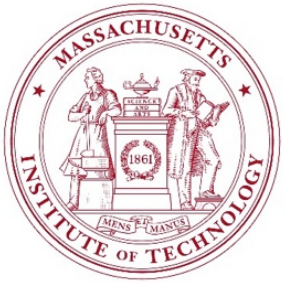
Rate Adaptation for Multiuser MIMO Networks

Wei-Liang Shen , Yu-Chih Tung , Kuang-Che Lee,
Kate Lin and Ming-Syan Chen

Academia Sinica, Taiwan

Shyamnath Gollakota
Univ. of Washington

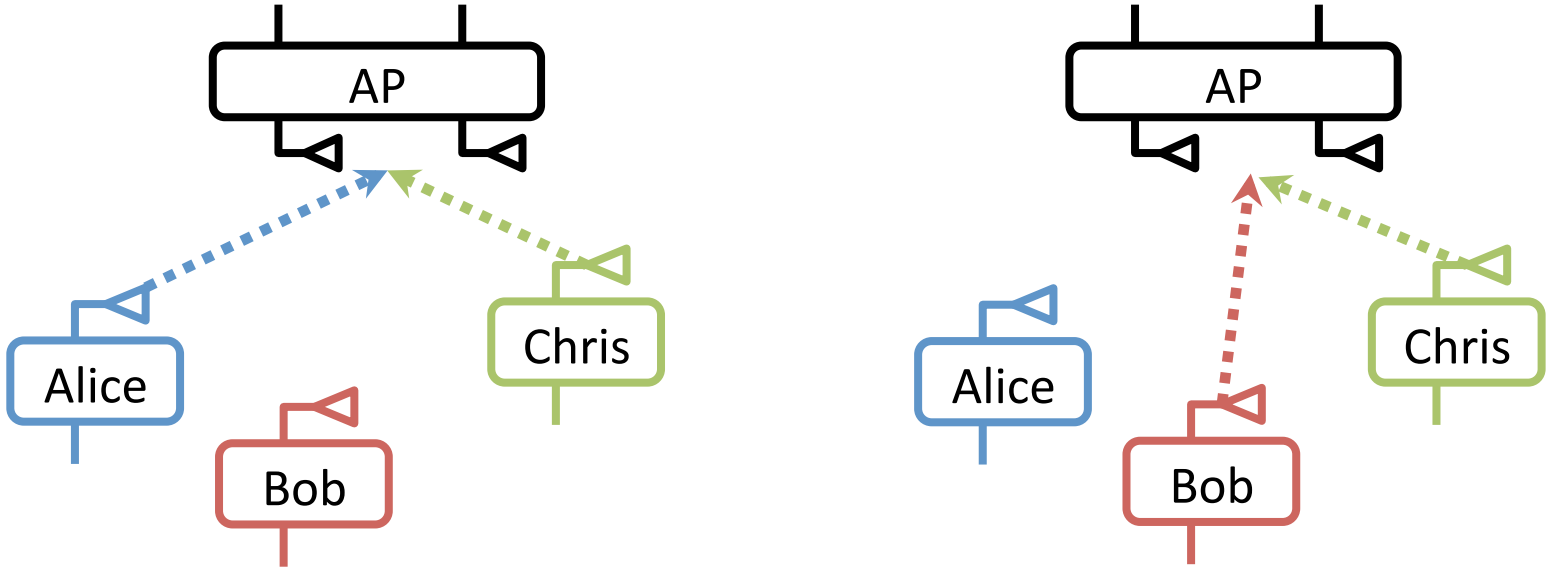
Dina Katabi
MIT



Multiuser MIMO Allows Concurrent Streams

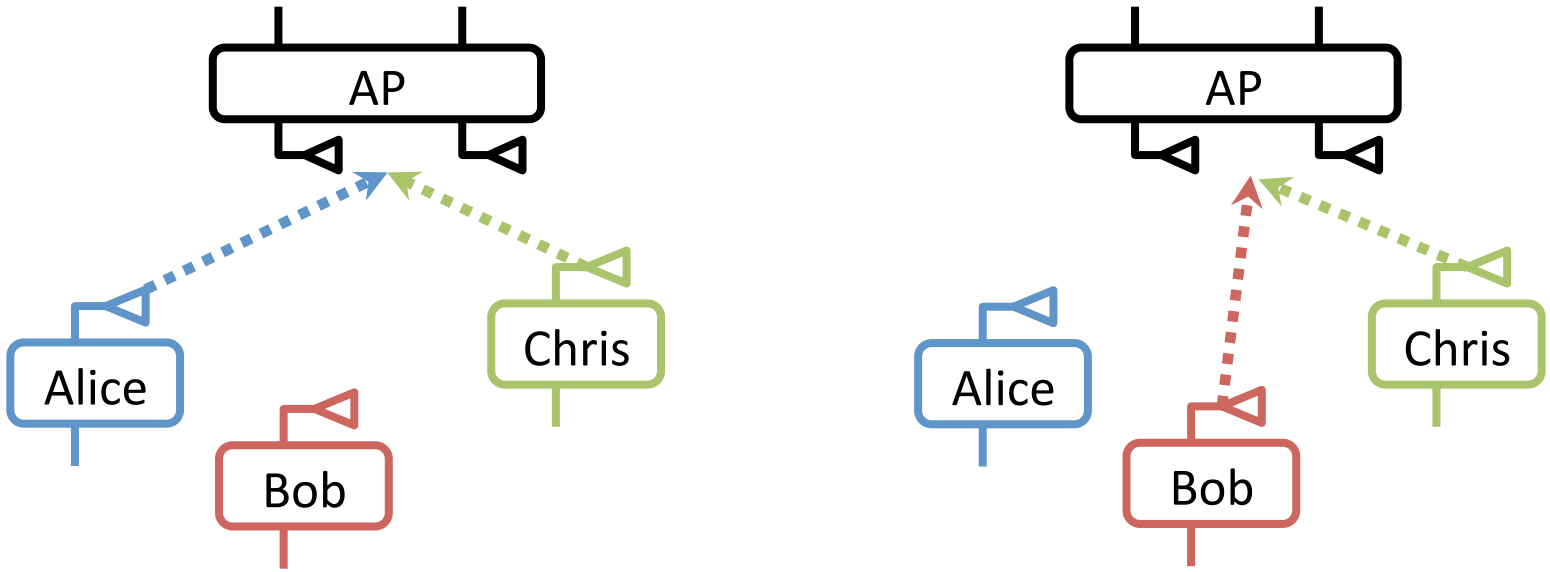
Clients contend for concurrent transmissions opportunities [K. Tan,MOBICOM'09]

A Client Could Transmit Concurrently With Different Clients



Traditional historical-based rate adaptation doesn't work → **Why?**

Best Rate Changes with Concurrent Client



- Chris's best-rate depends on
- but also Alice's/Bob's channel

Chris's best rate also changes packet to packet

Goal

Enable clients to adapt their rates
on a per-packet basis

TurboRate

TurboRate

- Allow clients to adapt their best rates by

  1. reacting to interaction between concurrent clients
  2. learning their rates passively without coordination

- Implemented and shown to deliver the gain of multiuser MIMO (MU-MIMO)

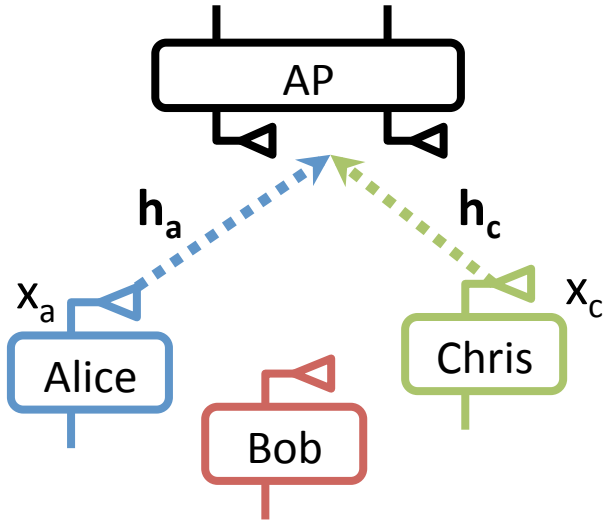
TurboRate

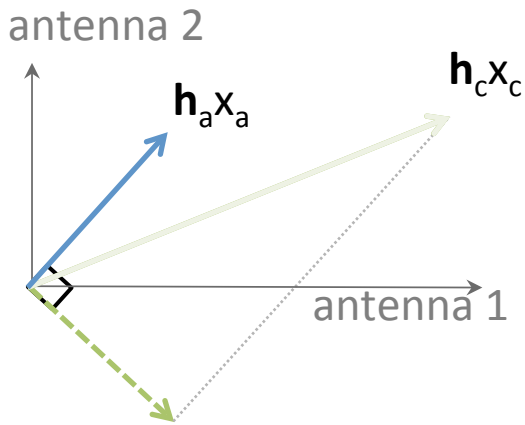
- Allow clients to adapt their best rates by

1. reacting to interaction between concurrent clients
2. learning their rates passively without coordination

How Concurrent Clients Interact?

How Does the AP Decode Streams? ZF-SIC





Decode Chris by Zero-Forcing (ZF)

- Project orthogonal to Alice

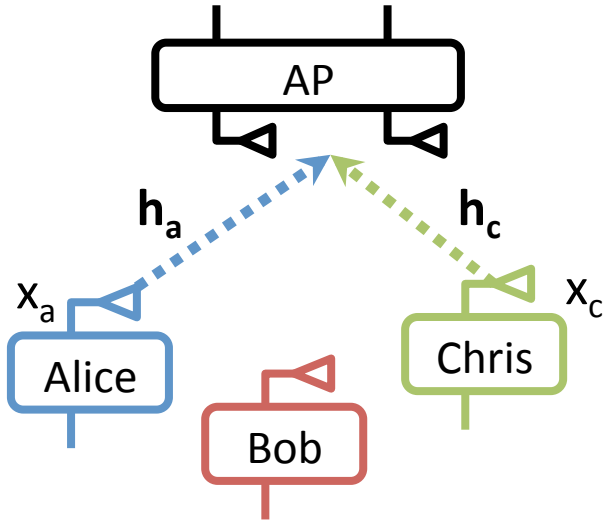
Decode Alice by Successive Interference Cancelation (SIC)

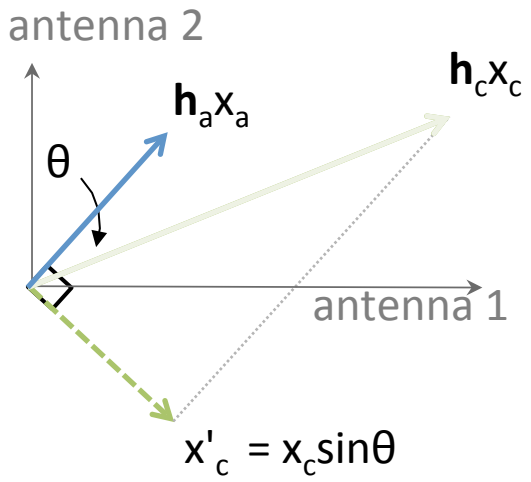
- Remove Chris's interfering signal

Alice can only be decoded if Chris is decoded correctly

How Concurrent Clients Interact?

