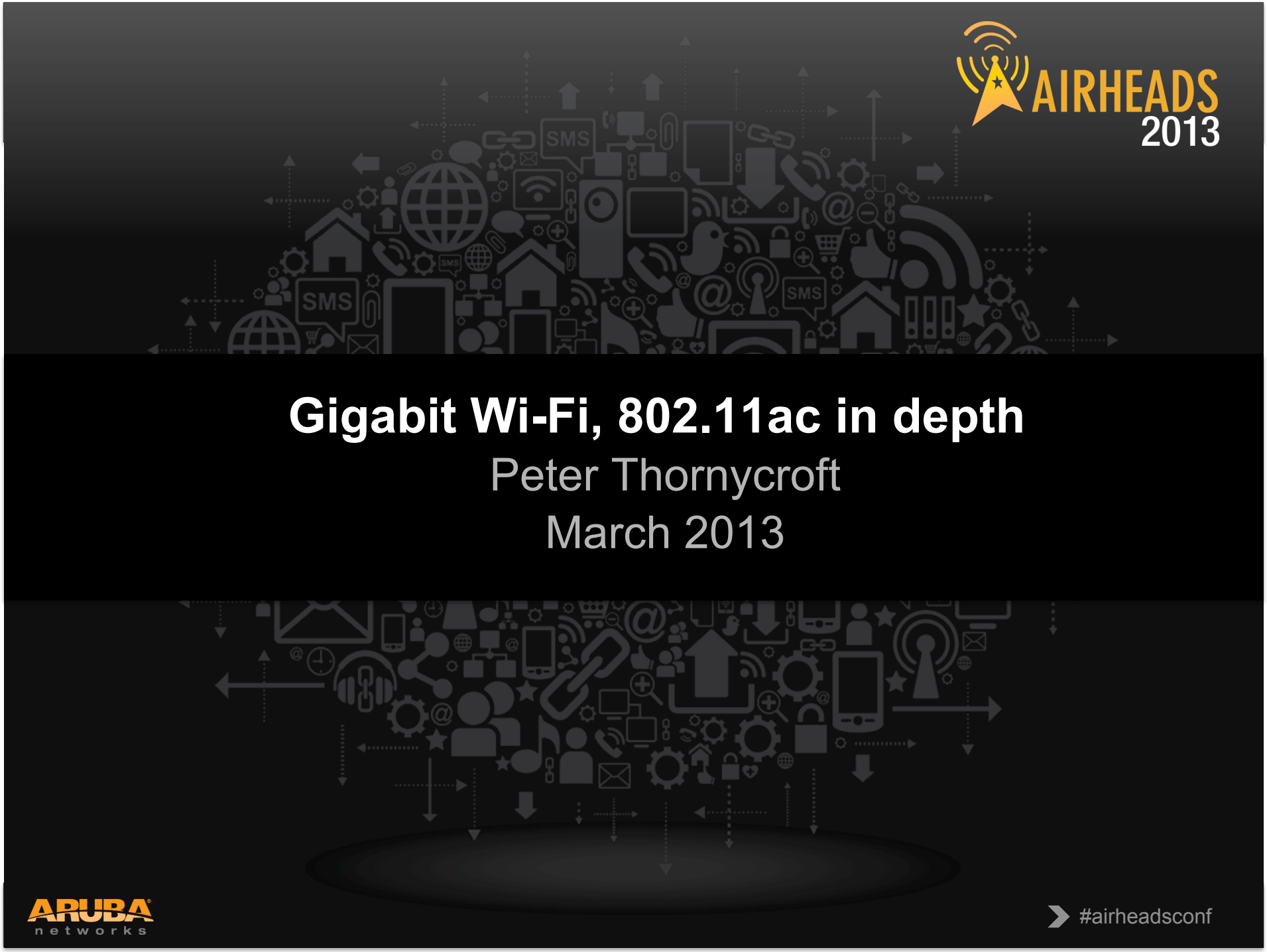
AIRHEADS
2013
Gigabit Wi-Fi, 802.11ac in depth
Peter Thornycroft
March 2013
ARUBA
networks
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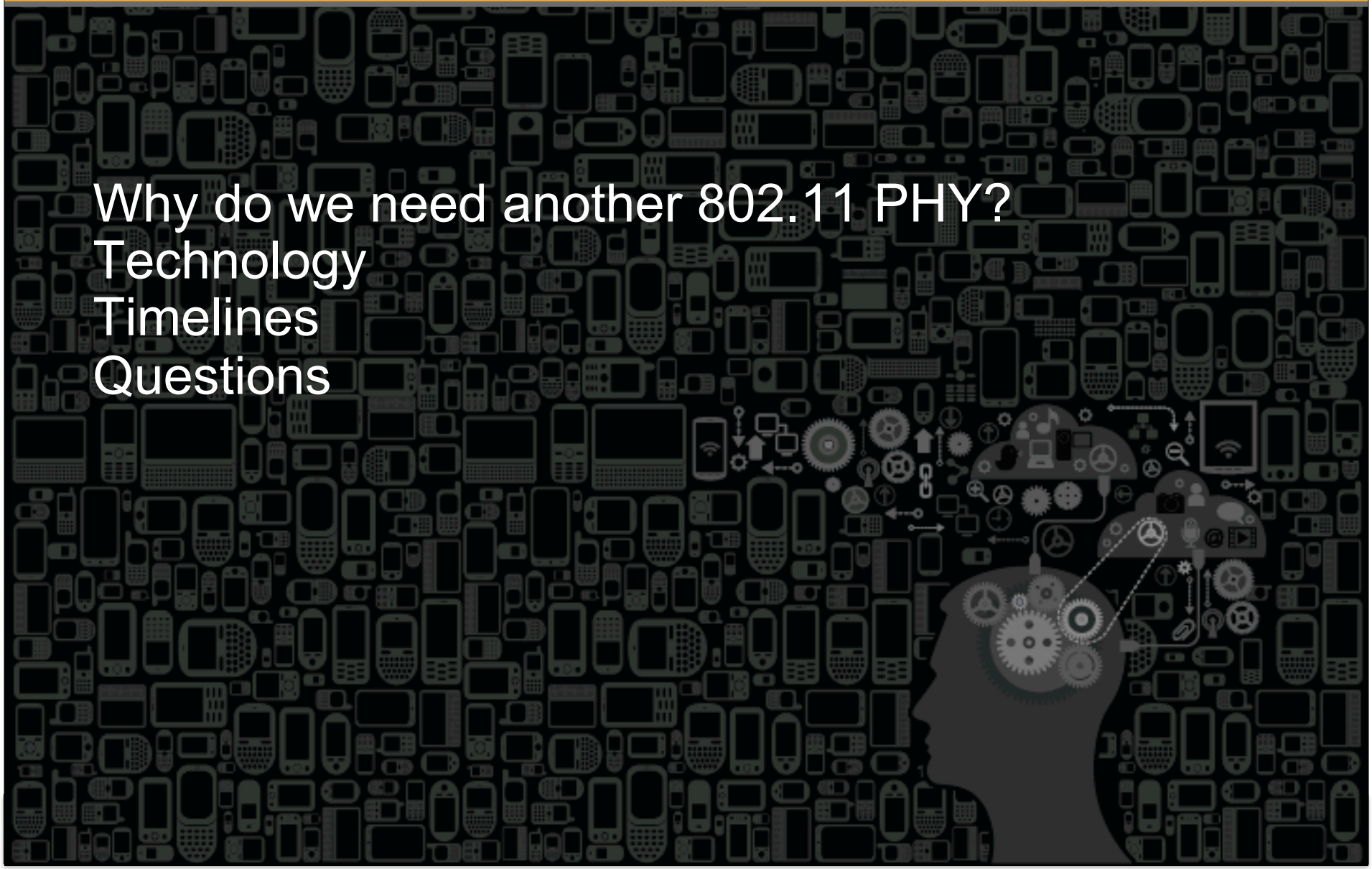
Agenda

AIRHEADS 2013

Why do we need another 802.11 PHY?
Technology
Timelines
Questions

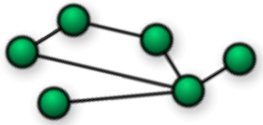


Why another 802.11 PHY?

