A Scalable Multi-User Uplink for Wi-Fi

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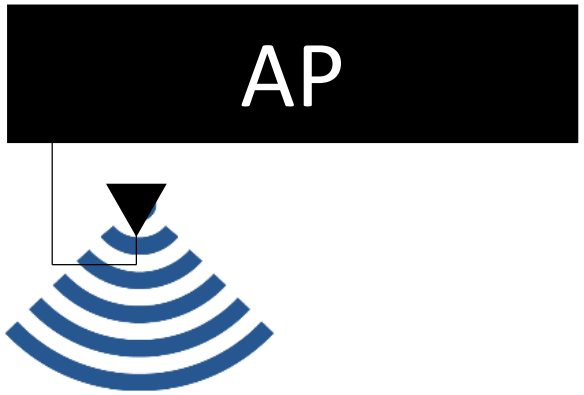
Sadia Quadri, and Edward W. Knightly

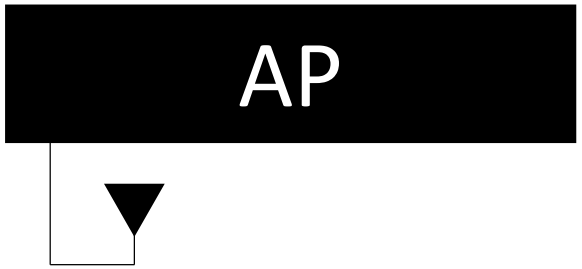
NSDI, March 2016

Start of Wi-Fi



- Standardized in 1997
- SISO
- Single user at a time
- Omni-directional transmission

MIMO in 802.11



- Multiple concurrent transmissions
- MxN MIMO increases throughput by min(Tx antennas, Rx antennas)

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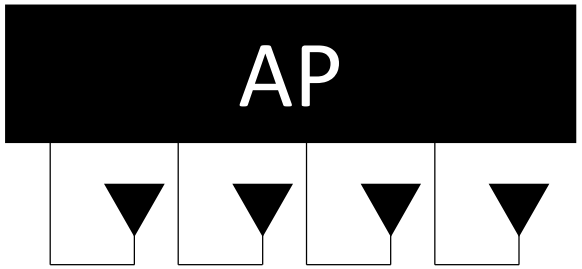

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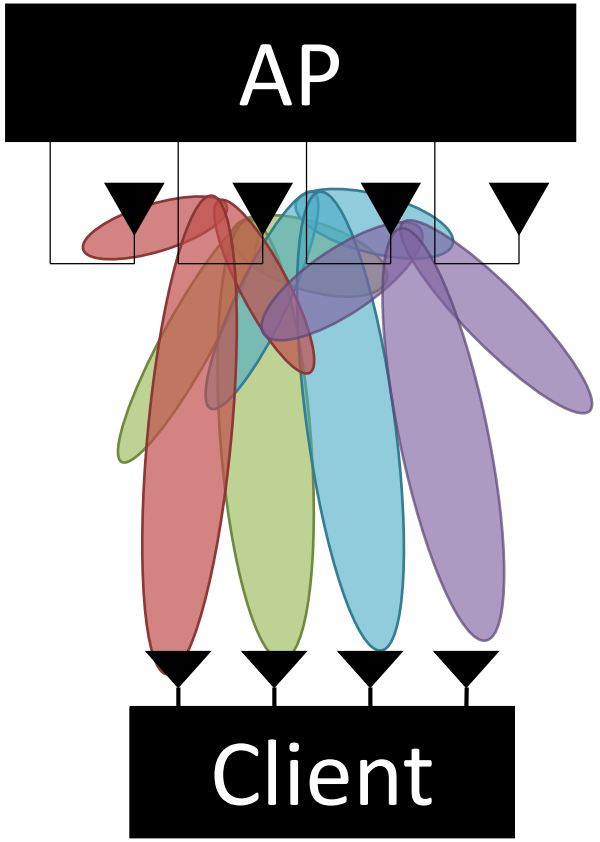

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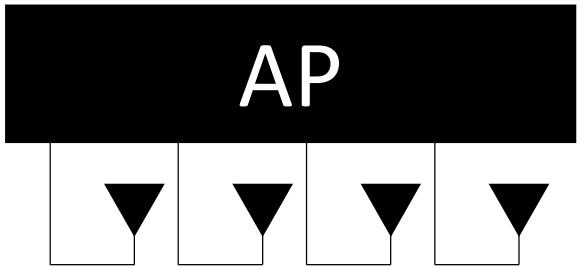

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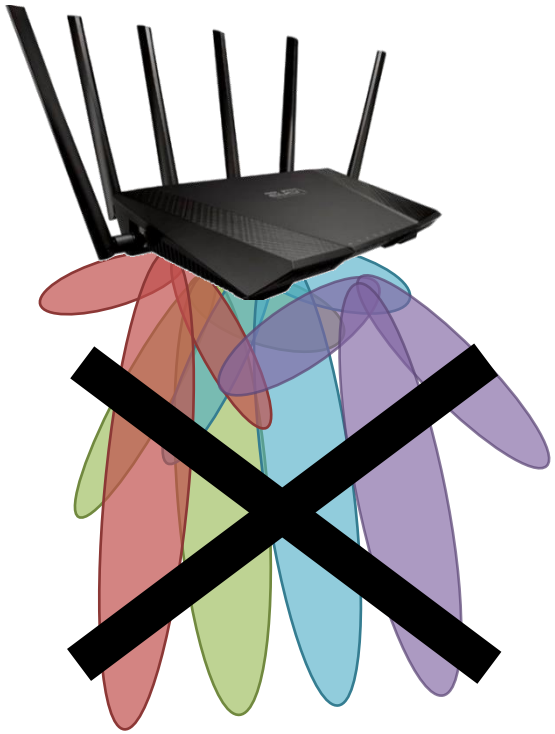

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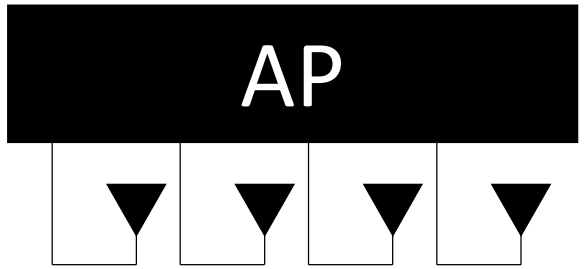

- MxN MIMO increases throughput by min(Tx antennas, Rx antennas)
- Downlink Multi-User MIMO allows for APs to leverage antennas
- Transmitter sends multiple streams concurrently to different users
- Remove Interference by “Zero-Forcing Beamforming” (ZFBF)

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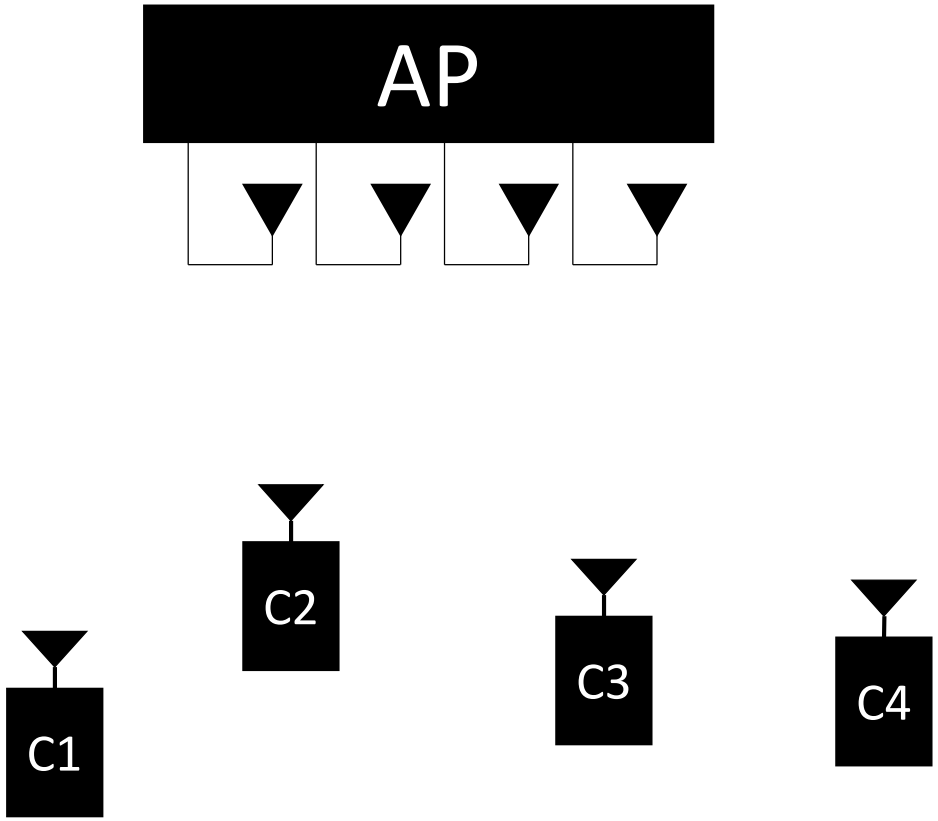

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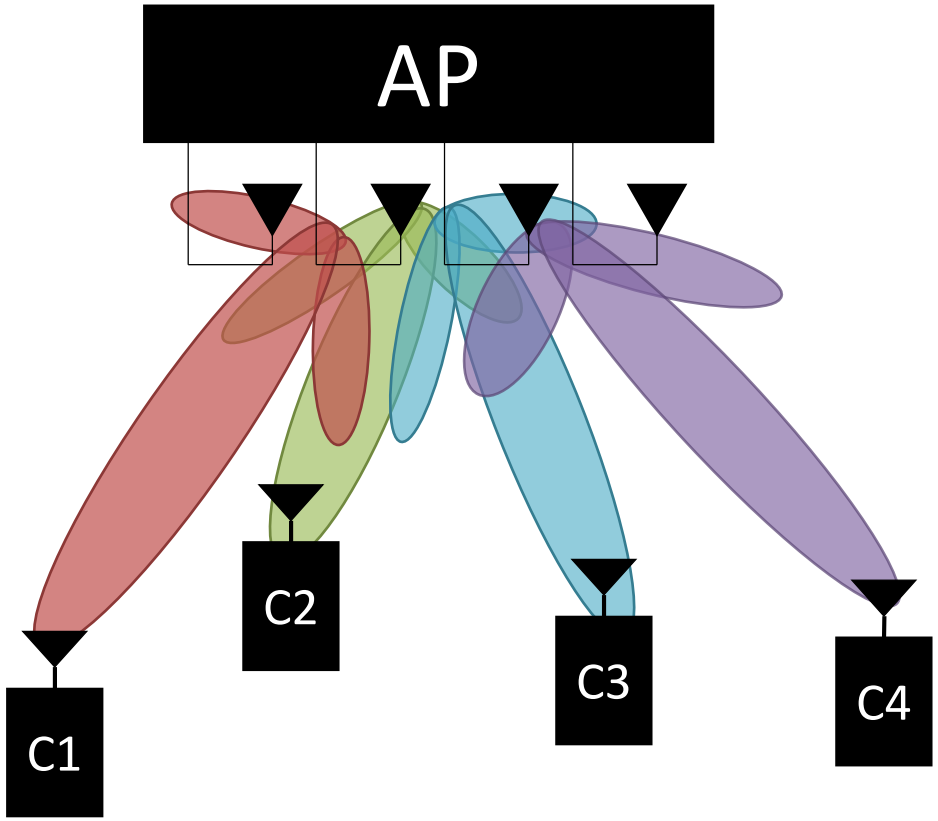

