ICE-MoCha: Intelligent Crowd Engineering using Mobile Internet of Things Characterization and Analytics

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Credit goes to Abdoh Jabbari, Khalid J Almalki, Baek-Young Choi

Have you been in any?

- Entertainment
  - Sport
  - Music
- Politics
  - Protest
- Religion
  - Hajj
  - Kumbha Mela

Problem motivation

https://prezi.com/p/xhqkt0dpemcj/embed

Crowd-caused Disaster Examples

- In many crowd events, a sudden human stampede causes huge casualties.

- Example: Hajj, an annual gathering of millions of Muslims in Mecca, Saudi Arabia.

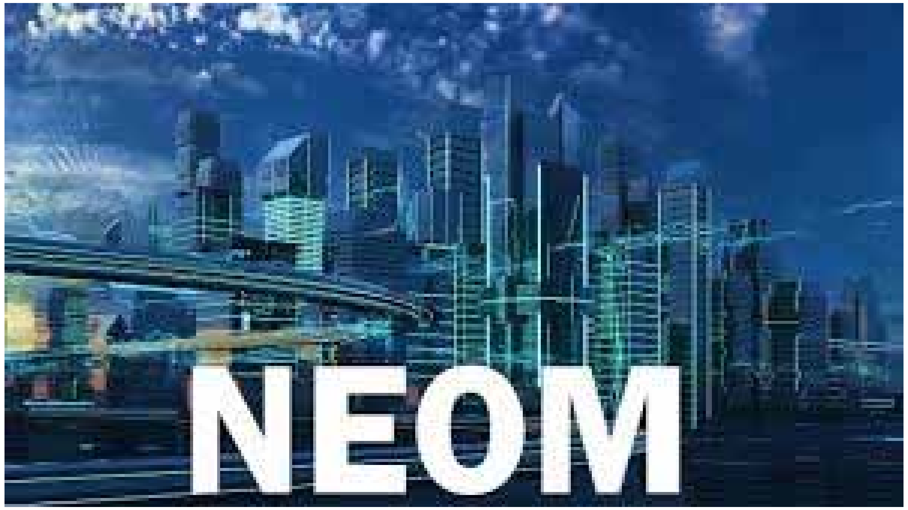
Location (Country/City)	Human Casualties	Year	Event Type
Bangladesh, Chittagong	60	2018	Religious
Italy, Turin	**1526**	2017	Entertainment
Ethiopia, Addis Ababa	300	2016	protests
Saudi Arabia, Macca	**2000**	2015	Religious
Brazil, Santa Maria	242	2013	Entertainment
Egypt, Port Said	74	2012	Sport
India, Jodhpur	224	2008	Religious
Iraq, Baghdad	**935**	2005	Religious
US, Rhode Island	100	2003	Entertainment
China, Luoyang	309	2000	Entertainment

World Crowd Disaster Map

Prove the necessity for the extra effort and research in the field of crowd management and control.

Upcoming problem of motivation

- 86% of the world population will be urbanized by 2050.
  - Example: Saudi Arabia, building Mega-City, '**NEOM**', with an investment of **$500 billion**!



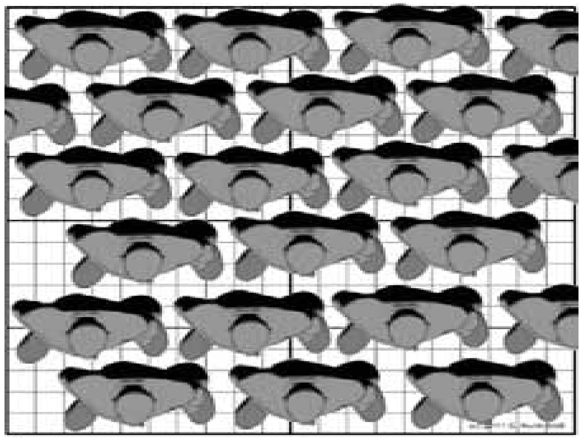
- **More crowd events** in normal life, religious, sport, and entertainment purposes **in Cities**
- An appropriate **crowd management** is one of the **essential** components in building **Smart Cities**!

Intelligent Crowd Engineering (ICE): Background

Crowd Types..

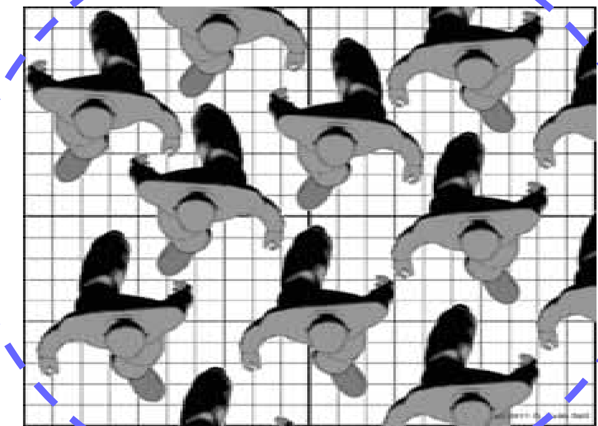
Standing Crowd.

- Crowds at specific location.
- Less space
- Easier to manage or control



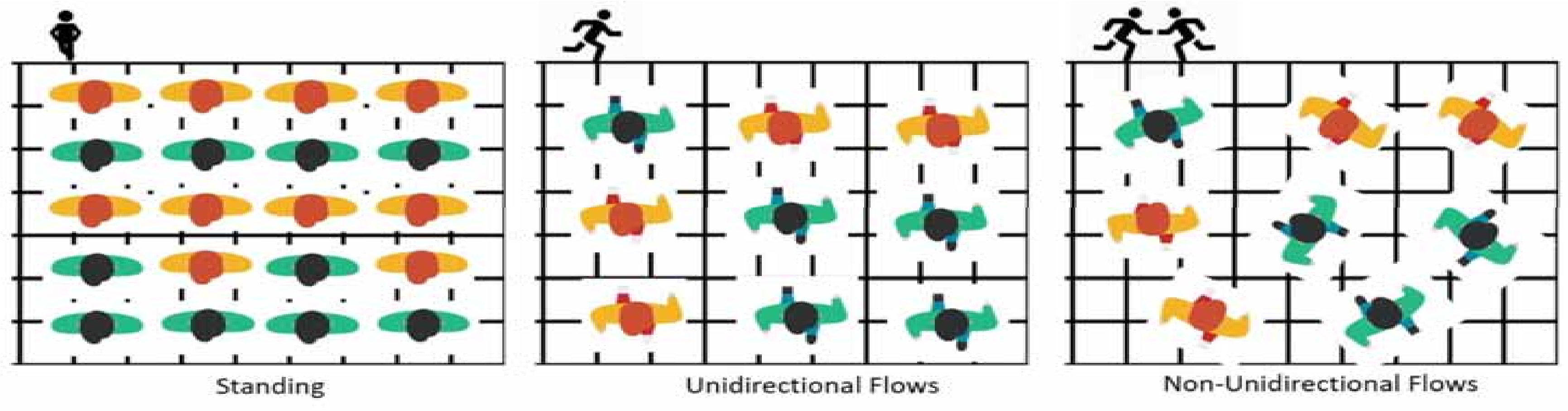
Mobile Crowd.

- Crowds traveling from point to another.
- Require more space
- Harder to be managed or control.

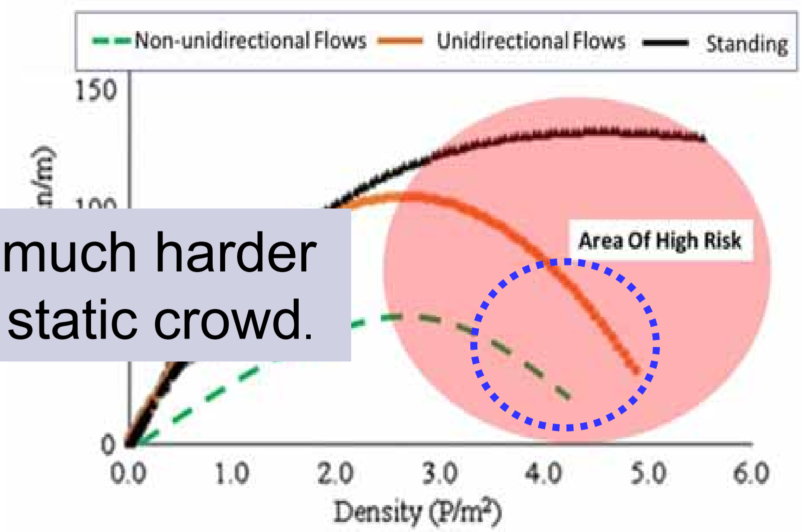


Still, G. Keith. Introduction to Crowd Science. Boca Raton:

Mobility Types



- Unidirectional
  - The flow of mobility going in the same direction.
  - Example: Protesters



Mobile crowd is much harder to manage than static crowd.

- Non-unidirectional
  - Objects mobility in multiple direction
  - Example: Malls, side walks.. Etc.
  - Riskier than unidirectional mobility

Object Mobility

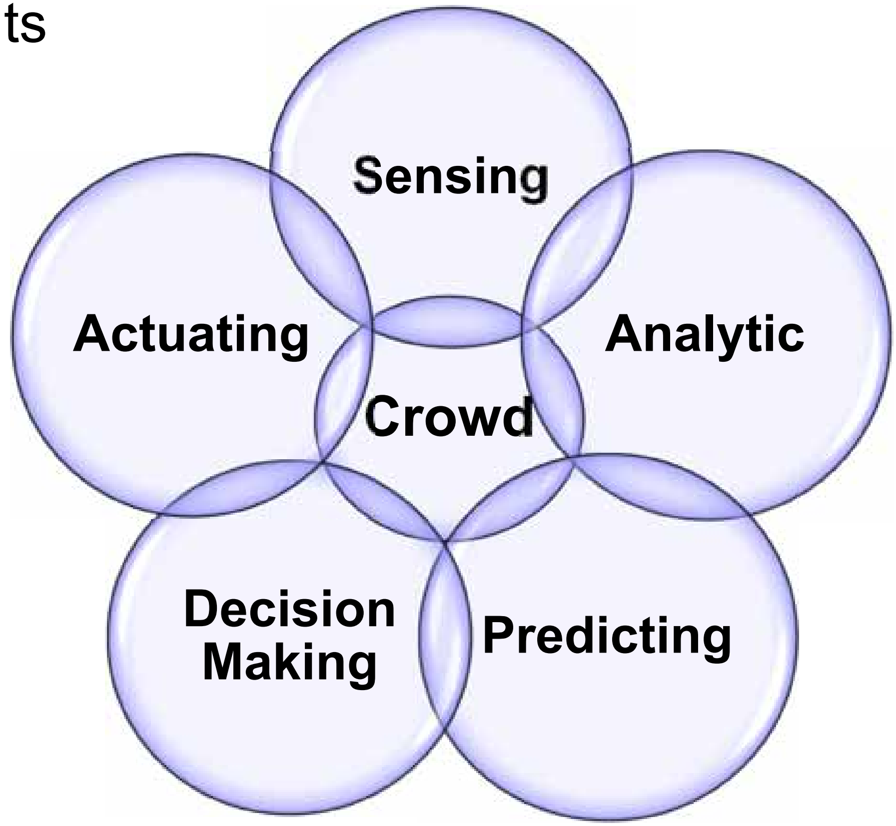
- Human mobility
  - Mobility pattern
    - Individual flow pattern
      - A student going home after school
    - Group flow pattern
      - the direction flow pattern of protesters.

