WiFi Networking and Design

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Cameron Champion Administrivia

Cameron began his career in hospitality management with Lodgian Inc in 1998 before enlisting in the USAF 94th Civil Engineer Squadron as an Explosive Ordnance Disposal engineer. After thousands of controlled detonations (and a few "not-so-controlled"), Cameron joined Apple in 2006. He formed his own independent consultancy shortly thereafter to serve a niche market of consumers created by Apple's Intel transition.

Part of the Atlanta consulting community and principal engineer for Administrivia, Cameron provides support, solutions, planning, and education for a variety of business customers.

Cameron spends his spare time drinking alcoholic beverages on parts of the planet that aren't littered with radio signals.

Before we start…

Huge shout out for curriculum to:

Jeanette Lee
jlee@ruckuswireless.com
@ruckusgirl

Let's Talk About

- WiFi overview
- WLAN design principals
- Planning for high density
- Troubleshooting and Performance Testing

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WiFi Fundamentals

What is it?

What is WiFi?

- IEEE wanted a catchier name than "IEEE 802.11b Direct Sequence"

- 802.11 is a standard for describing wireless local area networks for computer communication using radio waves.

- Fundamentally, a set of technologies for Ethernet via radio instead of copper cable.

- Client devices use built-in radios to talk to the network via Wireless Access Points, which are also equipped with one or more radios.

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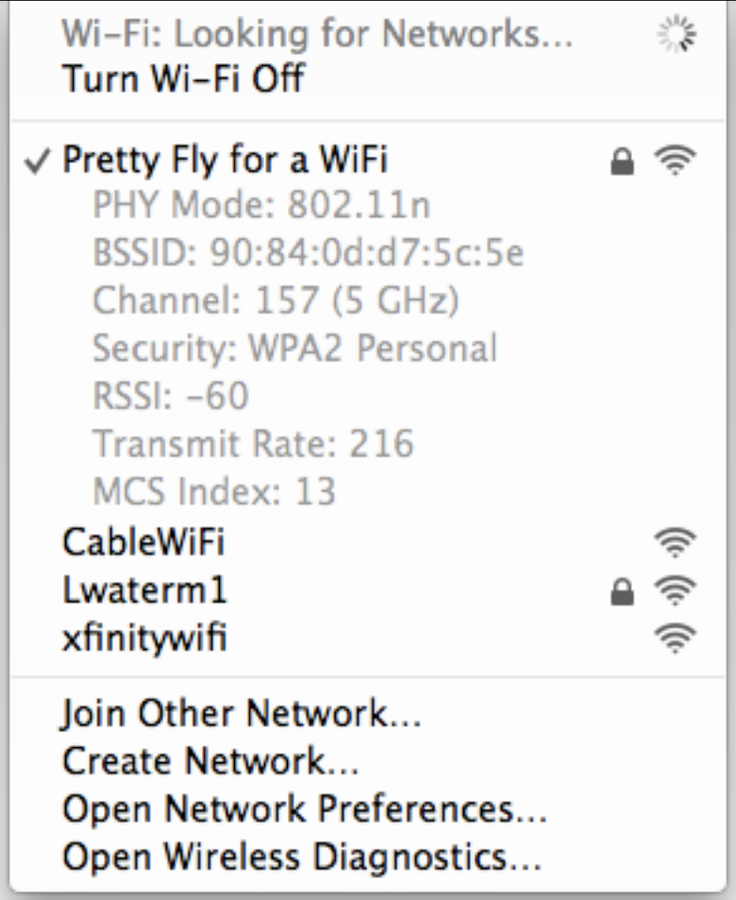
Wireless Access Point

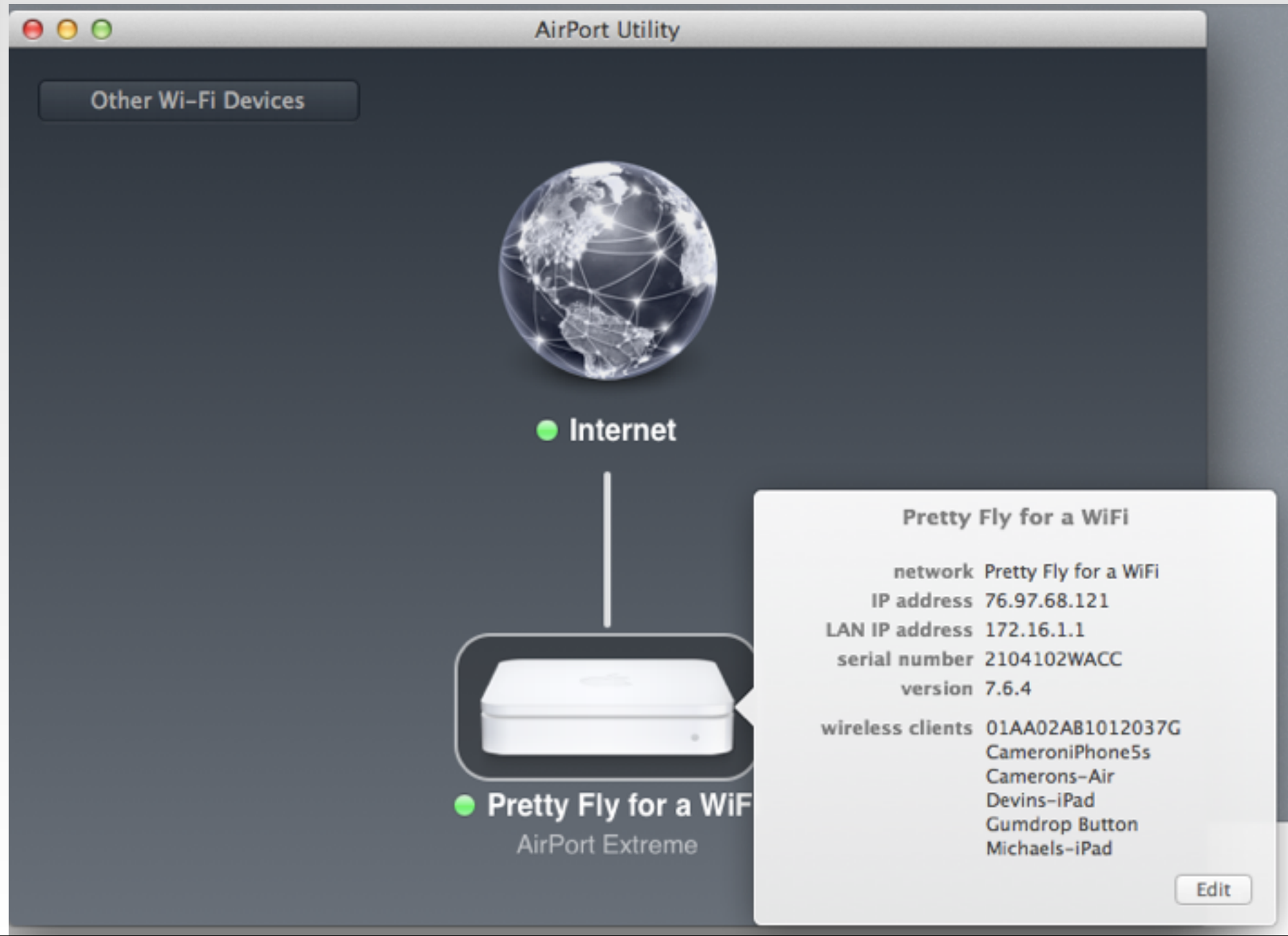
- Think of it like an Ethernet hub (as of 2014)
- Not an Ethernet switch, a hub
- The distinction is critical for understanding real world performance

It's a Shared Medium

- Half-Duplex by design:
  When one device on a channel talks, everything else has to listen
- the waiting typically referred to as "co-channel interference"
- Performance specs are thus somewhat idealized
- Things get "interesting" when you start adding devices or mixing device types
- Serious implications for design

in example…





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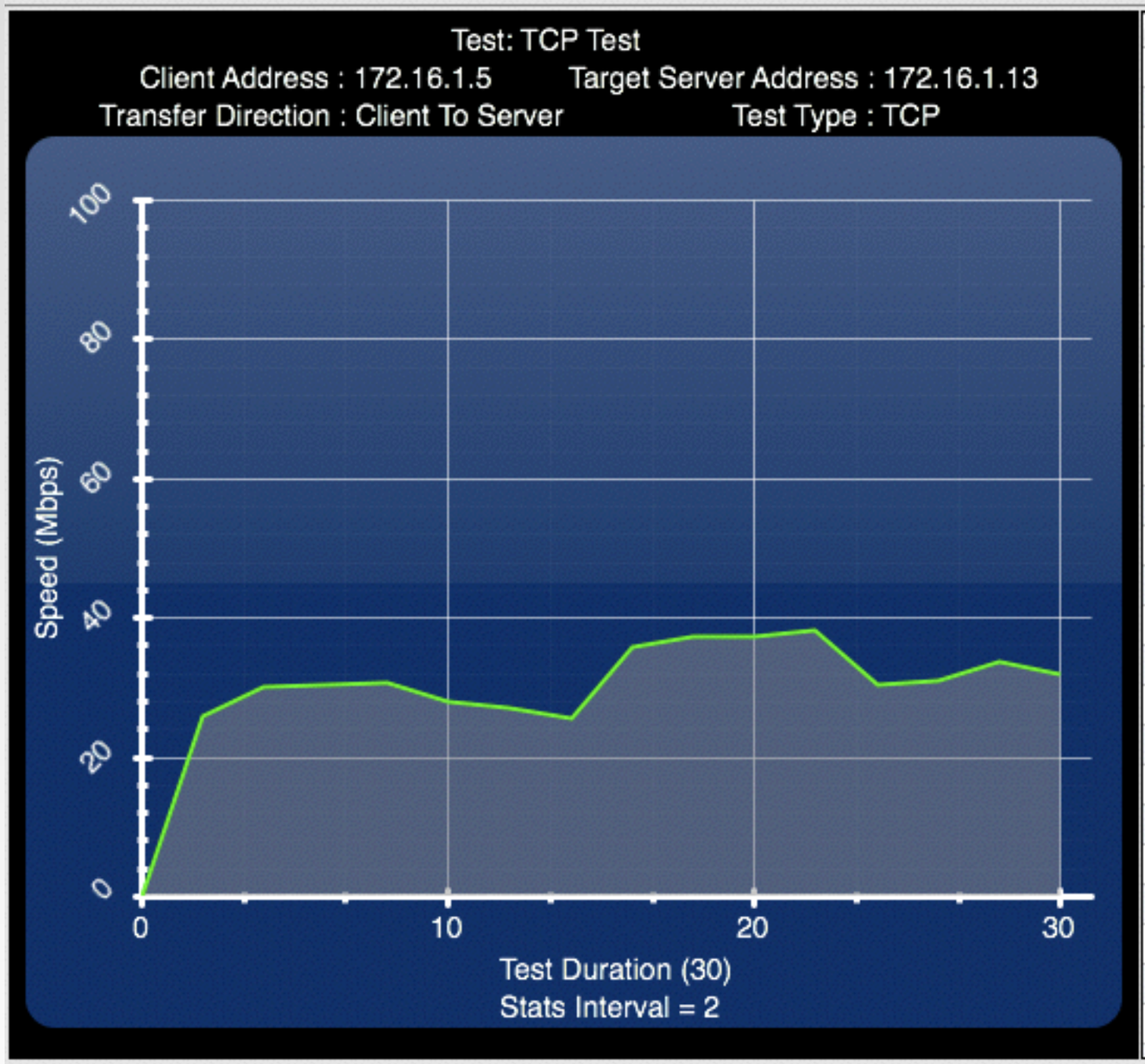
WiFi Perf Results



