HE PHY Padding and Packet Extension

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Overview

- HE PHY adopts 4x Numerology [1], mainly for: facilitate OFDMA design, facilitate outdoor channel support, increase PHY efficiency.

- **<u>Area Penalty</u>**: ~4x N_{DBPS} compared with 11ac with same BW.
  - Lead to big area or implementation complexity concern, if SIFS time duration is unchanged.
    - ~4x processing speed is required for the last OFDM symbol, for Rx→Tx turn-around within SIFS (FFT, MIMO-EQ, Decoding, MAC, Tx).
    - Especially at peak data rates (e.g. 256AM).
- **<u>Overhead Penalty</u>**: on the other hand, increasing SIFS or equivalently adding long packet extension (PE) may offset the throughput gain of 4x numerology.

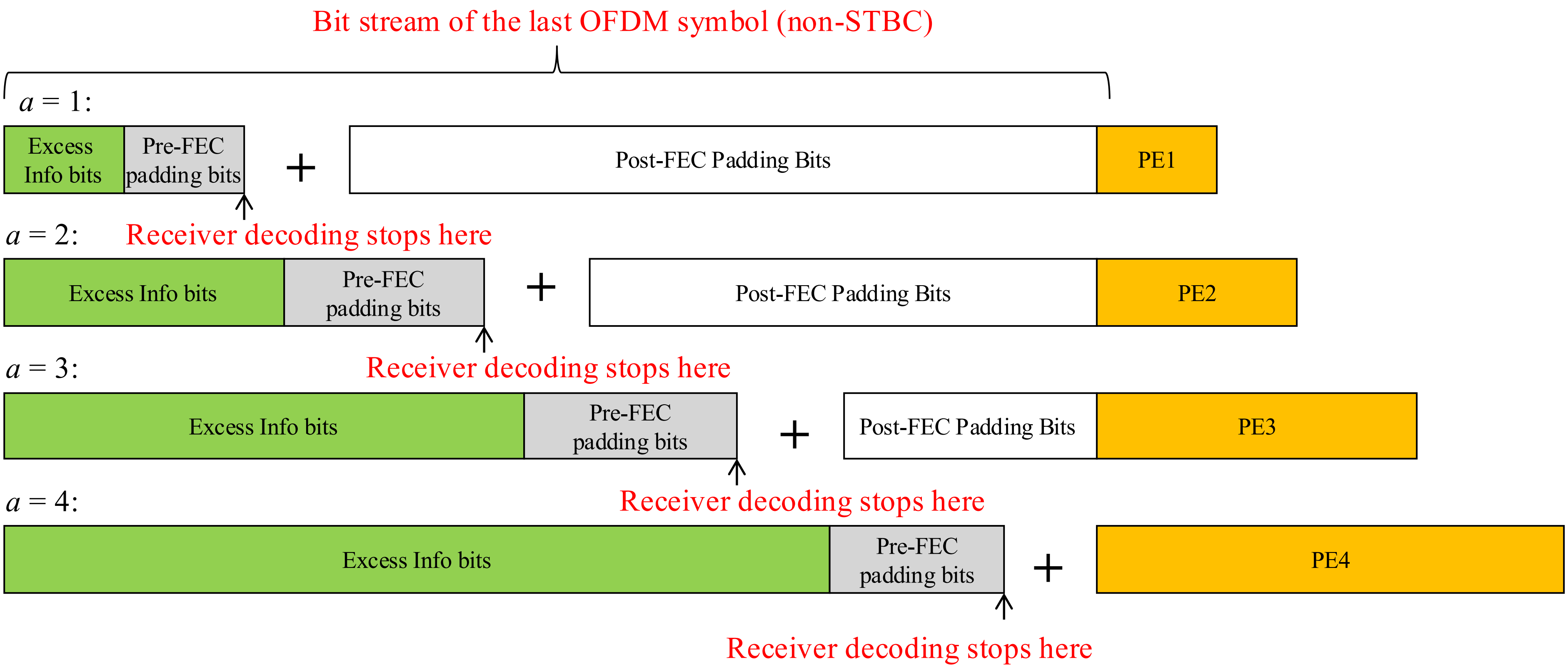
- **Tradeoff**s between Area and Overhead:
  - Challenging to optimize both at the same time.
  - Different options give different levels of tradeoffs, with different solution for either reducing area/complexity or reducing overhead.

Proposed HE Padding and Packet Extension

- The last m_{STBC} symbol(s) have 4x duration like other data symbols (12.8us+GI).
- Apply a two-step padding method in the last m_{STBC} OFDM symbol(s), i.e.: "Pre-FEC" padding, and "post-FEC" padding.
  - Four possible pre-FEC padding segment boundaries ("*a* –factor") are defined in the last OFDM symbol(s).
    - Based on number of excess info bits in the last symbol(s), pre-FEC pad (the same MAC/PHY padding as in 11ac) toward the nearest boundaries in the last symbol(s).
  - For LDPC, if "LDPC extra symbol" is needed after puncturing, increment one segment ($a = a_{init}+1$), instead of one long symbol.
  - After FEC, insert post-FEC padding bits to fill up the symbol(s).
    - Post FEC padding is added by PHY and does not need to be decoded by the receiver

- A Packet Extension (PE) field is applied at the end of PPDU, and its duration is a function of the followings:
  1. The pre-FEC padding boundaries in the last m_{STBC} OFDM symbols ("*a* – factor").
  2. Receiving STA's capability on its required PE duration, for the current {BW, N_{SS}, Constellation} combination.

