MU-MIMO

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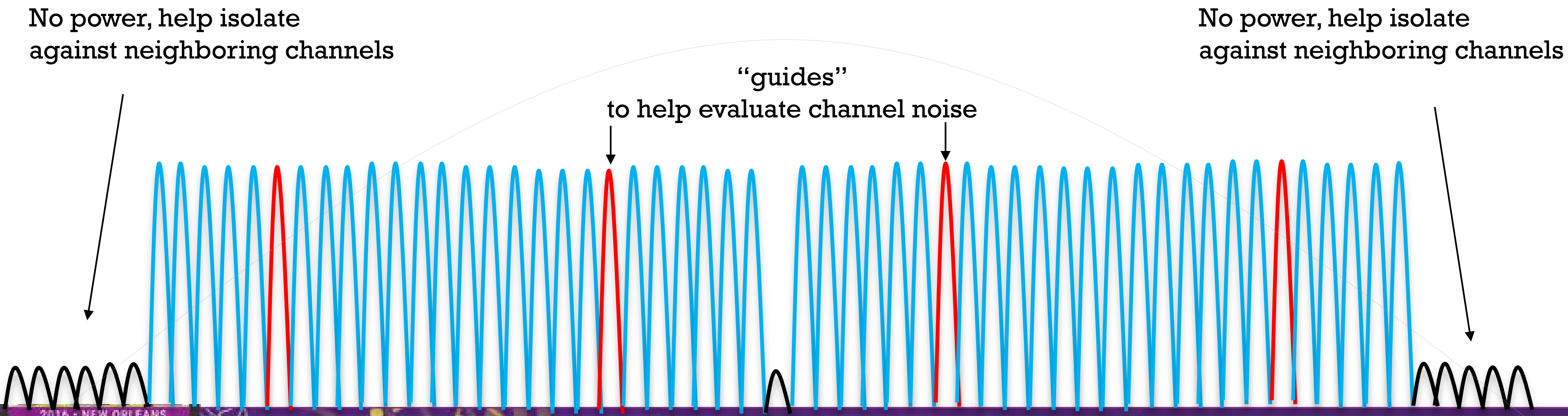
Channel Width

Guides and Sensitivity

OFDM:802.11g, 802.11a, 802.11n “Legacy Mode”

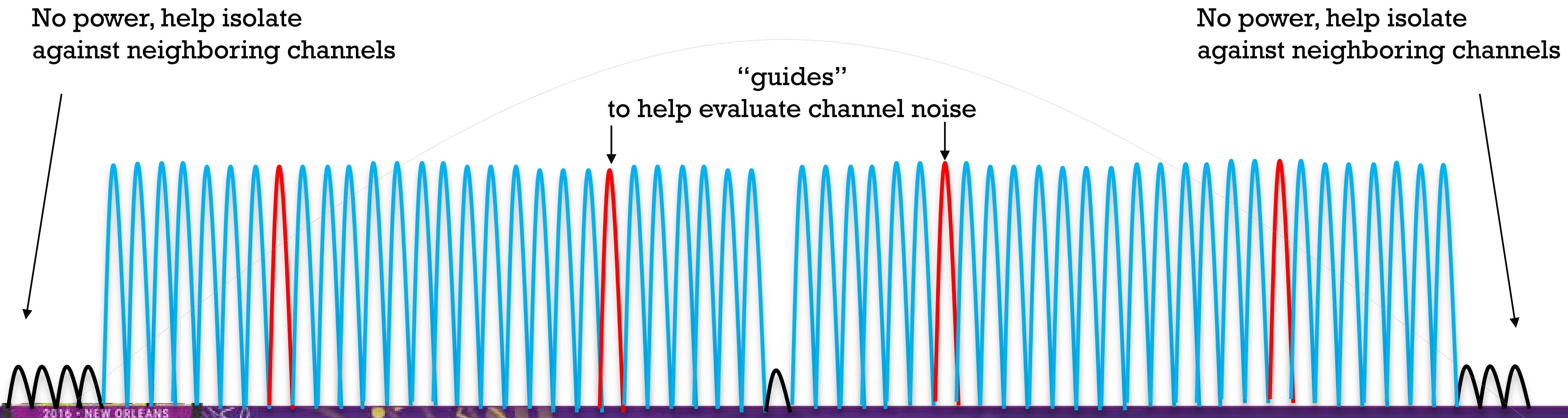
- 64 small waves (called Carriers, or Tones), using BPSK, QPSK… or QAM (Quadrature)
- 12 null, 4 pilot -> 48 active tones



8% pilots

802.11n/802.11ac 20 MHz

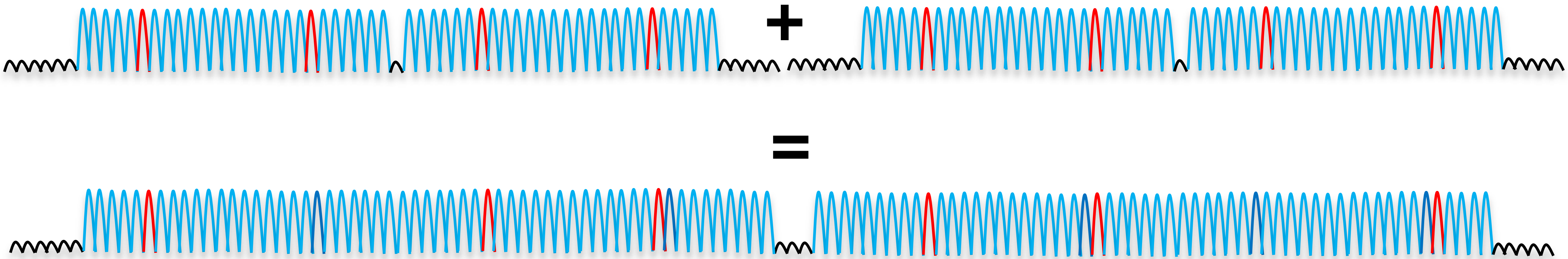
- 64 small waves (called Carriers, or Tones), using BPSK, QPSK… or QAM (Quadrature)
- 8 null, 4 pilots (+-7, +-21) -> 52 active tones



7% pilots

802.11n/802.11ac 40 MHz

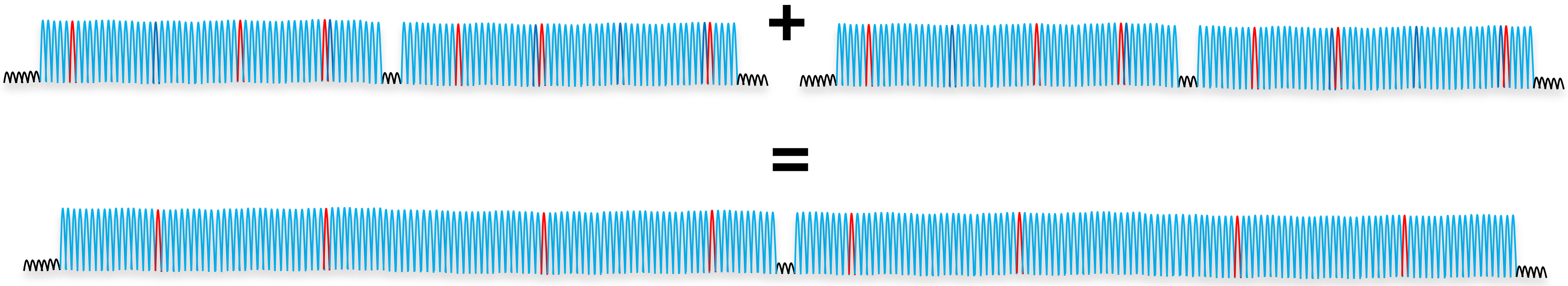
- 128 subcarriers (vs. 64)
- 14 (vs. 12/8) zero subcarriers on sides (6;5) and center (3)
- 6 pilot subcarriers (vs. 4): +-11, +-25, +-53
- 108 data subcarriers (vs. 48/52)



5% pilots, 2.3x 802.11a/g capacity

802.11ac 80 MHz

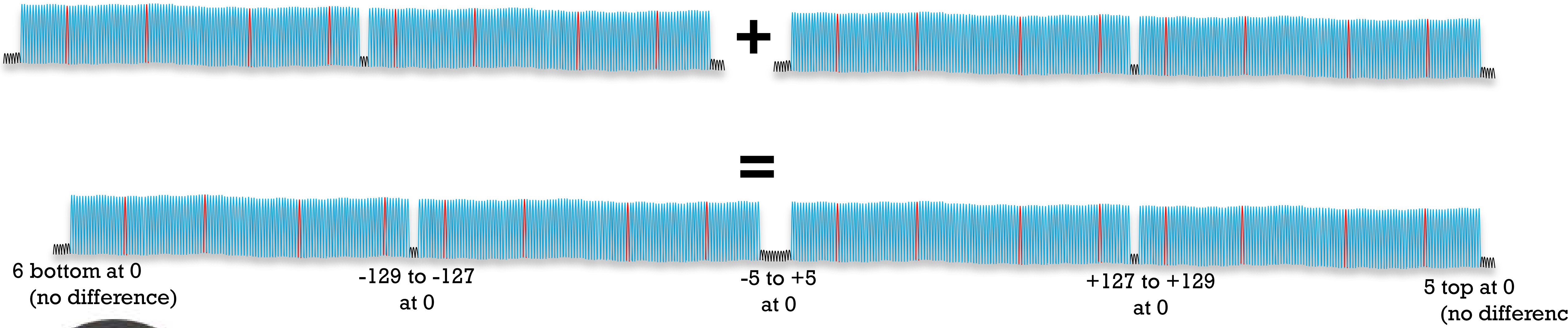
- 256 subcarriers (vs. 128)
- Still 14 zero subcarriers on sides (6;5) and center (3)
- 8 pilot subcarriers (vs. 6): +-11, +-39, +-75, +-103
- 234 data subcarriers (vs. 108)



