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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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Academic year 2019/2020

# 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 **detect and monitor 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

→ Many fields of application and several implementations

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

# 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**

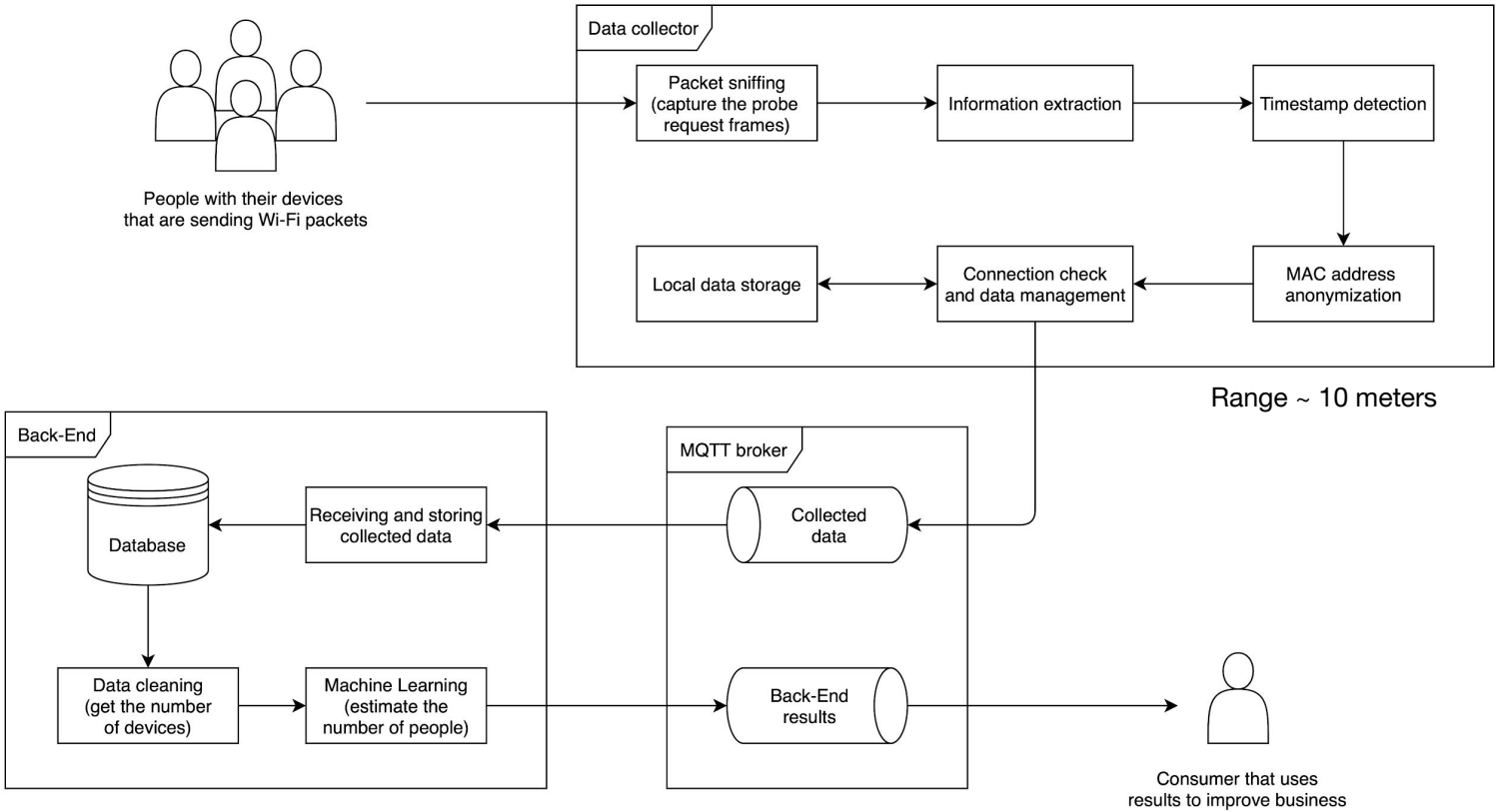
in a place of interest based on the Wi-Fi probe request frames?

