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A system for estimating crowd density based on Wi-Fi probe request frames

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About this Project

External internship at U-Hopper:

Big Data Analytics

Business Intelligence

Chatbot

IoT solutions

Artificial Intelligence solutions





Problem Statement

Badly handled demand in company that provides services to physical customers can lead to overcrowding and inefficiency of the services

- Inefficient and bad organized service leads to higher costs
- It is important to avoid generating crowds to reduce the risk of COVID-19 spreading during this global pandemic period



State of the Art

→ Analysis of different methods for estimating crowd density

Infrared sensors, LSE, treadle switch-based systems, Video methods,
Audio methods, Wi-Fi, Bluetooth, BLE, LTE, Radar, RFID approaches

→ Many fields of application and several implementations



Why Wi-Fi Solution?

High diffusion of Wi-Fi devices

Low-cost implementation

Real-time data transmission

User privacy ensured



Standard 802.11 → Management
frames → Probe request frames



Research Statement

Is it possible to continuously estimate the density of the crowd in a place of interest based on the Wi-Fi probe request frames?

Achievements

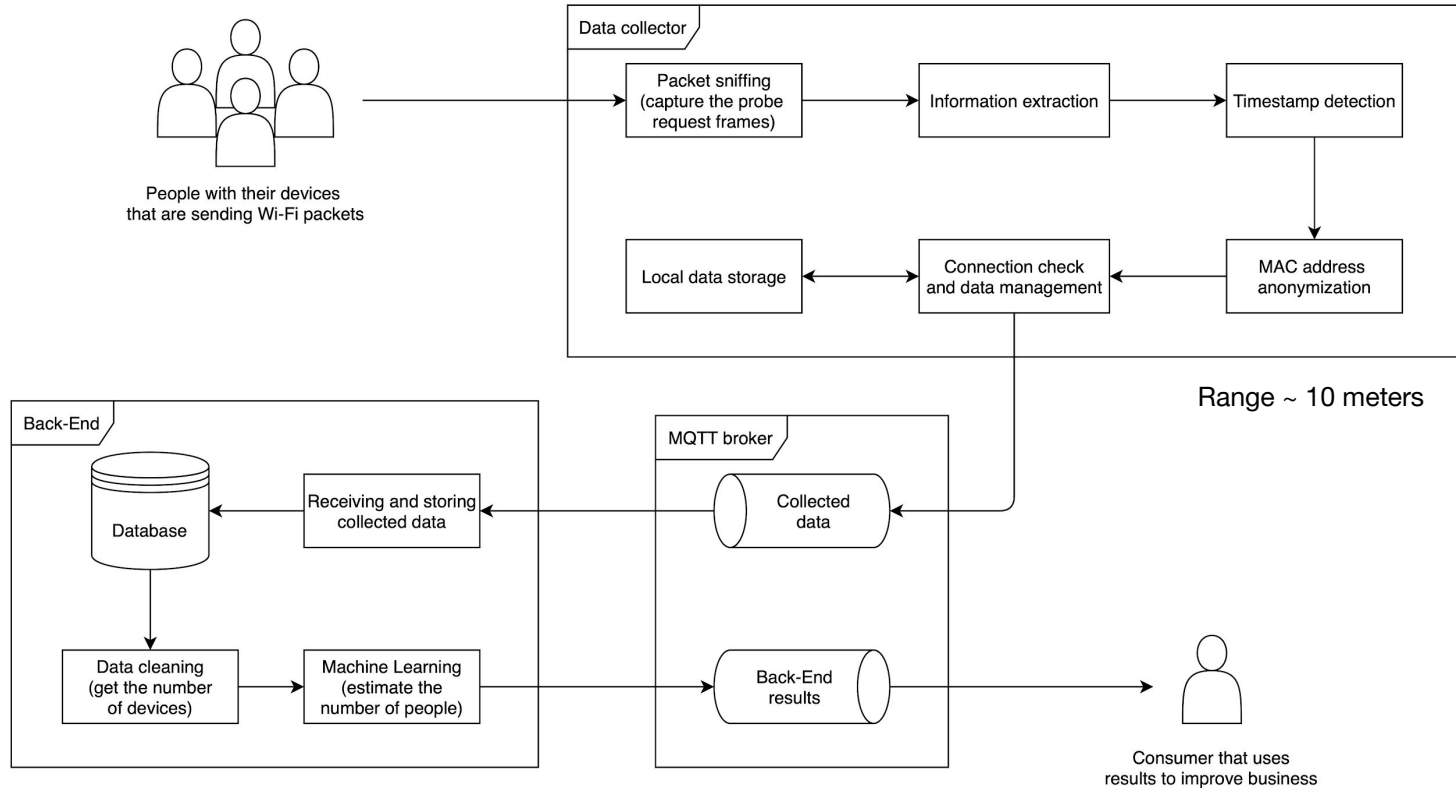
Designed and developed a system for this problem that could work in several context

Tested the system in a Cafe and
collected 4 weeks of data and
manually-annotated ground truth