- Autonomous vehicles mobility
  - Sensing
    - Collecting data from surrounding area
  - Analyzing
    - Processing and analyzing data
  - Decision making
    - Break, turns, speed

Intelligent Crowd Engineering (ICE): State-of-the-Art

Intelligent Crowd Engineering (ICE)

- Five essential crowd science research elements
  - **Sensing**
    - Data Collection
  - **Analytic**
    - Processing and Analyzing
  - **Predicting**
    - Predicting status (models)
  - **Decision making**
    - Deciding whether normal or abnormal behavior
  - **Actuating**
    - Dispatch officers to the location.



Human Mobility Prediction

- Mobility prediction
  - Flow pattern
  - The history of past movements
  - Type of the event
  - Structure of the Environment

Abnormal Behavior

Example:

Predicted Path **Observed Path**

Parents expected their kids to walk home after school, but kids went to game room.

Tracking abnormal behavior at events could alert the event planners earlier to avoid crowd disasters.

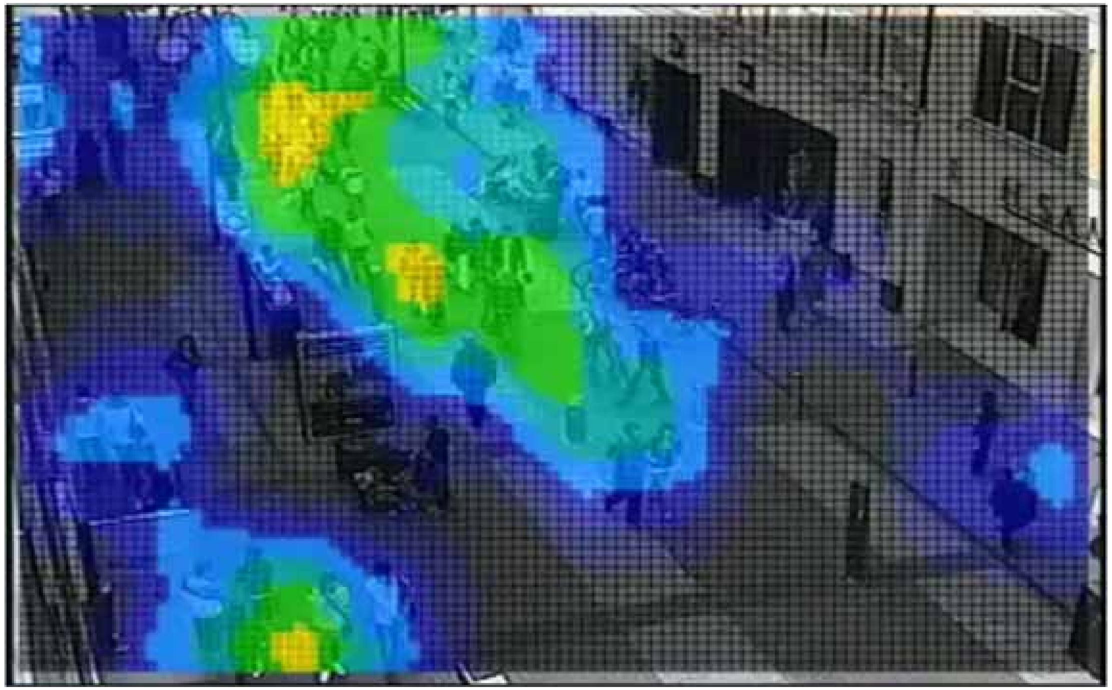
Abnormal Behavior Examples

- Behavior of not following the event policies
  - Behavior of waking faster or slower than normal
  - Behavior of walking in the wrong direction
  - Behavior of crossing over boundaries
  - Behavior of pushing others
  - Behavior of crowd density increasing sharply

What about the existing intelligent video approaches in crowd management?

Video Surveillance Approach

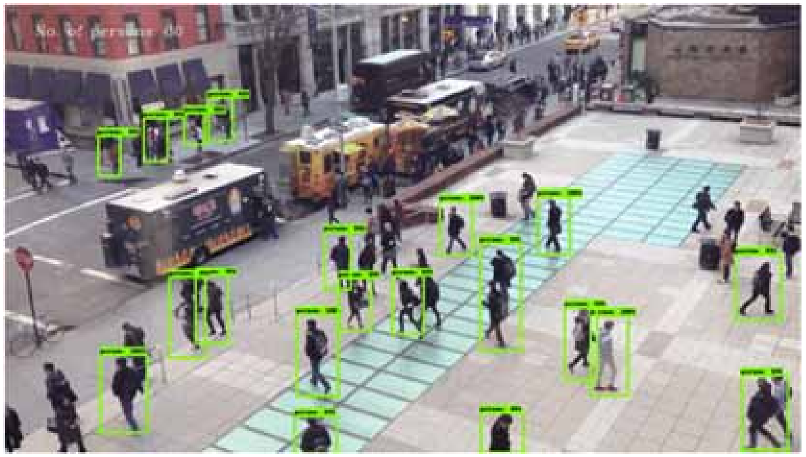
- Intelligent (ML) video surveillance can
  - Create crowd density heat map (object count and density)
  - Detect an object
  - Track multiple objects



Video Approaches for Crowd Monitoring

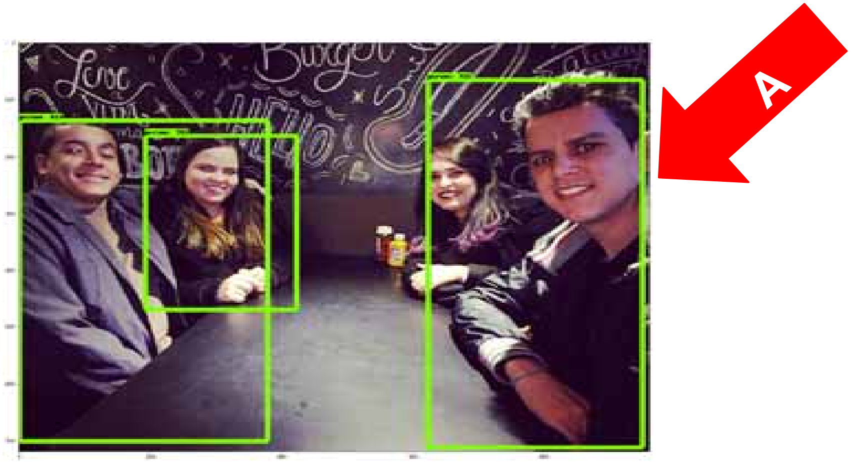
- **Shami et al. *"People Counting in Dense Crowd Images using Sparse Head Detections"***
  - proposed detects people head at the crowd for counting the density using Convolutional neural network CNN.
- **Alahi et al. "Unsupervised camera localization in crowded spaces,"**
  - proposed unsupervised learning to match multiple camera single-view in tracking pedestrians by estimating the distance between pair cameras.
- **Bek et al. "The crowd congestion level — A new measure for risk assessment in video-based crowd monitoring,"**
  - proposed an approach to measuring the crowd density flow for congestion risk assessment.

⇨ However, still cannot scale to track objects at massive crowd!



Faster RCNN Inception trained

Our Experiment of ML in Crowd Detection



MS COCO dataset trained

- Accuracy issues of using a model trained on the COCO dataset (in collaboration with Khalid and Dr. Sung).
  - A: One person on the right is missing.
  - B: Only two object is detected for a massive crowd with less resolution.

Challenges on Video Surveillance Approach

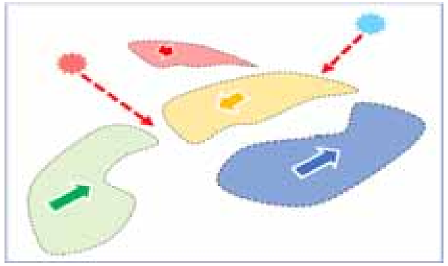
- Video surveillance alone cannot
  - Scale to handle entire crowd objects in real-time
  - Identify detailed crowd status such as group, direction, and speed of each flows

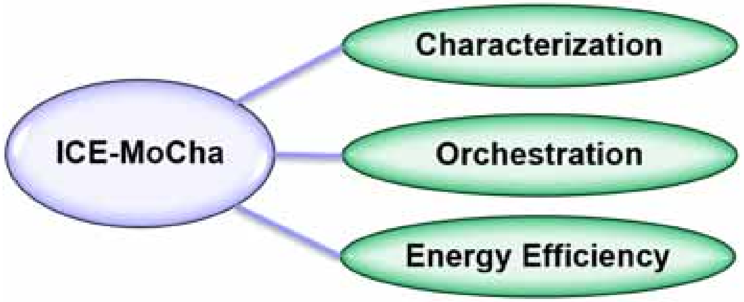
- Example:
  - Video surveillance accuracy can be affected in case of wearing umbrellas or human blocked by other objects.
  - More than 5000 cameras to monitor Hajj event.

Hybrid Approach: *RF signals to fill the scalability and capability gaps of the existing video surveillance as well as improve ML training.*

ICE-MoCha Layer

Semantic Knowledge





Video / Image Surveillance

Introduction

- New events keep coming:
  - Entertainments (more than 800 music festivals in the US, 2018 alone).
  - Political events (more frequently nowadays).
  - Religion.

- Number of attendees are increasing:
  - Religion: i.e., Hajj, 45% increased from 1999 to 2018.
  - Music: 32 million attendees last year only in the U.S.
  - Political: protests (everywhere).

What is needed:

- A real-time tracking system that is capable of tracking the attendees and predict any abnormal behavior such as:
  - Walking in the wrong direction
  - Flow that is faster or slower (stopped) than the normal speed
  - Sudden increase of density
  - And other abnormal situations (from stable to mobile)

- An IoT tracking system can:
  - Give additional information that video surveillance cannot give
  - Improve capabilities and scalabilities of video surveillance

CROMO

Crowd Mobility Characterization

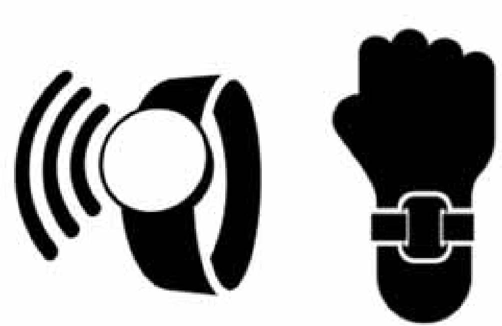
Best Paper Award!!!