# Achievements

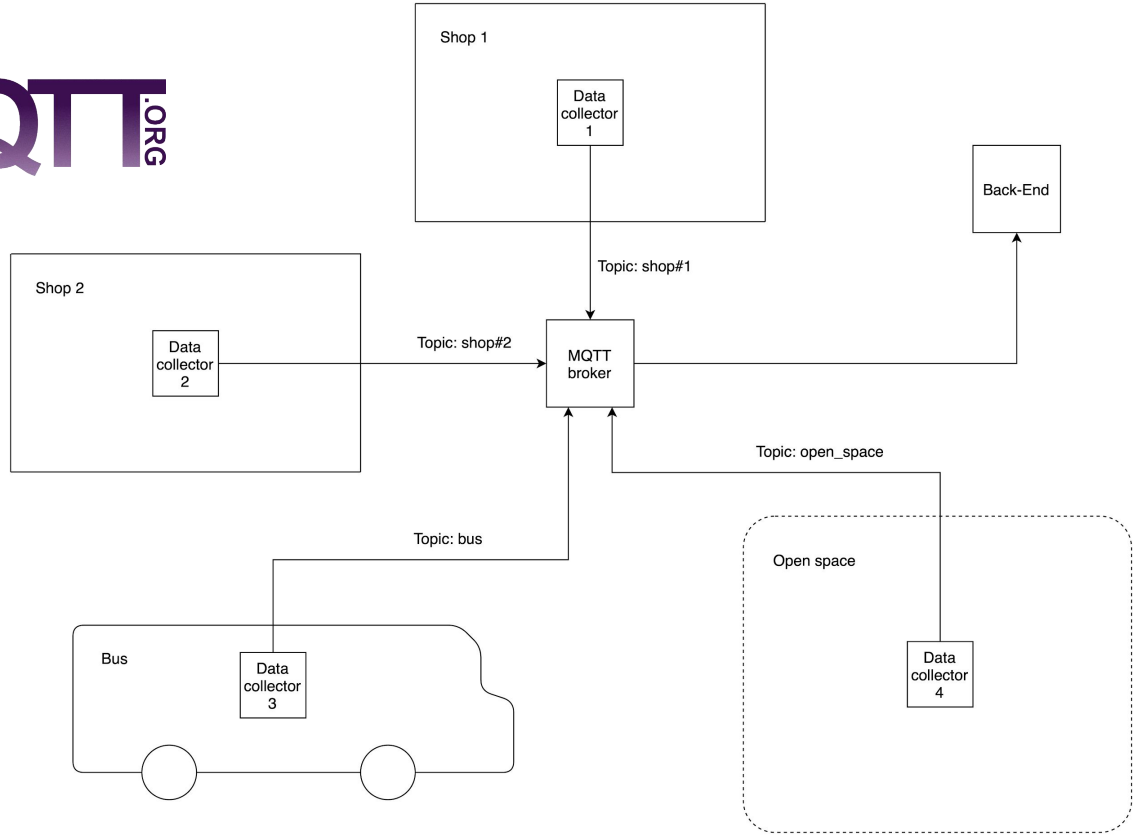
**Designed and implemented** a system for this problem that could work in several contexts

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

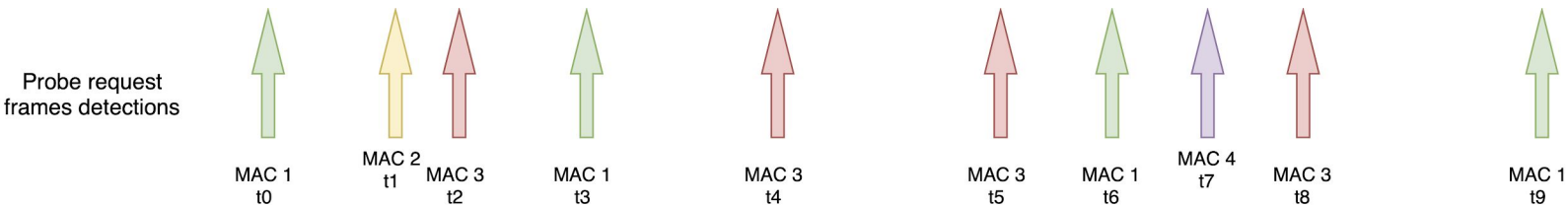
# System Architecture



# Scalable Architecture



# Presence of Devices



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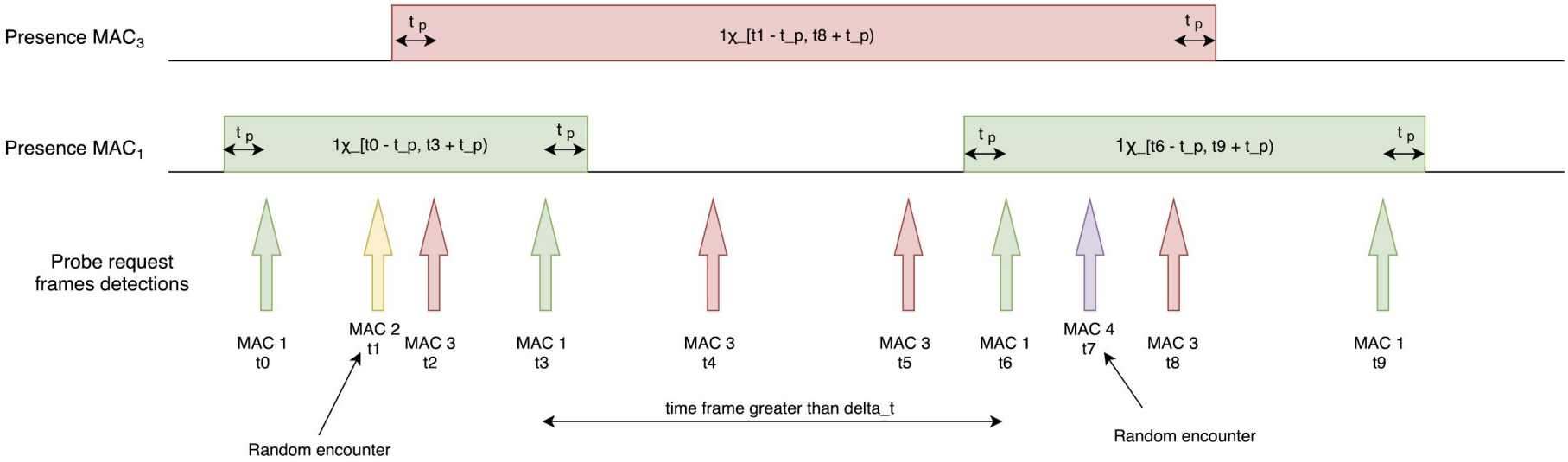

