SLIM-SENSE: A Resource Efficient WiFi Sensing Framework towards Integrated Sensing and Communication

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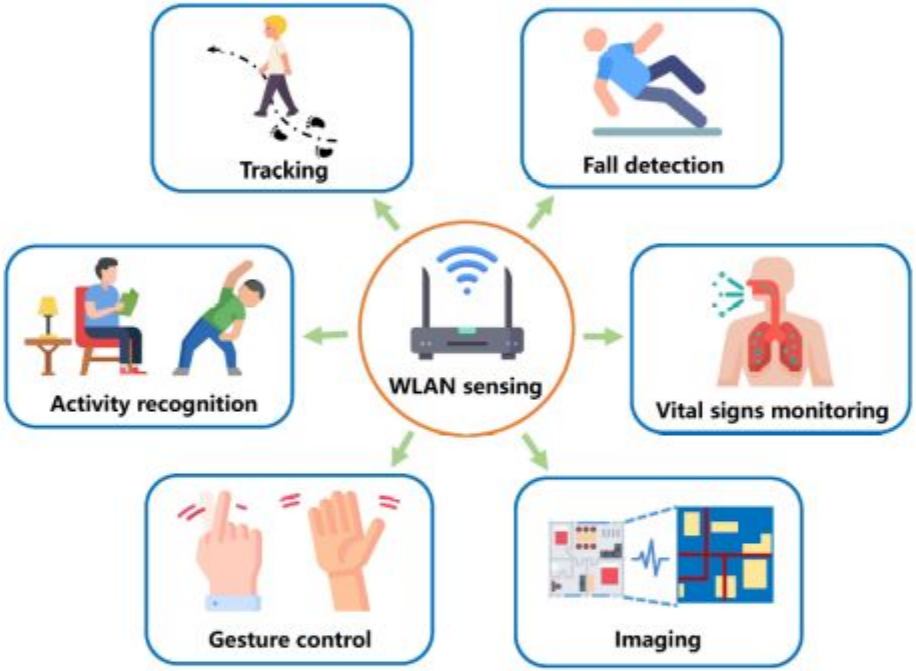
UBICOMP ISWC2025

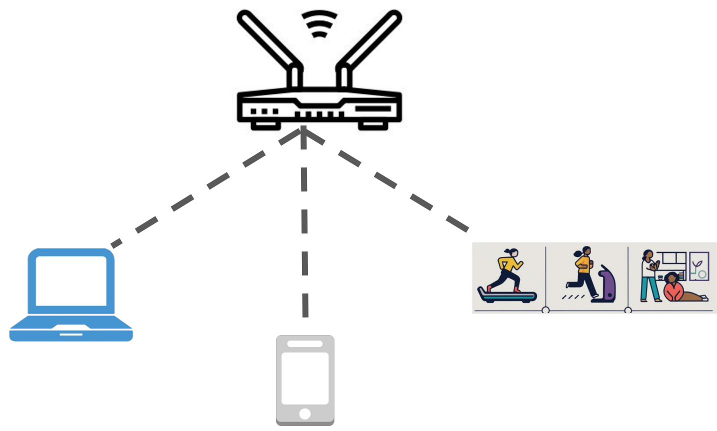
WiFi CSI-based Sensing



Non-intrusive, Pervasive, Low-cost

Integrate with data communication

Integrated Sensing and Communication (ISAC)



– Coexistence of Sensing and Communication

– Sharing the Existing WiFi Infrastructure
  - Spectrum resources: channel bandwidth, antennas

Improves spectrum efficiency and hardware utilization

Challenges of Current Approaches towards ISAC

Utilize Entire Available Bandwidth ↑

High CSI Sampling Rate ↑

– Hurts WiFi communication, prevents coexistence of communication and sensing.

– Only ≅ 200 packets/sec for sensing reduces 40% of communication throughput [1].

Zheng et al. (2024) [1]

ISAC: Existing Works

Reduced Sampling Rate

WiImg, TMC 2024

- **Lack of sufficient data**
- **Reduces accuracy drastically**
- **Mitigation is compute-intensive**

