

DL-OFDMA for Mixed Clients

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Authors:

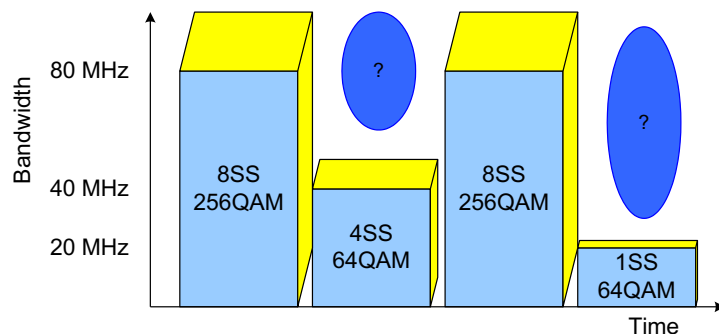
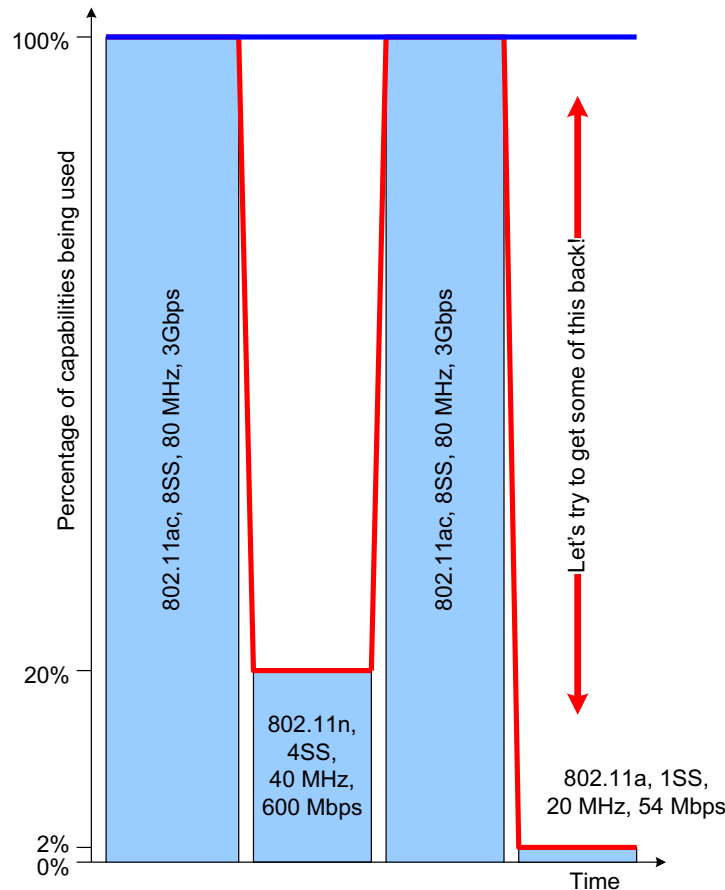
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Motivation

- **Customers tend to accumulate a range of 802.11 devices**
- **These are 11a/g and 11n and (soon) 11ac**
- **Typically the 802.11 NIC is but one component of the perceived value of the device to the customer, so is subject to the replacement cycle of the device**
 - E.g. a gaming console or a hospital pump may be retired only when it breaks, in 3 or 5 or *more* years
- **Therefore many BSSs will have clients with a mixture of PHYs, potentially “forever”**

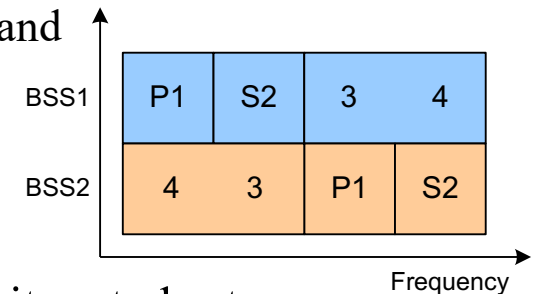
Problem (1)

- Historically we deal with client mixture by invoking MAC protection (or a mixed mode preamble)
 - Provides no improvement and actually decreases efficiency
 - The AP resources are underutilized and its capabilities are wasted for much of the time
 - This inefficiency reduces the motivation to upgrade AP and, in turn, the client



Problem (2)

