Concurrent Channel Access and Estimation for *Scalable* Multiuser MIMO Networking

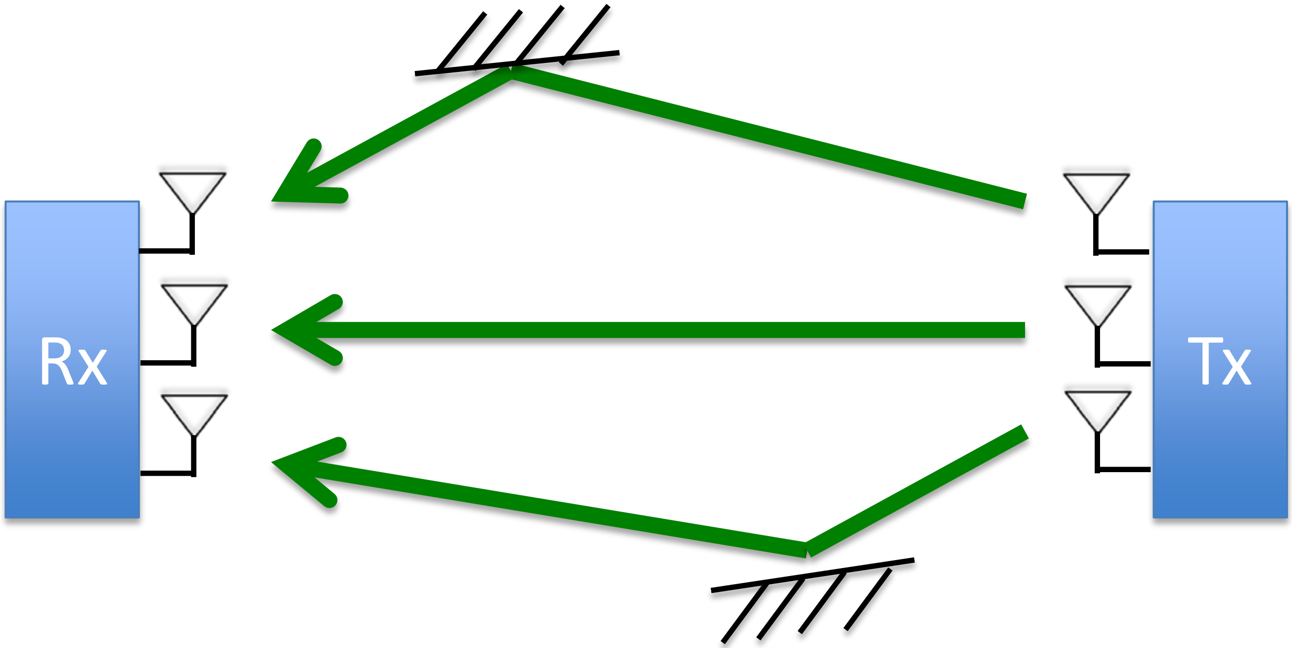
Tsung-Han Lin and H.T. Kung

IEEE INFOCOM 2013

HARVARD
School of Engineering
and Applied Sciences

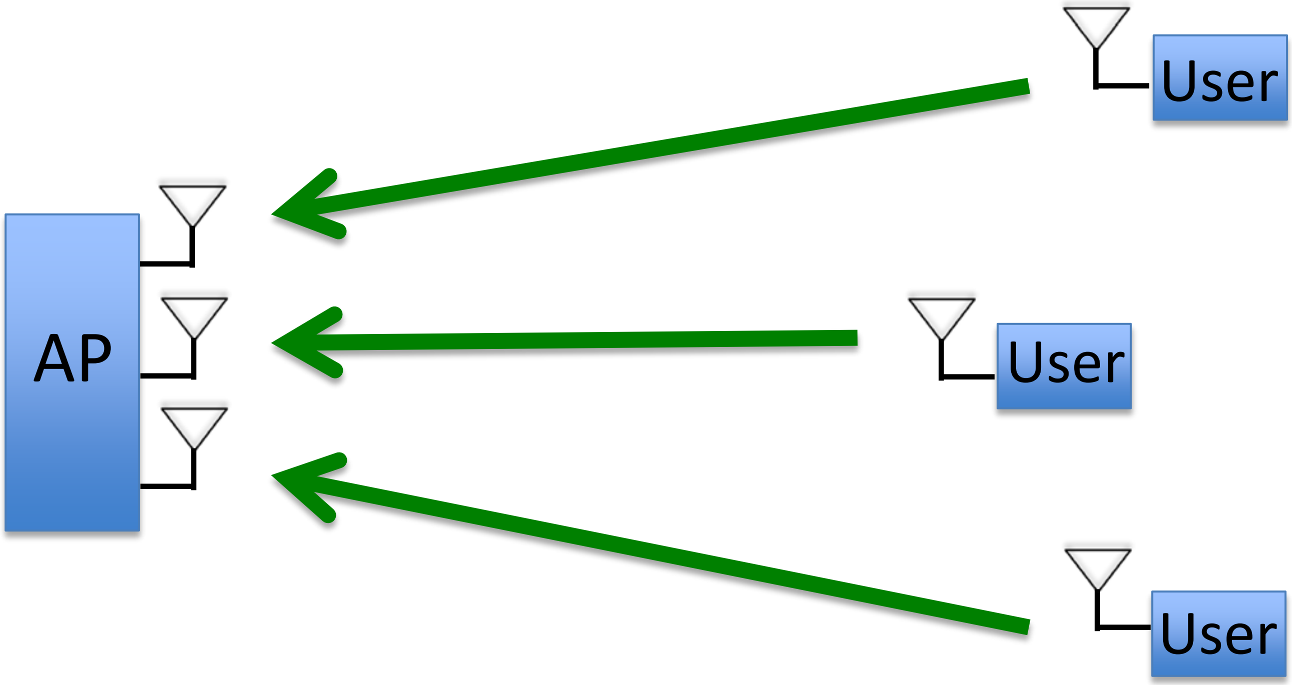
MIMO Communication

- Multiple antennas create additional degree-of-freedom
- Limited by scattering environments

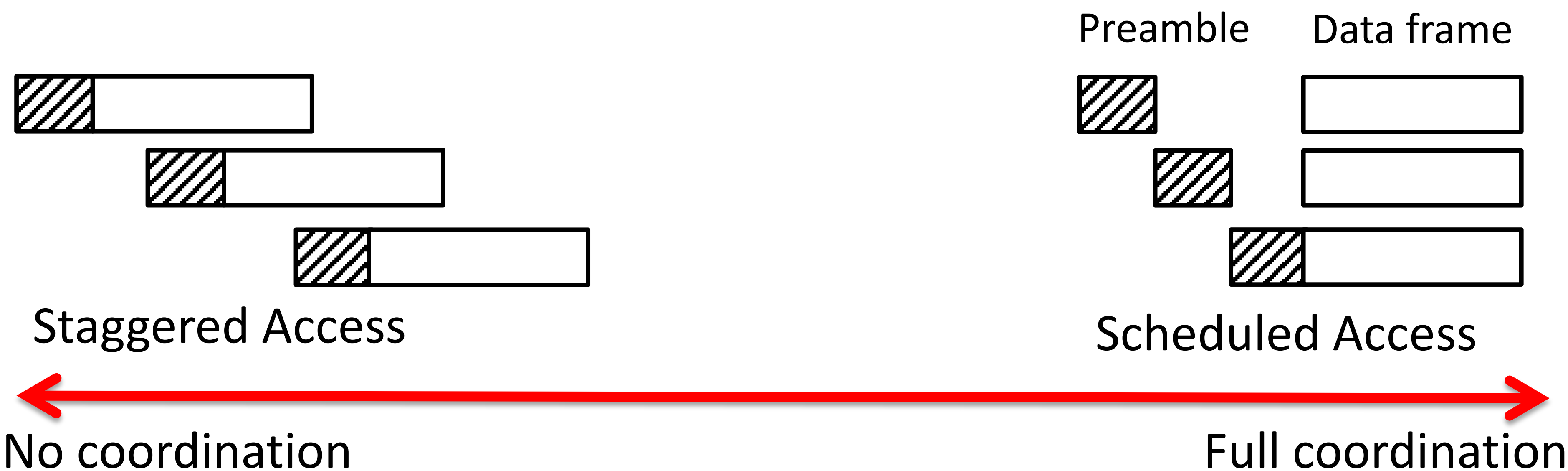


Multiuser MIMO

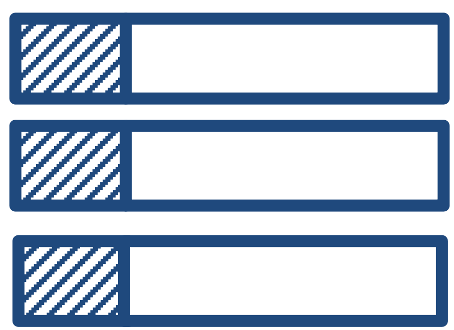
- Rich spatial diversity from geographically separated users
- *K* antennas on the AP, expect *K*-times throughput improvement



