SleepMore: Inferring Sleep Duration at Scale via Multi-Device WiFi Sensing

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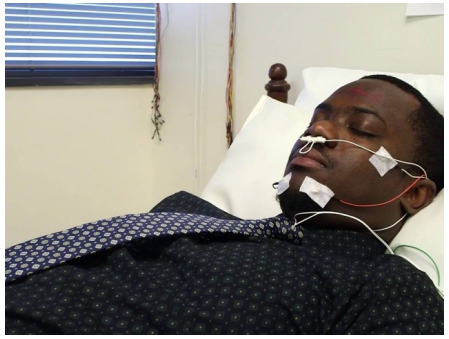
Sleep Disorder, a Public Health Concern

- 7-9 hours of sleep every night is most ideal - National Sleep Foundation
- 67% of adults have sleep disturbances at least once every night - Philips Global Sleep Survey, 2019
- Sleep disorder include insomnia, breathing disorder
- Risk factors associated with performance and cognitive deficits



Polysomnography

Fitbit

Oura Ring

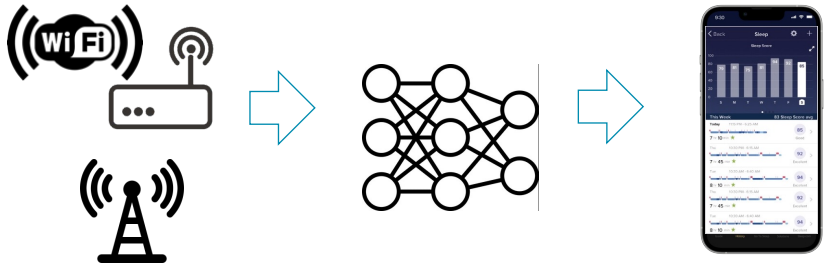
Sensing Sleep **Passively Without a Wearable**

Smart Devices

Fitbit

Oura Ring

Network | Cloud | Application



Practical Challenges

"I forgot to charge!"

"I don't feel comfortable wearing a device to bed."

"It is too expensive for me to own the device."

"… and what about my privacy!"

Proposed Solution

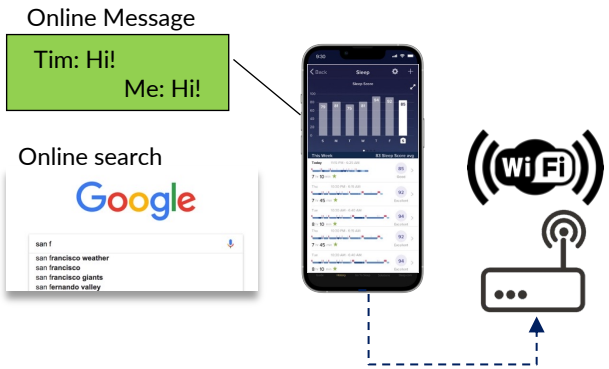
Neither directly nor actively from user device

