MIMO As a First-Class Citizen in 802.11

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MIT

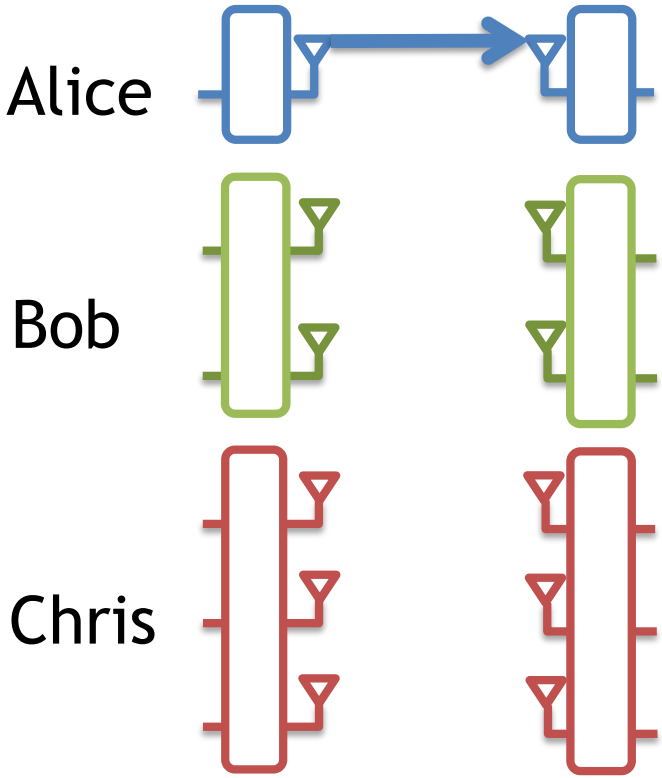
1-antenna devices

2-antenna devices

3-antenna devices

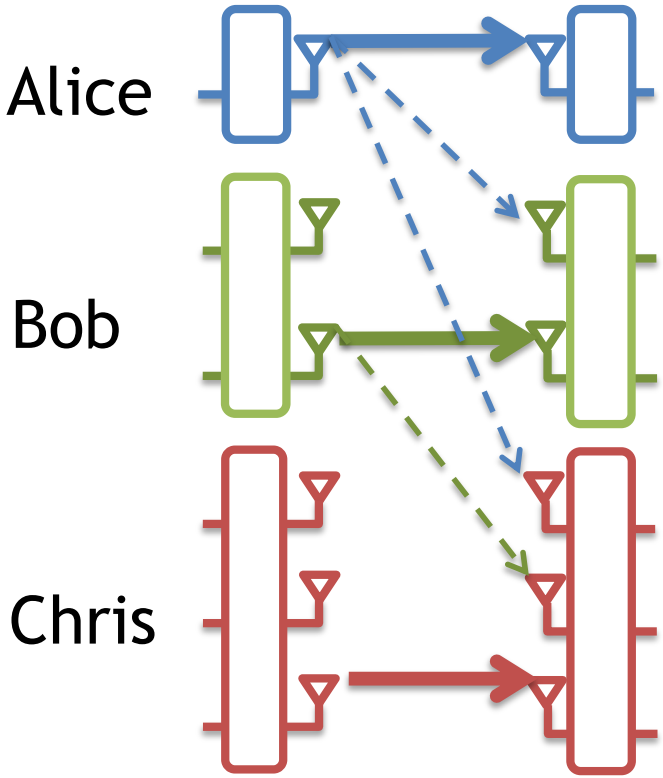
Wireless nodes increasingly have heterogeneous numbers of antennas

802.11 Was Designed for 1-Antenna Nodes

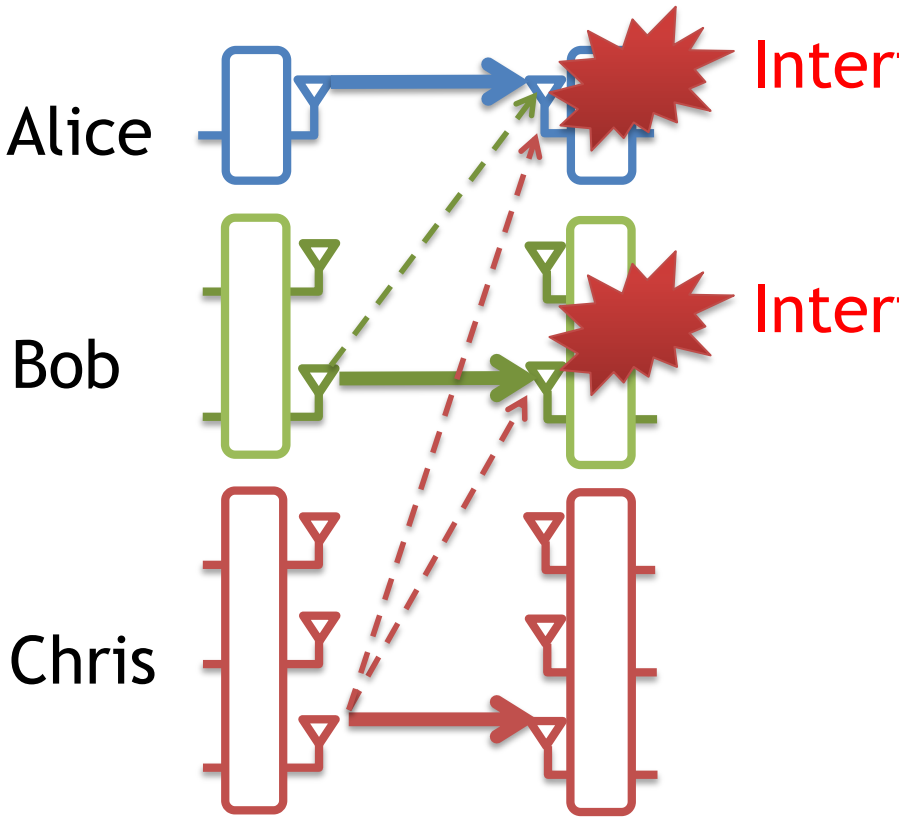


When a single-antenna node transmits, multi-antenna nodes refrain from transmitting

But, MIMO Nodes Can Receive Multiple Concurrent Streams



It's Not That Simple

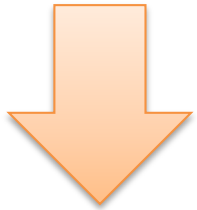


But, how do we transmit concurrently without interfering with ongoing transmissions?

Goal

Enable concurrent transmissions

without harming ongoing transmissions



802.11n+

802.11n^{+}

- Allows MIMO nodes to join ongoing transmissions without interfering with them
- Maintains 802.11 random access
- Implemented and shown to significantly improve the throughput

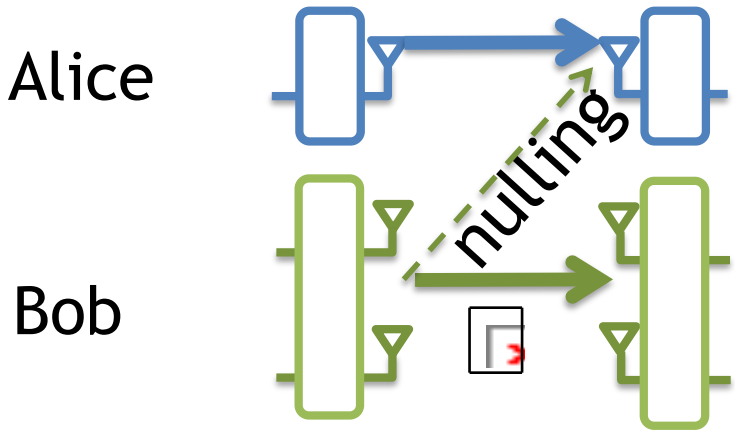
1. How to transmit without interfering with ongoing transmissions?

2. How do we achieve it in a random access manner?

1. How to transmit without interfering with ongoing transmissions?

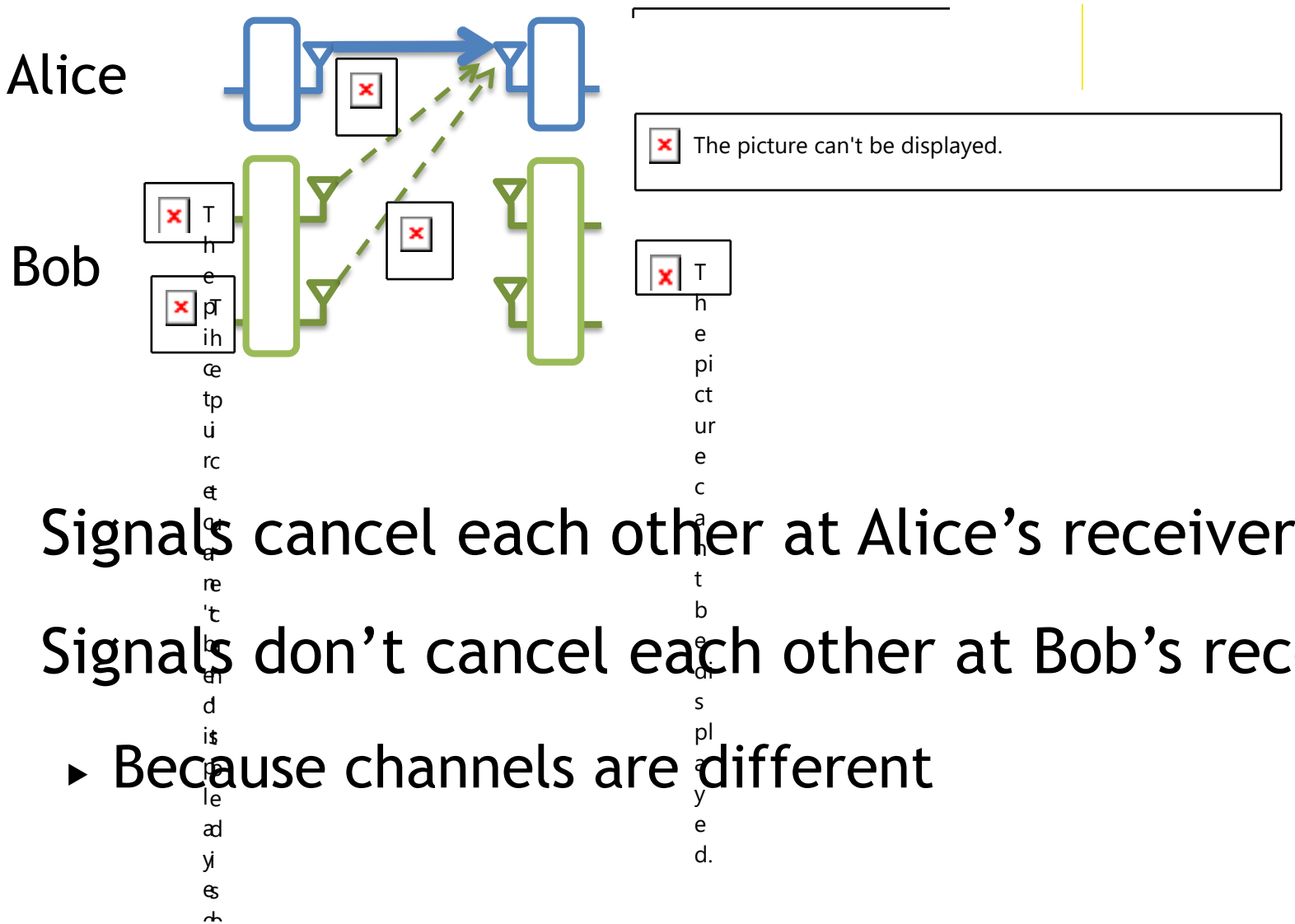
2. How do we achieve it in a random access manner?

Interference Nulling



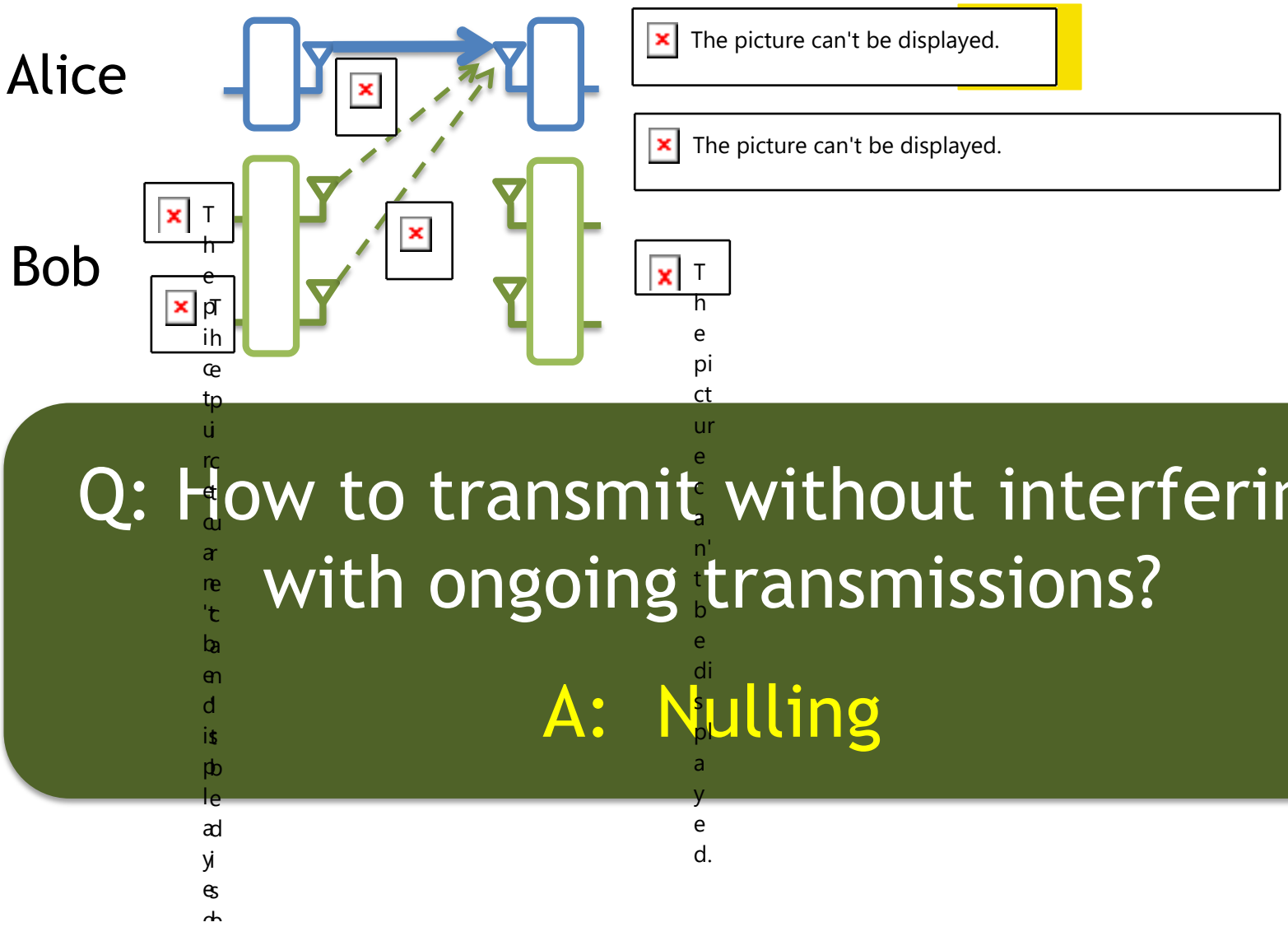
- Signals cancel each other at Alice's receiver

Interference Nulling



- Signals cancel each other at Alice's receiver
- Signals don't cancel each other at Bob's receiver
  - Because channels are different

Interference Nulling

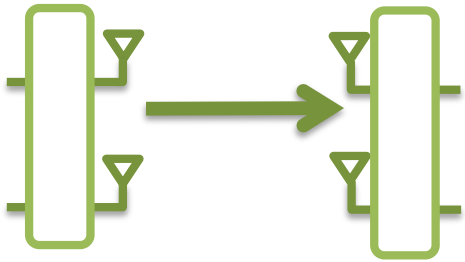


Q: How to transmit without interfering with ongoing transmissions?

