Design & Implementation of a Wireless Video Surveillance System

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Video Surveillance: Pervasive and Useful

One surveillance camera for every 11 people in Britain, says CCTV survey

Expand New York City's surveillance camera network

A large network isn't nearly big enough. Look to London as a model.

BY BRYAN JOSHUA SCHONFELD / NEW YORK DAILY NEWS / Monday, February 16, 2015, 11:40 AM

- London & Beijing: 1 million cameras deployed

- **Intrusion detection** – campus, airport, train station
- **Customer analytics** – store, toll booth, parking garage
- **Traffic monitoring –** cities, freeways

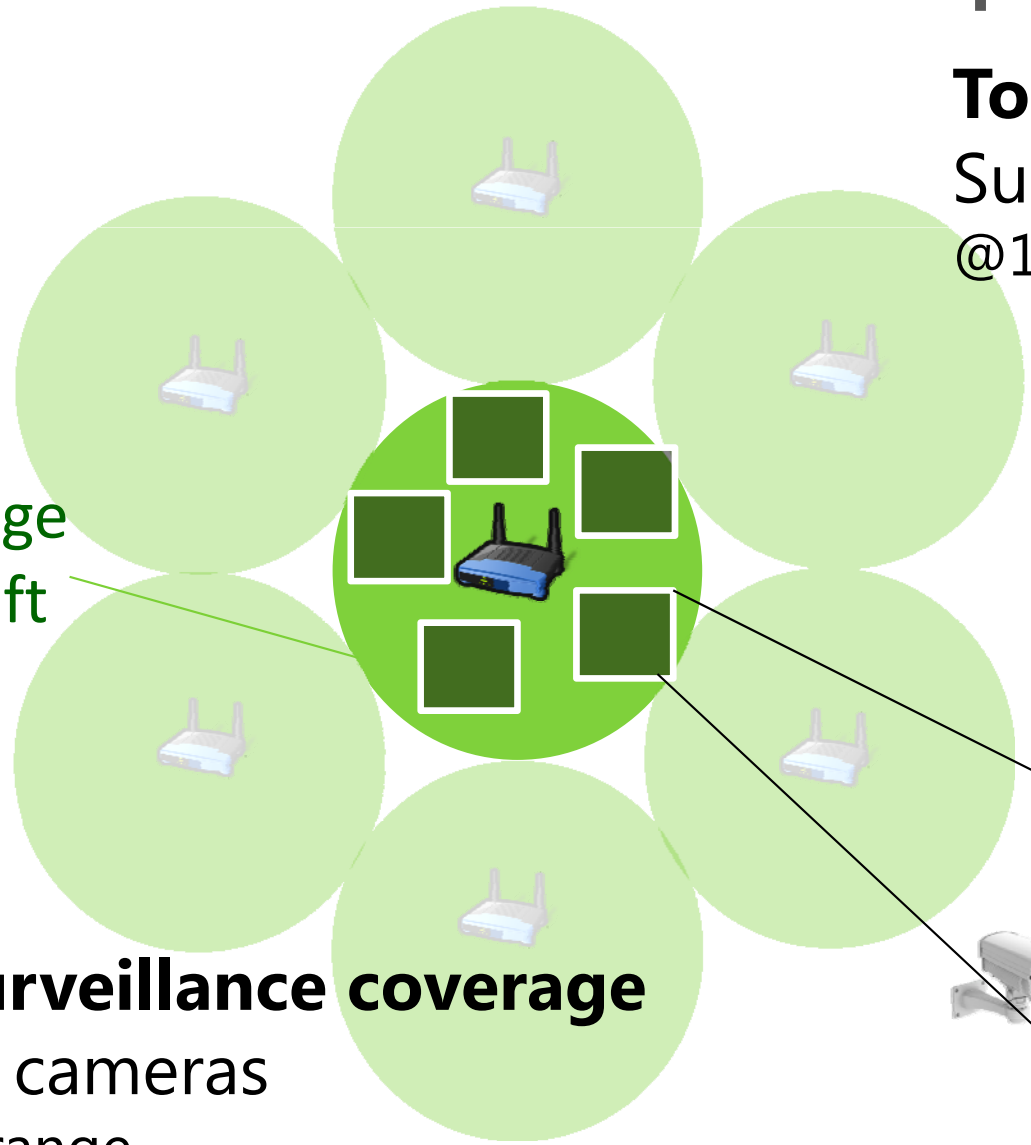
Wireless surveillance cameras

- Easy to install
- No need for wired backhaul to camera
- Comprehensive coverage

How do we build a large-scale wireless video surveillance network?

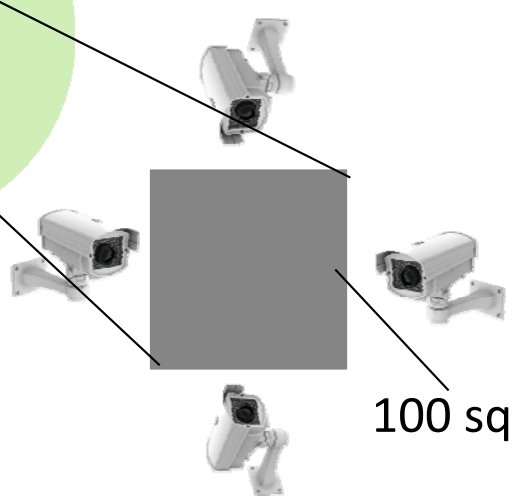
Video Cameras overwhelm wireless capacity quickly

- Wireless is a **shared medium** in **scarce spectrum**



Today's wireless
Supports **20** cameras
@1 Mbps streams

Wireless Coverage
Area: 10,000 sq ft



Complete Surveillance coverage
Requires **400** cameras
@10 ft camera range

Vigil: Wireless Video Surveillance System

Goals:

1. **Maximize** surveillance application accuracy
2. **Minimize** wireless capacity usage

Techniques:

Edge Computing

Redundancy Suppression

Content-aware Traffic Scheduling

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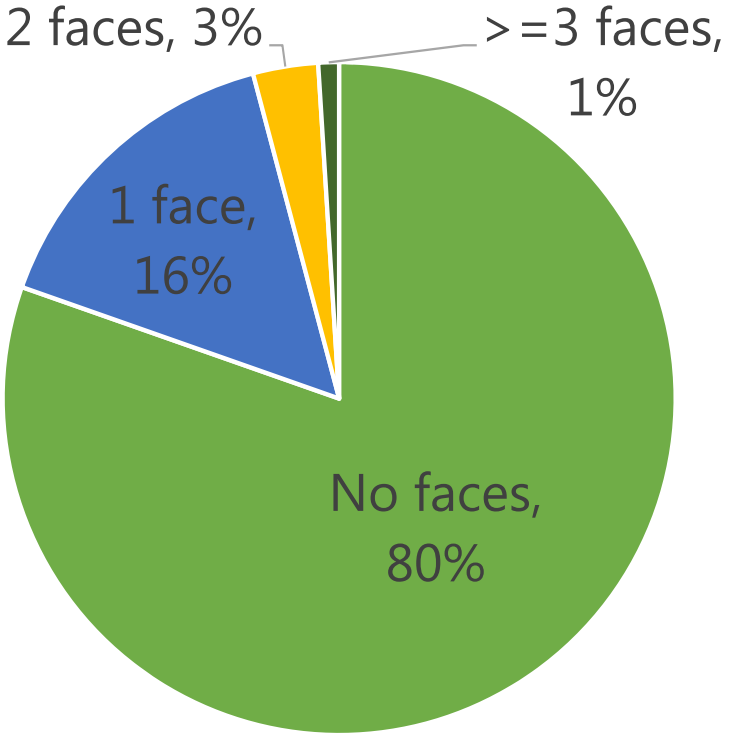
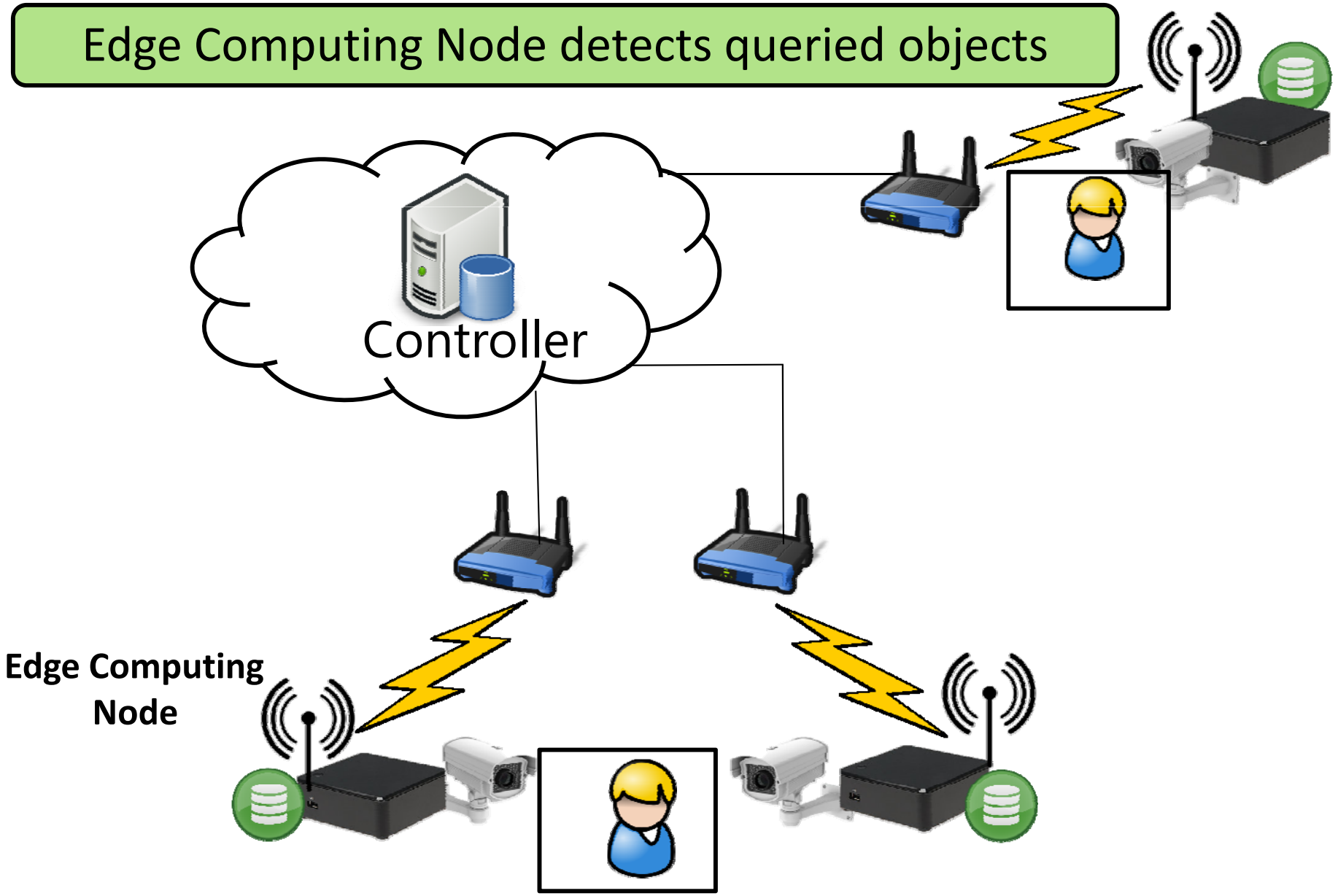
Useful video content is sparse

- Example: find a person of interest by face
- 250 hours of video feed in busy office halls

