

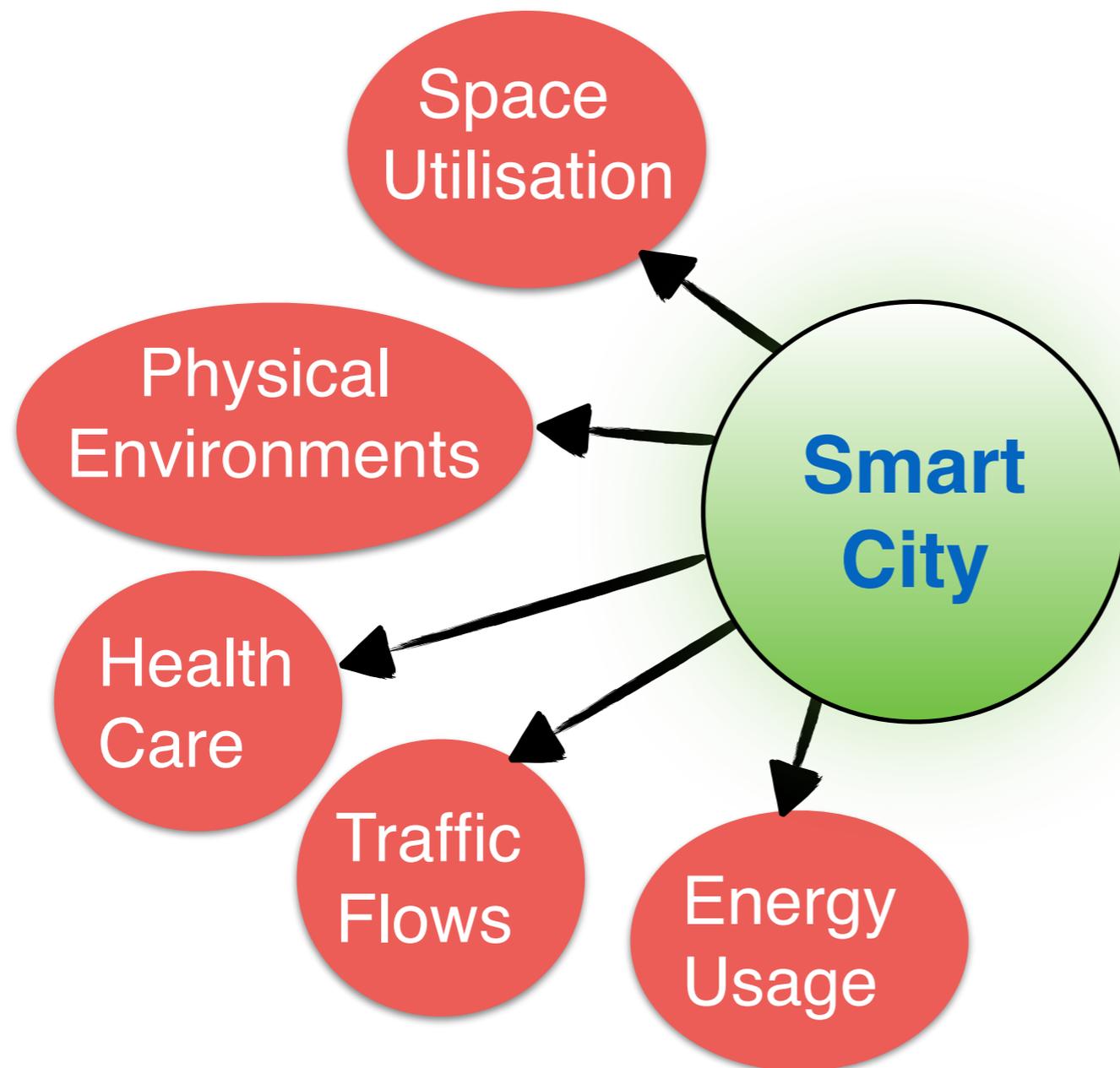


# A city needs to be smart?

*“The goal of building a smart city is to improve quality of life by using urban informatics and technology to improve the efficiency of services and meet **residents'** needs.” — Wikipedia*

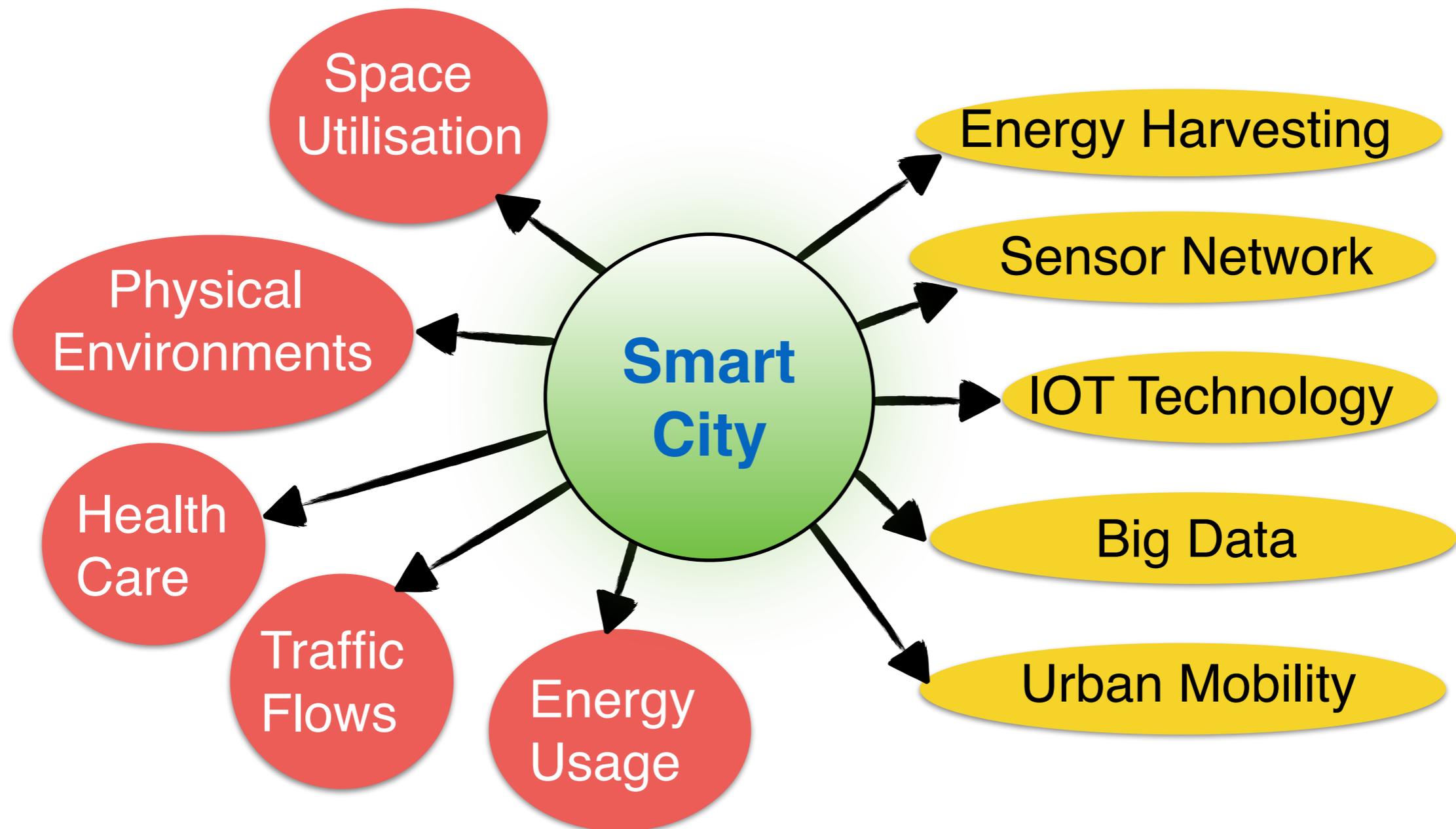
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# Motivation of Human Sensing



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Which building has the most number of people? How the workers move between the buildings?

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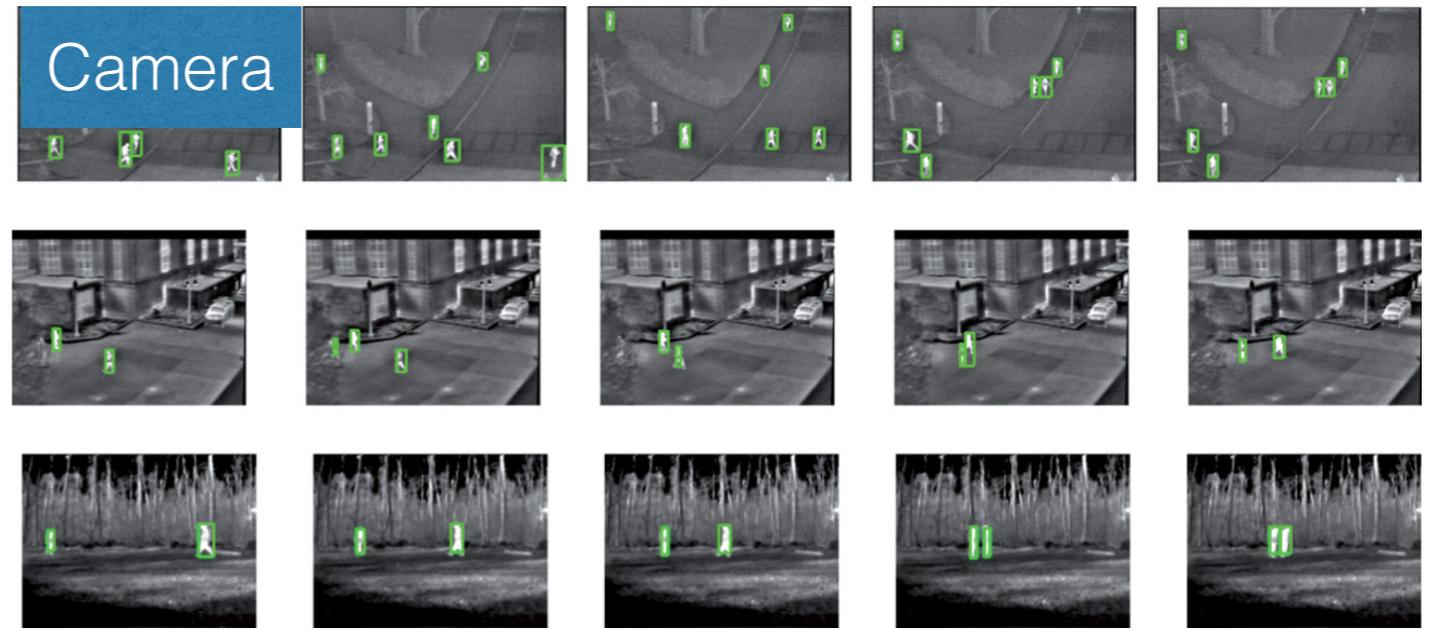
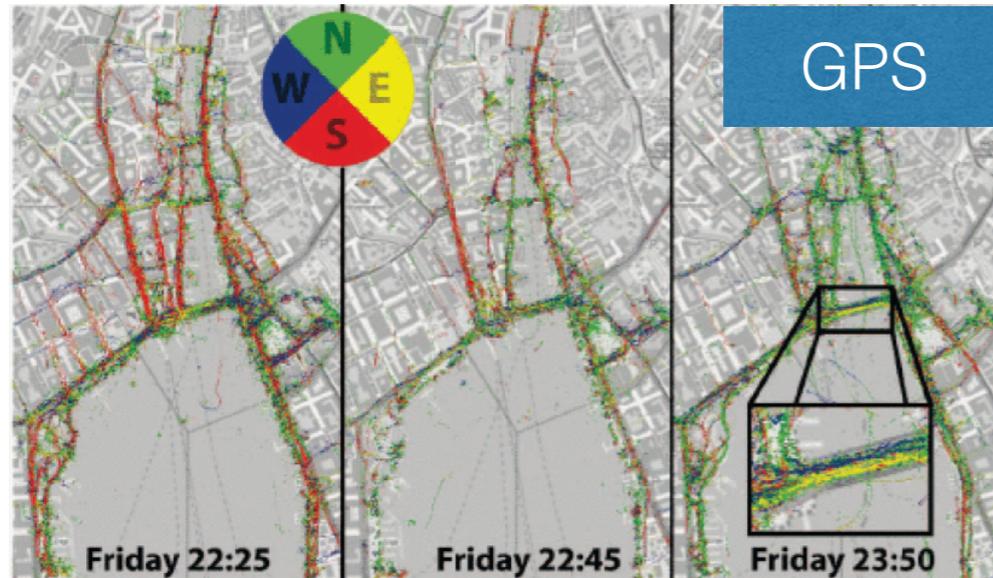
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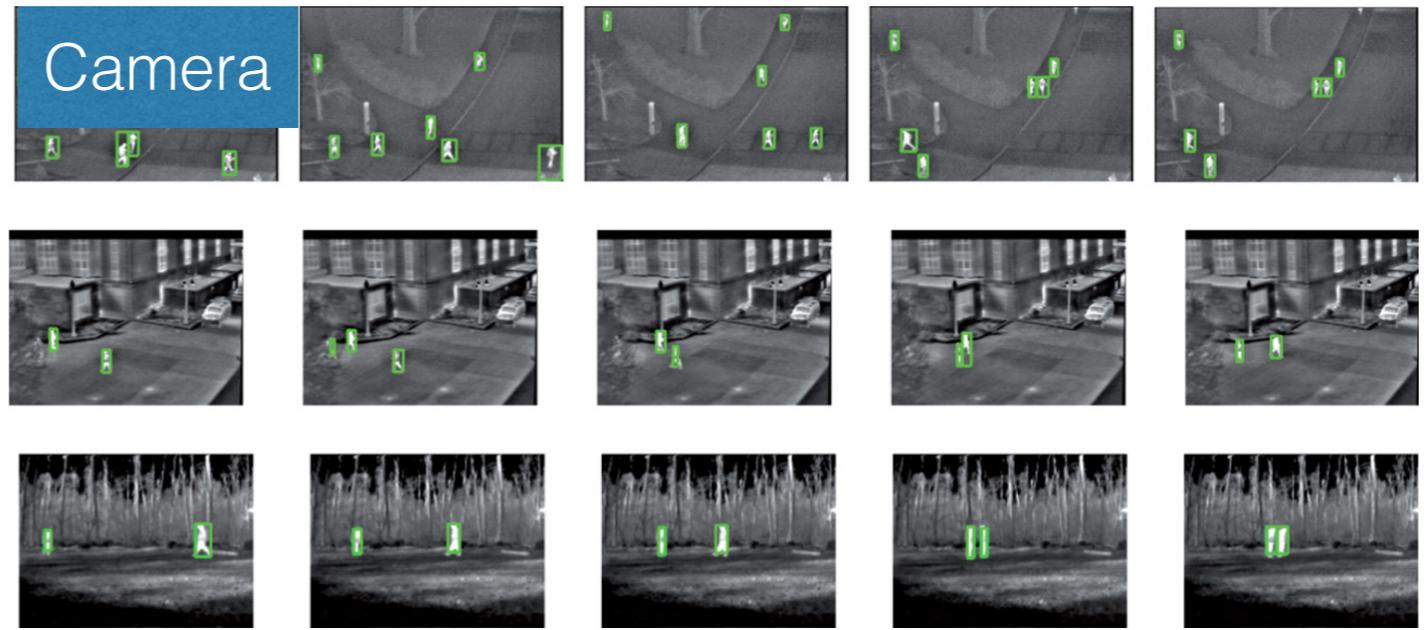
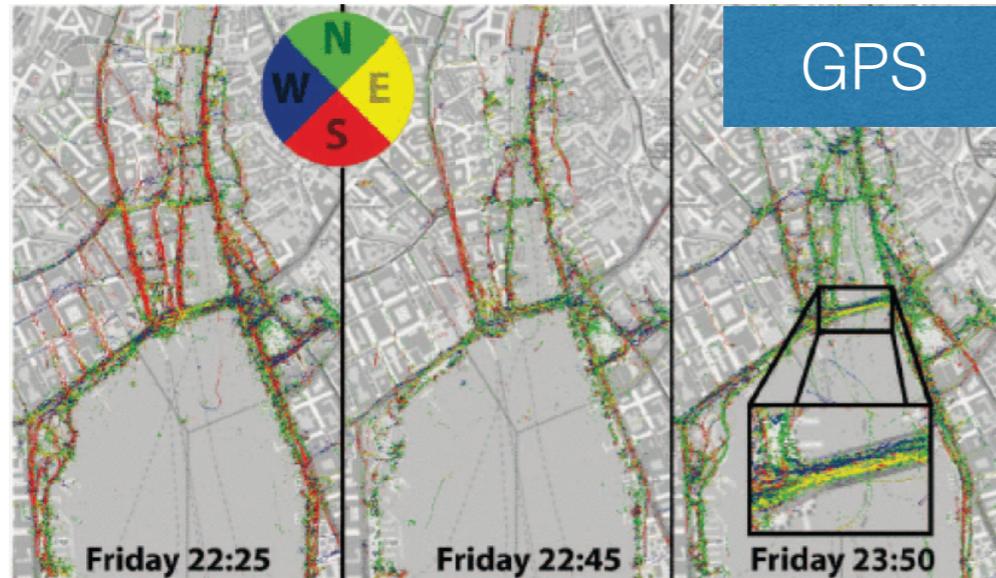
Improve resource allocation of public facilities and space usage

