Troubleshooting Range: Understanding the Cell Size

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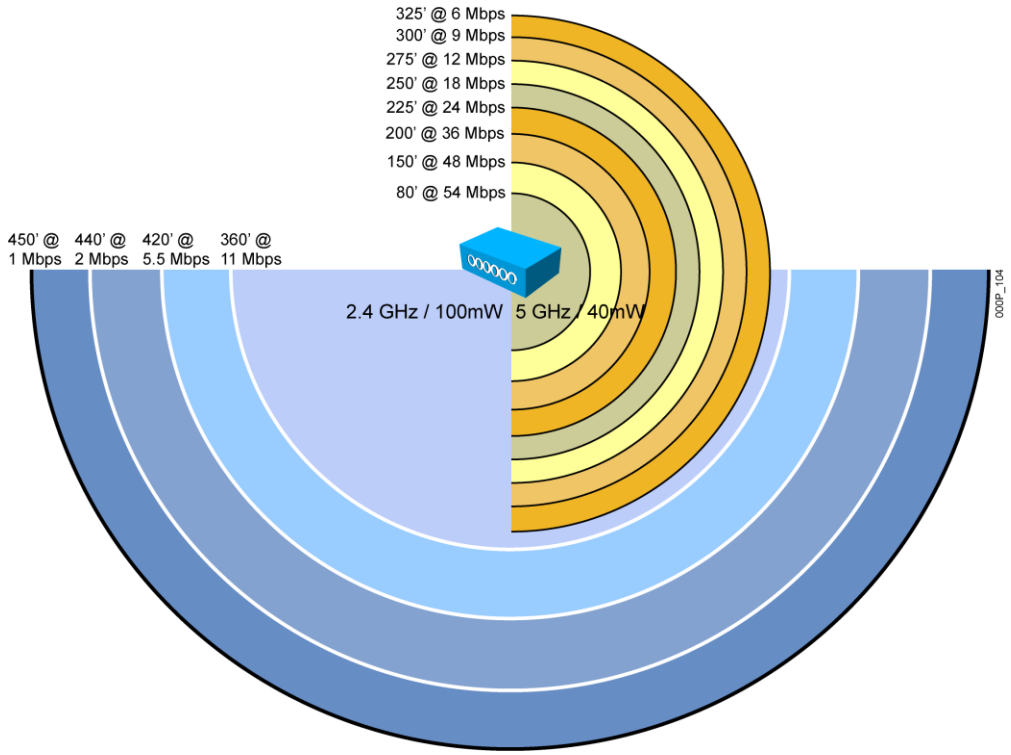
How Large is My Cell?

- Long ago, vendors used to be able to provide this…
- Most don't provide cell ranges anymore, and for good reasons…

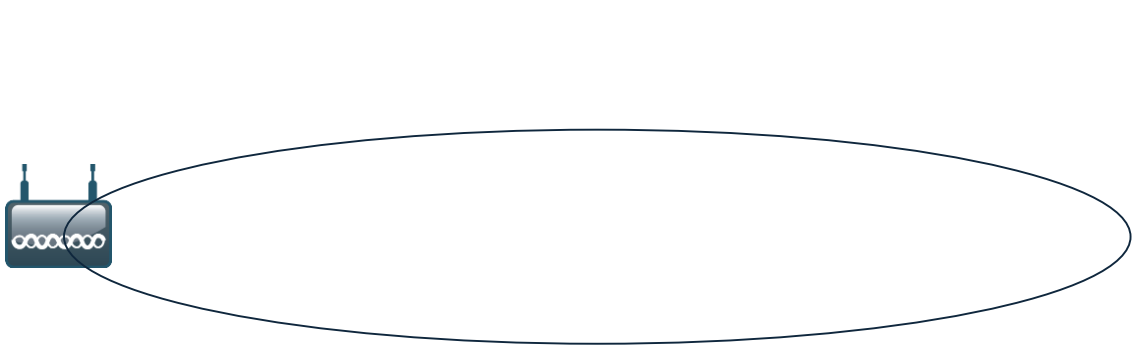


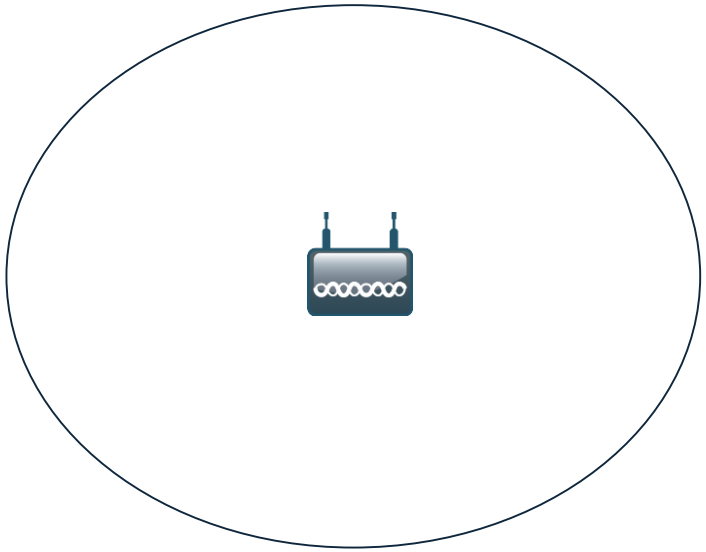
How Large is My Cell?

- 5 years ago, your clients were this 
- And your APs were these 
  - Today, your clients are these 
  - And your APs are these 
- And this changes everything…

Cell Shape and Cell Size

- Your cell shape depends on the antenna you use:
  - Directional
  - Omnidirectional





Cell Shape and Cell Size

- Your cell shape depends on the antenna you use:
  - Directional
  - Omnidirectional
- The cell size depends on 3 parameters:
  - The AP Power level
  - The protocol you use (802.11a/b/g/n/ac)
  - The Data rates you allow

What Does 802.11 say?