- **Specifically, with 80 MHz BSSs**
 - 60 MHz of bandwidth is wasted to/from legacy 11a devices,
 - 40 MHz of bandwidth is wasted to/from legacy 11n devices
 - The wastage is recoverable in the enterprise in a system sense if:
 - there are overlapping BSSs with different primary channels, and
 - overlapping non-primary channels, and
 - both BSSs have something to send, and
 - both BSSs have a solid CCA, and
 - both BSSs have reasonable multi-channel fairness
 - But in general, your 11ac AP will be working at far below its rated rate whenever there are 11a/11n transmissions in progress
- **11ac has new degrees of freedom that may allow better ways to recover this wastage**
 - MUMIMO, with one legacy and (N-1) 11ac clients
 - Yet very challenging preamble design even for DL-MUMIMO
 - OFDMA, including DL-OFDMA, with one legacy and (N-1) 11ac clients



DL-OFDMA for Mixed BSSs

- **DL-OFDMA is much like DL-MUMIMO except multiplexing is in the frequency dimension rather than the spatial dimension**
- **Complexity is very, very comparable to DL-MUMIMO, but with reduced RF risk**

Simplified Performance Analysis (1)

- **For simplicity, assume:**
 - 3Gbps 11ac clients (1, 4 or 20 clients)
 - 600 Mbps 11n clients (1, 4 or 20)
 - 54 Mbps 11a clients (1, 4 or 20)
 - Fully loaded sources
 - Same length TXOPs for all PHYs
 - Downlink-only traffic (benefits reduce linearly with ↓ %DL)
 - Each device transmits nicely in turn (!)
 - No OBSS traffic (benefits reduce approx linearly with ↑ %OBSS)
 - 80 MHz 11ac (benefits increase approx linearly with ↑ BW)

54	54	54	54	3000	3000
2250	2250	2250	2250	3000	3000

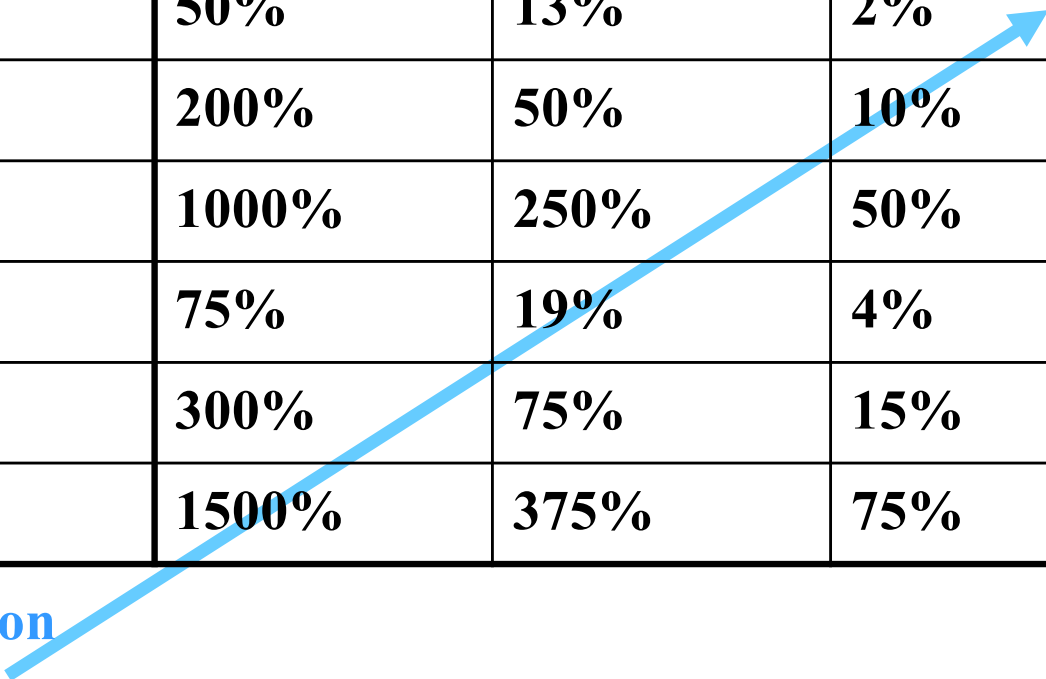
Without DL-OFDMA, 11ac client gets $3000/6$,
AP serves $4*54+2*3000$