Proposed **Concurrent Access** to Mitigate MAC Scalability Issue for MU-MIMO



Minimum control overhead



Concurrent Access

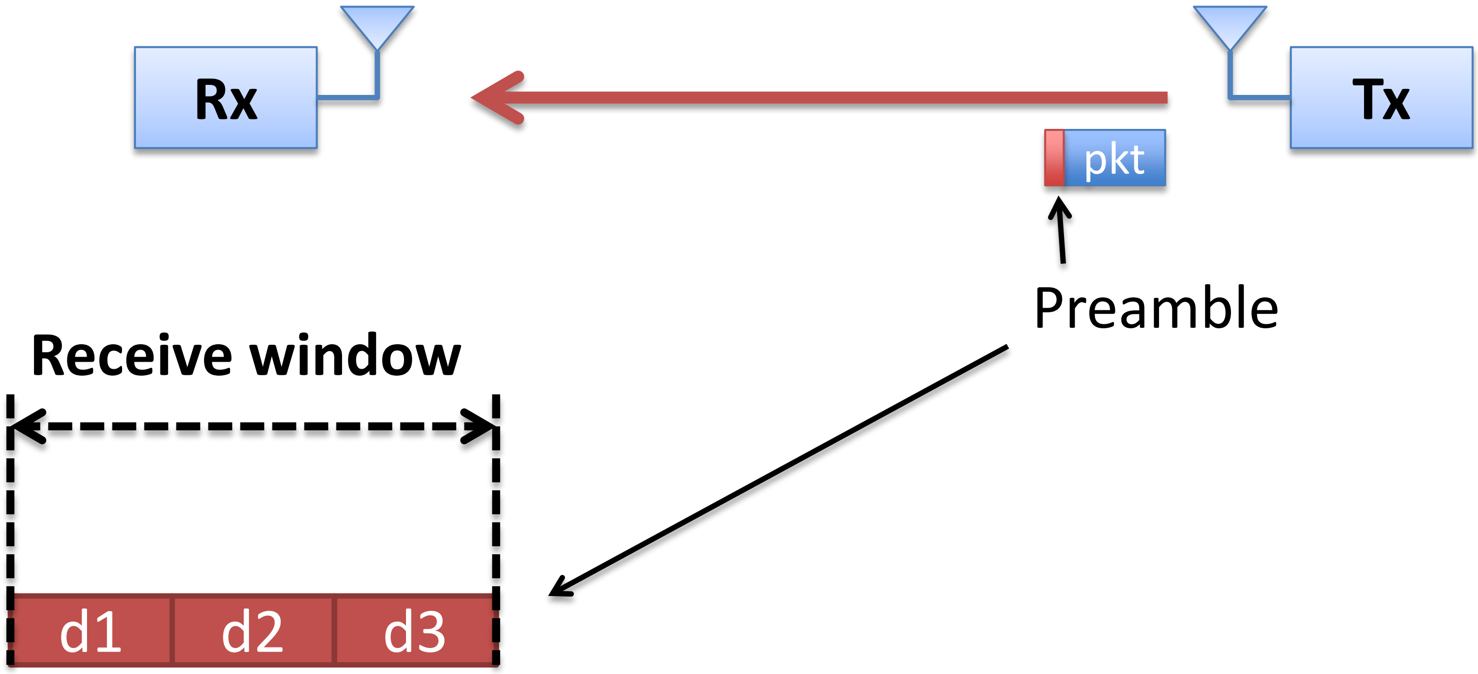
Fully parallelized data frame

Proposed MU-MIMO Concurrent Access in Support of Random Access

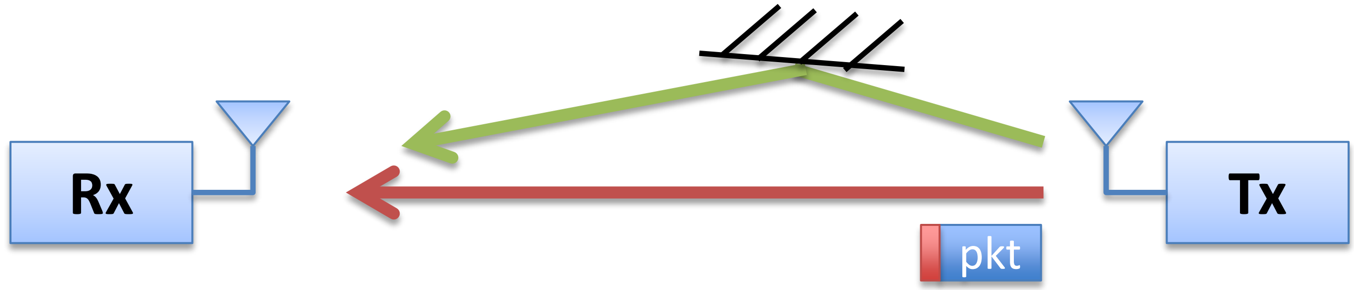
- More aggressive senders, i.e., smaller backoff window size
  - Standard tricks applied (e.g., CSMA with exponential backoff)
  - *Automatically* adapt to additional degree-of-freedom
- No coordination
  - Senders choose to join concurrent transmissions *independently*

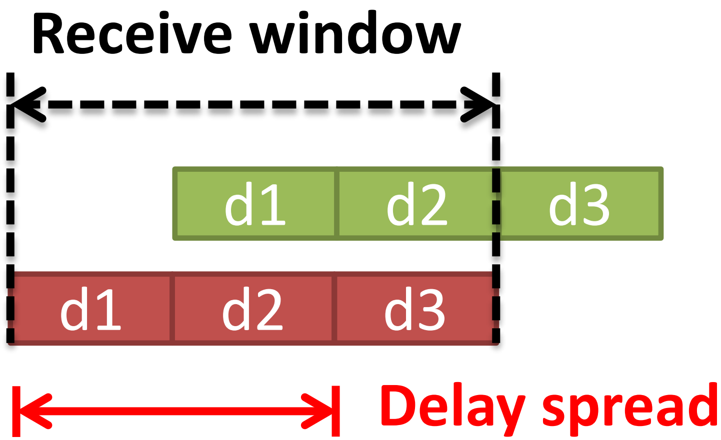
Challenges of Concurrent Access and Proposed Solutions

- Challenge: Precise synchronization is difficult
  - Proposed solution: Channel estimation from **loosely synchronized** preambles
  - Can be cast as a ***sparse recovery*** problem
- Challenge: Collision is expensive under MIMO
  - Proposed solution: Use **delay packet decoding** to exploit ***retransmissions*** to decode previously collided packets



Channel estimation with packet preambles measures channel distortion on data symbols

