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

Department of Information Engineering and Computer Science

Supervisors

Fabrizio Granelli
Daniele Miorandi

Student

Samuel Bortolin

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About this Project

External internship at U-Hopper:

→ Big Data Analytics

→ Business Intelligence

→ 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 badly organized service leads to higher costs

→ It is important to detecting and monitoring 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

Customer privacy ensured
(GDPR compliance)



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

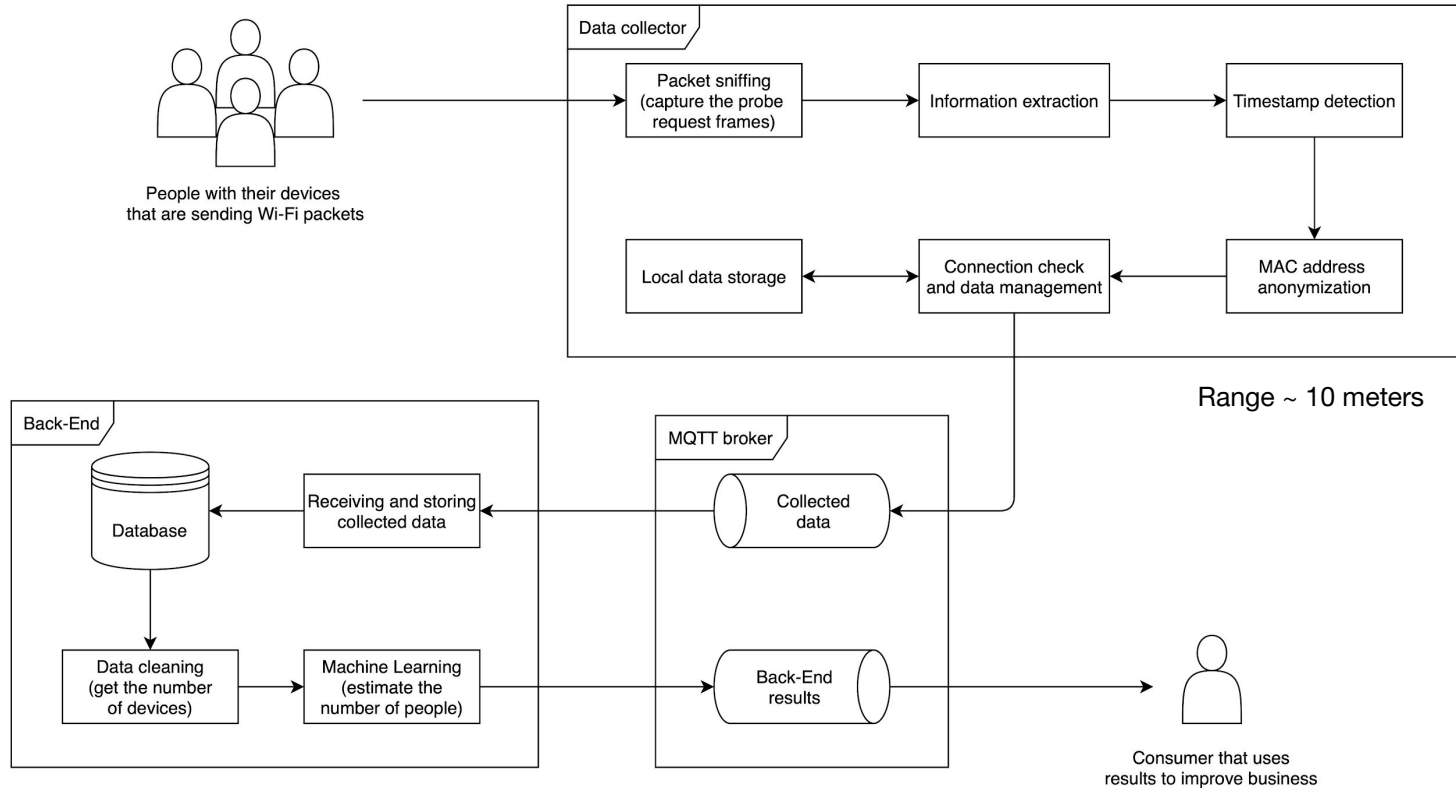
Designed and implemented a system for this problem that could work in several context

Tested the system in a Cafe and collected 4 weeks of data and manually-annotated ground truth (the actual number of people)