Social psychology studies

# Human Sensing System in Literature

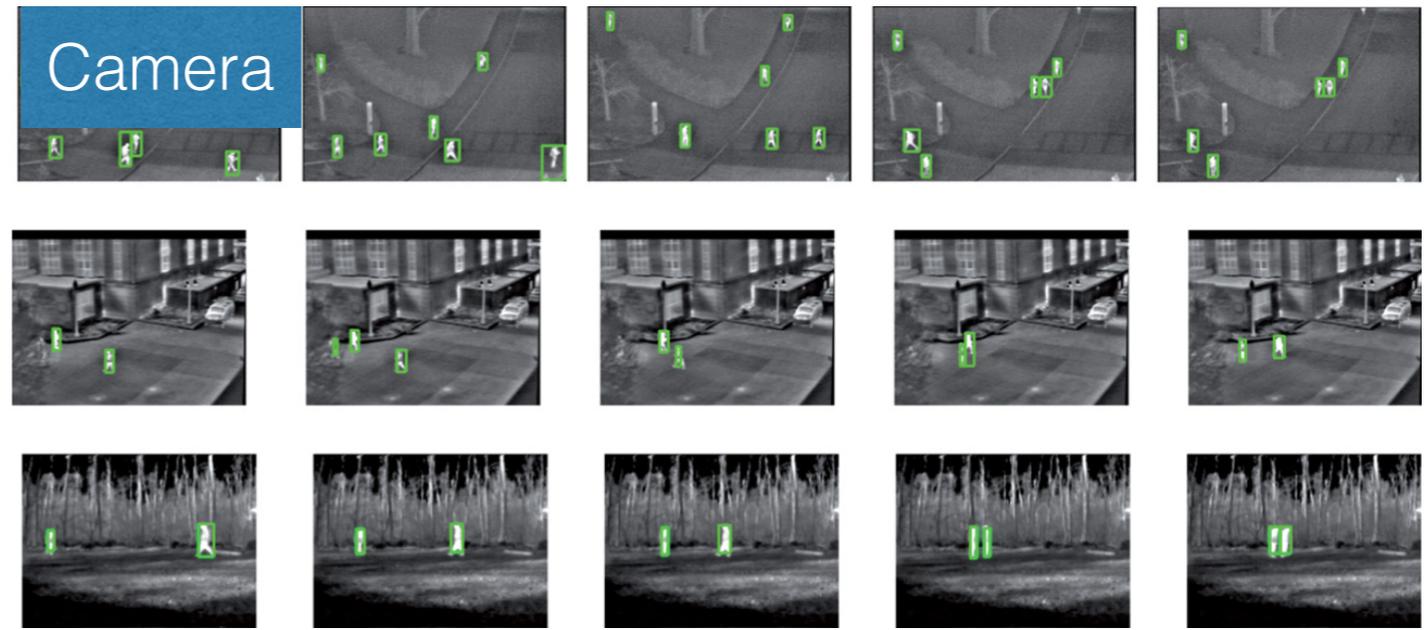
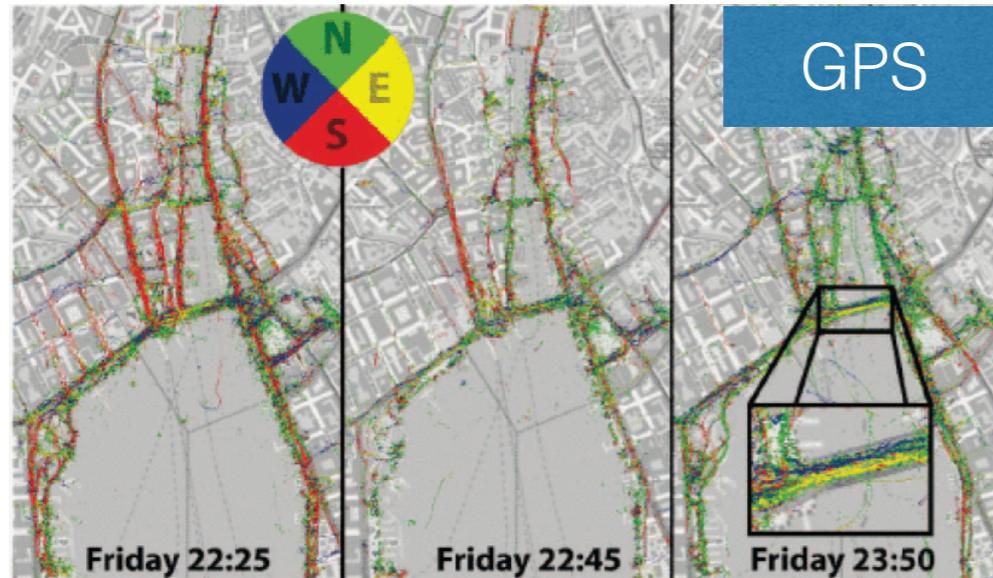


# Human Sensing System in Literature



	Camera	GPS	Range finders
Indoor tracking	Yes	No	Yes
Large-scale people tracking	No	Yes	No
Trajectories recognition accuracy	Low	High	Low
Tracking latency	High	Low	Low
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# SenseFlow System

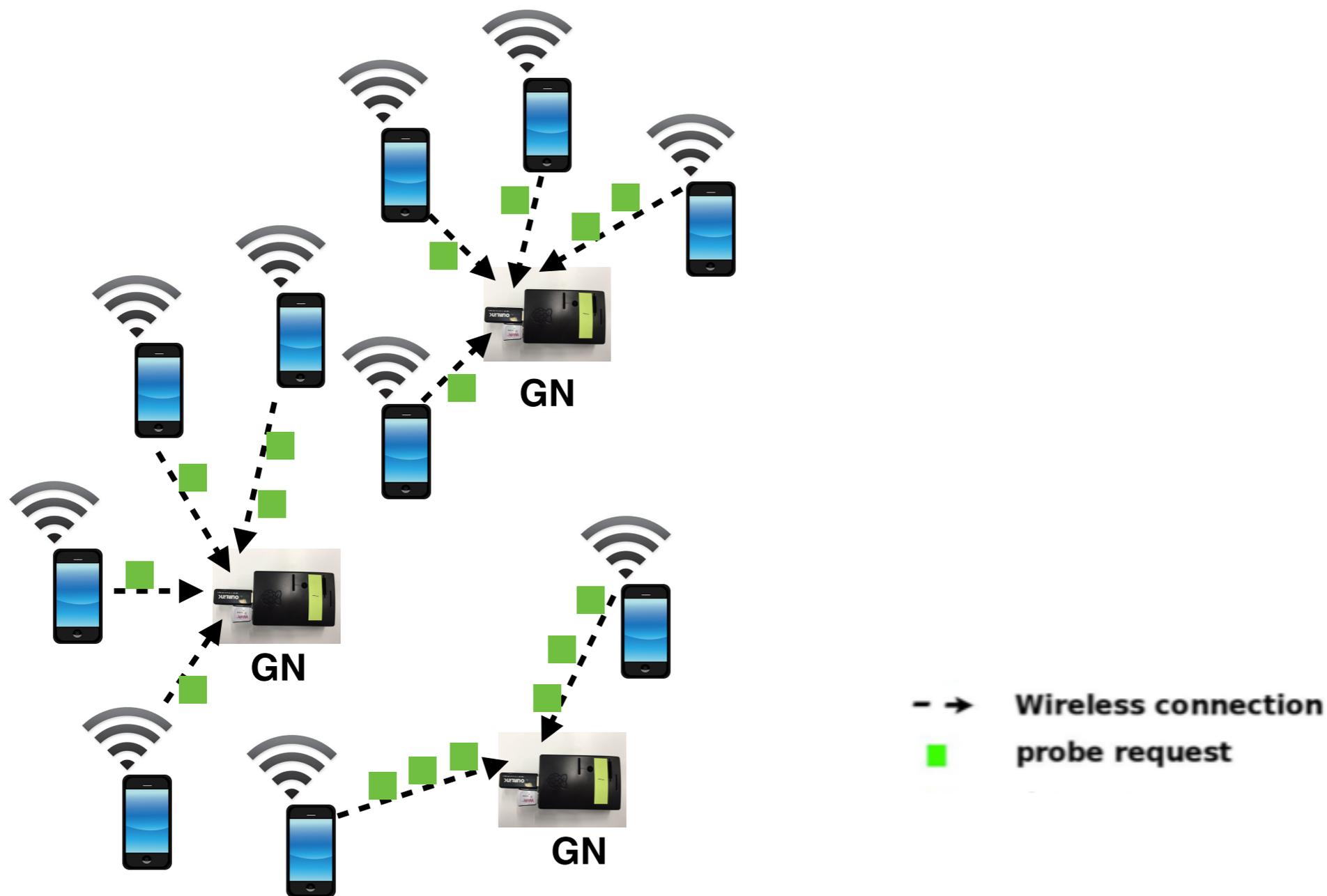
A lightweight WSN for large-scale people flow tracking and density monitoring [1].



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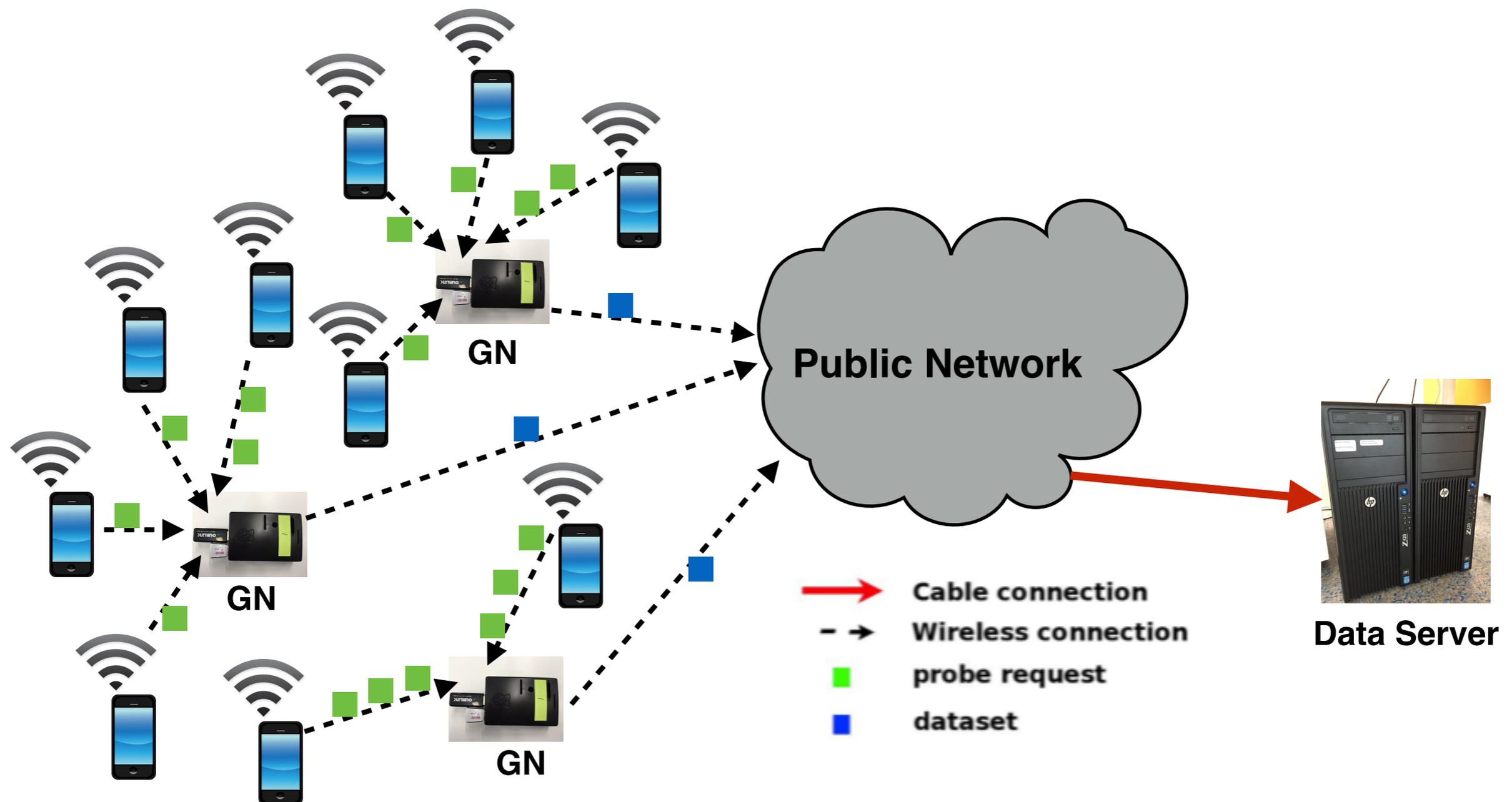
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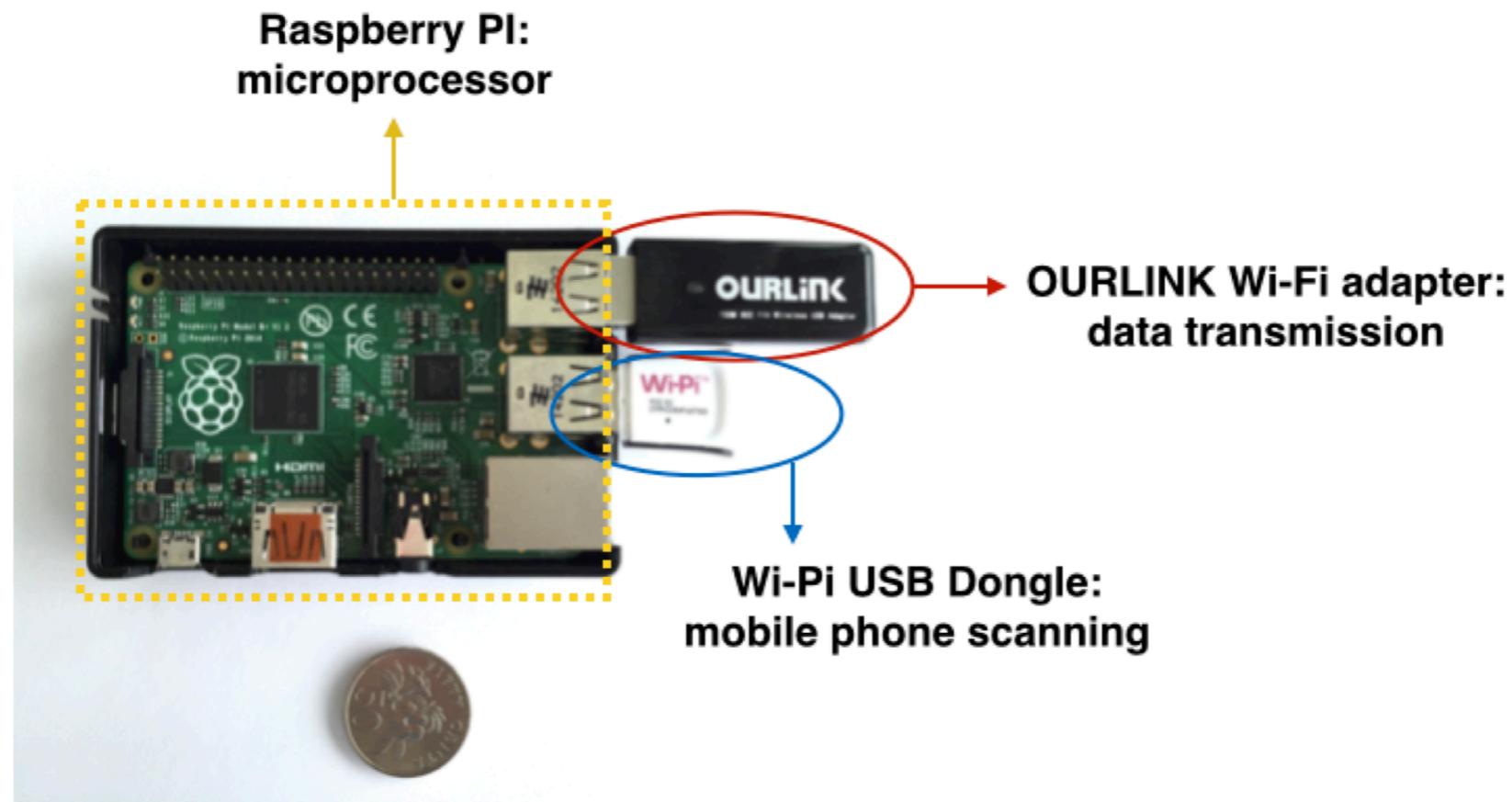
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# The Sensor Node

- The GN is a Raspberry Pi connecting with Wi-Pi (white colour) and OURLINK (black colour) wireless interfaces.
- Both of them work in 2.4GHz and provide a simultaneous probe request collection and dataset transmission.