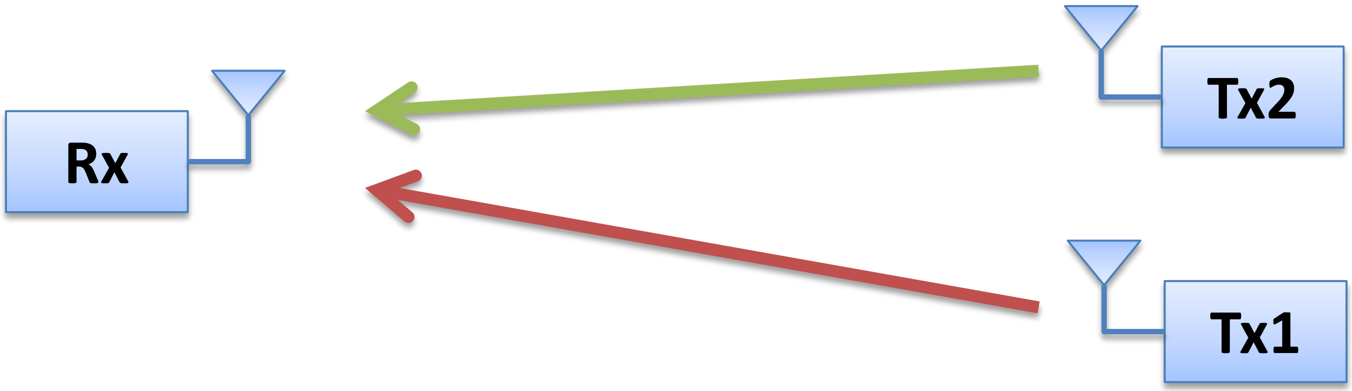


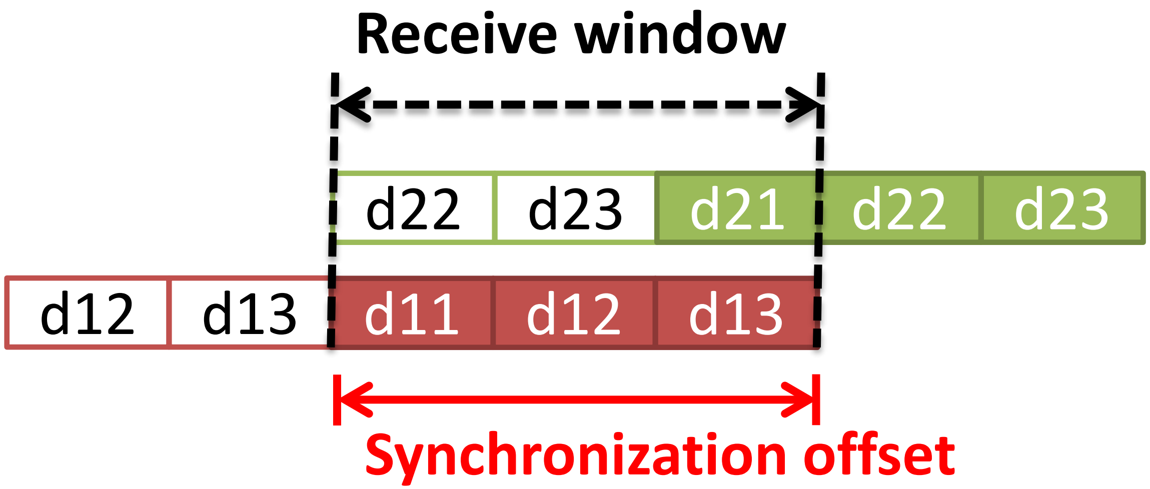


 # unknowns (h1, h2, etc.) in channel estimation proportional to delay spread

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} d_1 & \\ d_2 & d_1 \\ d_3 & d_2 \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix}$$

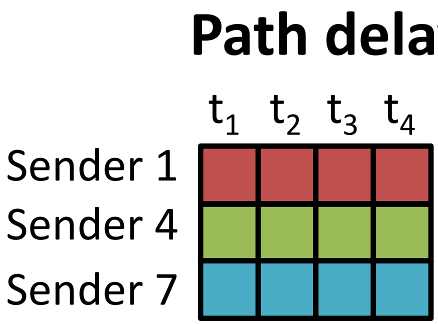
Multiuser case is analogous to multipath, but with much larger “delay spread”





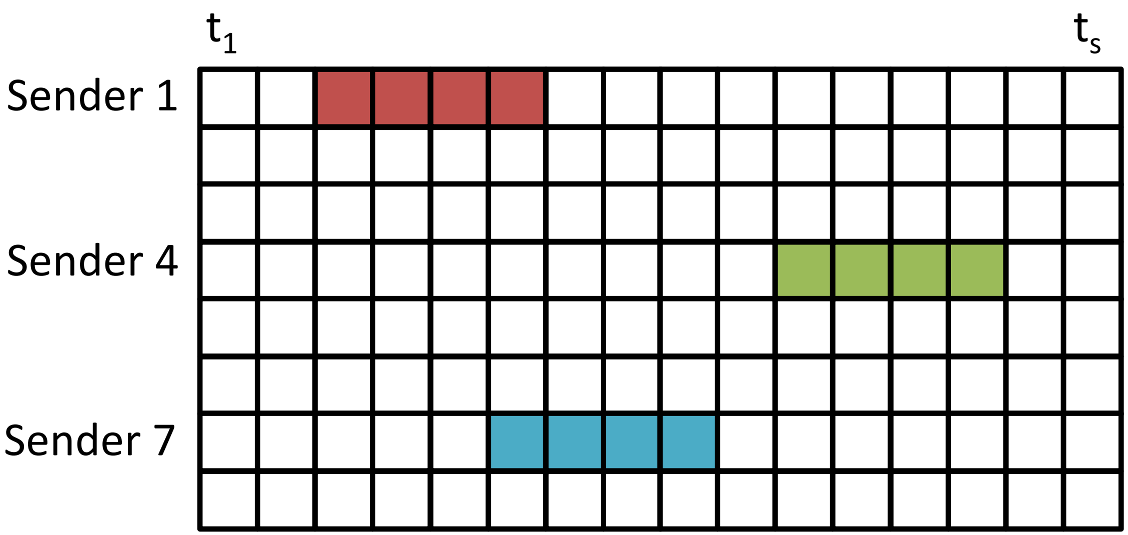
unknowns is proportional to sync offset, and # senders

$$
\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} d_{11} & d_{13} & d_{12} \\ d_{12} & d_{11} & d_{13} \\ d_{13} & d_{12} & d_{11} \end{bmatrix} \begin{bmatrix} h_{11} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} d_{21} & d_{23} & d_{22} \\ d_{22} & d_{21} & d_{23} \\ d_{23} & d_{22} & d_{21} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ h_{21} \end{bmatrix}
$$



