Scalable Multi-Modal Learning for Cross-Link Channel Prediction in Massive IoT Networks

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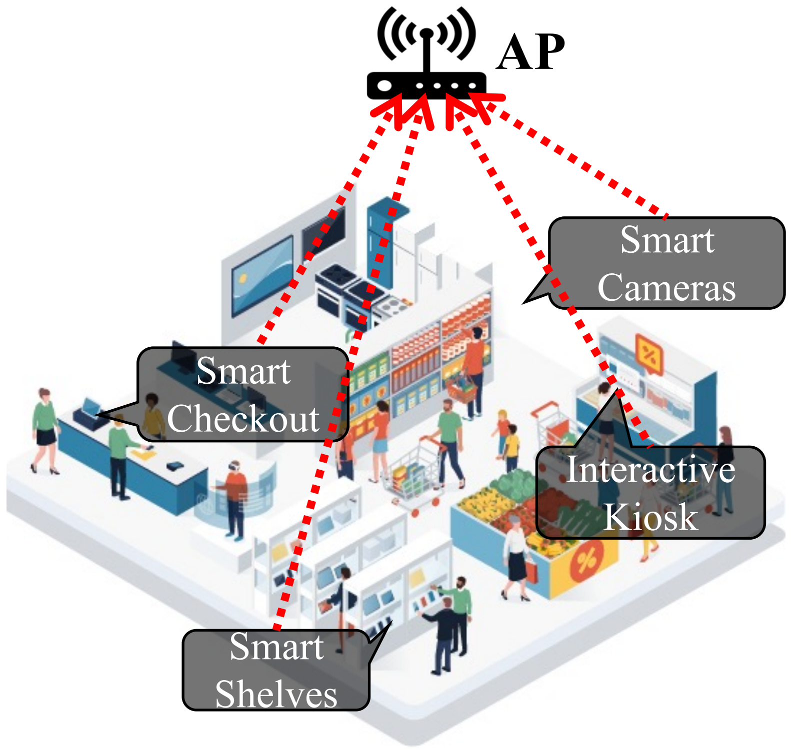
Outline

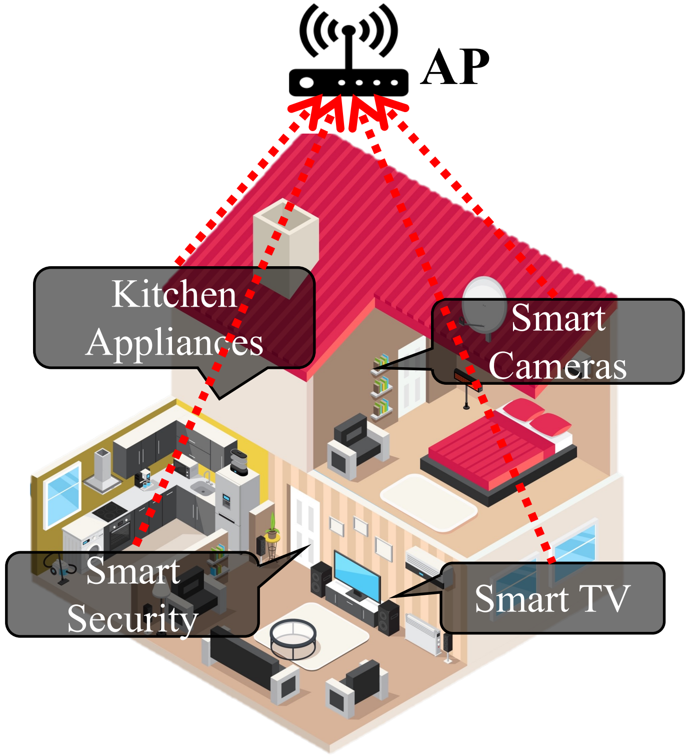
1. **Introduction: Massive IoT Networks**
   - Wi-Fi 6's key technologies and challenges
2. **Cross-Link Channel Prediction (CLCP)**
   - System overview
   - ML background on multi-view representation learning
   - Our solution: **CLCP**
3. **Implementation and Evaluation**
4. **Conclusion**

Today's wireless IoT sensor networks

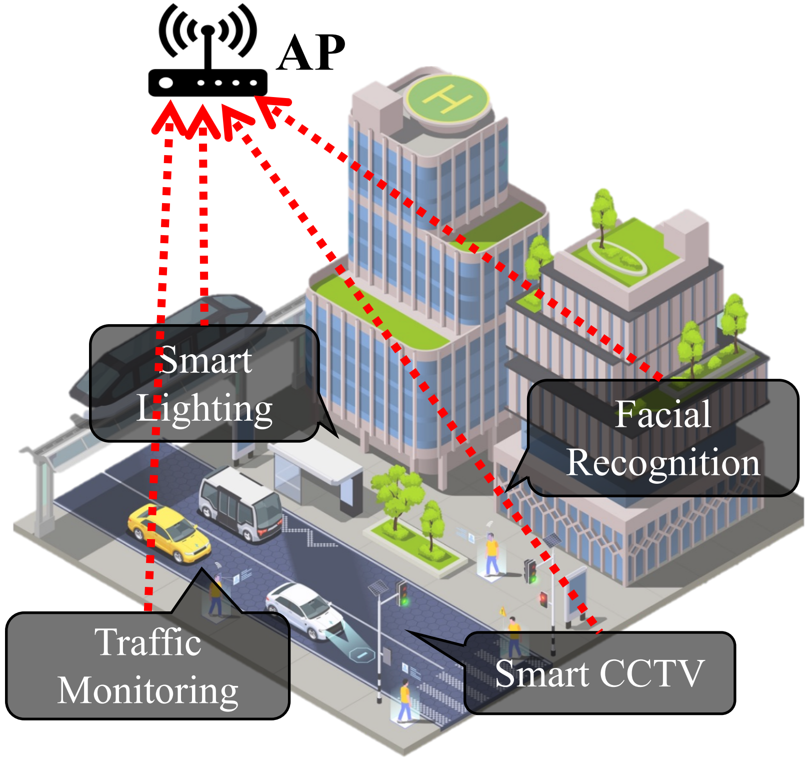
Wireless IoT sensor networks are changing, **scaling up in spectral efficiency, radio count, and traffic volume** as never seen before.



Cashierless Store



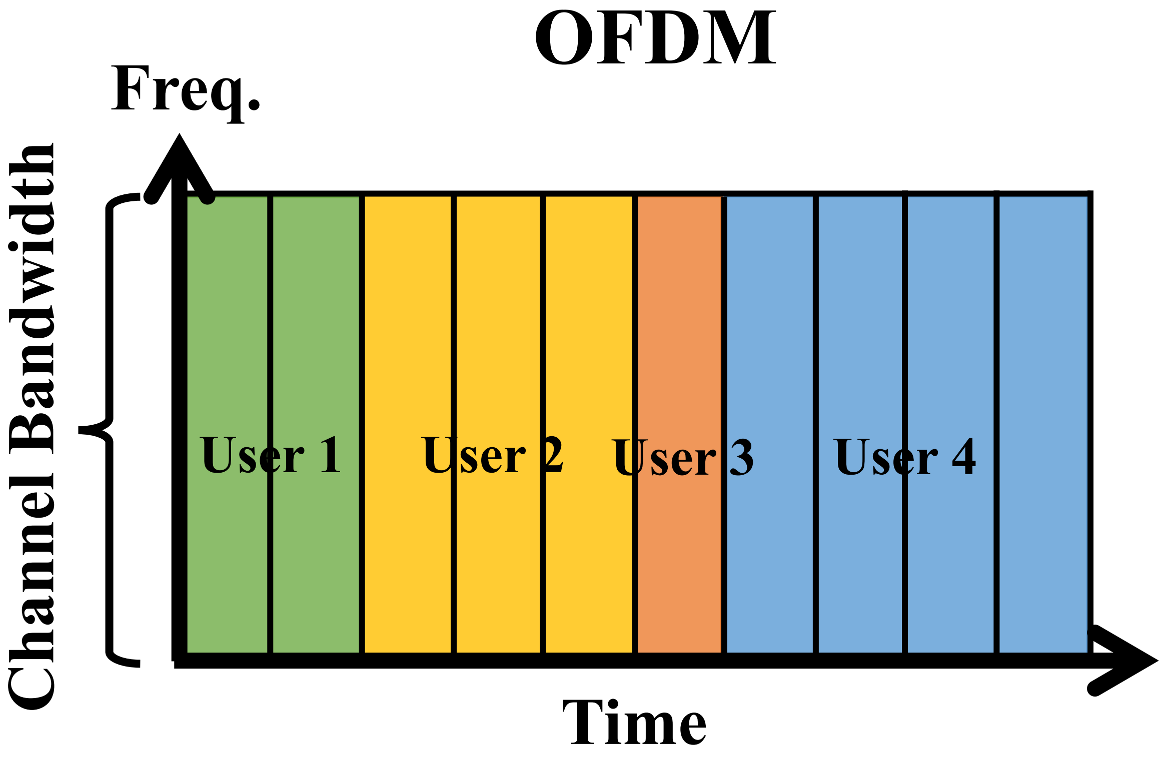
Smart Home



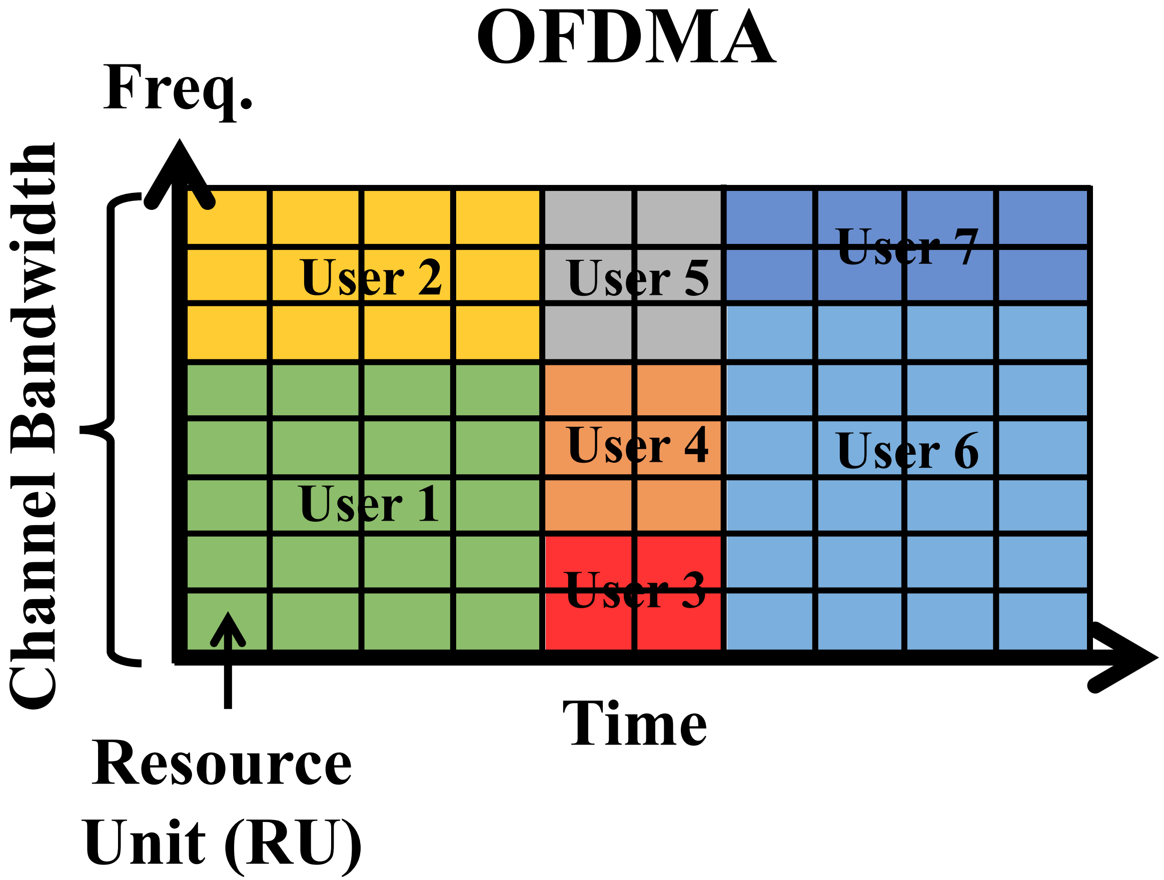
Smart City

Wi-Fi 6's Key Technology: Orthogonal Frequency Division Multiple Access

Previously:

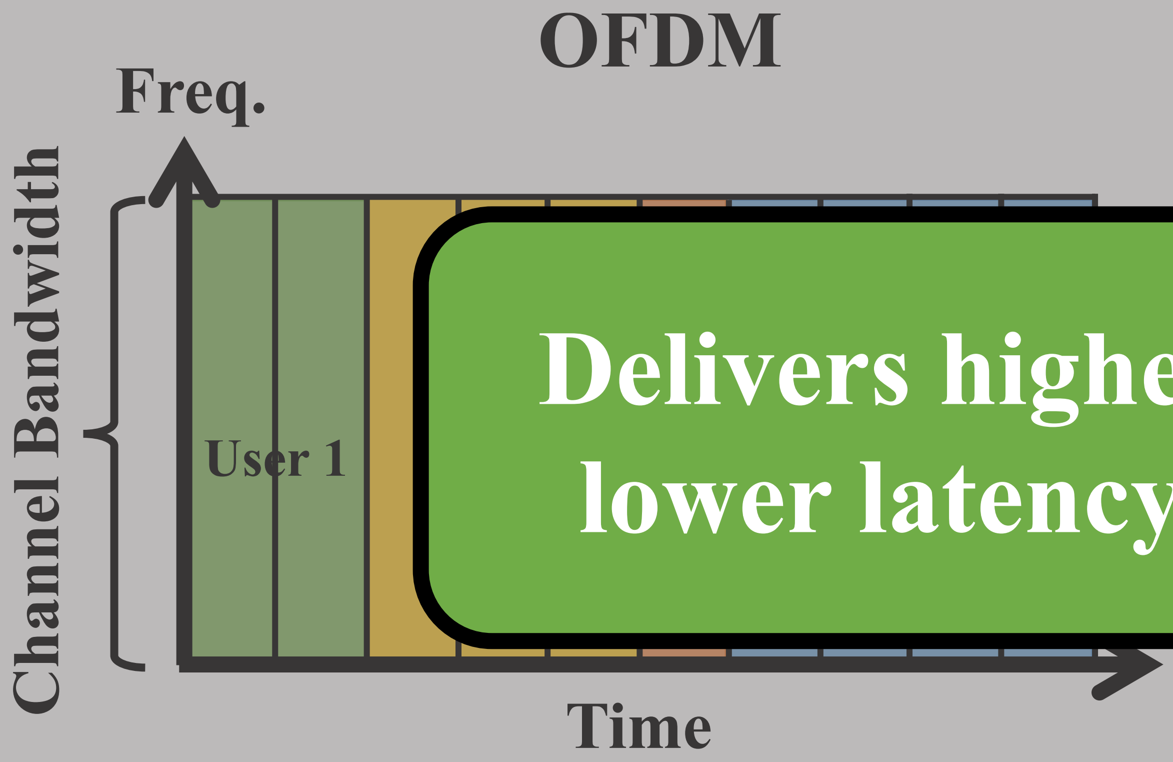


Wi-Fi 6:

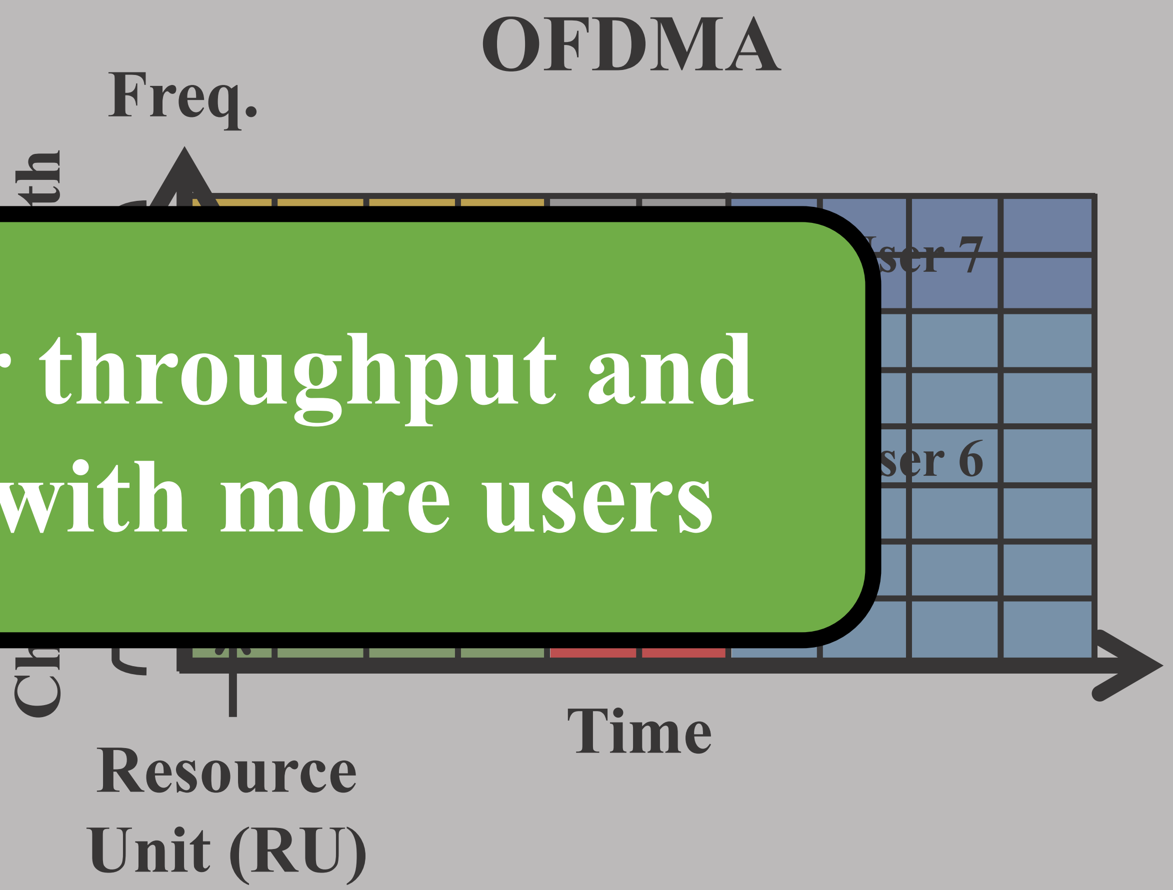


Wi-Fi 6’s Key Technology: Orthogonal Frequency Division Multiple Access

Previously:

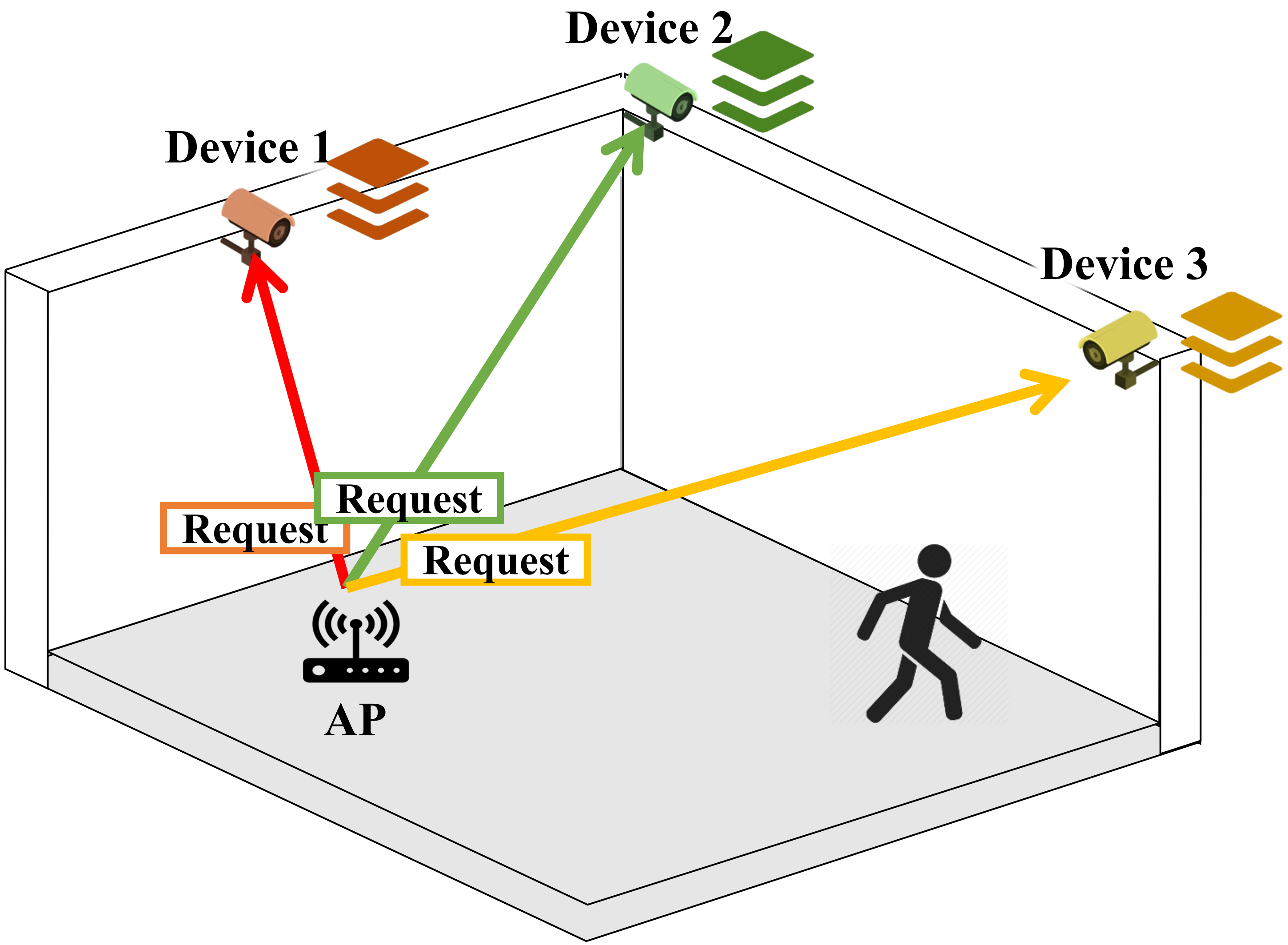


Wi-Fi 6:



Delivers higher throughput and lower latency with more users

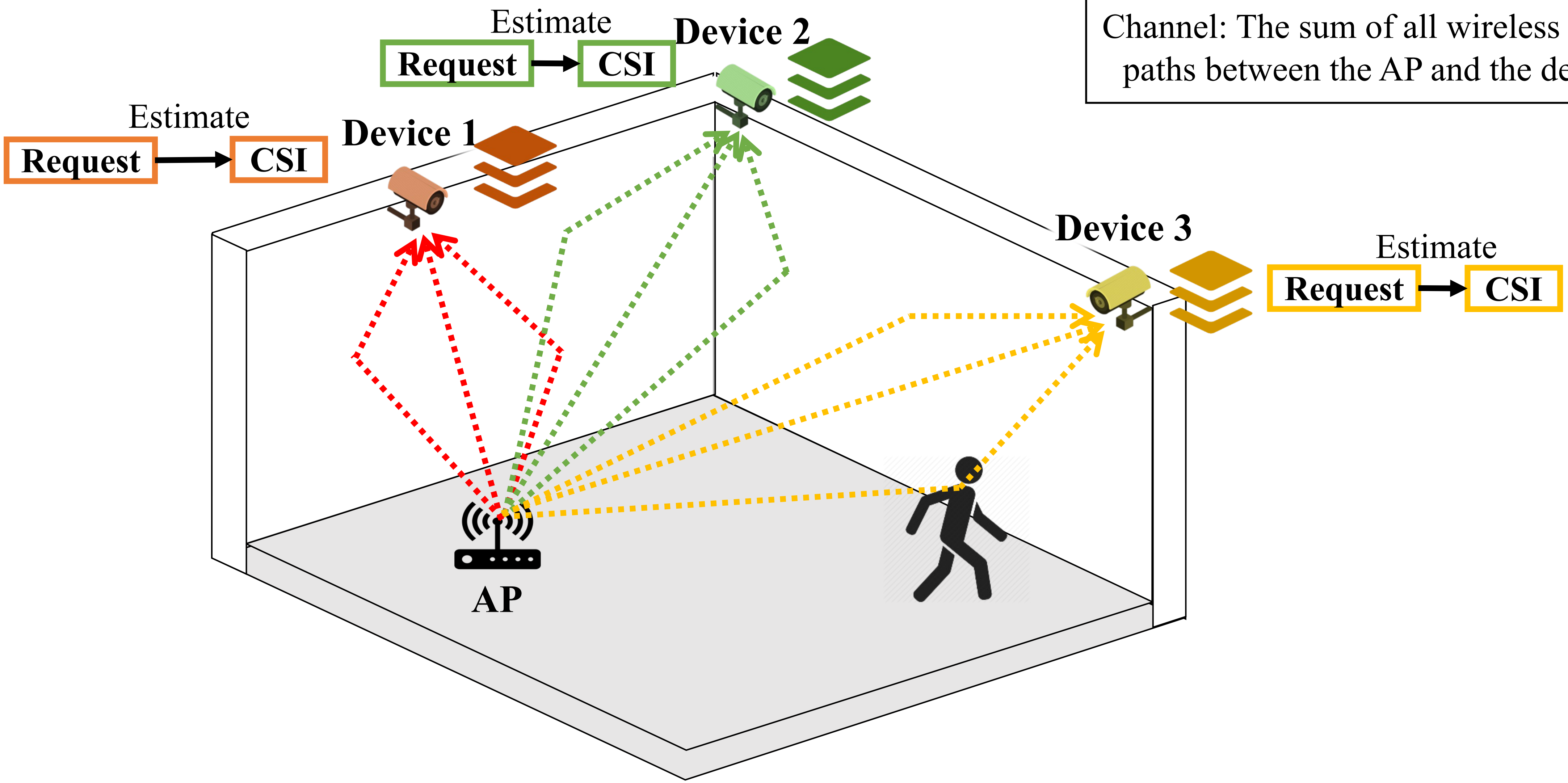
How does OFDMA work?



2. AP periodically requests the buffer status info. (BSR) and channel info. (CSI) to all devices.

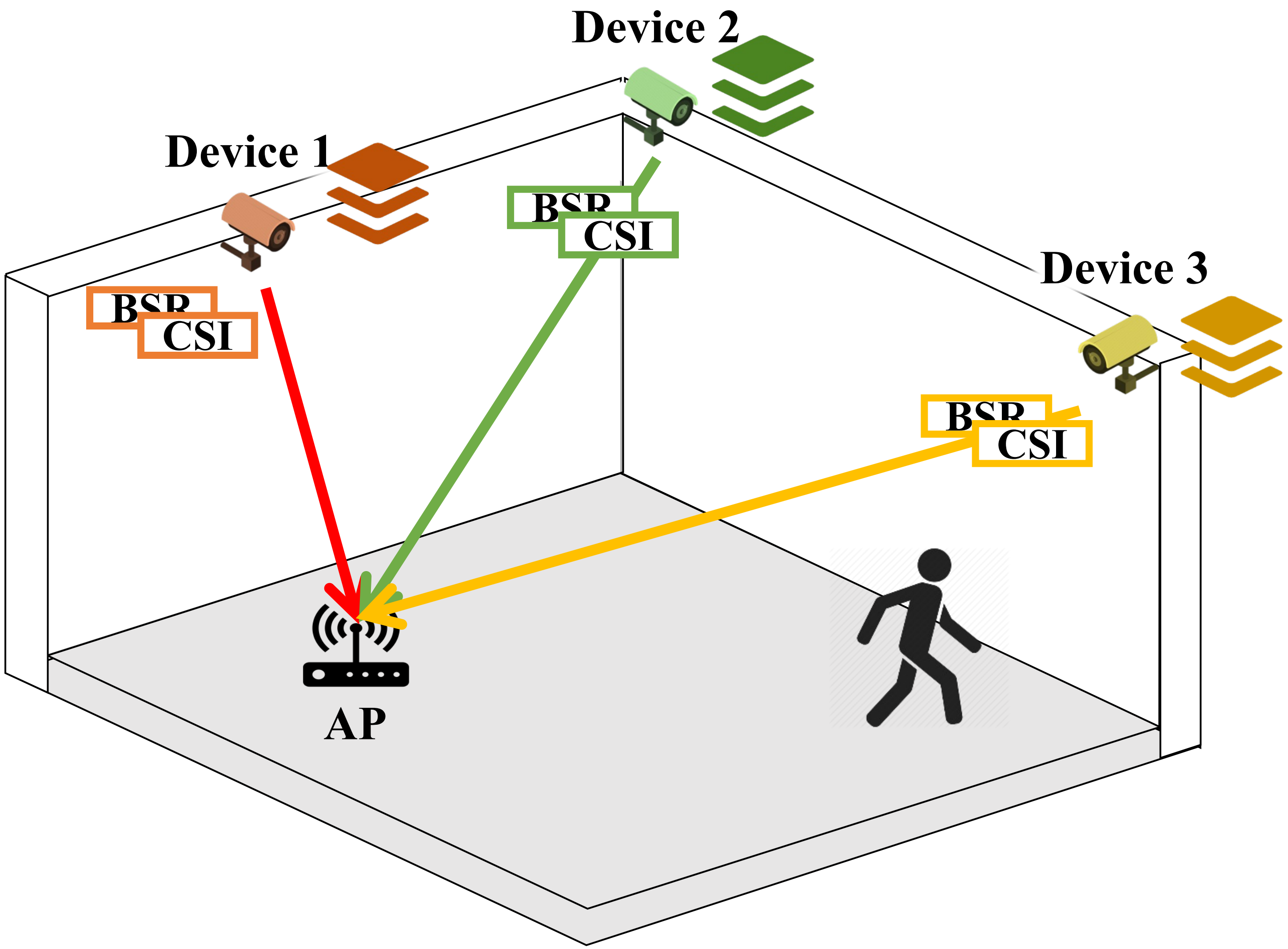
How does OFDMA work?