- 802.11 does not dictate power levels
  - This is the job of the FCC, ETSI etc.
- But, 802.11 (up to 2007) was quoting (Annex J in 802.11-2007) the max power known for each regulatory domain (“regulatory class’) and band

The Power Limits – 5 GHz

- Max power depends on the country… and the channel

Regulatory class	Channel starting frequency (GHz)	Channel spacing (MHz)	Channel set	Transmit power limit (mW)	Emissions limits set	Behavior limits set
1	5	20	36, 40, 44, 48	40	1	1, 2
2	5	20	52, 56, 60, 64	200	1	1
3	5	20	149, 153, 157, 161	800	1	1
4	5	20	100, 104, 108, 112, 116, 120, 124, 128, 132, 136, 140	200	1	
5	5	20	165	1000	4	

FCC limits (Tx power, assuming a 6 dBi antenna)

Regulatory class	Channel starting frequency (GHz)	Channel spacing (MHz)	Channel set	Transmit power limit (EIRP)	Emissions limits set	Behavior limits set
1	5	20	36, 40, 44, 48	200	1	2, 3
2	5	20	52, 56, 60, 64	200	1	1, 3, 4
3	5	20	100, 104, 108, 112, 116, 120, 124, 128, 132, 136, 140	1 W	1	1, 3, 4
4–255	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved

ETSI limits (EIRP)

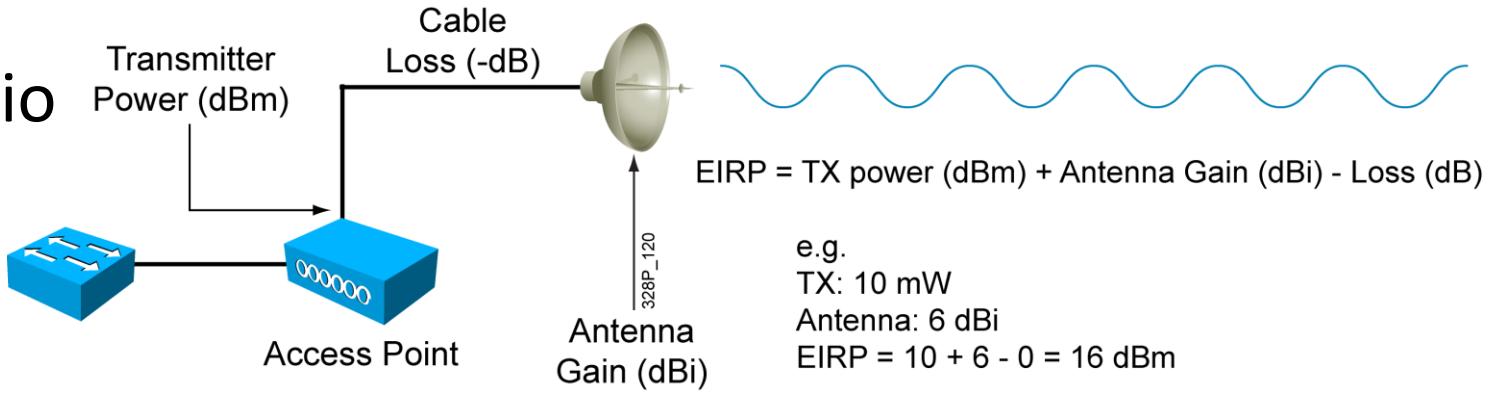
Can you tell the Range from the Power?

- 802.11 also tells you about the expected receive performances
  - E.g. 802.11-2014, table 22-25, non-STBC modes, 800 ns GI, BCC, and VHT PSDU length of 4096 octets, expected packet error ratio (PER) should be less than 10%

Modulation	Rate (R)	Minimum sensitivity (20 MHz PPDU) (dBm)	Minimum sensitivity (40 MHz PPDU) (dBm)	Minimum sensitivity (80 MHz PPDU) (dBm)	Minimum sensitivity (160 MHz or 80+80 MHz PPDU) (dBm)
BPSK	1/2	–82	–79	–76	–73
QPSK	1/2	–79	–76	–73	–70
QPSK	3/4	–77	–74	–71	–68
16-QAM	1/2	–74	–71	–68	–65
16-QAM	3/4	–70	–67	–64	–61
64-QAM	2/3	–66	–63	–60	–57
64-QAM	3/4	–65	–62	–59	–56
64-QAM	5/6	–64	–61	–58	–55
256-QAM	3/4	–59	–56	–53	–50
256-QAM	5/6	–57	–54	–51	–48

Did the Power Rules Change?

