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at Northeastern University

SAWEC: Sensing-Assisted Wireless Edge Computing

Foysal Haque, Francesca Meneghello, Ebtidaul Karim, **Francesco Restuccia**
Institute for the Wireless Internet of Things (WIoT)
Northeastern University

MENTIS Group Website: http://mentislab.info

AR/VR: Next Frontier in Pervasive Computing

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We are **very far** from ***truly seamless***

and ***immersive*** AR/VR experiences

What is the current bottleneck?

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Semantic Segmentation

Object Recognition

Compute-Intensive AI/ML Tasks

120 Hz frame rate and 8K resolution are needed!

M Gallagher, ER Ferrè, "Cybersickness: a multisensory integration perspective", Multisensory Research, 2018.
Ars Technica, "Virtual Perfection: Why 8K resolution per eye isn't enough for perfect VR", 2013.

State of current wireless AR/VR headsets

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Meta Quest 3
1.5-2 hours

Weight
515 grams

Refresh Rate
Up to 90 Hz

Apple Vision Pro
Up to 2 hours

Weight
650 grams plus
353 grams battery

Refresh Rate
Up to
90 Hz

Wireless Edge Computing

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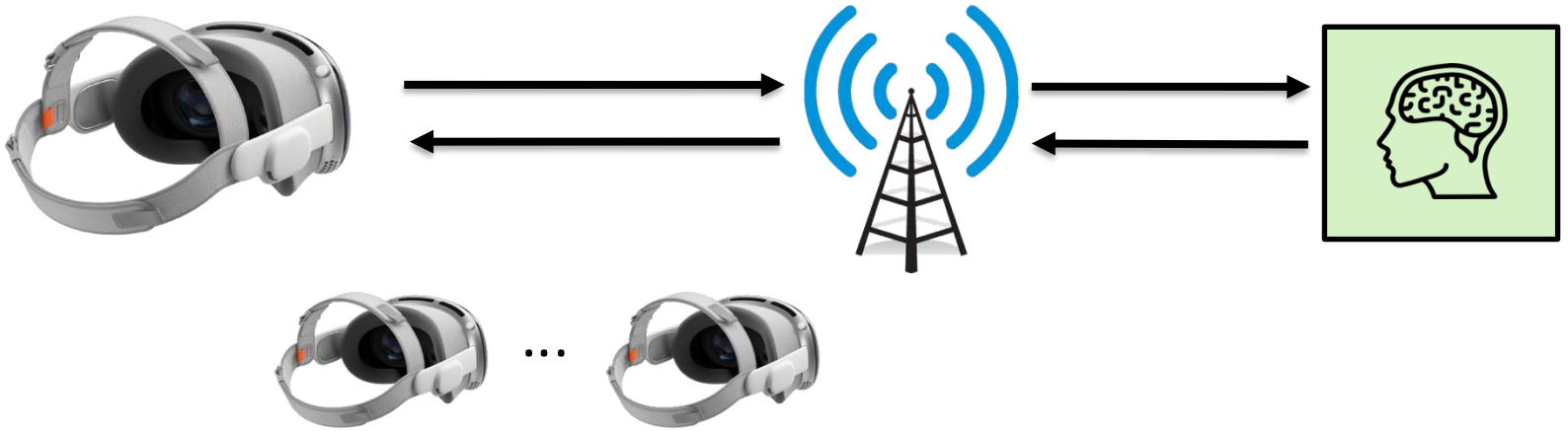
120 Hz ⟶ E2E latency of 8 milliseconds



120 Hz @ 8K → 40 Gbps → Wi-Fi supports 1.2 Gbps

What Has Been Done So Far?

