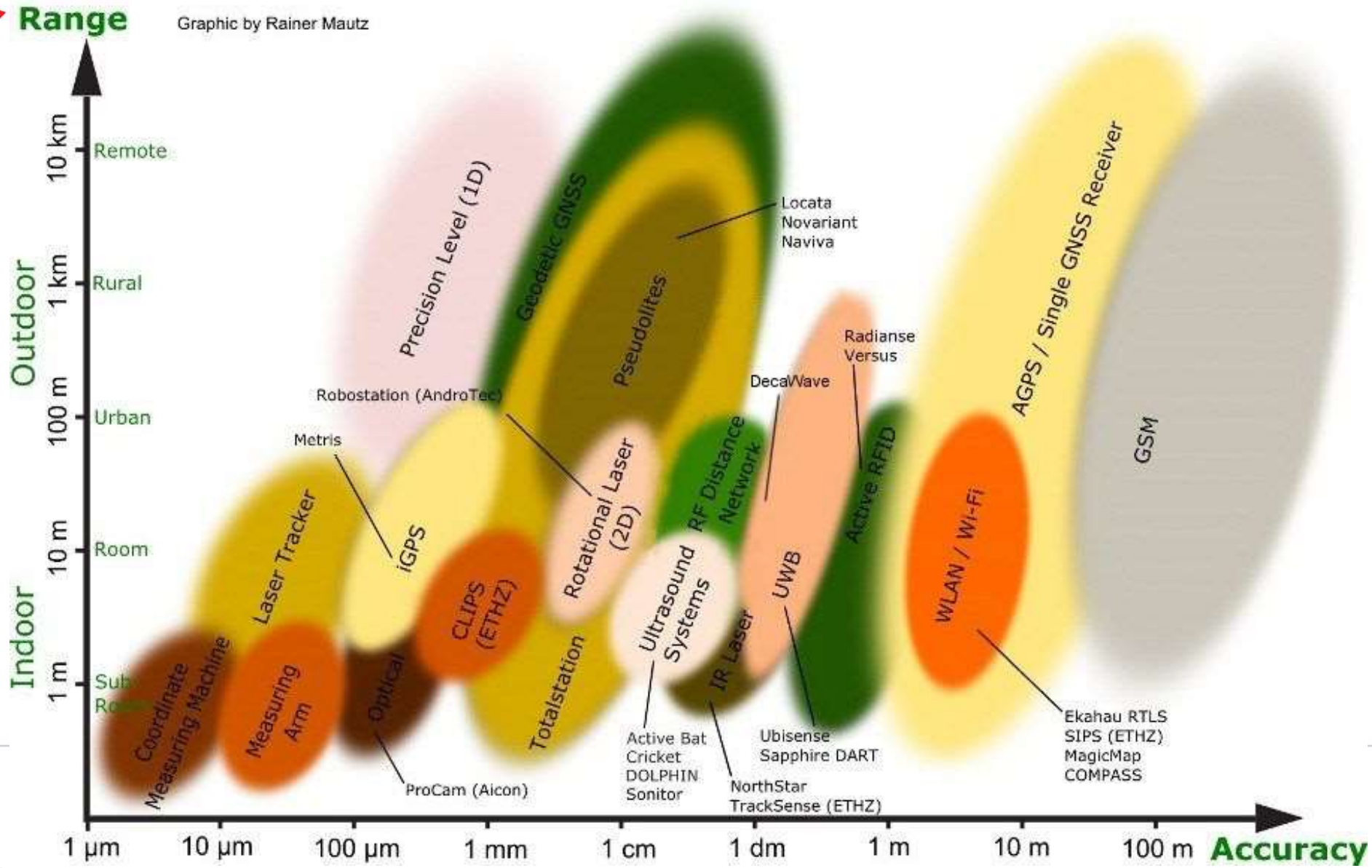
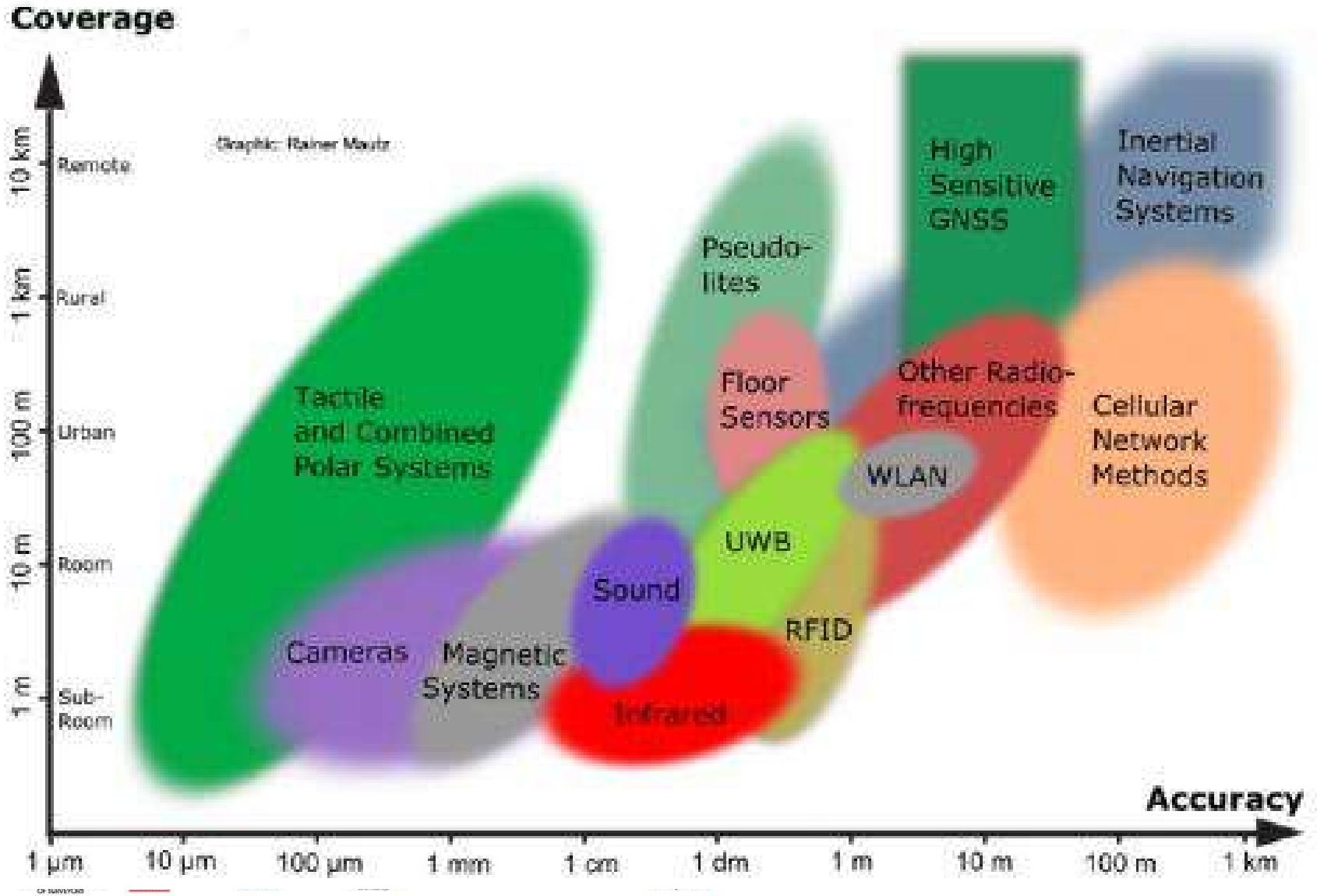

