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DI TRENTO

Estimating the number of people based on Wi-Fi probe request frames

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About this Project

Internship at U-Hopper:

Big Data Analytics

Business Intelligence

Chatbot

IoT solutions

Artificial Intelligence solutions

Problem Statement

Badly handled demand (the number of people who require the service)

can lead to overcrowding and inefficiency of the services

→ Inefficient and bad organized service leads to higher costs

→ Badly managed overcrowding (e.g. in supermarkets) during this global

pandemic period due to COVID-19 leads to long queues and new infections

Research Statement

Is it possible to continuously estimate the number of people

based on the Wi-Fi probe request frames?

Thesis Objectives

→ Capture and analysis of Wi-Fi probe request frames

→ Data extraction, transmission and storage

→ Analysis of Wi-Fi probe request frame patterns

→ Provide an estimation of the number of customers

State of the Art

→ Analysis of different methods to count/estimate people

Infrared sensors, LSE, treadle switch-based systems, Video methods,

Audio methods, Wi-Fi, Bluetooth, BLE, LTE Radar, RFID approaches

→ Many fields of applicability and different implementations

Why Wi-Fi solution?

High diffusion of Wi-Fi devices,

high accuracy using machine learning,

low-cost implementation,

real-time data transmission,

user privacy ensured.

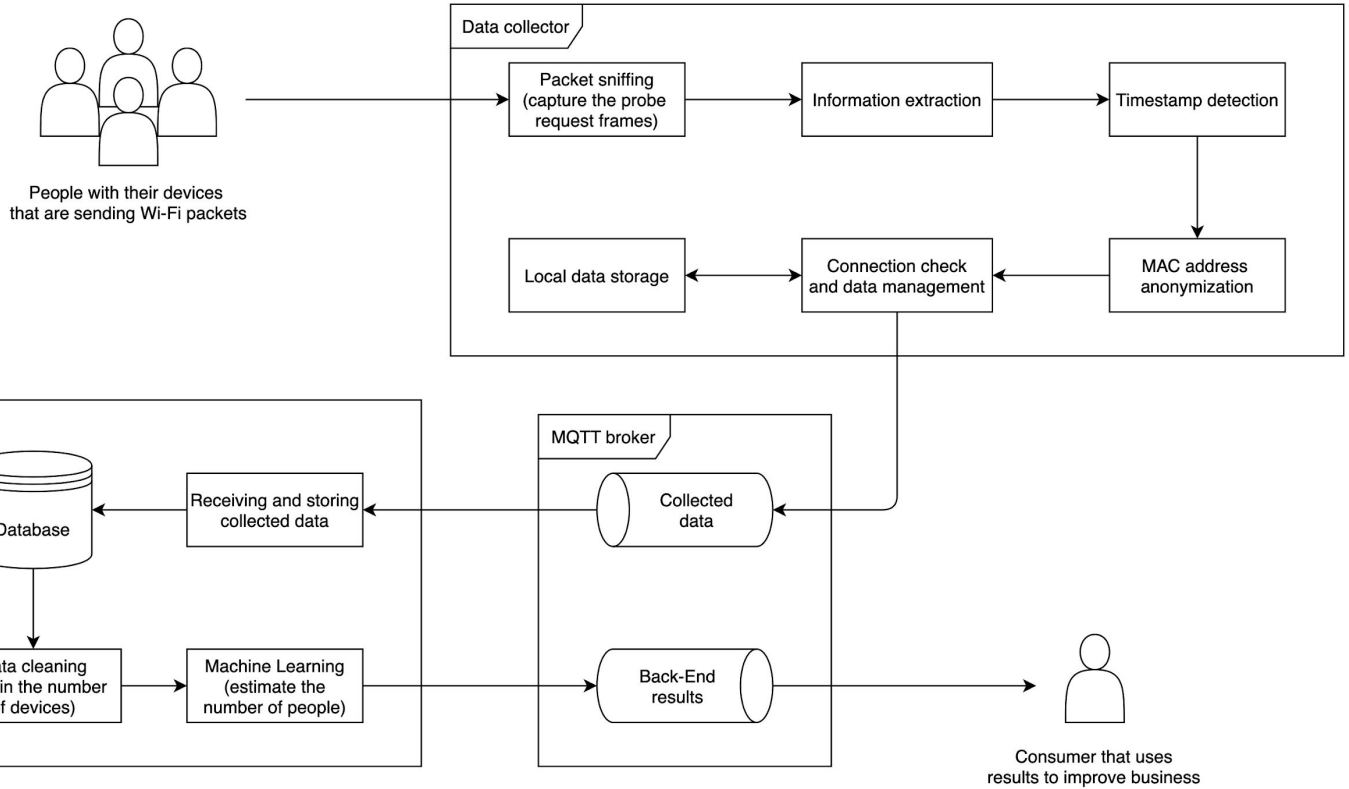
Standard 802.11 → Management frame → Probe request frames