Channel: The sum of all wireless signal paths between the AP and the device



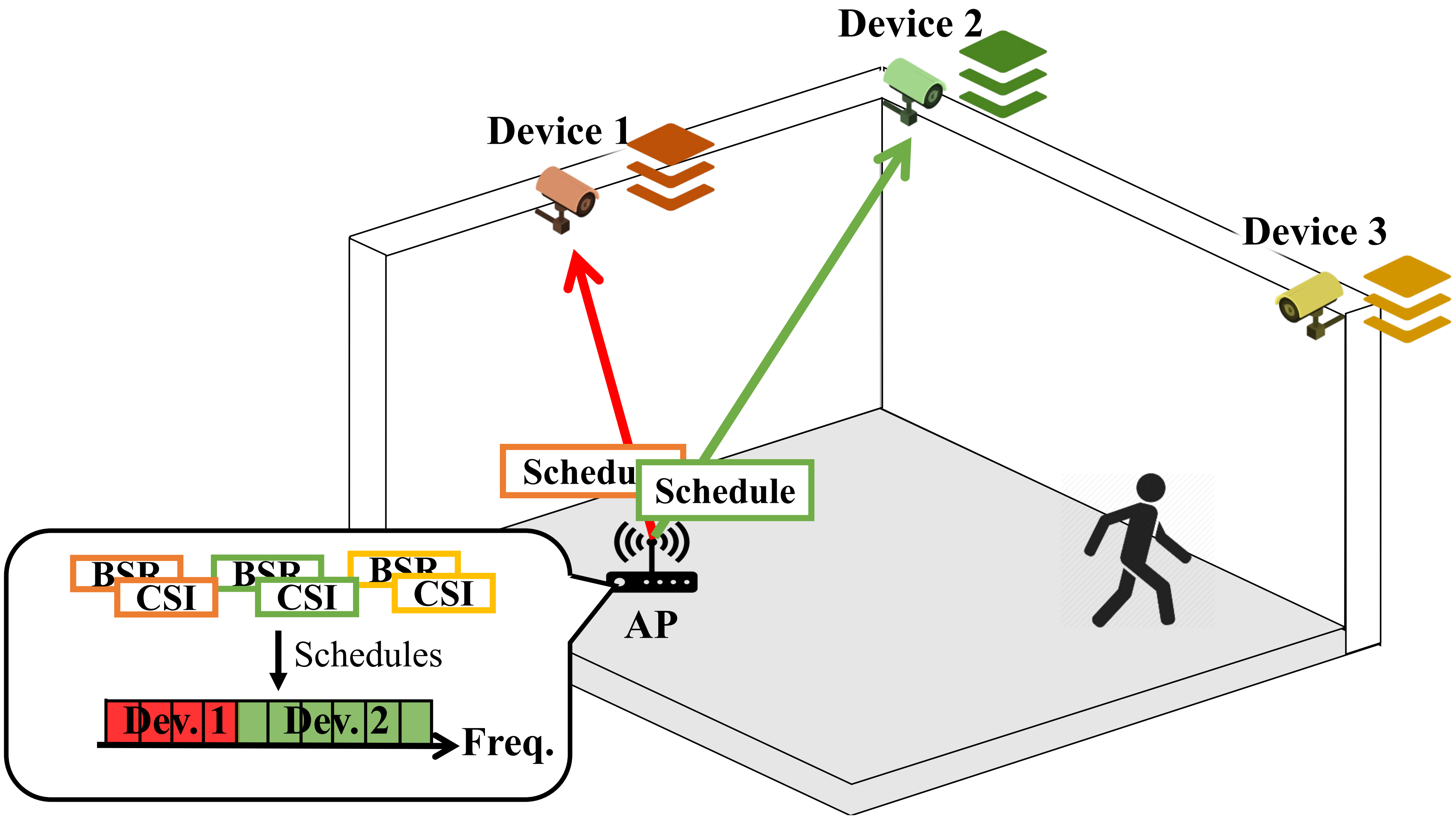
3. Each device calculates its CSI based on the request from the AP.

How does OFDMA work?



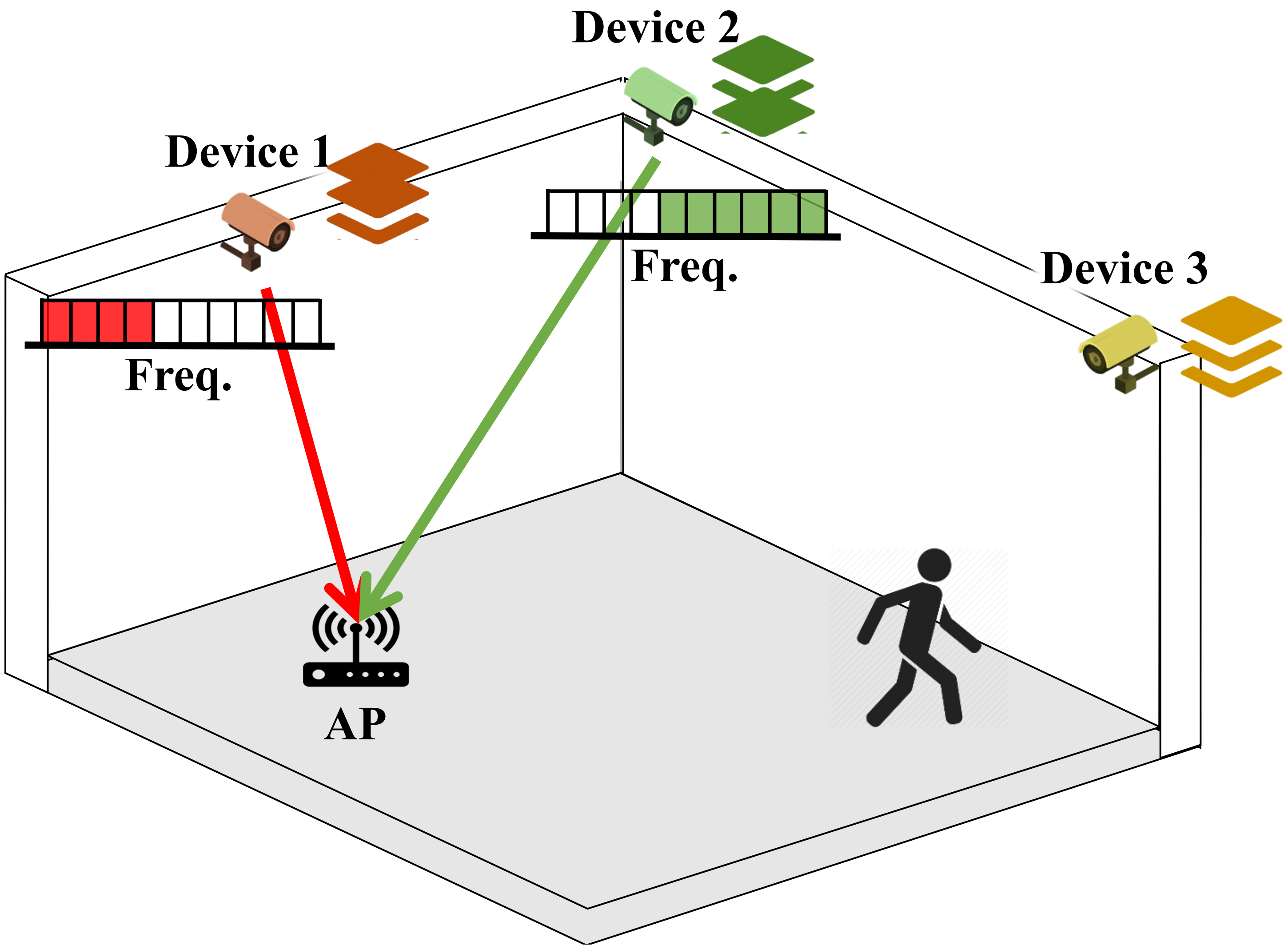
4. Each sensor sends BSR & CSI sequentially.

How does OFDMA work?



6. AP tells scheduled devices to transmit their data in the assigned freq.

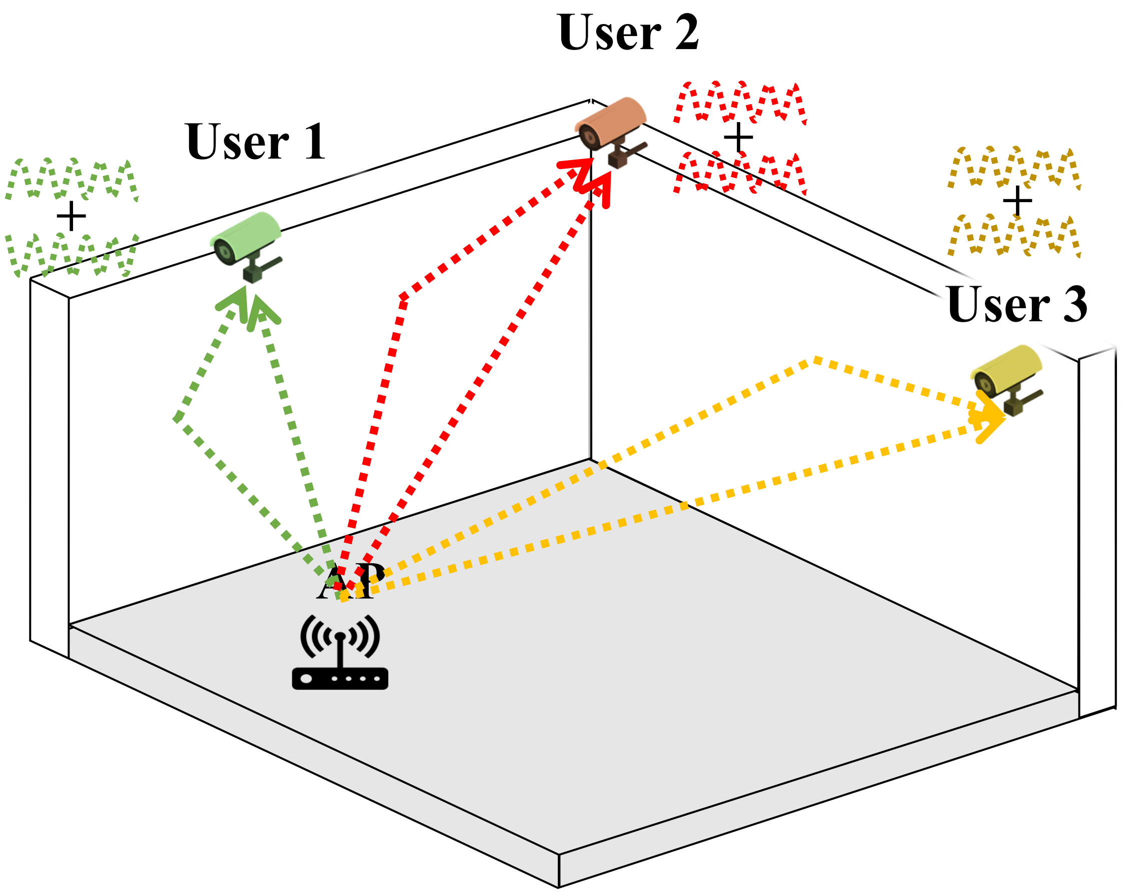
How does OFDMA work?



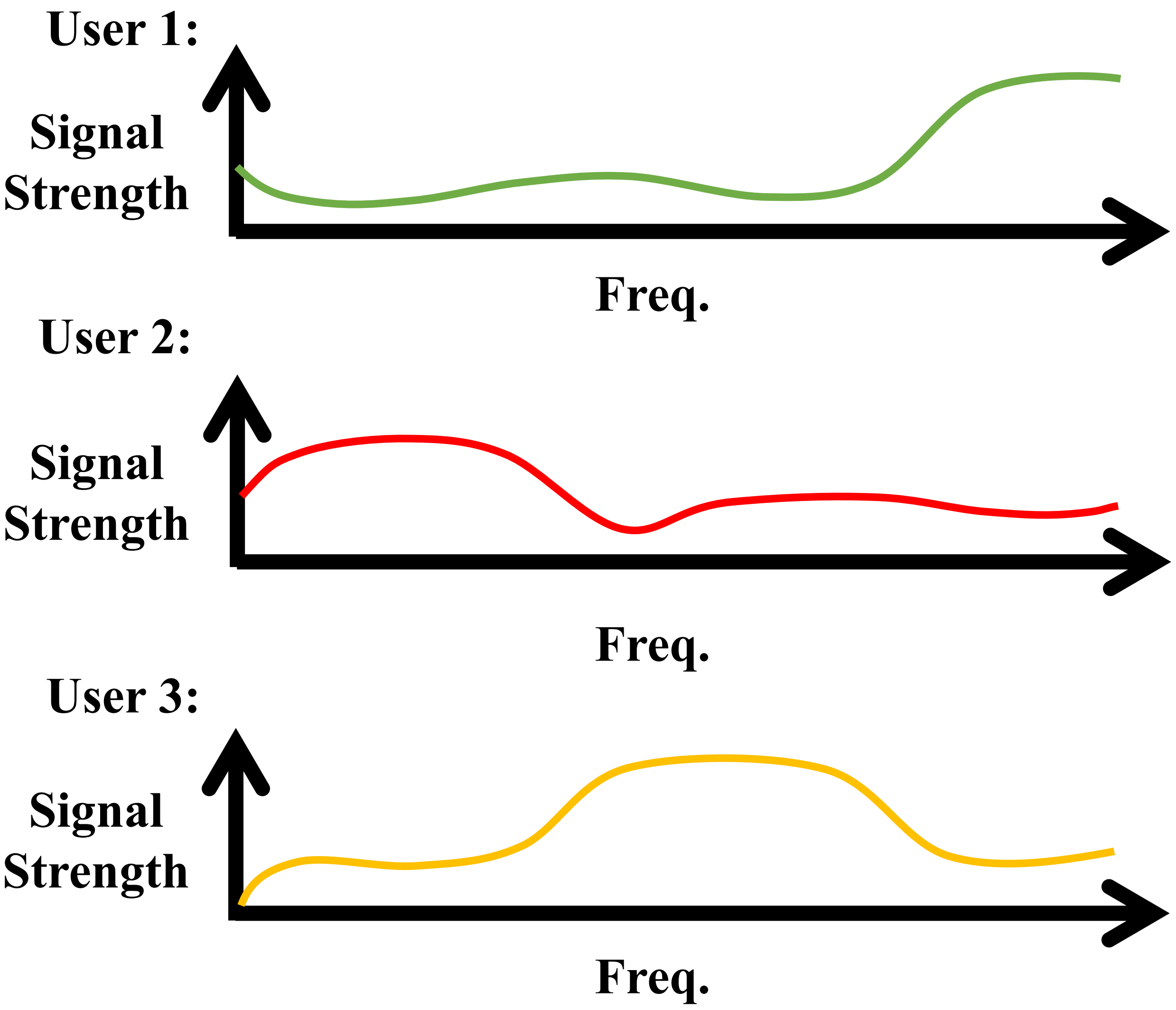
7. Scheduled devices transmit data in its assigned freq. simultaneously

Scheduling OFDMA requires the channel information!

Channel: The sum of all wireless signal paths between the AP and the device

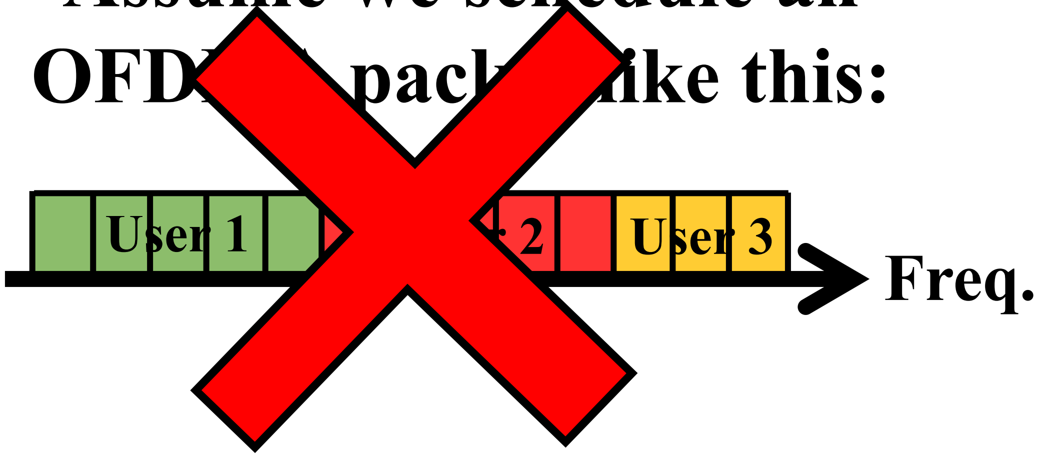


At time t_0, channels look like:

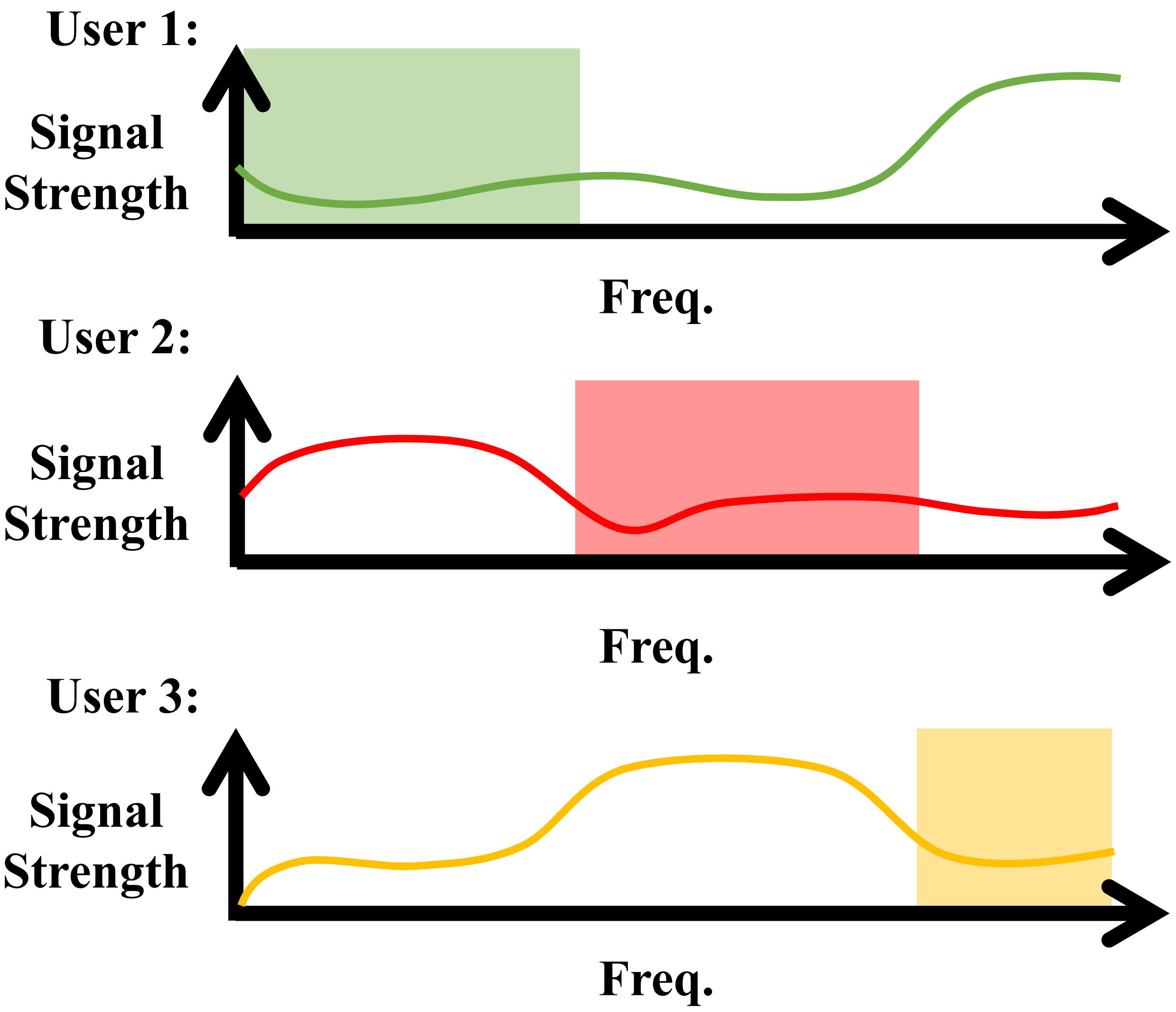


Scheduling OFDMA requires the channel information!

Assume we schedule an OFDMA packet like this:

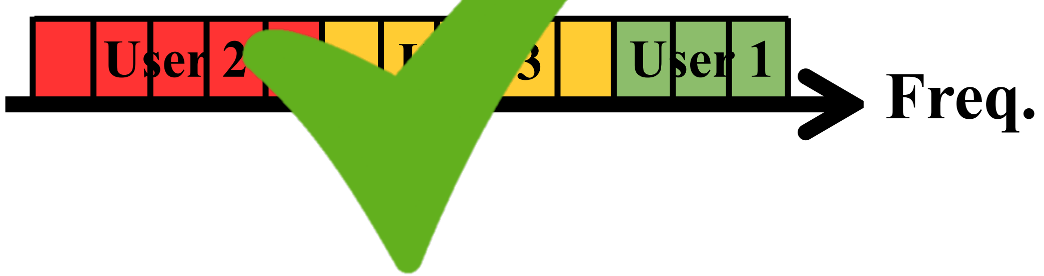


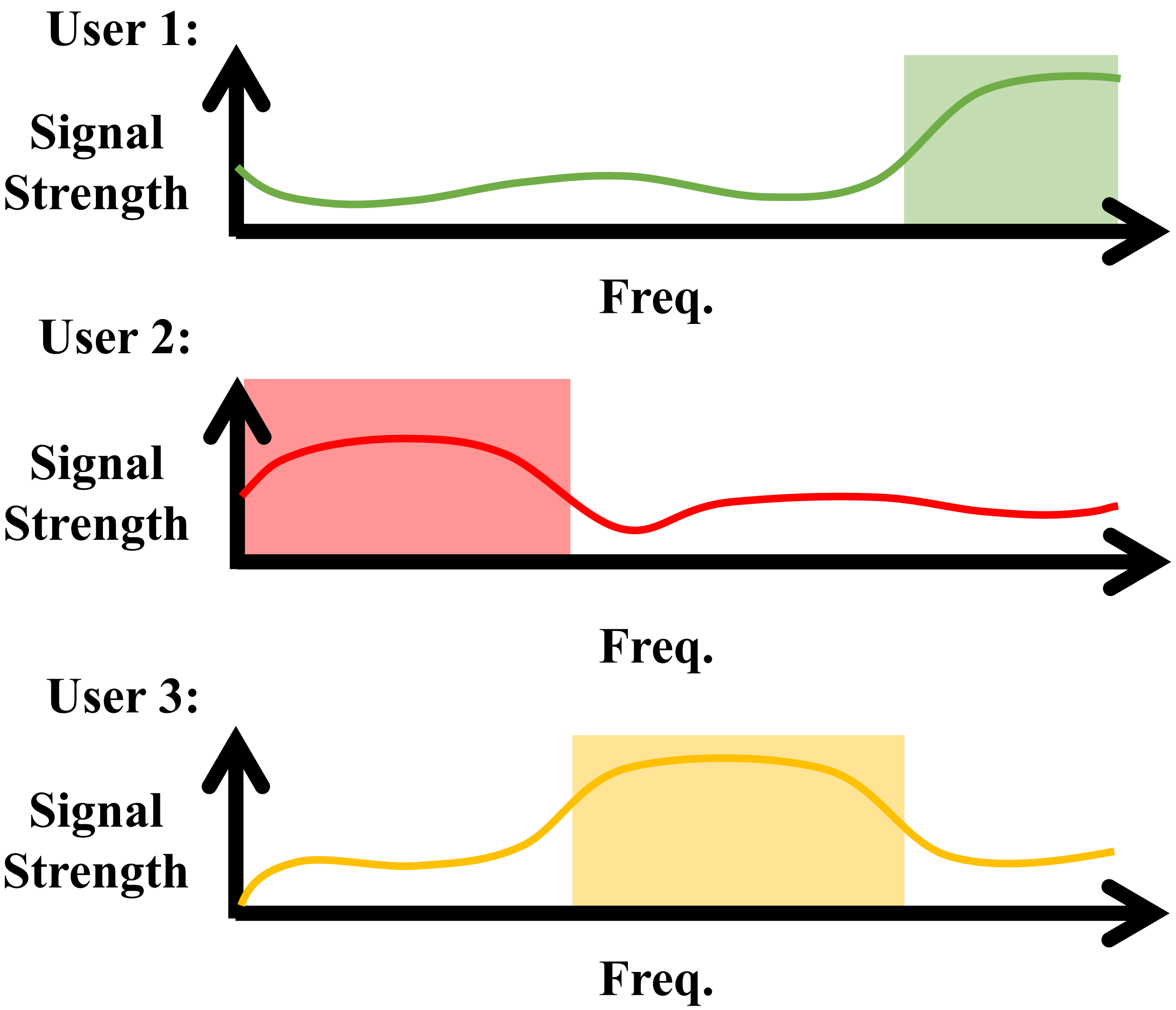
Weak signal → packet lost



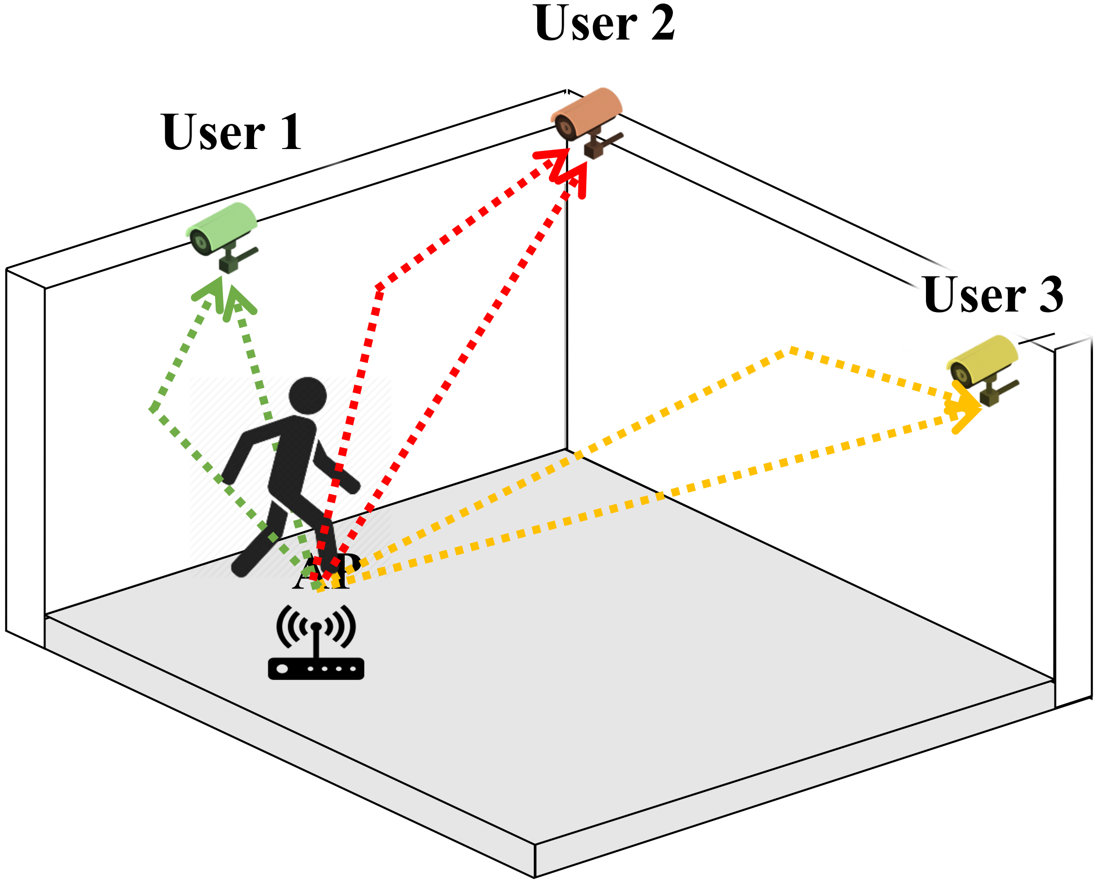
Scheduling OFDMA requires the channel information!

Instead, we schedule OFDMA based on the channels:

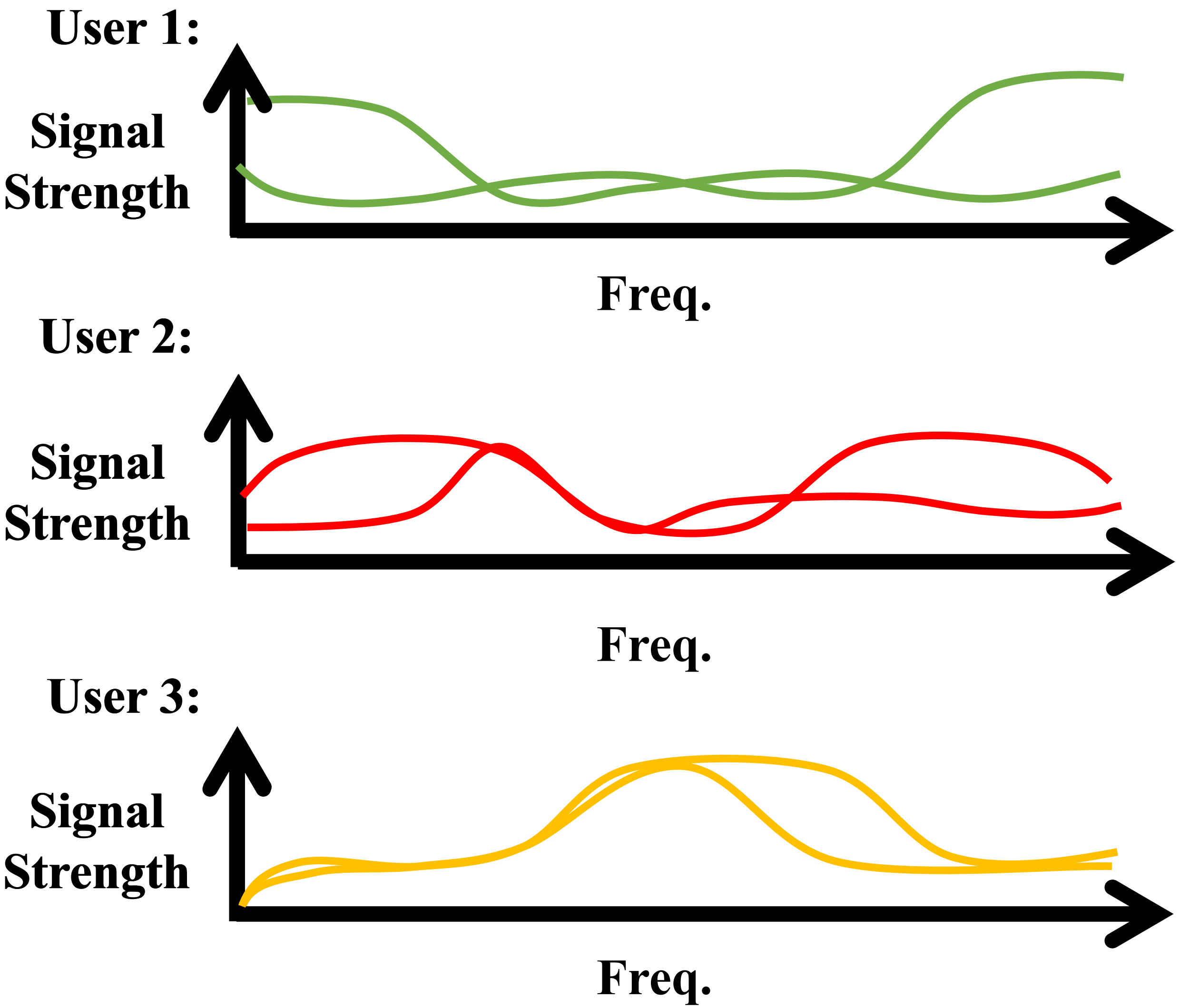




But channels vary over time!