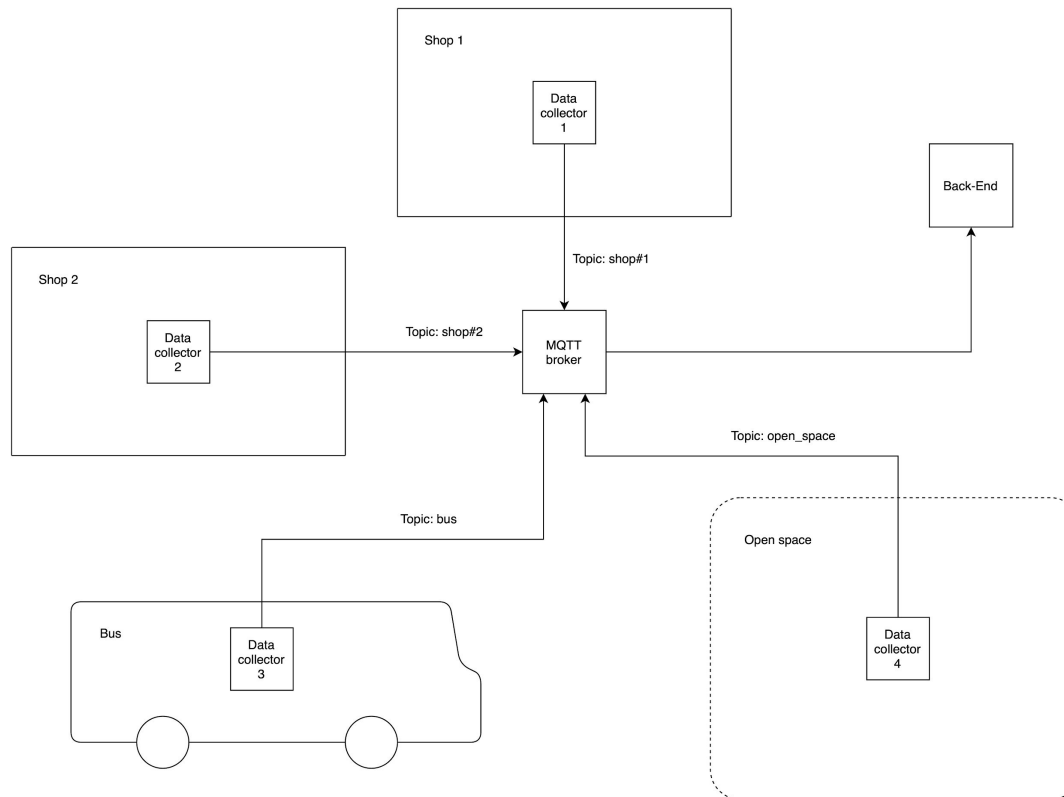


System Architecture

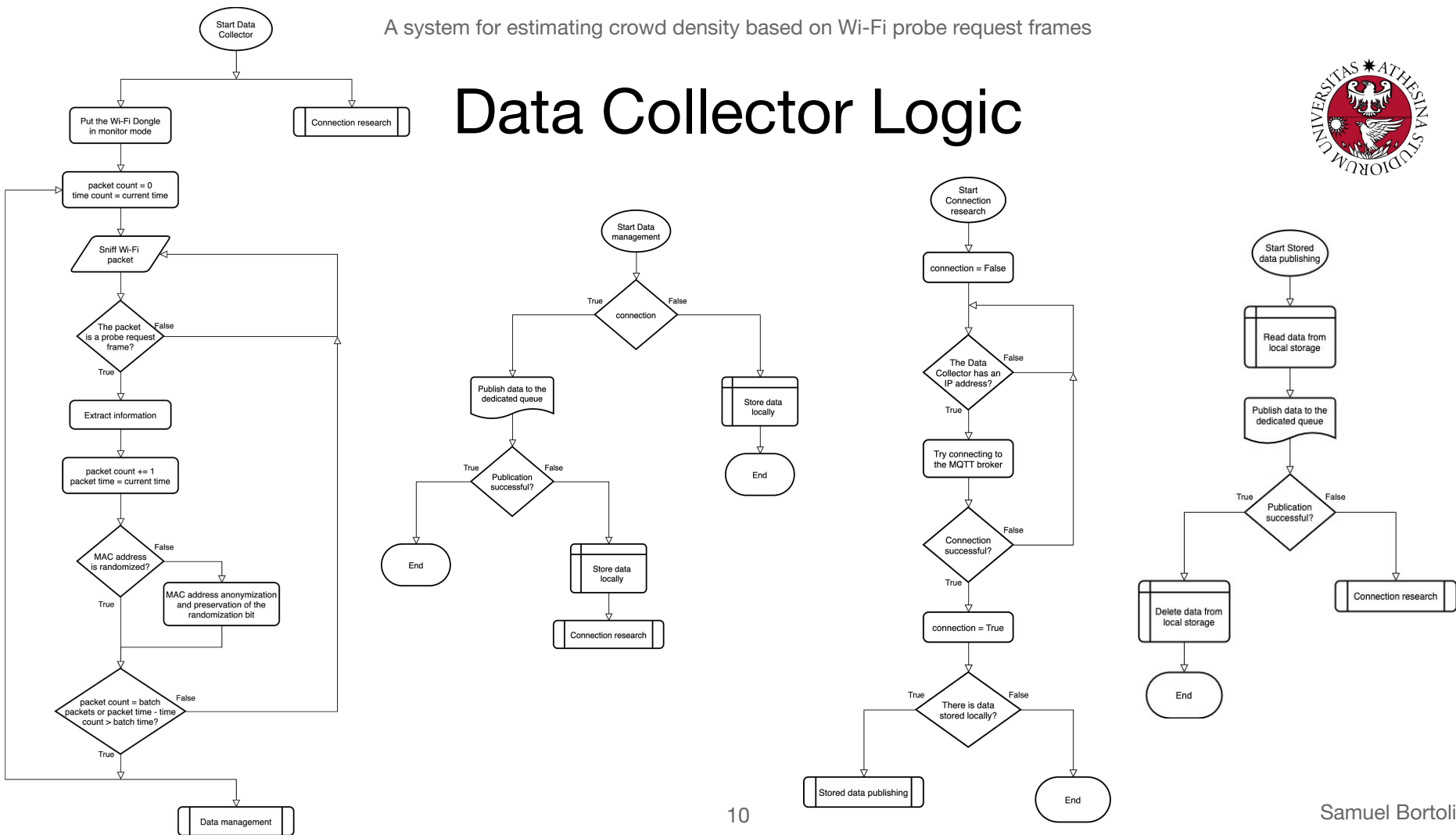




Scalable Architecture