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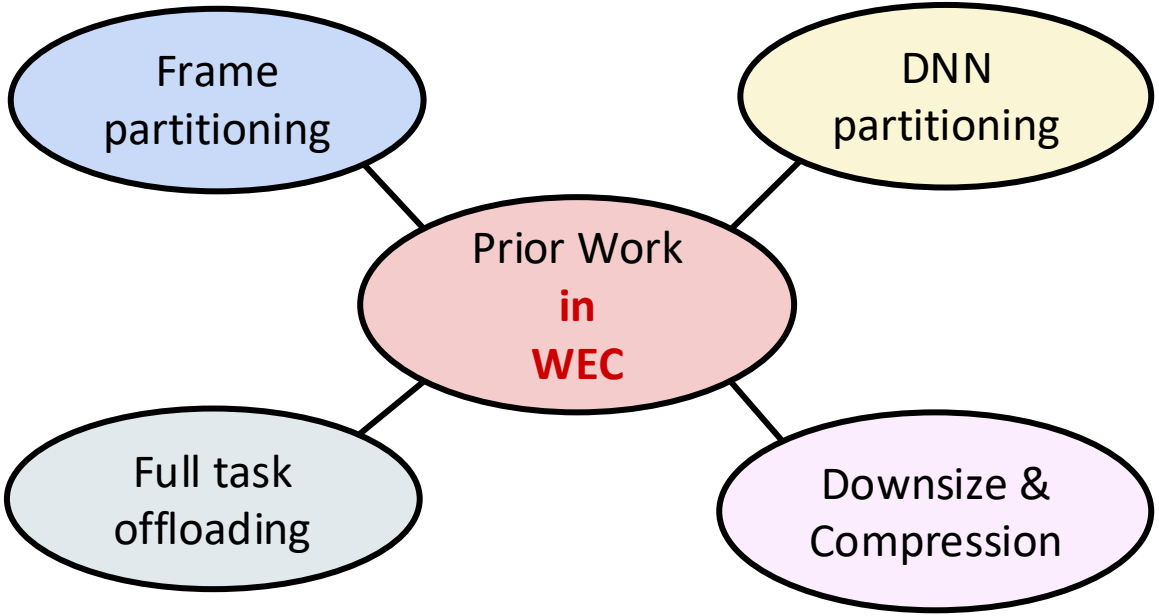
- Z. Yang et al., "Edgeduet: Tiling Small Object Detection for Edge Assisted Autonomous Mobile Vision," IEEE/ACM Transactions on Networking, 2022.
- S. Laskaridis wt al., "SPINN: Synergistic Progressive Inference of Neural Networks Over Device and Cloud," in Proceedings of MobiCom, 2020, pp. 1–15.
- R. Xu et al., "ApproxDet: Content and Contention-Aware Approximate Object Detection for Mobiles," in Proceedings of SenSys, 2020, pp. 449–462
- W. Jiang, Z. Teng, M. Li, and L. P. Qian, "Energy-Efficient Data Compression and Resource Allocation for Edge Assisted IoT Networks," in Proc. of ICCC, IEEE, 2023, pp. 1–6.



Does Compression Degrade Performance?

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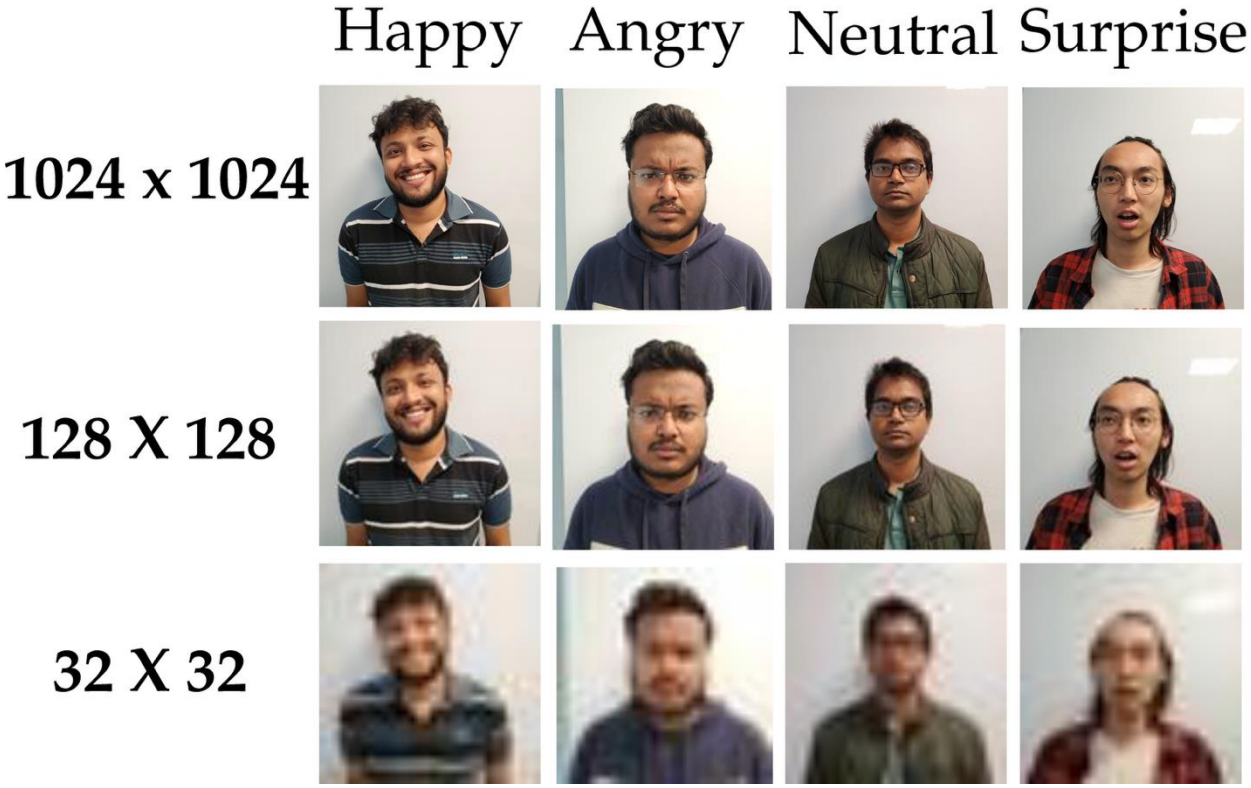

Six facial emotion classes from six different subjects

Does Compression Degrade Performance?