IEEE International Smart Cities Conference (ISC2 2018)
http://sites.ieee.org/isc2-2018/

Upcoming 2019 IEEE ISC2: https://ieee-isc2.org/

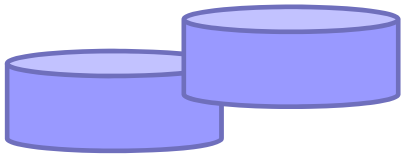
CROMO for a Smart Crowd Tracking

- Internet of Things (IoT) meet crowds:
- Make a practical and field usable RF signal framework (transmitters and scanners)
  - Practical and energy efficient wearable tags for mobile objects
  - Scalable and accurate scanners for data analytics
- Real-time analysis of the data for the potential collision prediction and protection
- Facilitate CROMO on the existing video surveillance

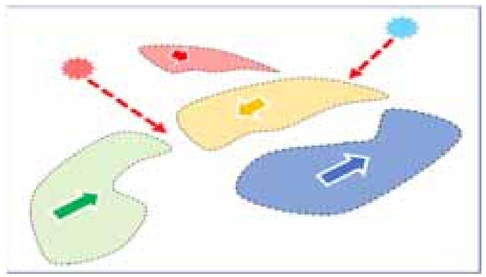


CROMO Layer

Intelligent Crowd Management System



Semantic Knowledge



CROMO Layer

Video / Image Surveillance

RF Transmission Approaches

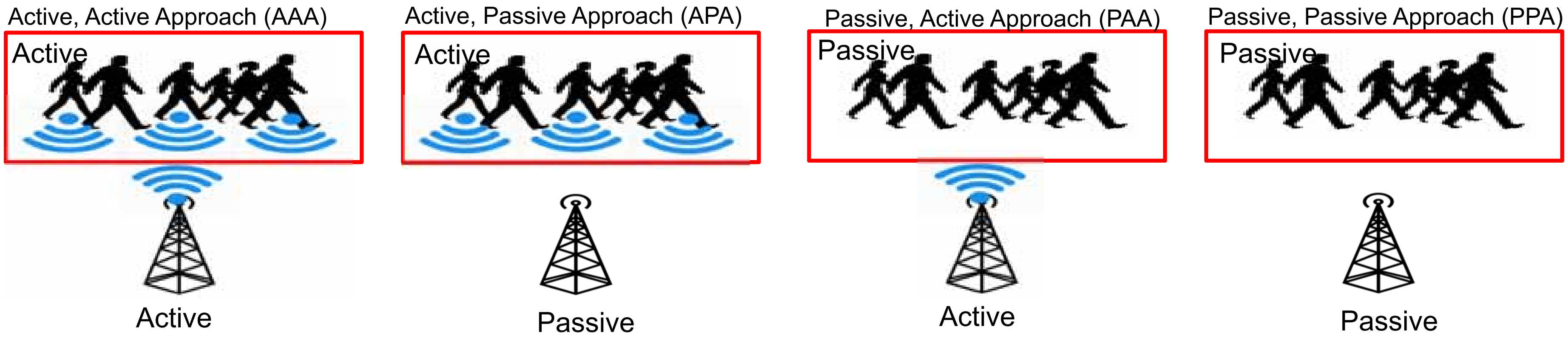
Protocol	Range	Mobility	Deployment
BLE	> 100 m	< 5 Mph	Ubiquitous Low power usage
WiFi	> 100 m	< 5 Mph	Ubiquitous Long association time
Cellular	< 10 Km	> 60 Mph	Ubiquitous Long association time

- Bluetooth Low Energy (BLE)
  - Low power consumption
  - Low cost
  - Flexibility in size and design
  - Ubiquitous

Useful Metrics

- Using rudimental BLE data metrics such as Beacon count, RSSI power, and variation, it can
  - Identify crowd density
  - Collect object group identification
  - Detect crowd flow direction (i.e., wrong direction)
  - Find an object location
  - Determine crowd flow speed (still, slow, or fast)

Potential Scanning Approaches



- **Active, Active Approach (AAA):** both scanners and tags are in active mode.
  - both scanners and tags periodically sending beacons
- **Active, Passive Approach (APA):** Scanners are in passive mode while tags in active mode.
  - Tags are periodically sending beacons
- **Passive, Active Approach (PAA):** Scanners are in active mode and tags in passive mode.
  - Scanners are periodically sending beacons
- **Passive, Passive Approach (PPA):** both scanners and tags are in passive mode.
  - both scanners and tags are not sending beacons

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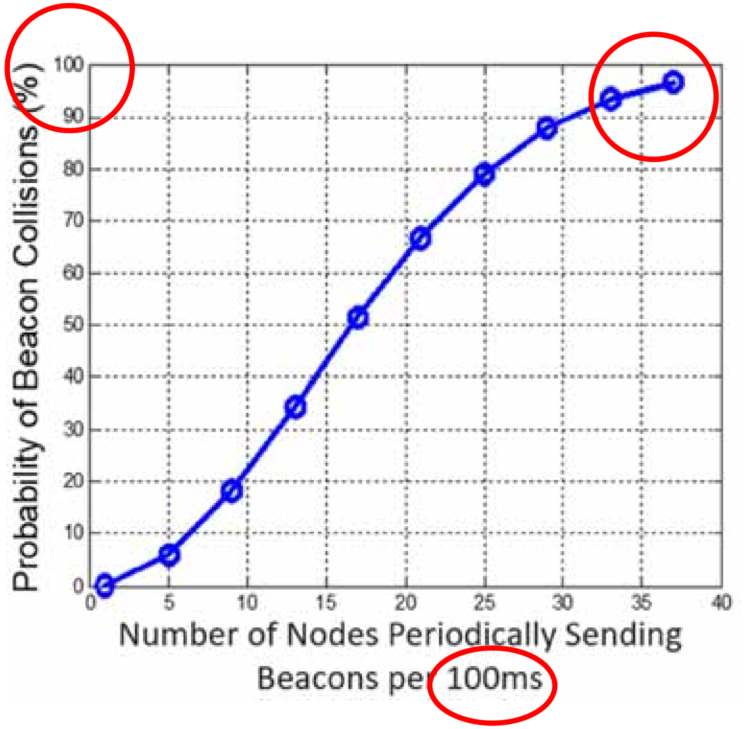
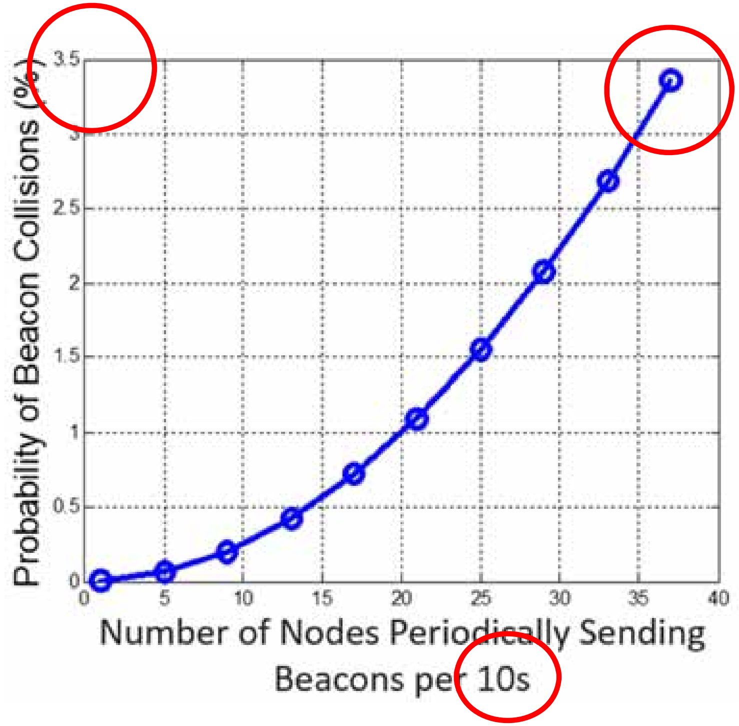
RF Signal Scalability

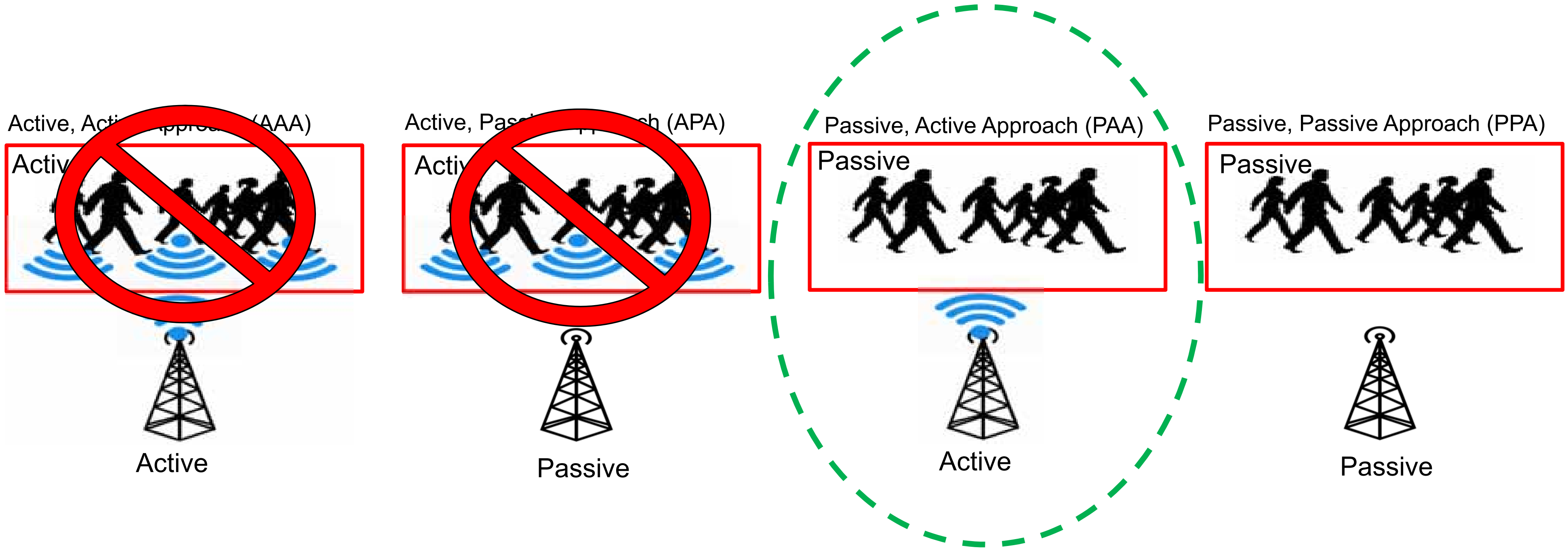




Periodic beacon approaches are not scalable for handling massive crowd.