With DL-OFDMA, 11ac client gets $3000/6 + 4/2*2250/6$,
AP serves $4*54+4*2250+2*3000$

Simplified Performance Analysis (2)

- % benefit of DL-OFDMA wrt no DL-OFDMA per 11ac client
- Huge client gains at start; moderate gains while legacy devices remain

#11n	#11a \ #11ac	1	4	20
1	0	50%	13%	2%
4	0	200%	50%	10%
20	0	1000%	250%	50%
0	1	75%	19%	4%
0	4	300%	75%	15%
0	20	1500%	375%	75%



Market evolution

Simplified Performance Analysis (3)

- **AP utilization**
 - Mean data rate/maximum data rate at AP as a percentage
 - Without DL-OFDMA (%) → with DL-OFDMA (%)
- **Huge AP gains at start; moderate gains while legacy devices remain**

#11n	#11ac #11a	1	4	20
1	0	60% → 85%	84% → 94%	96% → 99%
4	0	36% → 76%	60% → 85%	87% → 95%
20	0	24% → 71%	33% → 75%	60% → 85%
0	1	51% → 88%	80% → 95%	95% → 99%
0	4	21% → 81%	51% → 88%	84% → 96%
0	20	6% → 78%	18% → 81%	51% → 88%

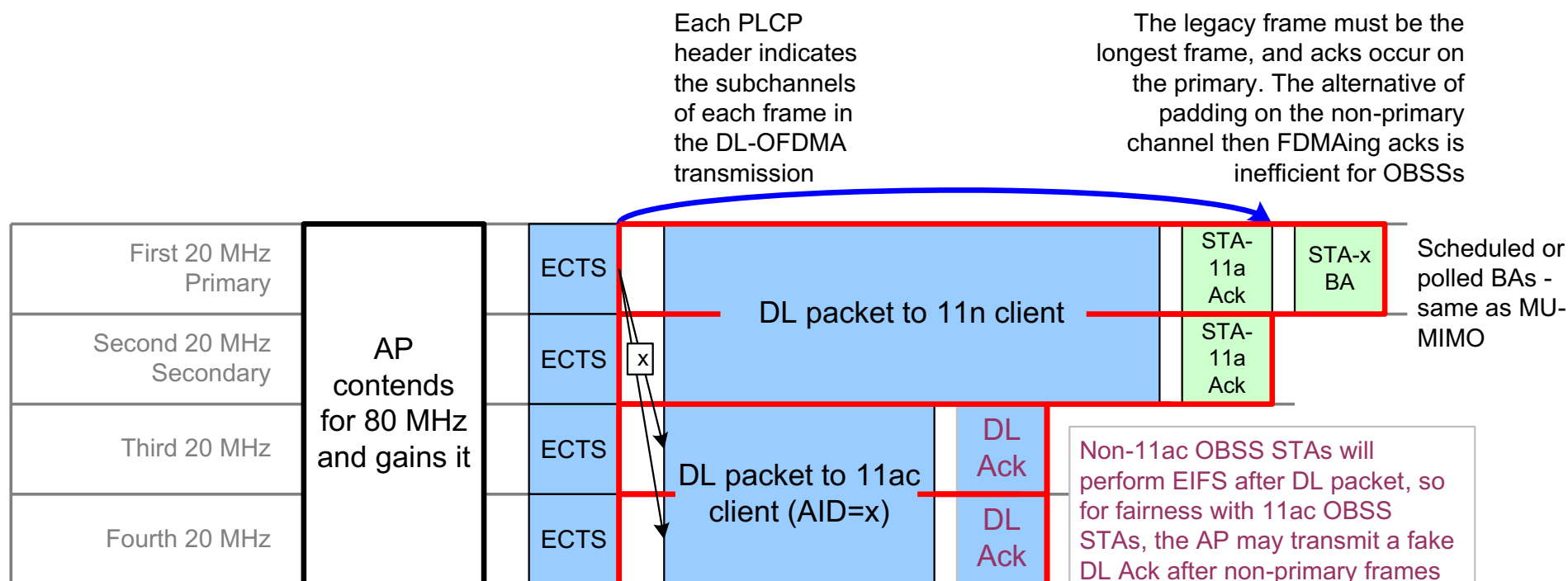
Market evolution

Proof-of-Existence:

Is there a simple and practical system?

