Person Detection Techniques for an Internet of Things(IoT)-Based Emergency Evacuation System

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Setting the Stage

- Fire kills more Americans than all natural disasters combined. Every year more than 5,000 people die in fires, over 25,000 are injured and direct property loss is estimated at over $9 billion [Federal Emergency Management Agency (FEMA)]
- OSHA standards explicitly require the employer to train employees in safety and health aspects of their jobs [Occupational Safety and Health Administration (OSHA), USA]
- Fire Protection Systems Market worth 98.24 Billion USD by 2022 [Markets and Markets]

Emergency Preparedness

- Emergency preparedness is the answer
- Ethical responsibility of employers
- Compliance requirement in many jurisdictions
- It costs time and resources

Not all emergencies can be avoided or predicted

Typical Setup

- Initial installation and training
- Periodic maintenance of safety equipment
- Training of volunteer employees to become emergency response coordinators (ERCs)
- Periodic preparedness drills

During an Emergency

- Emergency responders
- ✓ Grab attention (whistles, signs)
- ✓ Direct everyone to assembly point (AP)
- ✓ Ensure everyone has left the building
- ✓ Account for everyone at the assembly point

ERCs perform coordination

Simulate evacuation as closely as possible to a real emergency

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Problems with Fire Drills

- ERCs and employees have ample notice
- ERCs pre-prepare by printing attendance lists
- Reconciliation process is time consuming
- Creates lack of faith in the process

Life is Priority One

- Saving lives is the most important priority during an emergency
- Accounting for every life is crucial
- Attendance systems are used to get a baseline
- Manual reconciliation done at the AP

Problems with Manual Reconciliation

- Baseline accuracy is directly dependent on the accuracy of attendance systems
- Attendance requires
  - Registration
  - specific “arrival action”
  - Not suitable for public areas such as malls
  - Consumes valuable response time
  - Particularly in large evacuations with multiple ERCs and APs

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Impacts of Reconciliation Errors

False Negatives

- Wrongly counting someone as “Not-trapped”
- Most dangerous to lives

False Positives

- Wrongly counting already safe people as “trapped”
- Wastes valuable resources in searching

Advantages of Proposed IoT-Based Solution

- Improve Accuracy of Attendance
  - Automatic
  - Supplements existing attendance system
- Automate Reconciliation
  - Automatic recognition of personnel at APs
  - Ad-hoc network to prevent duplicates
  - Quick production of still-trapped report
- Augment report with location

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What's the Idea

- People Carry Multiple Detectable Devices
  - Smartphone with multiple channels
  - RFID-based identity card
  - Wearables with Bluetooth
- Each has "unique enough" ID
- Use IoT-based devices placed around the building to detect these and count them

Why IoT?

Low-cost commercially available hardware

Mobile applications for ERCs

Enough research in IoT-based ad-hoc, robust networks crucial during disasters

Personal devices can be considered IoT devices

Setup

- IoT sensors- placed across the building(s)
  - Single-board computer (Raspberry-Pi)
- Every sensor has one or more channels it can detect, e.g. RFID, WiFi, Bluetooth
- Software is built with
  - Fault-tolerance
  - Integration with attendance systems
  - Integration with mobile apps for ERCs

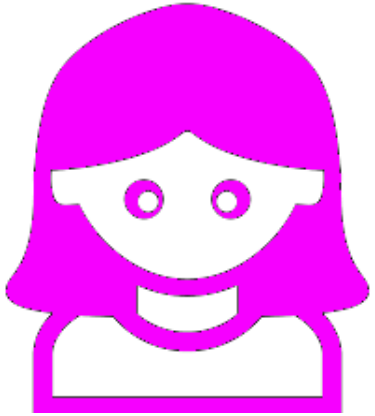
Example

Earl
70-year old, security desk, carries a single dumb phone and a company ID card

