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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

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About this Project

External internship at U-Hopper:

→ Big Data Analytics

→ Business Intelligence

→ IoT solutions

→ Artificial Intelligence solutions

U·HOPPER

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

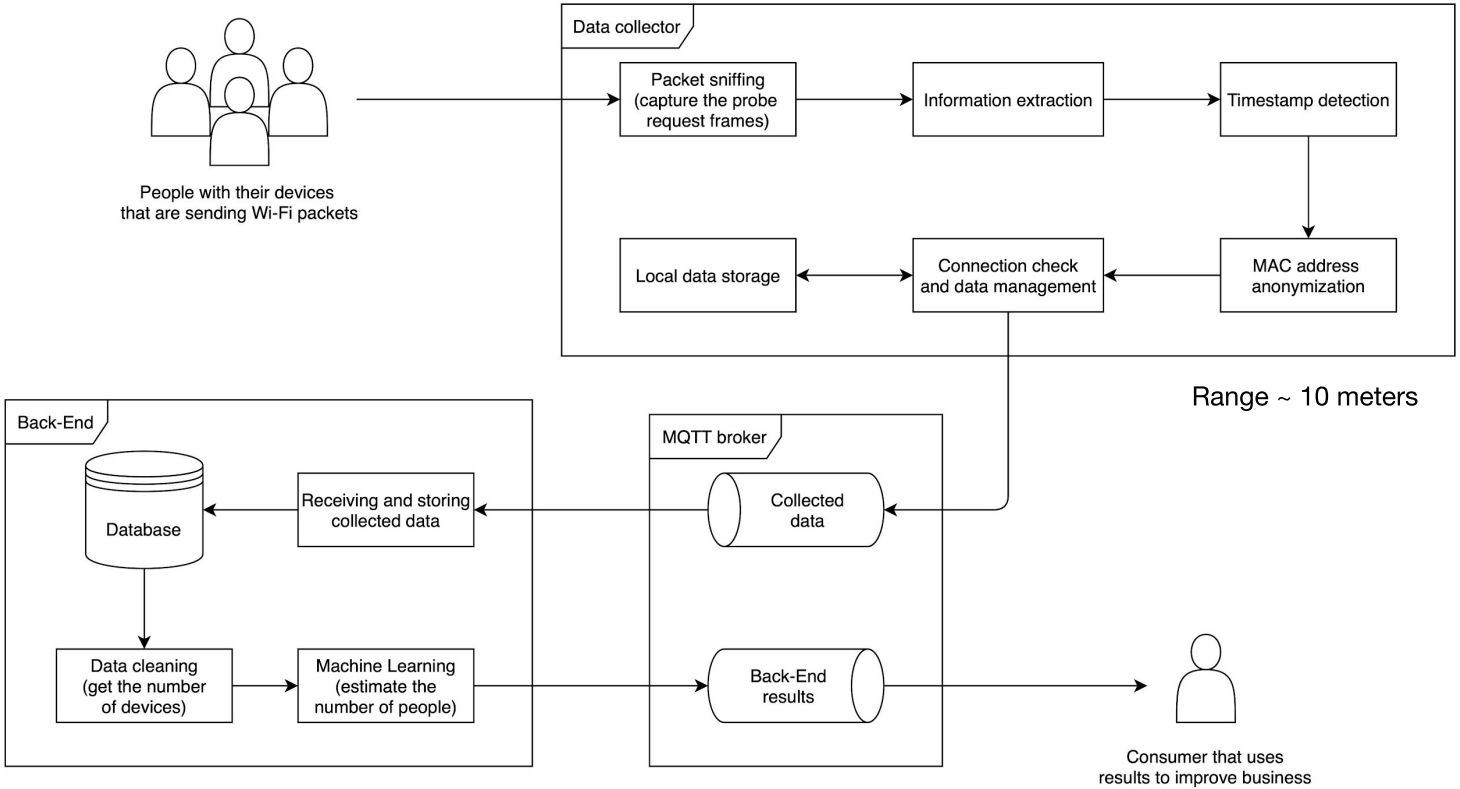
in a place of interest based on the Wi-Fi probe request frames?

