Wi-Fi for Everyone

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Let's Talk About …

- What you need to know about Wi-Fi
  - It's easier than you think
- 802.11ac
- Best practices for WLAN design
- Basic troubleshooting moves
- Becoming a Wi-Fi Kung Fu master

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802.11 – a Brief History

	2.4 GHz	5 GHz
1997	802.11 (DSSS, 1-2 Mbps)	
1999	802.11b (CCK, 11 Mbps)	802.11a (OFDM, 54 Mbps)
2003	802.11g (OFDM, 54 Mbps)	
2009	802.11n (MIMO-OFDM, 600 Mbps)	802.11n (MIMO-OFDM, 600 Mbps)
2014		802.11ac (MIMO-OFDM, 6.9 Gbps)

Wi-Fi uses unlicensed spectrum (formerly known as ISM) – it is mostly unregulated, i.e. anyone can set up a transmitter, receiver any where, any time they want

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A Word About Radio Frequency (RF)

RF is based on two fundamental powers in the universe

RF is analogue not digital. Ask me if it's zero or one and I'll tell you the answer is somewhere between -10 and 14.

-Victor Strom
Ruckus co-founder

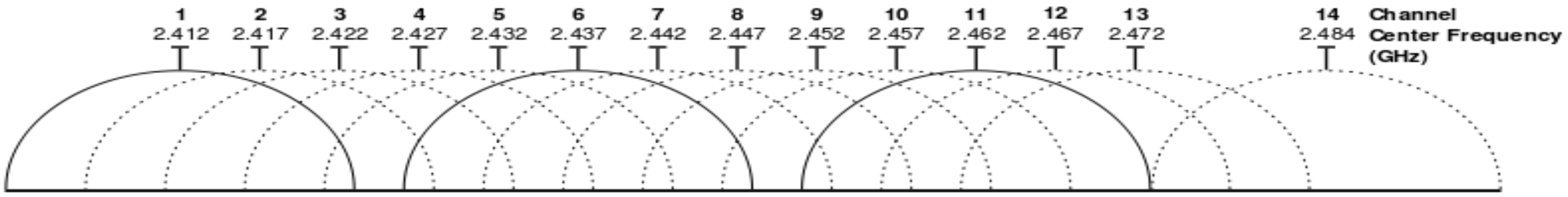
- Electricity and magnetism
- Neither of these cares about IEEE standards
- Understanding how RF itself works will get you further than any standard
- Keep this in mind as we go

2.4 GHz

- Only 3 non-overlapping channels (1, 6 and 11)
- Propagates better through obstructions like walls
- Widely adopted frequency for millions of devices
- Heavily congested
- 40MHz channels are not feasible

Channel Width

802.11	22 Mhz
802.11a/b/g	20 Mhz
802.11n	20/40 Mhz



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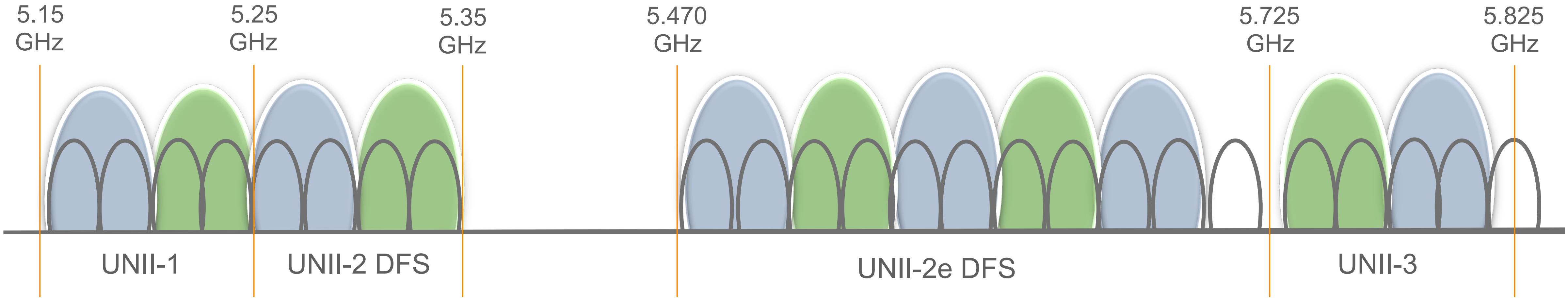
The Wi-Fi Spectrum: 5 GHz



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 40 MHz
- Creates channel planning problems similar to 2.4 GHz
- 5 GHz isn’t a panacea, RF management is still king

Channel Width

802.11n	20/40 Mhz
802.11ac	20/40/80/160 Mhz

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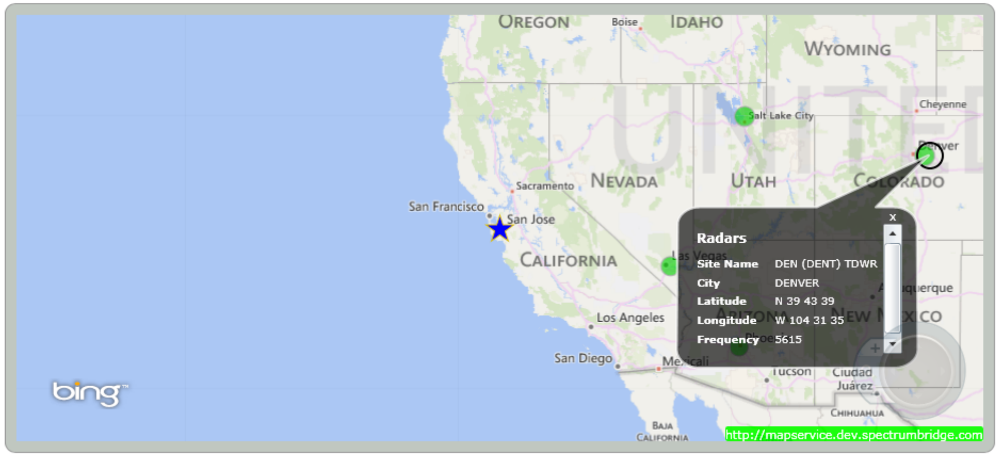
Dynamic Frequency Selection (DFS)

- FCC requirement
- All Wi-Fi vendors must vacate designated 5 GHz (DFS) channel
  if they hear a radar event
  - Typical source is a Terminal-area Doppler Weather Radar (TDWR)
  - Locations for US installations near you can be looked up - http://udia.spectrumbridge.com/udia/search.aspx
  - 802.11h is used to co-ordinate channel changes



	CITY	STATE/TERRITORY	LATITUDE	LONGITUDE	FREQUENCY	TERRAIN ELEVATION	ANTENNA HEIGHT ABOVE TERRAIN
Zoom	PHOENIX	Arizona	N 33 25 14	W 112 09 46	5610	1024	64
Zoom	DENVER	Colorado	N 39 43 39	W 104 31 35	5615	5643	64
Zoom	FT LAUDERDALE	Florida	N 26 08 36	W 080 20 39	5645	7	113
Zoom	MIAMI	Florida	N 25 45 27	W 080 29 28	5605	10	113

If the number of DFS radar events is low (or non-existent), it is a good idea to enable use of these channels for the extra capacity