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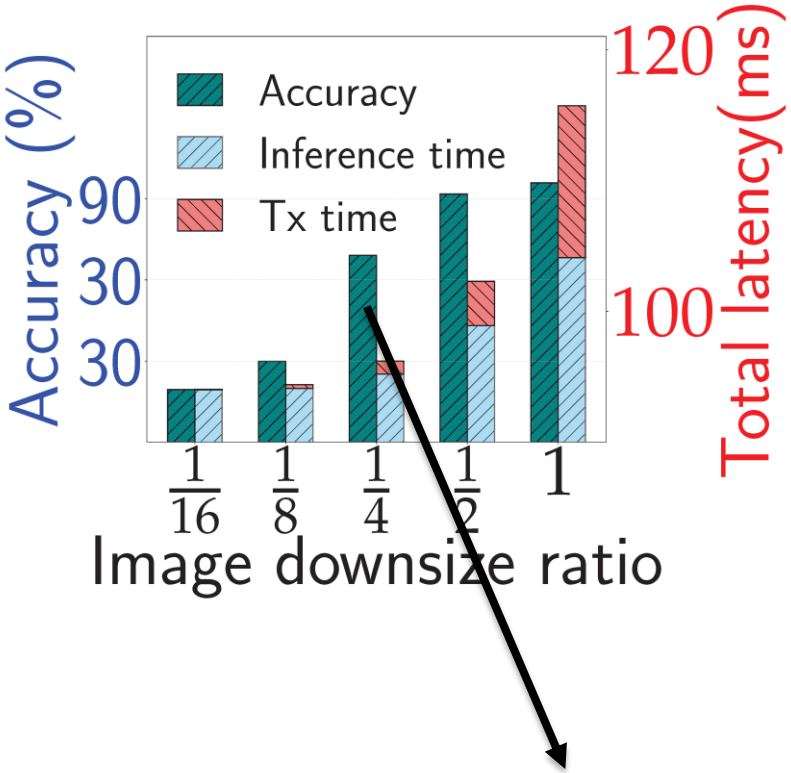

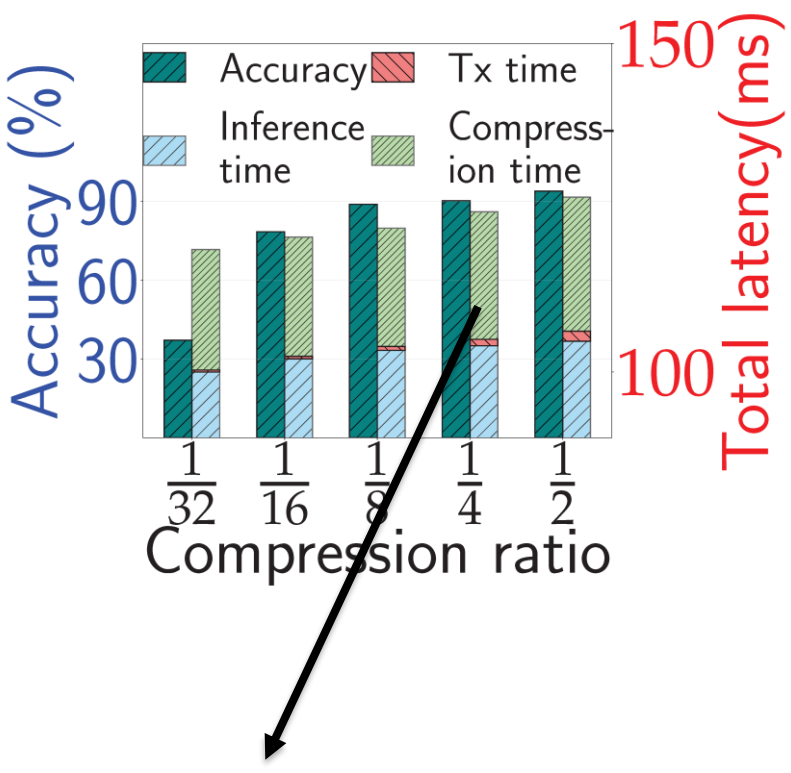

Up to 50% drop with 1/4

~30 ms compression time!