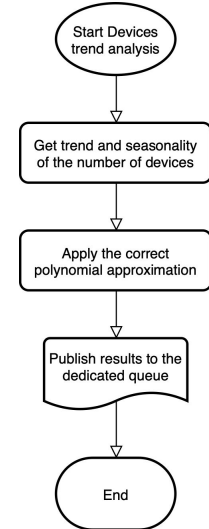
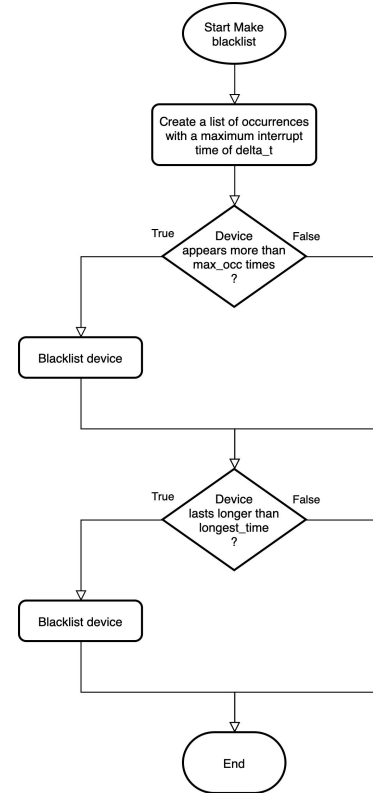
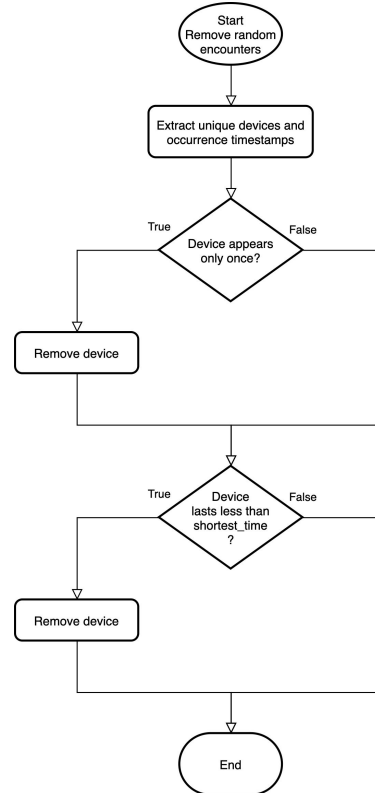
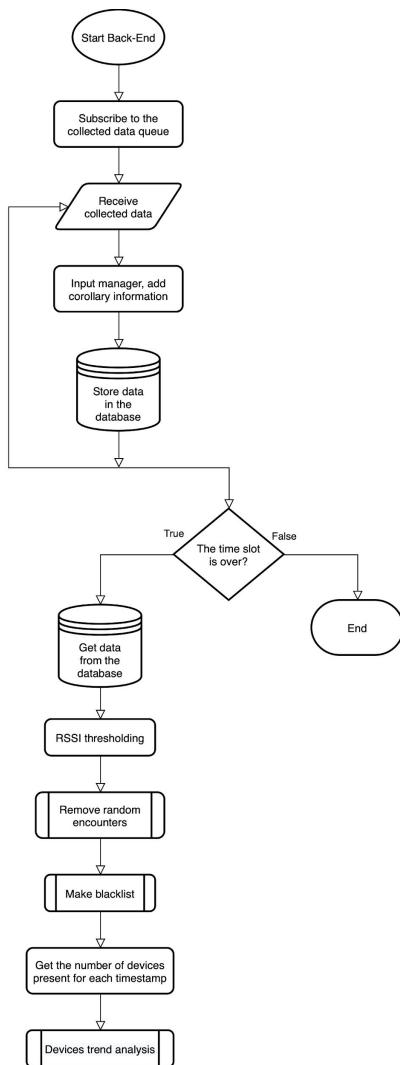