Interval	Transfer	S/R Bandwidth
0.00-30.06 sec	114.62 MB	31.98 Mbps
26.51-28.54...	8.12 MB	33.60 Mbps
24.51-26.51...	7.38 MB	30.89 Mbps
22.41-24.51...	7.62 MB	30.54 Mbps
20.33-22.41...	9.50 MB	38.21 Mbps
18.31-20.33...	9.00 MB	37.33 Mbps
16.29-18.31...	9.00 MB	37.39 Mbps
14.24-16.29...	8.75 MB	35.87 Mbps
12.15-14.24...	6.38 MB	25.63 Mbps
10.11-12.15...	6.62 MB	27.19 Mbps
8.09-10.11 sec	6.75 MB	28.04 Mbps
6.08-8.09 sec	7.38 MB	30.84 Mbps
4.08-6.08 sec	7.25 MB	30.35 Mbps
2.02-4.08 sec	7.38 MB	29.97 Mbps
0.00-2.02 sec	6.25 MB	26.00 Mbps

#	SSID	BSSID	CH.	RSSI	Open	Encryption	Signa
8	ATT424	30:60:23:78:59:60	1	-52		WPA2	
12	Pretty Fly for a WiFi	90:84:0d:d7:5c:5e	157	-50		WPA2	
2	Pretty Fly for a WiFi	90:84:0d:d7:5c:5d	11	-56		WPA2	
24	CableWiFi	00:0d:67:2c:15:c6	1	-63		--	
45	xfinitywifi	00:0d:67:2c:15:c5	1	-68		--	
54	ATT952	90:3e:ab:5a:73:f0	1	-65		WPA2	

107 Networks Found

▼ 01AA02AB1012037G

Connection	Excellent
Data Rate	72 Mb/s
IP Address	172.16.1.7
Hardware Address	18:B4:30:03:D0:A2
RSSI	-48 dBm
Mode	802.11b/g/n

▶ CameroniPhone5s

▶ Camerons-Air

▶ 01AA02AB1012037G

▶ CameroniPhone5s

▶ Camerons-Air

▼ Devins-iPad

Connection	Excellent
Data Rate	300 Mb/s
IP Address	172.16.1.16
Hardware Address	F0:DB:F8:32:DF:12
RSSI	-62 dBm

▶ 01AA02AB1012037G

▼ CameroniPhone5s

Connection	Excellent
Data Rate	135 Mb/s
IP Address	172.16.1.13
Hardware Address	18:AF:61:C9:4B:17
RSSI	-66 dBm
Mode	802.11a/n

▶ Camerons-Air

▶ Devins-iPad

▶ Gumdrop Button

▼ Michaels-iPad

Connection	Excellent
Data Rate	39 Mb/s
IP Address	172.16.1.3
Hardware Address	84:85:06:AA:9A:7E
RSSI	-28 dBm
Mode	802.11a/n

▶ 01AA02AB1012037G

▶ CameroniPhone5s

▼ Camerons-Air

Connection	Excellent
Data Rate	270 Mb/s
IP Address	172.16.1.5
Hardware Address	04:0C:CE:D2:FC:EC
RSSI	-61 dBm
Mode	802.11a/n

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One Client, One WAP

WiFiPerf

Client | Server

Test Duration: 30

Stats Interval: 2

Data/BandWidth Format: (•) Mbps ( ) Kbps

Graph Max Speed (Mbps): 1000

Transfer Direction: ( ) Client To Server (•) Server To Client

[ ] Voice Alert

Test Type: TCP

Run Test

Stats Interval: 2 sec Transfer Direction: Server To Client Test Type: TCP

ess : 10.253.254.21
: TCP

Interval	Transfer	S/R Bandwidth	Interface Name	SSID	RSSI	Tx Rate	Signal/Noise	PHY Mode
0.00-30.00 sec	480.50 MB	134.35 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
26.07-28.08 sec	32.00 MB	133.48 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
24.07-26.07 sec	33.38 MB	139.94 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
22.07-24.07 sec	32.75 MB	137.33 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
20.07-22.07 sec	32.38 MB	135.67 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
18.06-20.07 sec	33.00 MB	137.64 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
16.05-18.06 sec	32.00 MB	134.10 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
14.05-16.05 sec	31.38 MB	131.41 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
12.05-14.05 sec	32.38 MB	135.65 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
10.04-12.05 sec	31.75 MB	132.67 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
8.04-10.04 sec	32.12 MB	134.32 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
6.02-8.04 sec	32.50 MB	135.32 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
4.02-6.02 sec	32.62 MB	136.56 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
2.00-4.02 sec	33.00 MB	137.39 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
0.00-2.00 sec	27.38 MB	114.72 Mbps	WiFi	Wheelwrights	-55	270	37	802.11n

Two Clients, One WAP

WiFiPerf

Client | Server

Test Duration: 30

Stats Interval: 2

Data/BandWidth Format: (•) Mbps ( ) Kbps

Graph Max Speed (Mbps): 1000

Transfer Direction: ( ) Client To Server (•) Server To Client

[ ] Voice Alert

Test Type: TCP

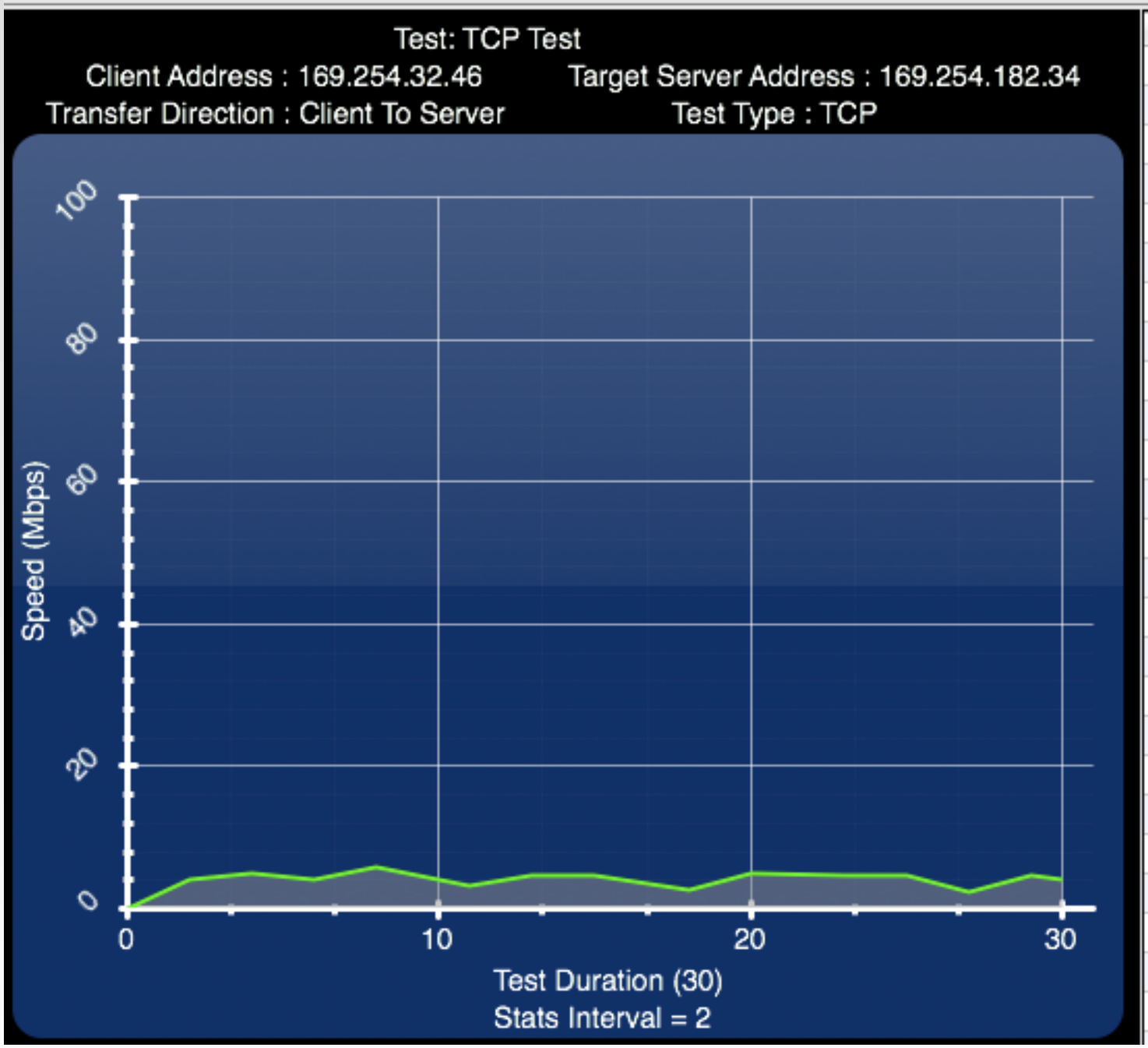
Run Test

Stats Interval: 2 sec Transfer Direction: Server To Client Test Type: TCP

dress : 10.253.254.21
: TCP

Interval	Transfer	S/R Bandwidth	Interface Name	SSID	RSSI	Tx Rate	Signal/Noise	PHY Mode
0.00-30.01 sec	296.00 MB	82.74 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
26.11-28.11 sec	13.00 MB	54.51 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
24.09-26.11 sec	11.38 MB	47.22 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
22.09-24.09 sec	13.38 MB	55.93 Mbps	WiFi	Wheelwrights	-52	270	40	802.11n
20.08-22.09 sec	11.00 MB	45.90 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
18.07-20.08 sec	11.62 MB	48.53 Mbps	WiFi	Wheelwrights	-53	300	39	802.11n
16.05-18.07 sec	13.00 MB	53.94 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
14.04-16.05 sec	15.75 MB	65.94 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
12.04-14.04 sec	12.88 MB	53.96 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
10.03-12.04 sec	24.38 MB	101.79 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
8.03-10.03 sec	33.38 MB	139.95 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n
6.03-8.03 sec	33.88 MB	141.78 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
4.01-6.03 sec	33.12 MB	137.71 Mbps	WiFi	Wheelwrights	-54	270	38	802.11n
2.01-4.01 sec	32.00 MB	134.13 Mbps	WiFi	Wheelwrights	-53	270	15	802.11n
0.00-2.01 sec	27.00 MB	112.77 Mbps	WiFi	Wheelwrights	-53	270	39	802.11n

This Conference Center
9:33 AM



Interval	Transfer	S/R Bandwidth	Interfac...
0.00–30.02 sec	14.88 MB	4.16 Mbps	WiFi
27.39–29.46...	1.12 MB	4.57 Mbps	WiFi
25.19–27.39...	0.62 MB	2.39 Mbps	WiFi
23.19–25.19...	1.12 MB	4.71 Mbps	WiFi
20.89–23.19...	1.25 MB	4.56 Mbps	WiFi
18.51–20.89...	1.38 MB	4.84 Mbps	WiFi
15.63–18.51...	0.88 MB	2.54 Mbps	WiFi
13.36–15.63...	1.25 MB	4.63 Mbps	WiFi
11.32–13.36...	1.12 MB	4.63 Mbps	WiFi
8.98–11.32 sec	0.88 MB	3.13 Mbps	WiFi
6.80–8.98 sec	1.50 MB	5.78 Mbps	WiFi
4.52–6.80 sec	1.12 MB	4.13 Mbps	WiFi
2.36–4.52 sec	1.25 MB	4.87 Mbps	WiFi
0.00–2.36 sec	1.12 MB	3.99 Mbps	WiFi