SAWEC: Sensing-Assisted Wireless Edge Computing

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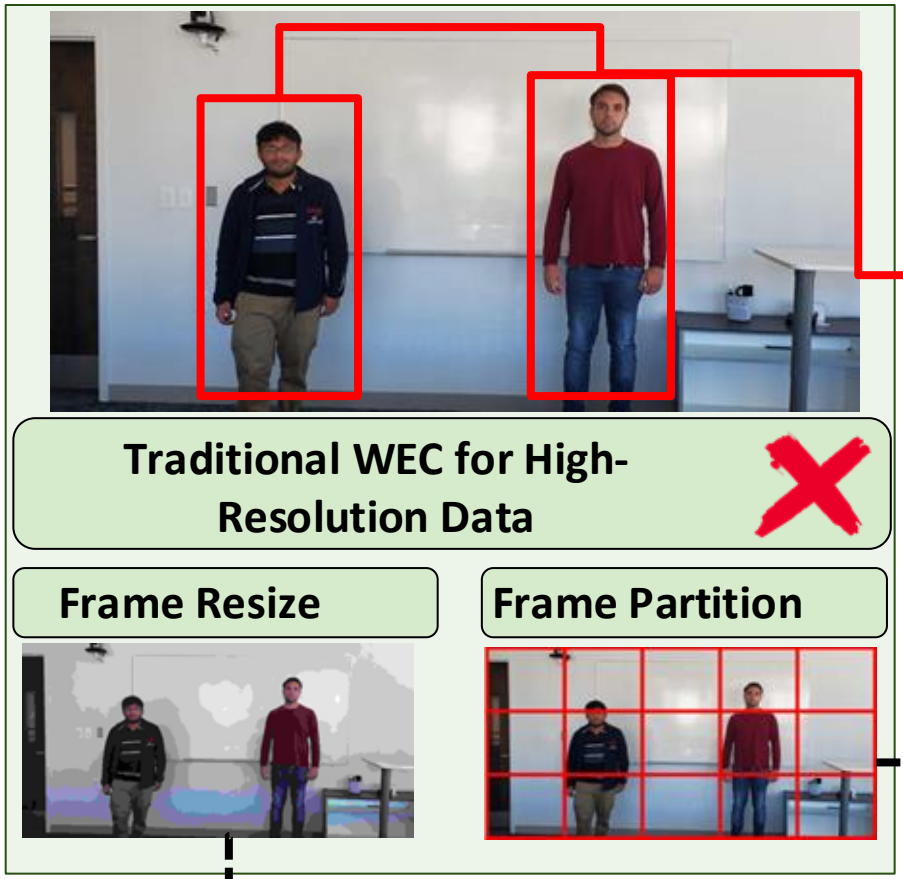

Summary of Key Contributions

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- ✓ We propose SAWEC, a new paradigm for wireless edge computing
- ✓ E2E latency is optimized by offloading only the relevant data
- ✓ SAWEC reduces the channel occupation and E2E latency by 94% and 96%
- ✓ Improves the instance segmentation performance by 47%

Overview of SAWEC

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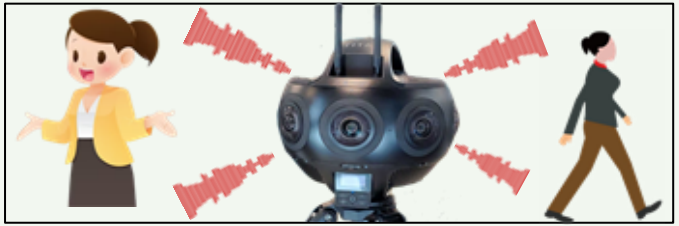
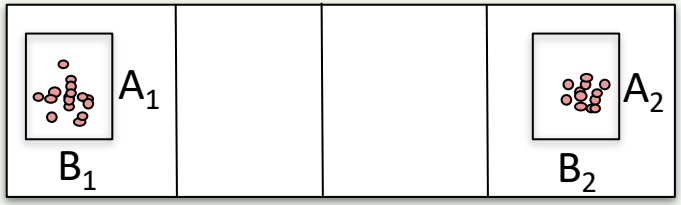
1

Sensing-Assisted ROI Detection



Find ROI with Wireless Sensing



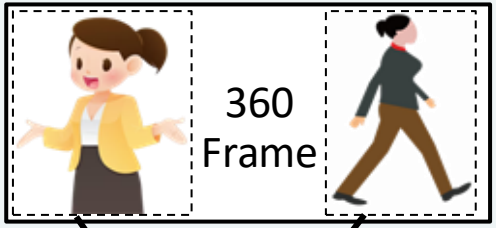
Find A_x,B_x For all ROI_N

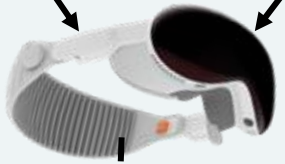
N = 1, 2, 3, ……n

2

ROI Offloading

ROI *1* · · · · · ROI *N*



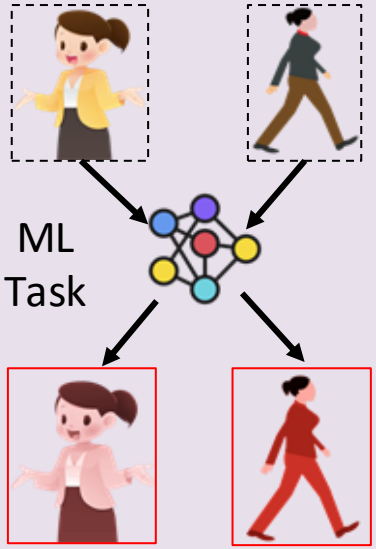


VR System

Edge Server

3

Task Execution at Server



Detection of the Region of Interest (ROI)

