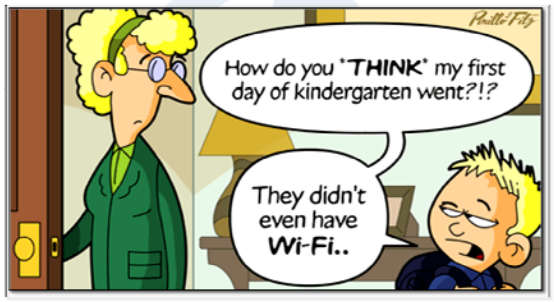
Wireshark Developer and User Conference

Wireshark and 802.11ac Wireless Evolution
Joe Bardwell – Connect802 Corporation



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Wireshark Developer and User Conference

Wireshark and 802.11ac Wireless Evolution

June 24 and 25, 2012

Joe Bardwell
Chief Scientist | Connect802 Corporation

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About Connect802 Corporation

- Founded in 1994 with headquarters in the San Francisco Bay area and East Coast engineering out of Knoxville, Tennessee
- Providing nationwide Wi-Fi, WiMAX, cellular and other wireless solutions
- Applying 3-dimensional RF CAD modeling and simulation to the design process
- Equipment sales, installation and support

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3-D RF CAD Modeling and Simulation

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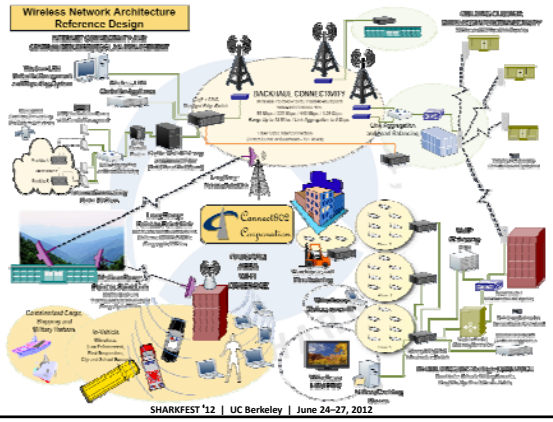
The Connect802 Landscape



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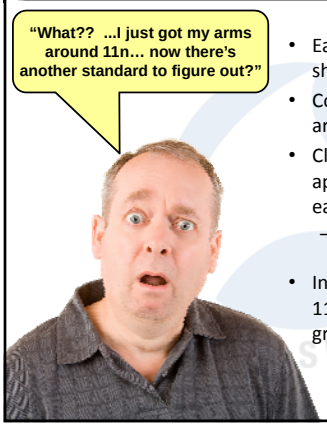
Here it comes: 802.11ac



- Early consumer products are shipping today
- Commerical-grade access points are expected in 2013
- Client-side 11ac may begin to appear in mid-to-late 2013 or early 2014
  - Apple may even have 11ac support in products by the end of this year!
- Infonetics Research expects the 11ac market to have a spike in growth in 2015

The Evolving End-User Community

- 25 users in the -65 dBm coverage cell from a single access point
- Each user will videoconference, transfer files, use a VoIP handset, check email, and more
- 802.11n does not have the capability of meeting these requirements

Plus:
High Density Environments including…
- Dormitories
  - HD Video and Gaming
- College Amphitheater Classrooms
  - 100+ Simultaneous Users
- Stadiums and Auditoriums
  - 20,000 to 70,000 Side-by-Side Users

And Requirements For:
- Cellular Offload
  - Minimum latency and jitter required
- Video Gaming
  - Minimum latency
  - High Bandwidth Video
- HD IPTv (25 Mbps Stream)
- Uncompressed 1920X1080 (3.7 Gbps Stream!)

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The Evolving 802.11 Standards

802.11	802.11b	802.11g/a	802.11n	802.11ac
2 Mbps	11 Mbps	54 Mbps	600 Mbps	6.9 Gbps

"The time's they are 'a changing.."
- **Per-User Capacity Demand**
- **Coverage Cell User Density**
- **Reliance on Wireless Infrastructure**
- **Application Sophistication**

In the end, it's packets…
all the way down!