Frequency Band Fundamentals

802.11 principles and standards

802.11 Standards

Standard	Frequency	Supported Data Rate	Modulation	Date release
802.11	2.4GHz	1, 2 Mbps	FHSS, DSSS	1997
802.11b	2.4GHz	1,2,5.5, 11 Mbps	DSSS	Sept 16th, 1999
802.11a	5GHz	6,9,12,18, 24,36,48,54	OFDM	Sept 16th, 1999
802.11g	2.4 GHz	1,2,5.5,6,9,11,12,18,24 ,36,48,54	DSSS, OFDM	June 2003
802.11n	**2.4 / 5 GHz**	Up to 600Mbps	All previous, plus HT-OFDM	Sept 11th, 2009
802.11ac	5 GHz	Up to 6.93 Gbps	OFDM	Draft

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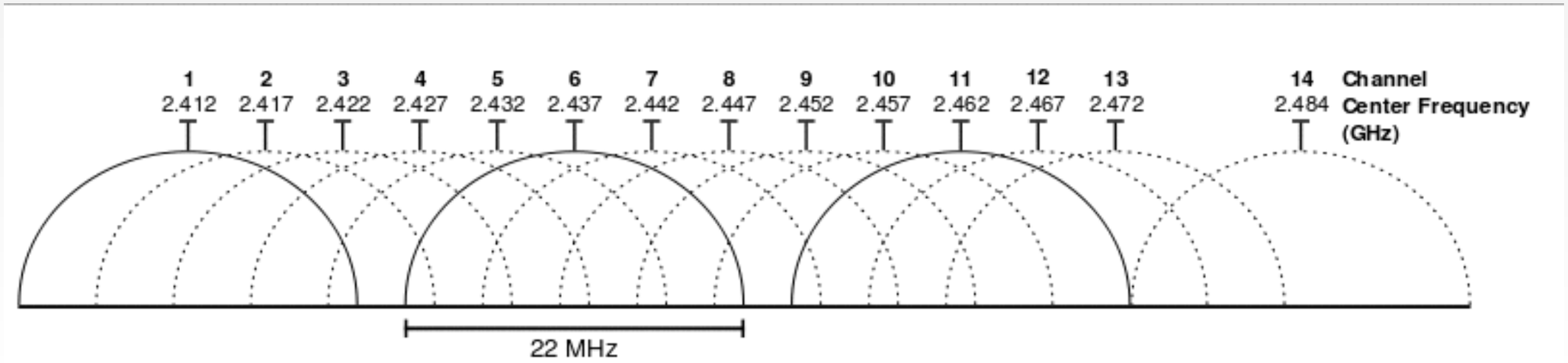
2.4 GHz Spectrum

- Only 3 non-overlapping channels (1, 6 and 11)
- Propagates readily through obstructions such as walls and support columns
- Heavily used due to early adoption; millions of devices from computers to phones
- Heavily congested frequency
- 40MHz channels is not feasible



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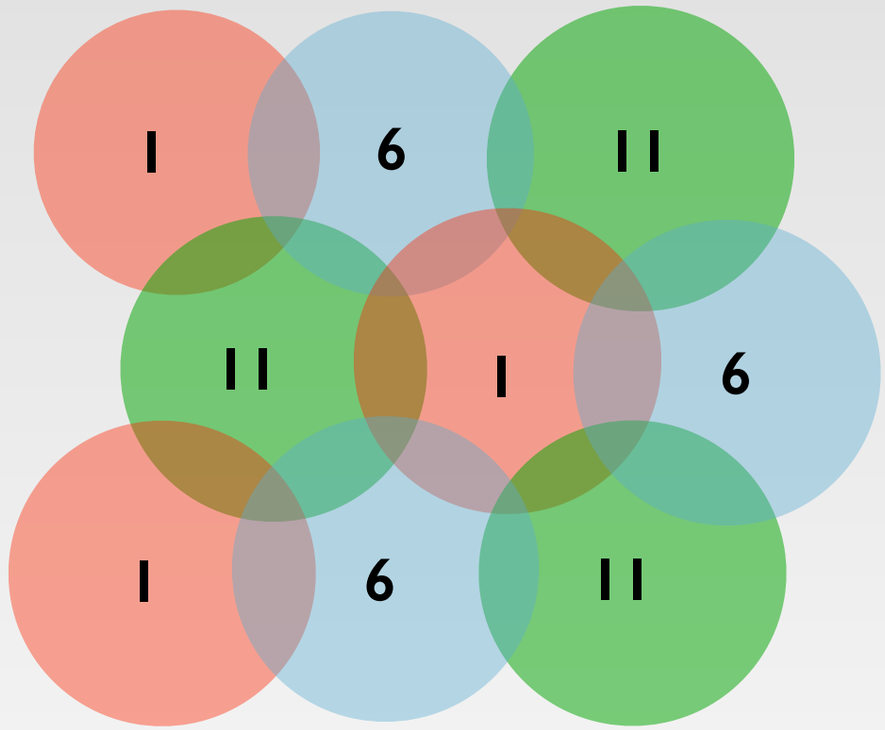
2.4 GHz Channel Planning Theory

- Goal: As little interference as possible with non-overlapping channels



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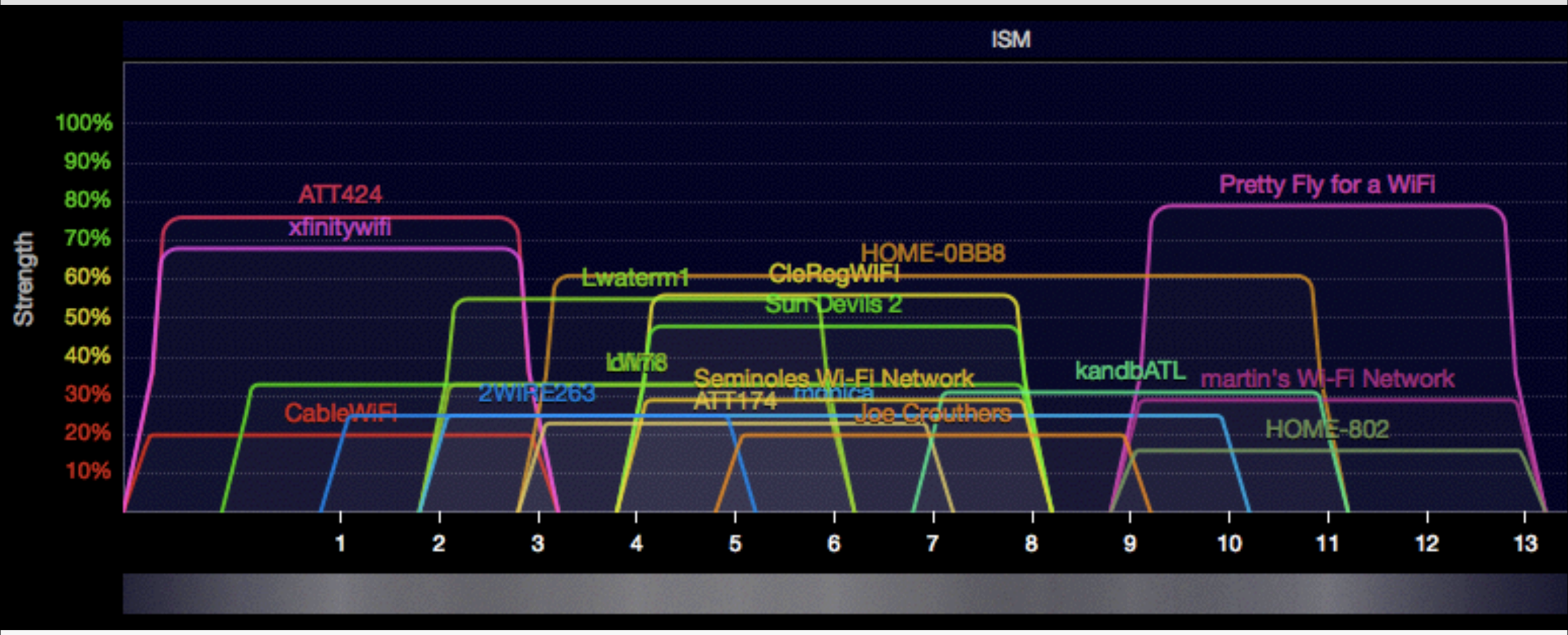
2.4 GHz Band Visualized



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Why 2.4 GHz Presents Problems

- Lots of APs on 2.4 GHz, particularly in urban areas.
- Attenuation (reduction in strength) of 2.4 GHz happens relatively slowly, meaning suite or apartment networks can interfere with one another either via co-channel or adjacent channel interference
- Some kits comes from the factory with odd channel assignments (not 1, 6, or 11), which can cause adjacent channel interference.

Adjacent Channel Interference

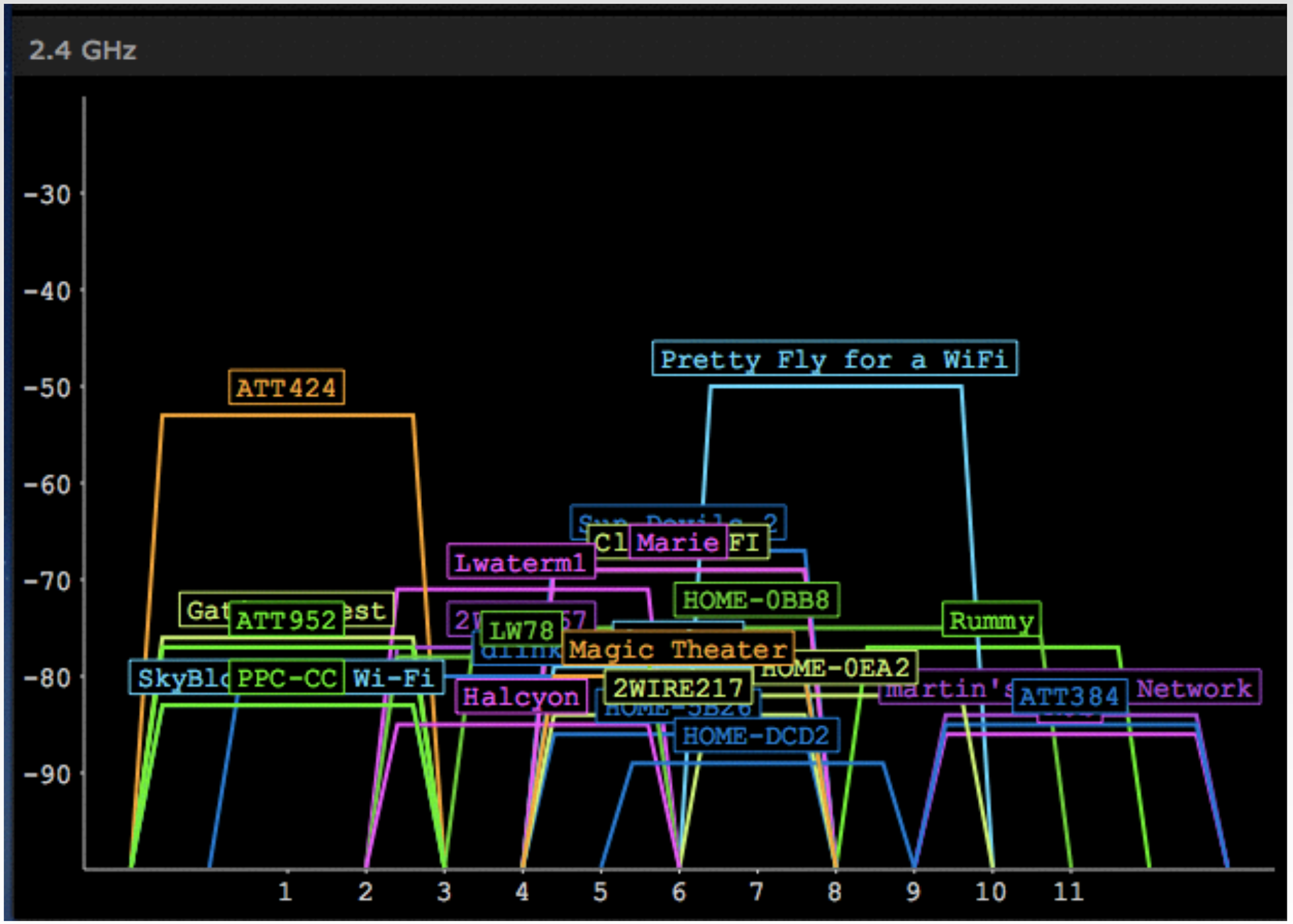
- Two sets of transmitters are assigned to channels close enough that each's will broadcast in the other's spectrum. This garbles things.
- As a poor analogy, imagine eavesdropping on a conversation.
- Now imagine trying to eavesdrop simultaneously on a second conversation, with that second conversation occurring in another language.