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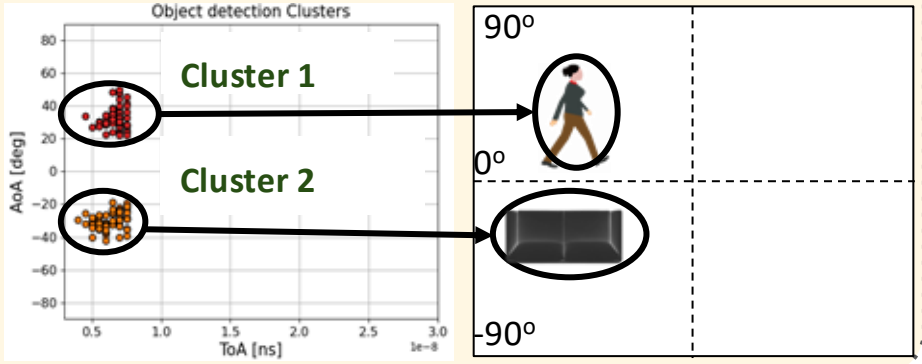
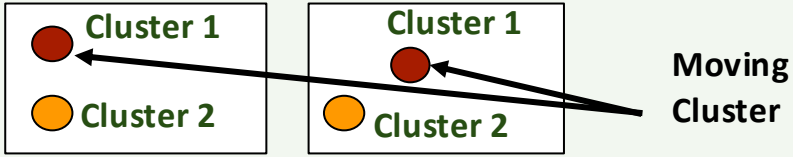
1

Localization based on AoA and ToA



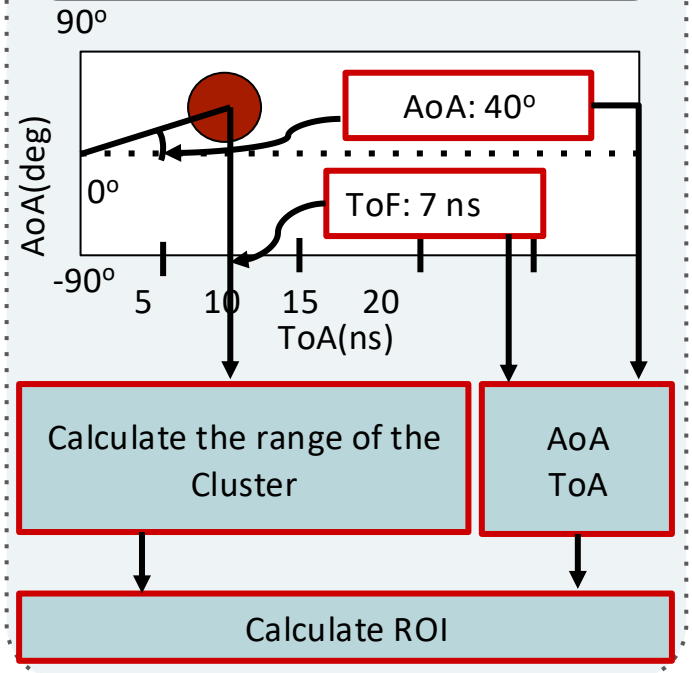
2

Track Environmental Change Through Moving Cluster



3

Find ROI based on AoA, ToA and Cluster Radius



Cluster Projection to Camera Ref. System (1)

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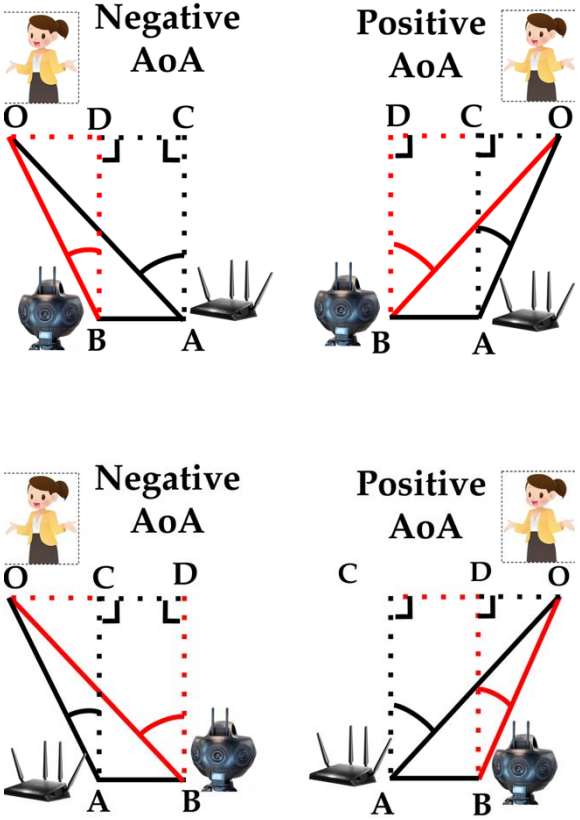