Achievements

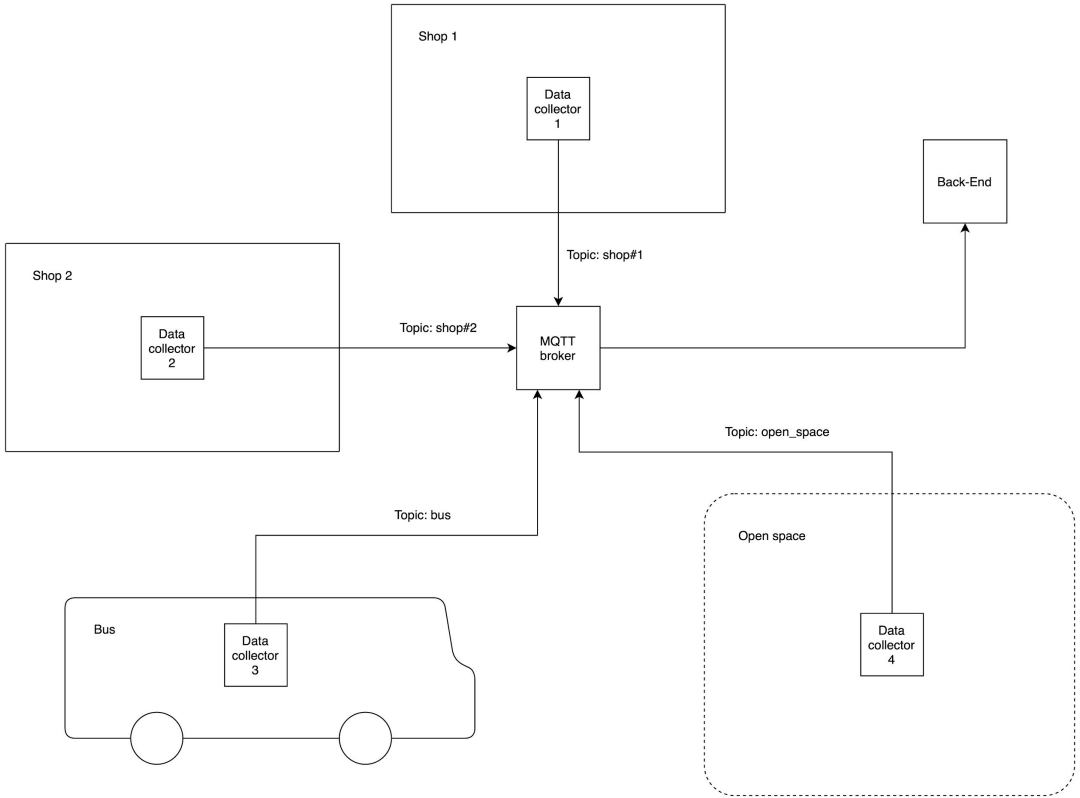
Designed and implemented a system for this problem that could work in several context