Results

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

Tested the system in a Cafe and collected 4 weeks of data

System Architecture



Data Collector Logic

Packet sniffing with Scapy → Information extraction

MAC address anonymization using BLAKE2s

Check connection → Local storage / MQTT transmission

Connect (clean_session = False) and login to the MQTT broker (username e password) → Publish batches to the dedicated queue (QoS = 2)

Back-End Logic

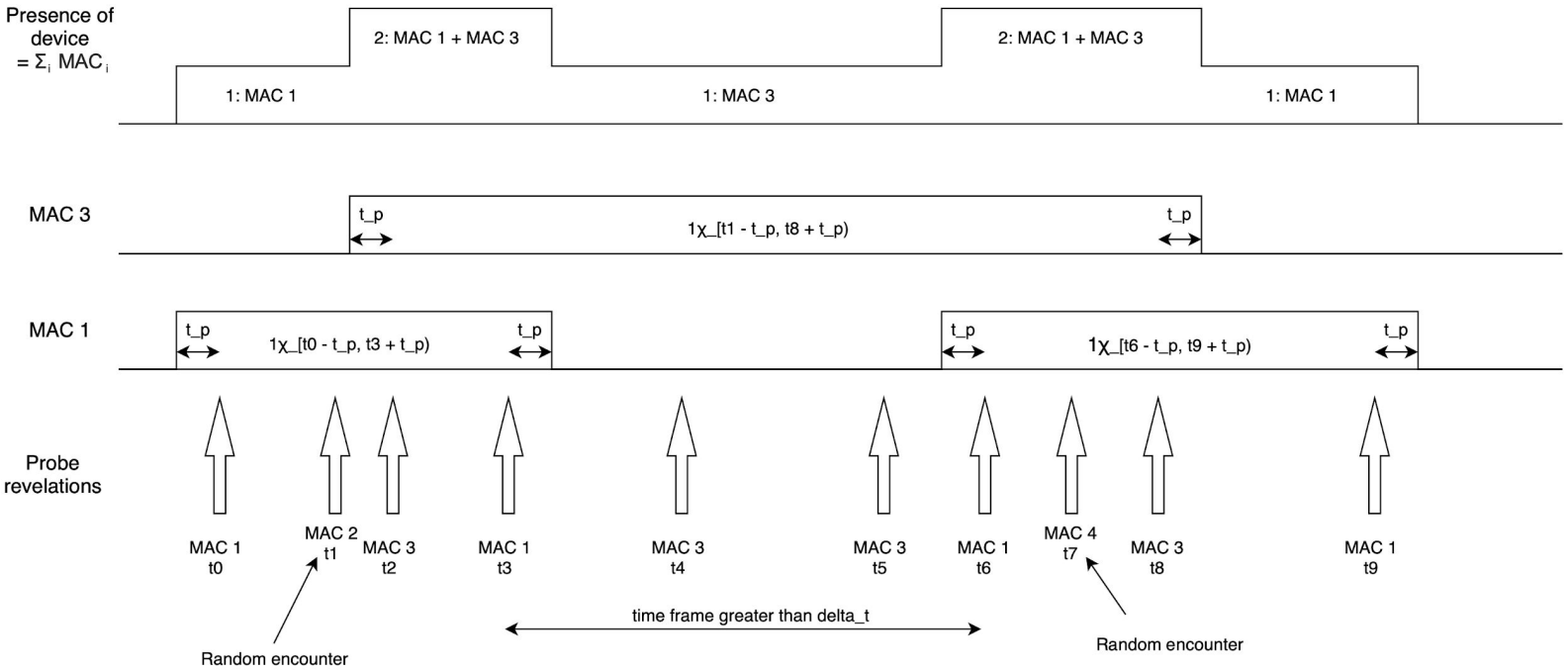
Publish to a topic → MQTT broker forwards the data to the subscribers

