Application for the Doctoral Contract 2025

Indoor Localization System for Patient Behavior Analysis in the Context of Connected Healthcare

Ph.D. Candidate:

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Pr. Huaqiong Li	UCAS

11 / 09 / 2025

Outline

Personal

- Academic Background
- Research Experience
- Graduation Internship

Research

- Research Context
- Research Objectives
- Challenges
- Roadmap

Summary

- PhD Timeline
- Key Strengths
- Research Fit

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Academic Background

Engineering Diploma in Wireless Communication & IoT Systems   2022-2025

ISEP – École d'ingénieurs du numérique, Paris, France

- IoT & Wireless Networking, AI/ML for communications, Wi-Fi Systems, Embedded Sensors

Bachelor's Degree in Computer Science   2018-2022

- *With Honors (Mention Très Bien)*

Université Clermont Auvergne, Clermont-Ferrand, France

- Machine Learning, Signal Processing, Programming, Path Recognition, Sensor Integration

Research Experience

1. **Performance Evaluation of Wi-Fi Networks with TDMA Coexisting with CSMA/CA**

   Xiaofan Guo et al. *Wireless Personal Communications*, Springer, 2020
   - Introduced TDMA into Wi-Fi to enhance real-time performance and reliability.
   - Results: **Reduced delay**, **improved reliability** with minimal impact on CSMA/CA throughput.

2. **Indoor Localization in IoT Networks Based on Graph Neural Networks**

   Xiaofan Guo, Wafa Njima. *Article under preparation*, 2025
   - Comparative study : Graph Neural Networks (GNNs) vs Deep Neural Networks (DNNs) for fingerprinting-based indoor localization.
   - Results: GNN achieved lower localization error and faster runtime, showing greater robustness.

Graduation Internship

Energy Optimization in 5G Core Networks – Orange Innovation (24 Mar – 22 Sep 2025)

Objective

- Analyze and optimize the energy consumption of open-source 5G cores (free5GC vs OAI).

Key Findings

- Contrary to theoretical expectations, OAI consumed more energy than free5GC.

- Frequent **heartbeat signaling** identified as the main cause of high energy consumption.

Results

1. Extending heartbeat **reduced OAI's energy consumption** without affecting stability.

2. Findings were integrated into Orange's AI assistant to guide future deployments.

Figure1 Testbed Architecture for 5GC
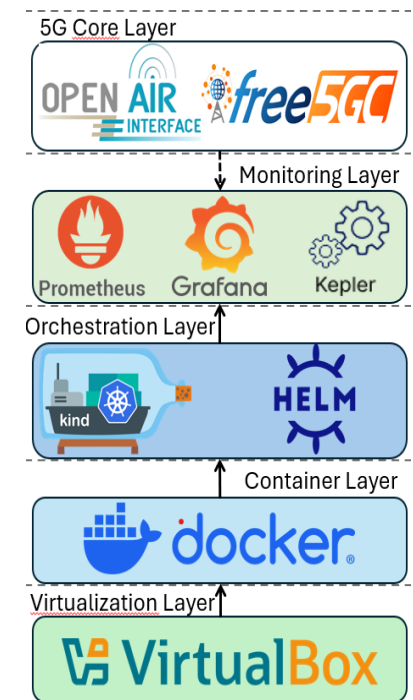
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Research Context

Hospital Needs

- Accurate Indoor Localization
- Behavior Analysis
- Operational Efficiency
- Patient Safety & Quality of Care

Limitations Current Methods

- Low accuracy in indoor positioning
- Limited behavior analysis
- Lack of integration

Figure2: Indoor Tracking of Patients in a Hospital

Ref-1: Bibbò L., Carotenuto R., Della Corte F. (2022). An overview of indoor localization system for human activity recognition in healthcare. Sensors, 22(21):8119.
Ref-2: Figure2 Source: J. Lachmann, Indoor Tracking of Patients in Hospitals, July 12, 2018.