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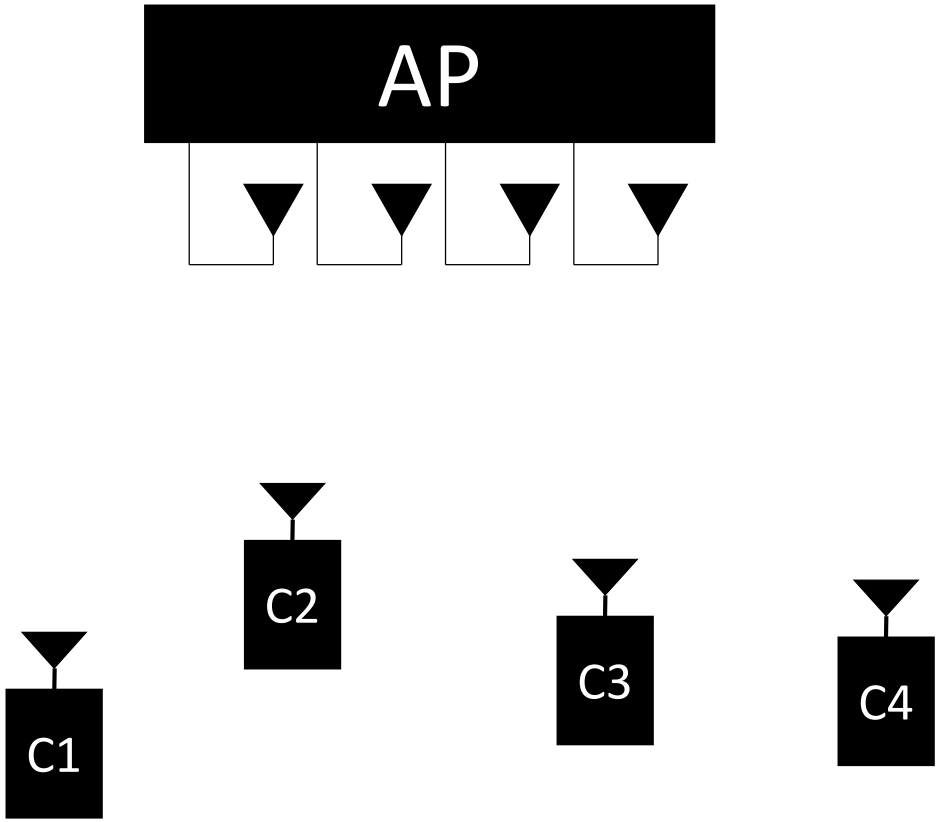
Uplink Multi-User MIMO?



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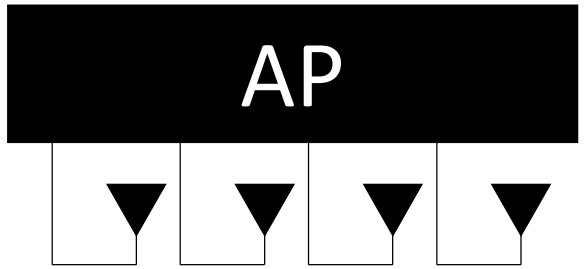

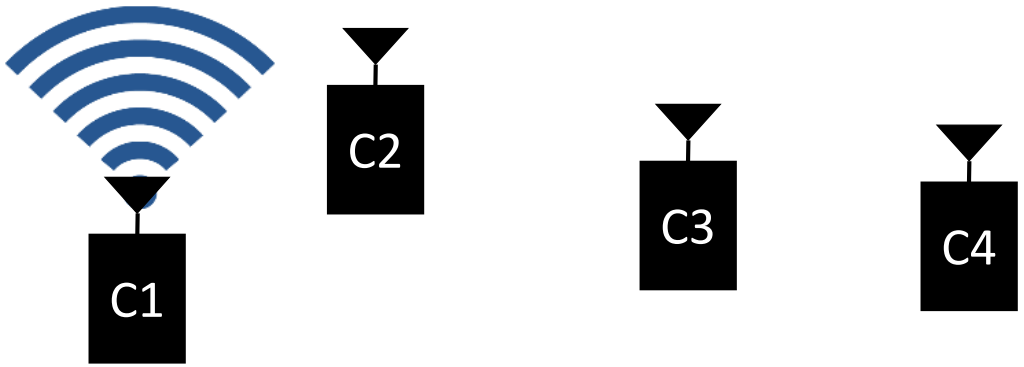

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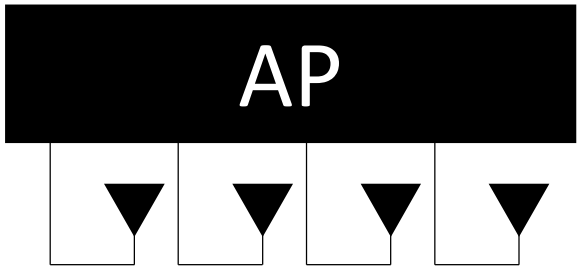
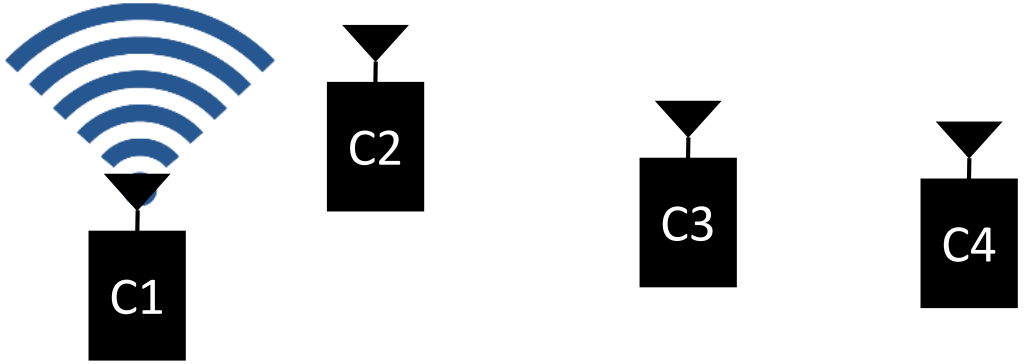
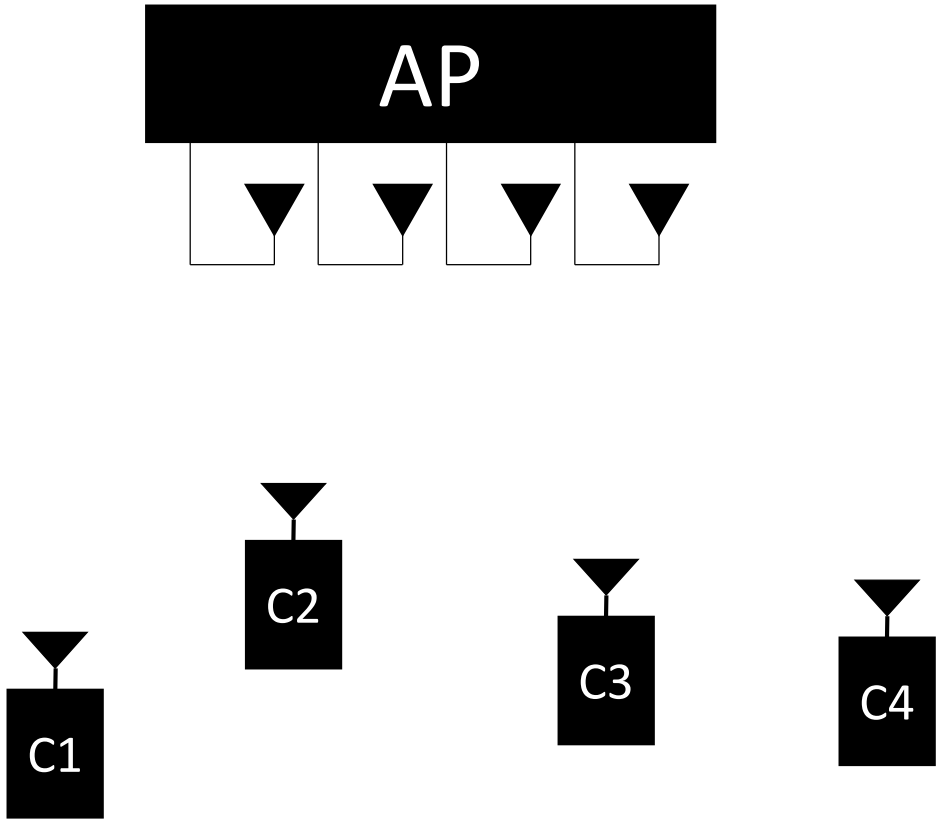
Why Not Mimic Downlink MU-MIMO?





- Paradigm Shift
- Many → One
- No connection between devices
- How do we remove interference?

MUSE : Multi-User ScalableE Uplink



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- No control signaling

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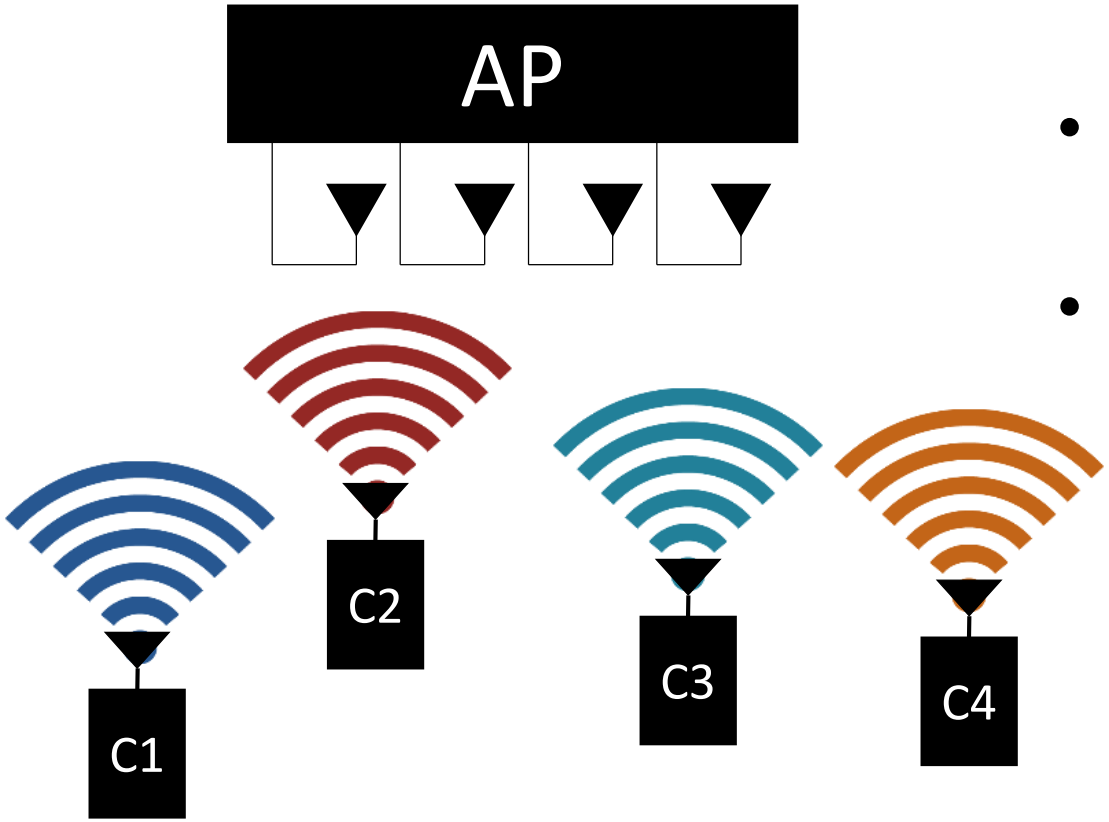