3% pilots, 4.9x 802.11a/g capacity, 2.15x 11n/ac 40 MHz capacity

802.11ac 160 MHz

- 512 subcarriers (vs. 256)
- 28 zero subcarriers
- 16 pilot subcarriers (vs. 8): +-25, +-53, +-89, +-117, +-139, +-167, +-203, +-231
- 468 data subcarriers (vs. 234)



3% pilots, 9.75x 802.11a/g capacity, 2x 11ac 80 MHz capacity

Some 802.11ac Rx Sensitivity

MCS	Channel	SS	Data Rate (NGI)	RSSI Min	SNR Min
7	20 MHz	1	65	76.5	17.5
7	40 MHz	1	135	74.5	19.5
7	80 MHz	1	292.5	71.5	22.5
7	20 MHz	3	195	71	23
7	40 MHz	3	405	71	23
7	80 MHz	3	1053	63	31

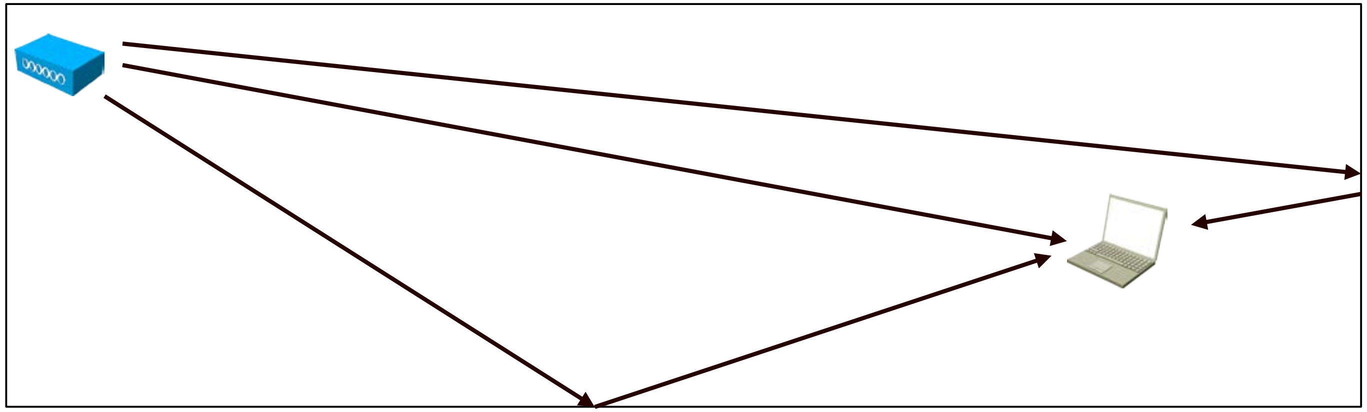
You need 5 dB more to read a 80 MHz 1SS signal than to read a 20 MHz 1SS signal
You need 8 dB more to read a 80 MHz 3SS signal than to read a 20 MHz 3SS signal
You need 13.5 dB more to read a 80 MHz 3SS signal than to read a 20 MHz 1SS signal

MU-MIMO

Interesting Challenges

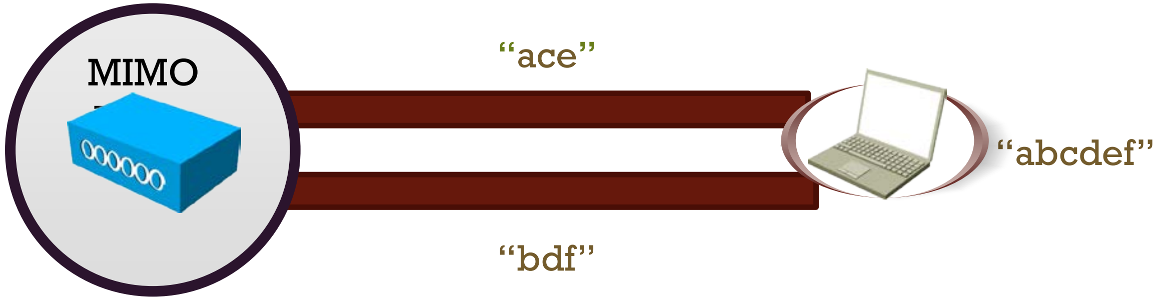
MU-MIMO

802.11n taught us to love multipath…

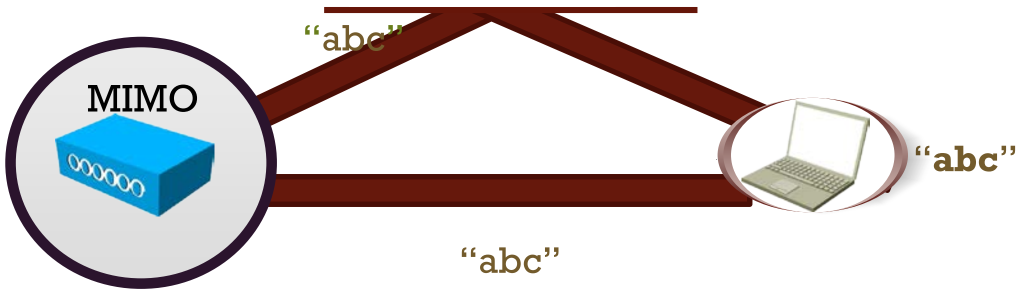


MU-MIMO

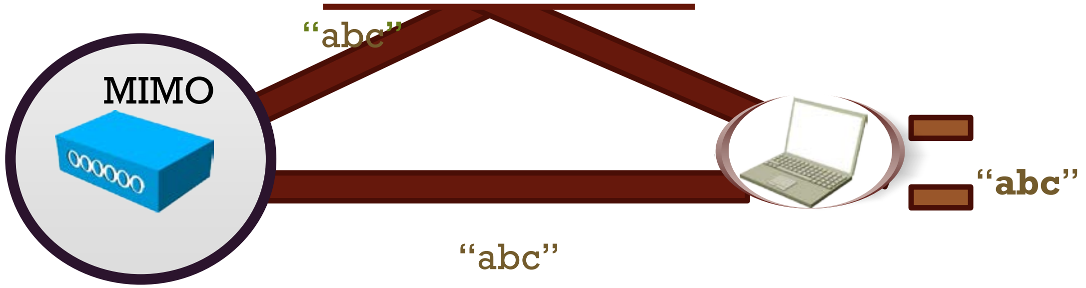
802.11n taught us to love multipath… because with MIMO, we can do:



Send more symbols,
in parallel (spatial multiplexing)



Sending side: synchronize signals for better resulting signal at receiving end (Transmit Beamforming, TxBF, ClientLink)



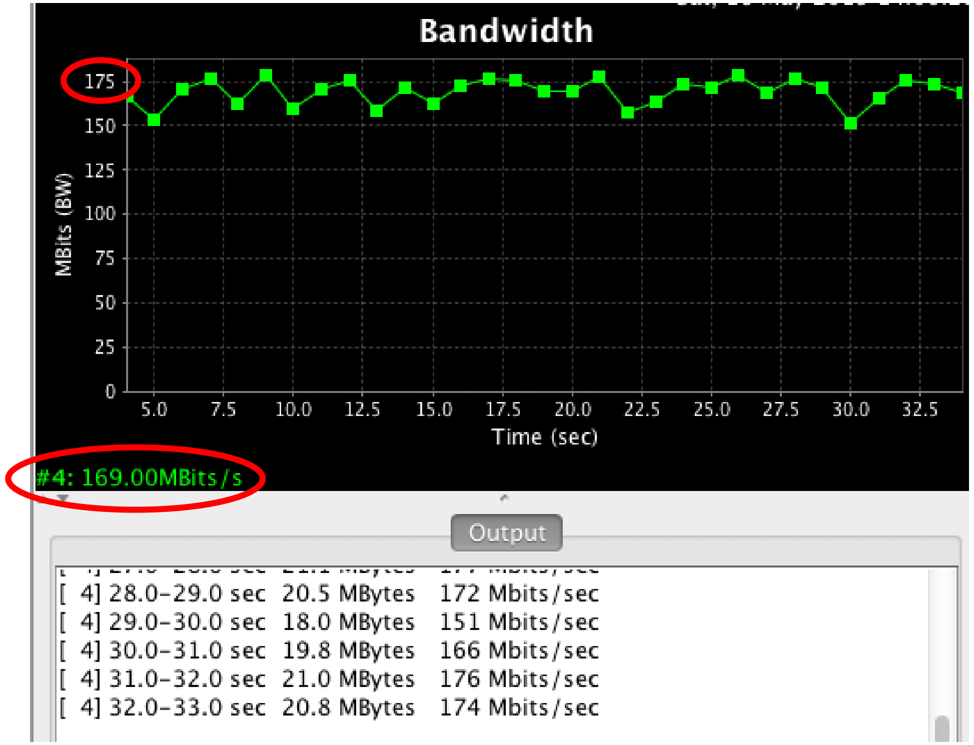
Receiving side: synchronize signals for better signal (Maximal Ratio Combining, MRC)

