

# MU-MIMO

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IT Professional Wi-Fi Trek 2016



# Channel Width

Guides and Sensitivity



IT Professional Wi-Fi Trek 2016



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

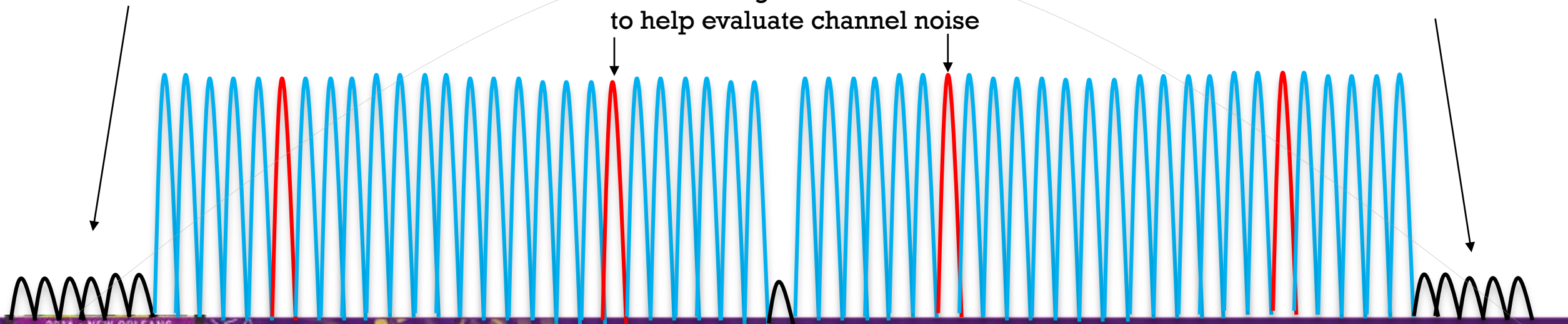
- 64 small waves (called Carriers, or Tones), using BPSK, QPSK... or QAM (Quadrature )
- 12 null, 4 pilot -> 48 active tones

No power, help isolate  
against neighboring channels

No power, help isolate  
against neighboring channels

“guides”

to help evaluate channel noise



8% pilots



# 802.11n/802.11ac 20 MHz

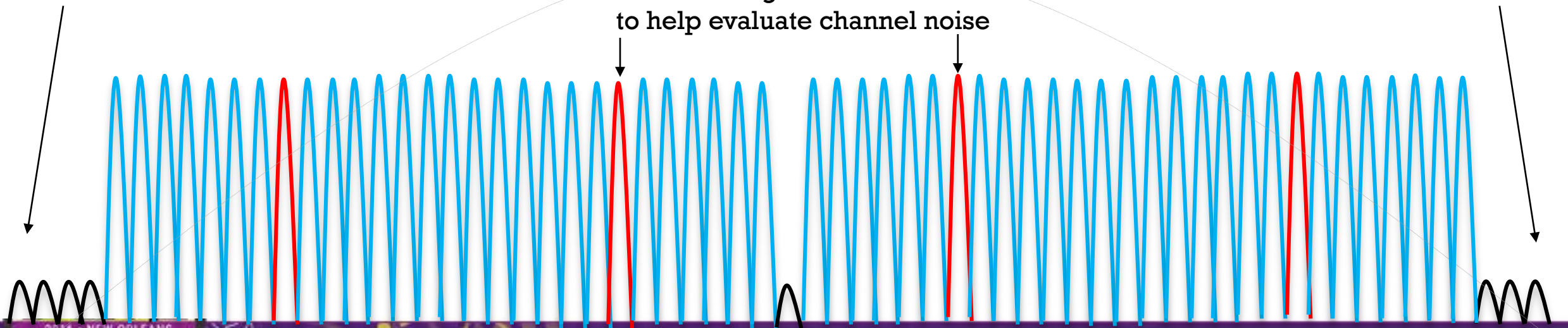
- 64 small waves (called Carriers, or Tones), using BPSK, QPSK... or QAM (Quadrature )
- 8 null, 4 pilots (+-7, +-21) -> 52 active tones

No power, help isolate  
against neighboring channels

No power, help isolate  
against neighboring channels

“guides”

to help evaluate channel noise

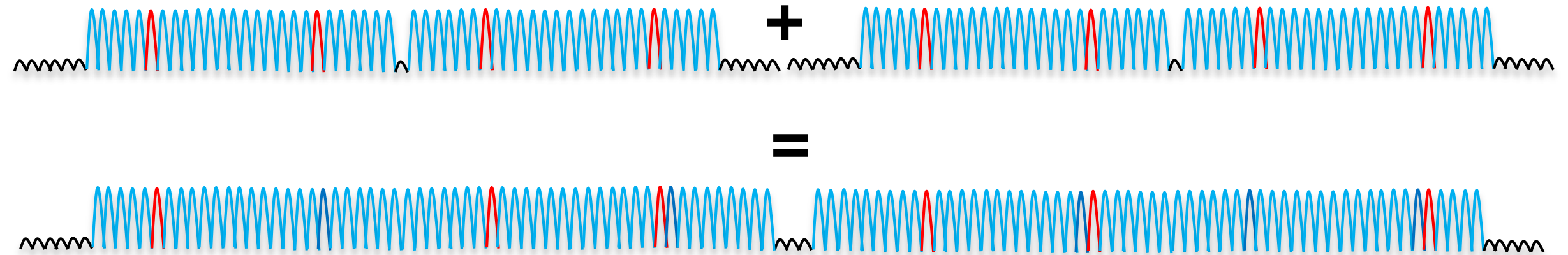


7% pilots



# 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):  $\pm 11$ ,  $\pm 25$ ,  $\pm 53$
- 108 data subcarriers (vs. 48/52)