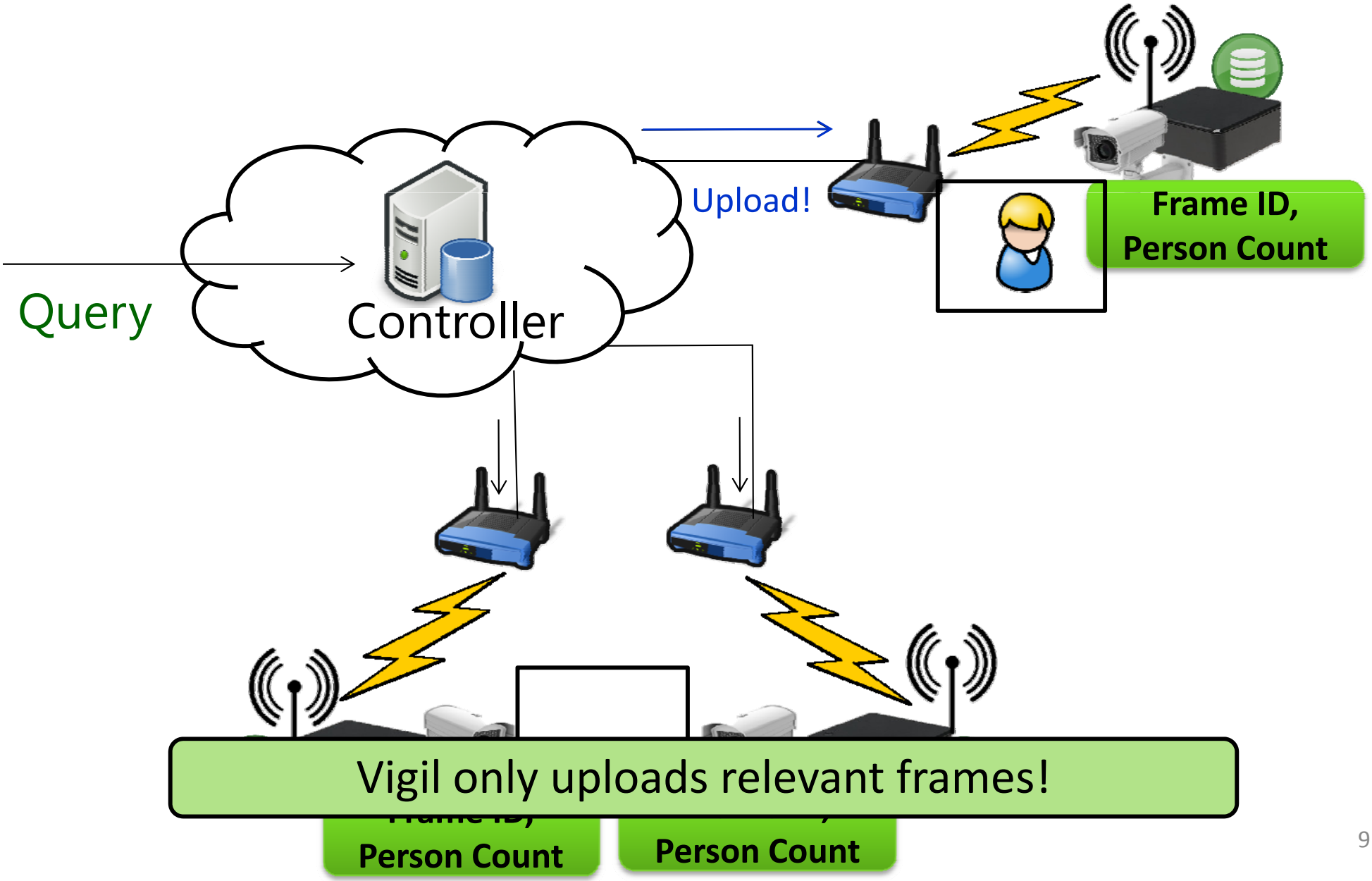


Less than 20% feed has people

Edge Computing Node



Vigil Architecture with Edge Computing



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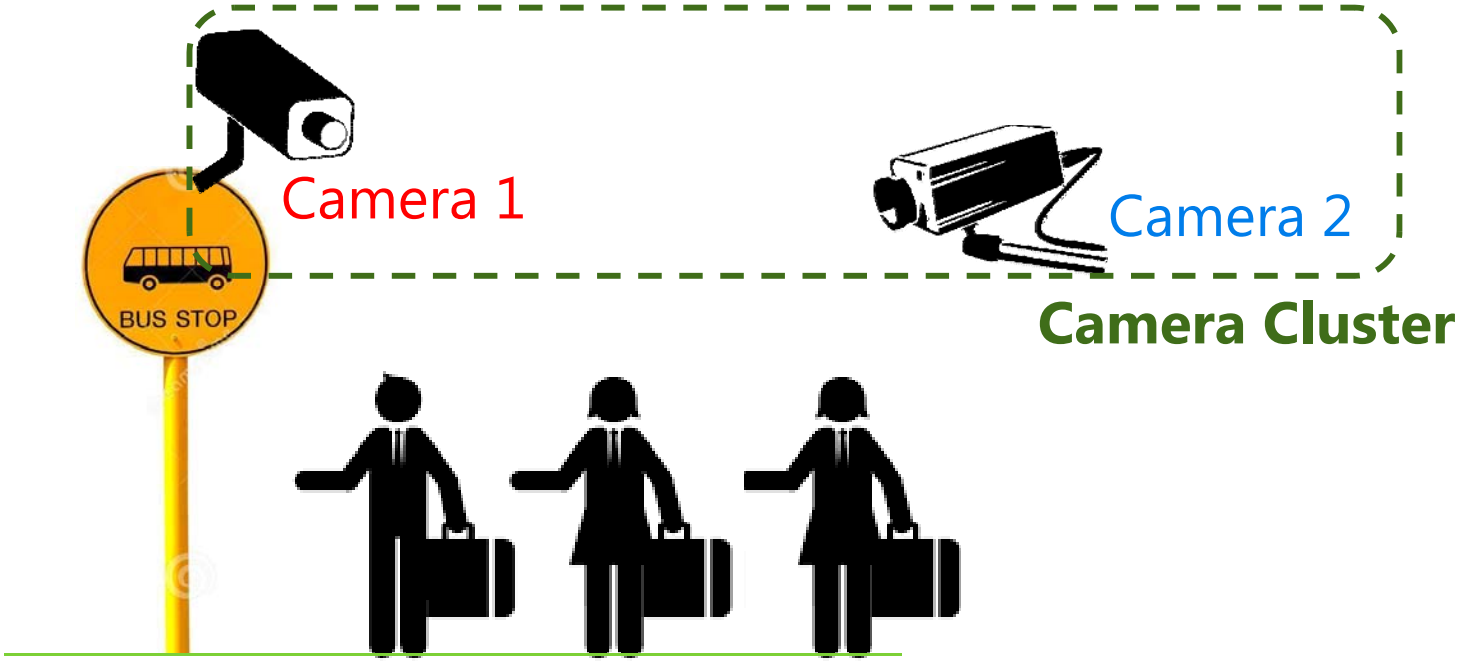
Video Codecs compress frames temporally