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

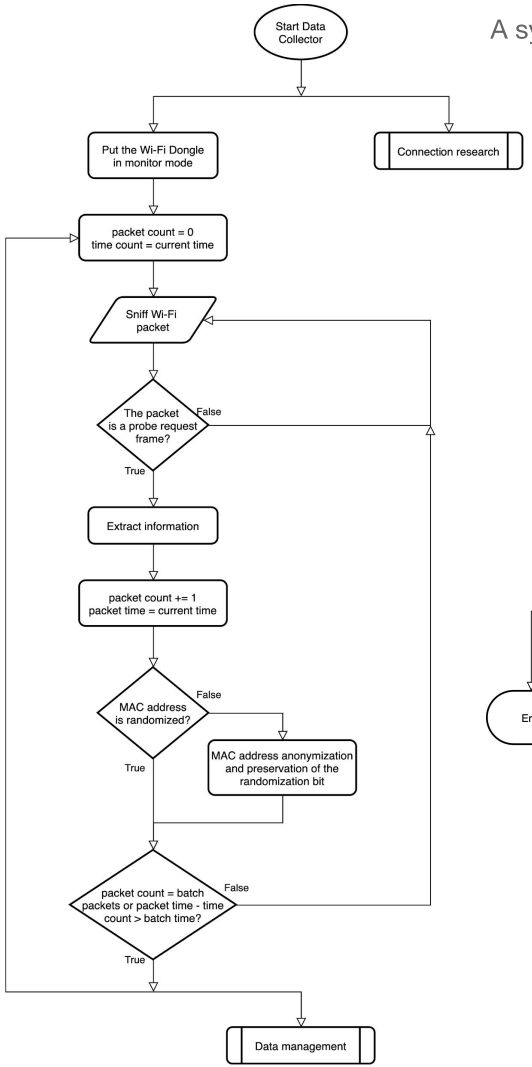
System Architecture

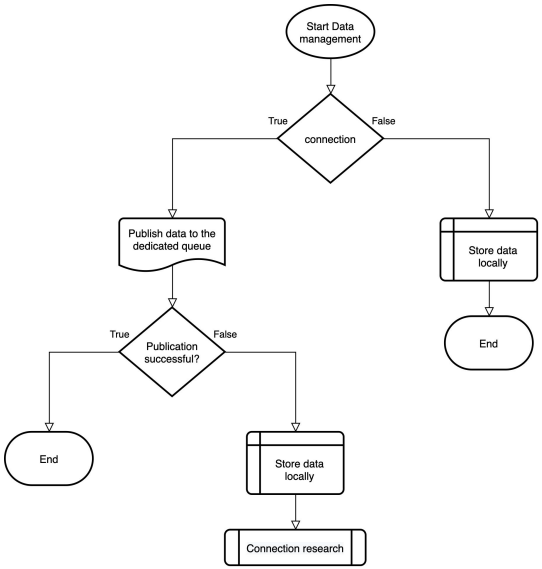


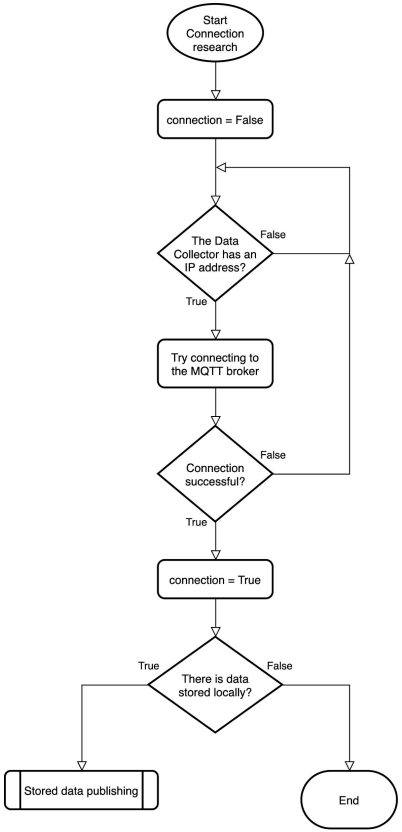
Scalable Architecture

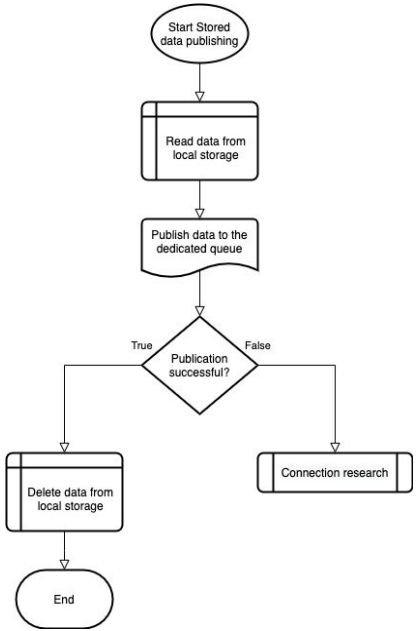


Data Collector Logic

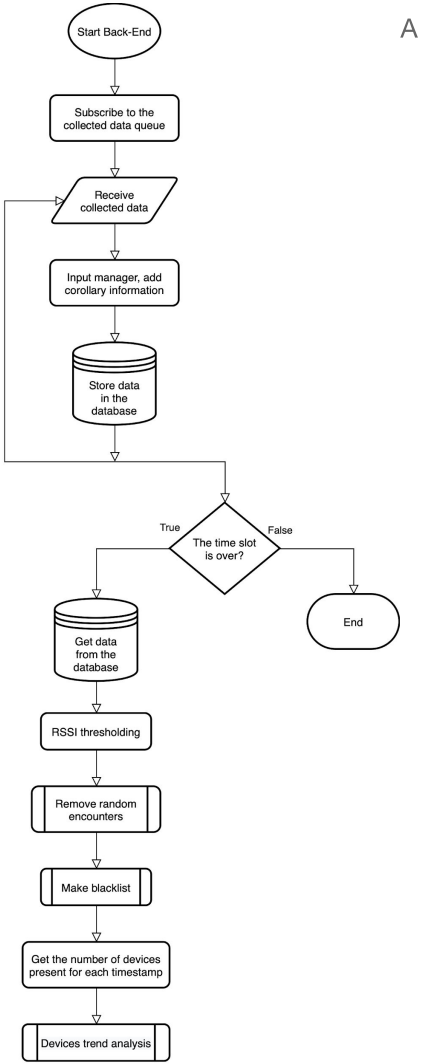


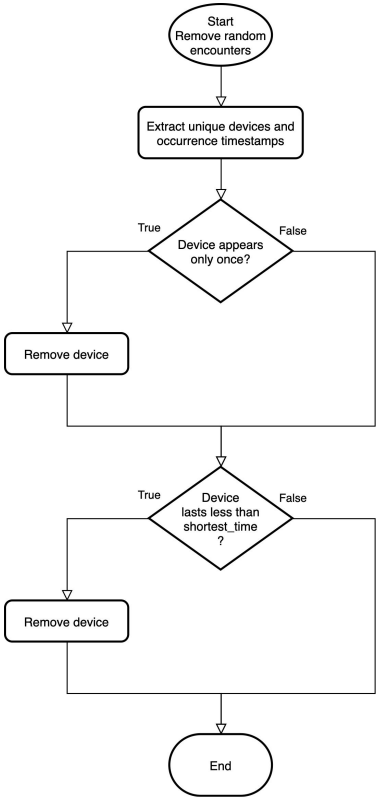