Range
Graphic by Rainer Mautz
Outdoor
Indoor
10 km
1 km
100 m
10 m
1 m
Remote
Rural
Urban
Room
Sub
Precision Level (1D)
Geodetic GNSS
Pseudolites
Locata
Novariant
Naviva
Radianse
Versus
DecaWave
Robostation (AndroTec)
Metris
Laser Tracker
iGPS
CLIPS (ETHZ)
Rotational Laser (2D)
RF Distance Network
Active RFID
AGPS / Single GNSS Receiver
GSM
WLAN / Wi-Fi
UWB
Ultrasound Systems
IR Laser
Totalstation
Coordinate Measuring Machine
Measuring Arm
Optical
ProCam (Aicon)
Active Bat
Cricket
DOLPHIN
Sonitor
NorthStar
TrackSense (ETHZ)
Ubisense
Sapphire DART
Ekahau RTLS
SIPS (ETHZ)
MagicMap
COMPASS
1 µm
10 µm
100 µm
1 mm
1 cm
1 dm
1 m
10 m
100 m
Accuracy


Coverage
Graphic: Rainer Mautz
10 km
Remote
1 km
Rural
100 m
Urban
10 m
Room
1 m
Sub-Room
Tactile and Combined Polar Systems
Pseudo-lites
High Sensitive GNSS
Inertial Navigation Systems
Floor Sensors
Other Radio-frequencies
Cellular Network Methods
WLAN
UWB
Sound
RFID
Cameras
Magnetic Systems
Infrared
Accuracy
1 µm
10 µm
100 µm
1 mm
1 cm
1 dm
1 m
10 m
100 m
1 km

Classification (i)

- Designated infrastructure-based positioning technologies
  - Infrared, ultrasonic signals, Bluetooth, ZigBee, RFID, UWB or other RF-Based systems
- Signals-of-opportunity
  - RF signals not intended for positioning, such as Wi-Fi, digital television, mobile telephony, FM radios and others
- Technologies not based on signals
  - Dead reckoning (DR) using inertial sensors
  - Vision/camera systems

Classification (ii)

i. Radio Frequency Signals (RF).
   - A very generic term related to the frequency of radio signals, used in many popular communication protocols such as Wi-Fi and Bluetooth.

ii. Light.
   - Both visible and infrared light. Although this is an electromagnetic signal just as the RF signals, the associated technologies are quite dissimilar.