MU-MIMO

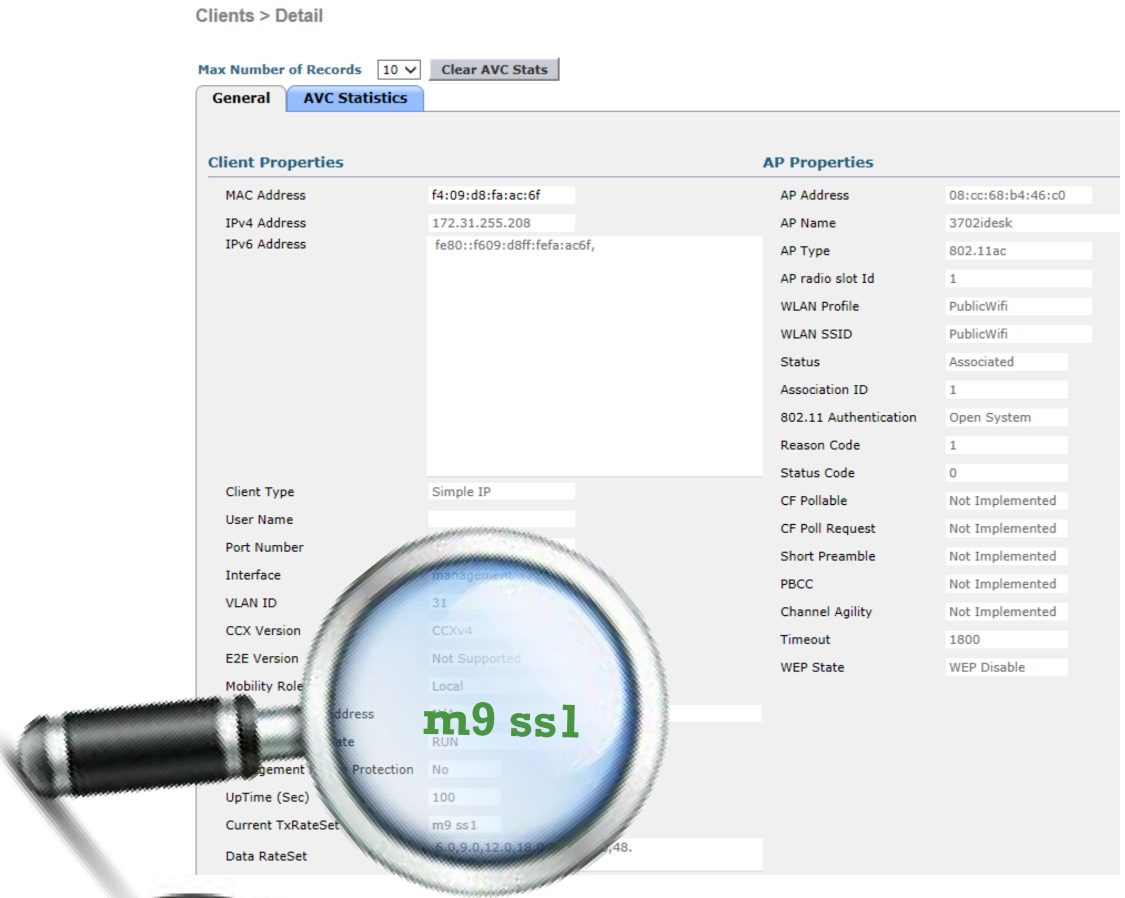
But wait: as soon as you have more than one stream, you need to become good at estimating the channel…

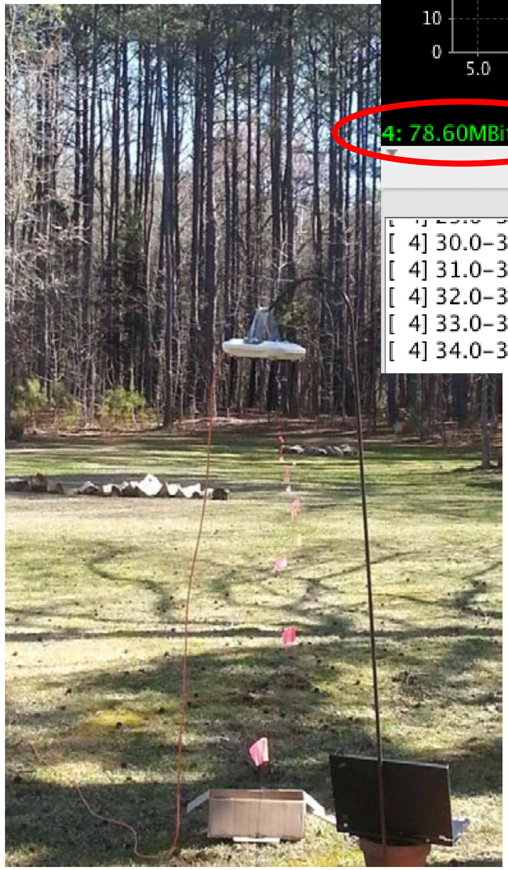
And this is where multipath helps…

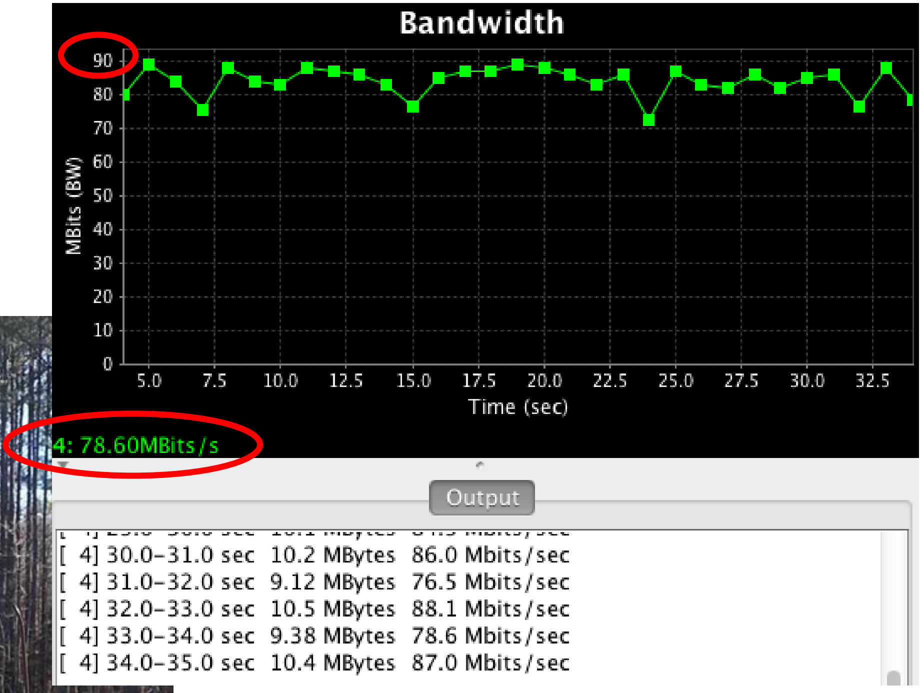
With Multipath



Without Multipath





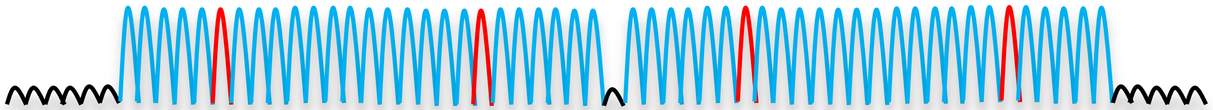


Outdoor, multipath is not enough for the phone to differentiate streams

MU-MIMO

Why the difference?

Remember the pilots?