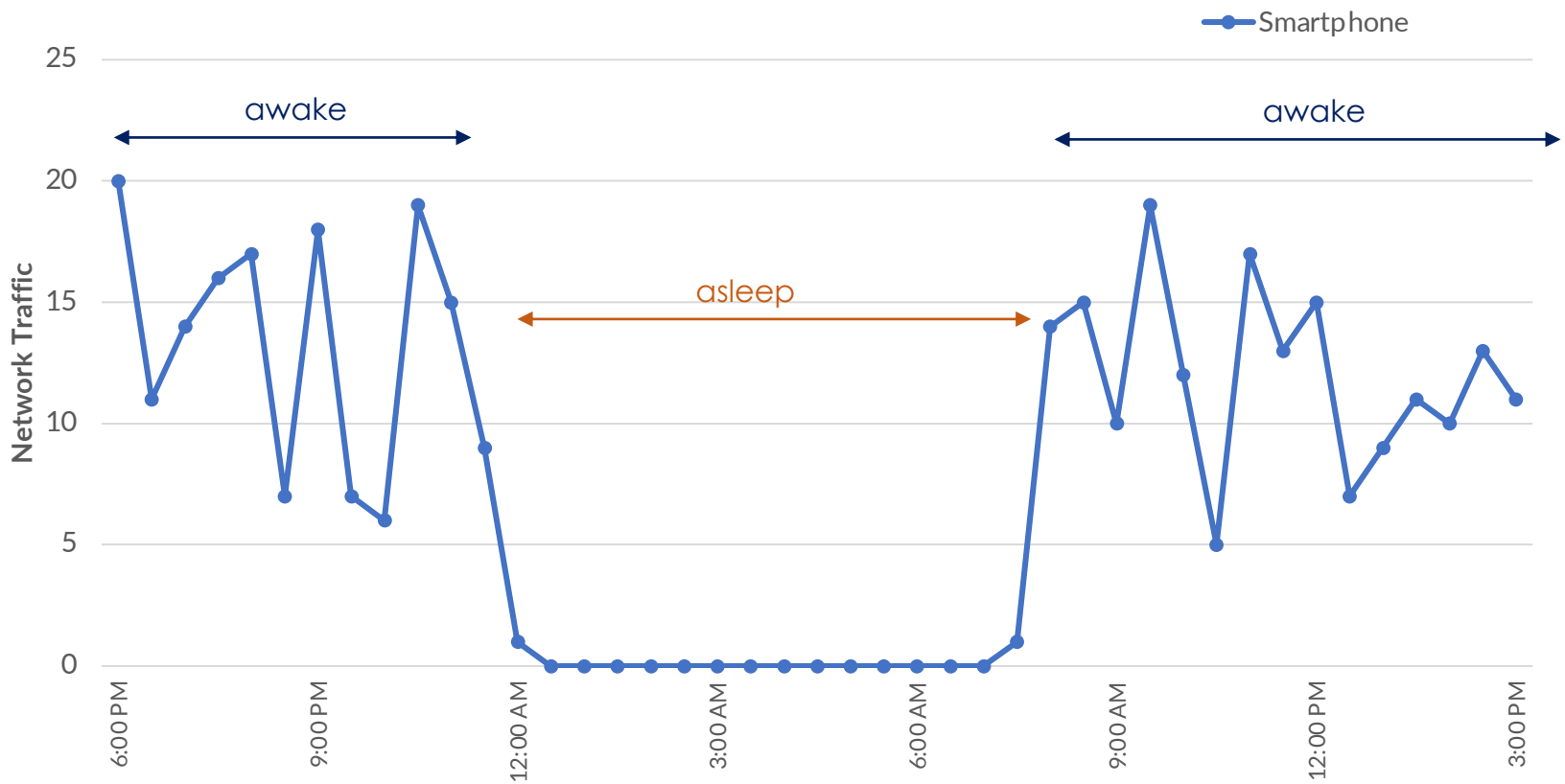
Network traffic to **observe** device behavior