MQTT receiver in the Back-End → Subscription and storage in MongoDB

Data cleaning → RSSI threshold, random encounters, blacklist → # devices

Machine Learning algorithm → Fit degree and coefficients of polynomial approximations using trend and seasonality of the # devices → # people

Presence of device



Implementation

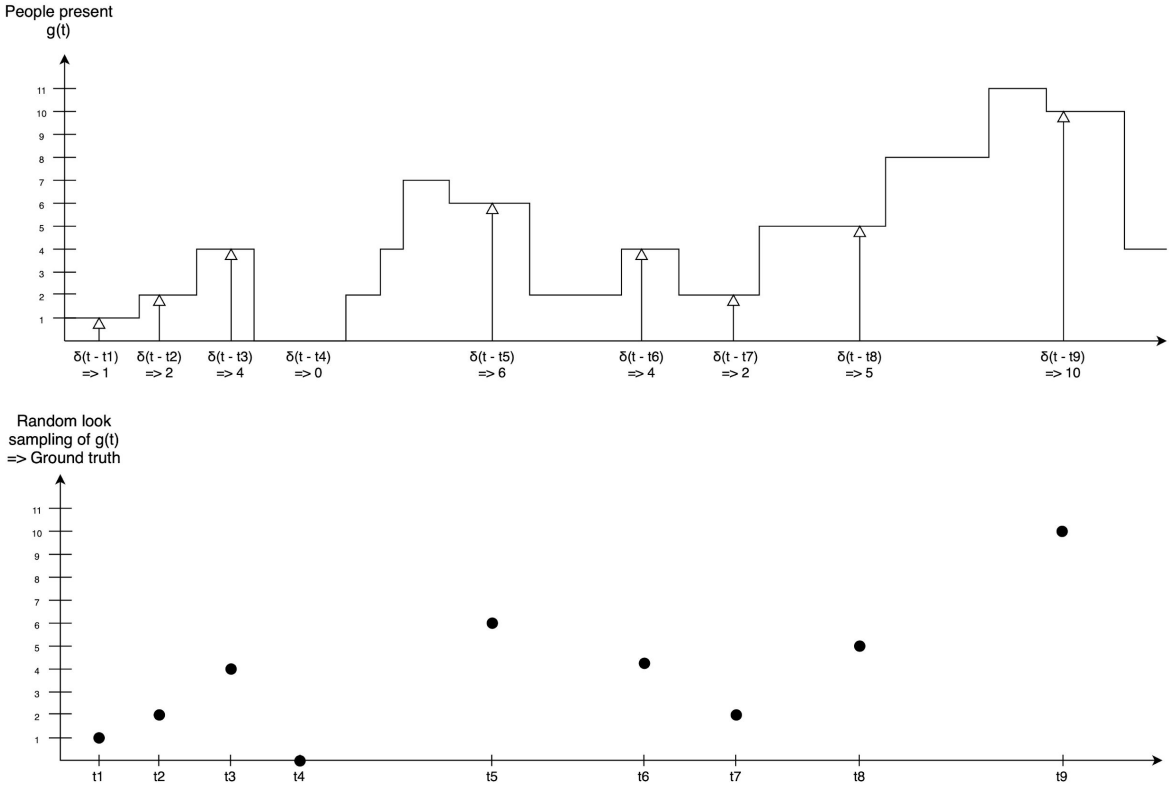
Packet sniffing on RPi → MQTT broker

→ MQTT receiver in the Back-End → Storage in MongoDB

→ Ground truth (random look) → Data cleaning → # device

→ Machine Learning algorithm → # people

Ground Truth Collection



Feasibility Test

Devices		Day 1			Day 2			Day 3		Comments
	# probes	RSSI range 1	RSSI range 2	# probes	RSSI range 1	RSSI range 2	# probes	RSSI range 1	RSSI range 2	
Wi-Fi gate	6410	-75 ÷ -81		4959	-65 ÷ -77		4819	-65 ÷ -75		omnipresent, send 2/4 probe every ~ 30 sec, static, ~ 6/7 m away
Smart TV	6	-83 ÷ -89		/			/			static in the living room, ~ 6/7 m away
PlayStation 4	13660	-71 ÷ -83		5	-71 ÷ -75		5	-75 ÷ -81		static in the living room, ~ 6/7 m away
iMac	294	-83 ÷ -91		197	-79 ÷ -87		59	-75 ÷ -85		static in my bedroom, ~ 10 m away
MacBook	32	-87 ÷ -91	-61 ÷ -67	/			/			range 1 → far, not in the kitchen; range 2 → nearby, in the kitchen
Mom's Samsung	38	-75 ÷ -91		3	-73 ÷ -79		/			far, not in the kitchen (Wi-Fi usually turned off)
Grandma's Samsung	/			/			39	-71 ÷ -81	-57 ÷ -65	range 1 → far, not in the kitchen; range 2 → nearby, in the kitchen
Thomas's Samsung	103	-75 ÷ -89	-57 ÷ -69	49	-71 ÷ -79	-51 ÷ -69	166	-73 ÷ -81	-47 ÷ -69	range 1 → far, not in the kitchen; range 2 → nearby, in the kitchen