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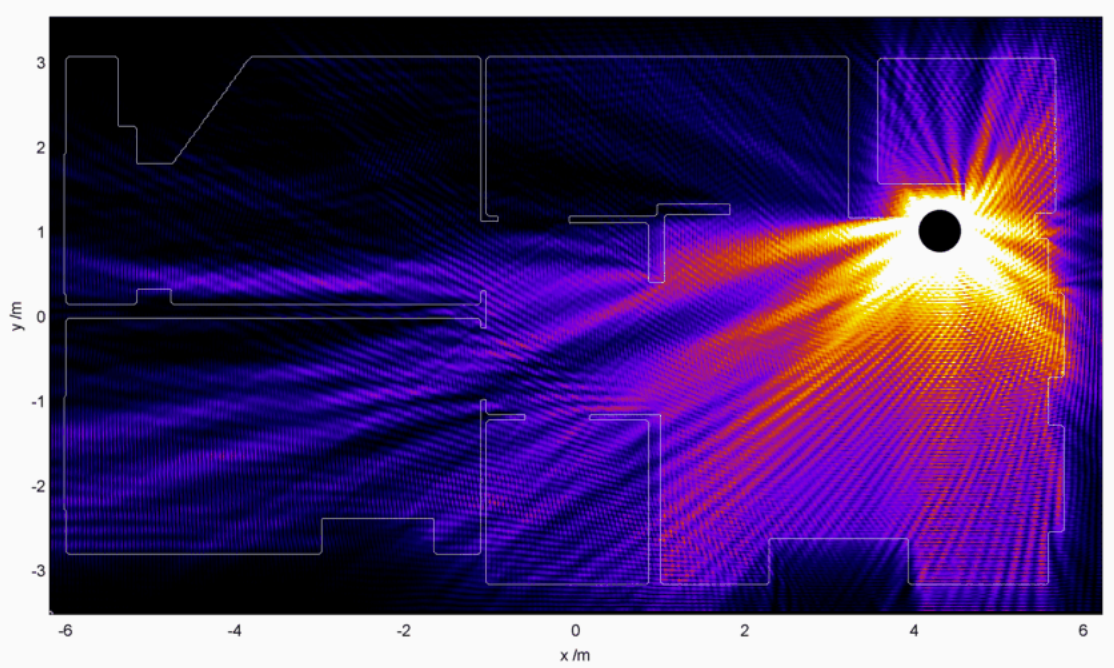
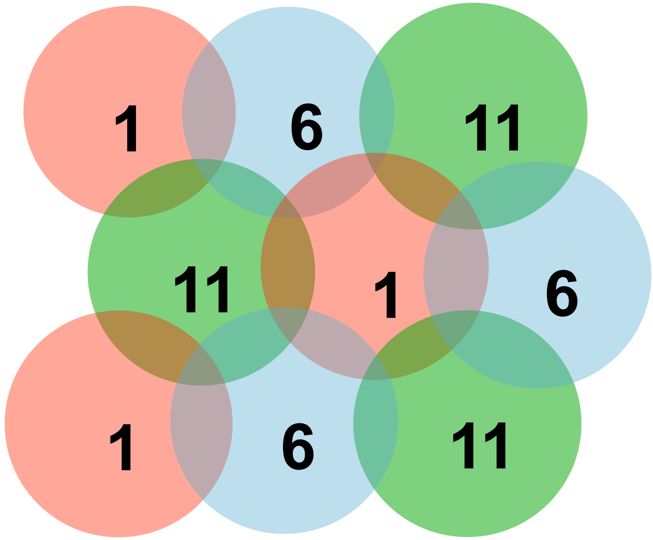
RF Signal Propagation

RF is affected by reflections, absorption and refraction. It's convenient to imagine perfectly shaped "cells" of signal around APs, but the reality is very different. It takes a very long time for an RF signal to degrade into background noise and that won't happen equally in each direction.

Looks like this



Not this!



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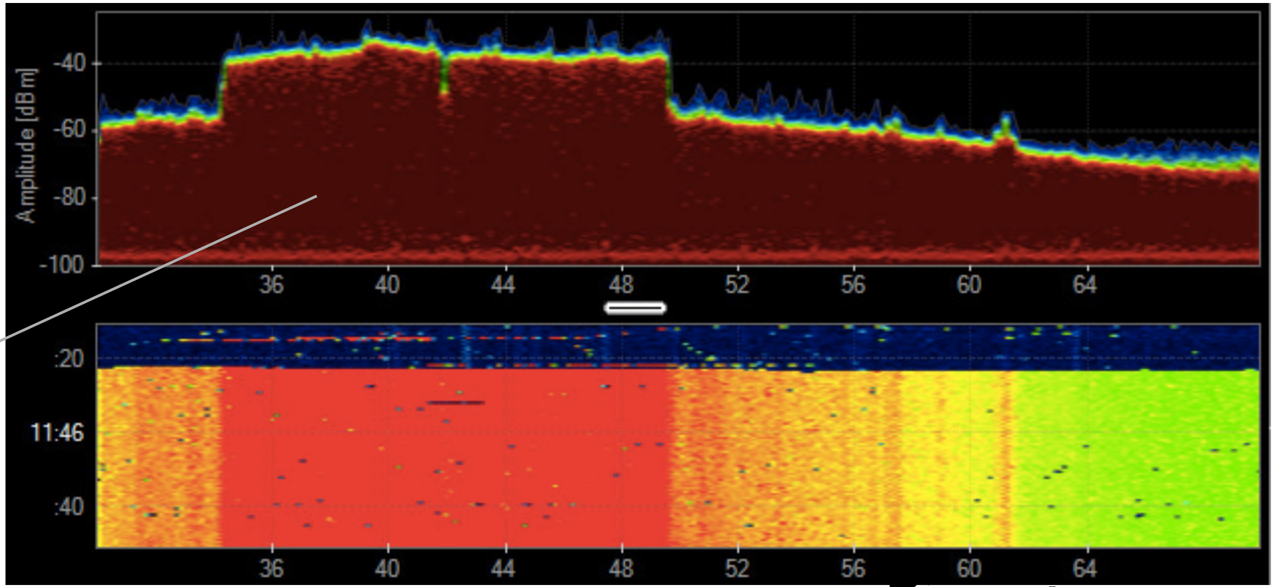
Co-channel Interference

- Wi-Fi is the biggest cause of interference to itself
- If 802.11 clients or AP hear each other
  - Must stop transmitting and wait (back-off time) to try again
  - Only one device out of both groups can talk at a time!

- Goals of channel planning:
  - Pick the best channels in each location
  - As few APs per/same channel as possible
  - As little interference as possible

Every possible channel is heavily used
(complete saturation)



Why Channels 1,6,11 Often Suck

- Only one device can talk at a time
- Everyone else stops and waits

- **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
  - … if it wasn't for their damn preambles popping out!
- Stops one group from transmitting at all!
- If both APs are ours
  - We only get half of them talking at any time
  - Half the performance for twice the cost

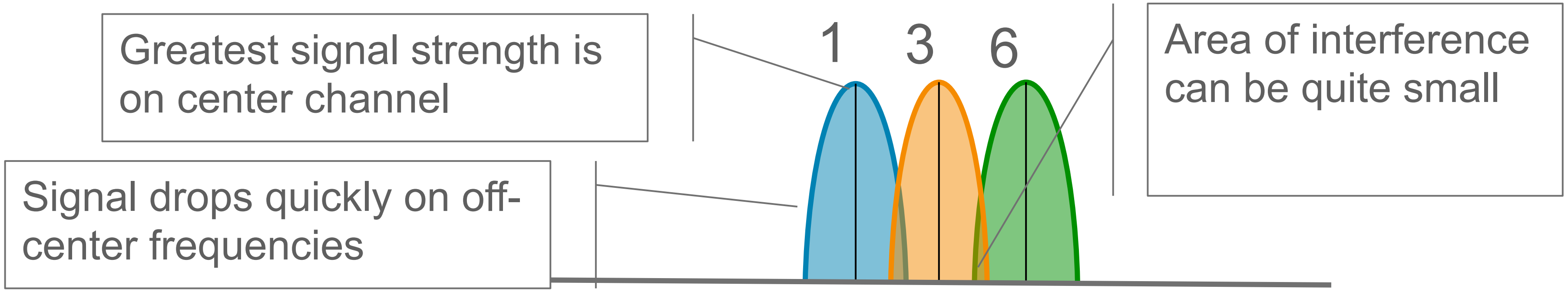
Nothing can transmit here!