Betty
45-year old, admin role, carries a smartphone and a company ID card

Example

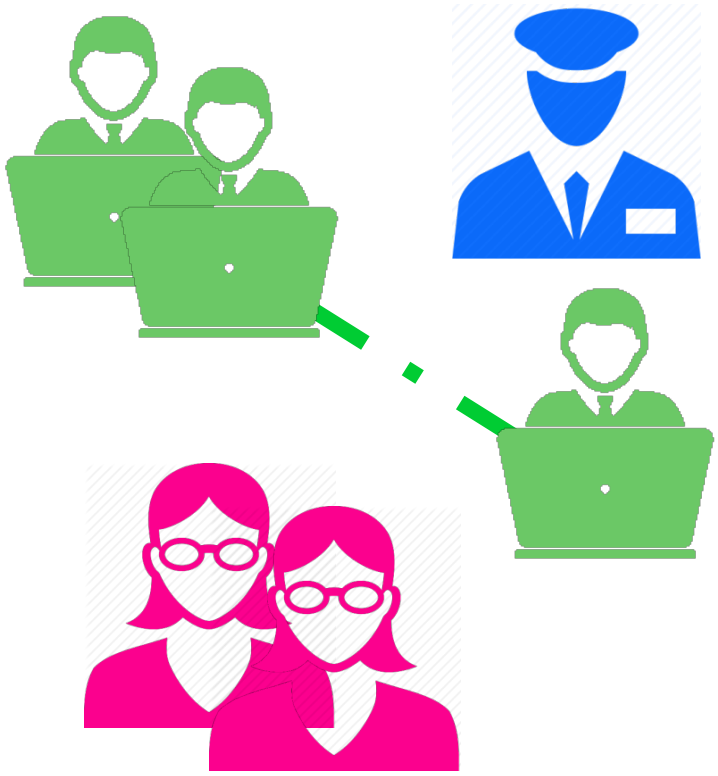
Ezra
28-year old, software developer, carries multiple devices



Grace
8-year old, visiting her dad. Carries no ID at all

Detection of Movement

- Same ID detected by different IoT devices
- Initially each moving ID is assumed to be a different person
- Exit/Entrance nodes do special processing – subtract/add person counts