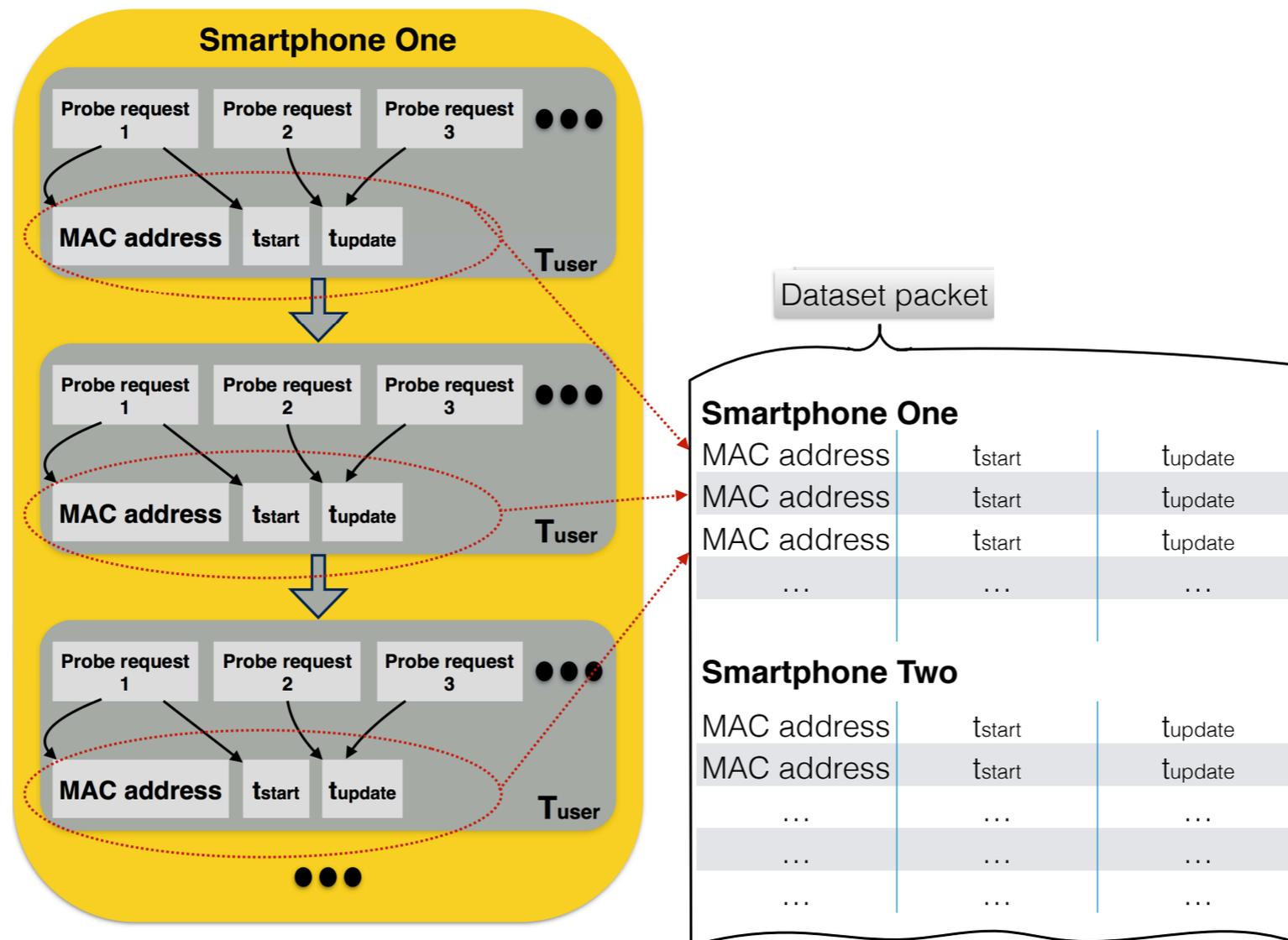


# SenseFlow Framework

- The SenseFlow framework consists of two major components, the **sensing module** and **processing module**.

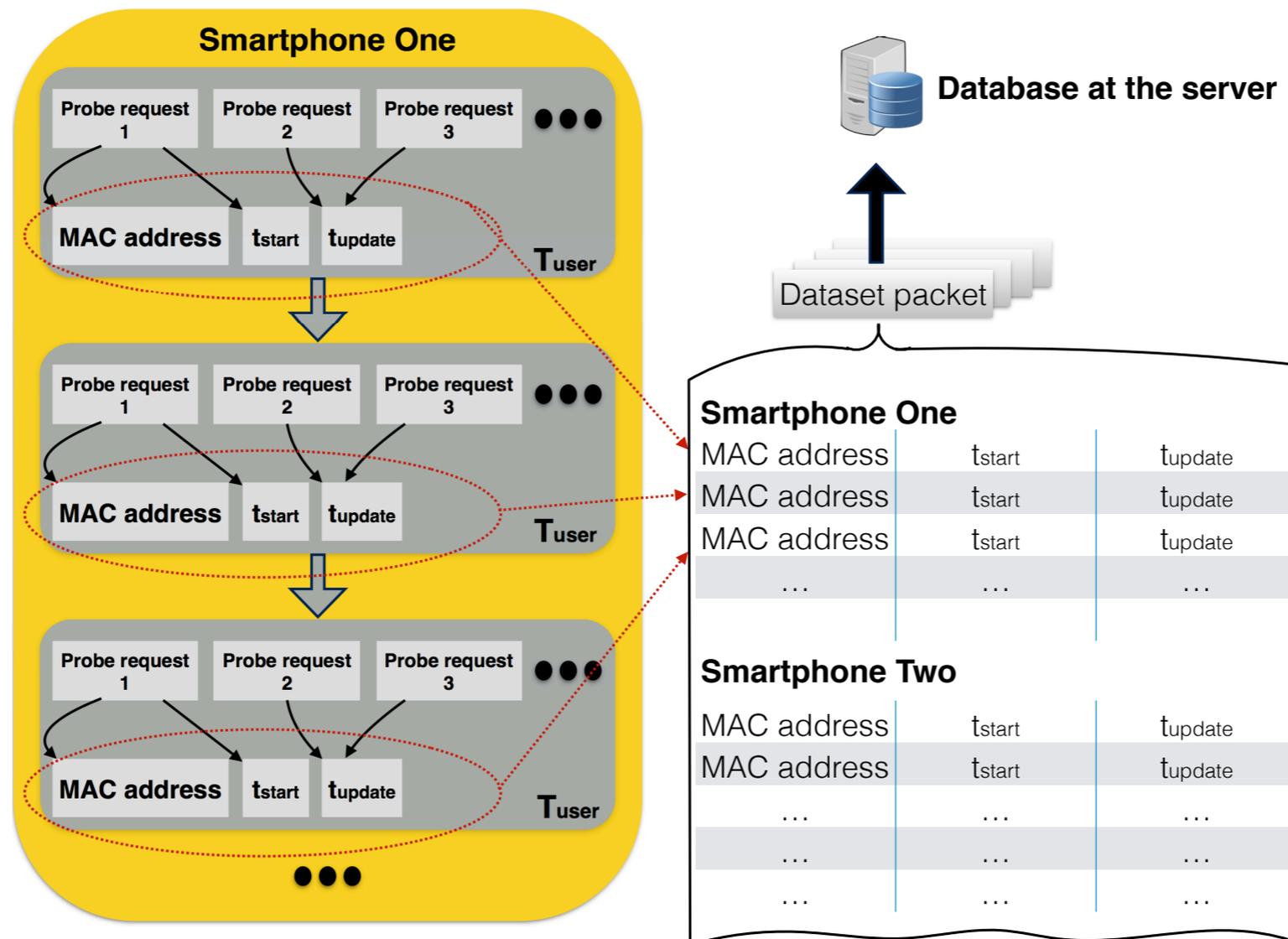
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- The set of locations that people flow travels during  $t_{start}$  and  $t_{end}$

$$\Lambda = ALCS(\mathbb{X}, j_{t_{start}}, j_{t_{end}})$$

# Probe Request Interval Measurement

- Three typical smartphone models:

**iPhone 6**



**Samsung  
Galaxy Nexus**



**Nokia Lumia 520**

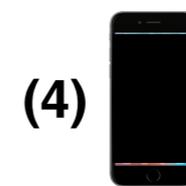


# Probe Request Interval Measurement

- Three typical smartphone models:



- Four statuses for each smartphone:



# Probe Request Interval Measurement

- Three typical smartphone models:



- Four statuses for each smartphone:



Table 1: Average probe request interval of smartphones in different Wi-Fi and screen status.

Devices	Wi-Fi non-registered		Wi-Fi registered	
	screen on	screen off	screen on	screen off
iOS	70.6s	109.8s	1200.8s	1204.4s
Android	0.8s	1s	2.11s	2.15s
Windows	10.9s	13.9s	1200.8s	1204.4s

# Human Walking Behaviour Effect

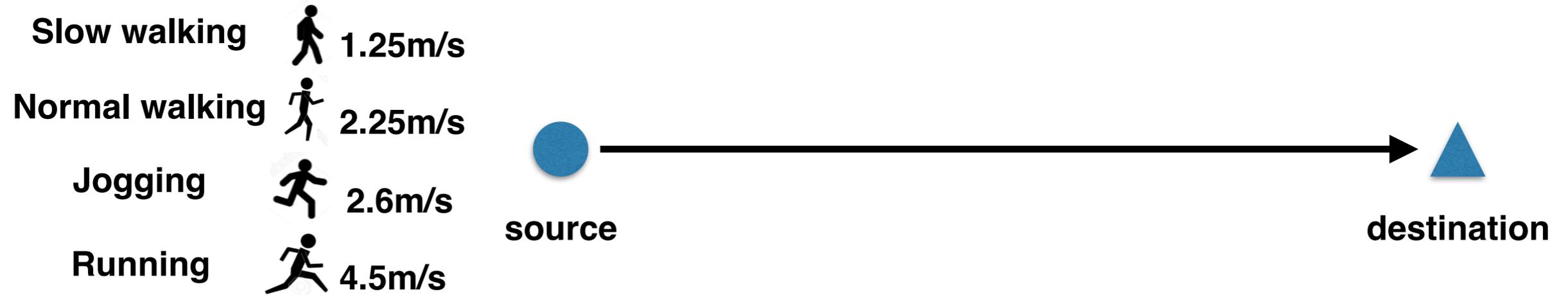


**source**



**destination**

# Human Walking Behaviour Effect



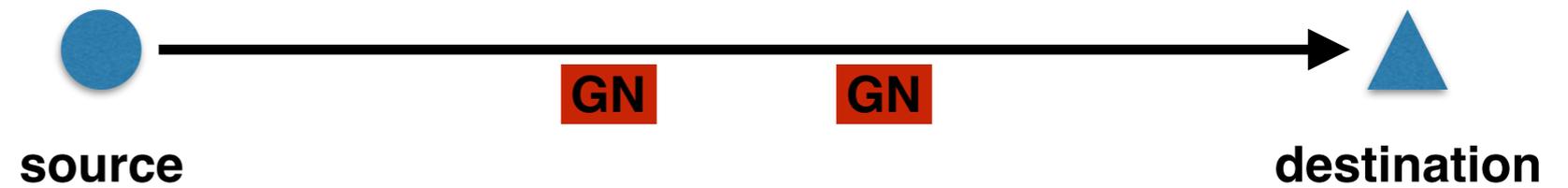
# Human Walking Behaviour Effect

Slow walking		1.25m/s
Normal walking		2.25m/s
Jogging		2.6m/s
Running		4.5m/s



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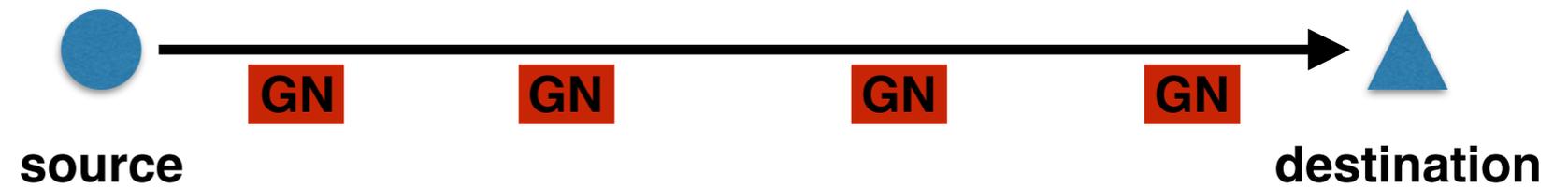
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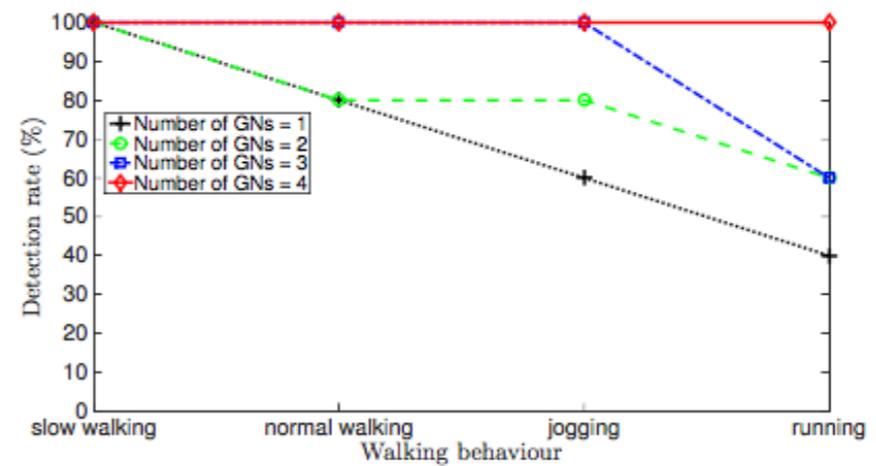
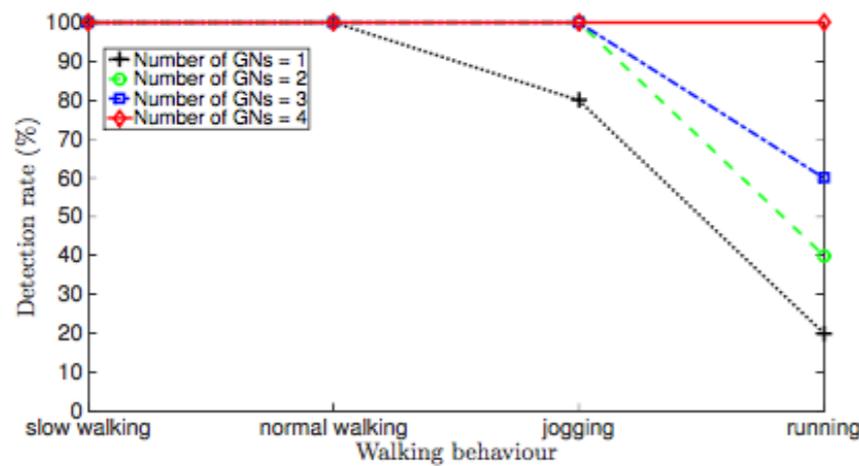
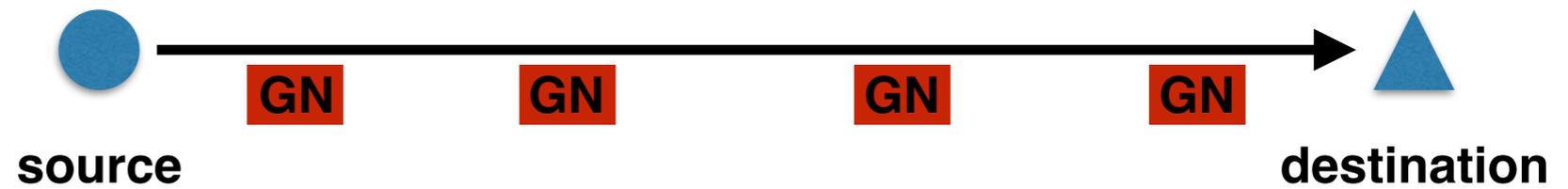
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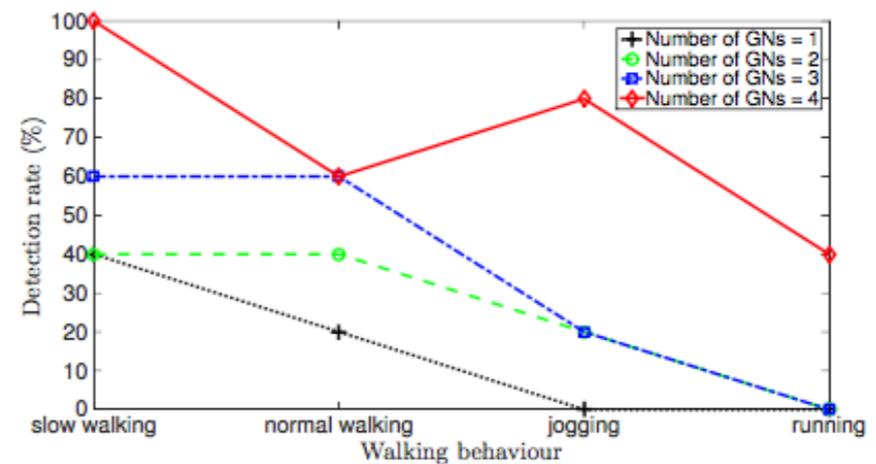
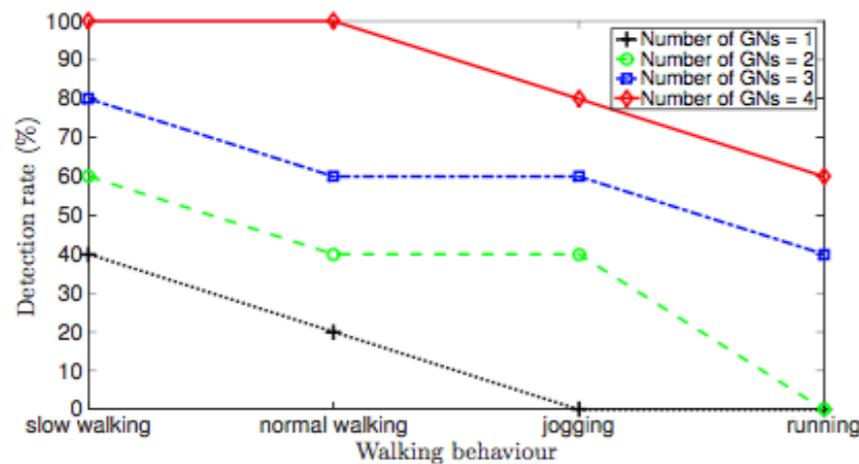
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(a) Smartphone status: (screen on, Wi-Fi non-registered)