Nothing can transmit here!

Leaving 1,6,11 can fix this problem

Going Off Channel – Tradeoffs and Decisions

- Wi-Fi collision avoidance only occurs when devices are on the same center frequency (channel)
- If they are slightly off (channel 1 and 3, for example) they don't have to wait
- Deliberately introduces interference, but the payoff is both APs can transmit at the same time
- Signal strength drops off from the center frequency, distance and obstacles
- Pick an off-channel that is ideally in between the neighbors



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Getting the Message Across

Techniques used by Wi-Fi radios to get better performance

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Bigger and Better Performance

- How data is transmitted has a huge impact on ultimate performance
- Several antenna-based techniques are available
  - Many use MIMO (introduced in 802.11n standard)
- Each relies on a specific use of the AP antennas
- Different kinds of performance
  - **MIMO** – multiple antenna chains (foundational)
  - **Multiple spatial streams** (enabled with MIMO)
  - **Transmit Beamforming** - higher signal gain
  - **BeamFlex** - higher signal gain with less interference

Send More Data Better and Faster

What can you do?

- Increase throughput
  - MIMO (Multiple In, Multiple Out)
  - Spatial multiplexing
  - Wider channel widths
- Stronger signal
  - Transmit Beamforming (TxBF)
  - Adaptive antenna arrays
  - Directional antennas

MIMO/Spatial Multiplexing

- Multiple Transmit/Receive chains (MIMO)
  - Uses Tx:Rx notation, e.g. 3x3
  - Fewer errors, more robust, multi-path is an advantage
  - Introduced with 802.11n

I love mimo

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

- Spatial multiplexing
  - Send different data on different paths = twice the throughput!
  - Streams indicator notation: 3x3:3

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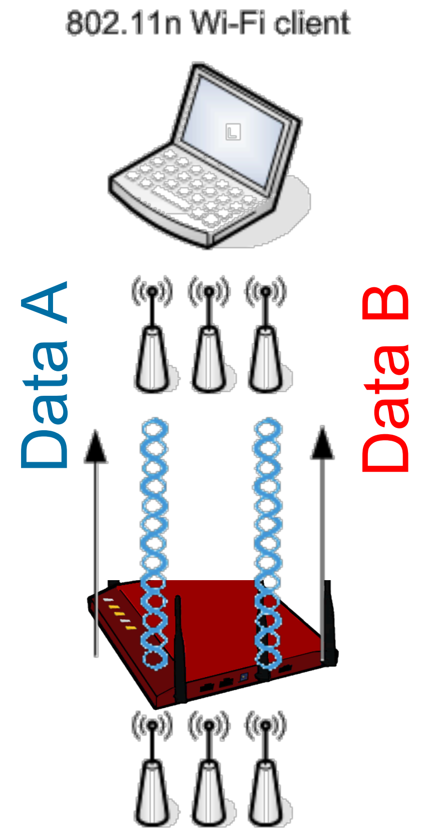
Multiple Spatial Streams

- Designed to increase throughput
- Multiple streams transmit different data

- Number of radio chains must be equal to or greater than the number of spatial streams
- Streams must look different so the client can tell them apart!
- Requires support on both sides (AP and client)

- 3x3:3 = 3-stream client/AP
- 2x2:2 = 2-stream client/AP
- 1x1:1 = 1-stream client/AP (SISO)
- 2x3:2 = 2-stream client



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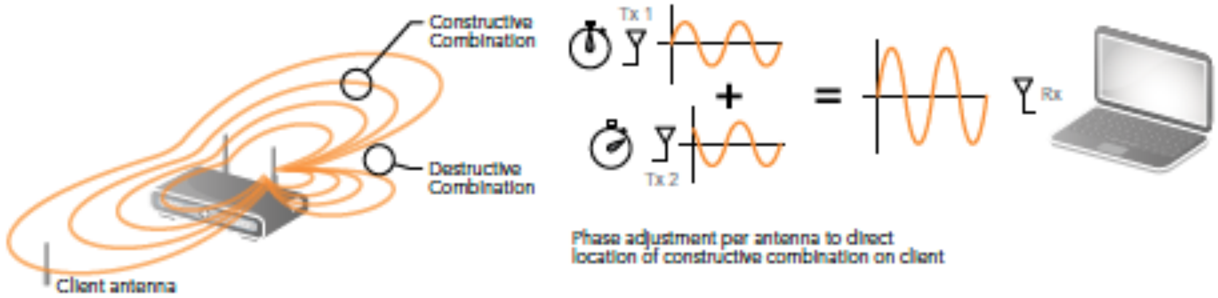
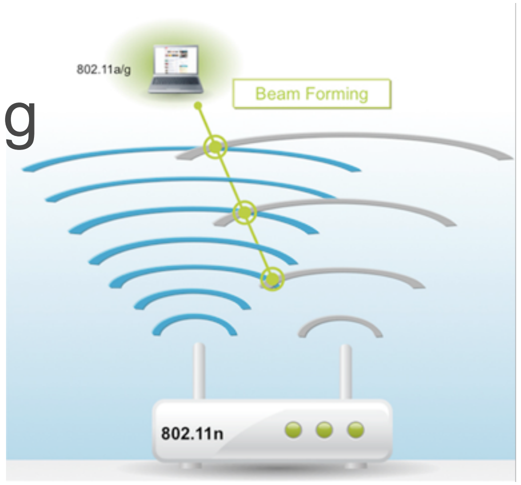
Transmit Beamforming (TxBF)

- A technique to increase signal gain introduced with MIMO
- Sends the same data over two radio chains
  - Each signal is out of phase with the other
  - Goal is to get signals to positively combine at the client for a bump in signal gain
- Loses a spatial stream to support TxBF
- Works best when both AP and client can participate in sounding





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802.11ac – Why It's Cool

- Very High Throughput (VHT)
- Gigabit Wi-Fi
  - Next generation
- Nearly 7 Gbps max data rate

Applications

- File transfer
- Backup/Sync
- Media sharing
- Outdoor bridging
- Low capacity, high bandwidth

6.9 Gbps!

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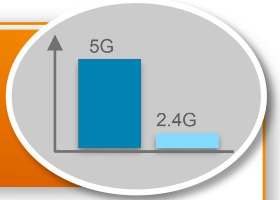
802.11ac: An Overview

Increased Speed

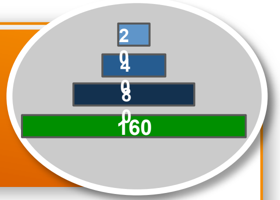
- Breaks “gigabit” barrier
- Max of 6.9 Gbps

5 GHz Only



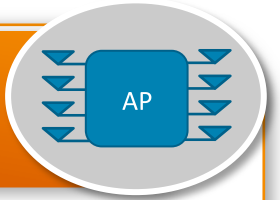
- Focuses on capacity-rich, low-interference spectrum
- Benefits entire Wi-Fi ecosystem

