SHARKFEST '13

Wireshark Developer and User Conference

How 802.11ac Will Hide Problems from Wireshark

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Chief Scientist, Connect802 Corporation

Connect802 Corporation

- Your trusted wireless network engineering resource
  - Founded in 1994
    - Headquarters in San Ramon, CA
    - East Coast offices in Knoxville, TN
    - Pacific offices in Hawaii
- Complete system implementation
  - RF spectrum analysis
  - 3D RF CAD design
  - Hardware sales and support
  - WiFi, medical telemetry,
    first responder, point-to-point

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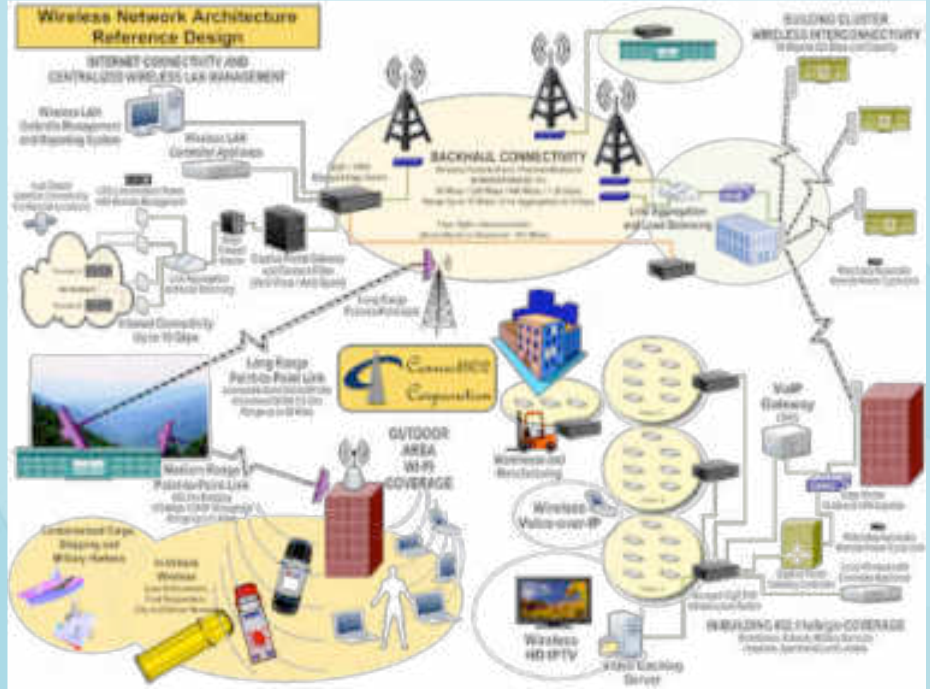

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Project Portfolio Overview

- Marine Corps Base Camp Pendleton
- Monterey Bay Aquarium
- Oceanside Unified School District
- Groupon
- abc 7
- Berkeley Lab — Lawrence Berkeley National Laboratory
- Johnson Controls
- Mountain Home Air Force Base
- UC Davis Medical Center
- Kenny Chesney Tour
- Martinez Unified School District — "Together we will ensure diverse paths to educate students in their quest for knowledge and success"
- Squaw Valley
- Fremont Unified School District
- Dräger
- Stanford School of Medicine
- CBS Interactive
- Tufts University
- JAXPORT — Jacksonville Port Authority
- United States Department of Veterans Affairs — San Francisco VA Medical Center
- InterContinental Hotels & Resorts
- Carmel Unified School District
- Kaufman County Sheriff's Department
- Vandenberg Air Force Base
- The FBI — Federal Bureau of Investigation
- Nestlé Purina
- Georgia Tech
- Genentech — A Member of the Roche Group
- Summerlin Hospital Medical Center
- Stanford Sierra Camp
- Connect802 — Wireless Data Solutions
- Port of Portland — Possibility. In every direction.
- Kaiser Permanente
- WaferGen
- sunrun
- Kern Medical Center
- Oakland City Center
- Saint Ignatius College Preparatory
- Federal Law Enforcement Training Center
- Homeland Security

You Have a New Baby!

- 802.11ac is here today
- Market rollout is expected to occur in phases
  - Q1 2013 Consumer Grade
  - Q3 2013 Early Enterprise Grade
  - 2014 Mid/High Enterprise Grade
  - 2015 Peak 802.11ac demand
- Some 802.11ac features will not be implemented until 2014

802.11ac
6930 Mbps

802.11n
600 Mbps

802.11bg
54 Mbps

Today's Challenges with 802.11n Packet Capture

- You can't capture a MIMO transmission if you're not standing in the MIMO "cluster"
  - The "cluster" is where the multiple streams converge for recovery by the intended receiver's antennas
  - You can't expect to capture 100% of MIMO transmissions in any given environment
- Wireshark AirPCap Adapter
  - Cannot capture packets with short guard interval
  - Cannot capture packets transmitted in Greenfield mode
  - Cannot capture 3-stream MIMO

- Wireshark with Linux (Ubuntu)
  - Does not pass checksums up to Wireshark by default
- Wireshark on MacBook Air
  - This configuration captures all packets properly

- AirMagnet 802.11n PCMCIA Adapter
  - Adapter cannot capture 3-stream MIMO

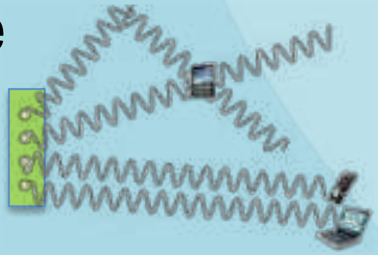
Overview of 802.11ac

- The 802.11ac Committee Was Formed in September, 2008
- Advanced Capabilities Will Not Be Present In 1st (or 2nd) Release Phase
  - Operation only in the 5 GHz ISM band
  - Backward-compatible changes to the 802.11ac packet preamble
  - 20, 40, 80 and 160 MHz wide channels (20, 40 and 80 mandatory)
  - Up to 8 MIMO spatial streams (only 1 is mandatory)
  - 256 QAM modulation (versus 64 QAM in 802.11n)
  - Cell capacity of at least 1 Gbps
  - Single client throughput of at least 500 Mbps
- FFT of 256 and 512 (up from 128 in 11n)
- New PPDUs (Procedural Protocol Data Units)
  - Support for the new 802.11ac preamble
    - 802.11ac uses the same greenfield preamble as 802.11n
  - Data for Automatic Gain Control
- Wi-Fi Alliance Compatibility Certification
  - Originally Planned for February, 2013 but postponed until "later in the year" by the WiFi Alliance

"As with 802.11n, don't expect all of the options and capabilities of the standard to be carried through to actual products."

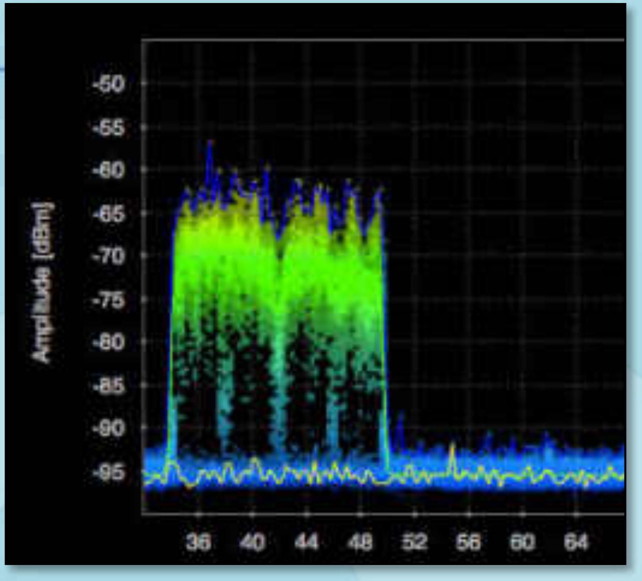
Overview of 802.11ac

- 234 OFDM data sub-carriers in an 80 MHz channel
  - Versus 108 sub-carriers in an 802.11n 40 MHz channel
- Two 80 MHz channels can be “bonded” together
  - 468 sub-carriers are dedicated to a single transmission
- An 802.11ac access point (with 4 antennas) can simultaneously transmit to 3 devices downstream at the same time
  - Multi-User MIMO (MU-MIMO)



- Beamforming has been standardized
  - Consistency in methodology allows compatibility between APs and clients
  - A “sounding frame” is transmitted by the access point
  - Feedback is provided by client devices to inform the AP about the state of the transmission channel

Modulation and Capacity



- New modulation methods and channel widths may prevent packet capture
- You can only capture packets that are recoverable by your wireless adapter
- You can only capture up to the capacity of your notebook computer to process packets

Real-World Capacity Expectations

Maximum "Connection Rate"	Conservative Practical Data Rate	Midrange Equipment Typical Data Rate	Maximum Realistic Data Rate
802.11n {4 X 150 Mbps/40 MHz}	**46 Mbps** {1 X 65 Mbps/20 MHz}	**90 Mbps** {2 X 65 Mbps/ 20 MHz}	**320 Mbps** {3 X 150 Mbps/40 MHz}
802.11ac 2014 {8 X 867 Mbps/160 MHz}	**210 Mbps** {1 X 293 Mbps/80 MHz}	**610 Mbps** {2 X 293 Mbps/ 80 MHz}	**910 Mbps** {3 X 293 Mbps/80 MHz}
802.11ac 2015 {8 X 867 Mbps/160 MHz}	**610 Mbps** {1 X 867 Mbps/160 MHz}	**1200 Mbps** {2 X 867 Mbps/ 160 MHz}	**1800 Mbps** {3 X 867 Mbps/160 MHz}

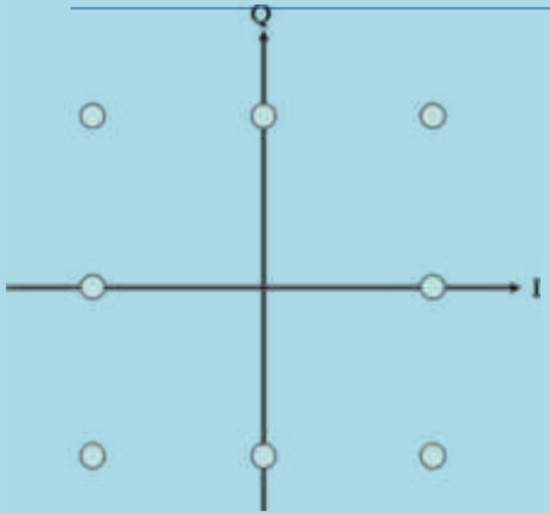
Don't Expect 6.93 Gbps From Your 802.11ac Access Point

http://www.cisco.com/en/US/prod/collateral/wireless/ps5678/ps11983/white_paper_c11-713103.pdf