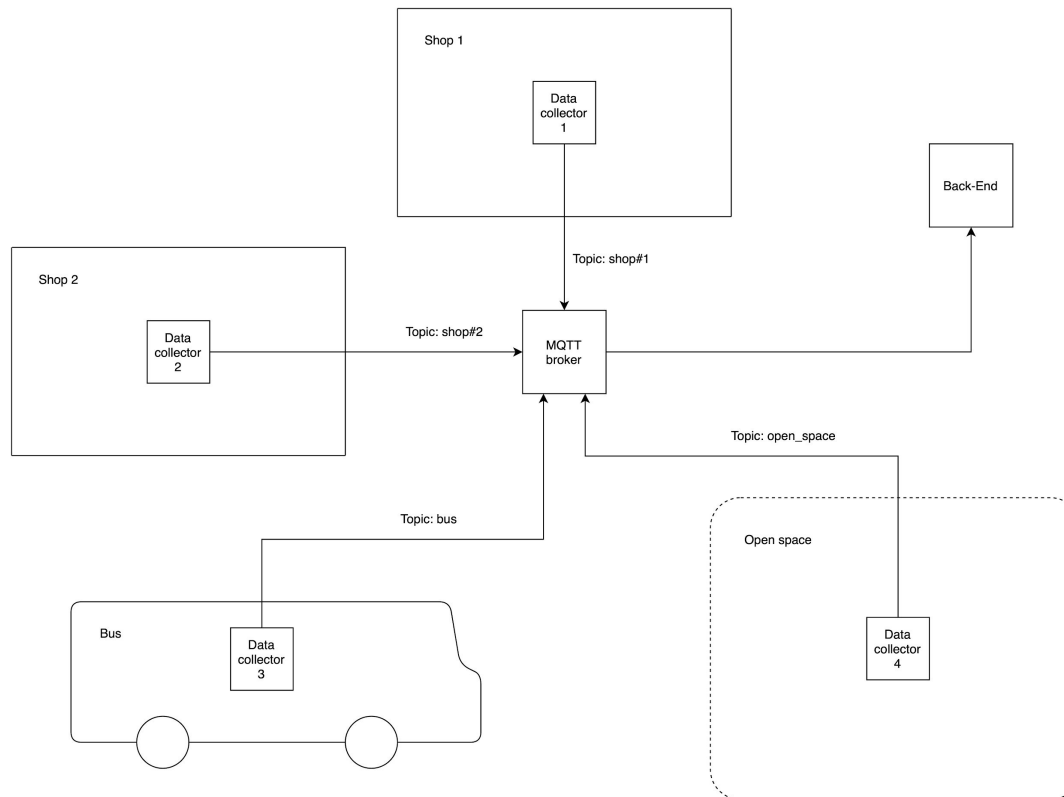


System Architecture

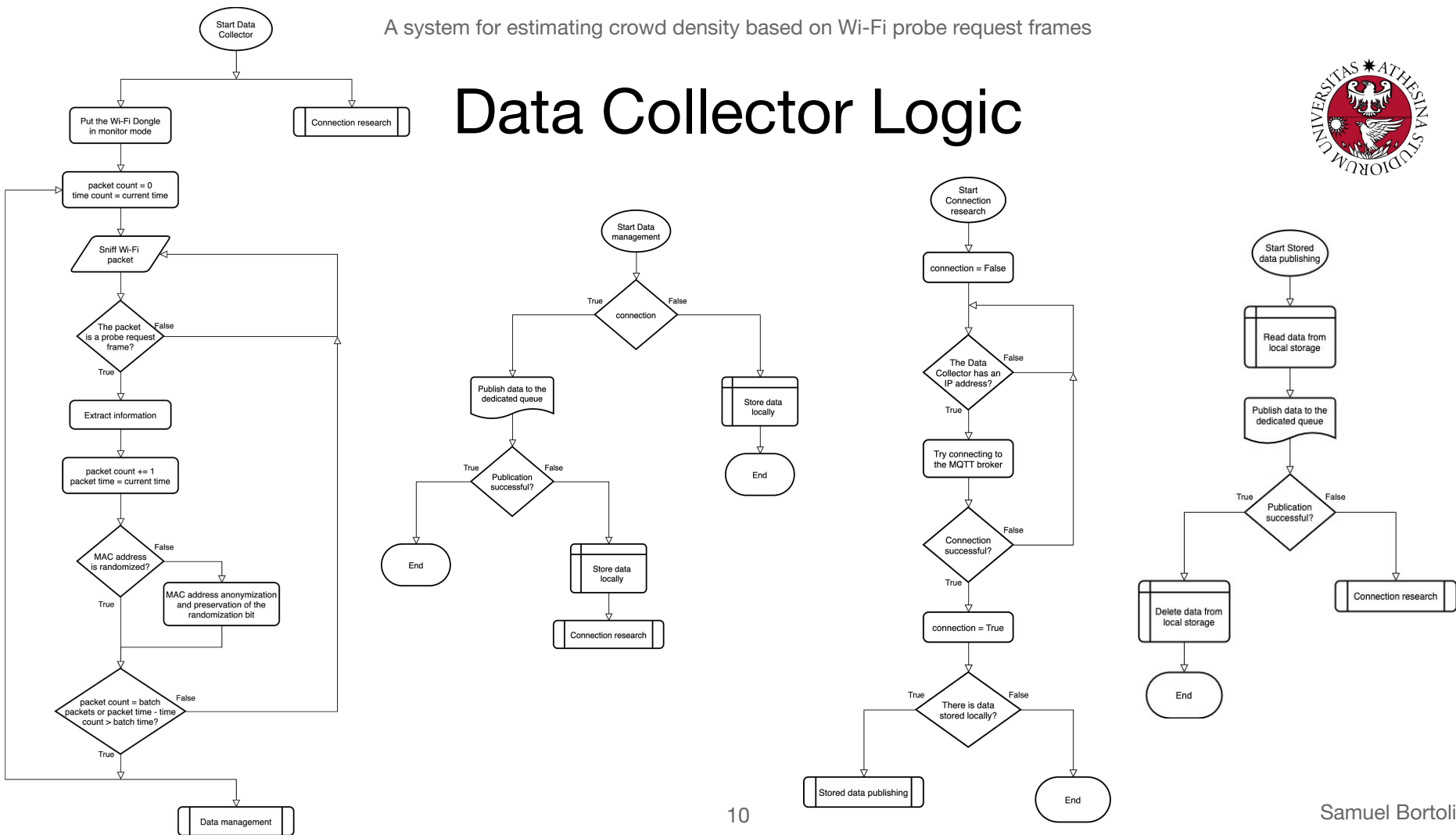




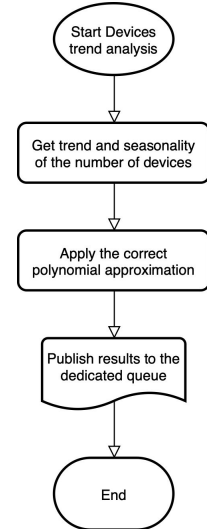
