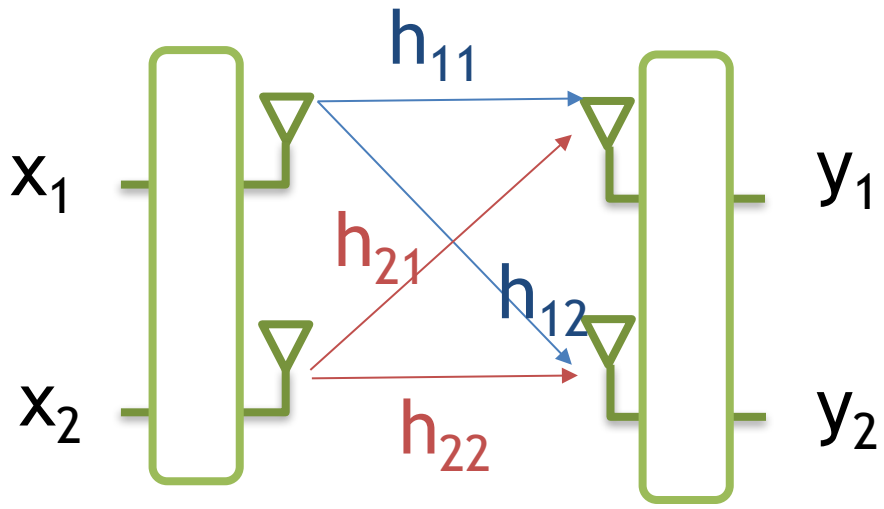
MIMO (802.11n)
&
Next Generation 802.11n

Some slides adapted from: Dina Katabi, Kate Lin, Shyam Gollakota

MIMO

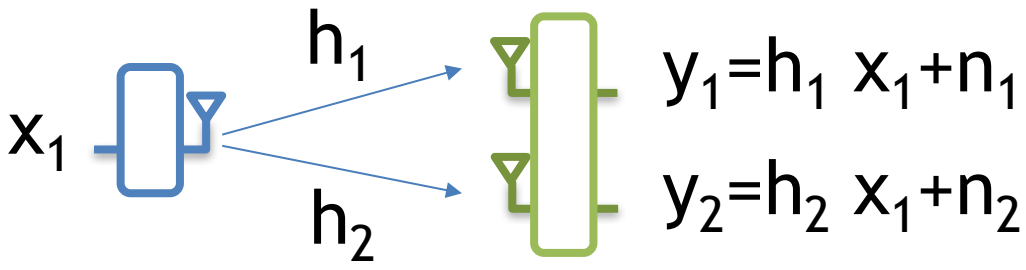
Multiple-input and multiple output (MIMO) is a method for multiplying the capacity of a radio link using multiple transmit and receive antennas



MIMO gains

- Multiplexing gain: send more packets at the same time
- Diversity gain: Increase SNR by sending packet along multiple streams

Receive Diversity

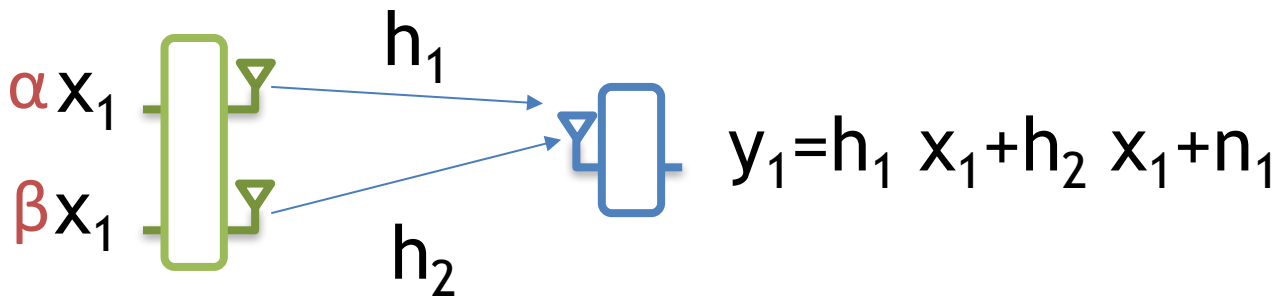


How Can we Decode?

1- Should We Sum?

2- Should We Decode Separately?

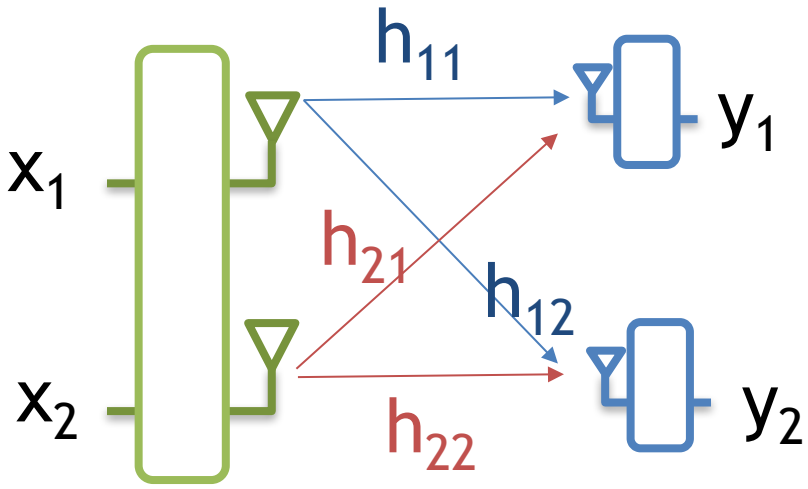
Transmit Diversity



Might add up destructively!

Pre-code the transmissions

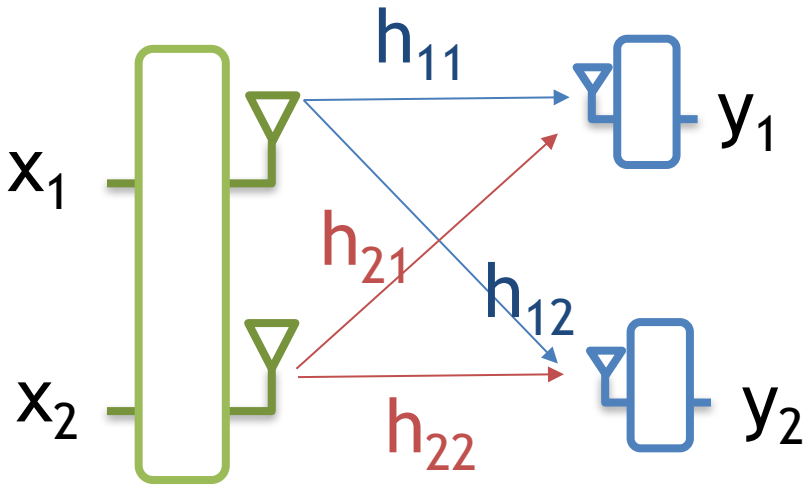
MU-MIMO (Multi-User MIMO)



Can't decode because Rx1 and Rx2 are separate

Solution: Interference Nulling

What if we have a two-antenna receiver?