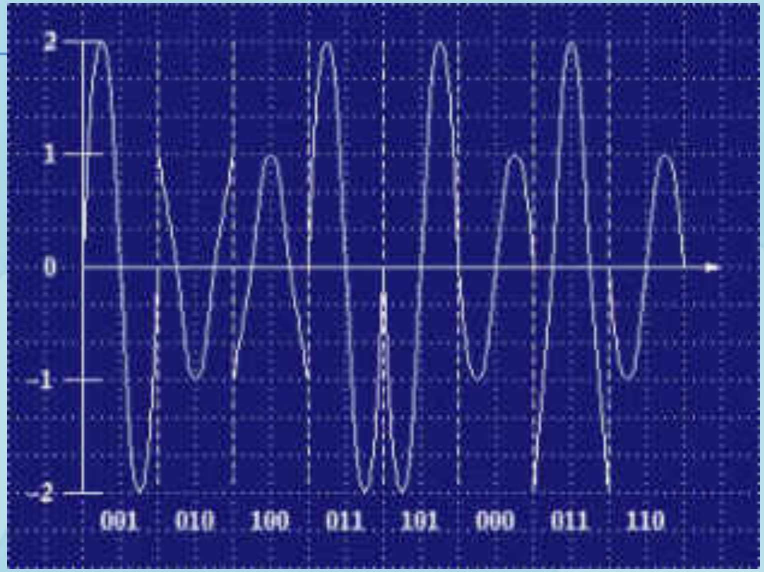
http://tinyurl.com/cisco80211ac

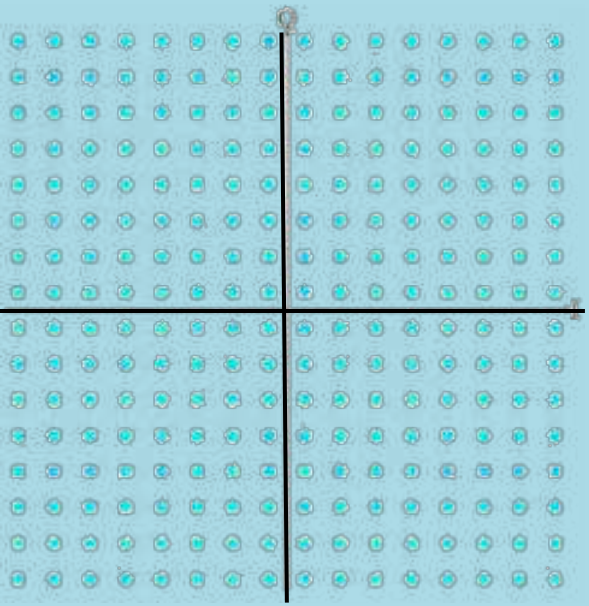
Quadrature Amplitude Modulation

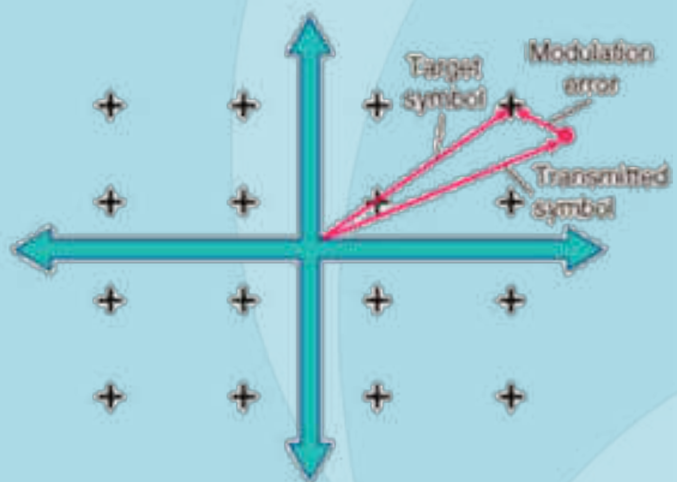
8-QAM: 3 bits/baud

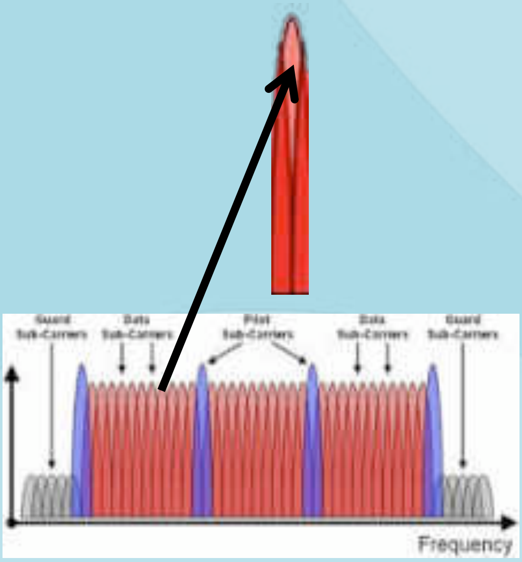


Bit value	Amplitude	Phase shift
000	1	None
001	2	None
010	1	1/4
011	2	1/4
100	1	1/2
101	2	1/2
110	1	3/4
111	2	3/4



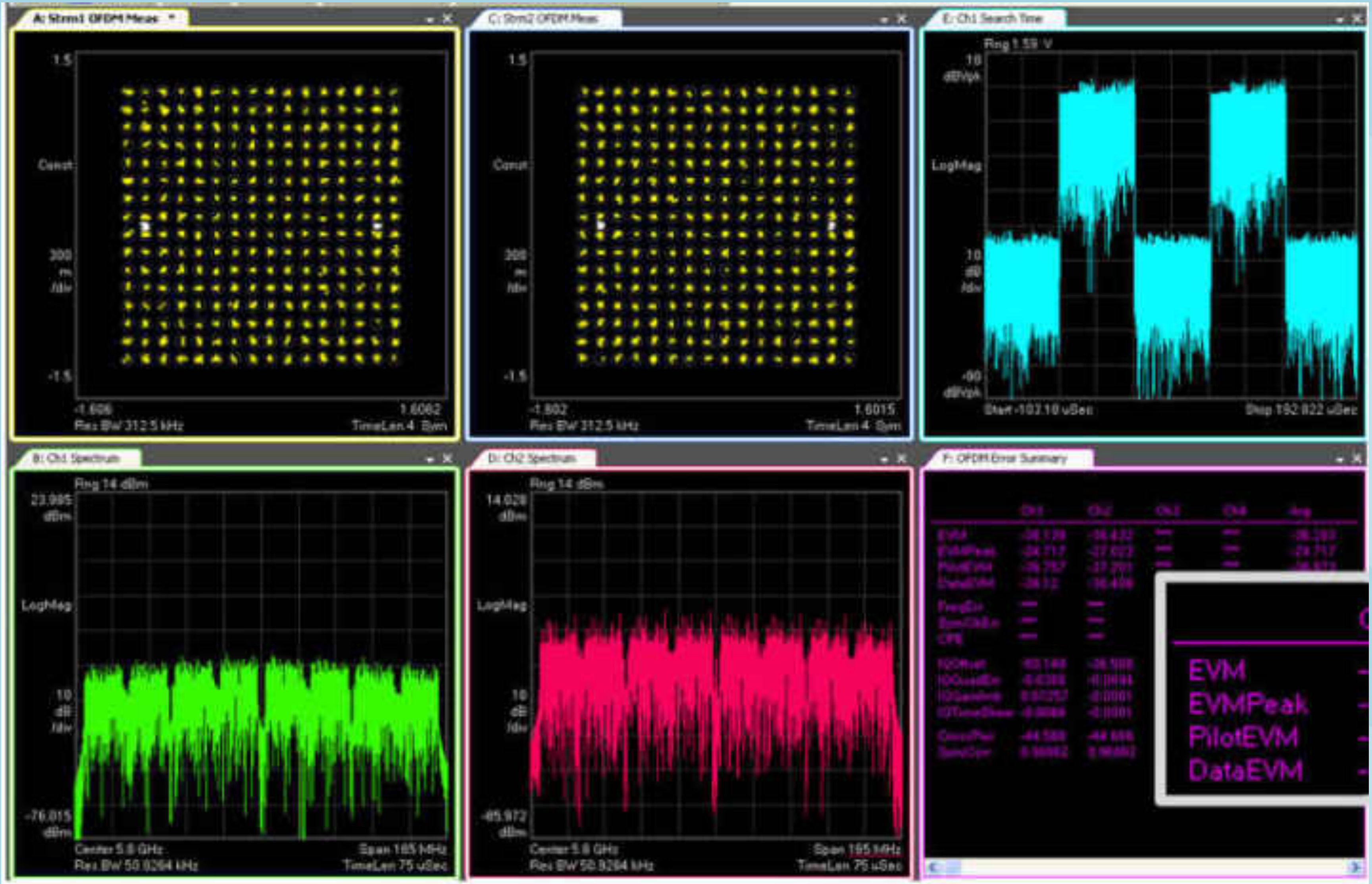






256-QAM: 8 bits/baud

Challenges with 256 QAM



MCS Index and FFT Enhancements

- 256 QAM Modulation
  - More bits encoded into each signal transition (“bits per baud”)
- 512 FFT (Fast Fourier Transform)
  - More granular sampling to recover bits with greater precision

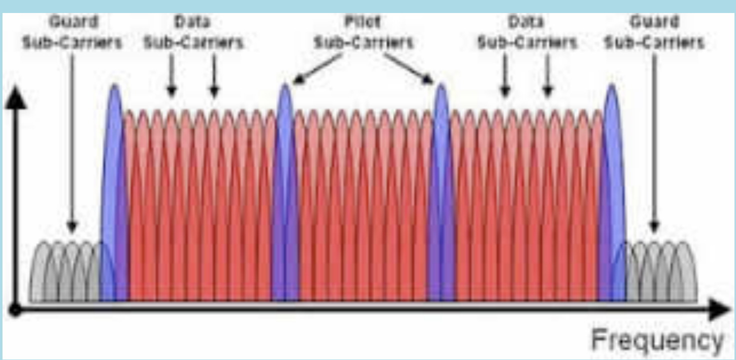
20 MHz N_{SS} =1 — N_{SS} = Number of Spatial Streams

MCS Index	Modulation	R	N_{BPSCS}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	N_{ES}	Data rate (Mb/s) 800ns GI	Data rate (Mb/s) 400ns GI
8	256-QAM	3/4	8	52	4	416	312	1	78.0	86.7
9										

160 MHz N_{SS}=8

MCS Index	Modulation	R	N_{BPSCS}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	N_{ES}	Data rate (Mb/s) 800ns GI	Data rate (Mb/s) 400ns GI
8										
9	256-QAM	5/6	8	468	16	29952	24960	12	6240.0	6933.3

N_{BPSCS} : # of coded bits per subcarrier per spatial stream. N_{CBPS} : # of coded bits per symbol.
N_{DBPS} : # of data bits per symbol. N_{ES} : # of BCC encoders for the Data field.



