Part II:
Terminology and Jargon
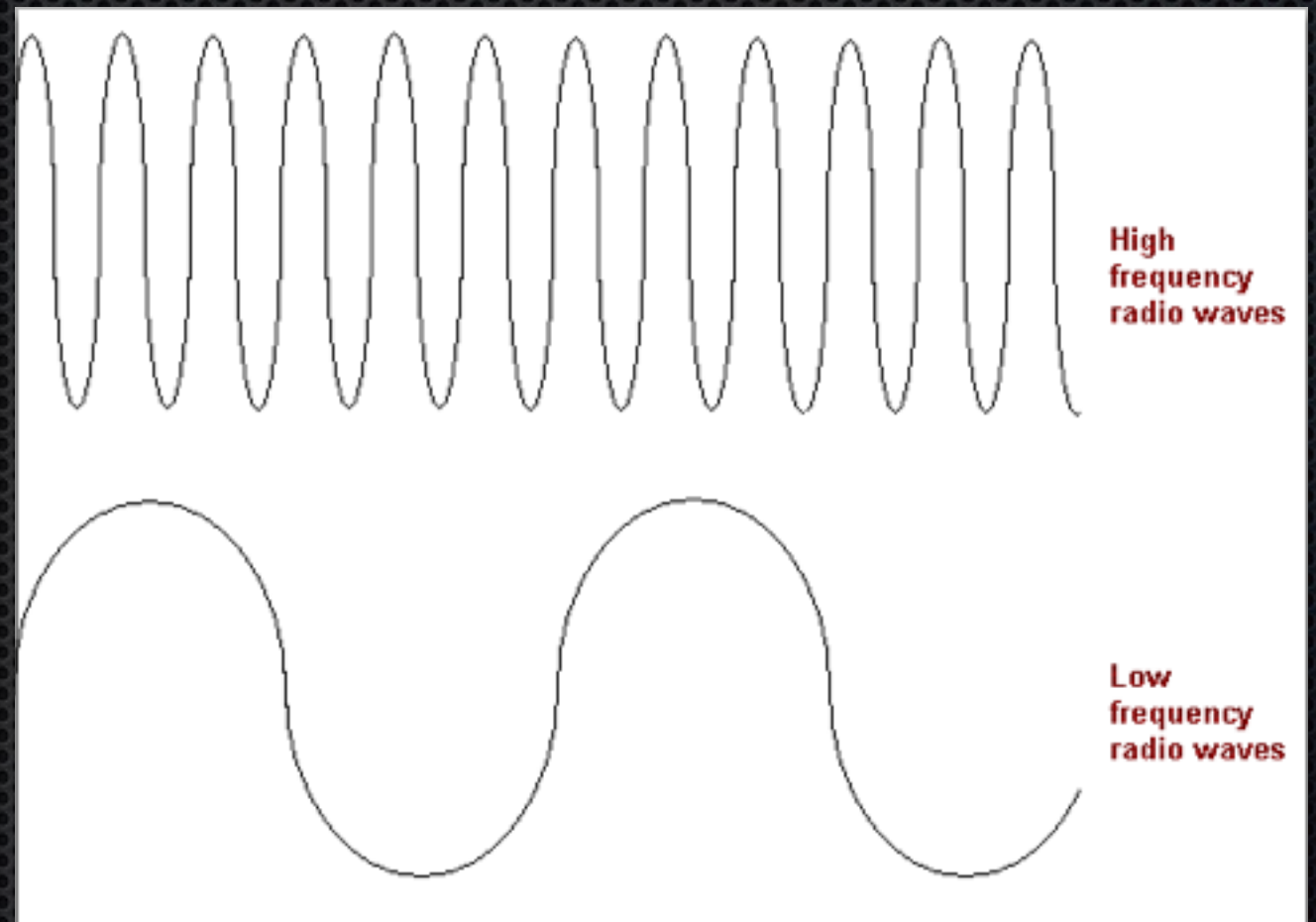
- Basic Radio Terminology

- WiFi Jargon

- How Some of the Terms Relate

- One or Two Lies

Basic Radio Terminology

- Frequency

- Transmission Power

- Attenuation

- Interference

- Signal Strength, Noise, and SNR (where the gold is)

Frequency

- When it comes down to it, frequency is how often something happens over a period of time.

- Measured in units of Hz

High frequency radio waves

Low frequency radio waves

Frequency

Transmission Power

- Transmission requires applying electrical power

- Increasing power increases transmission range.

- In Wi-Fi world, power output measured in dBM or mW, varying by vendor choice

Transmission Power

- All of your WiFi devices transmit

- All of your WiFi devices AP and STA have transmission power ratings

- Often the power ratings differ

MR32-01
MR32

Channel width

5 GHz: 40 MHz

Radio 1 (2.4 GHz)

Channel: 1
Power: 30 dBm

Radio 2 (5 GHz)

Channel: 44
Power: 17 dBm
Overlaps channels 44 to 48

Attenuation

Loss of signal intensity through any medium

Attenuation and the Inverse Square Law

Intensity of signal radiating from a point source is inversely proportional to the square of the distance from the source.