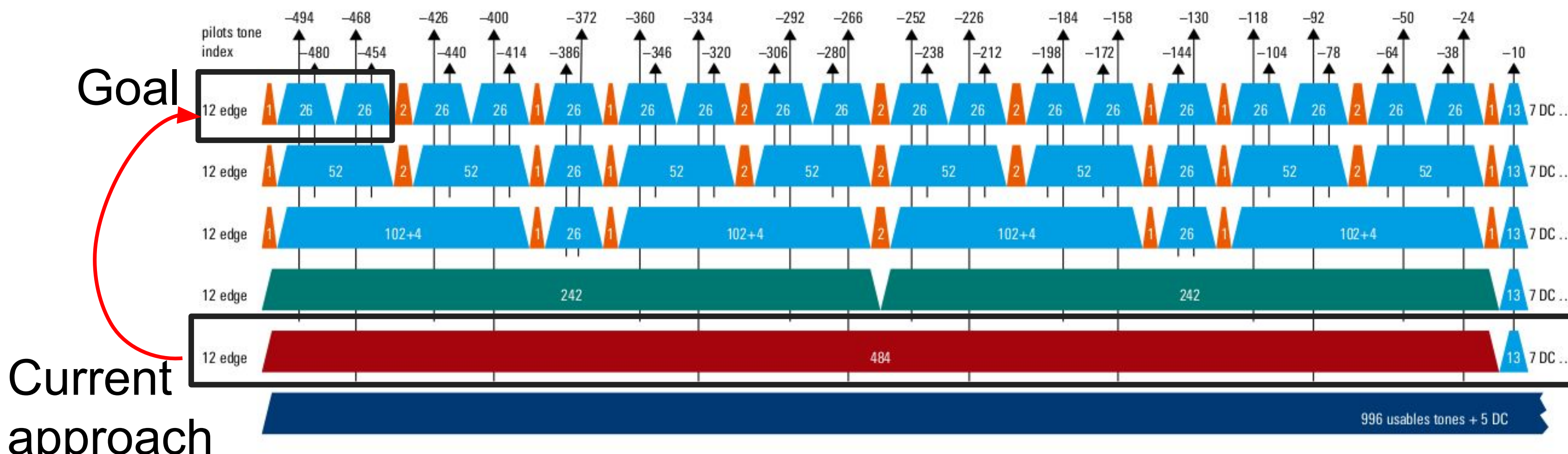
Utilize Existing Communication Packets

SenCom, Mobicom 2023
BeamSense, SIGCOMM 2023

- **Intermittent uneven traffic**
- **No communication traffic**
- **Hard to get quality & sufficient data**

Enabling ISAC using Part of WiFi Bandwidth

Core Question: Can we perform WiFi sensing by utilizing only a part of the bandwidth i.e., allocate parts of the bandwidth for sensing and leave the rest for communication?



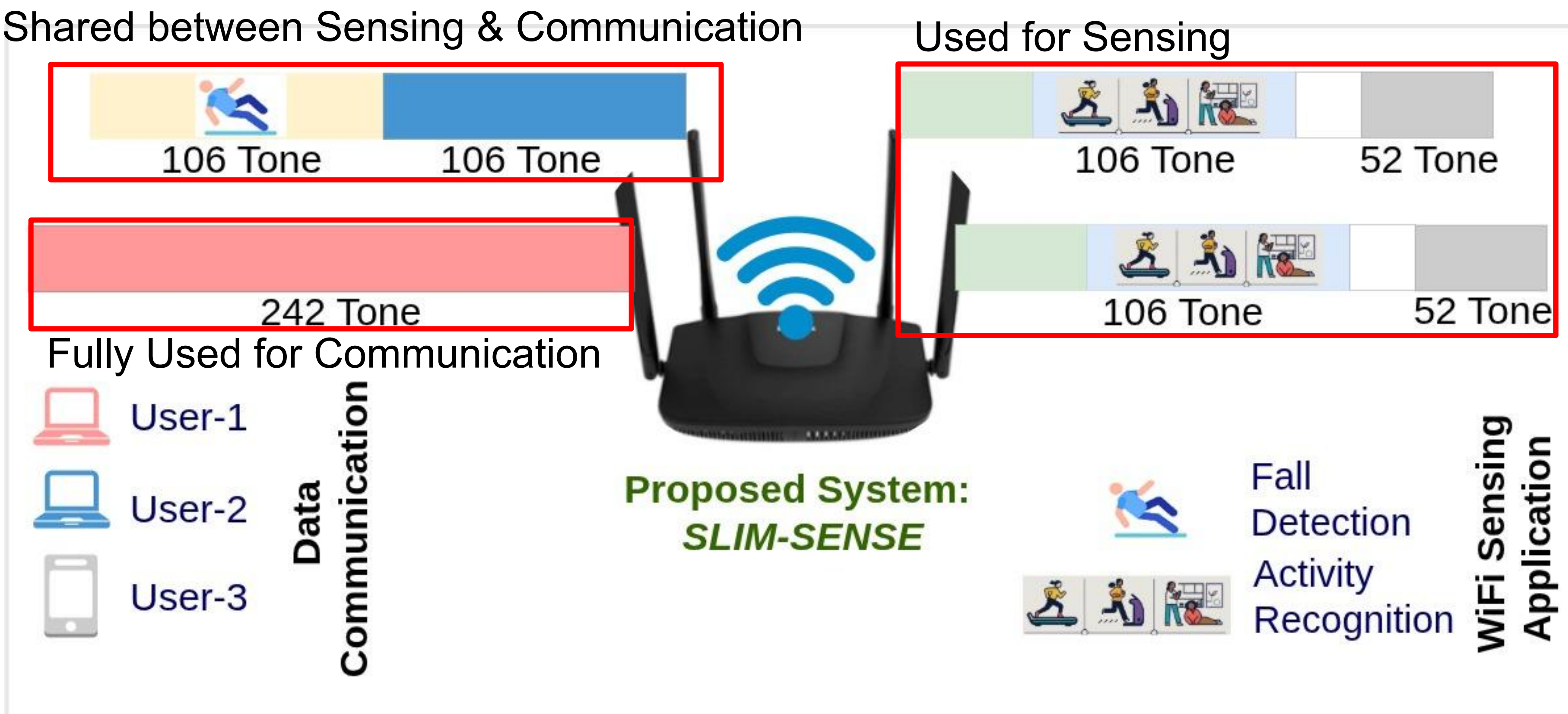
WiFi 6 allows splitting of bandwidth into predefined blocks