Channels 1, 6, and 11 can be a Problem, Too

- Lots of APs on these channels in urban environments
- Most of those APs are far away from our AP
- Most of those APs are using 1mbps for beacon/mgmt
- Constant sea of 1mbps beacons and probe responses
  - Very low rx power at our AP
  - Irrelevant to our AP
  - Can easily 'overpower' them for our own clients
- Leaving 1,6,11 can fix this problem!

2.4 GHz

- Damned if you do, damned if you don't.



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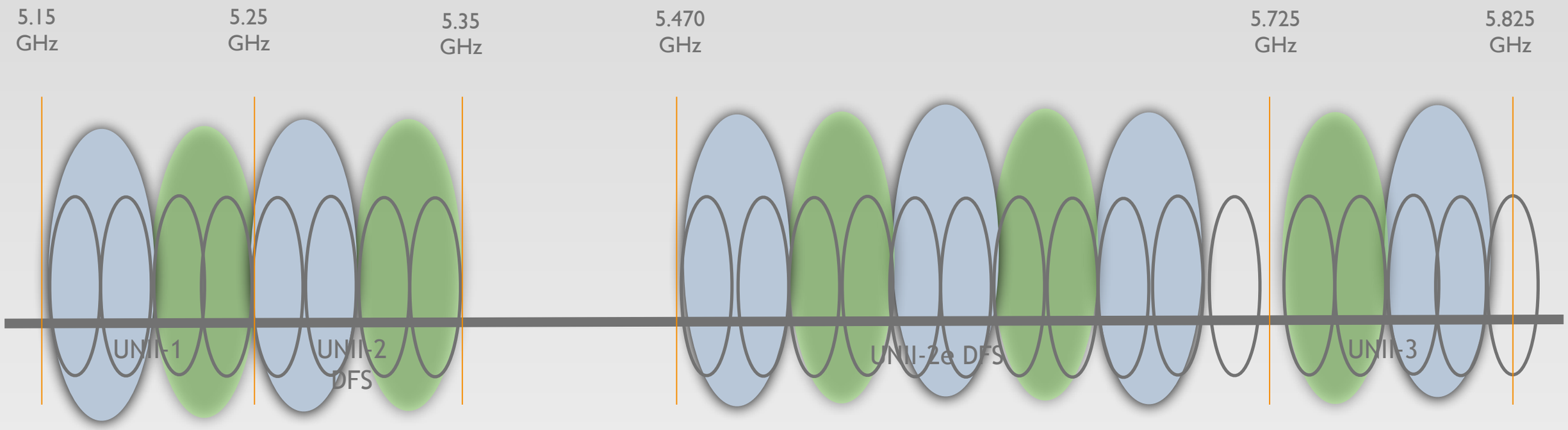
5 GHz Spectrum



NON-DFS CHANNELS

36, 40	40MHz
44, 48	40MHz
149, 153	40MHz
157, 161	40MHz

- 24 non-overlapping 20 MHz channels
- 11 non-overlapping 40 MHz channels
- Only 4 non-DFS channels for bonding
- Creates channel planning problems similar to 2.4 GHz
- 5 GHz isn't a panacea, RF management is still king

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5 GHz: The Future of Wi-Fi

- 5GHz band has 6-7 times the available bandwidth of 2.4GHz in most countries.
- Large number of channels allows frequency reuse factors of 4,7,9, or 12+ (compared to 3 for 2.4)
- Attenuates more readily
- Allows much denser AP placement
- 8 to 20x the mbps/m2 of 2.4 GHz band (!)

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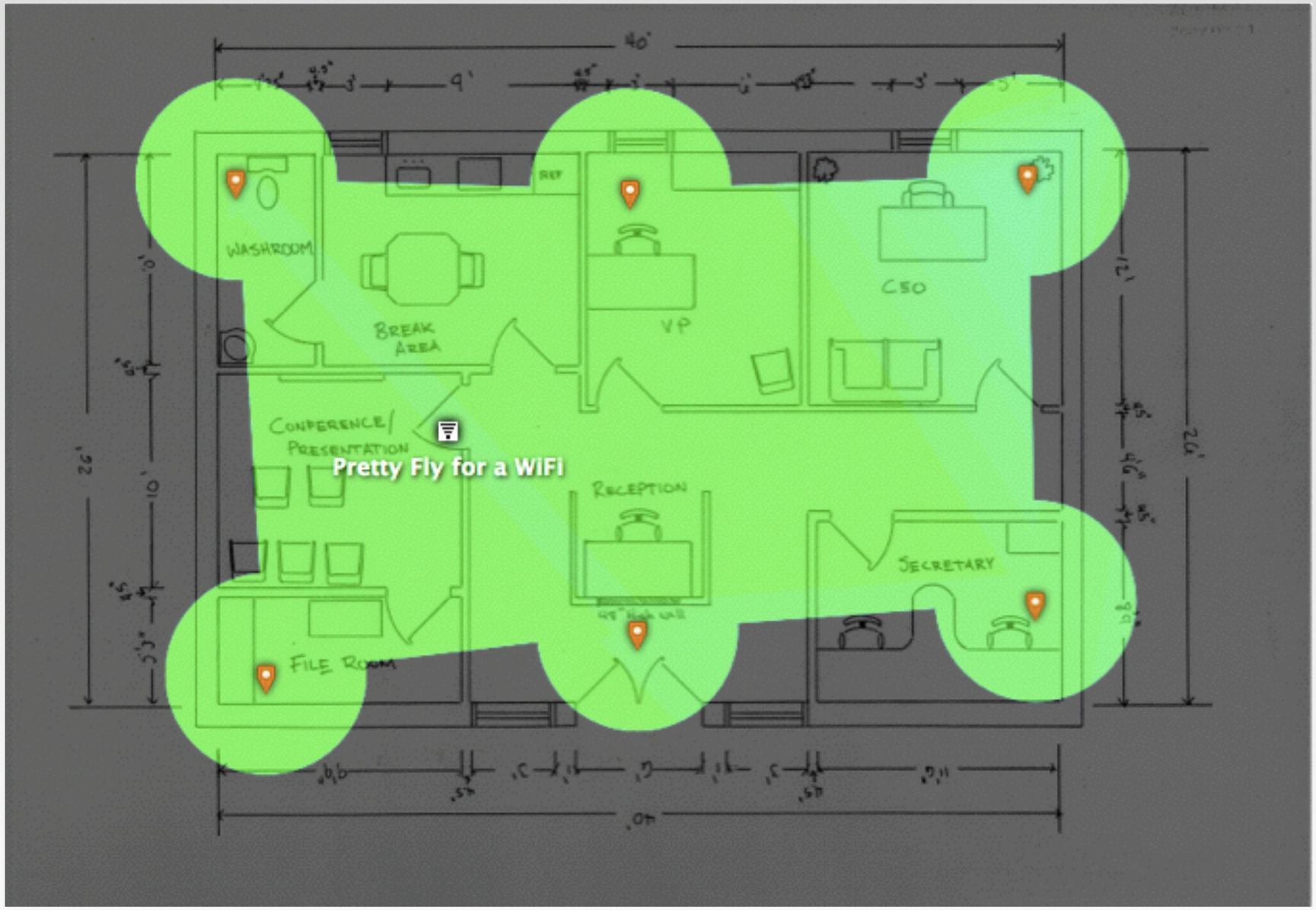
2.4 Survey: Attenuation



worse 0dB 43dB 86dB better

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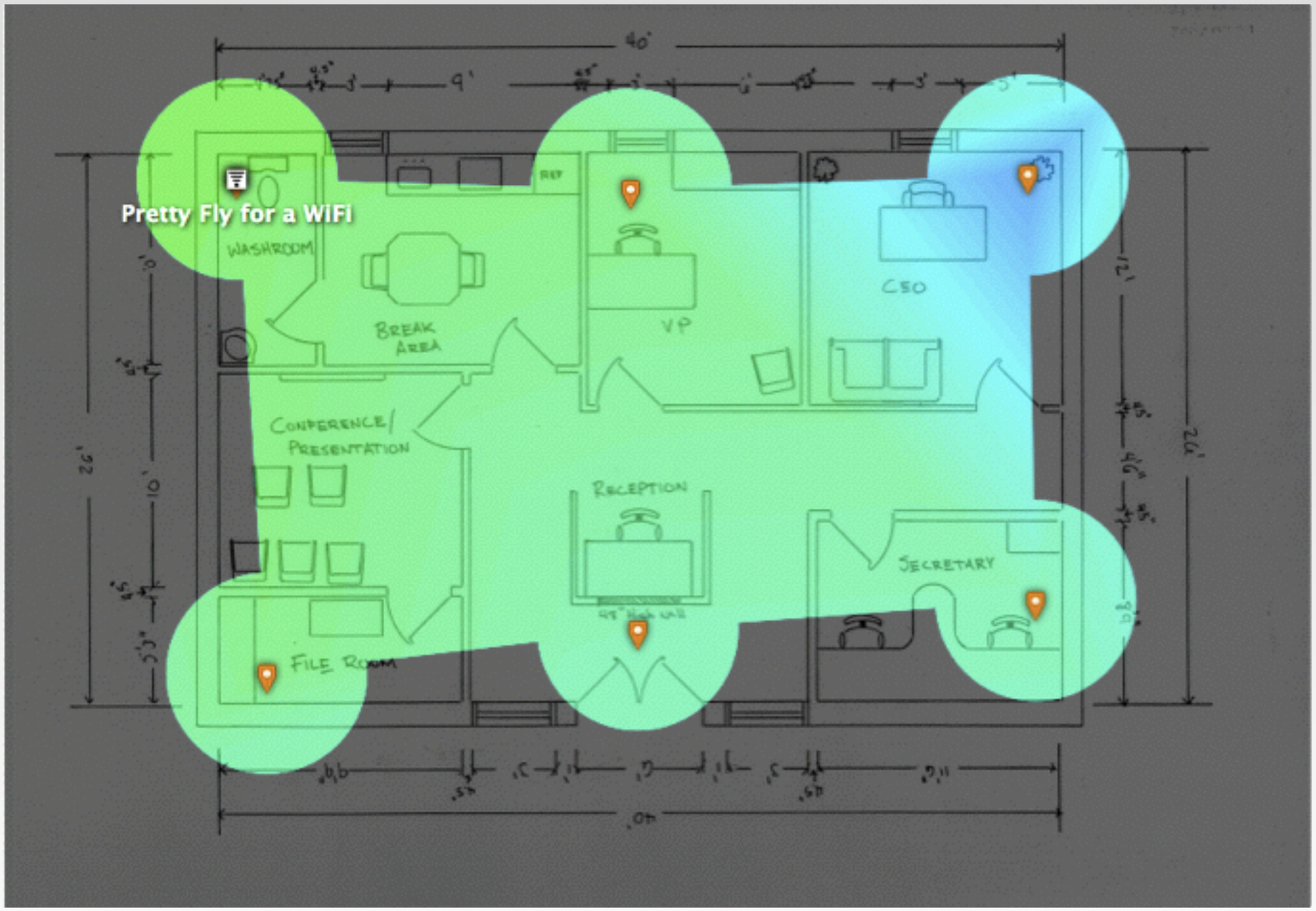
5 Survey: Attenuation