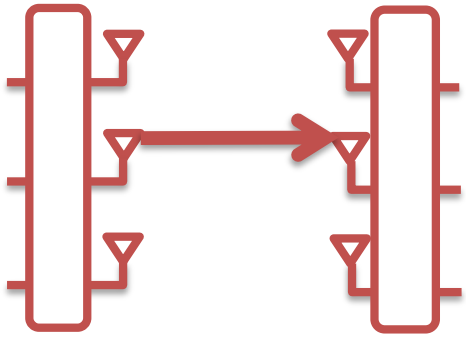
A: Nulling

Alice

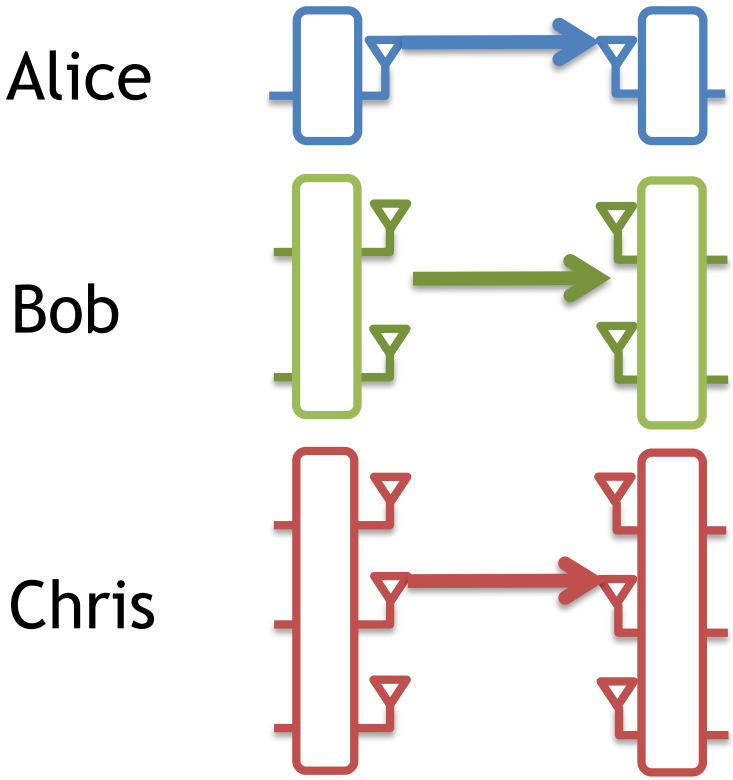
Bob



Chris



Is Nulling Alone Enough? NO!



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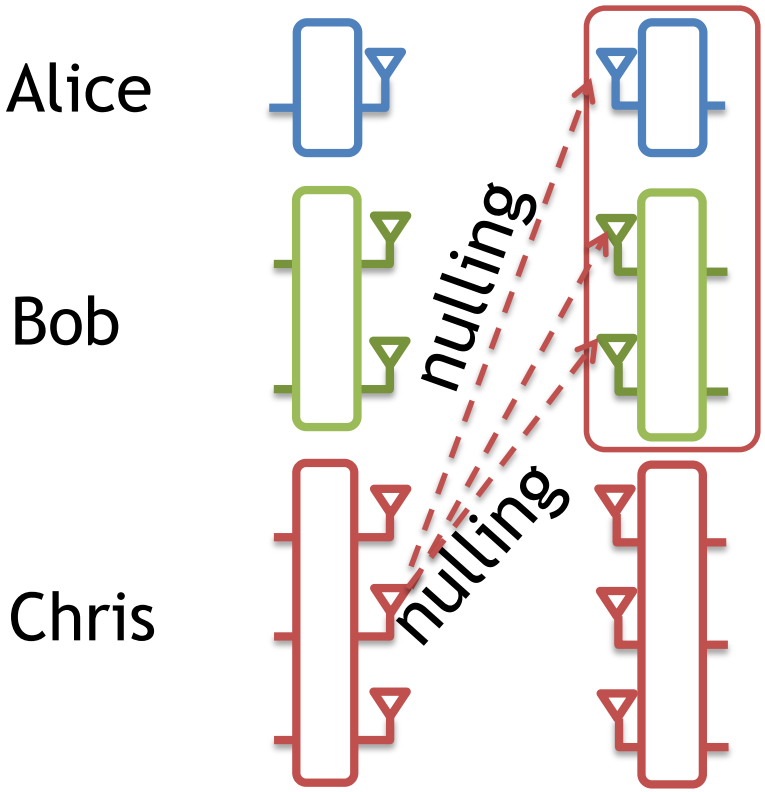
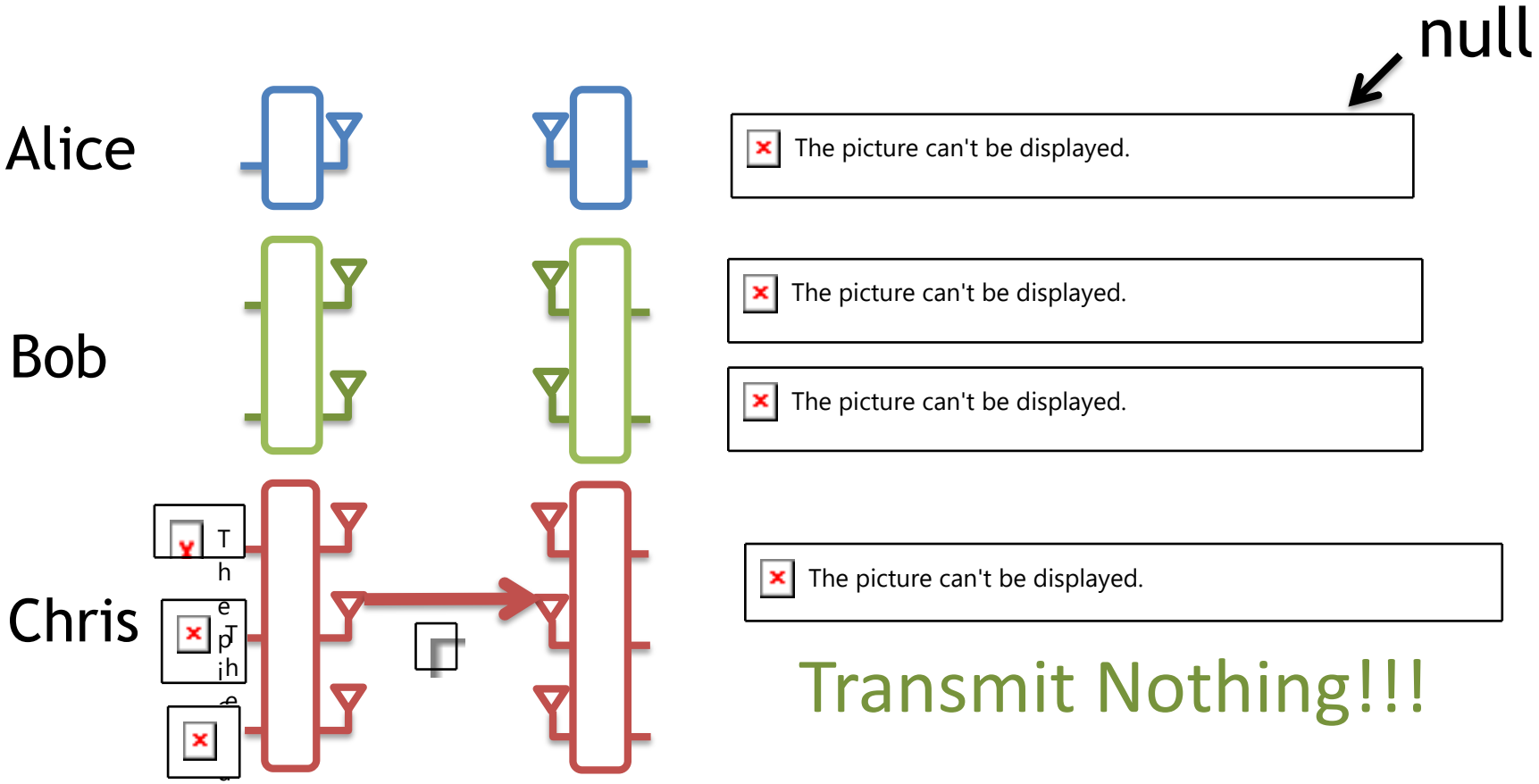


Chris needs to null at three antennas

→ But, he can't!

N-antenna transmitter cannot null at N receive antennas

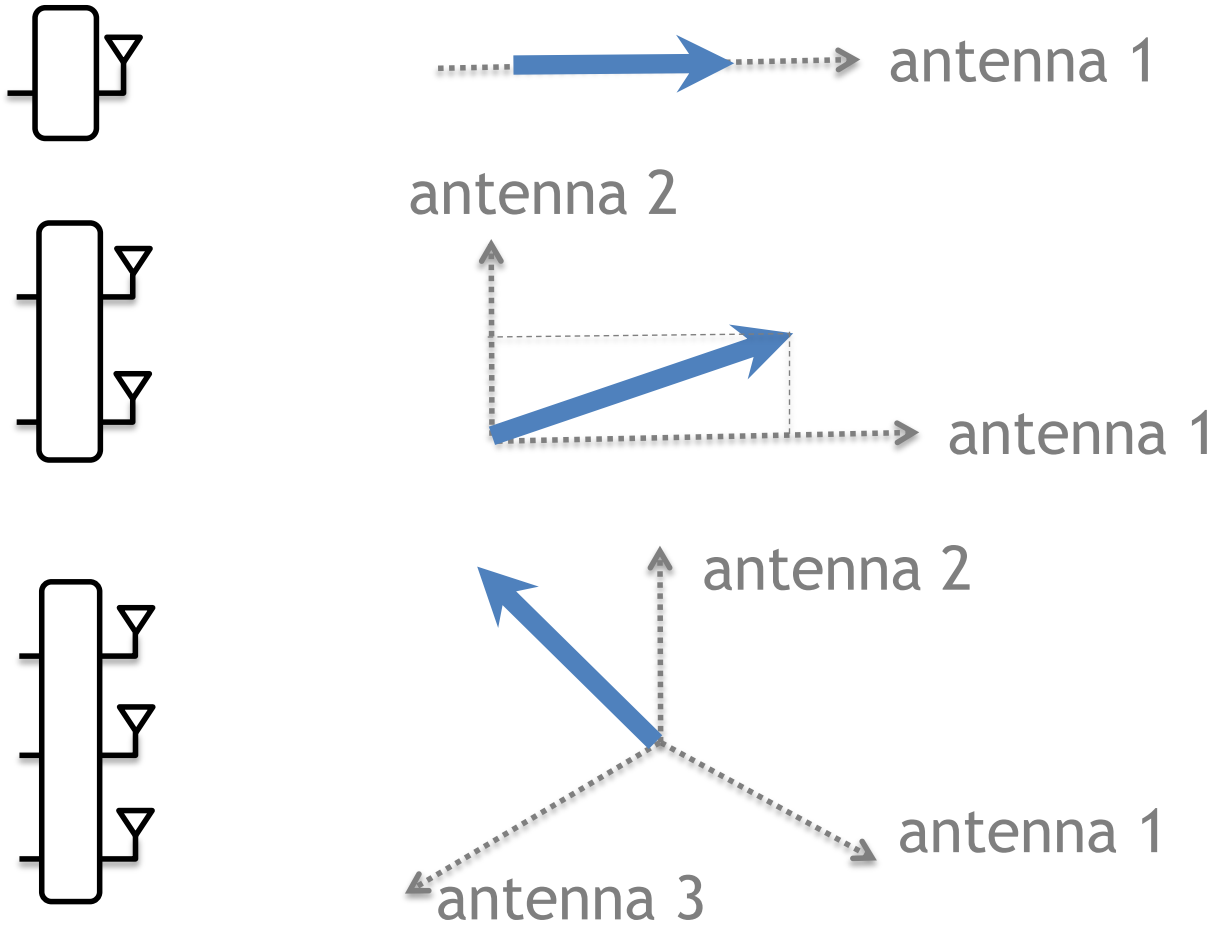
Is Nulling Alone Enough? NO!



Do we really need to null at all antennas?