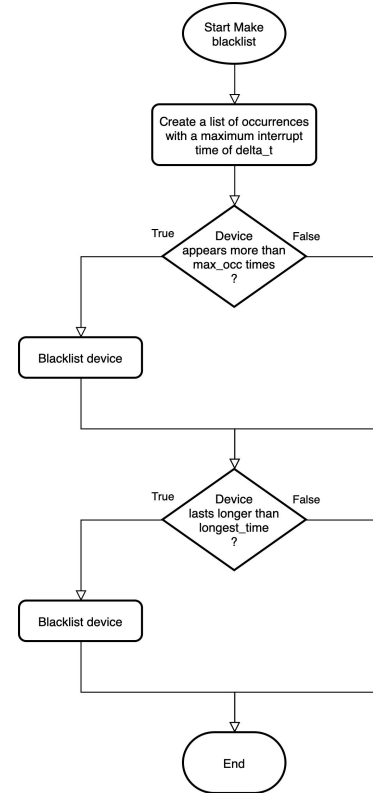
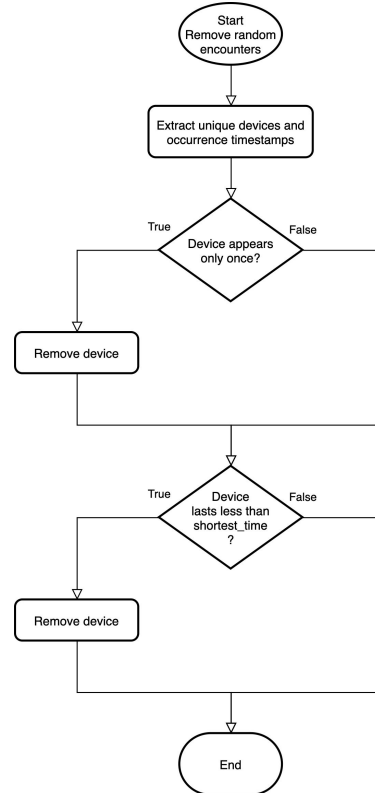
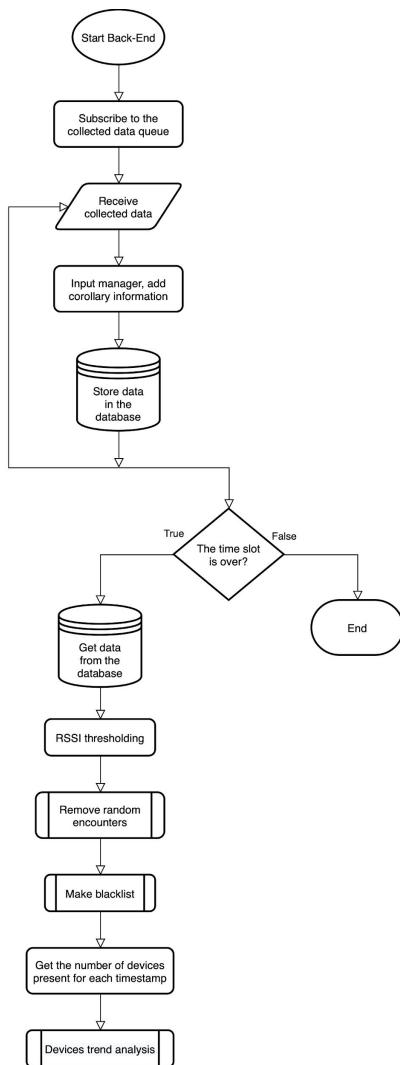
Scalable Architecture