80/160 MHz channels



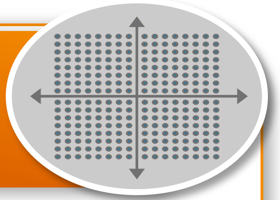
- Very wide channels
- One of the primary reasons for 11ac’s very high data rates

Up to 8 spatial streams



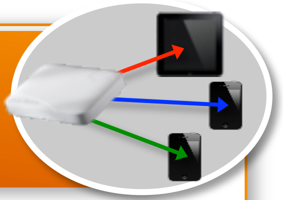
- N-fold efficiency improvement
- Requires client-side support
- Wave 2 only

256-QAM



- More efficient modulation
- 33% data rate gains
- Very short ranges only
- Requires 11ac clients

Multi-user MIMO (MU-MIMO)



- Simultaneous downlink Tx to single-stream clients
- Multiplies network capacity
- Key differentiator from 802.11n

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802.11ac Coming in Waves

Wave 1 – Q4, 2013

256-QAM	33% gain at very short range
80 MHz channels	Twice the capacity of 40 MHz 802.11n (but not recommended for multi-AP deployments)
3 spatial streams	Already supported by 802.11n (3x3)

Net gain → Slight efficiency improvement, most benefits are for 802.11ac devices

Wave 2 – Late 2015

Wave 1+	Includes all Wave 1 features, with additional chip improvements
80 / 160 MHz channels	Twice the capacity of 80 MHz 802.11ac (but not recommended for multi-AP deployments)
3+ spatial streams	Likely 4 spatial streams. N-fold throughput gain for high-end clients, more flexibility/capacity for MU-MIMO
MU-MIMO	Up to 4x capacity boost, multiplies aggregate capacity

Net gain → Multiples aggregate network capacity and efficiency, **ALL** devices benefit

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80 and 160 MHz Channels

OVERVIEW

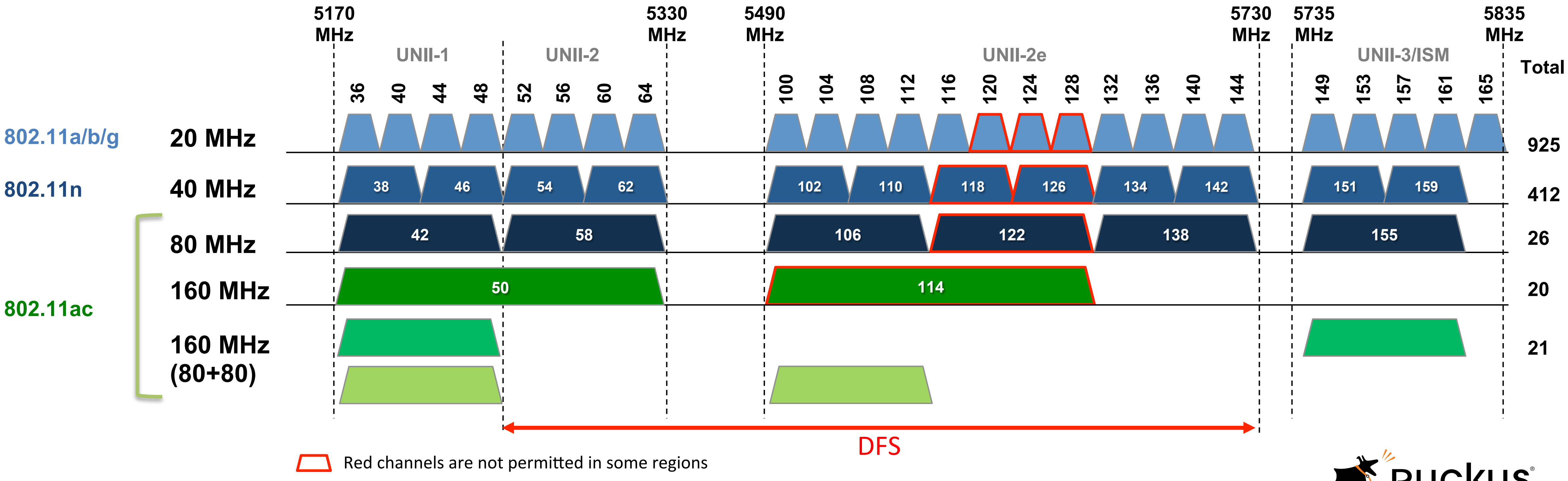
- 11ac devices must support 80 MHz channel width
- Optional support for 160 MHz
  - Contiguous or non-contiguous (80+80)
- Boosts maximum 802.11ac specs
- 160 MHz channels unrealistic for enterprise deployments

Pros

- Max data rate is more than doubled
- Boosts throughput in networks with few APs
- Improves backup, file transfer speeds

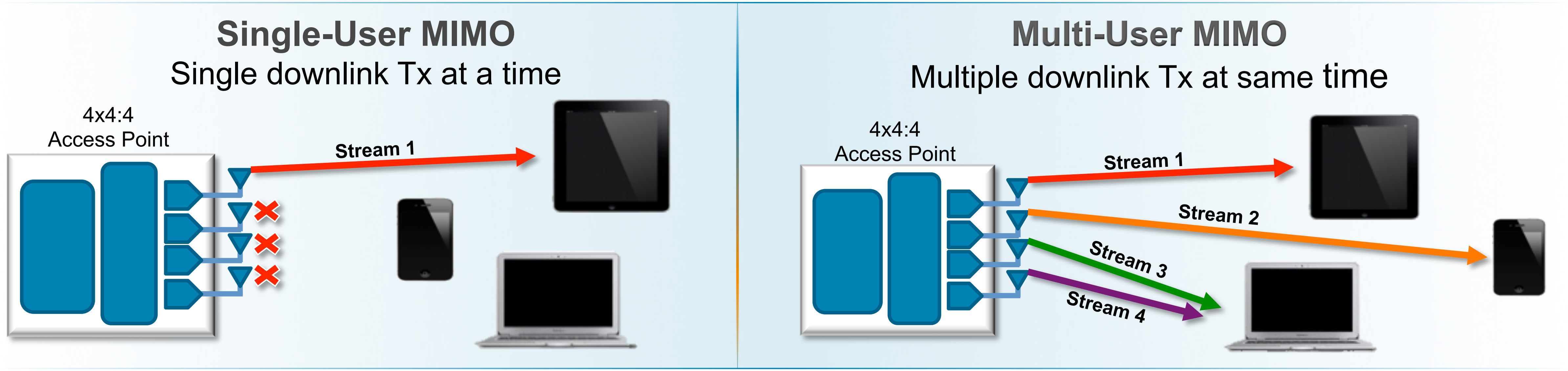
Cons

- Sub-optimal spectral reuse in multi-AP deployments
- Max of 5 non-overlapping 80 MHz channels
- Increases neighbor interference and contention
- Likely decreases aggregate capacity in enterprise



Multi-User MIMO (MU-MIMO)

- Transmit simultaneous downlink frames to different receivers
- Significant capacity enhancements in environments with many single-stream devices (tablets, smartphones)
- Requires Wave 2 11ac client(s) with TxBF feedback/support
- Creates new challenges related to signal steering and isolation
  - How to get…
    - DataA to StaA
    - DataB to StaB
    - No DataA to StaB
    - No DataB to StaA



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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

Table 1. Some 802.11n MCS Values

- Why is a client slow?
- MCS rates can give a clue
  - Not getting the max spatial streams
  - Not getting highest coding rate
  - Channel width does not support that rate

Don't go by what's on the box.
Max PHY rate is *always* dependent
on environmental factors

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802.11ac MCS Rates – Your Other New BFF

To determine the maximum data (PHY) rate, start with a 20 MHz 1-stream client and multiple with each additional spatial stream and channel width increase.