Attenuation and the Inverse Square Law

In other words, the further you get away from a signal source, the less intense it is.
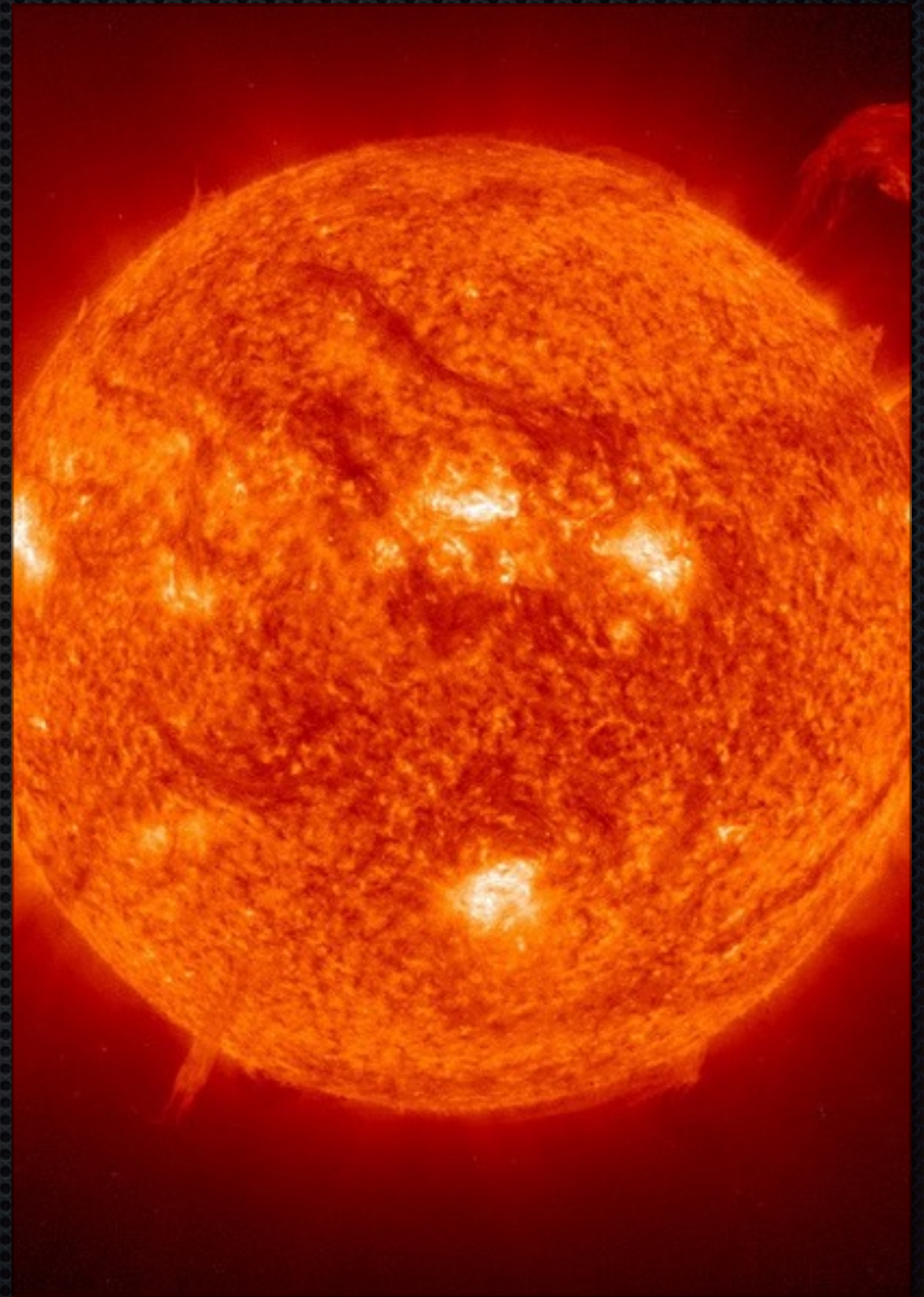
Courtesy NASA/JPL/CalTech
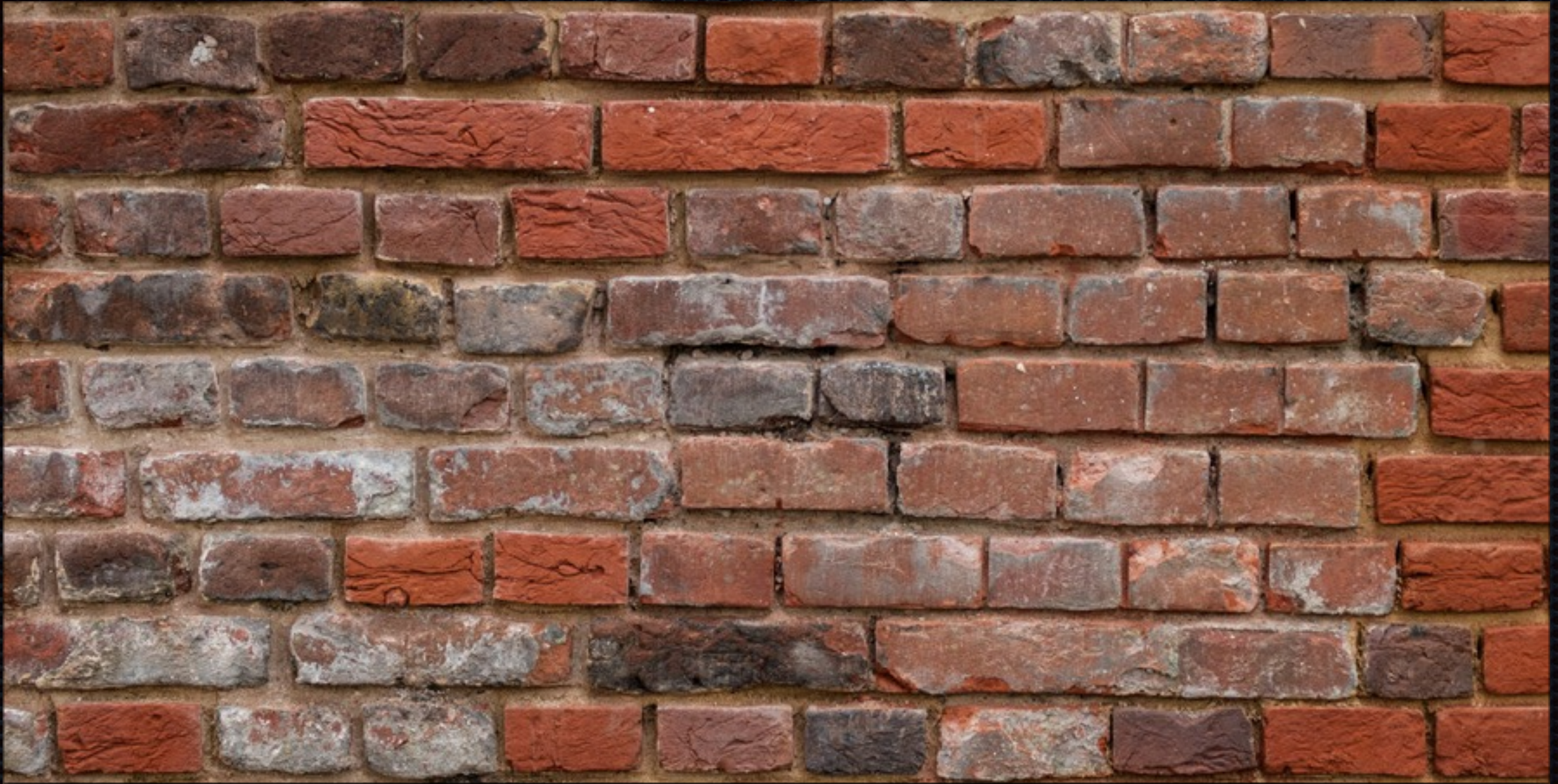
Attenuation

Occurs when signal passes through construction materials.

Attenuation

- Materials generally impose some level of attenuation, and you'll find listings in a lot of applications and documentation.

- Drywall imposes some, brick and concrete impose a *lot*

- Some other unexpected things impose it as well.