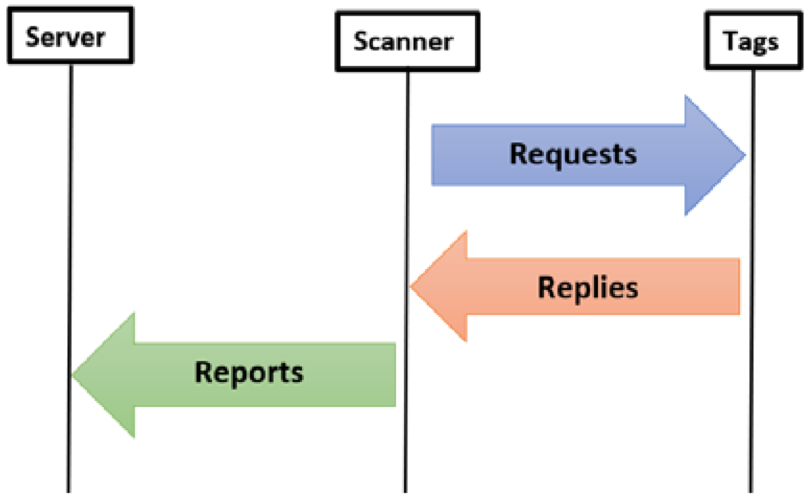
doc.: IEEE 802.11-07/2813r0

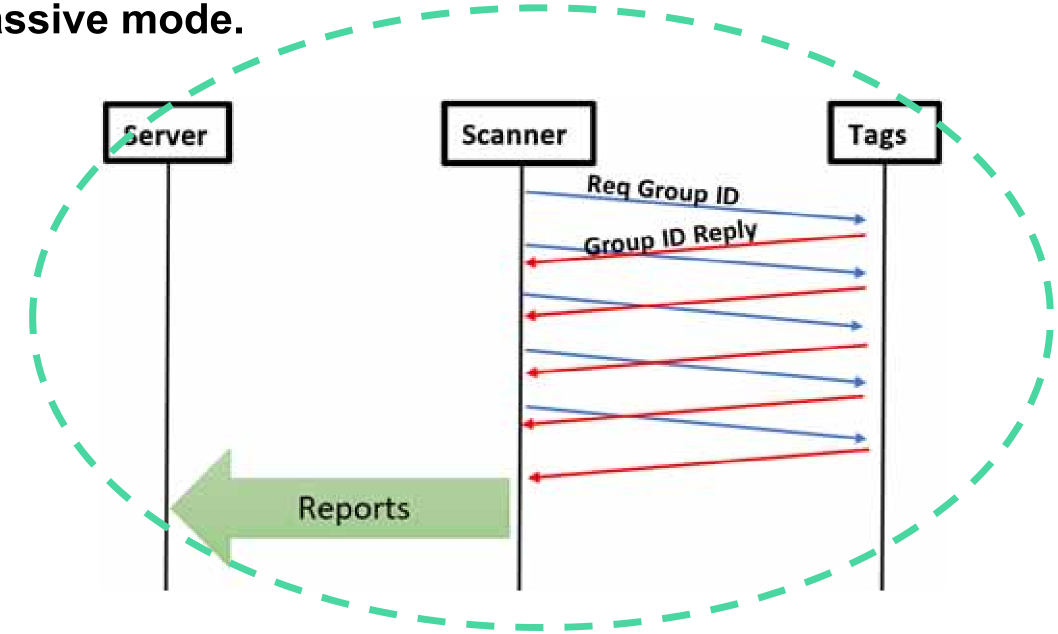
Potential Scanning Approaches



Passive, Active Approach (PAA) Approaches

"Passive, Active Approach (PAA)" approach: Request and Response mode that a scanner is in an active mode; pedestrian's bracelets are in a passive mode.





- Send a beacon request for all.
- All tags reply at the same time.
- Chance of potential **beacon collision**.

- Send distributed beacon requests for a selected groups.
- Only requested groups are responding.
- Reduce the collision possibility.

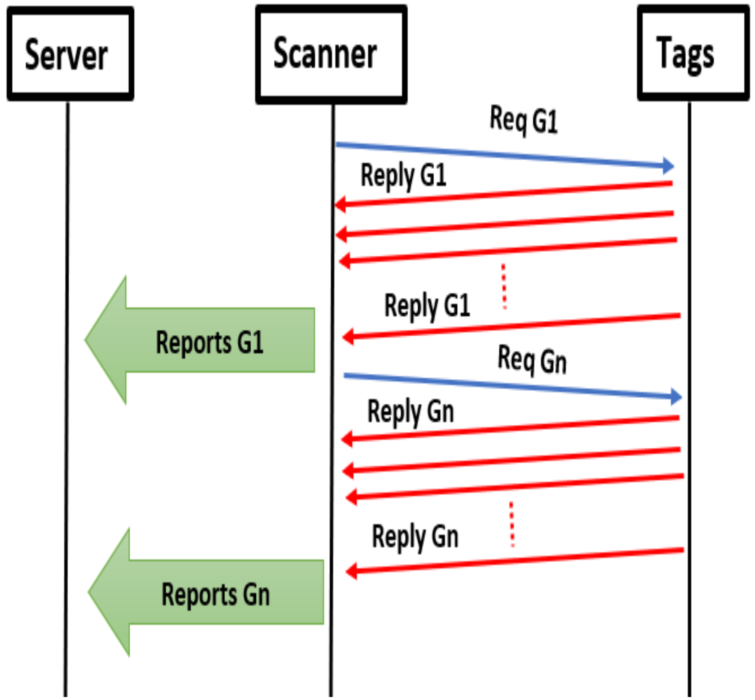
Our approach is a Distributed PAA

Distributed PAA Approach

- Response timing can be distributed by using group selection and responder % selection (i.e., mod() for Group ID or Object ID).
- Scalability is configurable.

Advantages:

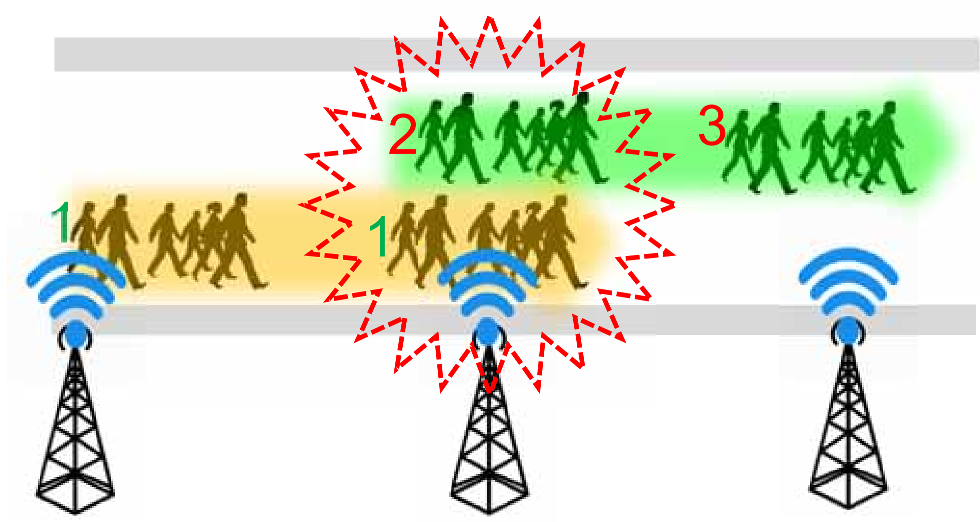
- Reduce beacon message collision.
- Provides reasonable message overheads.
- Ensures less power consumption at the pedestrian's bracelets.
- Increases data accuracy.



Group Selection Example

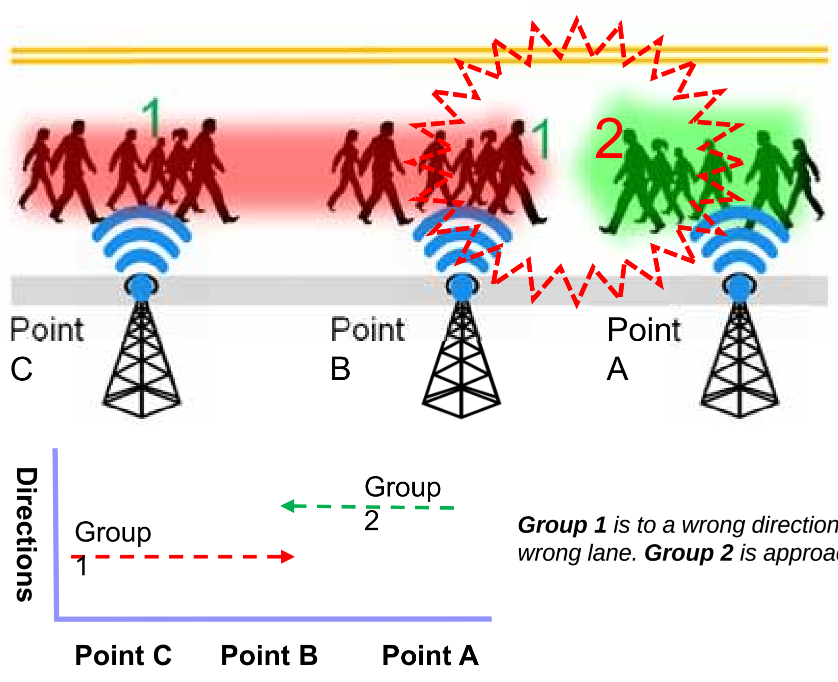
Scenarios 1: Group Speed Detection

- Group movement speed detection.
  - Too fast or slow crowd movement may cause flow congestion or back to back collision.