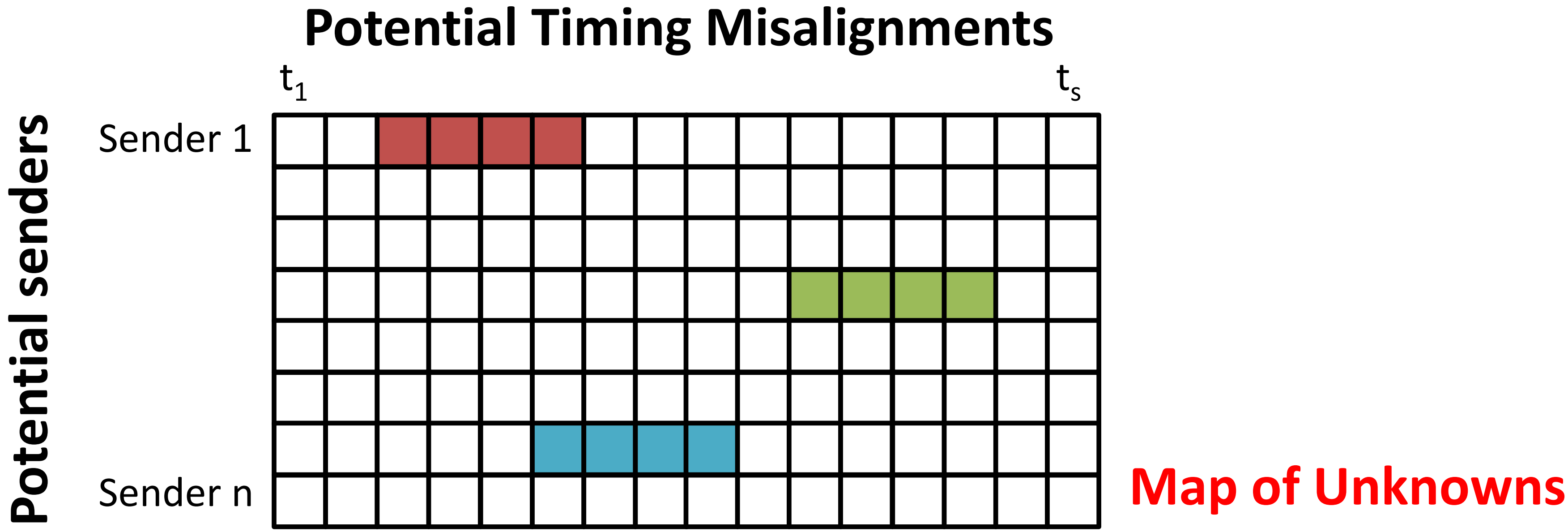
Scheduled and fully synchronized

 # unknowns = (# senders) x (# path delays)



Random access and loosely synchronized

 # unknowns =
(# *potential* senders) x (# *potential* timing misalignments)

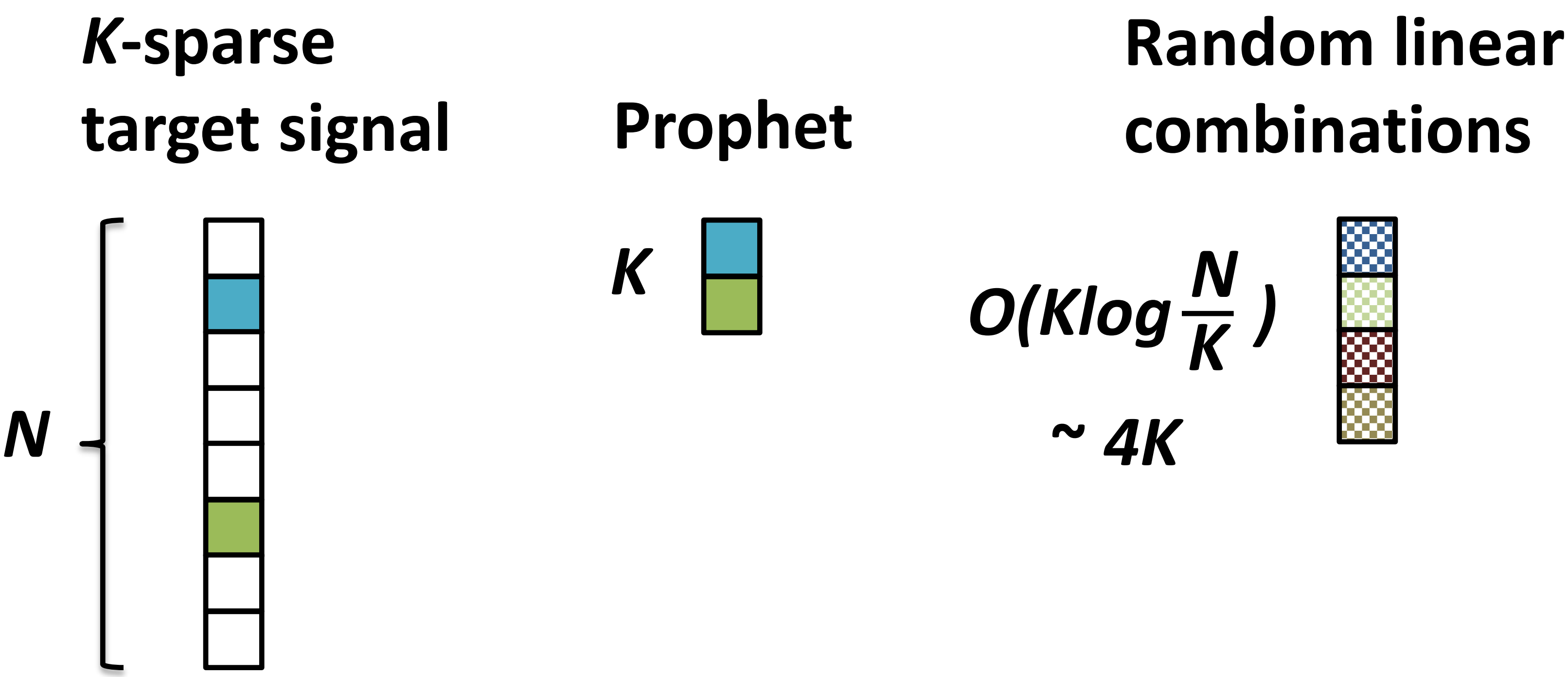


The dimensionality of unknowns is enlarged, but the amount of channel coefficients per transmitting sender is the same, i.e., **sparse** in the new space

... we just don't know ***where they are***

Compressive Sensing

- A few random projections preserve all information of a sparse signal



Random Preamble Sequence

- Assign senders **random preamble sequences {1, -1}** to create random measurements

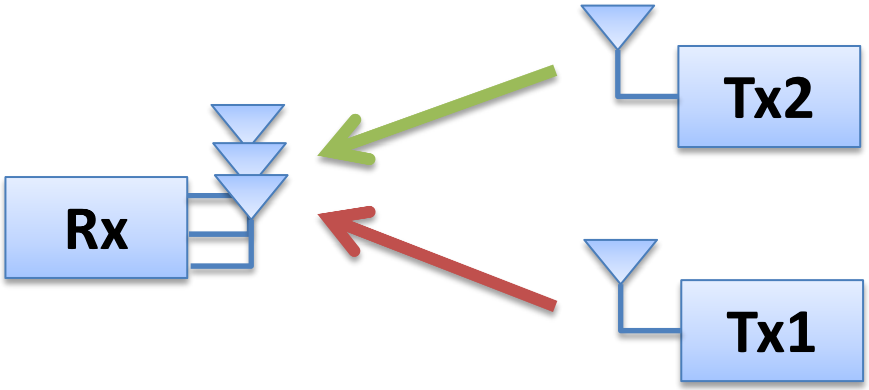
How long does the preamble need to be?

Ex: 4x4 MIMO, delay spread 60 ns, time sync offset 2 μs, 100 potential senders

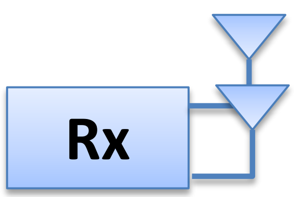
Solve all vars	Our strategy
100 x 2 = 200 μs	**4 x (4 x 0.06) ~ 0.96 μs**

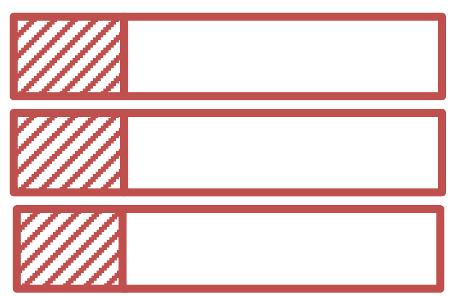
Furthermore, Exploit Receiver Diversity for Decoding

- *N*-antenna MIMO AP receives *N* copies of concurrent preambles
  - Channel coefficients to each antenna are different
  - Timing misalignment and senders are the same!
- Leads to **faster decoding** and **shorter preambles**

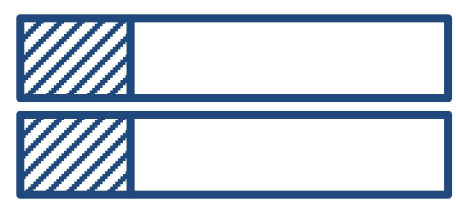


Not there yet, random access based concurrent transmission also means **collisions** are likely