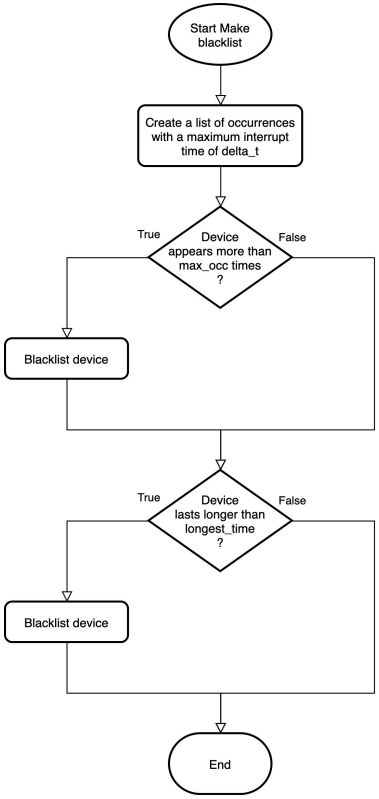


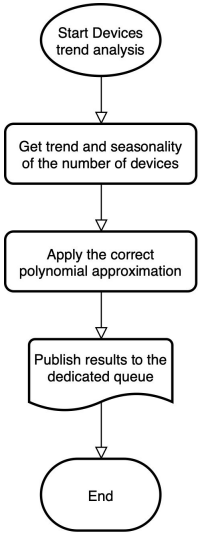


Back-End Logic

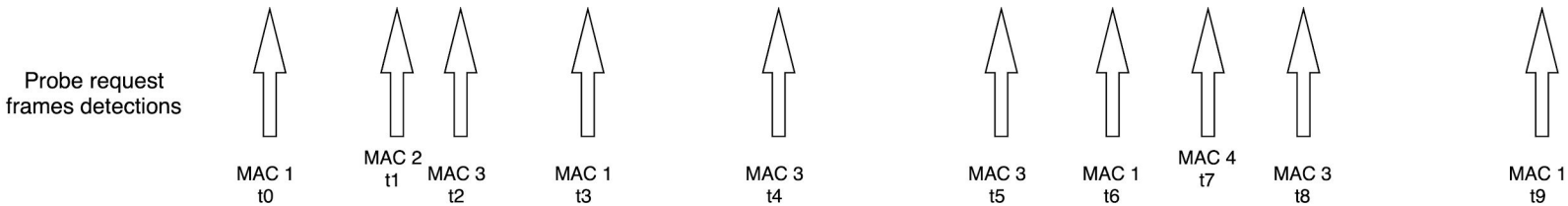








Presence of Devices



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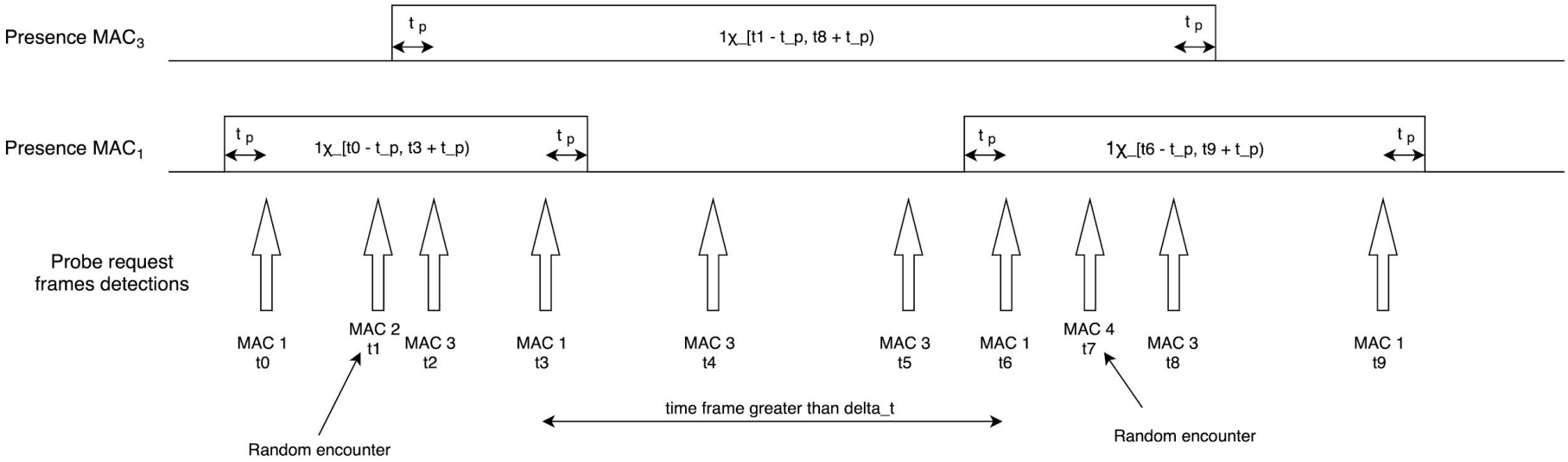

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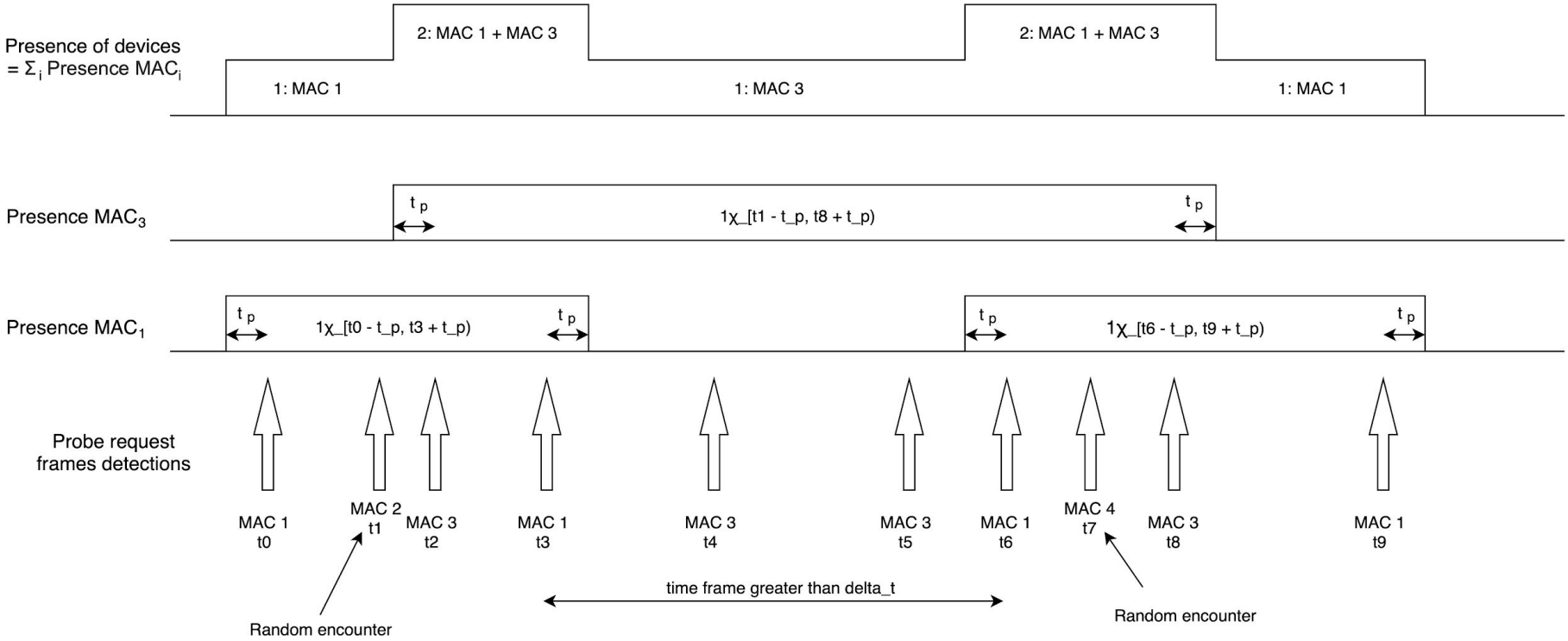