MCS Index	1x1:1 11ac Client 20 MHz Channel		Channel Width Multiplier	Spatial Streams Multiplier
	GI	SGI		
0	6.5	7.2	40 MHz = 2.1x 80 MHz = 4.5x 160 MHz = 9x	2 SS = 2x 3 SS = 3x 4 SS = 4x 5 SS = 5x 6 SS = 6x 7 SS = 7x 8 SS = 8x
1	13	14		
2	19.5	21.7		
3	26	28.9		
4	39	43.3		
5	52	57.8		
6	58.5	65		
7	65	72.2		
8	78	86.7		
9	N/A	N/A		

Throughput shown is PHY rate.

To estimate “goodput”, subtract 802.11 management frames, UDP and TCP/IP overhead from the PHY rate.

This will vary depending on the traffic mix, number of clients, etc.

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Planning for a Wi-Fi Deployment

How to be a Wi-Fu Guru

Common Questions

1. How far can the signal from an AP go?
   - Depends on the client
     - Handheld clients = smaller antennas/weaker radios
     - Watch out for battery saving – can step down power even more
   - Depends on the environment
     - Lots of interference will shorten the distance
     - Obstacles attenuates signal

2. How many clients can I have per AP?
   - Faster clients = more clients per AP
   - What's the application? High bandwidth, low latency reduces client count
   - Advanced Wi-Fu moves:
     - Airtime fairness, client load balancing, band balancing and more

Design Check List

Know what you want to achieve.

- More clients? Faster clients? Coverage? Bragging rights? ☺

Are the client devices ready?

- The more 802.11ac clients, the more efficient the Wi-Fi.
- Don’t forget 2.4 GHz for clients and band balancing!
- Weaker clients will limit distance from the AP

What is my channel plan design?

- Should I use 80 MHz-wide channels? 40 MHz? 20 MHz?
- More APs and wider channel widths = higher the potential for co-channel interference.

Maximizing Performance

Max performance = fastest data rate + greatest amount of data

- Data rate is affected by
  - Interference – clients back down to slower rates if there is too much interference (takes ***longer*** to send data)
- Amount of data is affected by
  - Number of spatial streams - fewer spatial streams reduces the ***amount*** of data sent

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Maximizing Data Rate

Reduce interference

- Fewer APs on the same channel (co-channel interference)
- Higher SNR
  - More likely to get that higher MCS rate

Get high SNR

- Transmit Beamforming (TxBF)
  - Phase shift same data over 2 radio chains
  - Requires client & AP support (chip-based)
- Adaptive antenna arrays (BeamFlex)
  - Use multiple directional antennas dynamically to focus RF energy to the client
  - Compatible with TxBF - can add to this incrementally
  - On average, TxBF will always be better with BeamFlex

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Designing for Faster Data Rates

- Typically driven by an application that requires a LOT of bandwidth
  - E.g.. Uncompressed video, etc.

- Majority (or all) devices must be 802.11ac

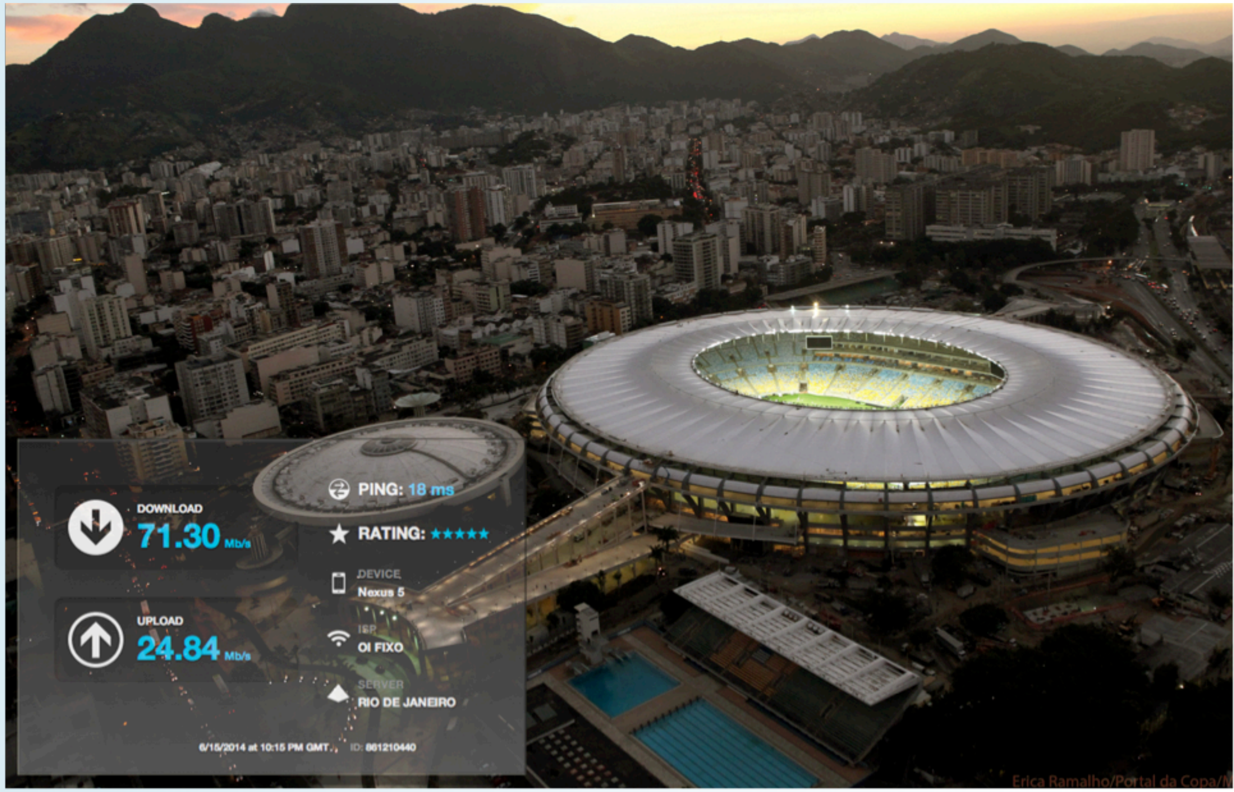
- Use 80 MHz-wide channels

Challenges

- Too many APs with wide channels will require high channel reuse
- Can cause high interference = lower data rates
- Slower performance can defeat the entire purpose of 802.11ac!

Designing for the Rest of Us

- Airtime usage is king in dense deployments
- The faster a client can get on/off the air the more time available for other devices
  - Increases the number of clients per AP
- MU-MIMO vs. multiple spatial streams
- Interference will kill you every time



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Interference in a High Density Environment

- More clients = more interference
  - Lots of APs needed for capacity = high channel reuse = co-channel interference
- High interference will prevent the highest data rates (esp. 256-QAM)
- 40 MHz-wide channels *might* be a good choice, depending on …
  - Number of clients, client capability (11n vs. 11ac) and amount of AP channel overlap
  - The tradeoff is lower overall throughput for less interference
- DFS channel usage can also help

Wi-Fi Client Challenges

- Not all clients are the same
  - Different speeds, 802.11n vs. 802.11ac, etc.
- Even when the specs look the same!
  - Better/worse radios, etc.
- Client drivers are incredibly important
  - Often, upgrading to the latest drive solves the problem
  - Upgrade early and often
- When designing coverage, always test with the weakest client
  - Lowest common denominator





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Why Won't My Client Roam?

