Hospital Indoor Localization & Behavior Analysis

USE CASE – V1.

1. Context (Project Background & Current Uncertainties)

Focuses on indoor localization and behavior analysis based on localization within hospital environments.

Indoor spaces, especially hospitals, are highly dynamic IoT environments where location awareness is essential. GPS is unavailable indoors, therefore a dedicated Indoor Positioning System (IPS) is required.

Behavior analysis relies on accurate position and movement data. Most medical activities involve spatial context - patient monitoring, staff dispatching, equipment allocation, and emergency responses which require *real-time* and *room-level* positioning accuracy.

Hospital radio environments are highly unstable due to:

- frequent movement of metallic medical devices
- human crowds in corridors
- door openings, bed movements, and staff traffic

These factors introduce severe multipath, fading, and RSSI fluctuations, making hospital localization more challenging than offices or malls.

The final use case has not been confirmed yet, including:

1.1 Target Subjects

- Patients?
- Healthcare staff?
- Mobile medical equipment?

1.2 Spatial Scope

- Single floor? Multi-floor?
- single building? Multi building?

1.3 Behavior Analysis Scope

- Behavior pattern recognition?
- Risk-event detection?
- Workflow analysis?
- Equipment usage behavior?

1.4 Allowed Sensors

- Not interfere with medical devices
- Not be strongly affected by medical devices
- Comply with privacy & ethics standards

2. Potential Application Scenarios

2.1 Patient-Related Scenarios

2.1.1Patient activities

- Room → corridor → public area paths
- Activity frequency, speed, dwell points

2.1.2Risk Event Detection

- Falls
- Entering restricted areas (ICU, operating room, isolation areas)

2.2 Healthcare Staff Scenarios

- Rounding paths
- Workload & crowded areas
- Process optimization

2.3 Mobile Medical Equipment Scenarios

- Mobility of hospital beds/wheelchairs/and other equipment
- Usage frequency

3. Sensor Categories & Comparison

Sensor	Principle	Data	Relevant	Considerations
Wi-Fi RSSI	Wi-Fi signal strength attenuates with distance, obstacles, and multipath. Localization uses RSSI pattern matching or path-loss models.	RSSI values	Use existing AP infrastructure; no deployment needed; suitable for coarse localization and area-level behavior patterns.	high interference, limited accuracy.
BLE	Broadcasts low-energy BLE packets; RSSI decreases with distance at the receiver.	RSSI beacon sequences	Easy to deploy and low-cost; works well for path tracking and dwell-time analysis.	requires beacon deployment; sensitive to environment.
UWB	Uses time-of-flight or two-way ranging of ultra-wideband pulses for high-precision distance/position.	Ranging distance / XYZ position	Essential for high-precision trajectories and cross-room behavior analysis.	expensive; requires approval; deployment complexity.
IMU	Measures 3-axis acceleration and angular velocity; enables motion	3-axis acceleration	Key for behavior detection (falls..)	wearable required; patient consent needed

POSITIONING TECHNIQUE COMPARISONS

Technique	Technology	Accuracy	Computation	Latency	Synchronization	Implementation
ToA	UWB	A few to tens of centimeters	Medium	Hard Realtime	Yes	LoS is required
TDoA	UWB	A few to tens of centimeters	Medium	Hard Realtime	Yes	Larger bandwidth and easier than ToA
RTT	UWB	A few centimeters	Medium	Hard Realtime	No	Higher delay in UWB
PoA	RFID	Tens of centimeter to a few meters	High	Soft Realtime	Yes	LoS is required for high accuracy, use as supplementary method
RSSI	BLE	Tens of centimeters to a few meters	Low	Hard Realtime	No	Prone to multi-path, environmental noise, inexpensive but labor intensive in wide areas
CSI	WiFi	Tens of centimeters with several APs	Medium	Hard Realtime	No	Labor-intensive site survey calibration
PSRP - PSRQ	Cellular	A few meters	High	Soft Realtime	No	Need Cellular
AoA	BLE 5.1	A few meters to tens of centimeter	High	Soft Realtime	No	Fewer nodes is required, not accurate in long distance and NLoS and few practical use cases

3.1 Distance-based Methods（ToA / TDoA / RTT）

- Used in UWB
- High accuracy (cm-level)

- Requires synchronization (ToA/TDoA)
- Infrastructure cost high → often used for equipment tracking

3.2 Angle-based Methods（AoA）

- Provides angle information
- Requires antenna arrays
- BLE 5.1 supports AoA
- Deployment cost high → limited use in hospitals