	Mandatory for 802.11ac Support			{Optional}
Channel Width	20 MHz	40 MHz	80 MHz	160 MHz
Sub-Carriers / Pilots	54/2	108/6	234/8	468/16

Connection Rates by MCS Index

20 MHz $N_{SS}=1$ — N_{SS} = Number of Spatial Streams

MCS Index	Modulation	R	N_{BPSCS}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	N_{ES}	Data rate (Mb/s) 800ns GI	Data rate (Mb/s) 400ns GI
0	BPSK	1/2	1	52	4	52	26	1	6.5	7.2
1	QPSK	1/2	2	52	4	104	52	1	13.0	14.4
2	QPSK	3/4	2	52	4	104	78	1	19.5	21.7
3	16-QAM	1/2	4	52	4	208	104	1	26.0	28.9
4	16-QAM	3/4	4	52	4	208	156	1	39.0	43.3
5	64-QAM	2/3	6	52	4	312	208	1	52.0	57.8
6	64-QAM	3/4	6	52	4	312	234	1	58.5	65.0
7	64-QAM	5/6	6	52	4	312	260	1	65.0	72.2
8	256-QAM	3/4	8	52	4	416	312	1	78.0	86.7
9										

160 MHz $N_{SS}=8$

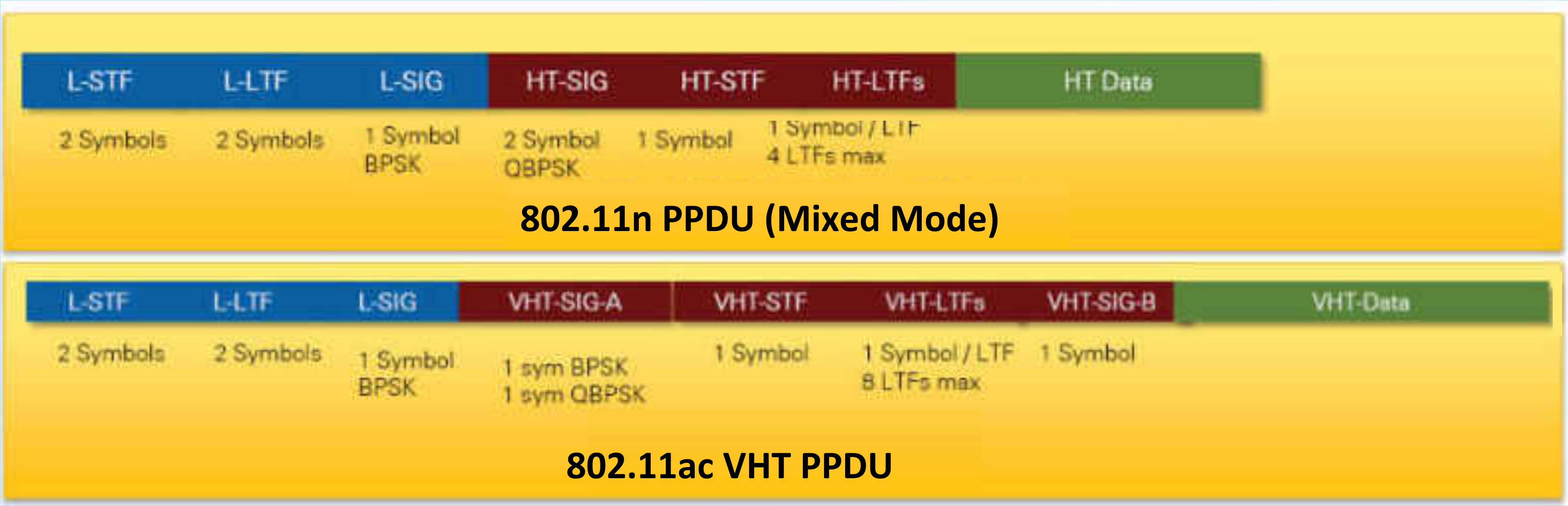
MCS Index	Modulation	R	N_{BPSCS}	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	N_{ES}	Data rate (Mb/s) 800ns GI	Data rate (Mb/s) 400ns GI
0	BPSK	1/2	1	468	16	3744	1872	1	468.0	520.0
1	QPSK	1/2	2	468	16	7488	3744	2	936.0	1040.0
2	QPSK	3/4	2	468	16	7488	5616	3	1404.0	1560.0
3	16-QAM	1/2	4	468	16	14976	7488	4	1872.0	2080.0
4	16-QAM	3/4	4	468	16	14976	11232	6	NA	3120.0
5										
6	64-QAM	3/4	6	468	16	22464	16848	8	4212.0	4680.0
7	64-QAM	5/6	6	468	16	22464	18720	9	4680.0	5200.0
8										
9	256-QAM	5/6	8	468	16	29952	24960	12	6240.0	6933.3

Assume actual data throughput to be roughly 70% of the MCS Index rate

R – Coding Rate
N_{BPSCS} – Bits/Subcarrier (per Spatial Stream)
N_{SD} –Modulated Data Symbols
N_{SP} –Pilot Symbols
N_{CBPS} –Coded Bits / Symbol
N_{DBPS} –Data Bits / Symbol
N_{ES} –Data Field BCC Encoders

The PLCP Protocol Data Unit (PPDU)

- Physical Layer Convergence Procedure
- Symbol duration: 4 microseconds (Optional 3.6 μs symbol with short guard interval)



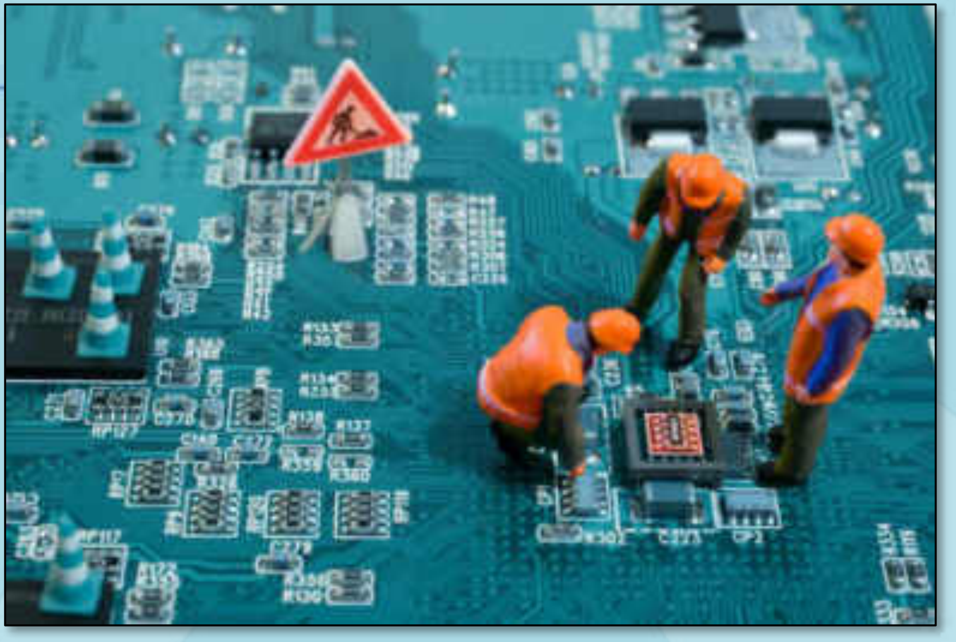
1 Symbol = 4μs

L: Indicates Legacy (802.11abgn) Field
HT: Indicates 802.11n High Throughput
VHT: Indicates 802.11ac Very High Throughput
SIG: Protection Mechanism Signal Field
VHT-SIG-A: Number of Streams, MCS, Beamforming Matrix
VHT-SIG-B: Length of Data and MCS for MU Mode
STF: Short Training Field
VHT-STF: Improves AGC Estimations for MIMO
LTF: Long Training Field (Mapping Matrix)

Things You Can't Capture

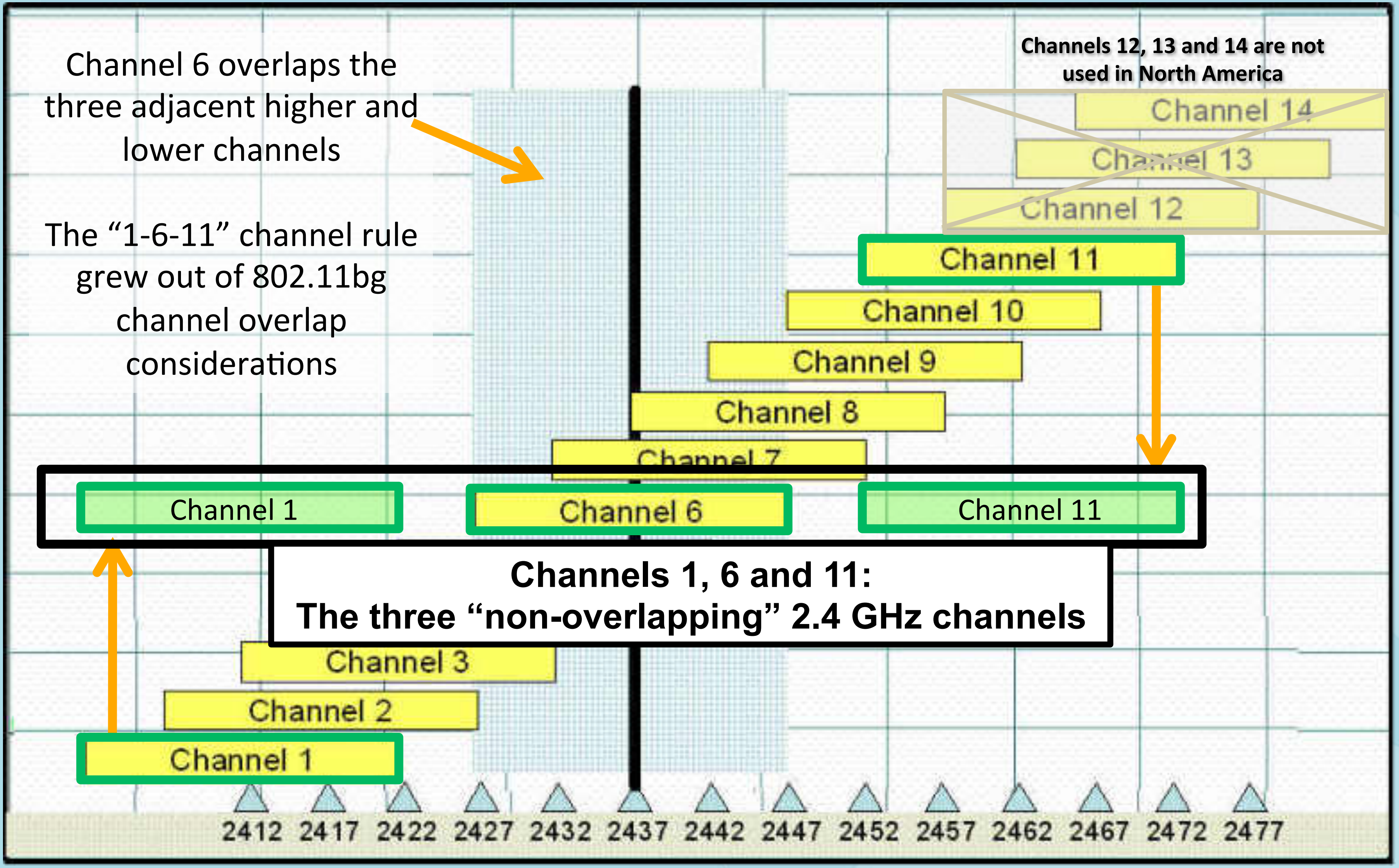
- A receiving adapter will discard any packet that it is unable to recover
  - Client devices may support data rates, modulation types, channel width or MIMO streams that aren't supported by your capture adapter
- Upstream and downstream data may be transmitted with a different MCS index
  - You may only see one side of a conversation when capturing in 802.11ac raw mode
- 802.11ac cell capacity may exceed a notebook computer's ability to buffer received packets
  - Client device hardware is designed to support the expected data transfer rates to and from the client device under normal application usage

Hardware Evolution



- The newest chipsets and radio designs allow for amazing operational enhancements
- Devices can operate in significantly noisy environments and access points can detect noise and interference
- If your capture adapter (and software) can't perform as well as the WLAN devices you'll loose packets