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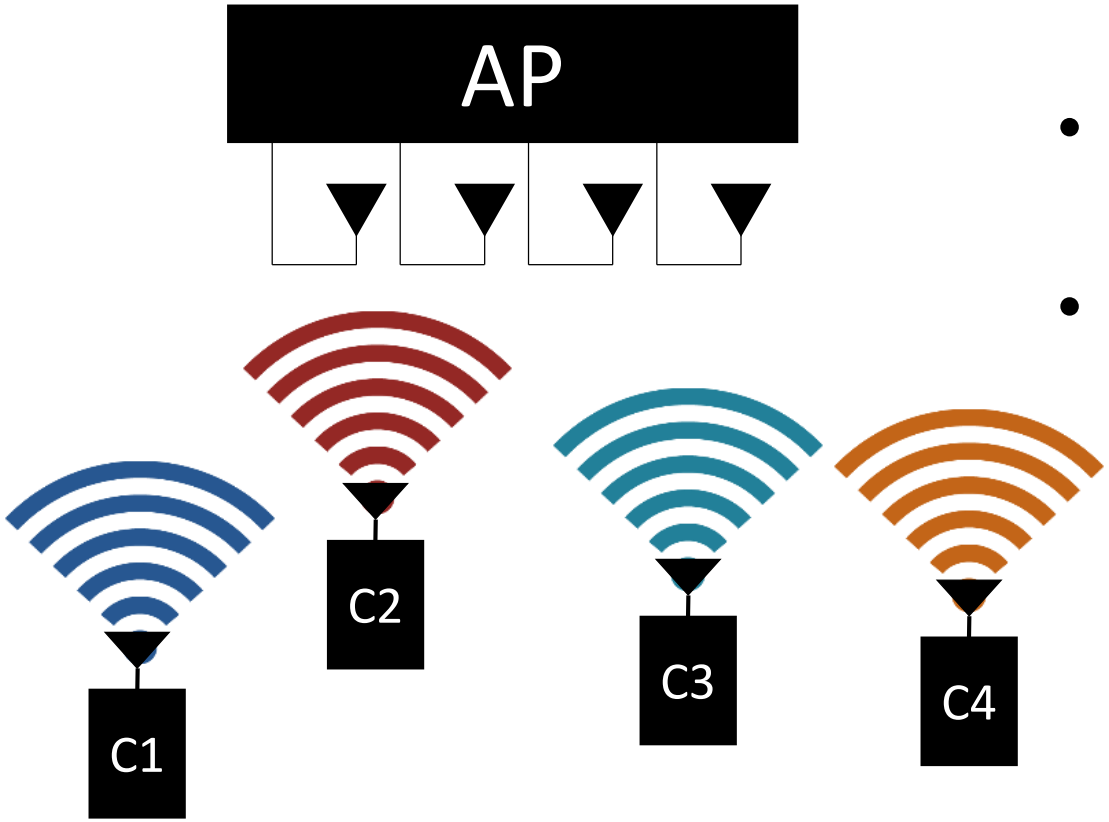
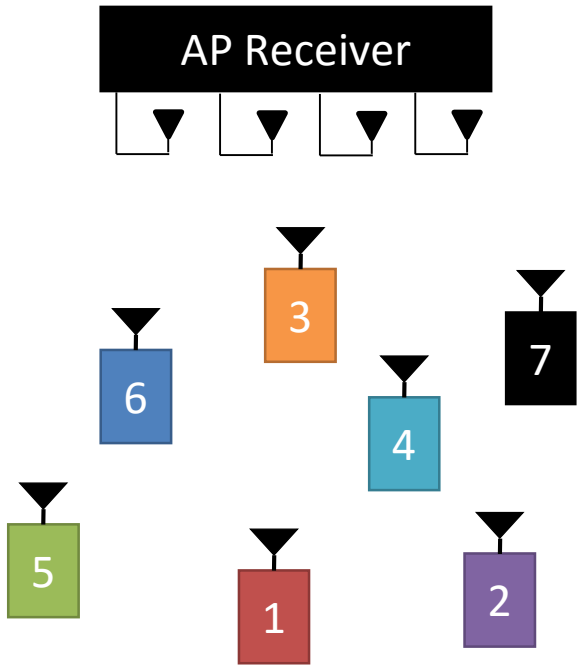


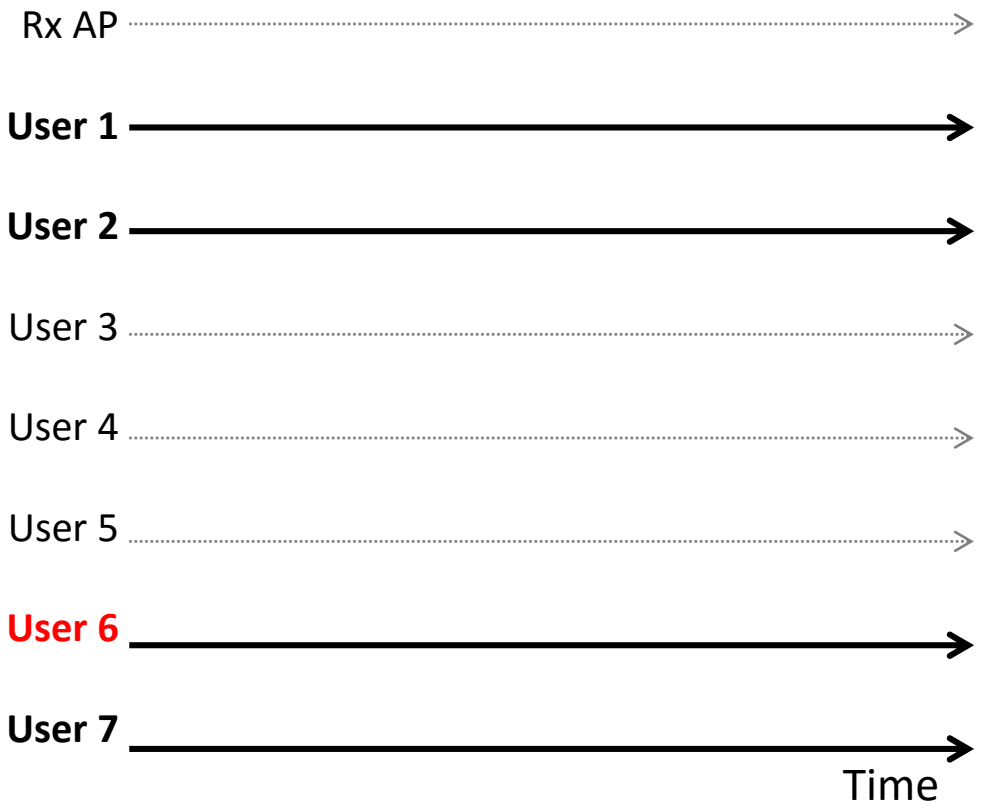
- Match the number of transmitters to the number of antennas at AP
- No control signaling

- Multiple transmitters act as a **single device** with multiple antennas
  - No control channel
  - Remove interference

Transmit Simultaneously

- **Association ID** for user selection and grouping
- **Arbitrary index** for each user
- AP informs the network the Max ID





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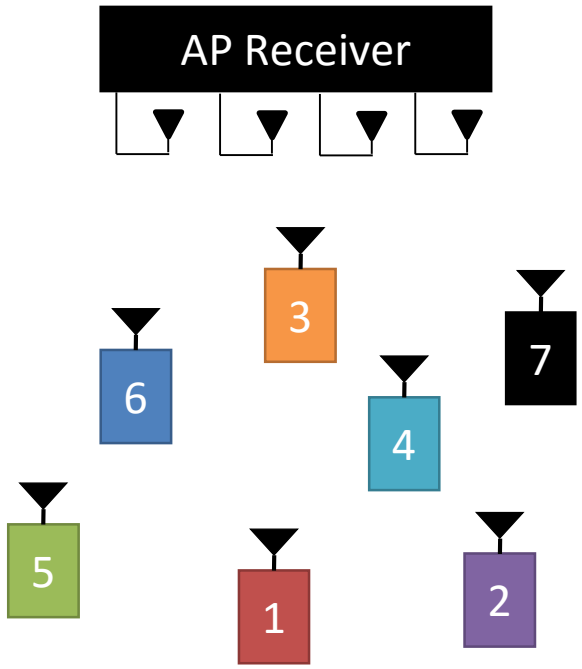

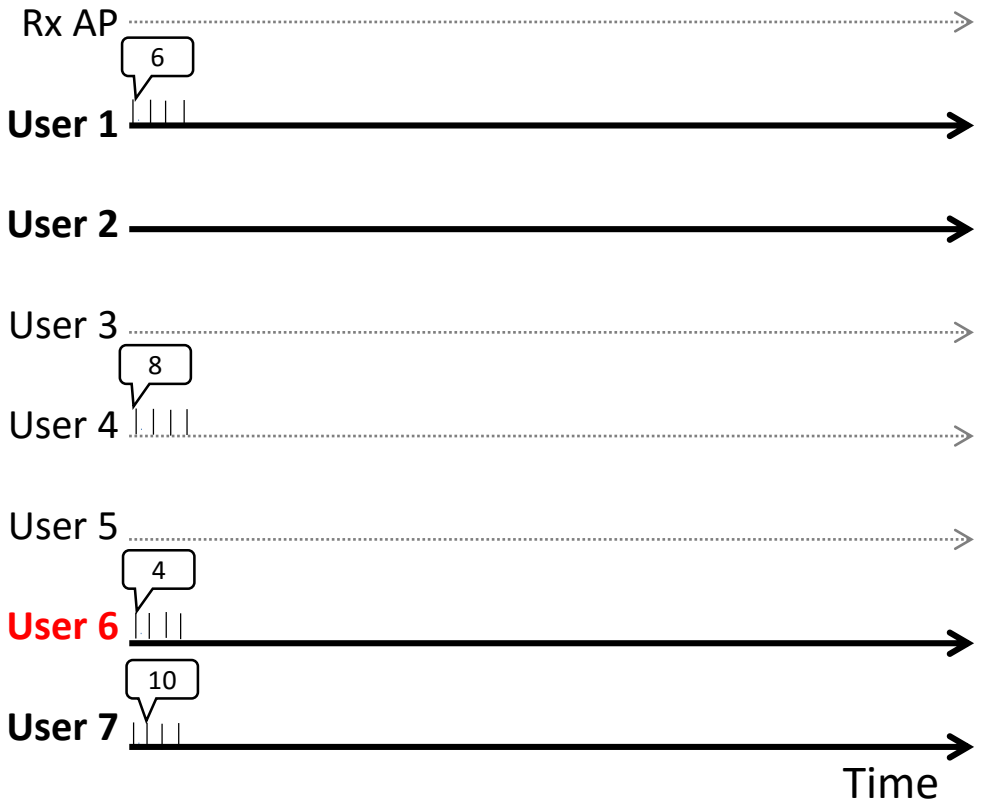

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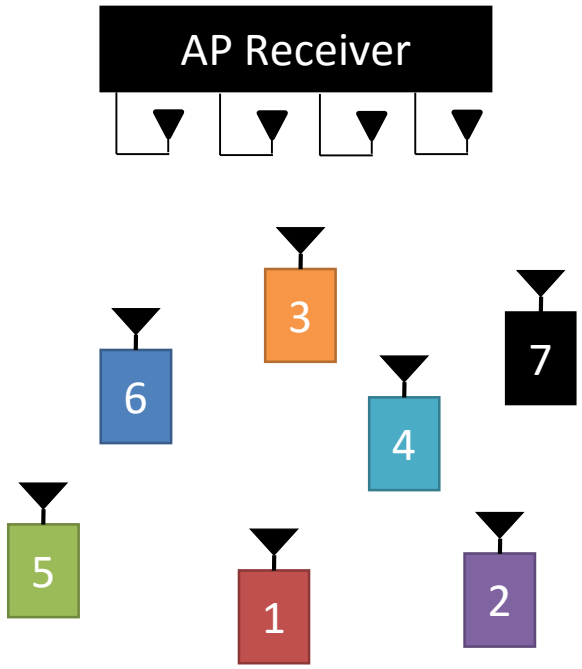