- Motion suppressed by difference coding (H.264)

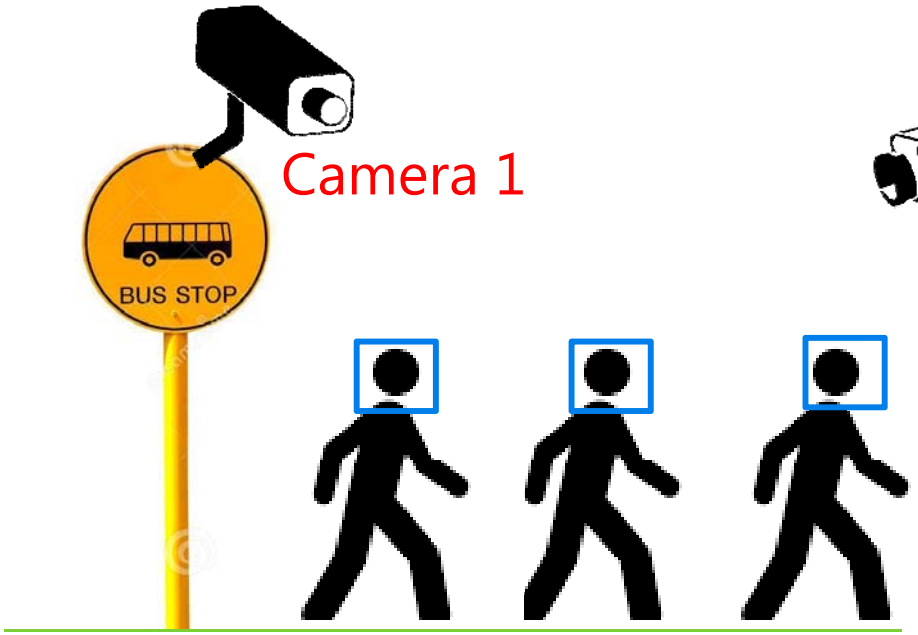
How can we compress frames from multiple cameras?

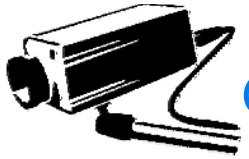
Compressing frames across cameras



How do we suppress redundant images between cameras in a cluster?

Vigil's Redundancy Suppression Algorithm





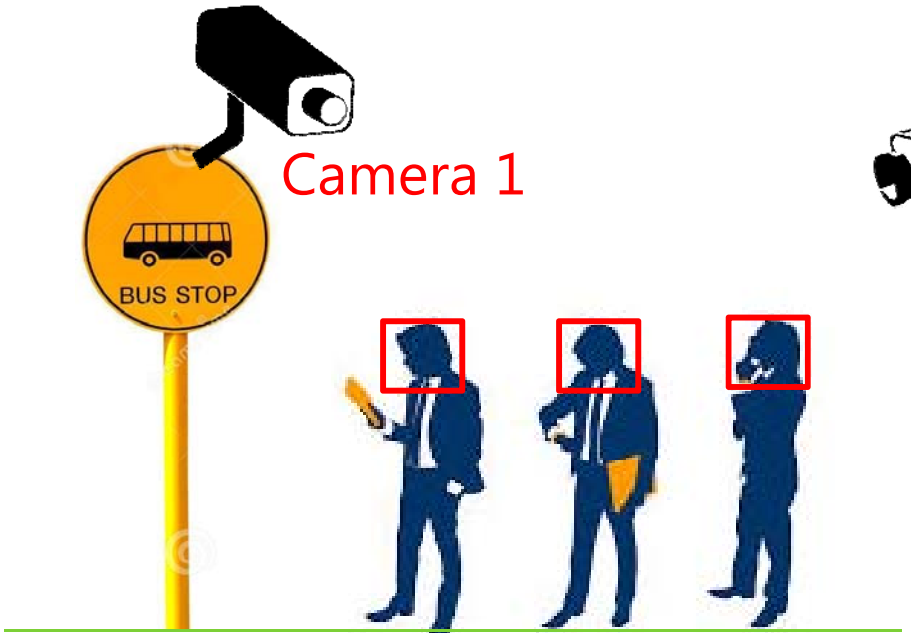
Camera 2

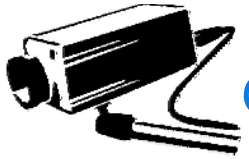
Frame Index	1	2	3	4	5
Camera 1	0	0	0	0	0
Camera 2	3	3	3	3	3

Camera 2 has higher utility

- Step 1: Frame Utility = Number of queried objects in frame
- Step 2: Select frames from camera 2