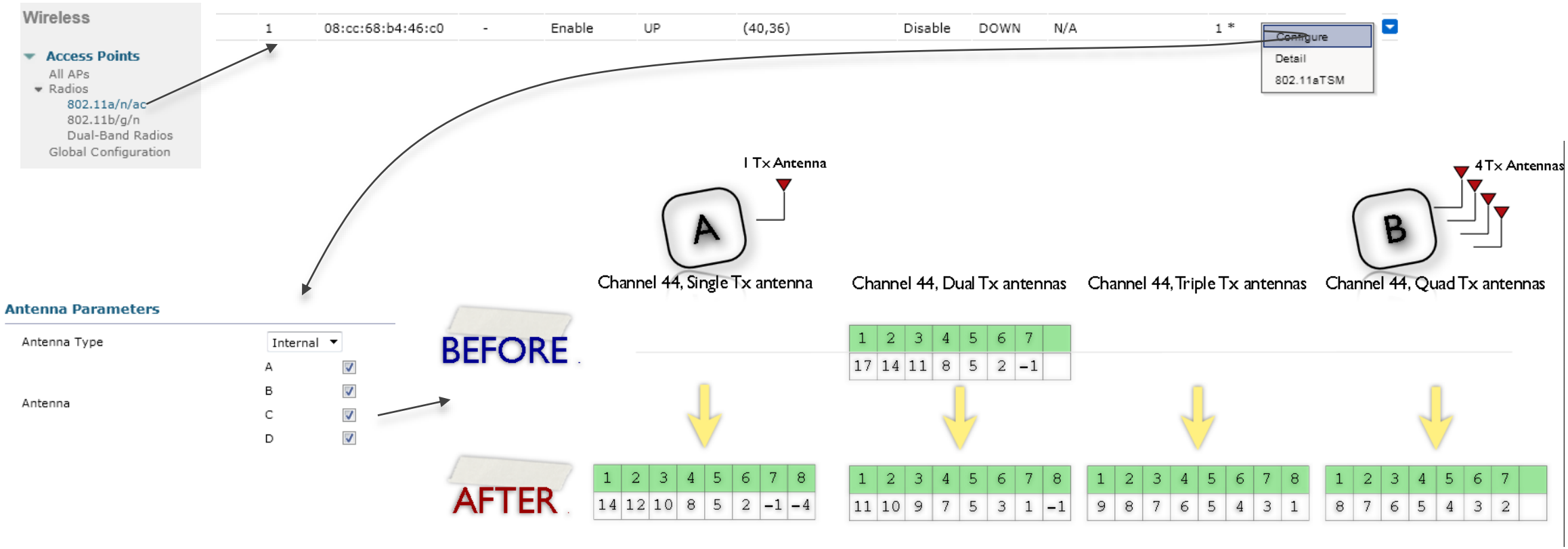
- Each country regulates the EIRP
- In Nov 2011, the FCC mandated that for multi-radio APs (802.11n/802.11ac), EIRP would be the total of all radiated energy (from all antennas)



- This changes the power levels (APs like the Cisco 1260 or 3500 use the old system, Cisco APs 3600/2600/2700/3700 use the new system)

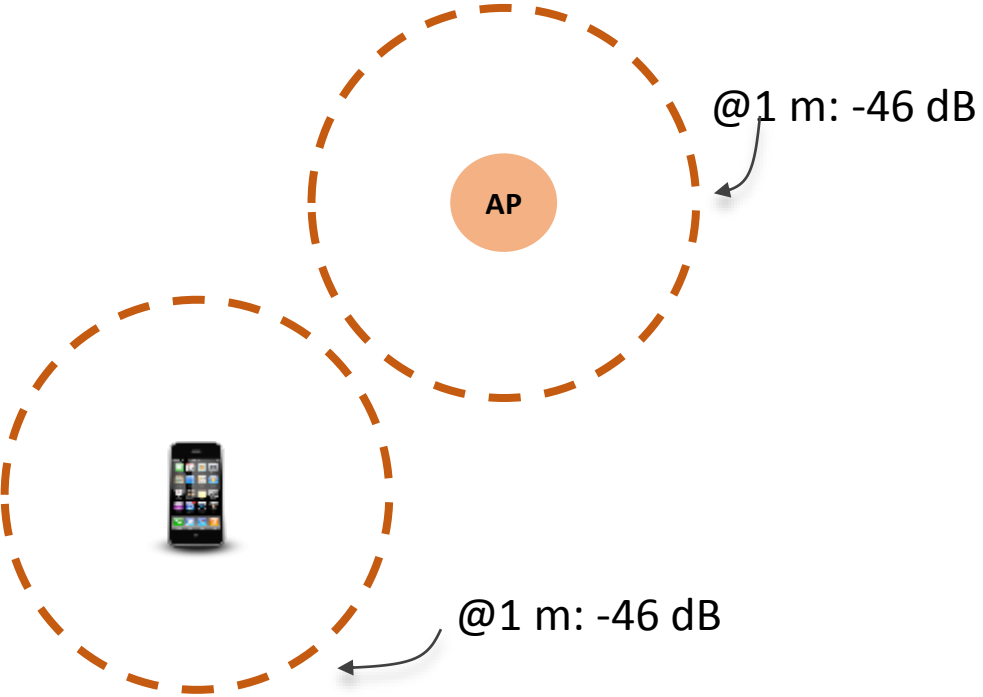
How can you tell the AP Power level?

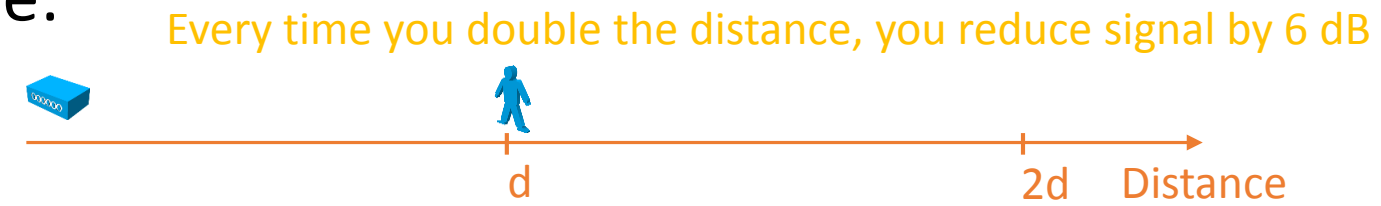
- The actual power per radio chain is modulated based on the number of chains you enable:



Can you tell the Range from the Power?