(b) Smartphone status: (screen on, Wi-Fi registered)

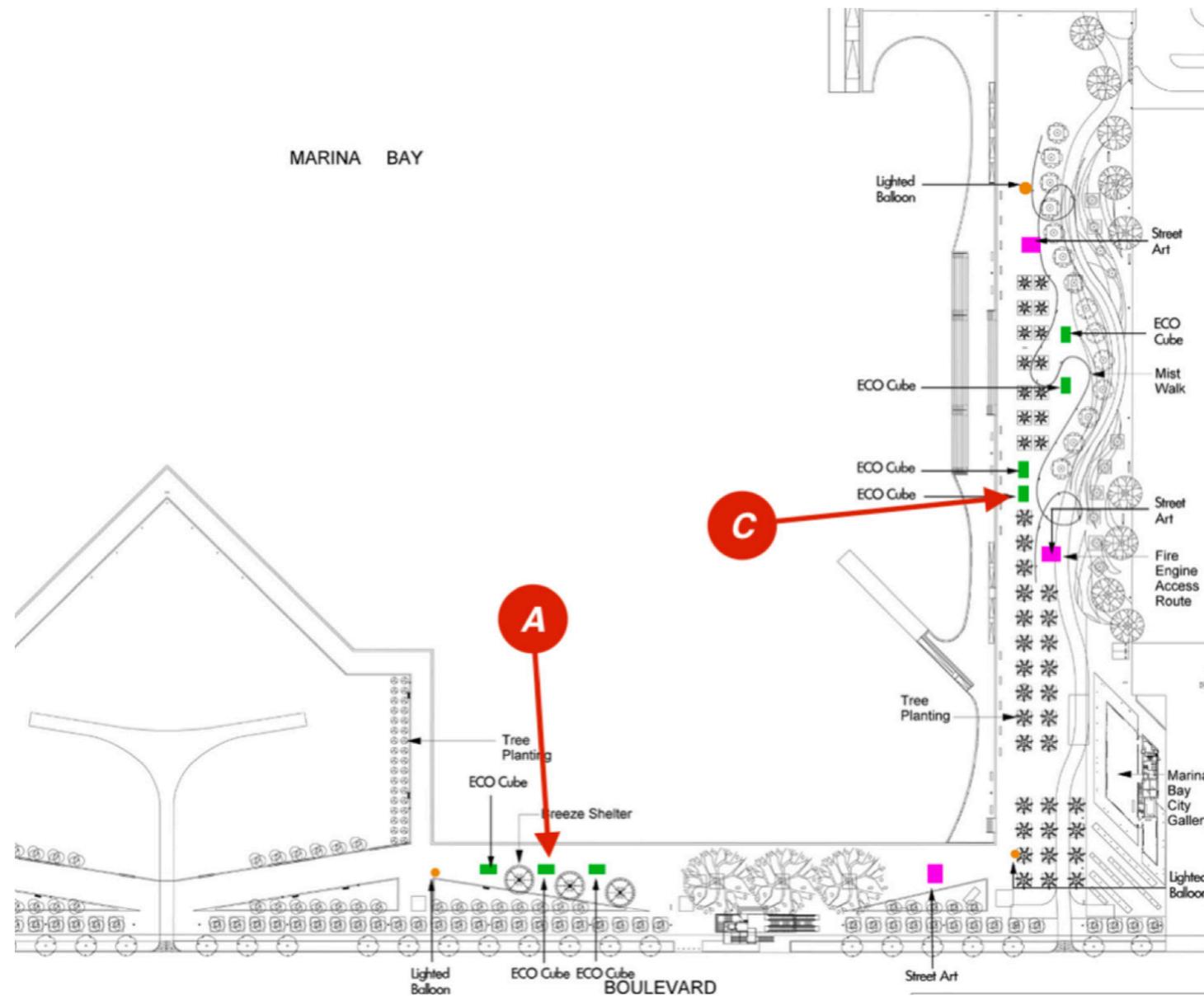


(c) Smartphone status: (screen off, Wi-Fi non-registered)

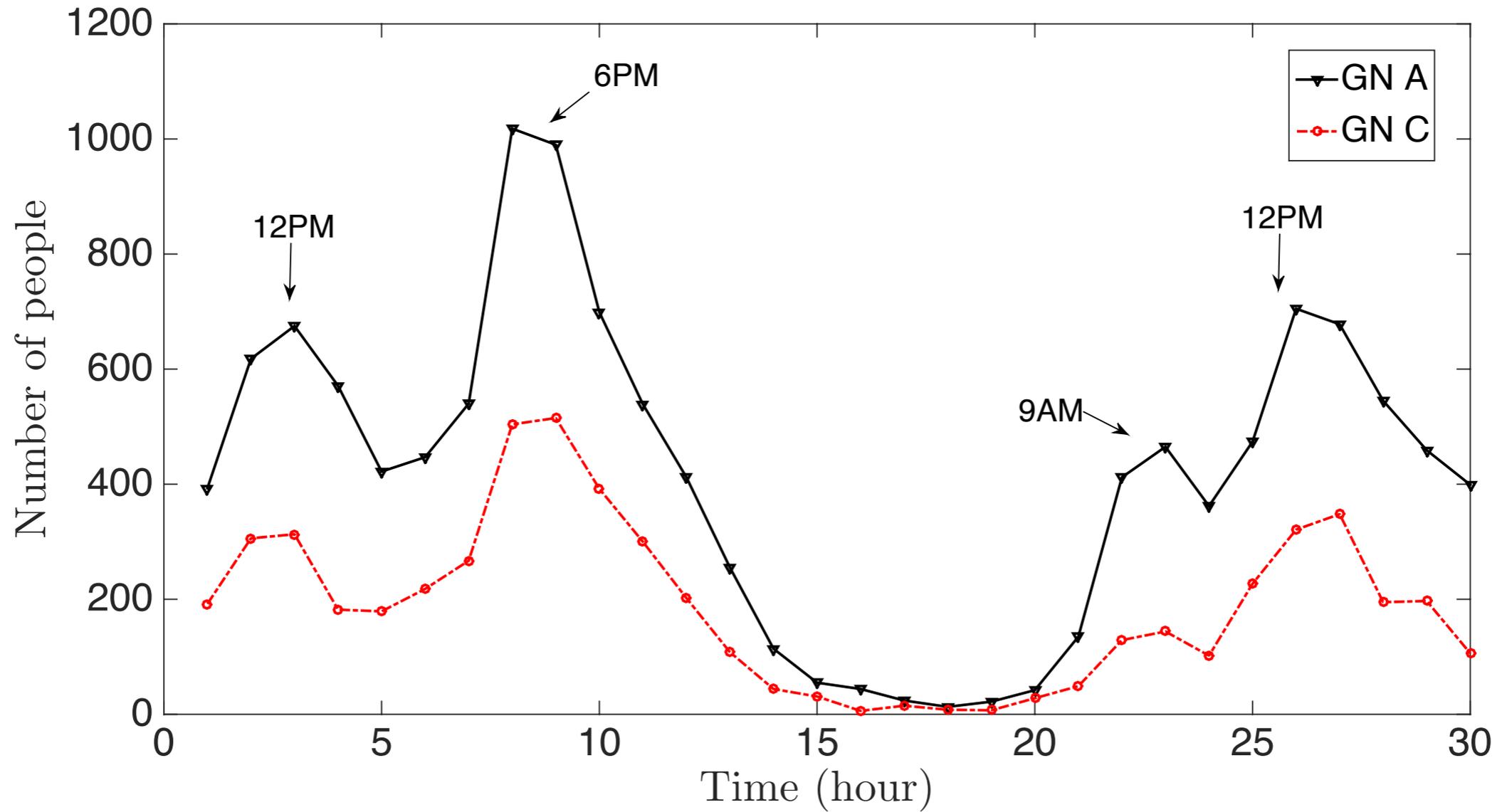
(d) Smartphone status: (screen off, Wi-Fi registered)

# System Scalability

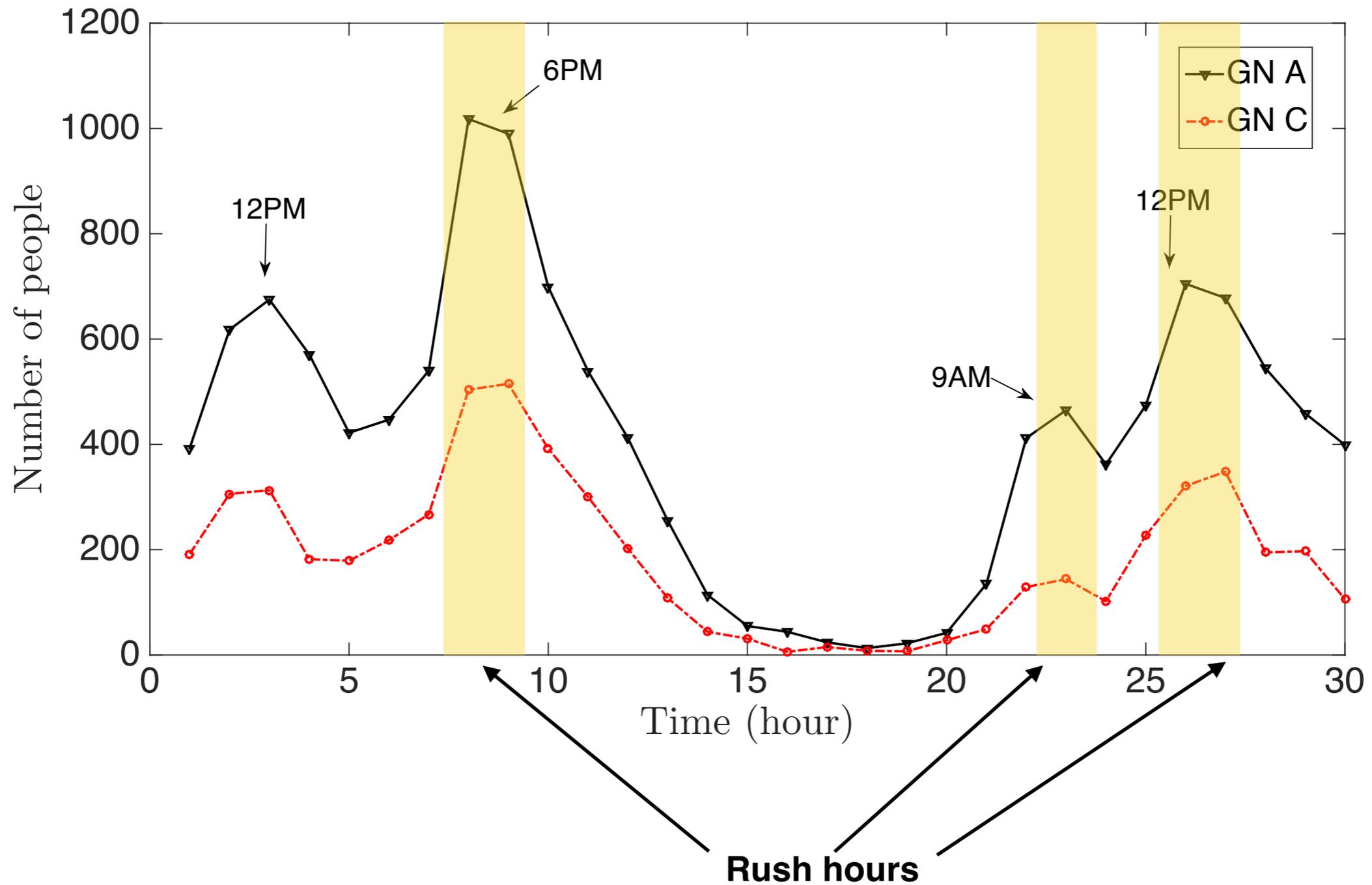
- Two GNs (GN A and C) are placed along the walking path in a shopping mall. The experiment starts from 11 A.M. 28 Oct to 5 P.M. 29 Oct, 2014 (30 hours in total).



# System Scalability

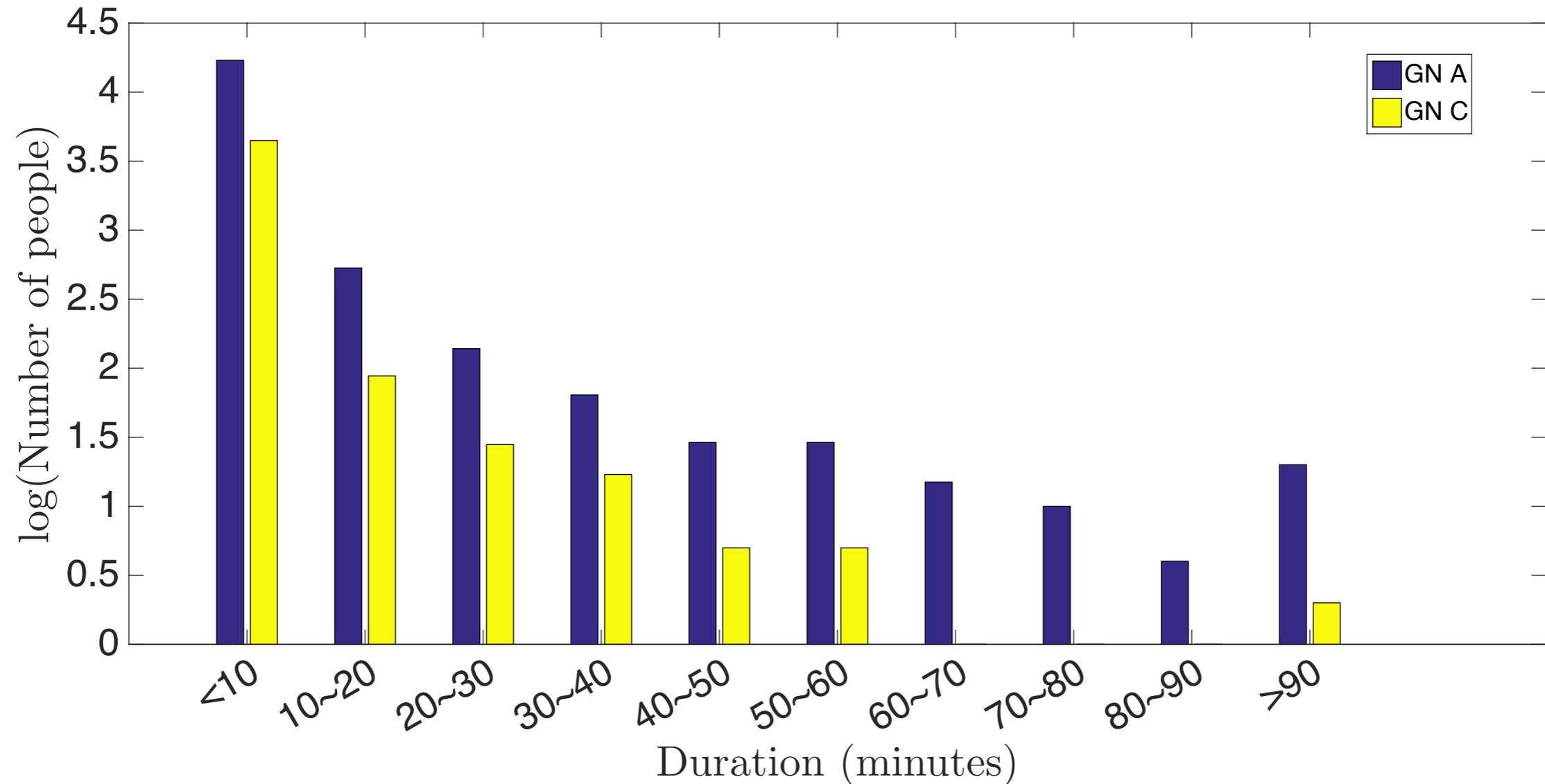


# System Scalability



- Location of GN A is more popular than the one of GN C.

# System Scalability



- The connection time of most of the phones is less than 20 minutes. A few smartphones connect to the GNs for more than 20 minutes.