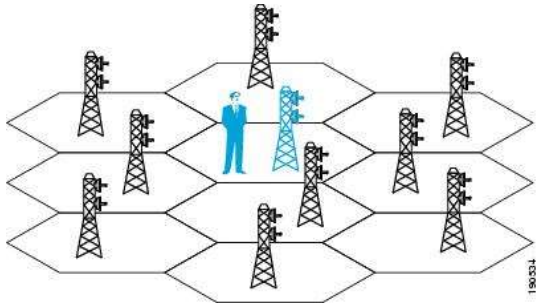
iii. Sound.
   - Both audible and ultrasonic.

iv. Magnetic Fields.
   - Both natural Earth's magnetic field, along with its irregularities, and artificially produced magnetic fields.

Classification(iii)

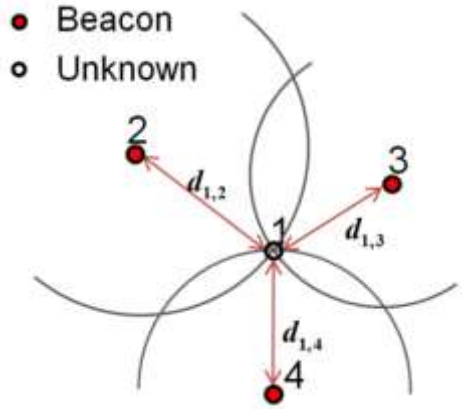
i. Cell-based positioning – Cell-of Orgin CoO

- Simplest and most straight forward technique. Mobile positioning technique for finding the basic geographical coverage unit.



ii. Angulation.

- Angle of Arrival AoA measurements.

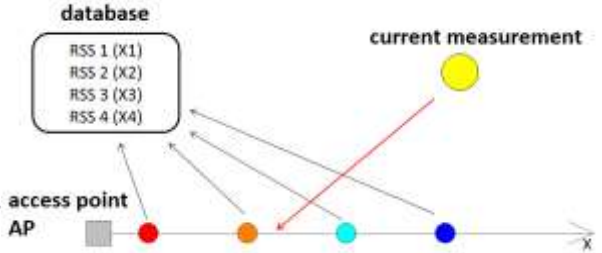


iii. Lateration.

- Time of Arrival ToA measurements. RSS-based techniqu employ path loss models for range conversion

iv. Fingerprinting.

- Training and positioning phase



Accuracy

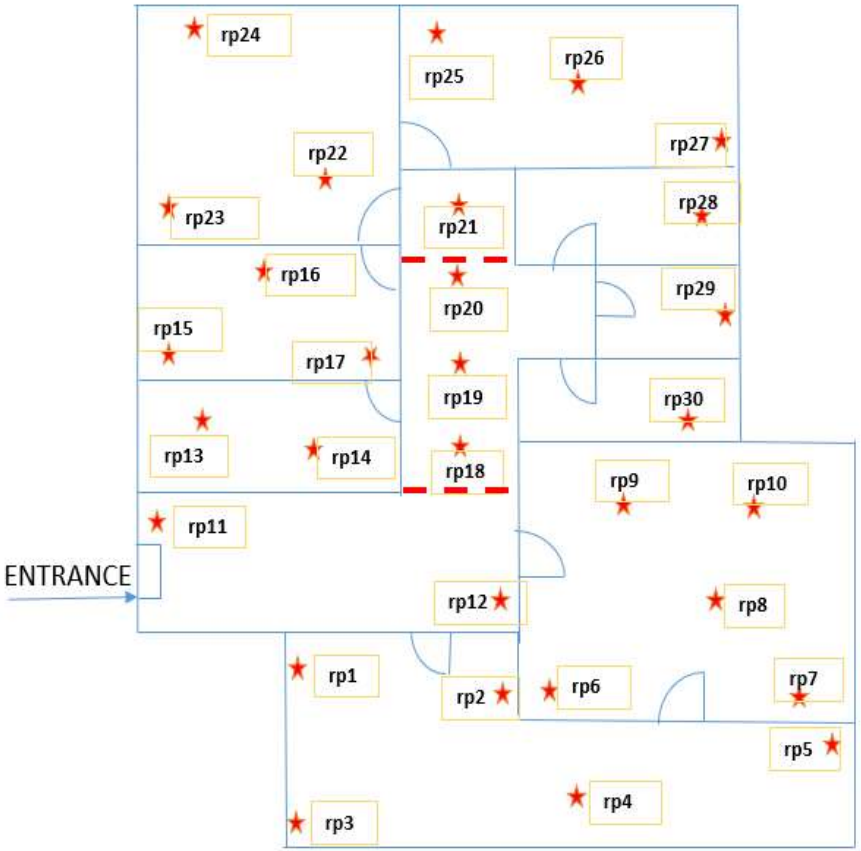
Method	Accuracy	Advantage	Disadvantage
COO	depending on cell size	simple algorithm	discrete positions; a large number of devices are required
Lateration	dm - m	continuous positioning; no training phase required	at least 3 receivers are required; poor accuracy may occur, caused by environmental effects
Fingerprinting	several m	continuous positioning; environmental effects are considered in training phase	poor accuracy in dynamic environments