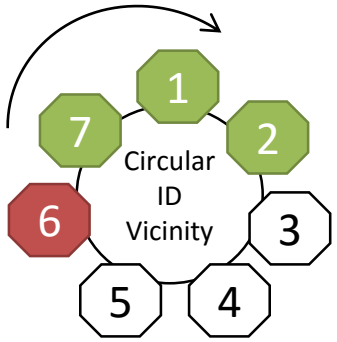

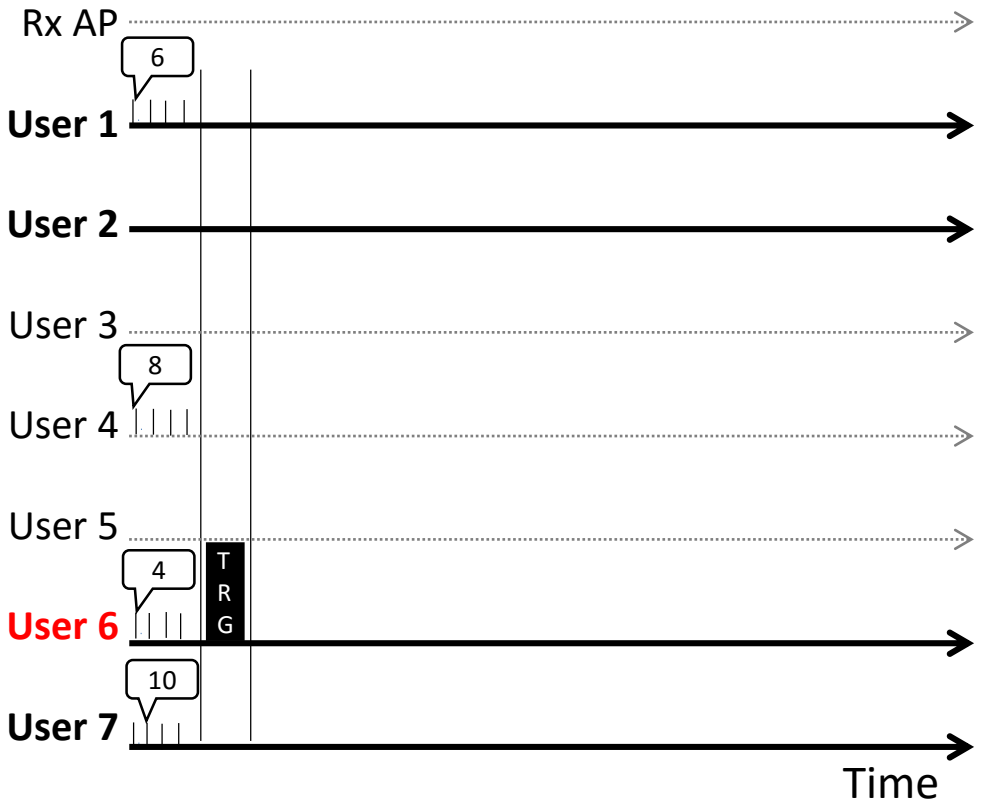

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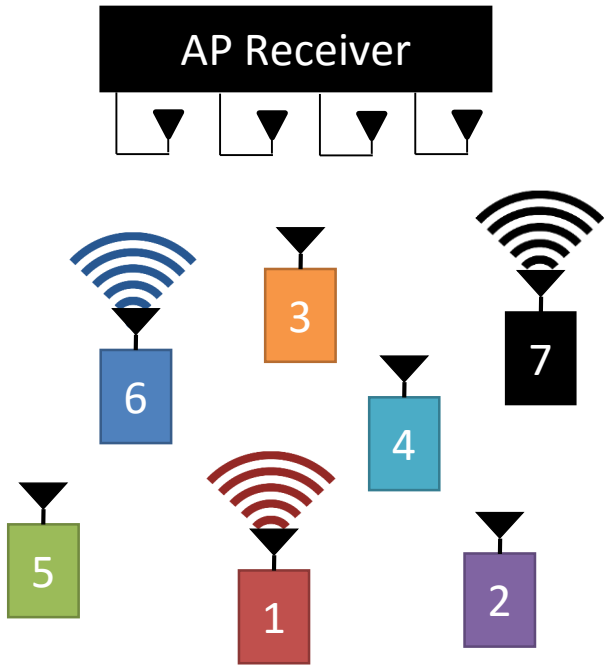

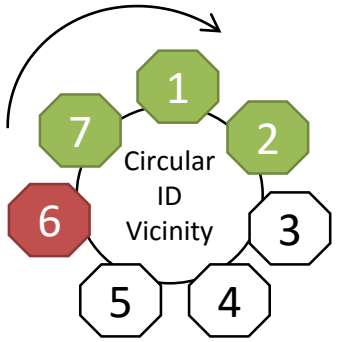

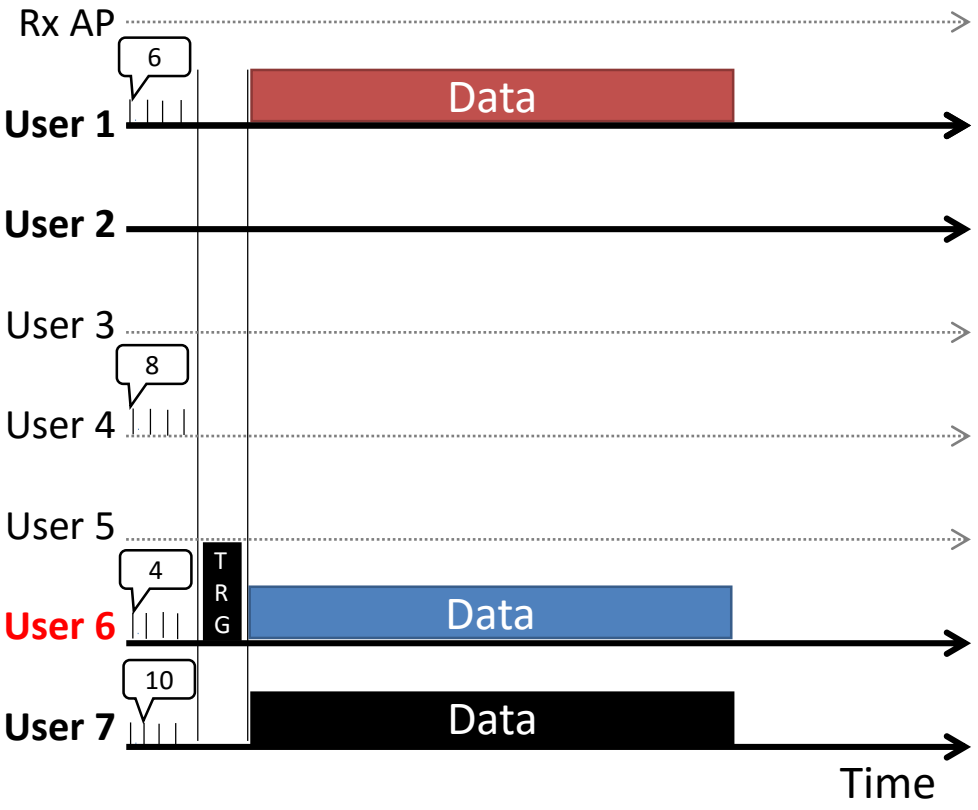

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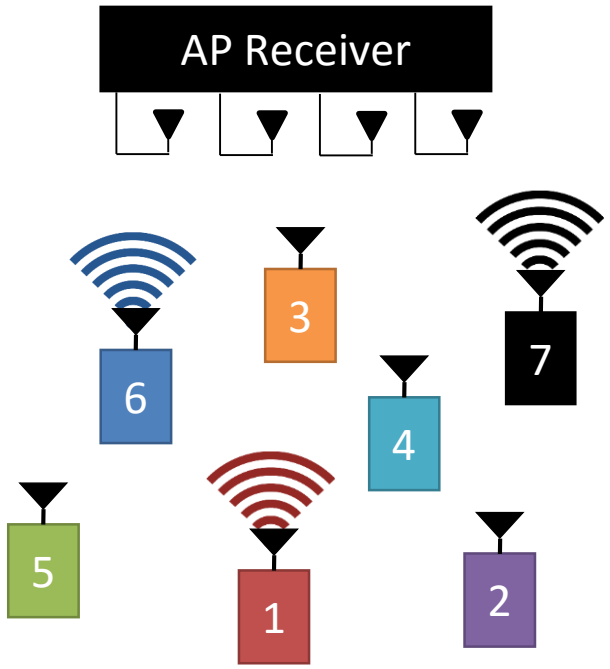