Data Collector Logic

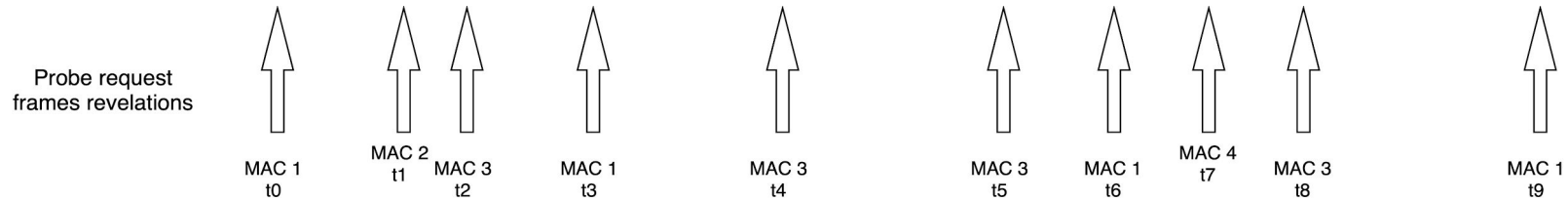


Back-End Logic



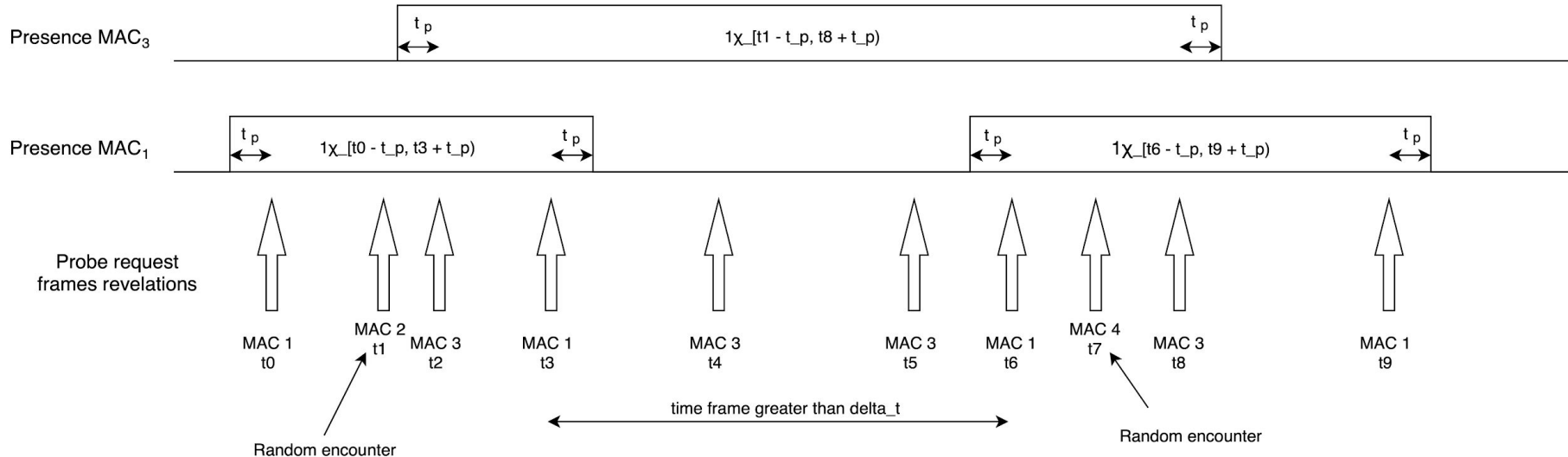


Presence of Devices



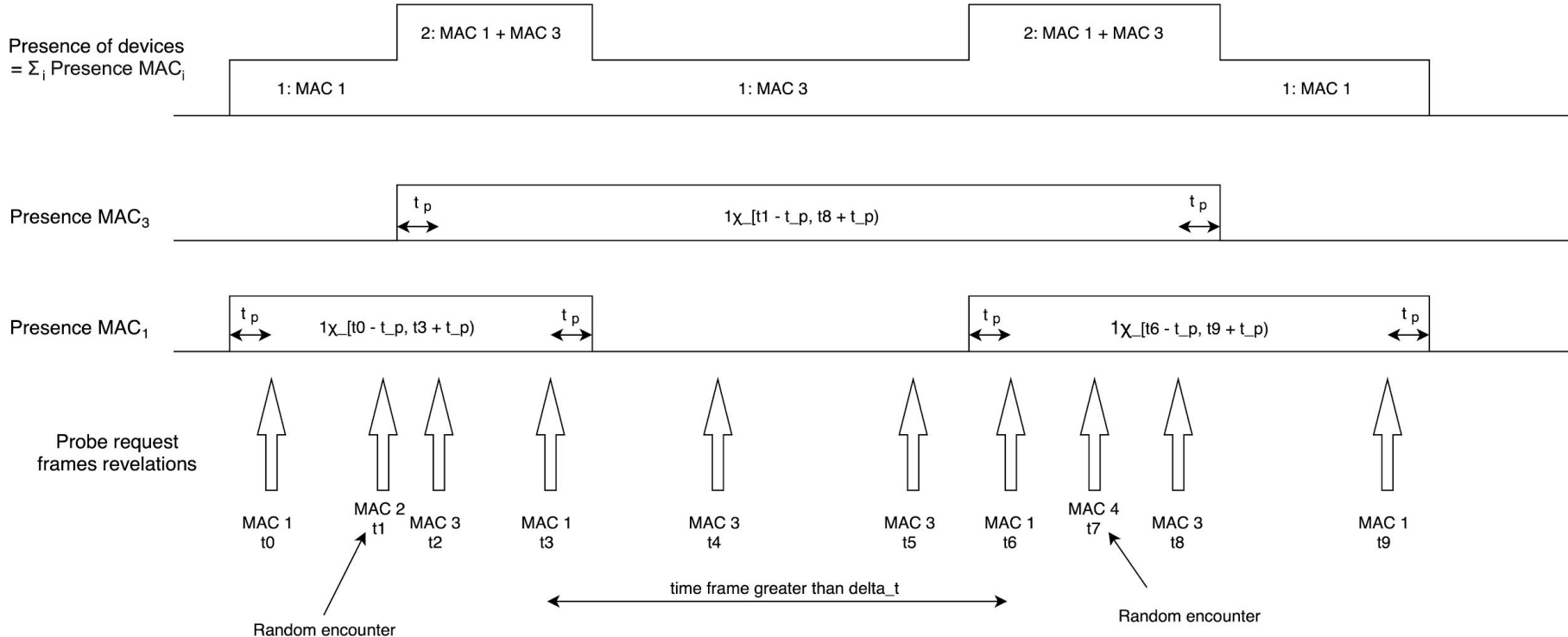


Presence of Devices





Presence of Devices





Feasibility Test at Home

Tests at home before validation

3 days of data collection

65928 probe request frames captured

12 home devices revealed

2 main range of RSSI $-71 \div -91$ not in the kitchen, $-35 \div -69$ in the kitchen