Data Collector Logic



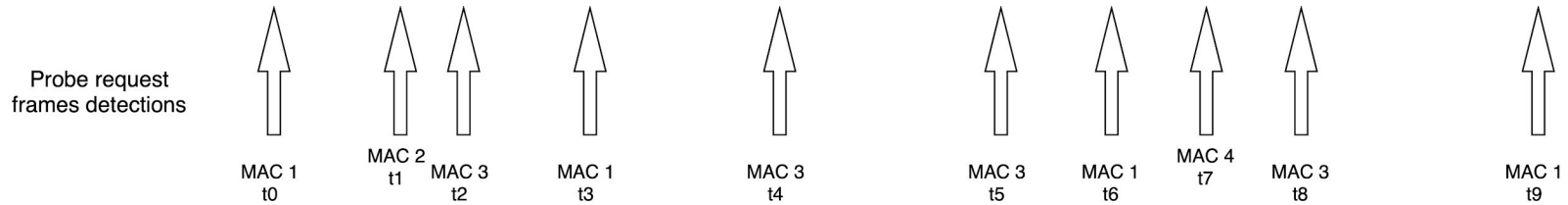


Back-End Logic



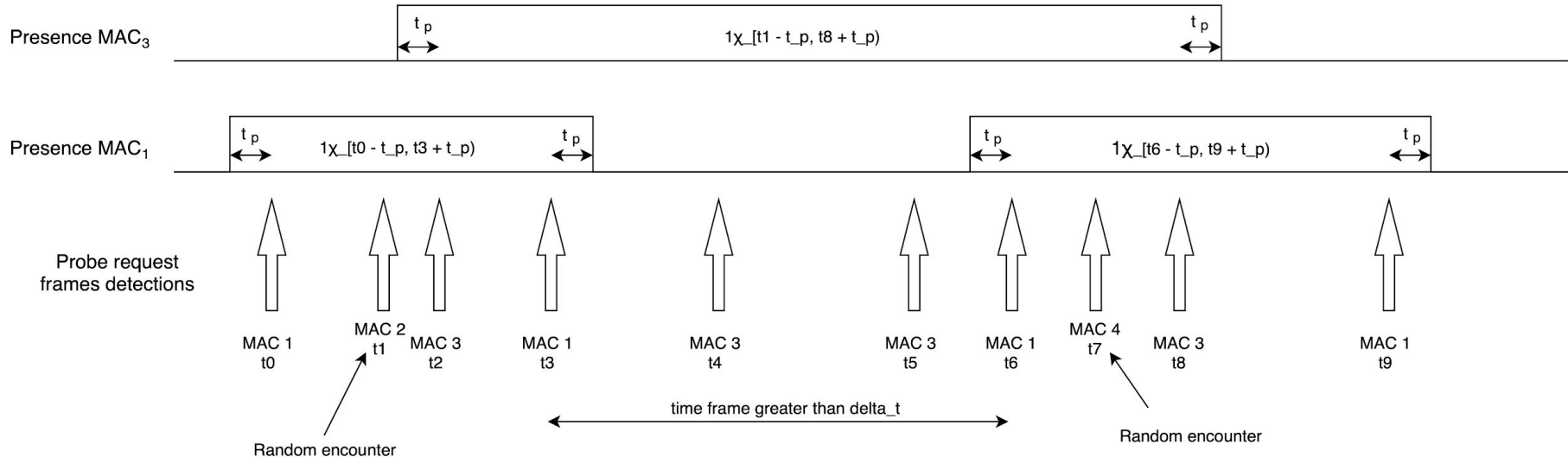


Presence of Devices



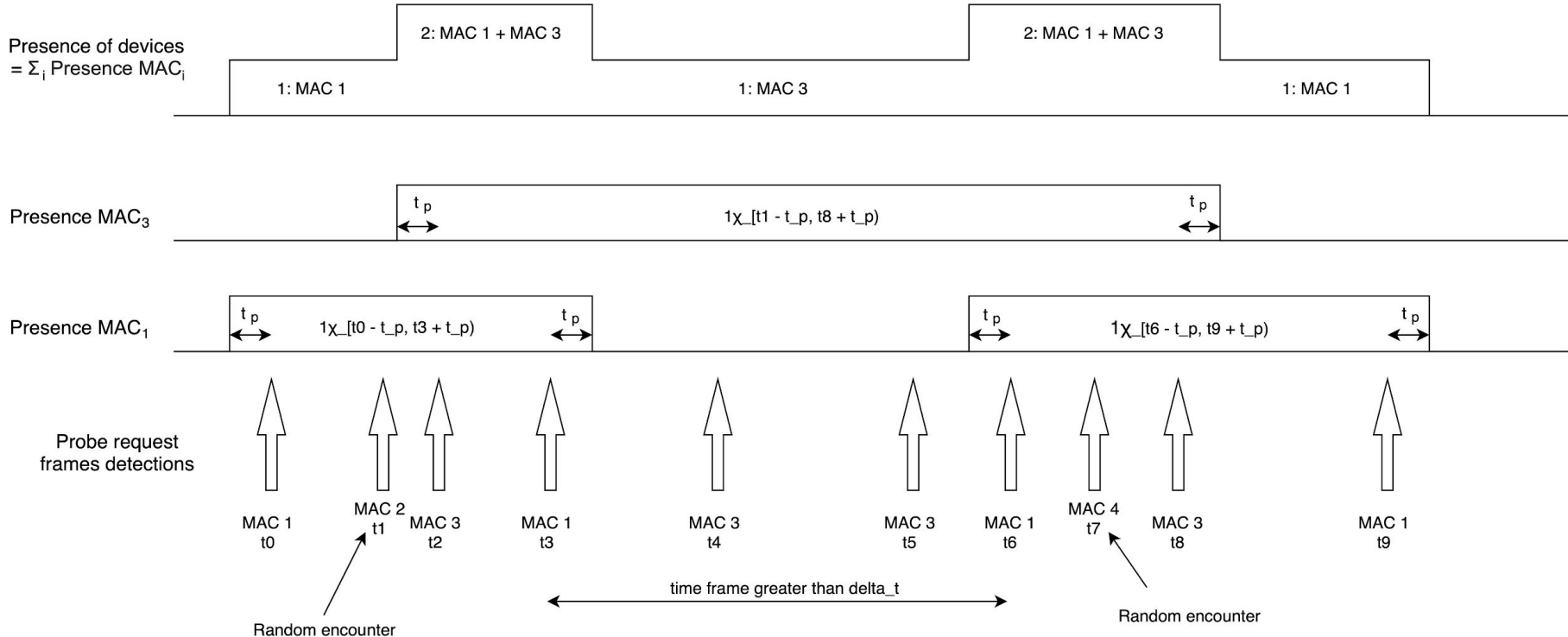


Presence of Devices





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 detected

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

→ Feasibility of the method for detecting devices in the area

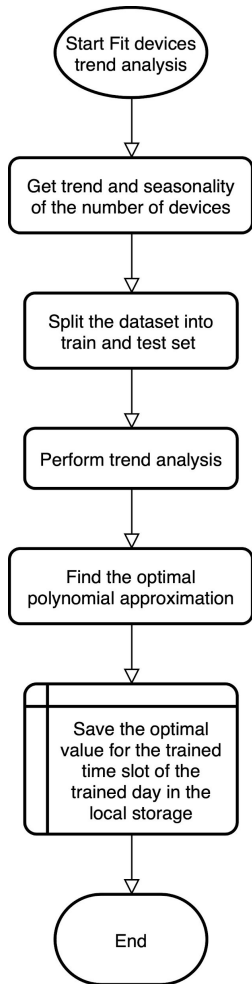