Dad's iPhone	94	-75 ÷ -91	-55 ÷ -65	1547	-77 ÷ -83	-49 ÷ -67	1170	-69 ÷ -83	-35 ÷ -67	range 1 → far, not in the kitchen; range 2 → nearby, in the kitchen
Mattia's iPhone	1377	-77 ÷ -91	-59 ÷ -75	978	-75 ÷ -85	-49 ÷ -65	2051	-73 ÷ -85	-49 ÷ -67	range 1 → far, not in the kitchen; range 2 → nearby, in the kitchen
My iPhone	40	-79 ÷ -91	-65 ÷ -67	54	-73 ÷ -85	59	98	-73÷ -83	-53 ÷ -67	range 1 → far, not in the kitchen; range 2 → nearby, in the kitchen
Printer	/			1	-81		/			static in my bedroom, ~ 10 m away
Other Wi-Fi dongle	/			13084	-19 ÷ -23	-37 ÷ -63	12188	-19 ÷ -23	-37 ÷ -61	another Wi-Fi dongle, 1/2 probe every 6/7 sec → value swings sometimes
Samsung Galaxy J3	17	-85 ÷ -91		/			/			non-home device
Samsung Galazy A20e	/			1	-83		/			non-home device
Randomized MACs	626			568			1190			probes with randomized MAC address, vague values of the RSSI
Total	22698			21445			21785			average of 22000 Wi-Fi probe request frames for ~ 18 hours

3 days of data collection, ~66.000 Wi-Fi PRF → detecting devices in the area

Validation

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

→ Broker MQTT (Mosquitto) of U-Hopper on their server

→ MQTT receiver and database (MongoDB) on U-Hopper server using Docker containers and using a volume for persisting data

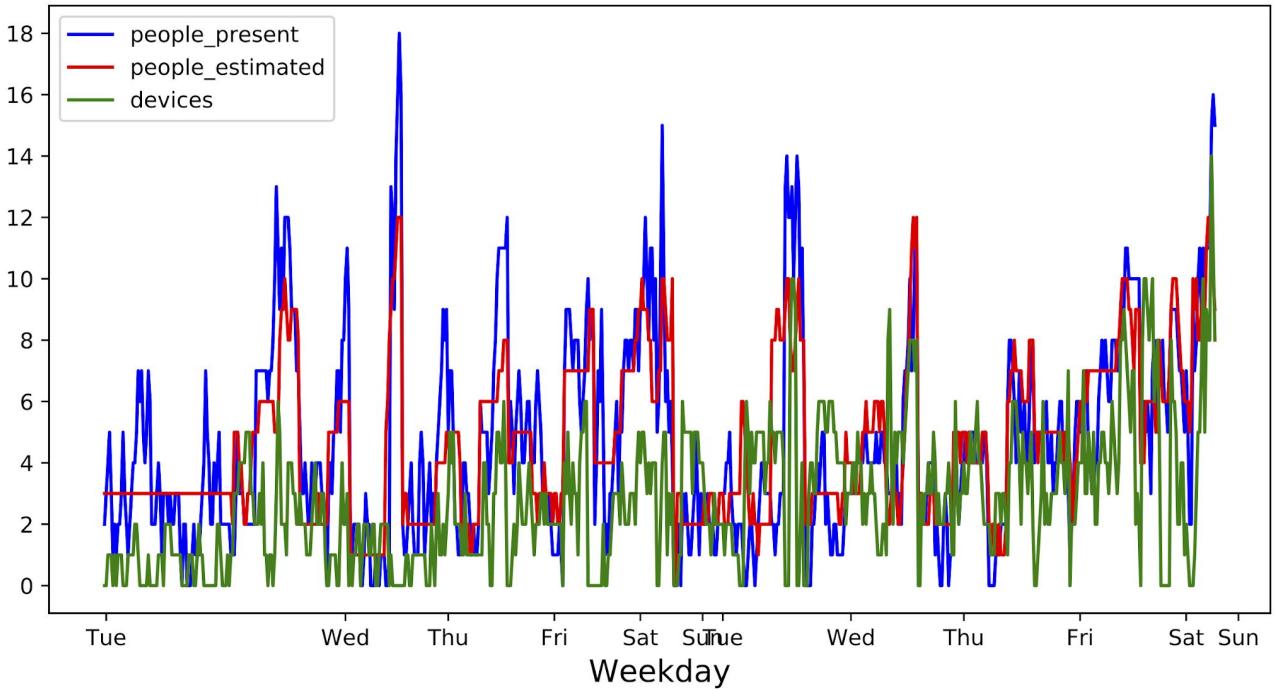
→ Analyzer/Estimator on my pc to use on the volume + collected ground truth to test accuracy and reliability of the proposed system

