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High Efficiency Wi-Fi: 802.11ax

(based on 802.11ax D1.0)

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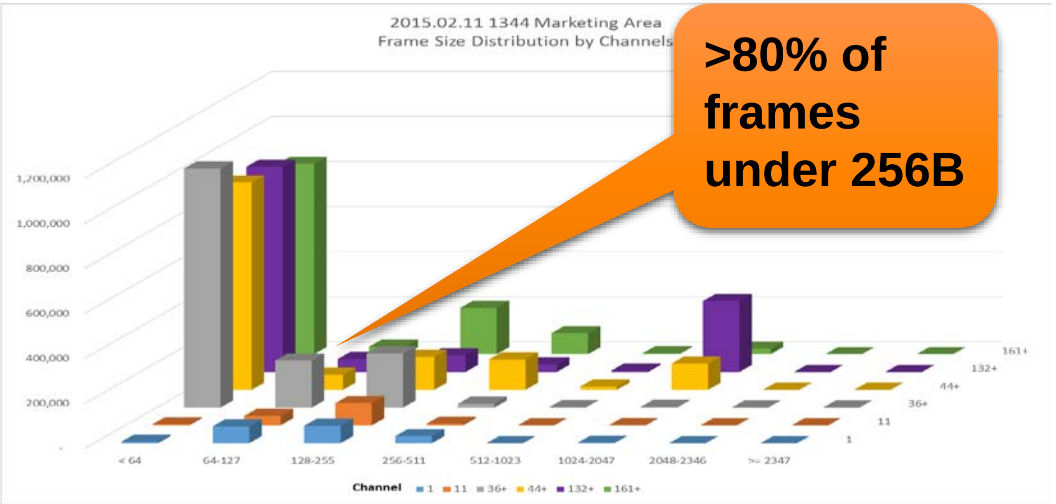
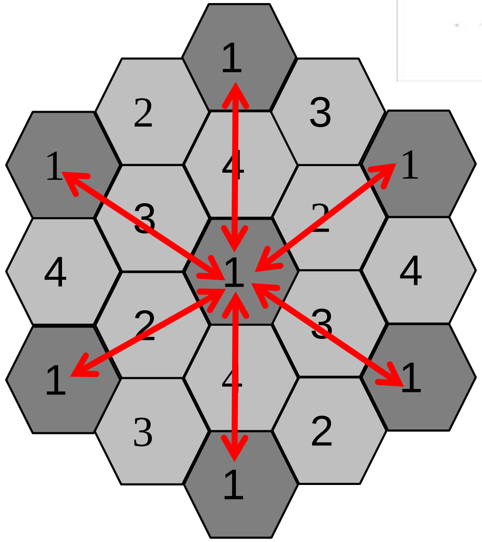
Issues Facing Wi-Fi Networks



– Preponderance of short data frames that are not aggregated; large number of users
  – Significantly degrading system efficiency



– Overlapping BSS's in dense deployments unnecessarily blocking each other from transmitting

– Improving performance in outdoor hotspots to better compete with cellular

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Goals of the 802.11ax Task Group

– Enhance operation in 2.4 & 5 GHz bands (11ac was only 5 GHz)

– Increase average throughput per station by at least 4x in a dense deployment scenario

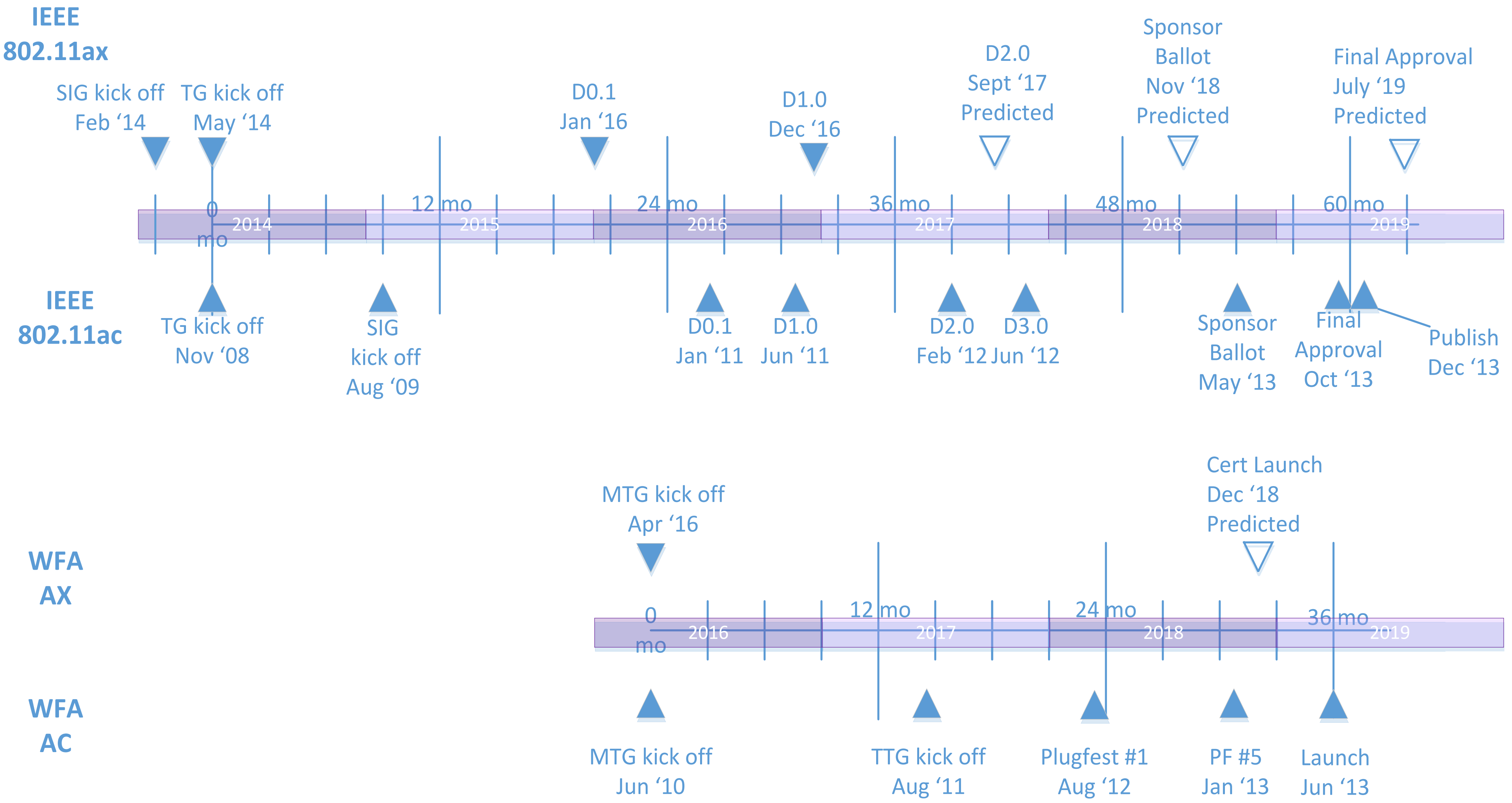
  – (11ac was aggregate throughput with no specification of scenario)

– Environments include indoor AND outdoor

– Scenarios include wireless corporate office, outdoor hotspot, dense residential apartments, and stadiums

– Maintain or improve power efficiency of the stations

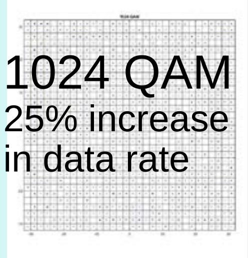
Timeline



IEEE 802.11ax
SIG kick off Feb ‘14
TG kick off May ‘14
D0.1 Jan ‘16
D1.0 Dec ‘16
D2.0 Sept ‘17 Predicted
Sponsor Ballot Nov ‘18 Predicted
Final Approval July ‘19 Predicted
0 mo
12 mo
24 mo
36 mo
48 mo
60 mo
2014
2015
2016
2017
2018
2019
IEEE 802.11ac
TG kick off Nov ‘08
SIG kick off Aug ‘09
D0.1 Jan ‘11
D1.0 Jun ‘11
D2.0 Feb ‘12
D3.0 Jun ‘12
Sponsor Ballot May ‘13
Final Approval Oct ‘13
Publish Dec ‘13
WFA AX
MTG kick off Apr ‘16
Cert Launch Dec ‘18 Predicted
0 mo
12 mo
24 mo
36 mo
2016
2017
2018
2019
WFA AC
MTG kick off Jun ‘10
TTG kick off Aug ‘11
Plugfest #1 Aug ‘12
PF #5 Jan ‘13
Launch Jun ‘13