System Validation

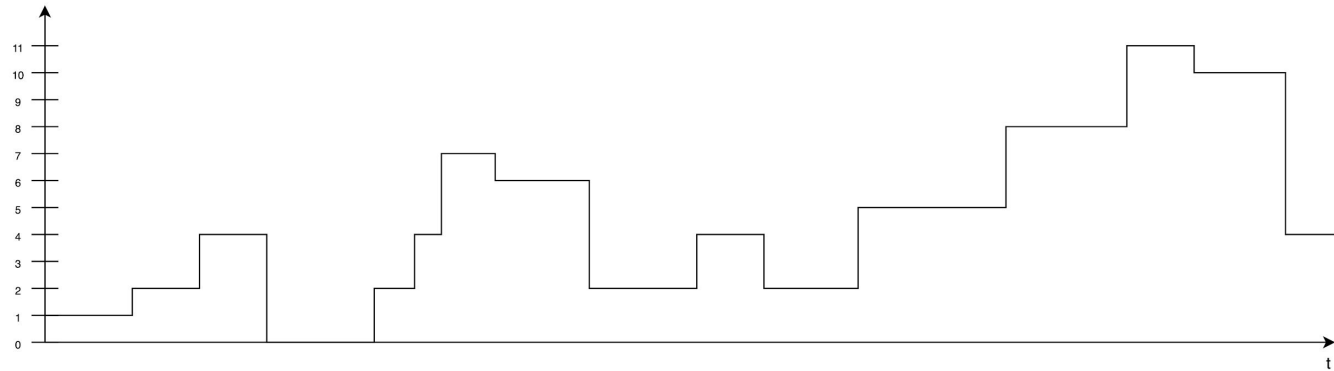
- Raspberry Pi in a Cafe where I annotate manually the ground truth
- Eclipse Mosquitto Broker MQTT of U-Hopper on their cloud infrastructure
 - MQTT receiver and MongoDB on U-Hopper cloud infrastructure
 - Analyzer and Estimator on my pc to use on the data + collected ground truth to test accuracy and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