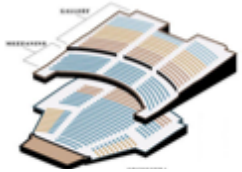
Wireless Display

In Home Distribution of HDTV and other content

Rapid Upload/Download of large files to/from server



Backhaul Traffic (e.g. Mesh, Point-to-Point)



Campus / Auditorium deployments

Manufacturing Floor Automation

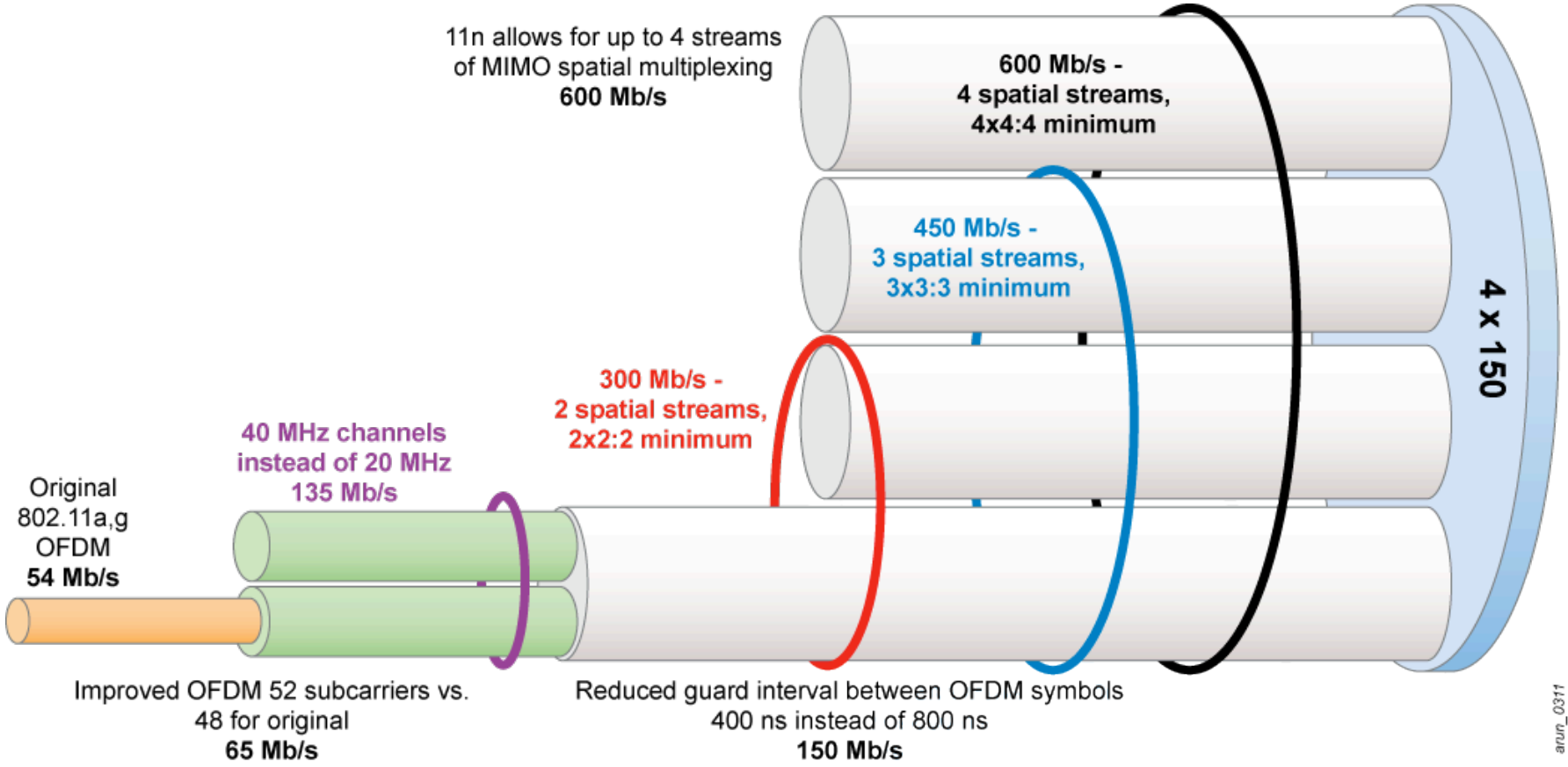
Source: IEEE

Video requirements

Video type	Description	Rate	Packet error rate	Jitter	Delay
Uncompressed	720p (RGB) 1280x720 pixels; 24 bits/ pixel, 60 frame/sec	1.3 Gbps	10^{-8}	5 msec	5 msec
	1080i (RGB) 1920x1080/2 pixels; 24 bits/pixel, 60 frame/sec	1.5 Gbps	10^{-8}	5 msec	5 msec
	1080p (YCrCb) 1920x720 pixel; 24 bits/ pixel, 60 frame/sec	1.5 Gbps	10^{-8}	5 msec	5 msec
	1080p (RGB) 1920x720 pixel; 24 bits/ pixel, 60 frame/sec	3.0 Gbps	10^{-8}	5 msec	5 msec
Lightly Compressed	Motion JPEG2000	150 Mbps	10^{-7}	10 msec	10 msec
	H.264	70 – 200 Mbps	10^{-7} 10^{-8}	20 msec	20 msec
Compressed	Blu-ray™	50 Mbps	10^{-7}	20 msec	20 msec
	HD MPEG2	20 Mbps	$3x10^{-7}$	20 msec	20 msec

Video bandwidth and error rate requirements source: IEEE

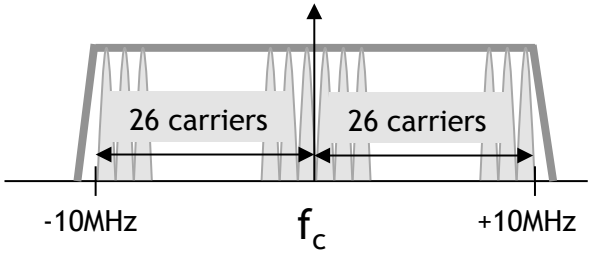
802.11n techniques



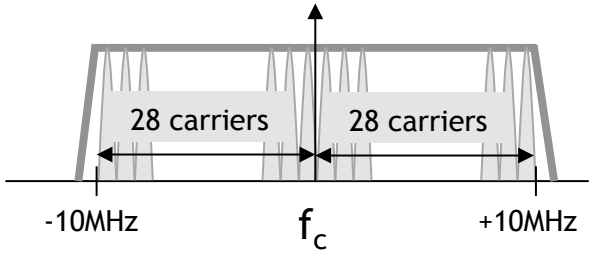
802.11ac goals

- Multi-station MAC throughput of at least 1Gbps, Single link at least 500Mbps
- Operation below 6GHz, but excluding 2.5 GHz
- Backward compatibility & coexistence with devices in 5 GHz band
- 256-QAM (optional)
  - Provides a 33% increase over 64-QAM
- Wider Channel widths
  - 80 MHz (mandatory) & 160 MHz (optional) channels
  - 80 MHz is contiguous, 160 MHz either contiguous or 2x 80 MHz slices
- More Spatial Streams
  - Up to 8 spatial streams
- Downlink Multi-user MIMO
  - One transmitting device, multiple receiving devices
  - Allows an AP to transmit to multiple stations simultaneously

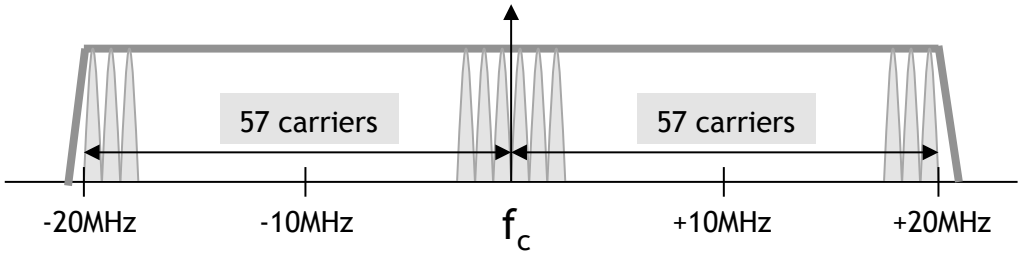
Sub-carriers for wider channels



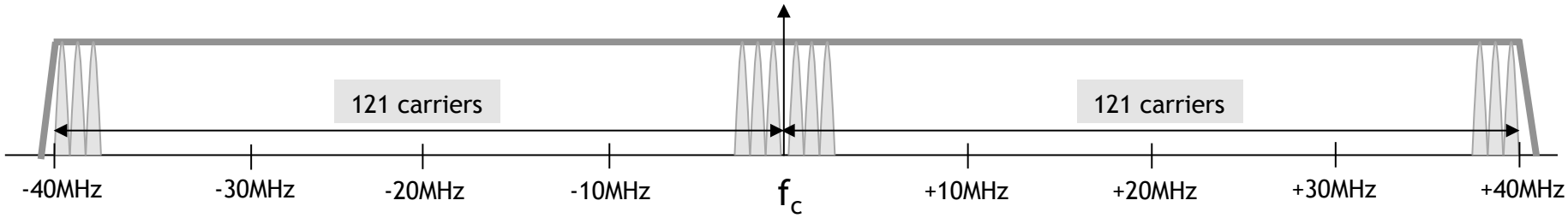
52 subcarriers (48 usable) for a **20 MHz non-HT** mode (legacy 802.11a/g) channel