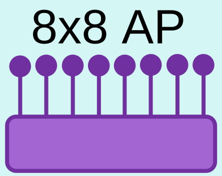
Categories of Enhancements

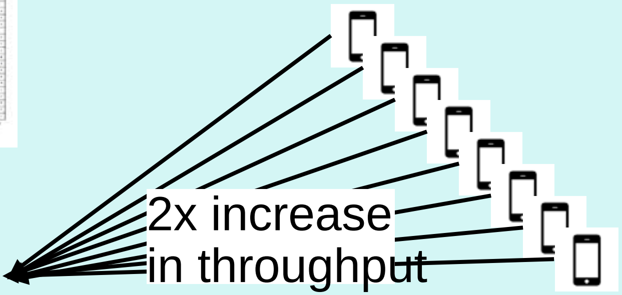
Spectral Efficiency & Area Throughput



1024 QAM
25% increase
in data rate

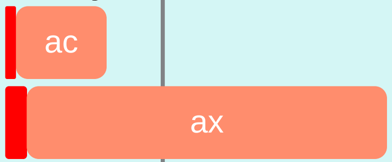
DL/UL MU-MIMO
w/ 8 clients





2x increase
in throughput

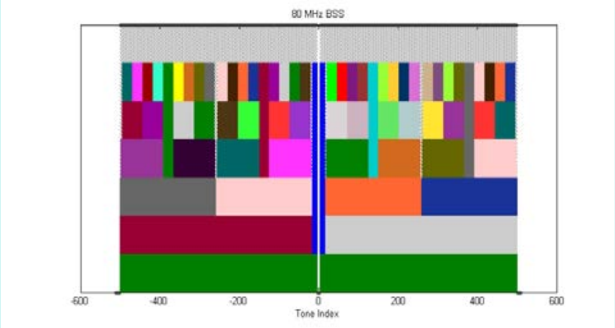
Long OFDM
Symbol



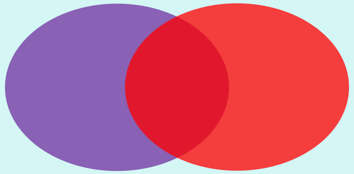
Up to 20%
increase
in data rate

High Density

OFDMA

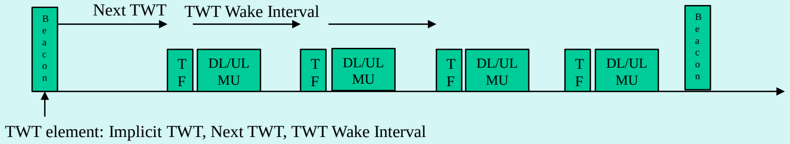


Spatial Reuse



Power Saving

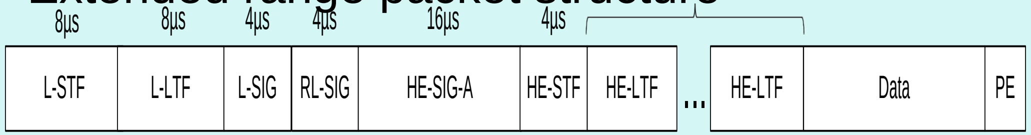
Scheduled sleep and wake times



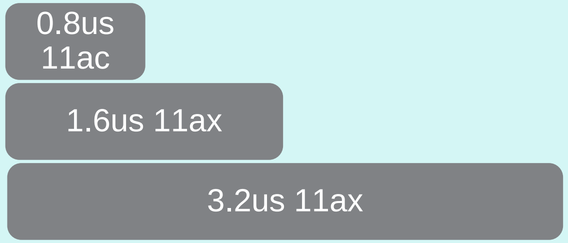
20 MHz-only clients

Outdoor / Longer range

Extended range packet structure



Enhanced delay
spread protection-
long guard interval



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OFDMA

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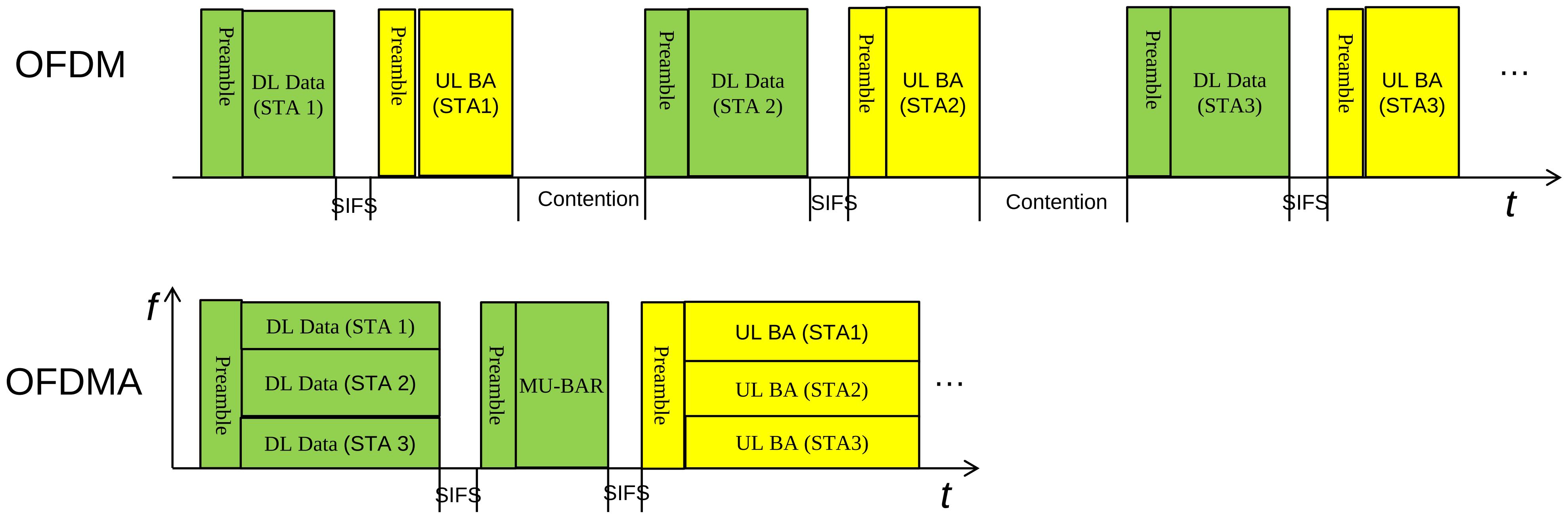
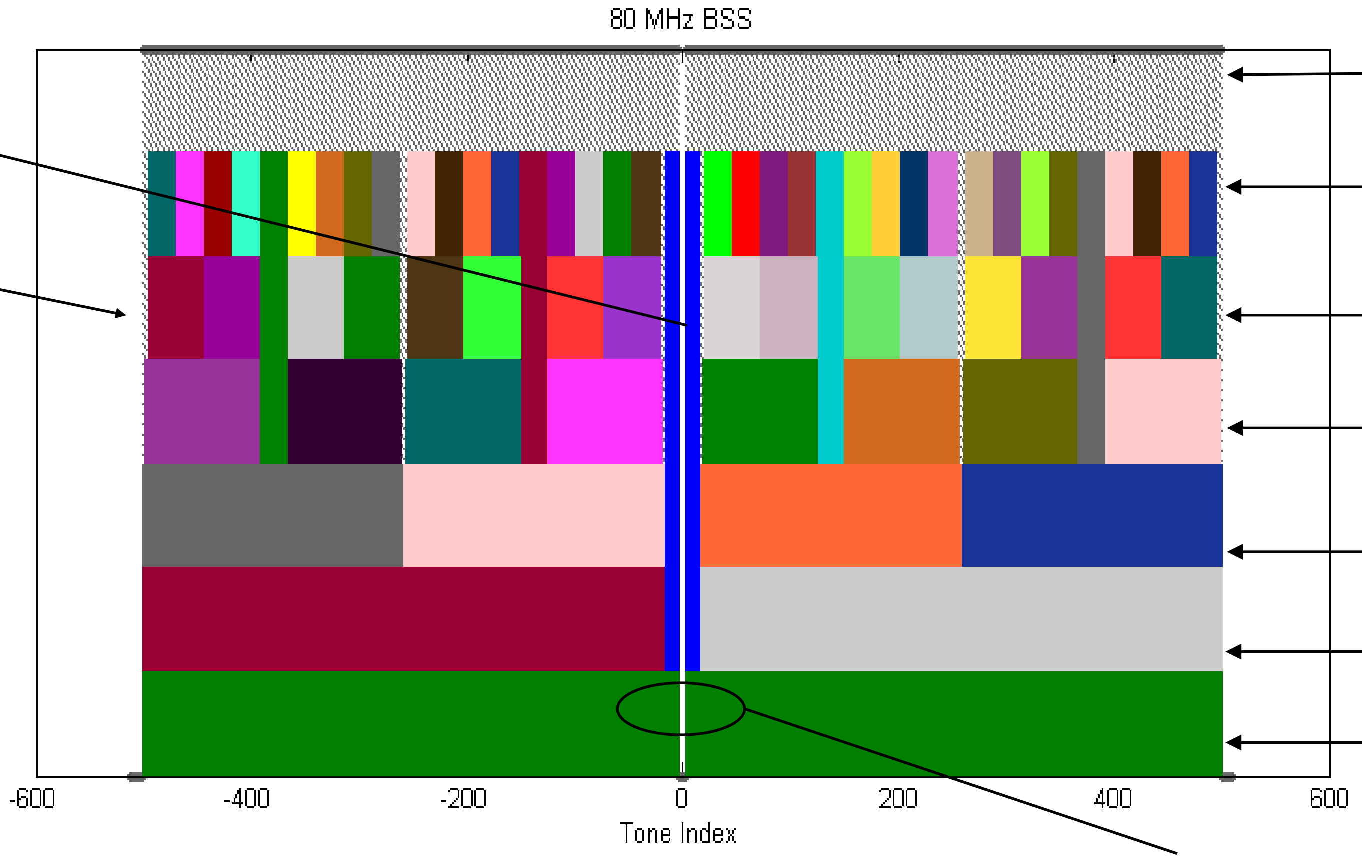
Orthogonal Frequency Division Multiple Access