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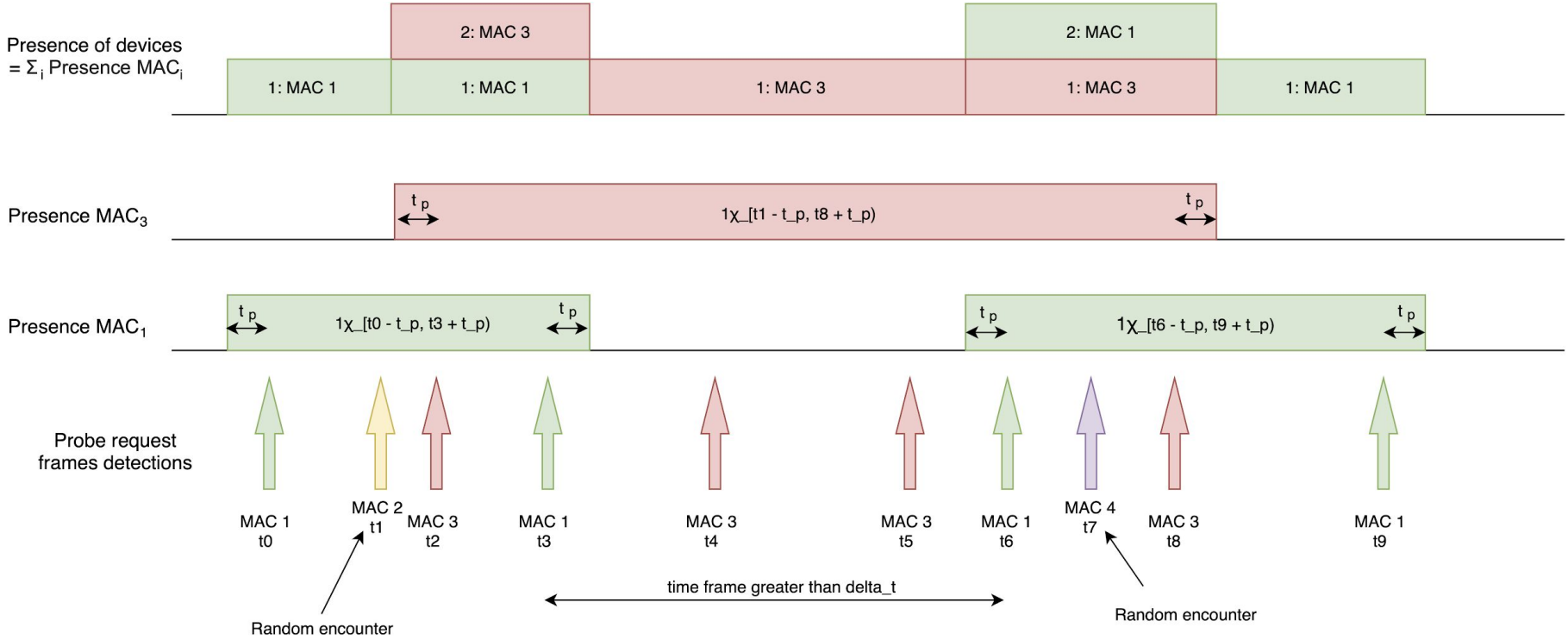


# Feasibility Test at Home


3 days of data collection

65928 probe request frames captured

12 home devices detected

2 main range of RSSI:

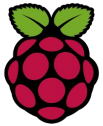
→ -35 ÷ -69 dBm in the kitchen

→ -71 ÷ -91 dBm not in the kitchen

Feasibility of the method for

**detecting devices in the area**

# System Validation

RaspberryPi in a Cafe where I annotate manually the ground truth


broker of **U-Hopper cloud infrastructure**

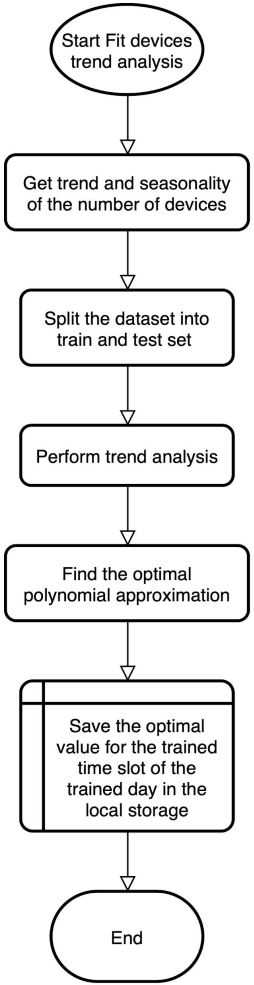


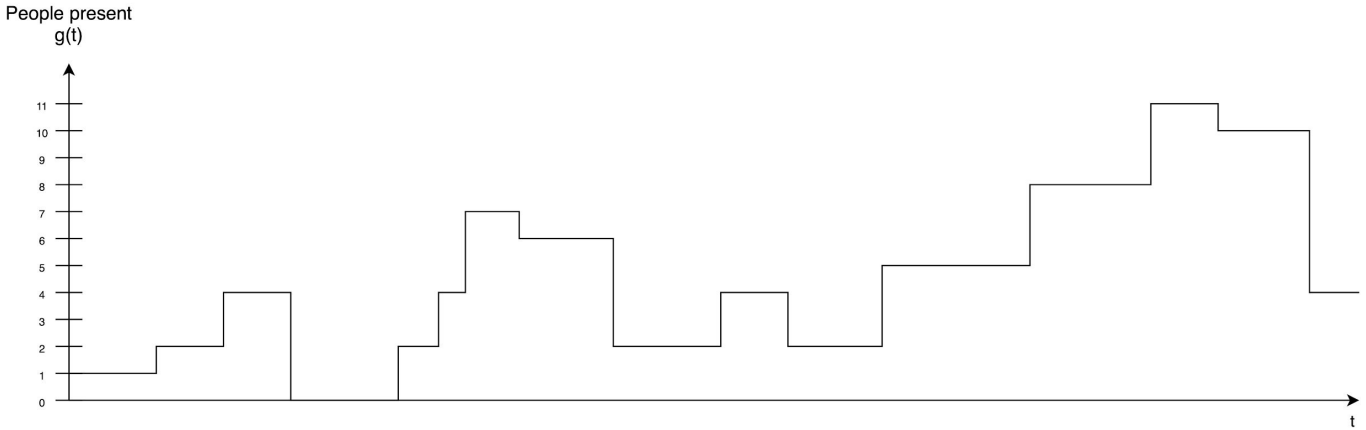
receiver and 


on U-Hopper cloud infrastructure

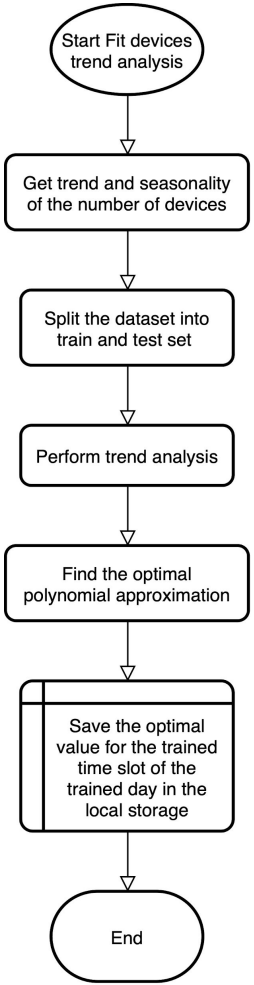
Analyzer and Estimator on my PC to use on the data and the annotated ground truth to test accuracy and reliability of the proposed system