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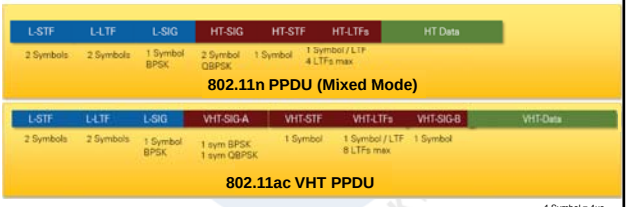
The PLCP Protocol Data Unit (PPDU)

- 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
VHT: Indicates 802.11ac Very High Throughput
VHT-SIG-A: Number of Streams, MCS, Beamforming Matrix
STF: Short Training Field
LTF: Long Training Field (Mapping Matrix)

HT: Indicates 802.11n High Throughput
SIG: Protection Mechanism Signal Field
VHT-SIG-B: Length of Data and MCS for MU Mode
VHT-STF: Improves AGC Estimations for MIMO

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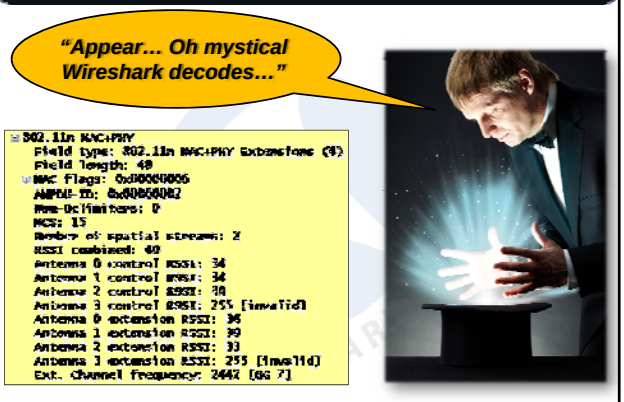
The Evolution of Wireshark



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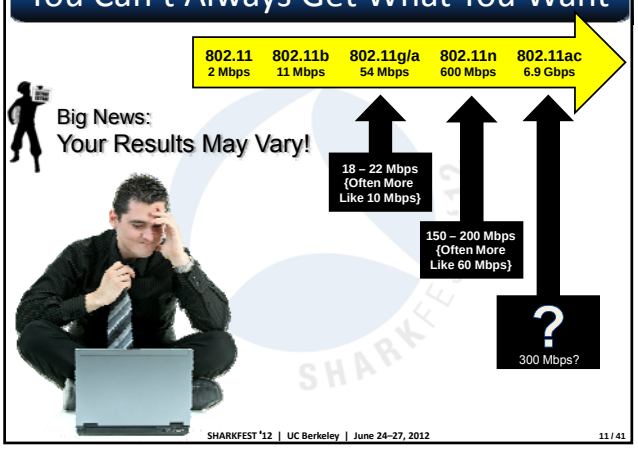
You Can't Always Get What You Want



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802.11ac is NOT 802.11ad

- Don't confuse 802.11ac with 802.11ad
  - WiGig Alliance initiated the standard
    - Confirmed in May 2010 as the basis for the 802.11ad draft standard
  - Operates in the 60 GHz Band
  - 4 X 2.16 GHz wide channels delivering up to 7 Gbps
  - Single carrier radio (allows 2.4 and 5 GHz Wi-Fi plus 60 GHz 11ad)
  - Very limited range at 60 GHz (HDMI Cable Replacement)
  - Up to 32 spatial streams with refined beamforming
- Oh – and there's also 802.11ah coming down the pike…
  - Sub-1GHz frequencies
    - US 902-928 MHz ISM Band
    - Does not include TV white space (802.11af)
  - Ultra low-power Wi-Fi
  - Targeted for product-to-market in 2014

In case you wondered: 802.11ae is a standard for prioritization of management frames when exchanged between LAN and WAN

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Today's Mind Meld

The Interesting World of 802.11ac:

- Overview of 802.11ac Features and Capabilities
- Spatial Streams in 802.11ac
- 802.11ac Beamforming
- Fast Collision Inference
- "Wi-Fi Direct" Connectivity
- ISM Channel Availability for Wider 802.11ac Channels
- Dynamic Channel Width Adjustments
- MCS Index and FFT Enhancements
- Unanswered Questions: Things We Know We Don't Know
- ~~Things We Don't Know We Don't Know~~

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Overview of 802.11ac

- The 802.11ac Committee Was Formed in September, 2008
- Wireshark Will Evolve to Capture and Decode 802.11ac Packets
  - 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
  - Planned for February, 2013

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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

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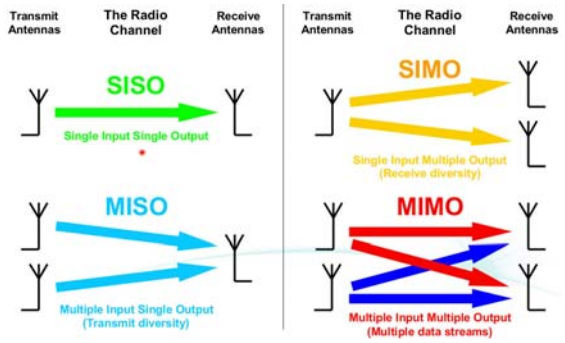
Spatial Streams in 802.11ac



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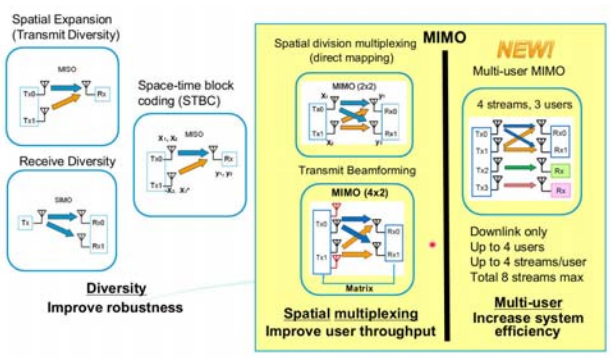
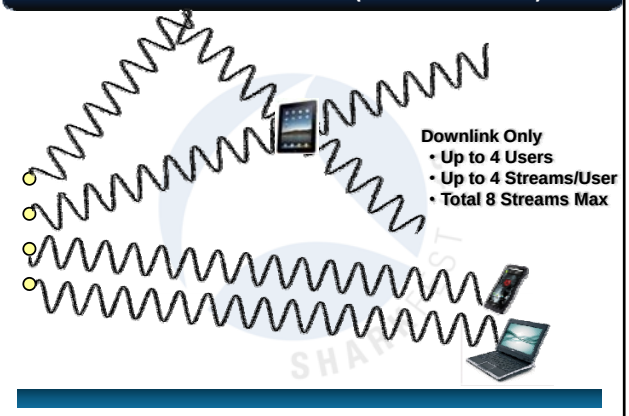
MIMO in 802.11ac



MultiUser MIMO (MU-MIMO)



802.11ac Beamforming

- Access point and client device share information about the communication's channel
- Both devices can coherently focus their transmission streams at each other
- The 802.11ac chipset adjusts the transmitted signals phase on each antenna to overcome multipath distortion and maximize the acquisition of multiple spatial streams
- 802.11ac beamforming is an optional feature but it is standardized in the spec
  - Unlike vendor-proprietary 802.11n beamforming methods
    - Ruckus BeamFlex
    - Cisco MRC and beamforming

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

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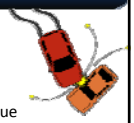
The Quantized Steering Matrix

- 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

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

DCF Fast Collision Inference



- DCF Fast Collision Inference on secondary channels
- Collision detection invokes exponential backoff
  - A random delay selected from an increasing maximum value
  - After the tunable Short/Long Retry Count is exceeded then rate reduction is invoked
- It may be faster to use RTS/CTS than to invoke CSMA/CA exponential backoff
  - Remember that 802.11ac can have dramatically higher throughput than 802.11n but exponential backoff is essentially the same in both
- RTS/CTS frames can implement collision inference
  - If a CTS is not received in response to an RTS then another RTS can be transmitted more quickly than would be the case when a long data frame is transmitted and no ACK is received