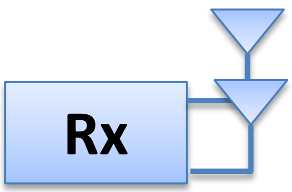


Collision

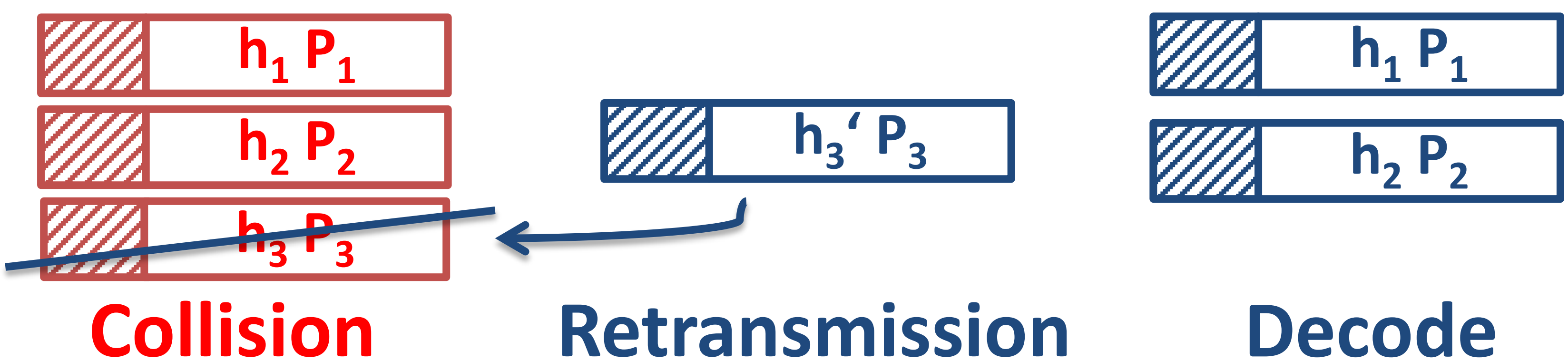


Full utilization

“Delay Packet Decoding”: Exploit Successful Retransmissions



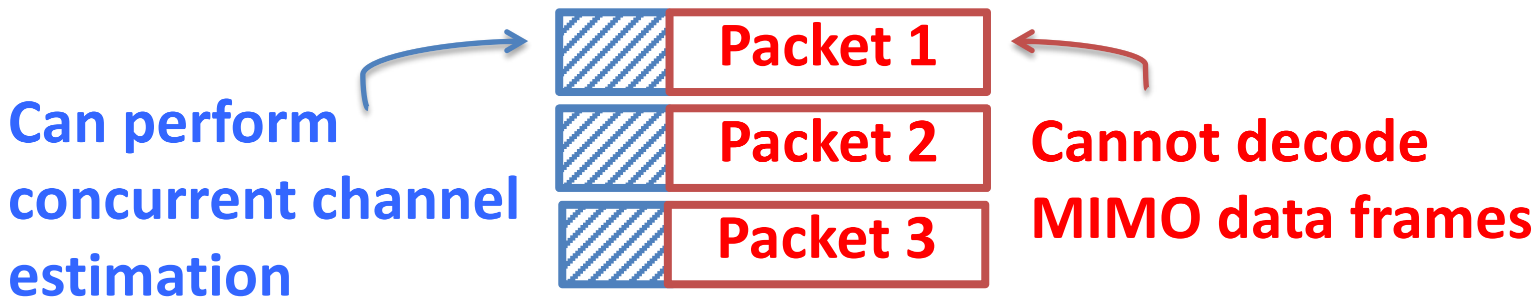
Successful retransmission can be used to cancel out packets in previous collisions



Need to learn h_1, h_2, h_3 from collided packets

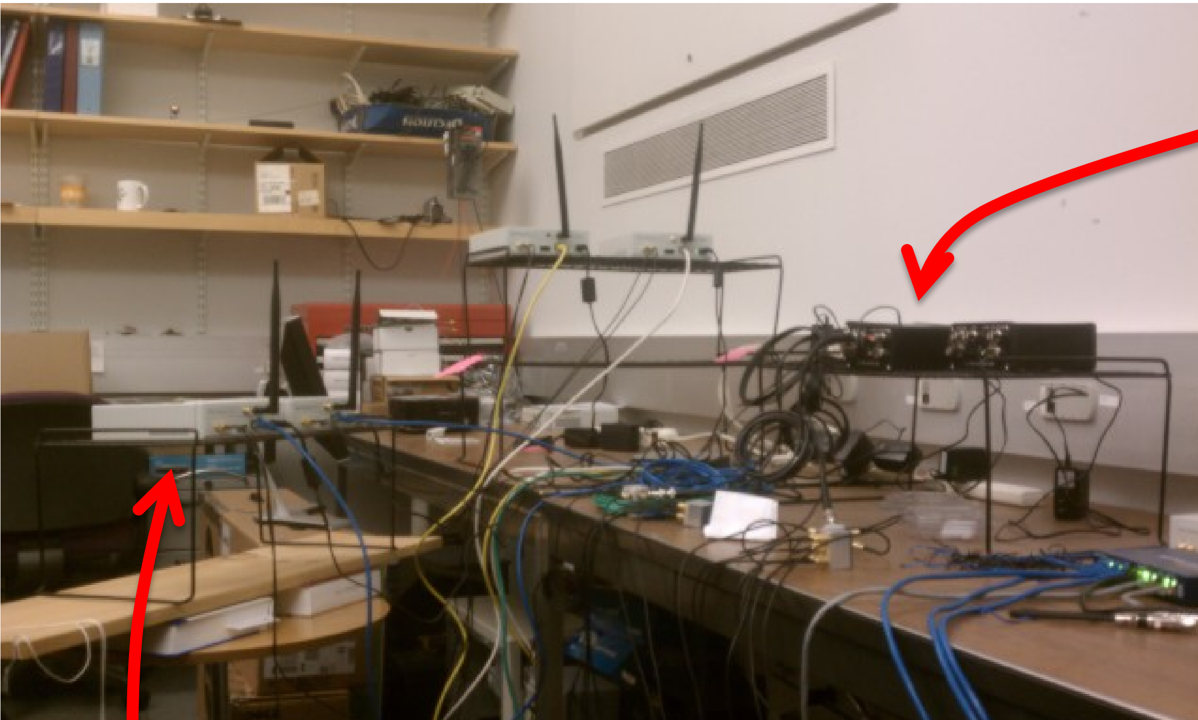
Enable Concurrent Channel Estimation for Collided Packets

- Most collisions are caused by only **a few** additional packets
- Slightly longer preamble allows concurrent channel estimation of these collided packets



<u>Tolerate small fluctuation in channel booking</u>

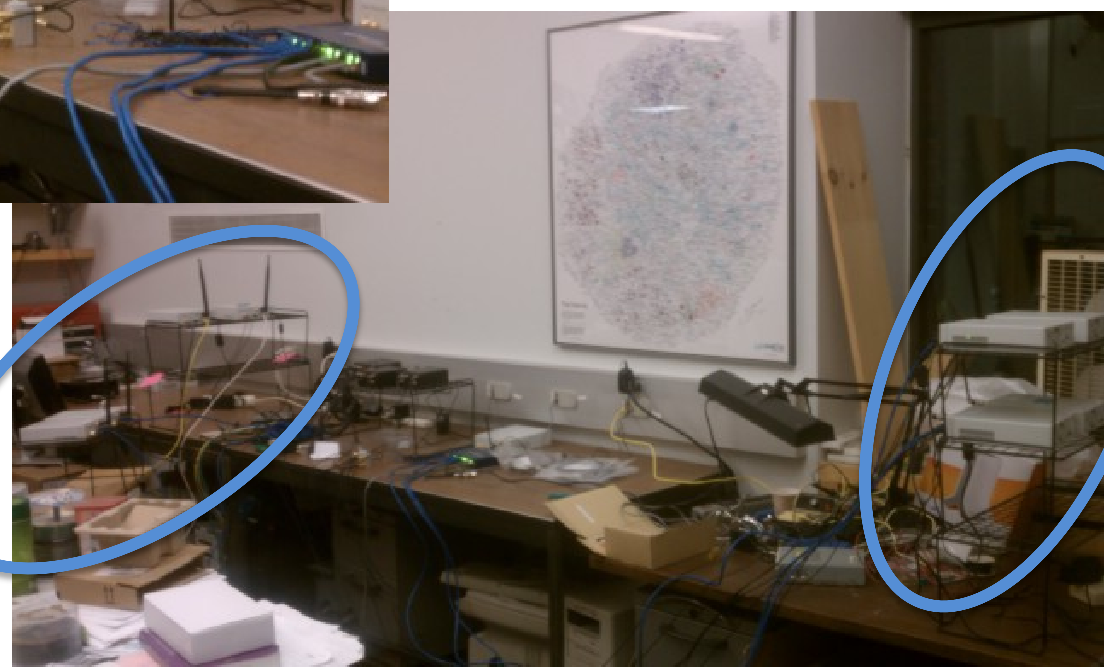
System Evaluation with a Software Defined Radio Testbed