How Does the AP Decode Streams? ZF-SIC





Decode Chris by Zero-Forcing (ZF)

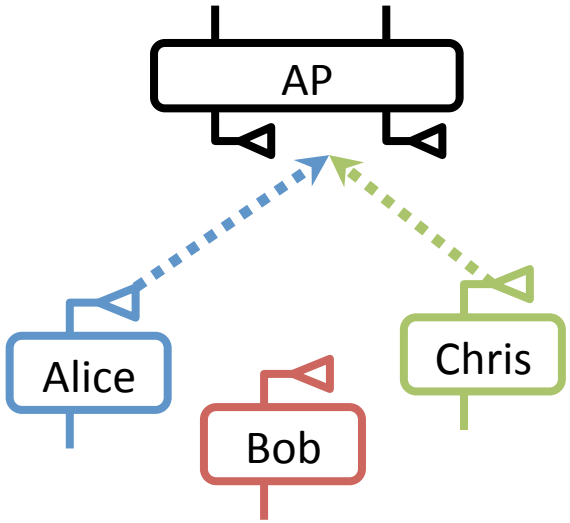
- Project orthogonal to Alice

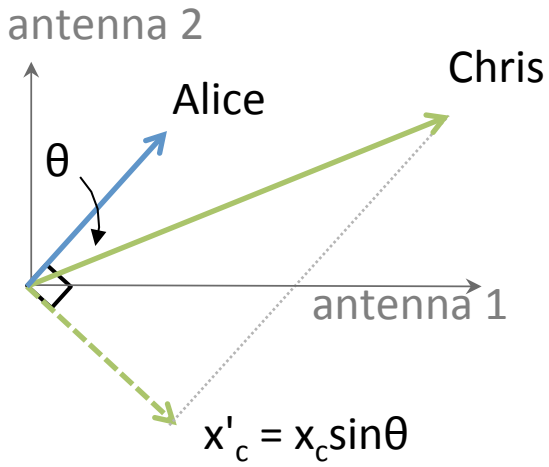
Decode Alice by Successive Interference Cancelation (SIC)

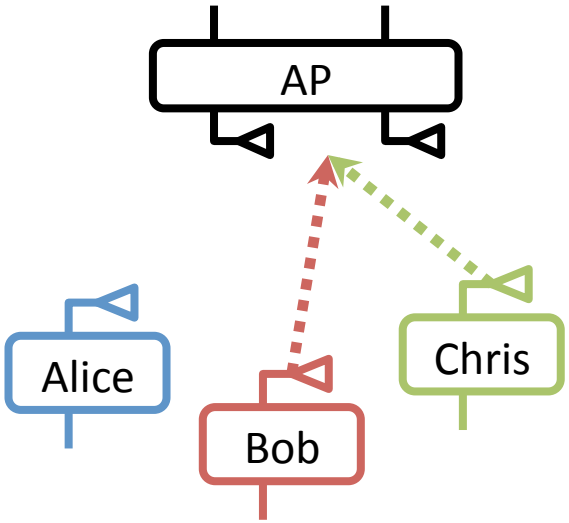
- Remove Chris's interfering signal

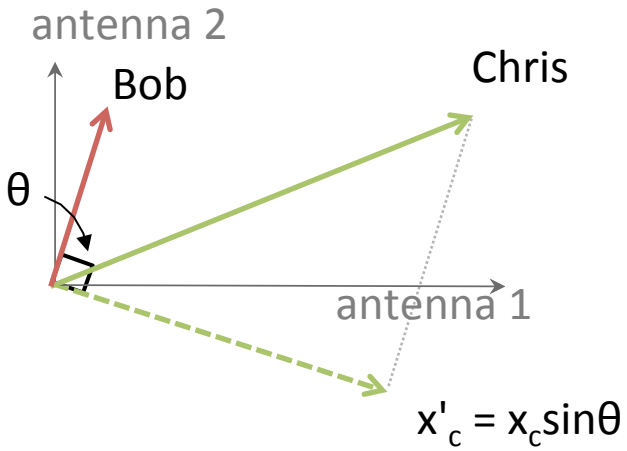
SNR reduction after projection

Concurrent Client Might Change



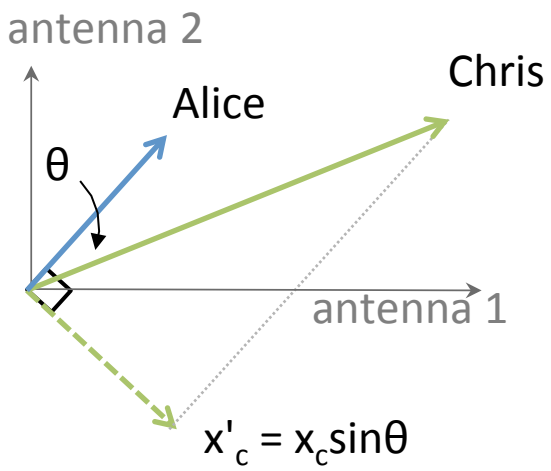




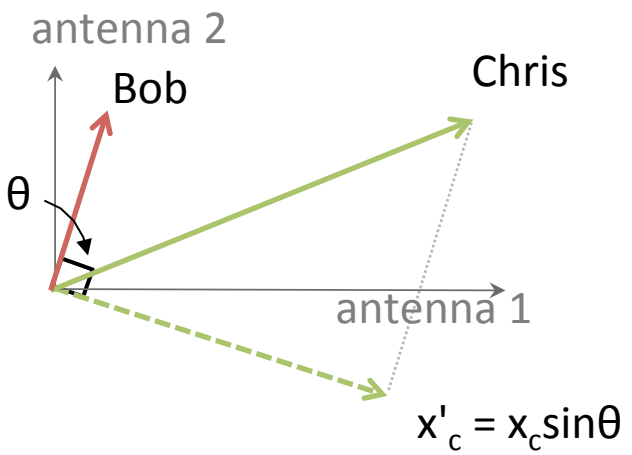


SNR_{proj} Changes with Concurrent Client

Select a lower bit-rate

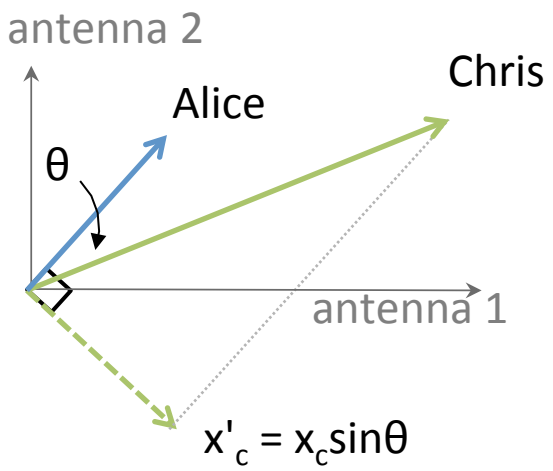


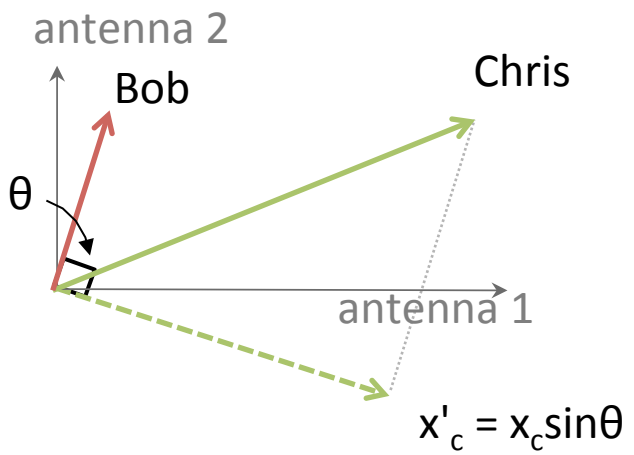
Select a higher bit-rate



Per-Packet Bit-Rate Selection

- Map SNR_{proj} to the best bit-rate
  - ESNR-based rate adaptation [D. Halperin, SIGCOMM'10]





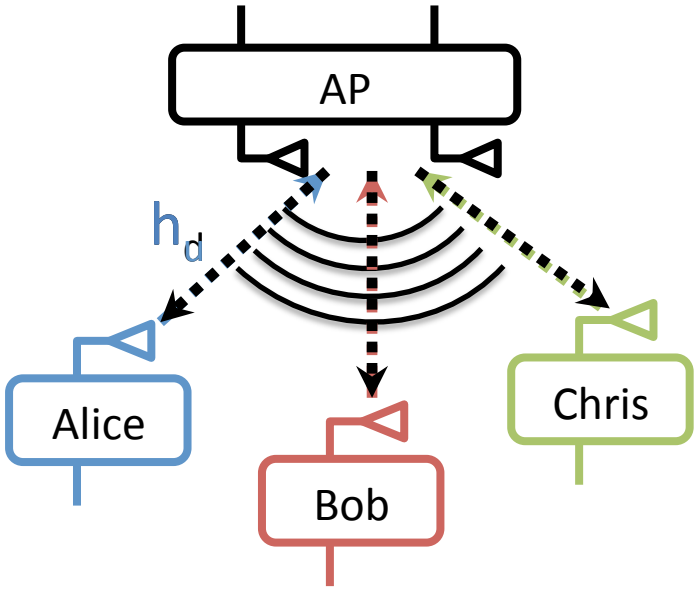
TurboRate

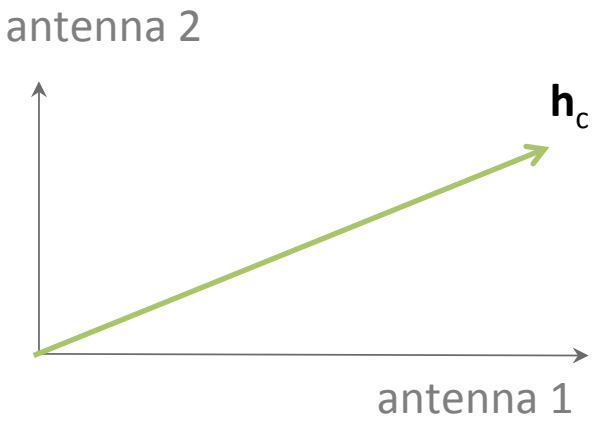
- Allow clients to adapt their best rates by

1. reacting to interaction between concurrent clients
2. learning their rates passively without coordination
   - the original SNR
   - the inter-client angle

1. Each Client Learns Its SNR_{orig}

- Leverage channel reciprocity
  - Forward channel = Reverse channel
- Estimate the uplink channel from AP's beacons
  - Compute the direction and amplitude (SNR_{orig})



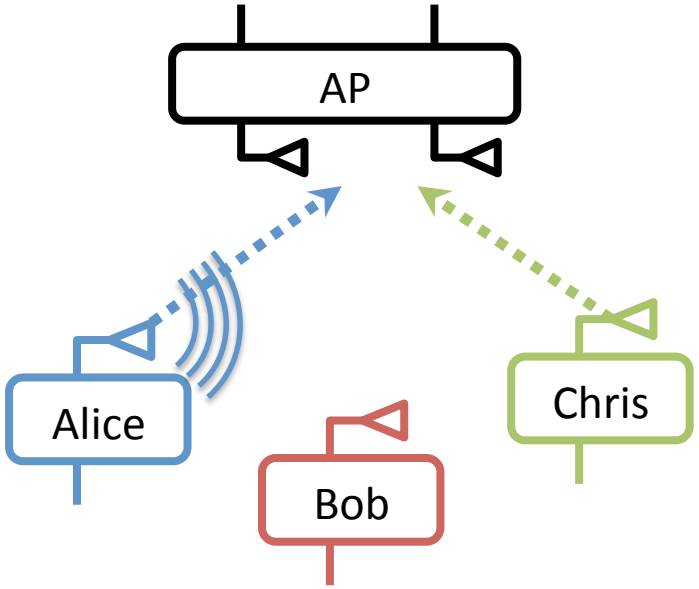


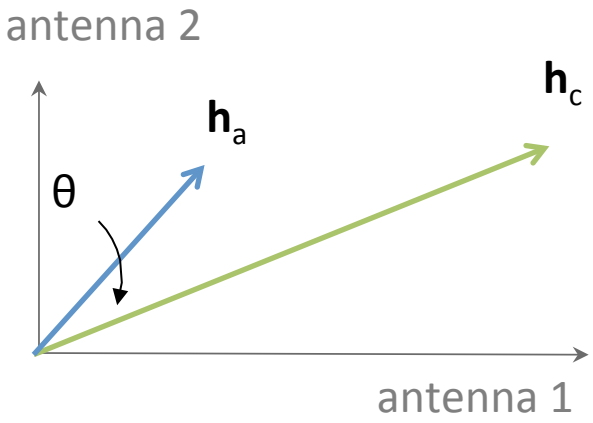
2. Learn Inter-Client Angle (θ)

Say Chris wants to learn the angle between two signals

- Learn his own channel
- Learn the direction of ongoing streams

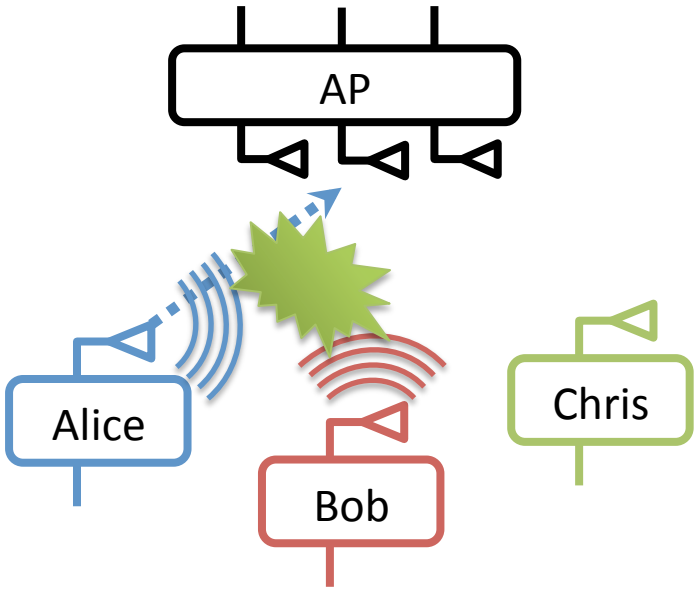
SNR_{proj} can be predicted by SNR_{orig} and inter-client angle