Vigil's Redundancy Suppression Algorithm





Frame Index	1	2	3	4	5
Camera 1	3	3	3	3	3
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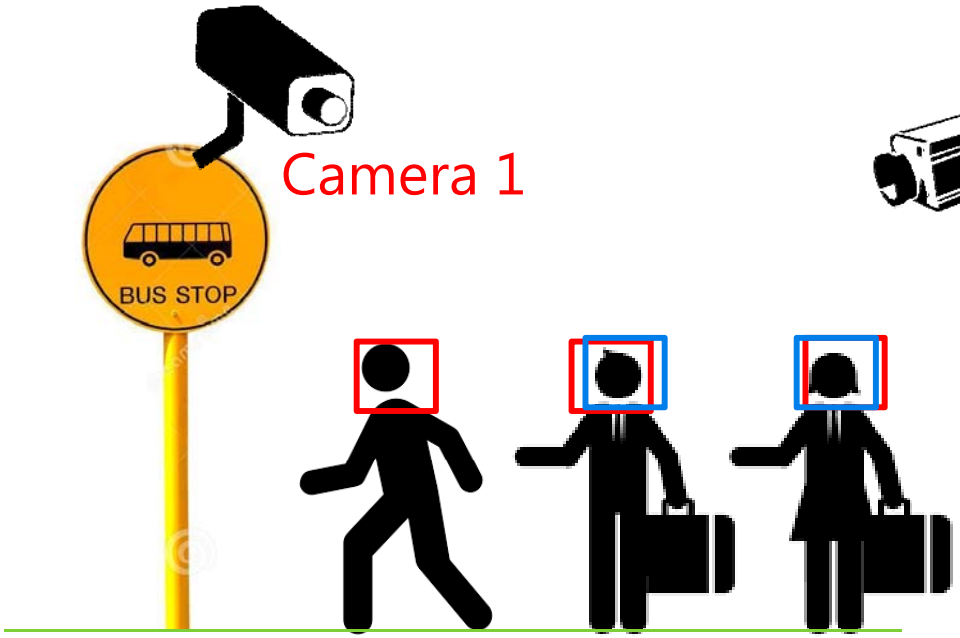
Camera 1 has higher utility

- Step 1: Frame Utility = Number of queried objects in frame
- Step 2: Select frames from camera 1

Vigil's Redundancy Suppression Algorithm

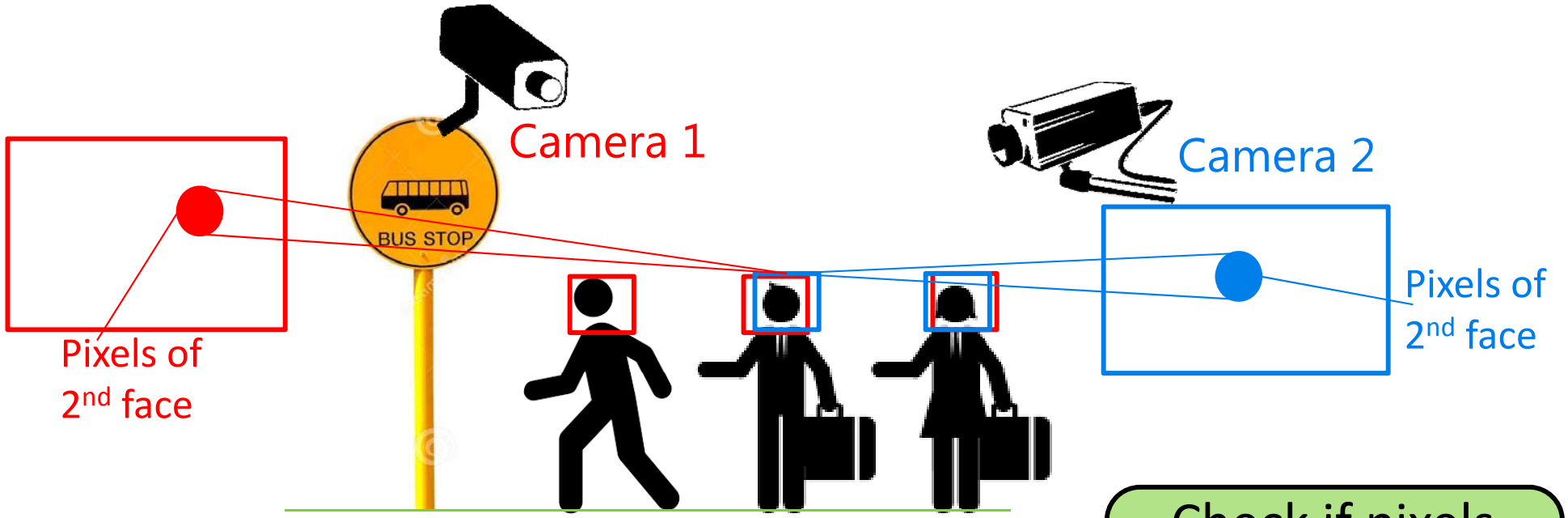


Frame Index	1	2	3	4	5
Camera 1	3	3	3	3	3
Camera 2	2	2	2	2	2

Camera 1 has higher utility

- Step 1: Frame Utility = Number of queried objects in frame
- Step 2: Re-identify objects from camera 2 in camera 1