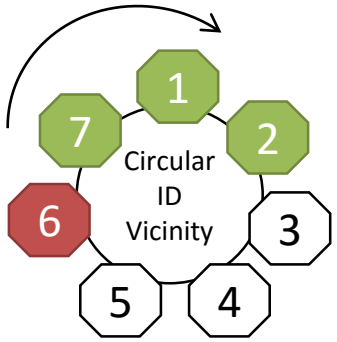

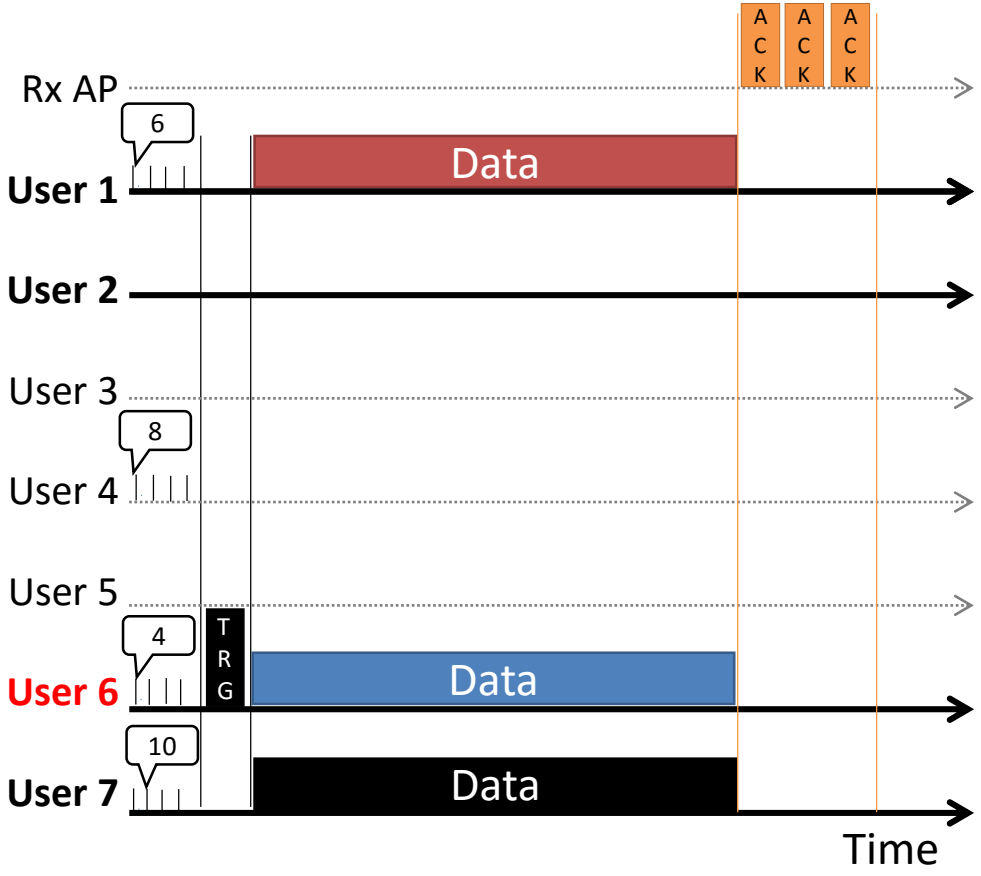

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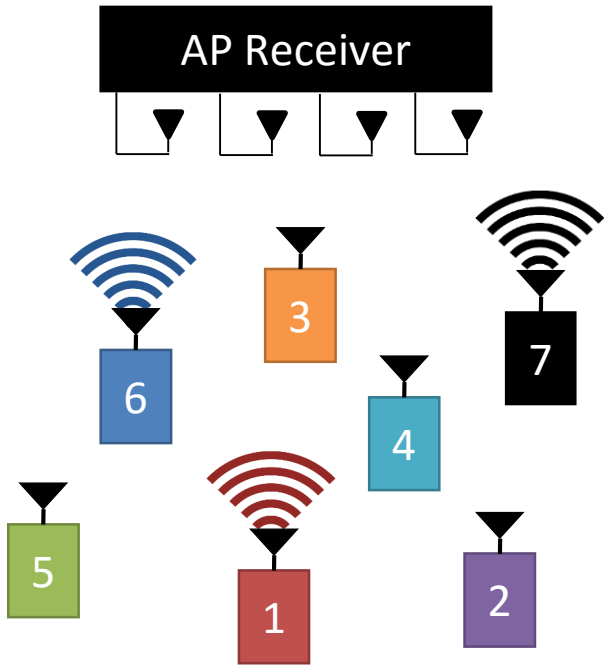
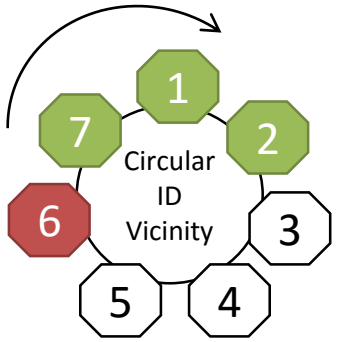
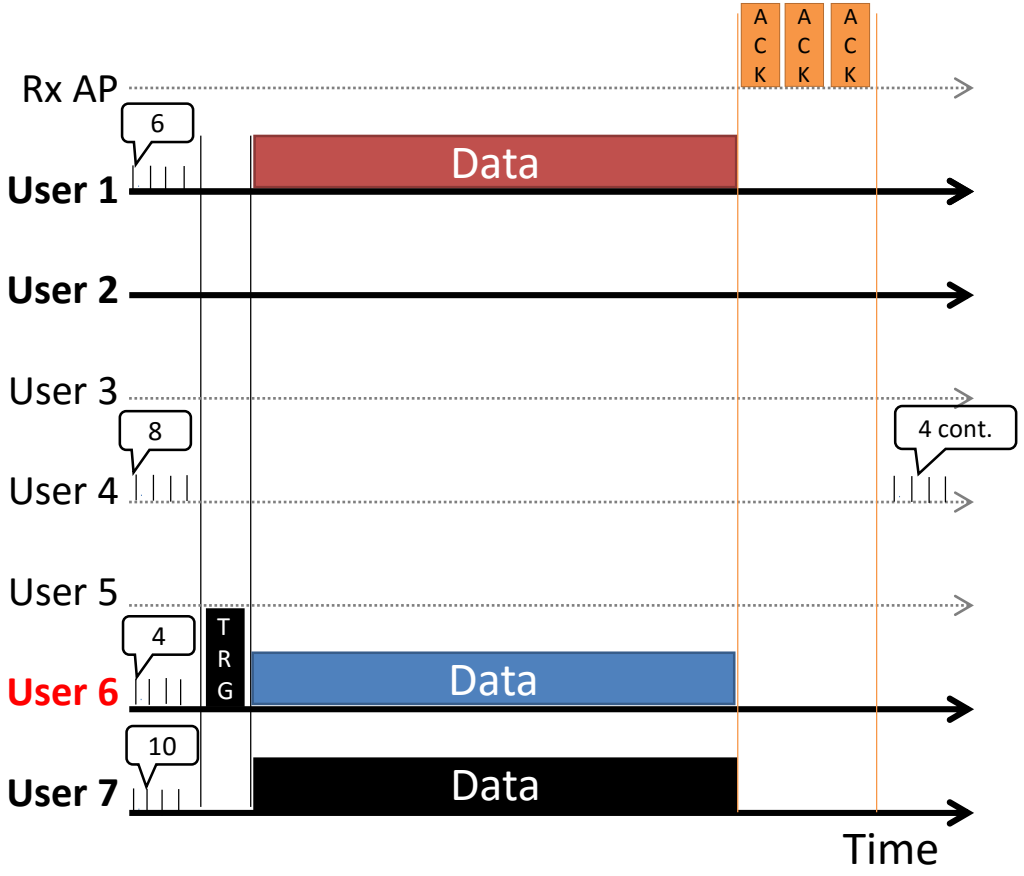
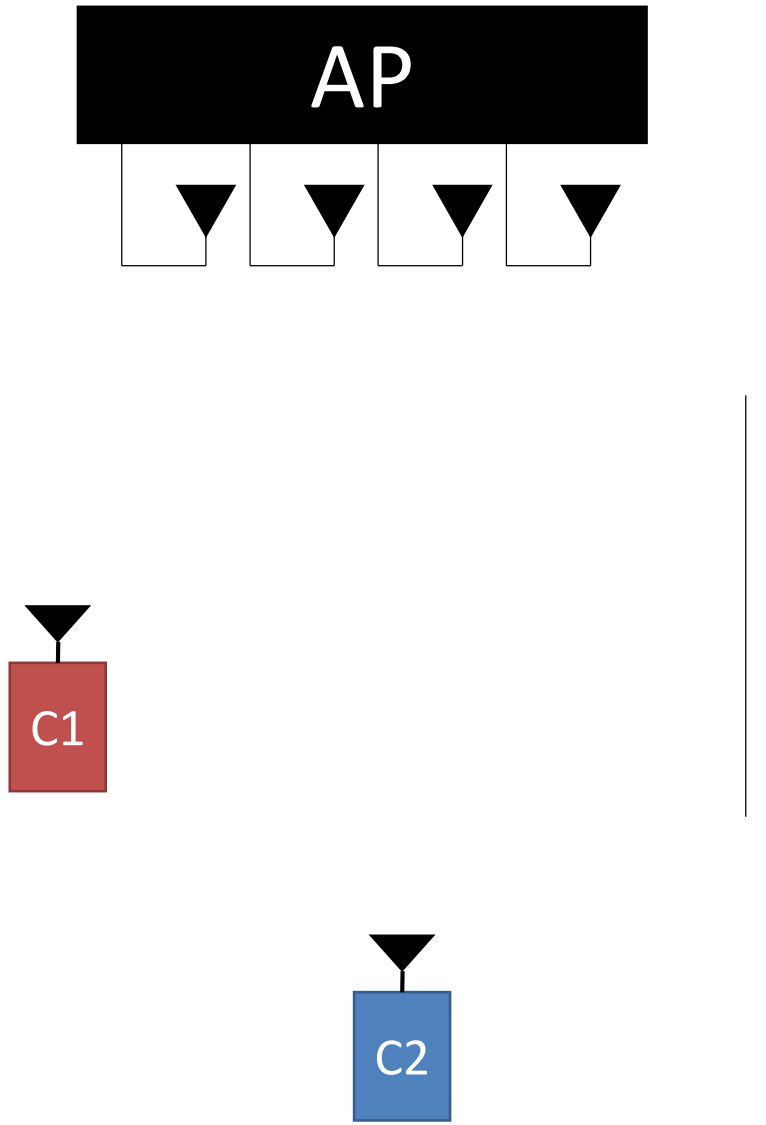






Remove Interference

- Environmental Multipath
- Independent paths (channels)
- Receiver (AP) estimate channels