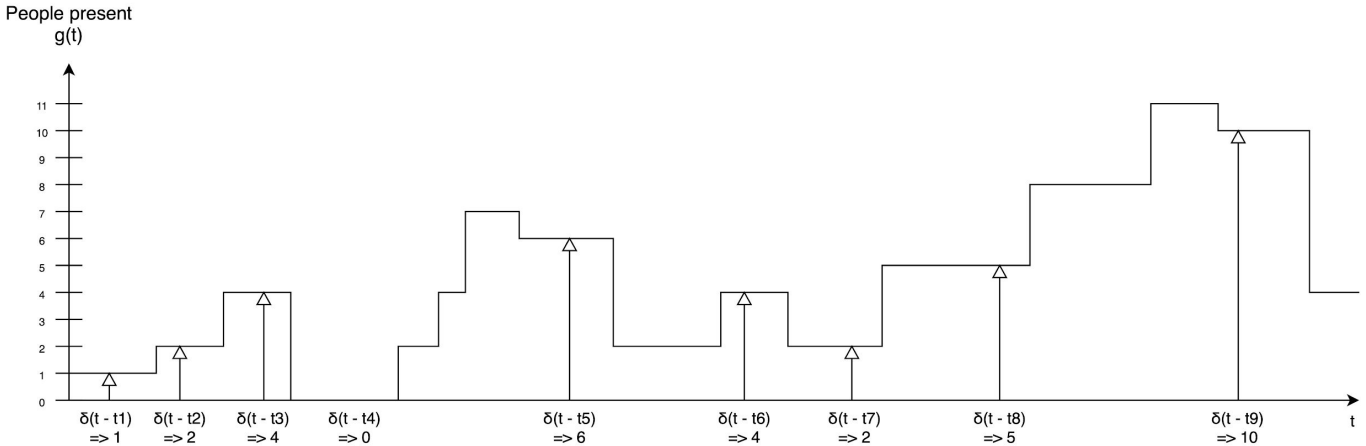
# Ground Truth Annotation



# Ground Truth Annotation



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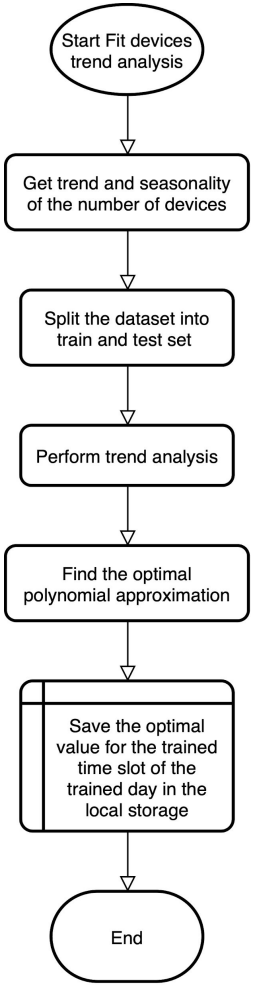
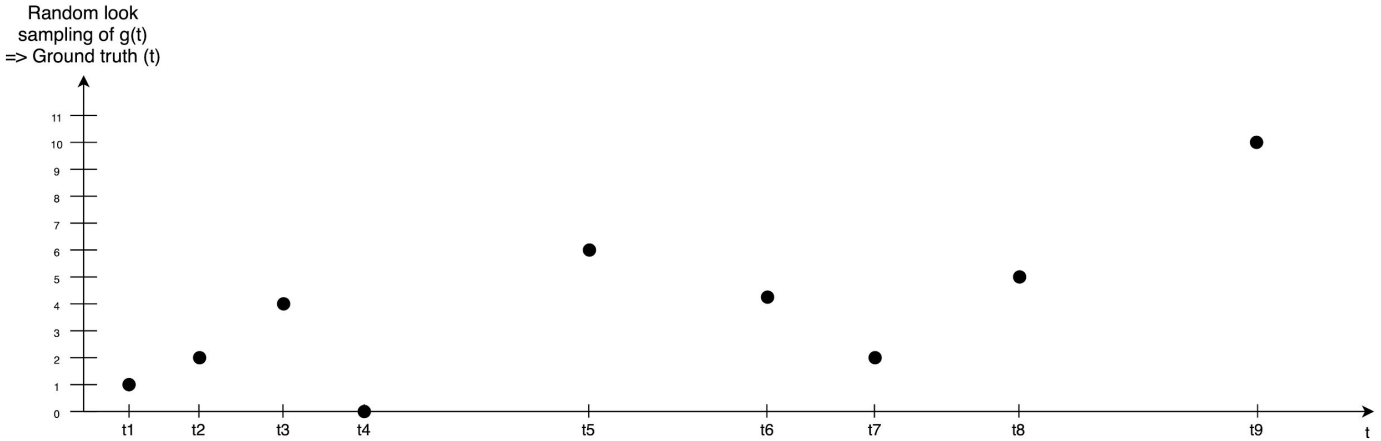


# Test Results at Cafe

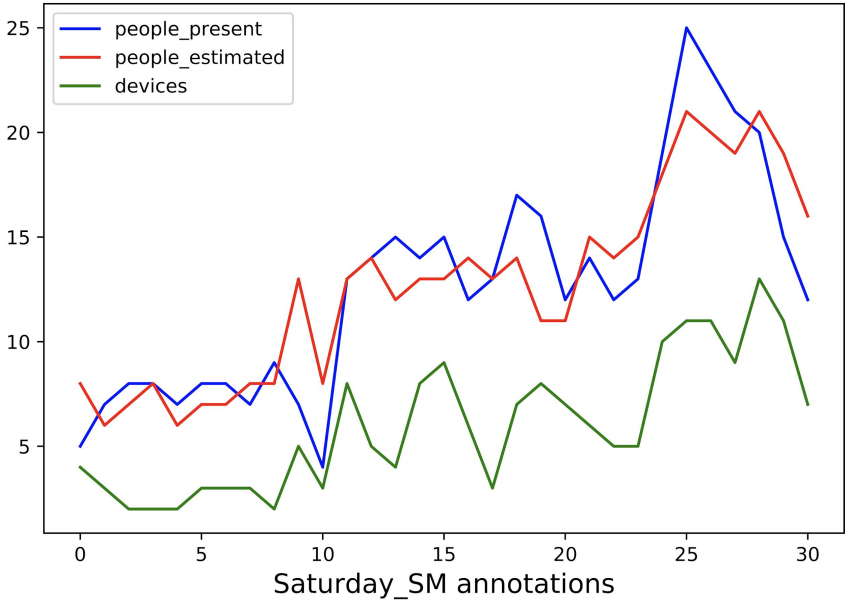

4 weeks of data collection (**24 days**)