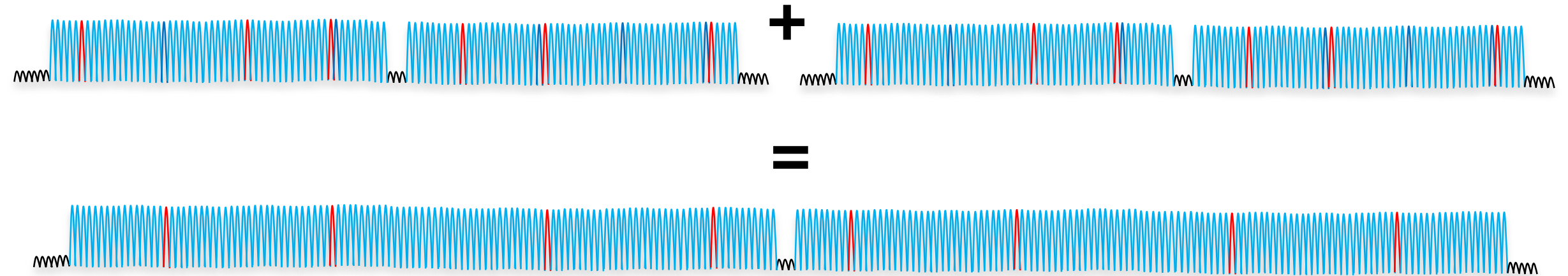


5% pilots, 2.3x 802.11a/g capacity



# 802.11ac 80 MHz

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

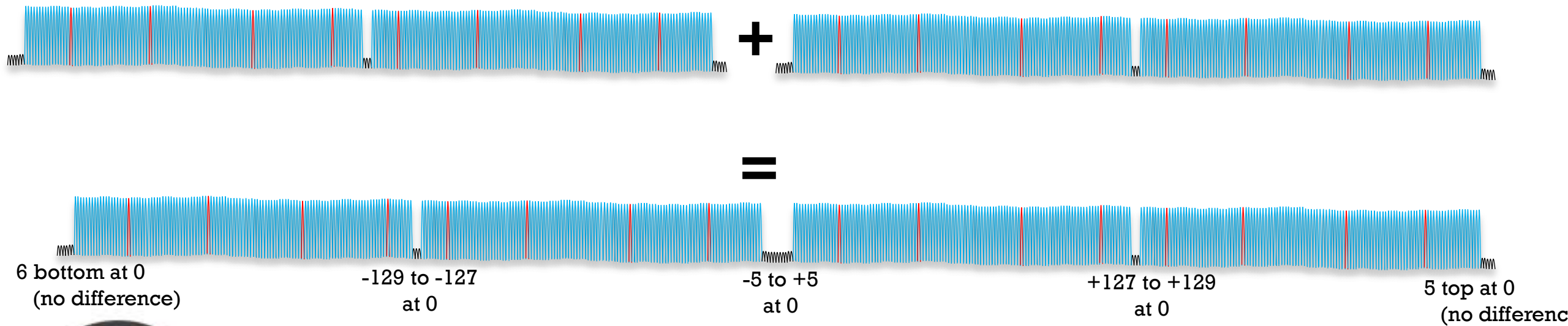


3% pilots, 4.9x 802.11a/g capacity, 2.15x 11n/ac 40 MHz capacity



# 802.11ac 160 MHz

- 512 subcarriers (vs. 256)
- 28 zero subcarriers
- 16 pilot subcarriers (vs. 8):  $\pm 25, \pm 53, \pm 89, \pm 117, \pm 139, \pm 167, \pm 203, \pm 231$
- 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

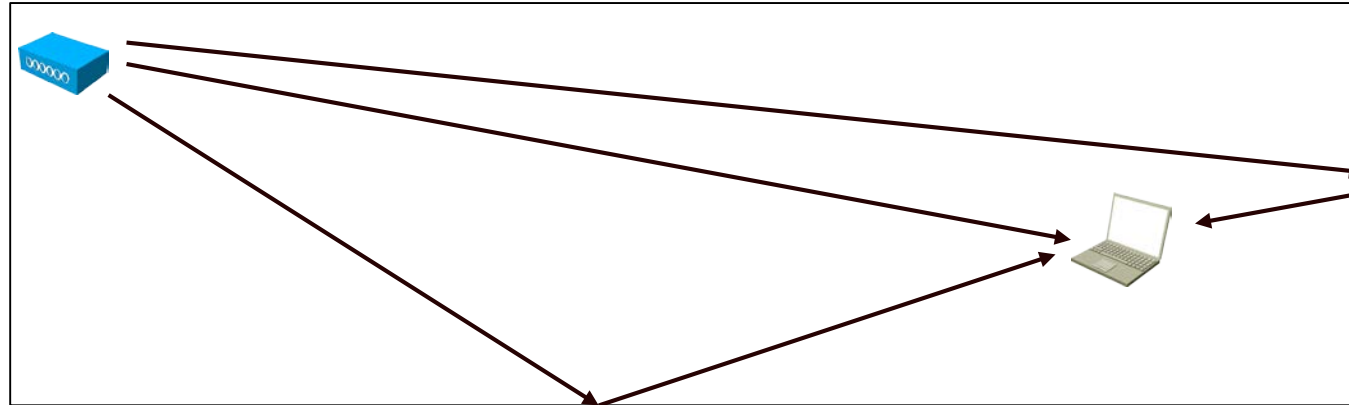


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# MU-MIMO

802.11n taught us to love multipath...

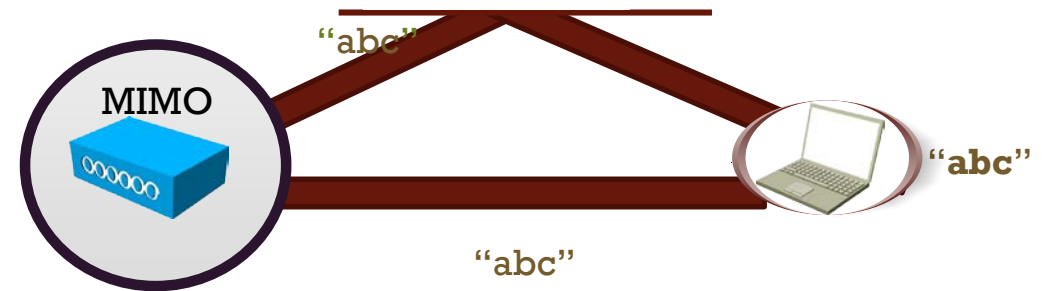


# MU-MIMO

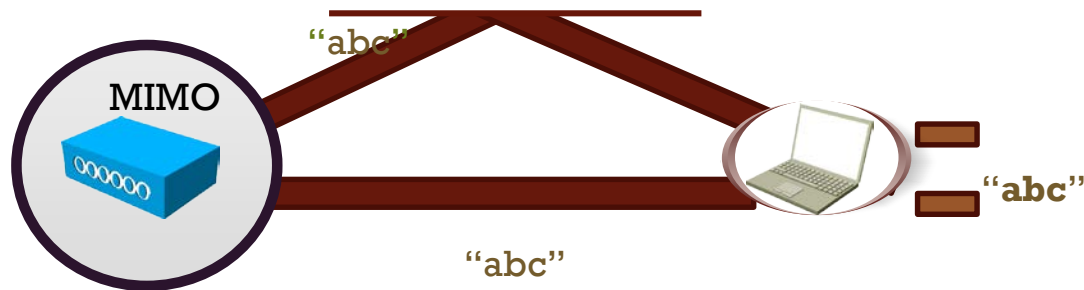
802.11n taught us to love multipath... because with MIMO, we can do:



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...

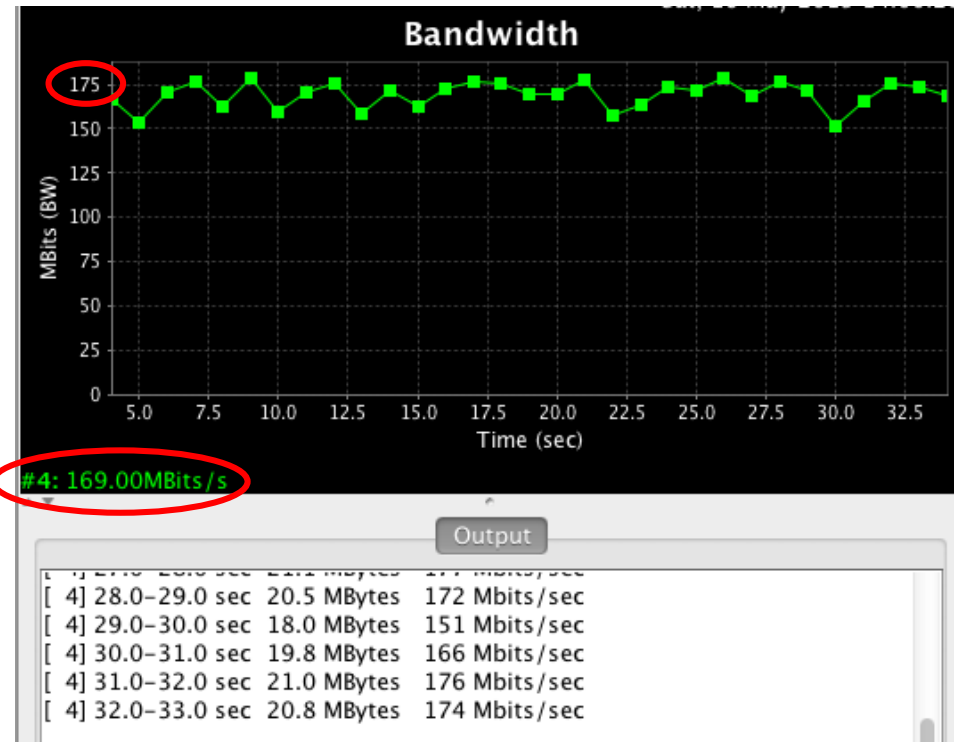
And this is where multipath helps...