Interference
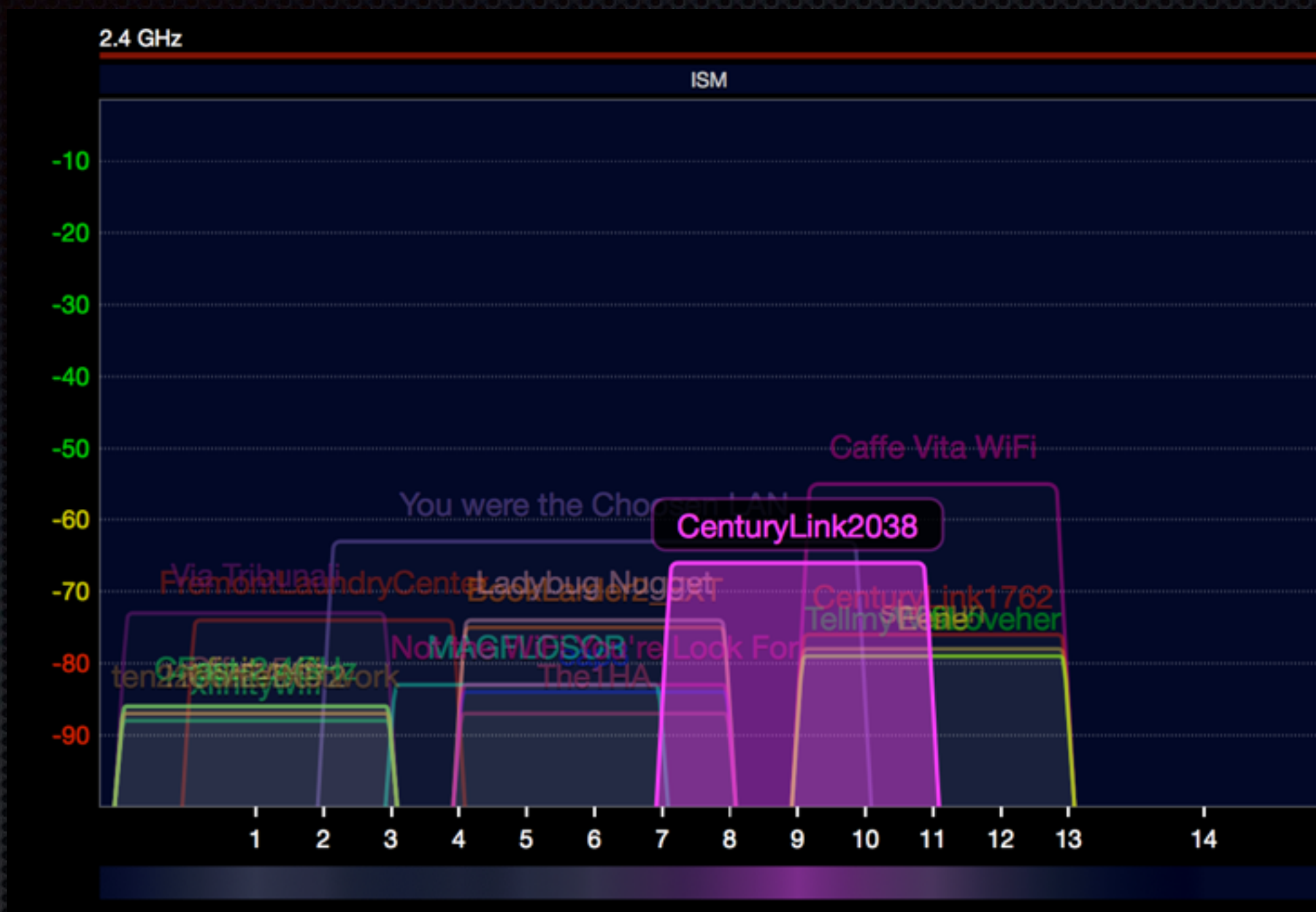
* Something that modifies or disrupts a signal as it travels

* Unwanted signal added to wanted signal

Electromagnetic Interference (EMI)

- Also known as radio frequency interference (RFI), this can be signal that's transmitted on the same frequency.

Adjacent Channel Interference

Caused by extraneous power in a nearby channel to that which is being used for communication.

Adjacent Channel Interference

CenturyLink 2308 is broadcasting on Ch. 9, which overlaps with everything on 6, 11, and the other non-9 channels between.

Signal (Strength)

* Measure of an electric field at a defined distance of from a transmitter.

Signal Strength

- In WiFi, we typically refer to RSSI (Received Signal Strength Indicator) as our measure.
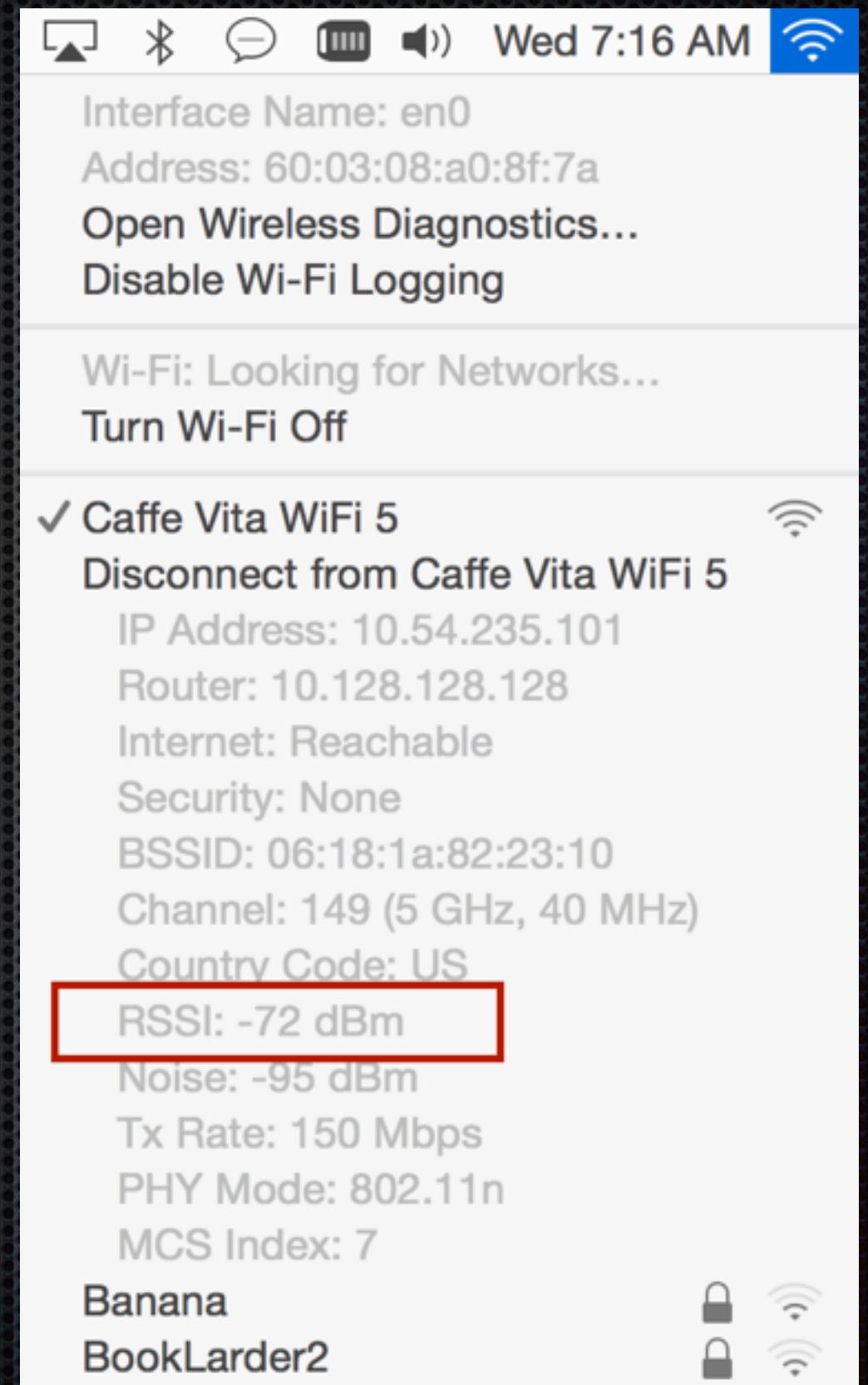
Signal Strength

- In WiFi, these numbers appear goofy and nonsensical; they're non-standardized.