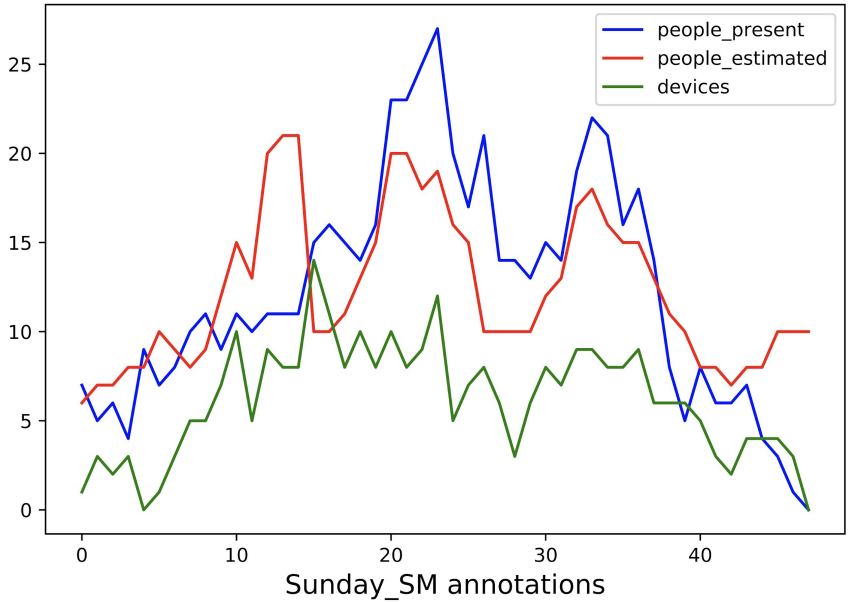
**1270** manual annotation of ground truth

861979 probe request frames captured (~ **560 MB**)