Motion Detection - Camera

1. Motion is detected

2. Try to detect the ID

- If the ID detected is known
  - No action

Motion Detection - Camera

1. Movement is detected

2. Try to detect the ID

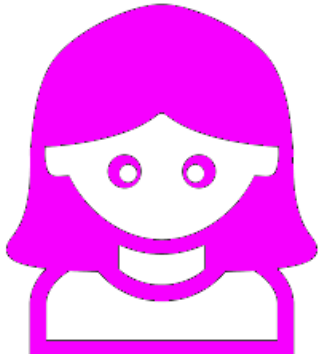
- New ID detected
  - Add person

Motion Detection - Camera

1. Movement is Detected

2. Try to detect the ID

- No ID detected
  - Electronically silent person



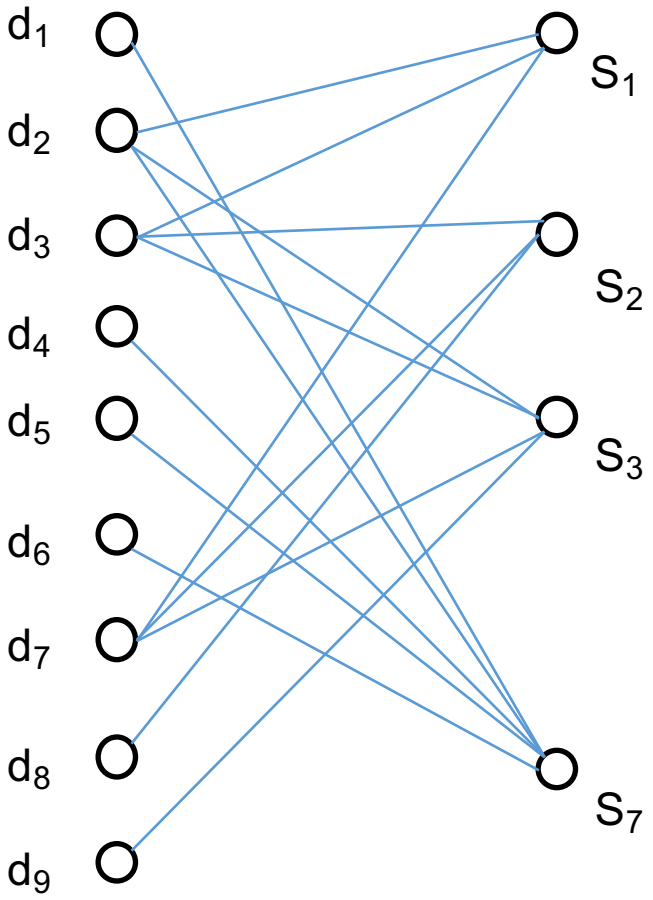
Co-occurring IDs

- Need to *detect and merge* IDs belonging to the same person
- Pairs of co-occurring IDs are enumerated
- If they co-occur more than threshold number of times, then merge
- Brute-force is computationally intensive
- Reverse indexing technique used to improve performance

Co-Occurrence (Structural Equivalence)

Let S_i and d_k denote snapshots and device IDs respectively. For e.g.

- $S_1 = \{ d_2, d_3, d_7 \}$,
- $S_2 = \{ d_3, d_7, d_8 \}$,
- $S_3 = \{ d_2, d_3, d_7, d_9 \}$, ...
- $S_7 = \{ d_1, d_5, d_6, d_4, d_2 \}$



Grouping device IDs that co-occur

- n – number of devices,
- m – number of snapshots
- N – total input size
- Checking if every pair of devices co-occurs is expensive: (${}^{n}C_{2}$) m
- If snapshots have no error, i.e. always detect an ID, optimal algorithm is possible.

Co-Occurrence Algorithm

Adjacency list of left partition (inverted list):

$d_1 = \{S_7\}$

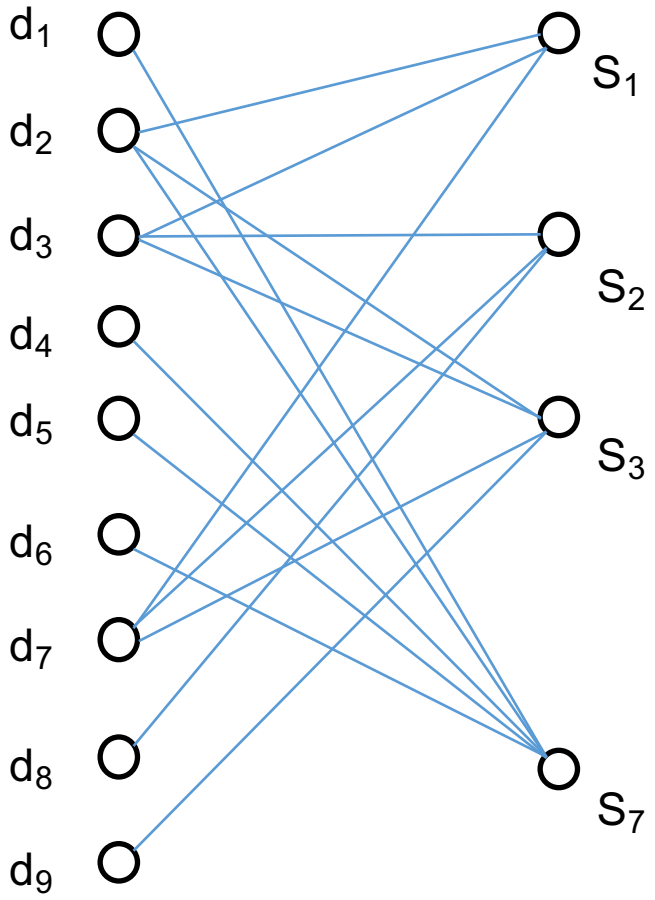
$d_2 = \{S_1, S_3, S_7\}$

$d_3 = \{S_1, S_2, S_3\}$

$d_4 = \{S_7\}$

and so on

- d_1 and d_4 co-occur – can be detected efficiently using a trie data structure
- d_2 and d_3 *approximately* co-occur. Harder problem.
- Jacard Index =
  - $|N(d_2) \cap N(d_3)| / |N(d_2) \cup N(d_3)| = 2/6$