Algorithm 1 AoA and ToA projection into the camera reference

Require: $A_x, B_x, \angle OAC, OA$

Ensure: $\angle OBD, OB$

$OC = OA \cdot \sin(\angle OAC)$

$CD = AB$

$BD = AC = OA \cdot \cos(\angle OAC)$

$\zeta_{\text{pos}} \leftarrow \text{sgn}(A_x - B_x)$ ▷ $\zeta_{\text{pos}} = 1$ if camera is on the left of Wi-Fi NIC

$\zeta_{\text{aoa}} \leftarrow \text{sgn}(\angle OAC)$ ▷ $\zeta_{\text{aoa}} = 1$ if positive AoA

$OD = OC + \zeta_{\text{pos}} * \zeta_{\text{aoa}} * CD$

$\angle OBD = \arctan\left(\frac{OD}{BD}\right); \quad OB = \left(\frac{OD}{\sin \angle OBD}\right)$

Cluster Projection to Camera Ref. System (2)

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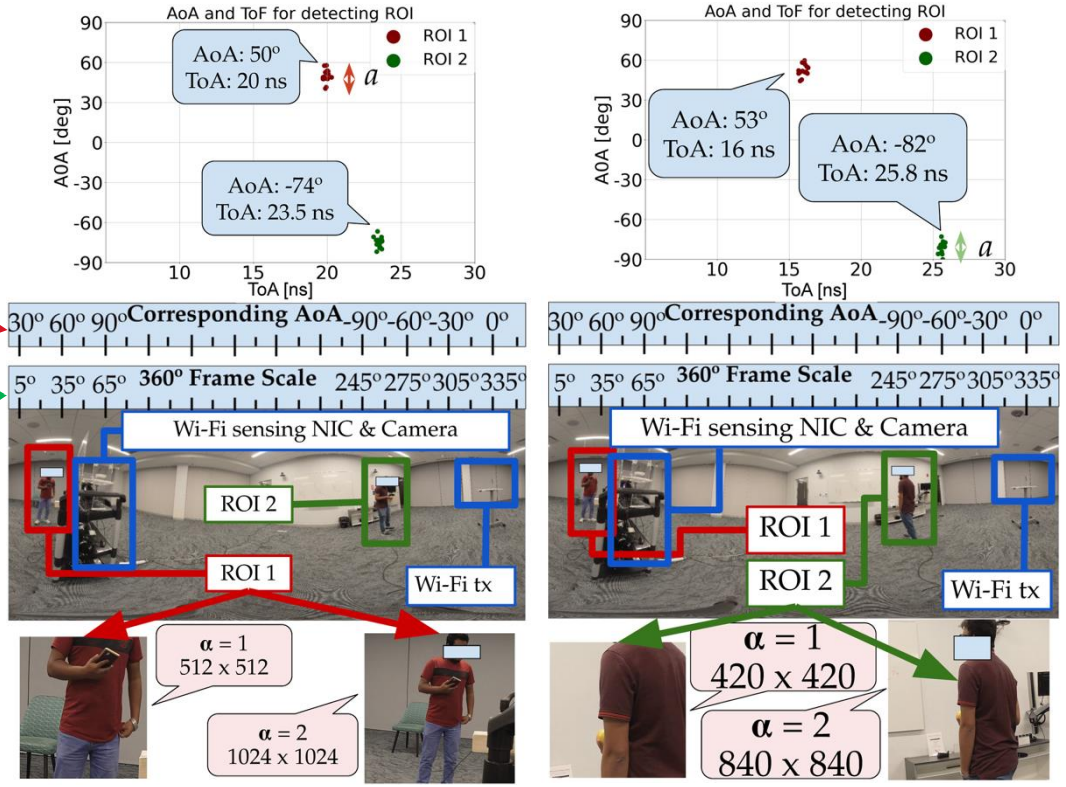
- $\theta = [(\angle OBD + \theta_{tx}) \bmod 360]$

Where,

- $\angle OBD$ is **AoA** for camera ref. system
- θ is the object in 360 frame scale
- θ_{tx} is **Wi-Fi tx** in 360 frame scale
- mod represents modulo operation