Solution: Interference Nulling

Next Generation 802.11n

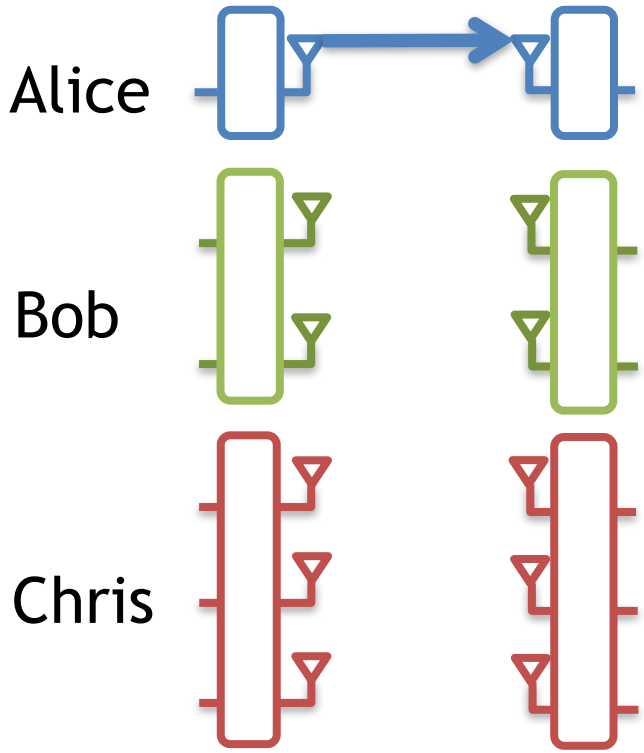
1-antenna devices

2-antenna devices

3-antenna devices

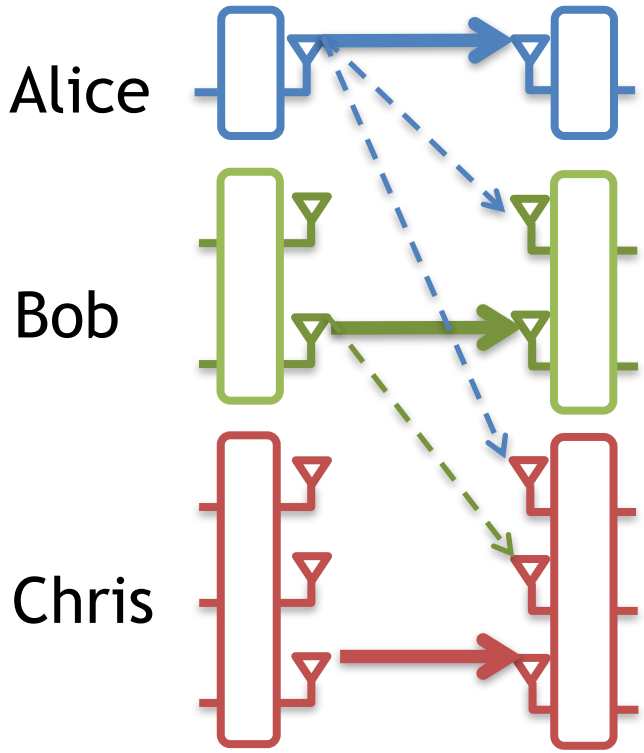
Wireless nodes increasingly have heterogeneous numbers of antennas

802.11 Was Designed for 1-Antenna Nodes

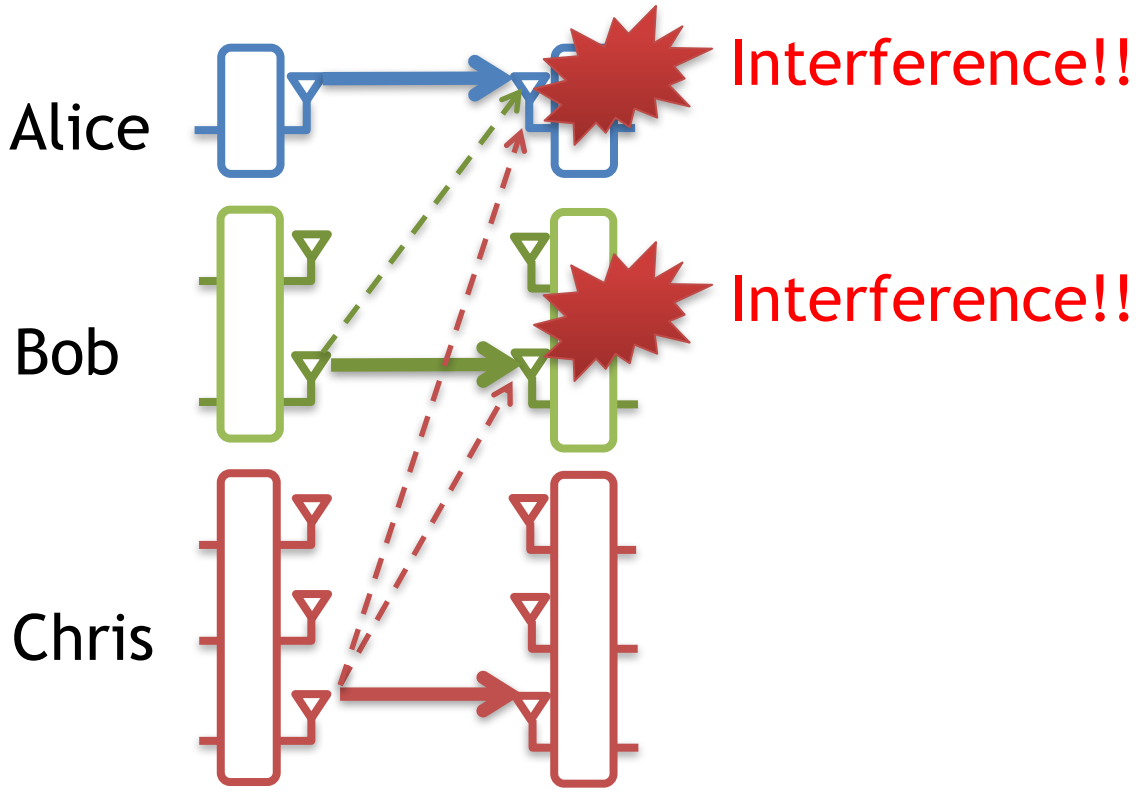


When a single-antenna node transmits, multi-antenna nodes refrain from transmitting

But, MIMO Nodes Can Receive Multiple Concurrent Streams



It's Not That Simple

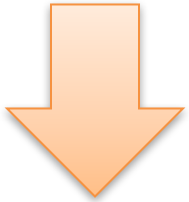


But, how do we transmit without interfering at receivers with fewer antennas?

Goal

Enable concurrent transmissions

without harming ongoing transmissions



802.11n+

802.11n+

- Enables 802.11 nodes to contend for both time and concurrent transmissions

- Maintains random access

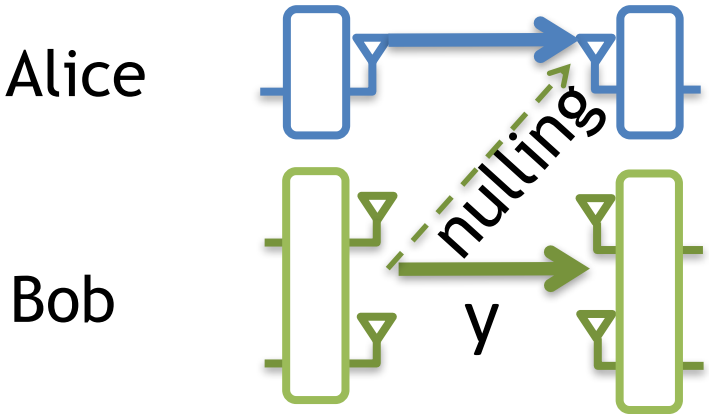
1. How to transmit without interfering with receivers with fewer antennas?