"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

Wi-Fi Direct

- **Wi-Fi Direct Provides Capabilities Similar to Bluetooth But At Wi-Fi Speeds and Ranges**
  - Support for Wi-Fi Direct is included in 1st Generation 802.11ac chipsets

From YouTube by the WiFi Alliance
"Wi-Fi Direct™: Connect with the possibilities"

YouTube Wi-Fi Direct

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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	9744	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

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

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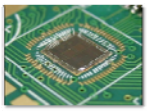
Error Correction With BCC

- Binary Convolutional Codes
  - A quantifiable number of errors can be guaranteed to be corrected
    - The "Correcting Capability" (t) can be calculated based on the complexity of the encoding scheme
    - The "Hamming Distance" (d) is the number of bits that are different in two strings of equal length

$$t = \frac{d-1}{2}$$

- Used In All 802.11 Implementations
  - The encoder(s) must be capable of processing the transmitted bit stream
    - 802.11n implements a single BCC encoder
    - 802.11ac can implement up to 12 separate encoders



Multiple BCC Encoders Implies High Processing Capabilities

- A Typical Encoding Process
  - A binary convolutional code is denoted by a three-tuple (n, k,m).
  - n output bits are generated whenever k input bits are received.
  - The current n outputs are linear combinations of the present k
  - Input bits and the previous m × k input bits.
  - m designates the number of previous k-bit input blocks that must be memorized in the encoder.
  - m is called the memory order of the convolutional code

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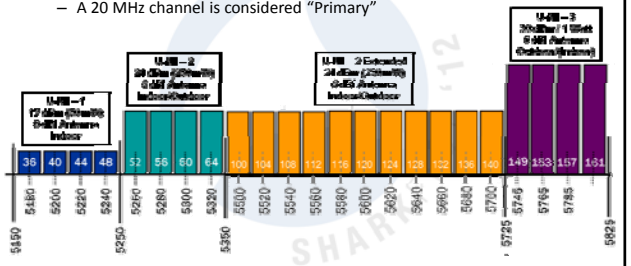
ISM Channel Availability

- 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"



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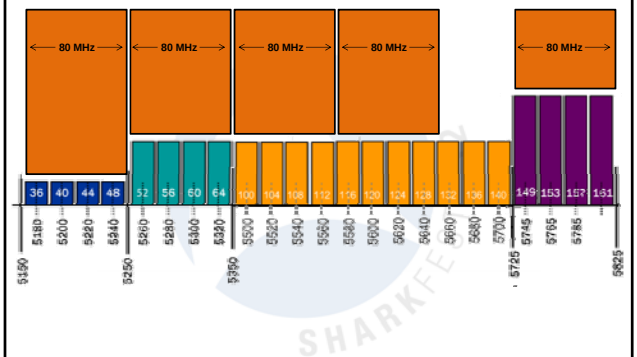
ISM Channel Availability



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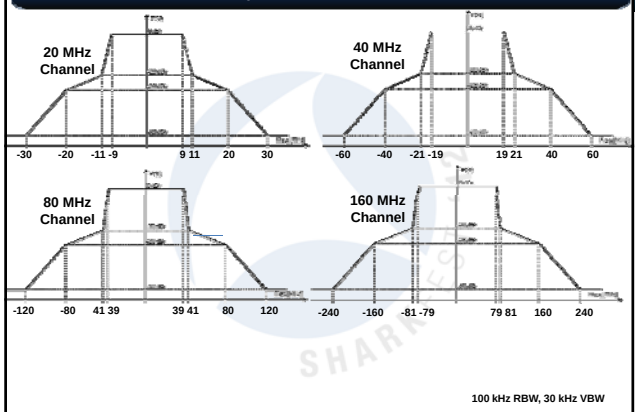
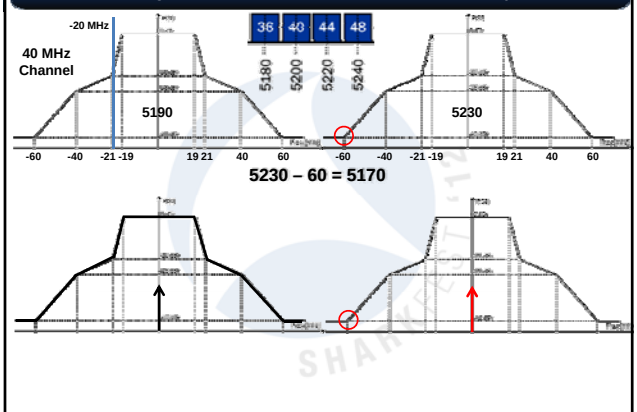
RF Spectral Masks