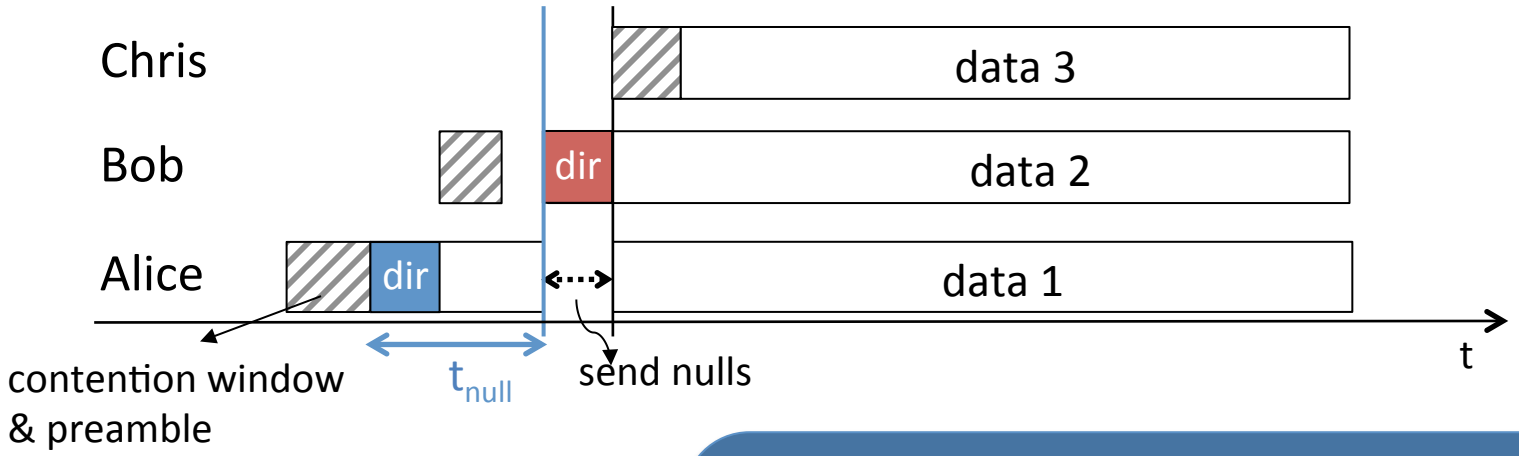


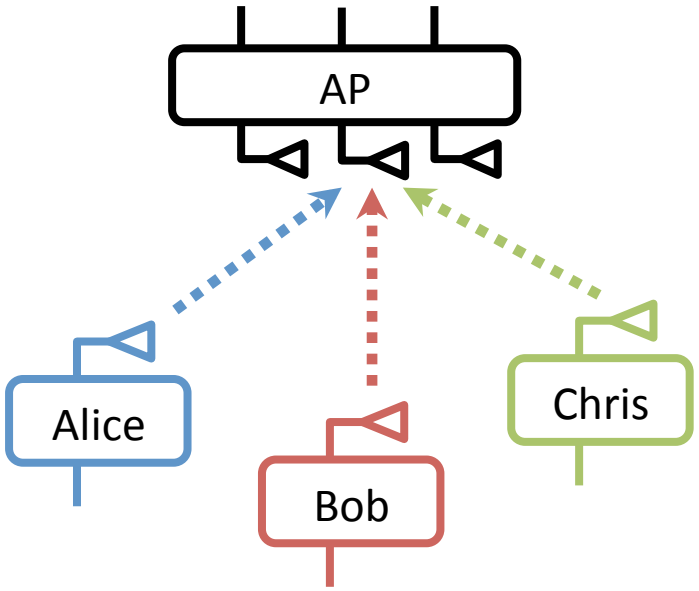
Doesn't Work for More Than 2 Antennas

- Both Bob and Chris can overhear Alice's direction
- Chris cannot decode Bob in the presence of Alice's signal



How to Extend to More Than 2 Antennas

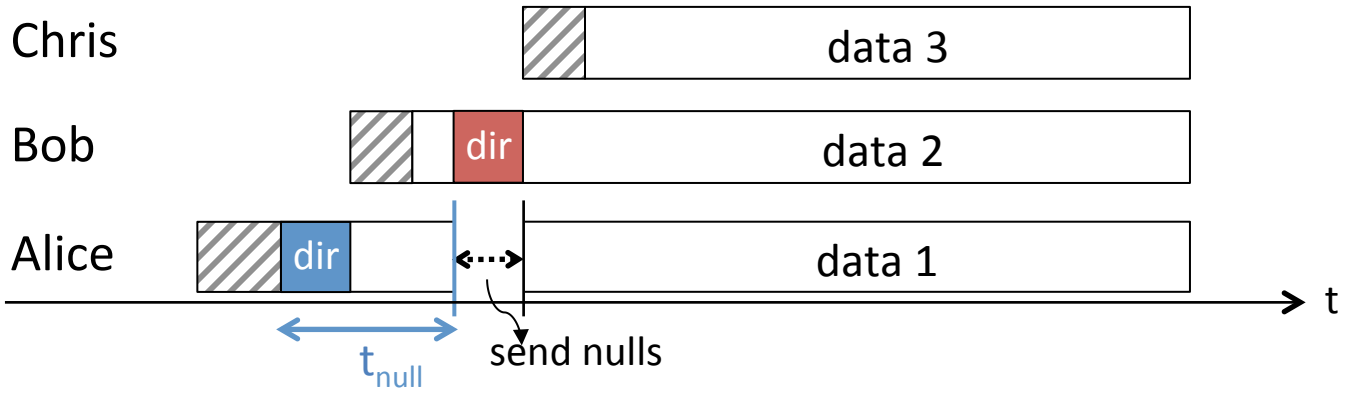




Ongoing transmitters
pause their streams
when later contention winners
announce the directions

TurboRate's MAC

- Alice wins the 1st contention
  - select the rate based on SNR_{orig}
  - broadcast her direction and pause transmission at t_{null}
- Bob wins the 2nd contention
  - select the rate based on SNR_{proj}
  - broadcast his direction
- Chris wins the 3rd contention
  - select the rate based on SNR_{proj}



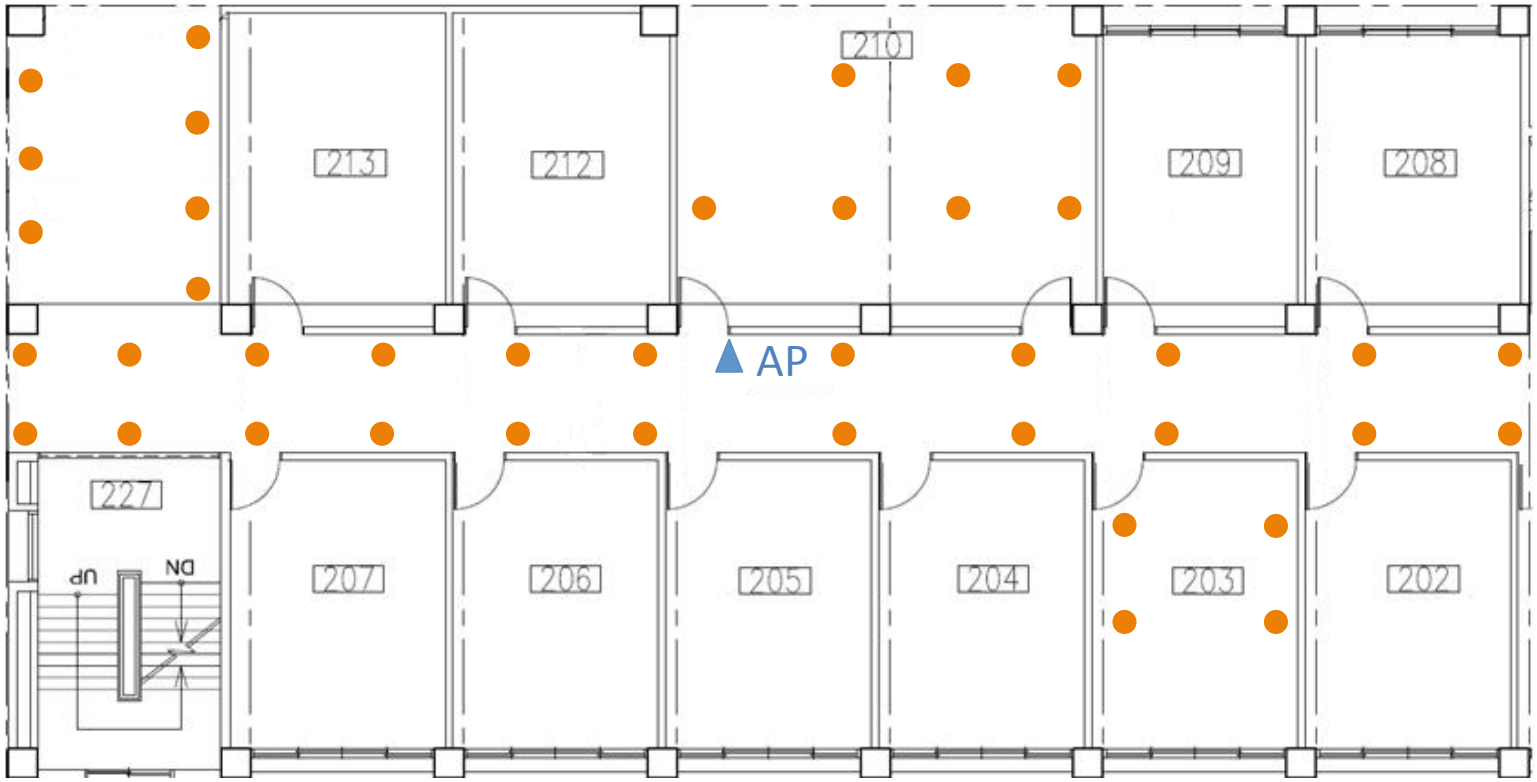
Performance

Implementation

- Implemented in USRP-N200
- OFDM with 802.11-style modulations and convolutional codes

Testbed

Randomly pick a subset of locations for evaluations



1) Is SNR estimation accurate enough?

2) What is the gain achieved by **TurboRate**?

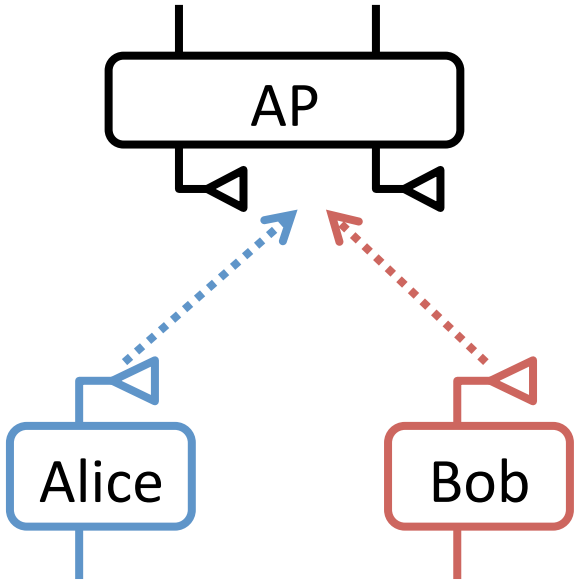
3) Where does the gain come from?

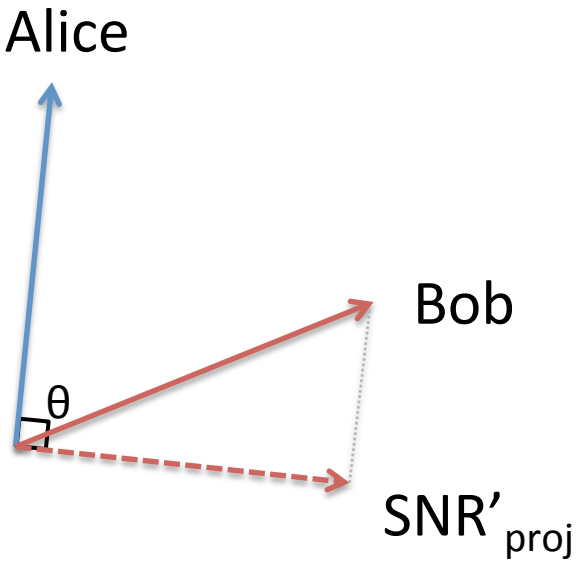
1) Is SNR estimation accurate enough?

2) What is the gain achieved by **TurboRate**?

3) Where does the gain come from?