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

1. How to transmit without interfering with receivers with fewer antennas?

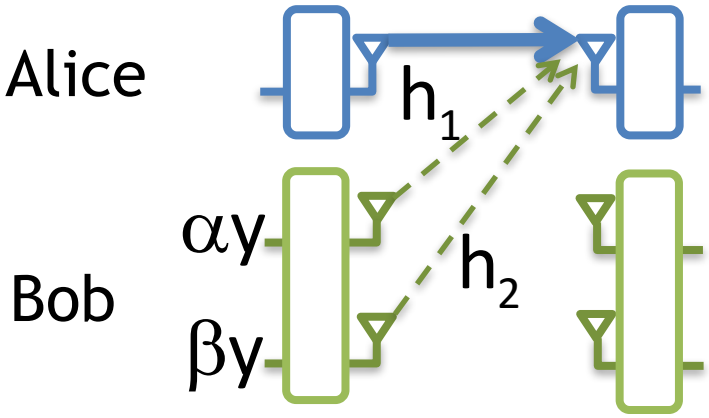
2. How do we achieve it in a random access manner?

Interference Nulling



- Signals cancel each other at Alice's receiver

Interference Nulling

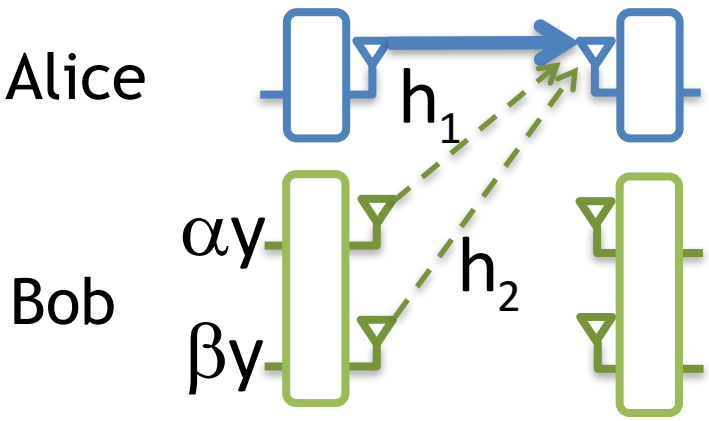


$$\Rightarrow \text{Nulling}: \; h_1\alpha = -h_2\beta$$

$$\neq 0$$

- Signals cancel each other at Alice's receiver
- Signals don't cancel each other at Bob's receiver
  - Because channels are different
- Bob's sender learns channels either by feedback from Alice's receiver or via reciprocity

Interference Nulling



$$h_1 \alpha y + h_2 \beta y = 0$$

$$\Rightarrow \text{Nulling}: \; h_1 \alpha = -h_2 \beta$$

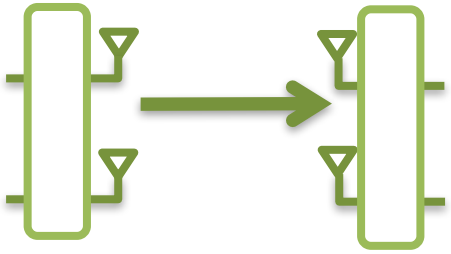
$$\neq 0$$

Q: How to transmit without interfering with receivers with fewer antennas?

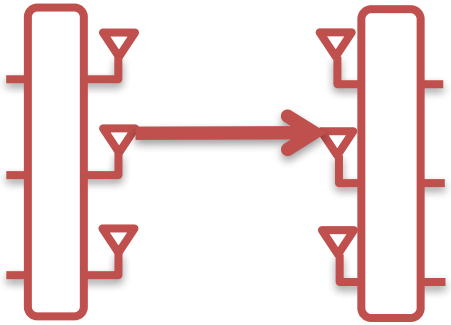
A: Nulling

Alice

Bob



Chris

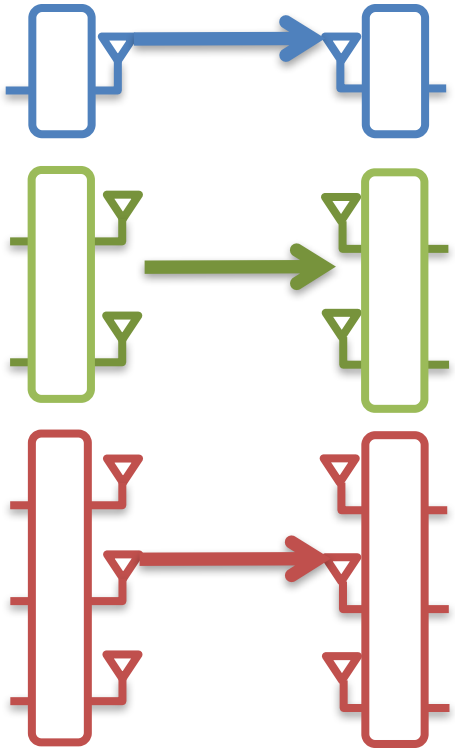


Is Nulling Alone Enough? NO!

Alice

Bob

Chris

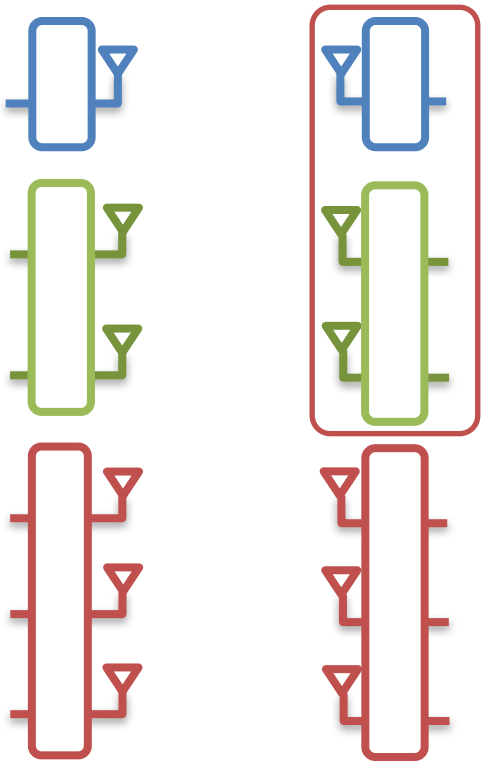


Is Nulling Alone Enough? NO!