- The higher the integer, the better the overall signal

- -85 to -45 are not unusual
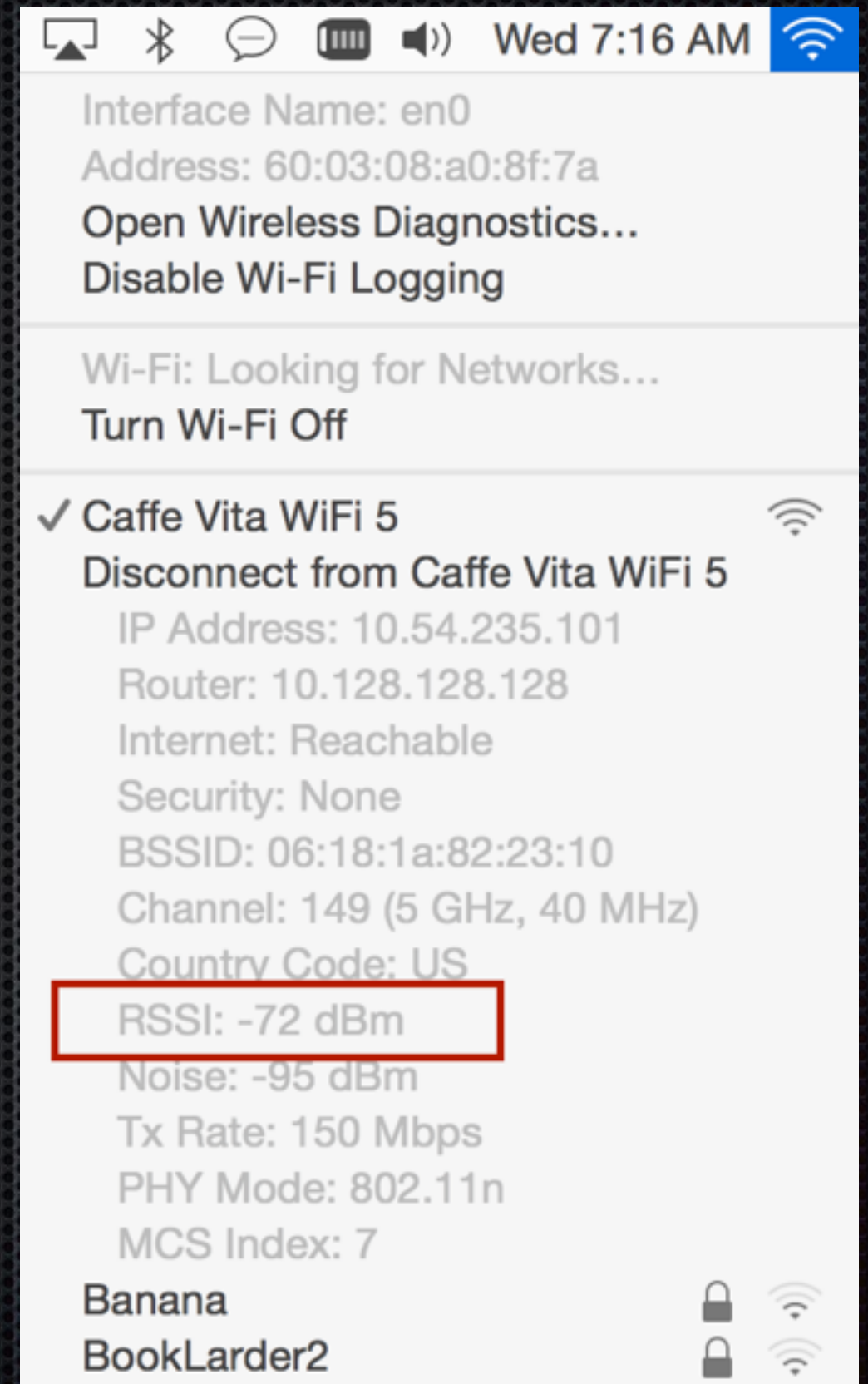
Caffe Vita WiFi 5

06:18:1A:82:23:10   300 Mbit/s

Poor   149 (40) 122   6
Signal Quality   Channel   Mbit/s   MCS Index

10.54.235.101   -72   -95   23
IP Address   Signal   Noise   SNR (dB)

Signal Strength
Some tools will try to tell you this.

Noise

- Superposition of white noise onto a signal, from a variety of sources

- A source of interference.

Noise

Measured and reported by the Mac OS X CoreWLAN framework
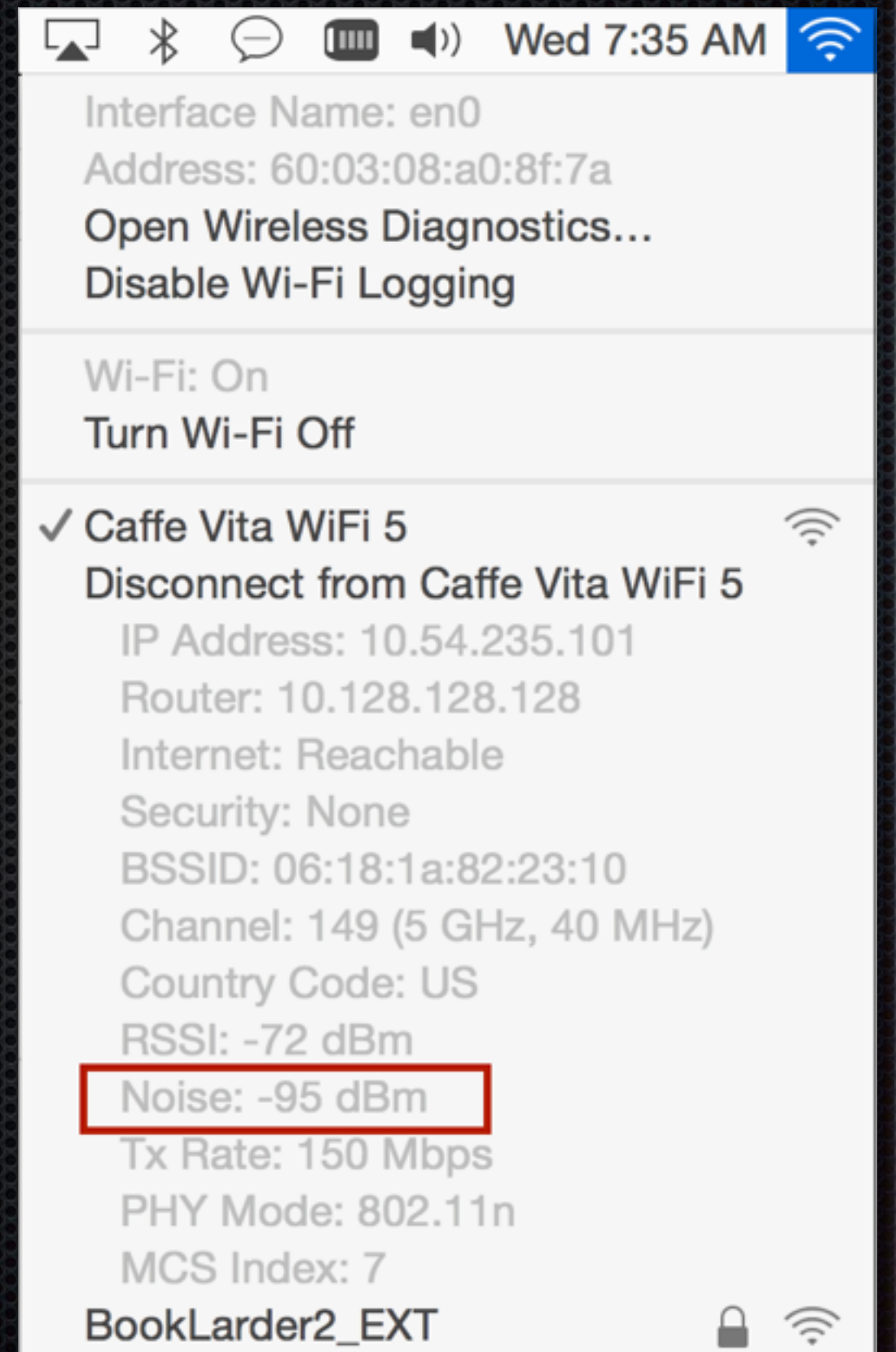
Caffe Vita WiFi 5

06:18:1A:82:23:10   300 Mbit/s

Poor   149 (40) 150   7
Signal Quality   Channel   Mbit/s   MCS Index

10.54.235.101   -71   -95   24
IP Address   Signal   Noise   SNR (dB)

Noise

The information is therefore available in a variety of tools.