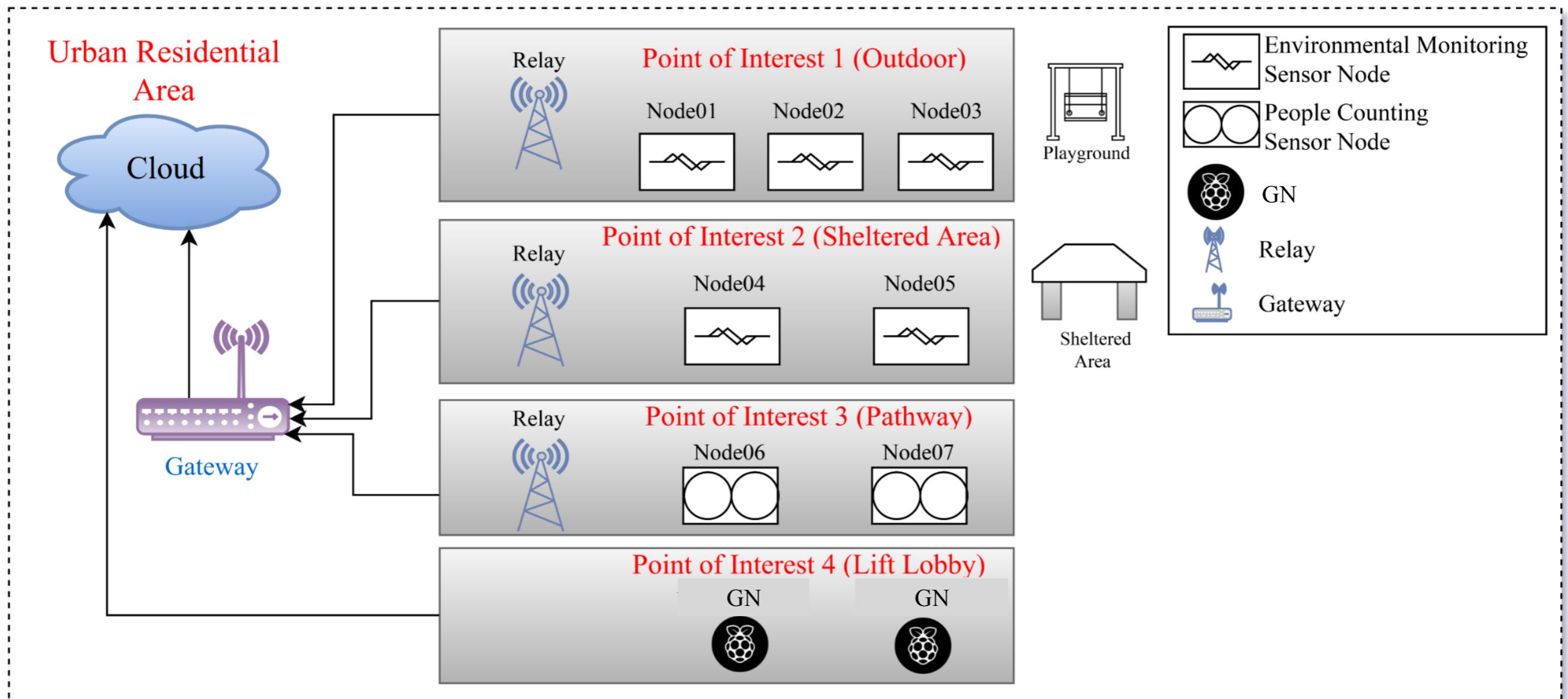
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Conduct big data analysis with SenseFlow system and a RWSN to study residential behaviour and space utilisation [2].

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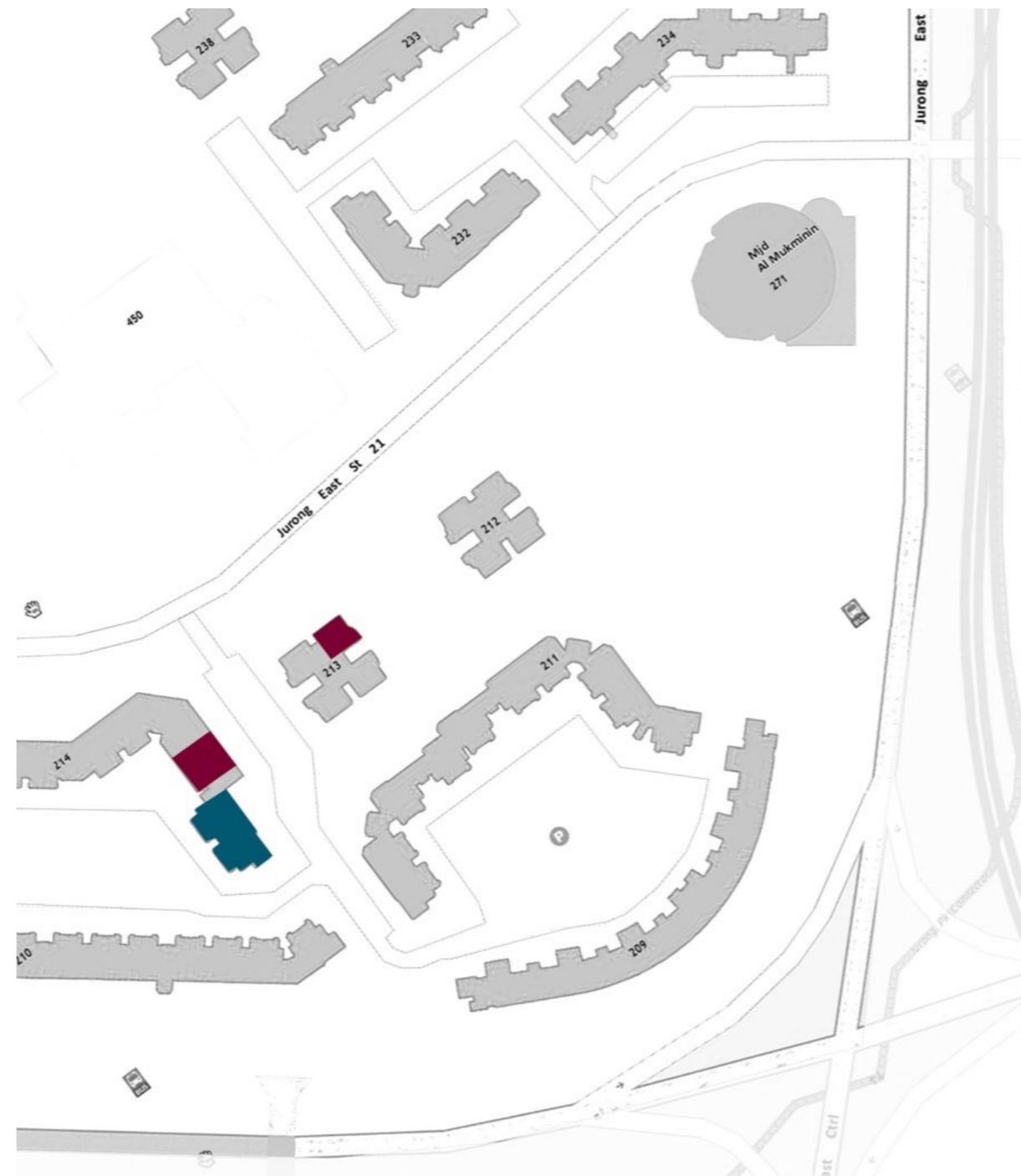
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# Nodes' Deployment (76 Days)

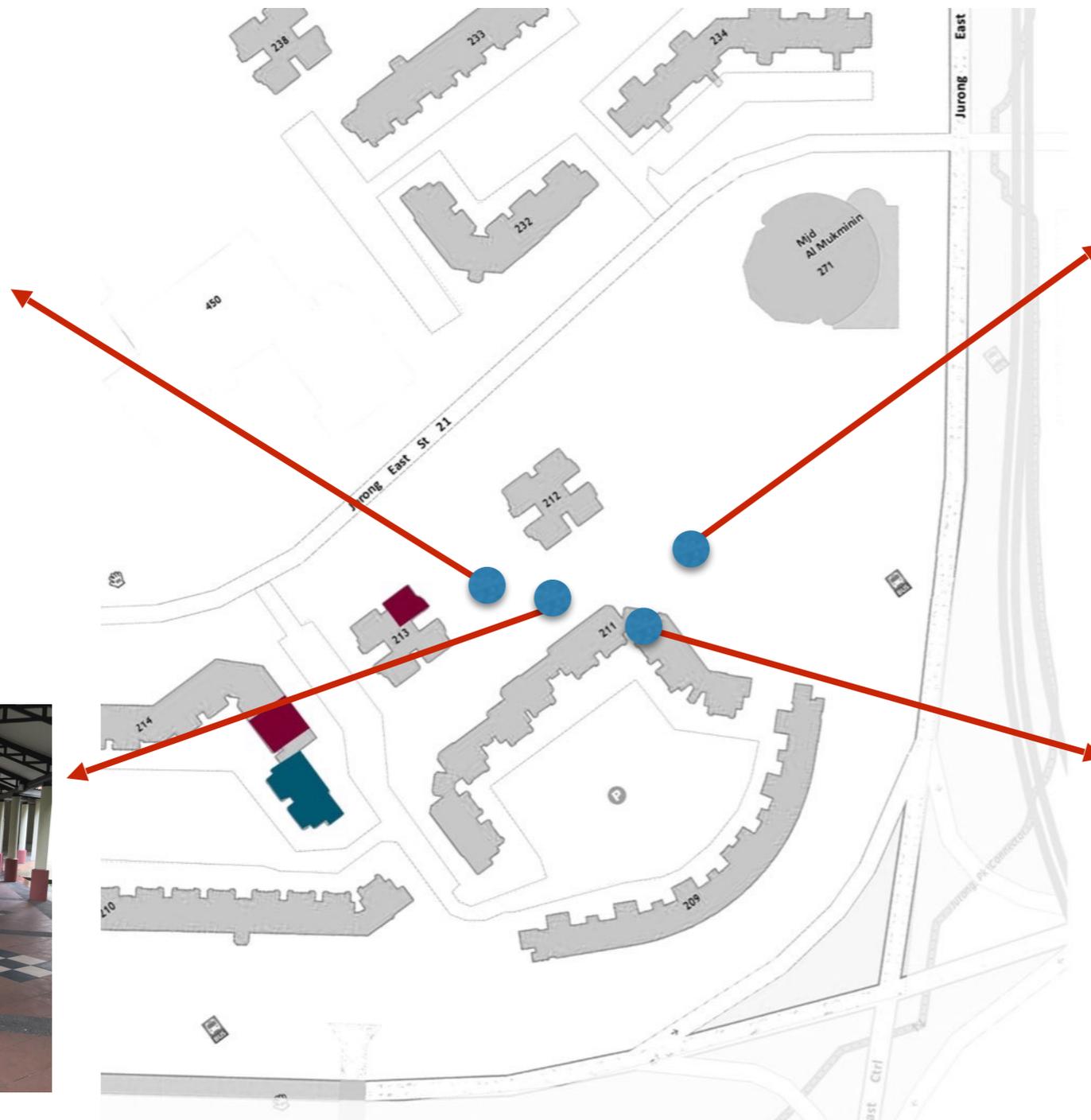


**Residential area, Jurong East, Singapore**

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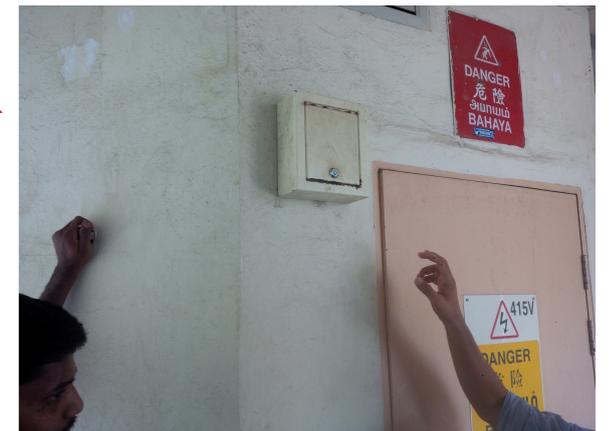
**POI 1**



**POI 2**



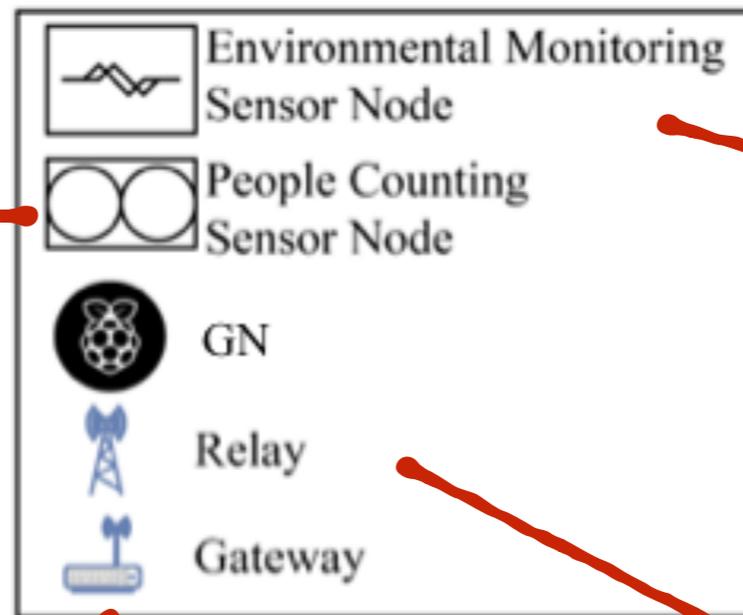
**POI 3**



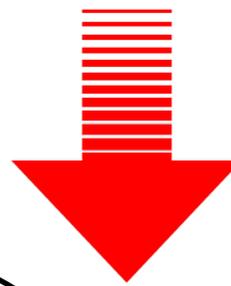
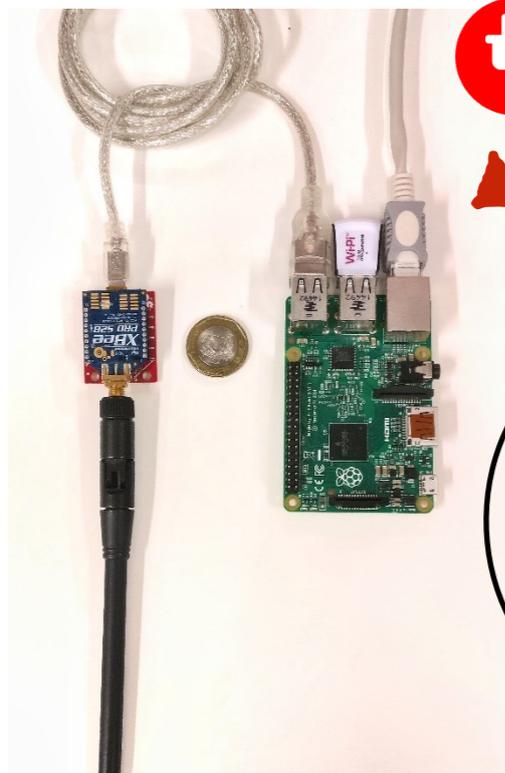
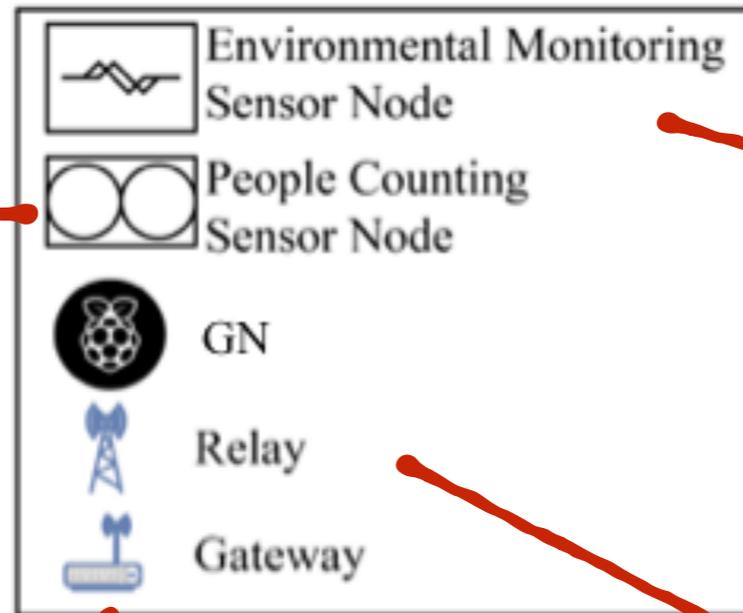
**POI 4**