**38771** unique MAC addresses detected

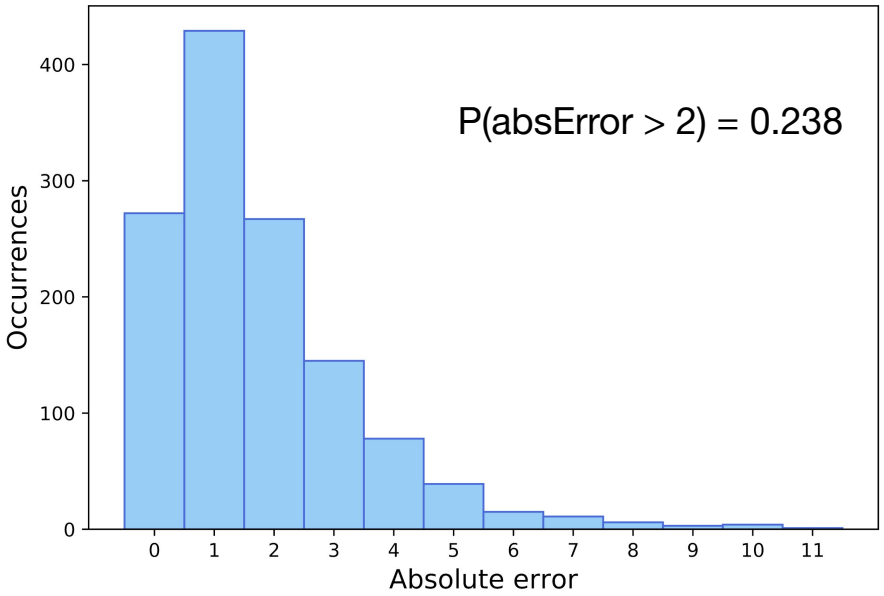
# Test Results at Cafe



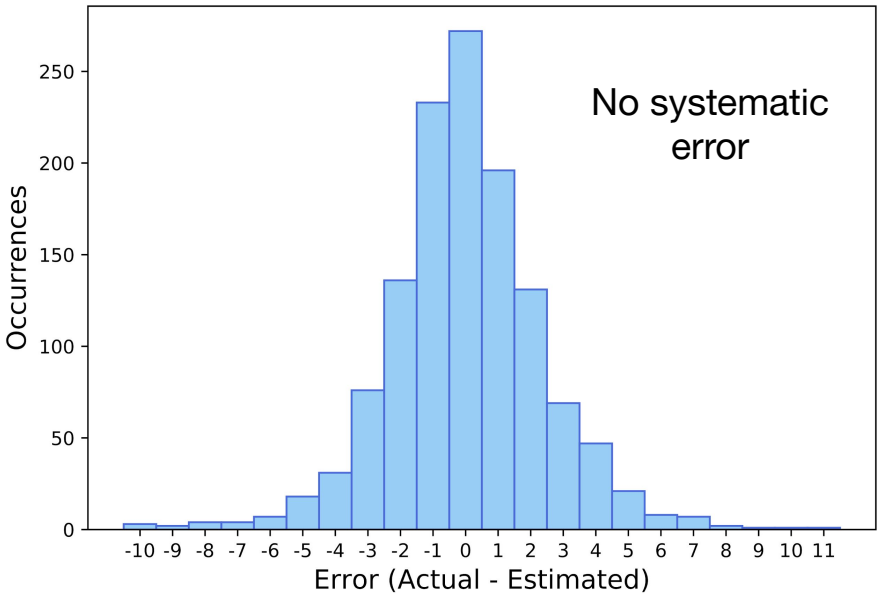



# Error Distribution

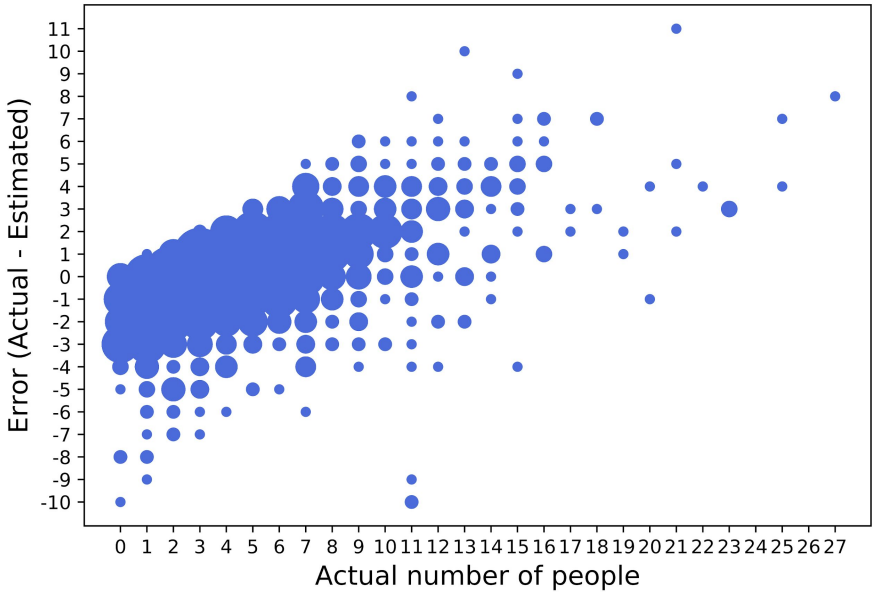
**Mean Absolute Error = 1.731**

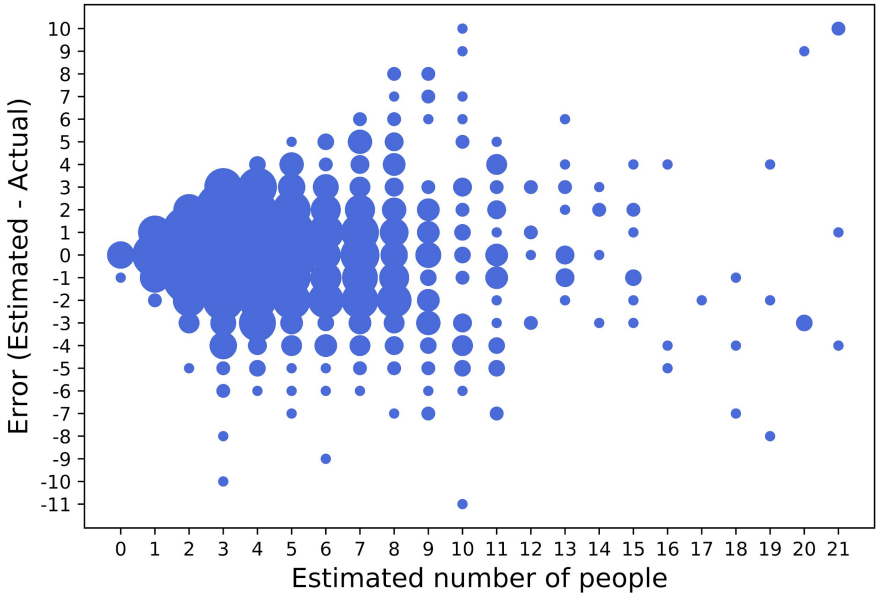



**Mean Squared Error = 5.710**



# 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 