- Issue: MAC efficiency drops as STA density increases and when short packets are transmitted (increase in contention, collision, IFS, preambles)
- Aggregation in 11n combines short packets in TIME from a single user, DL MU-MIMO in 11ac combines different users SPATIALLY, OFDMA combines different users together in FREQUENCY
- OFDMA does **NOT** increase the maximum PHY rate
- Downlink OFDMA: AP groups users to maximize downlink transmission efficiency
- Uplink OFDMA: Users are grouped together and transmit in sync to AP to maximize uplink transmission efficiency
- Transmit power can be adjusted per resource unit (RU) in either UL or DL to improve SINR for specific users

80 MHz BSS



7 DC Nulls For OFDMA

12 Guard

Usable tones

26 tone RUs (~2 MHz), 37 max RUs

52 tone (~4 MHz), and 26 tone RUs

106 tone (~8 MHz) and 26 tone RUs

242 tone RUs (~20 MHz) and 26 tone RU

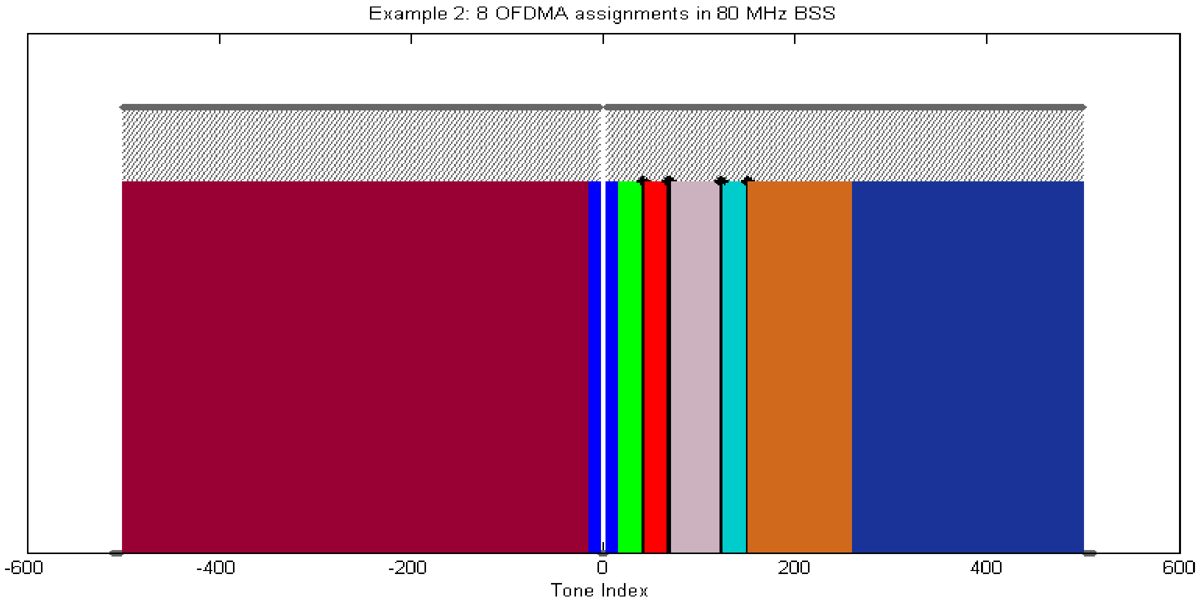
484 tone RUs (~40 MHz) and 26 tone RU

Non-OFDMA 996 tone (~80 MHz)

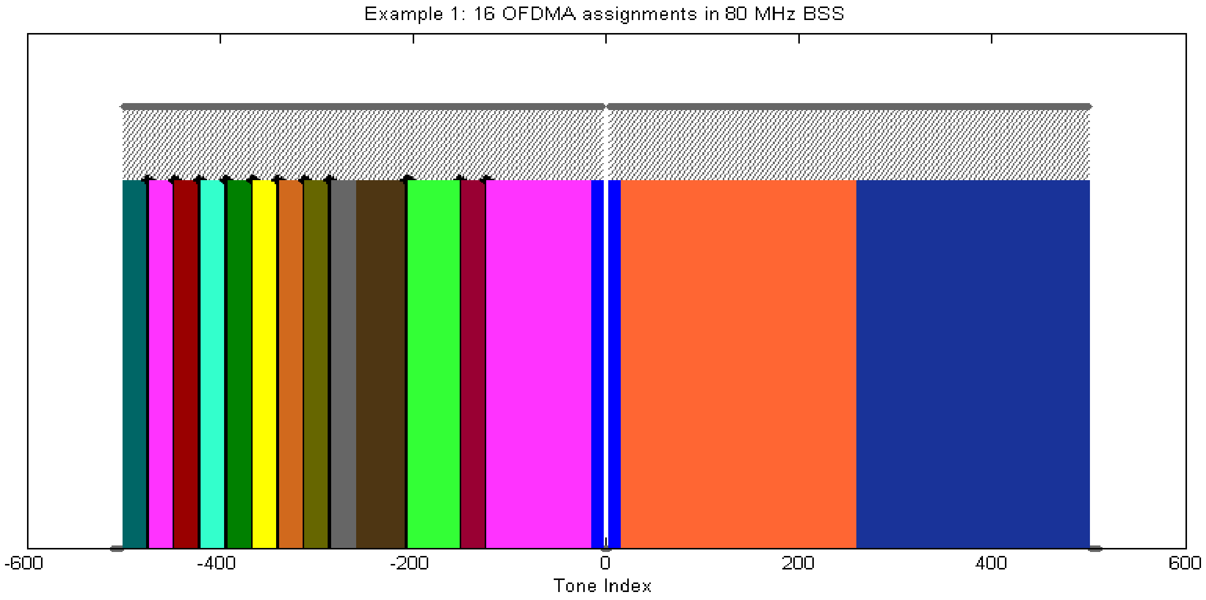
5 DC Nulls for Non-OFDMA

OFDMA Resource Unit Allocation Examples

8 OFDMA assignments in 80MHz BSS



16 OFDMA assignments in 80MHz BSS

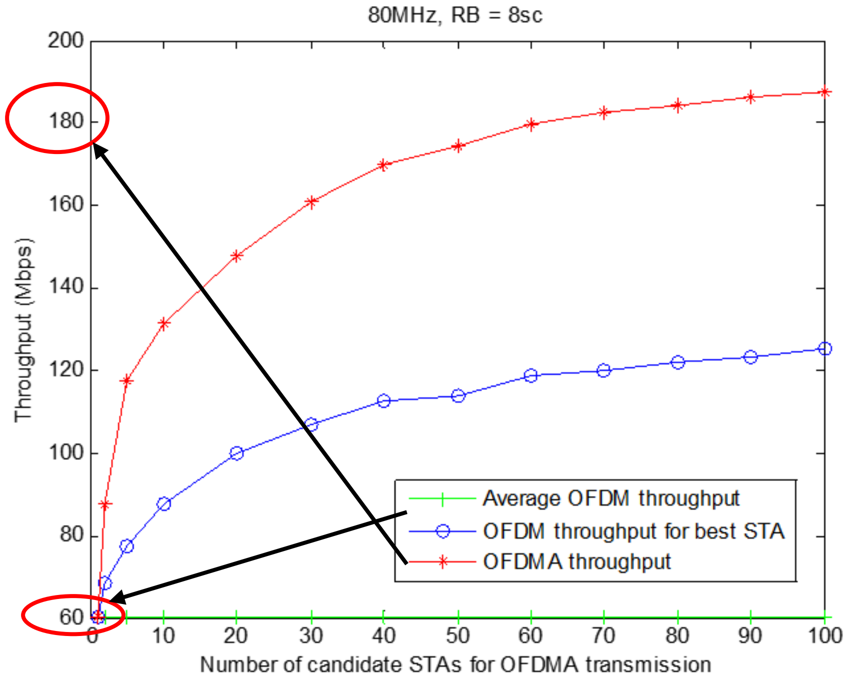


RU assignments can vary packet to packet

OFDMA Performance

OFDMA throughput vs Number of STAs

- More active STAs achieve higher throughput gain
- The number of active STAs restricted by delay and overhead
- 10-20 active STAs can achieve quite good throughput gain
- We use 10 active STAs in the following simulations.