But…

Individually, signal and noise alone aren't worth a bucket of warm spit.

Signal to Noise Ratio (SNR)

Where the magic happens.

Signal to Noise Ratio (SNR)

- Subtract the Noise measure from the Signal (RSSI) level

- The larger the number, the better the SNR

- Apple's WiFi Menu item *does not* explicitly provide this
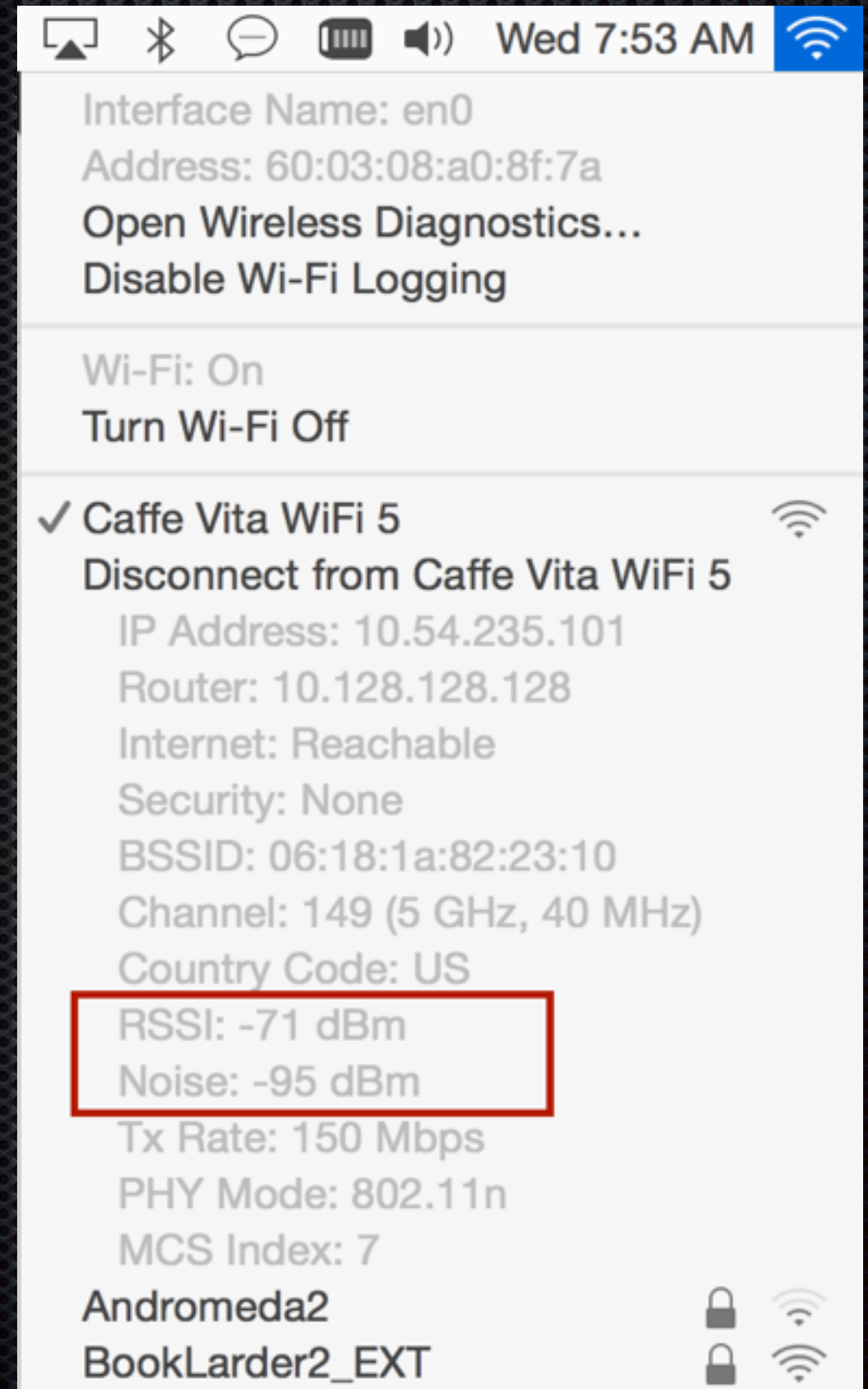
Caffe Vita WiFi 5

06:18:1A:82:23:10   300 Mbit/s

Poor		149 (40)	150	7
Signal Quality		Channel	Mbit/s	MCS Index
10.54.235.101		-72	-95	23
IP Address		Signal	Noise	SNR (dB)

RSSI - Noise = SNR
(-72) - (-95) = 23

WiFi-Specific Terminology

Basic Terms

- WiFi Equipment (The Pieces)

- Frequency Band

- PHY Mode

- Channel

- Co-Channel and Adjacent Channel Interference

Advanced Jargon:
Down the Rabbit Hole

- MIMO

- Spatial Streams

- Guard Interval

- MCS Index

- Transmit Rate

Basic WiFi Terminology

The Pieces

- AP (Access Point): A central transmitter.

- STA (Station): A client WiFi device.

- The official 802.11 documentation uses this, so we'll try to use it as well. (You see AP all the time, but STA not as much)