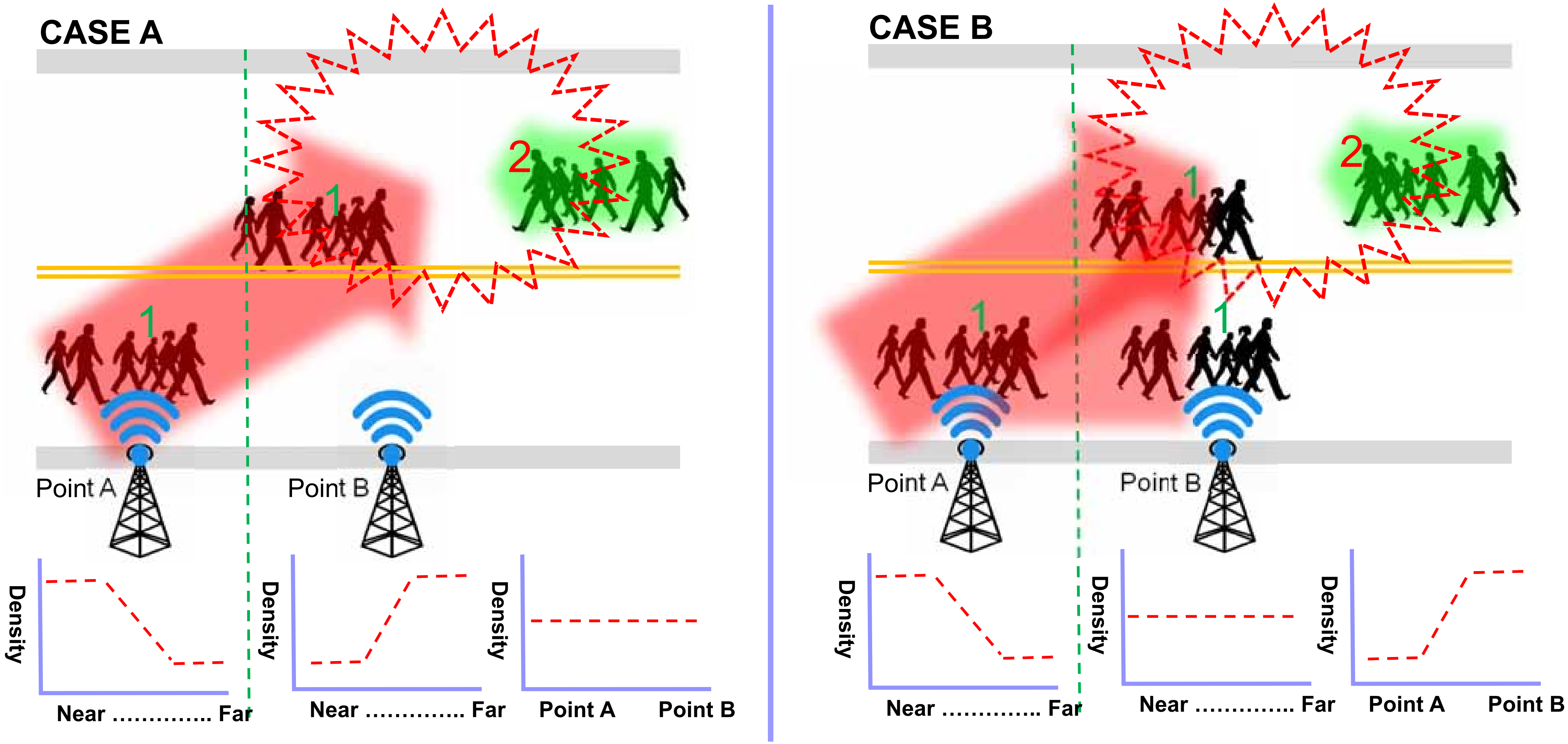
Scenarios 2: Group Direction Detection

- Wrong Direction detection
  - Crowd flow in wrong direction may cause serious tragedy.

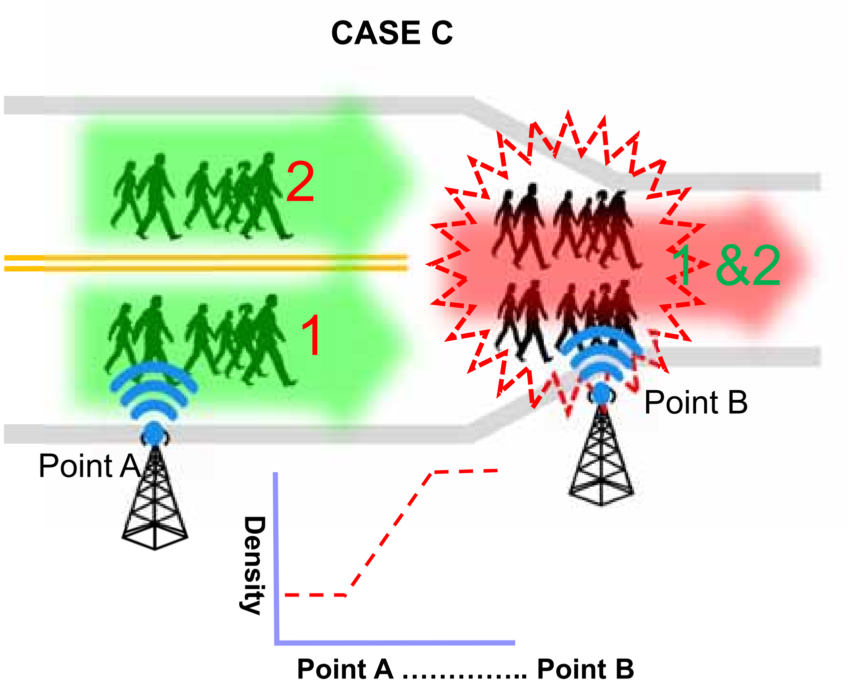


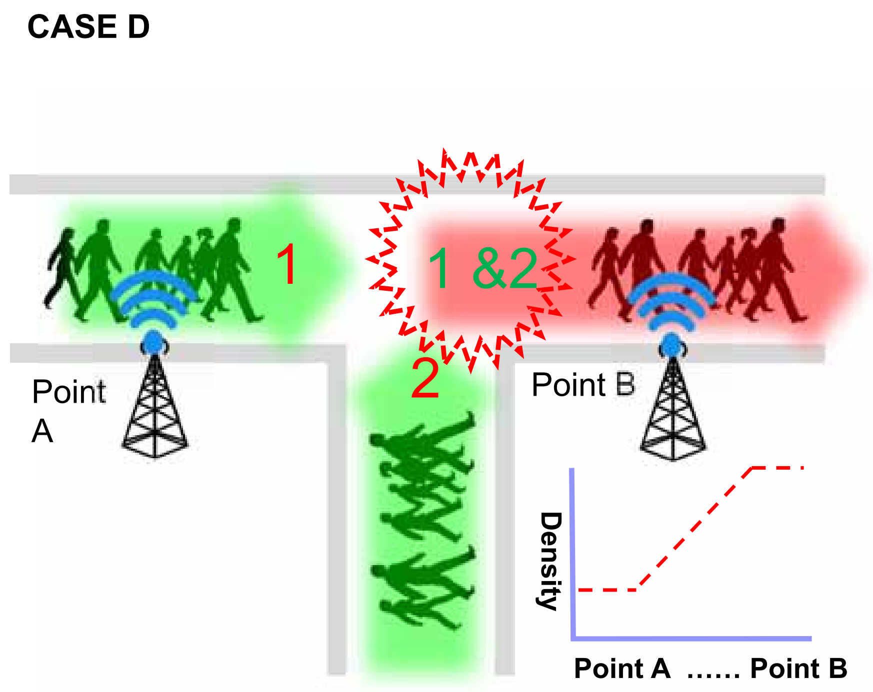
***Group 1** is to a wrong direction in a wrong lane. **Group 2** is approaching.*