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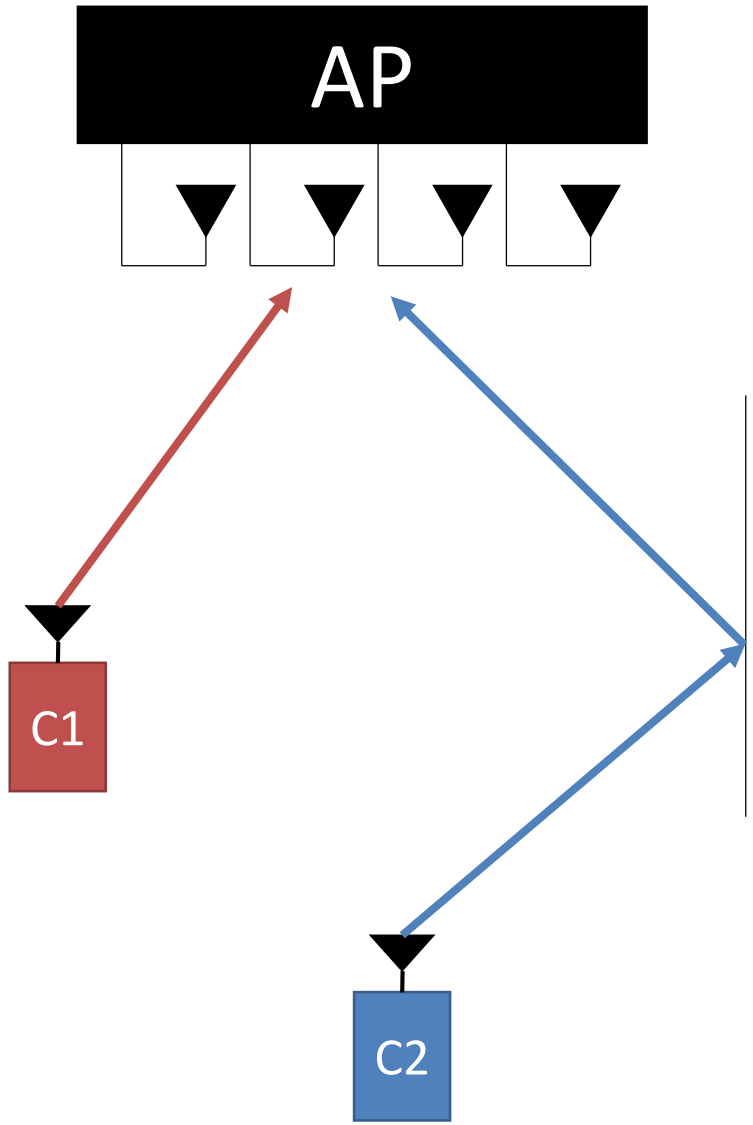
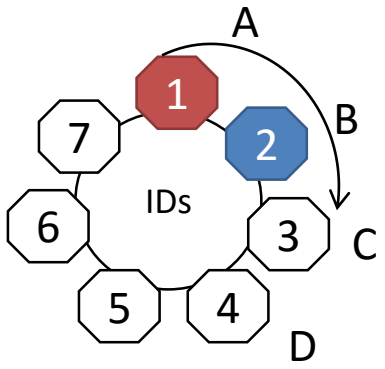
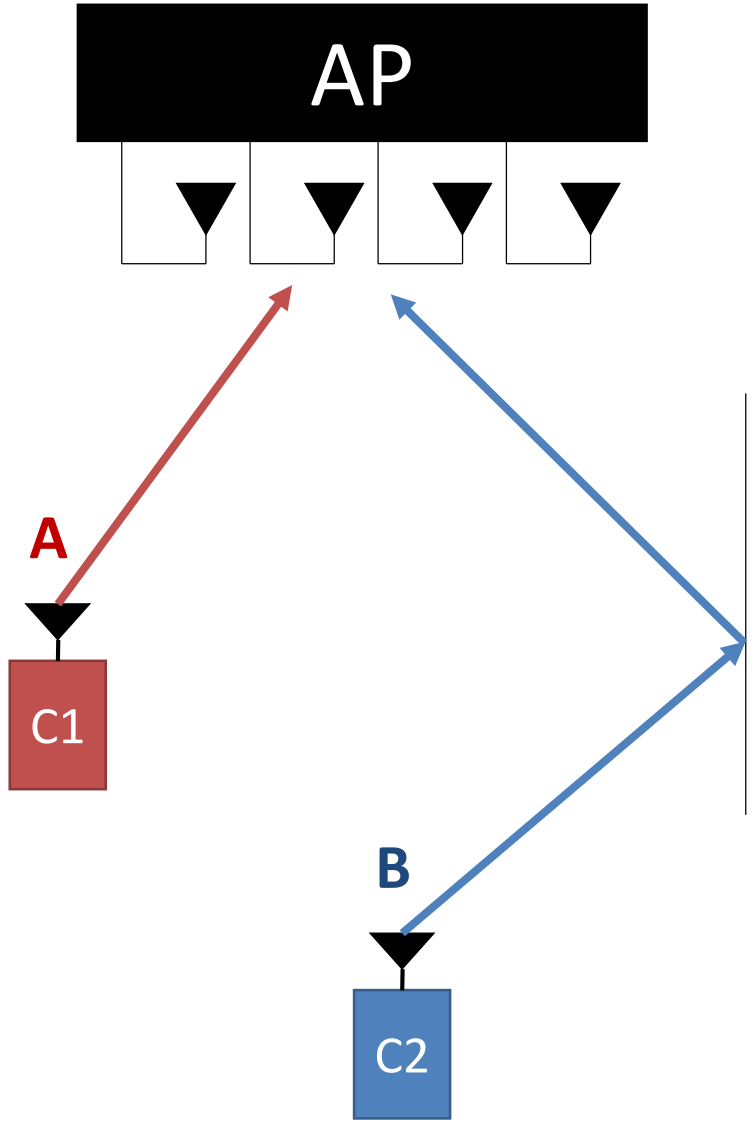


Receiver Channel Estimation

- Known set of training signals
- Enable distributed usage
- Fixed size (# Streams = # Rx antennas)
- User has assigned set of training signals
- Assignment through Association ID
- No control signaling (coordination) required





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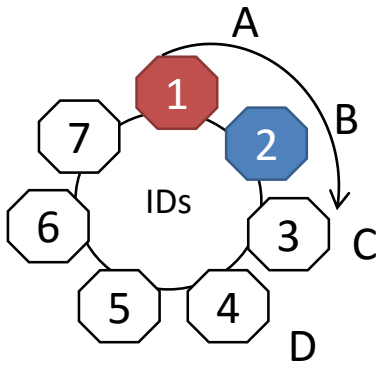
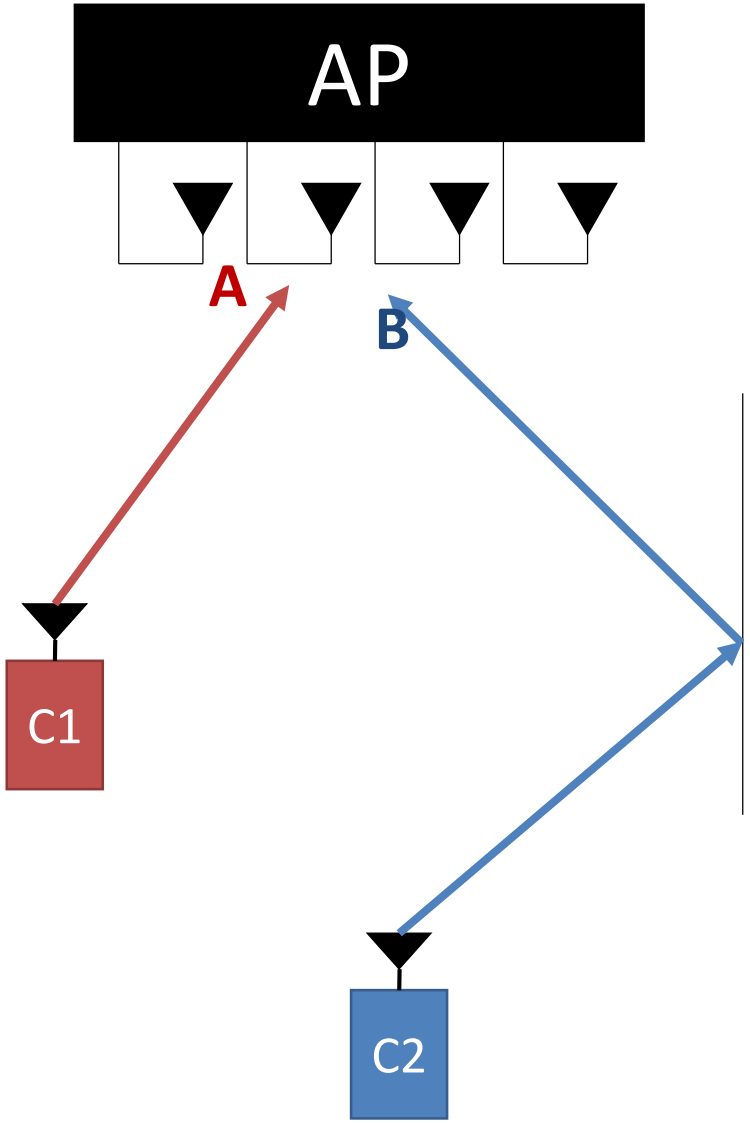
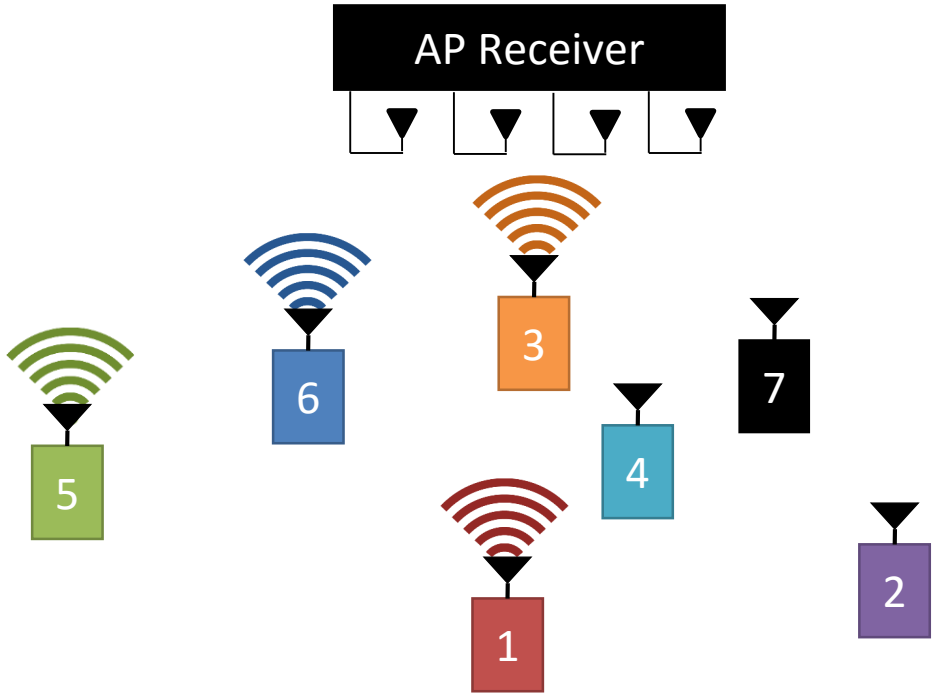
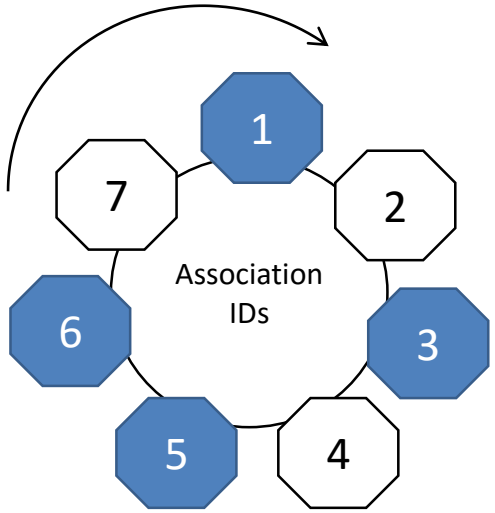




Group Adaptation

- **Association ID** Reassignment
- AP learning process: which users are most likely to transmit





Time

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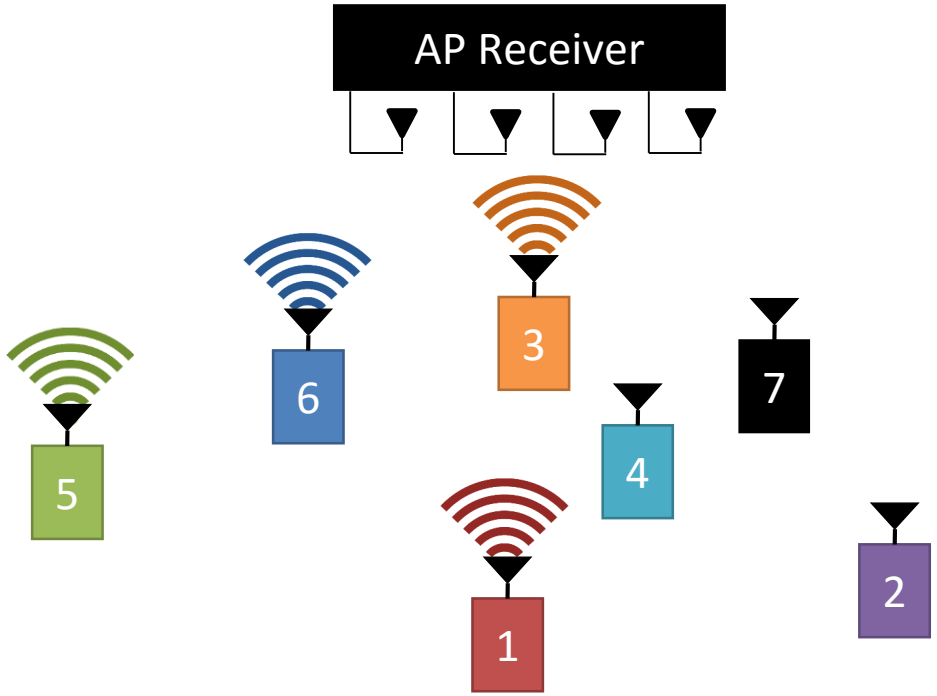