Goal:

– CSI sampling rate unimpacted

– Achieve quality CSI data

Idea: SLIM-SENSE



Objective of SLIM-SENSE

Selected bandwidth resources must align with the sensing application

Allocating optimal resources to sensing and rest to communication, i.e. minimize resources used for sensing

Achieve optimal trade-off between sensing accuracy and resource savings

SLIM-SENSE: Problem Formulation

$Q_1 = f_1$ (estimated output, ground truth)

1 **Quantify the error between ground truth and estimated output**

$Q_2 = f_2$ (selection of subcarriers)

2 **Quantify the number of subcarriers**

$Q_3 = f_3$ (selection of RUs)

3 **Quantify the number of sub-channel/RUs used across the antennas**

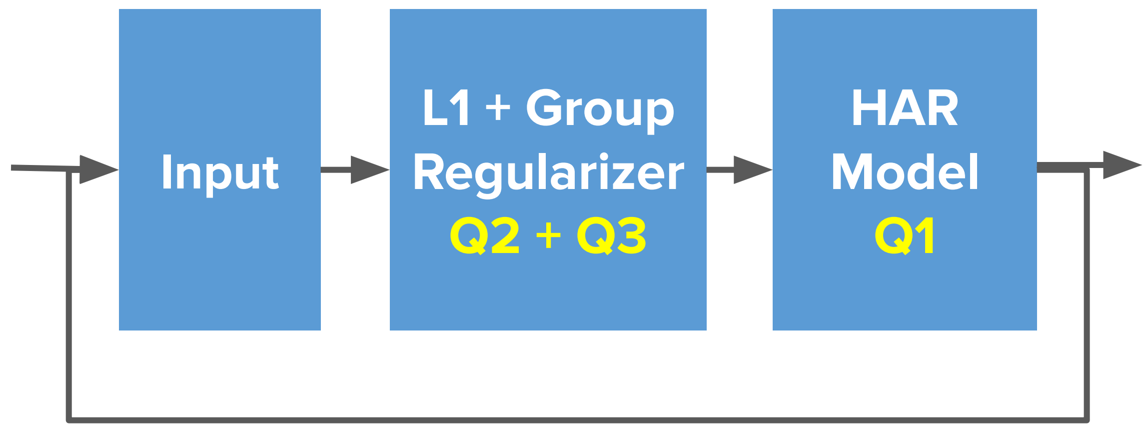
$$Q = \arg \min_{\substack{\hat{A} \in P(A) \\ \lambda_1 \in \Lambda_1 \\ \lambda_g \in \Lambda_g}} \{ Q_1 + \lambda_1 Q_2 + \lambda_g Q_3 \}$$

4 **Optimal trade-off between sensing accuracy and resource savings while selecting the minimum optimal resources for sensing**

Solution Approach

Sparse Group Regularizer

$$Q = \arg \min_{\substack{\hat{A} \in P(A) \\ \lambda_1 \in \Lambda_1 \\ \lambda_g \in \Lambda_g}} \{Q_1 + \lambda_1 Q_2 + \lambda_g Q_3\}$$



Integrate resource selection within the learning process

Hyperparameters Control the Trade-off between Sensing Accuracy and Resource Savings