- **Simple PHY**
 - Transmitting or receiving; never both simultaneously
 - Multiple transmitters, but not multiple receivers
- **Single MAC contention**
- **Receivers can unambiguously determine which sub-channel(s) their packets are on**
 - Akin to the Group Id problem in DL-MUMIMO
 - (Via a combination of control frame and PLCP header)
- **Maximum efficiency**
 - Minimize padding
 - Groupcast frames not duplicated on sub-channels
 - Since, unlike DL-MUMIMO, medium time on other subchannels is available to OBSSs

A Basic Example (11n legacy)



Assume we have a multi-channel contention mechanism that minimizes collisions and maximizes fairness and throughput

- 1) ECTS can set different NAVs per subchannel (red boxes)
- 2) Otherwise ECTS contents are the same: the duration to end-of-legacy-ack for ack scheduling, eolaDuration (blue arrow), plus subchannel assignments by AID (black arrows)
- 3) ECTS is broadcasted using a basic legacy rate

Subchannel field within PLCP Header

- In general every PLCP header needs to self-announce the subchannels occupied by the PPDU
- Without DL-OFDMA, this self-announcement could be as simple as a 20/40/80/160 MHz indication – 2 bits
- With DL-OFDMA, the number of bits depends on 11ac's max bandwidth and minimum bonding assumed within DL-OFDMA. Reasonable options include:
 - One bit per subchannel, so 80 MHz max requires 4 bits (1,2,3,4) but 160 MHz max requires 8 bits (1,2,3,4,5,6,7,8)
 - Or with more bonding of the “higher” subchannels, so 80 MHz max requires 3 bits (1,2,3+4) and 160 MHz max requires 5 bits (1,2,3+4,5+6,7+8)
 - See diagram
 - SU-MIMO PLCP header likely has more free bits
 - Etc
- **E.g. 3 extra PLCP bits**

36	40	44/48	52/56	60/64
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Legacy	1st 11ac STA 00100	Second 11ac STA 00011
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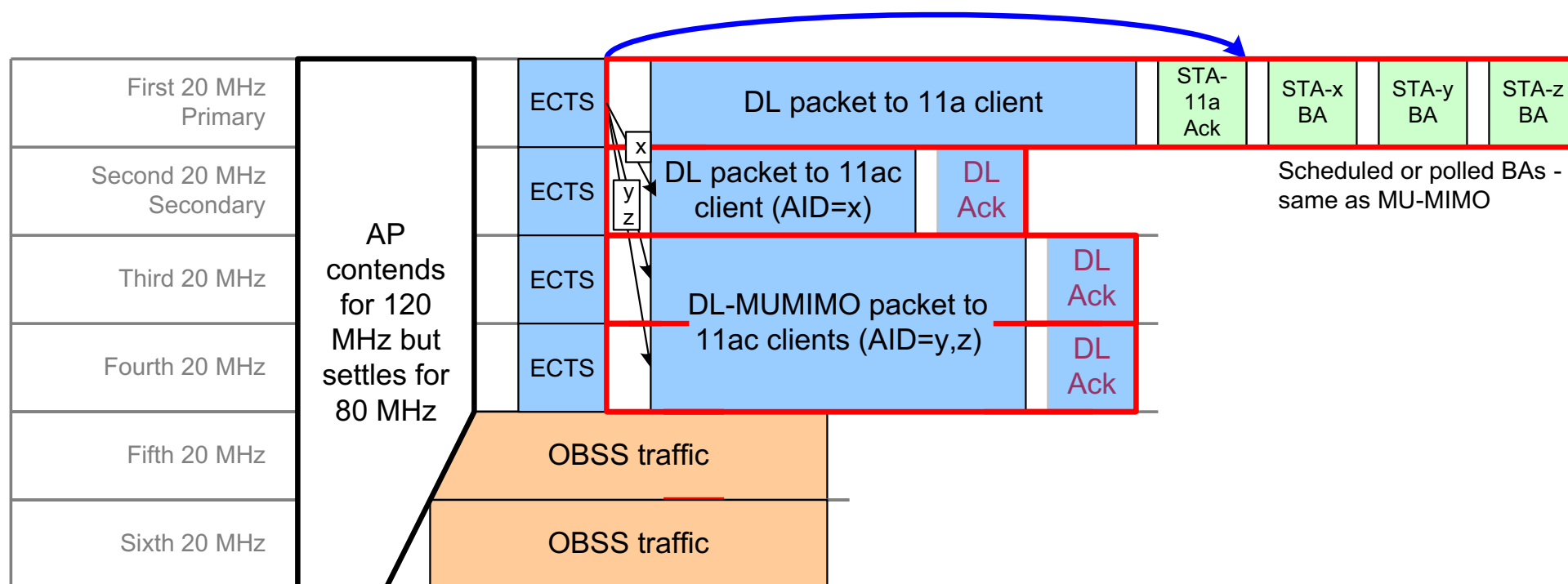
The Constraint on Legacy Length is Not Very Restrictive