Research Objective

🎯 Objectives
Enable real-time localization, monitoring, and behavior analysis

⚙ Solution
Develop a multimodal indoor localization system for hospitals with integrated behavior analysis

🔍 Hight Constraint
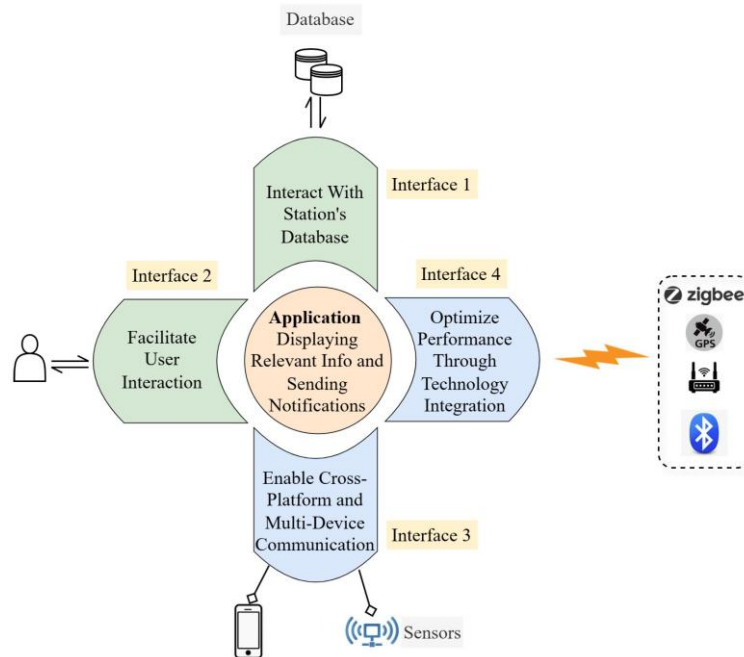Reliable behavior analysis; Achieve a balance between accuracy, latency, and energy efficiency

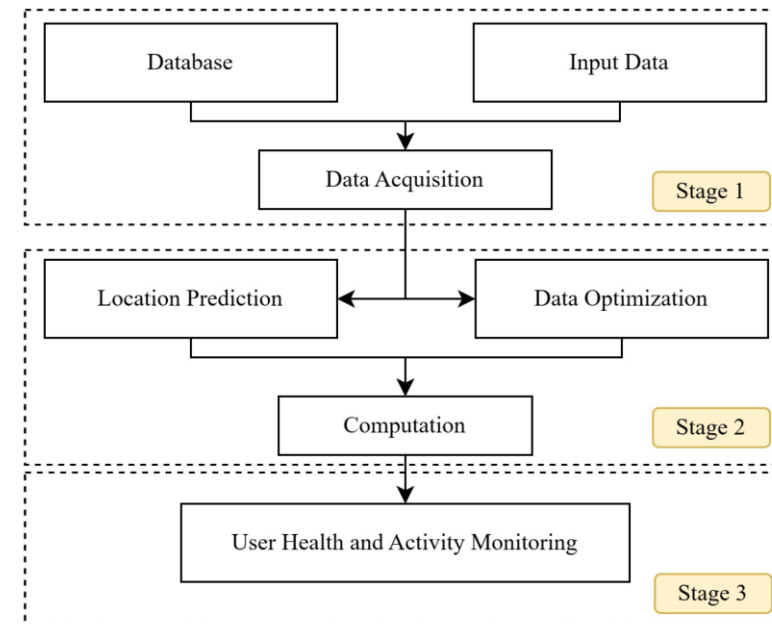Figure3: System architecture of BLE-based indoor localization