$\hat{A}$ — Most relevant subset of antennas

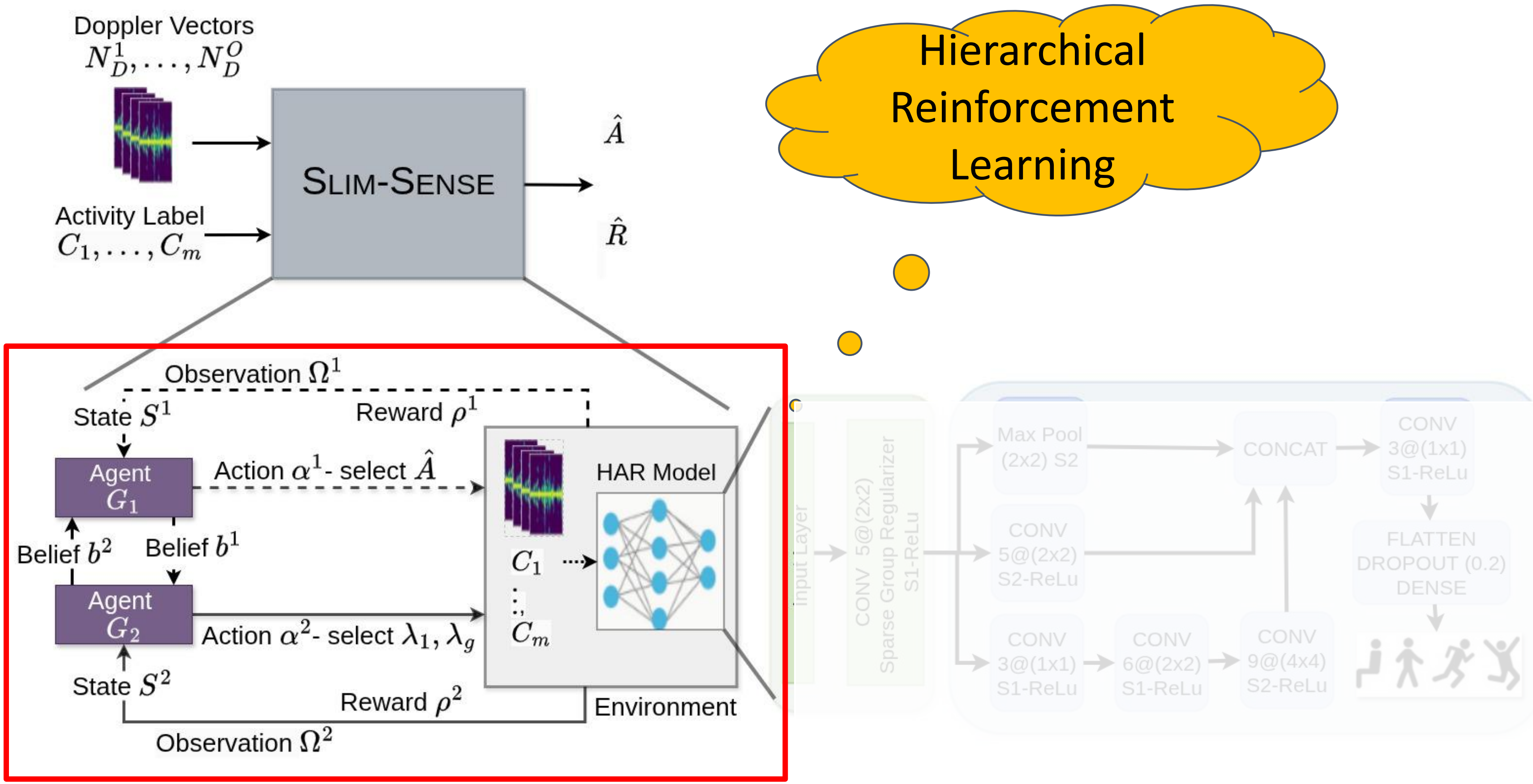
λ_1

λ_g — Optimal value of λ1 and λg provides most relevant RUs set

Hyperparameters	Possible Values
Λ_1	$\{0.0, \ldots, 1.0\}$
Λ_g	$\{0.0, \ldots, 1.0\}$
$\mathbf{P}(A)$ if $A = 4$	$\{\{0\}, \{1\}, \{2\}\{3\}, \{0,1\}, \{0,2\}, \{0,3\}, \{1,2\}, \{1,3\},$
	$\{2,3\}, \{0,1,2\}, \{0,1,3\}, \{0,2,3\}, \{1,2,3\}, \{0,1,2,3\}\}$

Need a lightweight method to find the right hyperparameters

Solution to Problem of Hyperparameter Tuning



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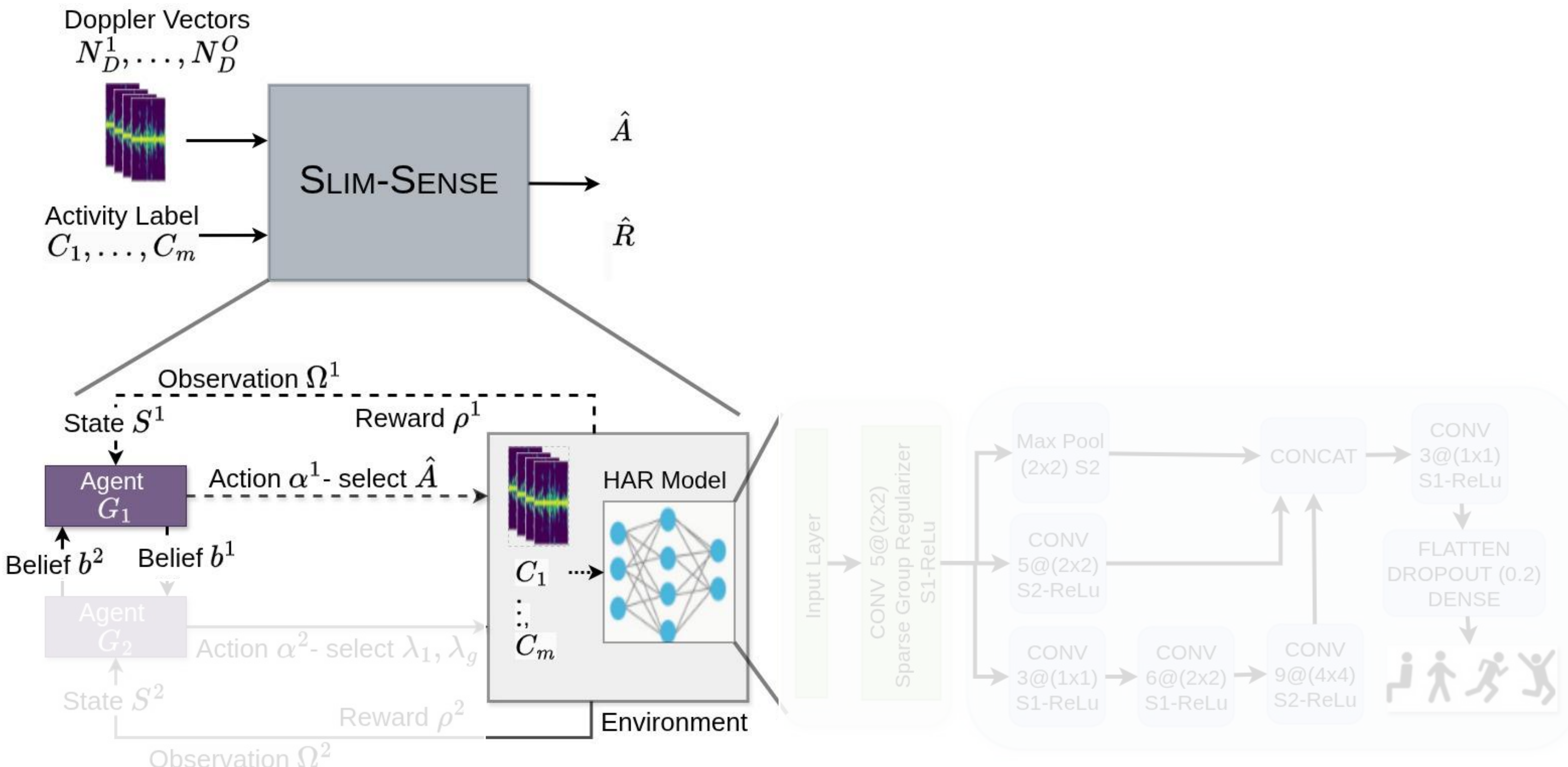