The Conventional "1-6-11" Channel Rule

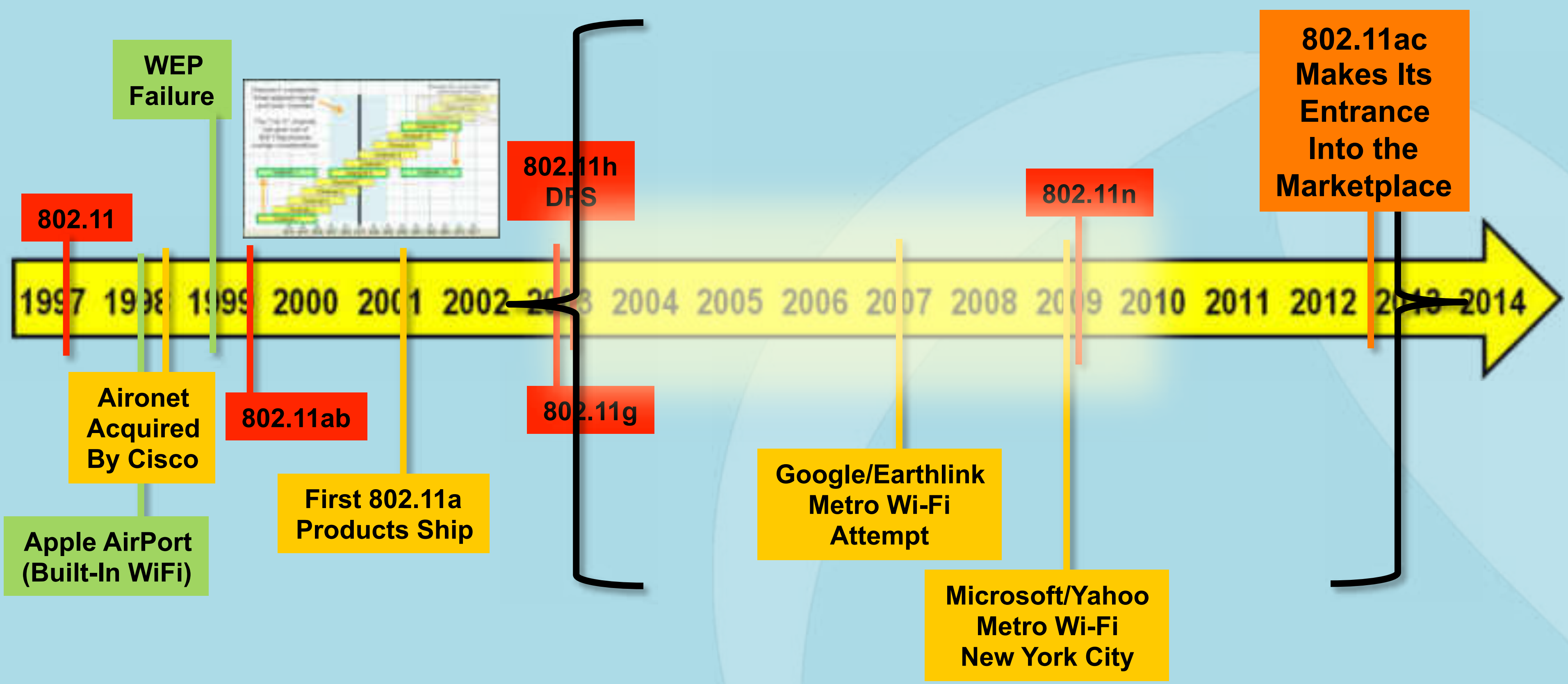


Channel 6 overlaps the three adjacent higher and lower channels

The "1-6-11" channel rule grew out of 802.11bg channel overlap considerations

Channels 1, 6 and 11:
The three "non-overlapping" 2.4 GHz channels

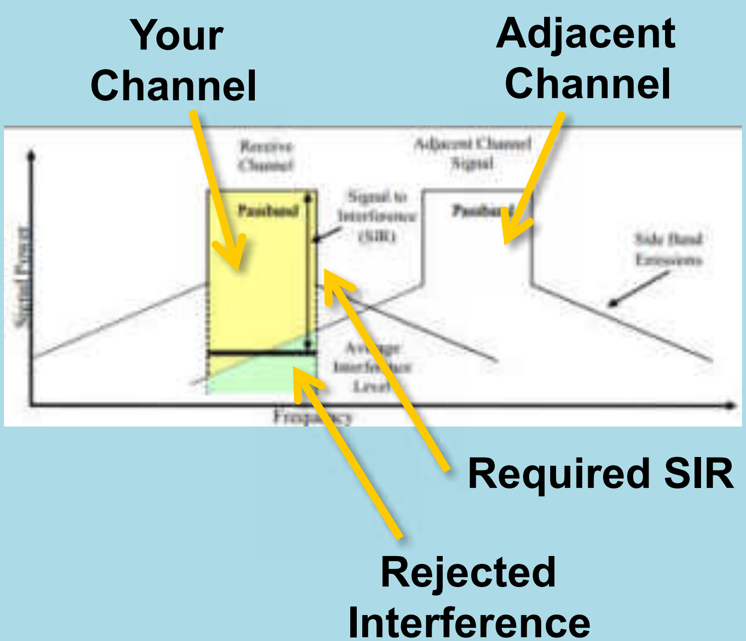
The WiFi Technology Timeline

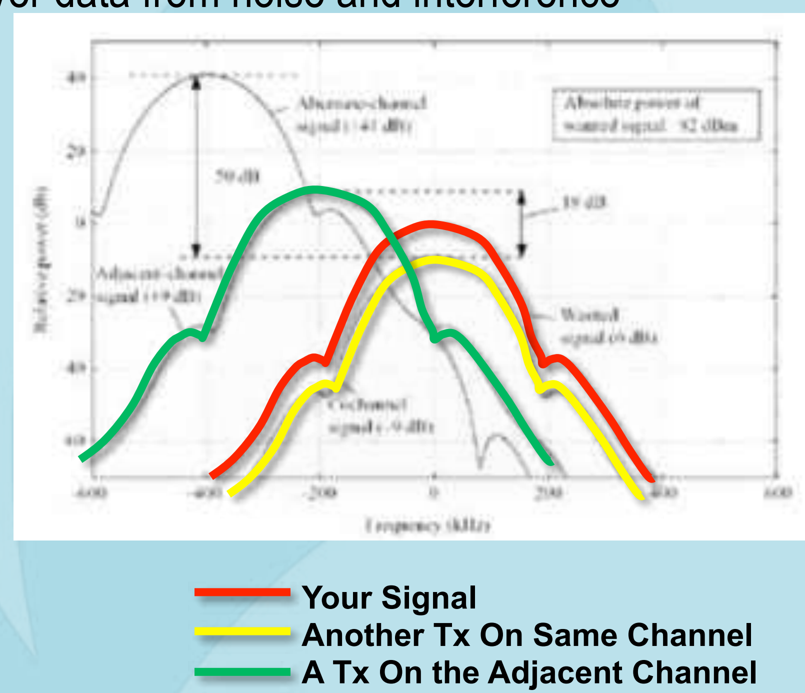


There's been a 9 year evolution in the sophistication of WiFi RF front-end design, processing algorithms and chipset manufacturing since 802.11g

Evolution of Receiver Architecture

- Adjacent Channel Rejection
  - Component examples circa 2001
    - IEEE specifies a minimum of 35 dB
    - Intel Prism 3 (2001) chipset provided 40 dB
  - Component examples circa 2013
    - IEEE allows a minimum as low as -9 dB (adjacent channel is stronger!)
    - Circuitry can more accurately recover data from noise and interference



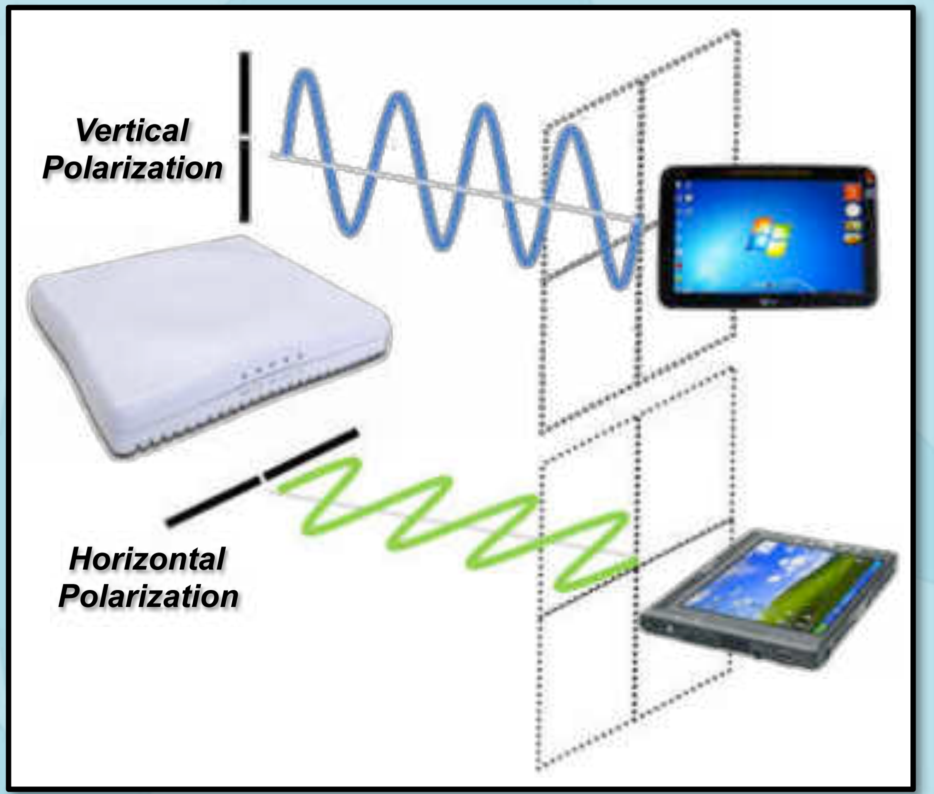


Dynamic Channel Management

- Access points have become noise- and interference-aware
  - Cisco CleanAir with Digital Signal Processor Vector Accelerator (DAvE)
    - Custom processing core performing filtering, decimation, rotation, sync-word detection and modulation detection
  - Ruckus ChannelFly
    - Real-time throughput measurement on all available channels with dynamic 802.11h channel switching for all client devices
  - Aruba Adaptive Radio Management (ARM) with RFProtect
    - Measures non-duty cycle noise floor, CRC errors and other factors to dynamically change channels for noise and interference mitigation