Vigil's Redundancy Suppression Algorithm: Re-identification

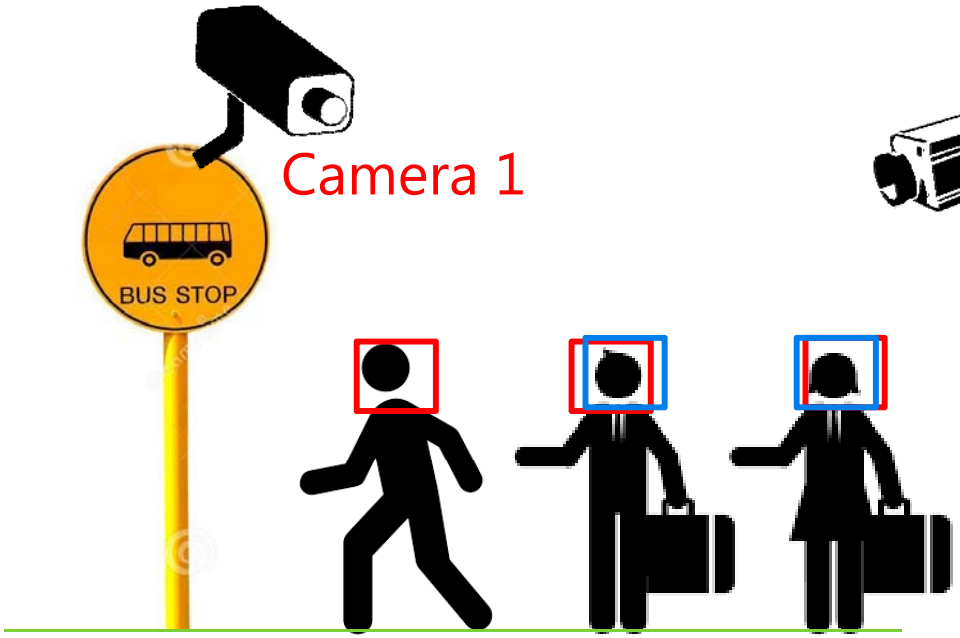


Frame Index	1	2	3	4	5
Camera 1	3	3	3	3	3
Camera 2	2	2	2	2	2

Check if pixels map to same **physical** location?

- Step 1: Frame Utility = Number of queried objects in frame
- **Step 2: Re-identify objects from camera 2 in camera 1**

Vigil's Redundancy Suppression Algorithm



Frame Index	1	2	3	4	5
Camera 1	3	3	3	3	3
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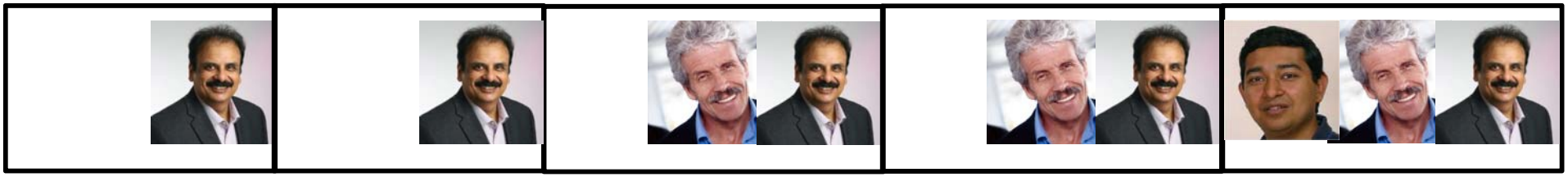
Upload only change frames

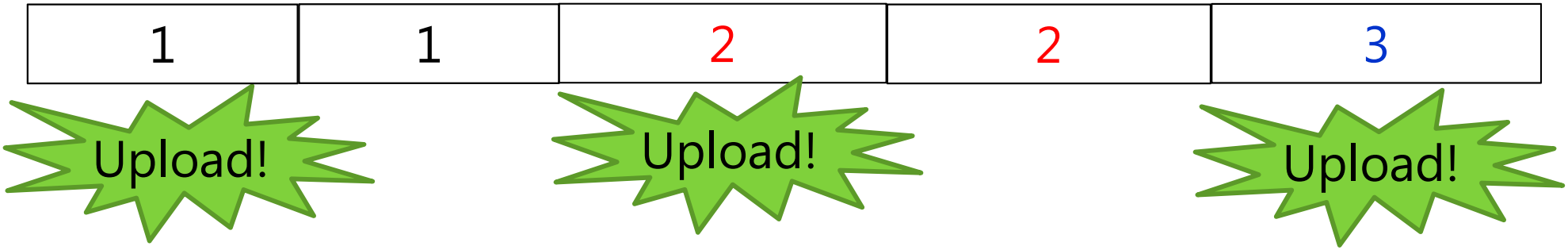
- Step 1: Frame Utility = Number of queried objects in frame
- Step 2: Re-identify objects from camera 2 in camera 1
- **Step 3: Upload frames from camera 1**