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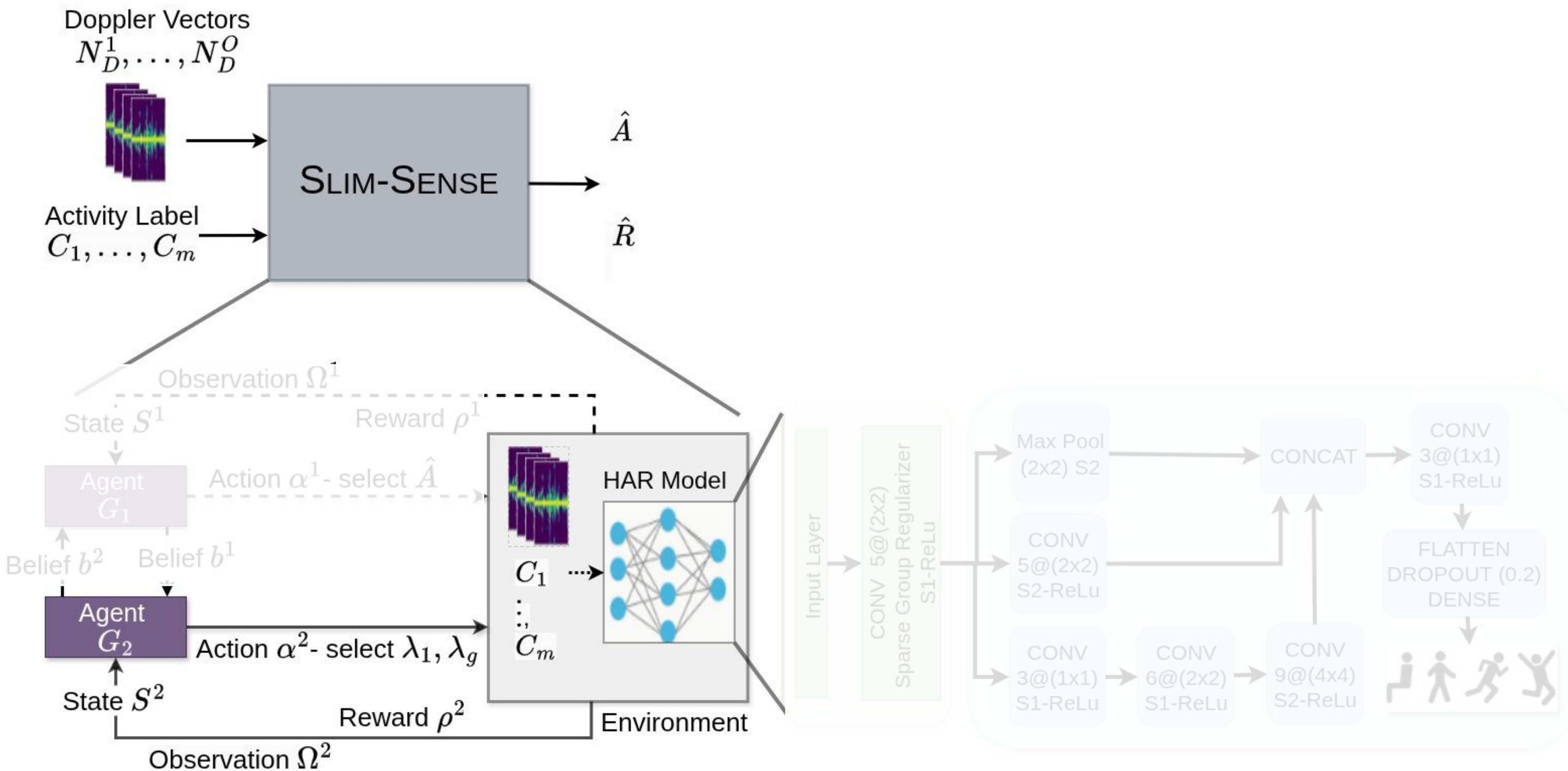