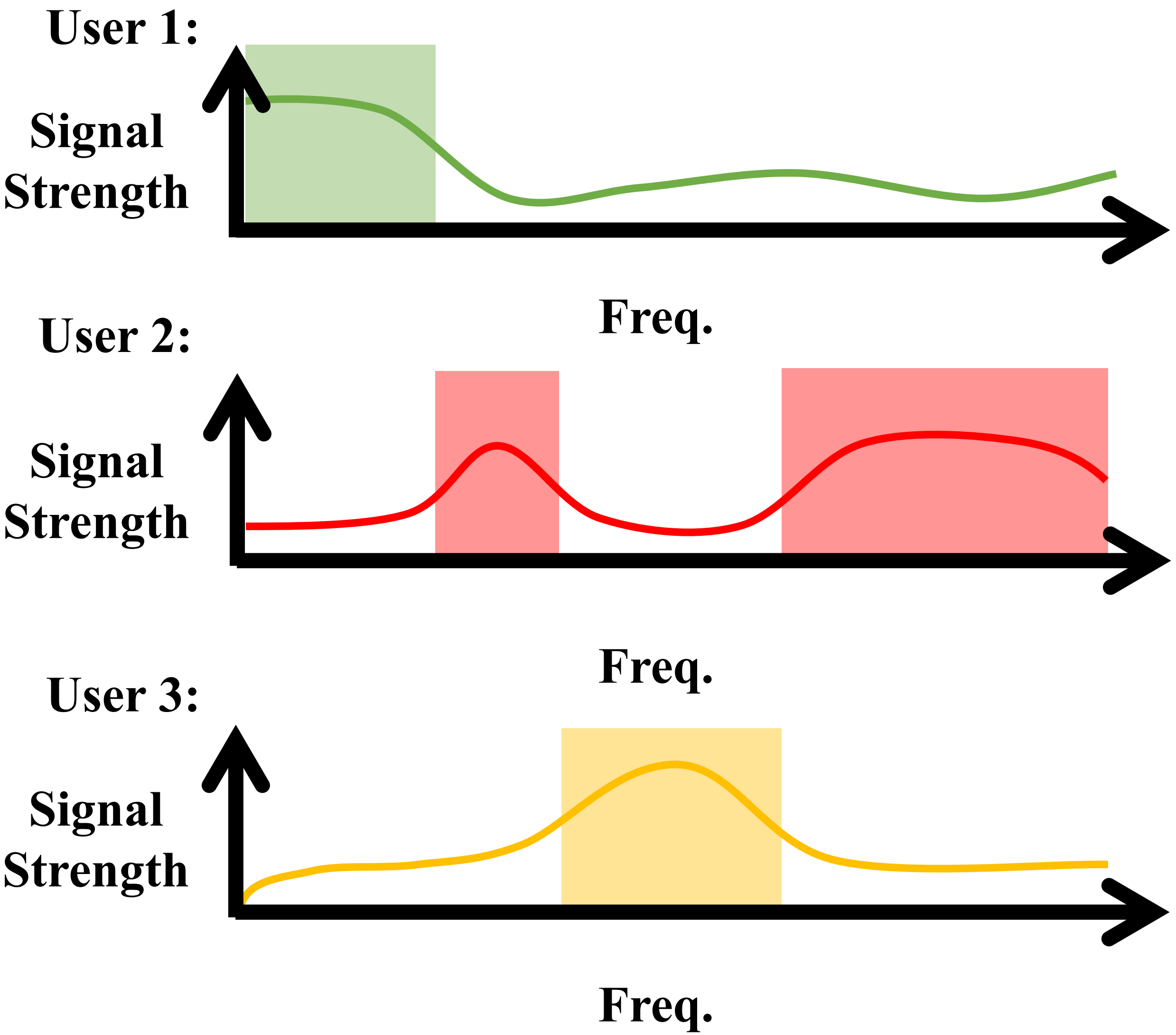
At time t_1, wireless channels change!



But channels vary over time!

We *reschedule* OFDMA based on the *updated* channels:

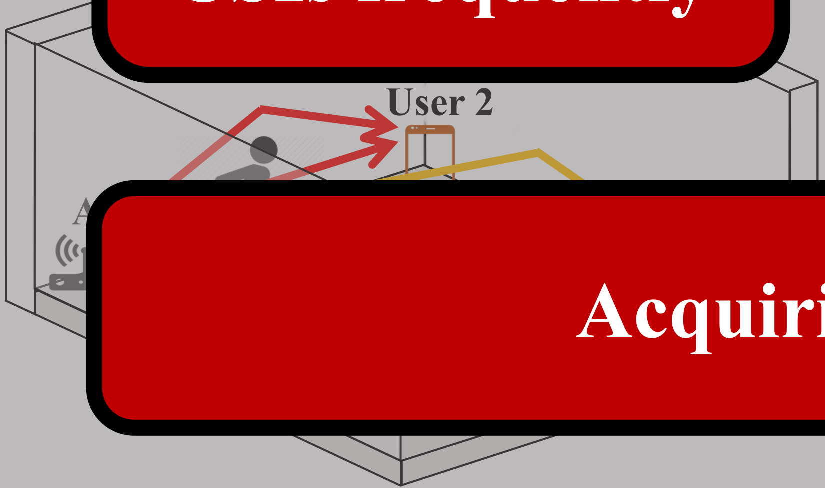
At time t_1, wireless channels change!



The overhead of collecting CSI deplete radio resources

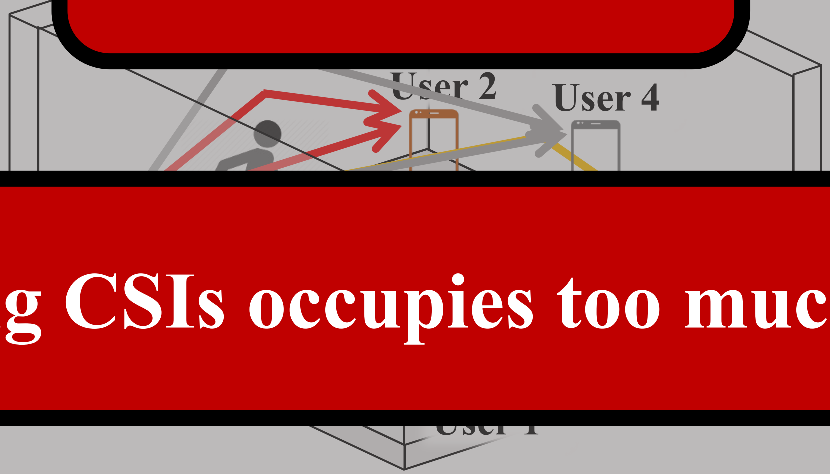
Highly-dynamic, busy environments

Need to collect CSIs frequently



Massive number of users

The quantity of CSIs increases



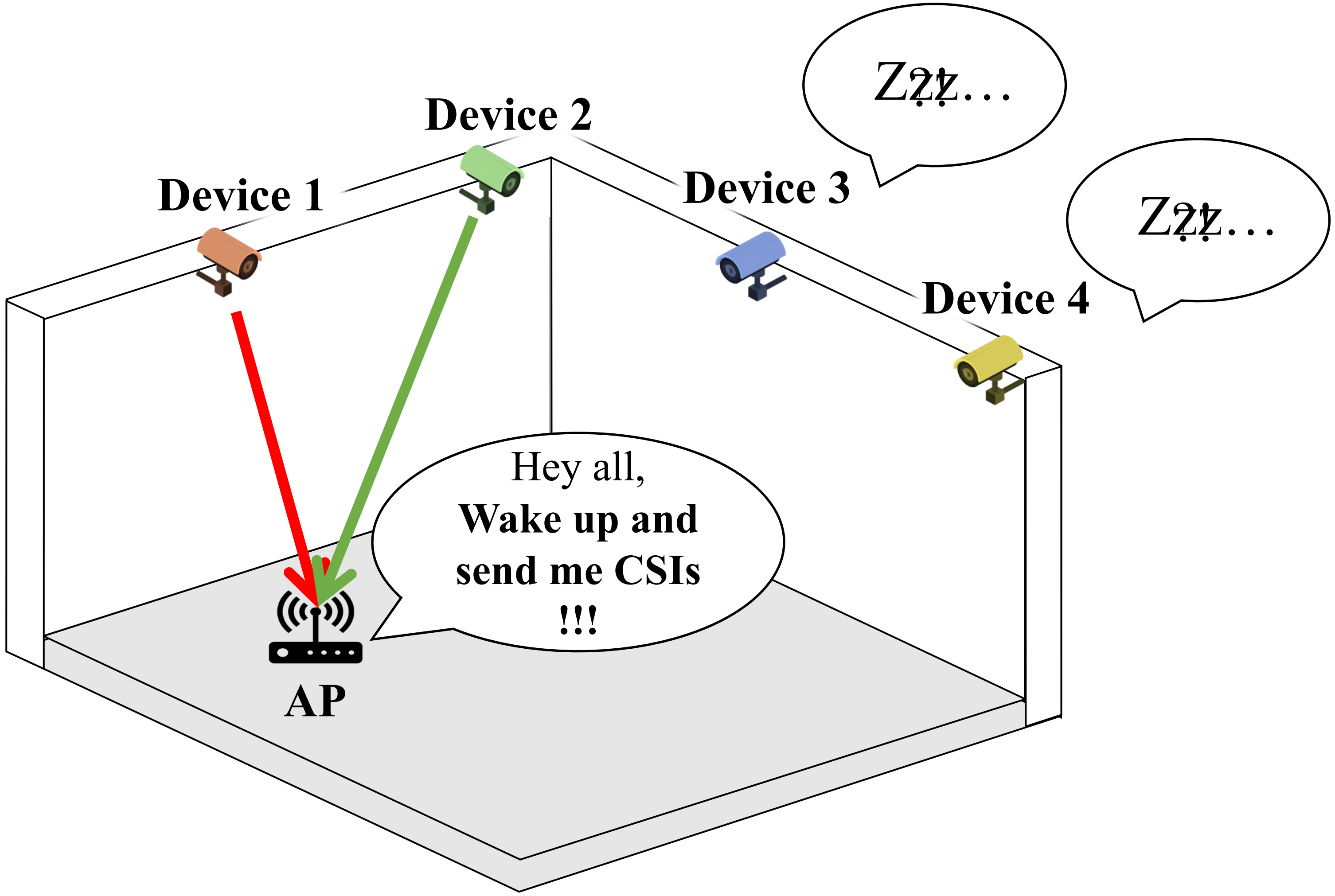
Increase in the channel bandwidth

The size of each CSI increases

Acquiring CSIs occupies too much time!!

Acquiring CSIs is also *power inefficient*

Wi-Fi 6 introduces **Target Wait Time (TWT)** to reduce power consumption of IoT devices but …



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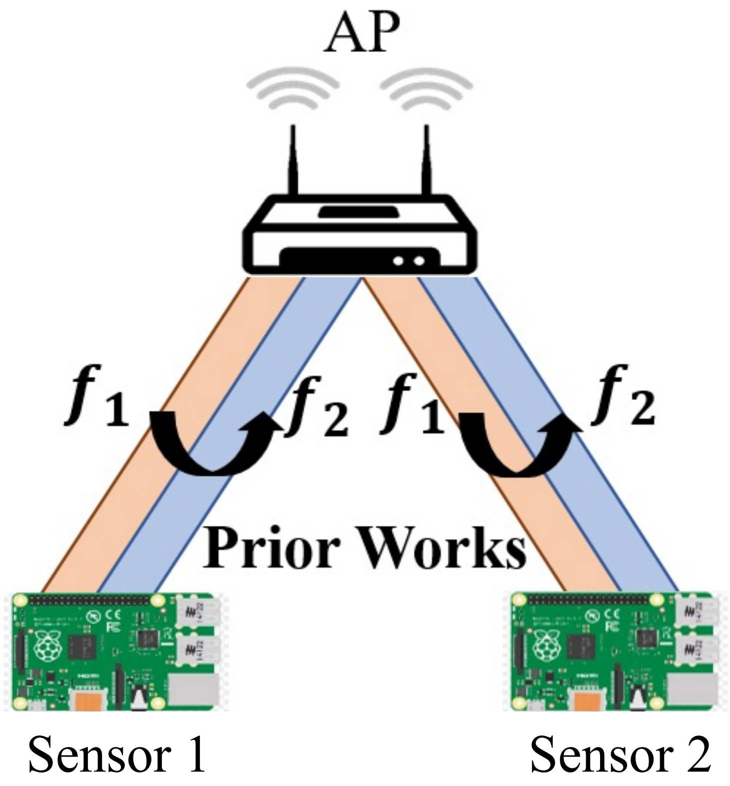
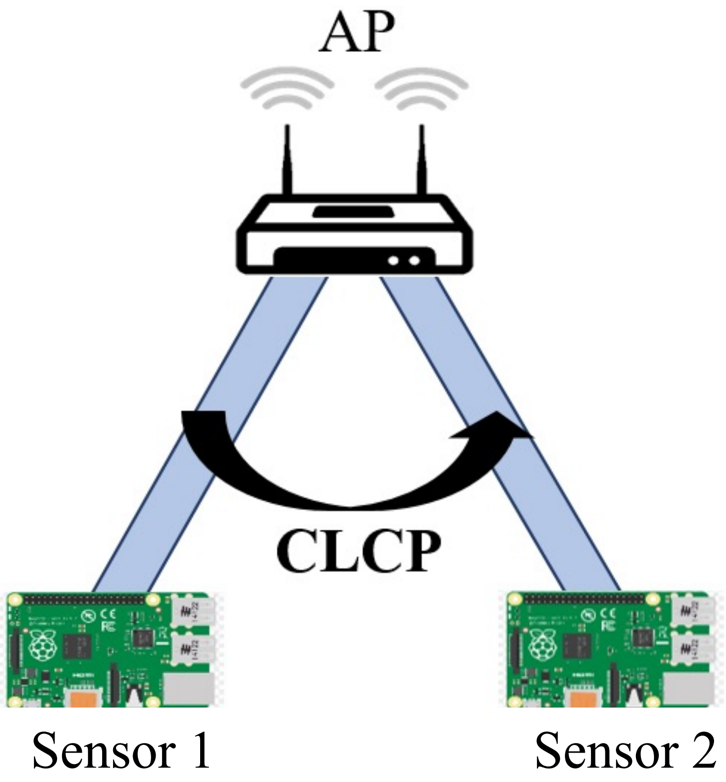
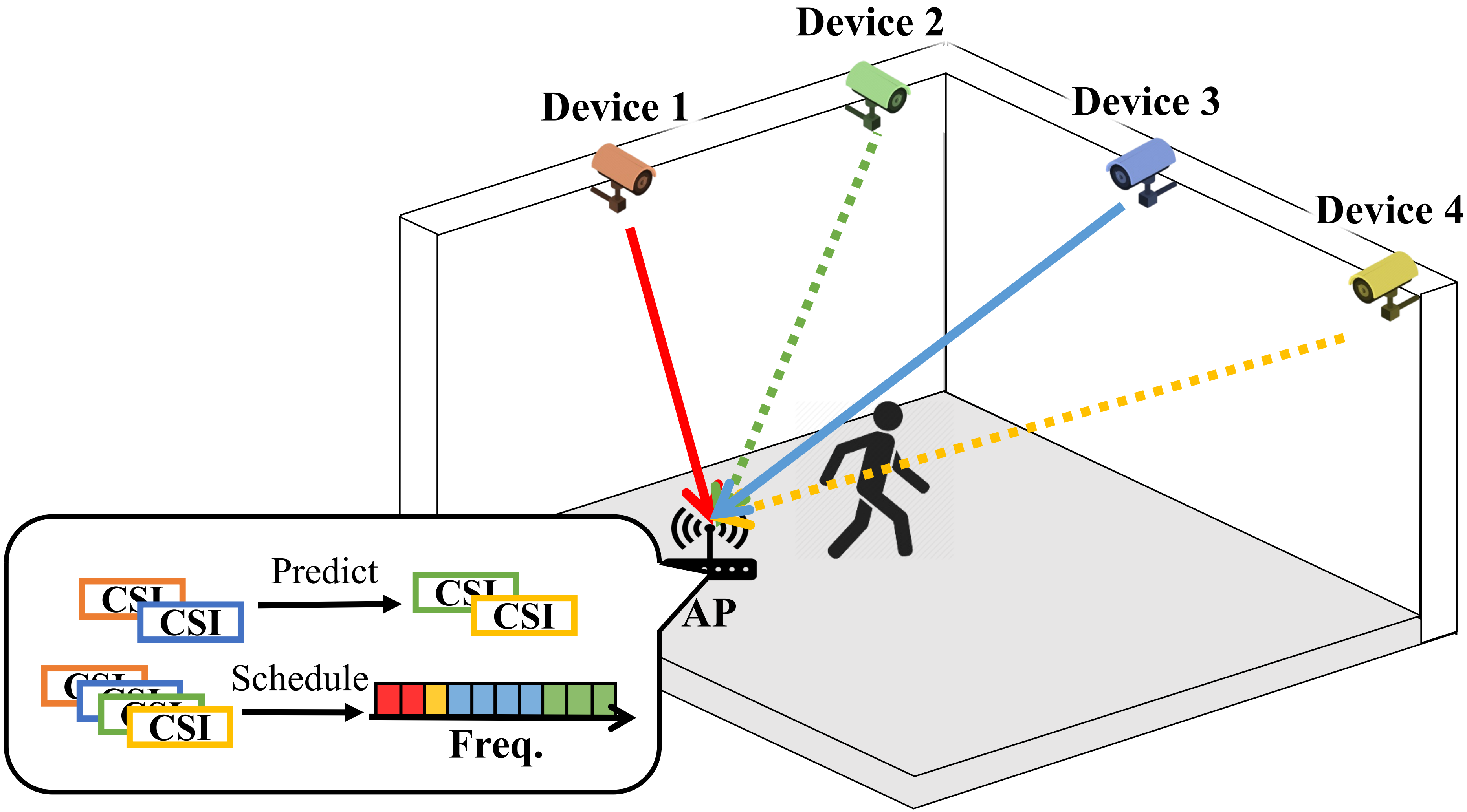
Cross-Link Channel Prediction (CLCP)