Alice

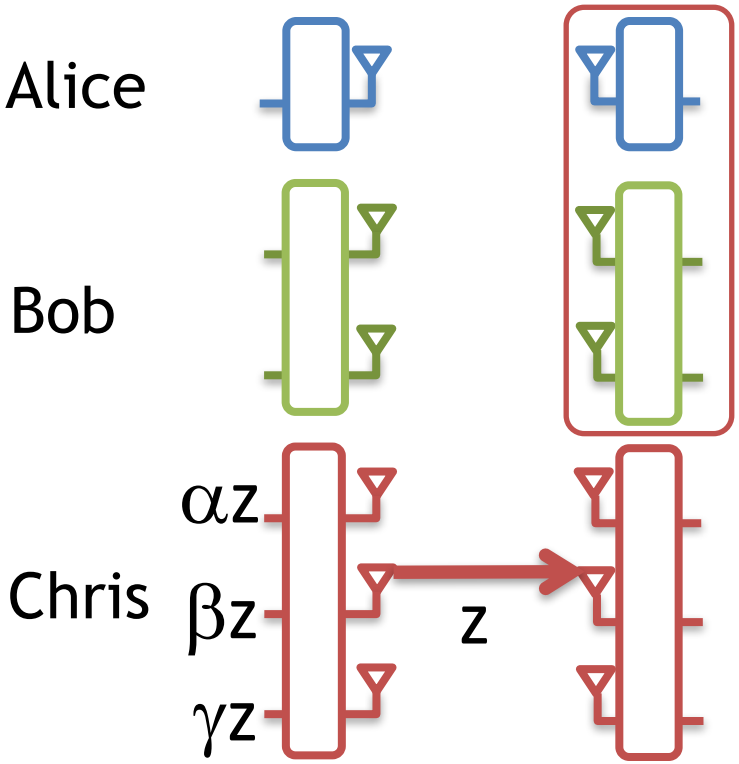
Bob

Chris



Chris needs to null at three antennas

Is Nulling Alone Enough? NO!



null

$$(h_{11}\alpha + h_{21}\beta + h_{31}\gamma)z = 0$$

$$(h_{12}\alpha + h_{22}\beta + h_{32}\gamma)z = 0$$

$$(h_{13}\alpha + h_{23}\beta + h_{33}\gamma)z = 0$$

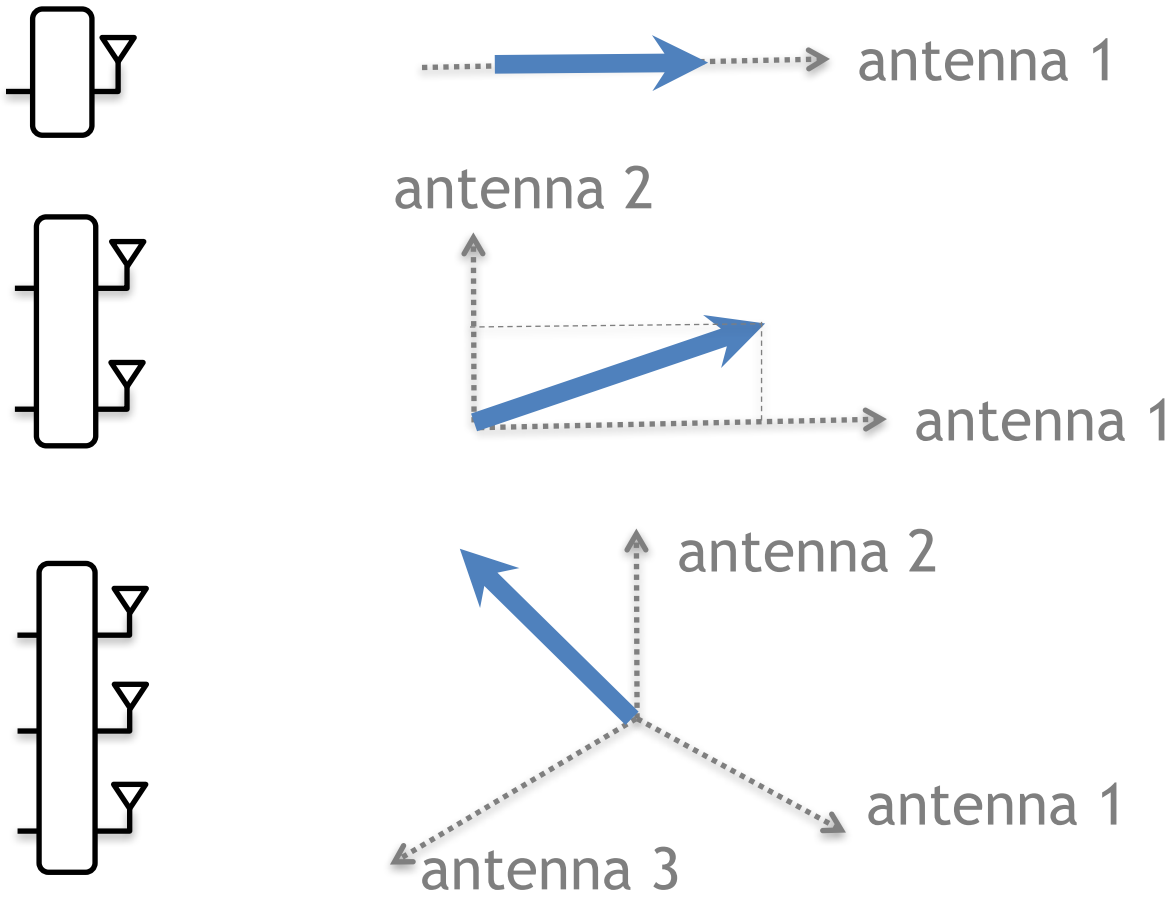
Only solution $\alpha = \beta = \gamma = 0$

Transmit Nothing!!!

Are we doomed?

MIMO Basics

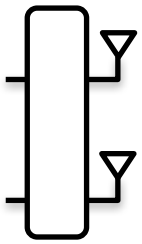
1. N-antenna node receives in N-dimensional space