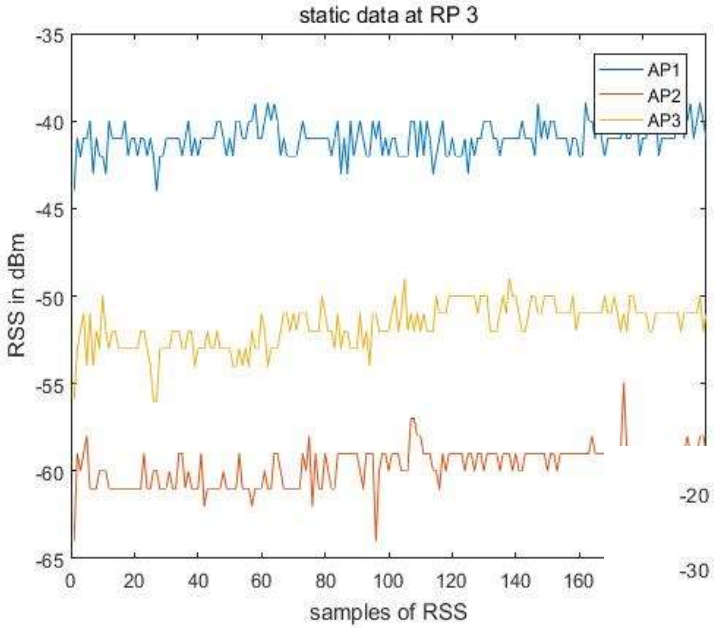
Environment, application….

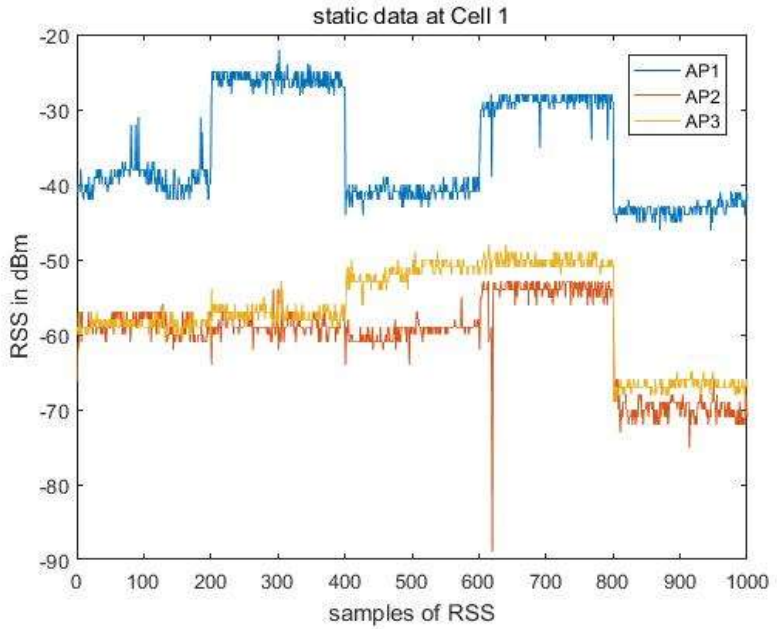
Fusion Algorithms

- Measurement
  - Infrared, ultrasonic signals, Bluetooth, ZigBee, RFID, UWB or other RF-Based systems
- Range determination
- Position estimation