300% gain

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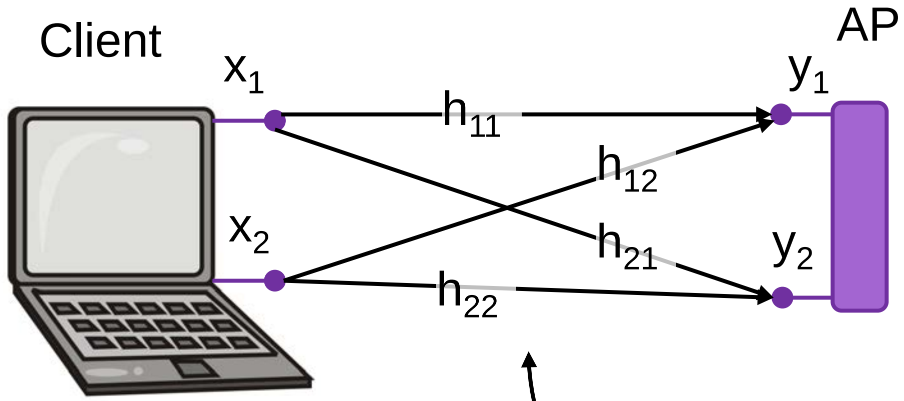
MU-MIMO

Multi-User MIMO

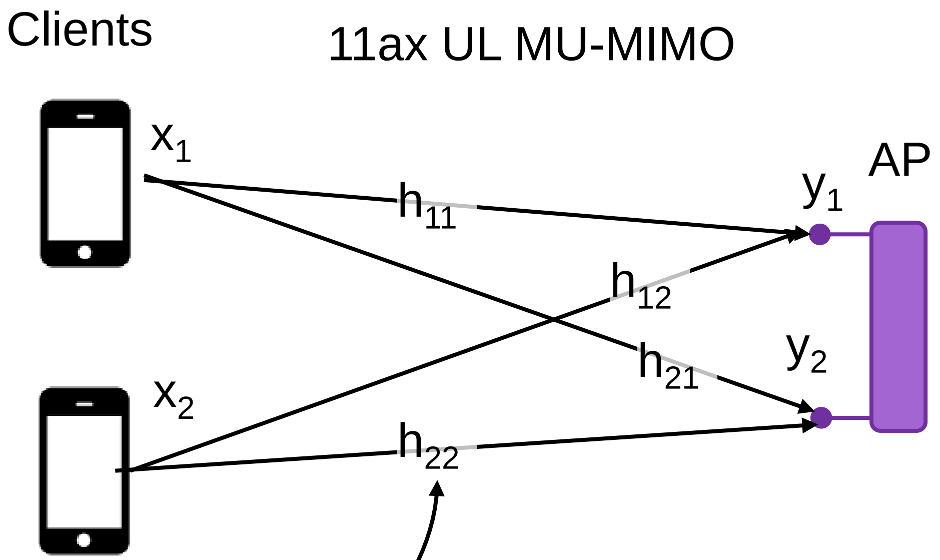
- 802.11ac introduced DL MU-MIMO, but we’re experiencing the following issues:
  - Many client devices are single antenna, and many two antenna clients switch to single stream mode for DL MU-MIMO for protection against interference
    - With 4 antenna AP, gains compared to Single User are modest
    - Even if we built an 8 antenna AP, groupings are limited to 4 users
  - Channel sounding responses from the users are transmitted serially in time resulting in high overhead
  - TCP/IP on downlink with TCP ACK on uplink is impaired with no UL MU enhancement
- UL MU-MIMO was initially considered in 11ac, but not included due to implementation concerns
- 802.11ax MU-MIMO enhancements
  - UL MU-MIMO
    - Sounding frames, data frames, etc can be grouped among multiple users to reduce overhead and increase uplink response time
  - Groups expanded to eight users for both DL and UL
    - Now even with devices in single stream mode, MU-MIMO throughput can be doubled or tripled over single user operation

Uplink Multi User-MIMO

11n/ac UL SU-MIMO



11ax UL MU-MIMO



$$y_1 = \sqrt{\rho/_2}\, h_{11}x_1 + \sqrt{\rho/_2}\, h_{12}x_2 + z_1$$

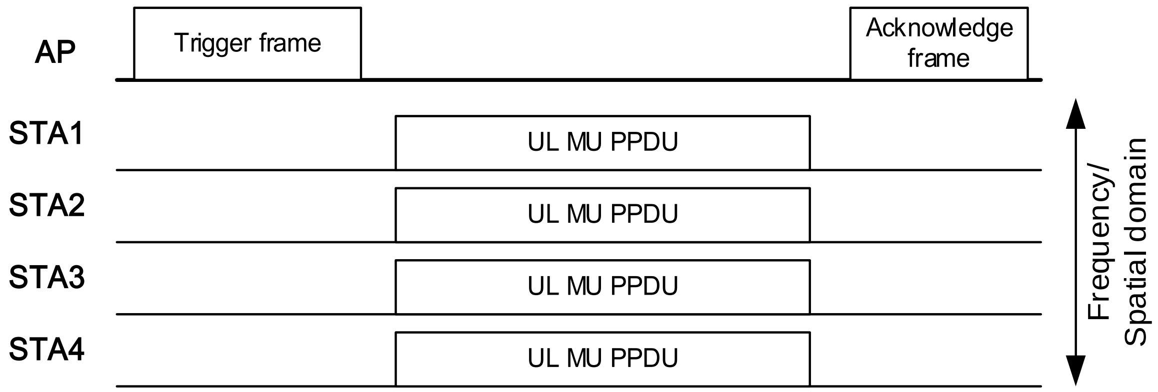
$$y_2 = \sqrt{\rho/_2}\, h_{21}x_1 + \sqrt{\rho/_2}\, h_{22}x_2 + z_2$$

- UL MU-MIMO is mathematically equivalent to UL SU-MIMO
- Why not included in 11ac? To maintain mathematical equivalency in practice requires time synchronization, frequency alignment, and power normalization between all clients in an MU group
- Protocol to address this has been added to 11ax for both UL OFDMA and MU-MIMO (trigger frame)

UL MU Operation

Basic Frame Exchange Sequence for UL MU transmissions

- New Trigger control frame
  - Specifies the length of the UL window
  - Specifies the users that may send during the UL window
  - Allocates resources for the UL-MU PPDUs:
    - RU allocation
    - Spatial stream allocation
    - MCS to be used by the user
  - Supports transmission time, frequency, sampling symbol clock, and power pre-correction by the participating users
- UL MU transmission may be OFDMA or MU-MIMO
- Acknowledgement frame can be
  - DL MU transmission with individually addressed BlockAck frames
  - New “Multi-STA BlockAck” frame contained in Legacy frame or HE MU PPDU
- Trigger frame can be used as a Beamforming Report Poll, MU-BAR, MU-RTS, Buffer Status Report Poll, Bandwidth Query Report Poll…



MU Performance

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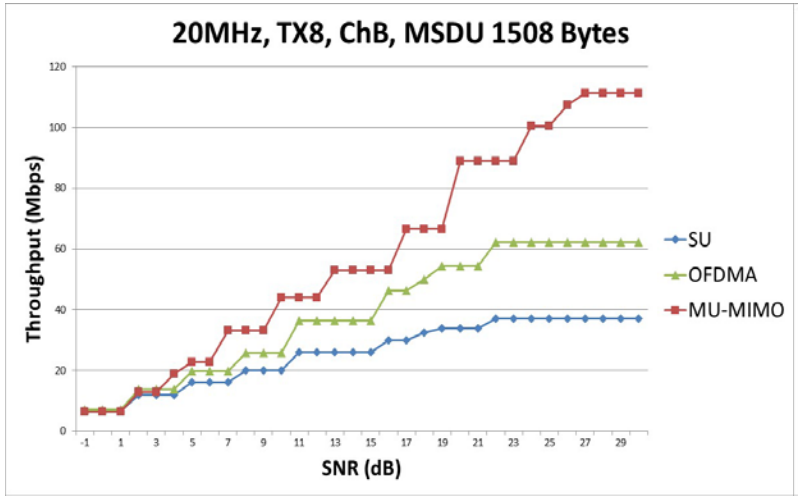
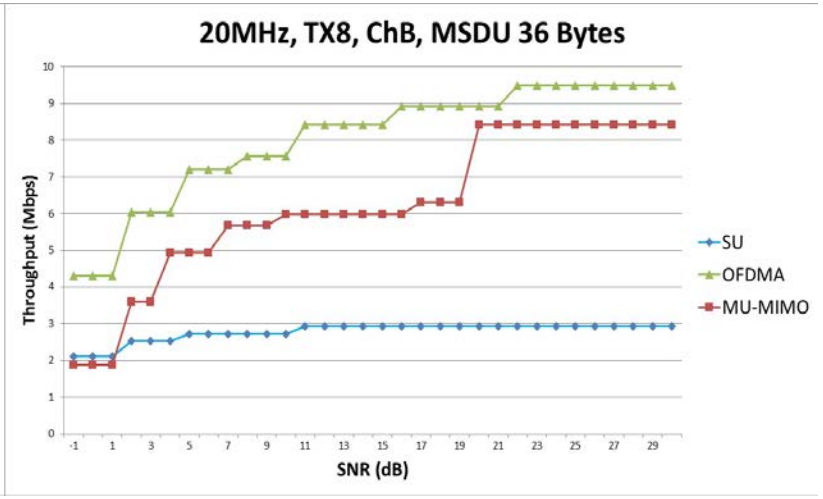
Downlink MU Performance