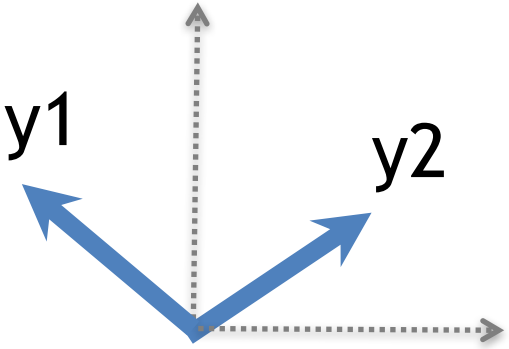


MIMO Basics

1. N-antenna node receives in N-dimensional space
2. N-antenna receiver can decode N signals

2-antenna receiver

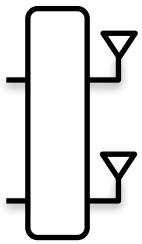


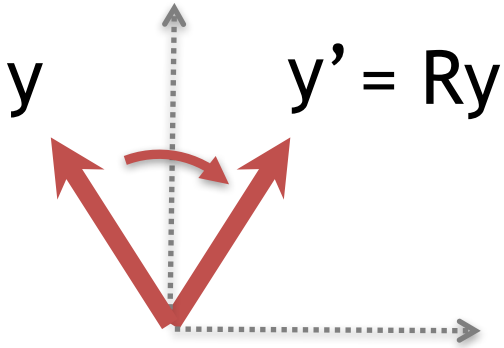


MIMO Basics

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

2-antenna receiver

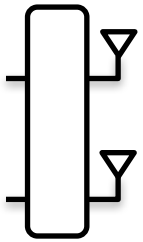


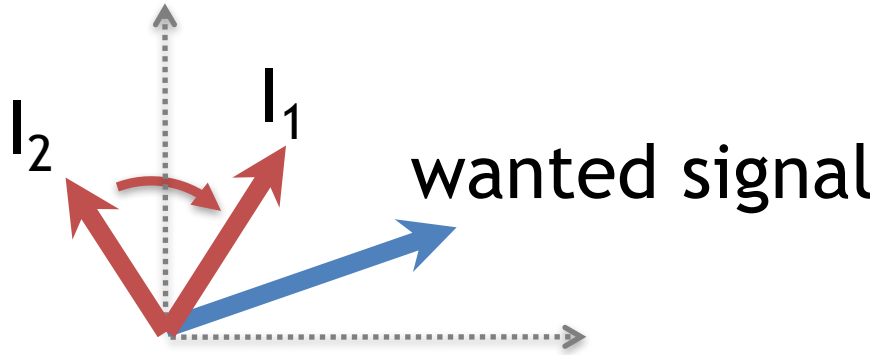


Rotate by multiplying transmitted signal by a rotation matrix R

Interference Alignment

2-antenna receiver

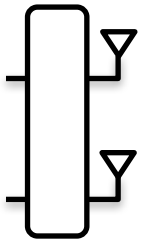


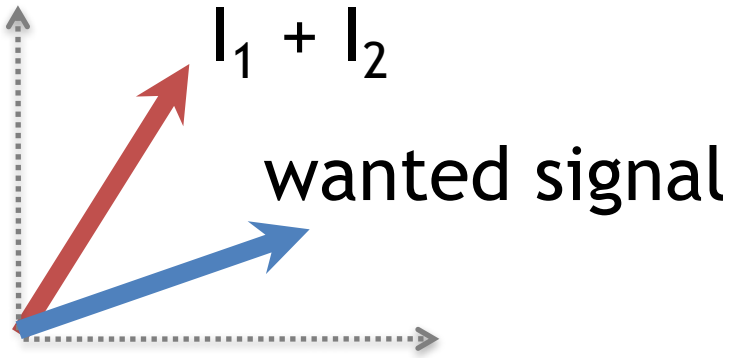


If I_1 and I_2 are aligned,

Interference Alignment

2-antenna receiver



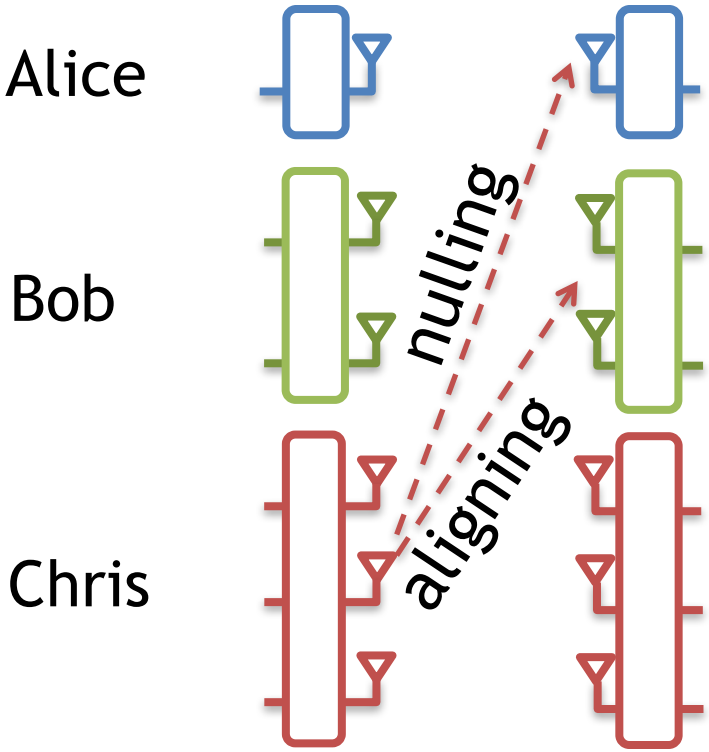


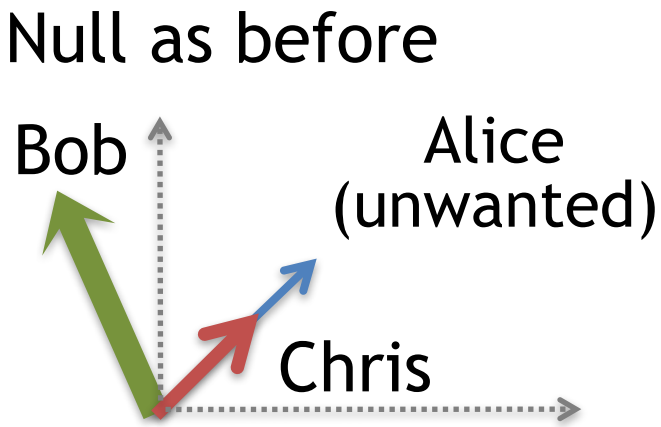
If I_1 and I_2 are aligned,

→ appear as one interferer

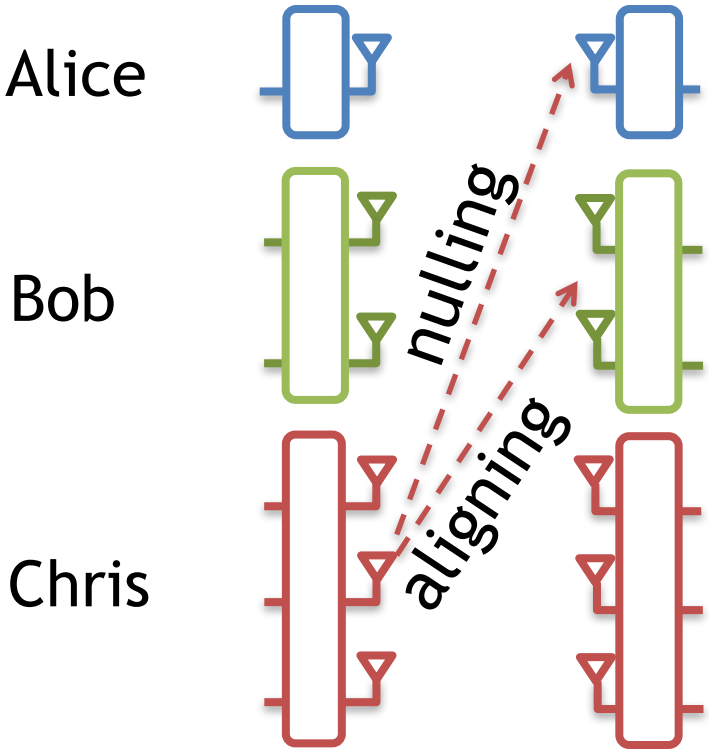
→ 2-antenna receiver can decode the wanted signal