# With Multipath

The screenshot shows the Cisco ISE Client Detail page. The 'AVC Statistics' tab is active, displaying client and AP properties. A magnifying glass highlights the SSID 'm9 ss2' in the Client Properties section.

Client Properties		AP Properties	
MAC Address	f4:09:d8:fa:ac:6f	AP Address	08:cc:68:b4:46:c0
IPv4 Address	172.31.255.208	AP Name	3702idesk
IPv6 Address	fe80::f609:d8ff:fe:fa:ac6f	AP Type	802.11ac
Client Type	Simple IP	AP radio slot Id	1
User Name		WLAN Profile	PublicWifi
Port Number	2	WLAN SSID	PublicWifi
Interface	management	Status	Associated
VLAN ID	31	Association ID	1
CCX Version		802.11 Authentication	Open System
E2E Version	Not Supported	Reason Code	1
Mobility Role	Local	Status Code	0
Mobility Role Address	N/A	CF Pollable	Not Implemented
Policy User State	RUN	CF Poll Request	Not Implemented
Management Frame Protection	No	Short Preamble	Not Implemented
UpTime (sec)		PBCC	Not Implemented
RateSet	6,0,9,0,12,0,18,0,24,0,30,0,36,0,54,0	Channel Agility	Not Implemented
KTS Capability	No	Timeout	1800
802.11u	Not Supported	WEP State	WEP Disable
802.11v BSS	Not Supported		



# Without Multipath

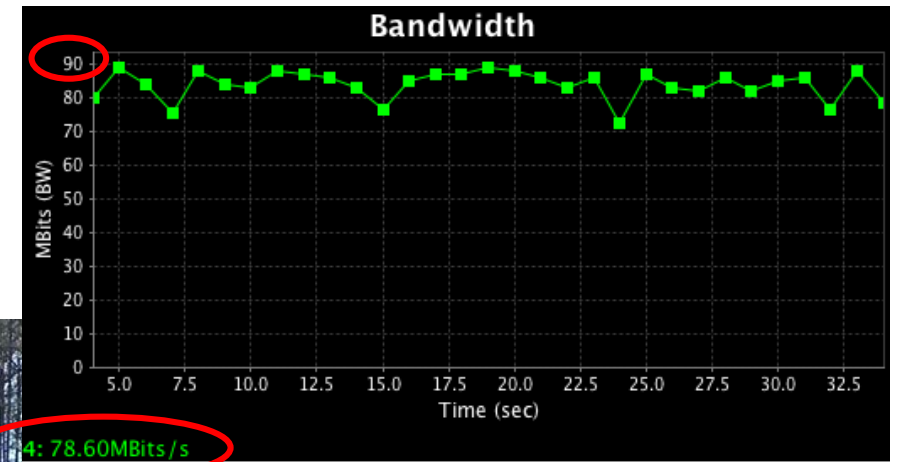
Clients > Detail

Max Number of Records 10 Clear AVC Stats

General **AVC Statistics**

Client Properties		AP Properties	
MAC Address	f4:09:d8:fa:ac:6f	AP Address	08:cc:68:b4:46:c0
IPv4 Address	172.31.255.208	AP Name	3702idesk
IPv6 Address	fe80::f609:d8ff:fefa:ac6f,	AP Type	802.11ac
		AP radio slot Id	1
		WLAN Profile	PublicWifi
		WLAN SSID	PublicWifi
		Status	Associated
		Association ID	1
		802.11 Authentication	Open System
		Reason Code	1
		Status Code	0
		CF Pollable	Not Implemented
		CF Poll Request	Not Implemented
		Short Preamble	Not Implemented
		PBCC	Not Implemented
		Channel Agility	Not Implemented
		Timeout	1800
		WEP State	WEP Disable

Client Type: Simple IP  
User Name:   
Port Number:   
Interface: management  
VLAN ID: 31  
CCX Version: CCXv4  
E2E Version: Not Supported  
Mobility Role: Local  
Address:   
State: m9 ssl  
Management Protection: No  
UpTime (Sec): 100  
Current TxRateSet: m9 ssl  
Data RateSet: 6, 9, 12, 18, 24, 36, 48.



Output

[ 4] 27.0-30.0 sec	10.1 MBytes	87.5 Mbits/sec
[ 4] 30.0-31.0 sec	10.2 MBytes	86.0 Mbits/sec
[ 4] 31.0-32.0 sec	9.12 MBytes	76.5 Mbits/sec
[ 4] 32.0-33.0 sec	10.5 MBytes	88.1 Mbits/sec
[ 4] 33.0-34.0 sec	9.38 MBytes	78.6 Mbits/sec
[ 4] 34.0-35.0 sec	10.4 MBytes	87.0 Mbits/sec

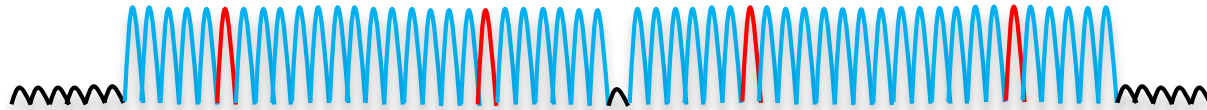
Outdoor, multipath is not enough for the phone to differentiate streams



# 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

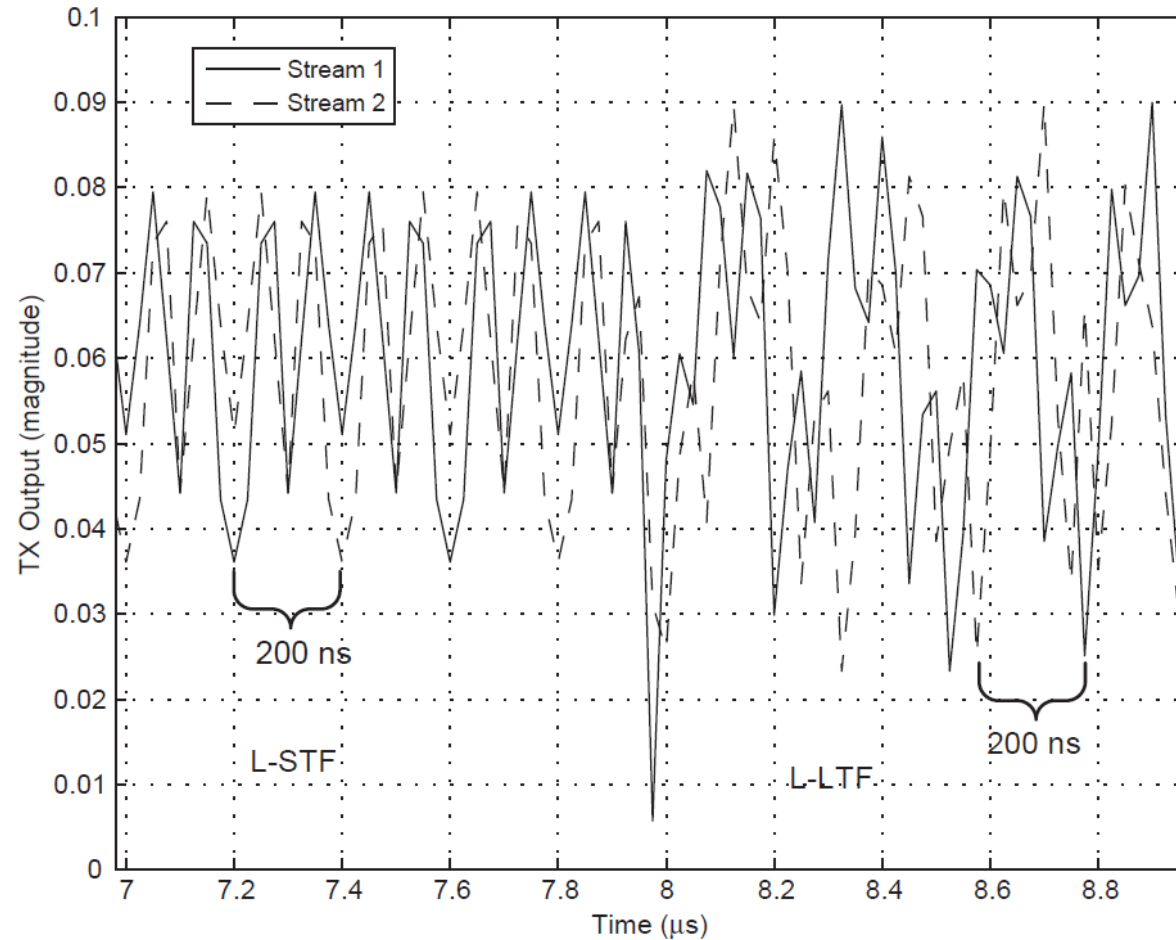
The chipset assigns one stream to receive per chain