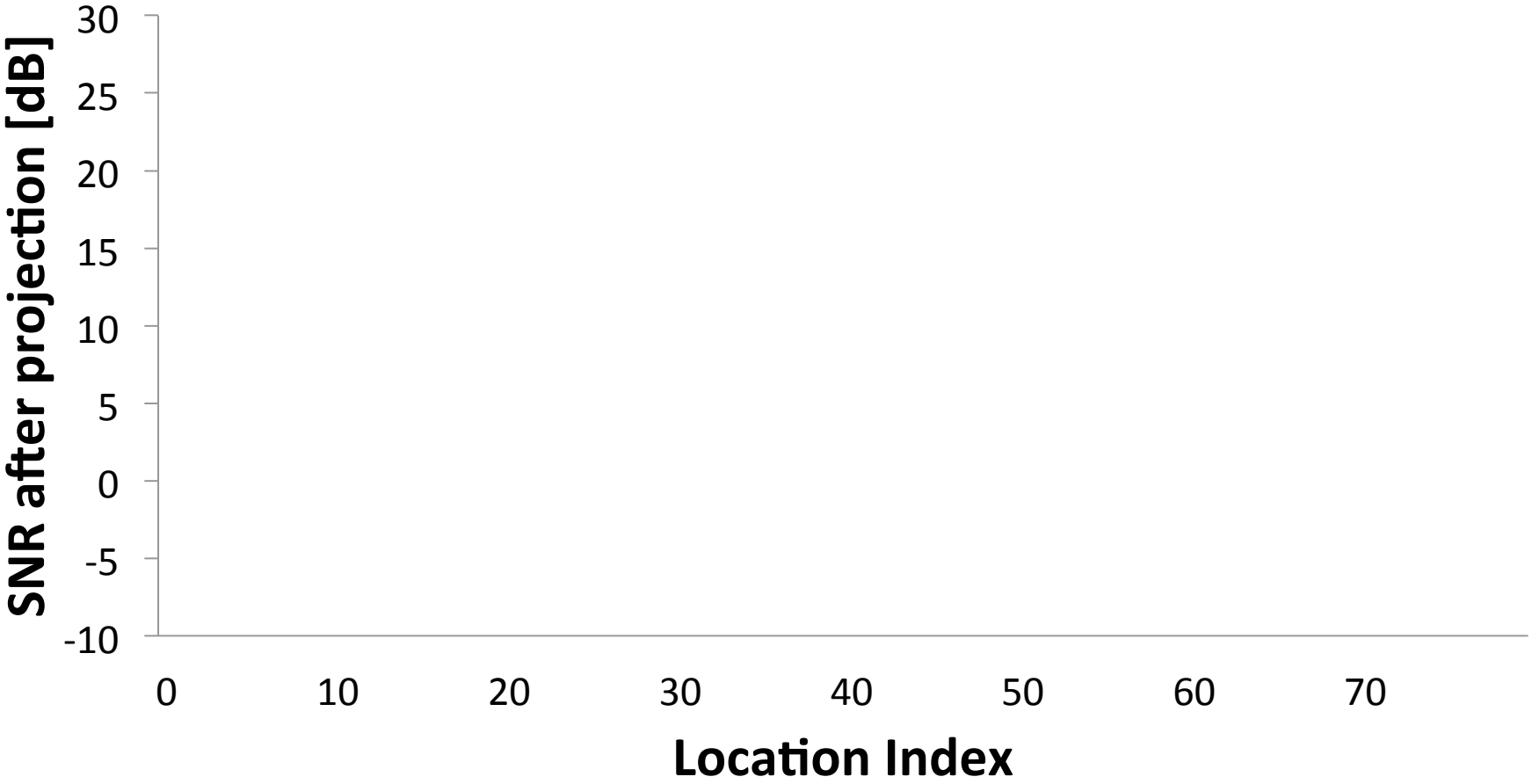
Accuracy of SNR Estimation



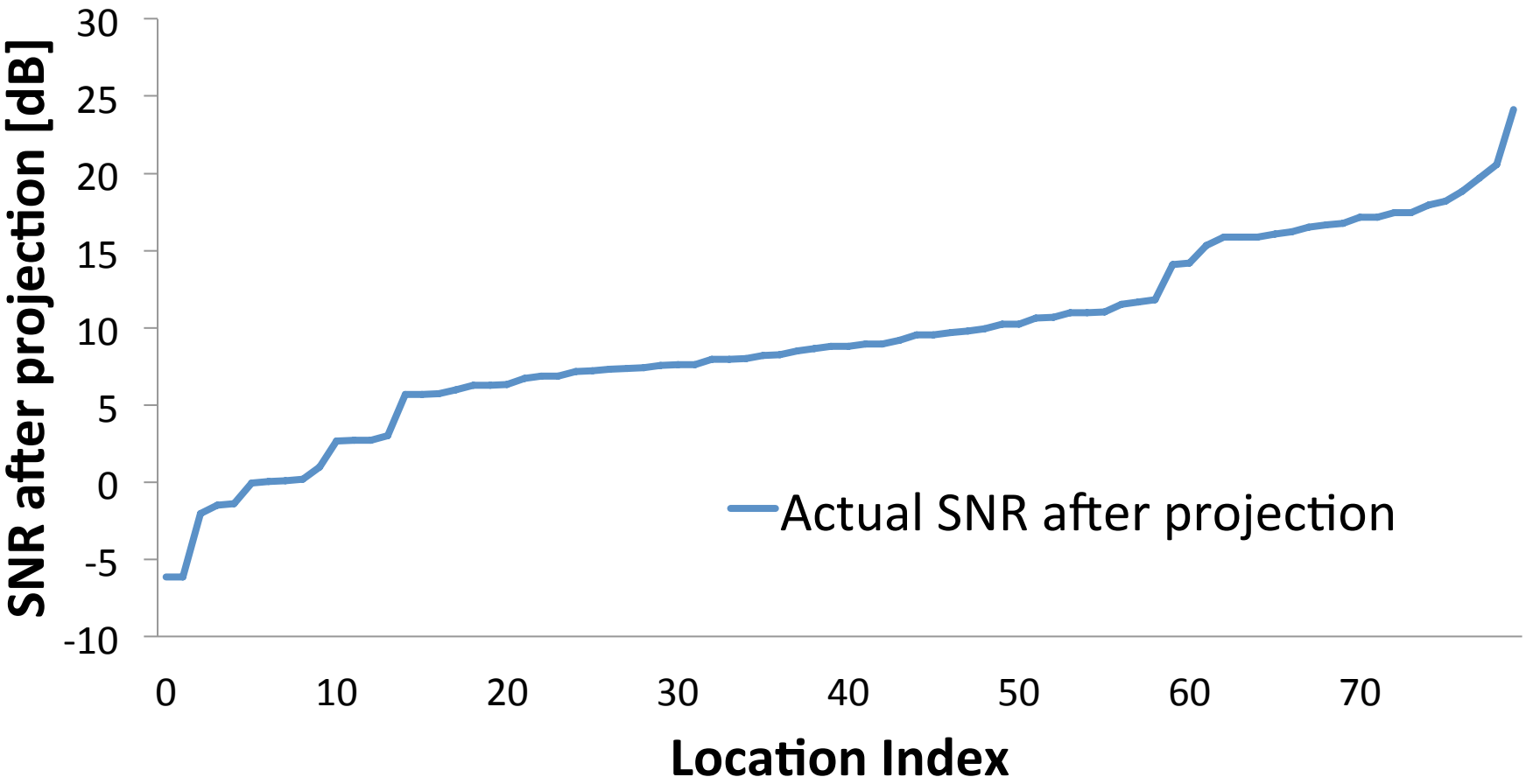


Compare the estimated SNR'_{proj} with the actual SNR_{proj}

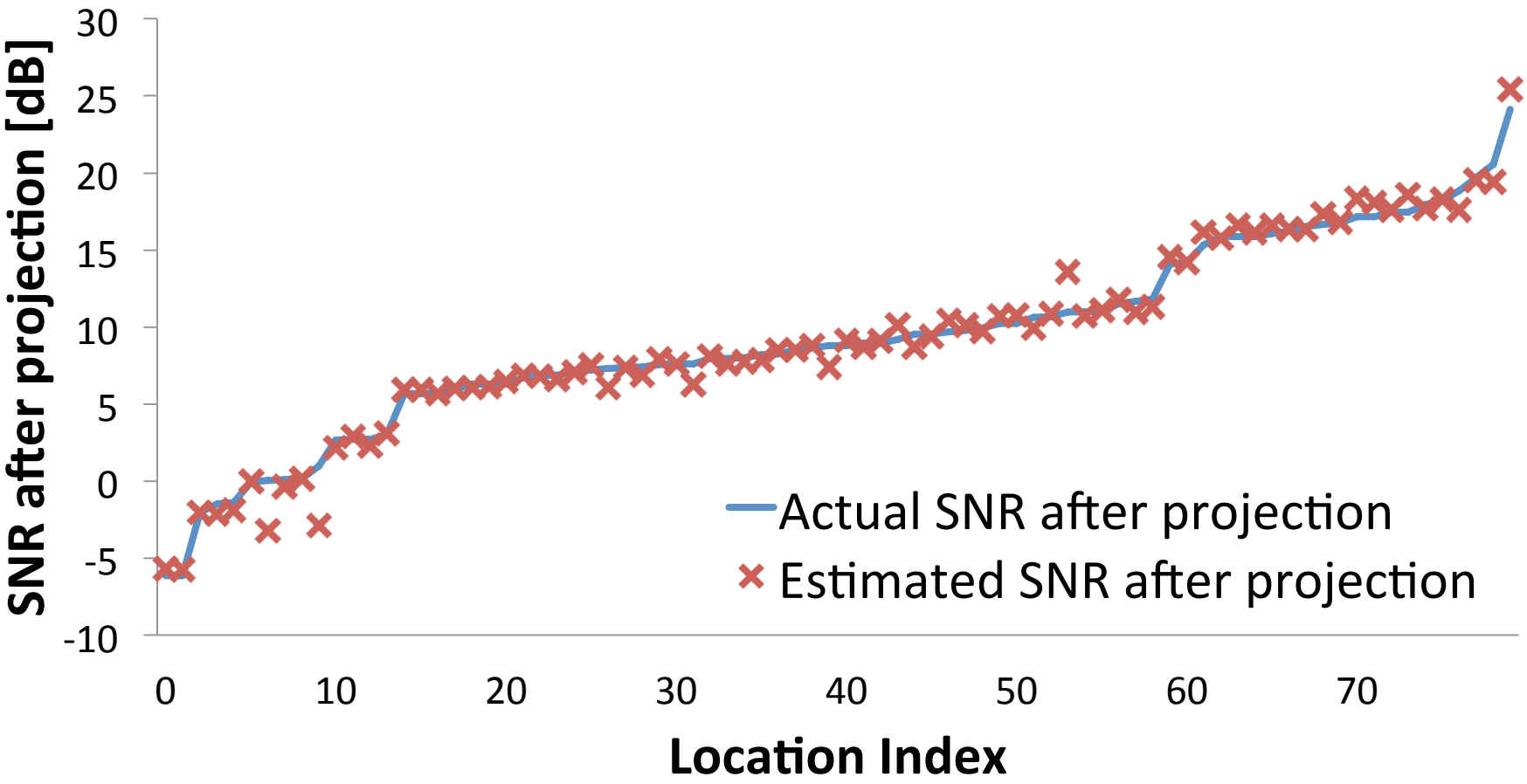
Accuracy of SNR Estimation



Accuracy of SNR Estimation

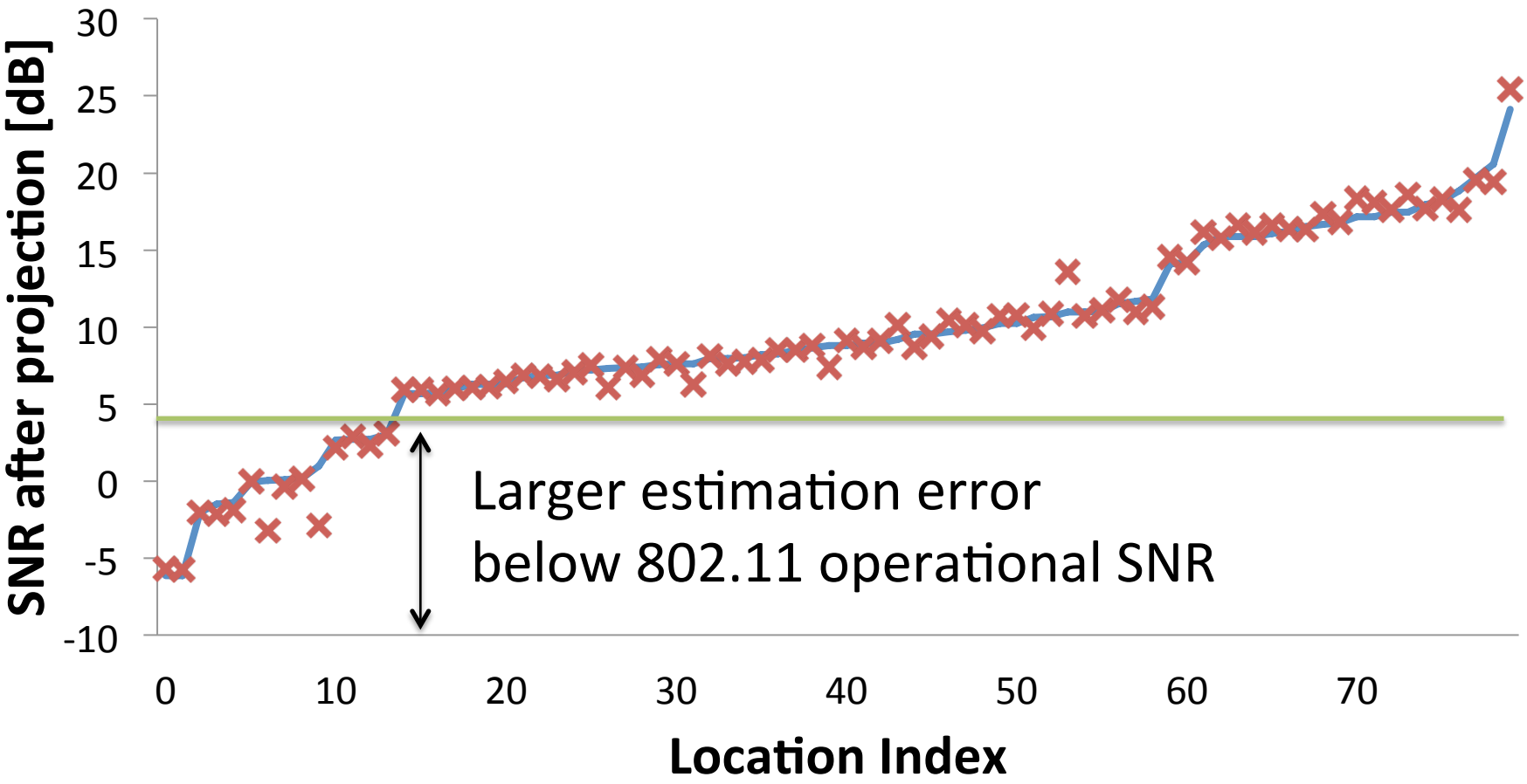


Accuracy of SNR Estimation



Estimated SNR closely matches the actual SNR

Accuracy of SNR Estimation



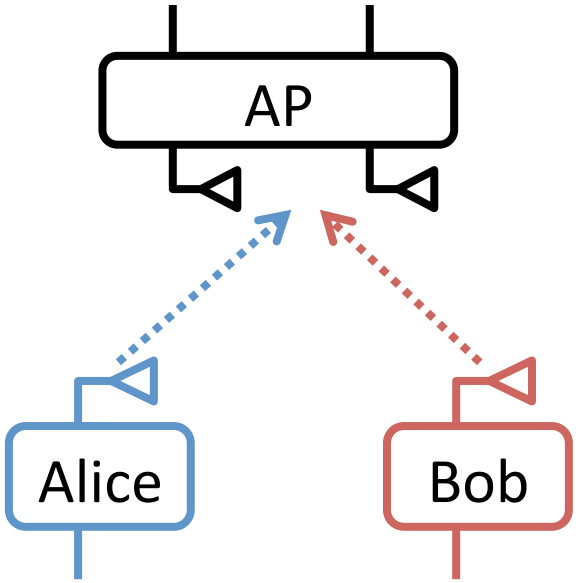
Larger error below 4dB → Avoided by TurboRate

1) Is SNR estimation accurate enough?

2) What is the gain achieved by ***TurboRate***?

3) Where does the gain come from?