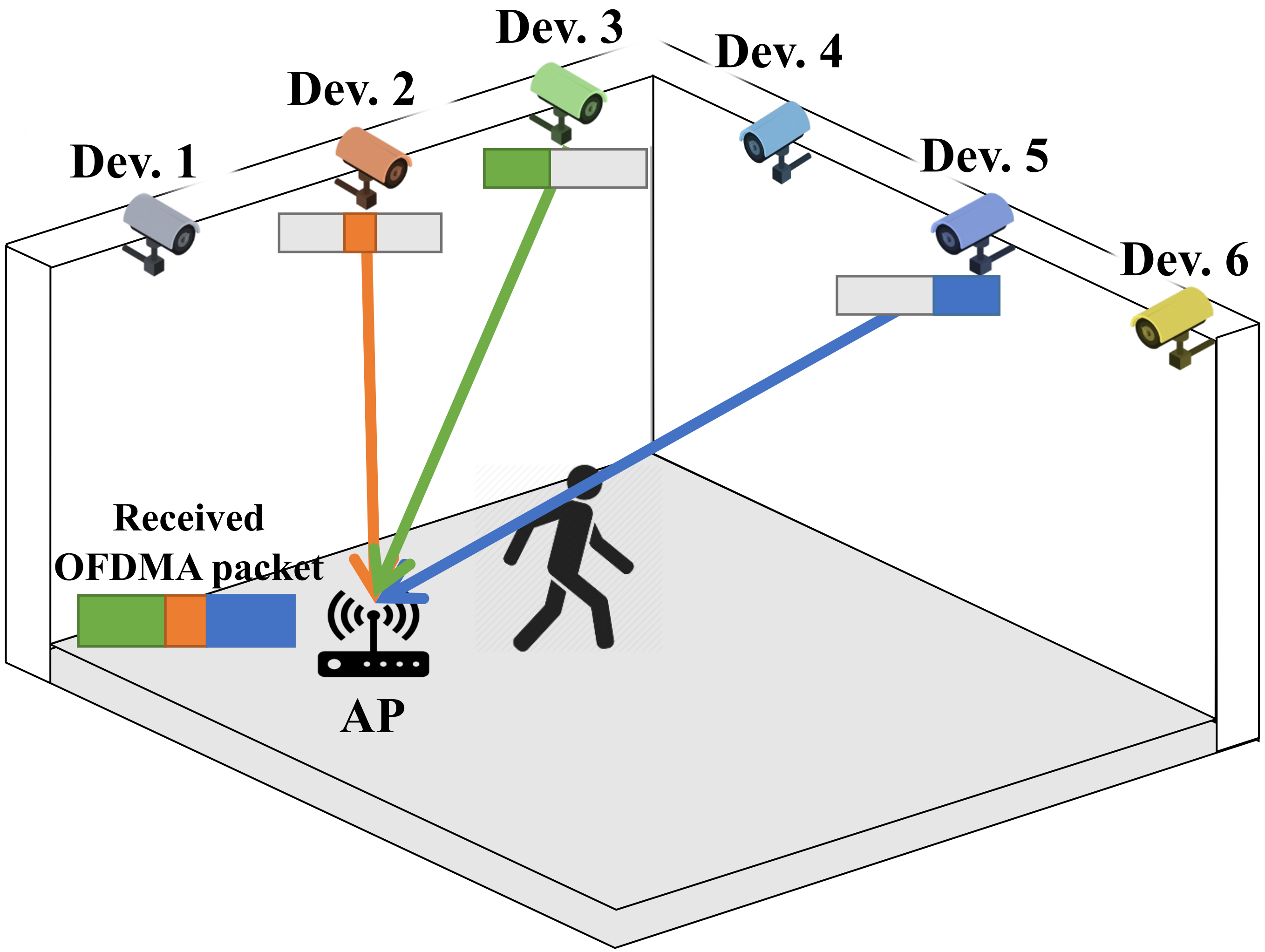




Our Solution: Predict CSIs instead of acquiring them

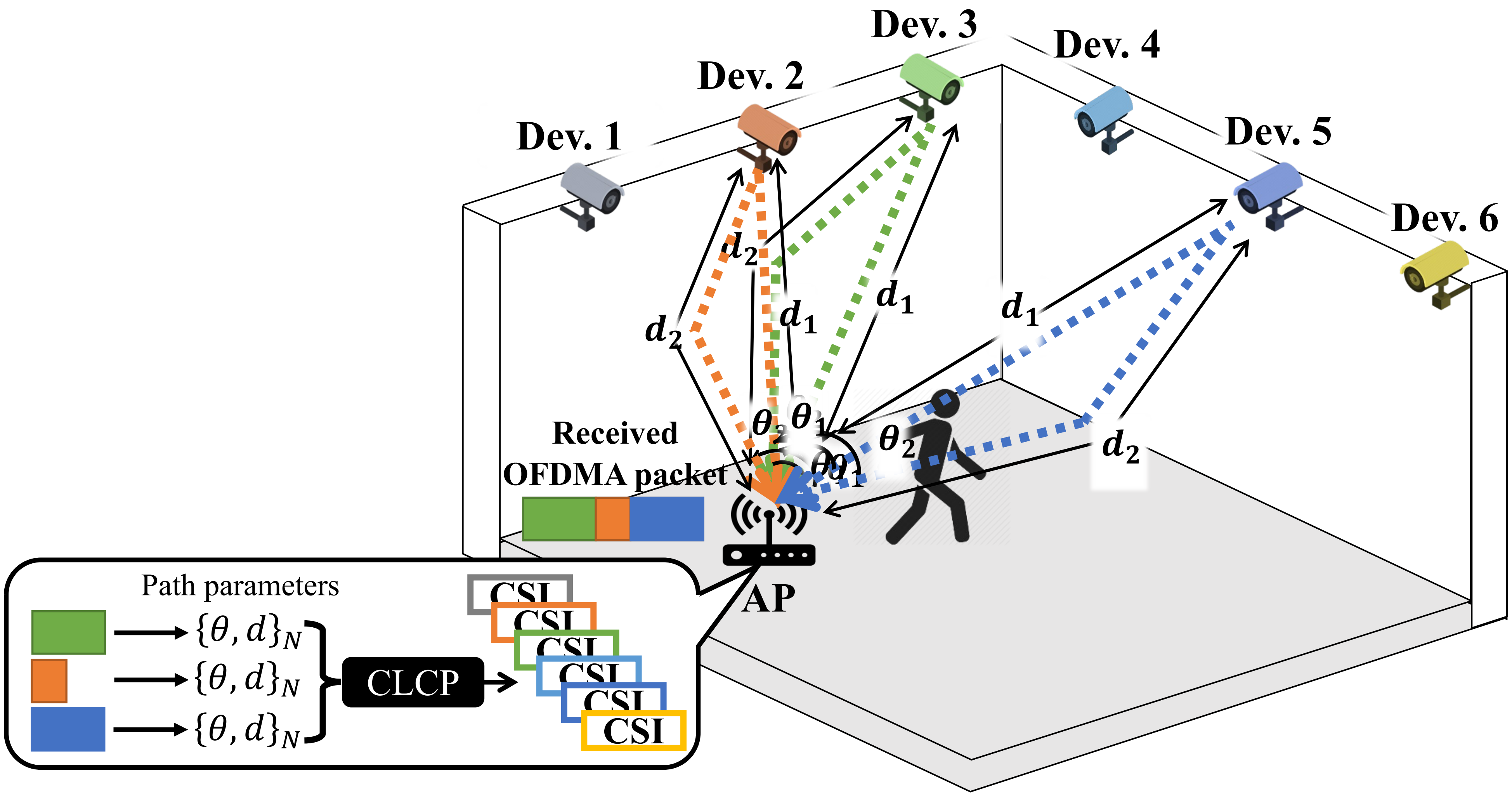


Our System Overview



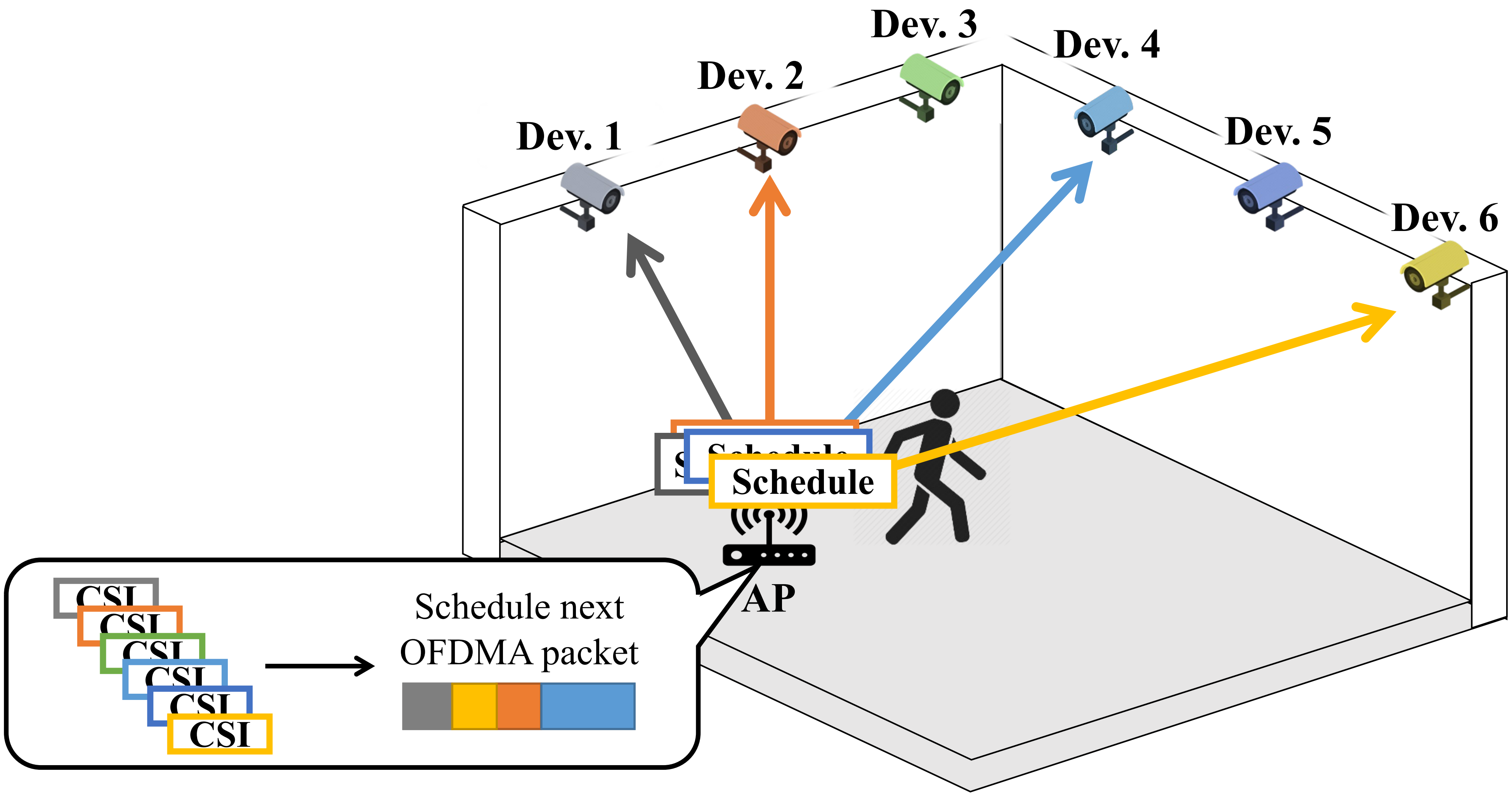
(1) OFDMA Transmission at T_1: AP receives the OFDMA packet.

Our System Overview



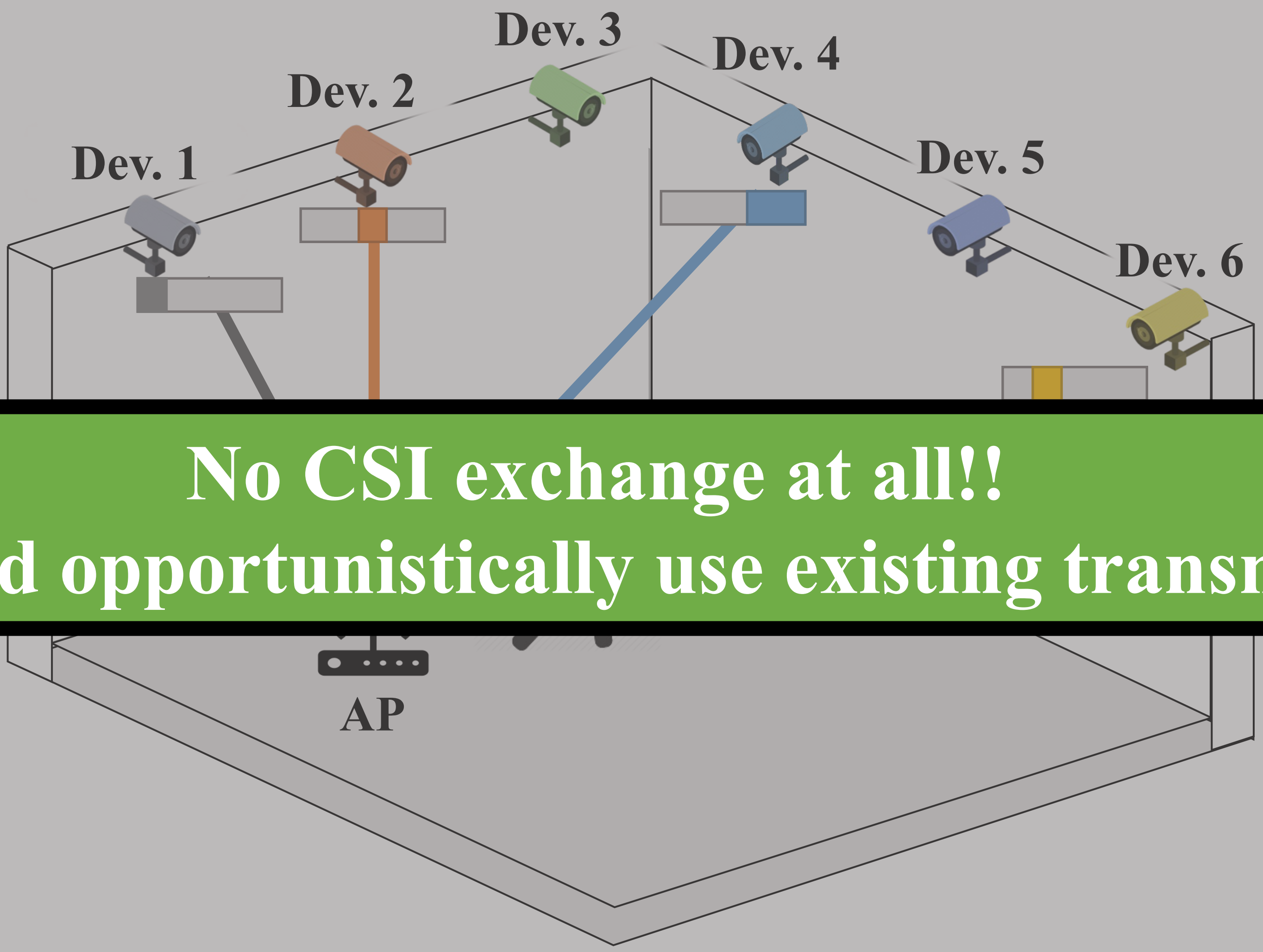
(2) Channel timeout at T_2: CLCP predicts CSIs of all users based on the measured wireless path parameters

Our System Overview



(3) Scheduling & Resource Alloc. at T_3: Based on predicted CSIs, the AP schedules the next OFDMA packet and asks the scheduled devices to transmit their data accordingly.