- Pop Quiz: Which device decides when a client should roam to a new AP?

- The **client** decides when to roam between APs, not the AP
  - Different clients have different drivers/software
  - The software decides when the current signal is too low before looking for a new AP
  - Clients also have different ways they scan for new networks

- How is client signal strength measured?
  - RSSI value = defined as 0-100 by the 802.11 standard (but no specific mapping)
  - Radio chipset, antenna and transmit power will be different for different devices

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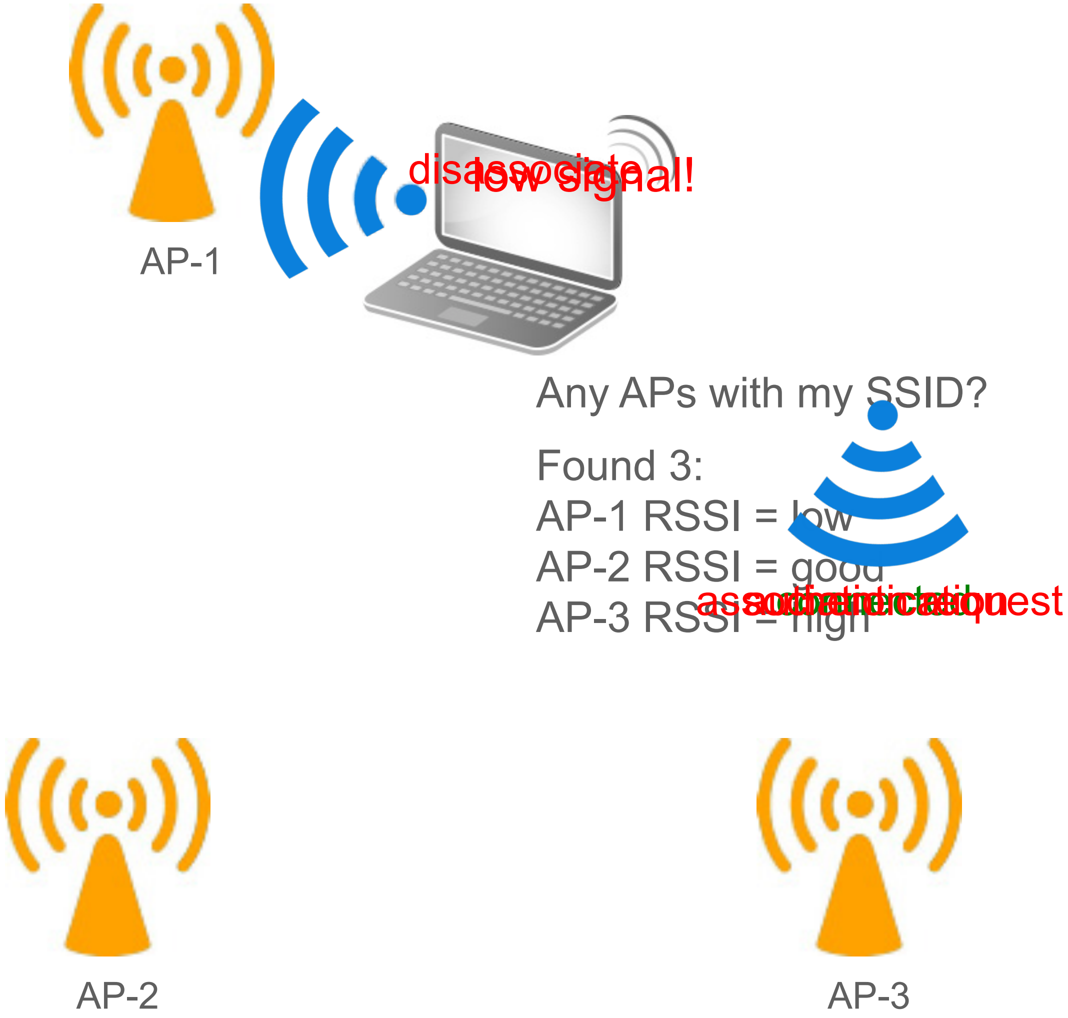
Understanding How Clients Roam

1. Client routinely checks if RSSI threshold is below limit
2. Scan for better APs
3. Disassociate from current AP
4. Associate to strongest AP
5. Authenticate
6. Once authenticated the client connects and roaming is complete



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Troubleshooting Roaming

- Try different clients
  - Issue may be specific to a particular device
  - If all clients are affected, issue might be RF/network related
  - Otherwise probably the client

?

- Update to the latest driver

- What roaming methods are used?
  - Leave decision to the client
  - Use key caching (PMK and OKC)
  - 802.11r/k

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Tweaking the Design

Cool Wi-Fu moves

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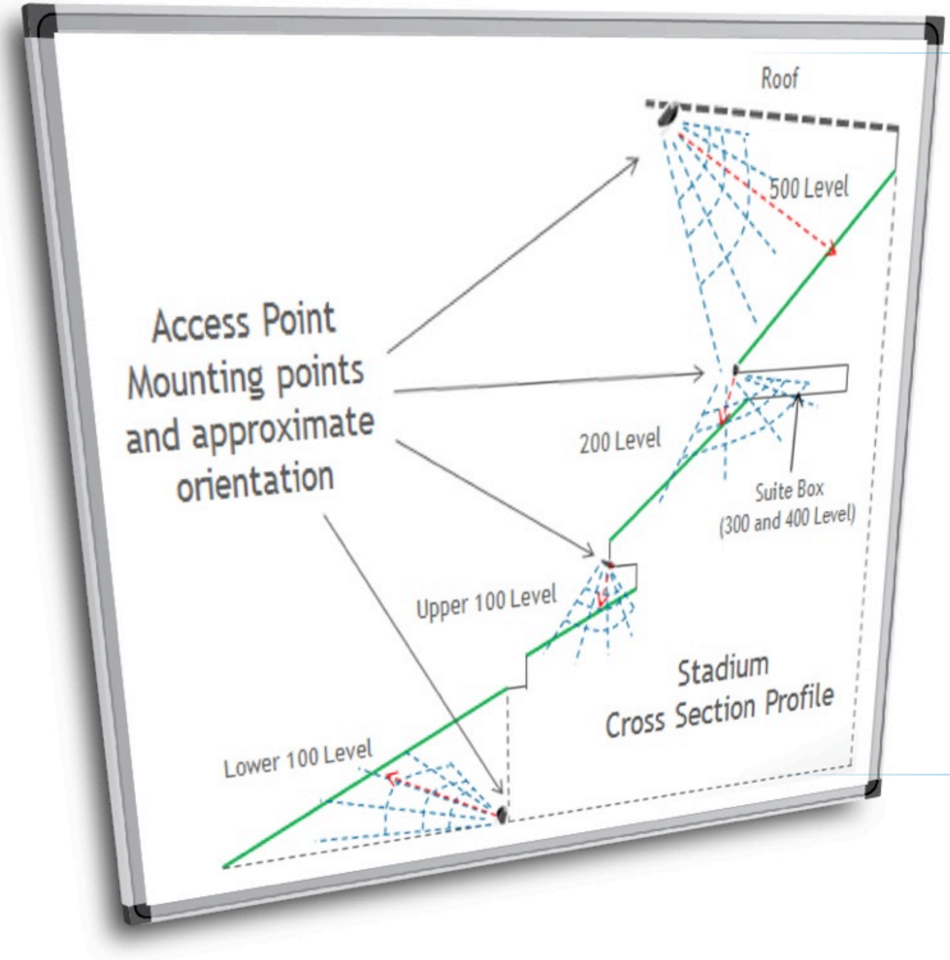
AP Placement: Location, Location, Location



- Get APs close to users
- Use narrow beam antennas for tight, focused- areas (stadiums, etc.)
- Use the structure to limit RF propagation
  - Corners, overhangs, roofs, poles, etc.
- Concrete is your friend - absorbs RF
- Minimal form factor APs are very desirable in many deployments

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Should I Reduce AP Power?