10MHz clock to synchronize USRPs

USRP-N200 operates at 916MHz, 6.25MHz bandwidth MIMO-OFDM

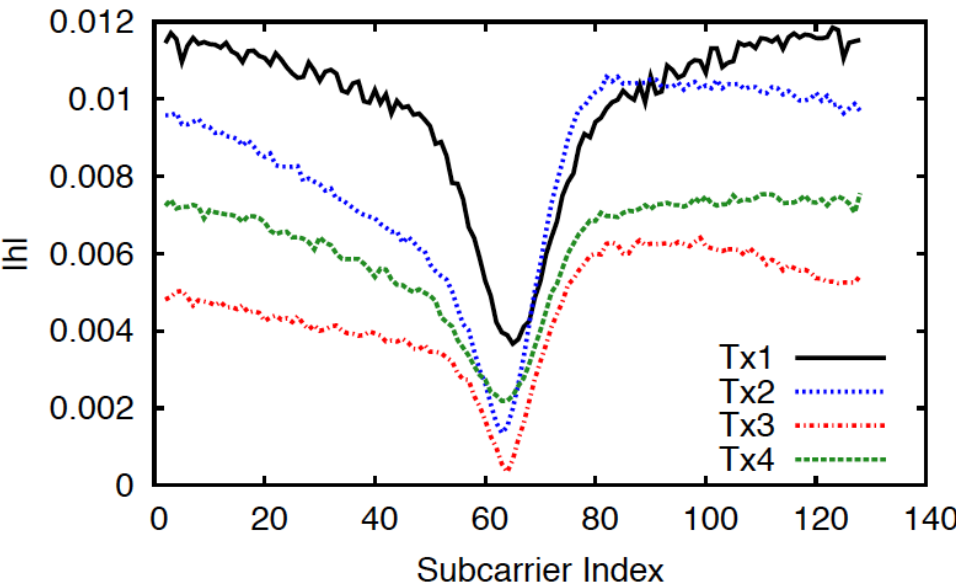
4 USRPs as four distributed users



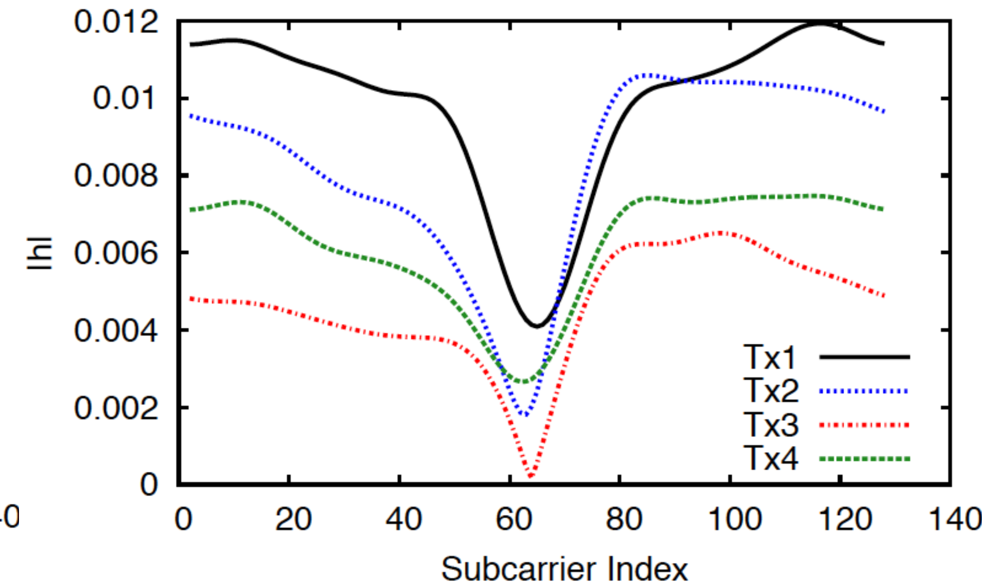
4 synchronized USRPs as one AP

Concurrent Channel Estimation vs. Sequential Channel Estimation

Clean, sequential preamble



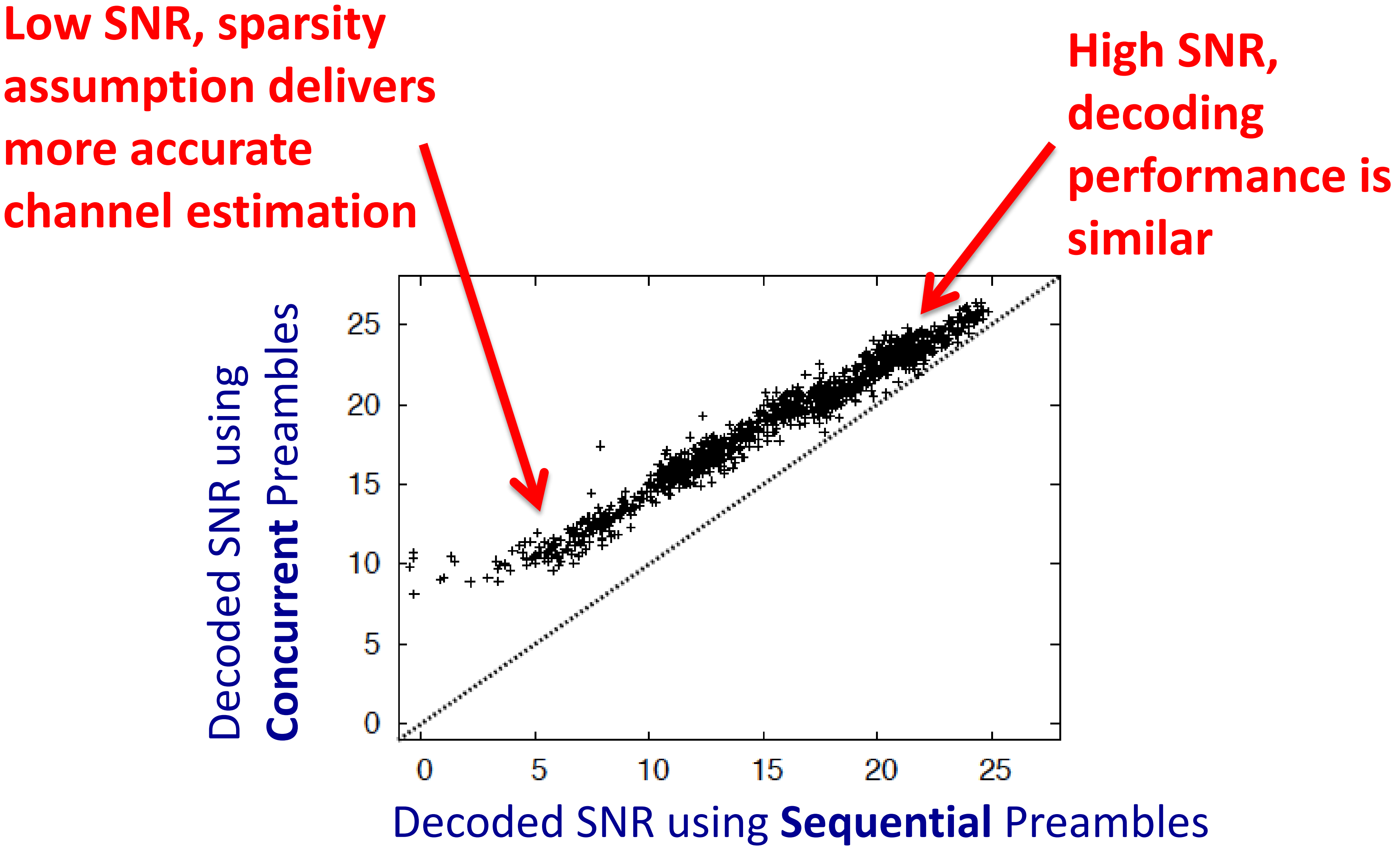
Concurrent preamble



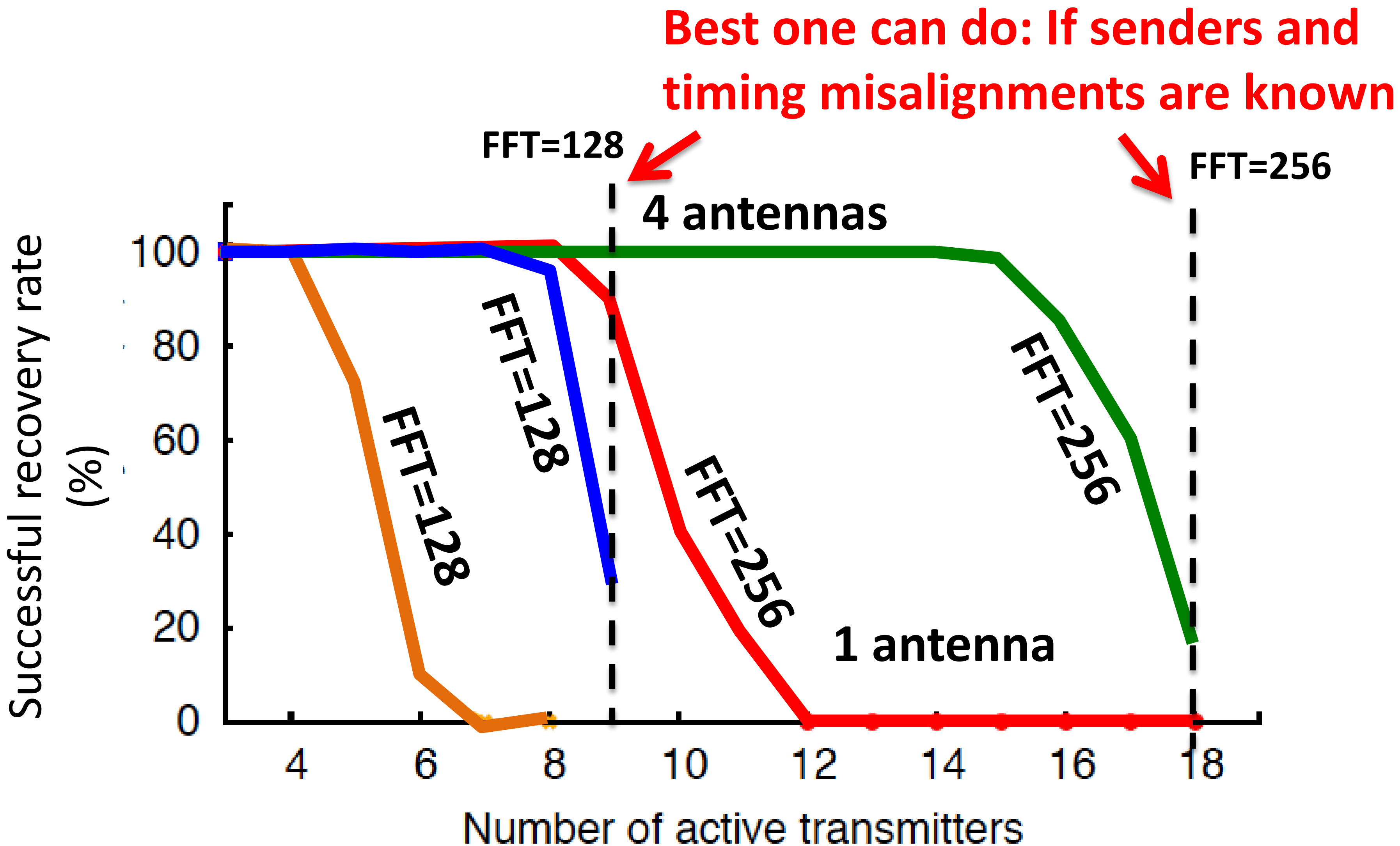
USRP-N200, 4x4 MIMO
6.25MHz Bandwidth
13 taps