Analysis Results for DL



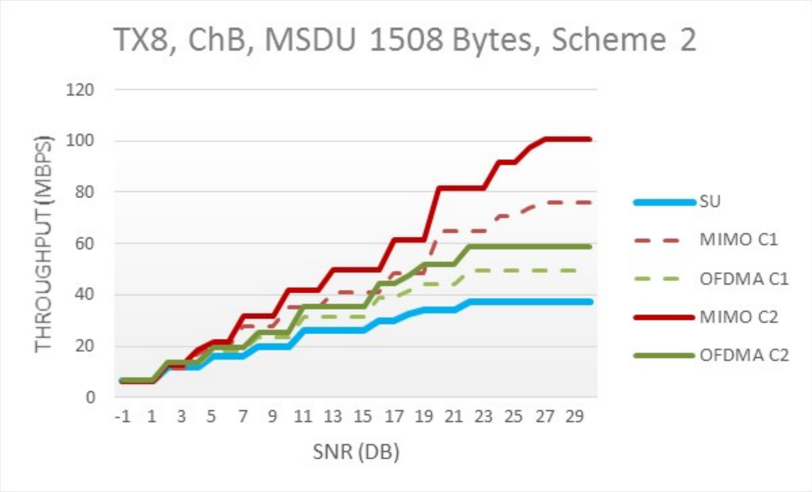


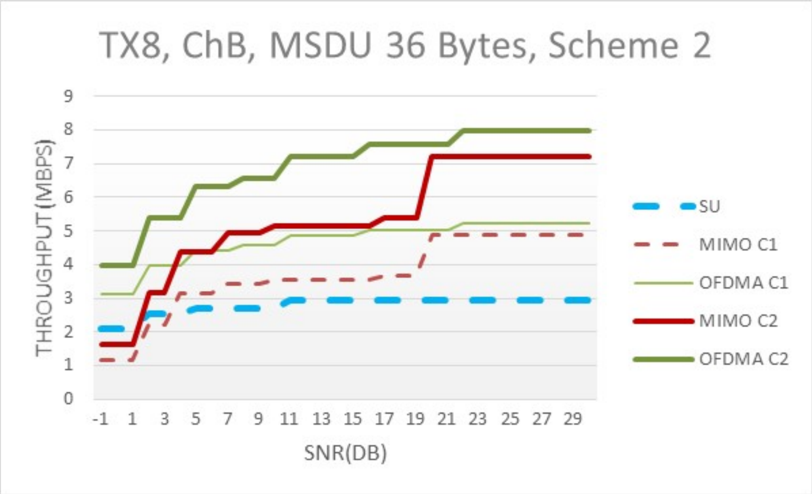
Observations

- Packet size:
  - Large packet: MU-MIMO is the most efficient at high SNR ranges
  - Small packet: OFDMA is the most efficient over entire SNR range
- SNR: At low SNRs, OFDMA always outperforms MU-MIMO

Uplink MU Performance

Analysis results for UL, Scheme 2





Observations

- For Scheme 2 (short control frame exchange), the performance gain over SU transmission is not as dependent on the control frame size as Scheme 1
- Packet size:
  - Large packet: MU-MIMO is most efficient at high SNR ranges
  - Small packet: OFDMA is most efficient over entire SNR operation range

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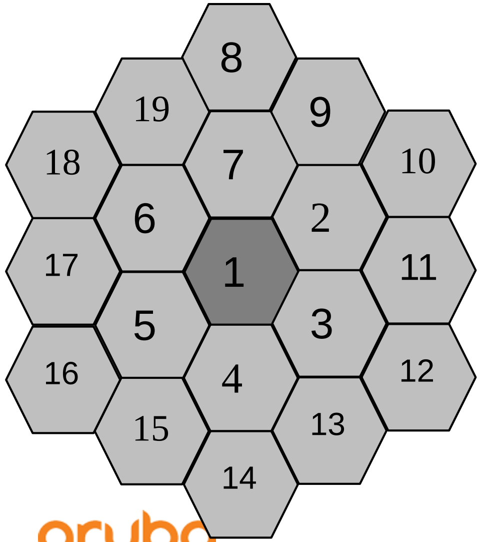
Spatial Reuse

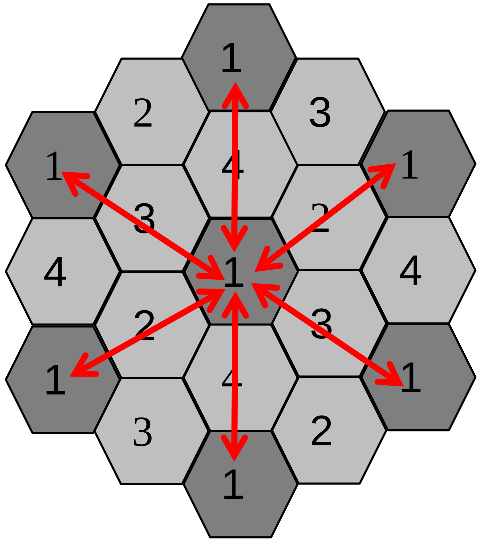
BSS Coloring

– To increase capacity in dense environment, we need to increase frequency reuse between BSS's
  – However, with existing medium access rules, devices from one BSS will defer to another co-channel BSS, with no increase in network capacity
– BSS Coloring was a mechanism introduced in 802.11ah to assign a different "color" per BSS, which will be extended to 11ax
– New channel access behavior will be assigned based on the color detected

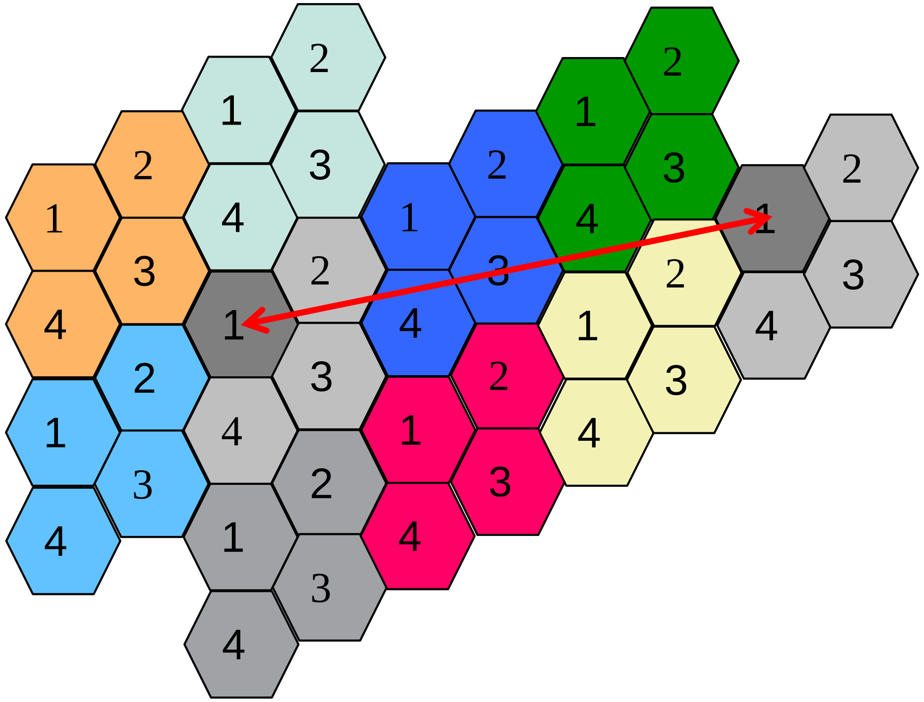
Low Frequency Reuse (w/ 20 MHz channels)