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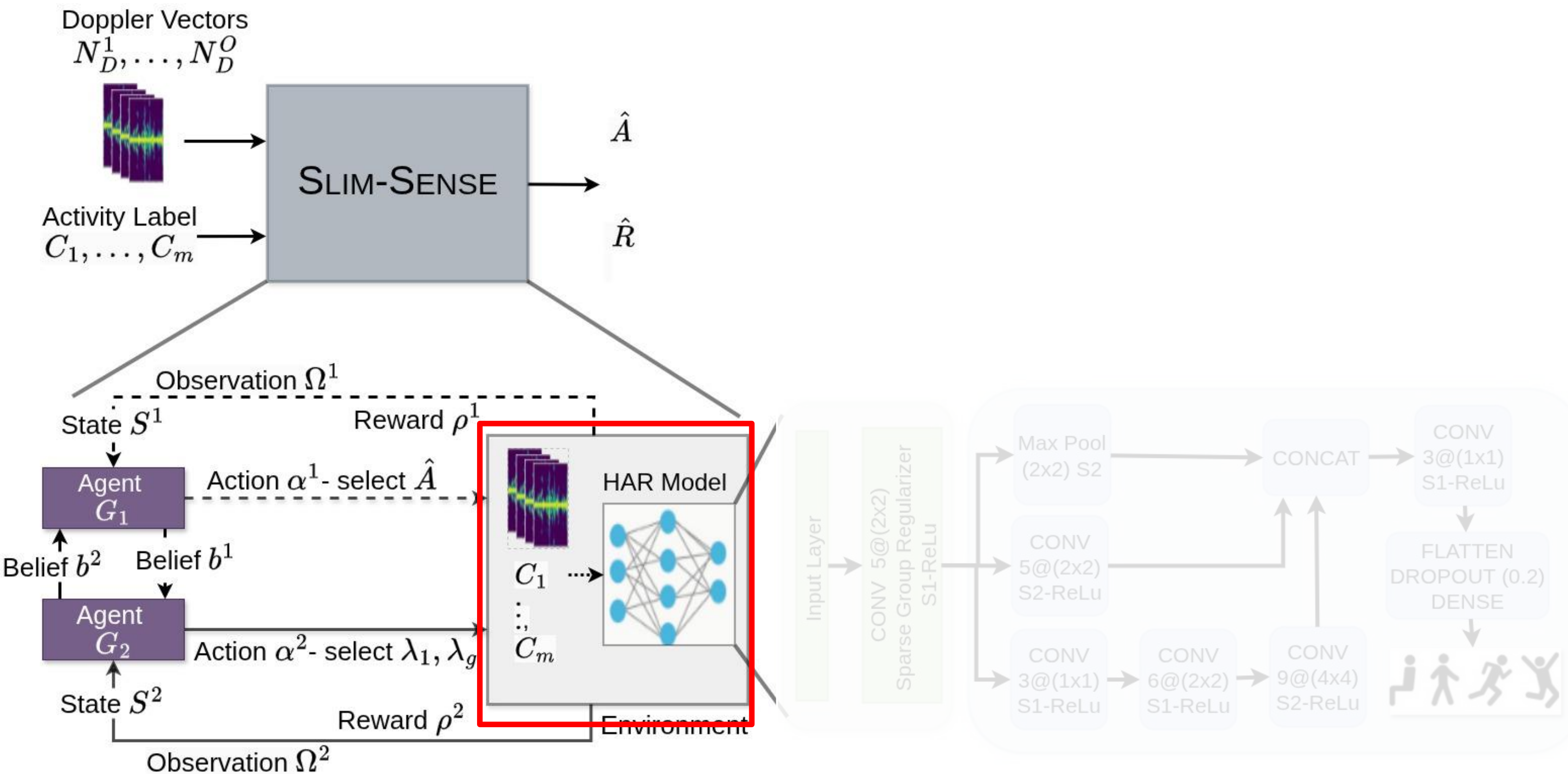