Scenarios 3: Group Cross-Over Detection

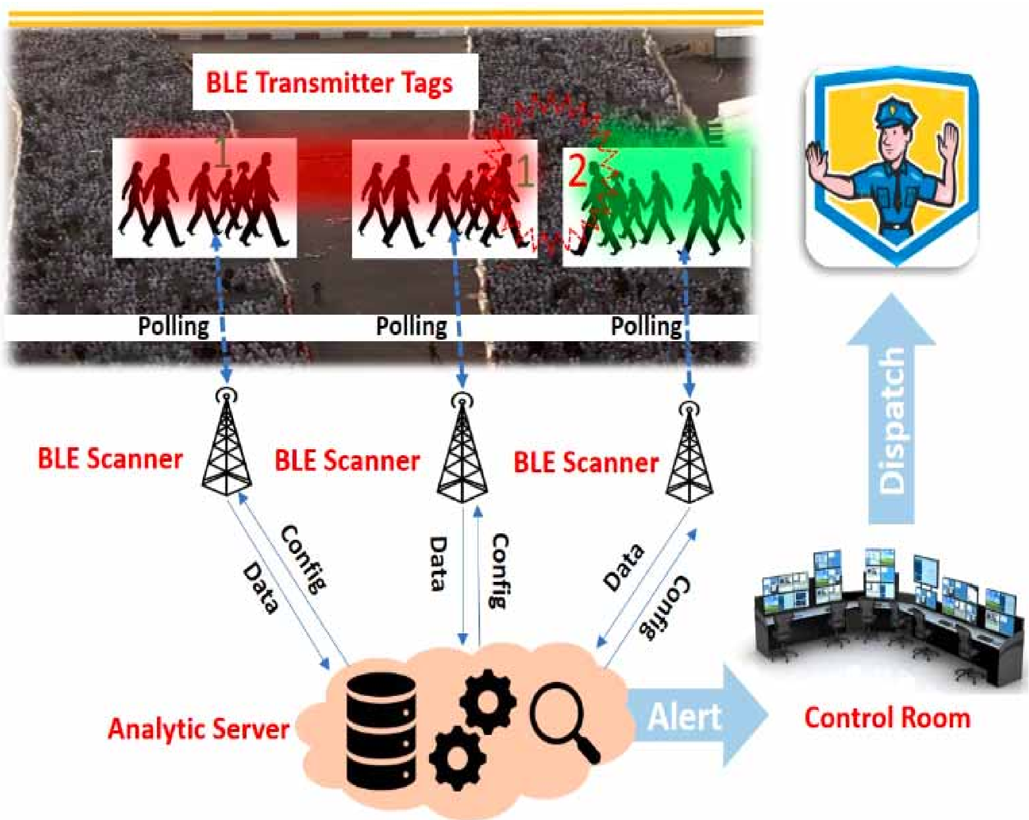


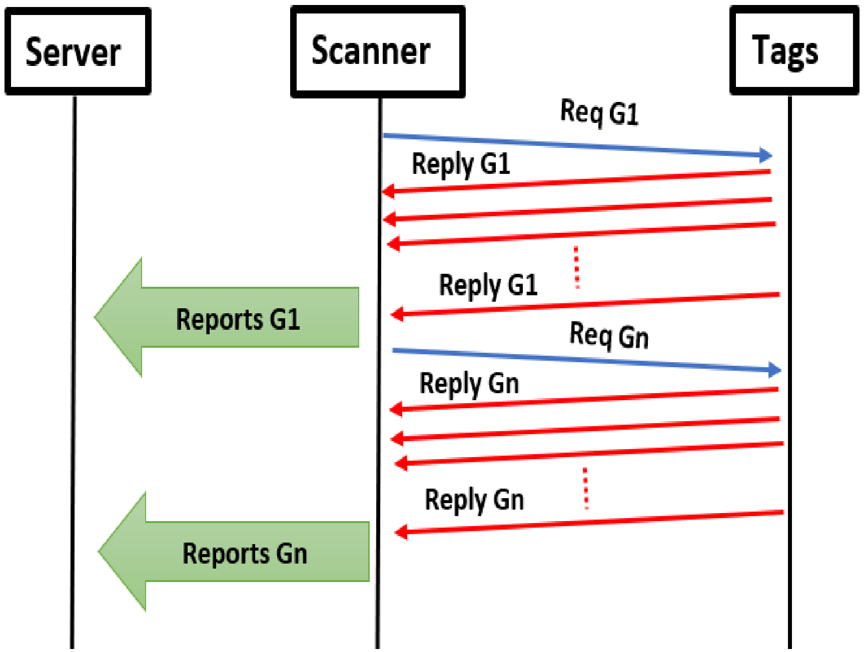
Scenarios 4: Density Change Detection





Implementation

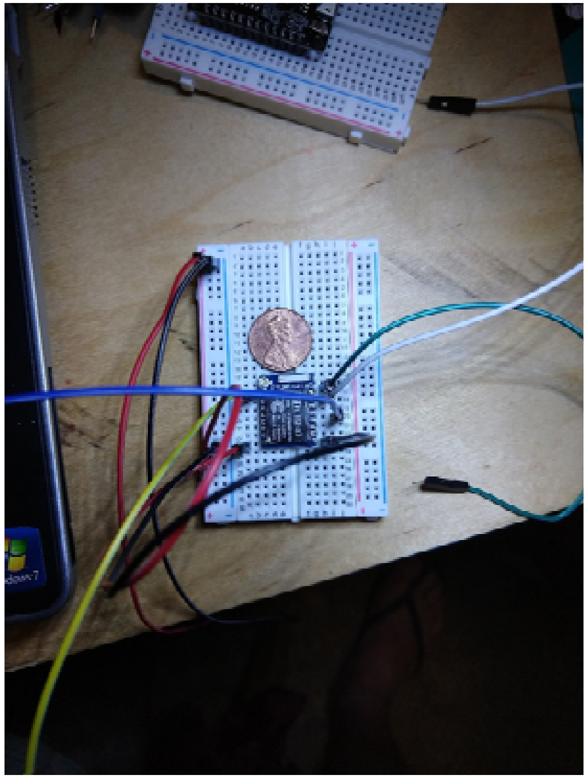




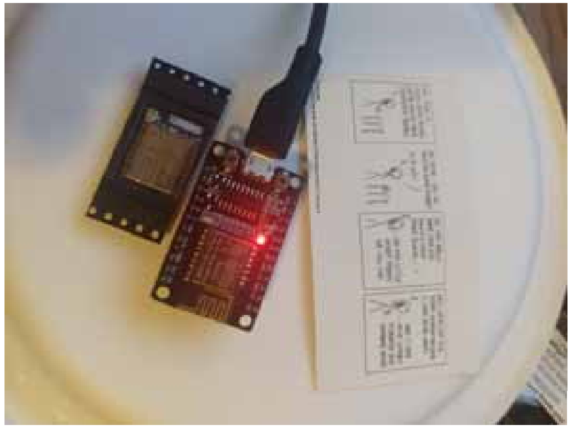
Experimental Setup

- A BLE scanning infrastructure is implemented on a Raspberry Pi 2 model B+
- The infrastructures are installed in different heights, 1m and 3m
- A wearable BLE beacon emitter is implemented on a smartphone as an app (A COTS bracelet tag will be used eventually)

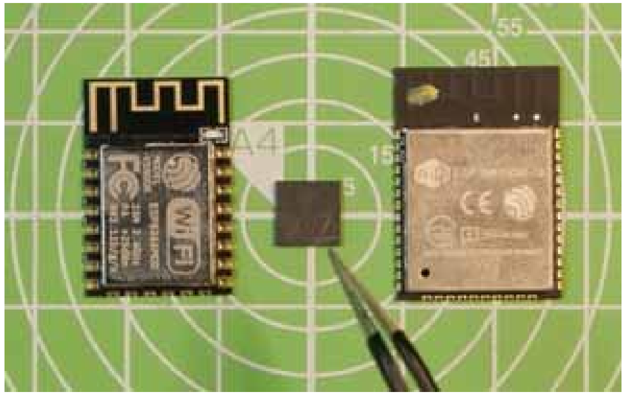
Tag Prototype (2019)



https://randomnerdtutorials.com/how-to-install-esp8266-board-arduino-ide/



Esp8266 based Tag

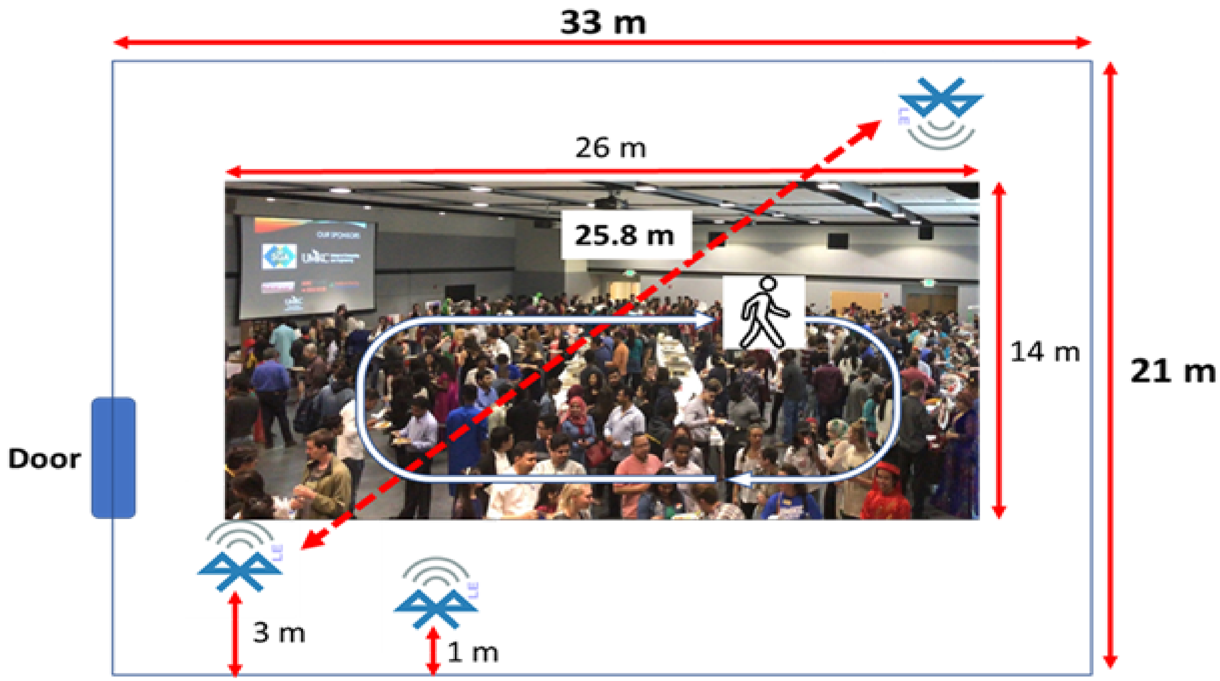


ESP8266 module (left),
ESP32 module (right),
with the new ESP32–S2 silicon (middle).

Beacon Count Experiments

- **Metrics:**
  - Density, Location, Speed, and Direction by using Beacon Count
- **System Settings:**
  - Environment (Indoor)
  - Scanner Position (1 m and 3 m)
- **Workload Settings:**
  - Crowd Density (NC, MC, and HC)

Type	Amount
No Crowd (**NC**)	Less than 10 (~ 0 per 1 m^2)
Medium Crowd (**MC**)	500 ~ 700 (~ 1.5 per 1 m^2)
High Crowd (**HC**)	Over 1000 (~ 3 per 1 m^2)

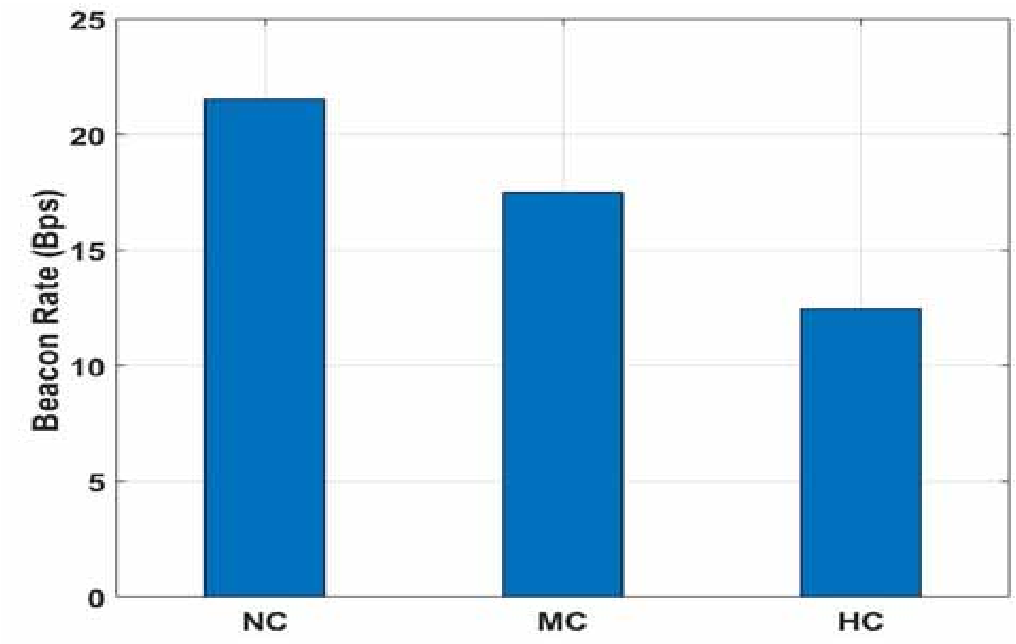


Average Beacon per second (Bps)