Device behavior to **infer** user behavior

User behavior to **predict** sleep duration

Inferring User ~~Observing Device~~ Behavior





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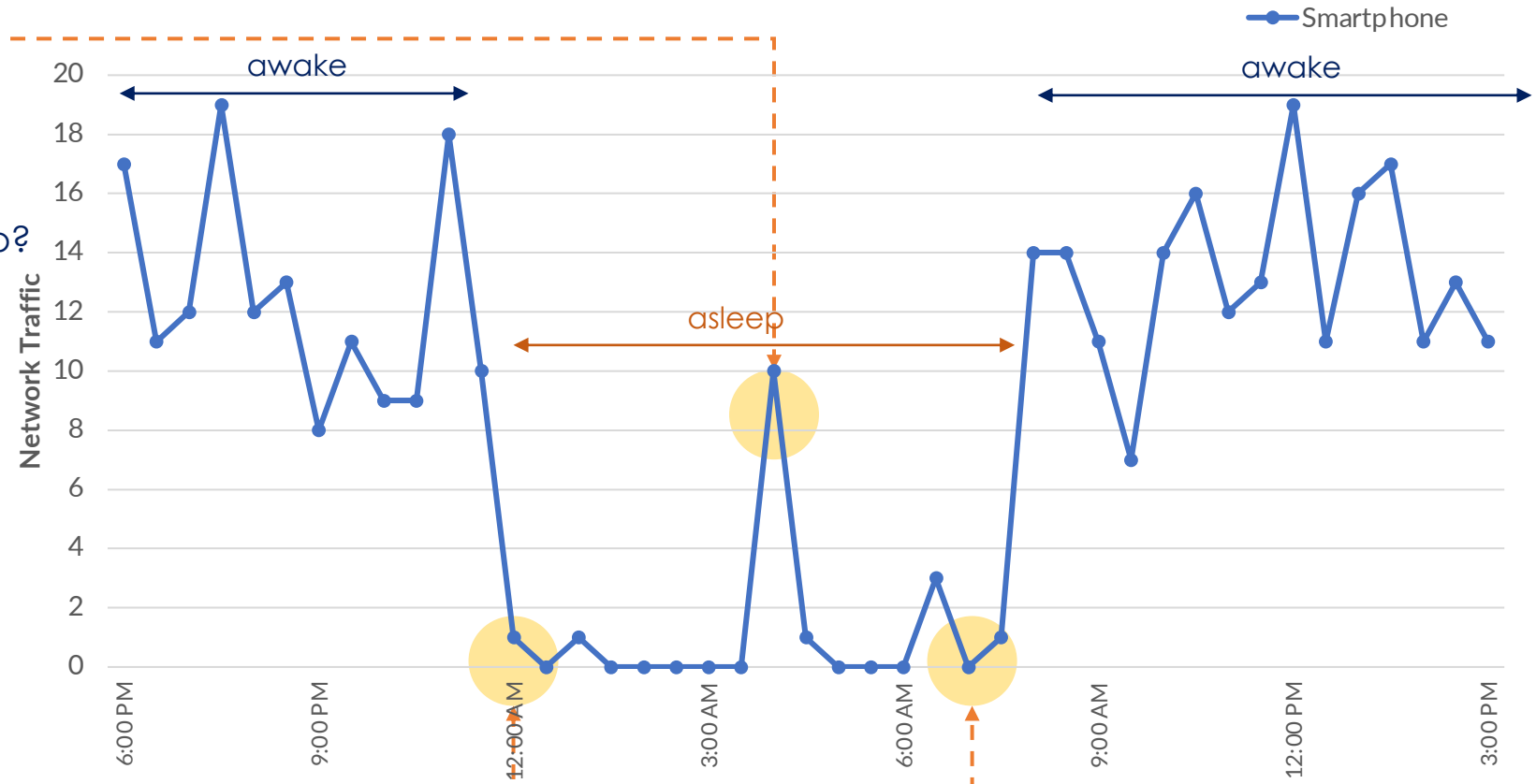
Challenges Inferring User Behavior