0dB 43dB 86dB better

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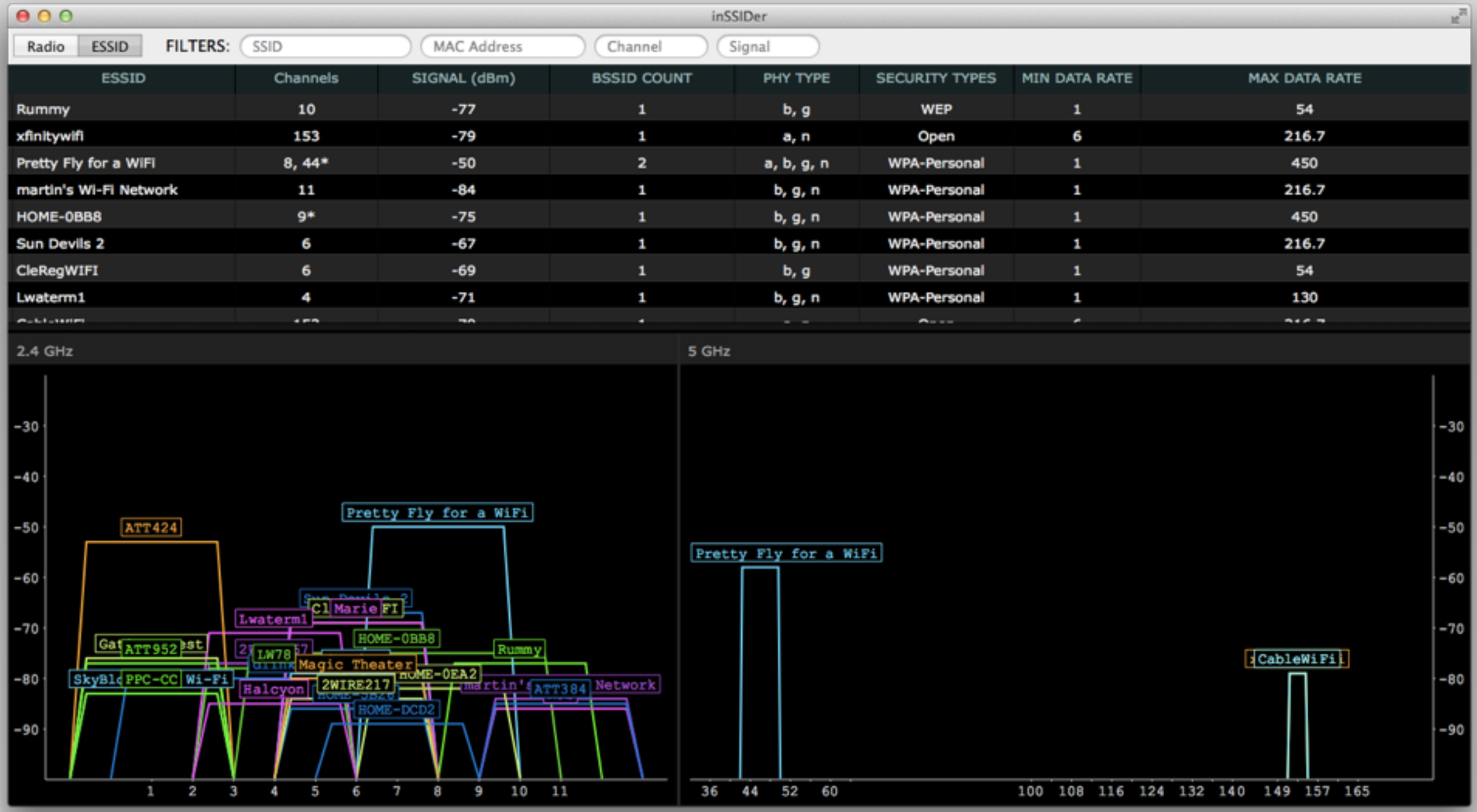
Sweet 5 GHz Relief



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802.11n: The Going Gets Weird

- Multiple Transmit/Receive chains (MIMO)
  - Uses Tx:Rx notation, e.g. 3x3
  - Multi-path is more robust and suffers fewer errors

- Spatial multiplexing
  - Different bits travel different paths (MOAR throughput)
  - Streams indicator notation: 3x3:3

	Minimum Tx/Rx Chains	Spatial Streams	Maximum Link Speed
Single stream	1x1	1	150 Mbps
2 stream	2x2	2	300 Mbps
3 stream	3x3	3	450 Mbps
4 stream	4x4	4	600 Mbps

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802.11n: The Going Gets Weird

- Data rates become complicated in 802.11n
- A variety of specs combine to give data rate
  - Channel width (20 MHz or 40 MHz)
  - Number of spatial streams (1, 2 or 3)
  - Guard interval (delay between bytes transmitted)

802.11 MCS Rates Your Best Friend

MCS Index	Type	Coding Rate	Spatial Streams	Data Rate (Mbps) with 20 MHz CH		Data Rate (Mbps) with 40 MHz CH	
				800 ns	400 ns (SGI)	800 ns	400 ns (SGI)
0	BPSK	1 / 2	1	6.50	7.20	13.50	15.00
1	QPSK	1 / 2	1	13.00	14.40	27.00	30.00
2	QPSK	3 / 4	1	19.50	21.70	40.50	45.00
3	16-QAM	1 / 2	1	26.00	28.90	54.00	60.00
4	16-QAM	3 / 4	1	39.00	43.30	81.00	90.00
5	64-QAM	2 / 3	1	52.00	57.80	108.00	120.00
6	64-QAM	3 / 4	1	58.50	65.00	121.50	135.00
7	64-QAM	5 / 6	1	65.00	72.20	135.00	150.00
8	BPSK	1 / 2	2	13.00	14.40	27.00	30.00
9	QPSK	1 / 2	2	26.00	28.90	54.00	60.00
10	QPSK	3 / 4	2	39.00	43.30	81.00	90.00
11	16-QAM	1 / 2	2	52.00	57.80	108.00	120.00
12	16-QAM	3 / 4	2	78.00	86.70	162.00	180.00
13	64-QAM	2 / 3	2	104.00	115.60	216.00	240.00
14	64-QAM	3 / 4	2	117.00	130.00	243.00	270.00
15	64-QAM	5 / 6	2	130.00	144.40	270.00	300.00
16	BPSK	1 / 2	3	19.50	21.70	40.50	45.00
...	...	...	...	...	...	...	...
31	64-QAM	5 / 6	4	260.00	288.90	540.00	600.00

Not just data rates 1, 2, 5.5 and 11 any more. Are you using a single, dual or three stream device? What do your performance numbers mean?

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http://mcsindex.com

Check Your MCS

- MCS will tell the real story
- RSSI is relative, and only marginally useful
- Data rates change over time, a one time glance guarantees nothing in the next second!

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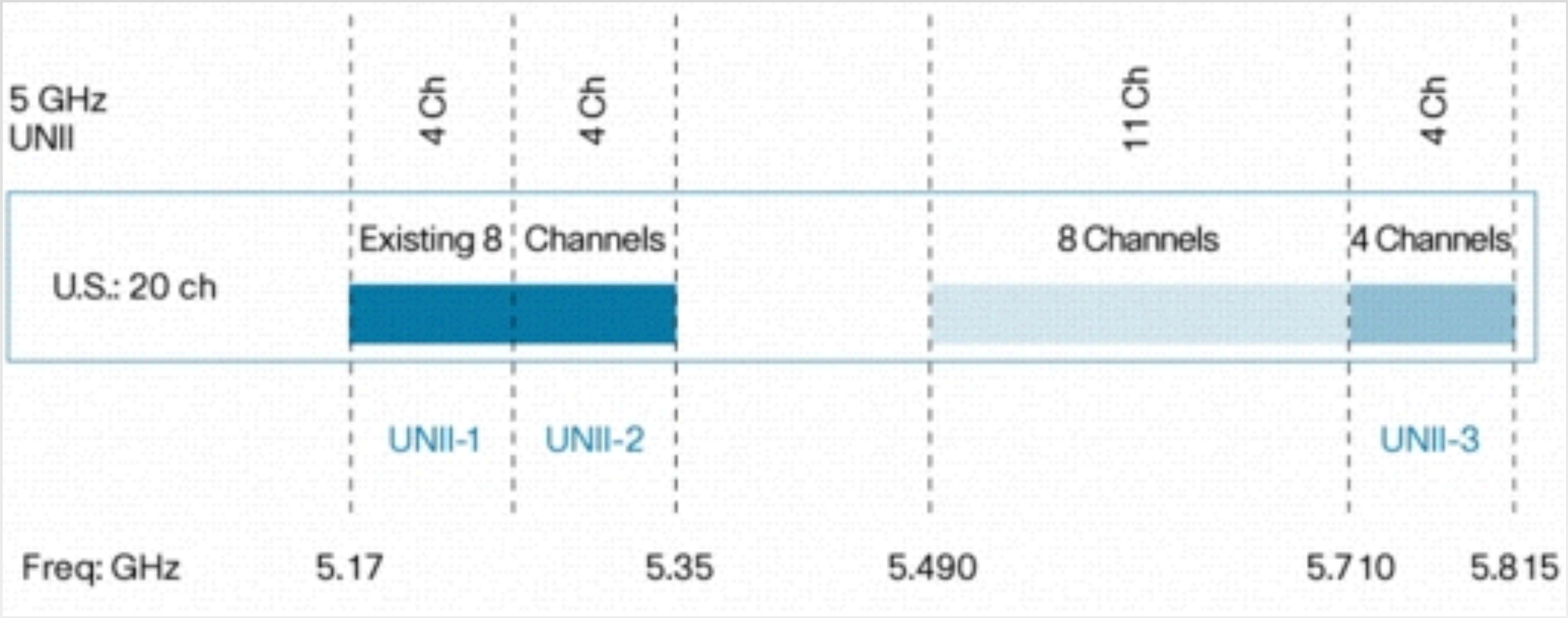
802.11ac: The New Kid

- The trigger for 5GHz everywhere
- Led by Apple and other consumer specialists
  - In-home device sync, video, backup, etc
  - “Gigabit Wi-Fi” on retail shelves
- 5GHz only: it’s best feature
- Apple devices equipped with 802.11ac
  - “Haswell” MacBooks Pro and Air + iMacs
  - Airport Extreme 802.11ac

802.11ac Performance



- Wave 1 (now)
  - Wider channels:
    80-160 MHz versus 20-40 MHz for 802.11n
  - Modulation: up to 256 QAM