Our System Overview



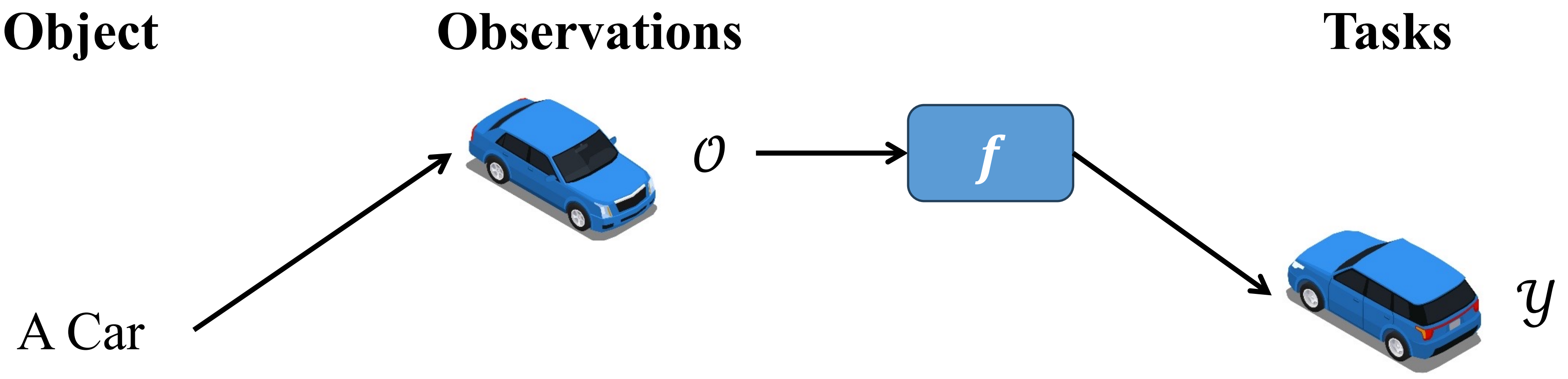
No CSI exchange at all!!
We instead opportunistically use existing transmissions

(4) OFDMA Transmission at T_4: devices transmit their data according to the instruction from the AP

Machine learning in a nutshell

- Learning a mapping between input (observation) and output (task).
- Single-view learning: an observation is constructed from a single source.

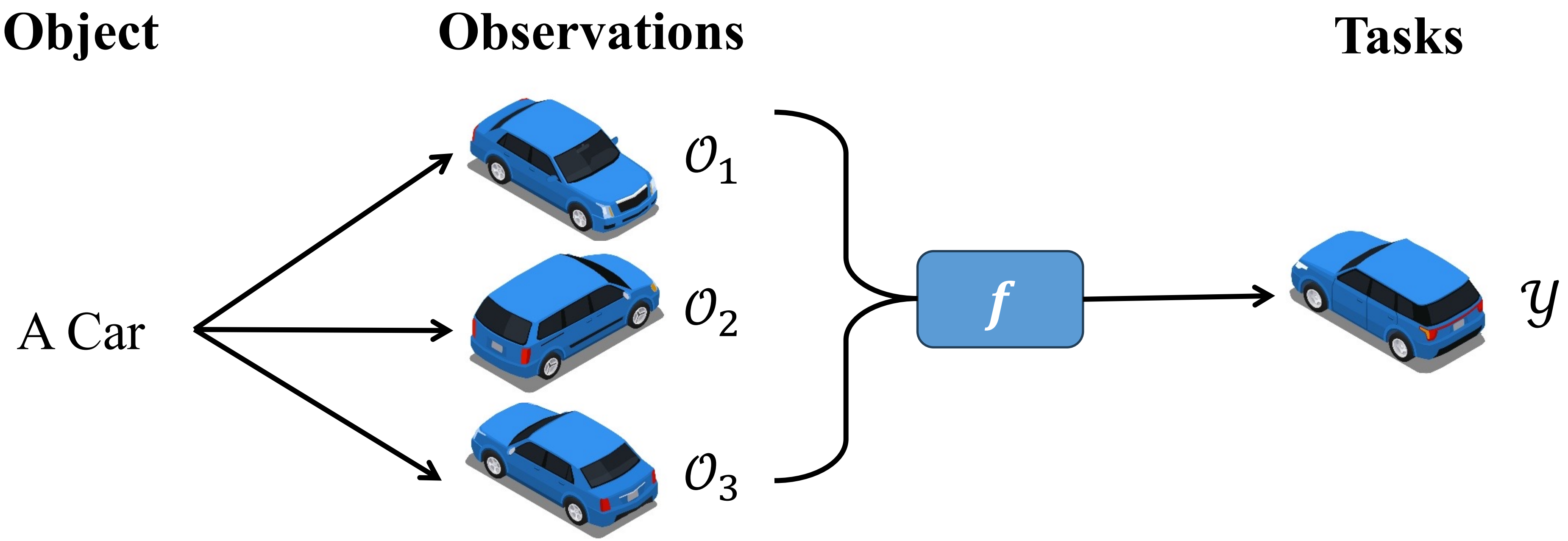
$$f : \mathcal{O} \rightarrow \mathcal{Y}$$



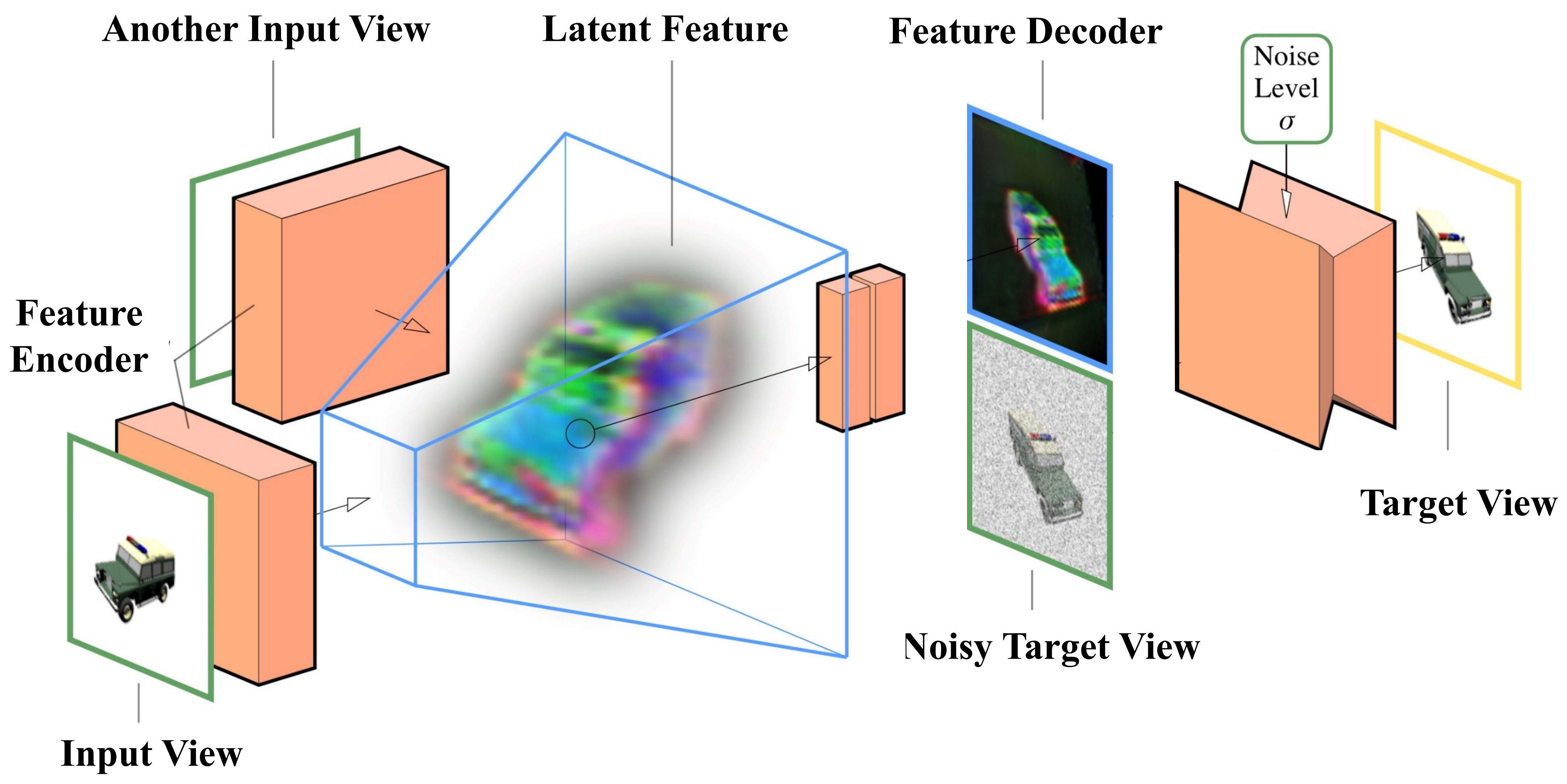
Machine learning in a nutshell

- Multi-view learning: an observation is constructed from *multiple* sources.

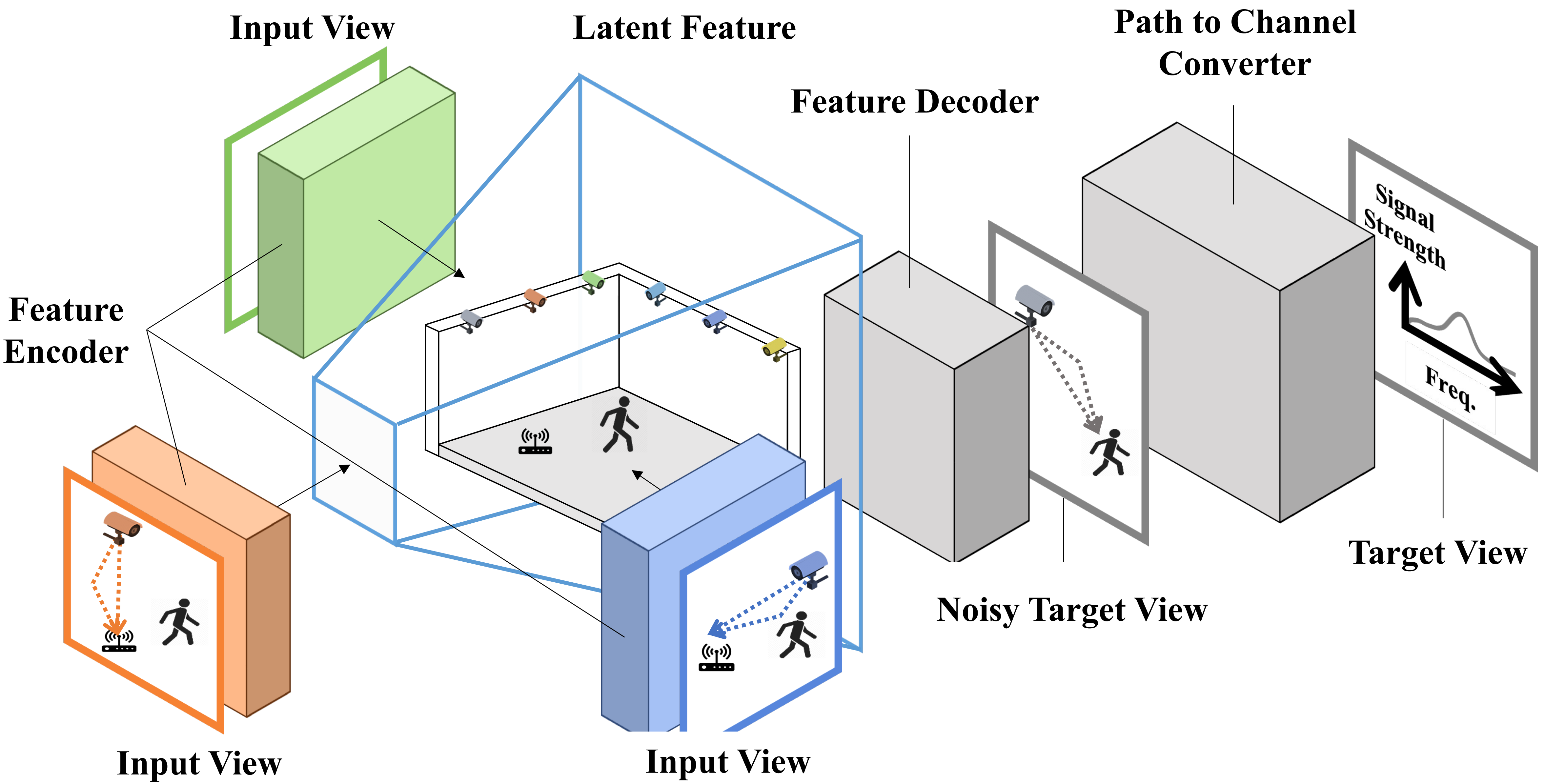
$$f: \vec{\mathcal{O}} \rightarrow \mathcal{Y}, \qquad where\ \vec{\mathcal{O}} = \{\mathcal{O}_1, \mathcal{O}_2, \dots, \mathcal{O}_V\}$$



Multi-view representation learning



CLCP: multi-view representation learning



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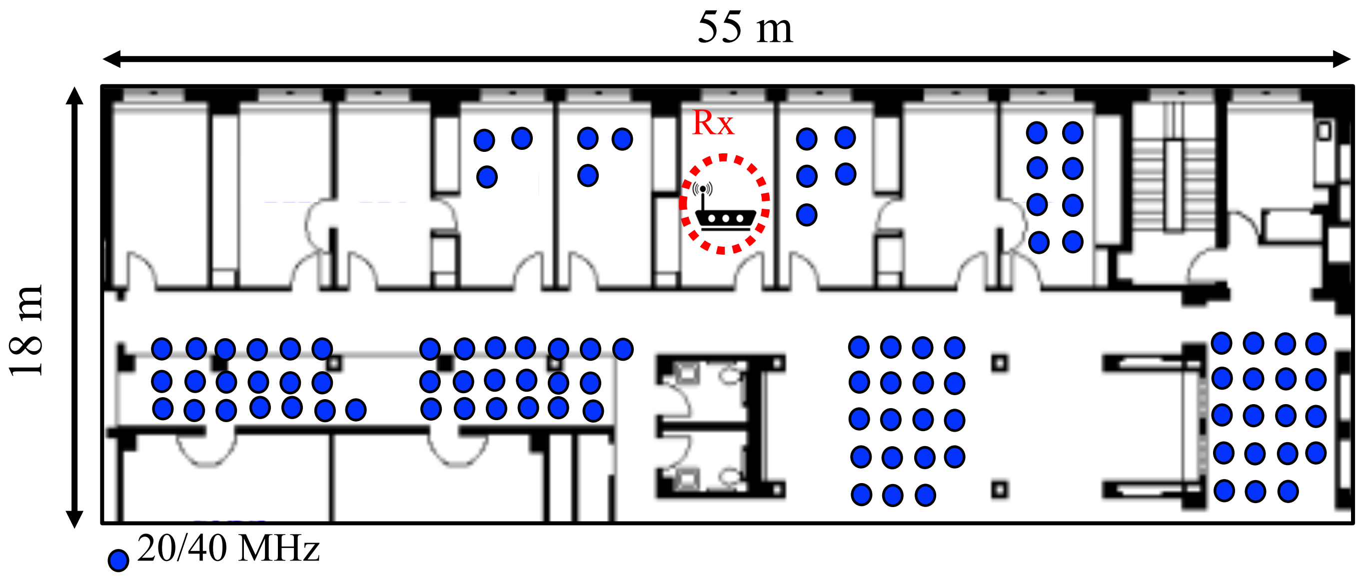
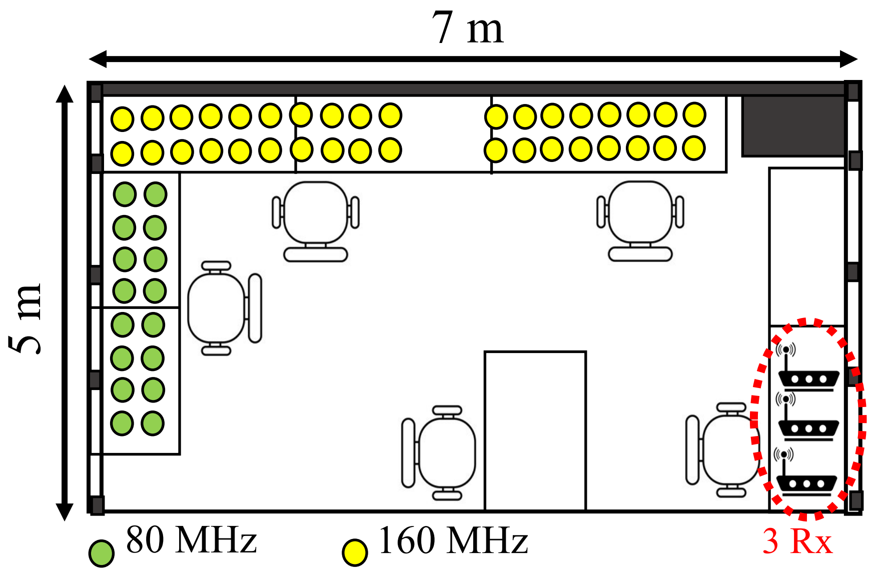
Implementation