1 Noisy Data
- Device updates
- App notifications
- User actually wakes up?

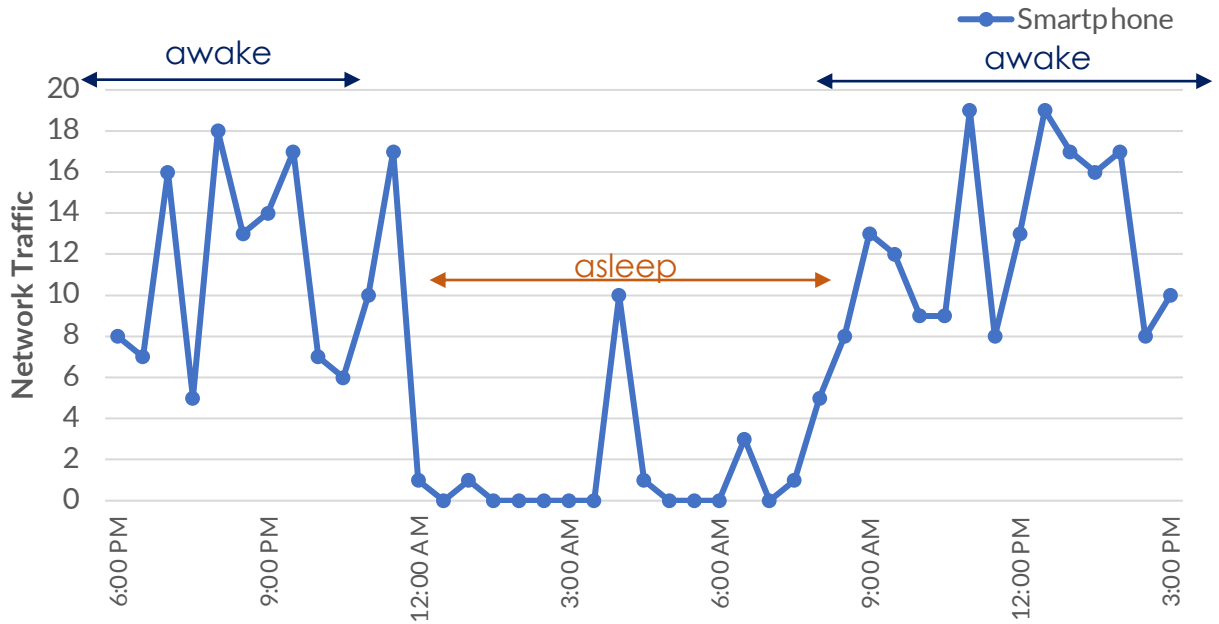


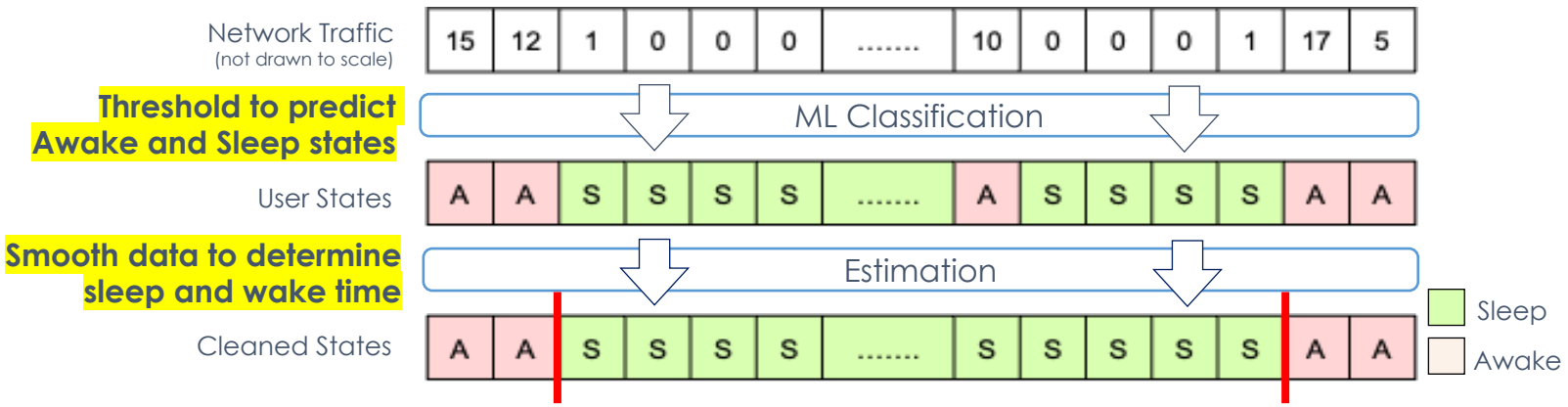
2 Accurate Prediction
- Putting device away
≠ user is asleep