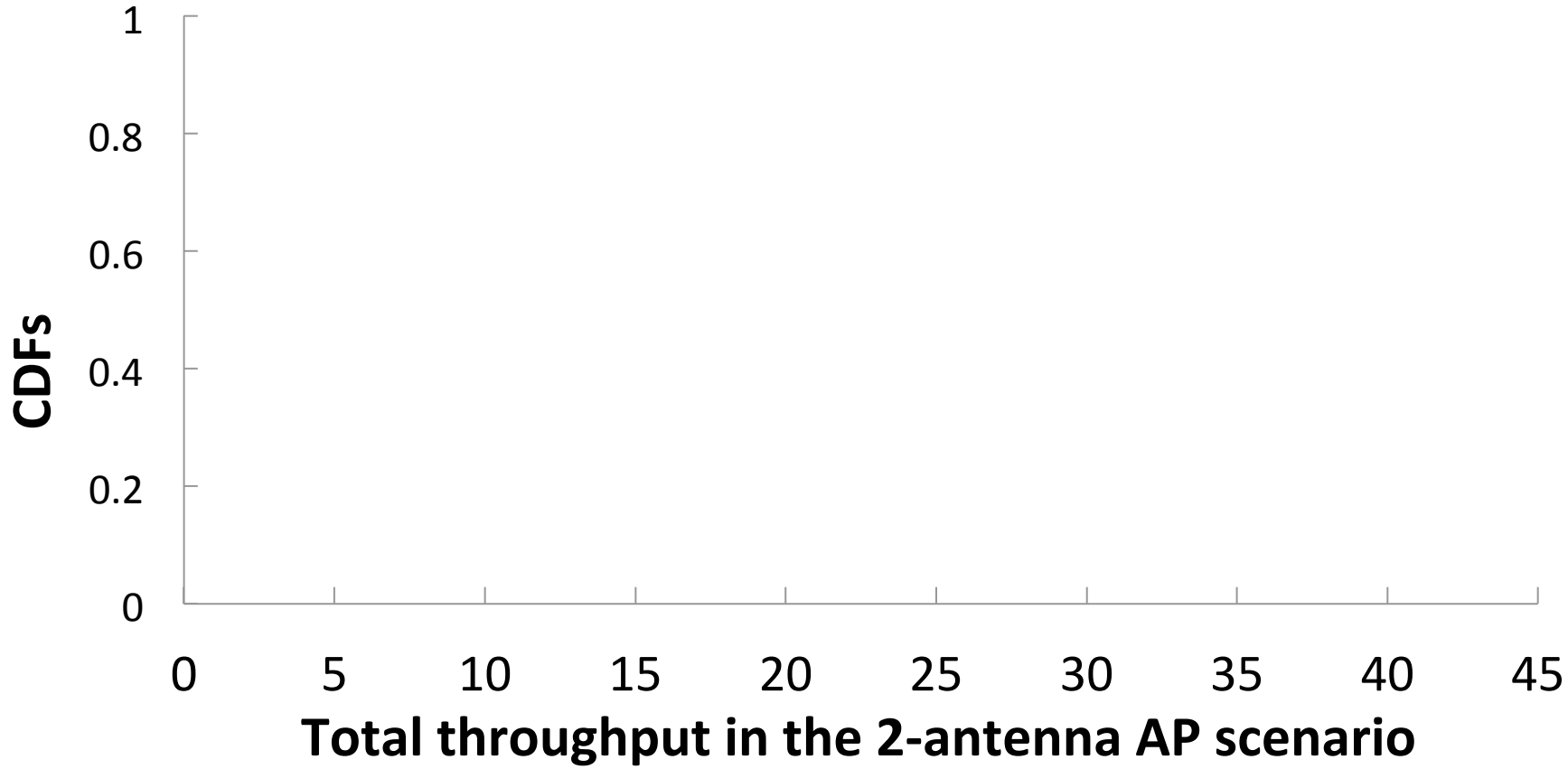
Throughput Gain for 2-Antenna AP



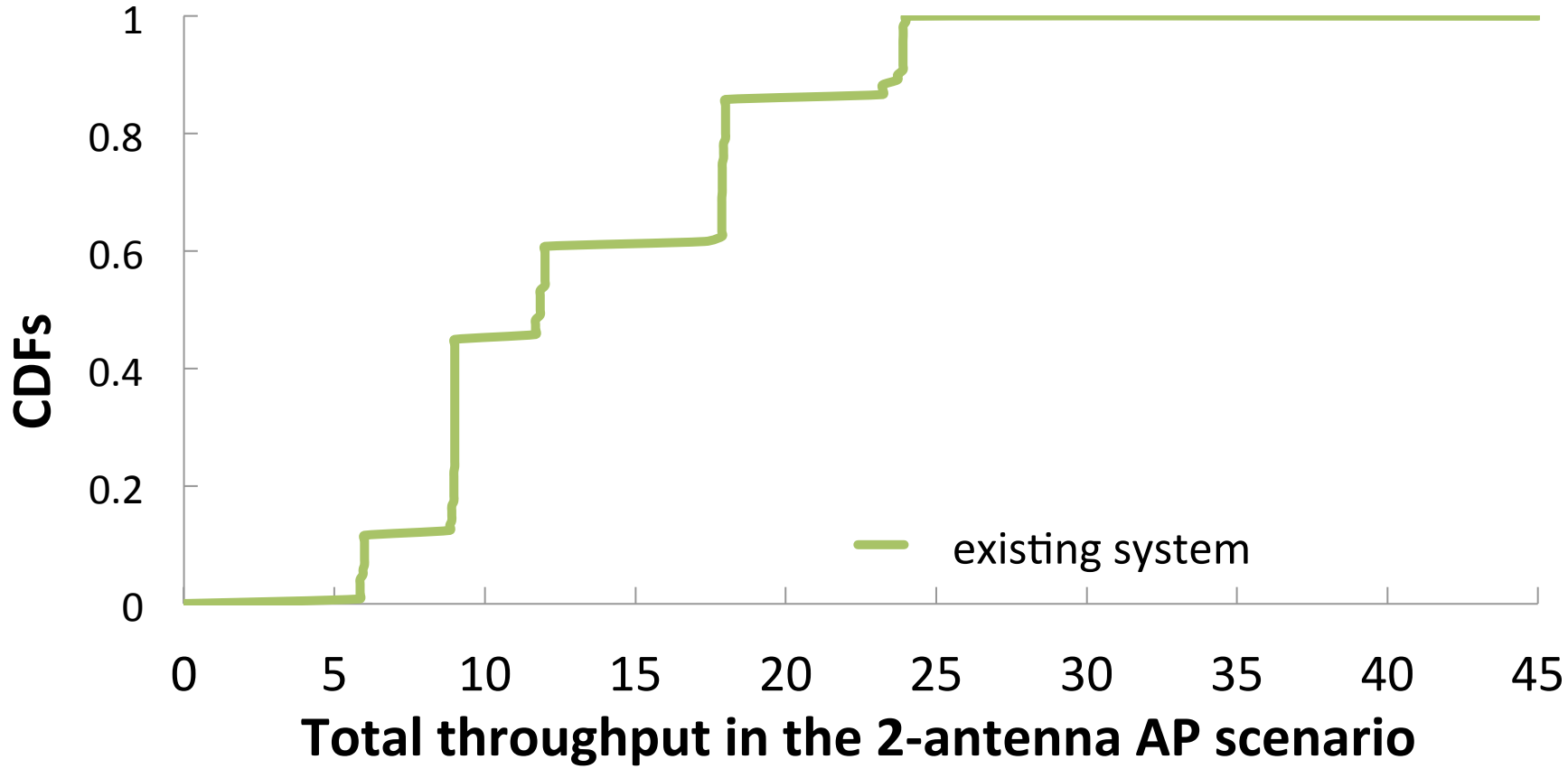
Compare the following schemes

1. Existing 802.11 (single stream)
2. MU-MIMO without TurboRate
3. MU-MIMO with TurboRate

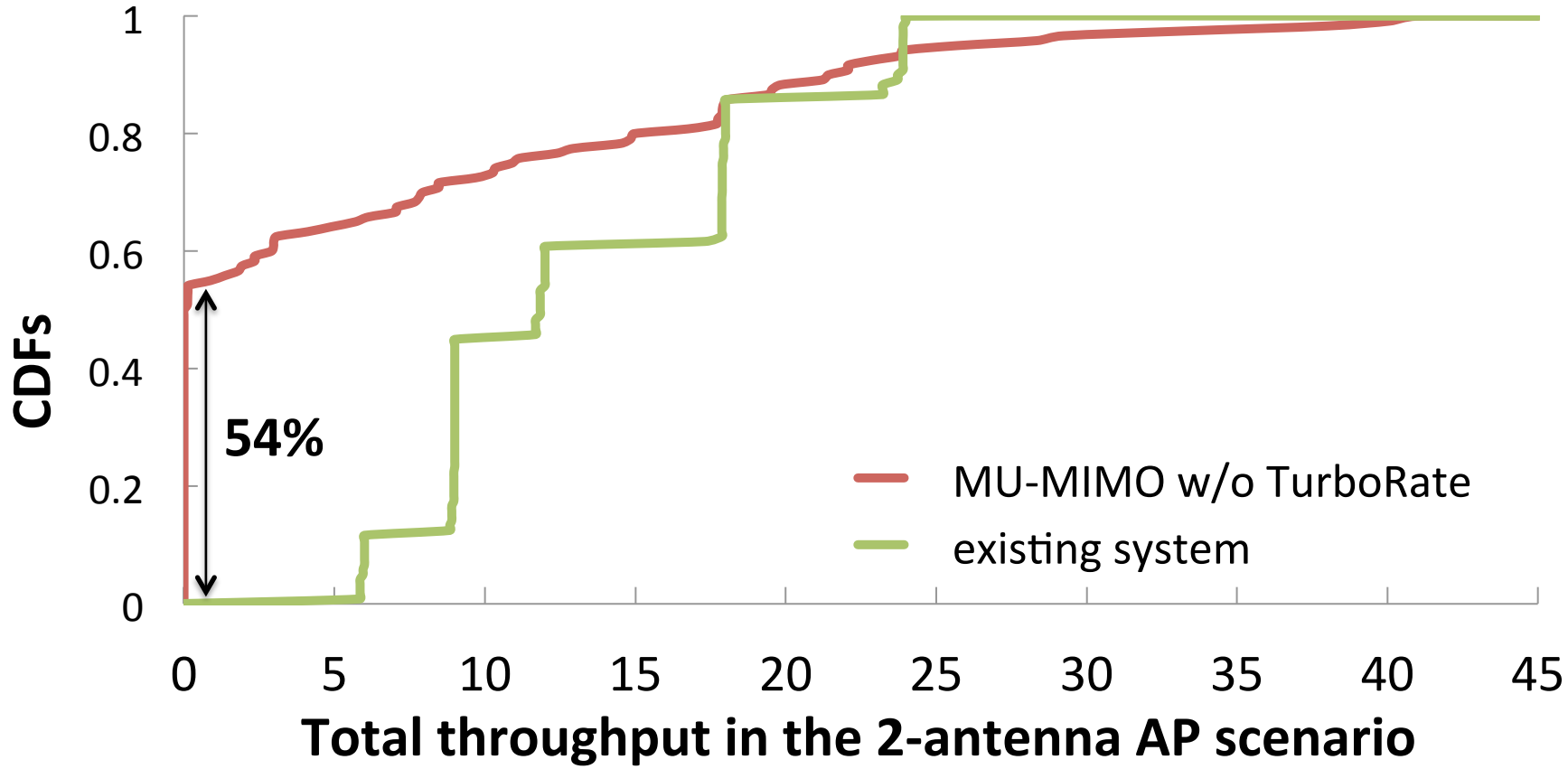
Throughput Gain for 2-Antenna AP



Throughput Gain for 2-Antenna AP

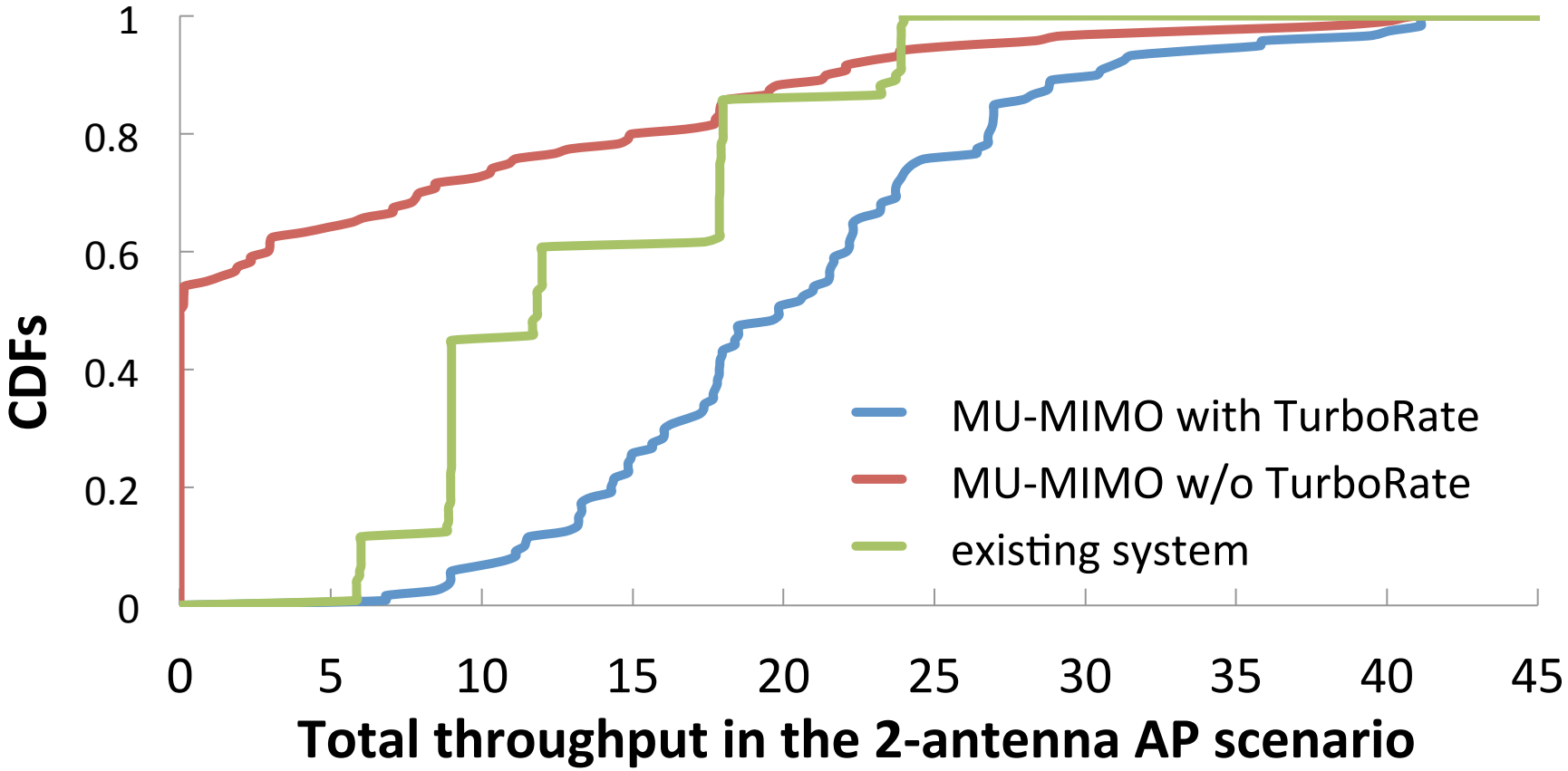


Throughput Gain for 2-Antenna AP



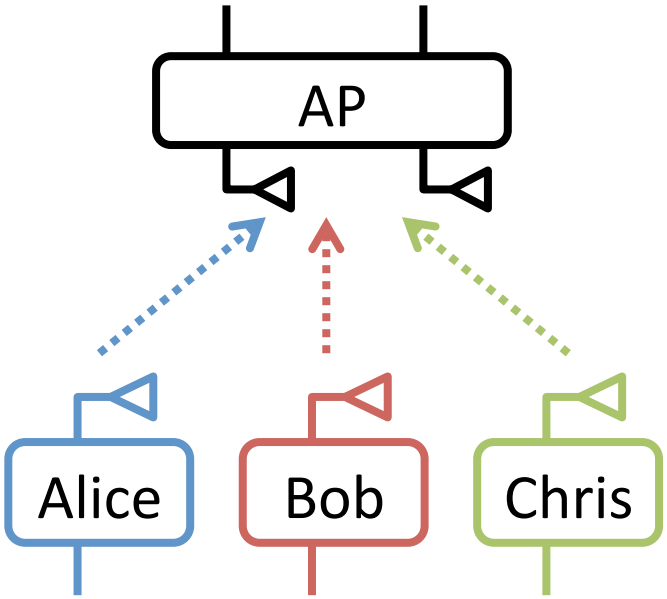
MU-MIMO without rate adaptation
leads to zero throughput for 54% of cases

Throughput Gain for 2-Antenna AP