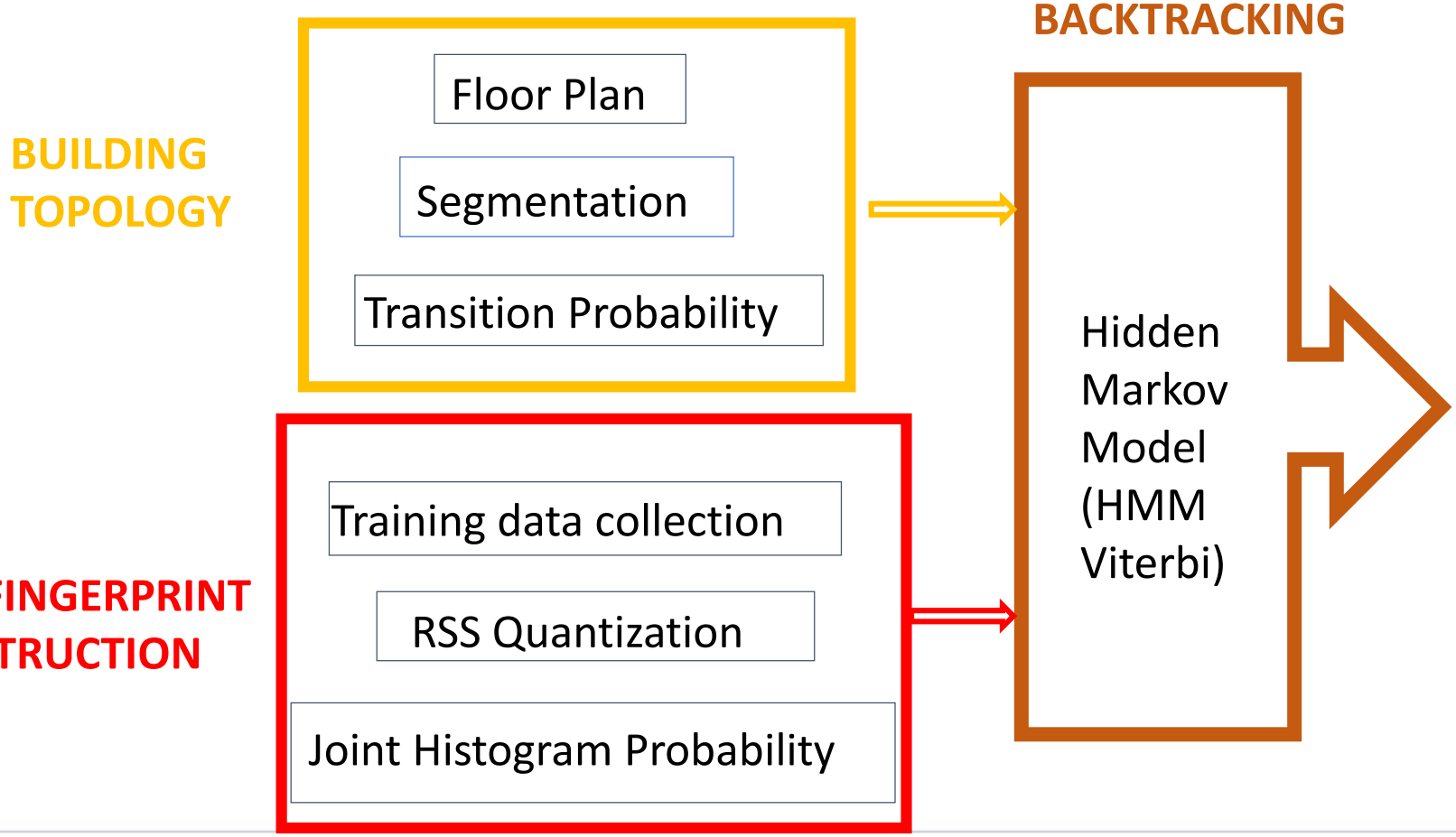
Example 1



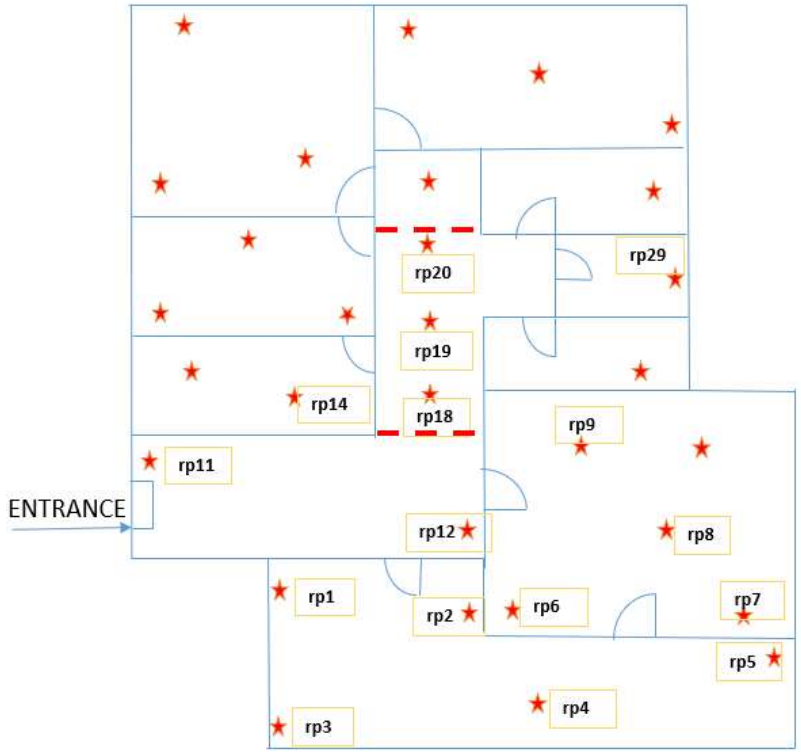




Example 1


TRAJECTORY BACKTRACKING
BUILDING TOPOLOGY
Floor Plan
Segmentation
Transition Probability
CELL FINGERPRINT CONSTRUCTION
Training data collection
RSS Quantization
Joint Histogram Probability
Hidden Markov Model (HMM Viterbi)