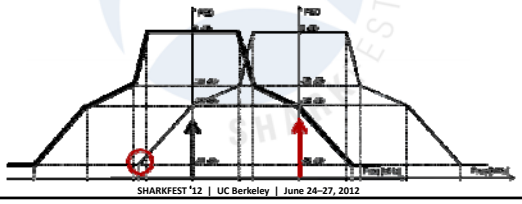
100 kHz RBW, 30 kHz VBW

Adjacent Channel Overlap



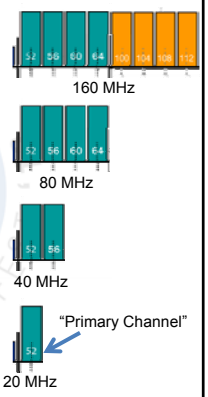
Interfering Channel Rejection

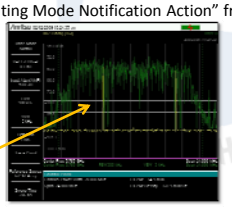
Modulation	Rate (R)	Adjacent channel rejection (dB)		Nonadjacent channel rejection (dB)	
		20/40/80/160 MHz Channel	80+80 MHz Channel	20/40/80/160 MHz Channel	80+80 MHz Channel
BPSK	1/2	16	13	32	29
QPSK	1/2	13	10	29	26
QPSK	3/4	11	8	27	24
16-QAM	1/2	8	5	24	21
16-QAM	3/4	4	1	20	17
64-QAM	2/3	0	-3	16	13
64-QAM	3/4	-1	-4	15	12
64-QAM	5/6	-2	-5	14	11
256-QAM	3/4	-7	-10	9	6
256-QAM	5/6	-9	-12	7	4



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





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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!

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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

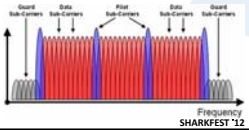
20 MHz N_{SS} =1 — N_{SS} = Number of Spatial Streams

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

160 MHz N_{SS}=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

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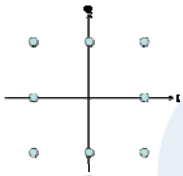
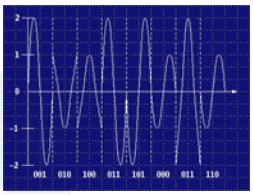
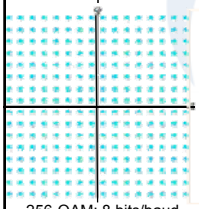
Quadrature Amplitude Modulation

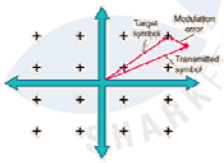
8-QAM: 3 bits/baud

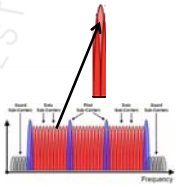


Bit value	Amplitude	Phase shift
000	1	None
001	2	None
010	1	1/4
011	2	1/4
100	1	1/2
101	2	1/2
110	1	3/4
111	2	3/4









256-QAM: 8 bits/baud

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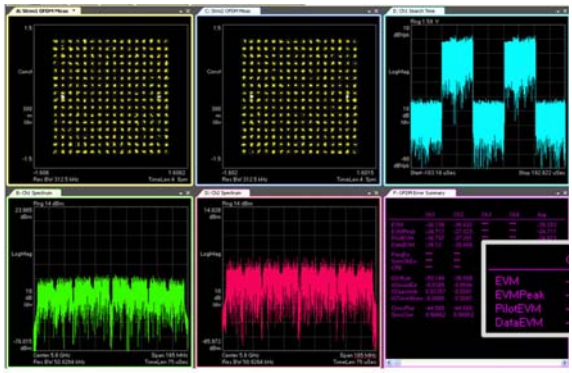
Challenges with 256 QAM