# MU-MIMO

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

Delete stream 2,  
keep stream 1



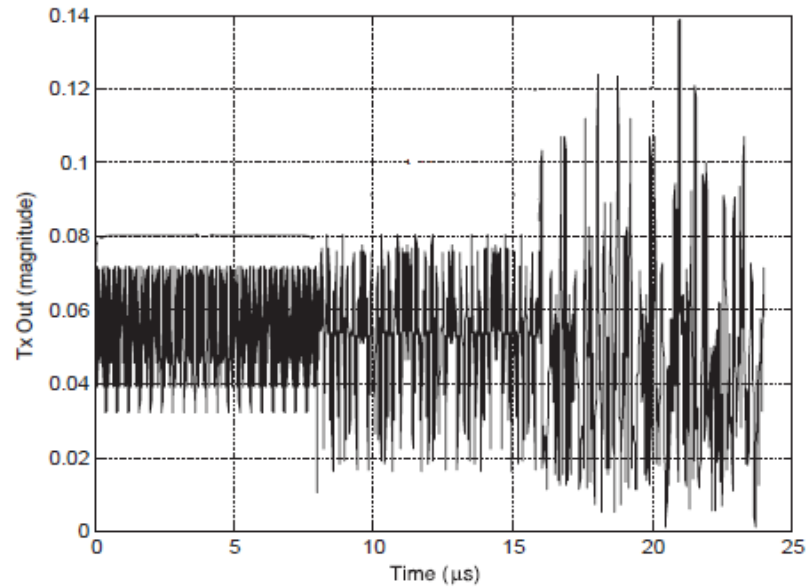


# MU-MIMO

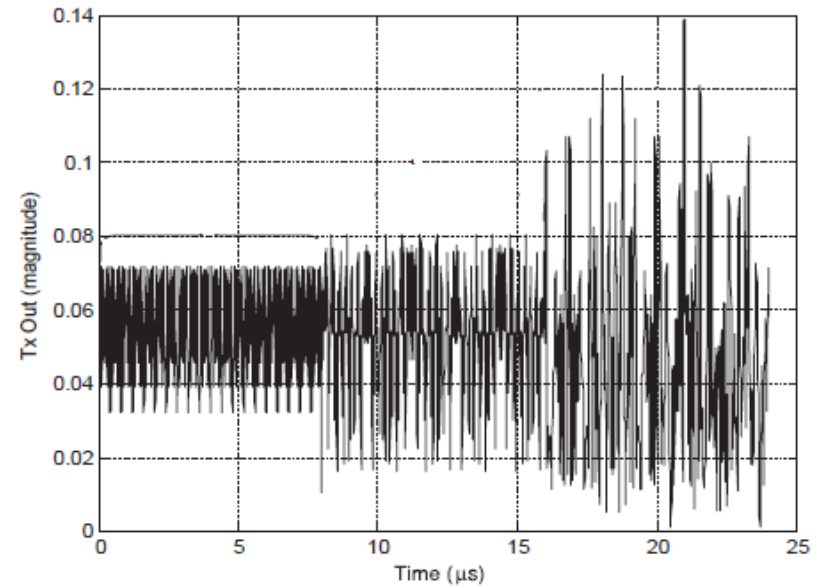
But this only works if the chains have a different view!

Otherwise:

Chain 1



Chain 2



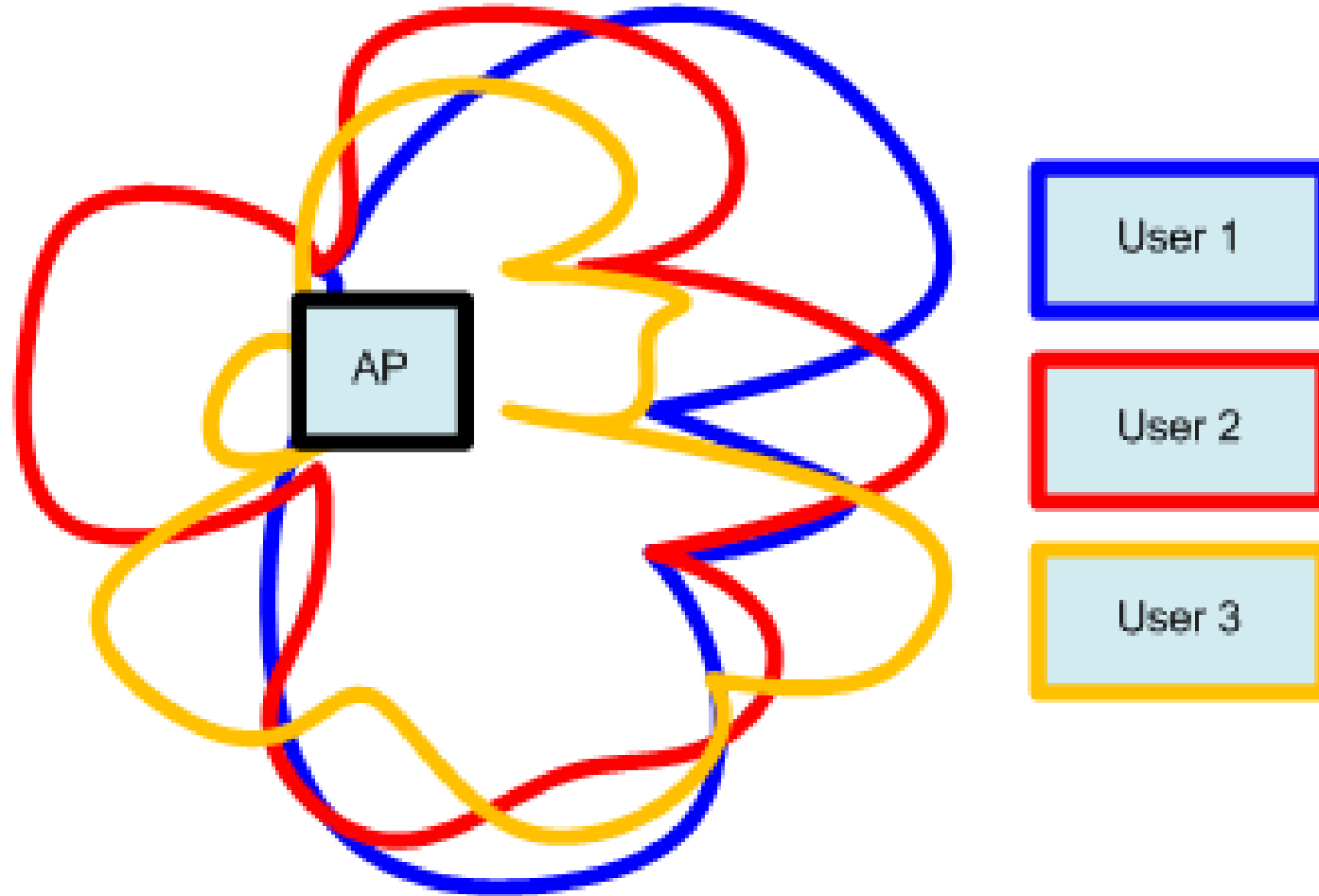
Differential: 