- First device usage in the morning
≠ user just woke up

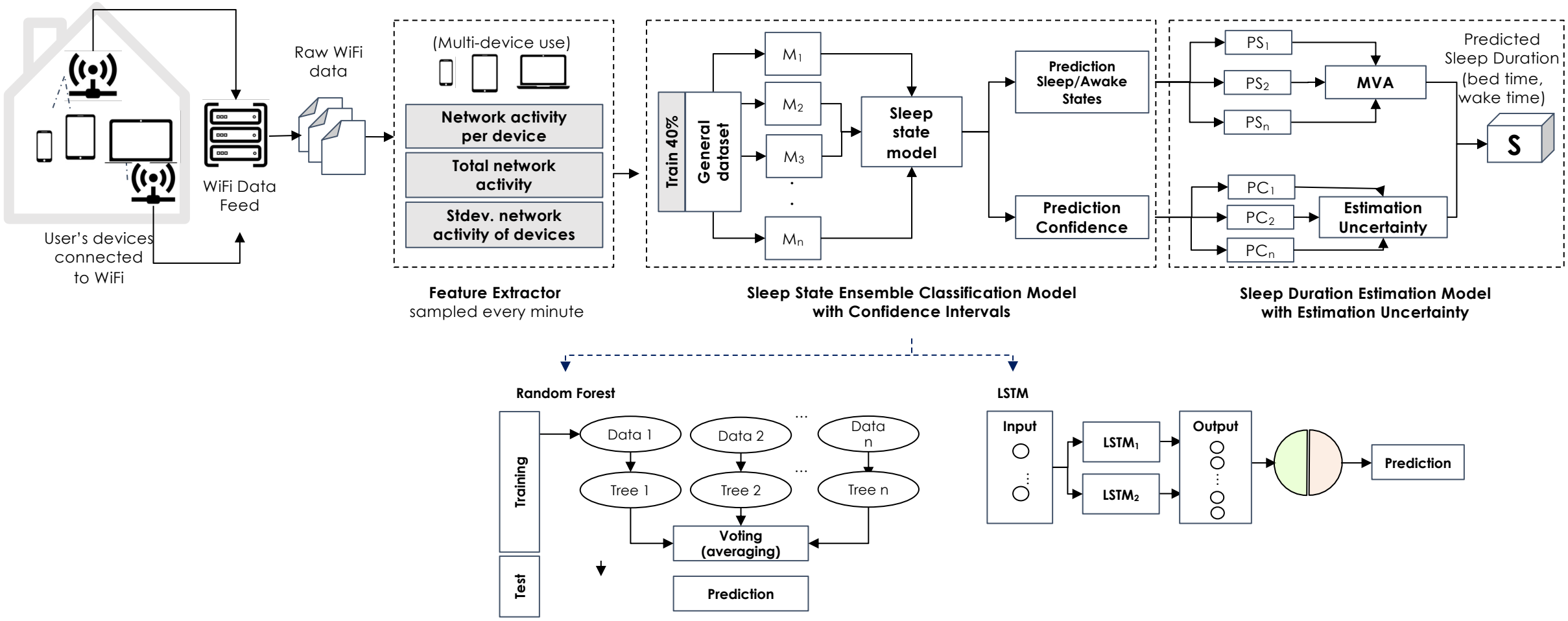
3 Missing Data
- Coarse-grained
- Naturally limits fine-grained capabilities (e.g., sleep stages, quality)

SleepMore Sensing





System Overview



User Study

Research Questions:

1. How accurate is SleepMore compared to state-of-the-art wearable, the Oura Ring?
2. How is sensing multiple devices better than single-device prediction?