- So the only question is: how far do you get those Rx numbers?
- In a lab, the answer is simple:

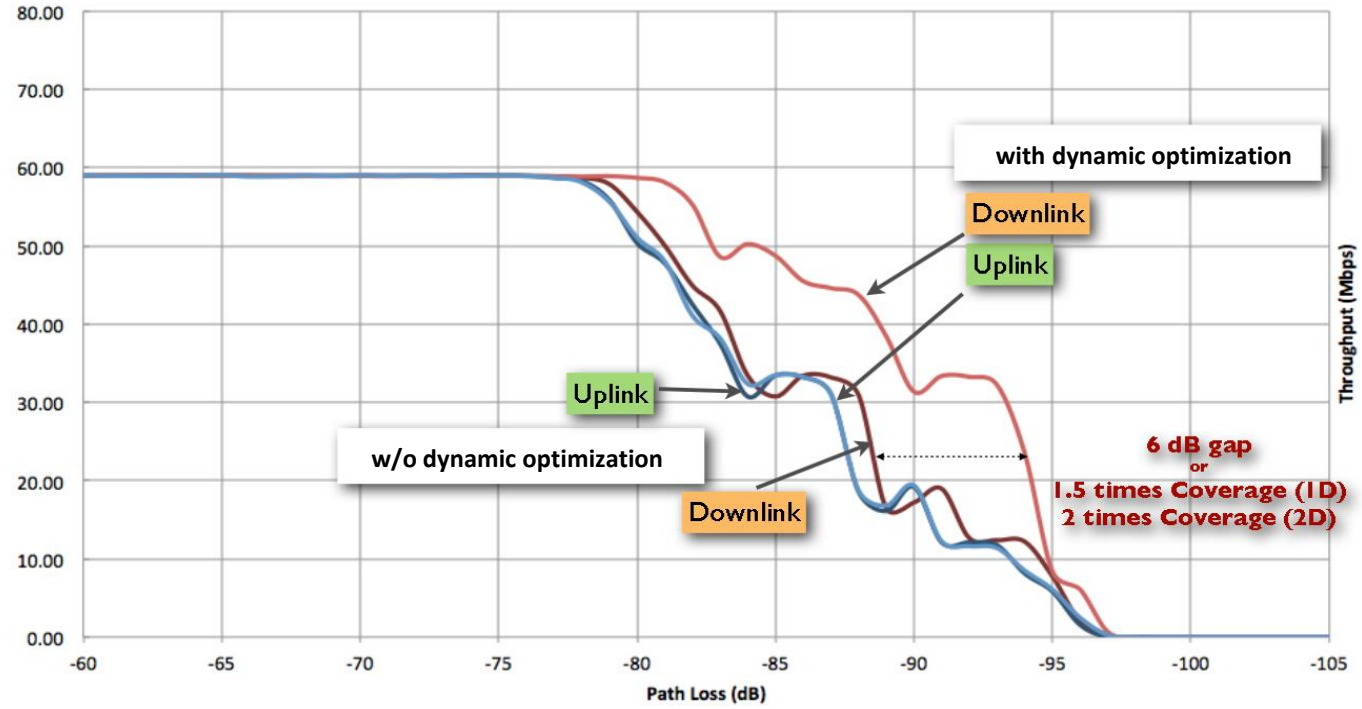




E.g.: -39 dBm at 10 feet…
@ 20 feet? About -45 dBm
@ 40 feet? About -52 dBm etc.
For the same reason, if you reduce your power by 6 dB
You get the same signal at half the distance
E.g.: AP at 17 dBm, RSSI -63 dBm @ 100 feet
AP at 11 dBm… -> signal about -63 dBm at 50 feet.

This Range vs Power works for Each Stream

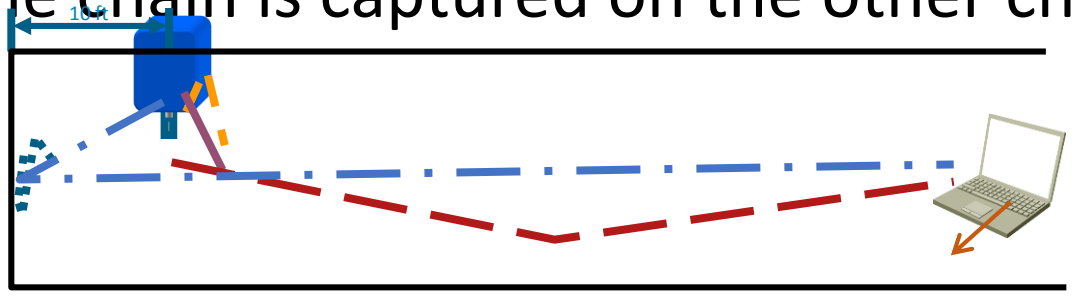
- But in fact, the AP dynamically adjusts its individual chain transmit powers, based on modulation, and also aligns its transmissions (beamforming) to offer the best signal for each frame at each modulation, at any distance:

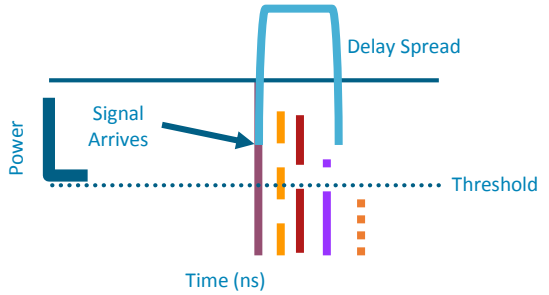


For uplink, we use another optimization technique called MRC

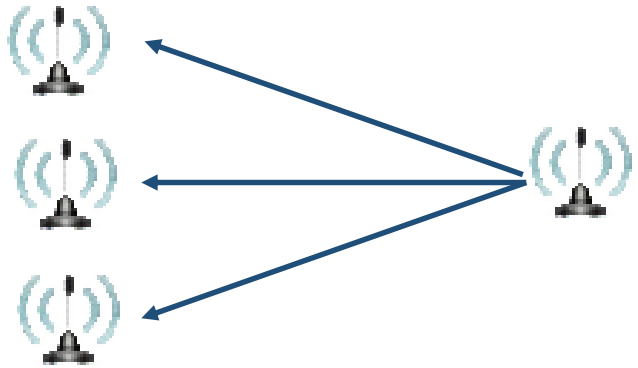
Advantage of Multiple Chains… beyond RSSI