Feasibility Test at Home

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 ÷ -91 dBm not in the kitchen, -35 ÷ -69 dBm in the kitchen

→ Feasibility of the method for detecting devices in the area

System Validation

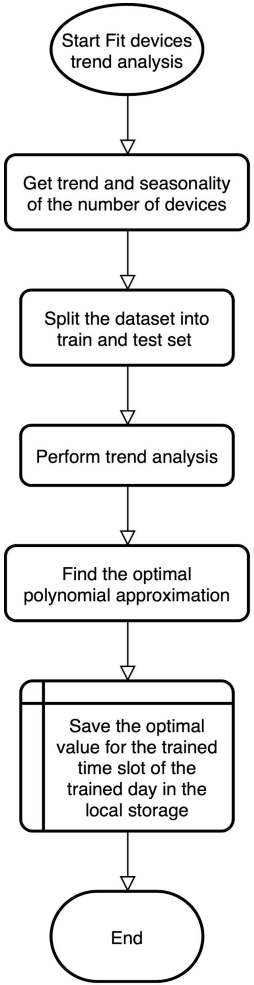
→ Raspberry Pi in a Cafe where I annotate manually the ground truth

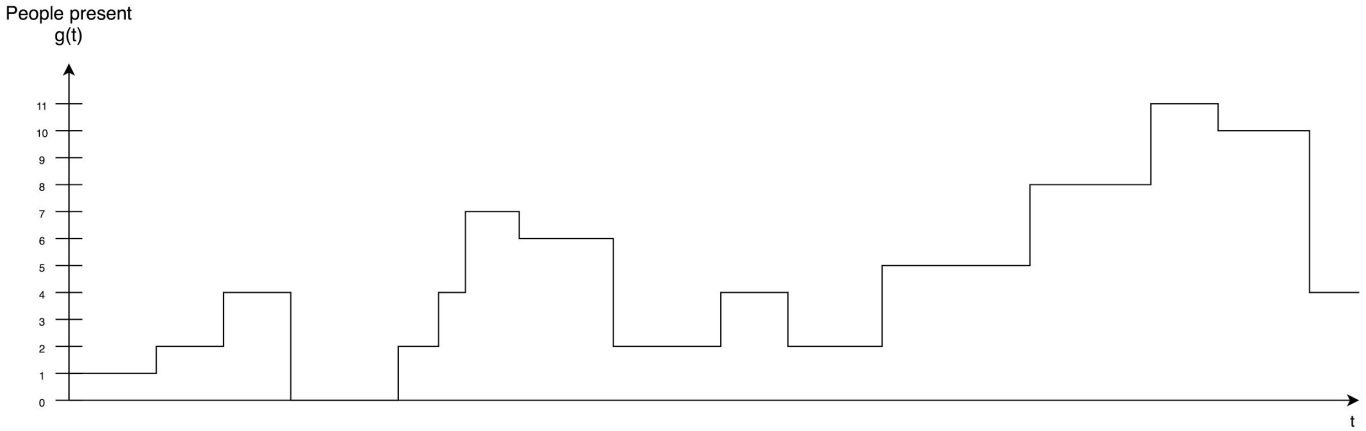
→ Eclipse Mosquitto Broker MQTT of U-Hopper on their cloud infrastructure

→ MQTT receiver and MongoDB on U-Hopper cloud infrastructure

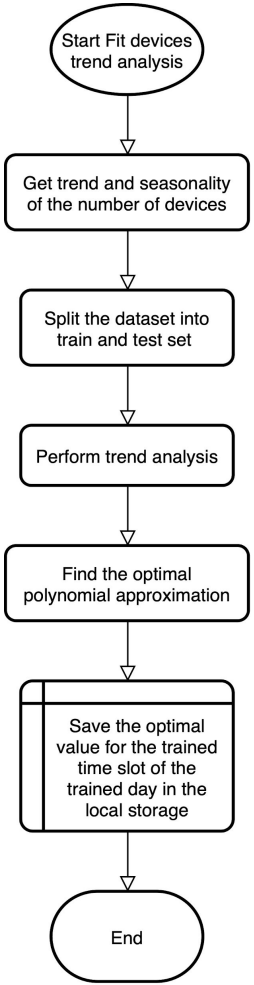
→ Analyzer and Estimator on my pc to use on the data + collected ground truth to test accuracy and reliability of the proposed system