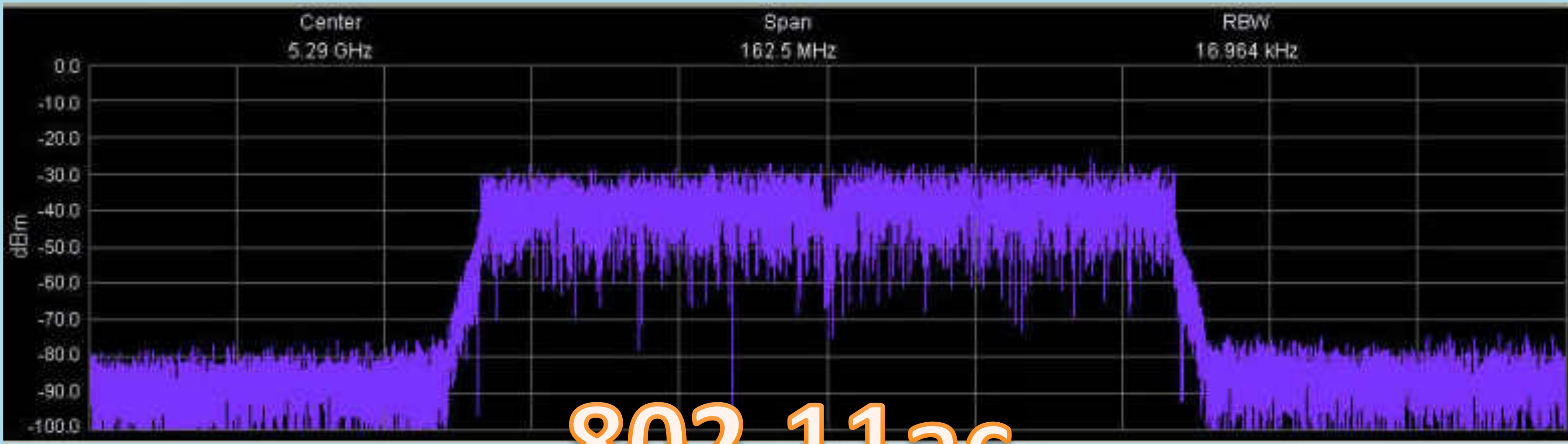
Polarization

- The electric field oscillates in the plane of an omnidirectional dipole antenna
  - "Vertical Polarization" versus "Horizontal Polarization"
- For maximum energy transfer the receiving antenna must have the same polarization as the transmitting antenna
  - As much as **40 dB** of loss can be measured in the real-world when antennas are cross-polarized
- The relative polarity between a conventional dipole antenna and a hand-held device is unpredictable
- BeamFlex allows for numerous polarization angles betweenvertical and horizontal to accommodate mobile devices



Things You Can't Capture

- Expect changes to 2.4 GHz channel planning
  - Using 3 capture adapters may no longer be sufficient in 2.4 GHz for 802.11n (remember that 802.11ac only operates in 5 GHz)
- Expect dynamic load balancing and channel adjustment
  - Client conversations can be moved to a different channel in real-time using 802.11h
- Smart antenna systems may be transmitting a signal that is cross-polarized relative to your capture adapter antenna
  - Your RSSI may be 30 dB less than the desired signal due to cross-polarization

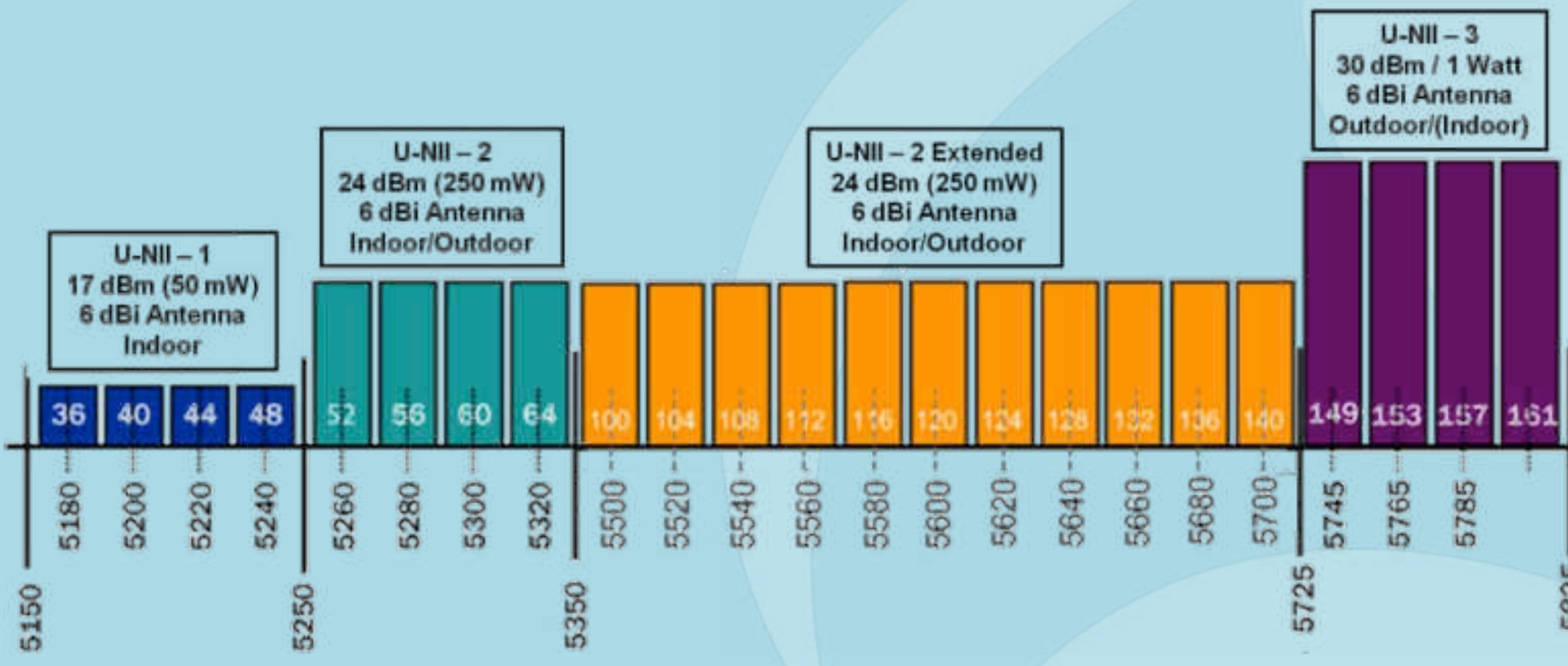


802.11ac Channel Width and Control

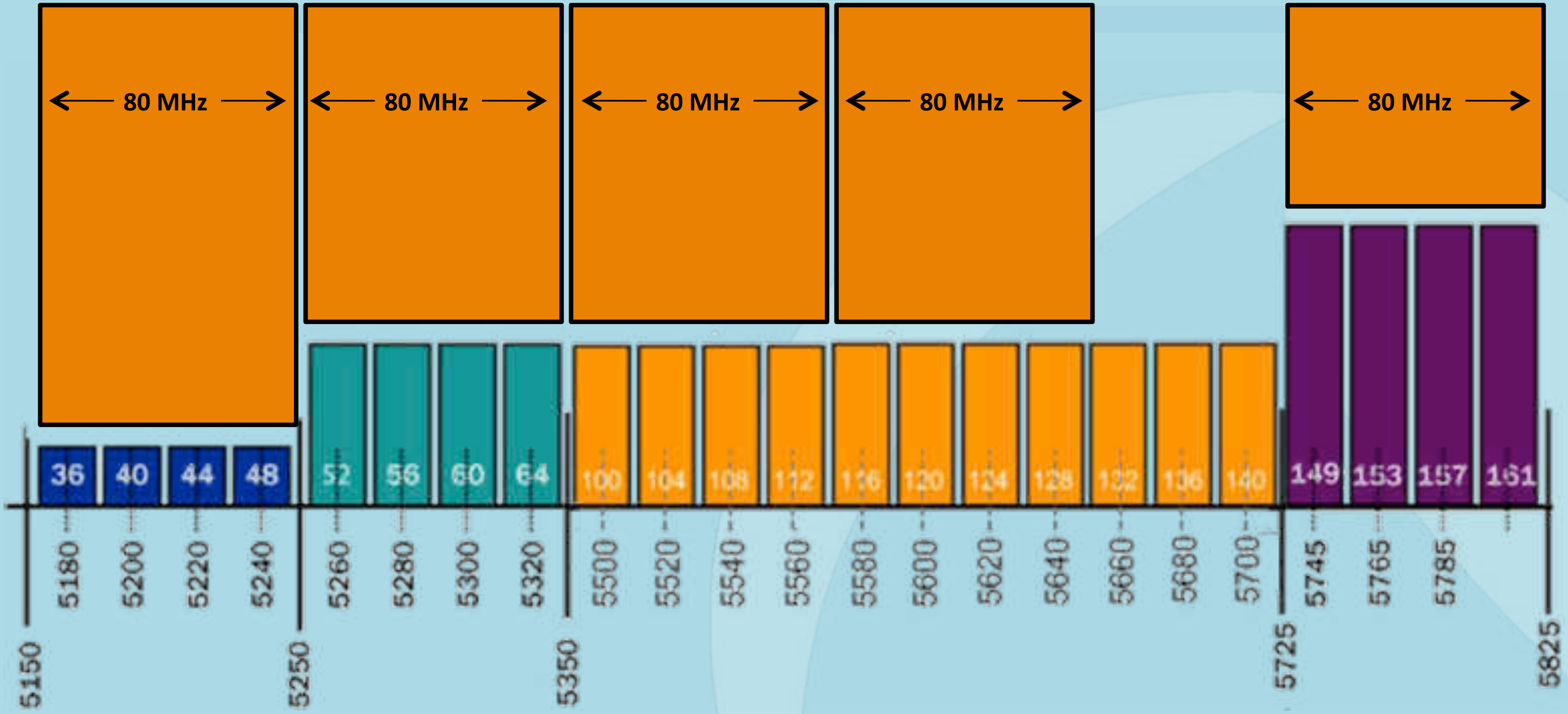
- 20 MHz, 40 MHz and 80 MHz channel width support is required for an 802.11ac-certified device
- The standard specifies the use of 160 MHz wide channels
- Channel width may be a factor that adds to the potential for packet loss during raw packet capture operations
- The 20 MHz channels that comprise a wider channel can change dynamically

ISM Channel Availability

- 802.11ac Channel Configuration Options
  - 20, 40, 80 and 160 Mbps
  - DFS is still required in U-NII-2 Extended (Channel 100 – 140)
  - A 20 MHz channel is considered “Primary”



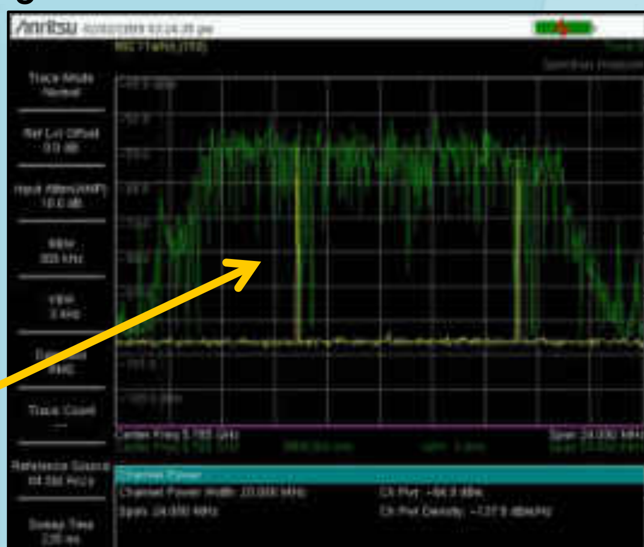
Current ISM Channel Availability



Dynamic Channel Width Adjustment

- Channel Width Can Change
  – Like Dynamic Rate Adjustment
- A 20 MHz Channel is “Primary”
  – Non-Primary channels must be reserved prior to transmission
- Maximum Accepted Channel Width is Exchanged Between Rx and Tx
  – “Operating Mode Notification Action” frame

How bad is the noise?