56 subcarriers (52 usable) for a **20 MHz HT** mode (802.11n) channel



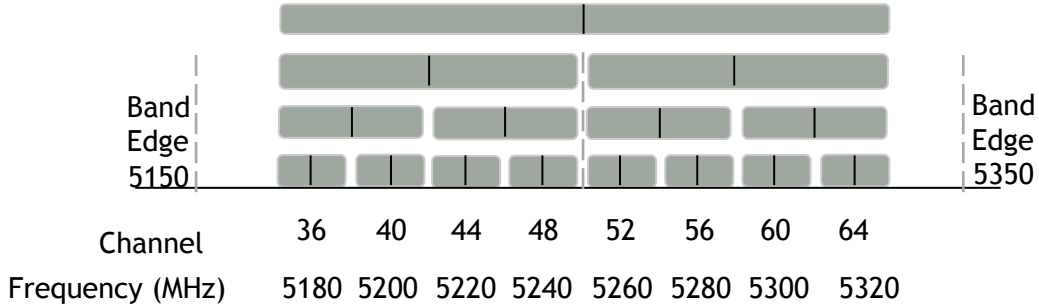
114 subcarriers (108 usable) for a **40 MHz HT** mode (802.11n) channel



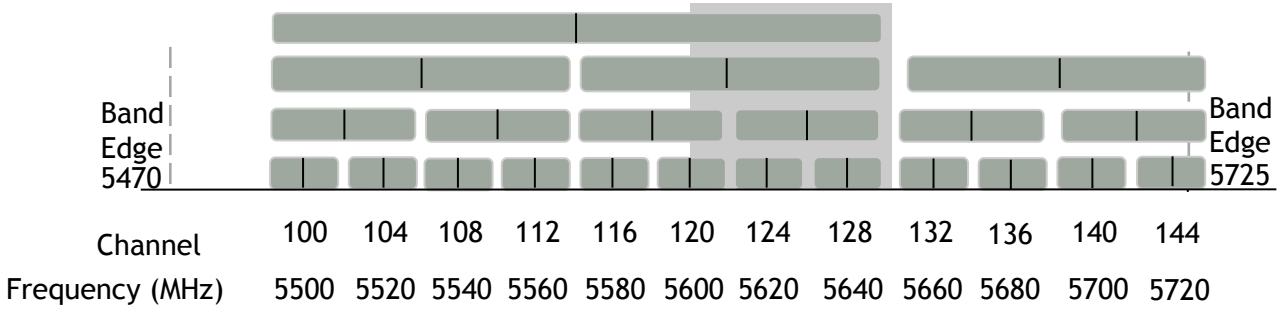
242 subcarriers (234 usable) for a **80 MHz VHT** mode (802.11ac) channel
An 80+80MHz or 16MHz channel is exactly two 80MHz channels, for 484 subcarriers (468 usable)

OFDM subcarriers used in 802.11a, 802.11n and 802.11ac

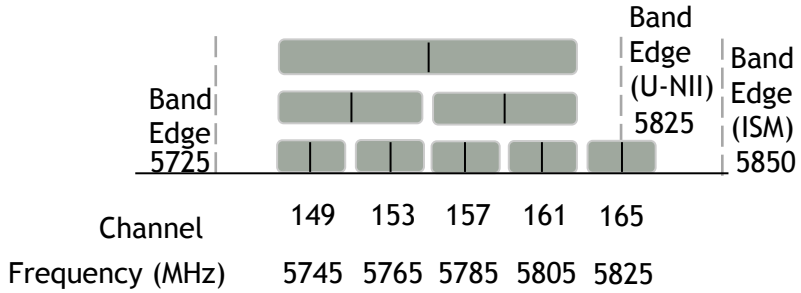
Current channels for 5GHz Wi-Fi (USA)



US U-NII I and U-NII II bands
U-NII I: 5150-5250 MHz (indoors only)
U-NII 2: 5250-5350 MHz
8x 20 MHz channels
4x 40 MHz channels
2x 80 MHz channels
1x 160 MHz channel
U-NII II requires DFS (& TPC if over 500mW / 27dBm EIRP)



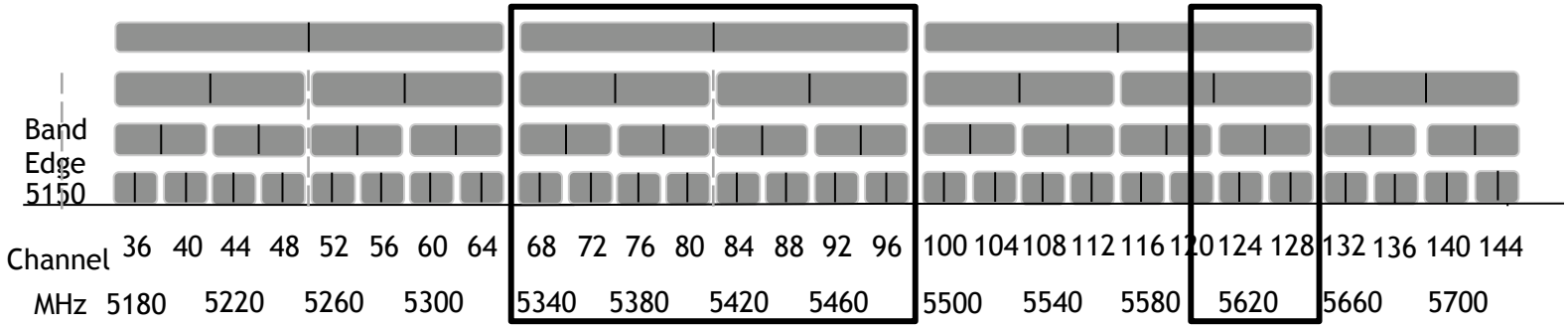
US intermediate band (U-NII 2 extended)
5450-5725 MHz
12x 20 MHz channels
6x 40 MHz channels
3x 80 MHz channels
1x 160 MHz channel
- Requires DFS (& TPC if over 500mW / 27dBm EIRP)
- 5600-5650 MHz is used by weather radars and is temporarily not available in the U.S.