- **With aggregation, the transmitter can lengthen an 11n frame without over-lengthening the 11ac frames**
- **During early 11ac adoption, 11a/11n frames will dominate, so there is “always” a legacy frame for an 11ac MSDU to piggyback onto**
- **During late 11ac adoption, 11ac frames will dominate, so there is “always” an 11ac MSDU to transmit alongside slow legacy frames**
- **On average, there will be a light tendency for legacy to be slower (fewer SS, no 256QAM), and so longer**
- **Worst comes to worst, if the legacy frame cannot be the longest, don't use this feature**

Groupcast

- **A groupcast frame intended for legacy always includes the primary subchannel**
- **Parallel DL-OFDMA frames in the same transmission are disallowed**

A More Complete Example (11a legacy) with 3 short 11ac packets



- Combining both DL-OFDMA and DL-MUMIMO in one transmission may be too complicated, but the option is available to the spec

Advantages

- **Net increase in single-BSS throughput whenever off-primary frames are longer than ECTS**
 - Especially valuable with legacy clients in an 80 MHz BSS
- **Similar complexity as DL-MUMIMO, but without the RF risk**
- **Simple PHY**
 - Transmitting or receiving; never both simultaneously
 - Multiple transmitters, but not multiple receivers
 - PHY filtering and processing is very similar to existing MIMO-OFDM requirements; can be done with digital changes only
- **Single MAC contention**
- **Minimizes usage of non-primary channels, so they can be shared between BSSs**
- **Compatible with DL-MUMIMO**
- **Huge benefits to early adopters of 11ac clients and APs**
- **Moderate gains while 11a/11n clients remain**

Comments, Questions?

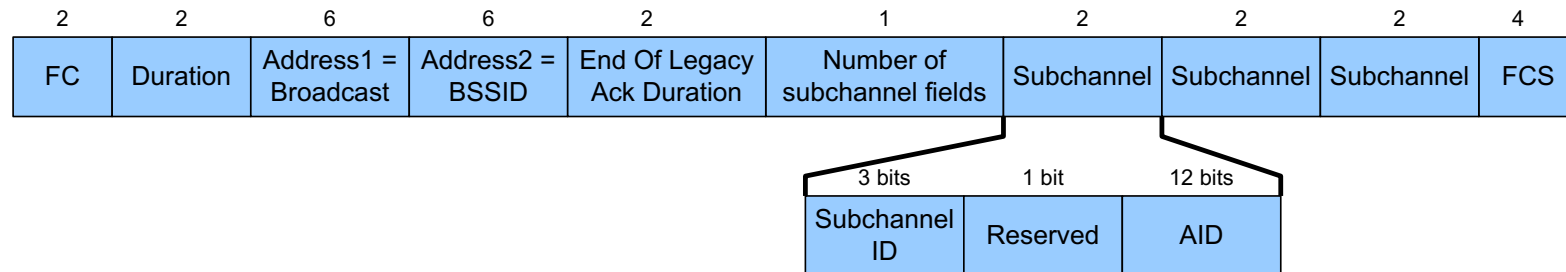
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Strawpoll

- **Do you agree that BSSs with non-AP STAs that have a mixture of PHY capabilities leads to inefficient use of the BSS resources, and reducing this inefficiency is a topic that merits further investigation?**
- **Y, N, A**