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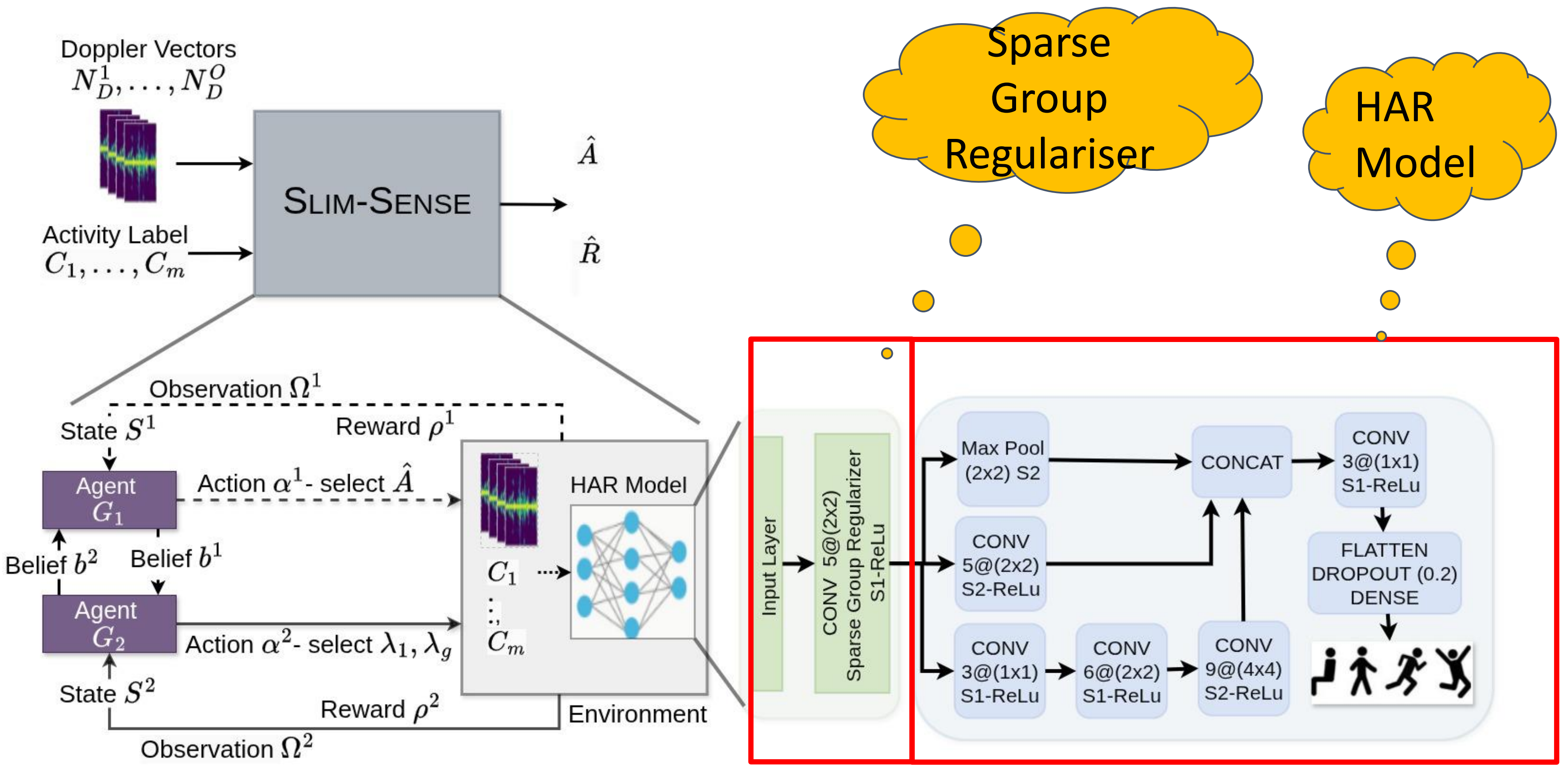


Datasets Description

Dataset Parameter	HeadGest (Our)	Exposing CSI[3]	SHARPax[4]	SimWiSense[5]
Access Technology	OFDM	OFDM/OFDMA	OFDM/OFDMA	OFDM
Bandwidth	40Mhz	160Mhz	80Mhz	80Mhz
sub-channels/RUs	2	8/74	4/37	4
#Participants	33	3	1	3
Activities	Looking Forward, Looking Down, Looking Up, Looking Left, Looking Right, Nodding and Shaking	Walk, Sitting, Wave hands, Wiping, Run, Empty room, Clapping, Squat, Jump, Standing, Lay down, Stretching	Walking, Running, Staying, Empty room	Push Forward, Rotate, Hands up and down, Waive, Brush, Clap, Sit, Eat, Drink, Kick, Bend forward, Wash hands, Call, Browsing phone, Check wrist, Read, Waive while sitting, Writing, Side bend, and Standing
Locations	Lab-1, Lab-2, Lab-3, Meeting Room and Housing Room	Lab, Office and Hall	Horse corridor	Classroom, Office
Uniqueness	Challenging and diverse experiment setups	11ax CSI data for 12 static, dynamic and physical activities	11ax data in simple scenario	Collected in multi-person activities environment