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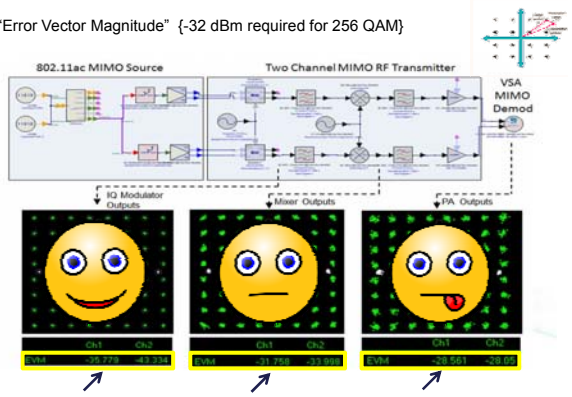
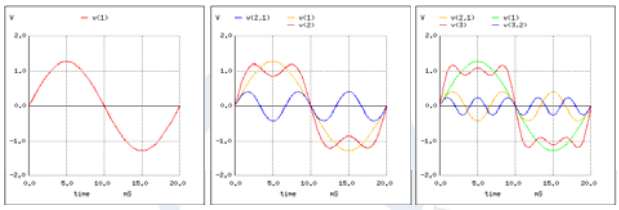
802.11ac Circuitry EVM

"Error Vector Magnitude" {-32 dBm required for 256 QAM}



The Fast Fourier Transform



A Fundamental Sine Wave (50 Hz)

Fundamental 50 Hz Wave: Orange
3rd Harmonic (150 Hz): Blue
Resultant: Red

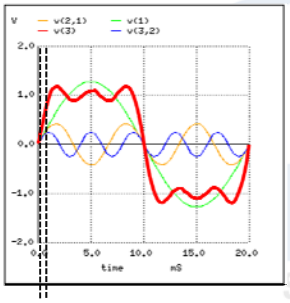
Fundamental 50 Hz Wave: Green
3rd Harmonic (150 Hz): Orange
5th Harmonic (250 Hz): Blue
Resultant: Red

- The "Fast Fourier Transform" (FFT) is the mathematical process whereby any repeating waveform can be deconstructed into a set of sine waves at specific frequencies.
- The result of the FFT is to change the view from the time domain (like an oscilloscope) into the frequency domain (like a spectrum analyzer).

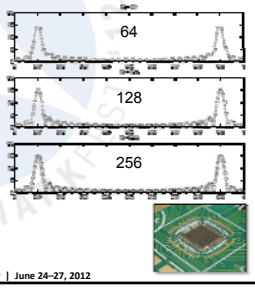
FFT Number: 802.11n VS 802.11ac

802.11g: 16, 64 802.11n: 128 802.11ac: 128, 256, 512

- The FFT number indicates the number of points measured over each sampling interval



Measurement Point



Unanswered Questions

- When will business-class 802.11ac enter the market?
- How will 4+ stream MIMO and MU-MIMO evolve?
- How soon will beamforming become commonplace?
- Will Wi-Fi Direct be adopted to replace Bluetooth for some applications?
- How will vendors handle 80 MHz channel allocation?
- What will Dynamic Channel Width Adjustment do to packet analysis?
- How much will all this new "fancy" hardware cost?
- When will 802.11ac capture adapters be available?
- When will Wireshark decodes be available for 802.11ac
- How quickly will "optional" features be implemented?

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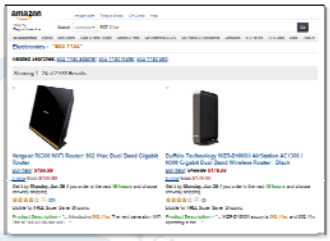
It's Coming.. Be Ready :-)

The ASUS G75VW with Broadcom 802.11ac WiFi



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