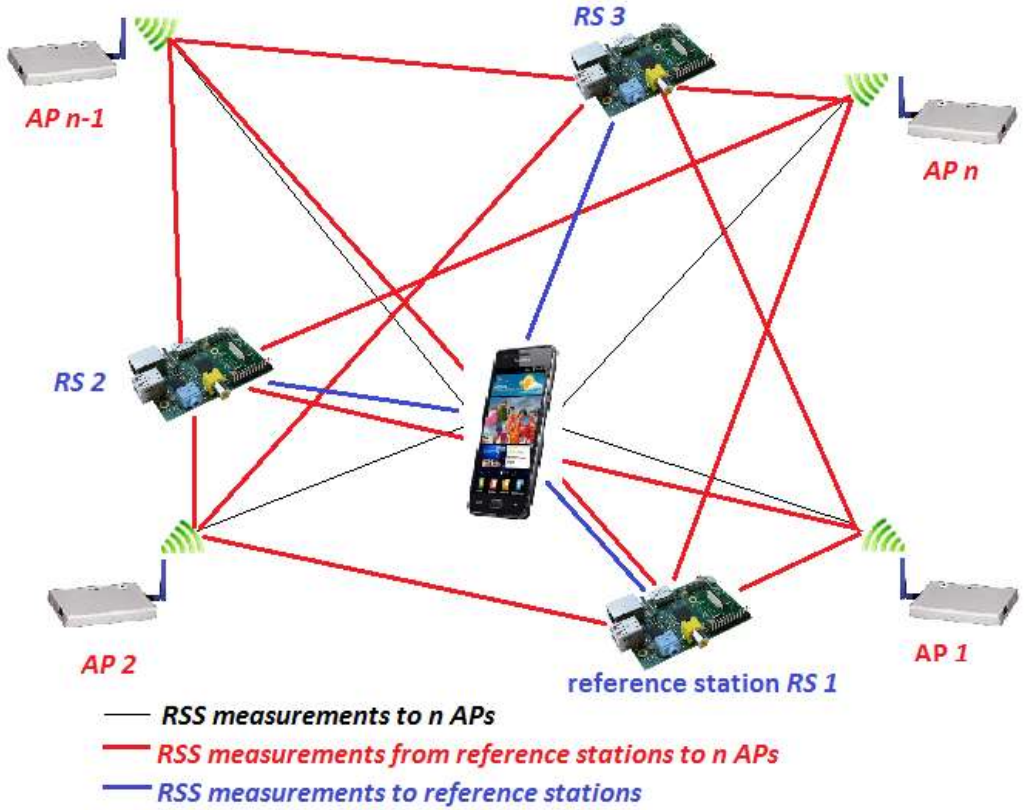
Example 1

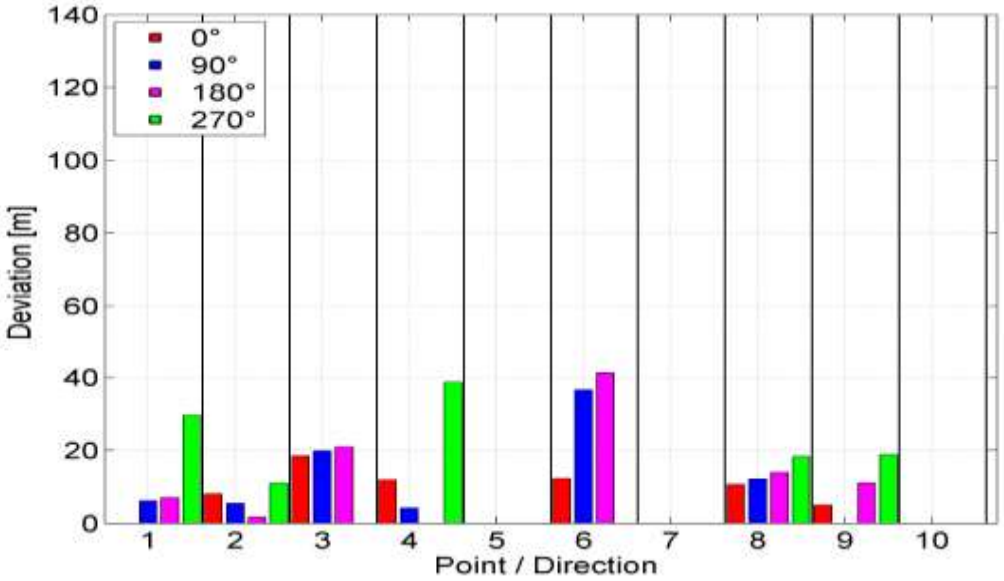


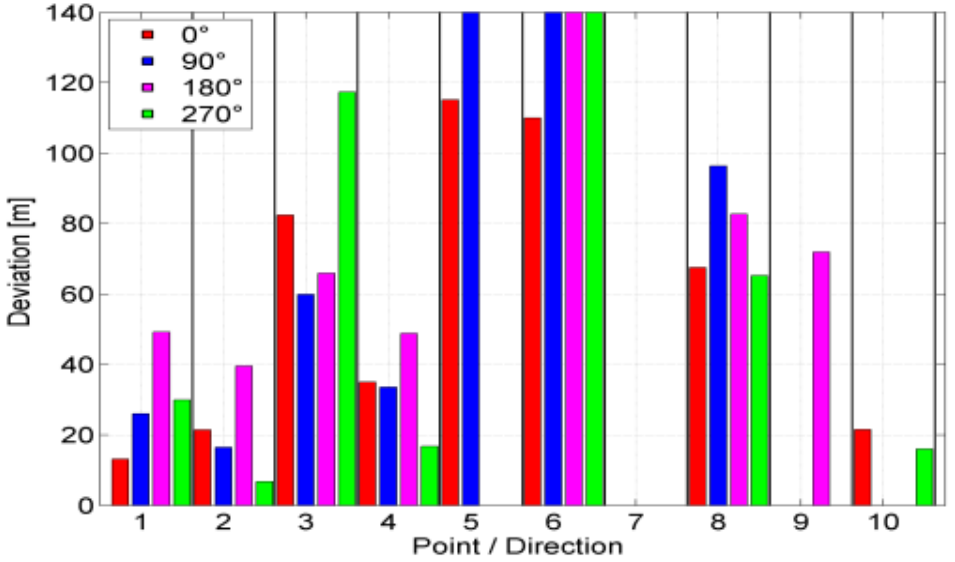
Bin number	Trajectory	Cell number covered	RP number in total	Mean matching accuracy
11	1	6	20	94.30%
	2	10	25	93.20%
	3	10	32	96.88%
	4	12	30	95.00%
	5	6	19	91.58%
	6	12	28	87.21%