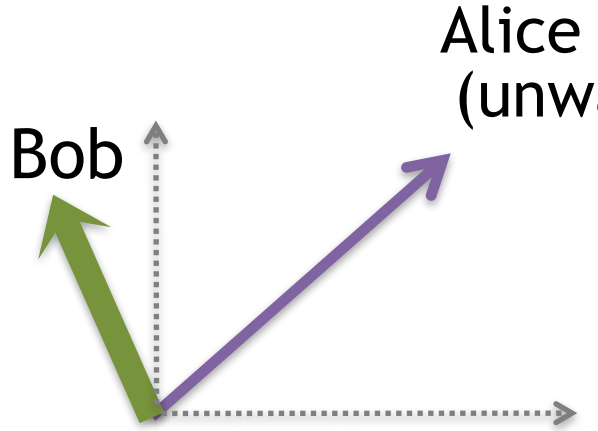
Use Nulling and Alignment





Use Nulling and Alignment

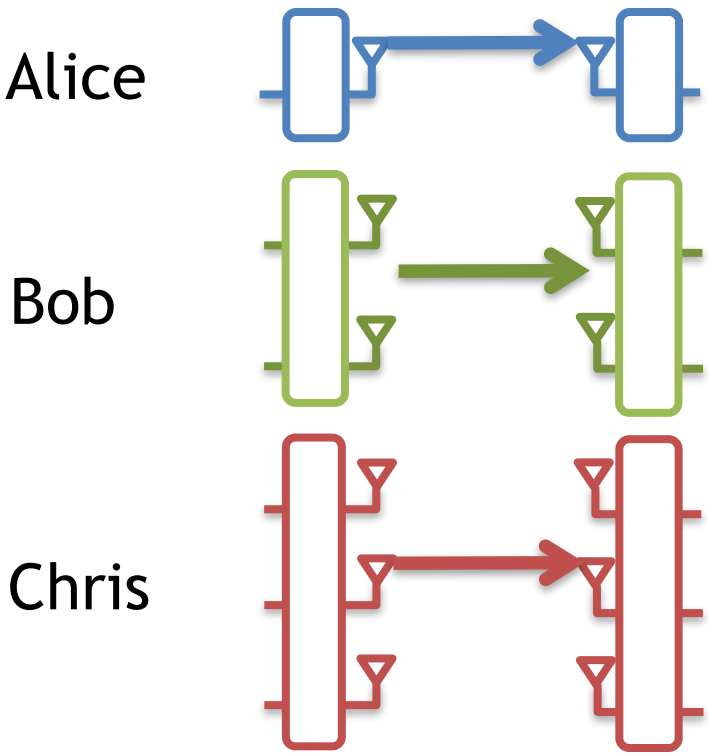




2-signals in 2D-space

➔Can decode Bob's signal

Use Nulling and Alignment



3 packets through receivers have fewer than 3 antennas

MAC Protocol

- Each sender computes in a distributed way
  - 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 receivers with fewer antennas?
   - Interference nulling
   - Interference alignment

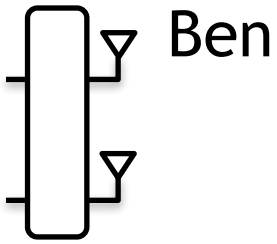
2. How do we achieve it in a random access manner?

In 802.11, contend using carrier sense

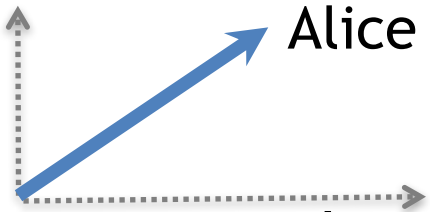
But, how to contend despite ongoing transmissions?

Multi-Dimensional Carrier Sense

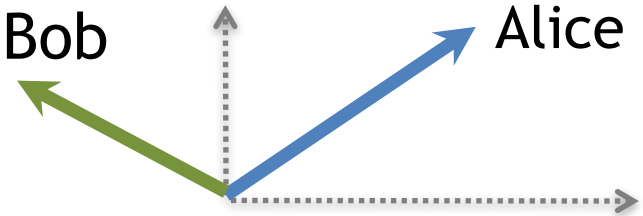
Say that Ben is performing carrier sense