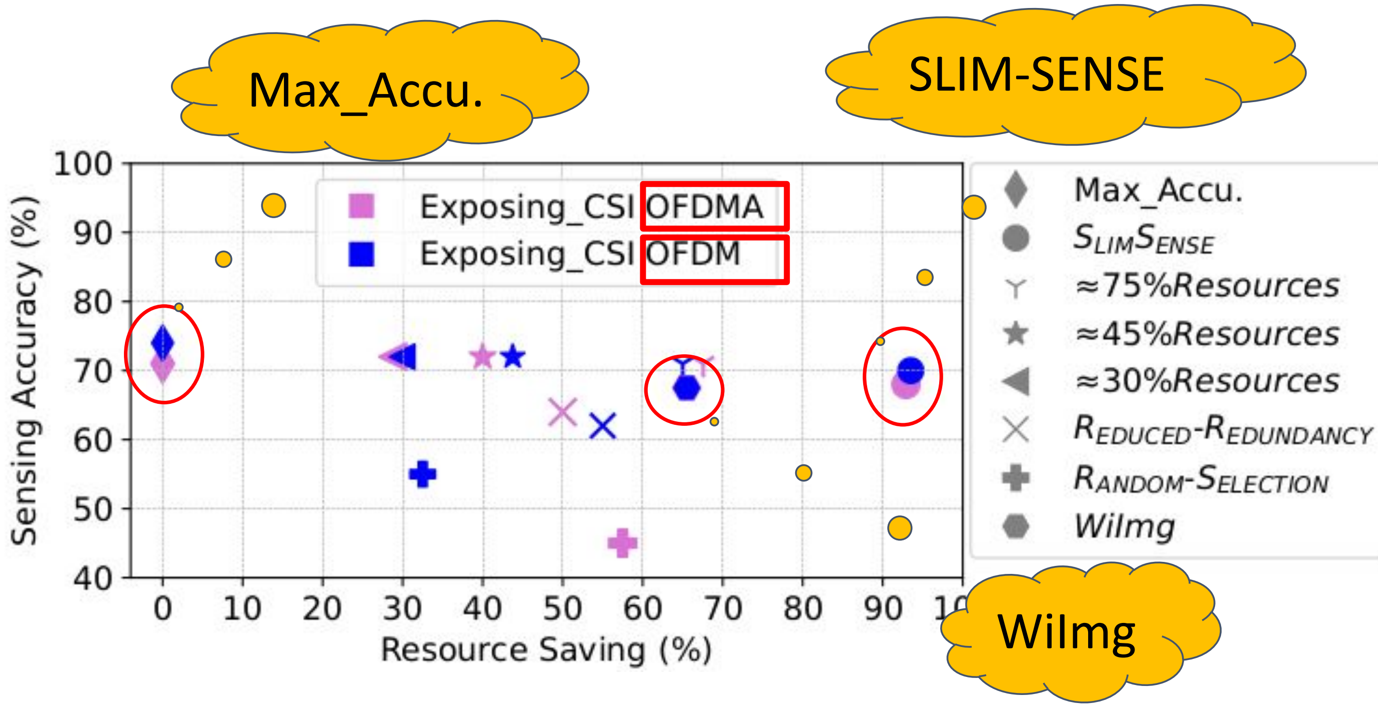
Cominelli et al, (2023) [3], Meneghello et al, (2023) [4], Haque et al (2023) [5]

Baselines

Static Configurations	≈ 75% Resources
	≈ 45% Resources
	≈ 30% Resources
Max Accu:	All Resources
Random-Selection	Randomly Selected Resources
Reduced-Redundancy	Reduce Redundant Resources
WiImg, TMC 2024	Low Sampling Rate

Evaluation: Accuracy vs Resource Saving

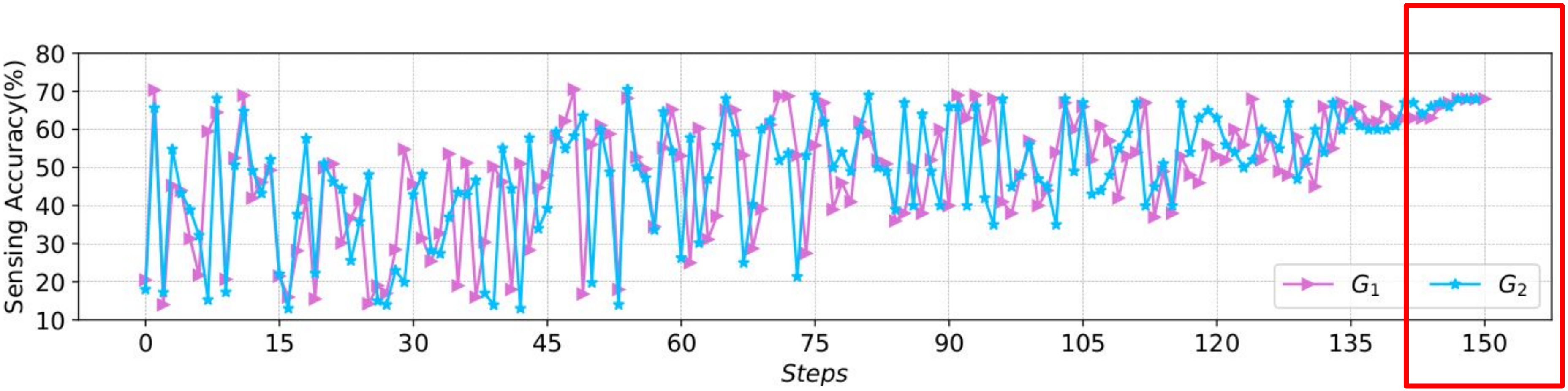
Tradeoff between sensing accuracy and resource saving



Resource saving > 90%, reduction in sensing accuracy < 5%.

Cominelli et al, (2023) [3]

Evaluation: Convergence of SLIM-SENSE



Used Q-learning to train the agents

Convergence of HRL to obtain the optimal values of three hyperparameters λ_1, λ_g, and $\hat{A}$ and providing the maximum accuracy

SLIM-SENSE: A Resource Efficient WiFi Sensing Framework towards Integrated Sensing and Communication

Demonstrates sensing using only part of the spectrum resources.

↓

SLIM-SENSE has potential to support ISAC in future WiFi networks.

↓

A live demonstration is planned as immediate future work.

Please read the full paper or look at our other works at WISE Lab.