Ground Truth Collection

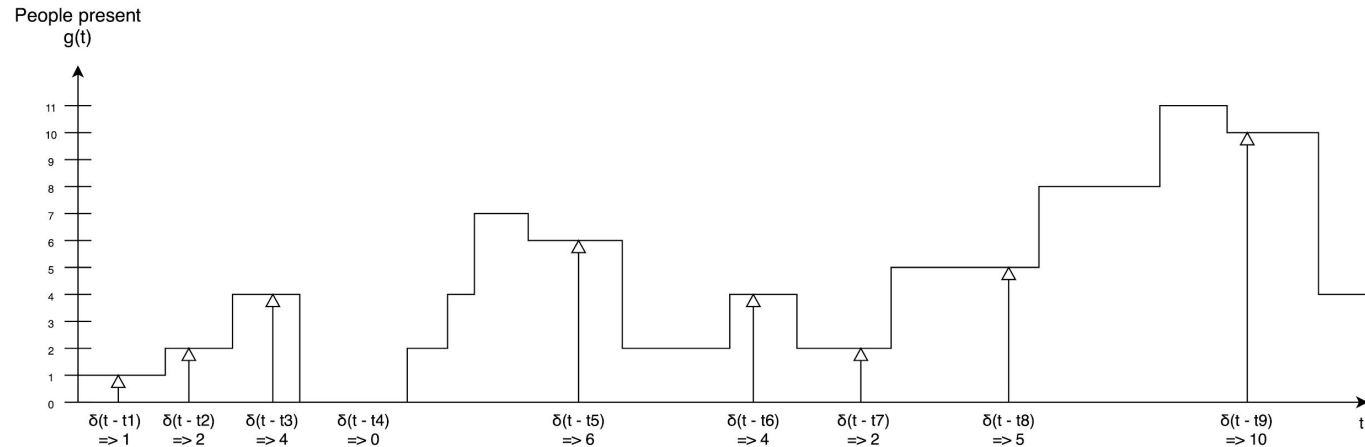
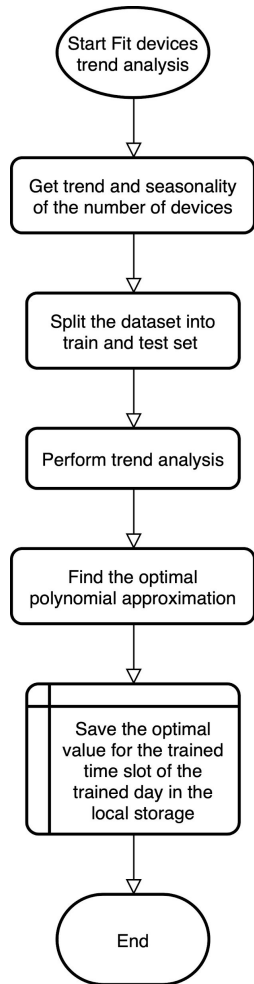