→ Feasibility of the method for detecting devices in the area

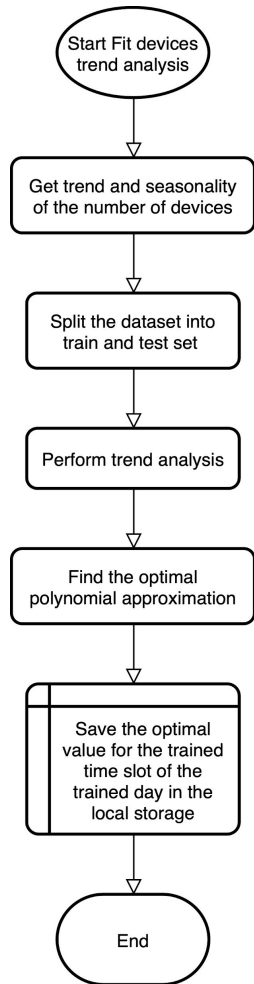


System Validation

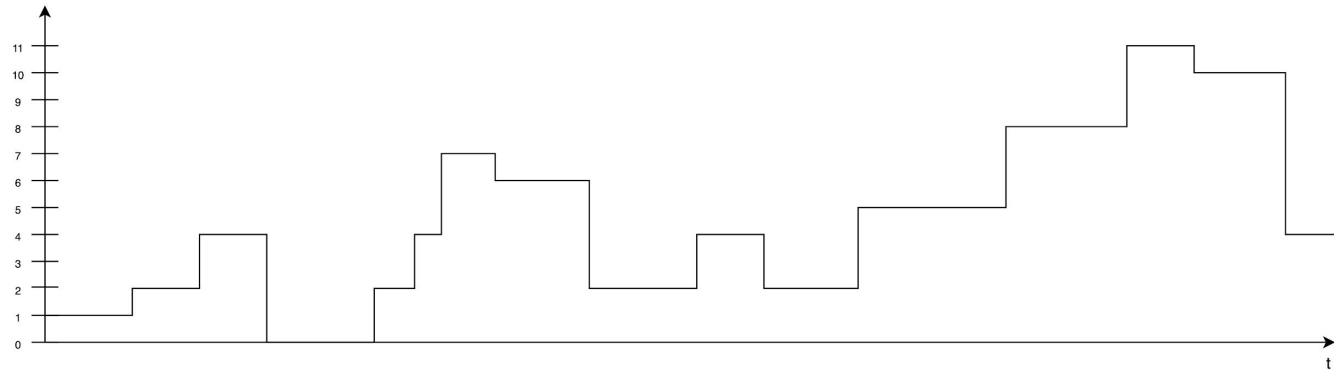
- Raspberry Pi in a Cafe where I annotate manually the ground truth
- Eclipse Mosquitto Broker MQTT of U-Hopper on their server
- MQTT receiver and MongoDB on U-Hopper server
- Analyzer and Estimator on my pc to use on the data + collected ground truth to test accuracy and reliability of the proposed system