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# MU-MIMO

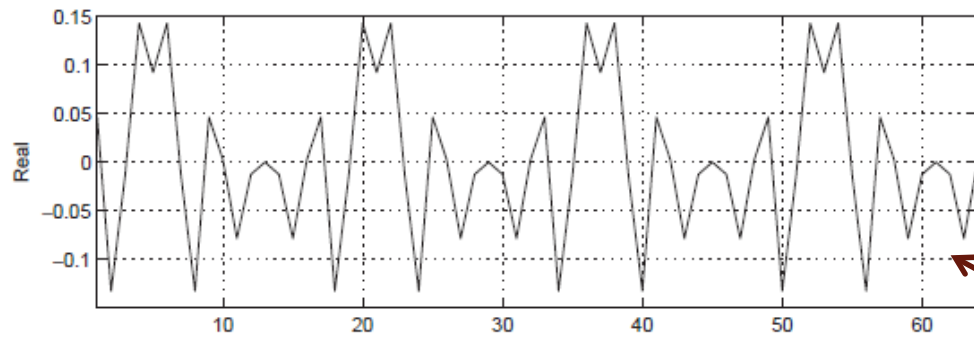
What it is about:



# MU-MIMO

Basic mechanic:

Each frame has a PHY header with several “training fields” (this is true for all 802.11’s)

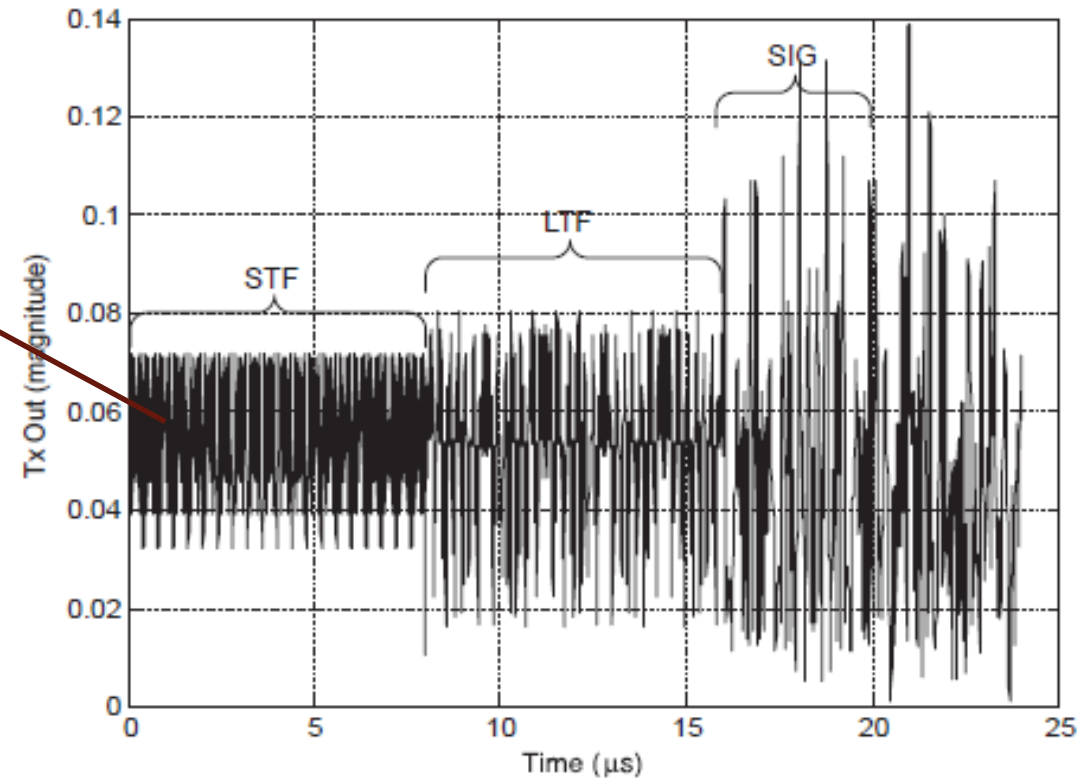


STF: uses 12 of 52 tones

0.8  $\mu\text{s}$  symbol repeated 4 times

Repeated 2.5 times (8  $\mu\text{s}$  total)

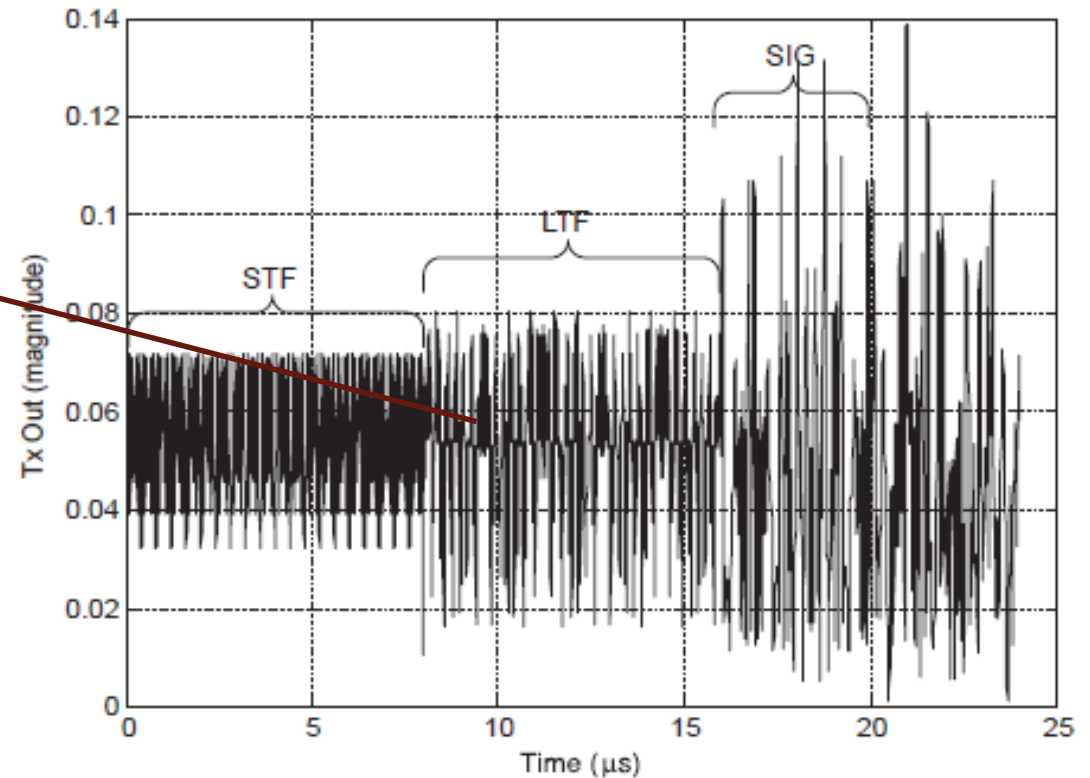
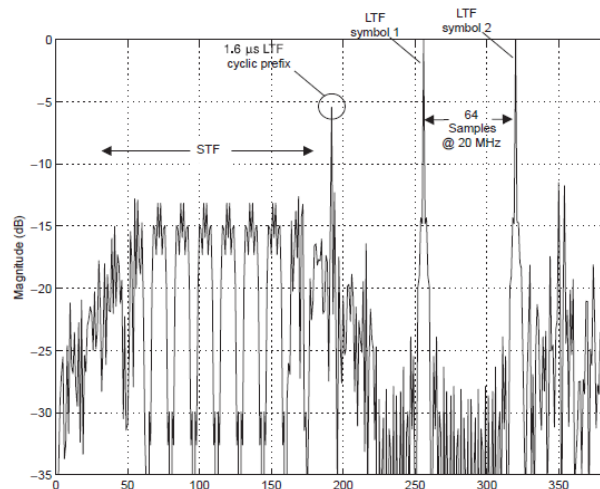
Good for estimating time, basic frequency offset