Backup Slides

Example of a ECTS Format

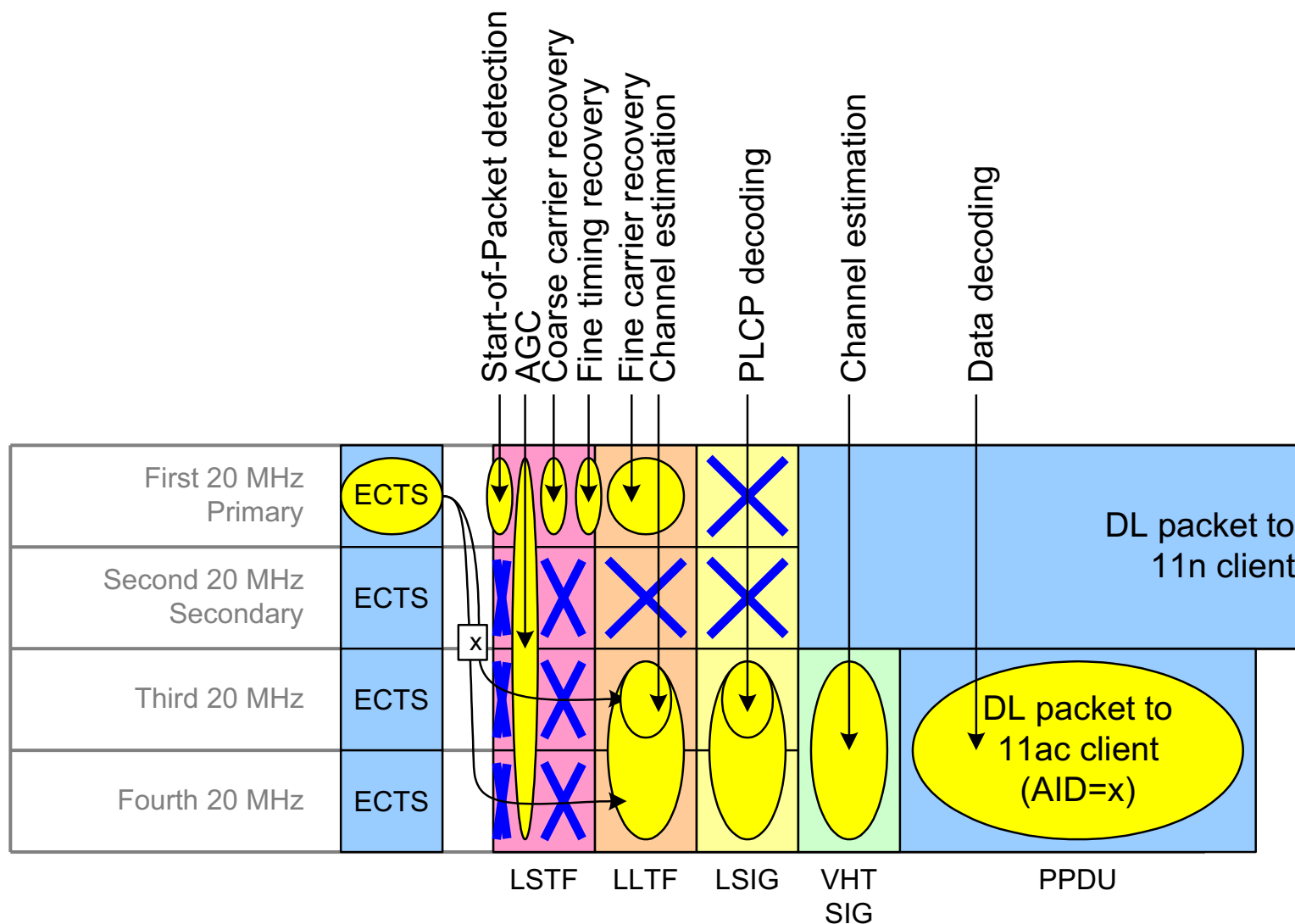


- End of Legacy Ack Duration is the elapsed time to the end of the legacy Ack, in microseconds (blue arrow on previous slide)
- A frame sent to an AID across N subchannels requires N Subchannel fields
 - **Subchannel ID identifies a 20 MHz channel within up to 160 MHz of bandwidth (3 bits)**
 - **E.g. one 40 MHz 11ac client uses 27 octets or 60us at 6 Mbps (11a)**
- Multiple AIDs are allowed per subchannel in order to support DL-MUMIMO
- ECTS is a variable length control frame
 - Fixed length would be preferred apart from the length: up to 8subchannels * 4AIDs/subch * 1.5 octets/AID = 48 octets + 20 MAC bytes
- Other formats are possible too, especially if the AID is limited to 8 bits