802.11ac Adaptive Adjustment

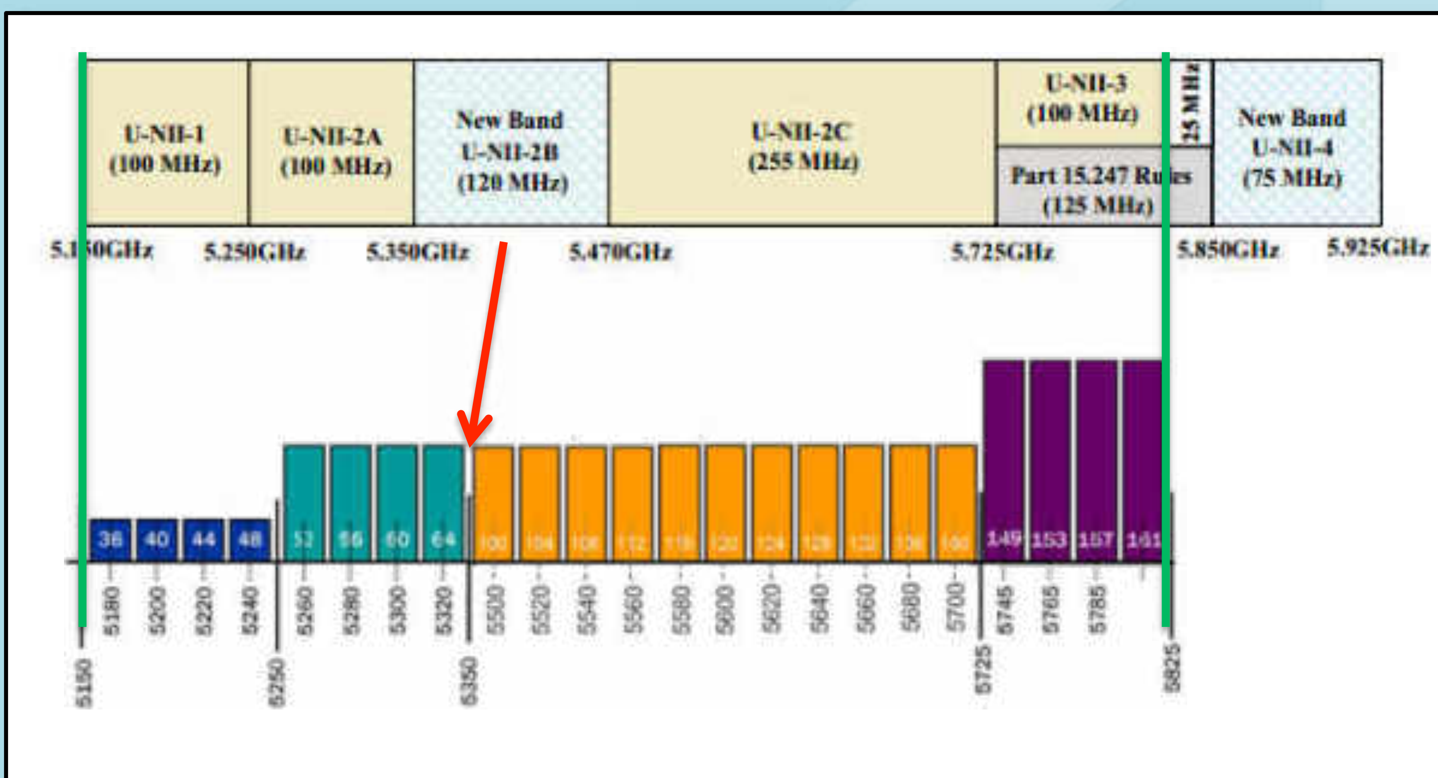
- As with 802.11g/n, devices reduce their modulation rates in response to channel degradation
- Unlike 802.11g/n, 802.11ac provides the capability of also adjusting the channel bandwidth (20, 40, 80, 160 MHz wide)
  - Channel adjustment is done using smaller transmission segments relative to the overall configured and allocated channel width
- The channel can also be “split”
  - A 40 MHz segment at the bottom of a 160 MHz channel and another 40 MHz segment at the top of the 160 MHz channel

80 MHz

- Optimal adjustment of both modulation rate and channel bandwidth can provide as much as an 85% improvement in throughput compared to modulation rate adjustment alone!

February 20, 2013 ISM Channel Reallocation

- Keep your eye on the FCC for rule changes
- Manufacturers may want to jump into newly opened frequency space as a competitive differentiator



As per Docket No. 13-49: Revision of Part 15 Rules for U-NII Devices – Adopted February 20, 2013
New channel allocations make the U.S. U-NII specifications match those used internationally.

What You Can't Capture

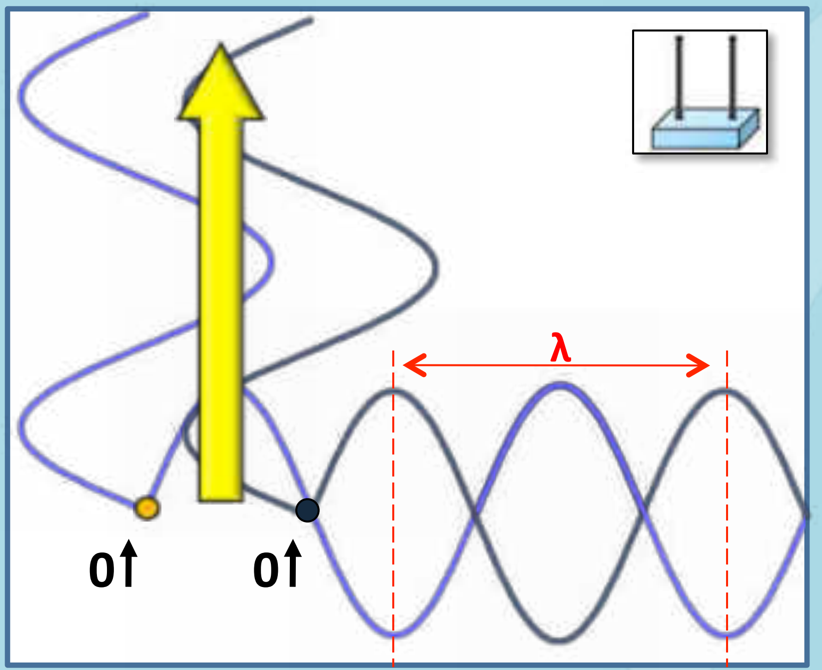
- You will not be able to capture 160 MHz transmissions with an 80 MHz adapter
  - There's every reason to believe that a Wireshark capture adapter as well as all phones, tablets and most notebook computers will be 80 MHz devices
- During a capture session the WLAN controller may adjust AP channel settings disrupting packet capture
- During a capture session you'll have clients operating with dynamic channel width
  - Early 802.11ac deployments are not expected to support dynamic channel assignment
  - Your capture adapter may not support dynamic channel assignment

Beamsteering and MIMO

- Beamsteering is standardized in 802.11ac
- Circuitry and algorithms for beamsteering are sophisticated and effective
- Beamsteering and MIMO are often mutually exclusive
- Multi-user MIMO makes it impossible to capture all traffic being transmitted in an 802.11ac environment

Chipset Beamforming – The Phased Array

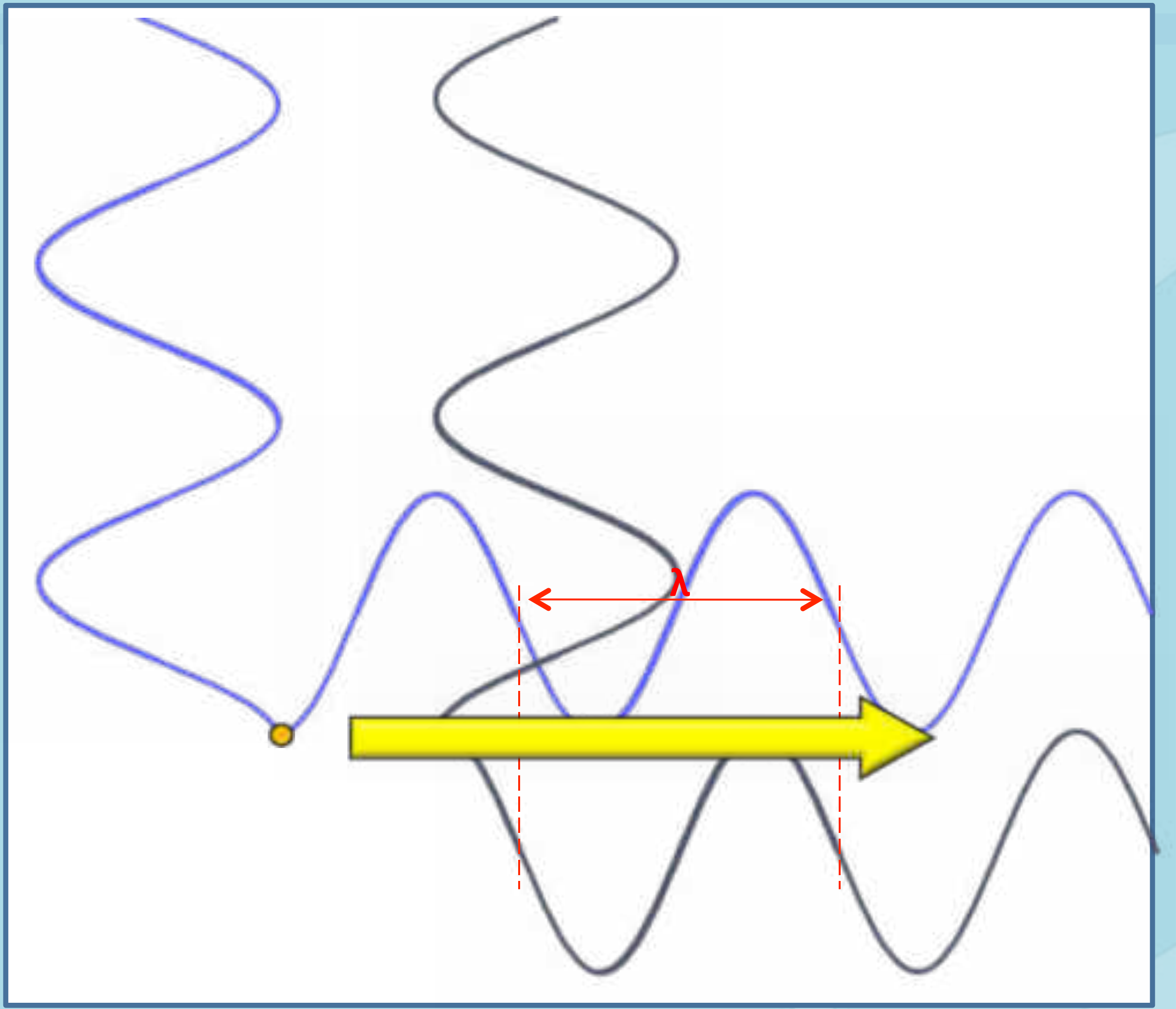
Beamforming, also called Beamsteering, allows electronic aiming of the strongest signal from (and the best reception angle to) an antenna array