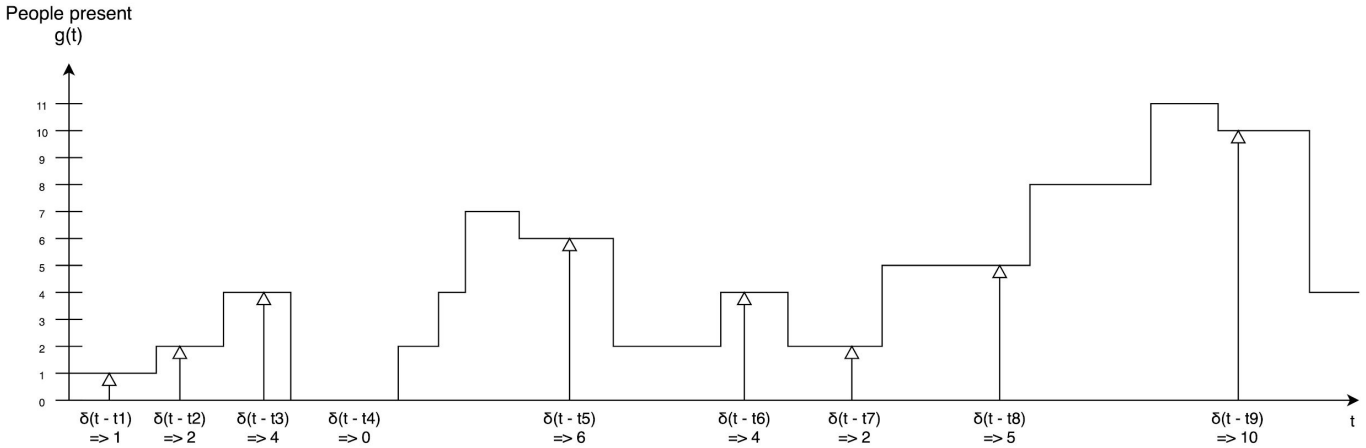
Ground Truth Collection





Ground Truth Collection





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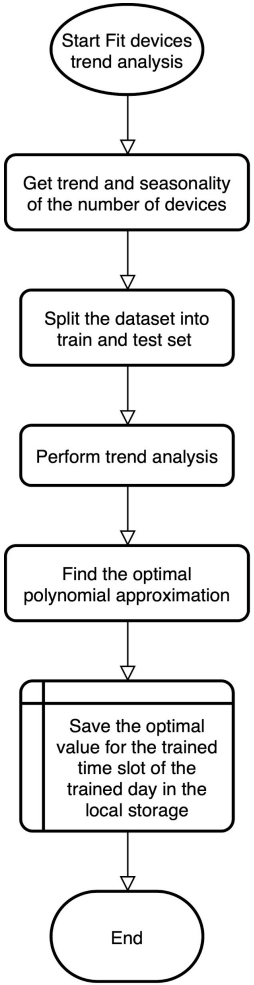
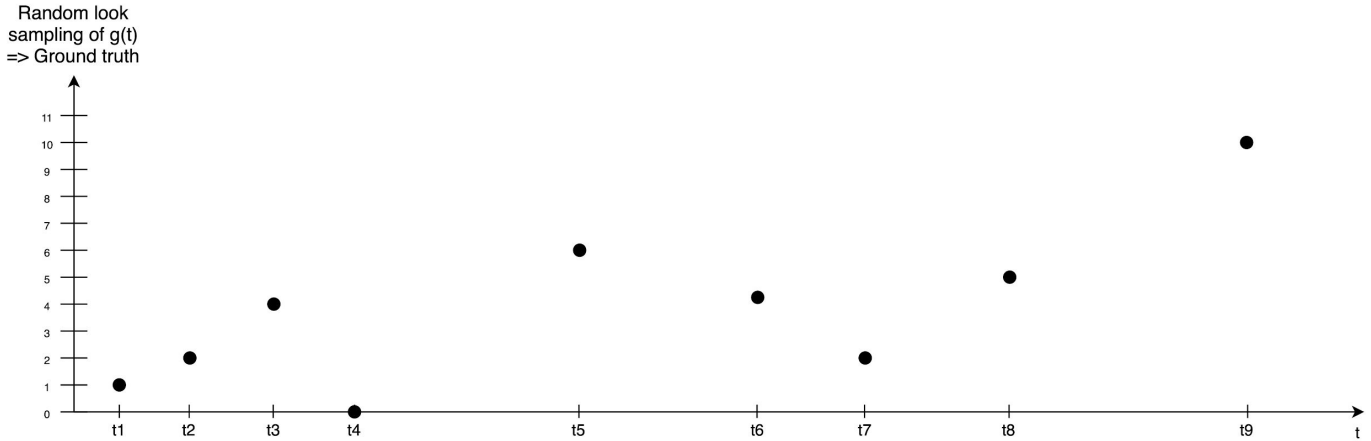