Sparsity constraint removes unwanted noise

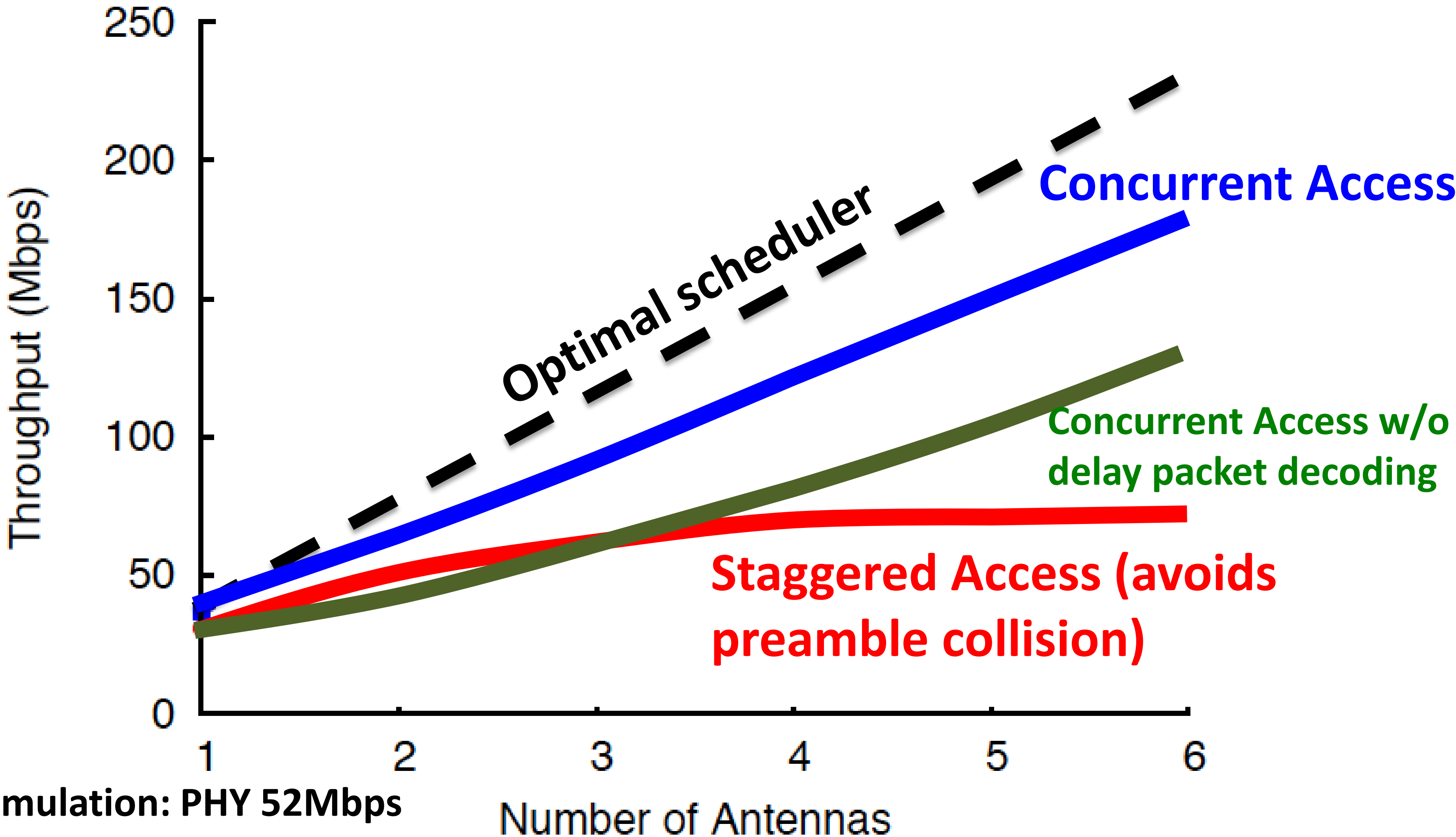
4x4 MIMO Decoding Performance



Number of Active Transmitters a Preamble Length Can Support

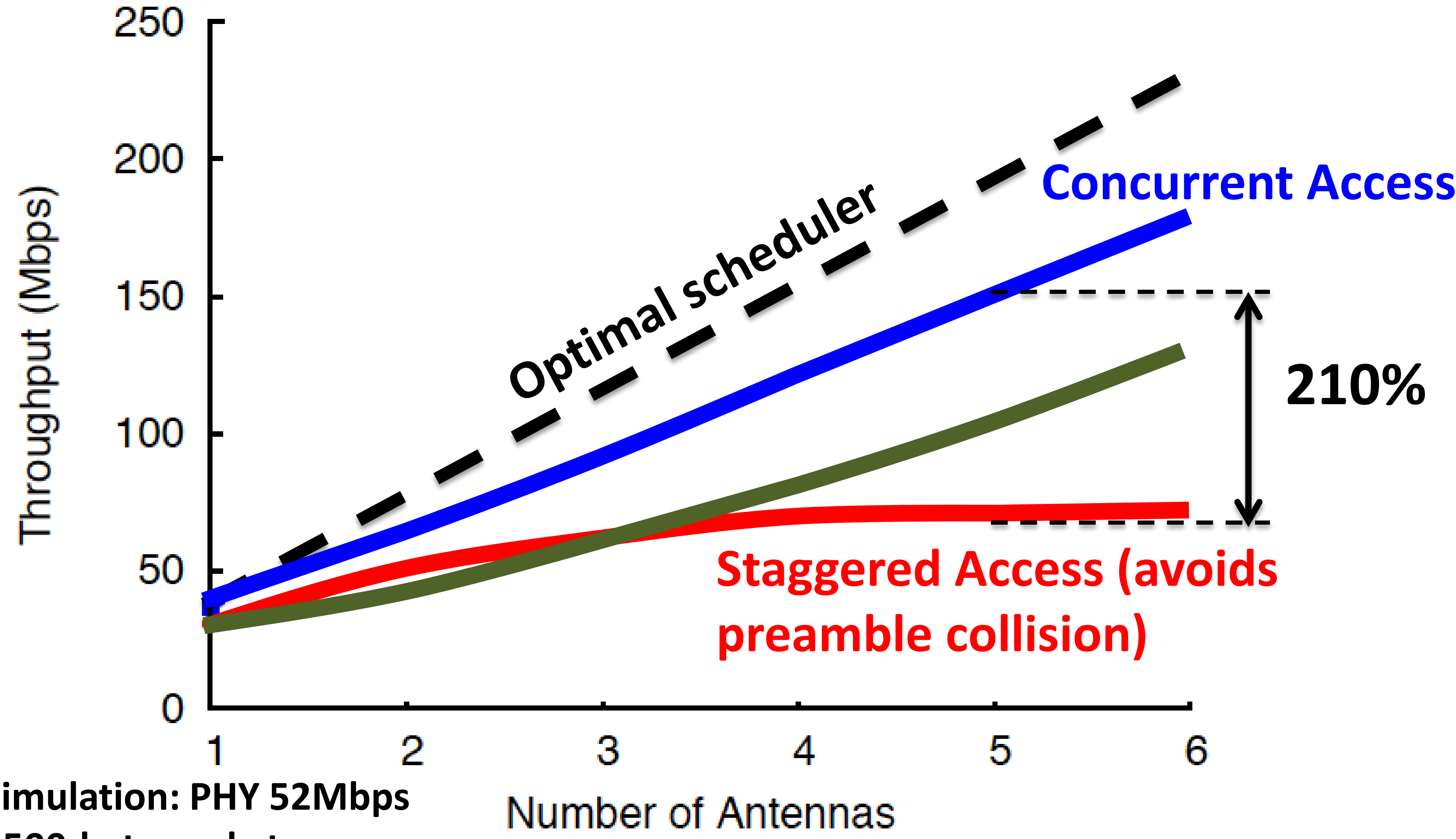


Aggregated Throughput Improvement



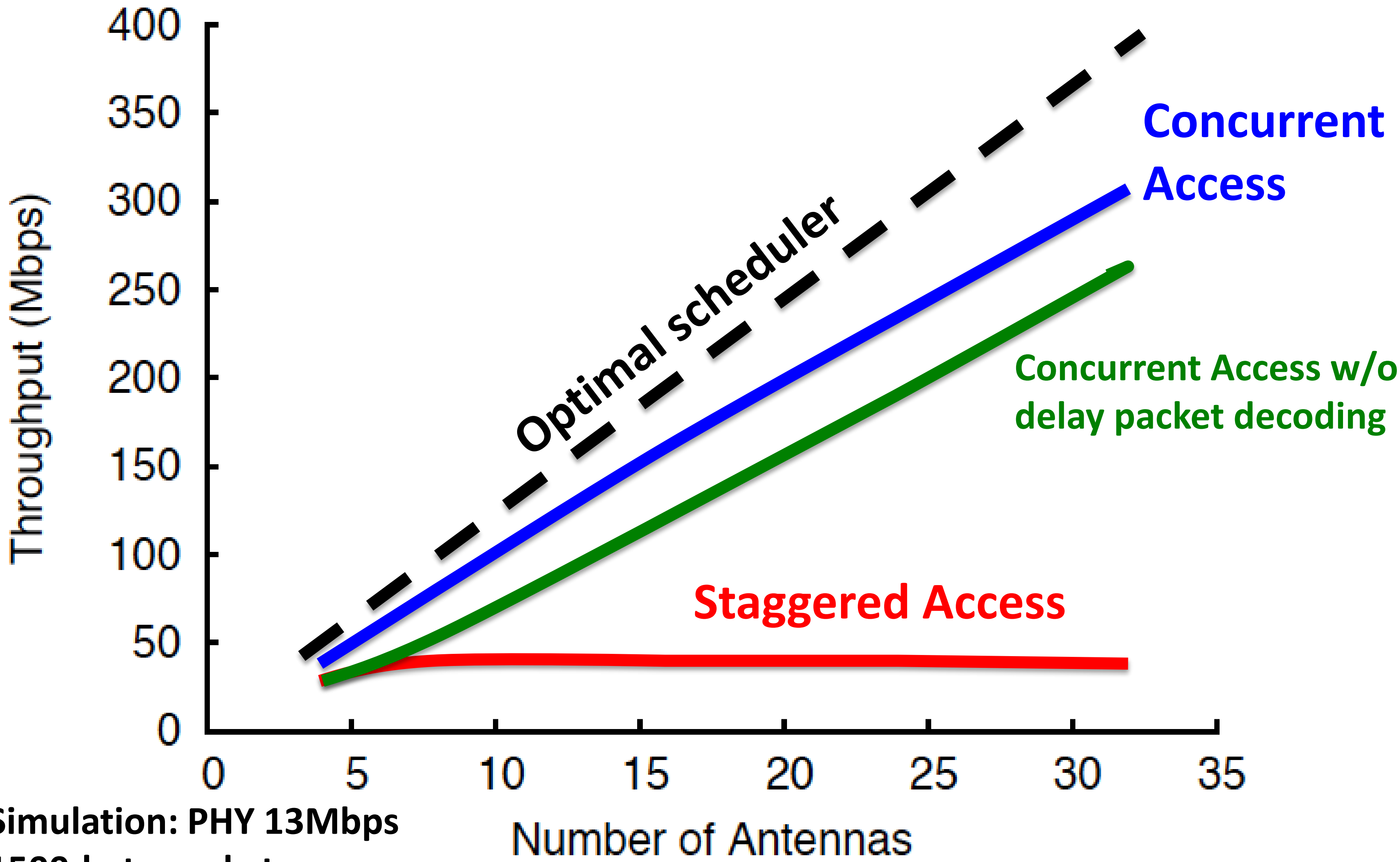
Simulation: PHY 52Mbps
1500-byte packet

Aggregated Throughput Improvement



Simulation: PHY 52Mbps
1500-byte packet

Throughput Scalability



Simulation: PHY 13Mbps
1500-byte packet

Conclusion

- Concurrent access allows efficient and scalable multiuser MIMO networking without strict synchronization and coordination
- Key enabling techniques
  - Compressive sensing to relax synchronization and coordination
  - Delay packet decoding to tolerate demand fluctuation in random access