MIMO Basics

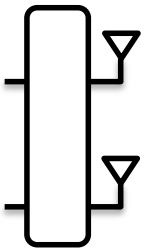
1. N-antenna node receives in N-dimensional space

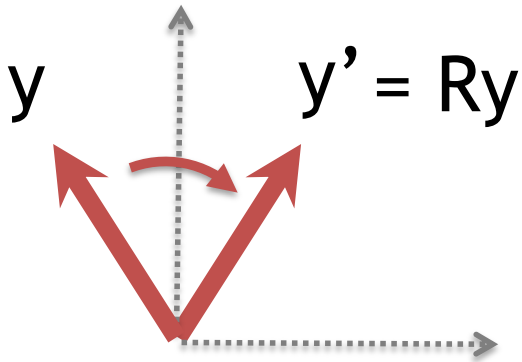


MIMO Basics

1. N-antenna node receives in N-dimensional space
2. Transmitter can rotate the received signal

2-antenna receiver

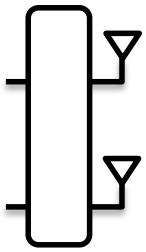


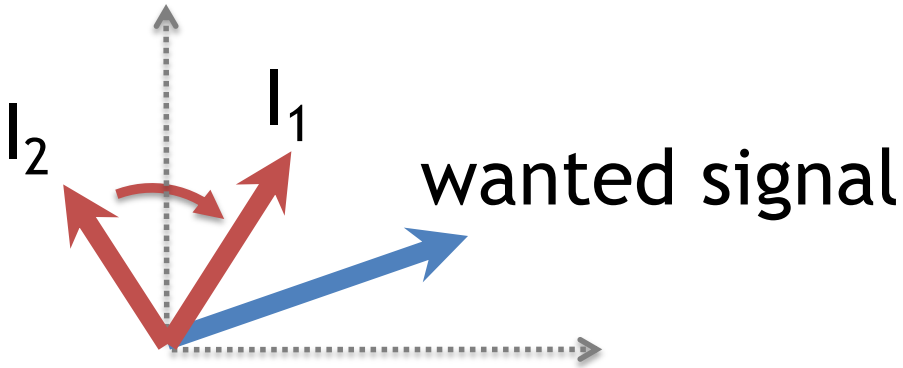


To rotate received signal y to y’ = Ry,

Interference Alignment

2-antenna receiver



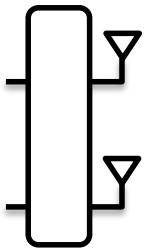


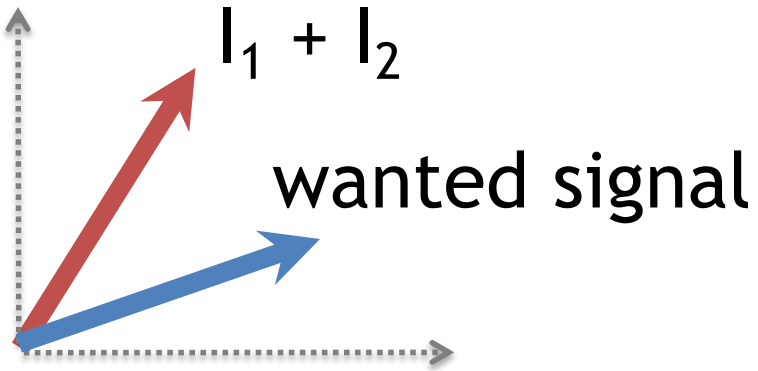
N-antenna node can only decode N signals

If I_1 and I_2 are aligned,

Interference Alignment

2-antenna receiver





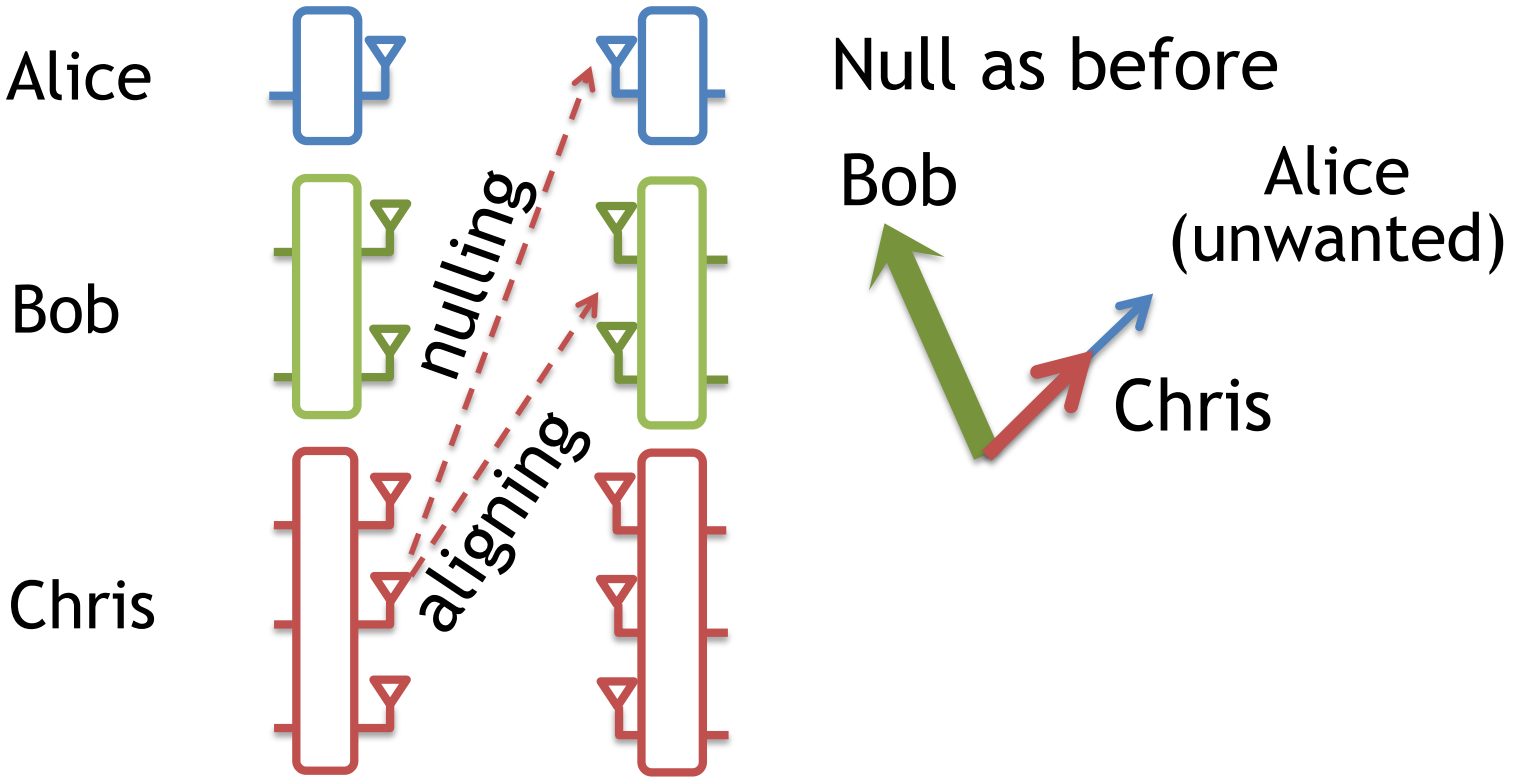
N-antenna node can only decode N signals

If I_1 and I_2 are aligned,

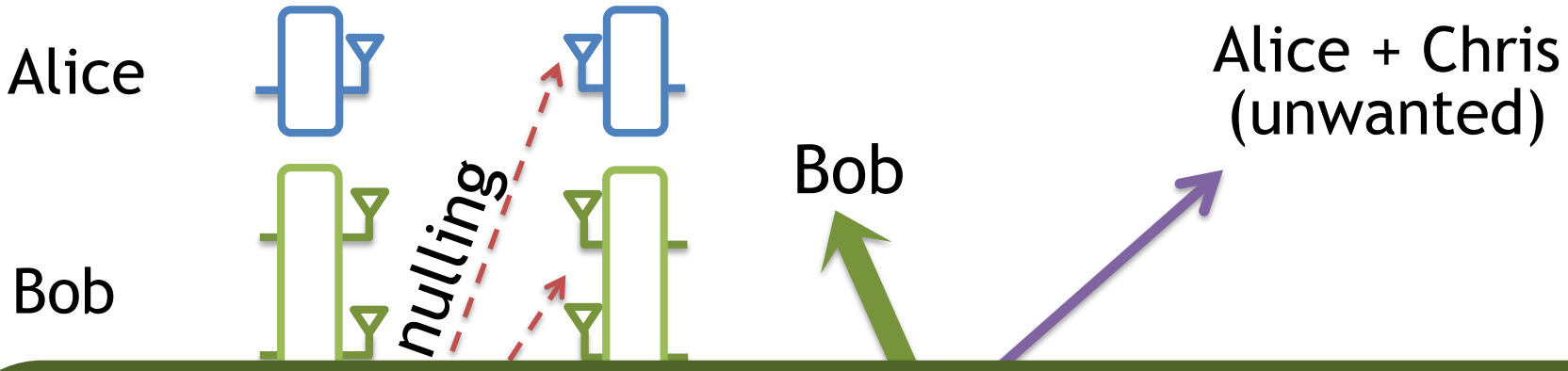
→ appear as one interferer

→ 2-antenna receiver can decode the wanted signal

Use Nulling and Alignment



Use Nulling and Alignment



All senders transmit,
but the throughput is as high as if only the 3-antenna node is transmitting all the time

General Protocol

- Each sender in a distributed way computes
  - where and how to null
  - where and how to align

- Analytically proved:
  - # concurrent streams = # max antenna per sender

1. How to transmit without interfering with ongoing transmissions?
   - Interference nulling
   - Interference alignment

2. How do we achieve it in a random access manner?

1. How to transmit without interfering with ongoing transmissions?
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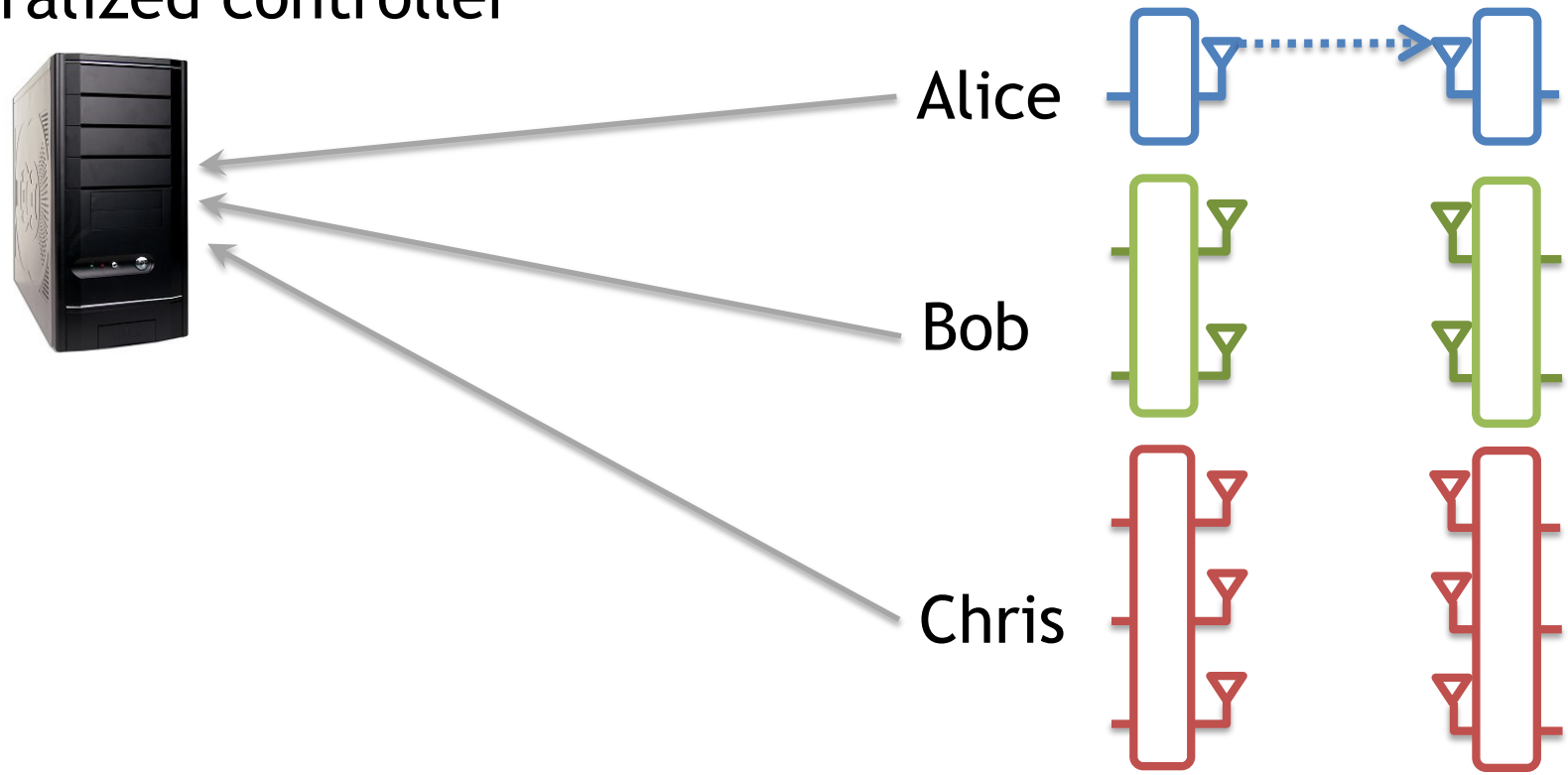
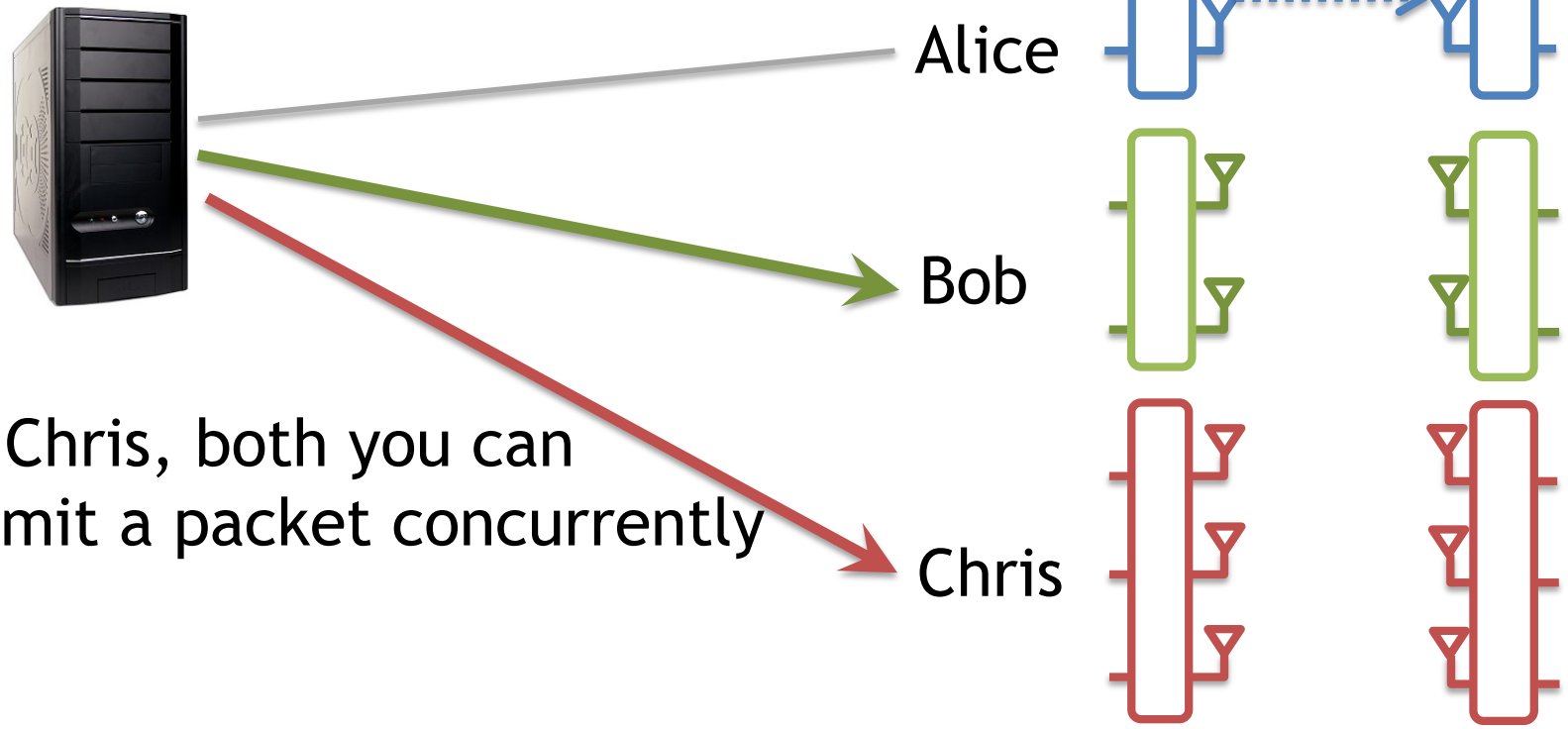
2. How do we achieve it in a random access manner?