**Residential area, Jurong East, Singapore**

# Sensor Nodes



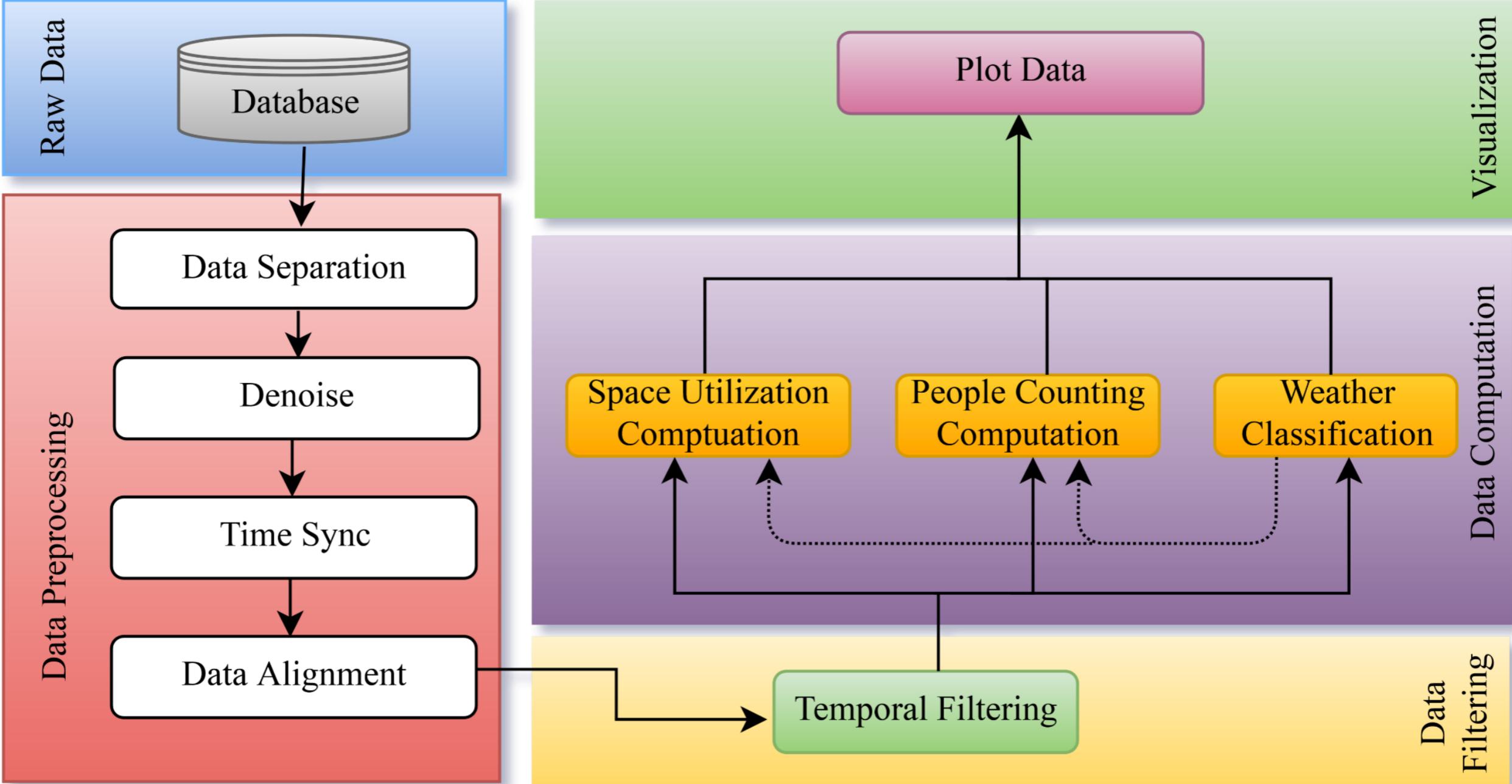
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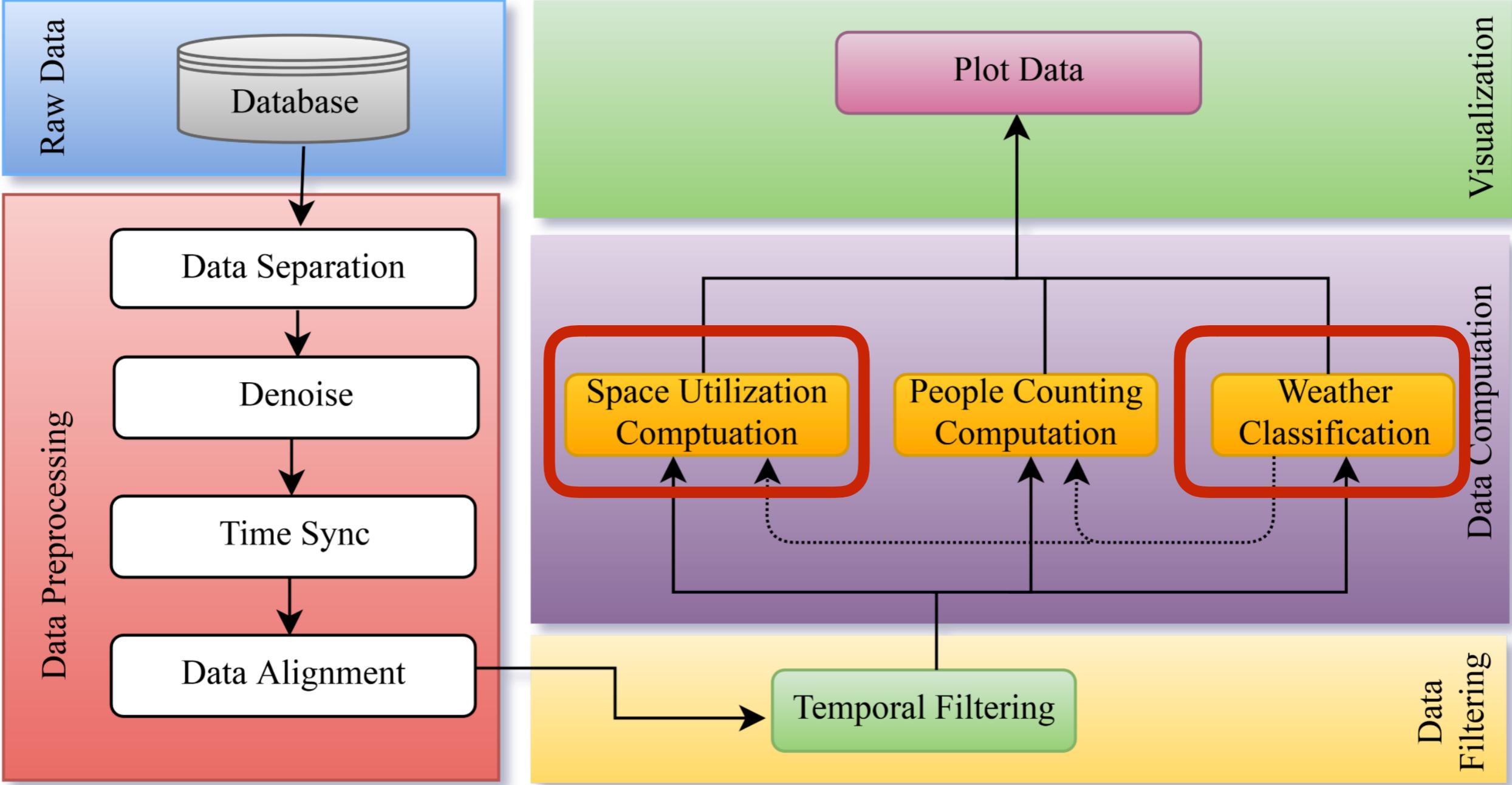
(1) Barometer, Temperature, Light intensity, Rain, Ultra-Violet (UV), Humidity, Motion, and Noise intensity.

(2) Probe requests from mobile devices.

# Data Processing Model



# Data Processing Model



# Definition of Urban Space Utilisation

**Monitoring place: Playground**

**Monitoring object: Residents**

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- Urban Space Utilisation (Motion + Noise)

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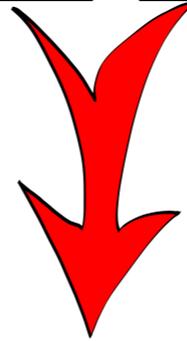
normalisation of  
motion dataset

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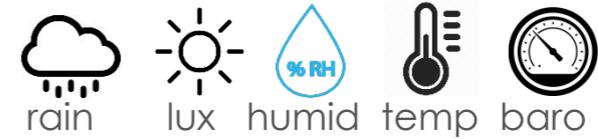
normalisation of  
motion dataset

normalisation of  
noise dataset

- Normalise Noise and Motion (based on 85.0% of data distribution)