TuboRate delivers the MU-MIMO gain
→ **1.7x** over 802.11

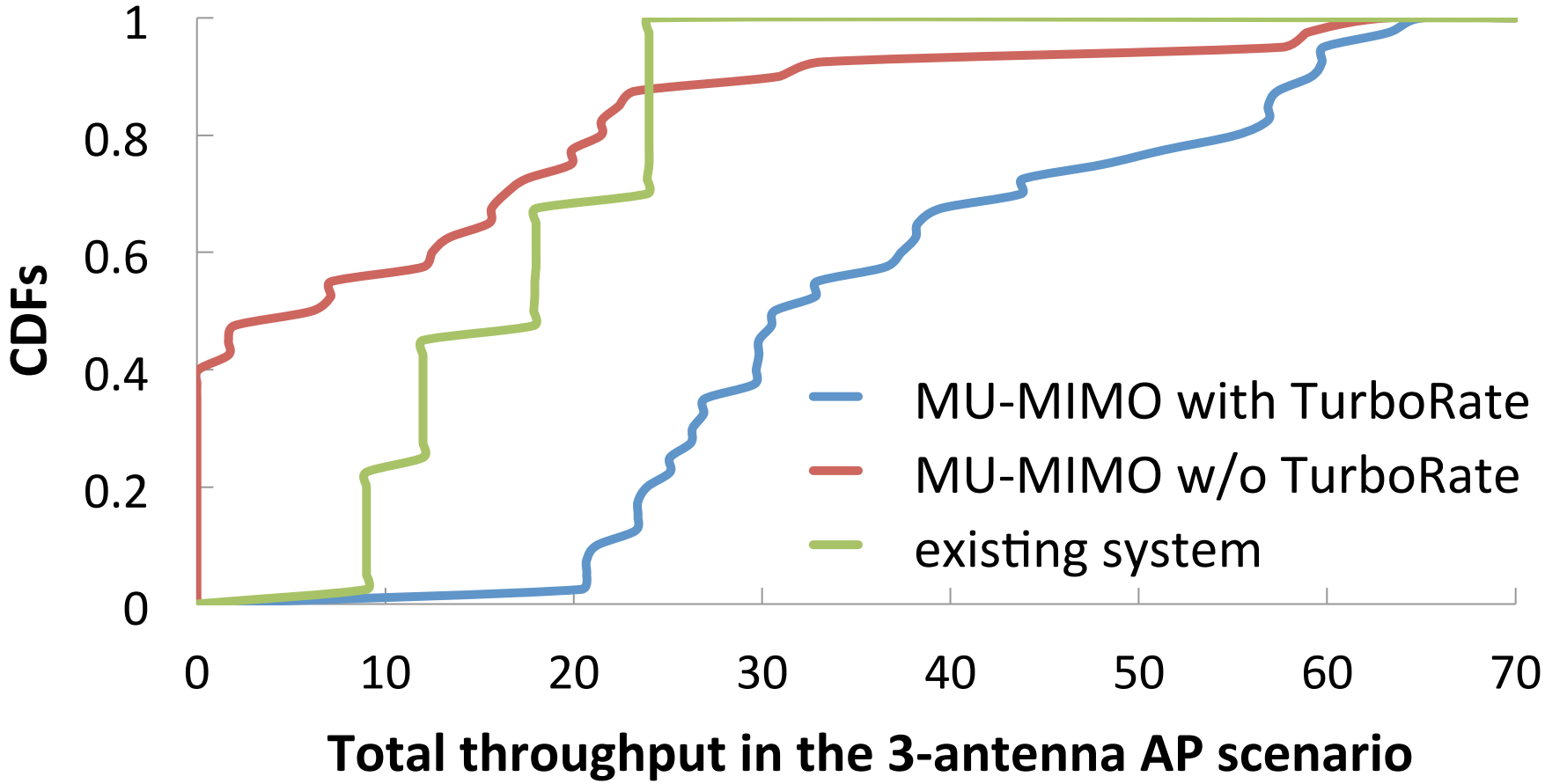
Throughput Gain for 3-Antenna AP



Compare the following schemes

1. Existing 802.11 (single stream)
2. MU-MIMO with TurboRate
3. MU-MIMO without TurboRate

Throughput Gain for 3-Antenna AP



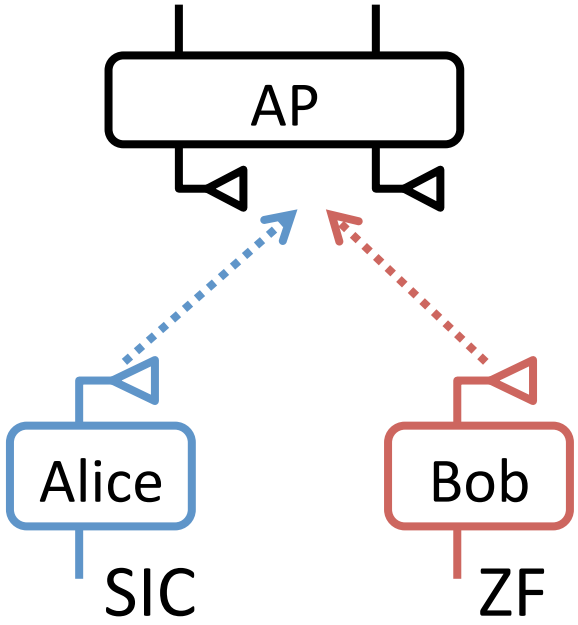
TurboRate improves the throughput by **2.3x** over 802.11

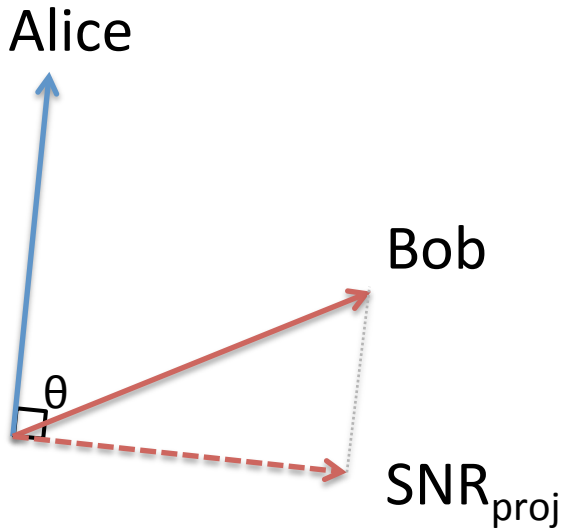
1) Is SNR estimation accurate enough?

2) What is the gain achieved by ***TurboRate***?

3) Where does the gain come from?