Figure4: Tracking workflow for patients and staff in healthcare settings

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Ref-3: T. Aziz and I. Koo, *"A comprehensive review of indoor localization techniques and applications in various sectors,"* Applied Sciences, vol. 15, no. 3, p. 1544, 2025.
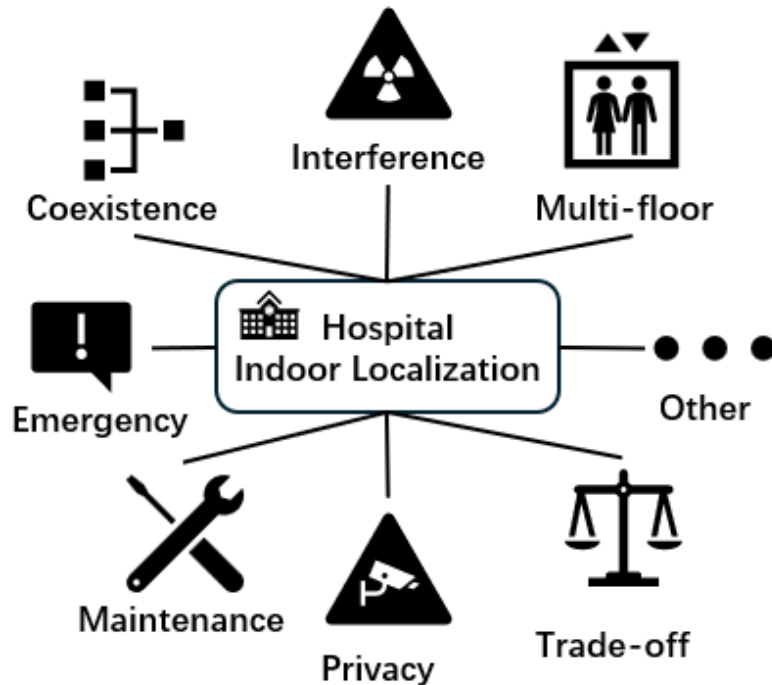
Challenges

Technical Challenges

- Multi-technology coexistence
- Dynamic and complex hospital environments
- Multi-floor & 3D localization
- Accuracy–latency–energy trade-off
- Reliable behavior recognition across heterogeneous sensor data

Operational Challenges

- Frequent calibration and database updates
- Scalability & robustness in large hospitals
- Seamless integration with existing IT systems

Security & Safety Challenges

- Protecting patient privacy
- Ensuring reliability in emergencies
- Ethical management of behavior-related data

Ref-4: T. Aziz and I. Koo, "A comprehensive review of indoor localization techniques and applications in various sectors," Applied Sciences, vol. 15, no. 3, p. 1544, 2025.
Ref-5: A. Sesyuk, S. Ioannou, and M. Raspopoulos, "A survey of 3D indoor localization systems and technologies," Sensors, vol. 22, no. 23, p. 9380, Dec. 2022.

Proposed Roadmap

Step 1 – Define Scenarios, metrics and sensors

Step 2 – Collect Data ← **Data Fusion and IT Integration**

Step 3 – Transfer / Modeling ← **AI and ML advanced methods**

Step 4 –Data Analysis ← **Evaluation and Insights**

Step 5 – Validation and Deployment

Build an intelligent healthcare indoor localization system with behavior analysis