Participants

46 On-campus student residents

Family in private residence

Clinical assessment

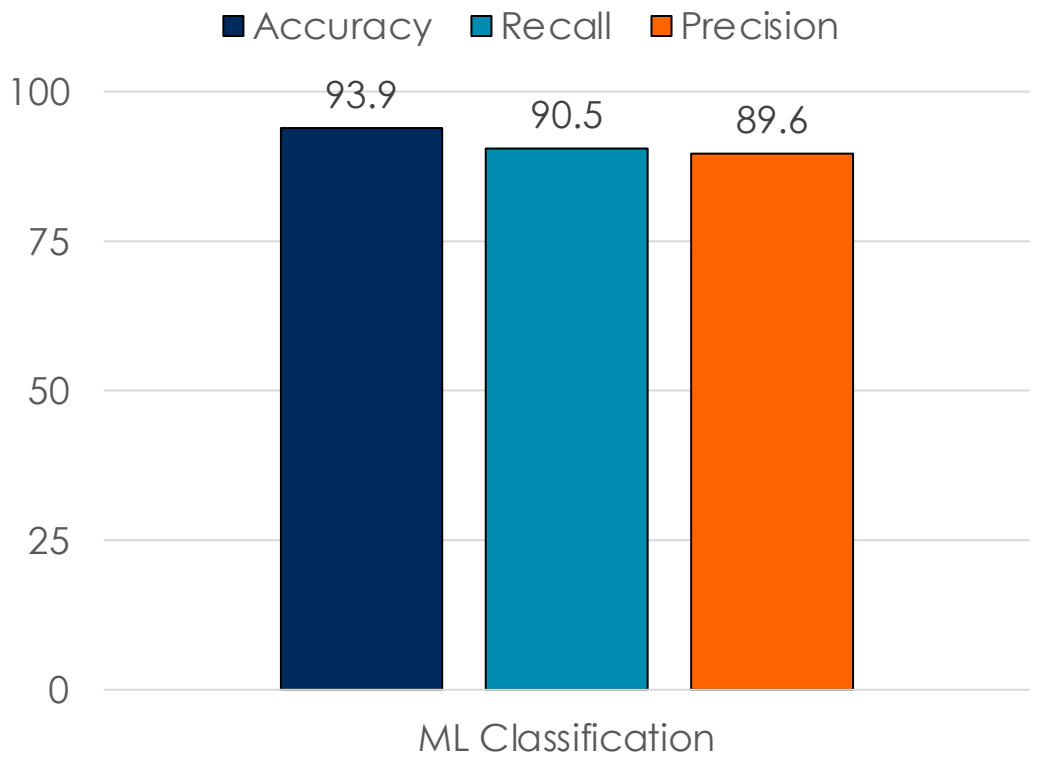
Mental health and sleep apnea
- Beck's Anxiety Inventory
- Beck's Depression Inventory
- Berlin Questionnaire
- (Students only)