ECTS Security Considerations

- An unsecured ECTS introduces a new DoS attack on target clients
- The attacker regularly a) sends a ECTS directing selected AIDs to a non-primary/secondary (little-used) subchannel then after SIFS b) sends a long packet on the indicated subchannel.
 - **During this attack, the selected STAs miss packets sent by the AP on the other subchannels – e.g. on the Primary/Secondary**
 - **The attack requires the attacker to transmit more-or-less continuously**
 - **A target client can mitigate the attack: if there is no energy on the primary after SIFS, or energy on the primary disappears well before eolaDuration-SIFS-TXTIME(Ack or BA) then an attack can be inferred**

Example PHY Processing Flow



PHY Considerations (1)

	MIMO OFDM	DL-OFDMA (11ac)	Legacy within DL-OFDMA
TX	a) Fixed 80 MHz analog TX filters, IFFT dynamically excites subcarriers (imperfect TX mask) b) Dynamic 20/40/80 MHz analog filters	Same, except, for legacy packets sent with 64QAMr3/4 or higher, legacy constellation points may be amplified by 1-2 dB wrt 11ac constellation points to not exceed legacy ACI spec, or 64QAMr3/4 not used	N/A
AGC	Set according to power out of analog filters and into ADC(s)	Same	Same, with a small amount of ACI always present
Start-of-packet detection, coarse carrier, fine timing, fine carrier recovery	a) Fixed analog 80 MHz RX filter, then 20 MHz filter on primary used for SOP detection, coarse carrier, fine timing, fine carrier recovery b) Fixed analog 80 MHz RX filter, then “smart” combining of 20 MHz subchannels (“smart” => ignores subchannels subject to ACI)	a) Same (since the start-of-packet, carrier offset and symbol timing are common to all subchannels, the RX can continue to process the Primary channel as usual, even if its intended packet lies on other subchannels [see Slide 21] b) Same. (For “smart” combining, the DL-OFDMA duplicate preambles are available for combining exactly like a OFDM packet)	Same, affected by a small amount of ACI imperfectly filtered out; fortunately this ACI conveys the same timing and carrier information

PHY Considerations (2)

	MIMO OFDM	DL-OFDMA (11ac)	Legacy within DL-OFDMA
FFT filtering	a) Time-domain filtering then 20/40/80 MHz FFT for 20/40/80 MHz signal b) 40/80/160 MHz FFT for 20/40/80 MHz signal c) 160 MHz FFT for 20/40/80 MHz signal In b) and c), discard unused subcarriers not part of desired signal	Similar to b) or c), except now the discarded subcarriers include subcarriers from the Primary subchannel [see Slide 21]	Same, except without 80 MHz signal and probably without 160 MHz FFT
PLCP Equalization/ Demod/ Decode	Estimate CSI for the Primary/Secondary subchannels (needed for 40 MHz GF), then equalize the PLCP header (optionally “smart” combining the PLCP header across the PS subchannels), then demod/decode	Similar. Estimate CSI for the Primary subchannel, then equalize the PLCP header [See Slide 21] (optionally “smart” combining the PLCP header across the intended subchannels), then demod/decode	Same, with a small amount of ACI possibly aliased in, but well below ACI requirements since the PLCP header is BPSK1/2
PSDU Equalization/ Demod/ Decode	Estimate CSI for the intended subchannels, then equalize the PSDU, then demod/decode	Similar. Estimate CSI for the intended subchannels, then equalize the PSDU, then demod/decode [See Slide 21]	Same, with a small amount of ACI possibly aliased in, but below ACI requirements by TX design

PHY Considerations (3)

	MIMO OFDM	DL-OFDMA (11ac)	Legacy within DL-OFDMA
RX to TX turnaround	A 20/40/80 MHz AP must be able to RX a 20/40/80 MHz packet that includes the Primary, then TX a 20/40/80 MHz packet on the same subchannels after SIFS. The TX and RX packets always include the Primary but dynamically include other subchannels	A 20/40/80 MHz client must be able to RX a 20, 40 and 80 MHz packet on one or more subchannels then TX a 20 MHz BA on Primary after 2*SIFS + TXTIME(Ack).	e.g. immediate Ack at SIFS