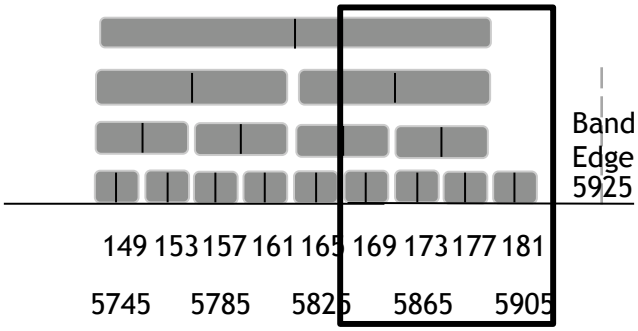


US U-NII 3 / ISM band
5725-5825 MHz
5x 20 MHz channels
2x 40 MHz channels
1x 80 MHz channel
- Slightly different rules apply for channel 165 in ISM spectrum

Channels defined for 5 GHz bands (U.S. regulations), showing 20, 40, 80 and 160 MHz channels
(channel 144 is now allowed in the U.S. for one additional 20 MHz, one 40 MHz and one 80 MHz channel)

New channels for 5GHz Wi-Fi (USA)*





Announcement in advance of public meeting on 20 February 2013 to introduce Notice of Proposed Rule Making

- Make available 5350 – 5470MHz for Wi-Fi
- Make available 5850 – 5925MHz for Wi-Fi
- Total of 195MHz new spectrum
- Publish new rules for the 5600 – 5650 band used by weather radars (Terminal Doppler Weather Radar)
- New spectrum will probably be subject to spectrum sharing rules and protocols – includes current Federal users and others

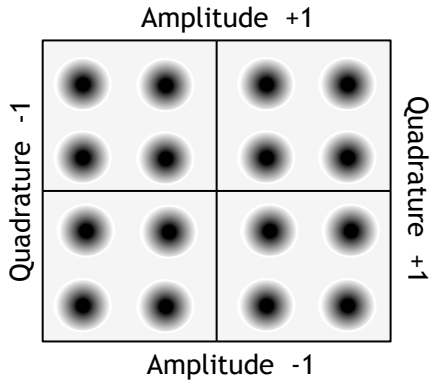
Channels proposed for 5 GHz bands (new U.S. regulations)

(* tentative conclusions from announcement by Julius Genachowski, FCC chairman, at CES 9 January 2013, and subsequent announcements)

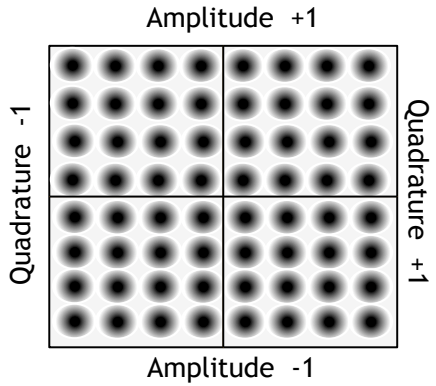
256-QAM Modulation

- New 256-QAM options with coding of 3/4 and 5/6
  - Compared to 802.11n: 64-QAM 5/6
- Provides a higher ‘raw data’ top speed
- Higher order modulation leverages advances in radio technology, to better distinguish constellation points
- All the earlier options are still available, used if SNR is too low to sustain the highest rates

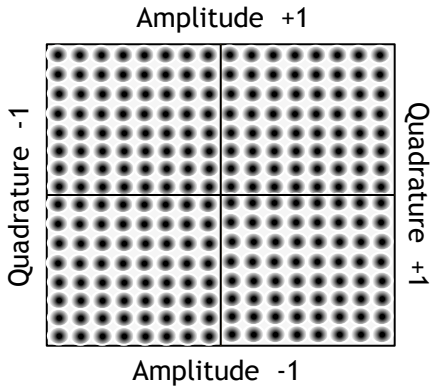
High-order modulation and sensitivity



16-QAM constellation

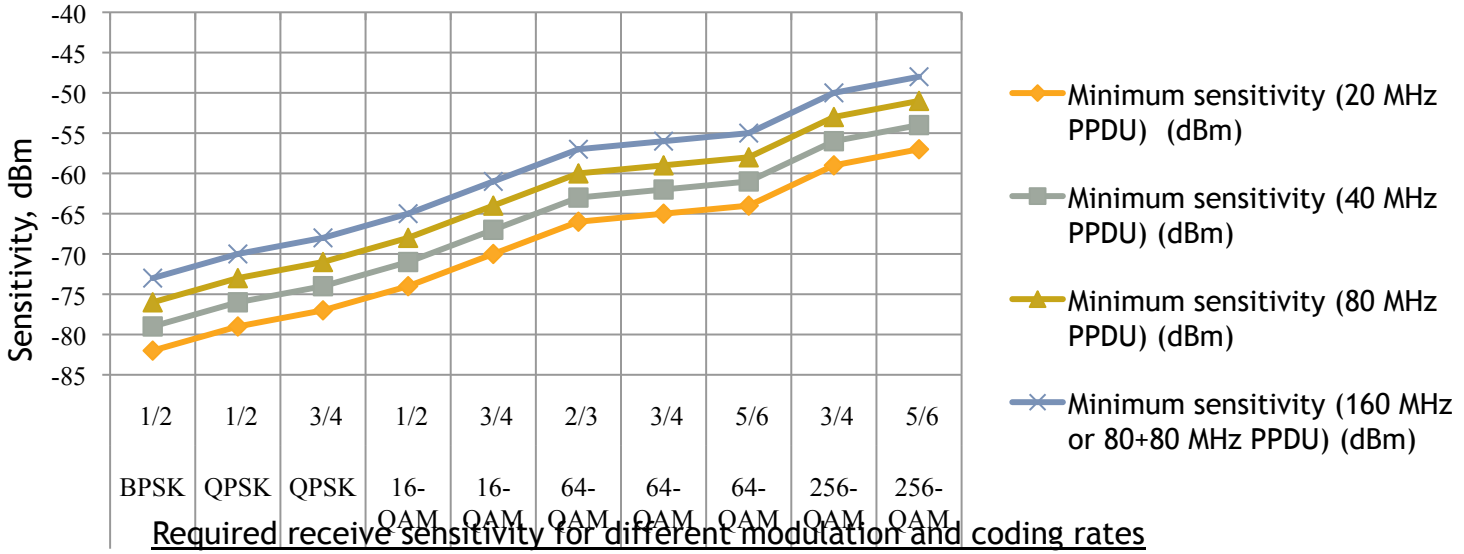


64-QAM constellation



256-QAM constellation

Constellation diagrams for 16-, 64-, 256-QAM



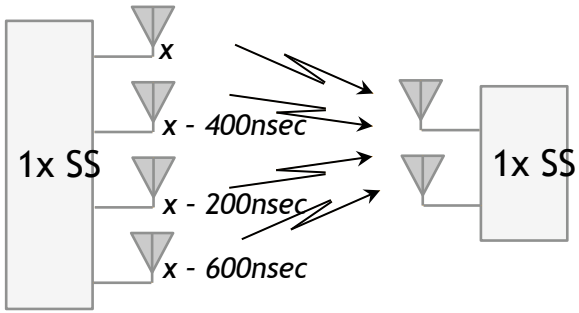
Required receive sensitivity for different modulation and coding rates

More spatial streams

- Up to 8 spatial streams in both single-user (SU) and multi-user (MU) (was 4 max in 802.11n)
  - 8SS performance will only be possible where both devices have 8 antennas
  - Without innovative antenna designs, this probably precludes handheld devices, but access points, set top boxes and the like will be able to use multiple streams

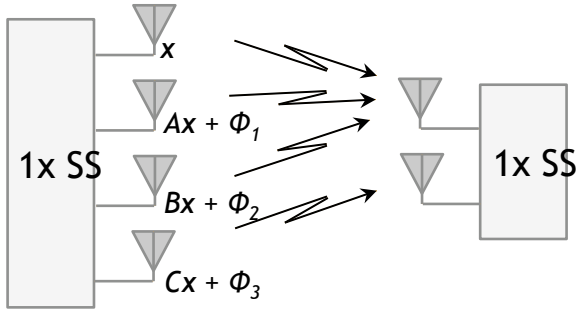
- Adding spatial streams increases throughput proportionally . Assuming multipath conditions are favorable,
  - Two streams offer double the throughput of a single stream
  - Eight streams increase throughput eight-fold
  - Higher throughput only possible at shorter distances

MIMO techniques



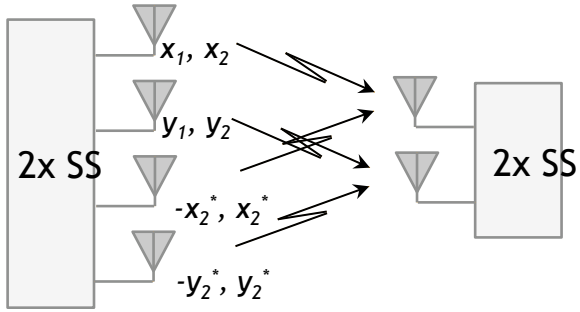
Cyclic Shift Diversity (CSD, CDD)

Transmit diversity by blindly transmitting from each antenna with a fixed phase shift. Receiver picks best signal. Can be combined with MRC.