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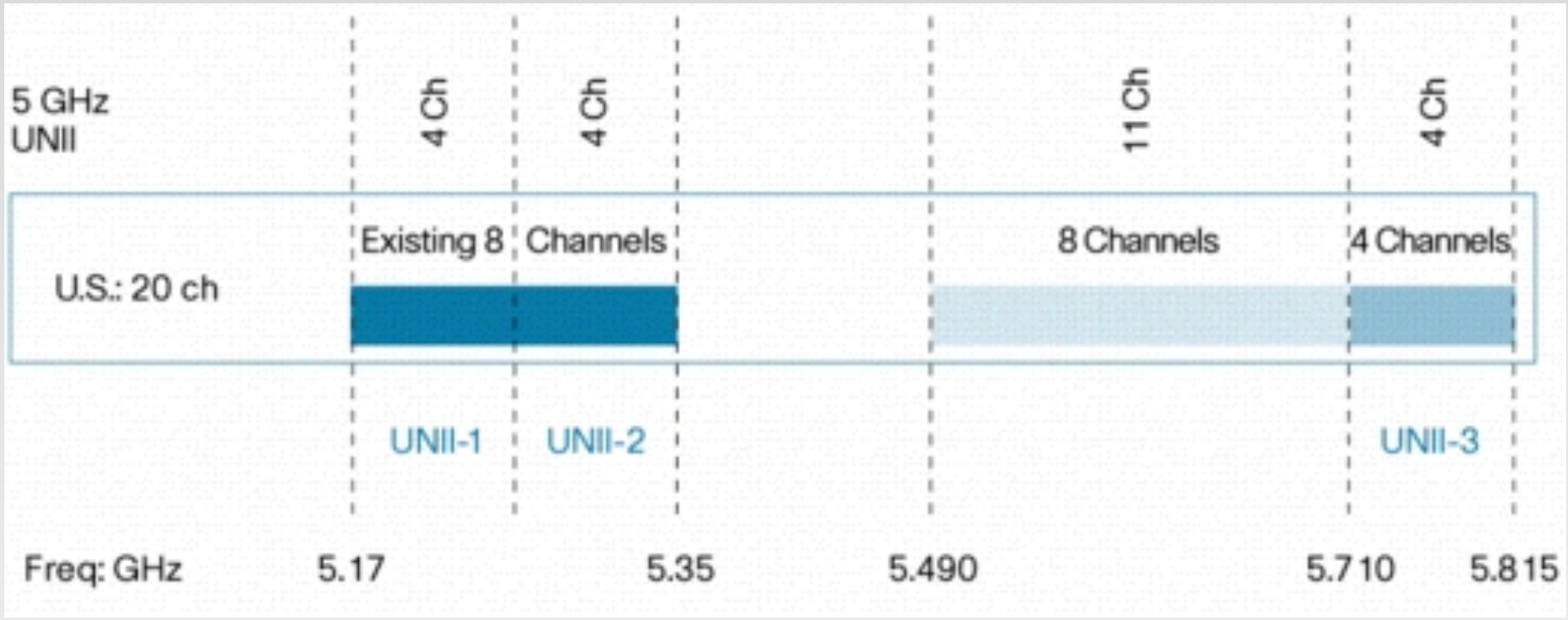
802.11ac Performance



- Wave 2 (2014+)
  - MOAR! spatial streams (up to 8)
  - Multi-user MIMO (Phase 2)
    - Multiple stations transmit/receive simultaneously
    - Streams separated spatially not by frequency

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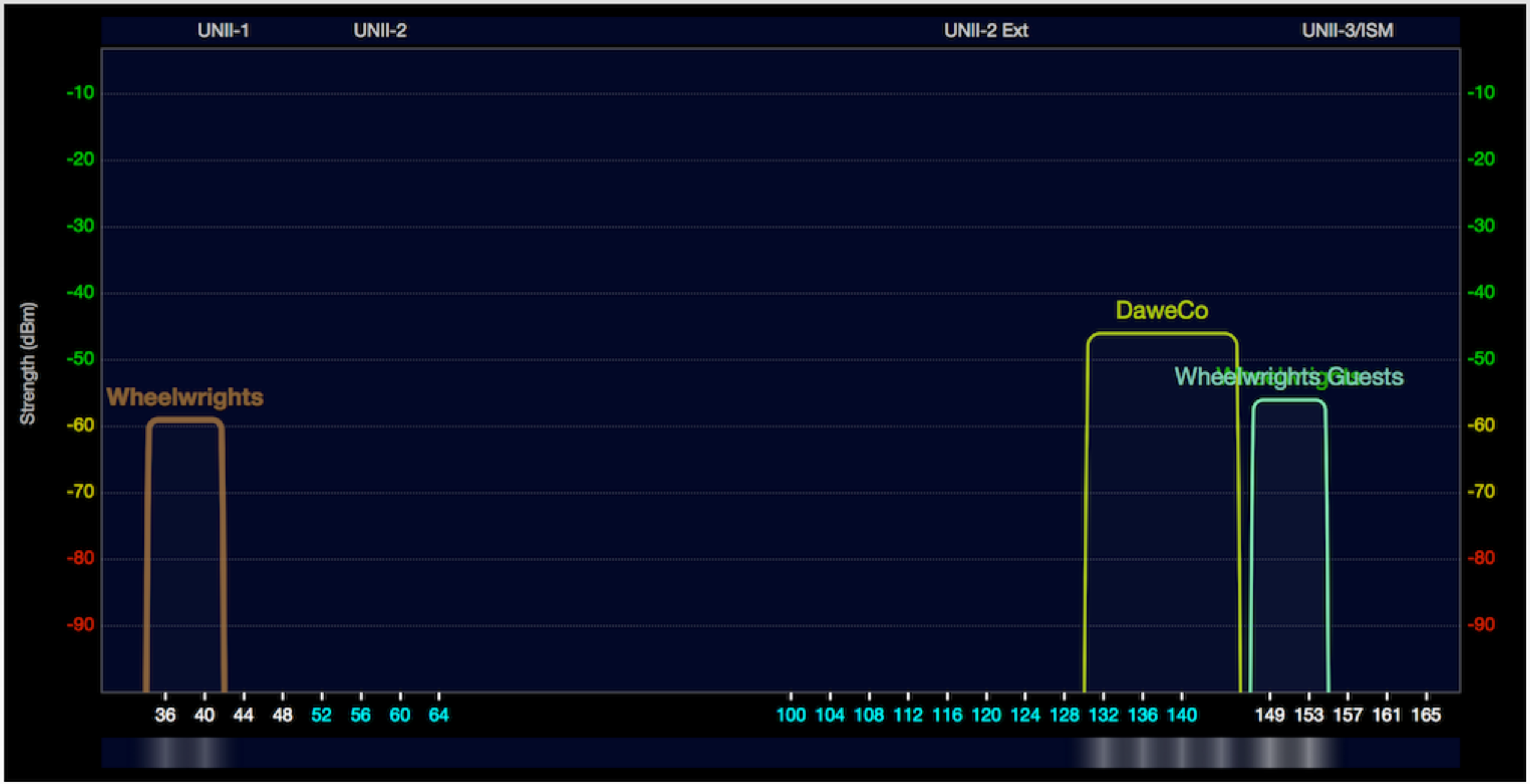
Add an 802.11ac AP



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802.11ac Performance

WiFiPerf

Client | Server

st Duration: 30

ats Interval: 2

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Graph Max Speed (Mbps): 1000

Transfer Direction: (•) Client To Server ( ) Server To Client

[ ] Voice Alert

Test Type: TCP

Run Test

ats Interval: 2 sec Transfer Direction: Client To Server Test Type: TCP

s : 10.253.254.21
CP

Interval	Transfer	S/R Bandwidth	Interface Name	SSID	Tx Rate	Signal/Noise	PHY Mode
0.00-30.01 sec	1929.88 MB	539.53 Mbps	WiFi	DaweCo	1300	53	802.11ac
26.02-28.03 sec	112.25 MB	470.28 Mbps	WiFi	DaweCo	1300	53	802.11ac
24.02-26.02 sec	105.12 MB	440.91 Mbps	WiFi	DaweCo	1053	53	802.11ac
22.02-24.02 sec	107.75 MB	451.88 Mbps	WiFi	DaweCo	1170	53	802.11ac
20.02-22.02 sec	107.38 MB	449.47 Mbps	WiFi	DaweCo	1300	53	802.11ac
18.02-20.02 sec	108.50 MB	454.28 Mbps	WiFi	DaweCo	1300	53	802.11ac
16.02-18.02 sec	107.88 MB	452.46 Mbps	WiFi	DaweCo	1300	53	802.11ac
14.01-16.02 sec	107.62 MB	451.20 Mbps	WiFi	DaweCo	1170	53	802.11ac
12.01-14.01 sec	111.25 MB	466.03 Mbps	WiFi	DaweCo	1053	53	802.11ac
10.01-12.01 sec	130.38 MB	545.97 Mbps	WiFi	DaweCo	1053	54	802.11ac
8.01-10.01 sec	168.12 MB	705.12 Mbps	WiFi	DaweCo	1300	54	802.11ac
6.01-8.01 sec	165.38 MB	692.69 Mbps	WiFi	DaweCo	1300	53	802.11ac
4.00-6.01 sec	162.00 MB	678.32 Mbps	WiFi	DaweCo	1300	53	802.11ac
2.00-4.00 sec	163.50 MB	685.77 Mbps	WiFi	DaweCo	1300	53	802.11ac
0.00-2.00 sec	162.38 MB	680.26 Mbps	WiFi	DaweCo	1300	53	802.11ac

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High Density Strategies

- Shoot for 5GHz
- Increase AP count to the extent possible
- Use attenuation (obstacles) to your advantage
- Frequency re-use via structural separation
- Configuration optimizations & adaptive algorithms

Reducing Transmit Power

- Sometimes recommended in high density deployments or in deployments with lower powered devices.
- Sometimes recommended when you have different power output ratings on devices than APs.

Reducing Transmit Power

- Does not help signal to interference at all
- Guaranteed to reduce signal to external interference; this can counterproductive
- Lower power = lower transmit speed = clients take longer to get on/off the air
- Reduces capacity

More Strategies

- Review the vendor mounting documentation; shapes are important
- Disable background scanning (non-Apple clients)
- Limit # of SSIDs if possible (more SSIDs generate more network overhead)

Real World Scenario

- Use MDM for greater iOS WiFi control & mgmt
- Prepping using Configurator
- It all goes “boom”

Troubleshooting and Performance Testing

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Identify the Problem

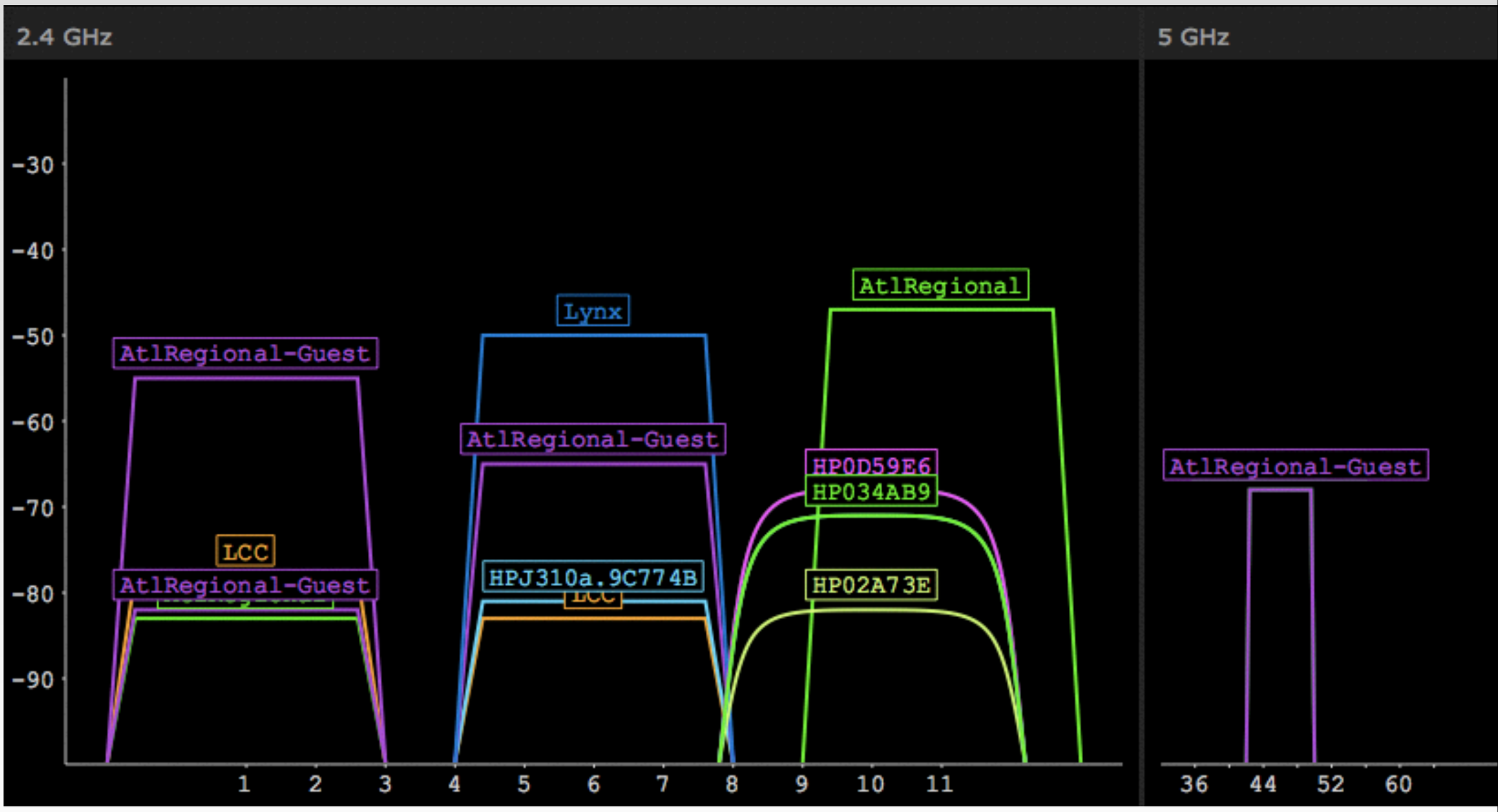
"It doesn't work" is not useful!