1 month Data collection

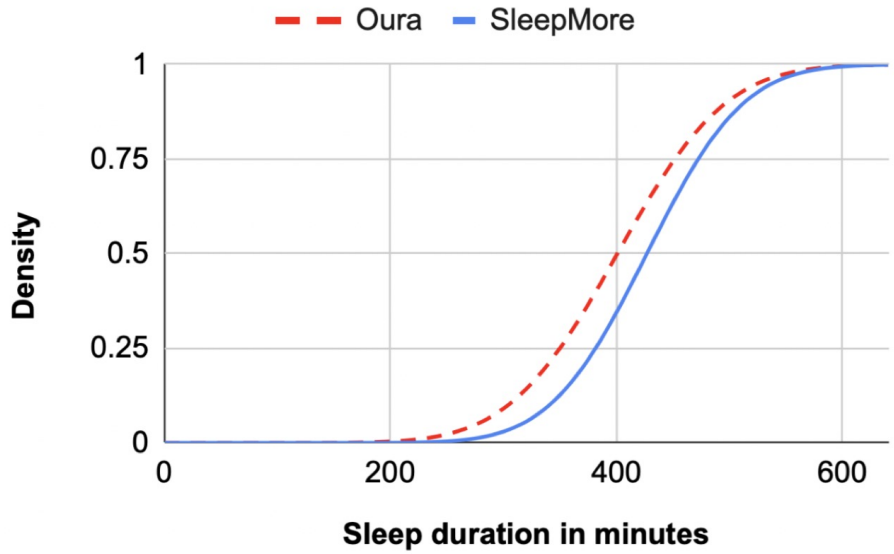
Device MAC addresses

Oura ring (gen 2) as baseline and manually-reported sleep logs

SleepMore's Performance



Bedtime error: 15-28 mins
Wake time error: 7-29 mins

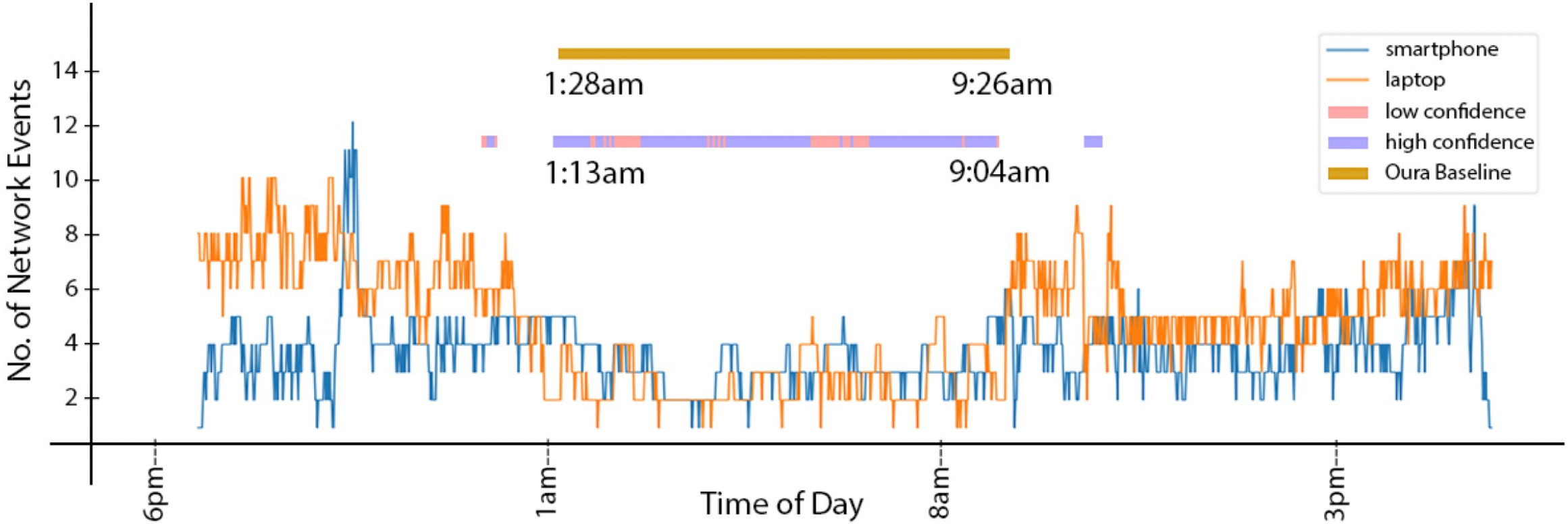


Insignificantly difference
from Oura Ring (p>.1)

Results: Similar to Oura (no statistics difference p>.1)

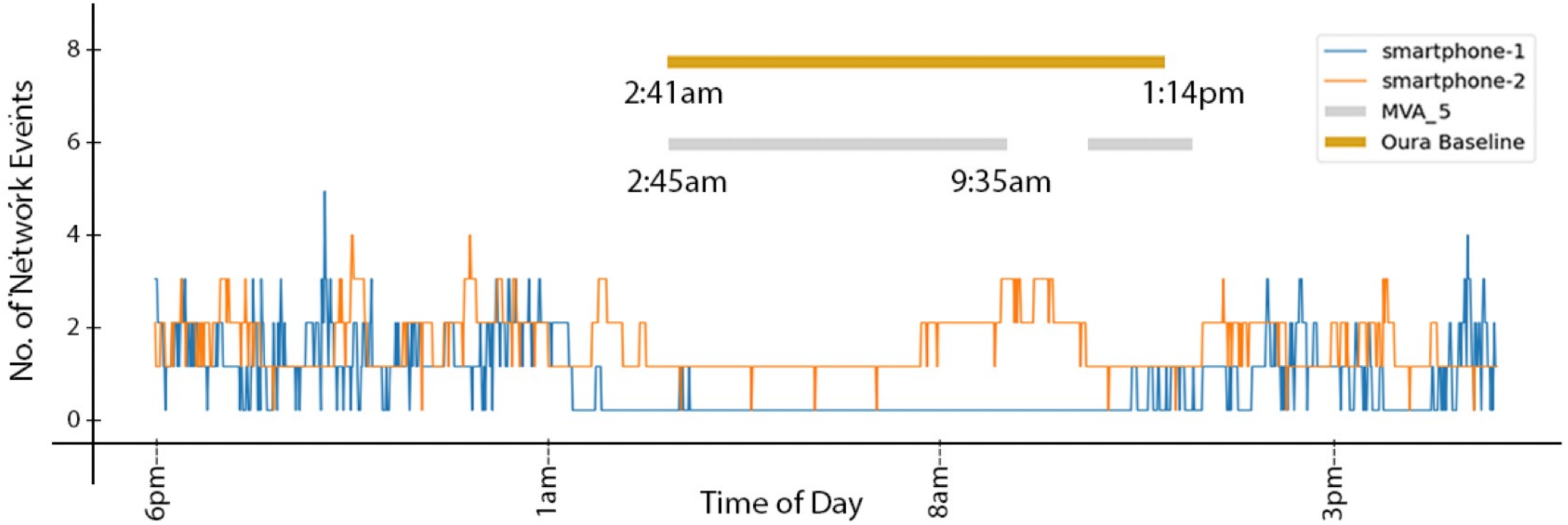
	Oura (mins)	SleepMore (mins)
Median	404	430
Mean	400	426
Mode	428	428
Q1	358	389
Q3	448	471
Min	240	210
Max	680	641