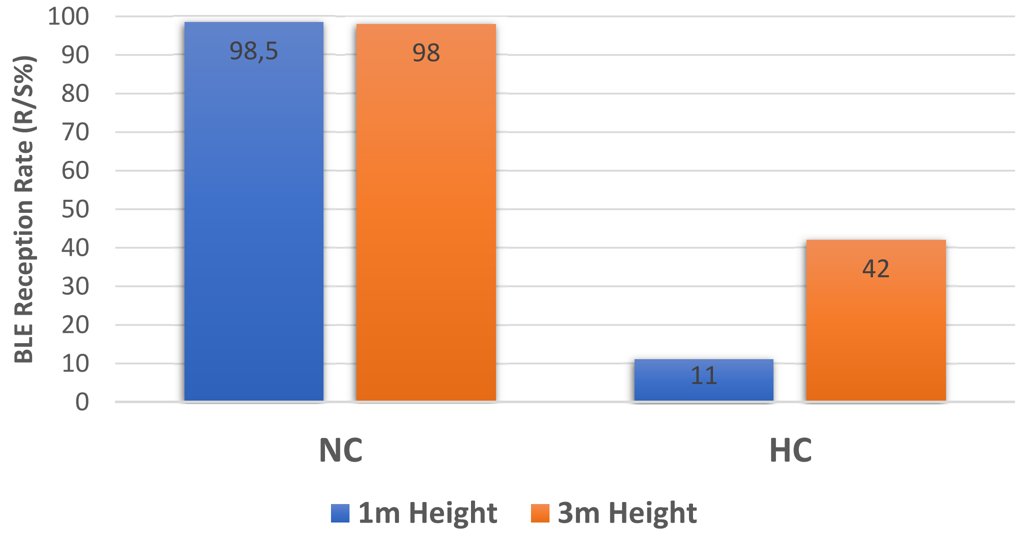
Given beacon interval of 20ms + delay of 0 ~ 10ms +10ms scan interval = ~ 40ms

- NC receives ~ 98%
- HC received ~ 50 %

Human object has an impact on the received beacons count

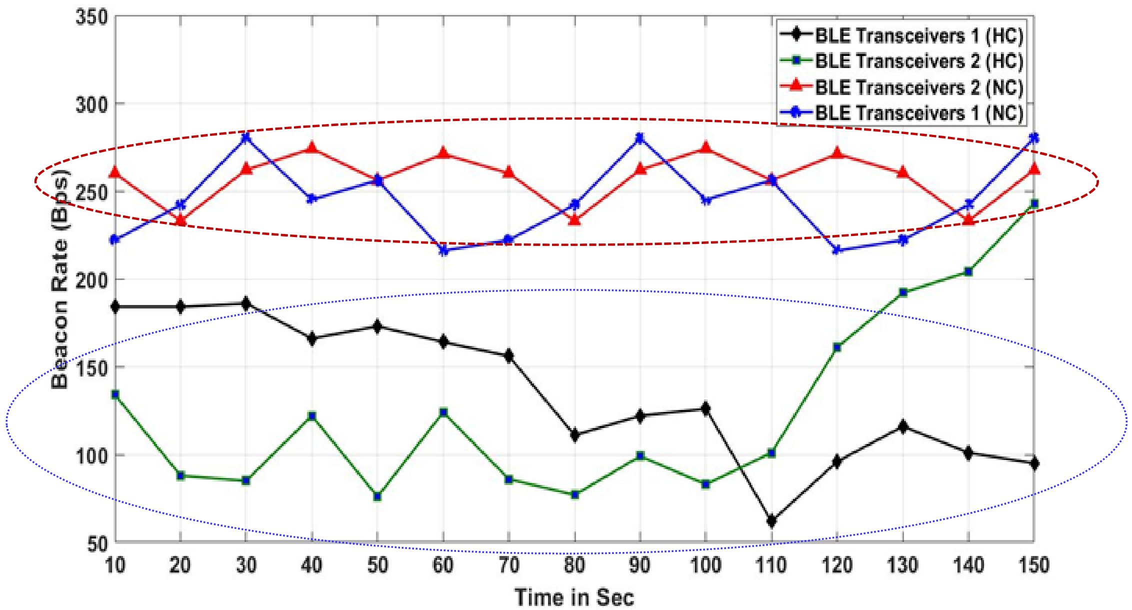


BLE Reception vs. Scanner Location



- No (minor) beacon loss for both 1 *m* and 3 *m* in **NC**
- About 50% beacon dropped for 3 *m* in HC
- Almost 90% beacon dropped for 1 *m* in HC
- Human has impact (NC vs. HC)
- Scanner location (height) matters in HC (should be higher than the human height)

Beacon Counts for Flow Direction



- No difference of Bps in NC; Object cannot be tracked with beacon count alone in NC
- In HC, the beacon count on a specific scanner increases when an object approaches near and decreases when an object goes away
- A location, direction, and speed of an object can be detected through the coordination of multiple scanners

Beacon RSSI Experiments

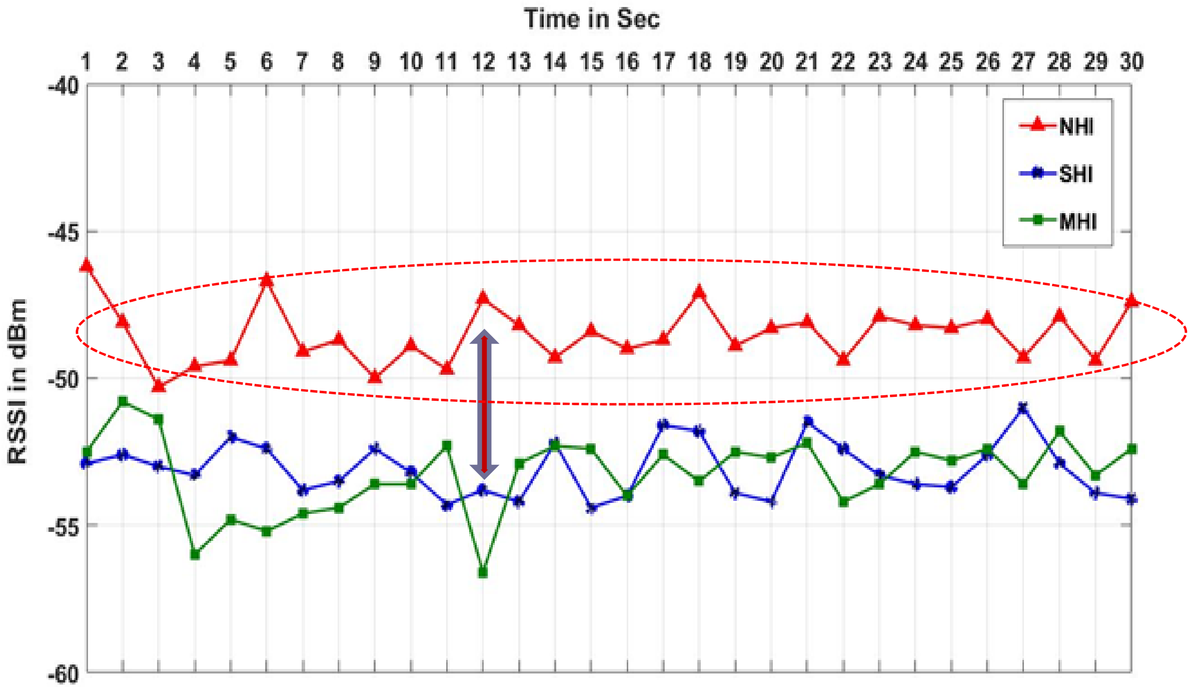
- **Metrics:**
  - Density, Location, Speed, and Direction by using Received Signal Strength Indicator (RSSI) Power and Variation
- **System Settings:**
  - Environment (Indoor and Outdoor)
- **Workload Settings:**
  - Human Effect (NHI, SHI, and MHI)

Type	Amount
No Human Interference (**NHI**)	0 human object
Single Human Interference (**SHI**)	1 human object
Multiple Human Interference (**MHI**)	4 human objects

Indoors

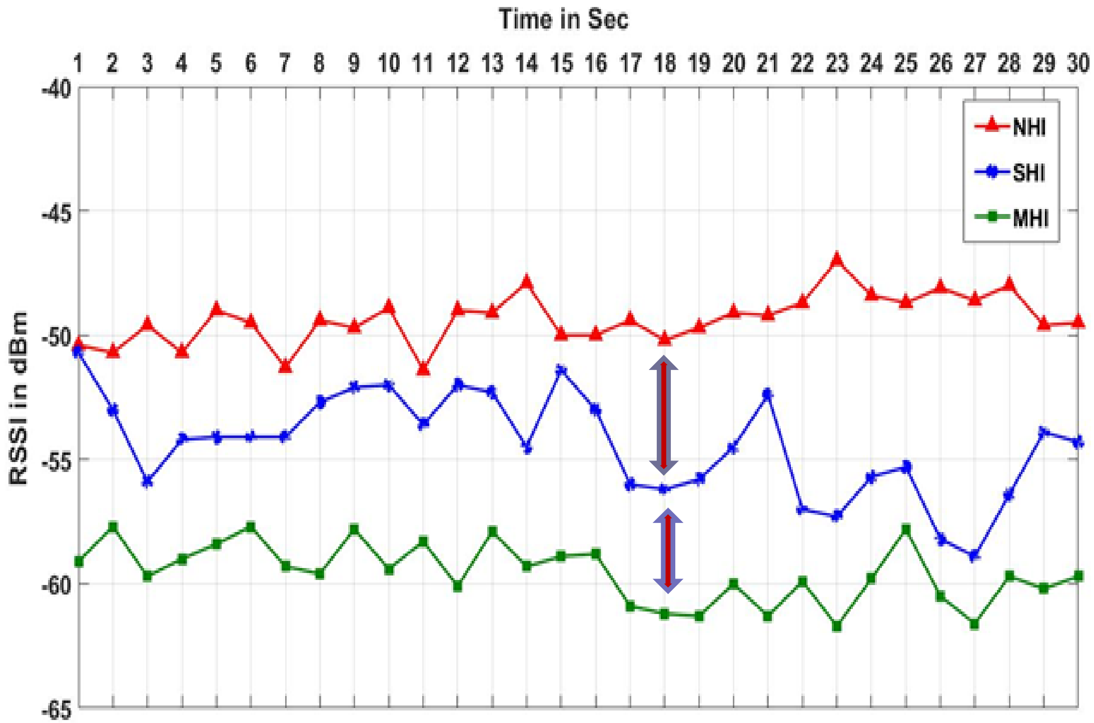
Outdoors

Indoor Average RSSI Power



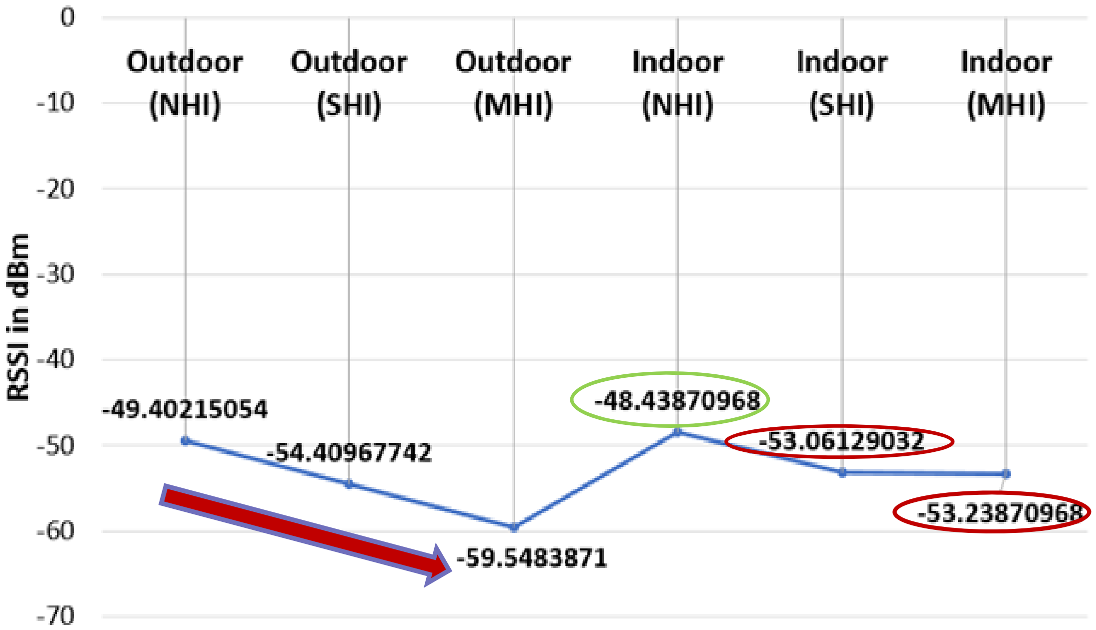
- NHI is stronger than both SHI and MHI
- No significant difference in signal power average between SHI and MHI
- NHI can be identified from others in indoor