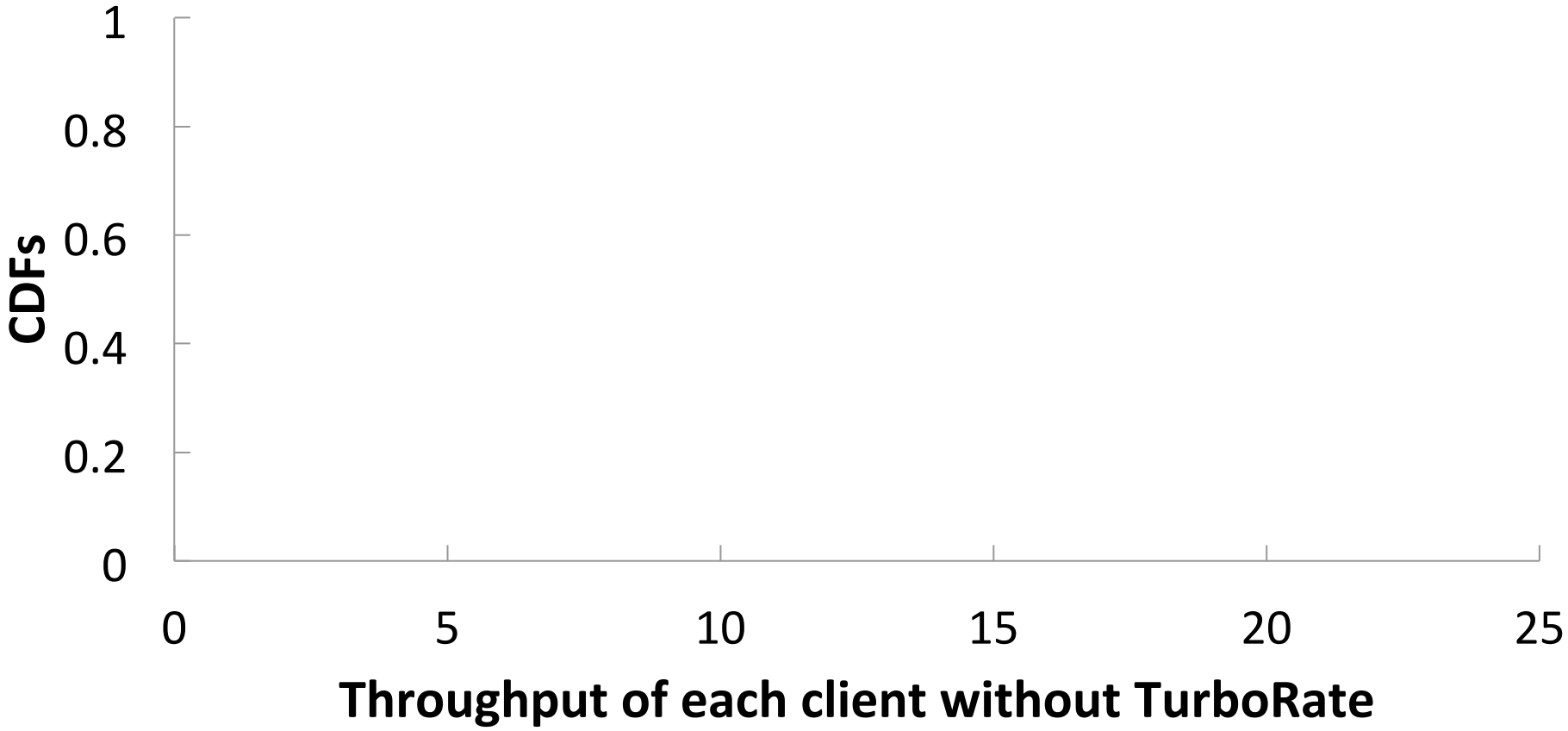
Throughput of Individual Clients



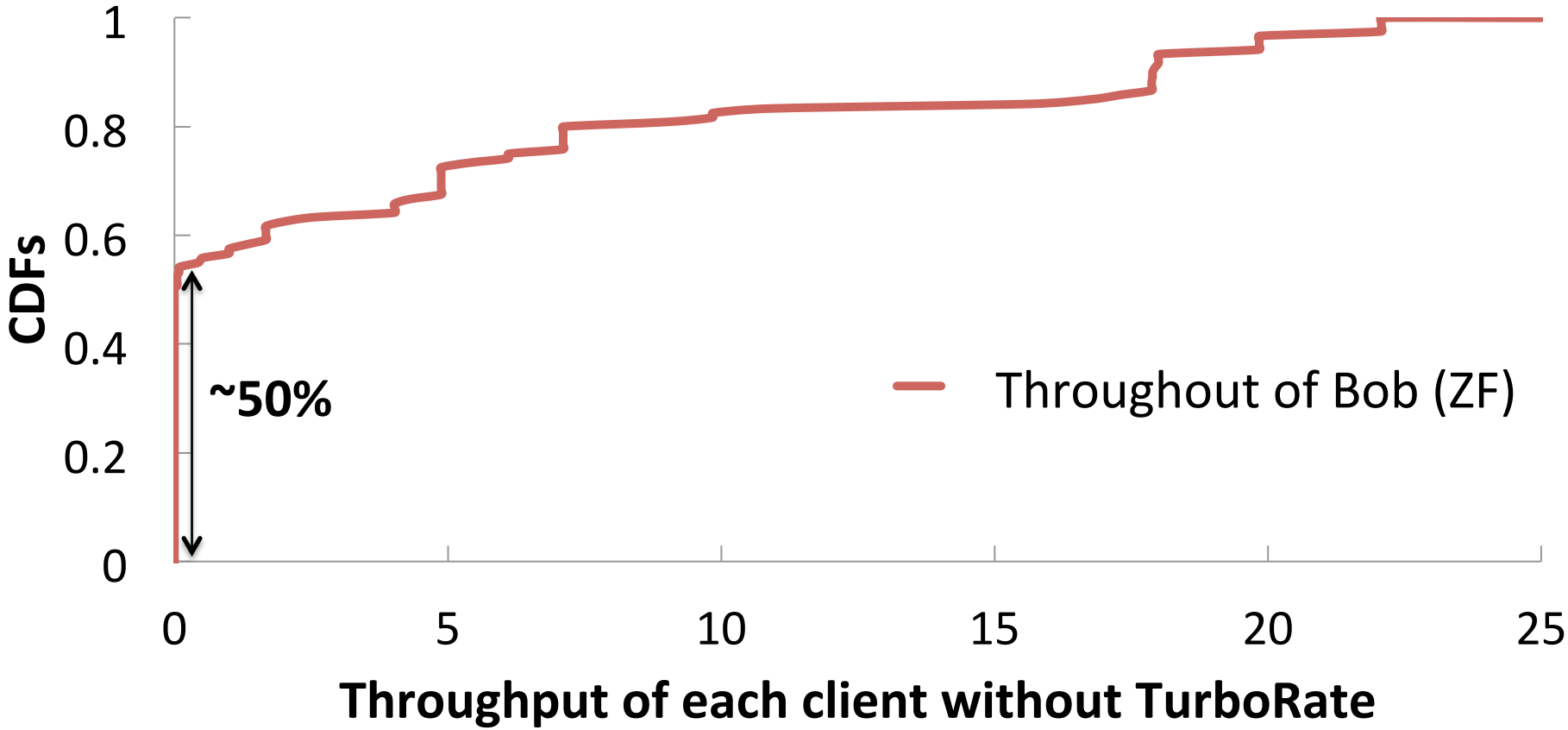


Check the throughput of each client
w/ and w/o TurboRate

Throughput w/o TurboRate

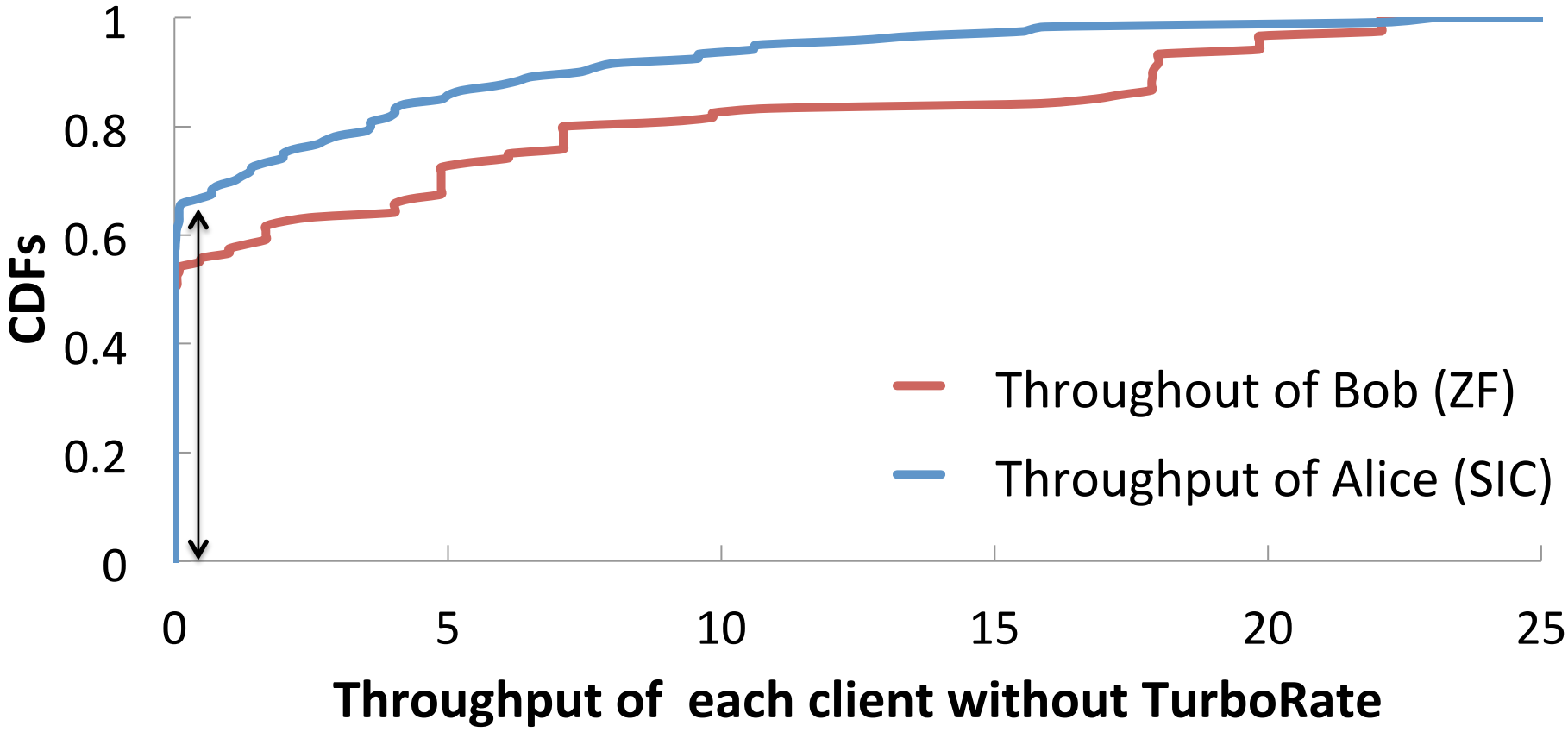


Bob's Throughput w/o TurboRate



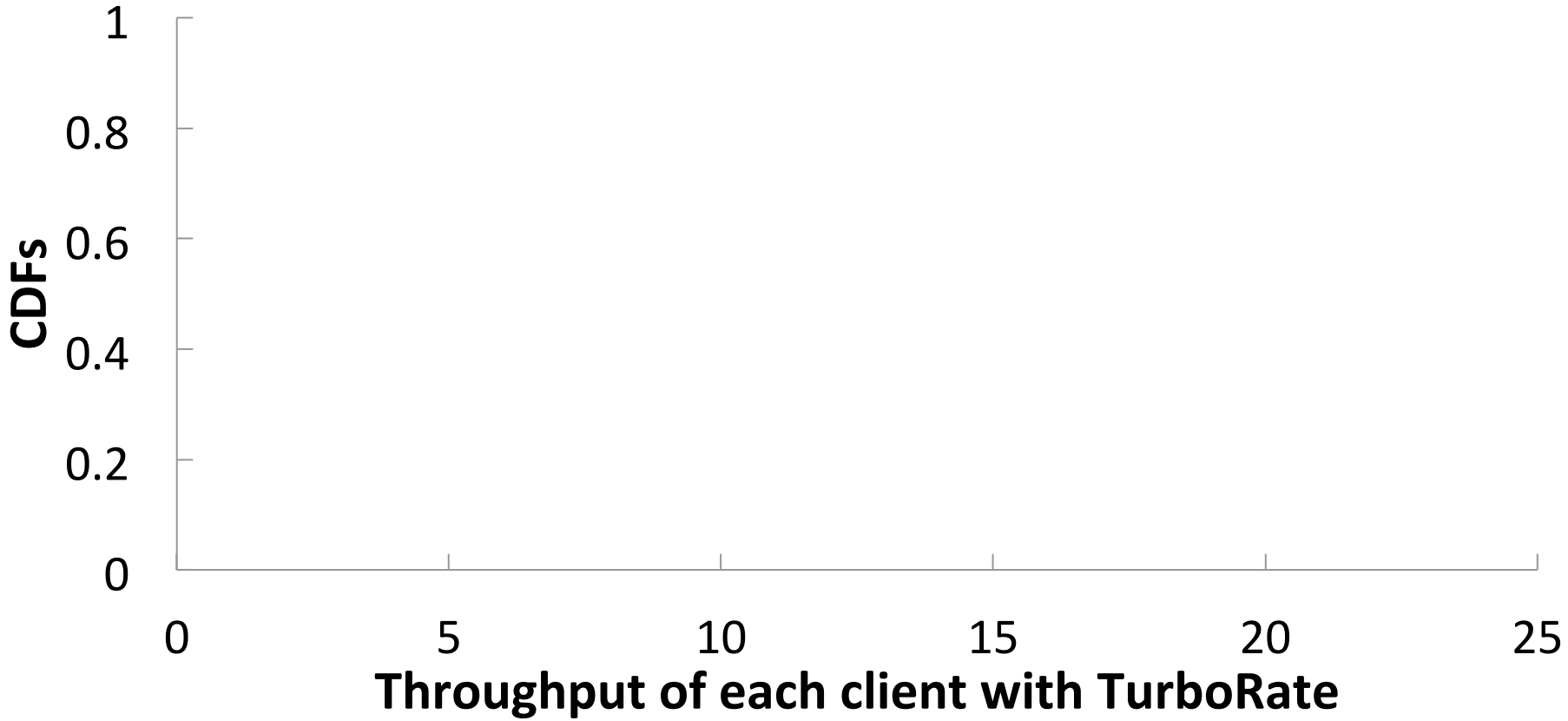
Packets are undecodable if Bob picks a wrong rate