People present
 $g(t)$



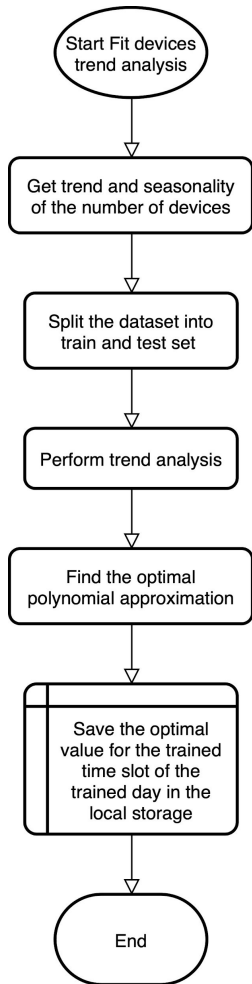


Ground Truth Collection

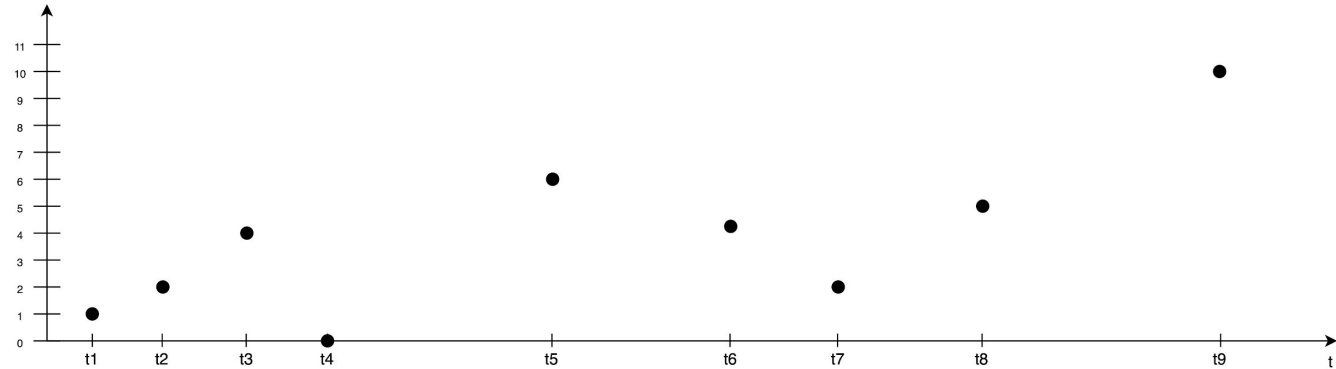




Ground Truth Collection



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



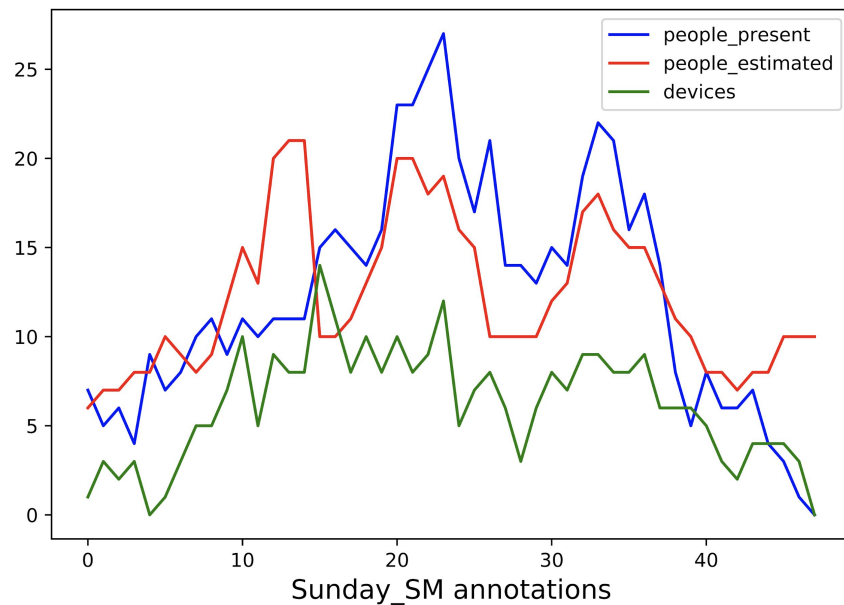
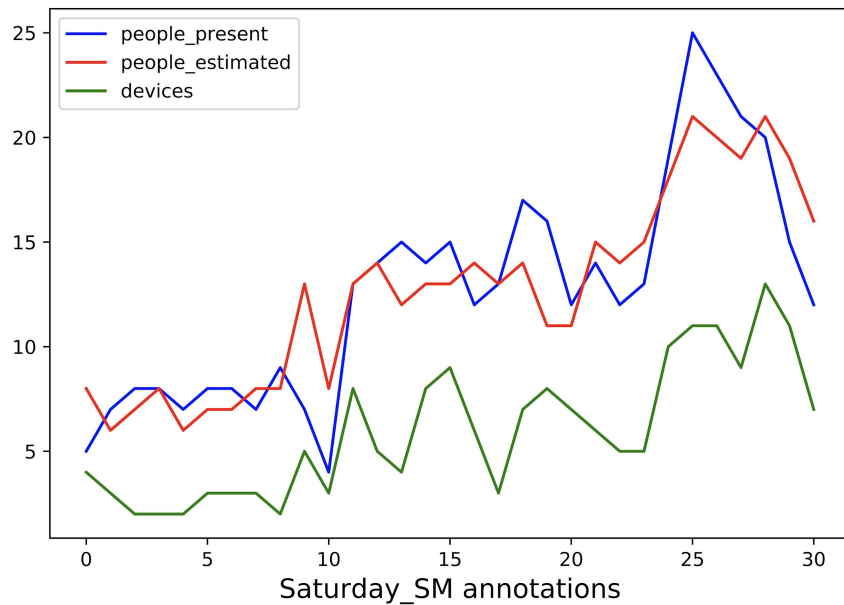