Ground Truth Collection

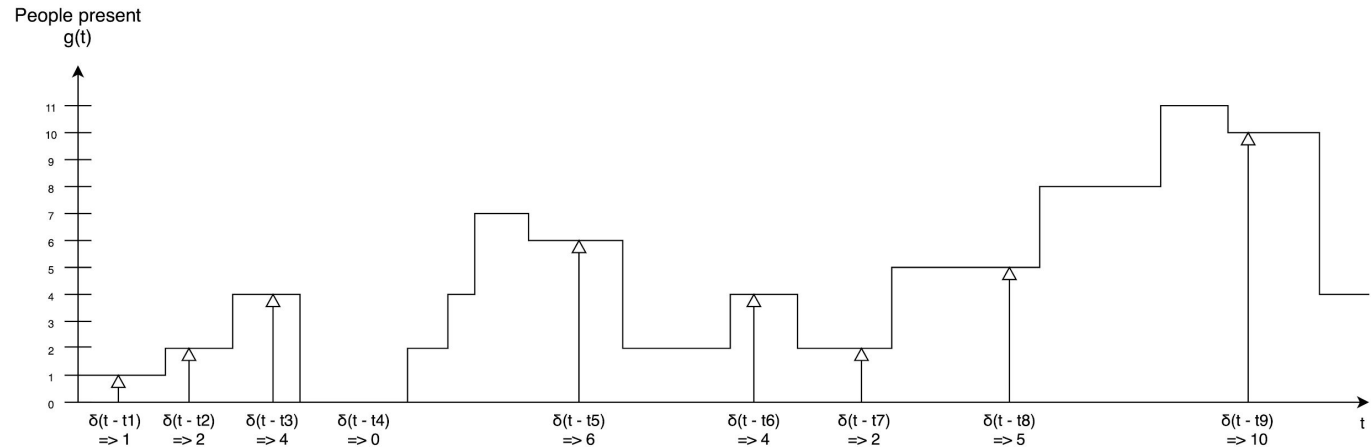
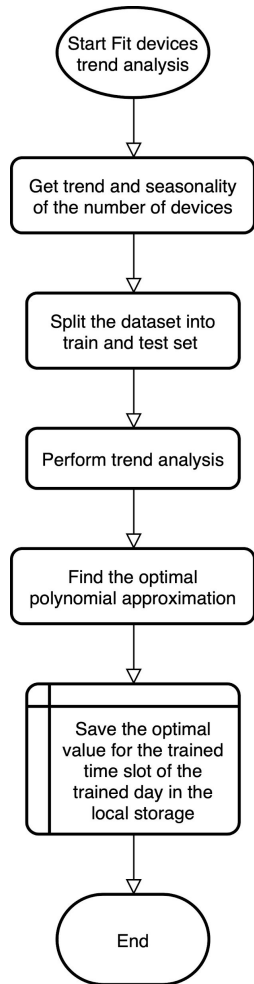