- Can the client connect?
- Can it authenticate?
- Low performance?
- Roaming?
- Are certain types of clients affected or all?

Client Can't Connect

- RF interference
- Client is not configured correctly
- Client does not support network configuration
  - OFDM-only will block 802.11b clients entirely
- Are there APs nearby that it can hear strongly?

RF Mgmt: Clear The Space



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Classic Symptoms of RF Interference

- Classic symptoms:
  - Clients drop off network randomly or have difficulty connecting
  - High latency or data loss
  - Huge number of PHY errors (>2500 per second)
- Can be difficult to detect without an RF analyzer, because WiFi only knows how to interpret WiFi

RF Interference Mitigation

- Things you can do:
  - Eliminate source of interference
  - Change channel assignments (if clear ones exist)
  - Lower transmit power
  - Move clients to 5 GHz – band steering or change WLAN adapter

Client Can't Authenticate

- Misconfigured authentication
- User name/password incorrect
- Client blacklisted
  - WIPS/WIDS
- Trying to connect to the wrong SSID

Low Performance

- No strong signal available (no nearby AP)
- High interference
- Low connection rate (MCS)
- Client stickiness
  - Roaming
- Too many clients per AP radio
- High latency
- Plain slow client

Performance Fixes

- Add more APs if coverage is too sparse, i.e. clients can get too far away = lower connection rate
- Reduce interference
- More channels
- Increase capacity in areas with excessive number of clients per AP
- Airtime fairness – allows differently capable clients to share medium in a managed fashion

Essential Troubleshooting Tools

- Apple Tools
- Performance test tools
  - iPerf (WiFiPerf)
  - MetaGeek inSSIDer/WiFi Explorer
  - Vendor tools like:
    - Ruckus SWAT, SpeedFlex, Zapper
- RF analyzer (MetaGeek Wi-Spy, AirMagnet, etc.)

Apple-specific Tools

- Check Wi-Fi connection on Mac
  - Hold down Option key and click airport icon in menu bar
- Hidden CLI Tool
  - airport
  - http://osxdaily.com/2007/01/18/airport-the-little-known-command-line-wireless-utility/

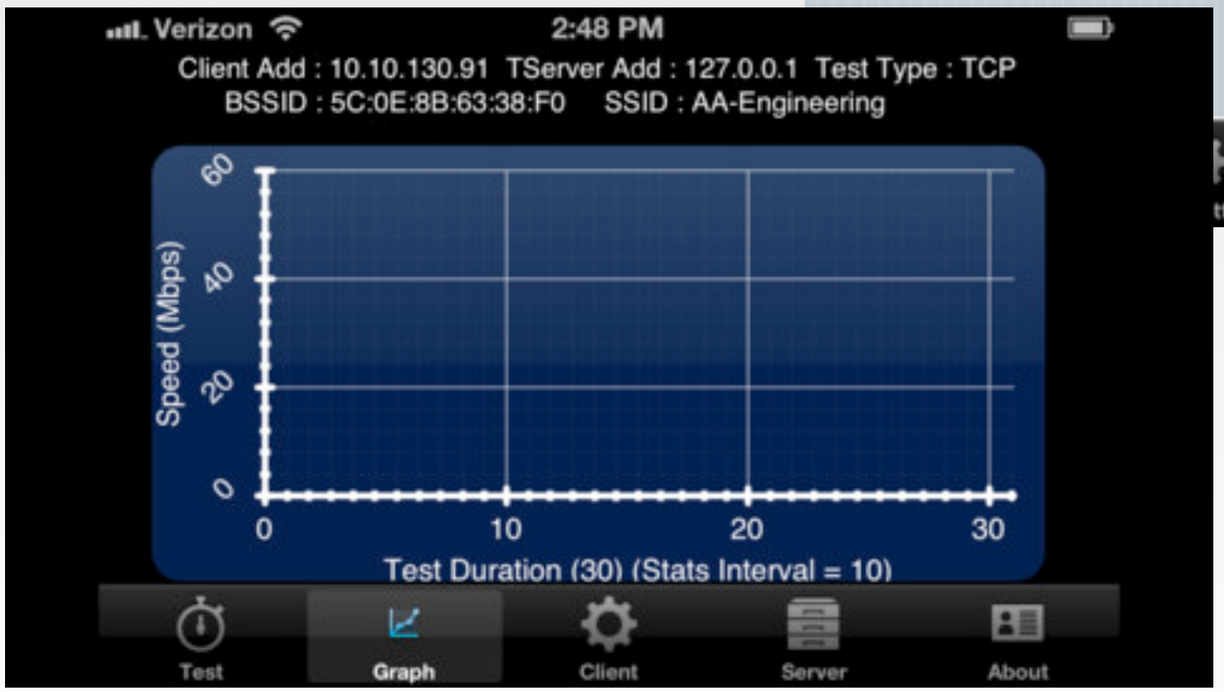
Apple-specific Tools

- wdutil

```
dawe — bash — 66×45 — ⌘1
DBP:~ dawe$ wdutil info
# --- Wi-Fi Interface
        Interface Name              : en1
        MAC Address                 : c8:bc:c8:e4:be:25
        Network Name                : Wheelwrights
        Active PHY Mode             : 802.11n
        Security                    : WPA2 Personal
        SSID                : Wheelwrights
        BSSID               : 08:ea:44:1a:df:a9
        Country             : US
        RSSI                : -54 dBm
        Noise               : -87 dBm
        Rate                : 150 Mbps
        Channel             : 36
        Channel Width               : 40MHz
```

ZapPerf and WiFiPerf (Access Agility)

- Based on zap/iperf3
- Available for iOS and Mac OS



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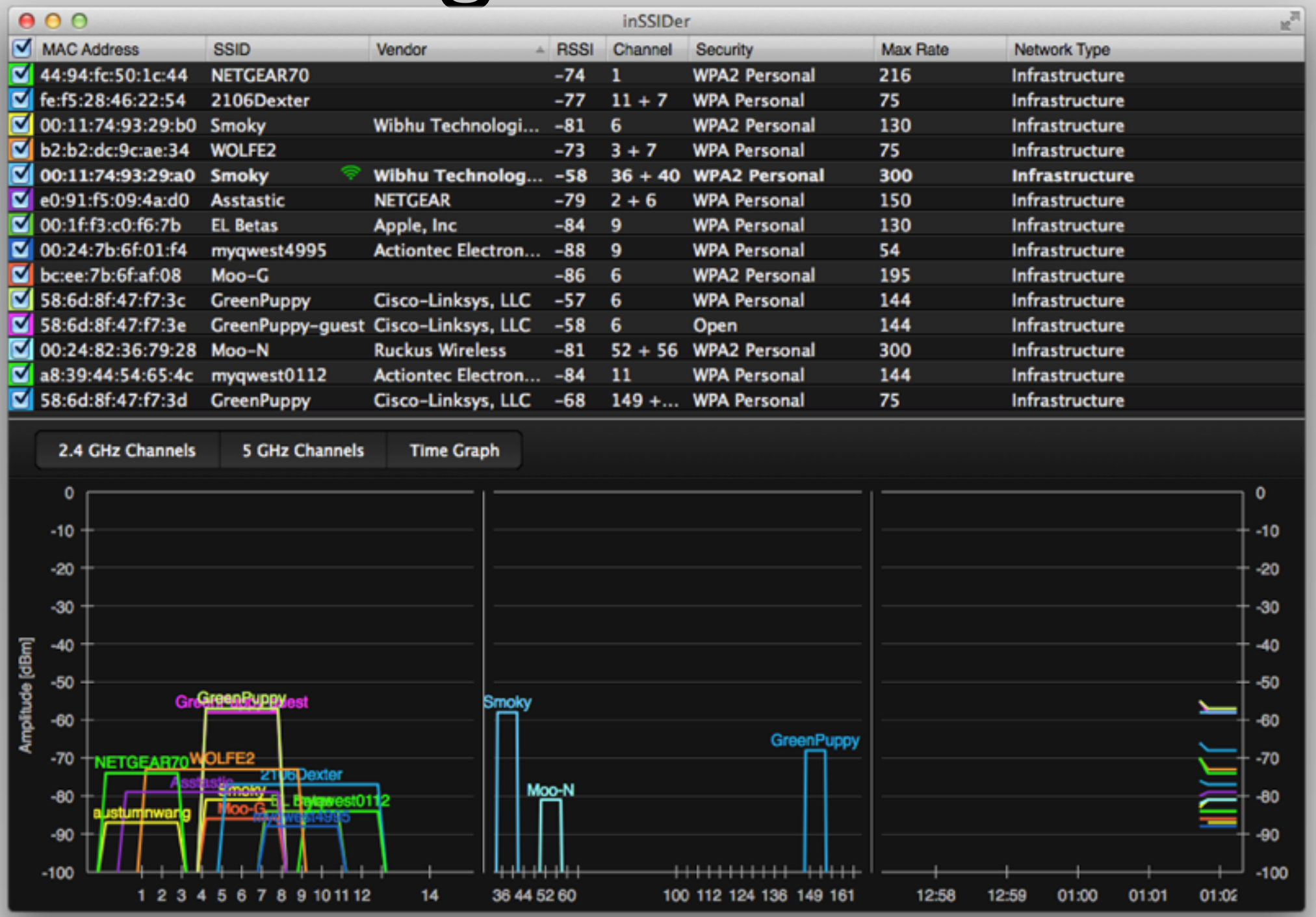
Metageek InSSIDer