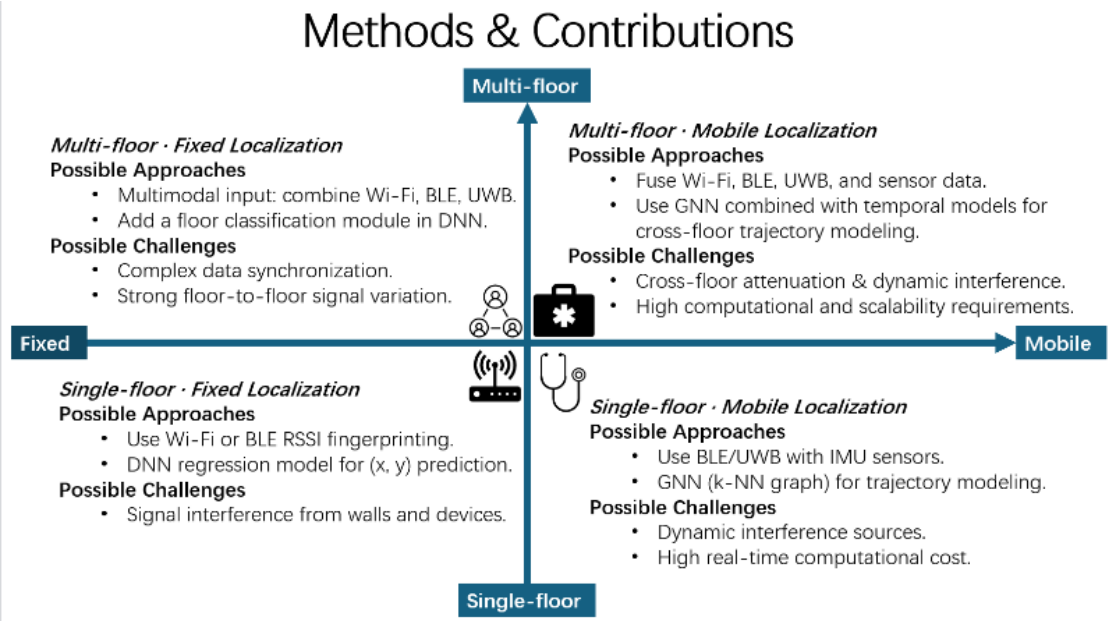
3.3 Fingerprinting (RSSI-based)

- Low-cost, widely used in hospitals
- No special hardwar
- Highly unstable due to multipath
- Requires offline survey → may be costly

3.4 Proximity (BLE beacon)

- Room-level localization
- Useful for geofencing (ICU alarms)
- Not accurate enough for movement trajectory

4. Possible Technical Directions



4.1 Single-floor Mobile Localization + Behavior Analysis

- BLE/UWB + IMU fusion
- RSSI-based temporal regression
- GNN (k-NN graph) trajectory modeling

4.2 Multi-floor Localization + Behavior Analysis

- Multi-modal fusion
- Spatiotemporal modeling
- Floor-transition attenuation modeling

4.3 Fusion-based Localization

- RSSI + IMU
- RSSI + proximity
- UWB + WiFi fallback
- Temporal smoothing (Kalman/particle filtering)

5. Data Types

5.1 Hospital provides (to be confirmed)

- Equipment movement
- Access control information
- Daily activity logs
- Building/floor identifiers
- Room/zone topology
- Floor plan constraints (walls, materials)

5.2 Data to collect (needs approval)

- Wi-Fi/BLE RSSI sequences
  - RSSI vectors
  - RSS time-series
  - Channel State Information (CSI)
  - Link quality indicators

    - Access Point metadata (SSID/BSSID, channel, floor tags)
- UWB trajectory points
- IMU 3-axis acceleration
- Behavior event labels
- Multi-AP transitions

6. Medical Environment Constraints

- wear devices?
- deployment requires approval
- complex radio environment
- behavior labeling need help
- multipath caused by metallic medical instruments
- human body shadowing
- signal absorption by medical liquids or equipment
- high-density AP deployment causing interference

7. Questions for Next Meeting

- Who are the target subjects? (equipment / staff / patients)
- What is the study area? (areas / floors / buildings)
- What level of accuracy is needed by the hospital? (room-level/bed-level)
- What anonymized data can the hospital provide?
- Real-time latency? (seconds/minutes)
- How can I obtain the devices?
- What time periods are allowed for data collection, and for how long?
- Which behaviors are most important to the hospital? Do you need visualized results?
- Is ethical/IRB approval required? How long will it take?