Test Results at Cafe

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



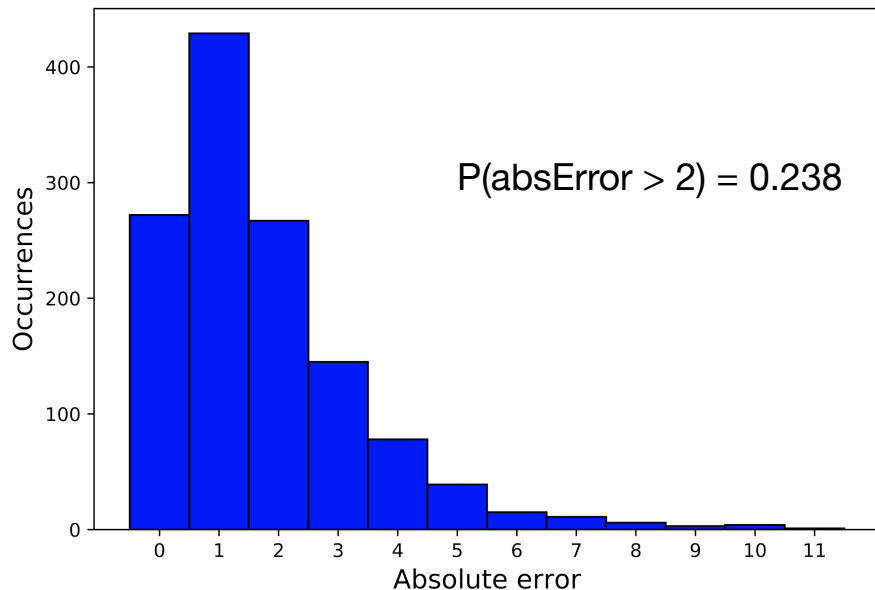
Test Results at Cafe



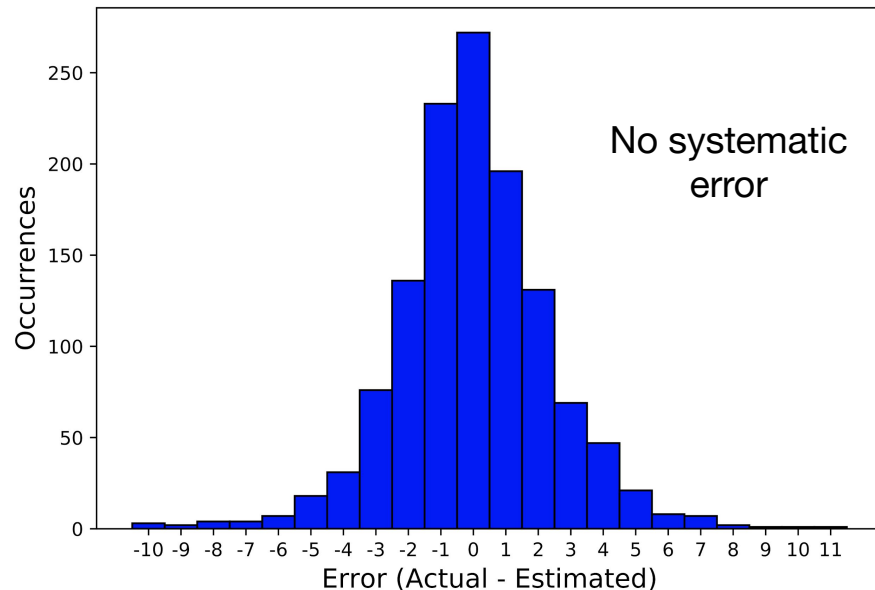


Error Distribution

Mean Absolute Error = 1.731

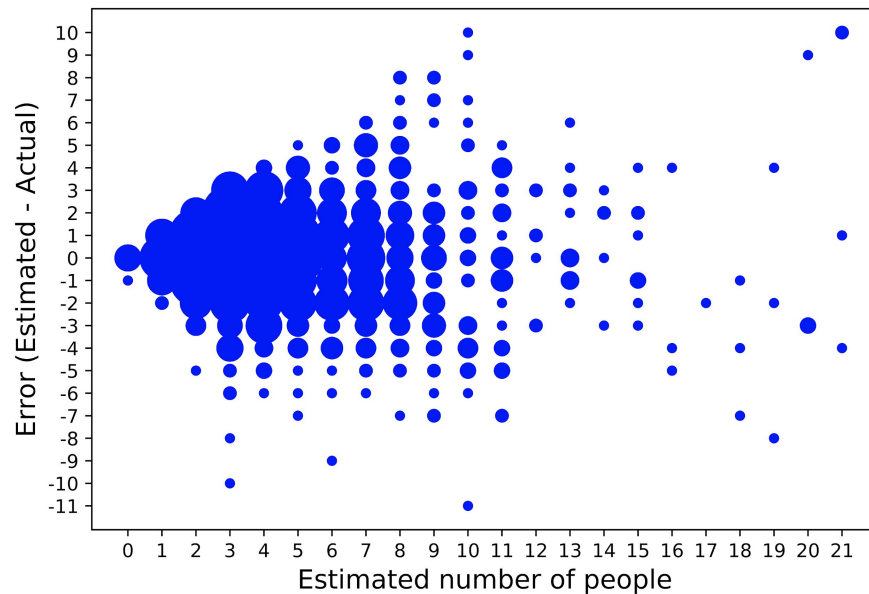
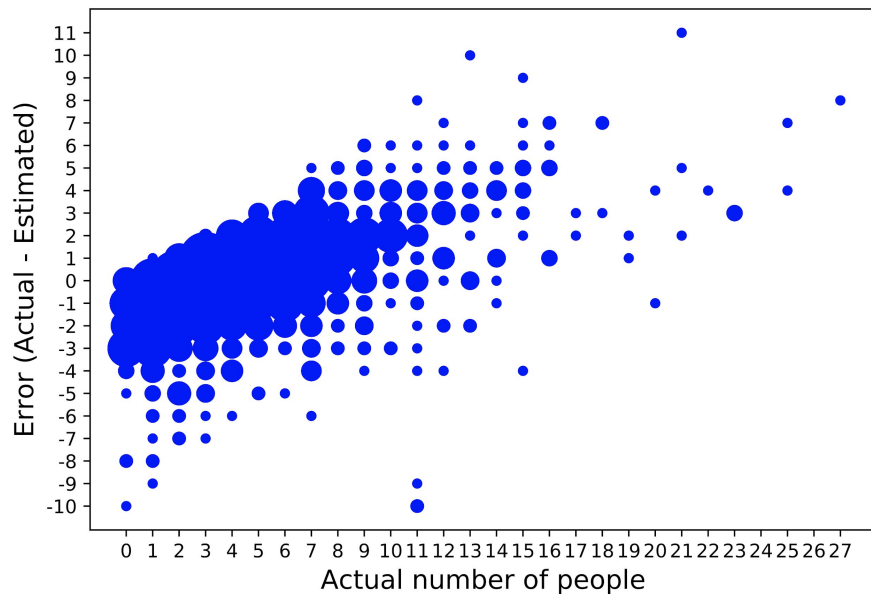


Mean Squared Error = 5.710





Scatter Plot of the Error





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 implemented 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