People present
 $g(t)$



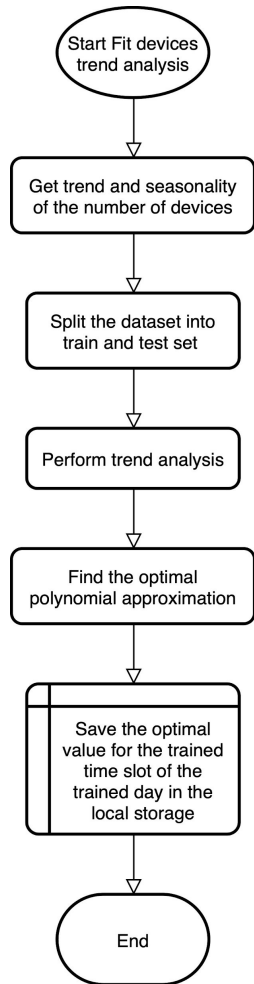


Ground Truth Collection

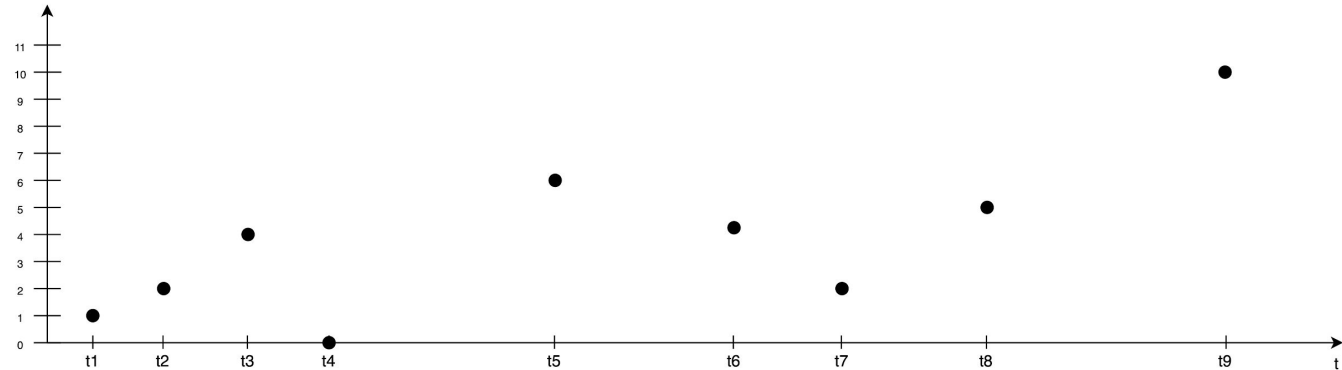




Ground Truth Collection



Random look
sampling of $g(t)$
 \Rightarrow Ground truth



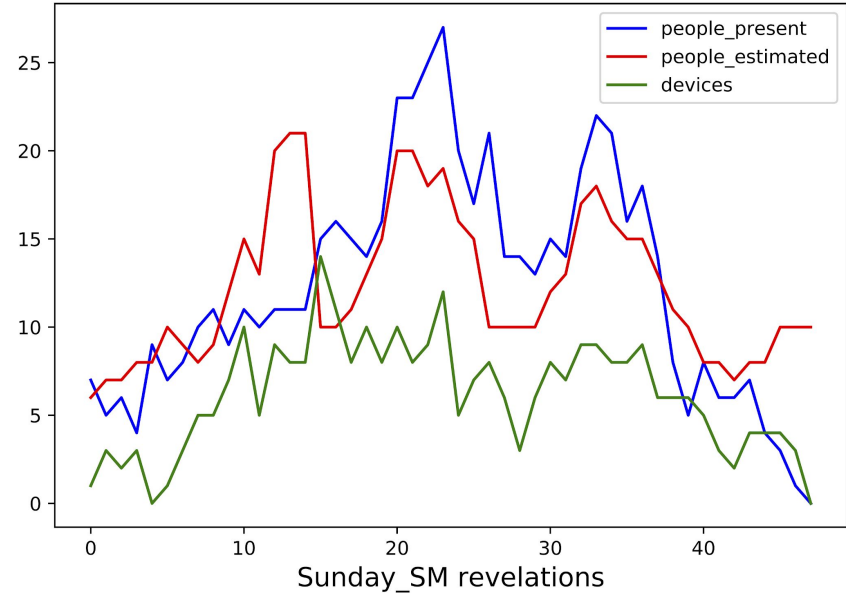
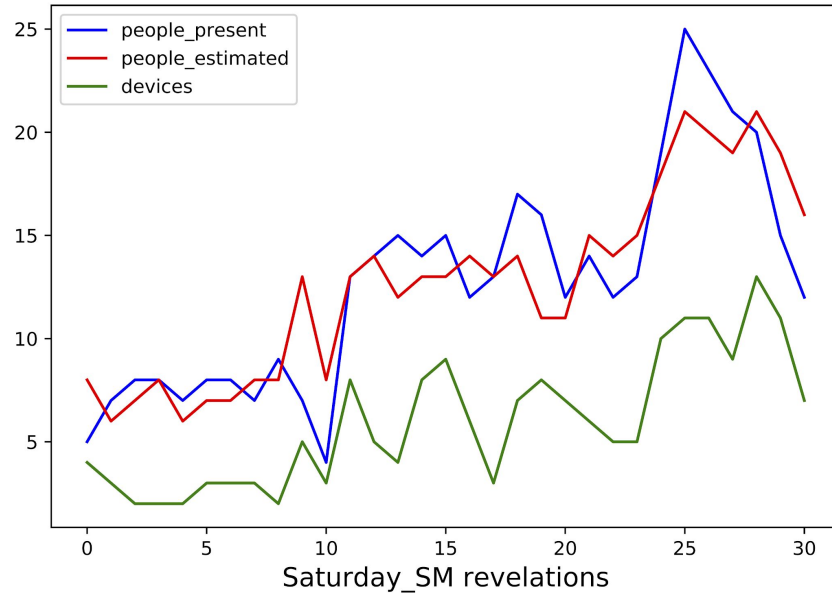


Test Results at Cafe

- 4 weeks of data collection (24 days)
- 1270 manual annotation of ground truth
- 861979 probe request frames captured (~ 560MB)
- 38771 MAC addresses revealed