Distinguishable using simple linear algebra

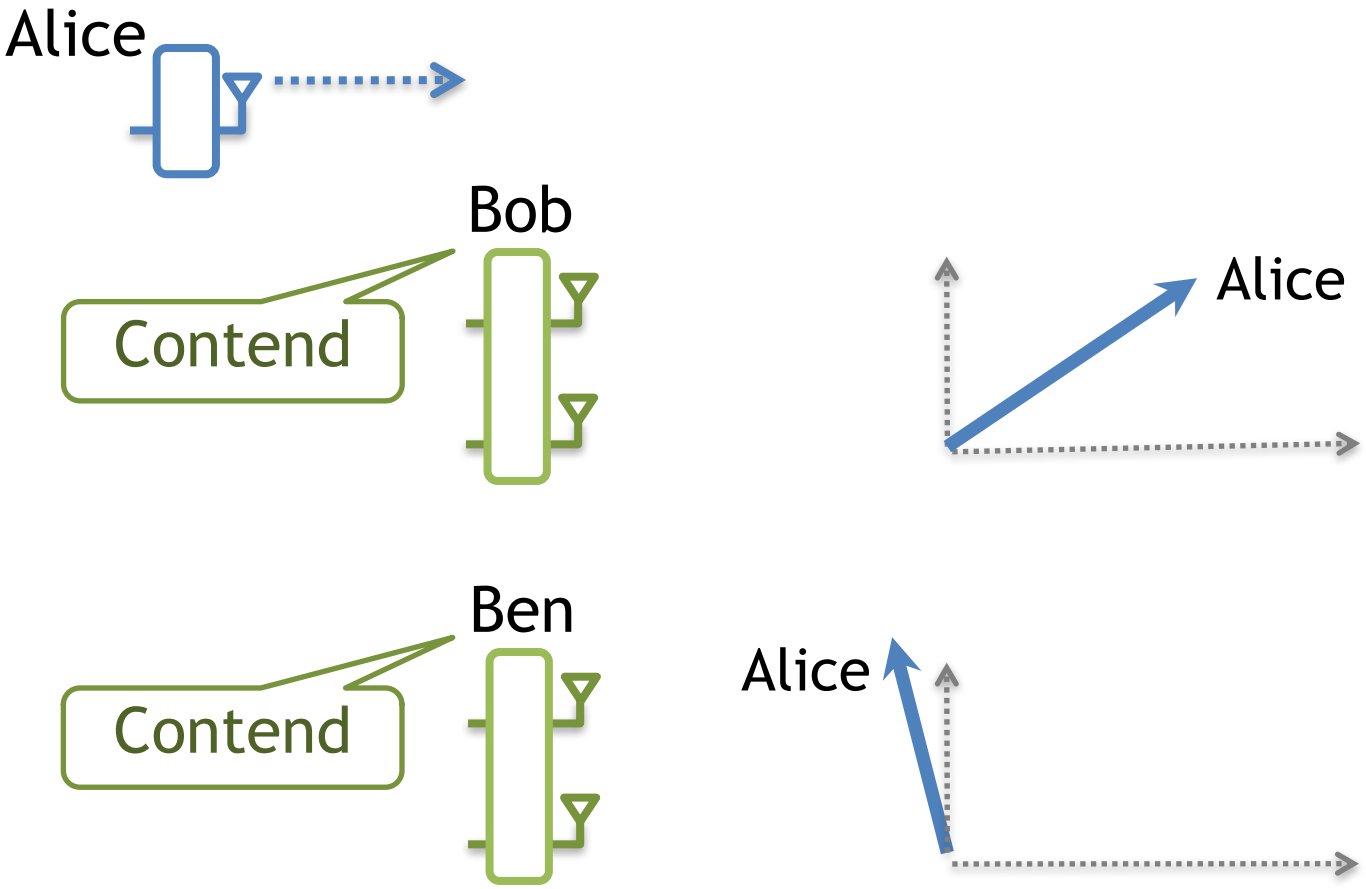


one signal



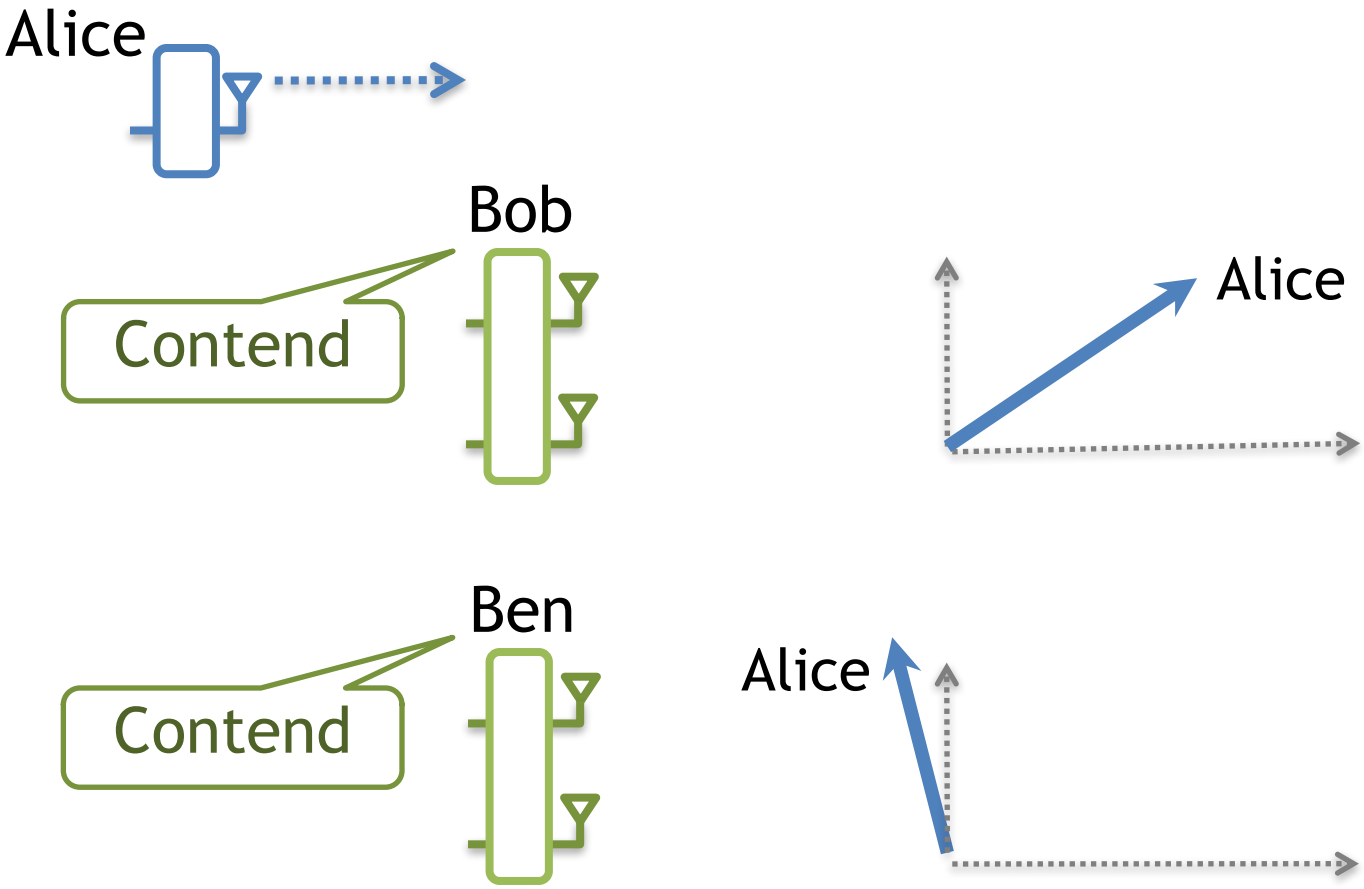
two signals

Multi-Dimensional Carrier Sense



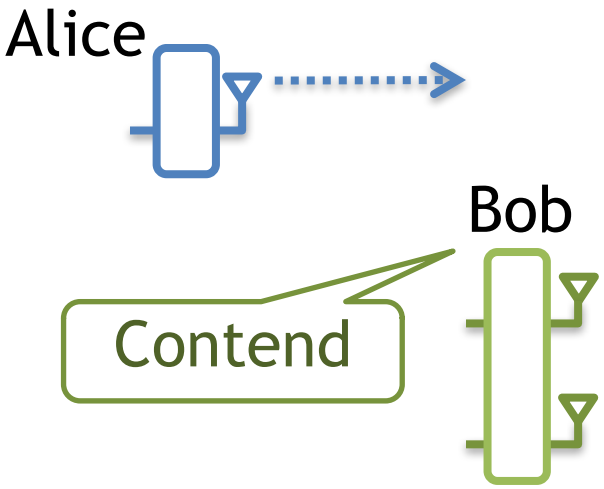
Bob and Ben contend for a second concurrent transmission