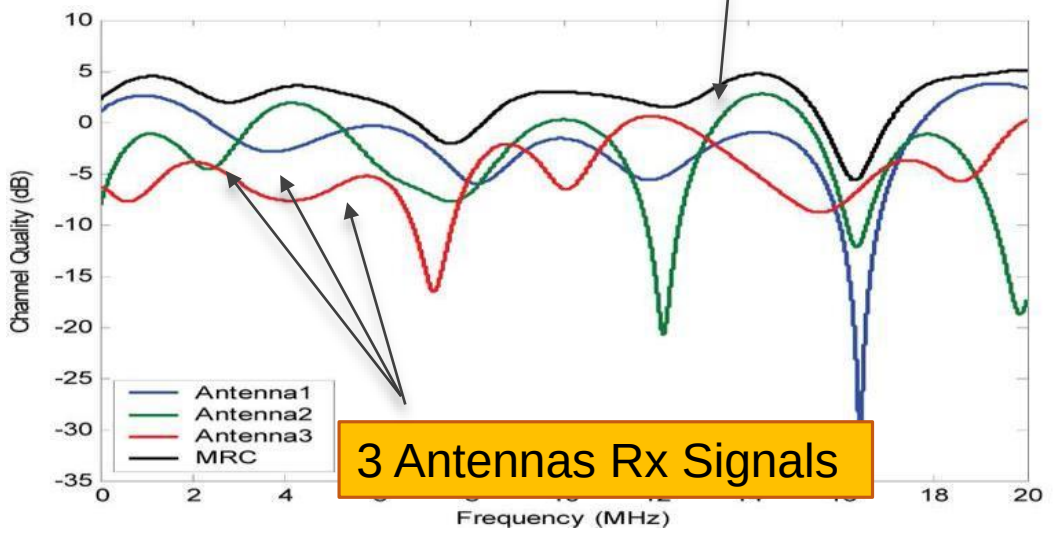
- Multiple chains dramatically improve error correction! What you miss on one chain is captured on the other chain





Survey with one antenna to be in worst conditions

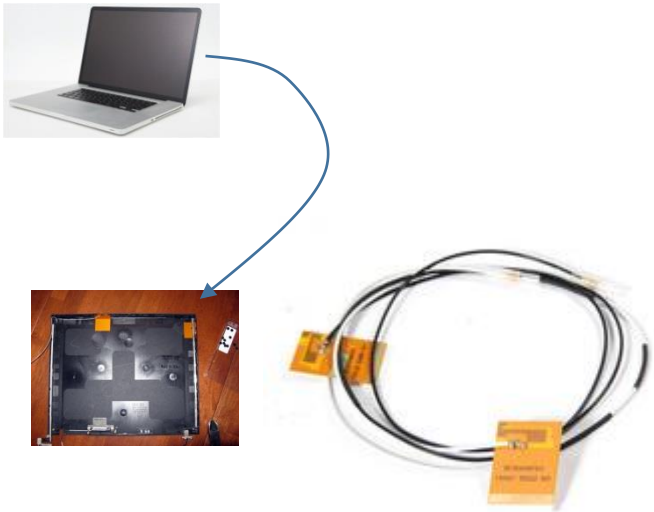




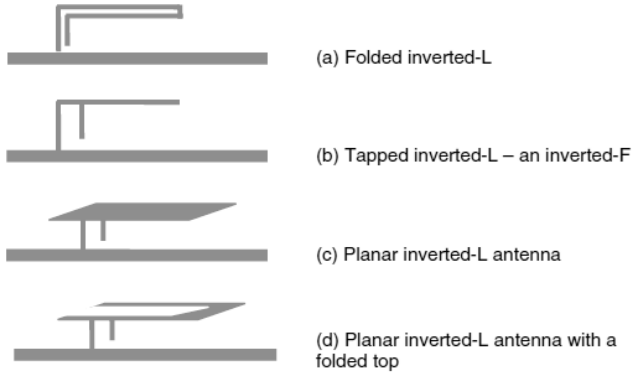
Clients vs Clients

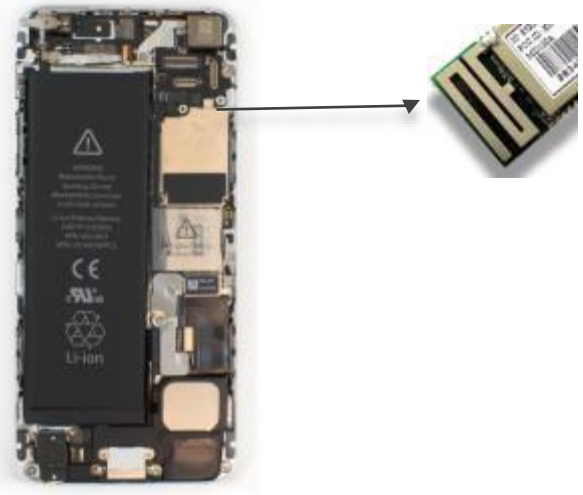
- Clients Tx and RX capabilities vary

Frequency (GHz)	Gain (dBi) Type: Pifa
2.400-2.480	-1.4
5.150-5.250	0.14
5.250-5.350	-1.66
5.47-5.725	-0.83
5725-5850	-2.85



Inverted L 4 dBi (2.4) / 6 dBi (5 GHz)





Clients vs APs

- There is of course no comparison between a small, battery-powered BYOD, and an AP:

Example: 3700i AP
(+4 dBi antenna on 2.4 GHz,
+6 dBi antenna on 5 GHz)