Centralized controller



Centralized controller



Bob, Chris, both you can transmit a packet concurrently

But, lost the benefit of 802.11 random access

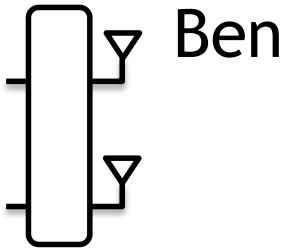
n^+ maintains random access!

In 802.11, contend using carrier sense

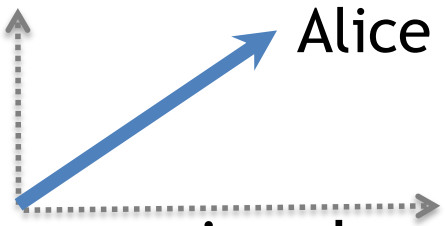
But, how to contend despite ongoing transmissions?

Multi-Dimensional Carrier Sense

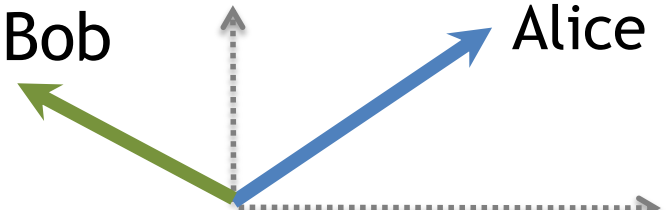
Say that Ben is performing carrier sense