Test Results at Cafe

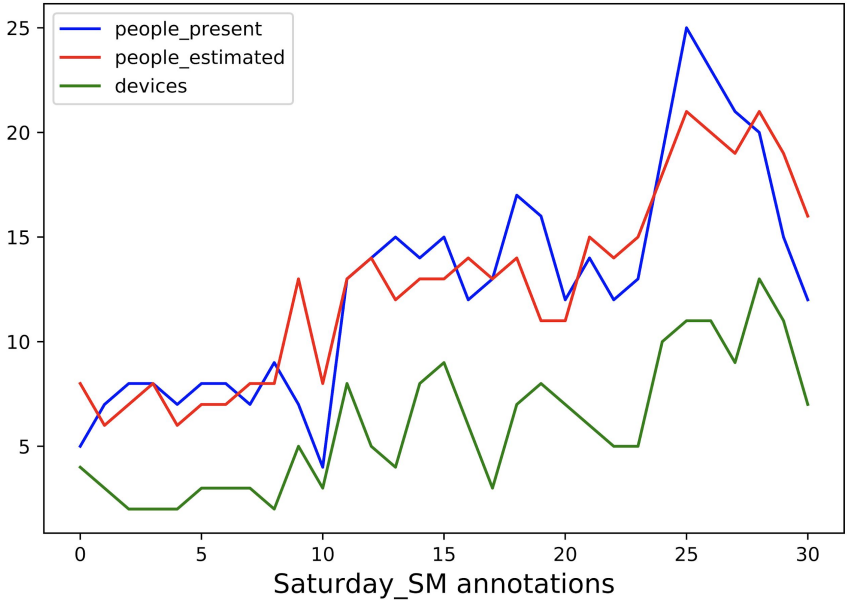
→ 4 weeks of data collection (24 days)

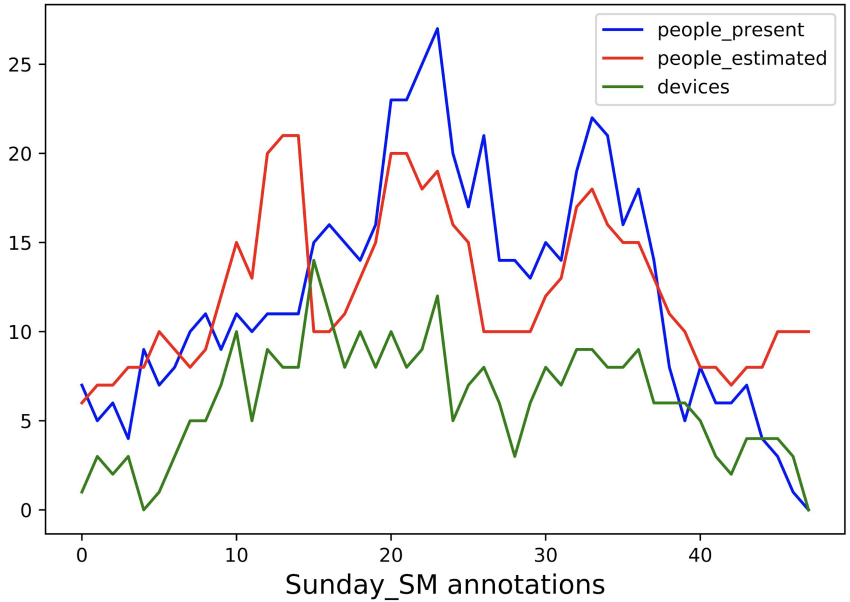
→ 1270 manual annotation of ground truth

→ 861979 probe request frames captured (~ 560 MB of data)