Increased Frequency Reuse (w/ 80 MHz channels) - All same-channel BSS blocking



Same-channel BSS only blocked on Color Match



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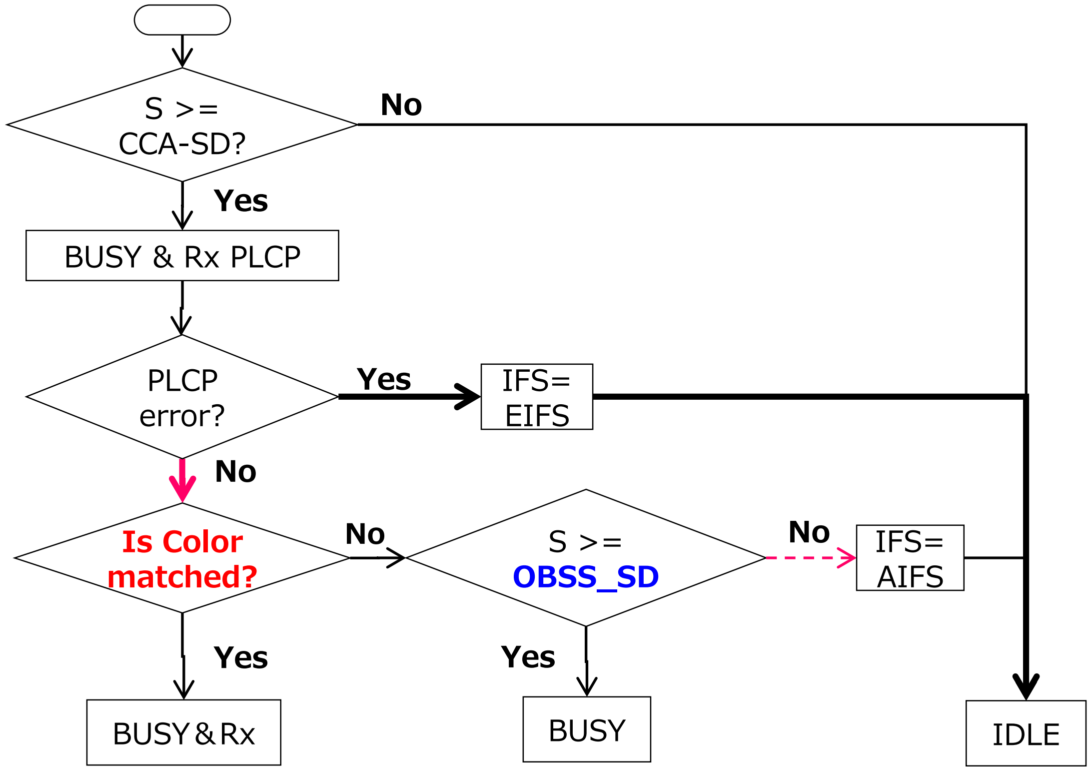
Spatial Reuse Channel Access Rules

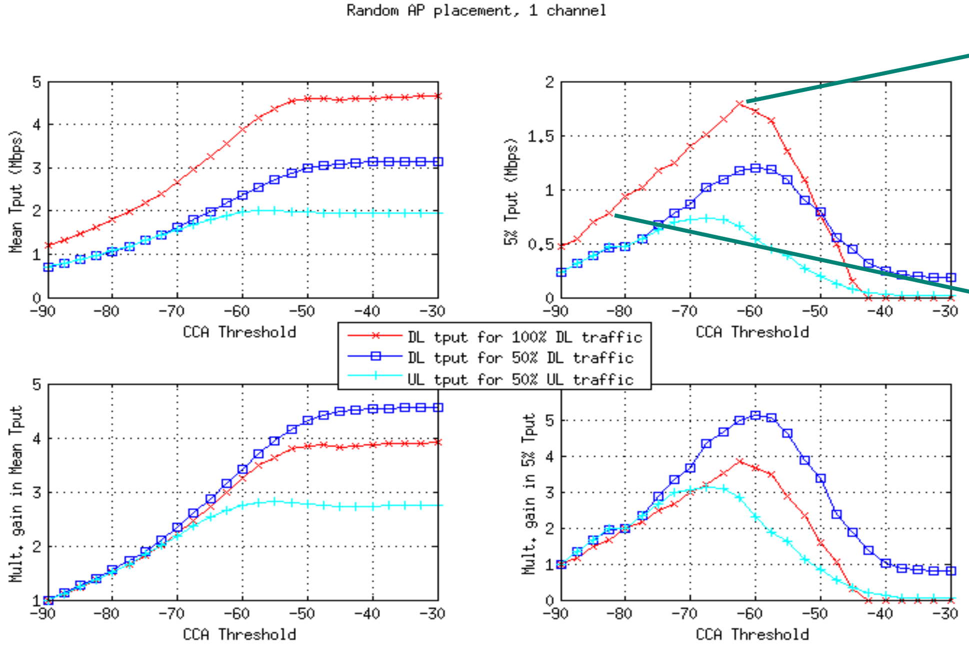
- BOTH the AP and clients can now differentiate between intra-BSS frames and OBSS frames with use of BSS Color bits and apply less sensitive CCA threshold to OBSS frames
  - Higher CCA value leads to more simultaneous transmissions, but potentially lowers SINR
  - The goal is to increase the reuse, while not causing a significant reduction to selected MCS due to interference
- Adaptive CCA
  - 802.11 signal detect and TXPWR threshold may be adjusted dynamically by both AP and clients



Spatial Reuse Capacity Improvement

2x1 11nB, 4 dB shadow, 100% DL vs. 50% DL traffic

- **With mix of UL/DL traffic, UL Tput lower than DL due to lower power**
  - Effect only shows up when CCA threshold high enough to enable meaningful interference
  - Gains for UL traffic smaller than for DL traffic, but still very large



Signal detect level of -62 dBm more than doubles 5% downlink throughput

Nominal SD level

PHY Enhancements

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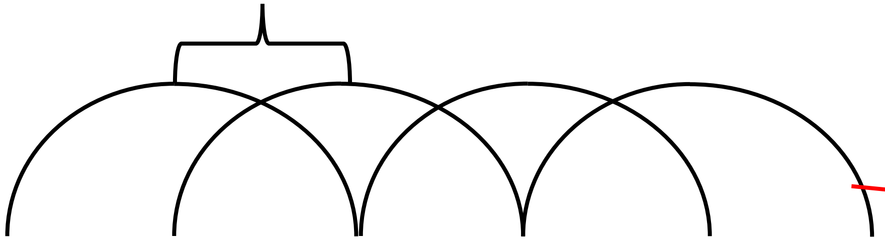
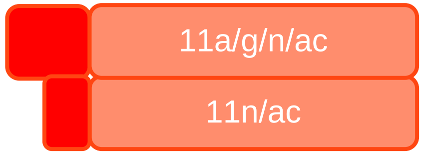
Long OFDM Symbol

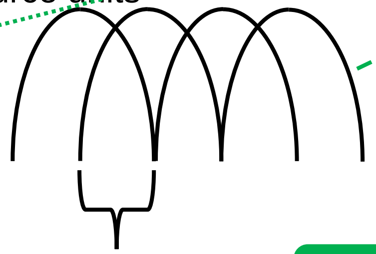
312.5 kHz





- The OFDM FFT size for 20 MHz for 802.11a/g/n/ac is 64 (for 17+ years)
- 802.11a guard interval is 0.8 usec, which decreased in 802.11n with the short guard interval for shorter indoor environments
- 802.11ax is adding
  - 1.6 and 3.2 usec guard interval for outdoor
  - OFDMA, whereby users get assigned smaller sections of the channel bandwidth (resource units)
- 256pt FFT enables
  - 4x longer OFDM symbol for more efficient symbol time (even with longer guard intervals)
  - Narrower and 4x more subcarriers to allow for finer granularity of OFDMA resource units
  - More efficient utilization of the data subcarriers

	802.11a/g	802.11n/ac	802.11ax
FFT size in 20 MHz	64	64	256
Subcarrier frequency spacing	20MHz/64= 312.5 kHz	20MHz/64= 312.5 kHz	20MHz/256= 78.125 kHz
# of data subcarriers	48	52	234
efficiency	75%	81%	91%
OFDM symbol	1/312.5kHz= 3.2 usec	1/312.5kHz= 3.2 usec	1/78.125kHz= 12.8 usec
Guard interval	0.8 usec	0.8, 0.4 usec	0.8, 1.6, 3.2 usec
Symbol time	4.0 usec	4.0, 3.6 usec	13.6, 14.4, 16.0 usec
efficiency	80%	80%, 89%	94%, 89%, 80%



78.125 kHz

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Outdoor / Longer range features