Vigil's Redundancy Suppression Algorithm

- Step 3: Upload only change frames

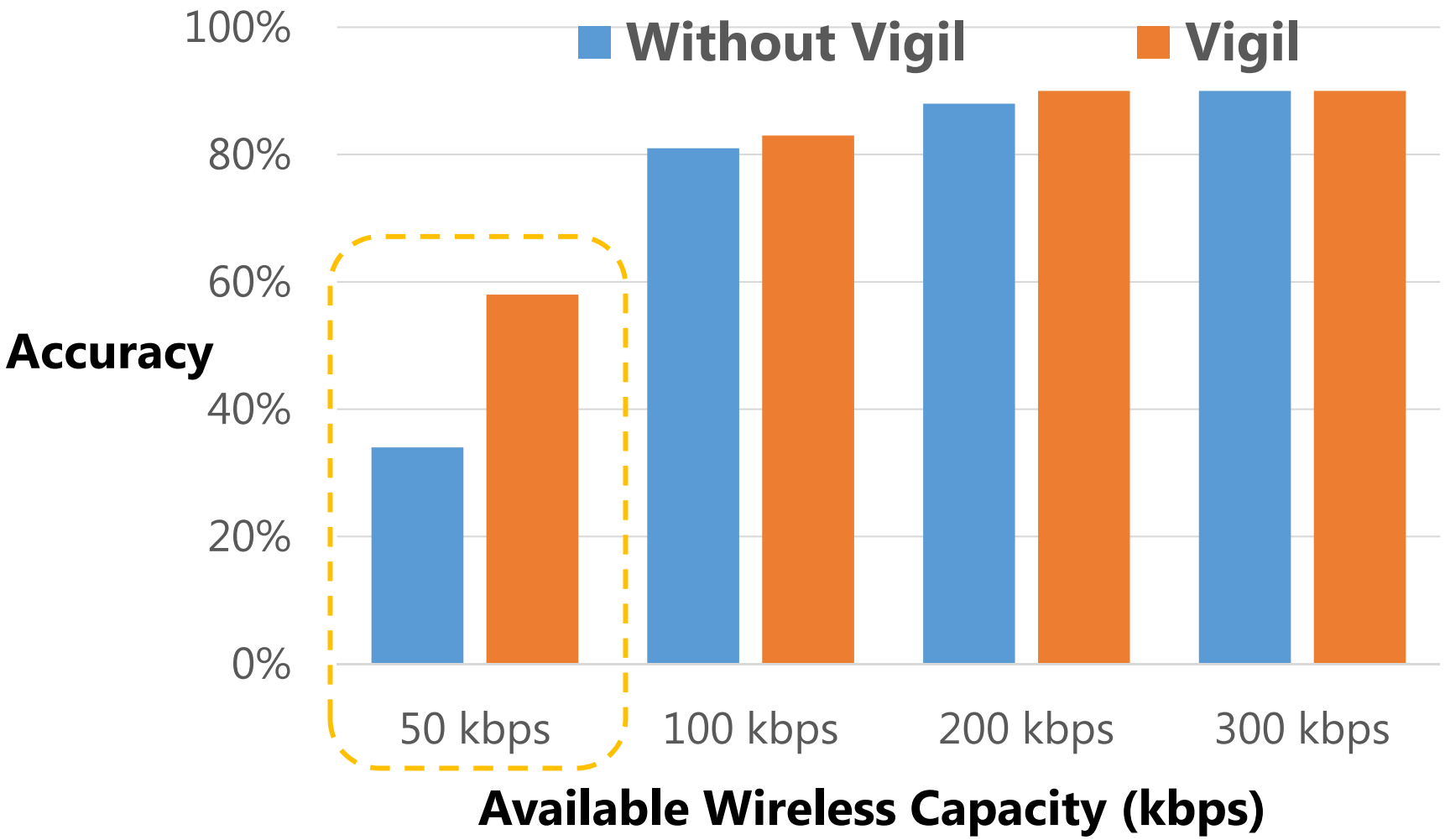


Frame Utility= Number of faces detected



Vigil increases surveillance accuracy when wireless capacity saturates

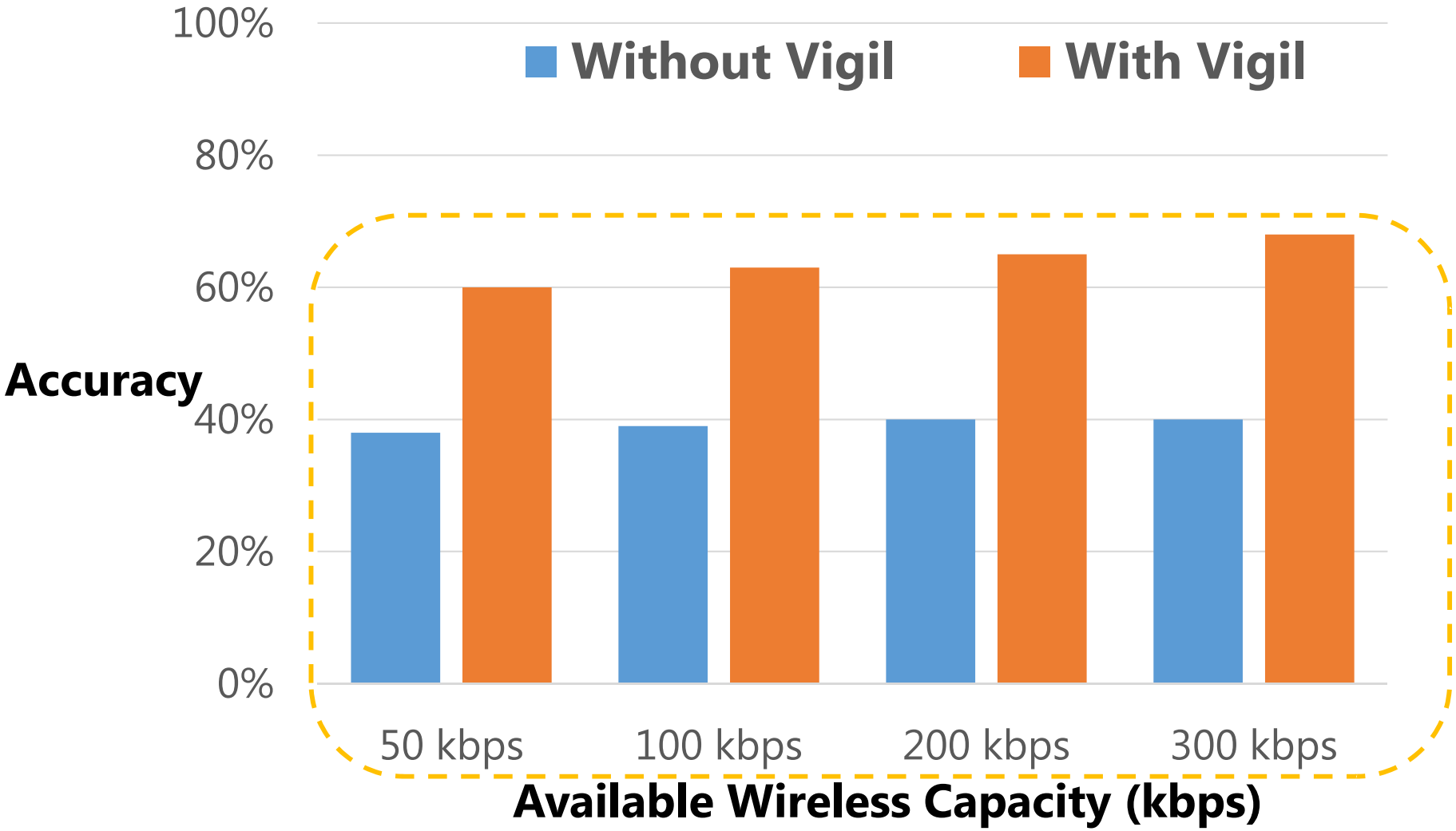
Single cluster, 3 cameras, **Medium activity of people**



Vigil provides 1.7x accuracy for same wireless capacity!

Vigil increases surveillance accuracy when wireless capacity saturates

Single cluster, 3 cameras, **High activity of people**



Vigil provides ≈1.7x accuracy for same wireless capacity!