Other Techniques

- Clean-up Routines
  - Exit persons not seen for a while
  - Detect static items and remove them from person list
  - Expire stale IDs
- Emergency time routines
  - Exit nodes count exited persons
  - Reconciliation routines kicked off

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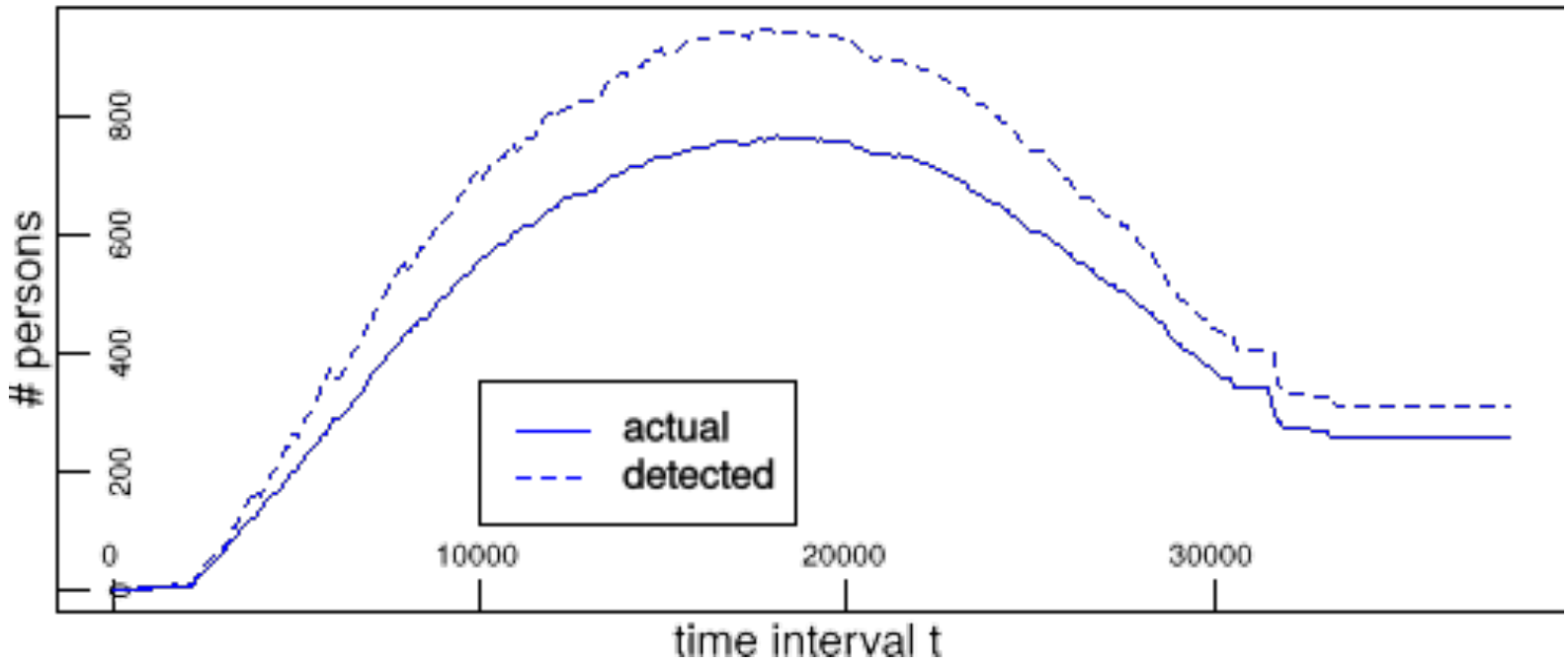
Implementation Details

- Part of larger comprehensive solution
- Simulation is used
- Effort is made to make it realistic
  - Real MAC IDs used
  - Real hashing is used
  - Realistic distributions used for
    - Assigning number of IDs per person
    - Entrance and Exit patterns for persons
    - IoT device locations