$$\text{norm}(X) = \min\left(\frac{X}{\text{normValue}}, 1\right)$$

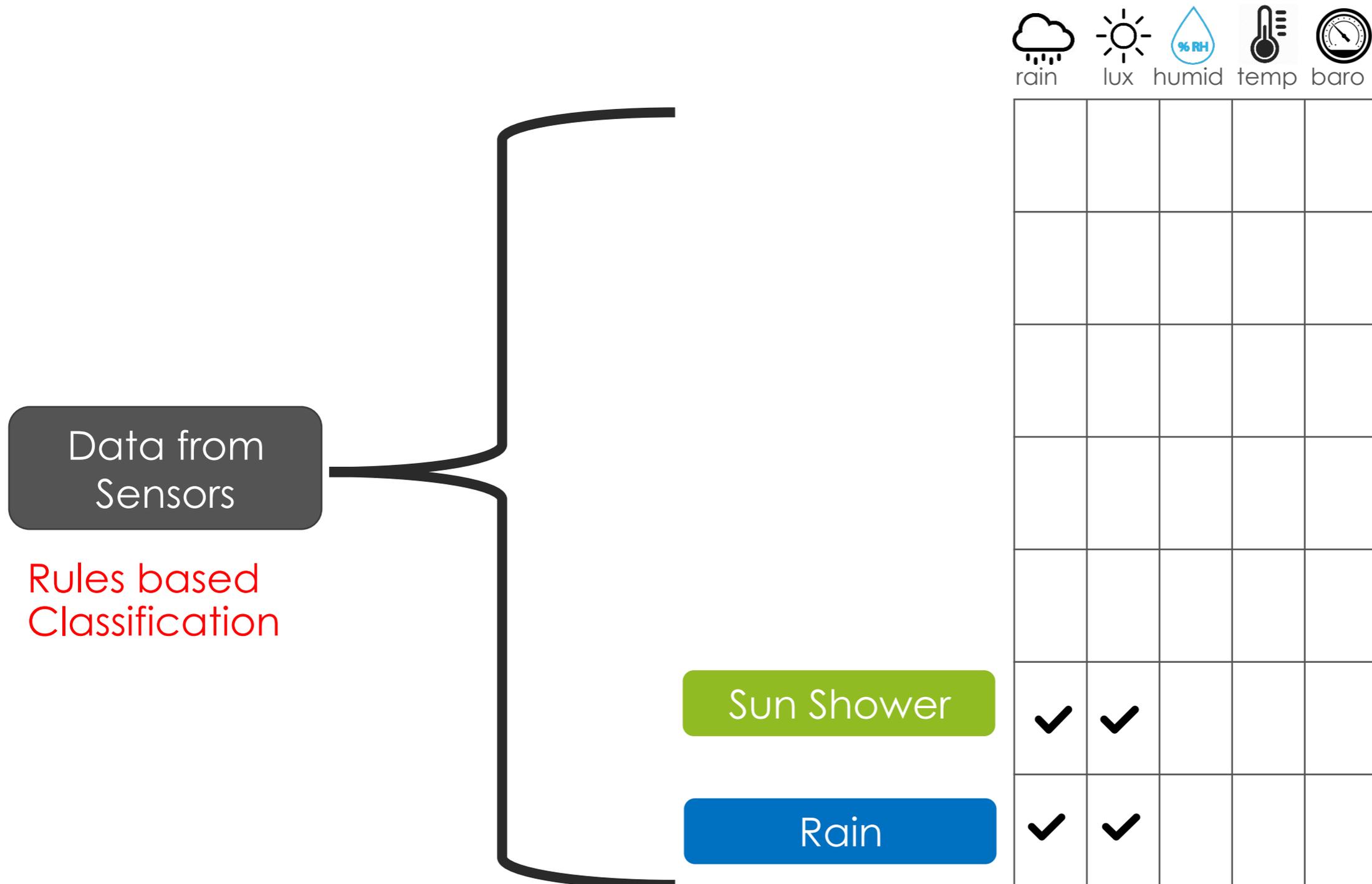
# Weather Classification



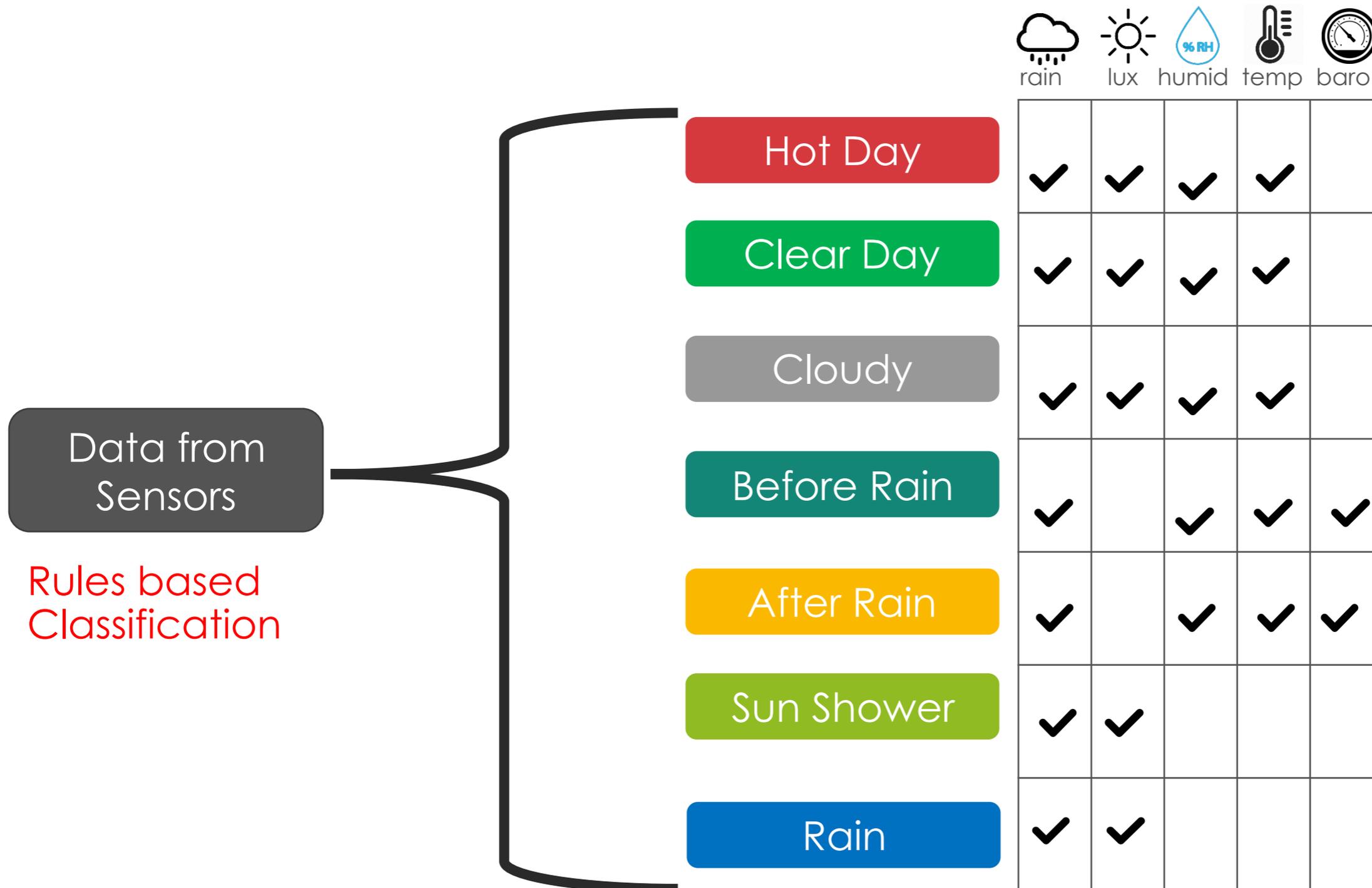

Data from  
Sensors

Rules based  
Classification

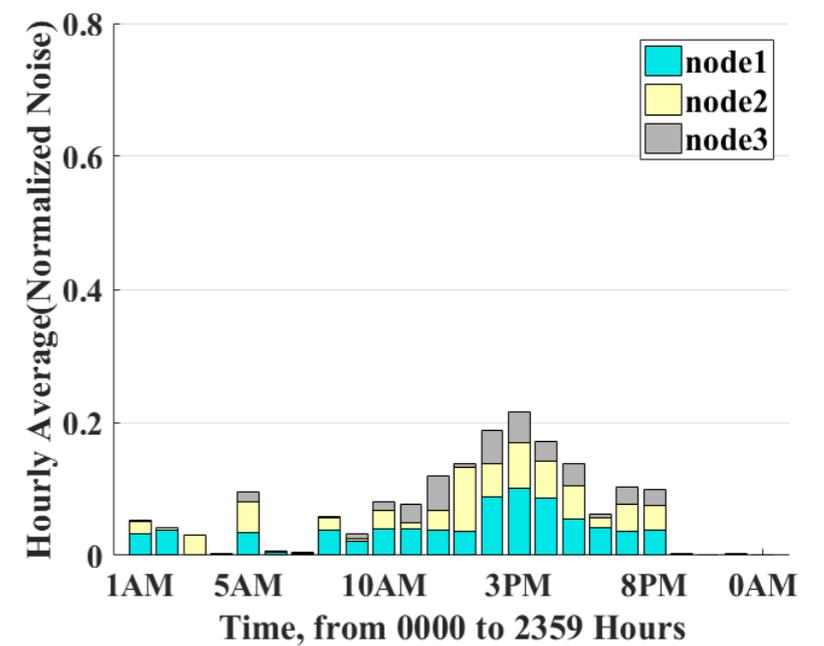
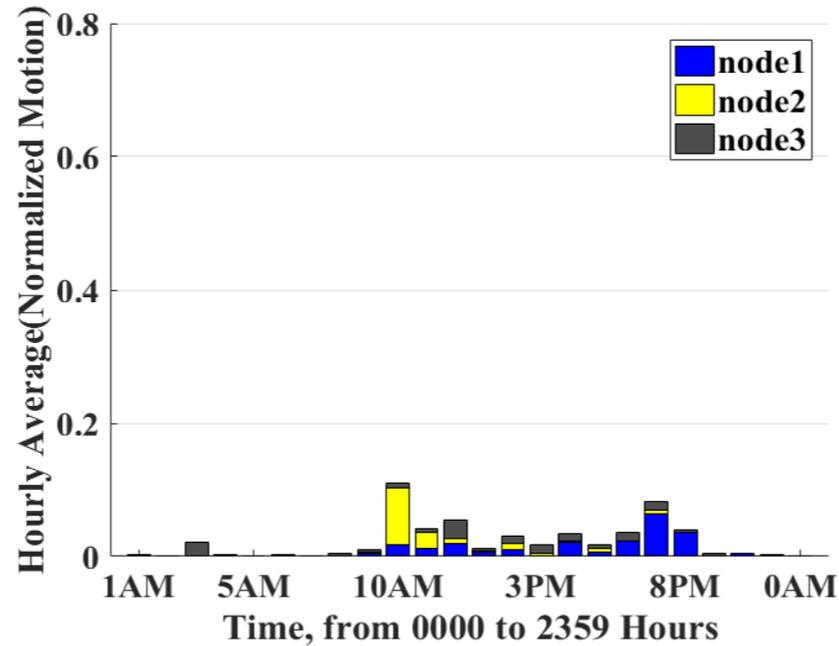
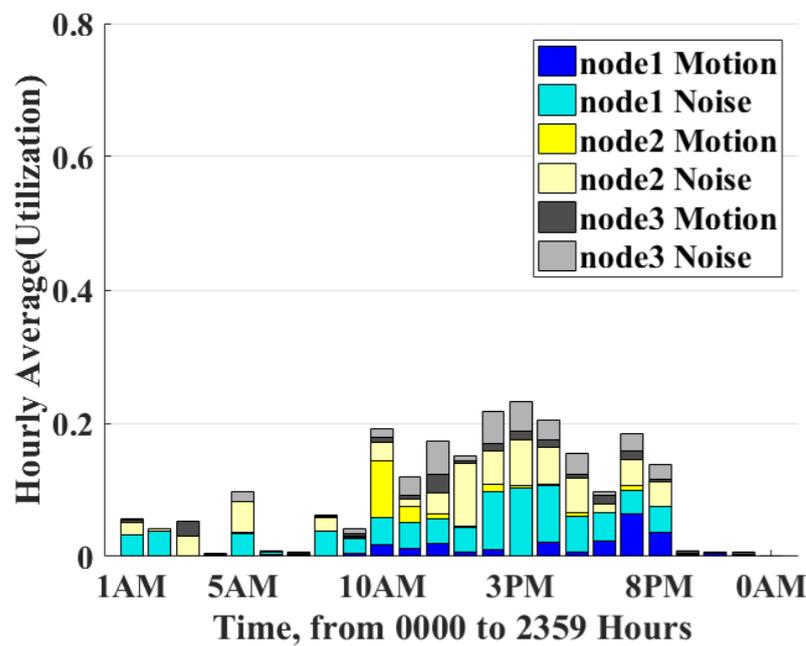
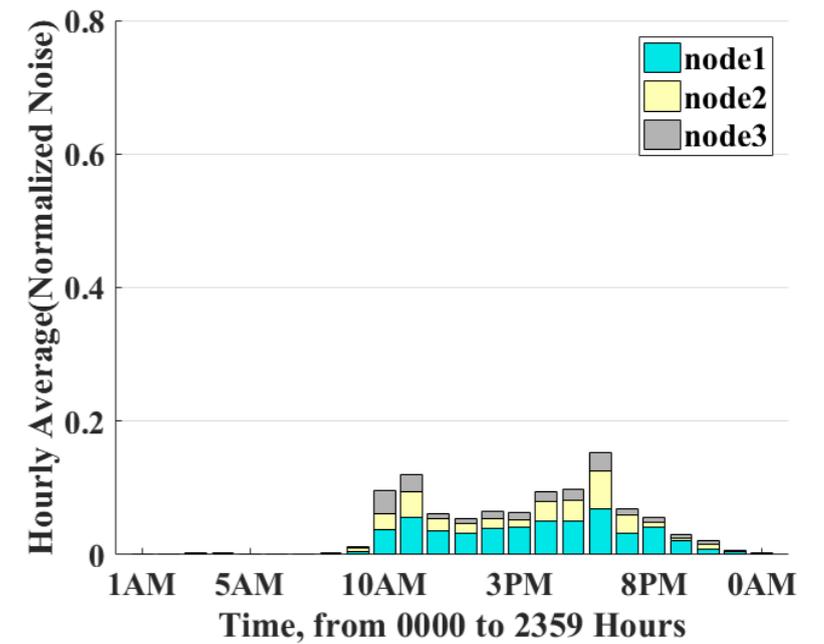
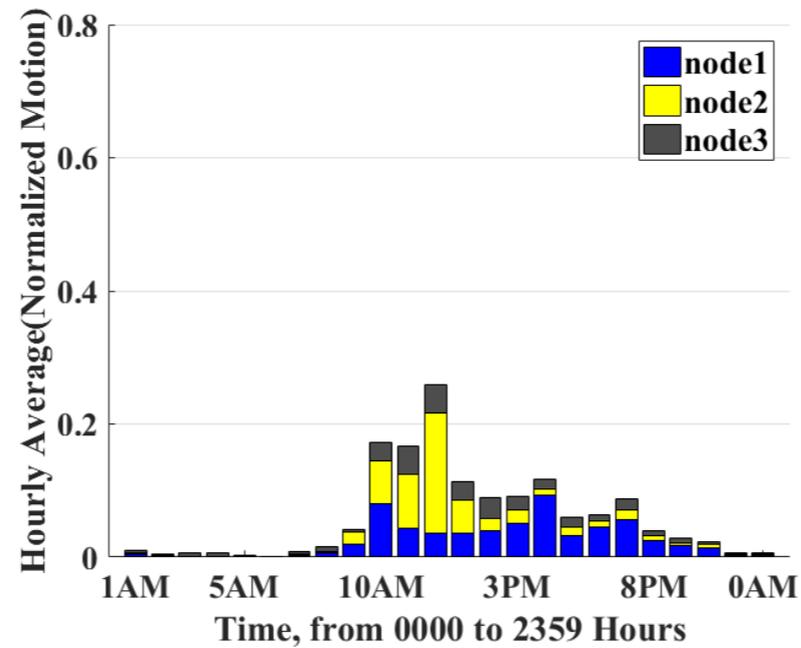
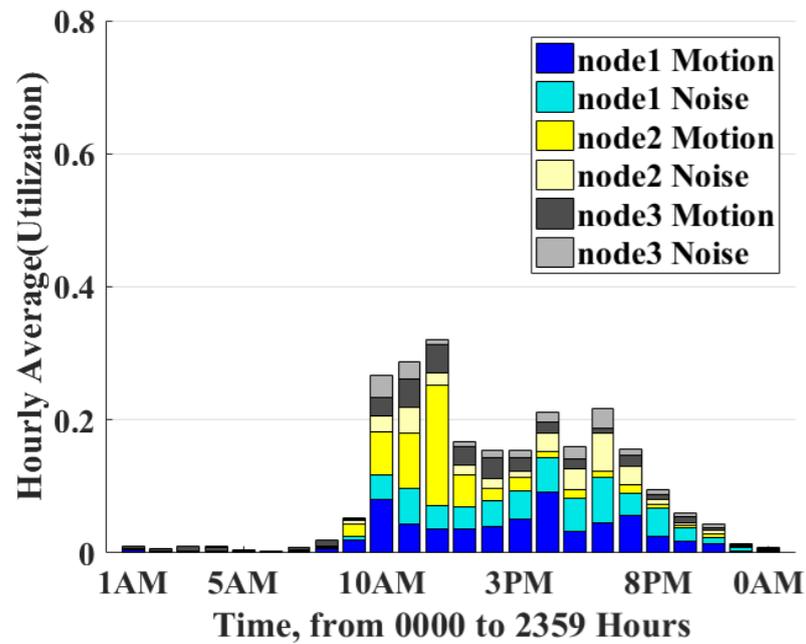
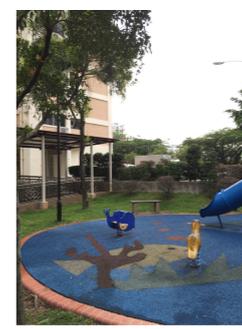
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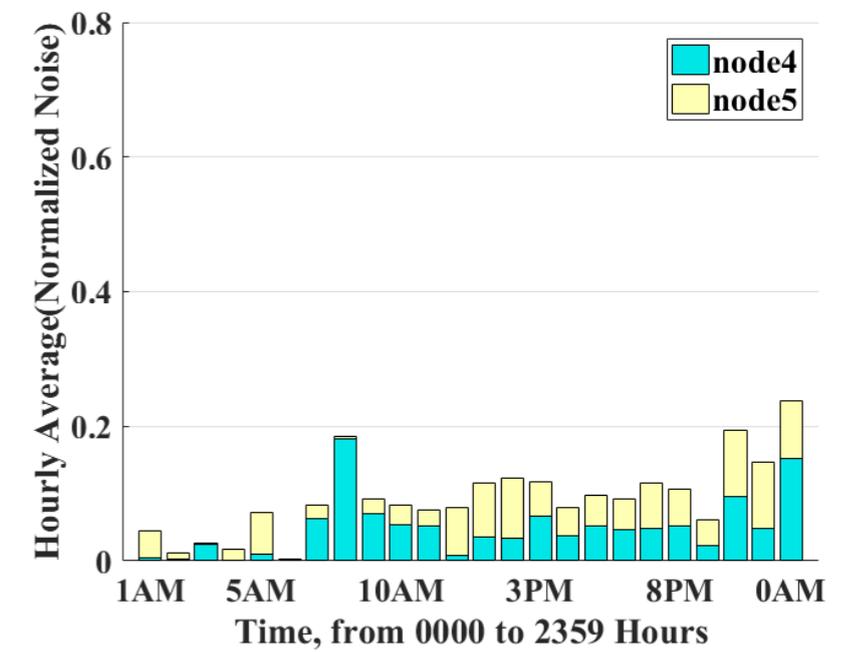
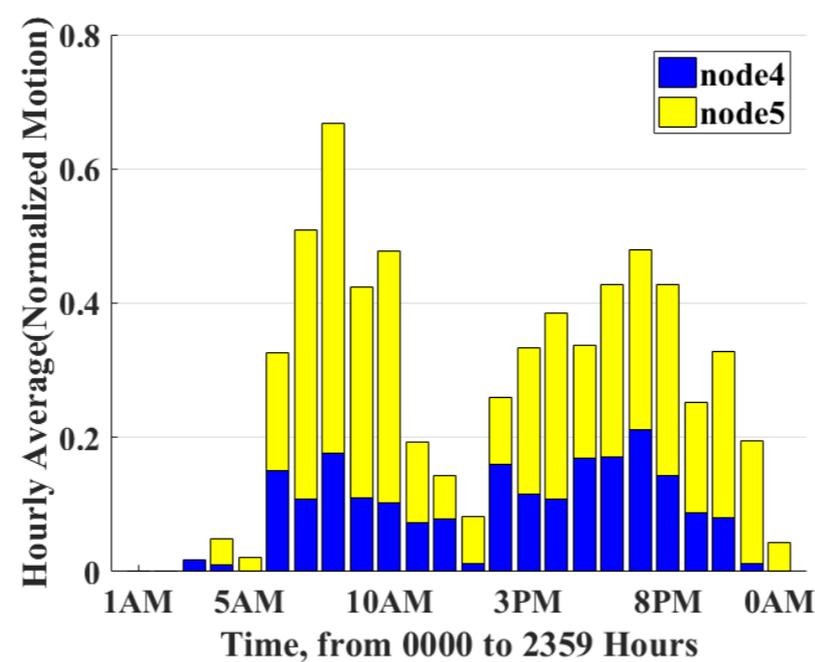
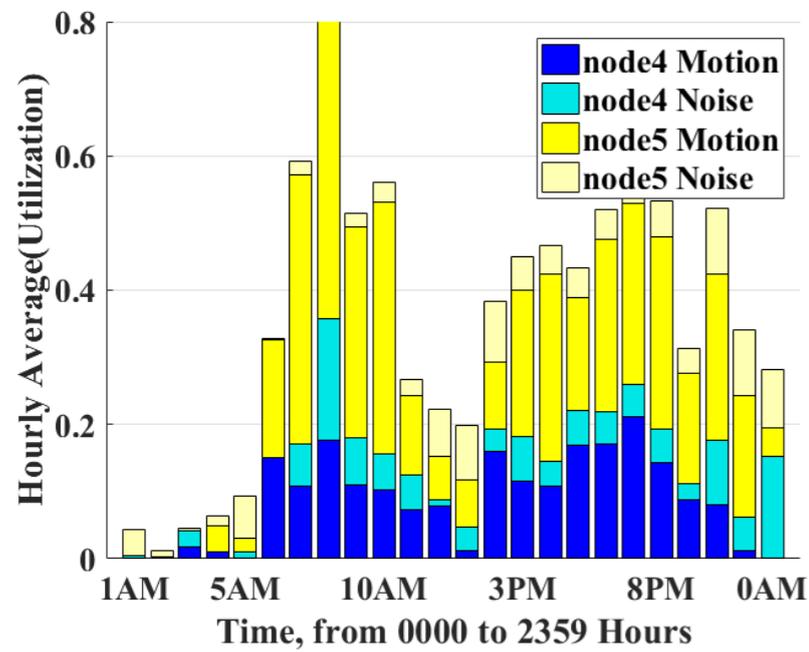
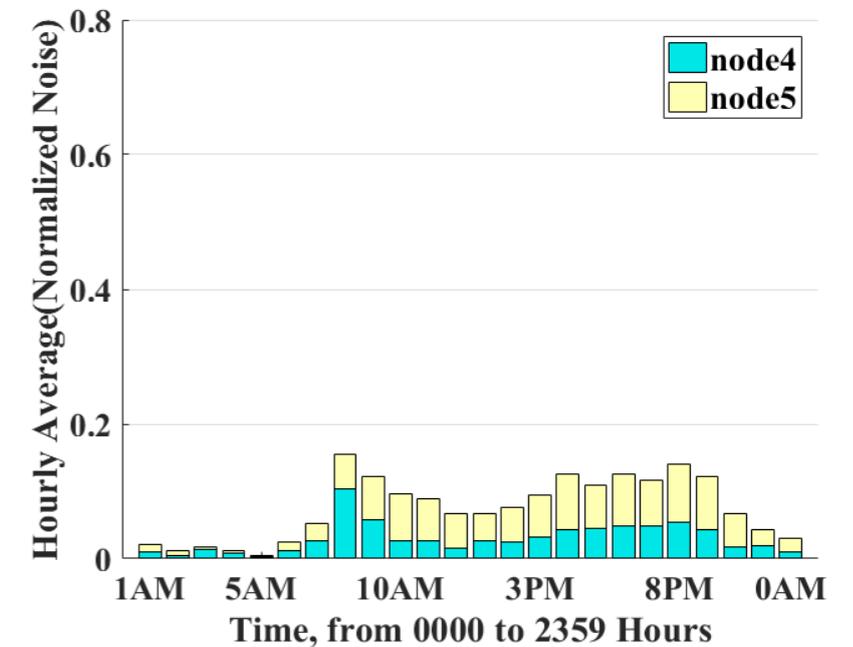
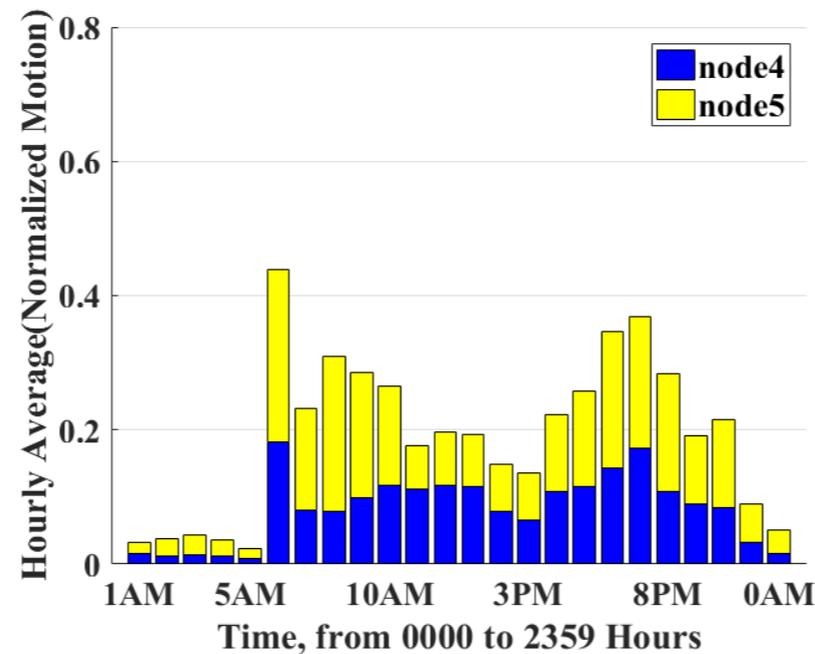
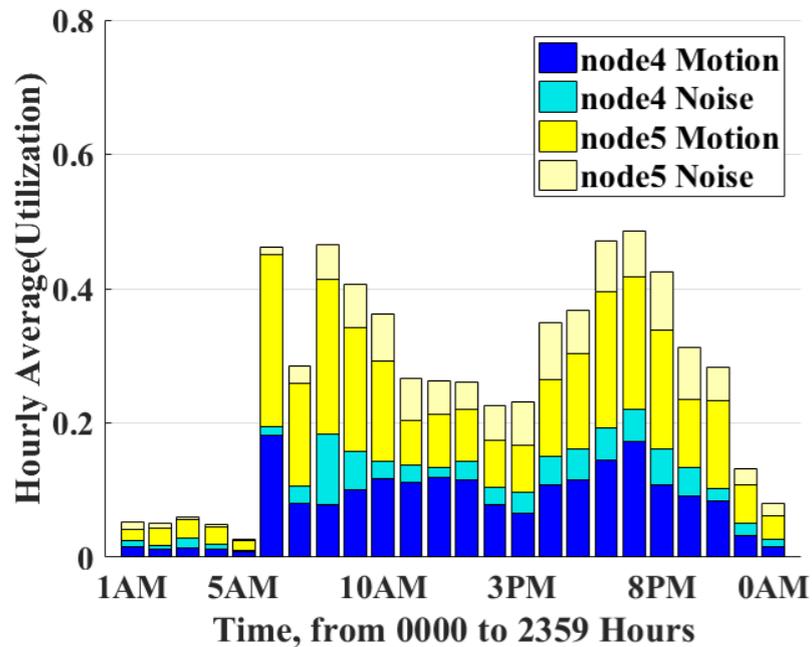
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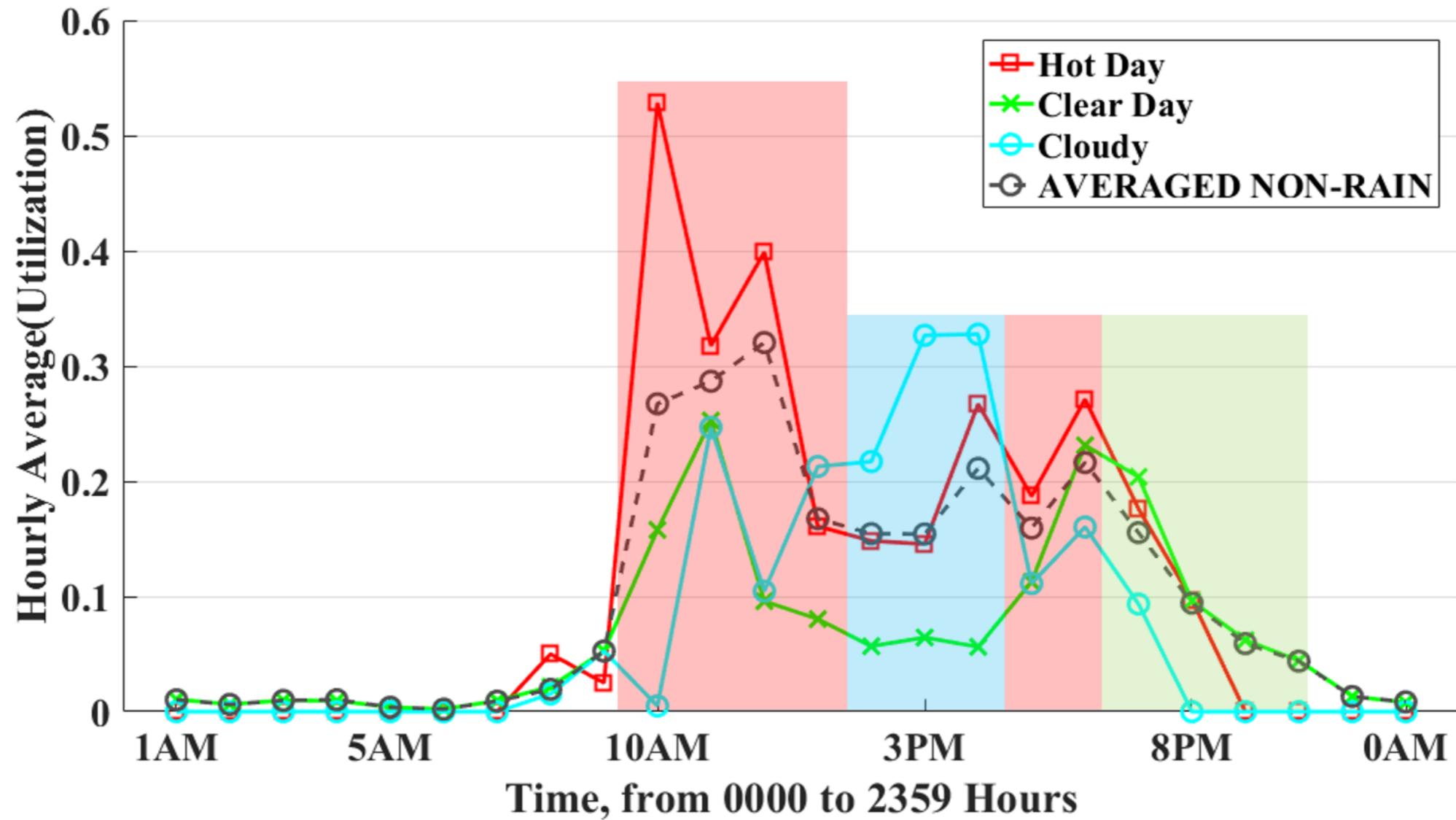
# POI 1 (outdoor)