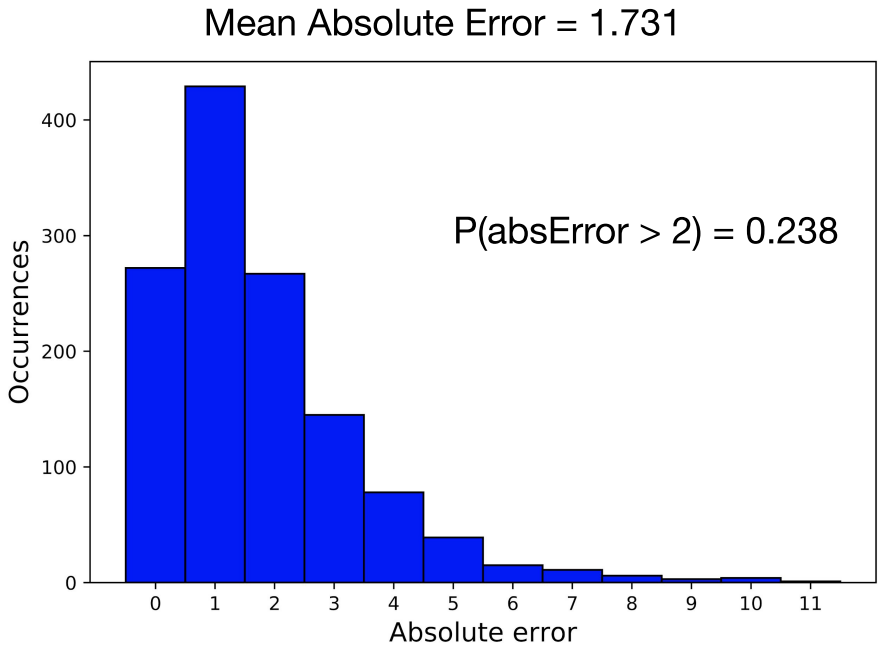
→ 38771 unique MAC addresses detected

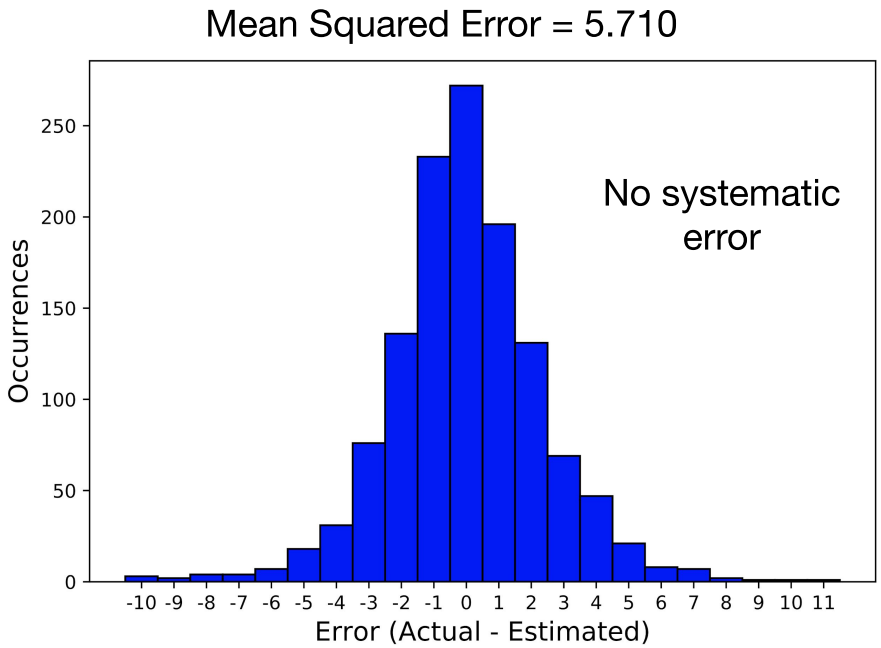
Test Results at Cafe



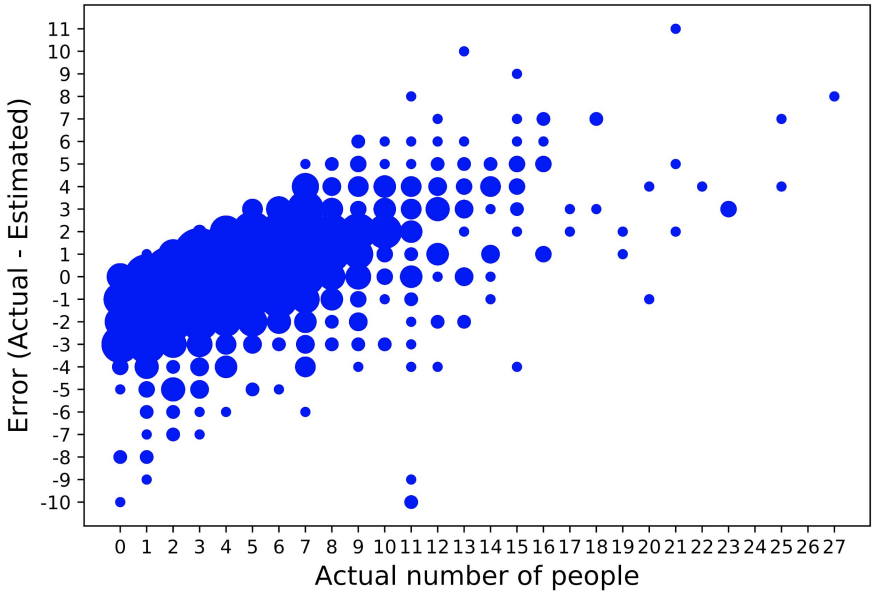


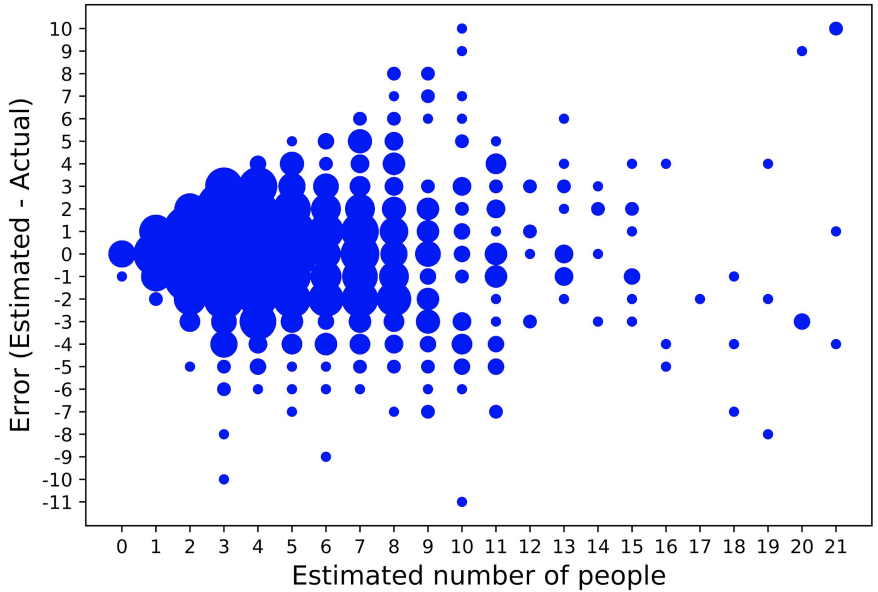
Error Distribution





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