Frequency Band

- Shorthand that describes a collection channels in the same general area of the spectrum.
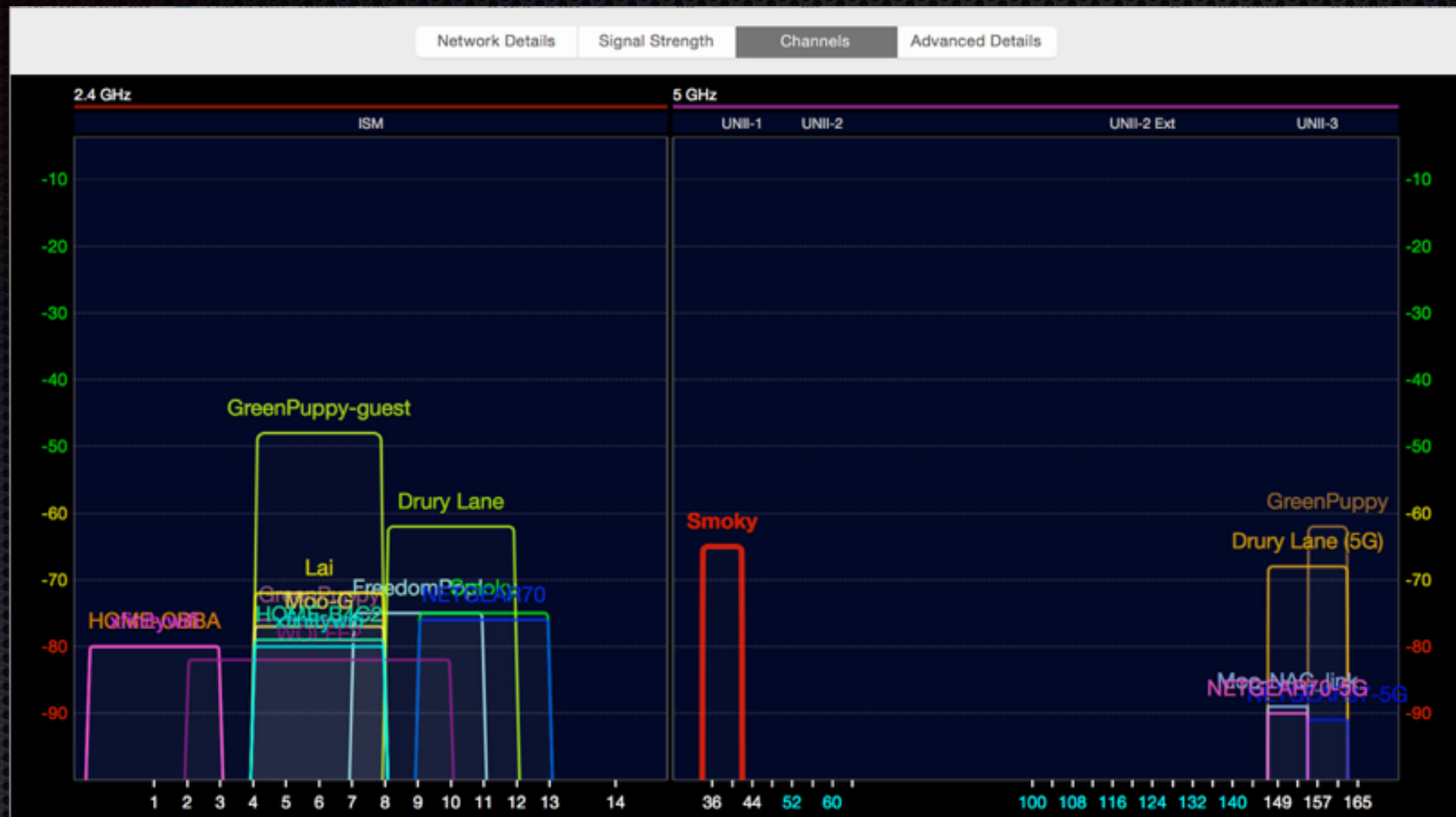
Frequency Band

The 2.4 GHz band consists of one collection of channels, while the 5 GHz band consists of another collection.

Frequency Band
2.4 GHz

- 11 (1-11) Channels in the United States

- 2412 MHz - 2462 MHz

- The original frequency band, used for 802.11b, 802.11g, and early 802.11n

Frequency Band
5 GHz

- Many more channels, depending on how you look at them

- 5180 MHz-5340 MHz, 5500 MHz-5700 MHz, 5745 MHz -5825 MHz

- 802.11n and 802.11ac

PHY Mode

- A shorthand way of stating the 802.11 standard in use within the 802.11 family

  - 802.11b

  - 802.11g

  - 802.11a

  - 802.11n

  - 802.11ac

- Can tell you a lot about the theoretical capabilities of a network.

▲ ✳ ⬭ ▭ ◀)) Wed 10:31 AM ⛛

Interface Name: en0
Address: 60:03:08:a0:8f:7a
Open Wireless Diagnostics…
Disable Wi-Fi Logging

Wi-Fi: Looking for Networks…
Turn Wi-Fi Off

✓ Smoky   🔒 ⛛
Disconnect from Smoky
    IP Address: 192.168.0.193
    Router: 192.168.0.1
    Internet: Reachable
    Security: WPA2 Personal
    BSSID: 00:11:74:93:29:a0
    Channel: 36 (5 GHz, 40 MHz)
    Country Code: US
    RSSI: -64 dBm
    Noise: -95 dBm
    Tx Rate: 162 Mbps
    PHY Mode: 802.11n
    MCS Index: 12

Channel

- Shorthand description of a defined frequency band in the spectrum.

- Channel 149 = 5745 MHz (5.745 GHz)

Co-Channel Interference

- WiFi standard *requires* that devices using the same channel be polite to one another.

- When one device transmits, all other devices on that channel *must* wait. The transmitting device has the Conch

- Technically this is *not* interference.

Co-Channel Interference

This behavior is determined on a channel-by-channel basis. Consequently, two different networks on the same channel that are detectable by the other will effectively interfere with one another.
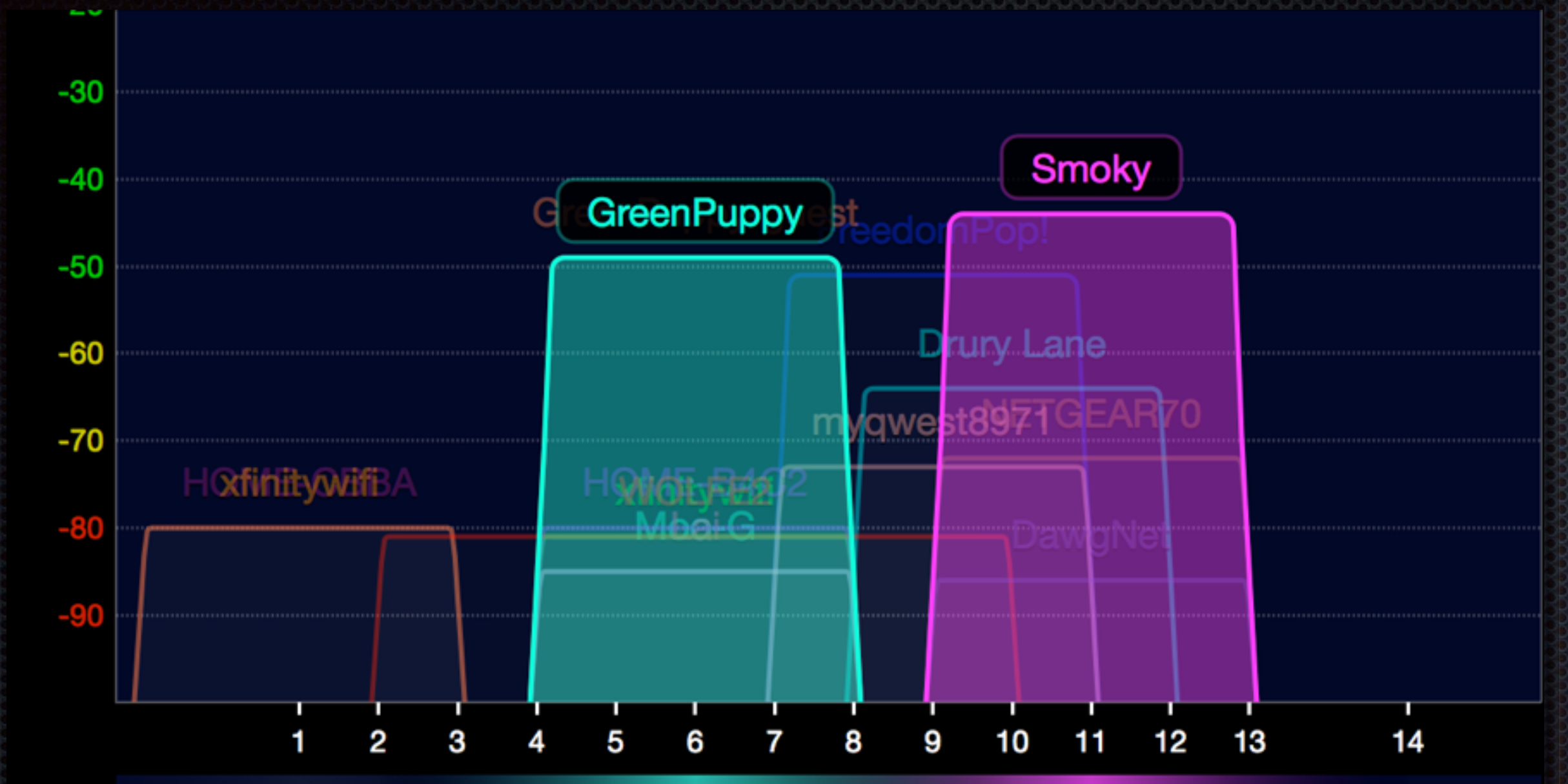
Co-Channel Interference

