MIMO (802.11n) &
Next Generation 802.11n

Some slides adapted from: Dina Katabi, Kate Lin, Shyam Gollakota
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
How Can we Decode?

1- Should We Sum?

2- Should We Decode Separately?
Transmit Diversity

\[ y_1 = h_1 x_1 + h_2 x_1 + n_1 \]

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
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
- Signals don’t cancel each other at Bob’s receiver

"Because channels are different"
Interference Nulling

- 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

\[ h_1 \alpha = -h_2 \beta \neq 0 \]
Q: How to transmit without interfering with receivers with fewer antennas?

A: Nulling

\[ h_1 \alpha y + h_2 \beta y = 0 \]

\[ \Rightarrow \text{Nulling: } h_1 \alpha = -h_2 \beta \neq 0 \]
Is Nulling Alone Enough?  NO!

Alice

Bob

Chris
Is Nulling Alone Enough? NO!

Chris needs to null at three antennas
Is Nulling Alone Enough? **NO!**

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

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

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

Only solution \(\alpha = \beta = \gamma = 0\)

Transmit Nothing!!!

Are we doomed?

null
MIMO Basics

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

- Antenna 1
- Antenna 2
- Antenna 3
MIMO Basics

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

2. N-antenna receiver can decode N signals

2-antenna receiver

\[ y_1, y_2 \]
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

\[
y' = Ry
\]

Rotate by multiplying transmitted signal by a rotation matrix R
If $I_1$ and $I_2$ are aligned,
Interference Alignment

If $I_1$ and $I_2$ are aligned,

→ appear as one interferer

→ 2-antenna receiver can decode the wanted signal
Use Nulling and Alignment

Null as before

Alice (unwanted)

Bob

Chris
Use Nulling and Alignment

Alice

Bob

Chris

2-signals in 2D-space

⇒ Can decode Bob’s signal

Bob

Alice + Chris (unwanted)
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

Alice

one signal

Bob

two signals

Alice

Ben
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

Alice

Bob

Ben

Contend

orthogonal to Alice
no signal from Alice!!

orthogonal to Alice
no signal from Alice!!

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