Transmit Beamforming (TxBF)

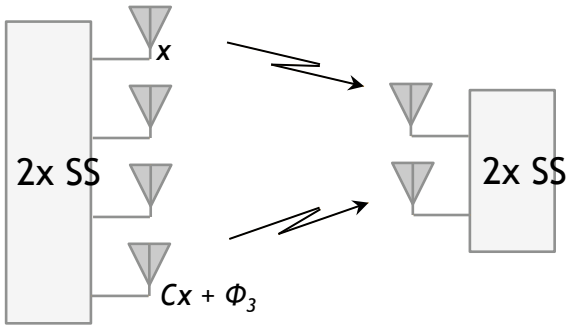
Transmitter receives channel state information from receiver (compressed V feedback matrix) and computes parameters to drive local signal maximum at receiver. The transmitter can form on several antennas if silicon allows.



Space Time Block Coding (STBC)

Transmitter codes a pair of symbols in successive timeslots from different antennas. Only works with even numbers of antennas, two per SS. All-or-nothing, all SS must use STBC if any use it. Here combined with SDM. STBC halves the effective data rate.

MIMO techniques

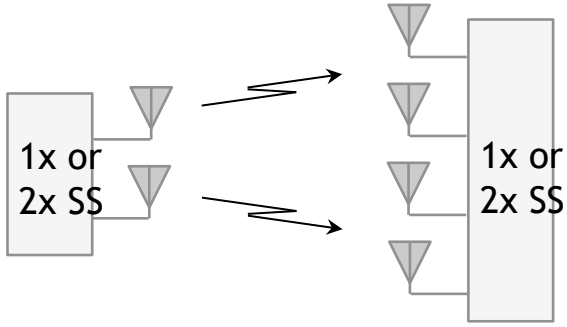


Spatial Division Multiplexing (SDM)

Transmitter sends one spatial stream per antenna, chosen for best performance. Feedback from the receiver is not required: channel state is inferred by assuming reciprocity. Can be combined with STBC.

Combining Techniques

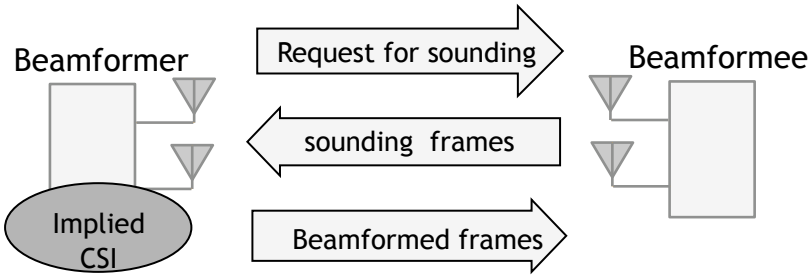
Some combinations are disallowed by the 'equal modulation' restriction, others by silicon implementation. Equal modulation requires all driven antennas to use the same MCS.



Maximal Ratio Combining (MRC)

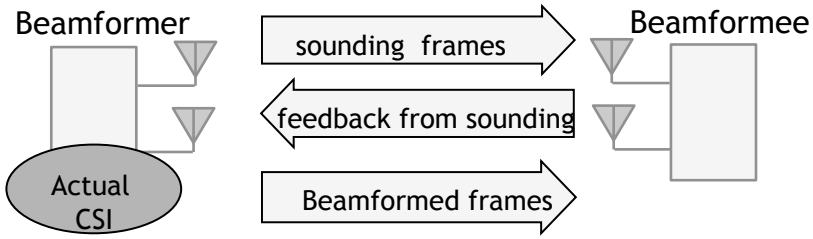
Receive-only technique to combine multiple copies of the same signal at RF for best SNR. Can be combined with CSD, SDM or SDBC.

Implicit and explicit beamforming



Implicit feedback for beamforming

1 (Beamformer) Send me a sounding frame
2 (Beamformee) Here's the sounding frame
3 OK, I'll pre-code assuming you hear me like I heard you

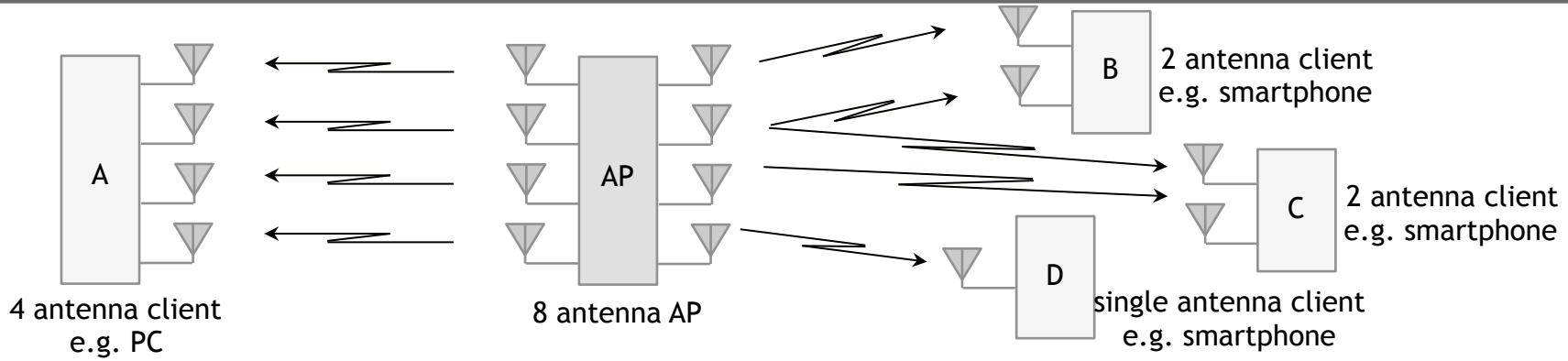


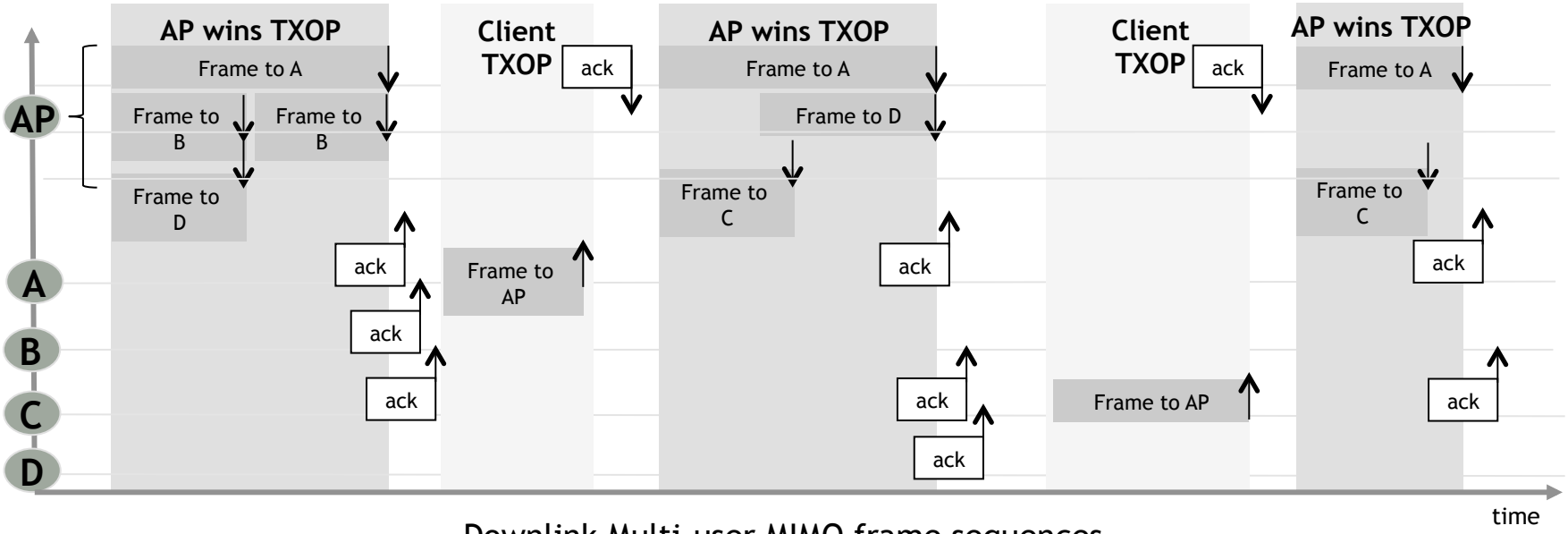
Explicit feedback for beamforming

1 (Beamformer) Here's a sounding frame
2 (Beamformee) Here's how I heard the sounding frame
3 Now I will pre-code to match how you heard me