Distinguishable using simple linear algebra

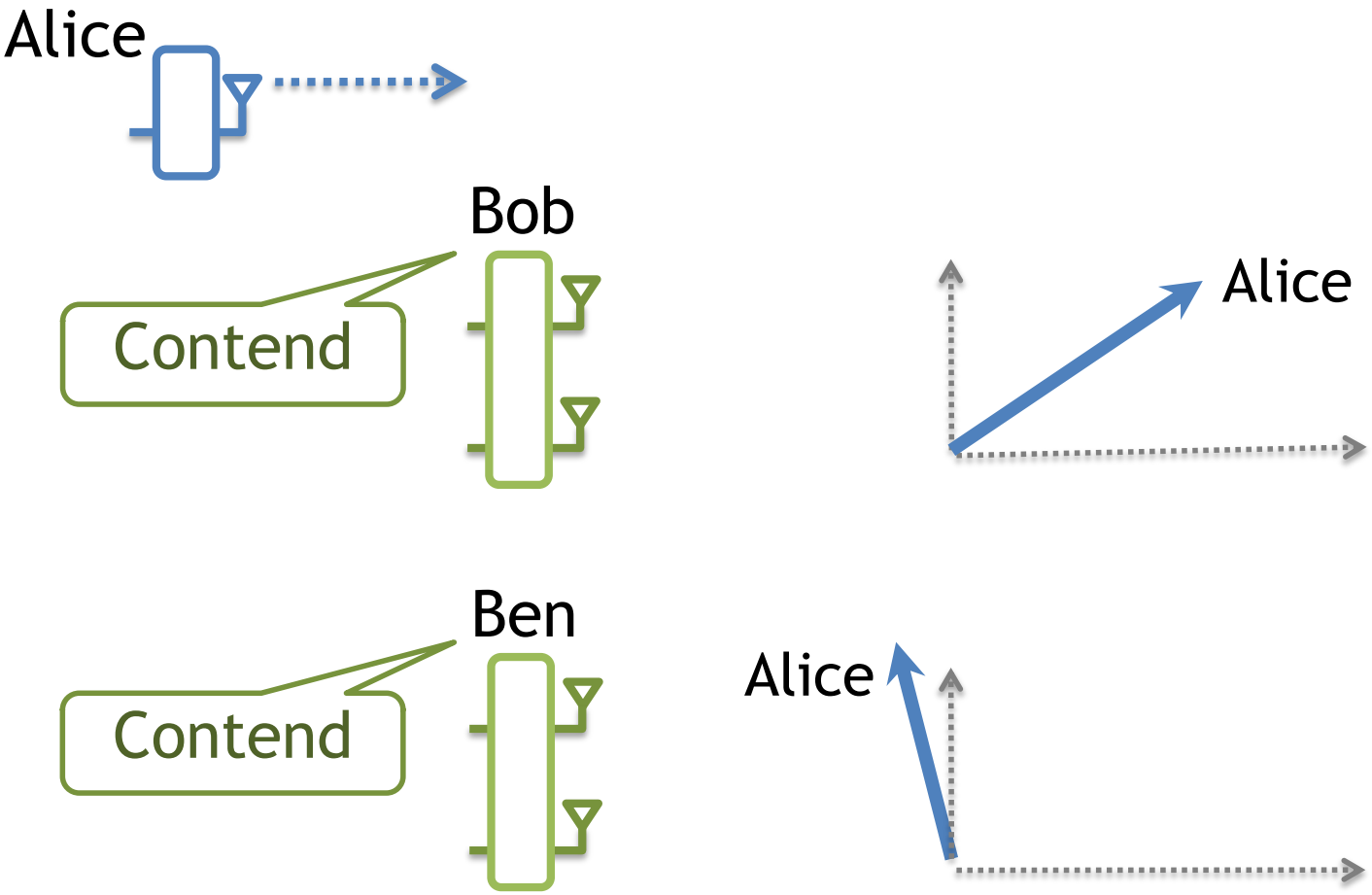


one signal

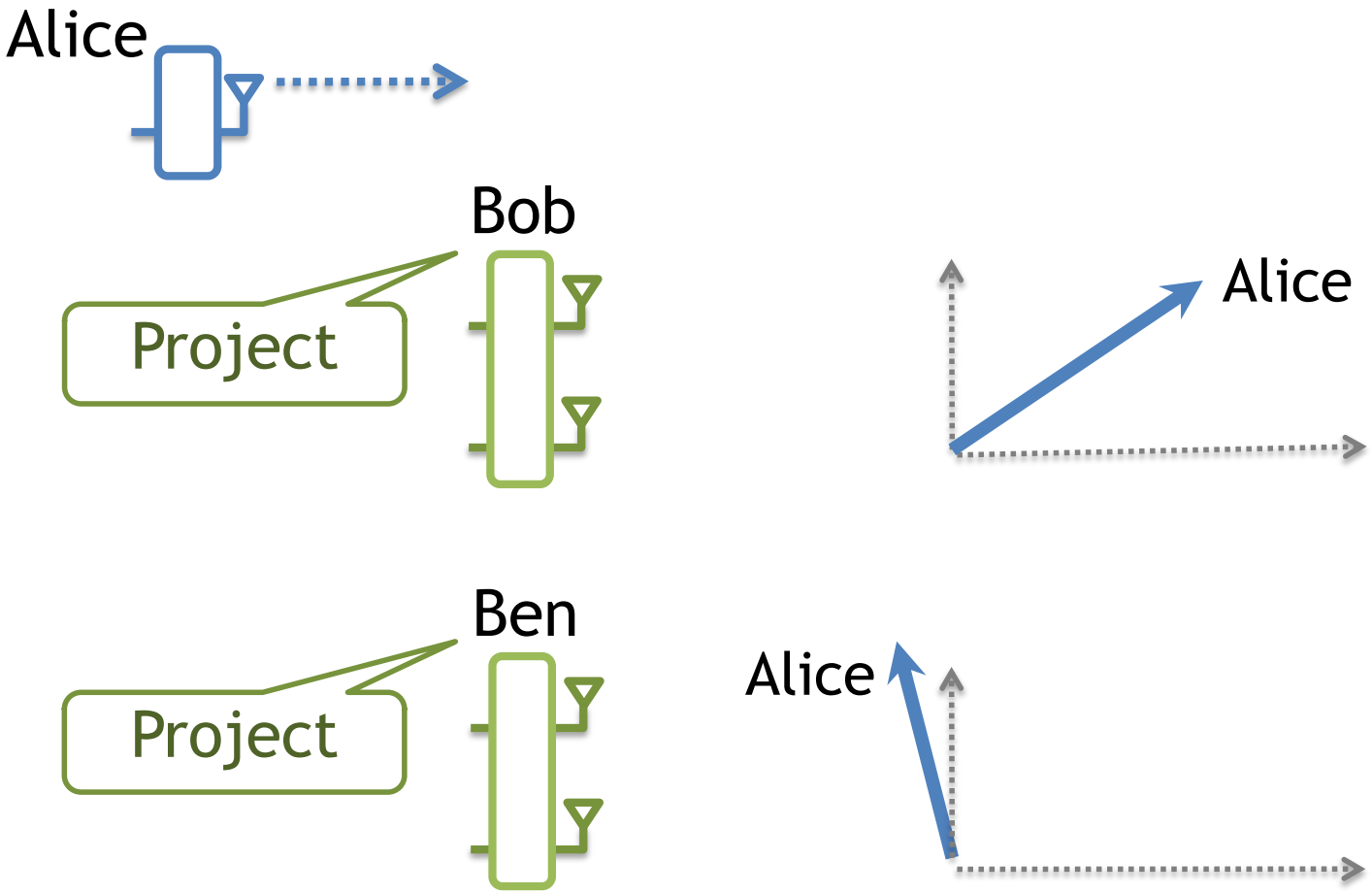


two signals

Multi-Dimensional Carrier Sense

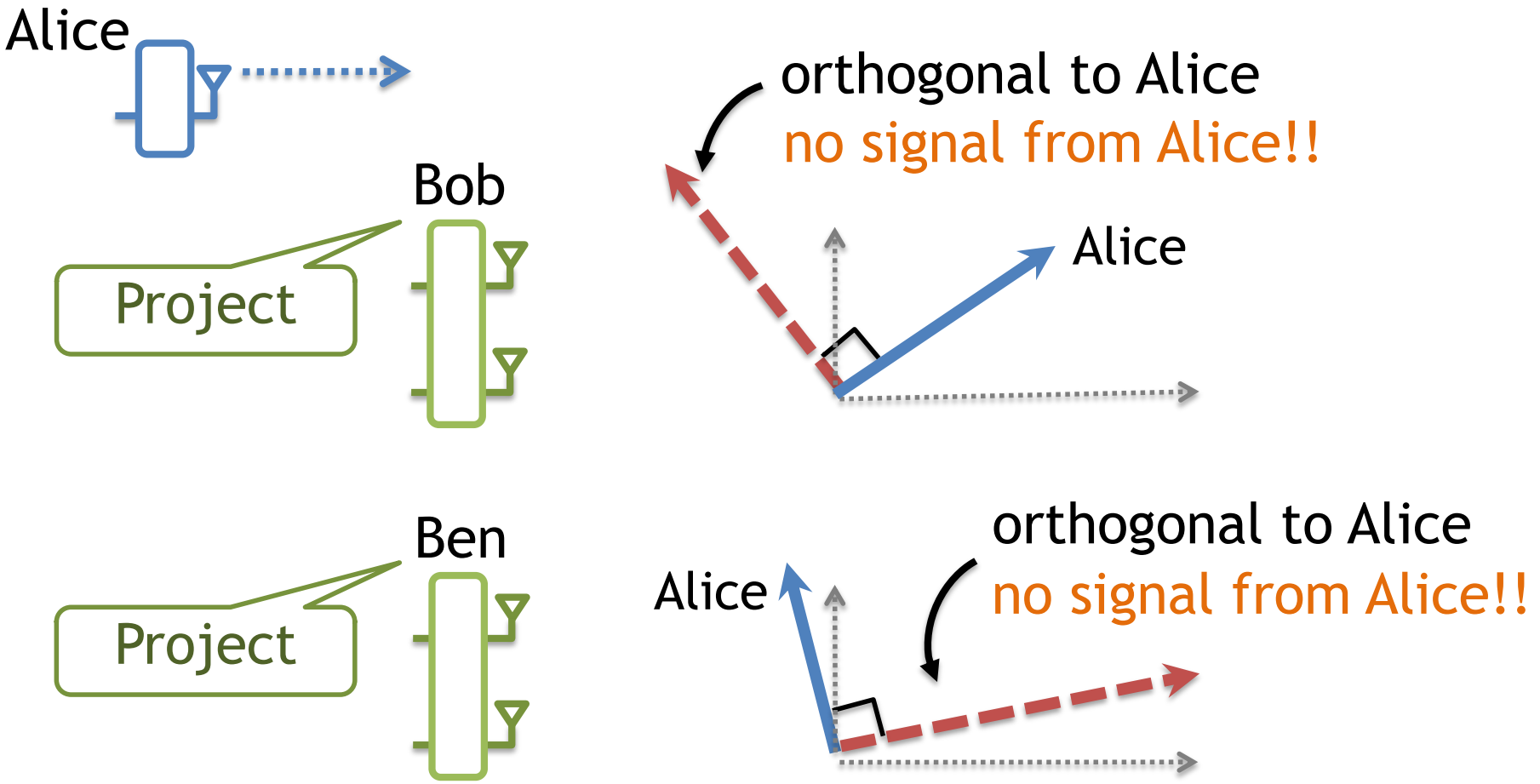


Multi-Dimensional Carrier Sense



Bob and Ben project orthogonal to Alice's signal

Multi-Dimensional Carrier Sense



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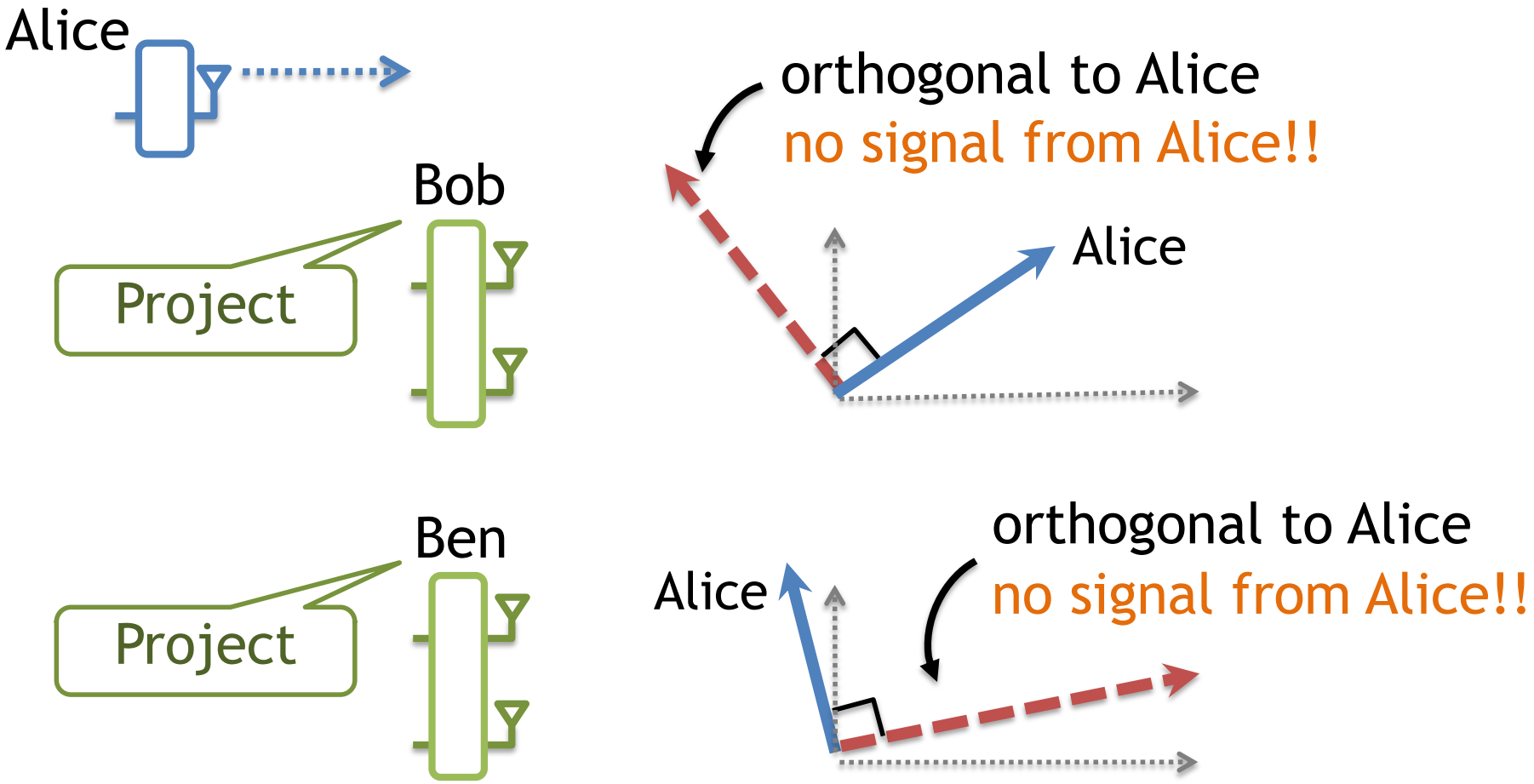
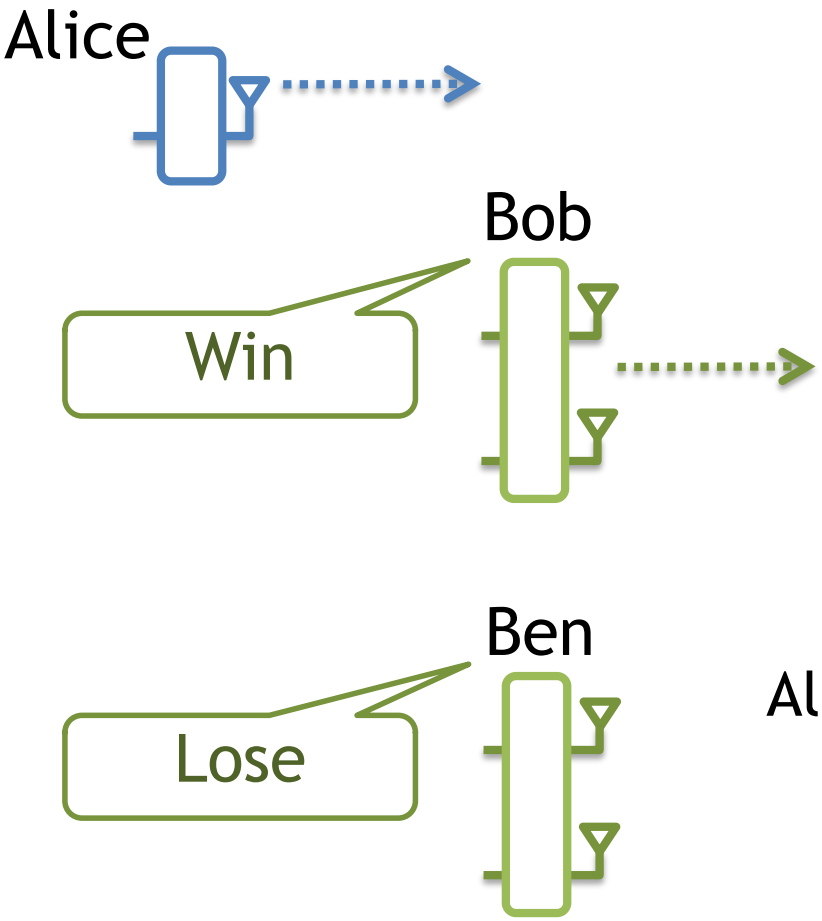
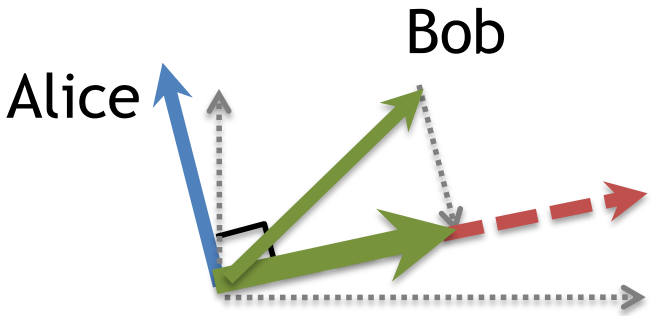
Multi-Dimensional Carrier Sense



Apply 802.11 contention after projection

Multi-Dimensional Carrier Sense





Works for arbitrary number of antennas

1. How to transmit without interfering with ongoing transmissions?
   - Interference nulling
   - Interference alignment

2. How do we achieve it in a random access manner?
   - Multi-dimensional carrier sense

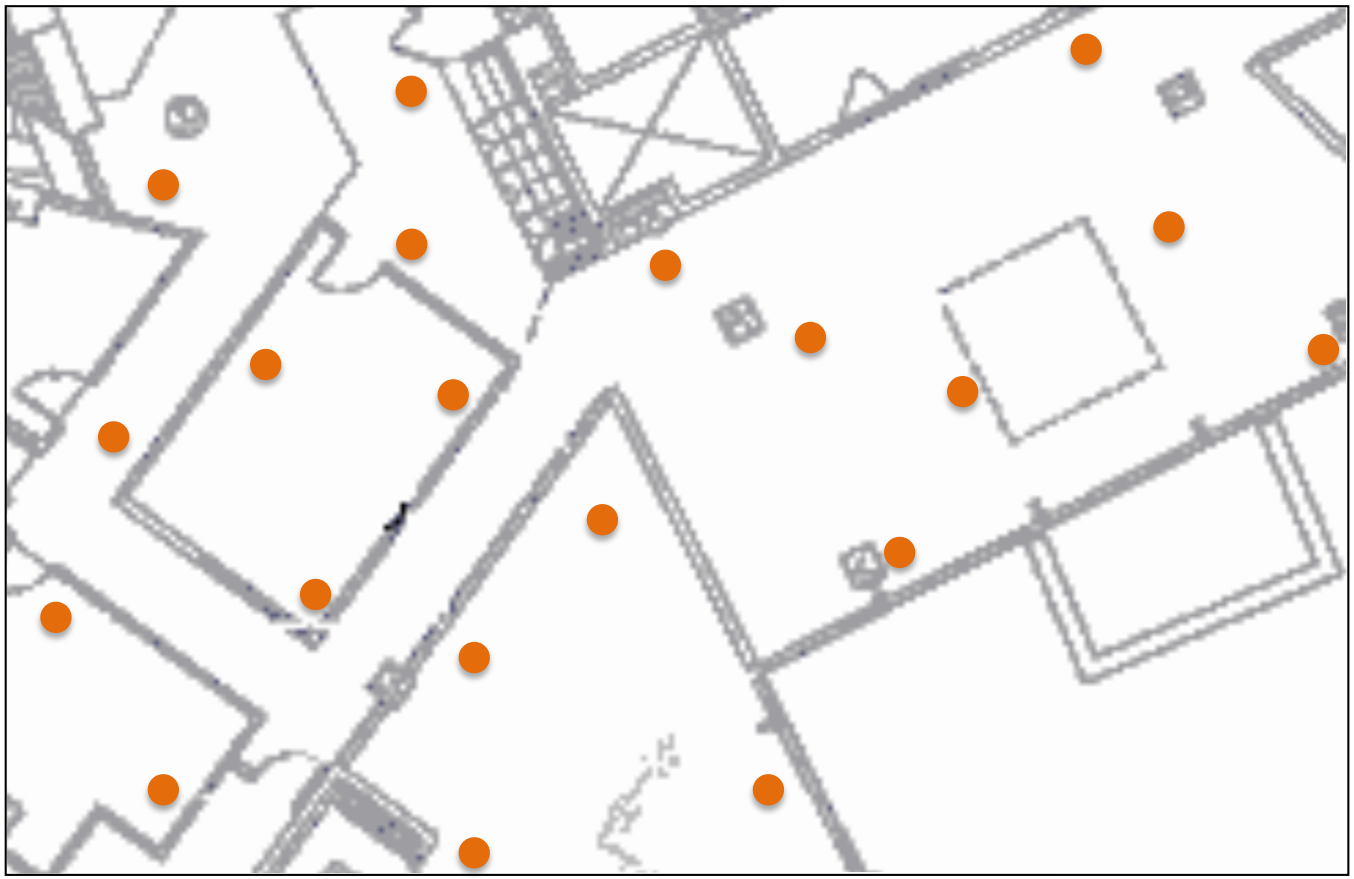
Performance

Implementation

- Implemented in USRP2
- OFDM with 802.11-style modulations and convolutional codes

Testbed

Randomly assign the nodes to the marked locations



1. How to transmit without interfering with ongoing transmissions?
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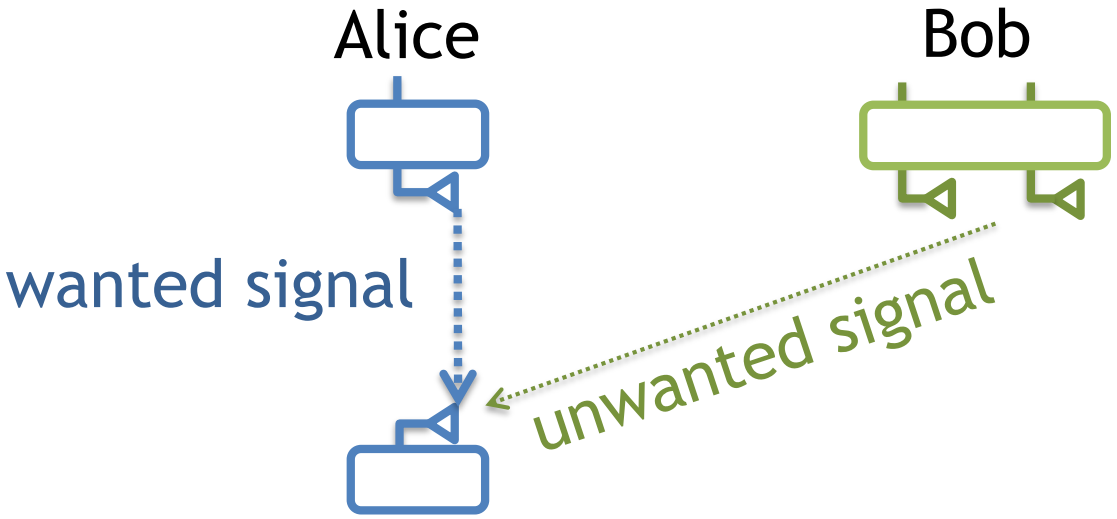
2. How do we achieve it in a random access manner?
   - Multi-dimensional carrier sense