Experimental Setup

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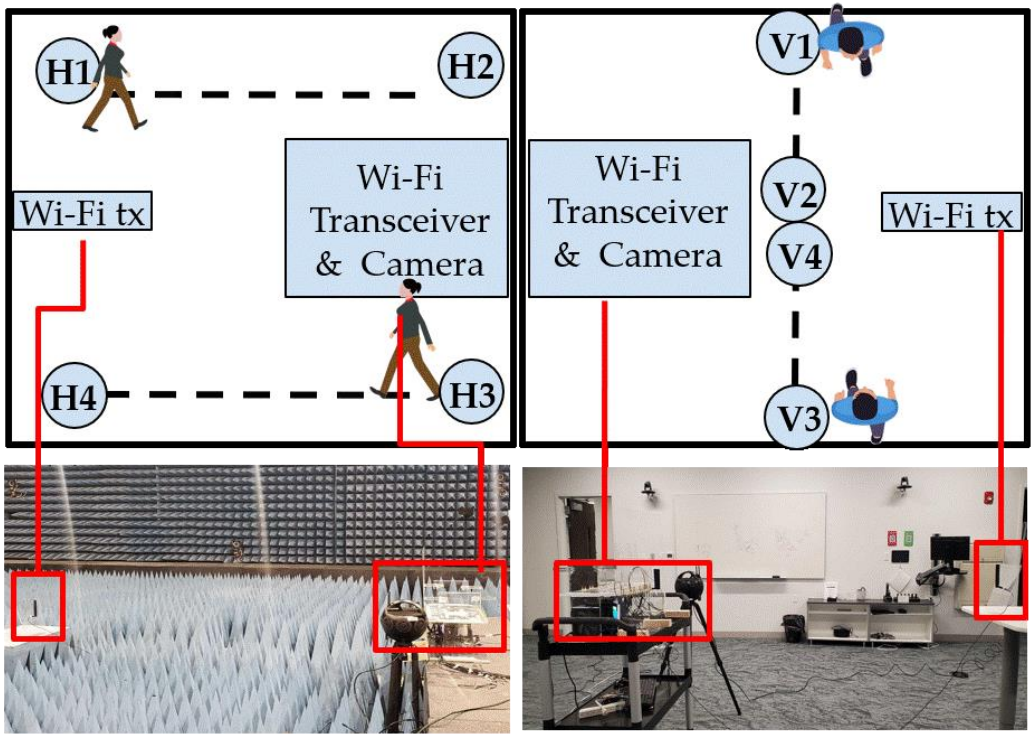
- Components:
  - Insta 360 camera
  - Co-located IEEE 802.11ax client operating at 160 MHz
- PicoScenes tool is used for CFR collection
- 360° video capture and CFR collection is synchronized
- Six different tests are performed in each of two different environment: anechoic chamber and hall room



SAWEC Performance

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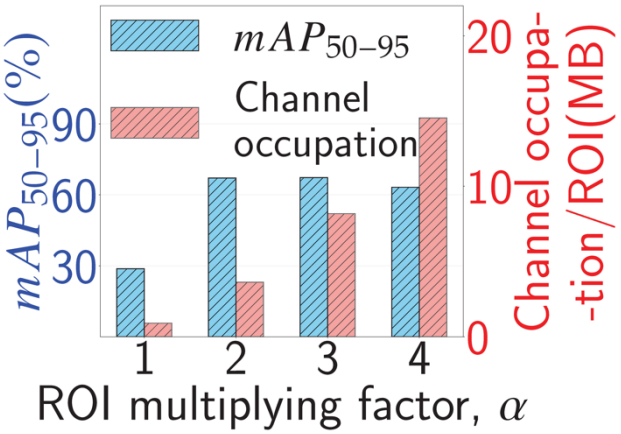
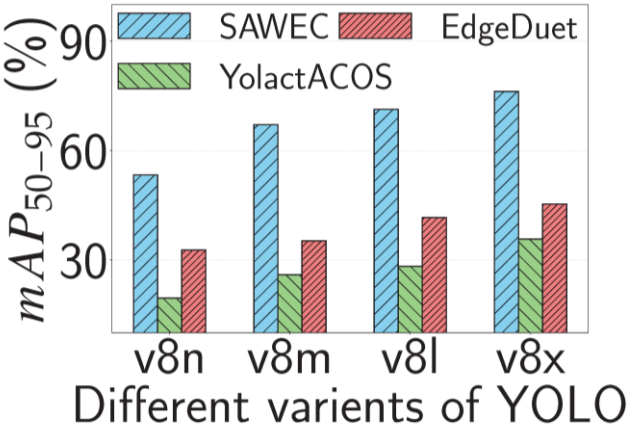
Instance segmentation mAP_{50-95} VS channel occupation at different α:



- At α = 2 the ROI is sufficiently large, and the mAP_{50-95} reaches 67% with YOLOv8m