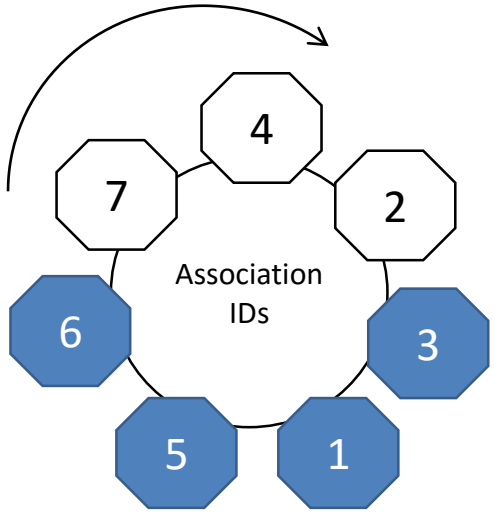

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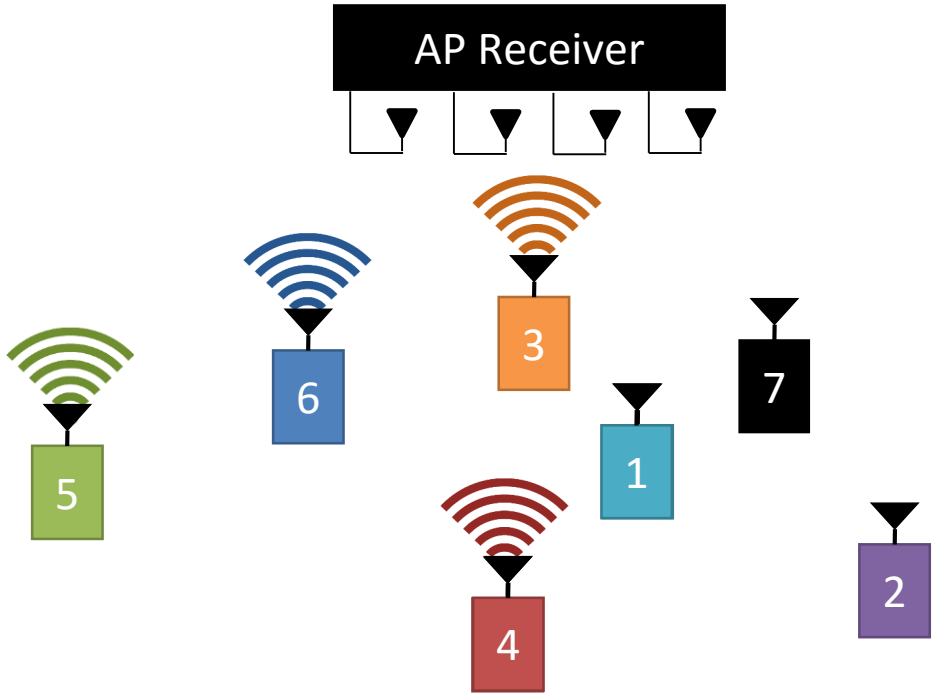
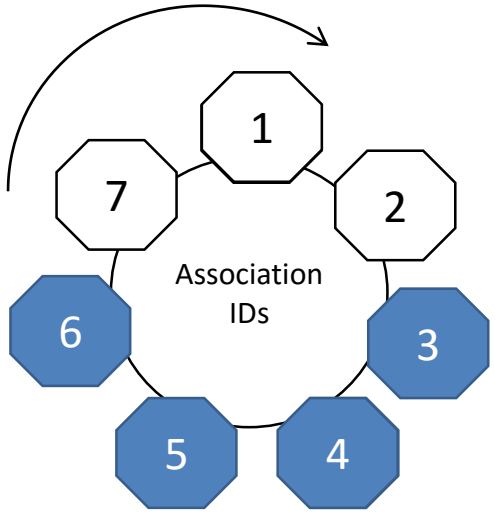
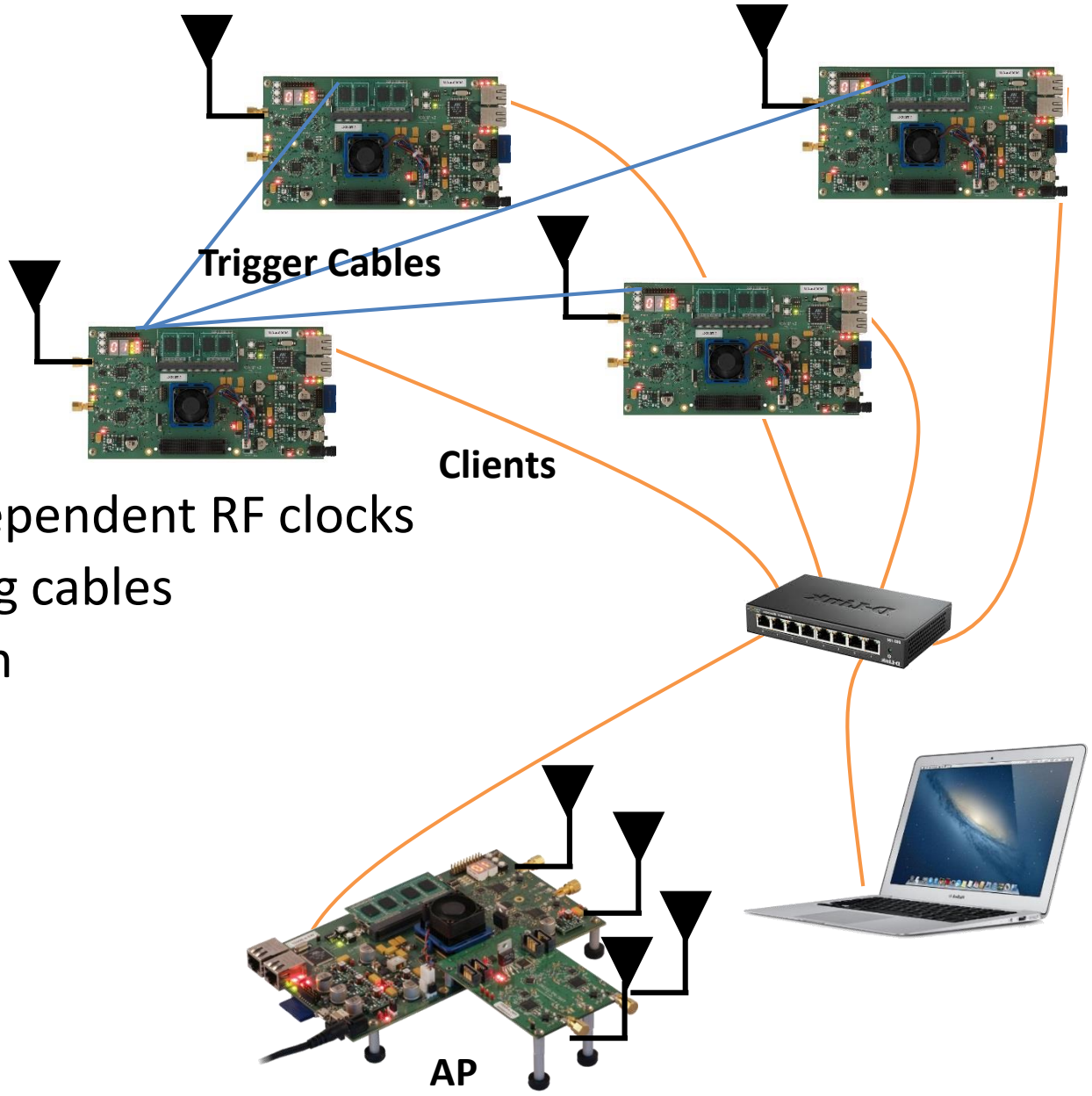




Time

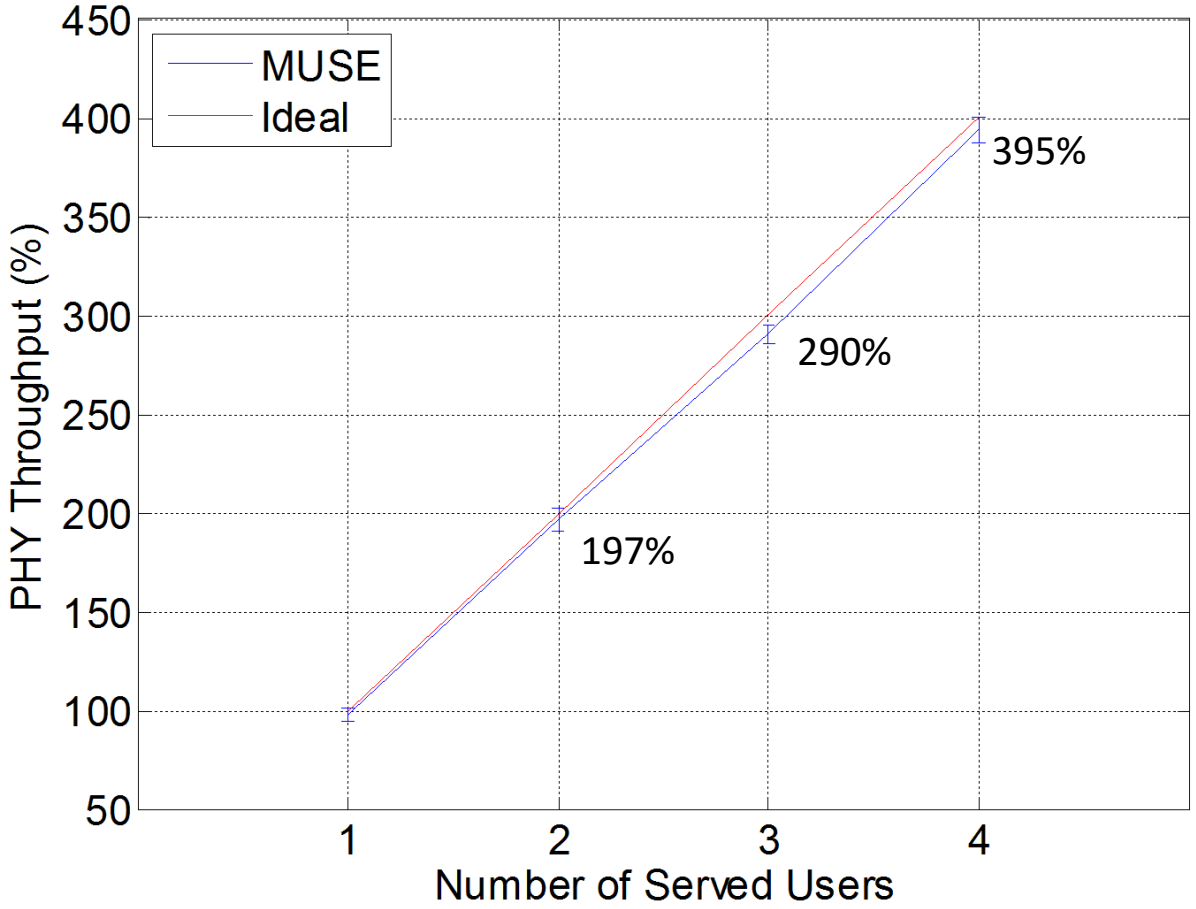
MUSE Implementation

- OTA experiments WARPLab
- 1 to 4 concurrent spatial streams
- Evaluation Setup:
  - Clients: single WARP board with independent RF clocks
  - Time synchronized through triggering cables
  - Conference room 645sq ft or 60 sq m
  - Evaluate over 20 locations