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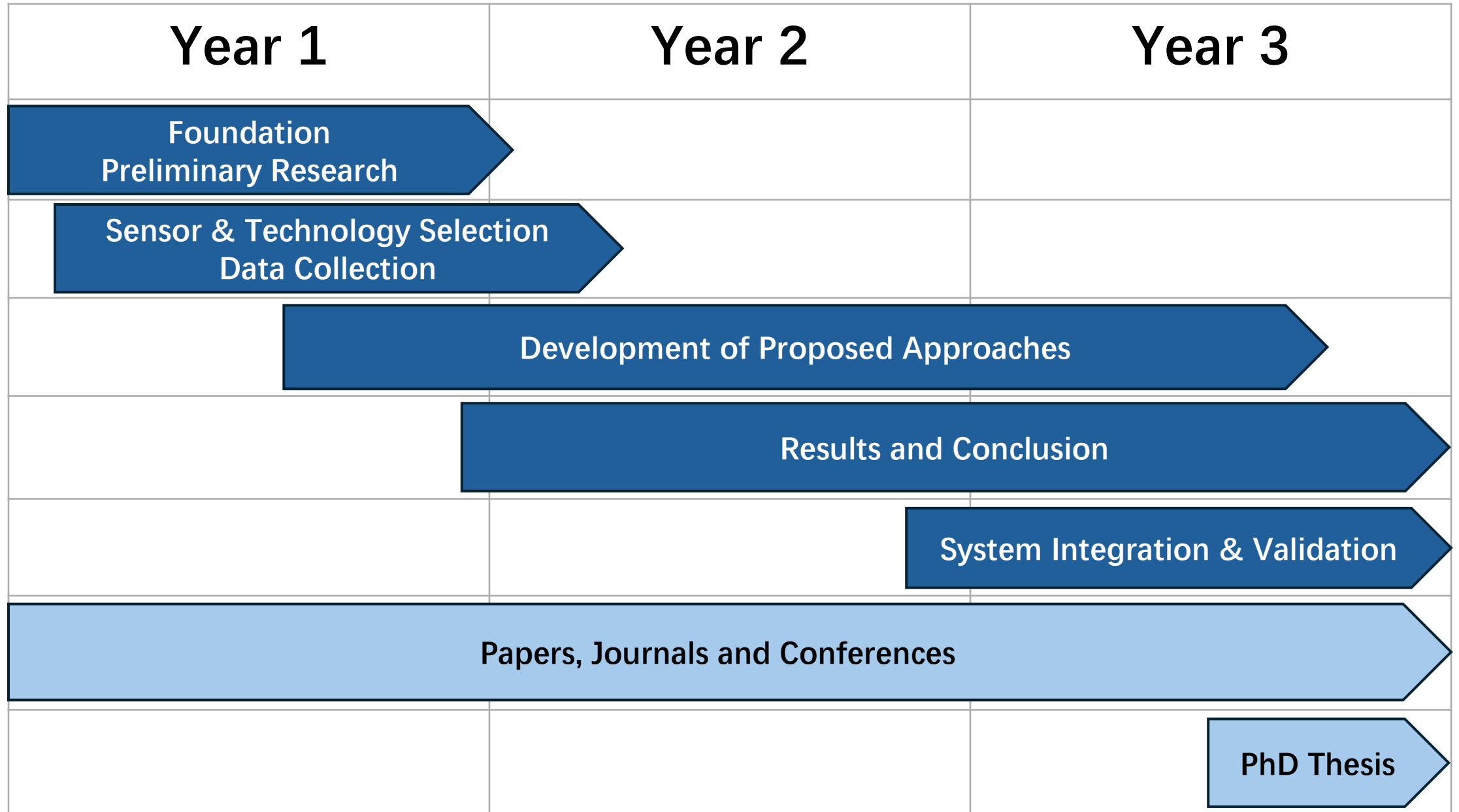
Key Strengths

Wireless & IoT	· Wi-Fi, 5G Core; Indoor Localization, Energy-efficient Systems
AI & Data	· DNN / GNN; Data modelling; Matlab-Signal processing; Python
Hardware & Sensors	· IoT devices; Health Data (temperature, fall detection)
Research & Innovation	· Publications; Problem-solving; Experimentation Skills
Collaboration	· Multilingual (EN/FR/中文); Academic & Industrial Teamwork
Soft Skills	· Analysis; Taste for Innovation, Research and Challenges

Research Fit

Orange Internship
- Reduce 5GC energy

Final Year Project
- Indoor localization

Wearable Sensors
- Health monitoring system

Multilingual
- EN, FR, 中

Energy-Efficiency   Localization   Healthcare   Collaboration

Indoor Localization System for Patient Behavior Analysis in the Context of Connected Healthcare

Behavior Analysis   Integrated   Incentive

Undergraduate Projects
- Path & image recognition

Interdisciplinary
- AI, Wireless, IoT, Healthcare, Energy Efficiency, Signal

Motivation
- Strong interest in Wireless & IoT and Research

Thank you for your attention.