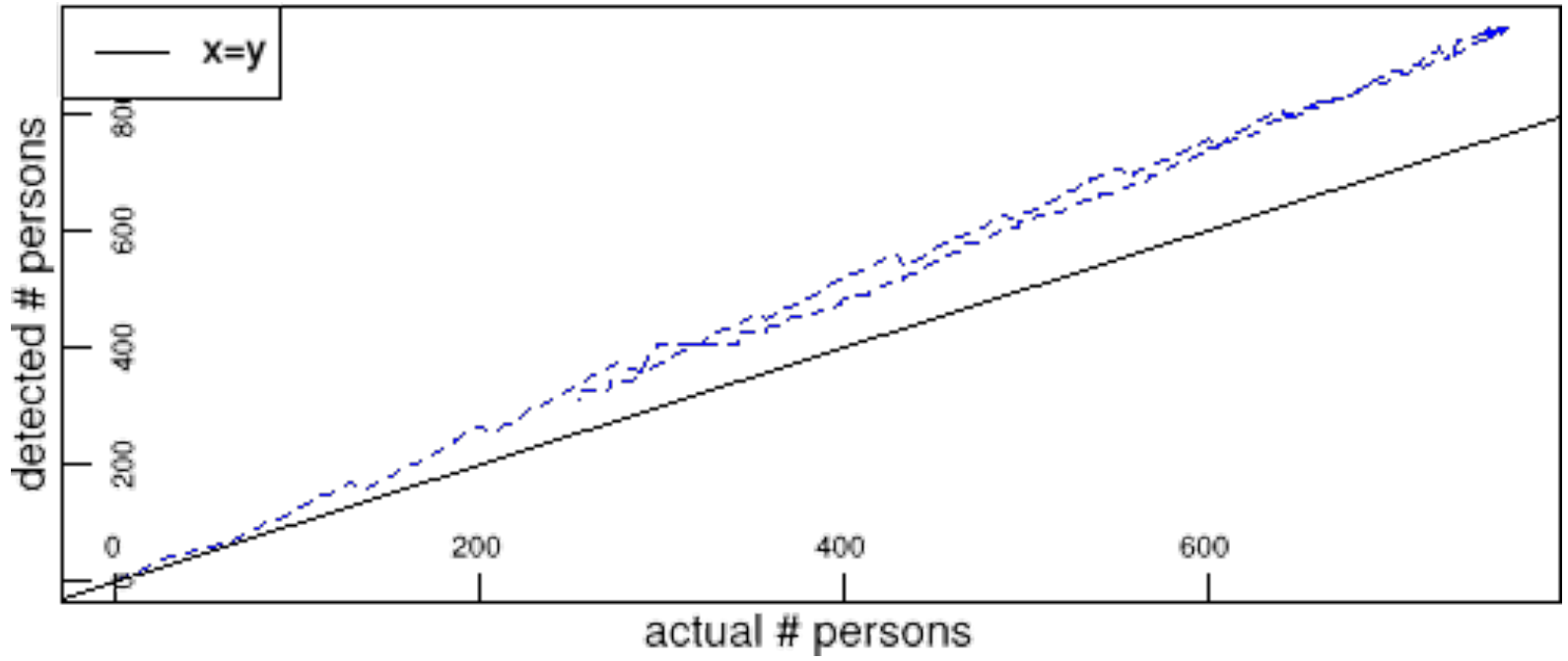
Results

- Time intervals simulated: 36000
- Number of people simulated: 1000
- Number of locations in the building: 1000



Results

- Parameters tuned to eliminate false negatives
  - Detected count is never lower than actual
- Most entrances in the morning & exits in the evening (two blue lines – curve in the previous slide is not symmetric around the vertical center)



Limitations

- All people have same speed and need of movement
- Motion/Camera are not simulated
- Electronically silent person detection is not possible
- Assumed perfect detection of IDs by sensors when in range (no noise introduced)
- Assembly point ID detection is not done
- Reconciliation is not simulated

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Conclusion

- Presented a set of simple techniques that enhance physical security by sensing persons in buildings including their locations
- Through simulation we showed that it is a viable pursuit
- Clear mathematical model and algorithms presented (in the paper)
- Saves time, money and most importantly lives

Future Direction

- These techniques become part of a comprehensive IoT-based evacuation solution
- Integration and testing with real attendance systems
- Simulation of special situations (e.g. moving assets such as projectors)
- Extend the system to public spaces and public safety

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