Alice's Throughput w/o TurboRate

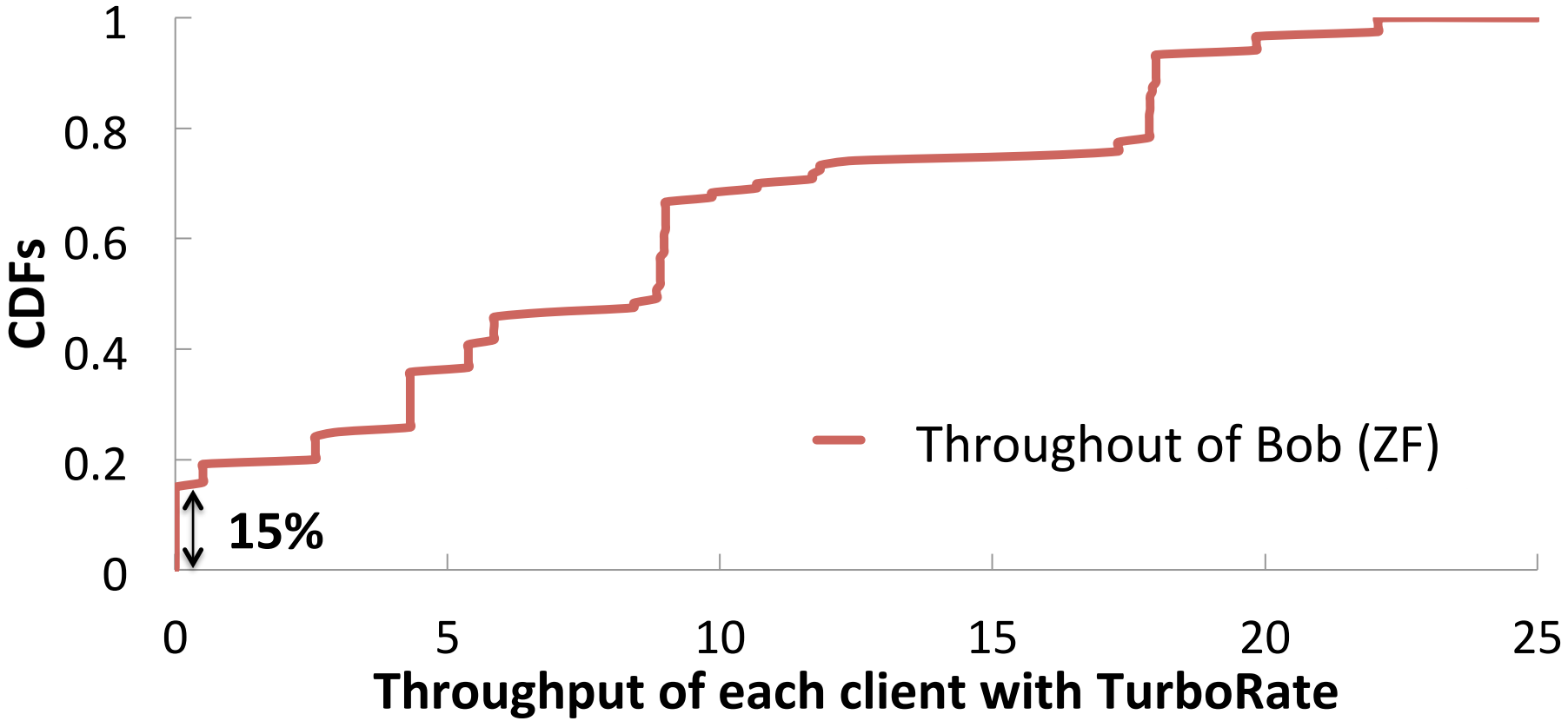


Alice also gets zero throughput

Throughput w/ TurboRate

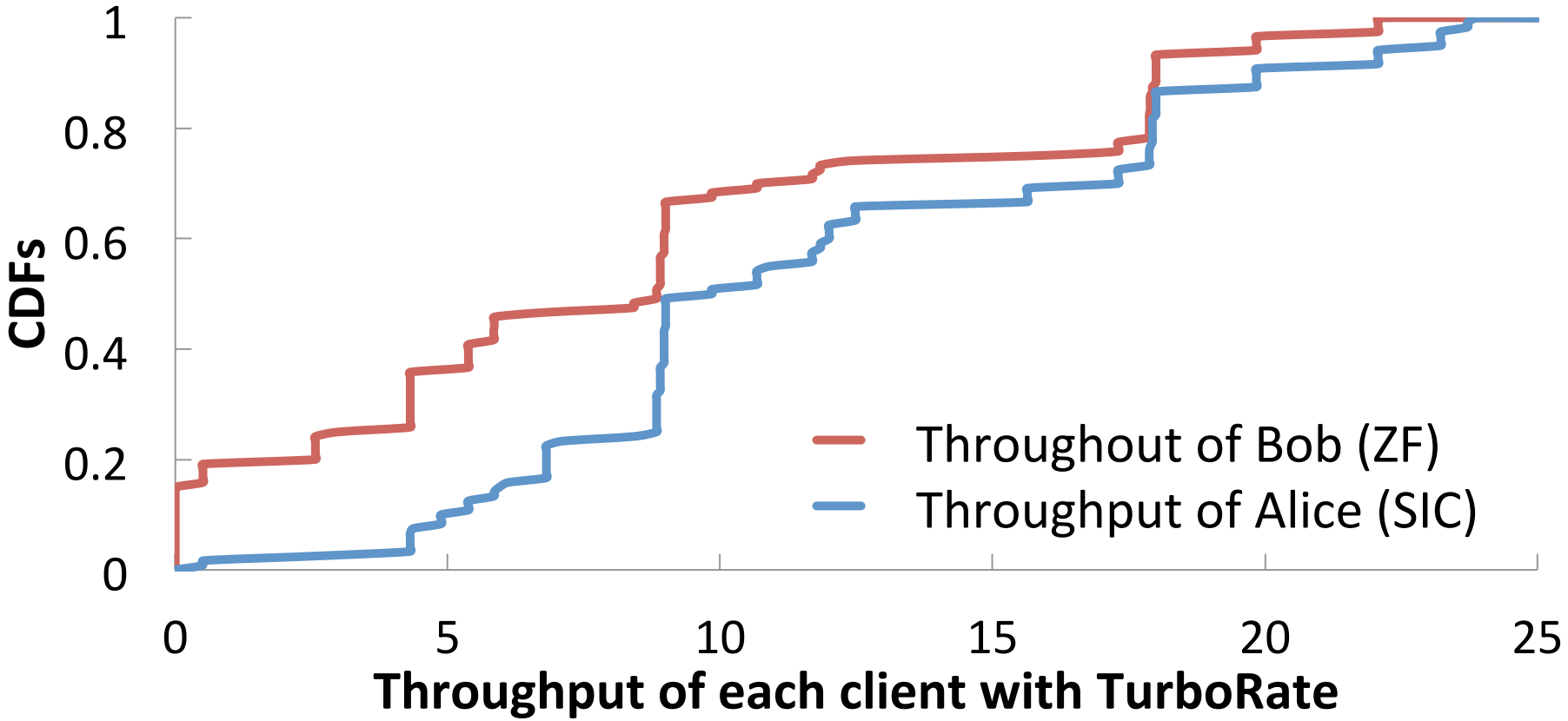


Bob's Throughput w/ TurboRate



SNR after projection is below 4dB

Alice's Throughput w/ TurboRate



Alice is not interfered by Bob
because Bob adapts the rate properly

Related Works

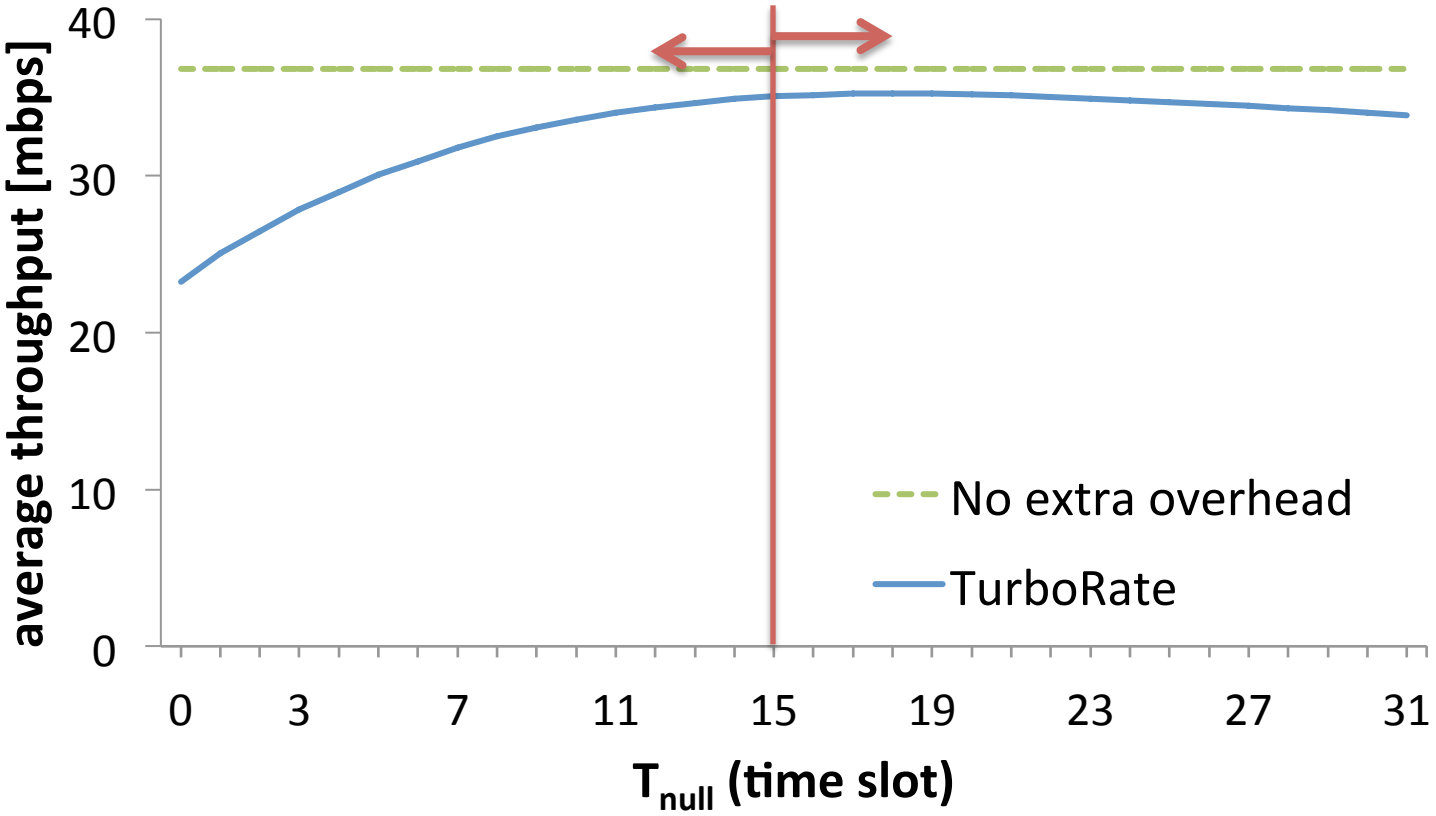
- MU-MIMO Systems
  - SAM[TLFWZC09], IAC[GPK09], 802.11n^{+}[LGK11], …
- Bit Rate Adaptation
  - [LCK], [ZJLMB08], [KCK07], …

First rate adaptation protocol for uplink MU-MIMO networks

Conclusion

- Distributed rate adaption protocol for MU-MIMO LANs
- Clients can select bit rate by passively learning
  - Its own SNR
  - The direction of ongoing transmitters
- Shown practical via implementation and testbed evaluation

Overhead for 3-antenna Scenario



small t_{null} : decrease concurrent transmission opportunities