Maximum transmit power	2.4 GHz	5 GHz
	• 802.11b	• 802.11a
	▪ 23 dBm, 4 antennas	▪ 23 dBm, 4 antennas
	• 802.11g	• 802.11n (HT20)
	▪ 23 dBm, 4 antennas	▪ 23 dBm, 4 antennas
	• 802.11n (HT20)	• 802.11n (HT40)
	▪ 23 dBm, 4 antennas	▪ 23 dBm, 4 antennas
		• 802.11ac
		▪ non-HT80: 23 dBm, 4 antennas
		▪ VHT20 23 dBm, 4 antennas
		▪ VHT40: 23 dBm, 4 antennas
		▪ VHT80: 23 dBm, 4 antennas
		▪ VHT20-STBC: 23 dBm, 4 antennas
		▪ VHT40-STBC: 23 dBm, 4 antennas
		▪ VHT80-STBC: 23 dBm, 4 antennas

This is the max Tx power

Example: Iphone 5

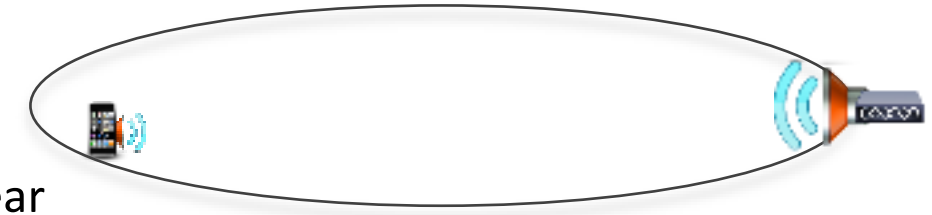
This is what the phone can actually send
(out of the antenna)

Band	Max EIRP
2.4 GHz ISM	14.6 dBm
UNII-1	14.2 dBm
UNII-2	12 dBm
UNII-2e	11 dBm
UNII-3	10 dBm
ISM (Ch 165)	10 dBm

Source: FCC

Why Does it Matter?

- RF is symmetrical on paper:
  - "If your AP signal is heard by a client, the AP should hear the client signal symmetrically" (because the antenna Rx matches its Tx gain)



- In real world, this is true… except that the client signal is so weak that the AP can't make sense out of it, unless both sides RF specs are identical
- 2 causes:
  - Client rate decision is based on CLIENT perception of AP signal – if AP signal is strong, client will use high rate
  - The client reaches the AP mixed in surrounding noise – SNR too low and AP cannot demodulate

This is the AP signal (at phone level)

This is the phone signal (at AP level)

Your cell will NOT Like Power Mismatches

- Bad design example: Client @ 12 dBm, AP @20 dBm

Based on Rx AP signal, BYOD thinks 54 Mbps rate is okay

But client message is too weak, and AP does not ACK

17	0.039879000	172.31.255.101	172.31.255.103	UDP	1420	34	-35 55 dB	54.0	Source port: 50857 Destination port: search-agent
18	0.040266000	172.31.255.101	172.31.255.103	UDP	1420	34	-35 55 dB	54.0	Source port: 50857 Destination port: search-agent
19	0.040648000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857 Destination port: search-agent
20	0.041938000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857 Destination port: search-agent
21	0.042217000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	36.0	Source port: 50857 Destination port: search-agent
22	0.043444000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	12.0	Source port: 50857 Destination port: search-agent
23	0.043445000		Cisco_0a:04:2e (RA)	802.11	40		-45 45 dB	12.0	Acknowledgement, Flags=........C
24	0.043850000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857 Destination port: search-agent
25	0.044245000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857 Destination port: search-agent
26	0.044641000	172.31.255.101	172.31.255.103	UDP	1420	34	-34 56 dB	54.0	Source port: 50857 Destination port: search-agent
27	0.045023000	172.31.255.101	172.31.255.103	UDP	1420	34	-35 55 dB	54.0	Source port: 50857 Destination port: search-agent
28	0.045750000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	36.0	Source port: 50857 Destination port: search-agent
29	0.046223000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	36.0	Source port: 50857 Destination port: search-agent
30	0.047450000	172.31.255.101	172.31.255.103	UDP	1420	34	-29 61 dB	12.0	Source port: 50857 Destination port: search-agent
31	0.047450000		Cisco_0a:04:2e (RA)	802.11	40		-47 43 dB	12.0	Acknowledgement, Flags=........C

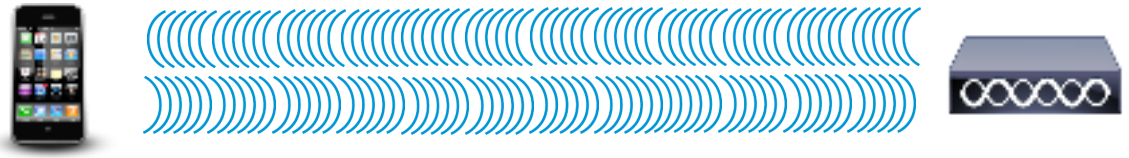
Retry @ 54
Again
and Again
Okay try 36
Wow, let's drop to 12
Now I get an ACK
Start over…

```
Frame 29: 1420 bytes on wire (11360 bits), 1420 bytes captured (11360 bits) on interface 0
Radiotap Header v0, Length 26
IEEE 802.11 QoS Data, Flags: ....R.F.C
  Type/Subtype: QoS Data (0x28)
⊟ Frame Control: 0x0A88 (Normal)
    Version: 0
    Type: Data frame (2)
    Subtype: 8
  ⊟ Flags: 0xA
      .... ..10 = DS status: Frame from DS to a STA via AP(To DS: 0 From DS: 1) (0x02)
      .... .0.. = More Fragments: This is the last fragment
      .... 1... = Retry: Frame is being retransmitted
      ...0 .... = PWR MGT: STA will stay up
      ..0. .... = More Data: No data buffered
      .0.. .... = Protected flag: Data is not protected
      0... .... = Order flag: Not strictly ordered
```

Each message takes 8 times more to be transmitted (including EIFS and retries)

So, what is the right Power?