achieve 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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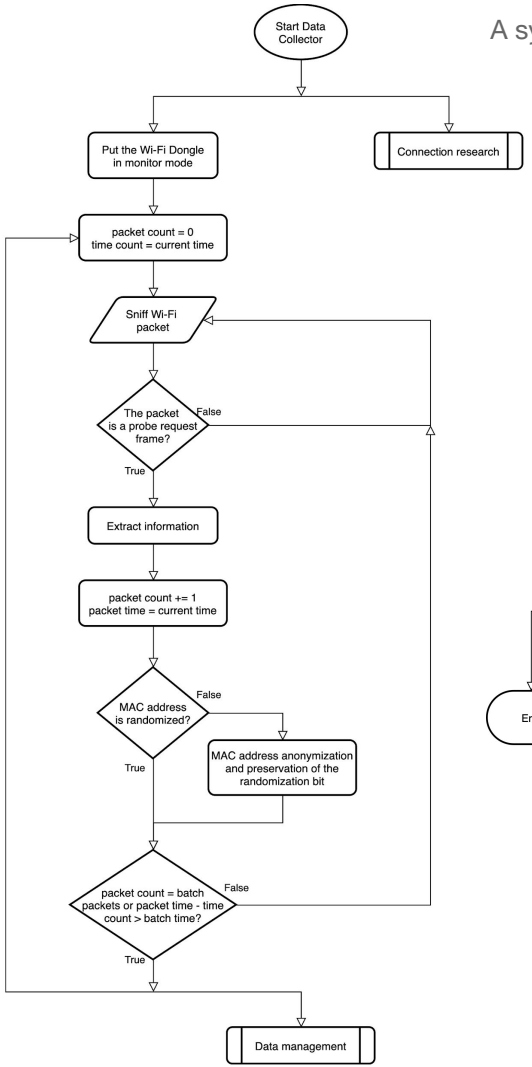
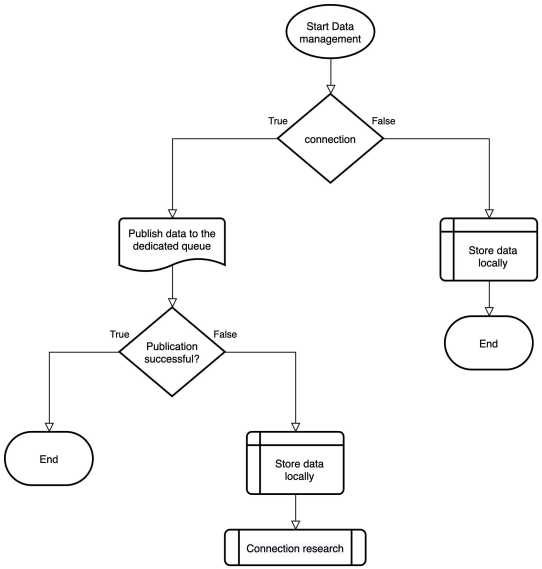
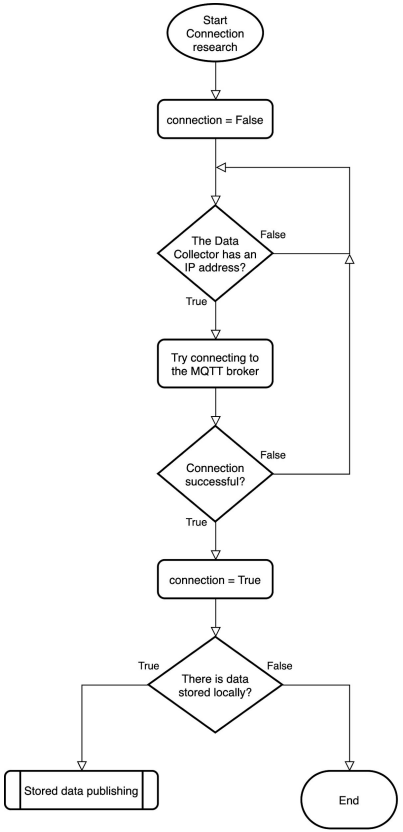
Thank you for your attention

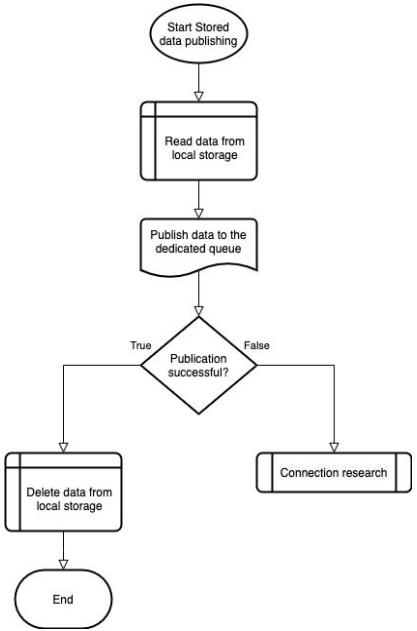
Samuel Bortolin

# Data Collector Logic



# Back-End Logic