# MU-MIMO

Basic mechanic:

Each frame has a PHY header with several “training fields” (this is true for all 802.11’s)



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



# 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)

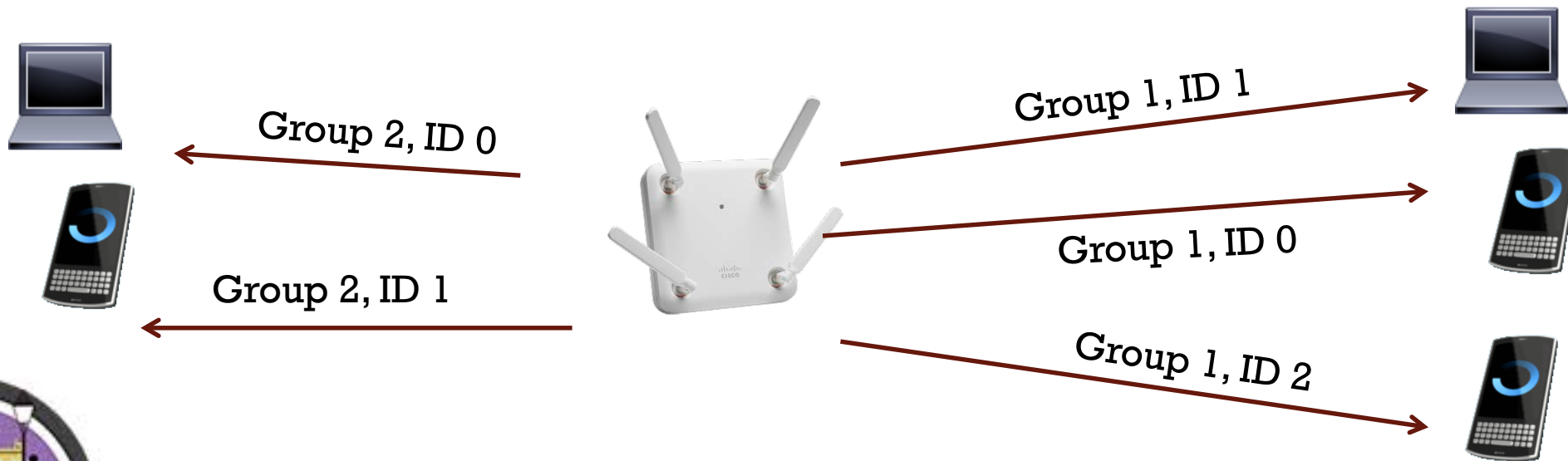


# MU-MIMO

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 😊



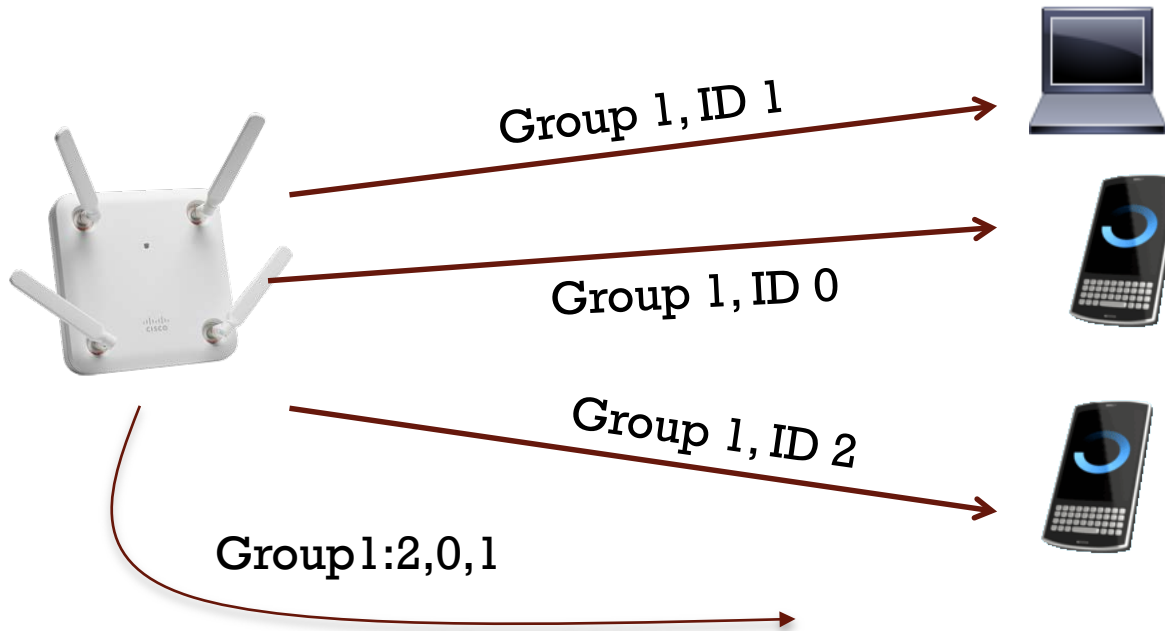
# MU-MIMO

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:

Group 1:2,0,1  
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

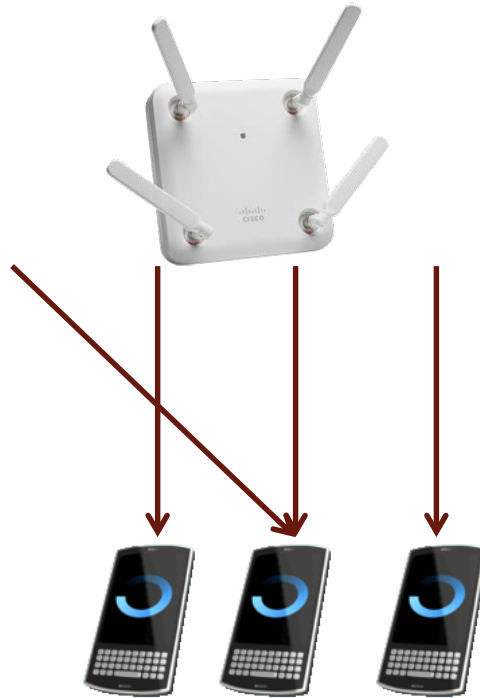
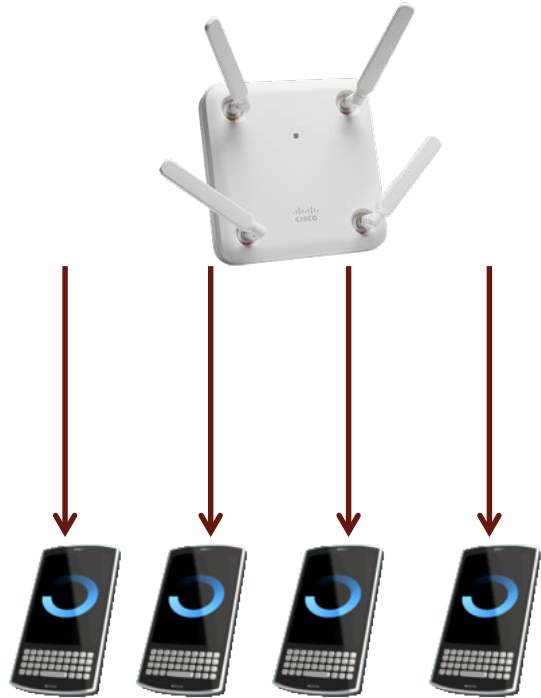
4 SS max per user