Note that the signal starts at 0-degrees and is rising

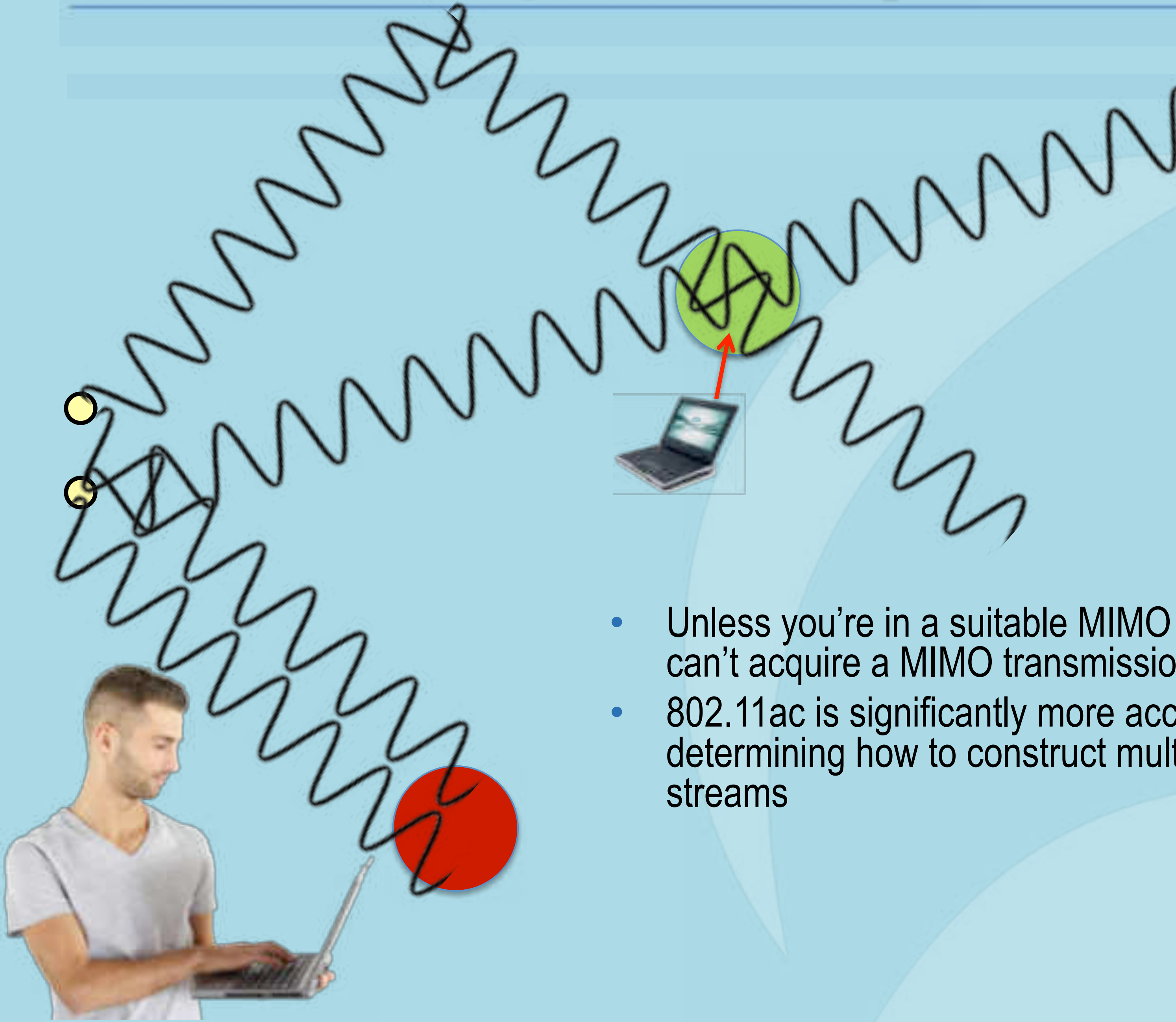
Two antennas, transmitting the same signal, with both antennas transmitting in-phase.
The ½ wavelength separation between the antennas makes the signal cancel to the left and right.

Chipset Beamforming – The Phased Array



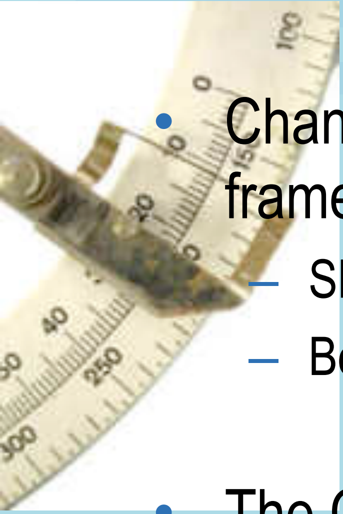
Now the two signals are 180-degrees out of phase but the ½ wavelength separation between the antennas makes the signal cancel in the up/down direction

MIMO Packet Capture Challenges



- Unless you're in a suitable MIMO "cluster" you can't acquire a MIMO transmission
- 802.11ac is significantly more accurate in determining how to construct multiple spatial streams

The Quantized Steering Matrix



- Channel information is conveyed in a VHT Compressed Beamforming frame
  - SNR for each space-time stream
  - Beamforming Feedback Matrix for each carrier
    - **Up to 56 arrival angles reported for 8X8 MIMO**
- The Compressed Beamforming Report field contains channel matrix elements
- Spatial mapping is performed following constellation mapping and space-time block coding of each contributing transmit stream

$$\psi = \frac{k\pi}{2^{b_\psi+1}} + \frac{\pi}{2^{b_\psi+2}} \text{ radians}$$

where

$k = 0, 1, \ldots, 2^{b_\psi} - 1$

b_ψ is the number of bits used to quantize ψ (defined by the Codebook Information field of the VHT MIMO Control field

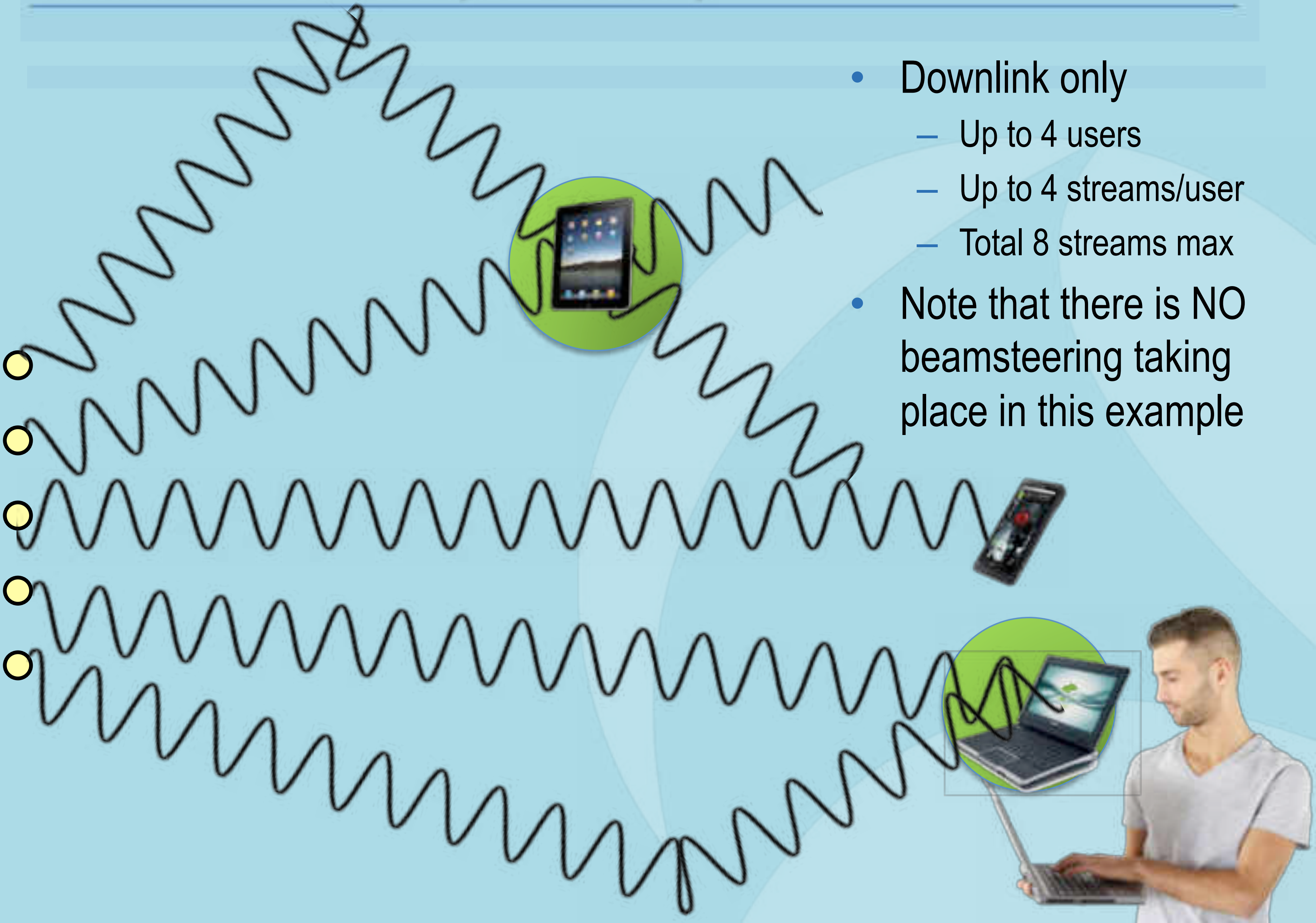
"So… I guess all this math stuff means that 802.11ac radios need a fast processor and really high quality hardware…"

VHT Sounding Protocol

- The environment is "sounded" to create a digital representation of the state of the transmission channel
  - A "Steering Matrix" is the mathematical representation of the current state of the environment
    - Attenuation and phase shift experienced by each spatial stream
- Transmit Beamforming and MU-MIMO require knowledge of the channel state to compute a steering matrix to optimize reception at one or more receivers
  - Individual space-time streams are sounded separately
  - Training symbols are transmitted ("Sounding Poll") and measured by the recipient station (or stations)
  - A channel state estimate is sent back to the beamformer from each station included in the Sounding Poll for the derivation of a steering matrix

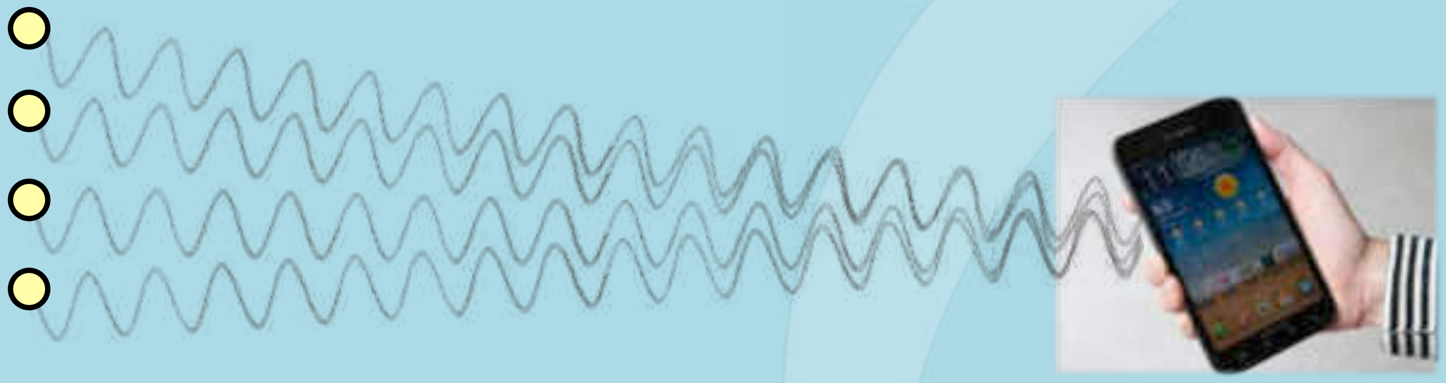
Multi-User MIMO (MU-MIMO)

- Downlink only
  - Up to 4 users
  - Up to 4 streams/user
  - Total 8 streams max
- Note that there is NO beamsteering taking place in this example



MIMO With Beamsteering

- To transmit 2 spatial streams with beamsteering would require 4 dedicated antennas