Data/Prediction for One User

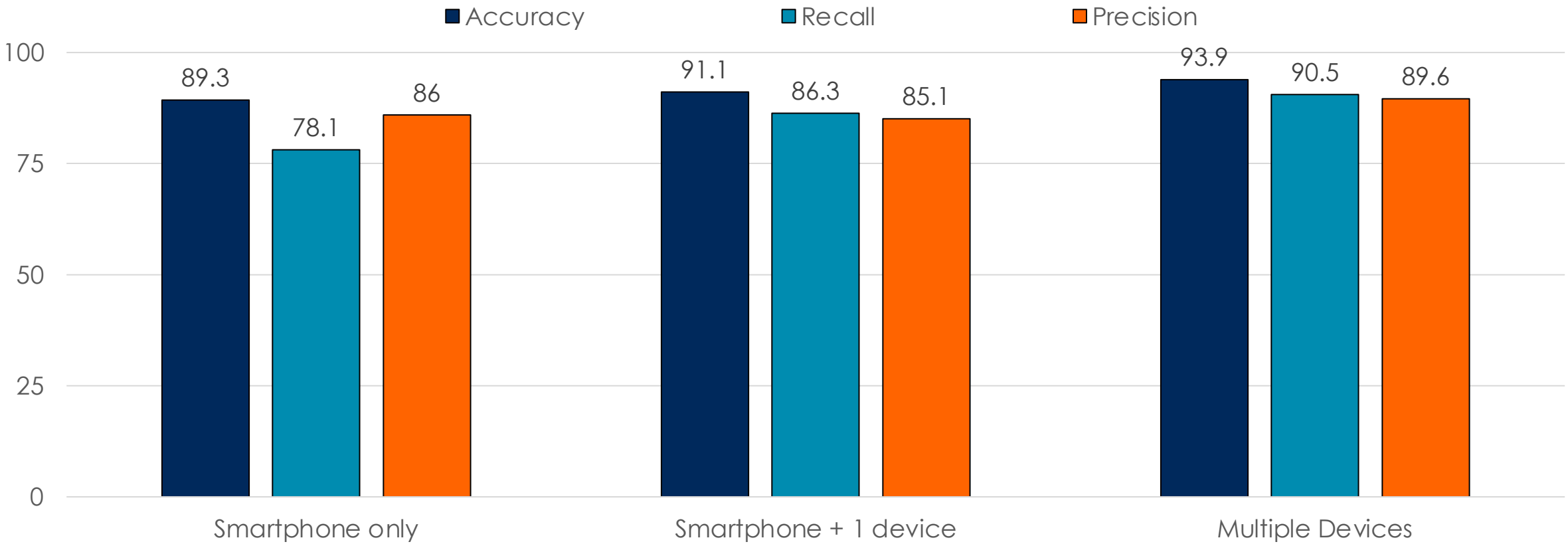


Split-like Sleep Behavior

Oura Ring (gen 2) WAS NOT equipped with a nap detection feature at the time of the study



One vs. More Devices



More device the better

Monitoring more devices does not add to the cost

Key Takeaway

- Complements wearable sensing methods to enable longitudinal monitoring
- Predictions with <= 5% uncertainty threshold make up 80% of the results
  - 93% Accuracy, 90% Recall, 89% Precision
  - Predicted Bedtime between 15-28 minutes error
  - Predicted Wake time between 7-29 minutes error
- Trialed on student residents of campus housing
  - Also tested student model on private home residents
- Ongoing effort in extending system to predict sleep quality
  - Privacy-preserving audio signal processing techniques

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