Instance segmentation mAP_{50-95} with different variants of YOLOv8



- YOLOv8x achieves an mAP_{50-95} of 76% while YolactACOS and EdgeDuet achieve only 36% and 45% respectively

Comparative analysis of SAWEC

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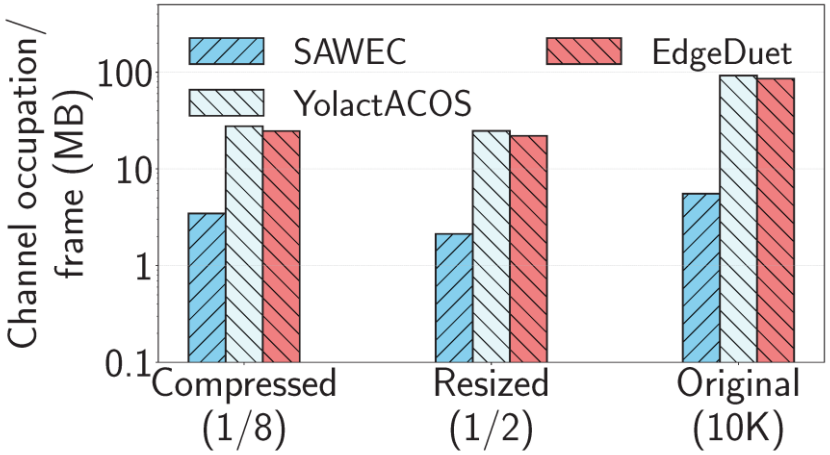
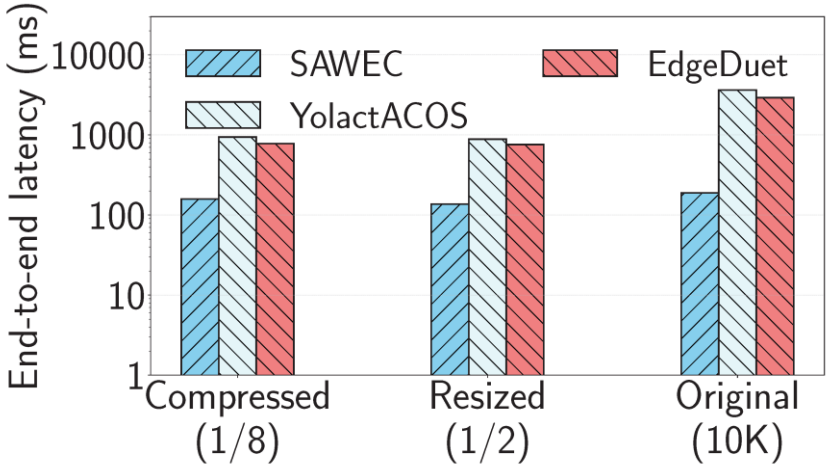
Analysis with original (10K), and tolerable compressed (1/8) and resized images (1/2)

Channel Occupation



End-to-end Latency



- The size of a 10K frame is 138.88 MB
- SAWEC, YolactACOS, and EdgeDuet require 5.5 MB, 92.2 MB and 85.9 MB per frame respectively

- At 10K resolution, SAWEC improves the latency by 94% on an average

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Possible Next Steps?

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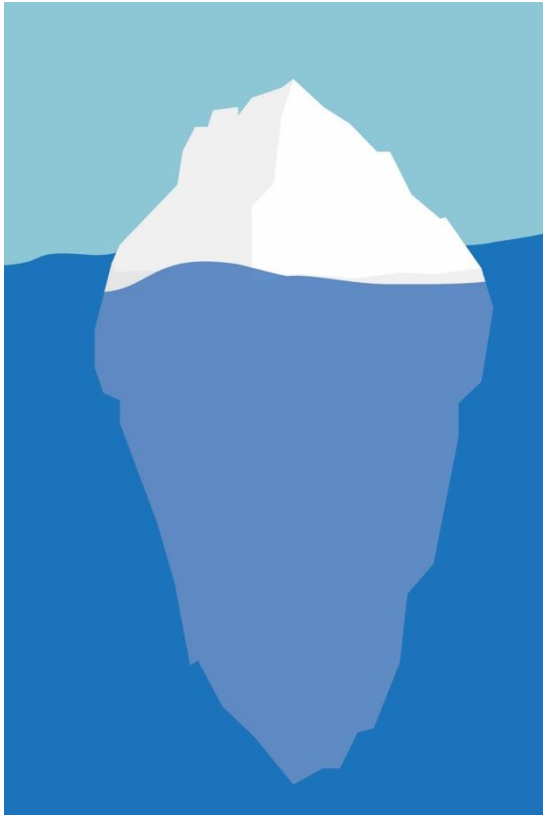

This work 💪

Things to do 😅

⚠ Improve localization accuracy

⚠ Scale the system to several moving objects

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PERCOM Pervasive Computing 2024

Thank You

haque.k@northeastern.edu