- Does not help signal to interference & noise (SINR)
- Lowering your power means clients can hear the other guys even better
- Lower power = lower transmit speed = clients take longer to get on/off the air
- Reduces capacity

- A better idea to reduce cell size is to use the environment (obstacles, etc.) to increase path attenuation outside the main coverage area
  - E.g. walls, ledges, etc.

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Wi-Fi Security

- Some WLAN equipment offers intrusion detection/prevention services
  - E.g. temporarily blacklist device after failed number of authentication attempts
- High levels of interference can corrupt a client's authentication attempts and result in blacklisting
  - Result is clients not getting serviced and complaints
- Rogue AP containment can hurt performance
  - How badly do you want it? More than high performance?
- May need to rethink anything that slows down clients

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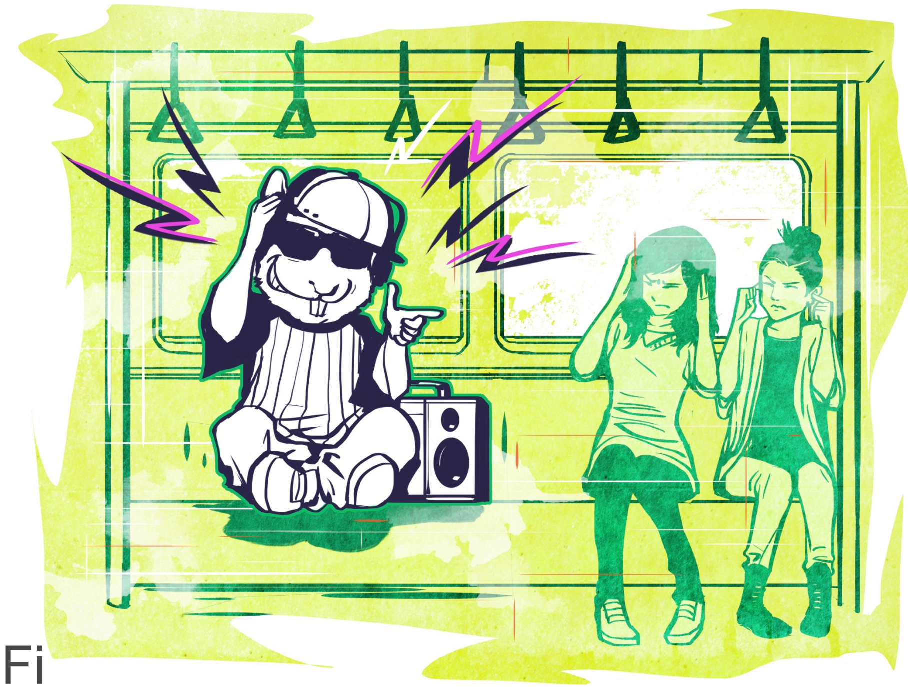
Traffic Optimization

- Broadcast/multicast traffic goes out every AP
  - Even if it is not meant for any wireless devices!
  - Takes up valuable airtime
  - No-one else can talk while useless traffic is broadcast
  - Reduces capacity



- Keep unwanted traffic off Wi-Fi
  - Ex. Wired-side broadcast/multicast traffic not used by Wi-Fi
  - Unused Wi-Fi broadcast/multicast: peer-to-peer, Bonjour, NetBEUI, etc.
  - Segment wireless subnet from wired networks

- Strategies include VLAN separation, firewall policies, ACLs, etc.

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Wired vs. Wireless: A true story

- **The problem**
  - Constant wireless disconnects at the school
  - APs would even go off-line sometimes
  - Wireless **must** be the problem – only wireless clients can't connect and the APs go offline

- **The REAL problem**
  - Wired and wireless were on the same L2 network
  - 4 wired devices were transmitting over 5,000 IPv6 multicast packets/second
    - School doesn't use IPv6(!)
  - Multicast flooded the wireless network - essentially an (unintended) DoS against the wireless and the APs

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Wired vs. Wireless: A true story

The solution

- Remove the offending wired devices
  - PC vendor had a patch – known problem on the wired PCs
  - Put wireless devices on a different VLAN than the wired network
    - Isolate traffic
  - Configure router to NOT forward unwanted multicast/broadcast traffic

- Excessively large broadcast domains are always a problem
  - Always looks like a wireless problem
  - Difficult to troubleshoot

- Nothing was required on the wireless side to fix this problem

Optimizations

- Keep AP tx power high
  - For max. data rate
- Use attenuation (obstacles) & frequency re-use via structural separation
  - Use DFS channels if you can
- Consider non-traditional 2.4GHz channel plans
  - Automatic channel assignment optimizations & adaptive algorithms
- Reduce/eliminate unnecessary broadcast traffic
- Limit background scanning
- Limit # of SSIDs
- Disable services that potentially deny service
- OFDM-only (no 802.11b)

Every bit adds up!

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Tools to Look Like a Wi-Fu Master

Measuring Performance

What do you want to measure?

- Connect speed?
- Throughput?
- Number of clients? (density)
- Latency?

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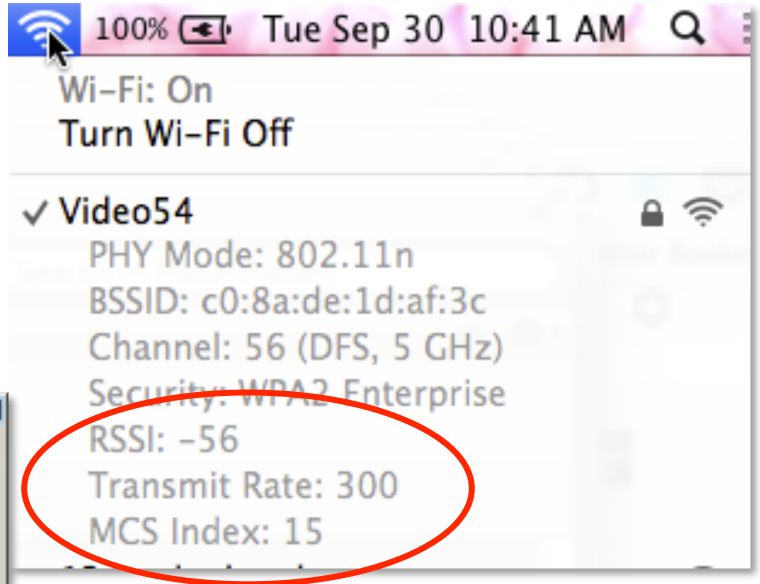
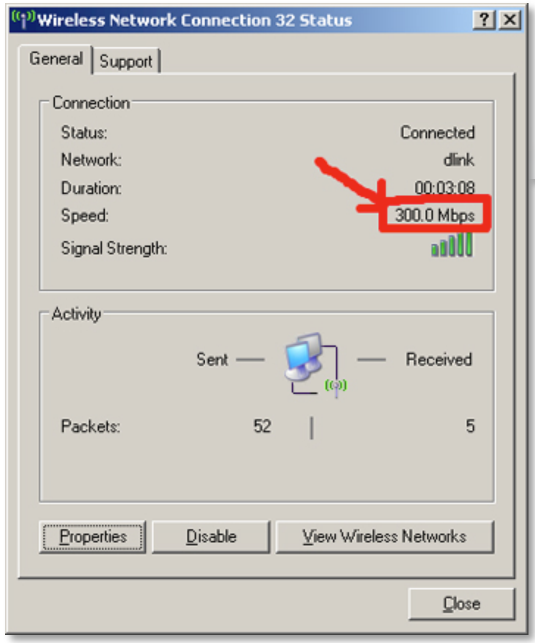
Connection Speed (Data Rate)