Implicit and explicit feedback for beamforming

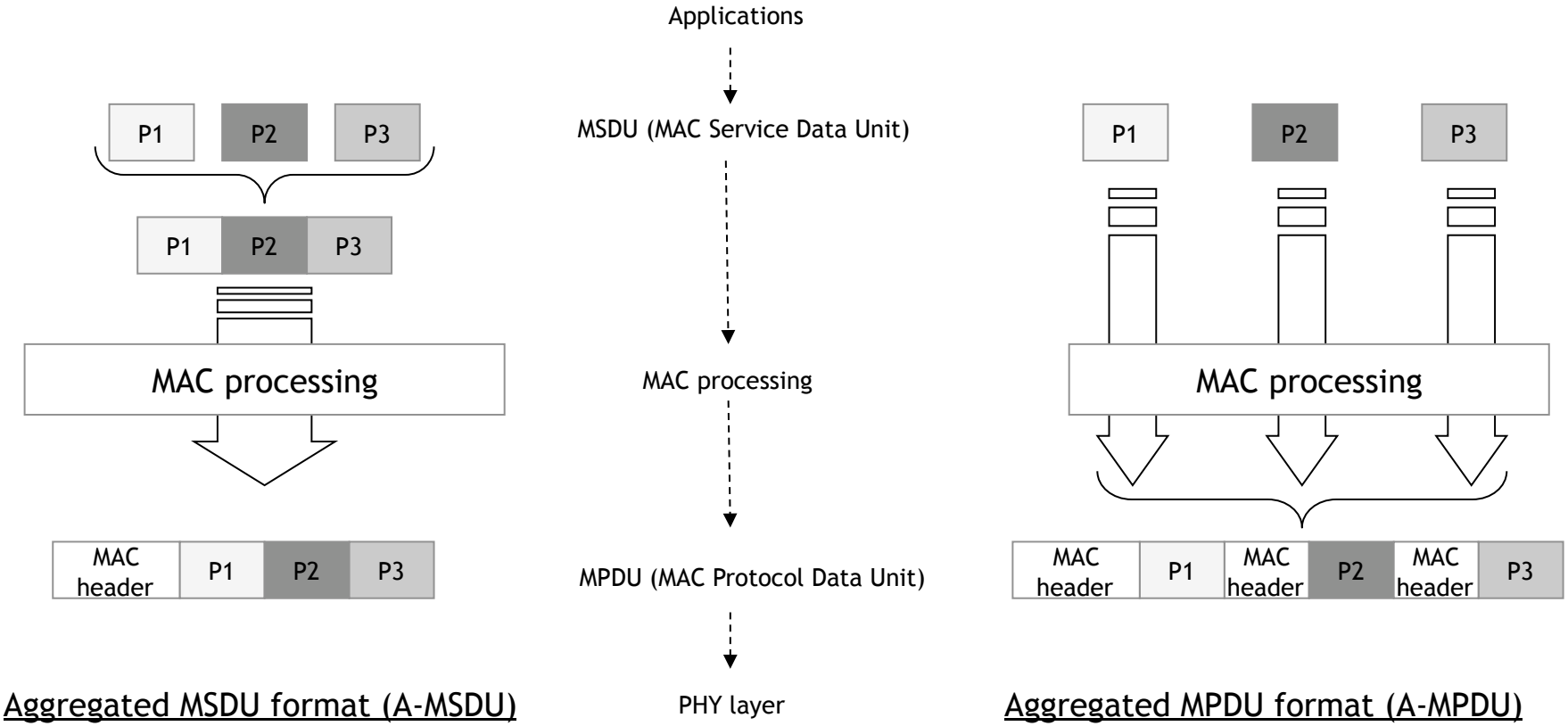
Downlink Multi-user MIMO





Downlink Multi-user MIMO frame sequences

MAC aggregation

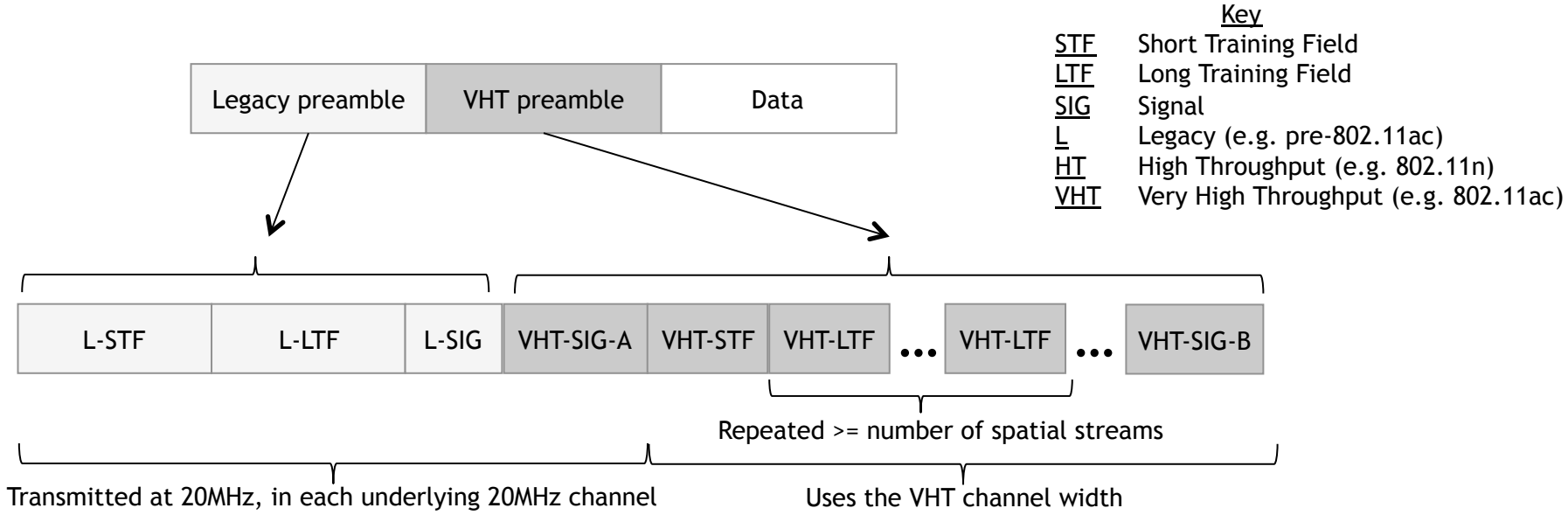


Aggregated MSDU format (A-MSDU)

Aggregated MPDU format (A-MPDU)