- In short: half your worst client max power
  - E.g. you design for 5 GHz, worst client max is at 11 dBm, set your AP power to 8 dBm
- Otherwise, you get this:



- Which BYOD the worst out there? No names, but 11 dBm is a good assumption

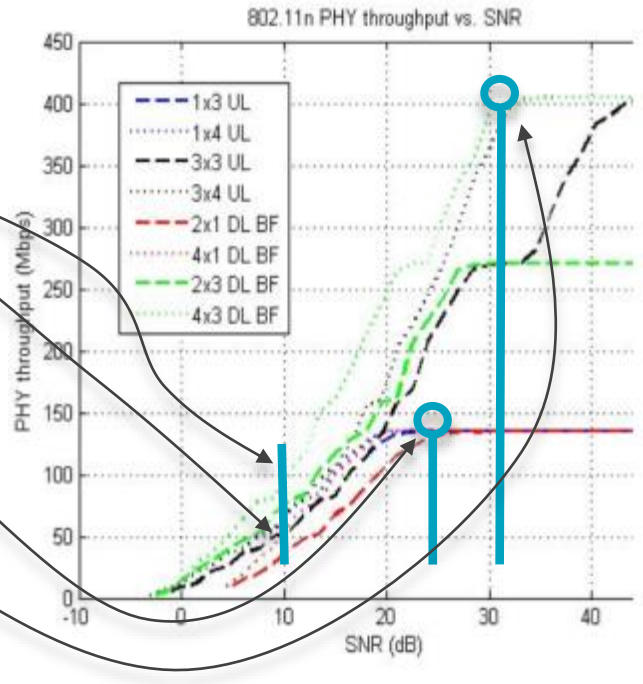
What About the Influence of Spatial Streams?

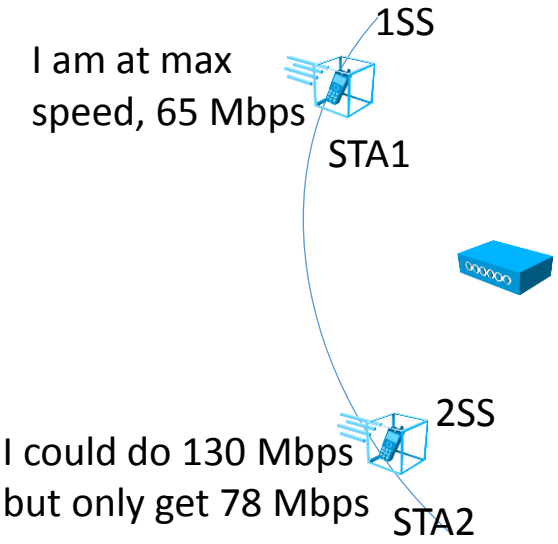
- Do not think that multiple stream devices are always better
- They may have higher power, but also require higher SNR

e.g.: 4 streams gives you a higher throughput at same SNR level, than 2 streams

BUT the 2 stream device reaches its max speed at 24 dB SNR,
while the 4 stream device needs 30+ dB

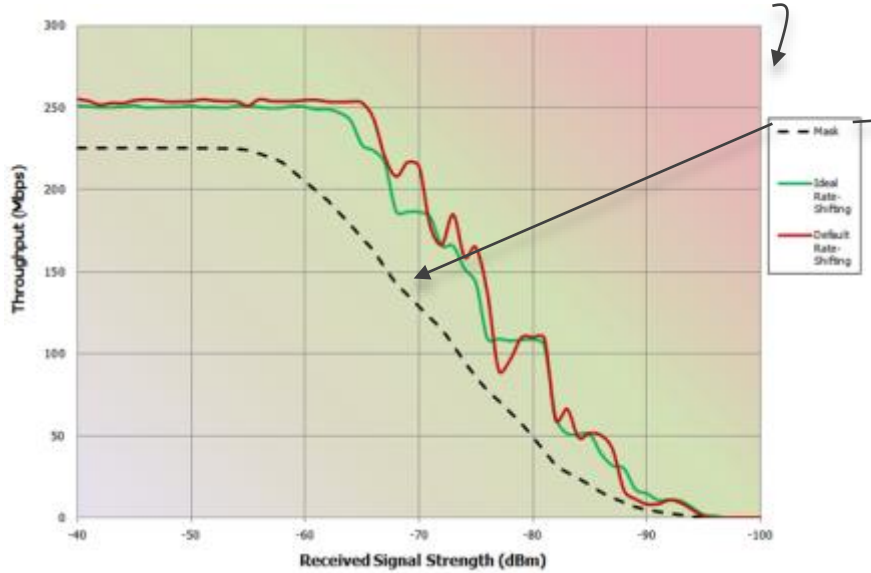
Conclusion: at same distance from the AP, multiple stream devices will operate faster than single stream device, but each individual stream is slower





Also Keep in Mind that 802.11 Specs are "Minimums"

- 802.11 determines "minimum RX performance values" – RSSI based
- Vendors achieve "at least" these values
- Example: Cisco 3700e Rx performances:



Modulation	Rate (R)	Minimum sensitivity (20 MHz PPDU) (dBm)	Minimum sensitivity (40 MHz PPDU) (dBm)	Minimum sensitivity (80 MHz PPDU) (dBm)
BPSK	1/2	–82	–79	–76
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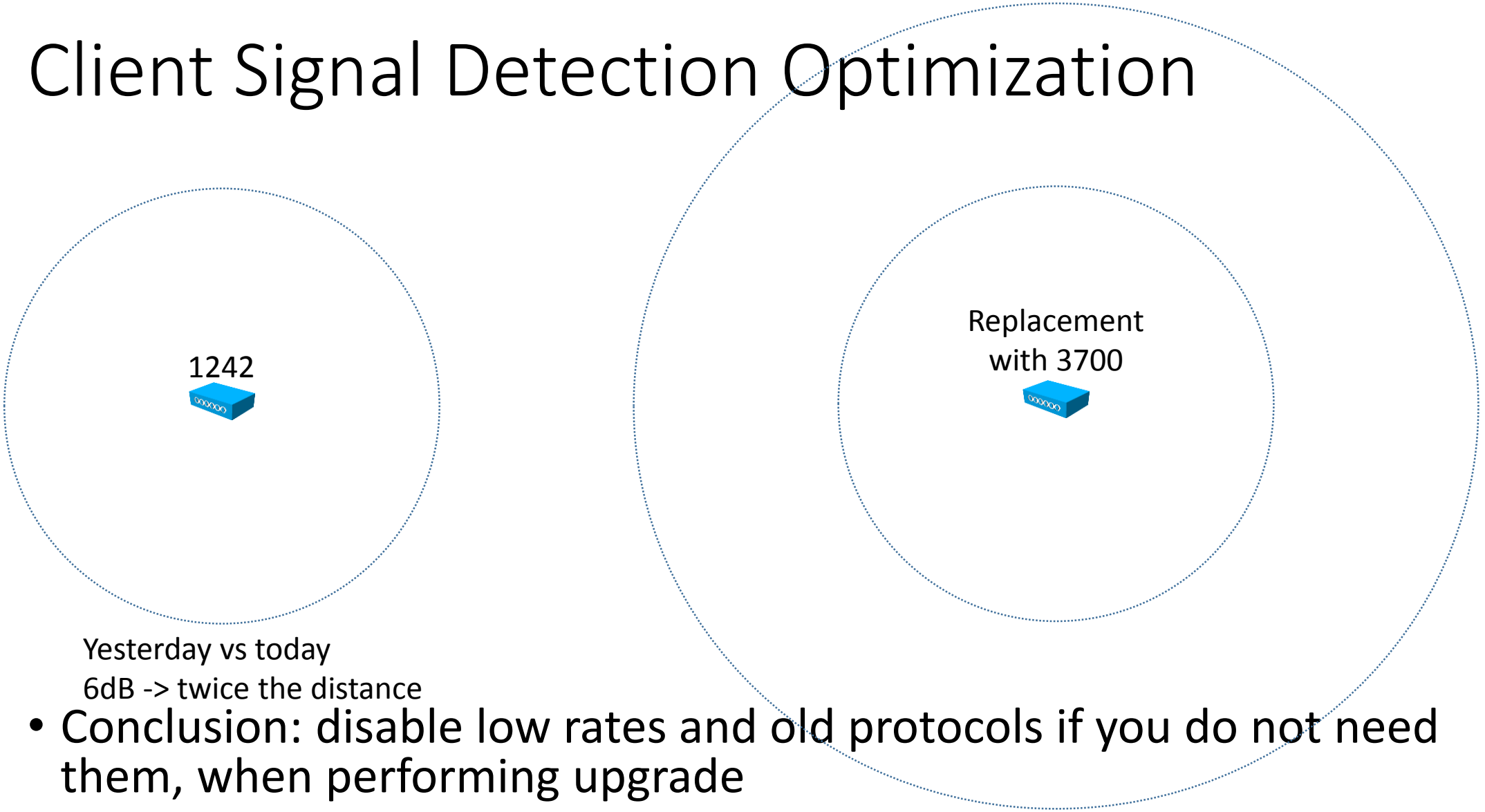
64-QAM	5/6	–64	–61	–58
256-QAM	3/4	–59	–56	–53
256-QAM	5/6	–57	–54	–51

Client Signal Detection Optimization

- AP Rx sensitivity is MUCH higher than that of most BYODs… and improved over the years beyond the 802.11 requirements
- E.g. 1242 Rx sensitivity at 1 Mbps is -96 dBm, with a typical SNR of 3 dB (so you need -96 dBm signal, with background noise not more than -99 dBm, to recognize and read a frame sent at 1 Mbps). With the 3700 AP, that threshold is -101 dBm (with the same SNR requirements), so we are 5 dB better
- We need more signal to read 802.11n than legacy protocols. If we disable legacy protocols on our new APs, the problem would probably more or less go away by itself, but the issue is that we keep the old protocols and at the same time build smaller cells to benefit from the additional throughputs.

Rate	1242 AP Min Rx Sensitivity	3500 AP Min Rx Sensitivity	3700 AP Min Rx Sensitivity
1 Mbps	-96 dBm	-101 dBm	-101 dBm
6 Mbps (5 GHz)	-88 dBm	-93 dBm	-93 dBm
MCS 0 20 MHz (6.5 Mbps) – 1 SS	N/A	-93 dBm	-94 dBm
MCS 8 20 MHz (13 Mbps) - 2 SS	N/A	-87 dBm	-94 dBm
MCS 0 80 MHz (	N/A	N/A	-86 dBm

Client Signal Detection Optimization



Yesterday vs today
6dB -> twice the distance

- Conclusion: disable low rates and old protocols if you do not need them, when performing upgrade

Take Away

- Your cell size depends on many factors:
  - Power at the AP
  - Power at the client
  - Rx sensitivity on both sides
  - Protocols you enable
  - Rates you enable
  - Number of spatial stream
  - AP type (enhancement techniques such as number of SS, beamforming, mrc, etc.)
- Do not assume that cell size is the same as you replace APs and change clients: survey, survey, survey

Thank you.