GreenPuppy (Ch. 6) and Smoky (Ch. 11) broadcast on different channels with no overlap, and therefore do not interfere with one another.
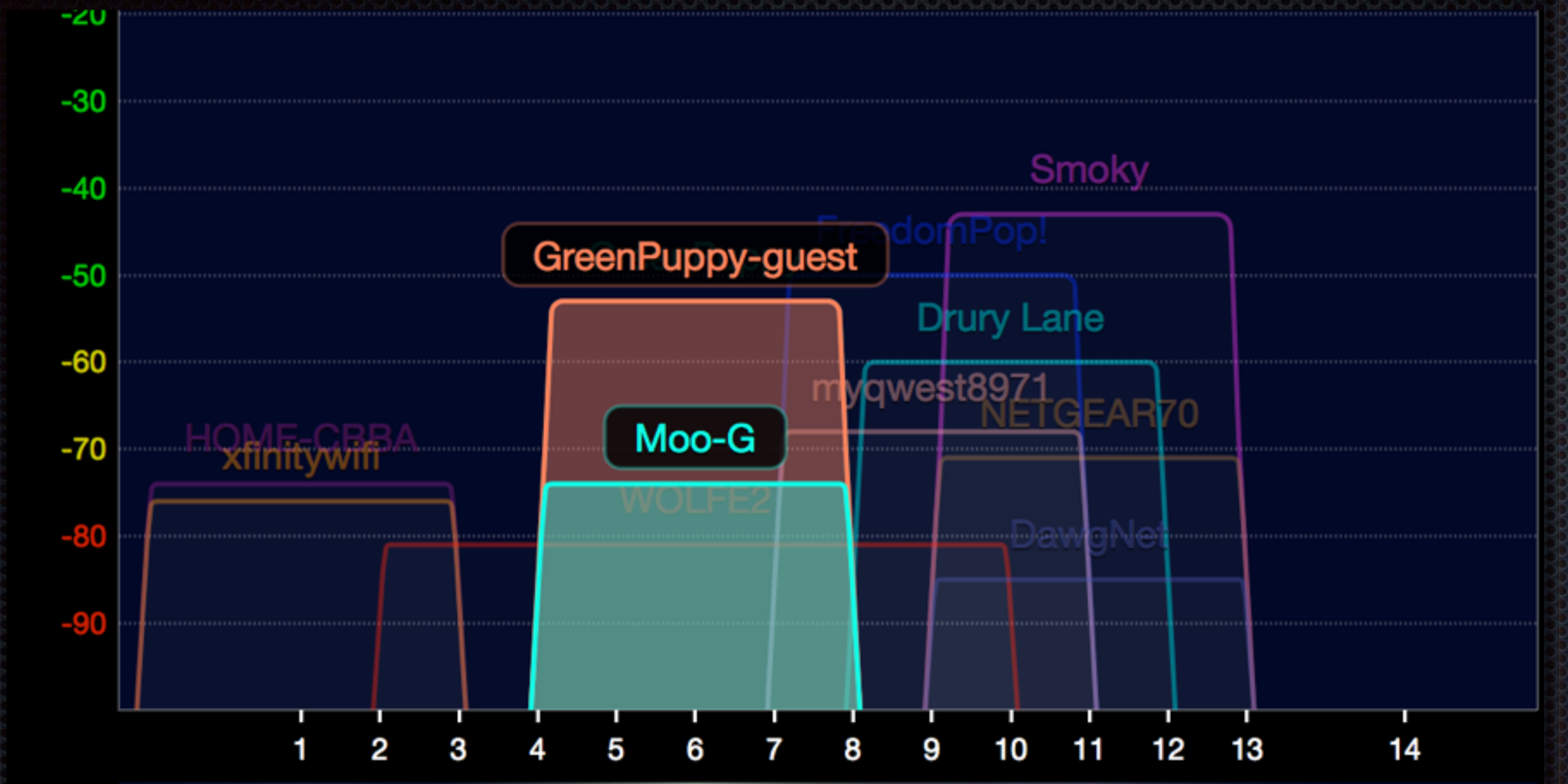
Co-Channel Interference

GreenPuppy (Ch. 6) and Moo-G (Ch. 6) broadcast on the same channel, so they and the clients connected to them must be polite to one another; effectively, then interfere with one another.

Co-Channel Interference

The more APs and STAs you have on the same channel, the more CCI will hurt your overall performance.

Co-Channel ~~Interference~~ Cooperation

Remember that Co-Channel Interference occurs *by design.* You'll sometimes see sources refer to it as "cooperation" as a result.

Co-Channel ~~Interference~~ Cooperation

Analogy Demonstration

Adjacent Channel Interference

- This is a form of actual interference

- We saw it before

Adjacent Channel Interference

CenturyLink 2308 is broadcasting on Ch. 9, which overlaps with everything on 6, 11, and the other non-9 channels between.

Adjacent Channel Interference

Analogy Demonstration

Transmit Rate (Tx)

- The agreed upon rate at which a STA can communicate with an AP

- Expressed in megabits per second (Mbps)

Advanced Jargon
Down the Rabbit Hole

Advanced Jargon:
Down the Rabbit Hole

- MIMO

- Spatial Streams

- Guard Interval

- MCS Index

MIMO
multiple-input, multiple-output

* Increase your transmit and receive capacity by using multiple transmit and receive antennas to send more data.

* Uses multiple signal paths, which can mitigate interference and attenuation.

MIMO

- Different configurations possible

- Equipment that usually specifies so on the spec sheet (unless the vendor is Apple)

- Antenna configuration represented by "#Tx Antenna x #RX Antenna"

3x3

MIMO

ZoneFlex™ R700
DUAL-BAND 3X3:3 802.11AC SMART WI-FI AP

802.11n Capabilities

2 x 2 multiple input, multiple output (MIMO) with two spatial streams

AP370
802.11ac/n Dual-Radio 3X3:3

MIMO

The number of transmit and receive antennas at *each* end of a wireless connection contribute to the overall performance available. The lowest number imposes a limit by defining the number of available *spatial streams*.

Spatial Streams

- Each transmit/receive antenna generates a spatial stream (a separate transmission of data)

- Hardware spec sheets display the number of spatial streams after the Tx x Rx, e.g. Tx x Rx: Streams

3x3:3

2x2:2

Okay, but why do I care about MIMO and Spatial Streams?