I would be happy to answer any questions.

Appendix

1. Research Experience-Published Article

2. Research Experience-Article Under Preparation

3. Graduation Internship

4. Methods & Contributions

5. Future Goals

Research Experience-Published Article

Performance Evaluation of the Networks with Wi-Fi based TDMA Coexisting with CSMA/CA

Wireless Personal Communications, Springer, 2020

➢ **Objective**:
- Introduce TDMA (Time Division Multiple Access) into Wi-Fi to improve real-time performance and reliability when coexisting with CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)

➢ **Method**:
1. **Canceling Carrier Sensing**: TDMA devices transmit directly in allocated slots without checking channel availability.
2. **Priority Mechanism**: TDMA devices gain priority over CSMA/CA devices on the shared channel.
3. **Collision Handling**: TDMA devices immediately retransmit data until an ACK is received, ensuring reliability.

➢ **Result**:
- The TDMA mechanism significantly reduced delay for real-time applications and improved reliability through retransmissions.
- As frame length and duty cycle increased, CSMA/CA throughput slightly decreased but the impact remained manageable.
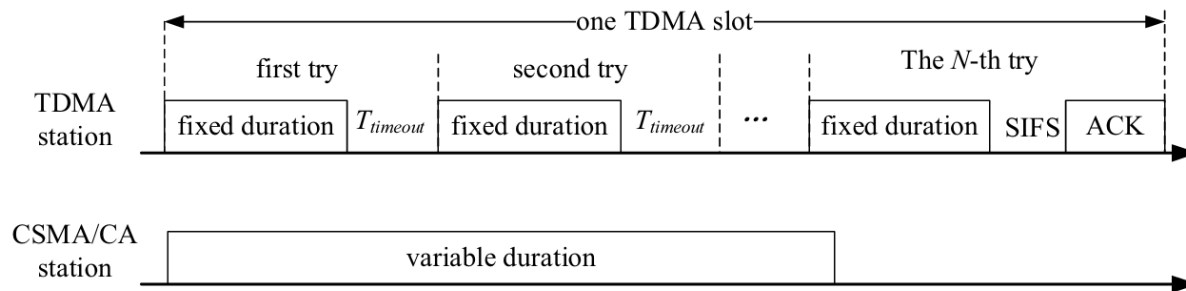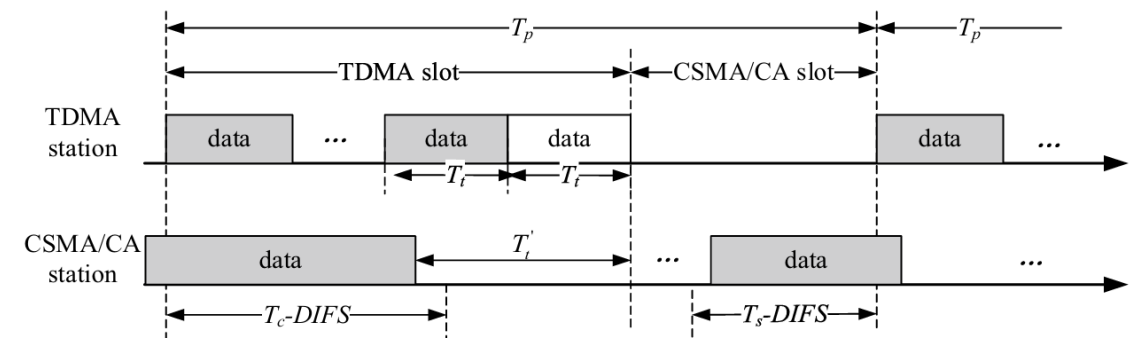