Outdoor Average RSSI Power



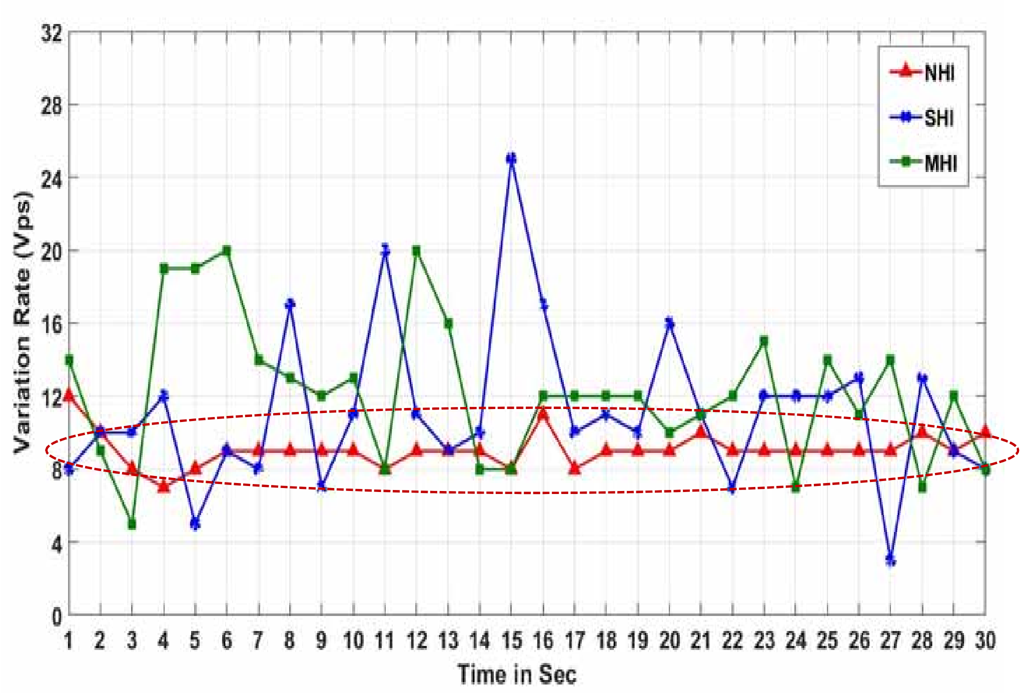
- NHI receives stronger signal (RSSI power) than SHI.
- SHI has stronger signal (RSSI power) than MHI.
- All cases (NHI, SHI, and MHI) can be identified in outdoor

RSSI Power Comparison



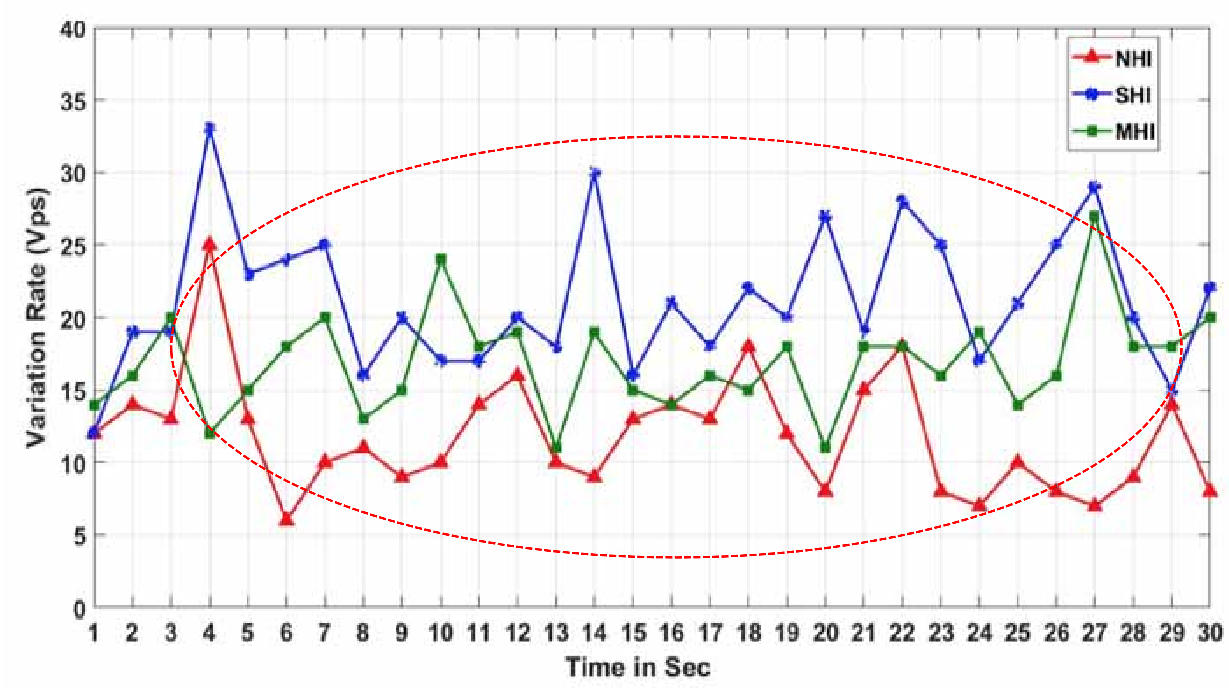
- Indoor RSSI power of both SHI and MHI is similar, but NHI is different
- Outdoor RSSI power shows a clear difference among NHI, SHI, and MHI
- Both indoor and outdoor results indicate that they can identify any human interference (i.e., NHI vs. non-NHI), but Indoor case cannot discern the density level difference (SHI from MHI)

Indoor RSSI Variation



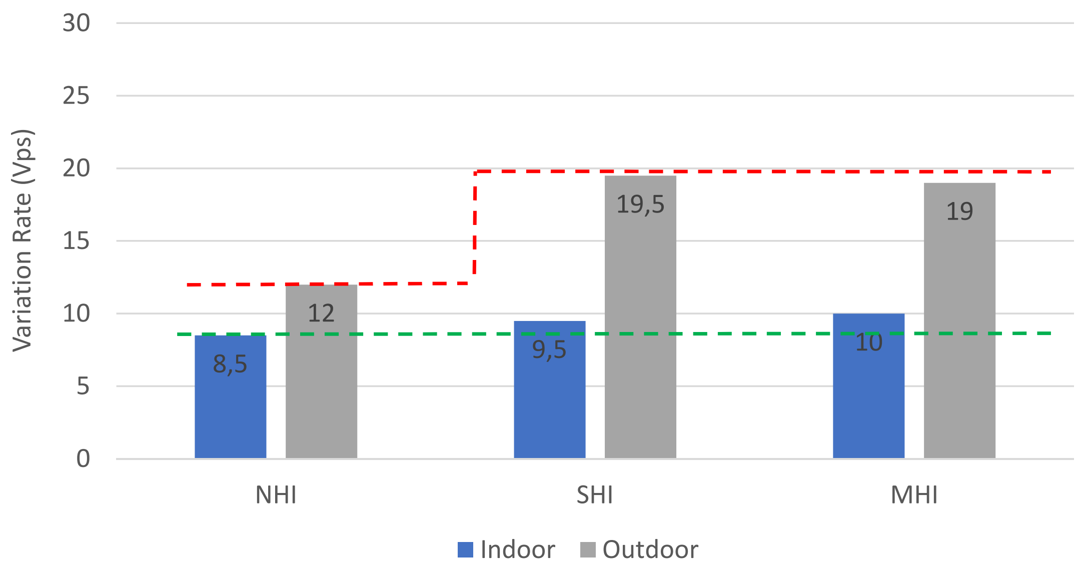
- The RSSI variation of NHI is stable while that in non-NHI (i.e., SHI and MHI) is greatly fluctuating
- NHI can be identified from others in indoor

Outdoor RSSI Variation



- The RSSI variation is greatly fluctuating in all cases
- The RSSI variation alone cannot discern human interference in outdoor

RSSI Variation Comparison



- Human interference from NHI to non-NHI can be detected in indoor by using the variation
- The variation alone cannot discern human interference in outdoor

Summary of Experiments

- BLE beacon count can be used to detect a location, direction, and speed of an object through the coordination of multiple scanners.
- Average BLE RSSI power can be used to detect human inference in outdoor.
- Average BLE RSSI variation can check the existing human inference in indoor, but it cannot evaluate the crowd density.
- By integrating multiple metrics including beacon count, RSSI power, and variation, CROMO can identify:
  - Flow direction and speed
  - Crowd density
  - Object group location

Conclusion

- Mobile crowds are tough to control due to
  - More dynamic factors
  - Bigger space requirement
- To reduce crowd caused disasters,
  - CROMO (Crowd Mobility Characterization) framework is designed, implemented, and tested through BLE beacon transmission and analytics
  - A CROMO layer fills the scalability and capability gaps of the existing video surveillance
  - Integrating the BLE data metrics (beacon count, RSSI power and variation), CROMO can identify the crowd density, the object group location, and the flow direction and speed in real-time

Limitation and Challenges

- Limitation
  - The experiments are done on small scale
- Challenges
  - Gaining public event experiment approval
  - Volunteers
  - Equipment setup