They get you partway to determining how fast your connection will go, but you need to know a few other things to get there.

Channel Width

- "Standard" channel width was 20 MHz

- 802.11n allows the creation of wider channels that use 40 MHz of spectrum, contributing to higher data rates.

- 802.11ac allows creation of 80 MHz and 160 MHz channels.

Channel Width

Because the spectrum is finite and constrained, each doubling of channel width roughly *halves the number of available channels.*

Guard Interval

- Guard interval is the period of time that a transmitter will pause between transmissions to prevent them from interfering with one another

- 800ns (Guard Interval) and 400ns (Short Guard Interval)

- Shorter pauses can increase your data rate

Modulation and Coding Scheme (MCS)

- Describes how data is encoded combined with a rating that describes how efficiently the data stream is being used to transmit data.

Let's Put it All Together

It's cheap magic, but we get it at Costco, so we get it in bulk.

"This landing is gonna get pretty interesting."

–Wash

MCS Index

Number of Spatial Streams

$+$ Modulation & Coding Scheme

determines   MCS Index

MCS Index to Transmit Rate

Now cross-reference   MCS Index

against   Channel Width

and   Guard Interval

to generate   Transmit Rate

MCS Index to Transmit Rate

"Cross reference using what, exactly?"

MCS Index - 802.11n and 802.11ac

802.11n 802.11ac

HT MCS Index	VHT MCS Index	Spatial Streams	Modulation	Coding	20MHz Data Rate No SGI	Data Rate SGI	40MHz Data Rate No SGI	Data Rate SGI	80MHz Data Rate No SGI	Data Rate SGI	160MHz Data Rate No SGI	Data Rate SGI
0	0	1	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	1	1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	2	1	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	3	1	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	4	1	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	5	1	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	6	1	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	7	1	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
	8	1	256-QAM	3/4	78	86.7	162	180	351	390	702	780
	9	1	256-QAM	5/6	n/a	n/a	180	200	390	433.3	780	866.7
8	0	2	BPSK	1/2	13	14.4	27	30	58.5	65	117	130
9	1	2	QPSK	1/2	26	28.9	54	60	117	130	234	260
10	2	2	QPSK	3/4	39	43.3	81	90	175.5	195	351	390
11	3	2	16-QAM	1/2	52	57.8	108	120	234	260	468	520
12	4	2	16-QAM	3/4	78	86.7	162	180	351	390	702	780
13	5	2	64-QAM	2/3	104	115.6	216	240	468	520	936	1040
14	6	2	64-QAM	3/4	117	130.3	243	270	526.5	585	1053	1170
15	7	2	64-QAM	5/6	130	144.4	270	300	585	650	1170	1300
	8	2	256-QAM	3/4	156	173.3	324	360	702	780	1404	1560
	9	2	256-QAM	5/6	n/a	n/a	360	400	780	866.7	1560	1733.3
16	0	3	BPSK	1/2	19.5	21.7	40.5	45	87.8	97.5	175.5	195
17	1	3	QPSK	1/2	39	43.3	81	90	175.5	195	351	390
18	2	3	QPSK	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
19	3	3	16-QAM	1/2	78	86.7	162	180	351	390	702	780
20	4	3	16-QAM	3/4	117	130	243	270	526.5	585	1053	1170
21	5	3	64-QAM	2/3	156	173.3	324	360	702	780	1404	1560
22	6	3	64-QAM	3/4	175.5	195	364.5	405	n/a	n/a	1579.5	1755
23	7	3	64-QAM	5/6	195	216.7	405	450	877.5	975	1755	1950
	8	3	256-QAM	3/4	234	260	486	540	1053	1170	2106	2340
	9	3	256-QAM	5/6	260	288.9	540	600	1170	1300	n/a	n/a

MCS Index - 802.11n and 802.11ac

HT MCS Index	VHT MCS Index	Spatial Streams	Modulation	Coding	20MHz Data Rate No SGI	20MHz Data Rate SGI	40MHz Data Rate No SGI	40MHz Data Rate SGI	80MHz Data Rate No SGI	80MHz Data Rate SGI	160MHz Data Rate No SGI	160MHz Data Rate SGI
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1	1	1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	2	1	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
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7	7	1	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
	8	1	256-QAM	3/4	78	86.7	162	180	351	390	702	780
	9	1	256-QAM	5/6	n/a	n/a	180	200	390	433.3	780	866.7
8	0	2	BPSK	1/2	13	14.4	27	30	58.5	65	117	130
9	1	2	QPSK	1/2	26	28.9	54	60	117	130	234	260
10	2	2	QPSK	3/4	39	43.3	81	90	175.5	195	351	390
11	3	2	16-QAM	1/2	52	57.8	108	120	234	260	468	520
12	4	2	16-QAM	3/4	78	86.7	162	180	351	390	702	780
13	5	2	64-QAM	2/3	104	115.6	216	240	468	520	936	1040
14	6	2	64-QAM	3/4	117	130.3	243	270	526.5	585	1053	1170
15	7	2	64-QAM	5/6	130	144.4	270	300	585	650	1170	1300
	8	2	256-QAM	3/4	156	173.3	324	360	702	780	1404	1560
	9	2	256-QAM	5/6	n/a	n/a	360	400	780	866.7	1560	1733.3
16	0	3	BPSK	1/2	19.5	21.7	40.5	45	87.8	97.5	175.5	195
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19	3	3	16-QAM	1/2	78	86.7	162	180	351	390	702	780
20	4	3	16-QAM	3/4	117	130	243	270	526.5	585	1053	1170
21	5	3	64-QAM	2/3	156	173.3	324	360	702	780	1404	1560
22	6	3	64-QAM	3/4	175.5	195	364.5	405	n/a	n/a	1579.5	1755
23	7	3	64-QAM	5/6	195	216.7	405	450	877.5	975	1755	1950
	8	3	256-QAM	3/4	234	260	486	540	1053	1170	2106	2340
	9	3	256-QAM	5/6	260	288.9	540	600	1170	1300	n/a	n/a

802.11n 802.11ac

Model	802.11 compatibility and frequency band	Maximum Transmit Rate	Spatial streams	MCS index	Channel width	Guard interval
iPad Air 2	802.11ac/n/a @ 5 GHz 802.11 n/g/b @ 2.4 GHz	866 Mbps	2	9 (VHT) 15 (HT)	80 MHz	400 ns
iPad mini 3	802.11n @ 2.4 GHz and 5GHz 802.11a/b/g	300 Mbps	2	15 (HT)	40 MHz	400 ns
iPhone 6 Plus iPhone 6	802.11ac/n/a @ 5 GHz 802.11 n/g/b @ 2.4 GHz	433 Mbps	1	9 (VHT) 7 (HT)	80 MHz	400 ns
iPhone 5s	802.11n @ 2.4 GHz	150 Mbps	1	7 (HT)	40 MHz	400 ns

MCS Index

Apple's occasional documentation

Tx Rate is a (necessary) Lie

Tx Rate is a (necessary) Lie

- WiFi is a *half-duplex* technology: it can only transmit or receive; it can not do both simultaneously

- In the *best possible* case, the maximum throughput is approximately *half* of the reported transmit rate

- Numerous environmental factors will reduce it.

Tx Rate is a (necessary) Lie

Consequences and Implications

What's the gist?

Equipment and Performance

The aggregate equipment in use in a network (AP and STA) will determine overall performance.

Environment and Performance

Attenuation and various forms interference will affect overall performance