Fig. 2 Preemptive TDMA scheme

Fig. 4 The interference a CSMA/CA frame suffered from the Wi-Fi TDMA station

Research Experience-Article Under Preparation

Indoor Localization in IoT Networks Based on Graph Neural Networks

2025

➢ **Objective**:
- Compare the performance of DNN and GNN in Wi-Fi RSSI fingerprint-based localization, Including predictions for longitude, latitude, floor and predicted time.

➢ **Method**:
1. **DNN Encoder–Decoder**: Built an encoder–decoder baseline model with multi-task regression to jointly predict.
2. **GNN with k-NN Graphs**: Constructed graphs using k-NN and applied GCN layers with message passing to capture spatial topology.
3. **Evaluation Metrics**: valuated models by comparing hidden layer configurations, localization error, and runtime performance.

➢ **Result**:
- GNN achieved lower localization error and shorter runtime with fewer hidden layers, improving accuracy and robustness.
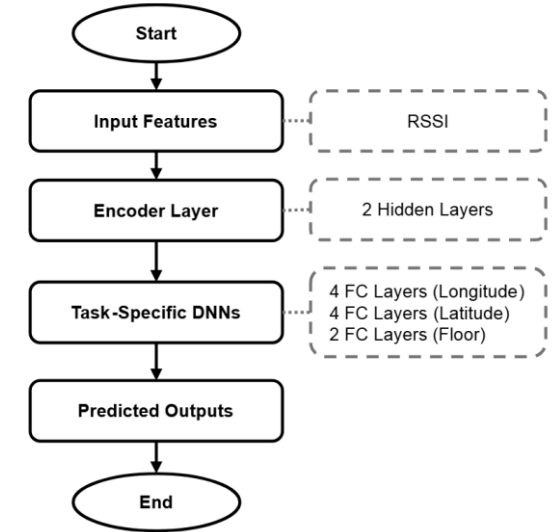

Fig. 1. Overall data preprocessing and prediction workflow of the DNN-based localization model. (FC: Fully Connected).
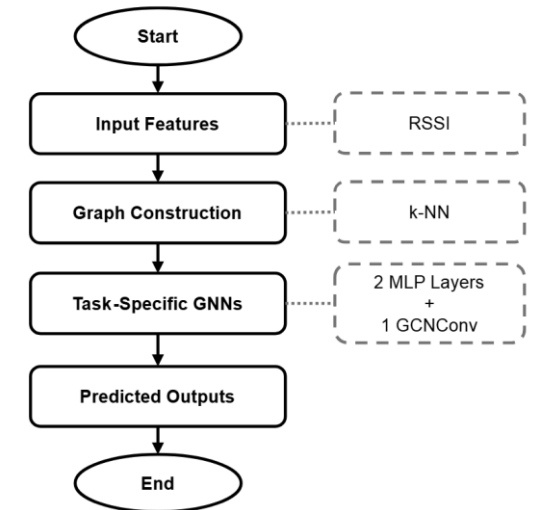

Fig. 2. Overall data preprocessing and prediction workflow of the GNN-based localization model. (MLP: Multi-Layer Perceptron, GCNConv: Graph Convolution layer).

Graduation Internship (24 Mar – 22 Sep 2025)

## Energy Optimization in 5G Core Networks – Orange Innovation

➤ **Objective:**
- Analyze the energy consumption of open-source 5G Core (free5GC and OAI) and explore methods to reduce it.

➤ **Method:**
1. **Deployed** an energy monitoring framework (Kepler + Prometheus + Grafana on Kubernetes).
2. **Installed and compared** free5GC and OAI; experiments revealed OAI consumed significantly more energy.
3. **Proposed three hypotheses**: database implementation differences, residual container processes, and frequent inter-Pod signaling.
4. Identified **frequent AMF heartbeat** signaling as the main cause, **modified** the source code, and extended the cycle from 10s to 100s.