- What is the highest achievable data (PHY) rate?
- Can clients connect at their maximum?
  - If no, why not?
- Some clients will report their connected PHY rate
- The highest rate may not **always** be possible
  - Interference
  - Unable to get all spatial streams
  - Etc.





- Other useful information:
  - Channel
  - RSSI

Client Throughput

- What you get after subtracting non-data traffic from PHY:
  - 802.11 overhead (management frames, etc.)
  - TCP or UDP overhead
  - Retries (interference, etc.)
  - Frame payload size
  - Anything else (encryption, etc.)

- TCP/IP connections: subtract ~40-50% of PHY
- UDP/IP connections: subtract ~20% of PHY

- Common measurement tools:
  - SpeedFlex
  - iPerf

Be careful when using WAN-based tools like SpeedTest!

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Latency

- Some applications are more sensitive than others
  - Voice
  - Video
  - Multiple authentication/logins

- Latency and bandwidth will vary throughout the day during network peaks and lows

- It is not always obvious when an application is latency sensitive
  - Multiple simultaneous logins - clients can time out if it takes too long to get back on the Wi-Fi and get a response from the authentication server

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Free Tools Everyone Should Have

- Ruckus
  - SpeedFlex - speed testing on the WLAN
  - Zapper - statistical analysis of throughput over time
  - S.W.A.T - performance assessment tool
  - http://www.ruckuswireless.com/products/mobile-apps
- NetSpot (free version) – Wi-Fi coverage analysis and surveys
  - http://www.netspotapp.com/
- Wi-Fi Explorer
  - https://itunes.apple.com/us/app/wifi-explorer/id494803304?mt=12
- Mac OS X
  - Built-in Wi-Fi diagnostics tool

NetSpot

Wi-Fi Explorer

More Tools (Commercial)

- inSSIDer – excellent tool to show Wi-Fi networks
  - http://www.inssider.com/
- NetSpot Pro
  - http://www.netspotapp.com/
- RF analyzers

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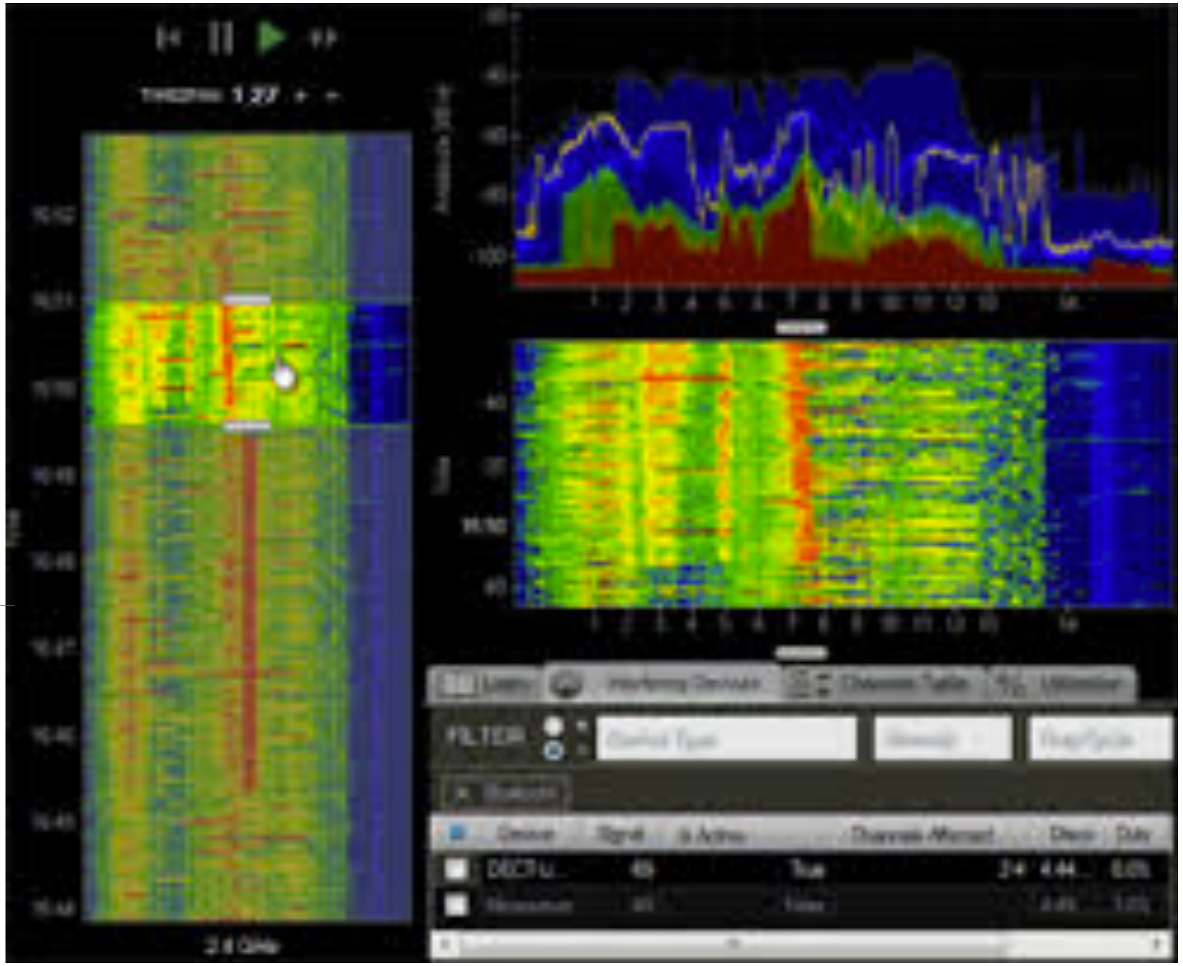
RF Analysis Tools

If you can see it, you can fix it

But …

- Cables are visible, RF is not
- RF analyzers are a very wise investment



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Find Out More

- *802.11ac: A Survival Guide*
  - Free to read online!
  - http://chimera.labs.oreilly.com/books/1234000001739
- CWNP
  - Professional certification tracks
  - But just buying the book is an excellent reference
  - http://www.cwnp.com
- Free 802.11 videos & white papers
  - http://www.ruckuswireless.com/technology

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So Now You Are a Wi-Fi Master

- Understanding how RF works is fundamental
  - If the RF doesn't work, Wi-Fi doesn't work
- Wi-Fi works very differently from wired networks
  - Wi-Fi is half-duplex (shared medium)
  - Only one device can talk at a time
- Know your clients
  - Not all are created equal – understand what to expect
- Write down performance goals
  - What are the key performance criteria? How to test?
- When all else fails, have the right tools

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