MUSE Scalability

- Scalability can be limited by inter-stream interference and channel correlation between users
- MUSE PHY ability to achieve full-rank capacity and permit scaling
- Setup:
  - 1x1, 2x2, 3x3, 4x4
  - 2000 packets
  - 24 Mbps



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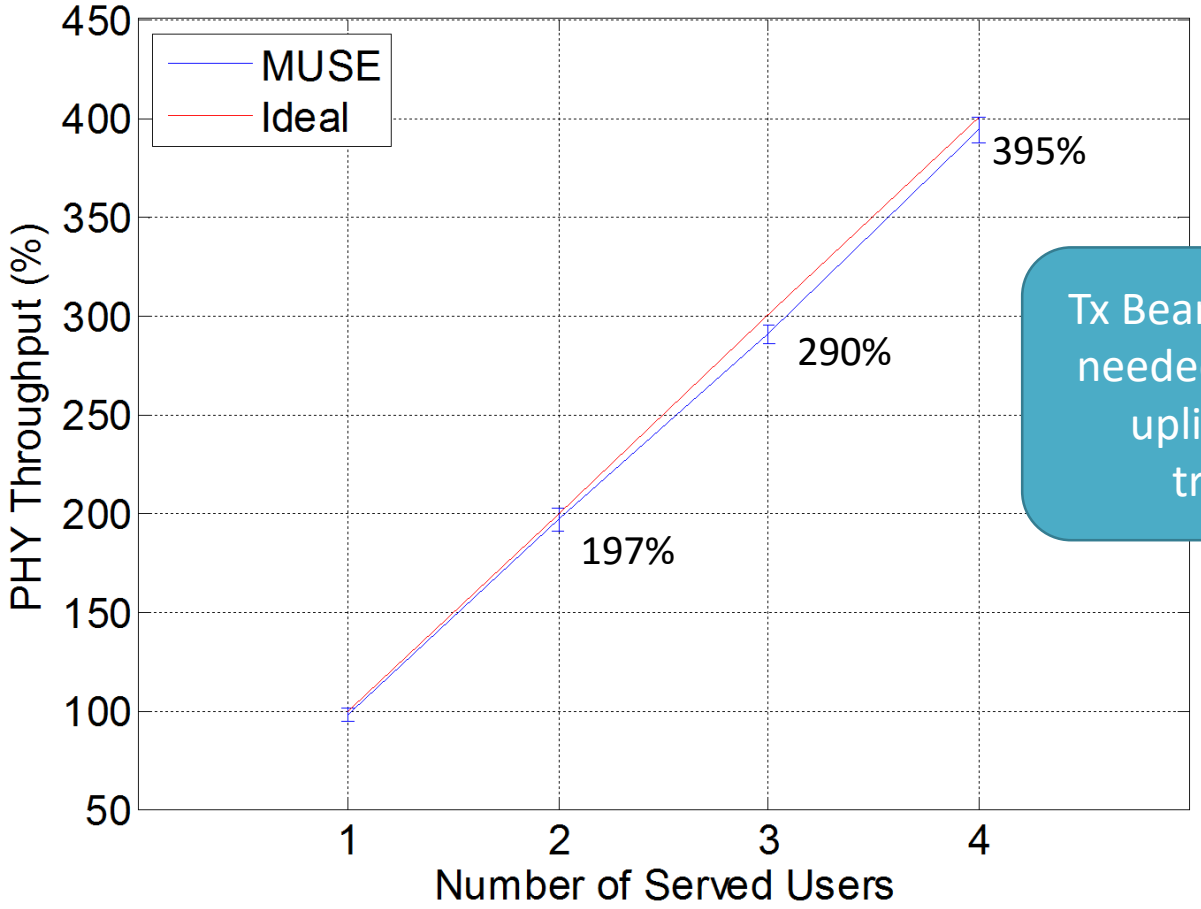
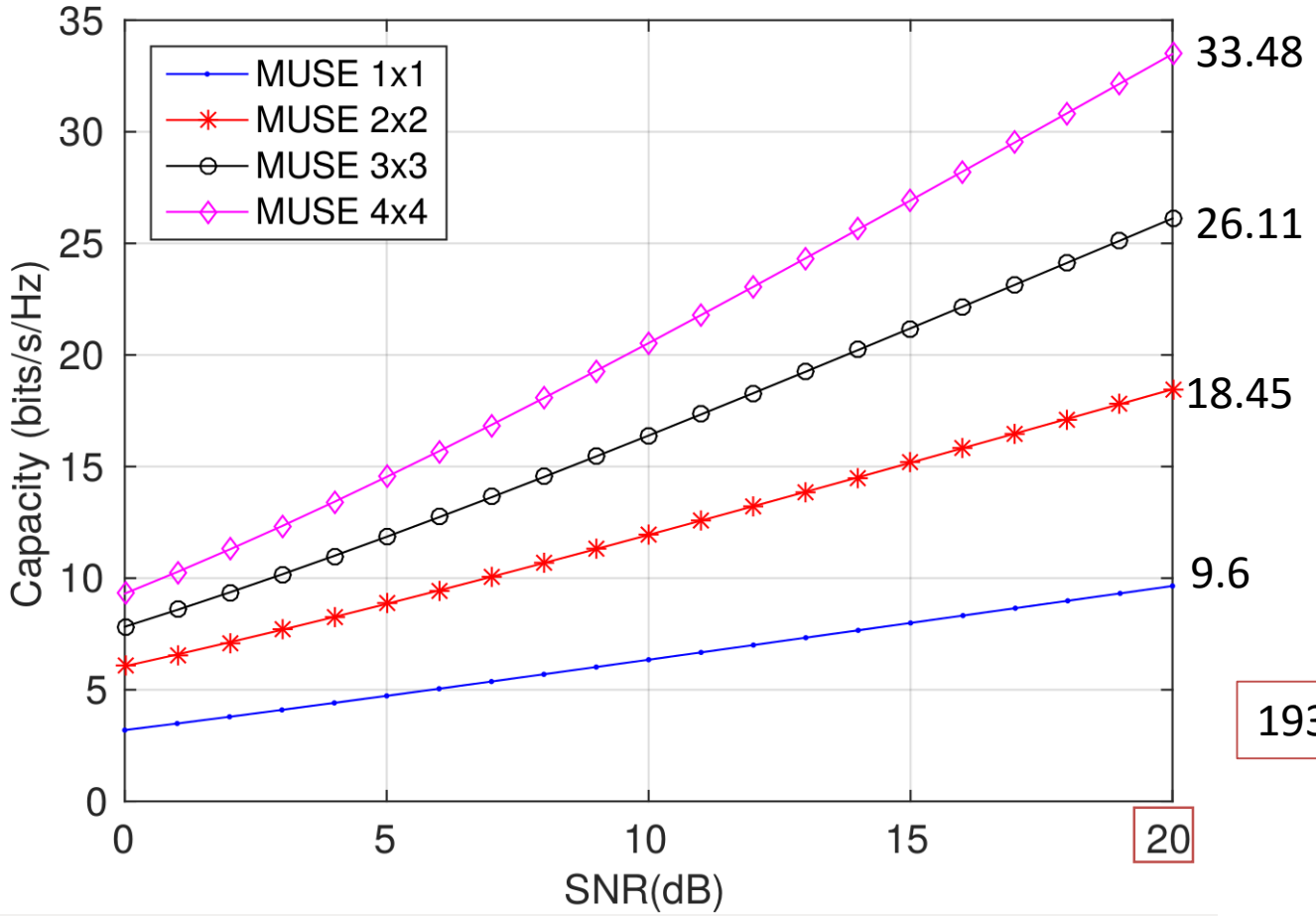


Tx Beamforming is **NOT** needed for distributed uplink multi-user transmission

MUSE Scalability

- Empirical capacity with estimated channels

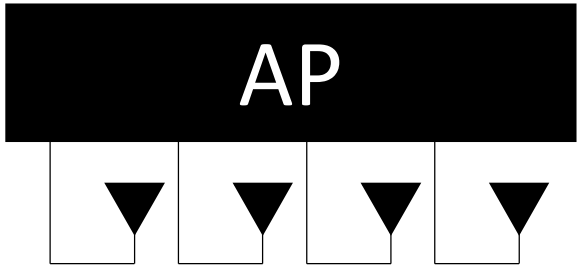
$$C(bps/Hz) = log2[\det(I_N + (SNR/M)(HH^*))]_{[1]}$$



193 Mbps to 669 Mbps

[1] Foschini, Gerard J. "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas."*Bell labs technical journal* 1.2 (1996).

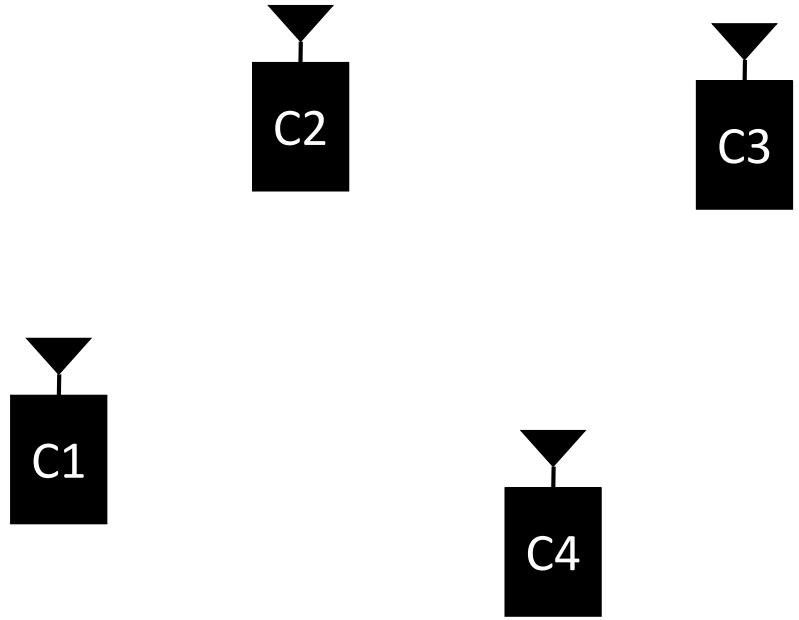
Conclusion MUSE



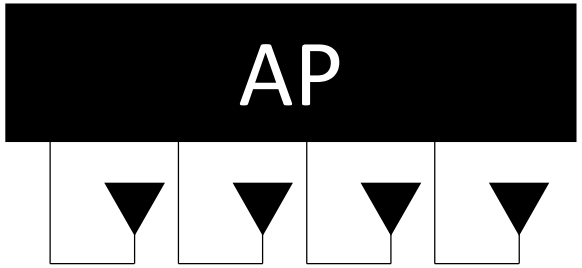
- **Scalable** Multi-User MIMO uplink WLAN
- Match the number of transmitters to the number of antennas at AP
- No control signaling

Emulate Single Multi-Antenna device

- Transmit Simultaneously
- ID-Based Grouping and Synchronization
- Enable distributed and dynamic Rx channel estimation
- Leverage environmental multipath
- Standard compatible



Conclusion MUSE



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