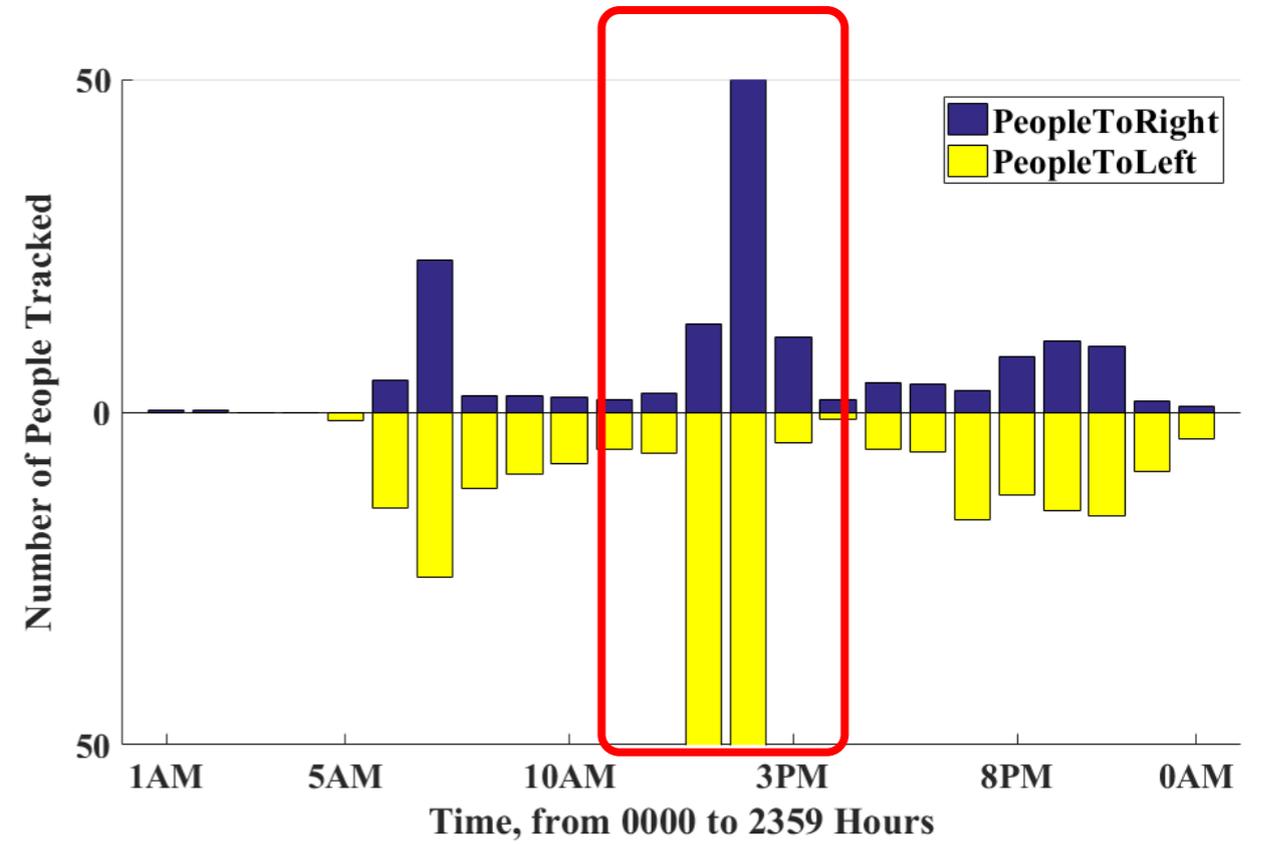
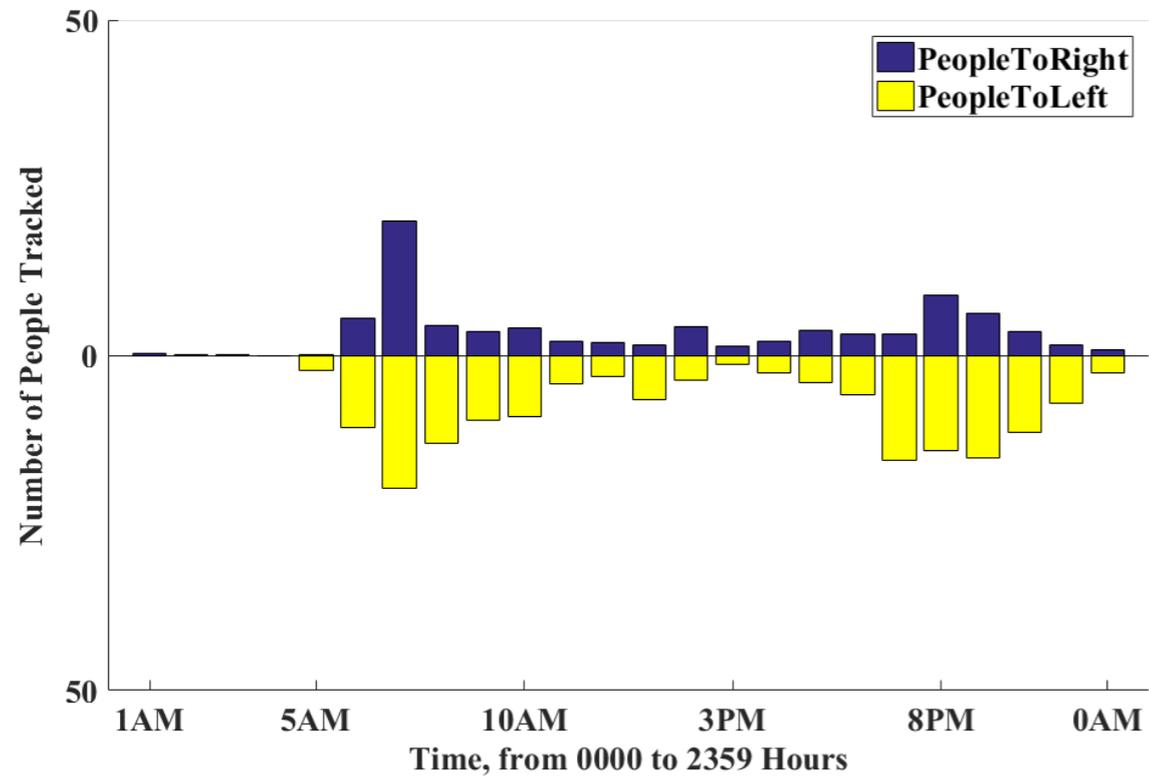
# POI 2 (Pavilion)



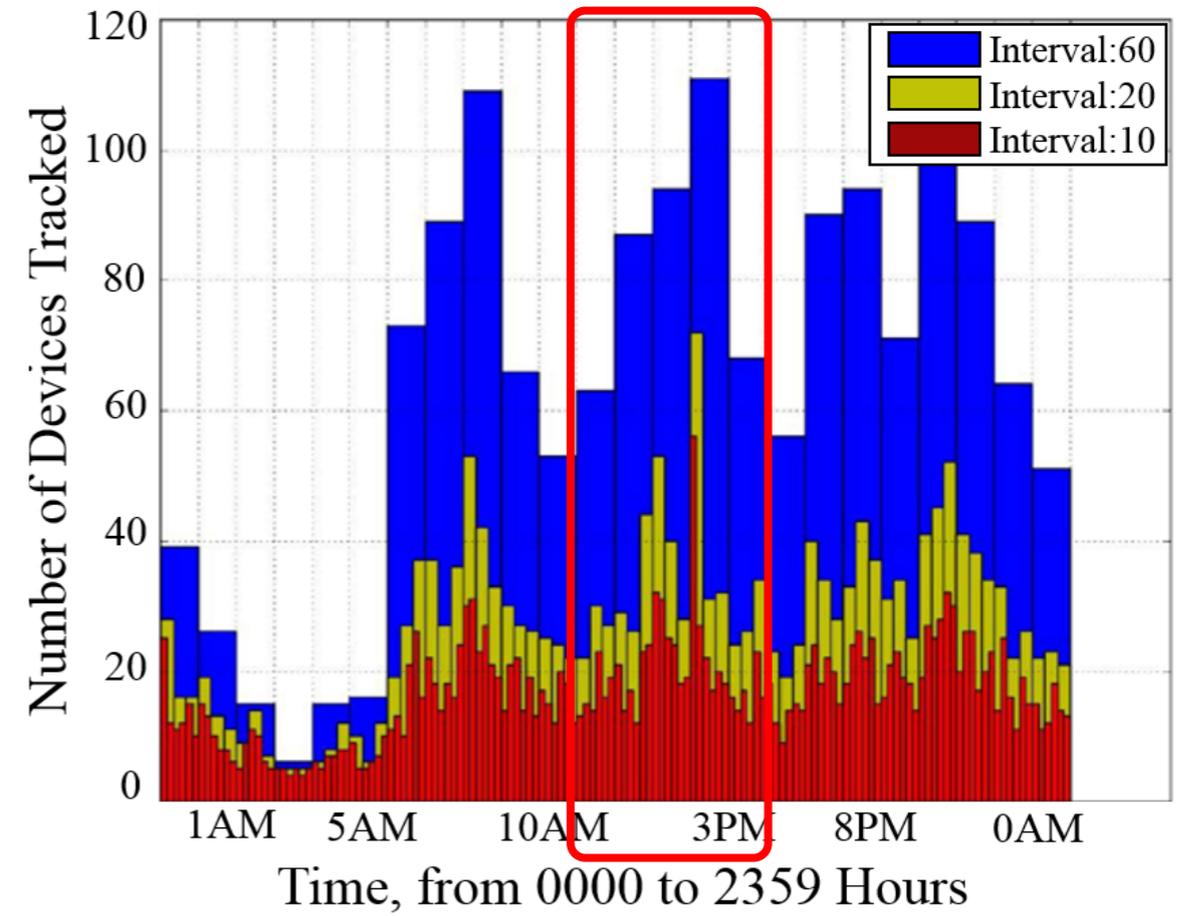
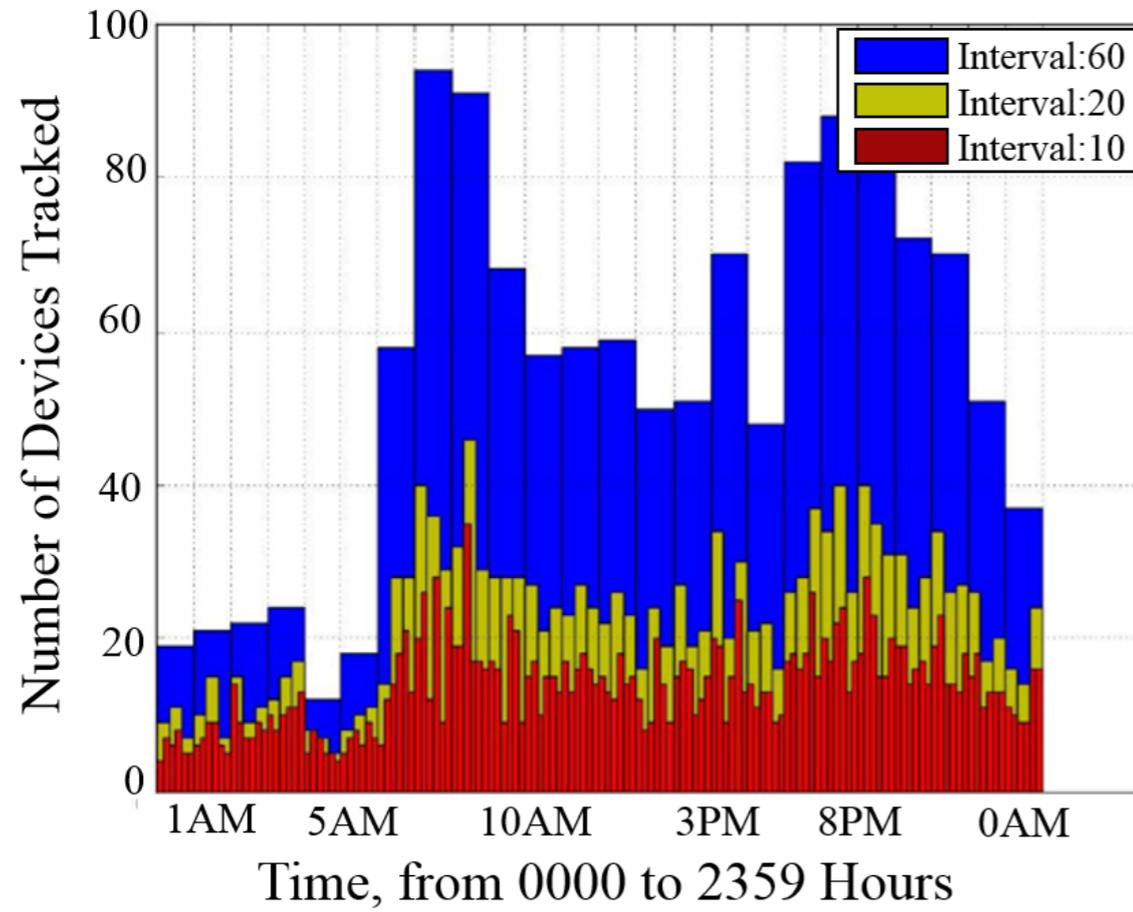
# POI 1 and POI 2



# POI 3 (Pathway)



# POI 4 (Lift lobby)



# Conclusions & Discussion

- SenseFlow, a lightweight human sensing system for smart cities.
- Exploring big data for understanding urban space utilisation, and residents mobility.

- Sensing coverage and density of SenseFlow.
- Real-time scheduling in heterogeneous and hierarchical sensor network, RWSN with Senseflow.
- Random MAC in new iOS.
- Smartphone activities effect.