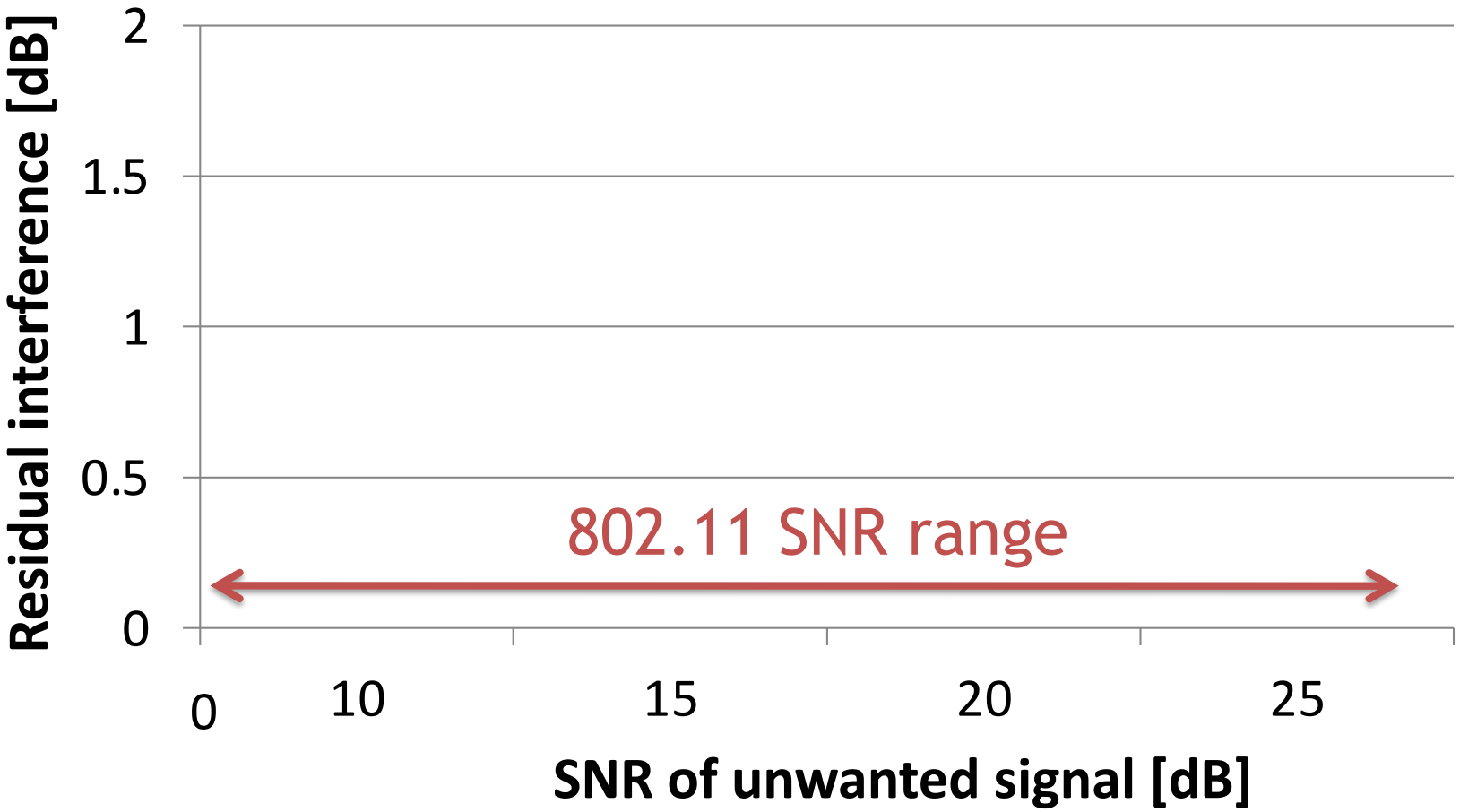
1. How to transmit without interfering with ongoing transmissions?
   - **Interference nulling**
   - Interference alignment
2. How do we achieve it in a random access manner?
   - Multi-dimensional carrier sense

Nulling Experiment

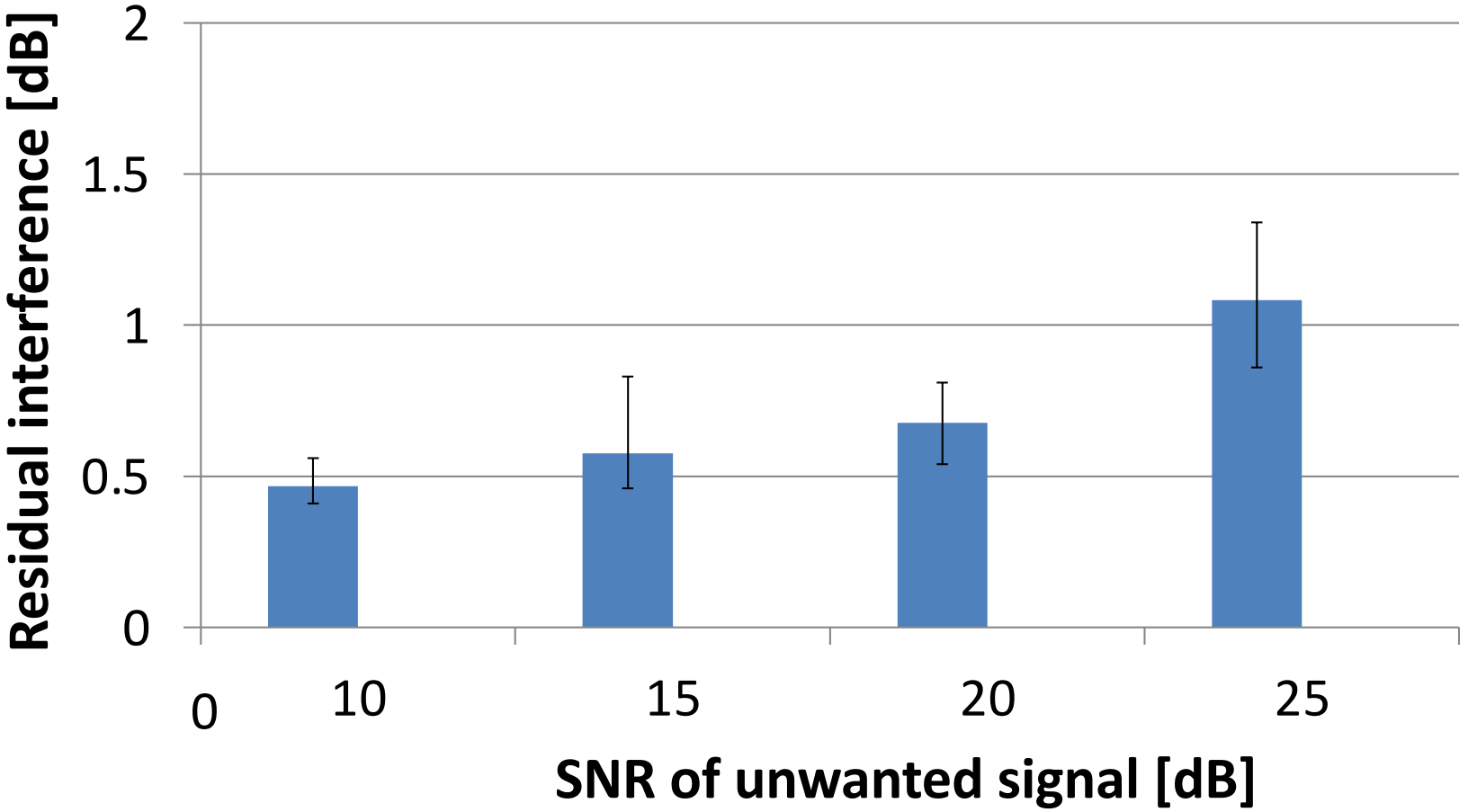


Can Bob null his signal at Alice’s receiver?