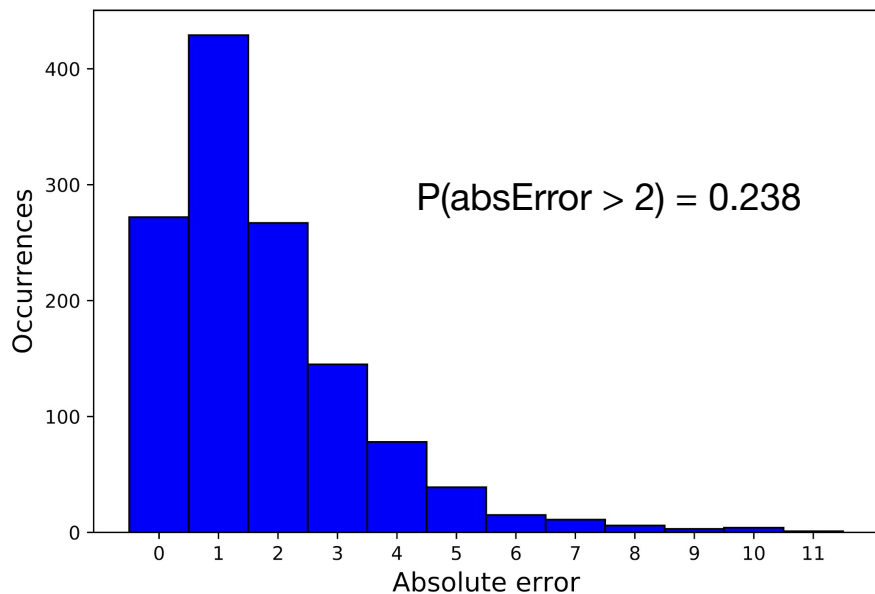
Test Results at Cafe



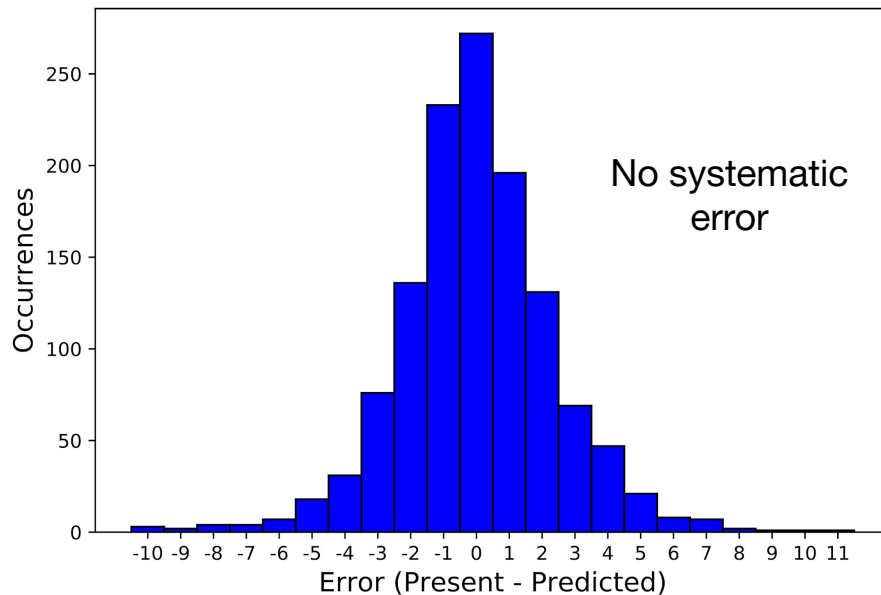


Error Distribution

Mean Absolute Error = 1.731



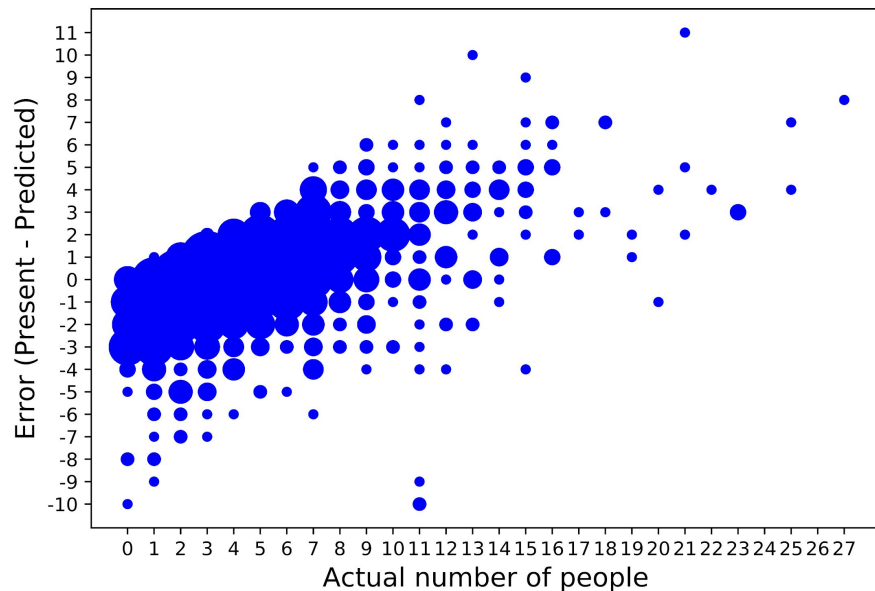
Mean Squared Error = 5.710



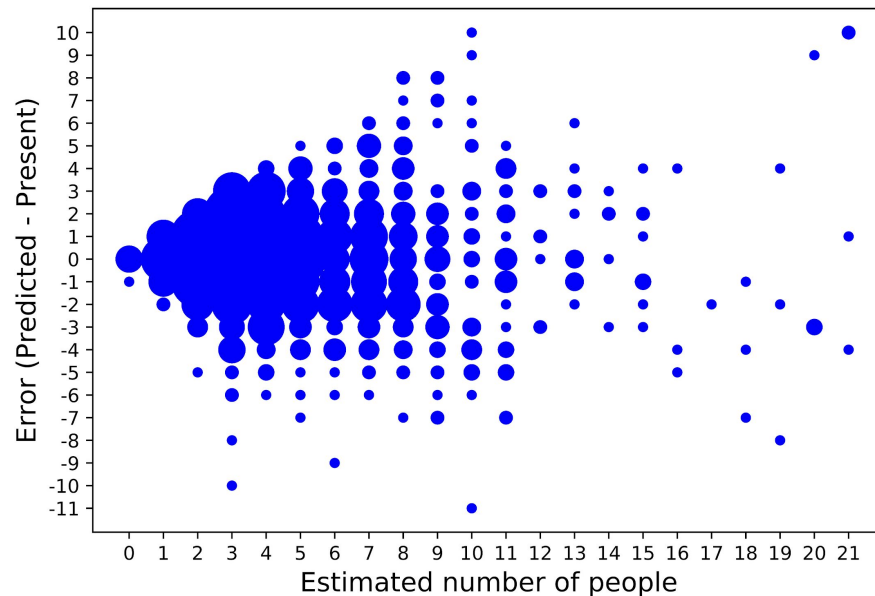


Scatter Plot of the Error

High number of people, lower predictions



No systematic error



Low number of people, higher predictions



Summary

- It is possible to continuously estimate the density of the crowd in a place of interest based on the Wi-Fi probe request frames
 - Designed and developed a reliable system to do that
- Tested the system in a Cafe and collected 4 weeks of data and manually-annotated ground truth with an overall MAE of 1.731



Future Works

- Real-time execution
- Test of the system in different contexts
- Extension to multiple data collectors
- Improvement of the Machine Learning model



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Thank you for your attention

Samuel Bortolin