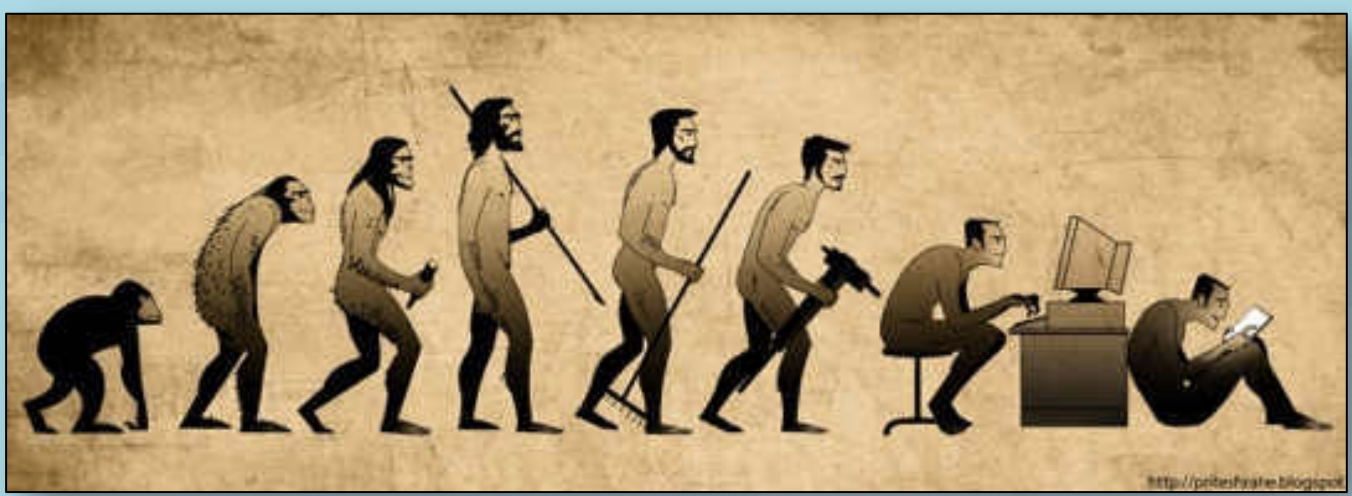


"Wi-Fi Direct" Connectivity

- Two devices can communicate directly
  - Supported by 802.11n but not implemented
  - Native support coming in Windows 8
  - Google Android will support Wi-Fi Direct over 802.11ac
- Wi-Fi Direct implementations are already in the market
  - Samsung Smart Cameras, Captivate Glide, Galaxy S2 and others
  - LG Optimus Black
  - Sony Bravia TV
  - Nook Color CM9
- 802.11ac Standardizes the Handshake Protocol
  - An enabled device advertises an ad-hoc network
  - A client connects and obtains WPA2 credentials
    - "Wi-Fi Protected Setup"
  - Connections can be one-to-one or one-to-many
    - Just like conventional access point topology

Things You Can't Capture

- You can't capture more spatial streams than your wireless adapter supports
- You can't capture a conversation if you're not in a compatible MIMO cluster
- You can only capture 1 conversation out of a possible 4 when MU-MIMO is in use
- You can't capture the "hidden" Wi-Fi-Direct transmissions even though they may impact the capacity of the coverage area

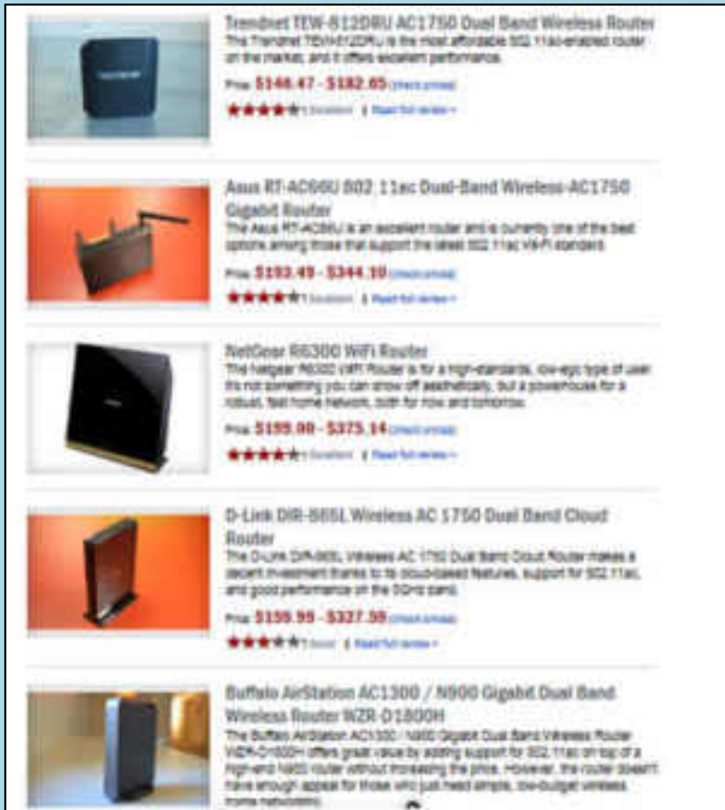


Current 802.11ac Evolution

- For the next few years it's not anticipated that aggregate cell capacity (per-AP throughput) will exceed roughly 1 Gbps
  - "1300 Mbps" specifications imply roughly 900 Mbps of actual data throughput
  - "1300 Mbps" is a best-case, 3-stream, 80 MHz channel, short guard interval transmission which is not likely to be the status-quo

Current Hardware Is Effectively Limited to 1 Gbps

- Cisco 3600 Series: 867 Mbps
- Ubiquiti UniFi Series: 1300 Mbps



MCS Index	NSS	GI = 400 ns		
		20-MHz Rate (Mbps)	40-MHz Rate (Mbps)	80-MHz Rate (Mbps)
0	1	7.2	15	32.5
1	1	14.4	30	65
2	1	21.7	45	97.5
3	1	28.9	60	130
4	1	43.3	90	195
5	1	57.8	120	260
6	1	65	135	292.5
7	1	72.2	150	325
8	1	86.7	180	390
9	1	-	200	433.3
0	2	14.4	30	65
1	2	28.9	60	130
2	2	43.3	90	195
3	2	57.8	120	260
4	2	86.7	180	390
5	2	115.6	240	520
6	2	130	270	585
7	2	144.4	300	65
8	2	173.3	360	780
9	2	-	400	866.7
0	3	21.7	45	97.5
1	3	43.3	90	195
2	3	65	135	292.5
3	3	86.7	180	390
4	3	130	270	585
5	3	173.3	360	780
6	3	195	405	877.5
7	3	216.7	450	975
8	3	260	540	1170
9	3	288.9	600	1300

Assume actual data throughput to be roughly 70% of the MCS Index rate

802.11ac Capture Hardware

- Hardware adapters are now available
  - PCIe and USB 3.0
  - Up to 1300 Mbps, 3X3 MIMO
- 802.11ac access points can act as capture devices
  - Up to 1300 Mbps, 3X3 MIMO
  - Requires RPCAP support
  - Many commercial-grade APs will provide this support
    - Cisco 3600 Series, Ubiquiti UniFi Series
- When 4X4 MIMO and >1Gbps speeds arrive (2015?) you may need to get a fiber connection to your notebook computer
  - USB 3.0 provides 3.2 Gbps (to 10 Gbps) throughput but it's unlikely that more than 3X3 MIMO can be practically supported in a USB form-factor
  - Apple Thunderbolt provides an optical interface of between 5.4 Gbps and 10 Gbps

ASUS AC1750 3X3 Adapter
PCIe Interface 1300 Mbps
{$98.99 on Amazon}

Belkin AC 2X2 USB Adapter
USB 3.0 Interface 867 Mbps
{$50.09 on Amazon}

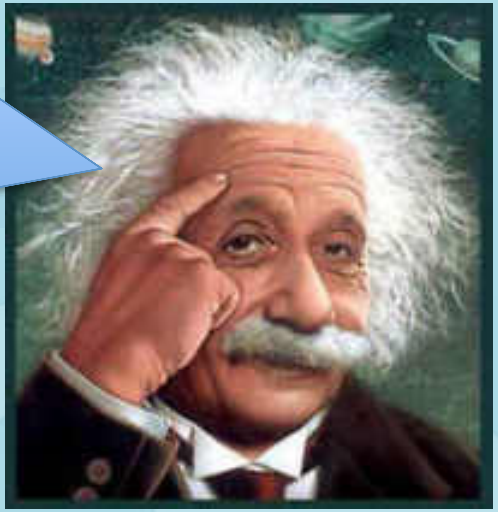
NetStor External PCIe Expansion
PCI Optical Interface 10 Gig
~$1000.00 on the Web

Wireshark And 802.11ac

- New MCS Index and PLCP Header decodes in the RadioTap Header
- New methodologies to account for MU-MIMO and tighter beamsteering
- Remember that you can only capture packets that your capture adapter is capable of recovering from the air
  - MIMO stream limitations
  - MIMO cluster limitations
  - MU-MIMO location limitations
  - Hardware capacity limitations

"We cannot solve our problems with the same thinking we used when we created them."

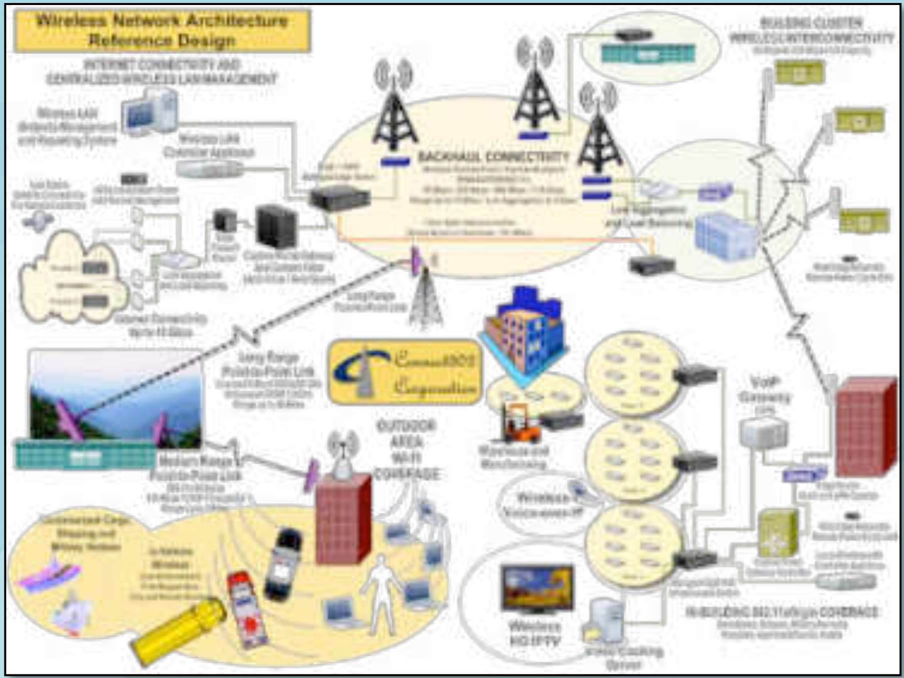
- Albert Einstein



Modulation and Capacity
Hardware Evolution
Channel Width and Control
Beamsteering and MIMO

- Packet capture methodology will have to adjust to meet the challenges of 802.11ac
- Wireless network design and capacity planning will be impacted by the unique technical features in 802.11ac
- Be vigilant as 802.11ac makes its way into the marketplace; marketing hype can obfuscate technical reality

Thank You !



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