Nulling Experiment

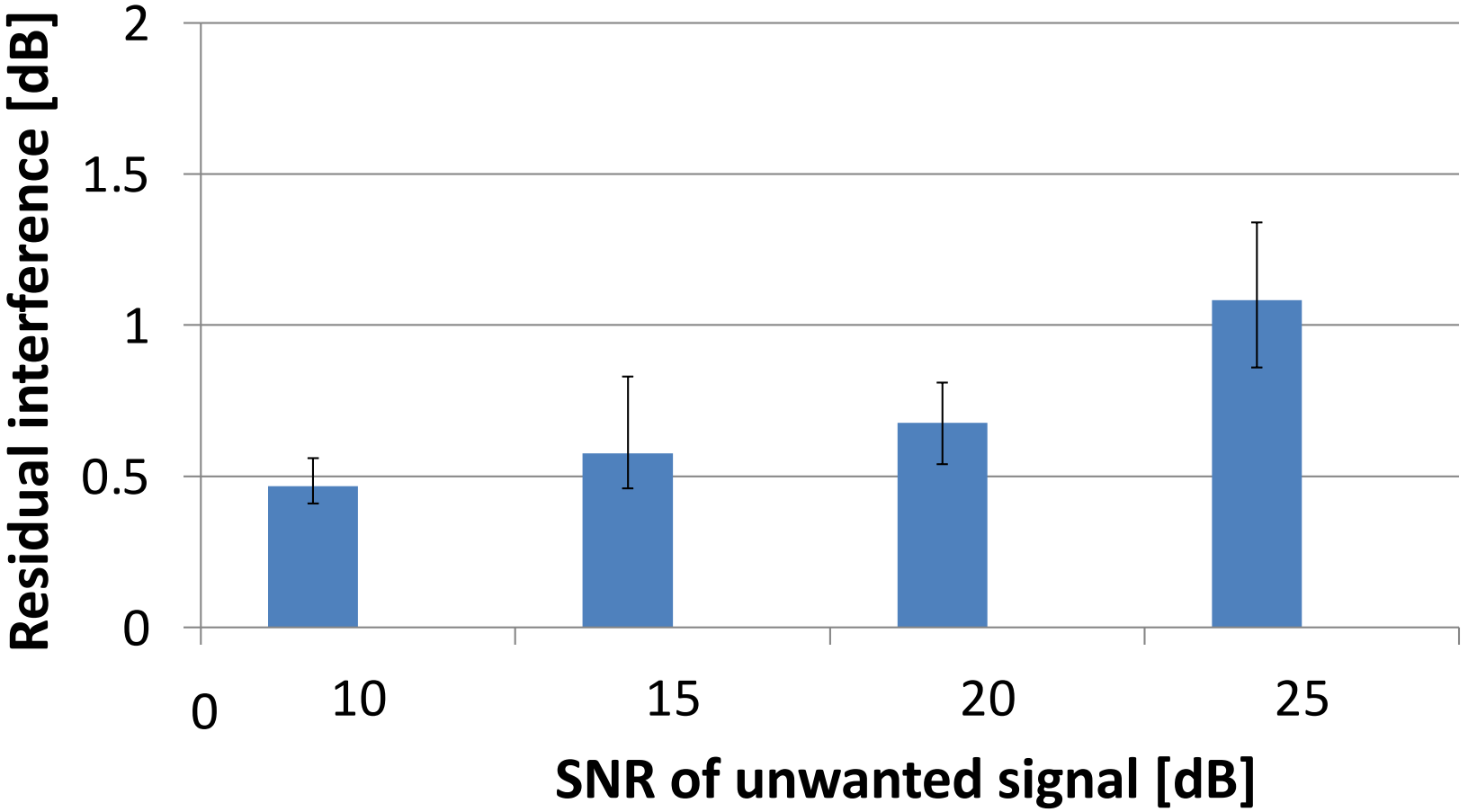


Nulling Experiment

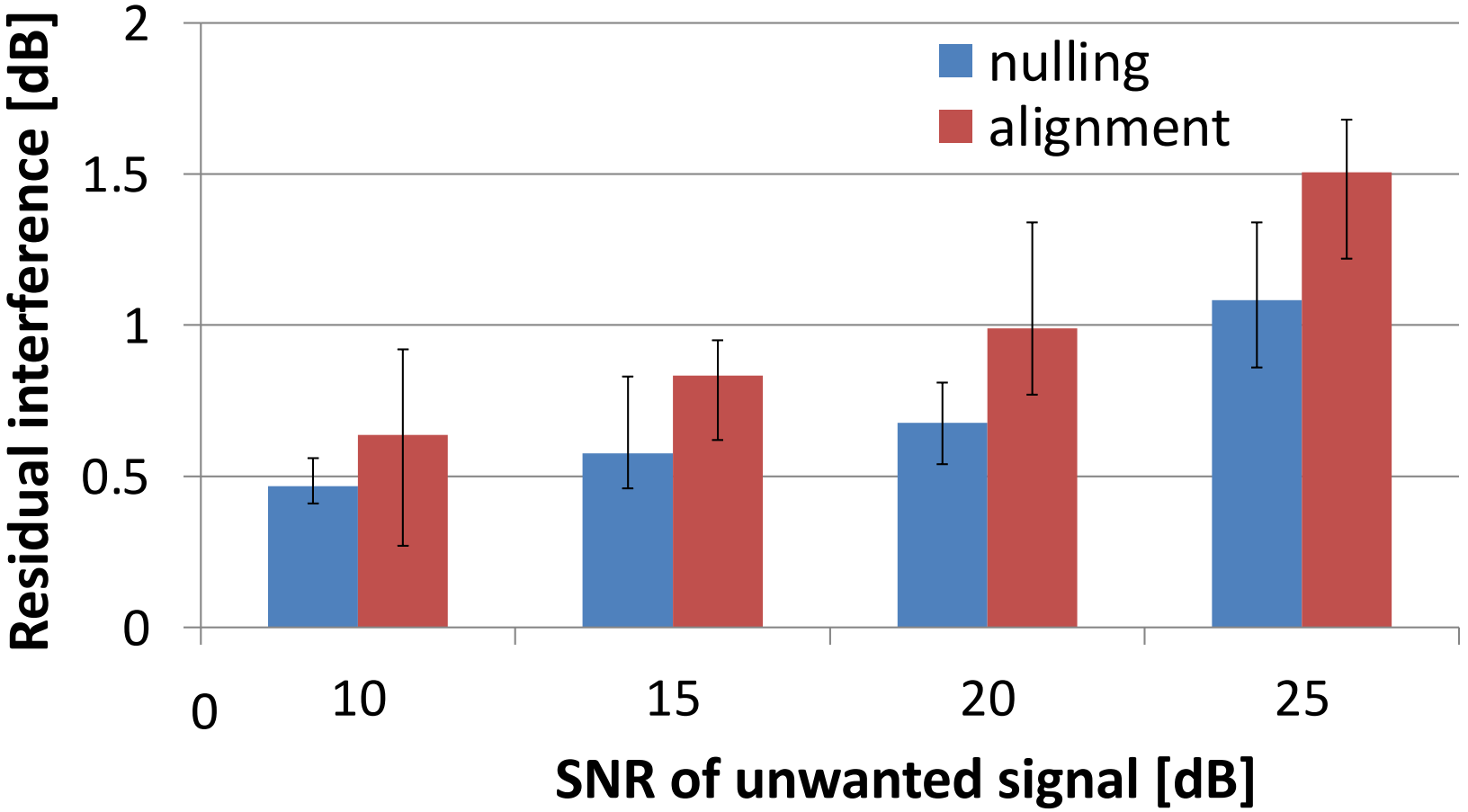


Residual interference from Bob can reduce the SNR of wanted signal by at most ~1dB

Alignment and Nulling Experiment



Alignment and Nulling Experiment

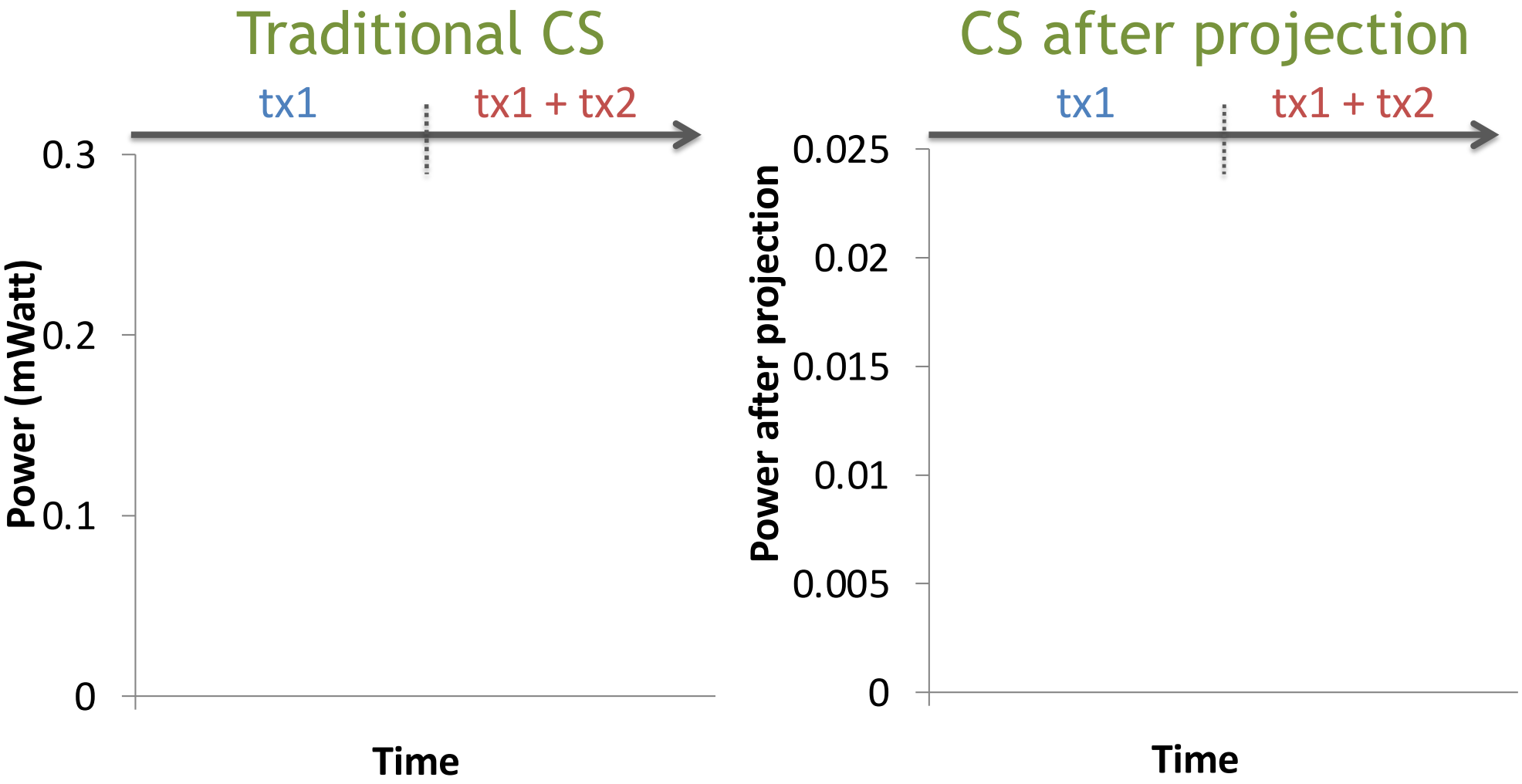


Though alignment is harder, residual interference is still small ~1.5dB

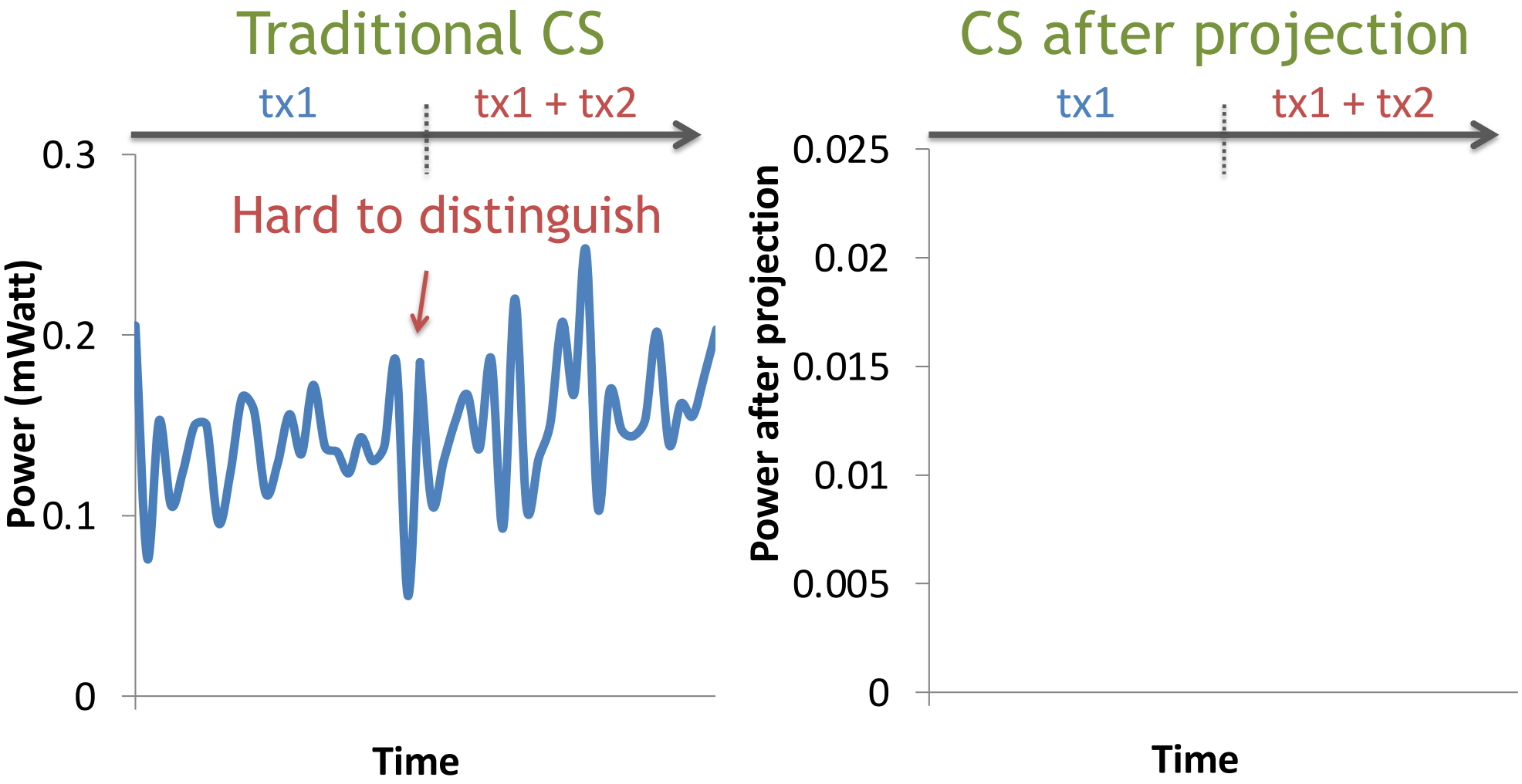
1. How to transmit without interfering with ongoing transmissions?
   - Interference nulling
   - Interference alignment