You need at least one radio chain per user

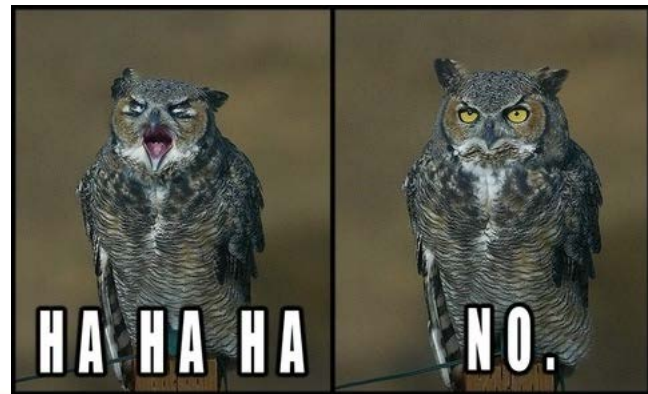




# MU-MIMO



“I Can Do That”



# MU-MIMO

MU-MIMO sends a strange frame:



To all users



# MU-MIMO

Sounding (channel estimation) is useful for both sides:



I know how to steer



I am better at  
removing noise

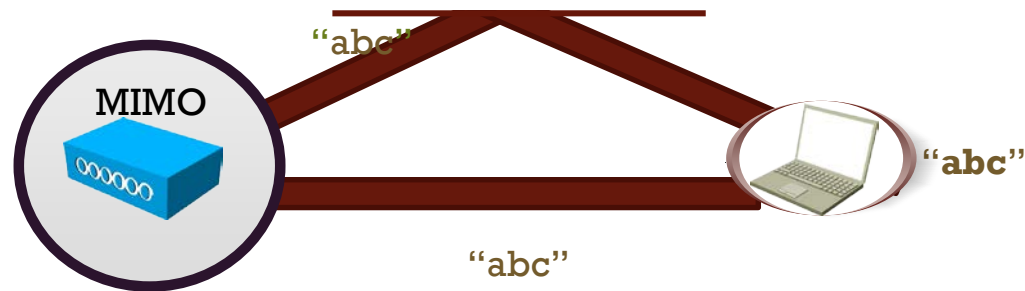


# MU-MIMO

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**)



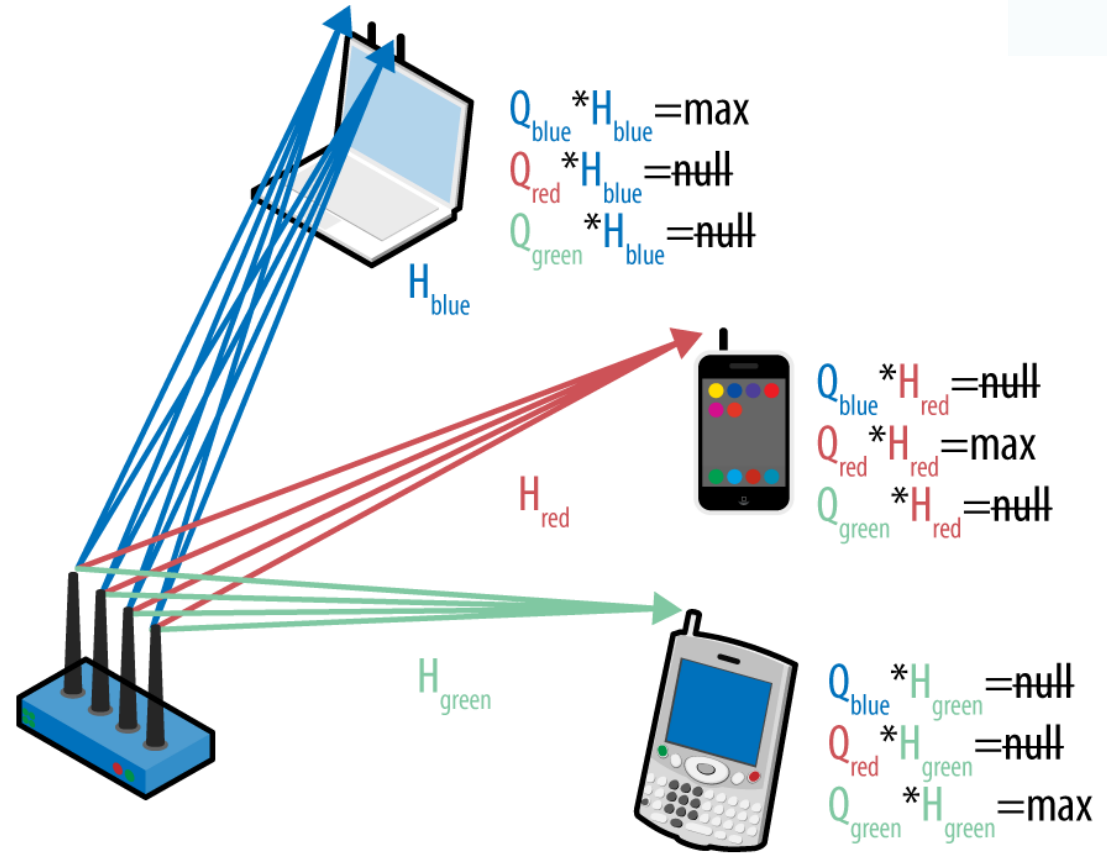
# MU-MIMO

Sounding (channel estimation) is useful for both sides:

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

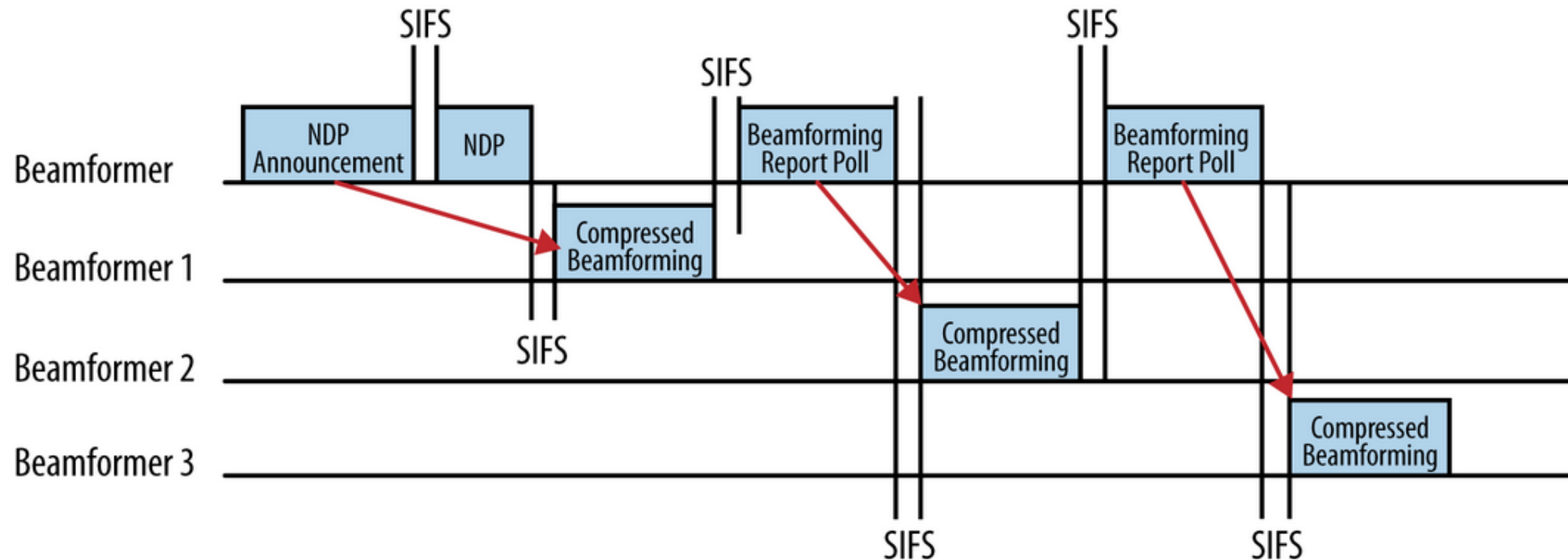
Each station needs to know the channel (including signal to the others)