They are predetermined sequences, used to determine the channel state (noise)

Each SS has a known, but different, sequence

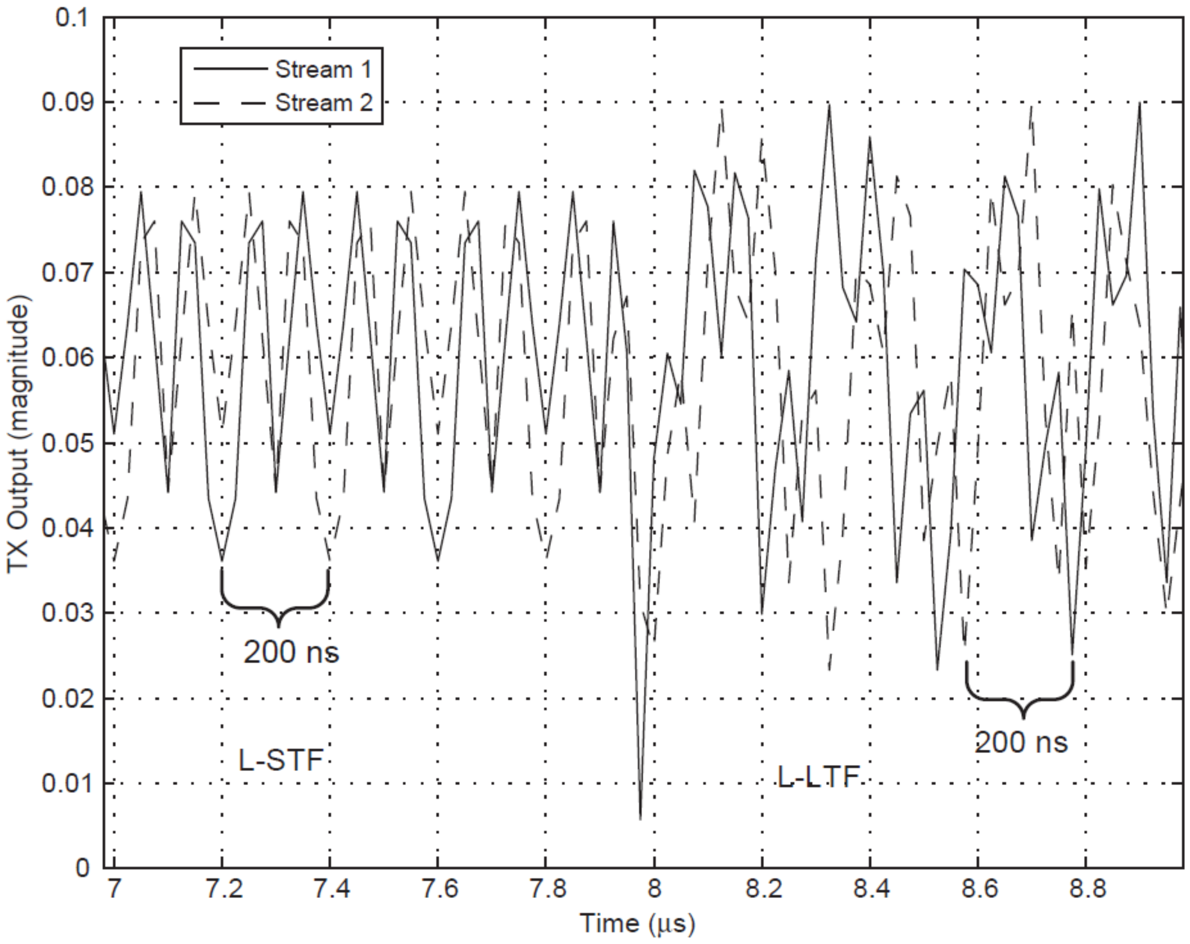
Each receive chain evaluates the channel, and checks which stream is seen best

The chipset assigns one stream to receive per chain

MU-MIMO

Each chain deduces the “useless streams” from the signal, to only keep the useful part

Delete stream 2,
keep stream 1



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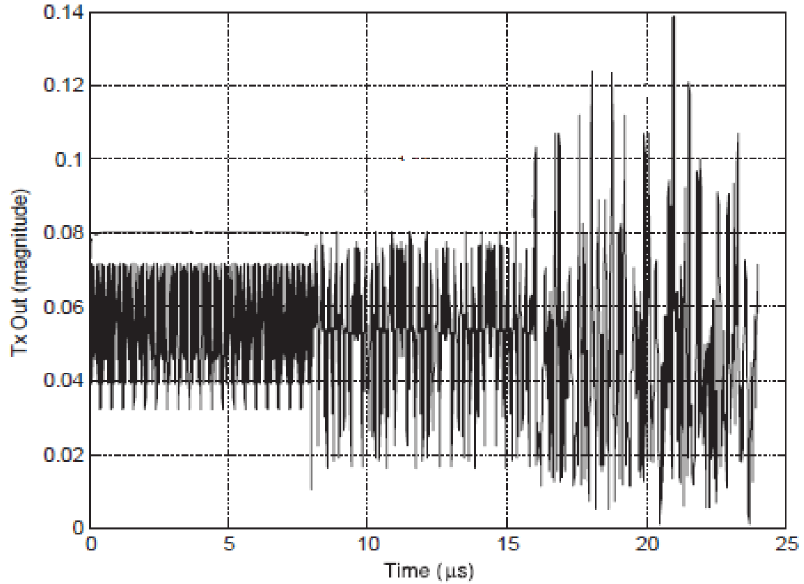
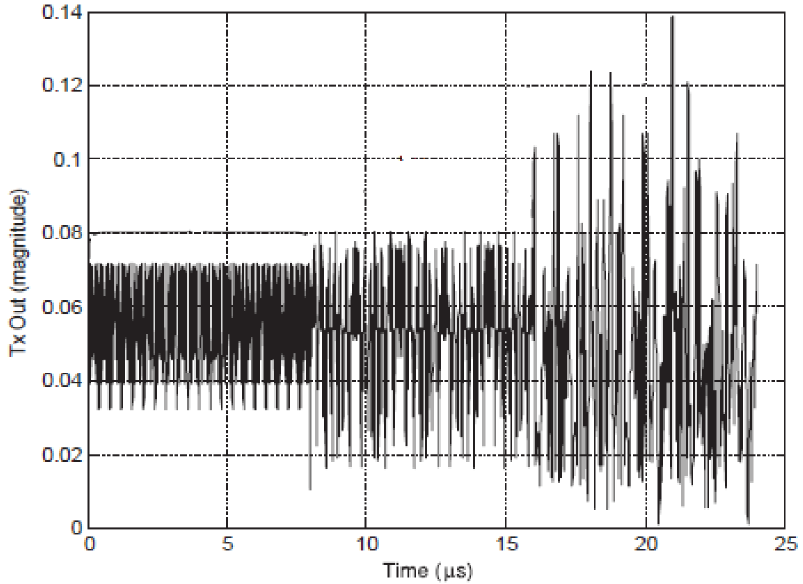
But this only works if the chains have a different view!

Otherwise:

Chain 1



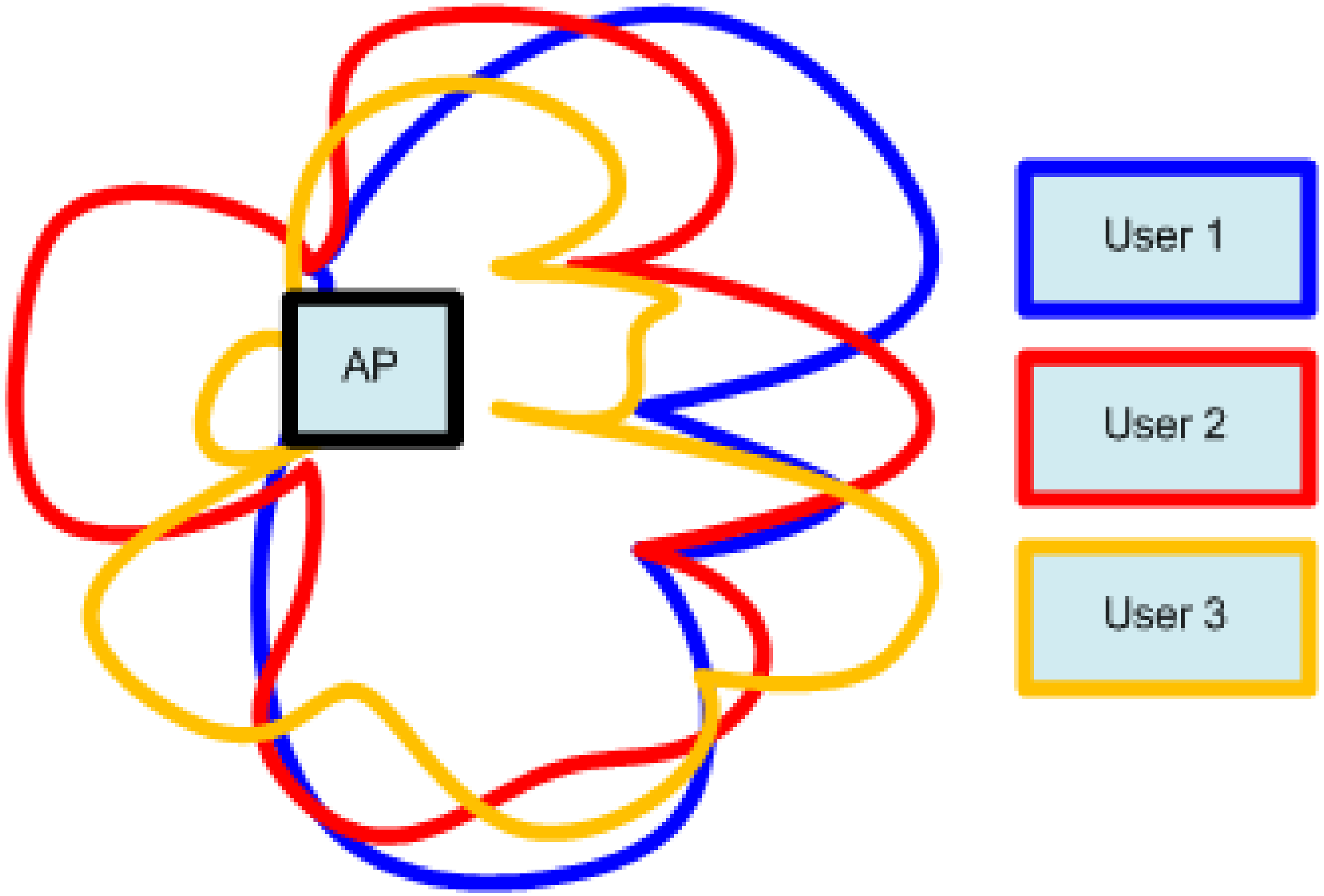
Chain 2



Differential: ______________________

MU-MIMO

What it is about:



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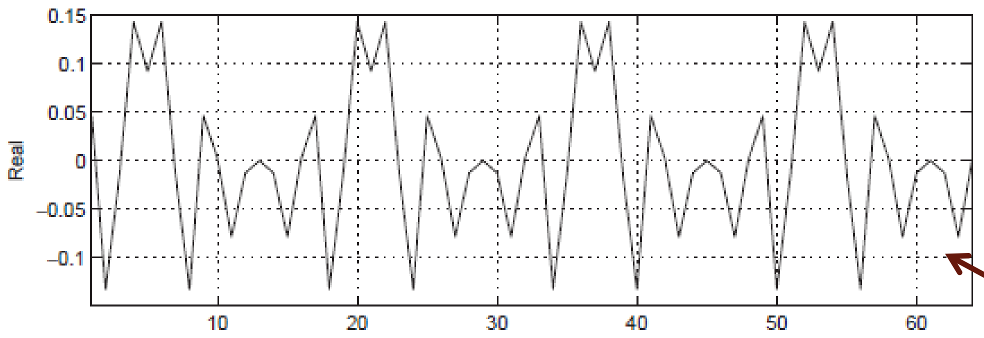
MU-MIMO

Basic mechanic:

Each frame has a PHY header with several "training fields" (this is true for all 802.11's)

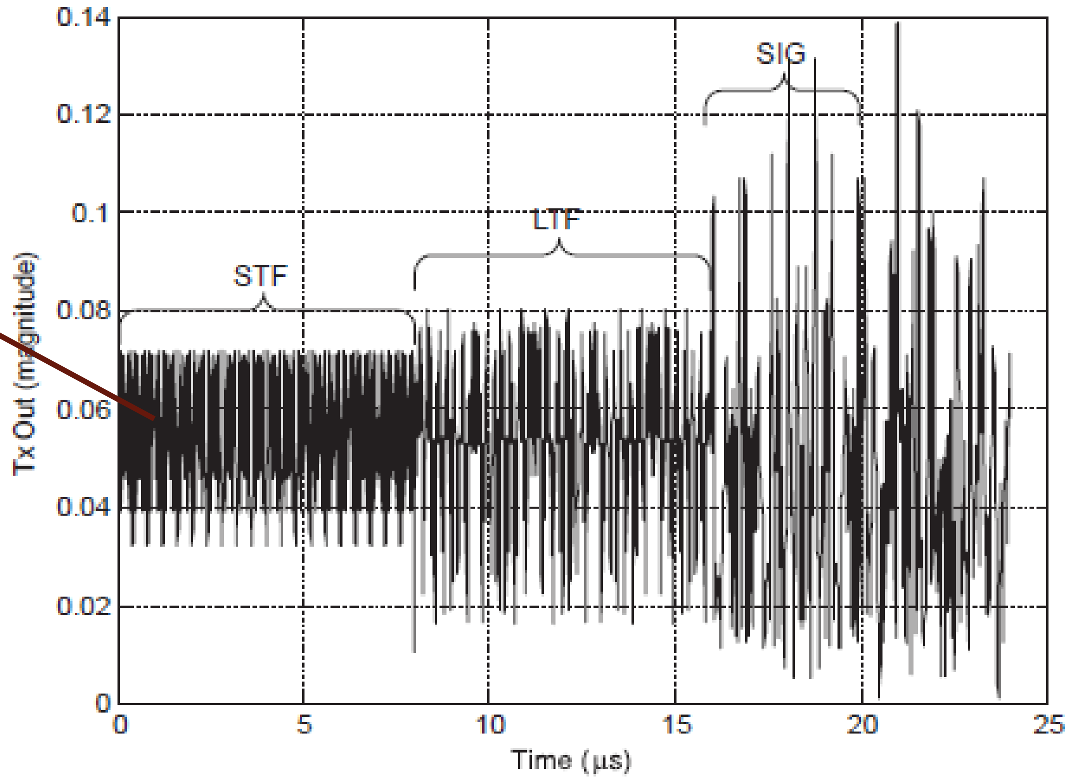


STF: uses 12 of 52 tones

0.8 μs symbol repeated 4 times

Repeated 2.5 times (8 μs total)

Good for estimating time, basic frequency offset



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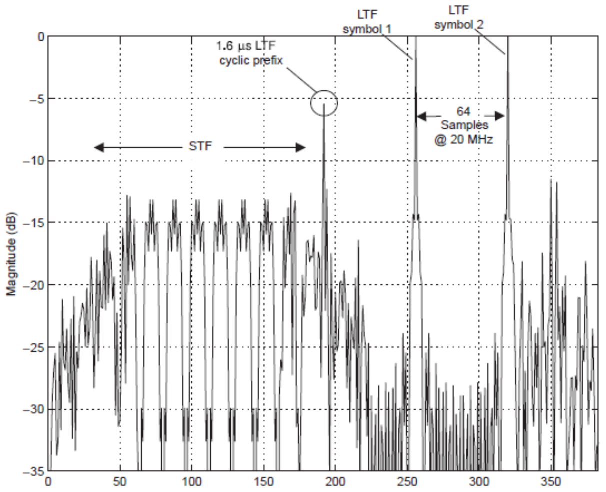
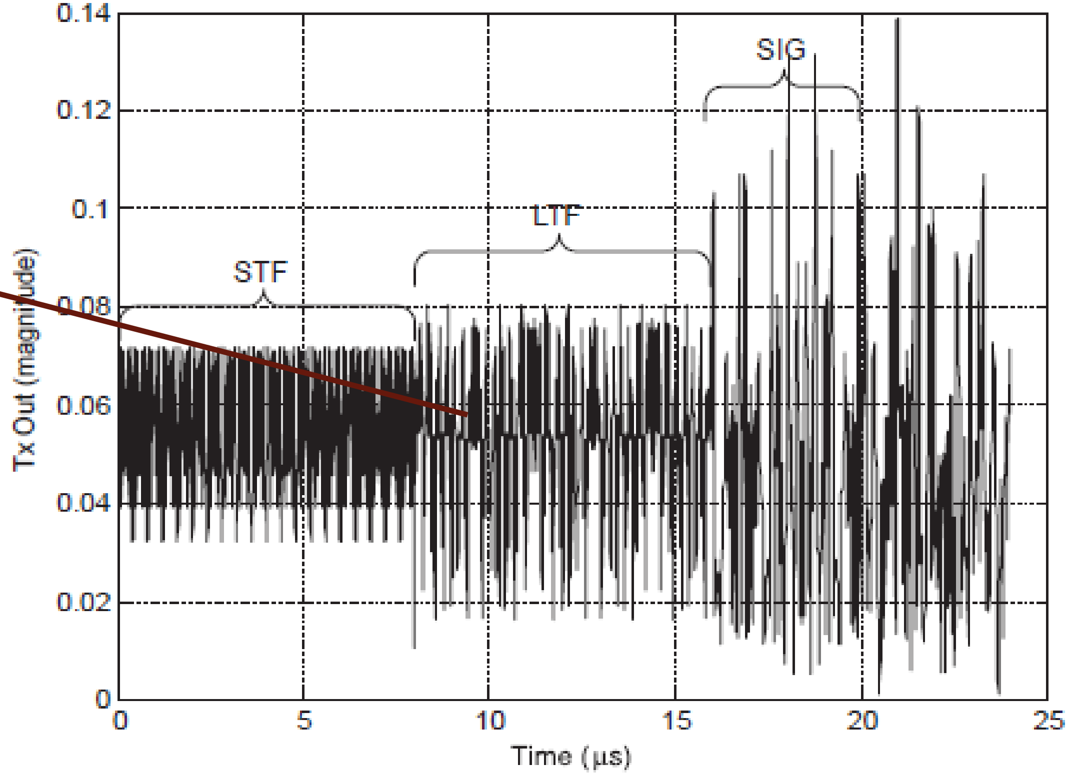


LTF: uses 48 of 52 tones

3.2 µs symbol repeated 2.5 times

Still 8 µs total

Good for estimating tone cross-correlation, channel estimation



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MU-MIMO

Basic mechanic:

802.11ac (and 802.11n optionally) uses Null Data Packet (NDP) frames:

The training fields are used to estimate the channel

AP sends an NDP announcement , then an NDP

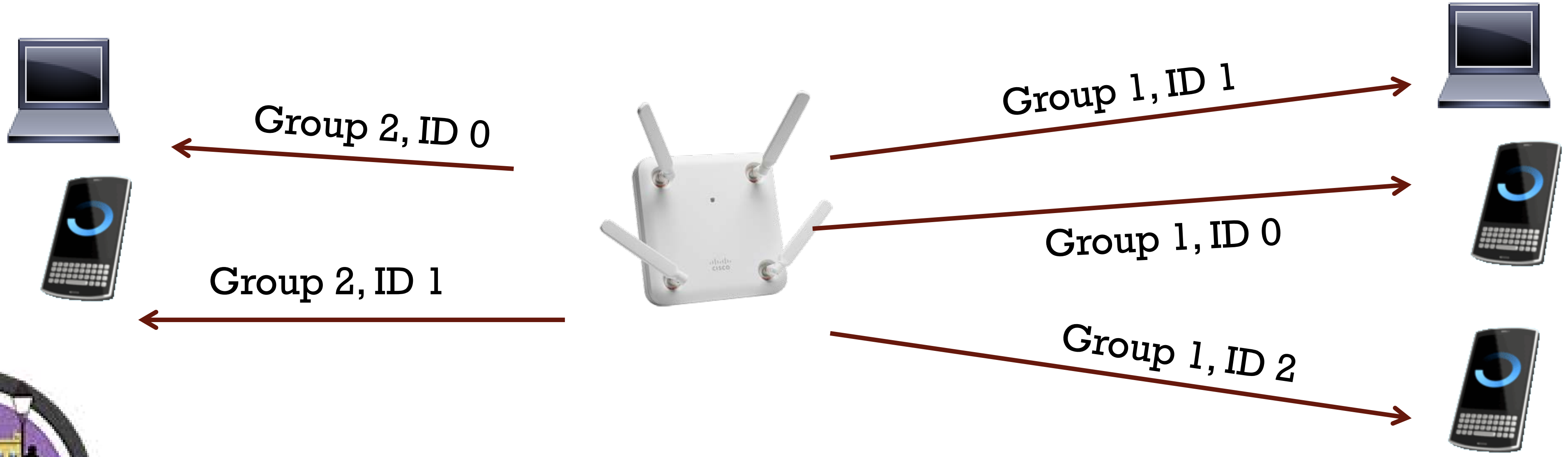
STA replies with VHT compressed beamforming, that contains CSI (Channel state information = this is how I heard you over the different carriers)

MU-MIMO

Basic mechanic:

AP then groups STAs of similar RF characteristics (implementation dependent) -> communicates group ID, and user ID in group

This can be a pretty large compatibility matrix ☺



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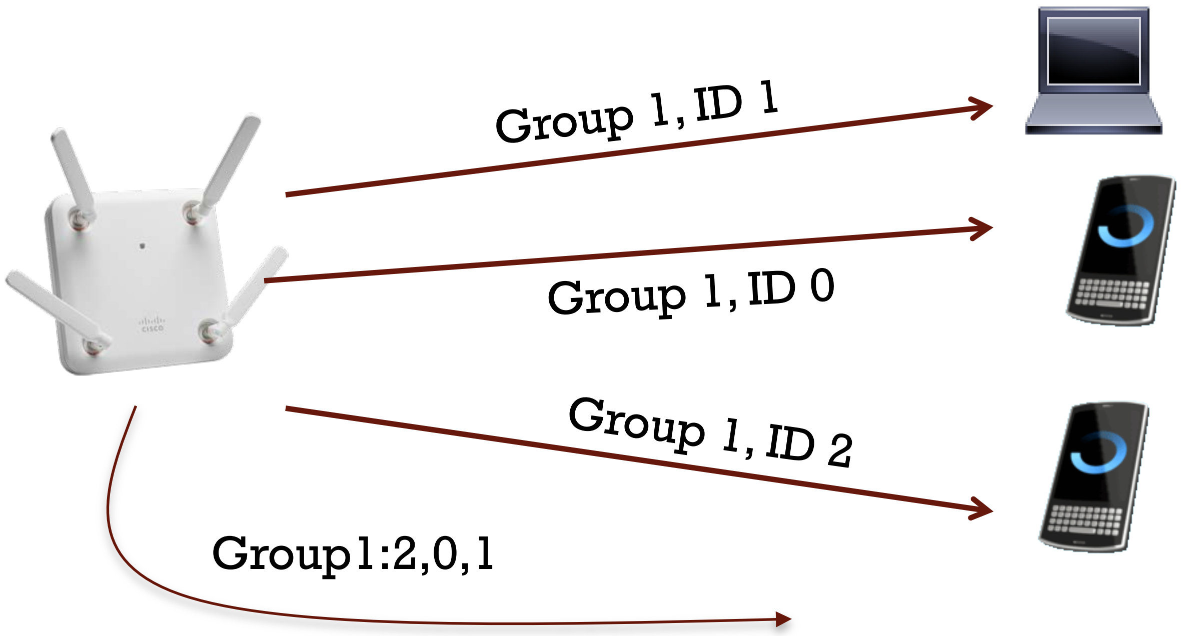
MU-MIMO

Basic mechanic:

AP then groups STAs of similar RF characteristics (implementation dependent) -> communicates group ID, and user ID in group

When AP transmits it indicates group ID, and how many streams for each member:

Group1:2,0,1
ID 0 gets first 2 streams (0,1)
ID 1 gets 0 next stream
ID 2 gets 1 next stream (2)



MU-MIMO

Basic mechanic limits:

Only one ACK can be received (one STA “block ACK”, all others “implicit block ACK” [block ack request will be sent later])

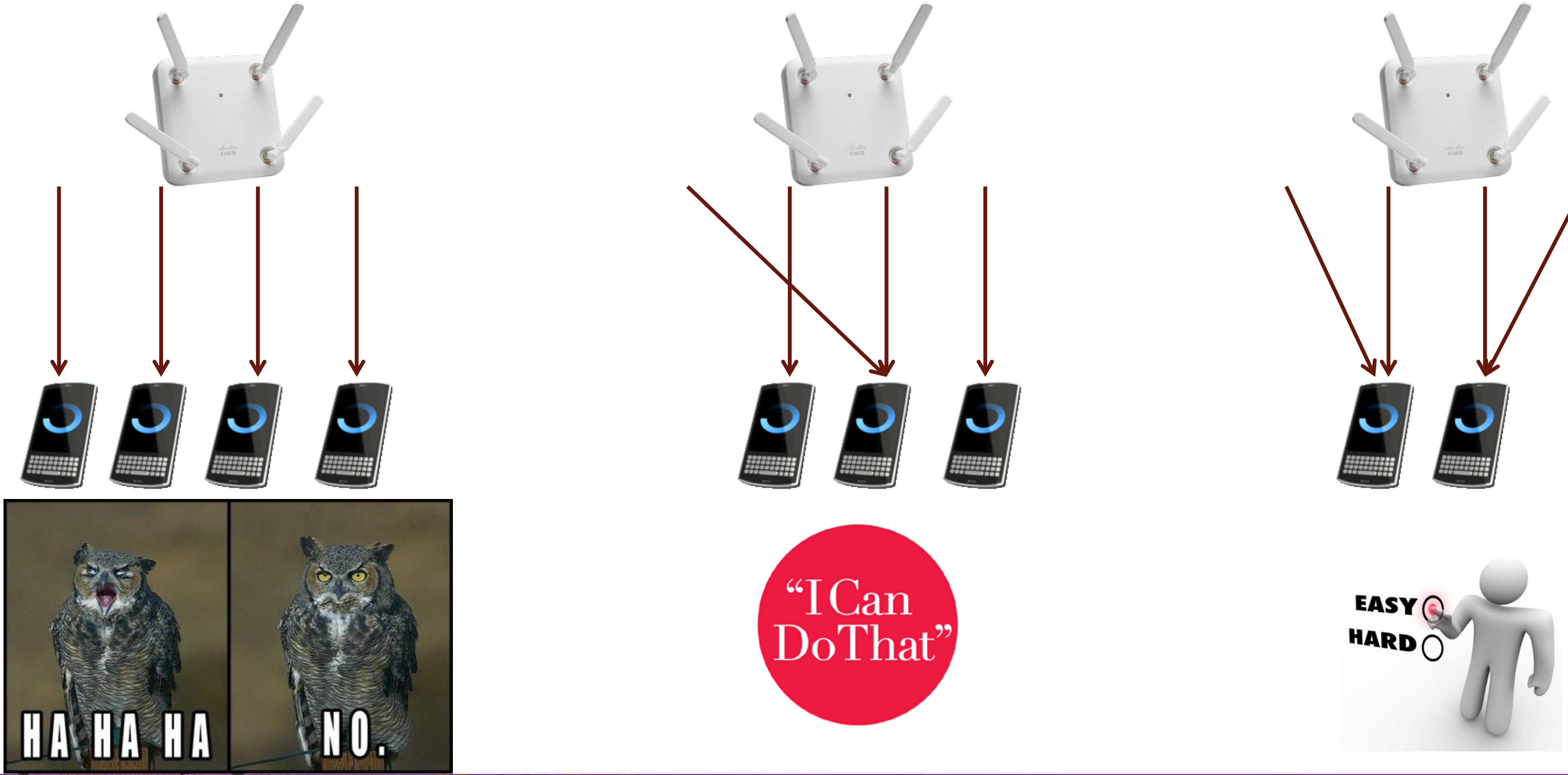
There can be “in theory” up to 62 groups (0 or 63 =SU)