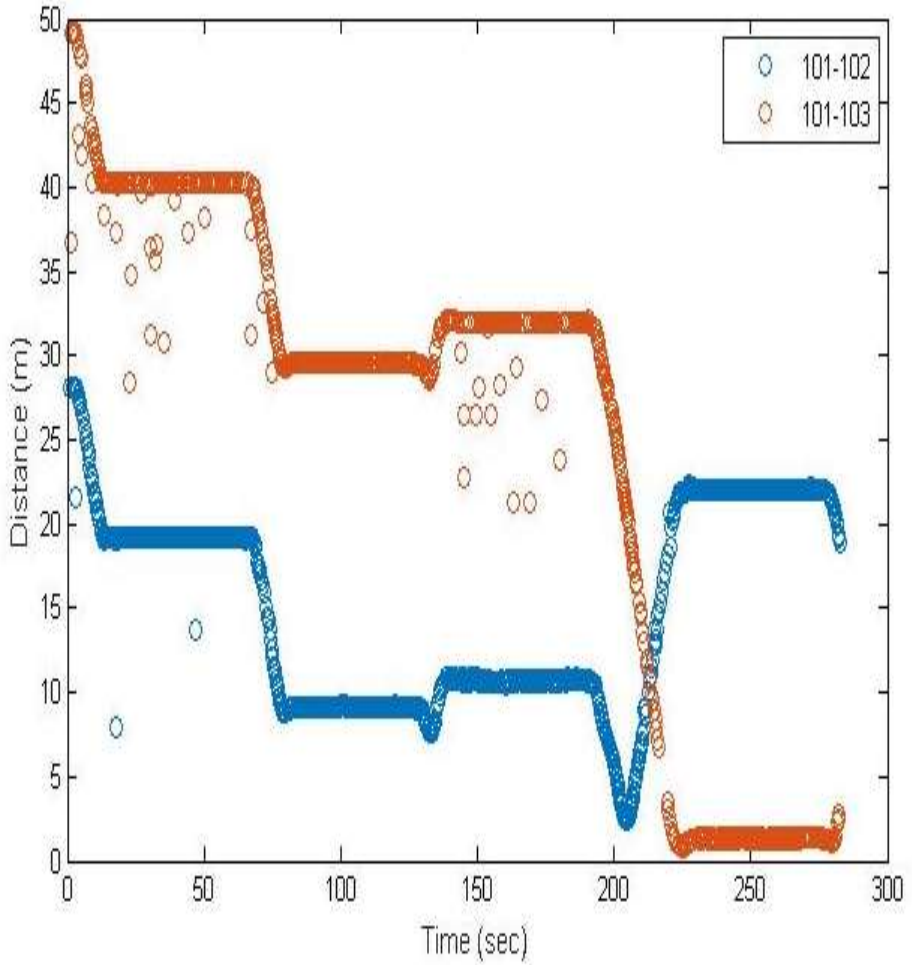
Example 2

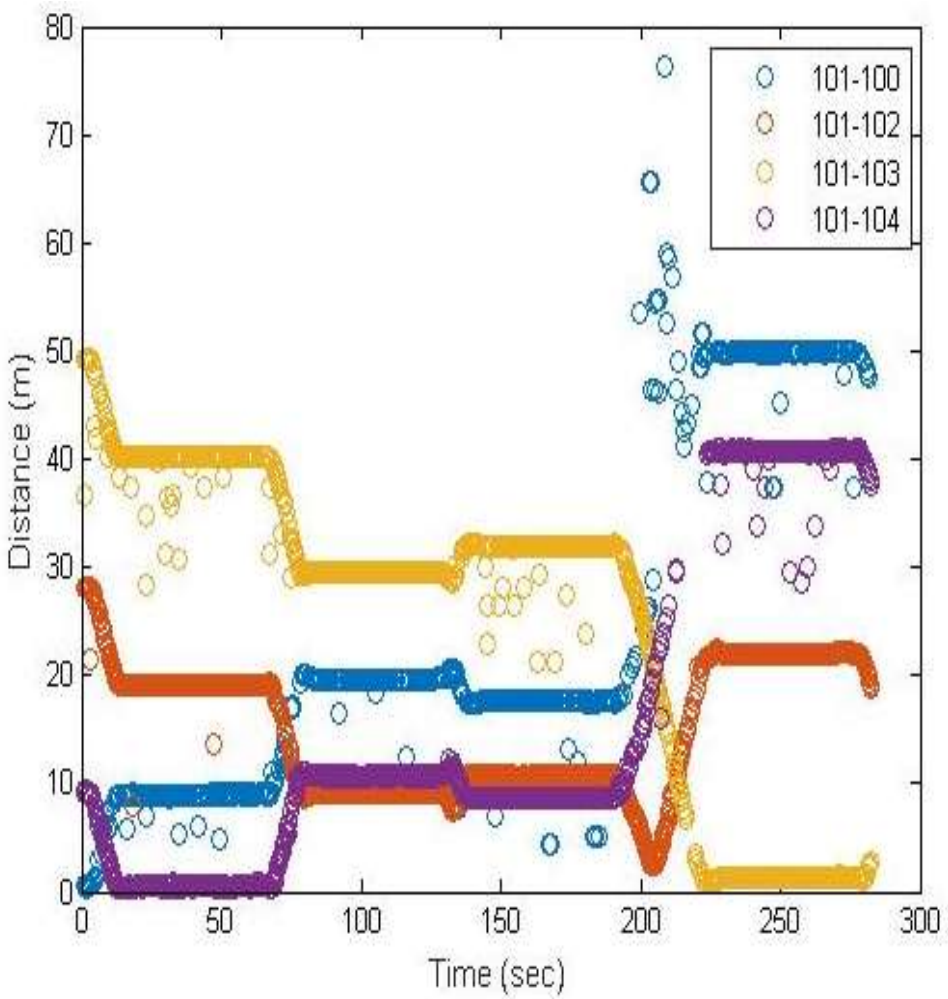
Differential Wi-Fi (DWi-Fi)



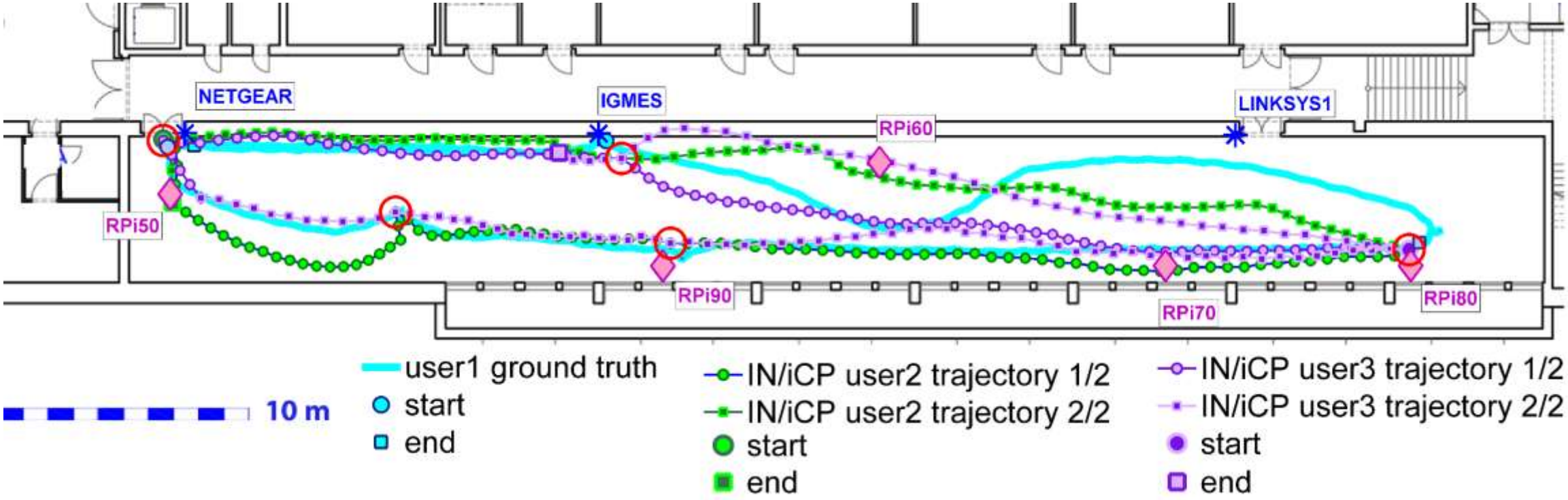





101-102
101-103
Distance (m)
Time (sec)
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300


101-100
101-102
101-103
101-104
Distance (m)
Time (sec)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300

Cooperative Positioning



Conclusions

- Delivering robust positioning metrics in indoor environments remain a challenge.
- Like GNSS, individual indoor positioning technologies have inherent strengths and weaknesses.
- Algorithms need to be responsive to changes in the environment.
- My proposal: redefine the concept of what is uboquitous positioning and focus on selecting the best measurememnts to provide the best metrics for the applications. Focus on identifying changes in state as well as implementing constraints.
- ONLY robust algorithms will give principled and robust solutions.