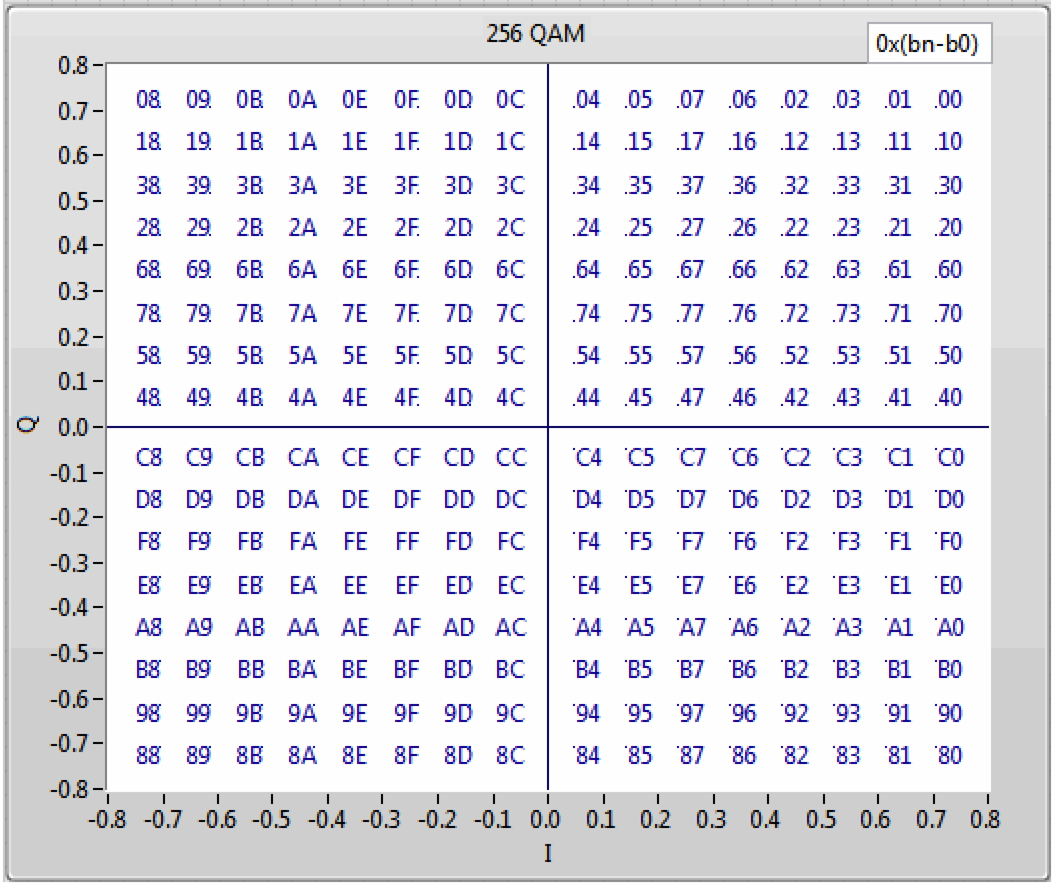
- One of the goals of 802.11ax task group is to address improved performance in outdoor environment
  - One of the issues in an outdoor environment is propagation conditions with delay spreads potentially longer delays spreads than the 11a/n/ac guard interval of 0.8 usec
  - 802.11ax modifies the guard intervals options to 0.8, 1.6, and 3.2 usec
  - In an outdoor environment, there could be multipath bounces off high speed vehicles. A Doppler bit is included in the signal field to indicate TBD Doppler mode of transmission
- To expand the coverage and robustness of an outdoor hotspot
  - New extended range packet format with more robust (longer) preamble
    - L-STF/L-LTF/HE-STF/HE-LTF are boosted by 3 dB
    - L-SIG and HE-SIG-A are repeated twice
  - Dual Carrier Modulation (DCM) – replicate the same information on different subcarriers for diversity gain and narrow band interference protection, ~3.5 dB gain
  - Narrower transmission bandwidth for Data field – 106 tones (~8 MHz) can be used to reduce noise bandwidth

						Variable durations per HE-LTF symbol				
8µs	8µs	4µs	4µs	16µs	4µs					
L-STF	L-LTF	L-SIG	RL-SIG	HE-SIG-A	HE-STF	HE-LTF	…	HE-LTF	Data	PE

HE extended range SU PPDU format

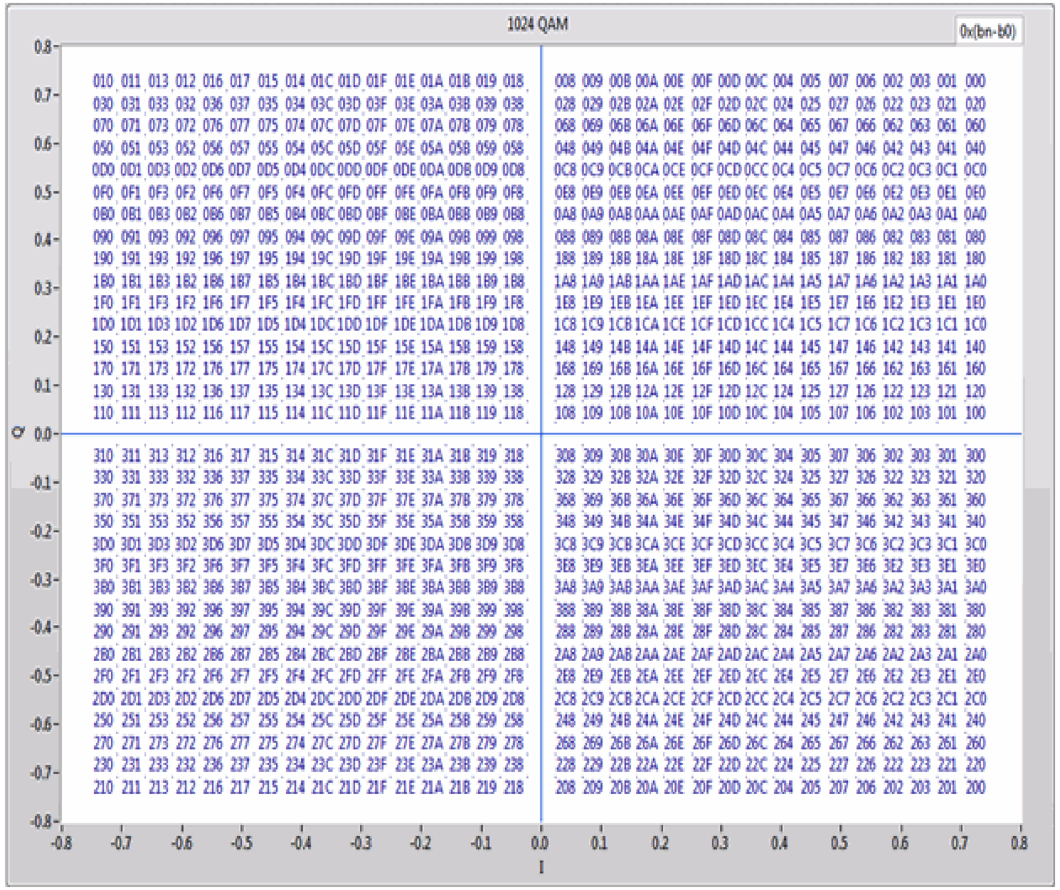
1024 QAM – 25% increase in PHY data rate

11ac – 256 QAM
8 bits per symbol



TX EVM MCS9 = -32 dB
Min Sens MCS9 (20 MHz, 80 MHz) = -57, -51 dBm

11ax – 1024 QAM
10 bits per symbol



TX EVM MCS11 = -35 dB
Min Sens MCS11 (20 MHz, 80 MHz) = -52, -46 dBm

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Example of New PHY Data Rates