Results

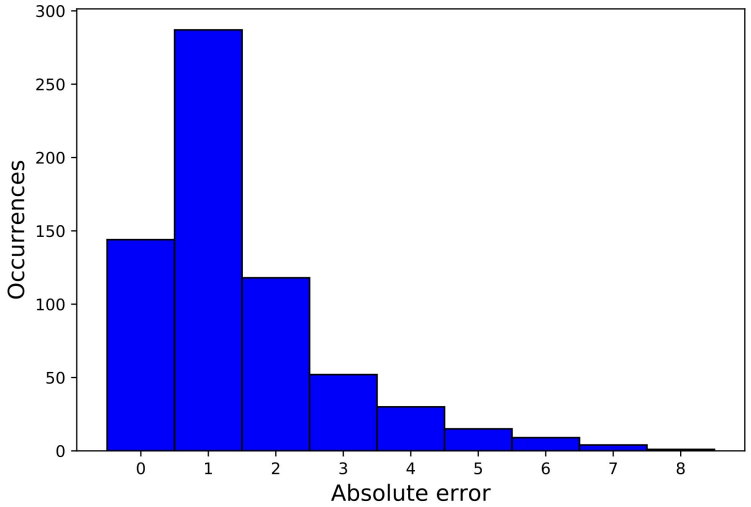
	2020-06-16	2020-06-17	2020-06-18	2020-06-19	2020-06-20	2020-06-21		Total1
Probe captured	24011	19329	22533	23041	19062	11238		119214
Ttotal MACs	1489	873	1281	1307	1447	1187		7584
MACs only registered once	909	504	753	852	1002	634		4654
MACs lasted shorter than 20 seconds	443	280	395	344	342	447		2251
MACs occurred more than 10 times throughout the day	2	3	3	3	2	0		13
MACs lasted longer than 7200 seconds in any of it's occurrences	4	2	5	5	4	3		23
MACs remained	131	84	125	103	97	103		643
Manual annotations	116	61	63	51	37	12		340
							Mean Absolute Error	1.461
							Mean Squared Error	4.039
							Scaled_MAE_trend/count	0.448
							Scaled_MSE_trend/count	0.700