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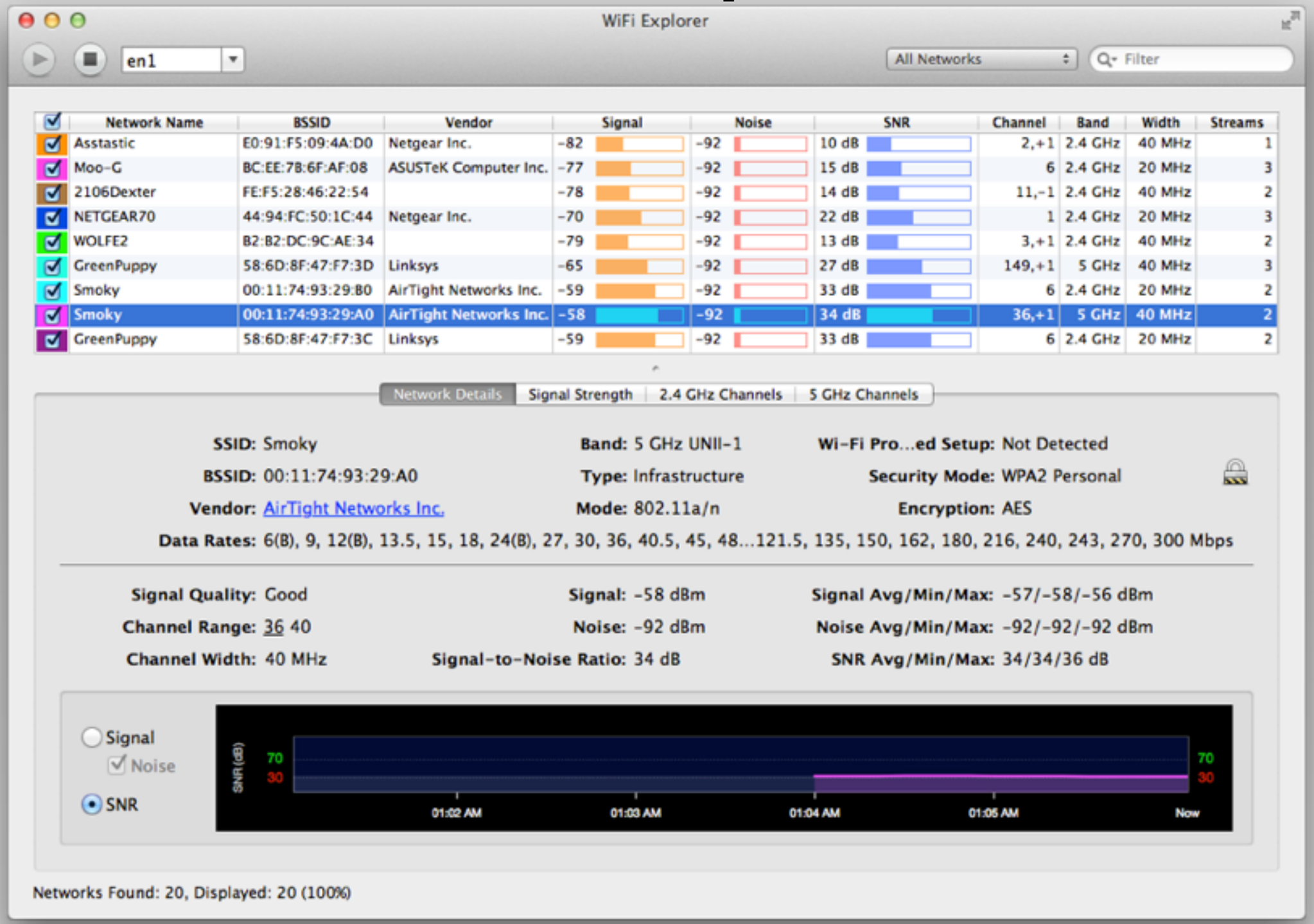
Wi-Fi Explorer



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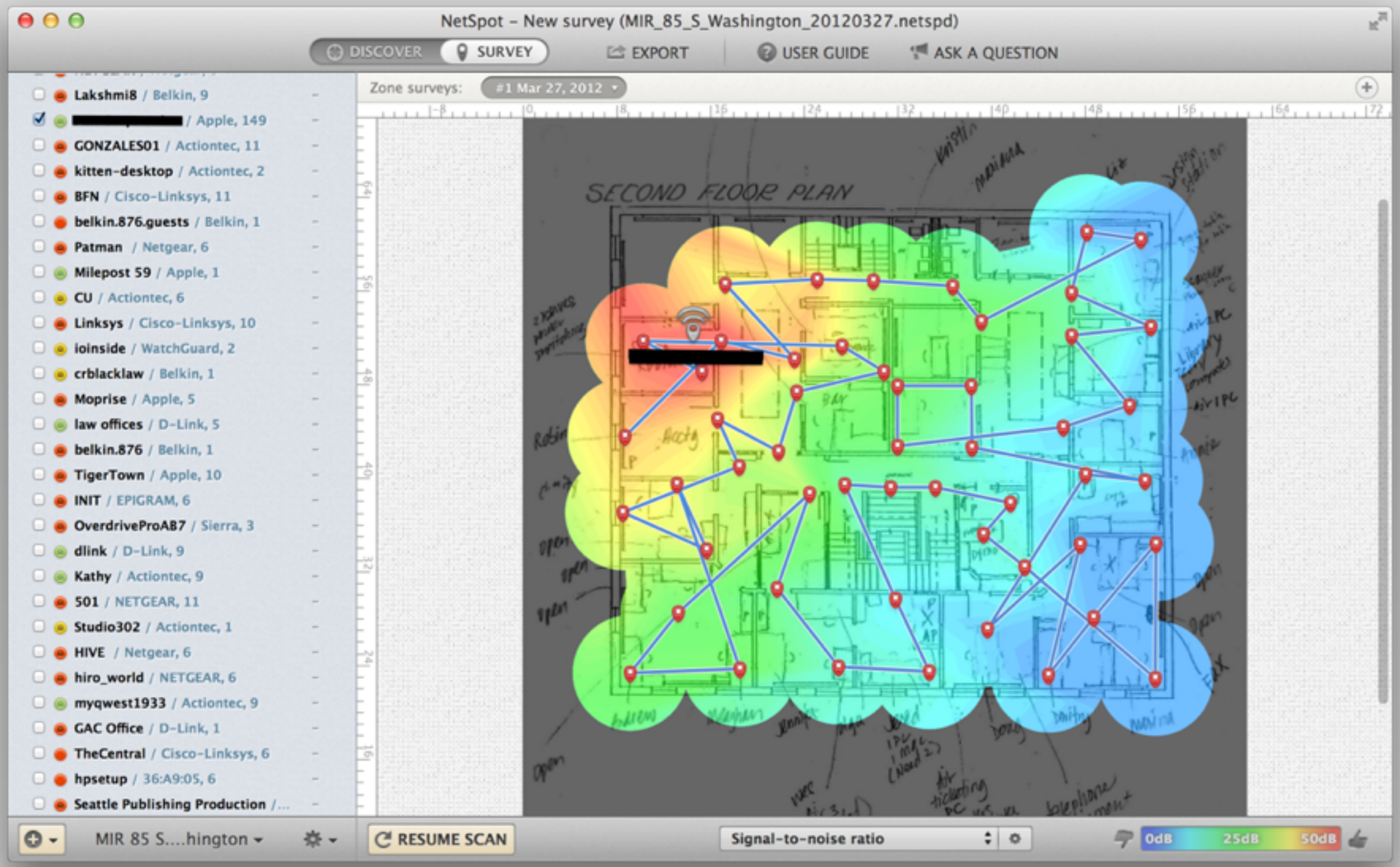
Netspot



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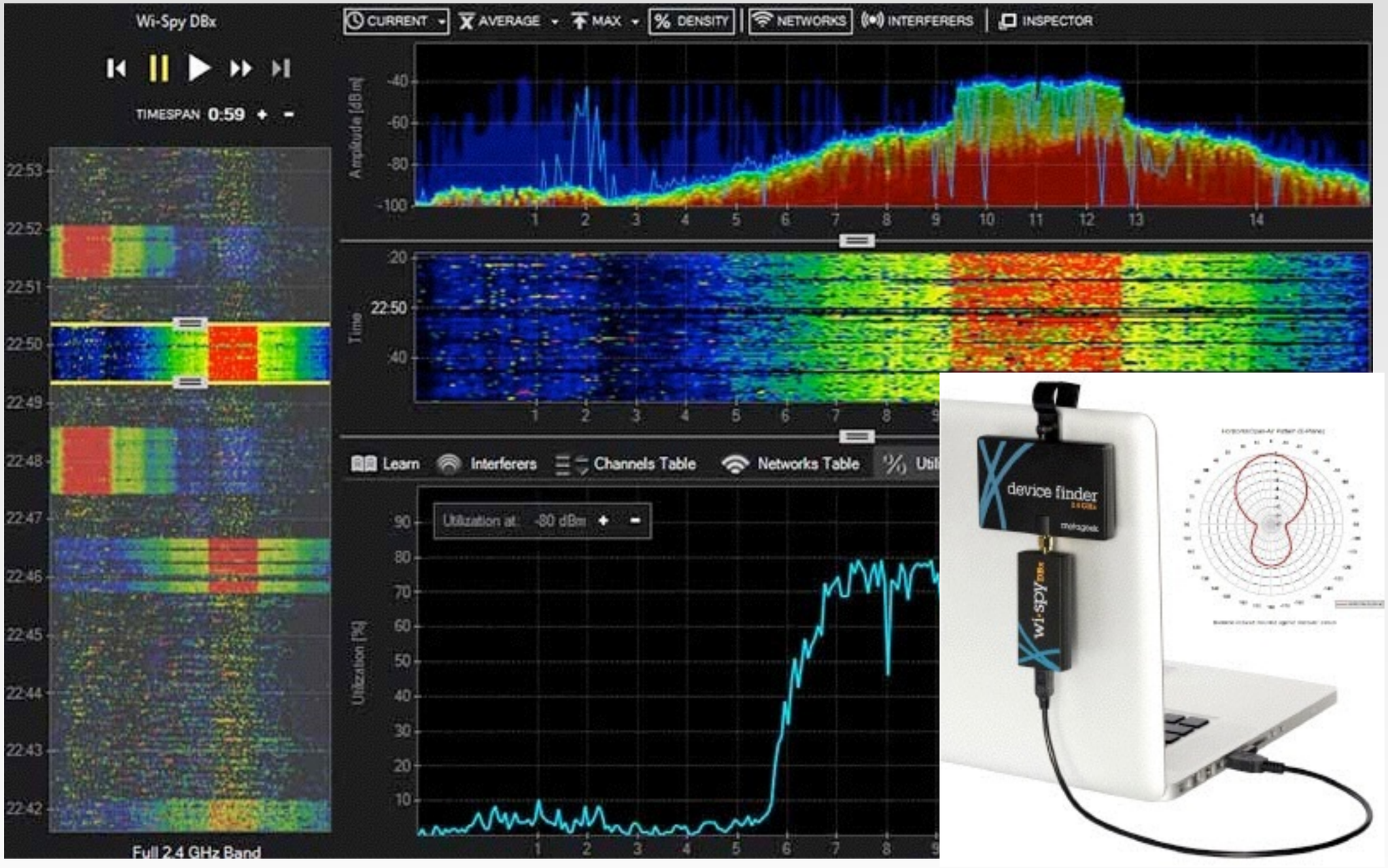
Vendor Apps (Ruckus)

- Apple iOS
  - SWAT
  - Zapper/SpeedFlex
  - ZD Remote
  - Product Guide
- Mac OS/Windows
  - SpeedFlex
- Android
  - SWAT
- More coming soon!

RF Analyzers



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And last...


AT&T 3G
18:59
47 %
Settings
Wi-Fi Networks
Wi-Fi
ON
Choose a Network...
5759AI1
pretty fly for a wifi
Other...
Ask to Join Networks
ON
Known networks will be joined automatically. If no known networks are available, you will be asked before joining a new network.

Questions?

Cameron Champion
cameron@administrivia.com

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