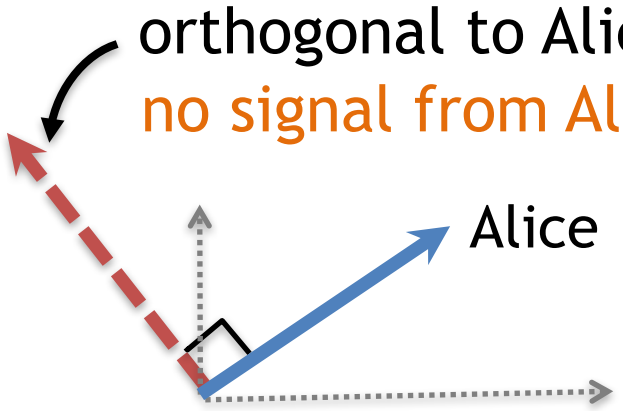
Multi-Dimensional Carrier Sense

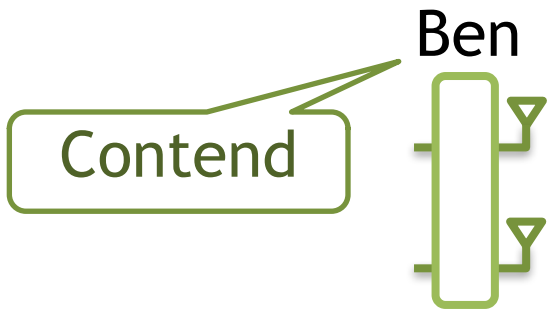


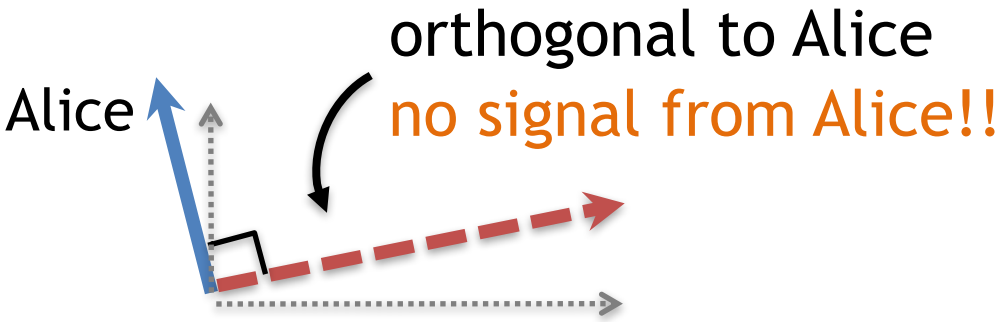
Project orthogonal to Alice's signal

Multi-Dimensional Carrier Sense



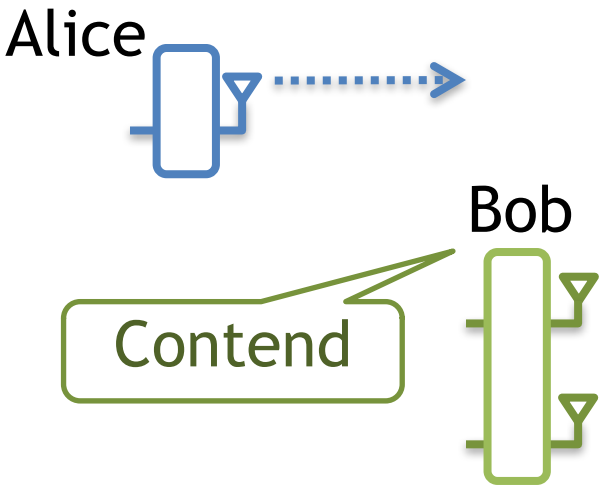


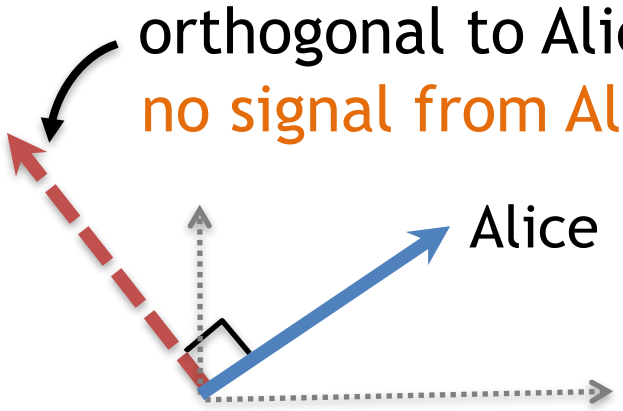


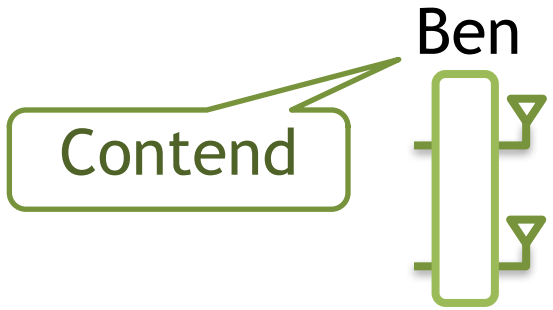


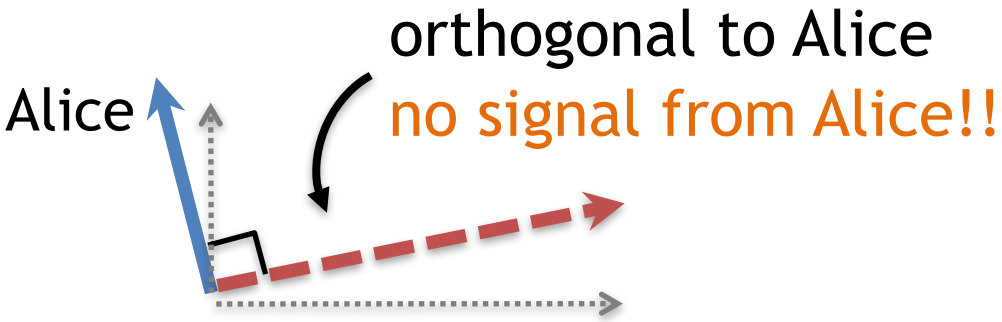
Project orthogonal to Alice's signal

Multi-Dimensional Carrier Sense



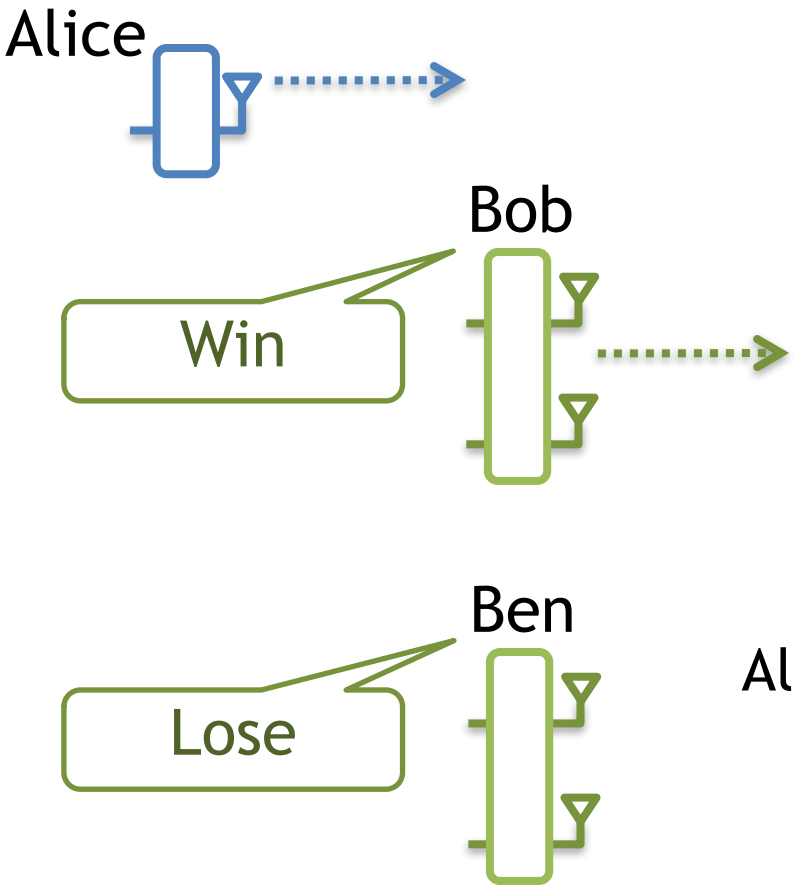


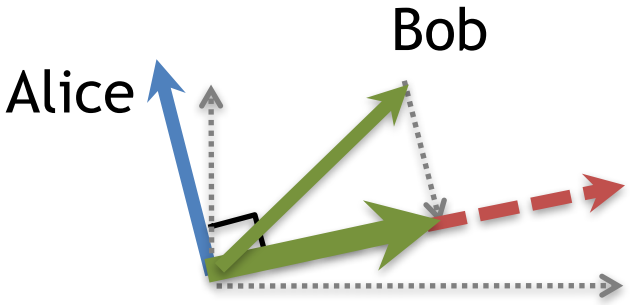




Apply carrier sense in the orthogonal space

Multi-Dimensional Carrier Sense





Detect energy after projection

Multi-Dimensional Carrier Sense

To contend for the next concurrent transmission

- Project orthogonal to ongoing signals
- Apply standard carrier sense

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