But 4 users max per group

4 SS max per user

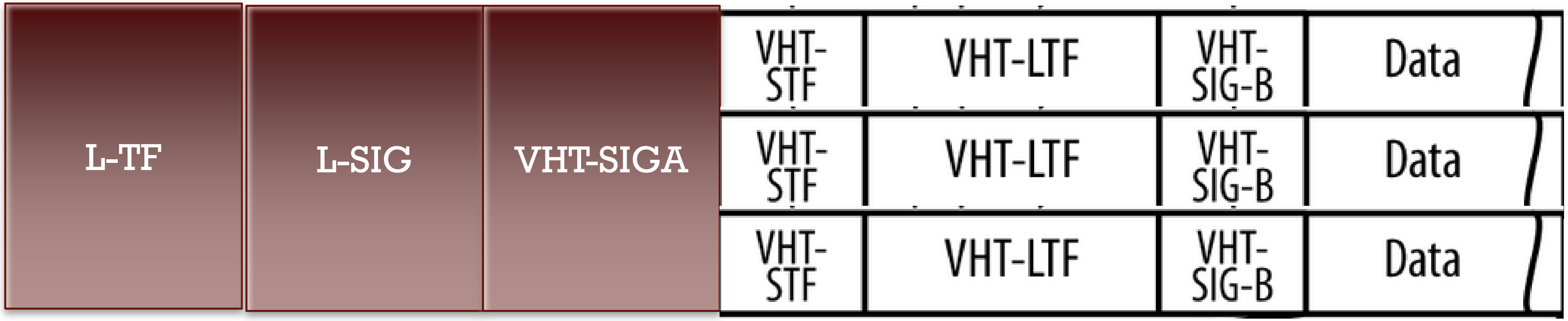
You need at least one radio chain per user

MU-MIMO



MU-MIMO

MU-MIMO sends a strange frame:



User-specific

User-specific

User-specific

To all users

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MU-MIMO

Sounding (channel estimation) is useful for both sides:

I know how to steer

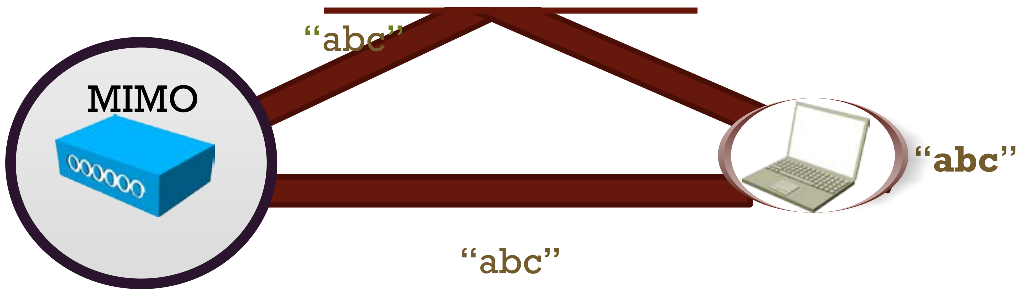
I am better at removing noise

MU-MIMO

Sounding (channel estimation) is useful for both sides:

With SU-MIMO, worse that can happen is “no TxBf gain”

Er… not well aligned…
oh well, only use one



Sending side: synchronize signals for better resulting signal at receiving end (Transmit Beamforming, TxBF, ClientLink)

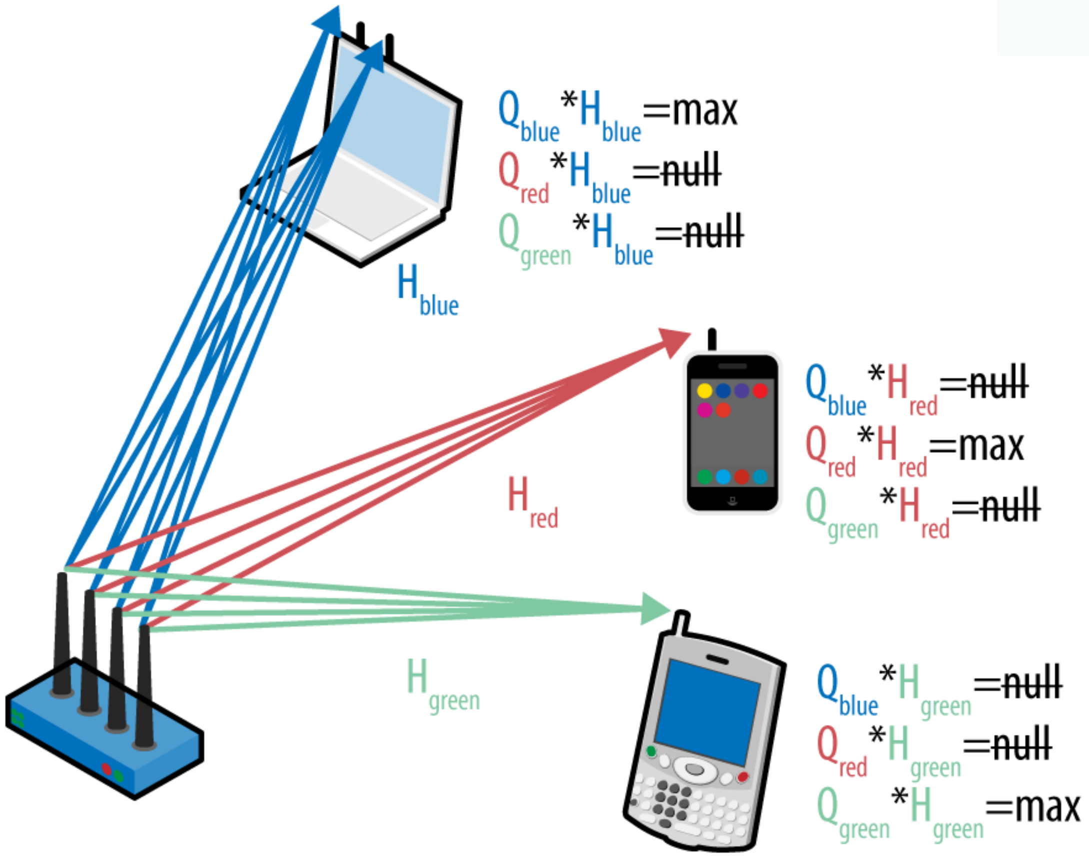
MU-MIMO

Sounding (channel estimation) is useful for both sides:

With MU MIMO, each station is an interference to the other

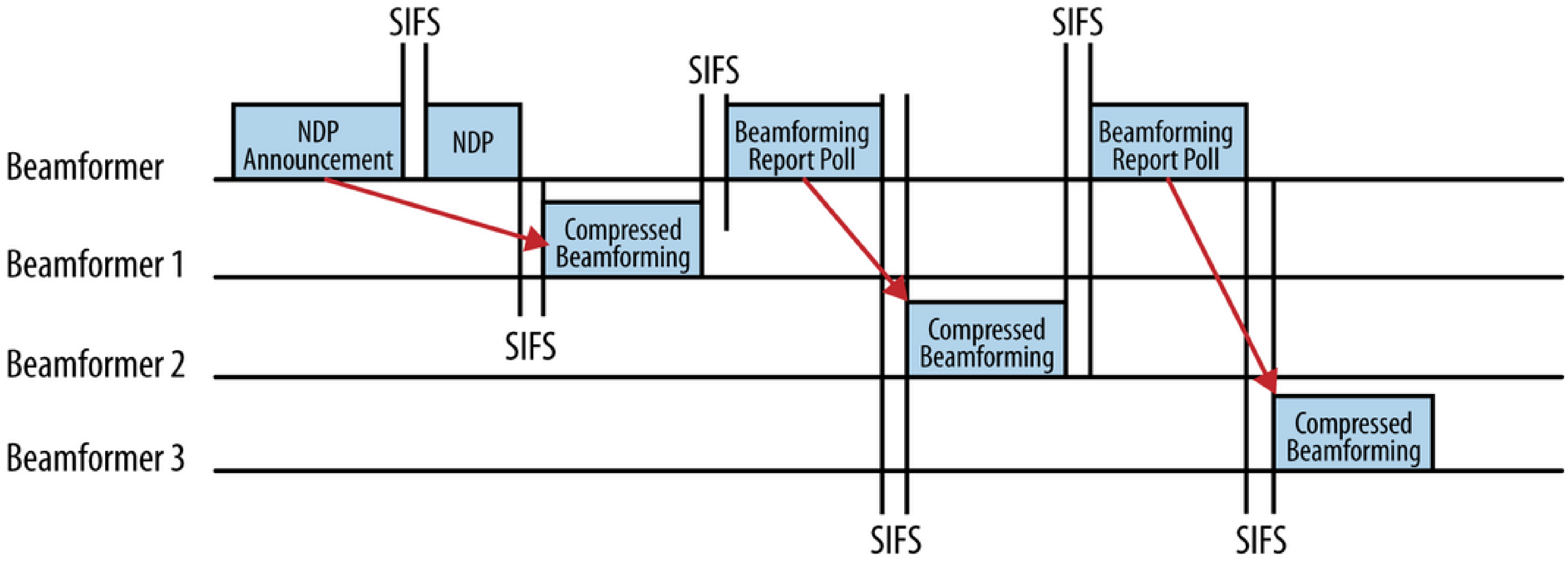
Each station needs to know the channel (including signal to the others)

Each other stream is interference
-> reduces the received RSSI dB



MU-MIMO

So users have to know the channel for each other client, and AP has to know the client channel in bursts (close time period):



In SU-MIMO, channel estimation is typically valid for 100ms

In MU-MIMO, any client move changes everything: 10 to 25 ms validity

MU-MIMO

Also… remember multipath?