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Goals:

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Content-aware Traffic Scheduling

Increases surveillance application accuracy when available wireless capacity is limited in camera clusters

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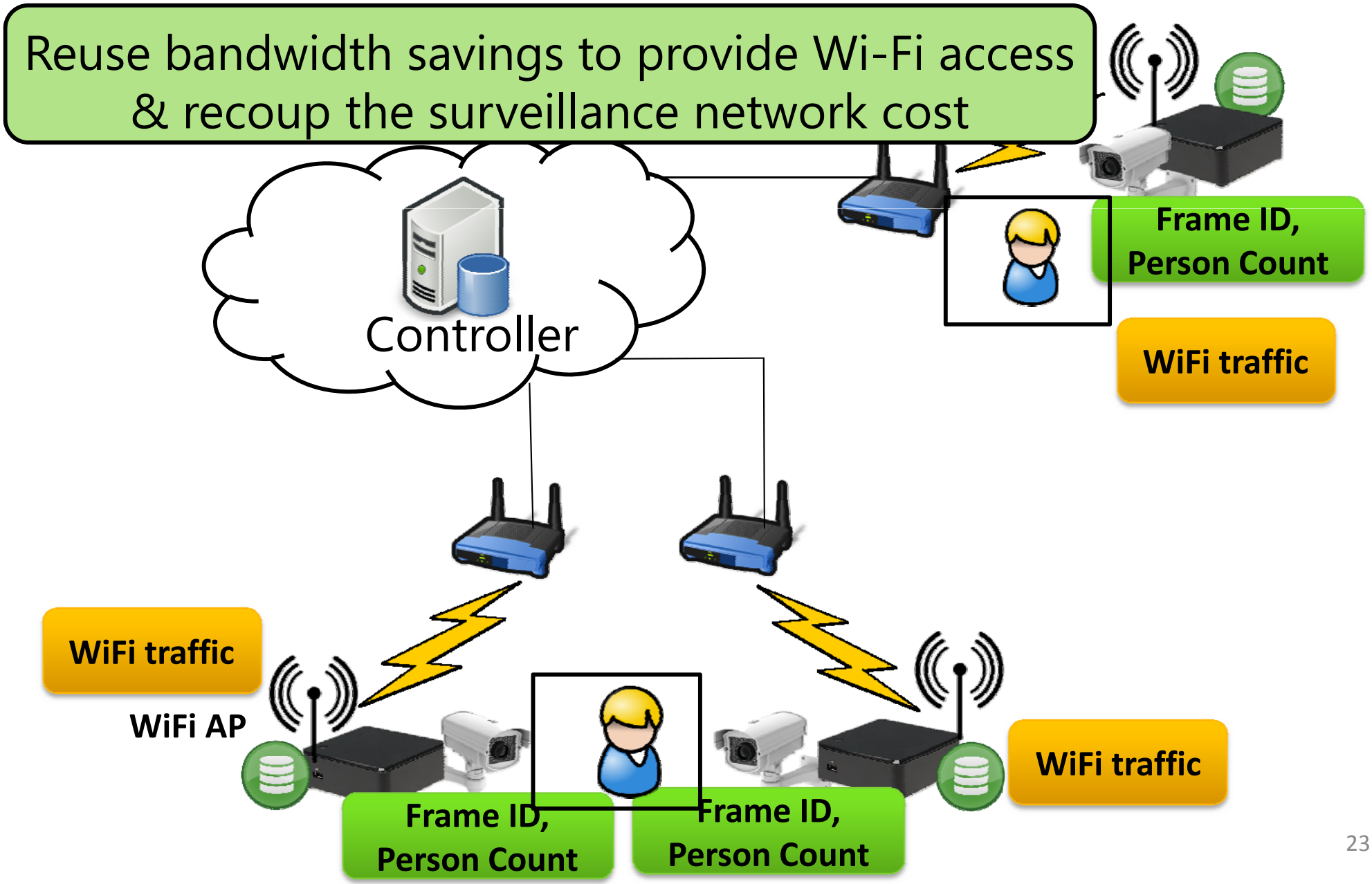
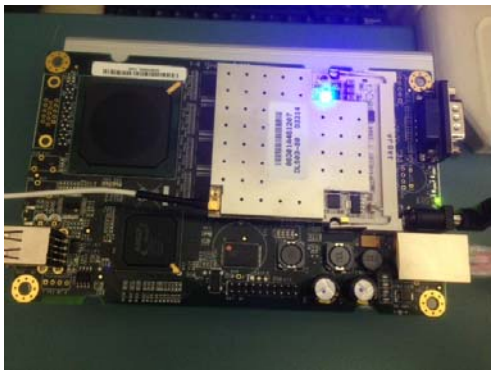
Prioritizes camera clusters with objects relevant to query

Hybrid surveillance-access network



System Deployment

- Whitespaces in MSR, UWisconsin; Wi-Fi in UCL
  - Using a 802.11 baseband protocol
  - Integrated frequency translator to operate at UHF band



System Deployment at Microsoft Research

Related work

- Cloudlets
  - VM-based Cloudlets (Pervasive Computing '09)
  - Dynamic offloading of mobile apps – Maui (MobiSys'10),Gabriel (MobiSys'14)
- Cloud-based video surveillance systems
  - Wired - IBM's Smart Surveillance System ('05)
  - Wireless - Dropcam ships video to cloud
- Video Compression algorithms
  - MPEG-4, H.264 eliminate redundancy across frames
  - Image similarity - Re-identification, Perceptual hashing
- Vision analytic algorithms on Mobile
  - Harr Cascade based face detection – Glimpse (MobiSys'14)
  - SIFT based object detection- CarSafe (MobiSys'13)

Conclusions

- Vigil's **edge computing** provides at least **5x reduction** in frames to be uploaded
- Vigil's **redundancy suppression** provides **1.7x surveillance accuracy** when available wireless capacity is limited
- Vigil's **content-aware traffic scheduling** uploads **25% more objects** relevant to the user's query