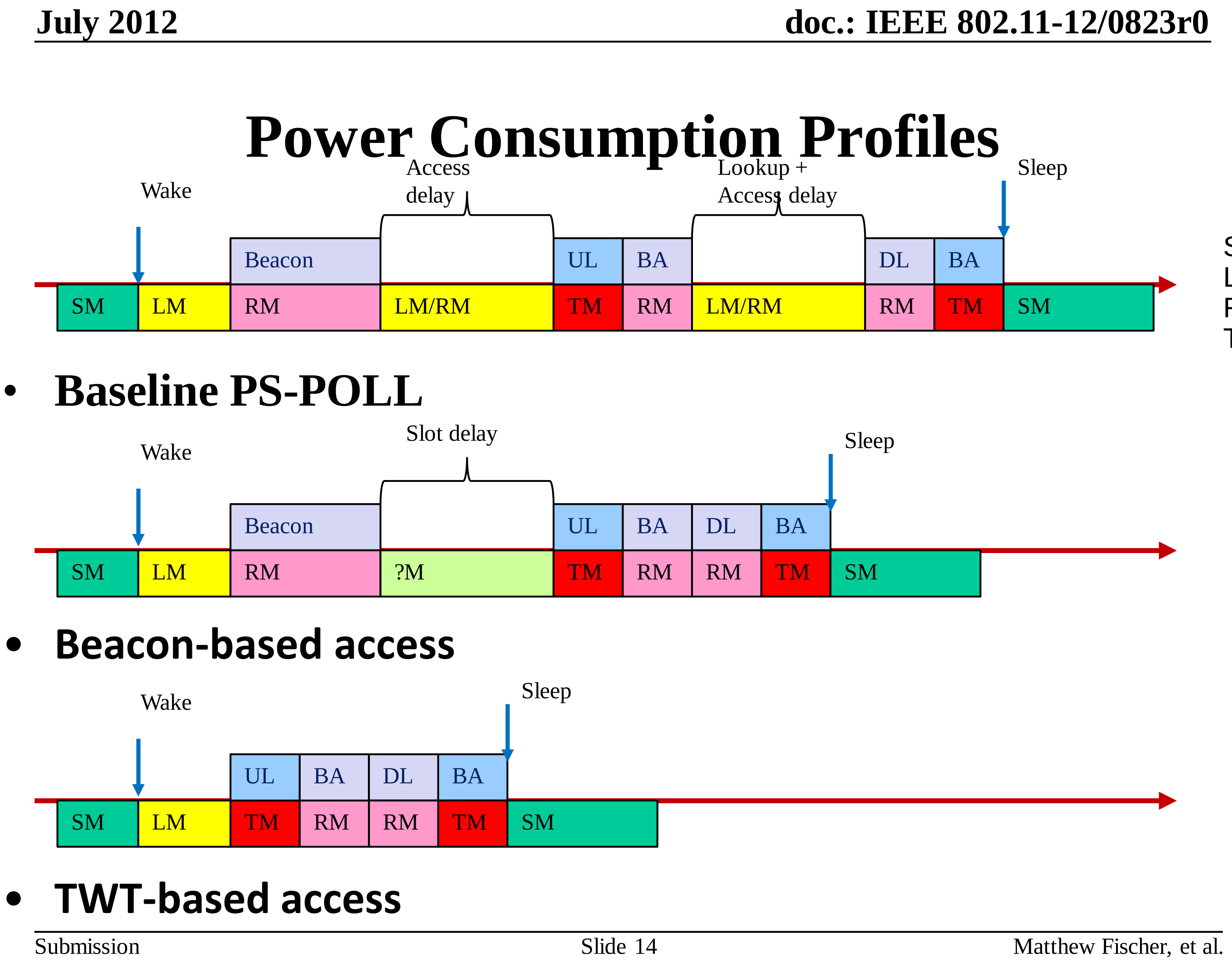
	11ax			11ac	
	Data rate (Mbps)	Mode	gain	Data rate (Mbps)	Mode
Min	0.375	1SS, MCS0, DCM, 26-tone		6.5	1SS, MCS0, 20 MHz
Max, 20 MHz	143.4*NSS	1024-QAM, r=5/6, 13.6 usec symbol	65%	86.7*NSS	256-QAM, r=3/4 (256-QAM, r=5/6 only valid for NSS=3,6), 3.6 usec symbol
Max, 40 MHz	286.8*NSS	1024-QAM, r=5/6, 13.6 usec symbol	43%	200*NSS	256-QAM, r=5/6, 3.6 usec symbol
Max, 80 MHz	600.4*NSS	1024-QAM, r=5/6, 13.6 usec symbol	39%	433.3*NSS	256-QAM, r=5/6, 3.6 usec symbol
Max, 160 MHz	600.4*2* NSS	1024-QAM, r=5/6, 13.6 usec symbol	39%	433.3*2*NSS	256-QAM, r=5/6, 3.6 usec symbol

NSS = 1…8 for both 11ac and 11ax

Power Saving

Target Wake Time

- Target Wake Time (TWT) is a power saving mechanism in 802.11ah, negotiated between a STA and its AP, which allows the STA to sleep for periods of time, and wake up in pre-scheduled (target) times to exchange information with its AP
- 802.11ah TWT mechanism modified to support triggered-based uplink transmissions
- New Broadcast TWT operation added in 802.11ax to support non-AP STAs that have not negotiated any implicit agreement with HE AP



SM: Sleep Mode
LM: Listen Mode
RM: Receive Mode
TM: Transmit Mode

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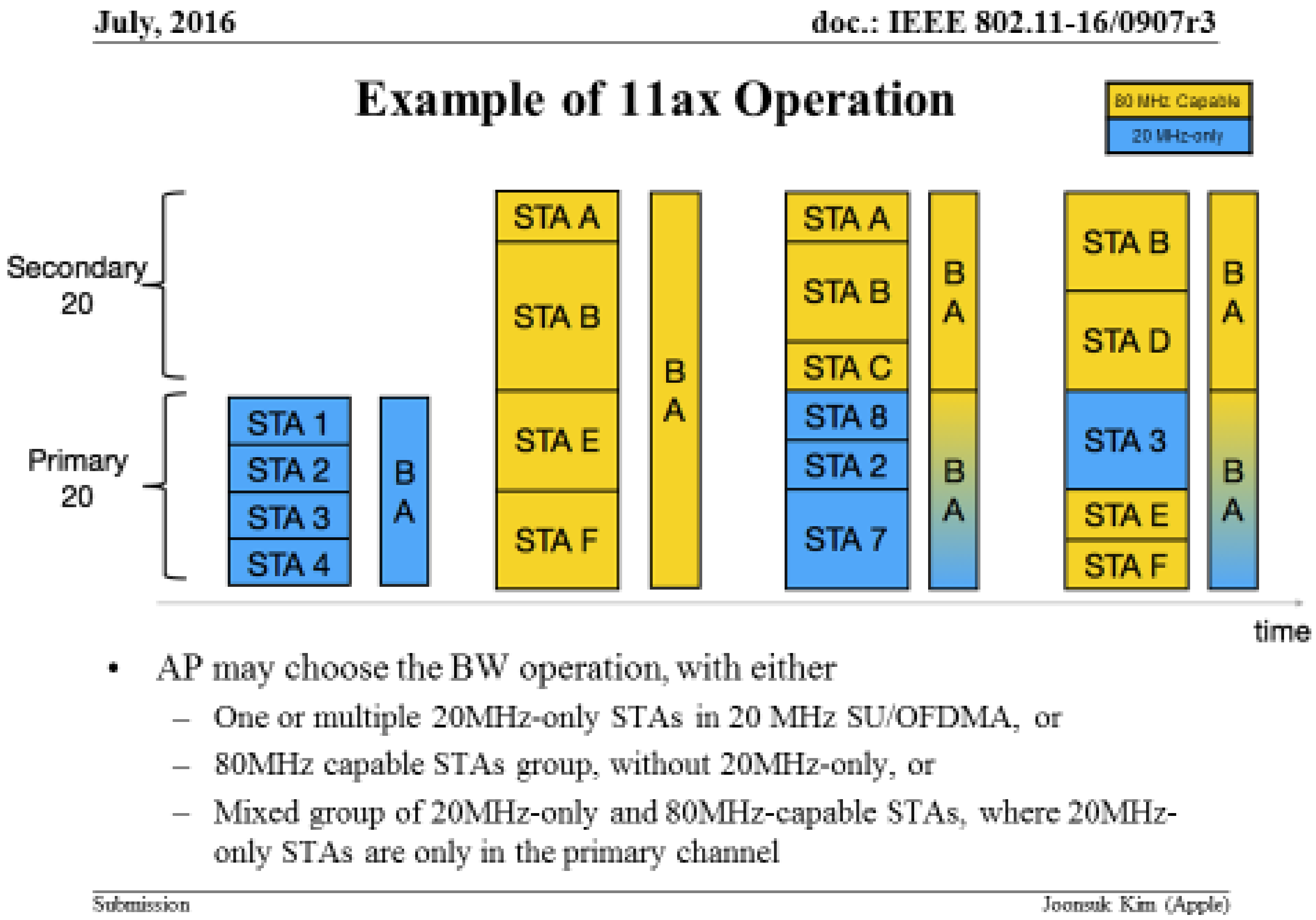
20 MHz-only Clients

– Provide support for low power, low complexity devices (IOT): wearable devices, sensors and automation, medical equipment, etc.

– Such devices do not need high bandwidth operation

– In actuality, this only applies to 5 GHz, as only 20 MHz support is mandatory in 2.4 GHz

  – "Normal" clients still required to support 80 MHz in 5 GHz



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Other Power Saving Features

– Receive Operating Mode indication is a procedure to dynamically adapt the number of active receive chains and channel width for reception of the subsequent PPDUs, by using a field in the MAC header of a Data frame,

  – rather than Operating Mode Notification management frame exchange (e.g. 11ac)
  – Minimal impact on channel efficiency

– Transmit Operating Mode indication is a procedure for client devices to dynamically adapt their transmit capability:

  – Channel width & maximum number of spatial streams
  – SU vs UL MU operation

– Use of BSS Color field and UL/DL flag in preamble to enable intra PPDU power saving

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Thank you