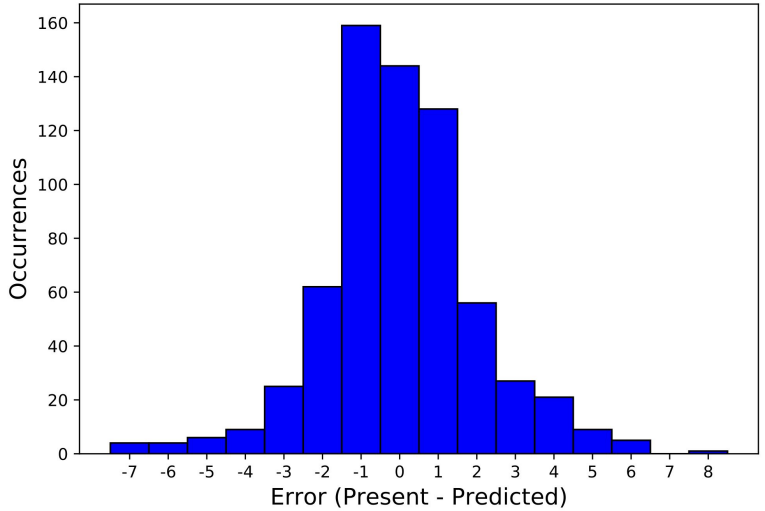
2020-06-23	2020-06-24	2020-06-25	2020-06-26	2020-06-27	2020-06-28		Total2	Total
45730	56835	58203	61900	28941	19768		271377	390591
1579	2260	2293	2282	1182	715		10311	17895
333	490	509	462	242	106		2142	6796
1060	1568	1543	1577	805	517		7070	9321
0	2	1	2	0	0		5	18
6	5	6	8	3	3		31	54
180	195	234	233	132	89		1063	1706
76	67	69	63	31	14		320	660
						Mean Absolute Error	1.461	1.461
						Mean Squared Error	4.039	4.039
						Scaled_MAE_trend/count	0.448	0.448
						Scaled_MSE_trend/count	0.700	0.700

Results

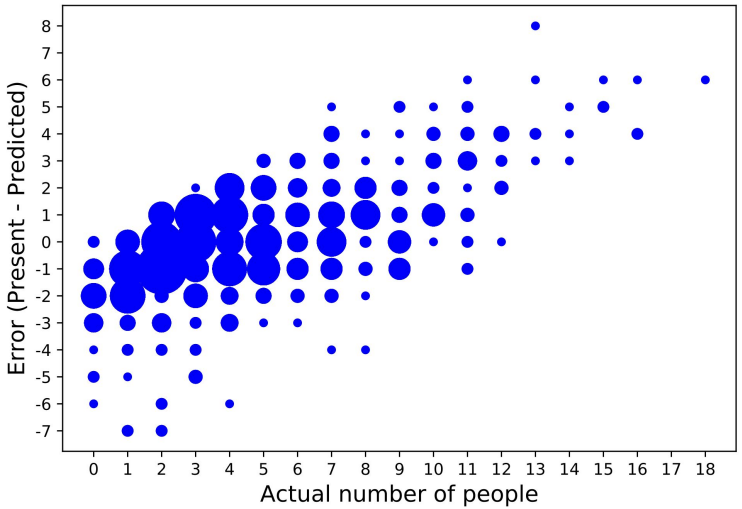

people_present
people_estimated
devices
18
16
14
12
10
8
6
4
2
0
Tue
Wed
Thu
Fri
Sat
Sun
Tue
Wed
Thu
Fri
Sat
Sun
Weekday

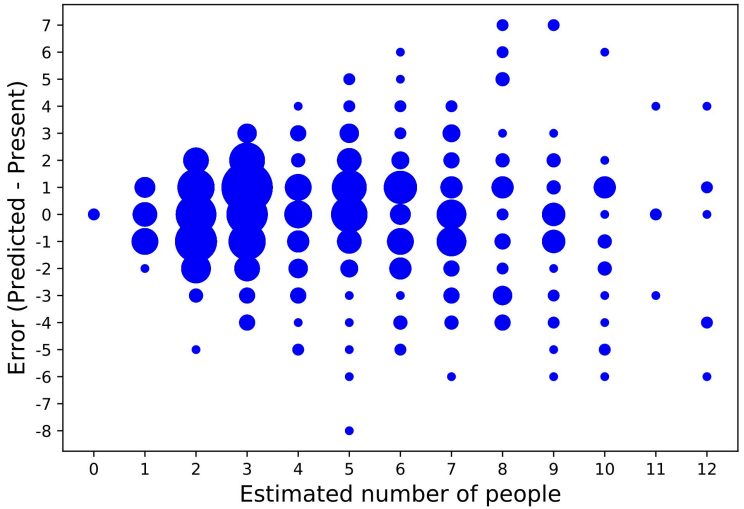
Results


Occurrences
Absolute error
0
50
100
150
200
250
300
0
1
2
3
4
5
6
7
8


Occurrences
Error (Present - Predicted)
0
20
40
60
80
100
120
140
160
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8

Results


Error (Present - Predicted)
Actual number of people
8 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18


Error (Predicted - Present)
Estimated number of people
7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7 -8
0 1 2 3 4 5 6 7 8 9 10 11 12

Summary

Future Works