Same issue applies for MU-MIMO:

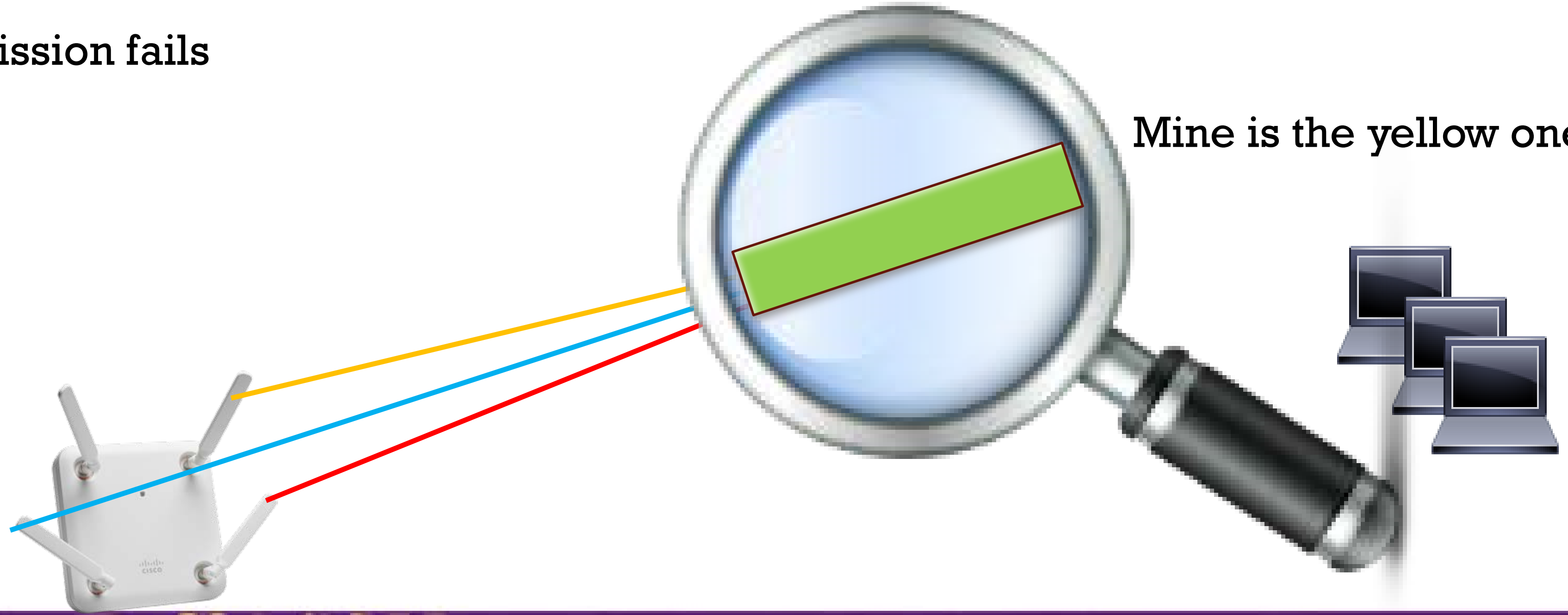
If target STAs are too close, they see the same channel

Can't tell one stream from the other

Can't isolate their stream

Transmission fails

Mine is the yellow one….er…



MU-MIMO

So… MU-MIMO works better if stations are:

"not too close", but still

"with the same RF characteristics" (close enough to estimate the others' channel)

Good news: with VHT-SIG B, each station stream can have its own MCS

Bad news: L-SIG determines the frame length

If you use different modulations, you add padding to some stations -> less efficient

MU-MIMO

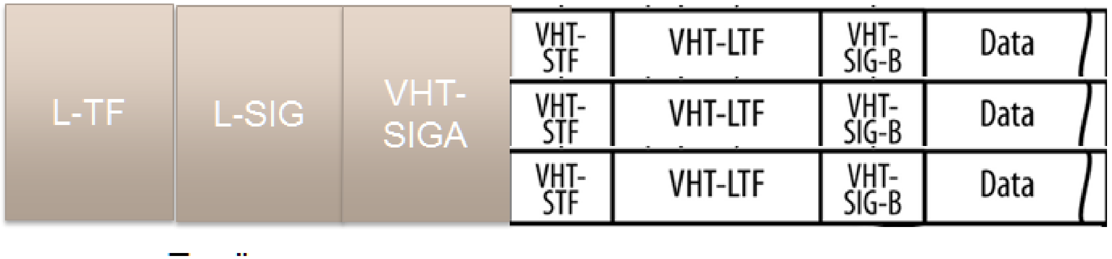
Let’s make things worse:

Imperfect nulling increases channel noise -> lower RSSI for each station

-> individual target MCS is typically lower than SU-MIMO MCS

Also.. How does each client know what is sent to the others in the group?

-> It needs to read all the VHT-TF, to learn how many streams are sent, each stream channel state, and use that as interference cancellation (IC)



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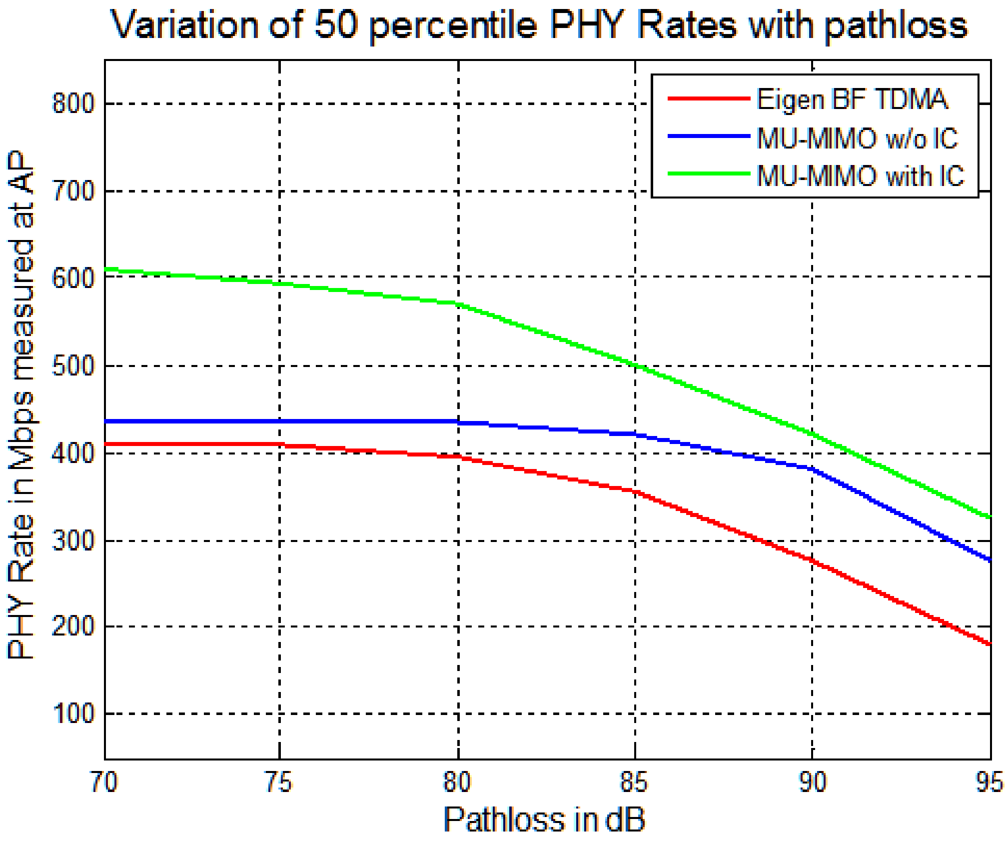
Without interference cancellation (IC), channel estimation is poorer, losses are higher, and throughput lower

IC is there, but this means more processing with MU-MIMO than with SU-MIMO



Conclusion

- Larger 802.11ac channels increase bandwidth, but decrease ability to estimate the channel: more degradation in noisy environments
- Do not expect to get all rates (e.g. no MCS 9 for 20 MHz 1SS)… and also expect some rates to add pollution (padding)
  - False impression of added speed
- MU-MIMO does not increase throughput: it makes the best of poor client performances (low rate, low number of SS)
  - In "real life" expect less throughput for each client when using MU-MIMO than when client is using SU-MIMO
  - In noisy conditions, "silent ACK" can make performances worse

Thank you.