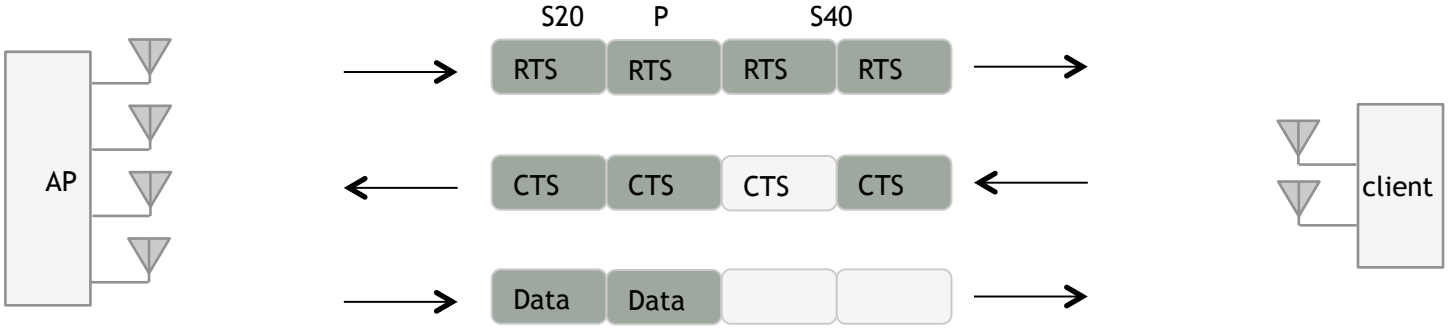
MAC frame aggregation in 802.11ac

Frame preambles

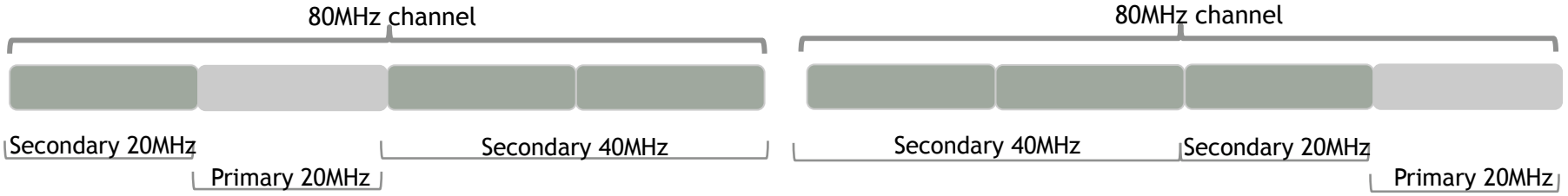


VHT preamble format

Dynamic bandwidth operation



Dynamic Bandwidth Operation, 80MHz channel



Dynamic Bandwidth and Channelization examples in 802.11ac, 80MHz channel

802.11ac rate examples

Channel bandwidth	Transmit - Receive antennas	Typical client scenario	Max individual link rate	Max aggregate link rate
40 MHz	3x3	PC	606 Mbps	606 Mbps
80 MHz	1x1	Smartphone	433 Mbps	433 Mbps
80 MHz	2x2	Tablet, PC	867 Mbps	867 Mbps
80 MHz	3x3	PC	1300 Mbps	1300 Mbps
160 MHz	1x1	Smartphone	867 Mbps	867 Mbps
160 MHz	2x2	Tablet, PC	1.73 Gbps	1.73 Gbps
160 MHz	4x Tx AP, 4 clients of 1x Rx	Multiple smartphones	867 Mbps per client	3.47 Gbps
160 MHz	8x Tx AP, 4 clients with total of 8x Rx	Digital TV, set-top box, tablet, PC, smartphone	867 Mbps to two 1x clients 1.73 Gbps to one 2x client 3.47 Gbps to one 4x client	6.93 Gbps

802.11ac rate table

MCS	Lowest rates Mbps (20MHz channel, 1x SS)		Channel width	Spatial streams	Highest rates Mbps (160MHz channel, 8x SS)	
	Long GI	Short GI			Long GI	Short GI
0	6.5	7.2	x2.1 for 40MHz x4.5 for 80MHz x9.0 for 160MHz	x2 for 2 SS x3 for 3 SS x4 for 4 SS x5 for 5 SS x6 for 6 SS x7 for 7 SS x8 for 8 SS	468.0	520.0
1	13.0	14.4			939.0	1040.0
2	19.5	21.7			1404.0	1560.0
3	26.0	28.9			1872.0	2080.0
4	39.0	43.3			2808.0	3120.0
5	52.0	57.8			3744.0	4160.0
6	58.5	65.0			4212.0	4680.0
7	65.0	72.2			4680.0	5200.0
8	78.0	86.7			5616.0	6240.0
9	(86.7)	(96.3)			6240.0	6933.3

IEEE 802.11ac mandatory and optional

Feature	Mandatory	Optional
Channel width	20, 40, 80MHz	80+80, 160MHz
Modulation & coding	MCS 0 – 7 (BPSK, QPSK, 16-QAM, 64-QAM, 1/2, 2/3, 3/4, 5/6)	MCS 8, 9 (256-QAM, 3/4, 5/6)
Spatial streams	1	2 - 8
Guard interval	Long (800nsec)	Short (400nsec)
Beamforming feedback		Respond to beamforming sounding
Space-time block coding		Transmit and receive STBC
Parity check	Binary Convolutional Coding (BCC)	Transmit and receive Low Density Parity Check (LDPC)
MU-MIMO		Up to 4 spatial streams per client, with same MCS
Encryption cipher	Counter Mode with Cipher-block chaining Message authentication code Protocol (CCMP)	Galois/Counter Mode Protocol (GCMP)

802.11ac compared with 802.11n

802.11ac enhancement	Notes	Medium-term improvement over current 802.11n	Max theoretical improvement over max 802.11n
80 MHz, 160MHz channel	Over 40MHz in 802.11n (but how often is a 160MHz channel practical?)	~ 2.1x (80MHz over 40 MHz)	4.2x (160MHz over 40MHz)
8 Spatial streams	Over max 4 spatial streams in 802.11n (but only just seeing 3SS)	~ 2x (4SS over 2SS)	2x (8SS over 4SS)
256-QAM 3/4 and 5/6 modulation	Over 64-QAM 5/6 in 802.11n	~ 1.2, 1.33x	~ 1.2, 1.33x
Beamforming (implementable BF)	No explicit BF in current 802.11n systems due to complexity	~1.5x	~2x
Multi-user downlink MIMO	Over single-user MIMO in 802.11n	~1.5x	~2x
Total improvement		~10x	~40x

802.11ad-2012 Very High Throughput 60GHz

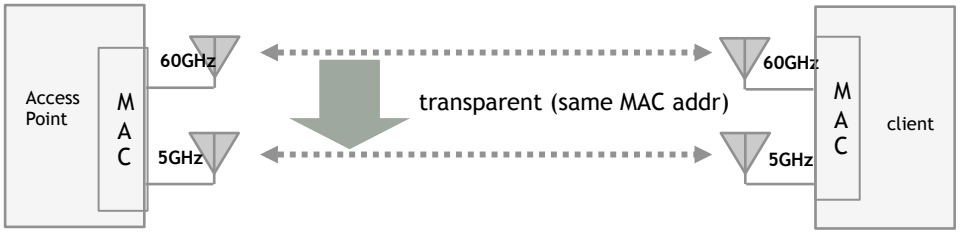
AIRHEADS 2013

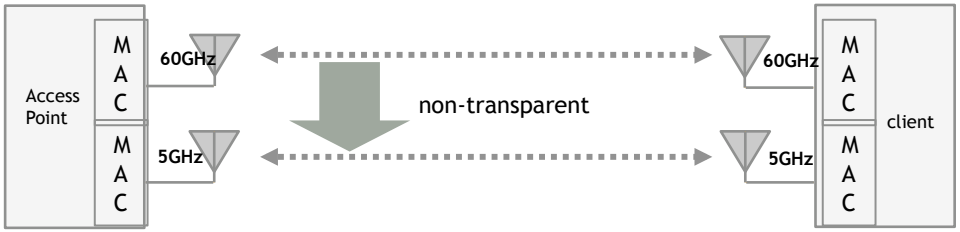
Requirements

Throughput > 1 Gbps @ 10 metres
Management plane from 802.11
Fast Session Transfer to 802.11n & ac
Coexistence with 802.15.3c (WPAN)

Applications

Room-scale uncompressed HD video
Set-top boxes & projection to TVs
DVRs, game consoles, other video
Rapid sync-&-go file transfer





MAC & PHY differ from other 802.11

Based on WiGig
PHY uses SC for 385 – 4620 Mbps
Or OFDM for 693 – 6756 Mbps
2.16 GHz channels
Beamforming required
Scheduled and contention access
Discovery with/out beamforming