2. How do we achieve it in a random access manner?
   - **Multi-dimensional carrier sense**

Carrier Sense Experiment

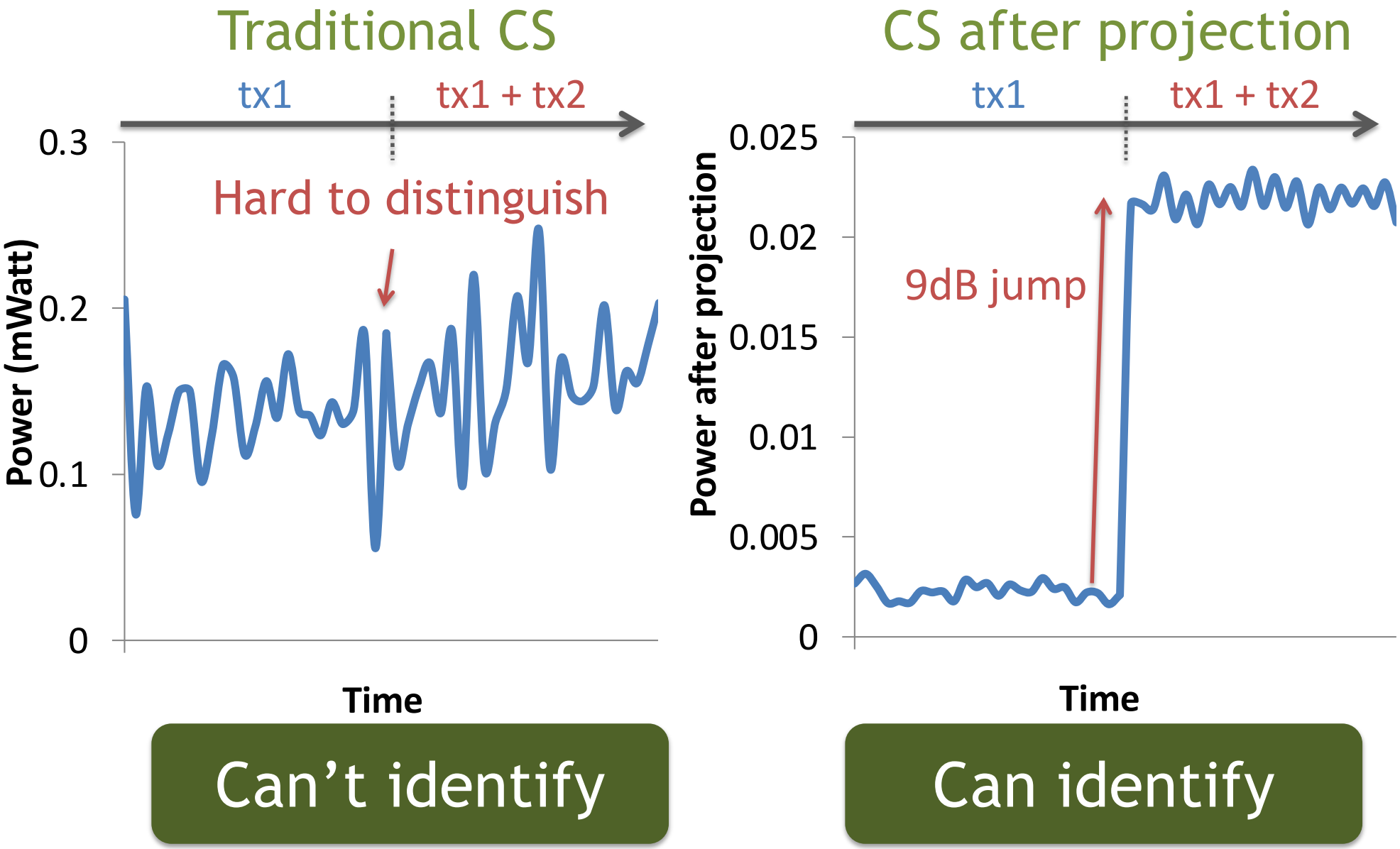


Carrier Sense Experiment

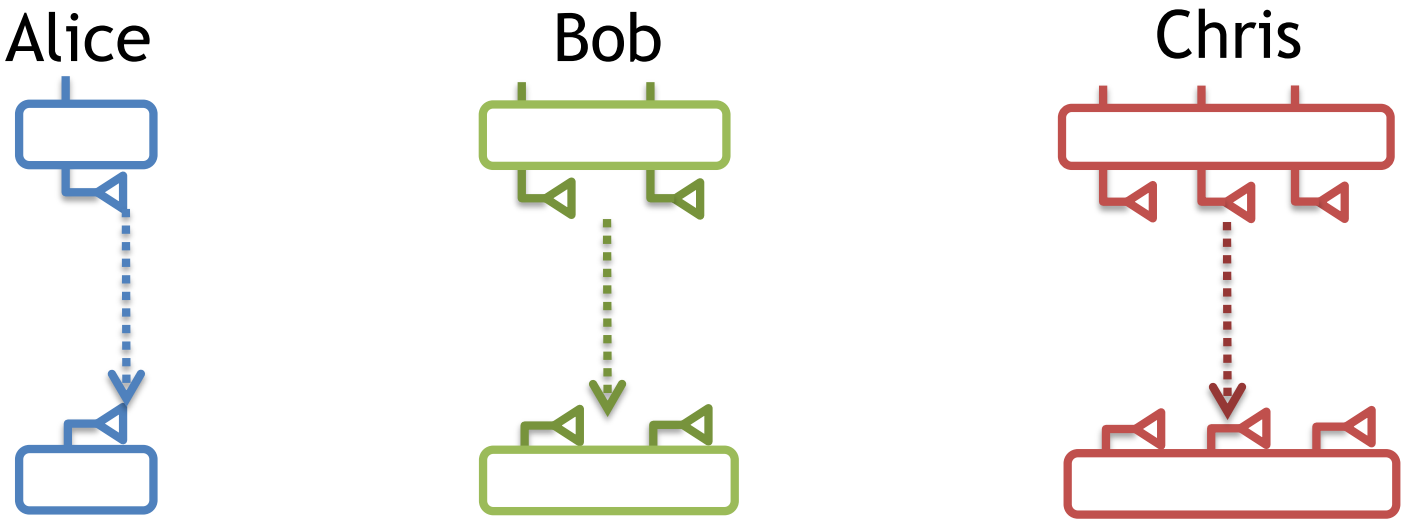


Can’t identify

Carrier Sense Experiment

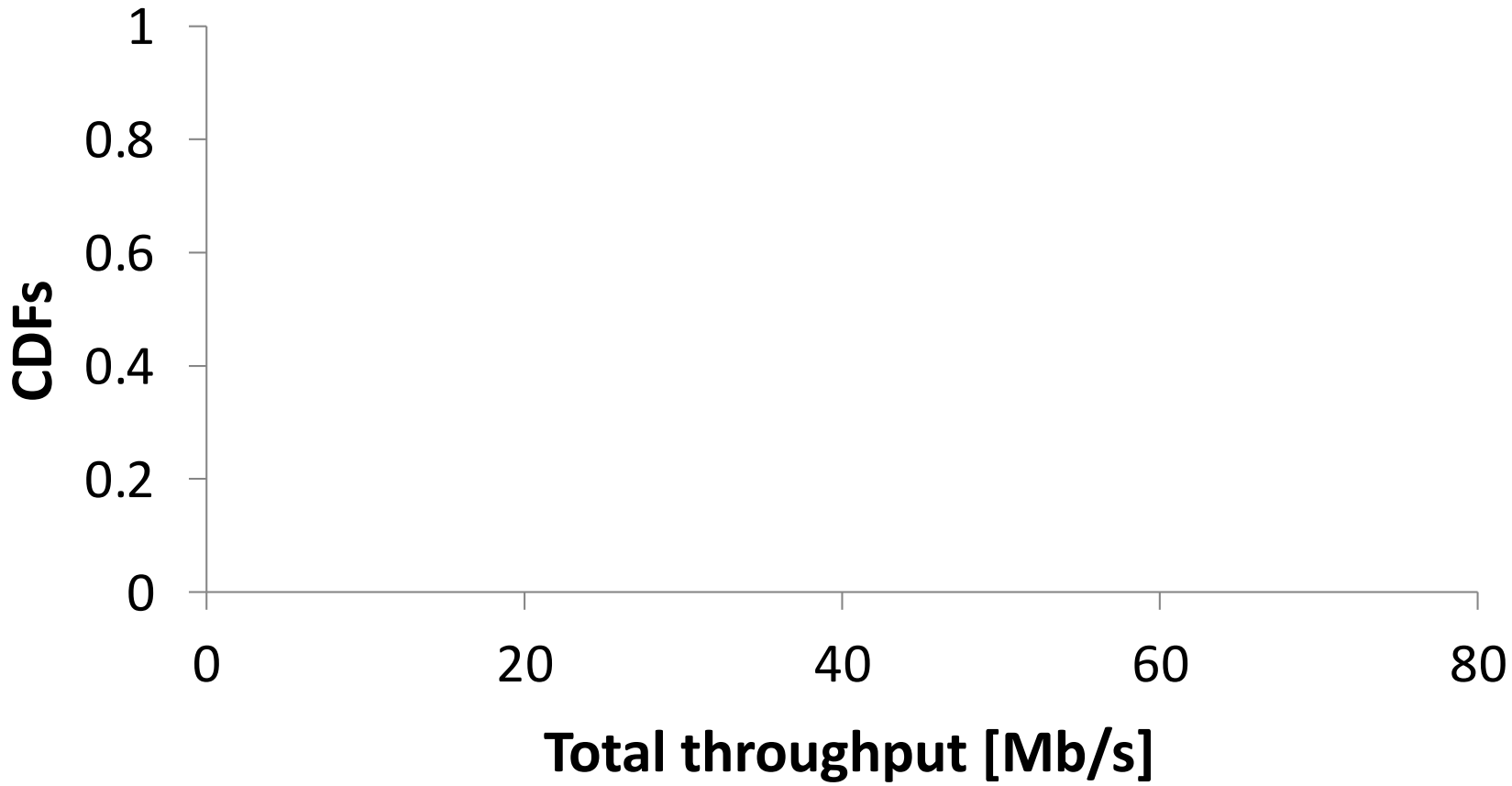


Throughput Experiment

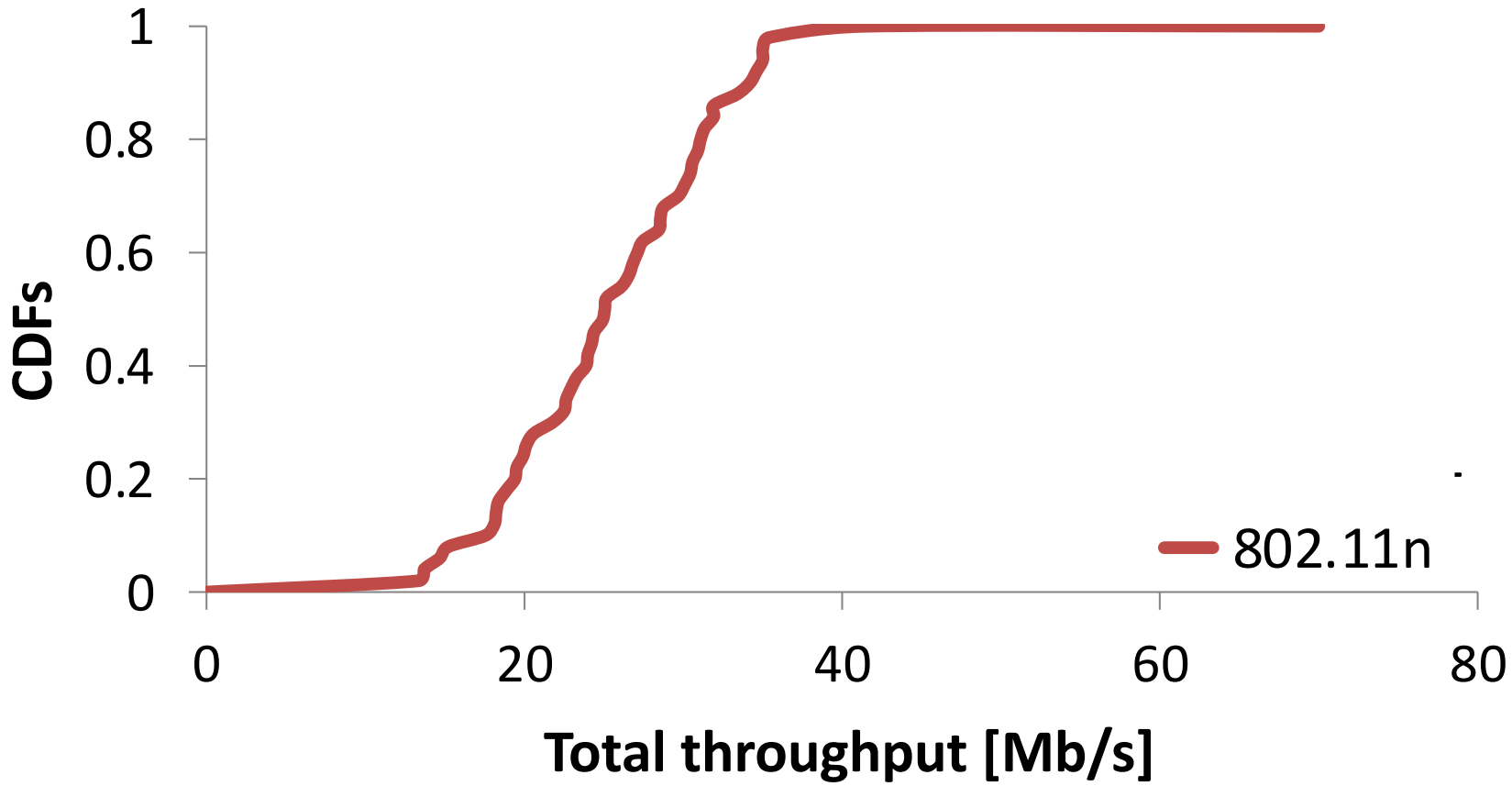


Compare 802.11n with 802.11n^{+}

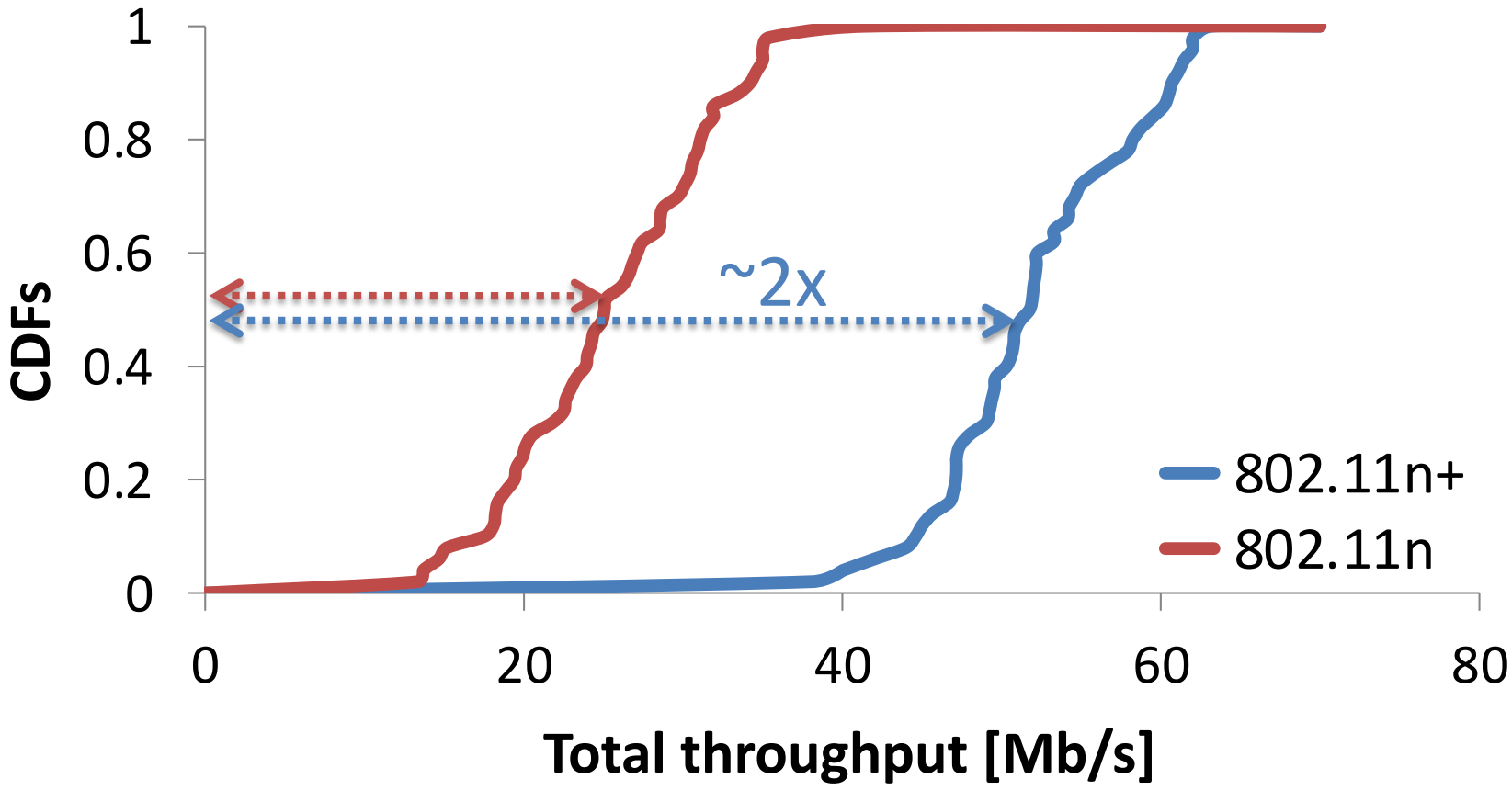
Throughput Experiment



Throughput Experiment



Throughput Experiment



n^+ delivers significant throughput gain in practice

Related Works

- Information theory
  - [CJ08], [MMK08], [JS08], …
- MIMO systems
  - Beamforming [AASK10], SAM [TLFWZC09], and IAC [GPK09]

First MIMO concurrent transmissions without any central coordination

Conclusion

- In today's 802.11, MIMO is an add-on
- In 802.11n^{+}, MIMO is a first-class citizen
  - Higher concurrency
  - With random access
- Shown practical via implementation and testbed evaluation