➤ **Result:**
1. Extending the heartbeat cycle significantly reduced OAI's energy consumption while maintaining system stability.
2. The achievements were integrated into an AI assistant at Orange to support rapid future deployment.
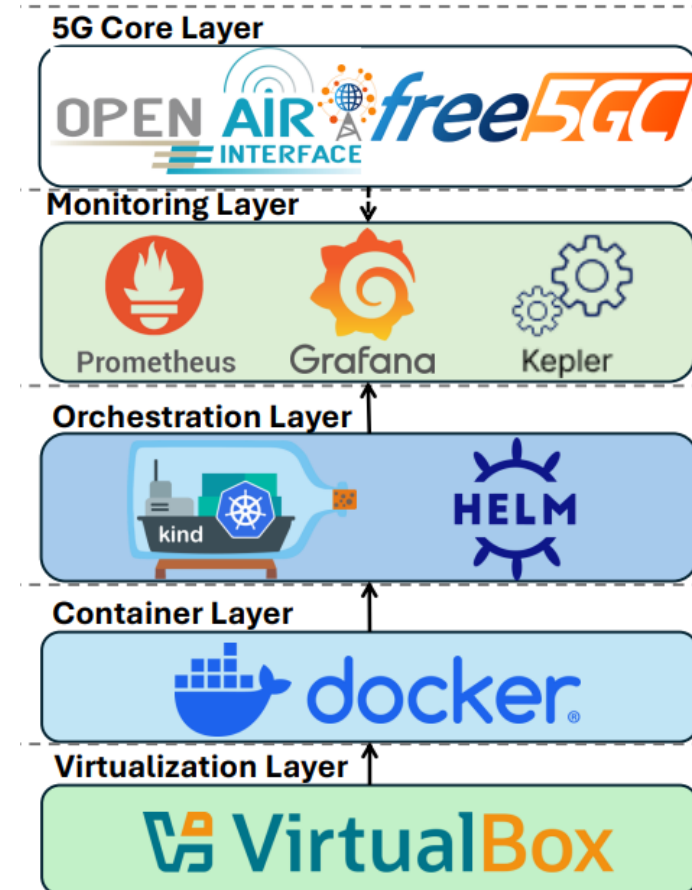
Methods & Contributions

Multi-floor

Fixed

Mobile

Single-floor

Multi-floor · Fixed Localization
Possible Approaches
- Multimodal input: combine Wi-Fi, BLE, UWB.
- Add a floor classification module in DNN.

Possible Challenges
- Complex data synchronization.
- Strong floor-to-floor signal variation.

Multi-floor · Mobile Localization
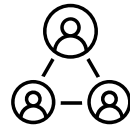**Possible Approaches**
- Fuse Wi-Fi, BLE, UWB, and sensor data.
- Use GNN combined with temporal models for cross-floor trajectory modeling.

Possible Challenges
- Cross-floor attenuation & dynamic interference.
- High computational and scalability requirements.

Single-floor · Fixed Localization
Possible Approaches
- Use Wi-Fi or BLE RSSI fingerprinting.
- DNN regression model for (x, y) prediction.

Possible Challenges
- Signal interference from walls and devices.

Single-floor · Mobile Localization
Possible Approaches
- Use BLE/UWB with IMU sensors.
- GNN (k-NN graph) for trajectory modeling.

Possible Challenges
- Dynamic interference sources.
- High real-time computational cost.

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Future Goals

Short-term (3 years)

Develop a multimodal AI indoor localization system with high accuracy, low energy cost, and scalability in smart hospitals.

Mid-term (5 years)

Promote the deployment and standardization of AI-based indoor localization and behavior analysis in healthcare.

Long-term (10 years)

Explore the integration of 6G networks and smart healthcare.