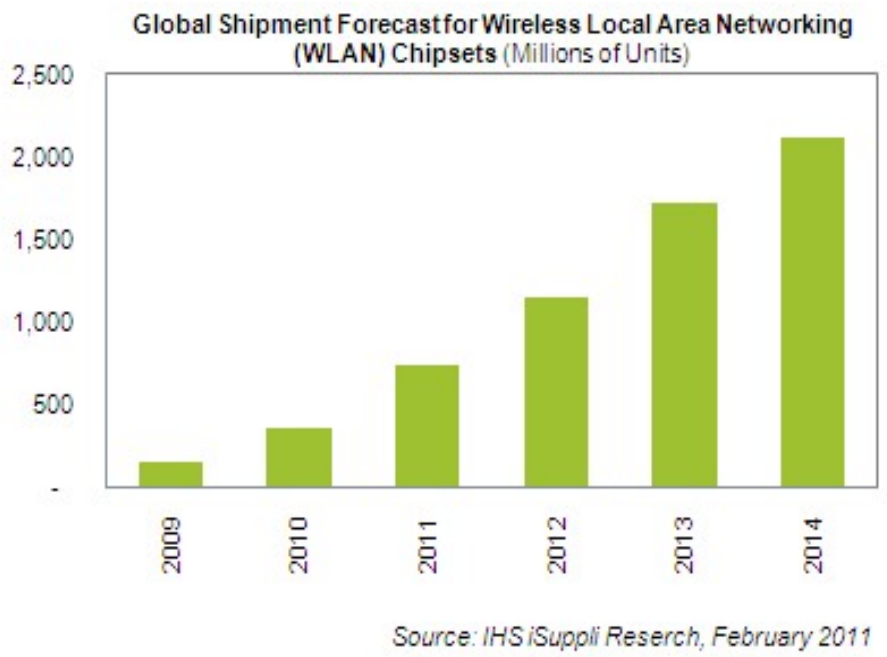
Milestones

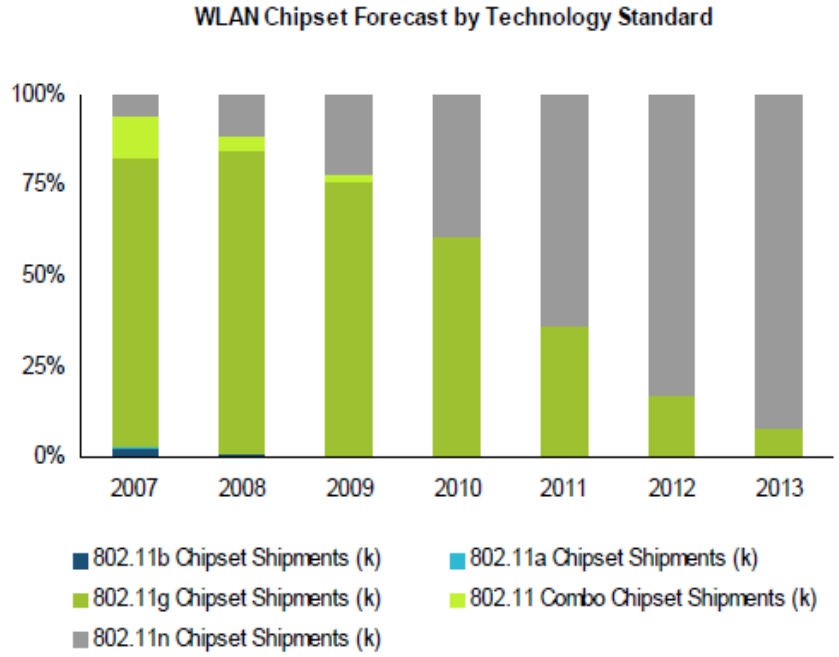
Jan 2009 IEEE task group started
Jul 2012 Final Approval for IEEE 802.11ad-2012
Jan 2013 WFA and WiGigAlliance consolidate activity
Dec 2013 WFA certification

Spectrum

Unlicensed
Worldwide spans 57 – 67 GHz
USA & Canada 57 – 64 GHz
Europe 57 – 67 GHZ
Japan 57 – 66 GHz

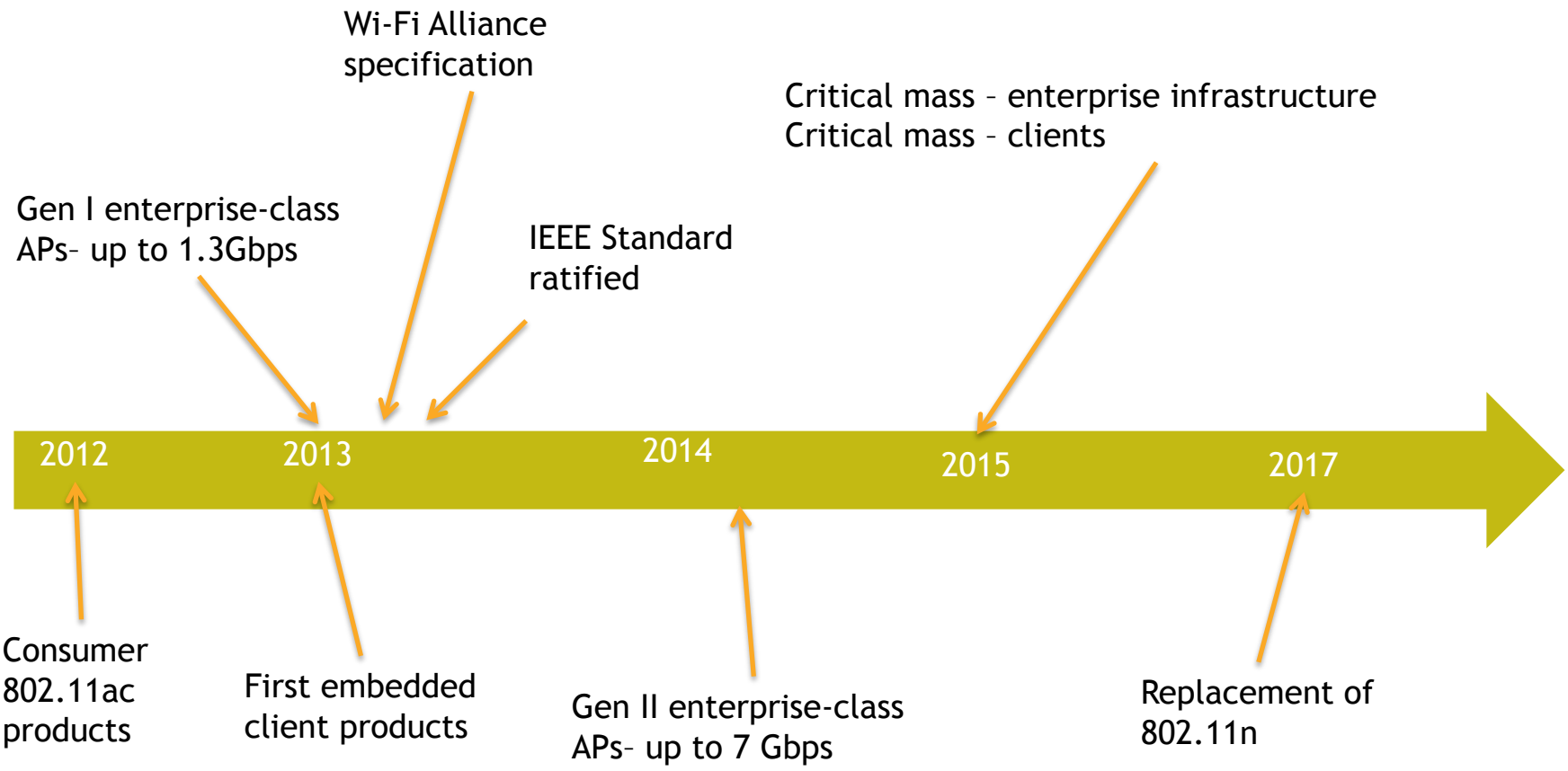
Chipset shipments forecast (802.11n)





Wi-Fi chipset shipments and penetration of 802.11n (actual & forecast) source: iSuppli

802.11ac Adoption Timeline



Phased delivery of 802.11ac

CY 2013/2014: Draft 802.11ac

Max data rate 1.3Gbps - 4x performance compared to 2x2 802.11n

5GHz only

Up to 3 spatial streams, up to 80MHz wide channels – reduced number of overall channels in 5GHz

Client devices start shipping mid-2013; Mass adoption early-2014

CY 2014/2015: IEEE ratified 802.11ac

Max data rate of 6.93Gbps – 10x performance & 50% better range compared to 2x2 802.11n

Up to 8 spatial streams &160MHz wide channels – even fewer 5GHz channels

Multi-User MIMO - Increased Capacity with simultaneous transmit to multiple receivers

Mass adoption mid-2015

Summary of 802.11ac

- **802.11ac Standard Update (IEEE and WFA)**
  - 5 GHz only
  - Draft (2.0) published Jan 2012
  - IEEE Standards Board ratification is targeted for December 2013.
  - Wi-Fi Alliance - WFA certification under development.
  - Initial WFA certification program, planned for 1H 2013
- **Provides up to 7 Gbps of throughput (eventually)**
  - 1.3 Gbps data rates in phase 1
  - Higher orders of modulation (256-QAM, 3/4, 5/6)
  - Wider Channel bandwidth
    - 80MHz
    - 160MHz
  - Up to 8 streams (3-4 streams in first generation)
  - Multi-user MIMO

* Second generation features estimated late CY 2014/1H CY 2015

Thank You

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