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?

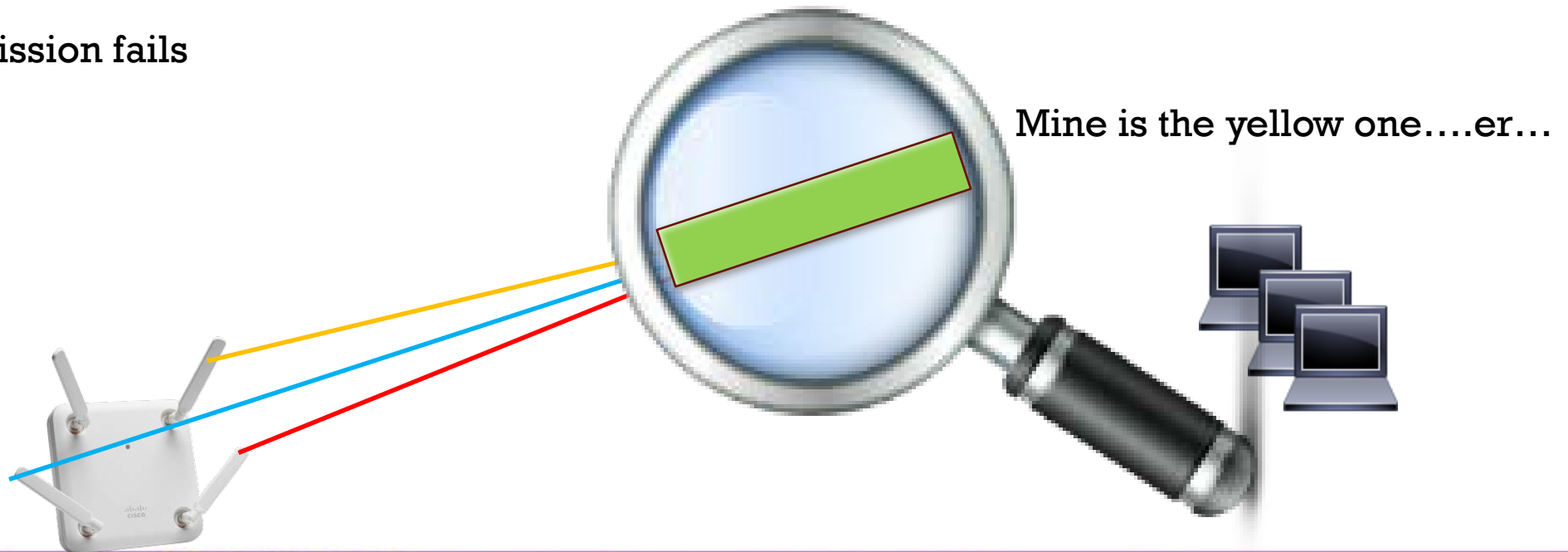
Same issue applies for MU-MIMO:

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



# 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

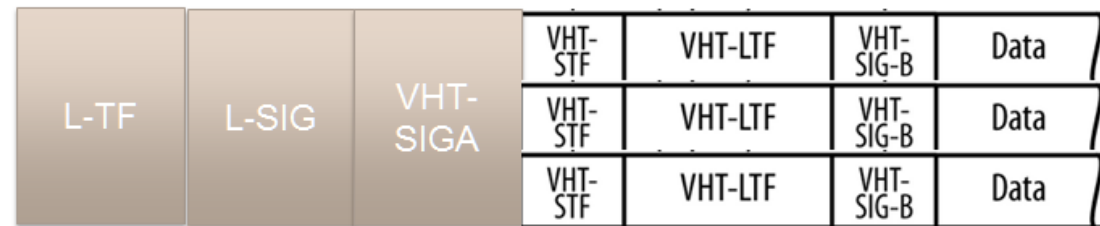
Let's make things worse:

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)

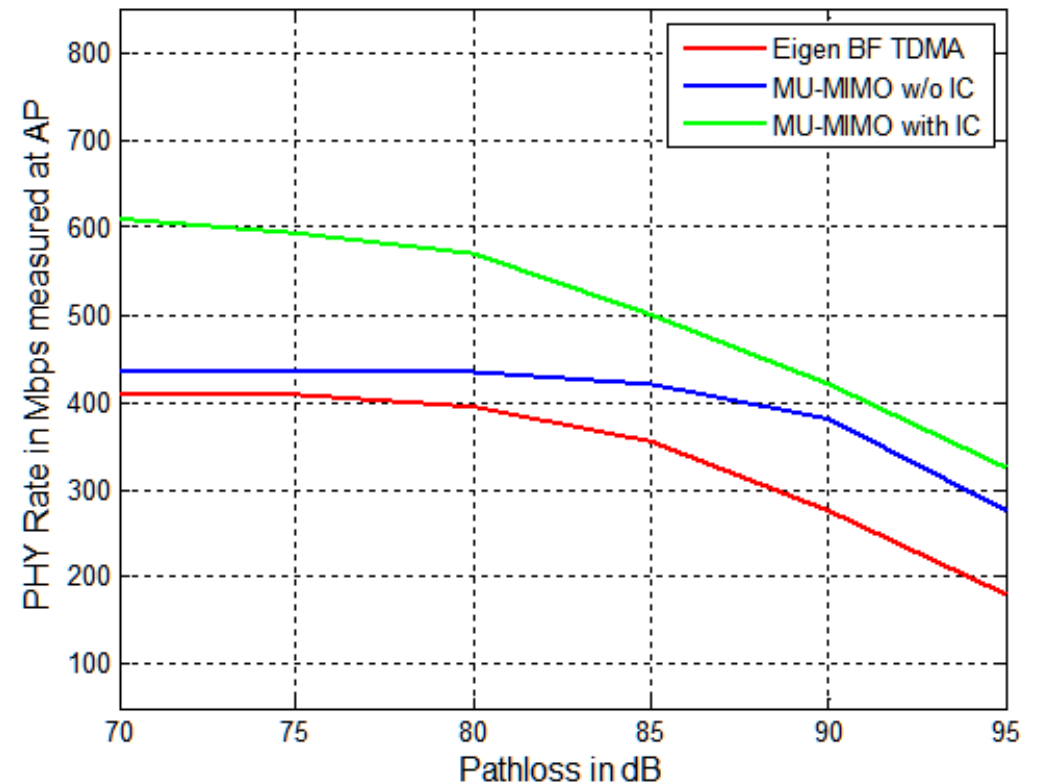


# MU-MIMO

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

Variation of 50 percentile PHY Rates with pathloss



# 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.