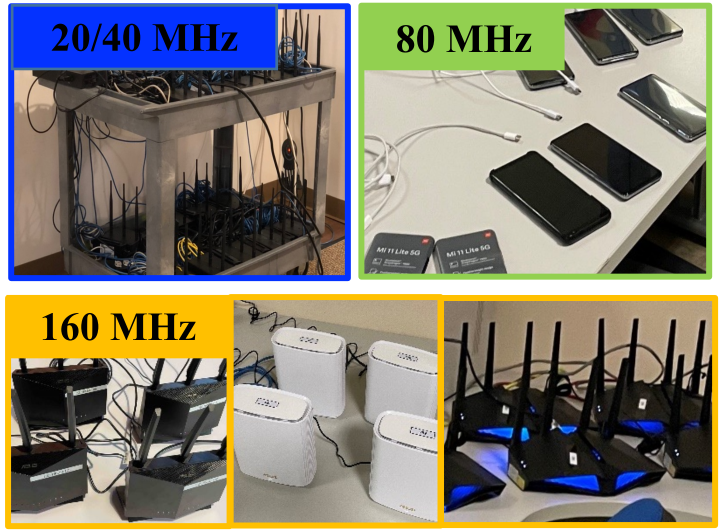
Testbed 1:



Testbed 2:

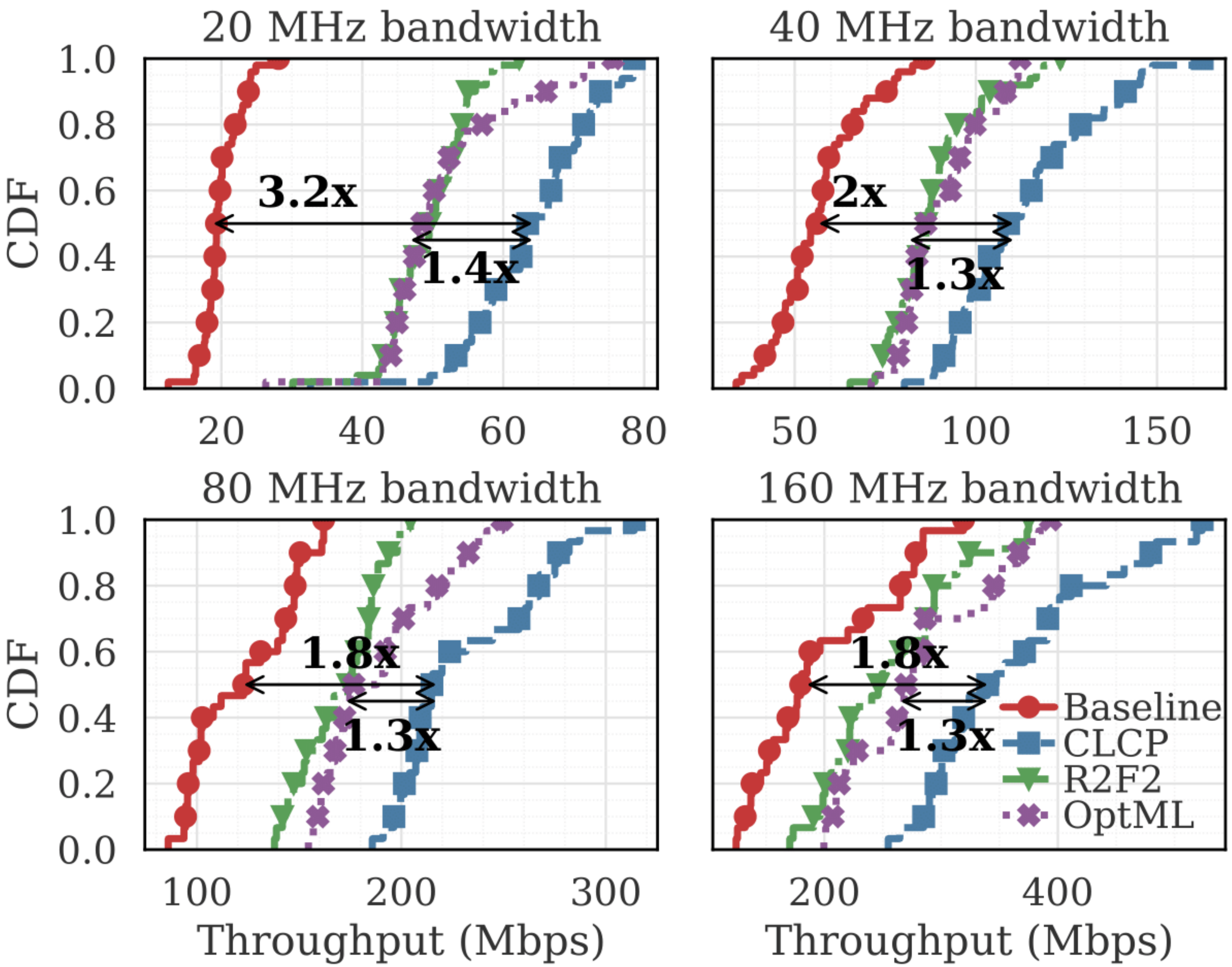


Hardware:

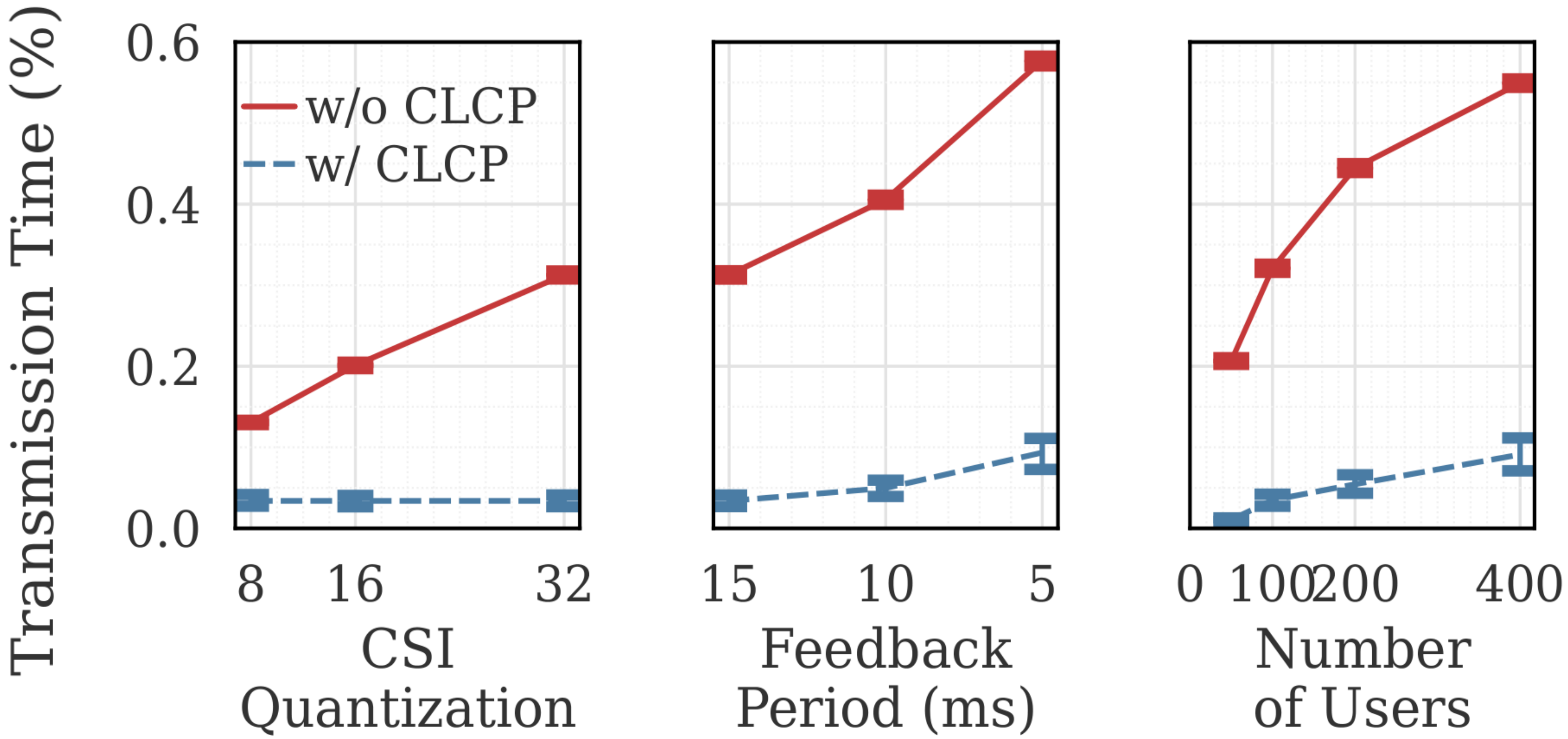


Significant throughput improvement

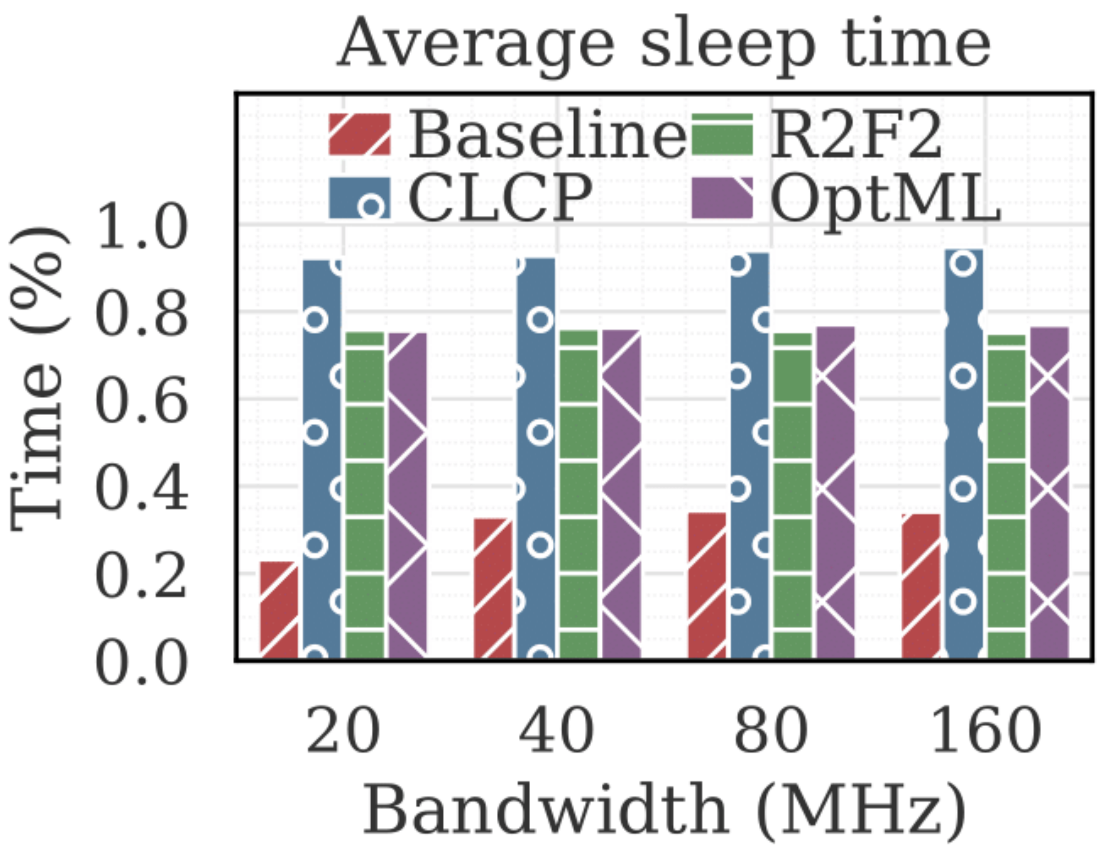
Aggregated throughput across time for every 500 ms:

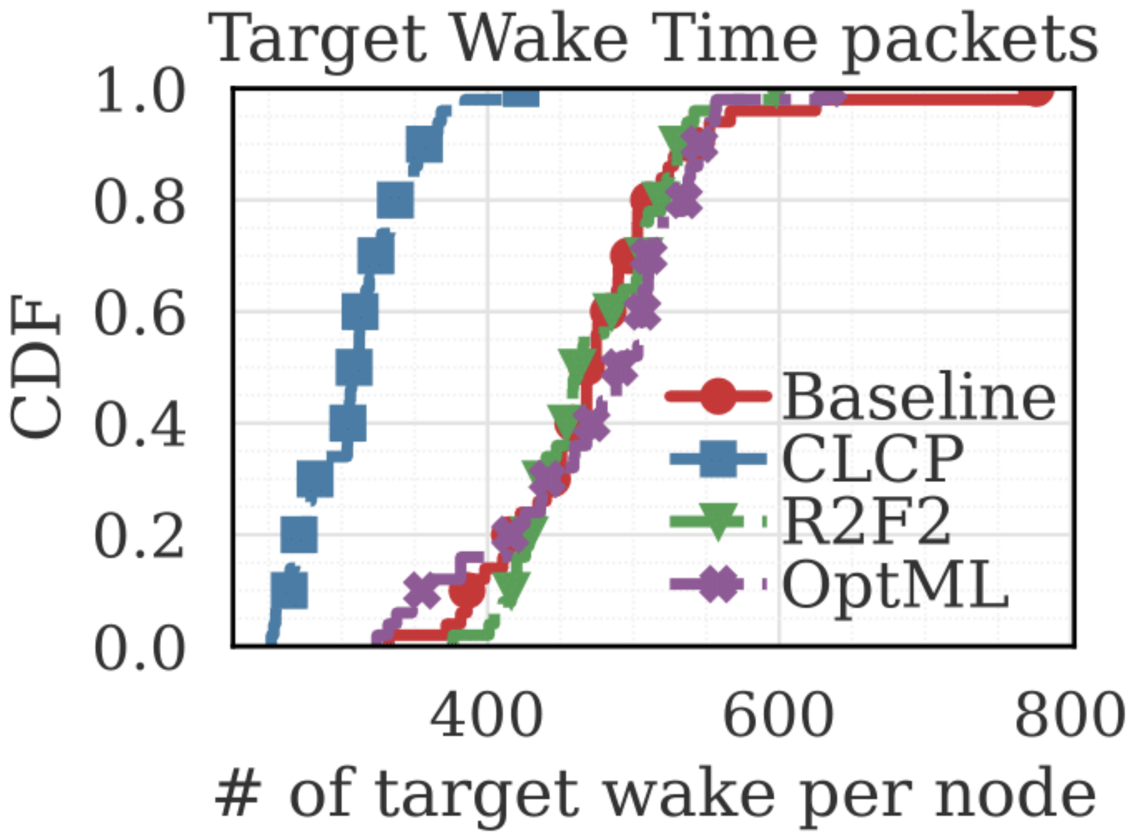


Overhead Reduction with Varying Parameters



CLCP significantly reduces the power consumption





Conclusions

- **CLCP** for predicting wireless channels
  - Adopting techniques from Computer Vision to Wireless Communications.
  - Allowing fast and power efficient data transmissions from IoT devices to the AP.
  - **Overcome fundamental challenges** in massive-IoT networks.