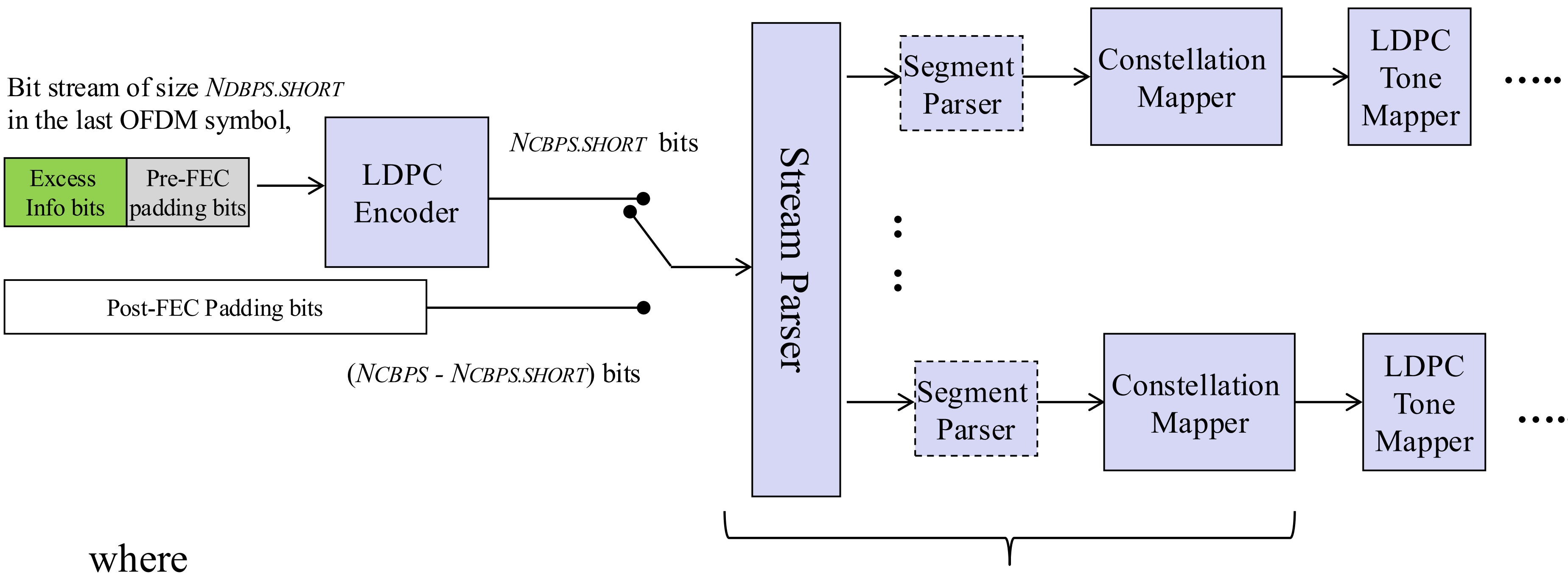
Bit Stream Illustration



Refer to Appendix for the Math

LDPC Encoding Illustration

- Use *a=1* and LDPC case as an example.



where

$$N_{CBPS,short} = N_{SD,short} \cdot N_{SS} \cdot N_{BPSCS}$$

$$N_{DBPS,short} = N_{CBPS,short} \cdot R$$

Processing Delay

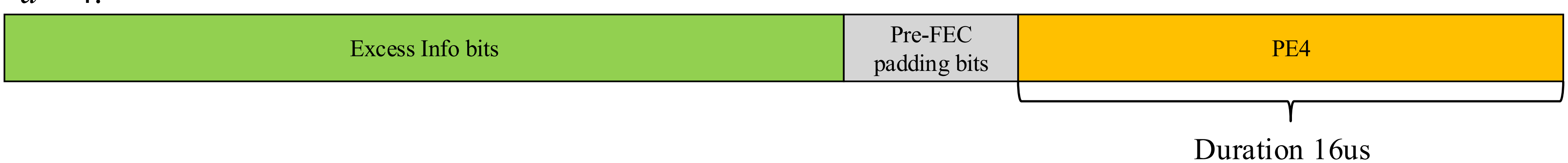
- For LDPC:
  - 4x FFT →4x Tone Demapper → Only take the first $N_{SD.SHORT}$ tones → FD processing (MIMO Equalizer, LDPC Decoder)→MAC processing.
  - Post-FEC padding bits are not processed.

- For BCC:
  - Almost all tones need to be processed due to interleaver.
  - However, we propose to disallow BCC in 40MHz, 80MHz and 160MHz. See [2] for more details.

Packet Extension Field

- PE durations for different pre-FEC padding boundaries (*a-factor* values).
  - Based on decoding capability of the device.
  - An Example where max PE duration is 16us:
    - T_{PE1} = 4us, or ~¼ long symbol (*a*=1)
    - T_{PE2} = 8us , or ~1/2 long symbol (*a*=2)
    - T_{PE3} = 12us, or ~3/4 long symbol (*a*=3)
    - T_{PE4} = 16us, or ~1 long symbol (*a*=4)
  - T_{PE} values are multiple of 4us, for easier L-LENGTH signaling and legacy spoofing.

a = 4:



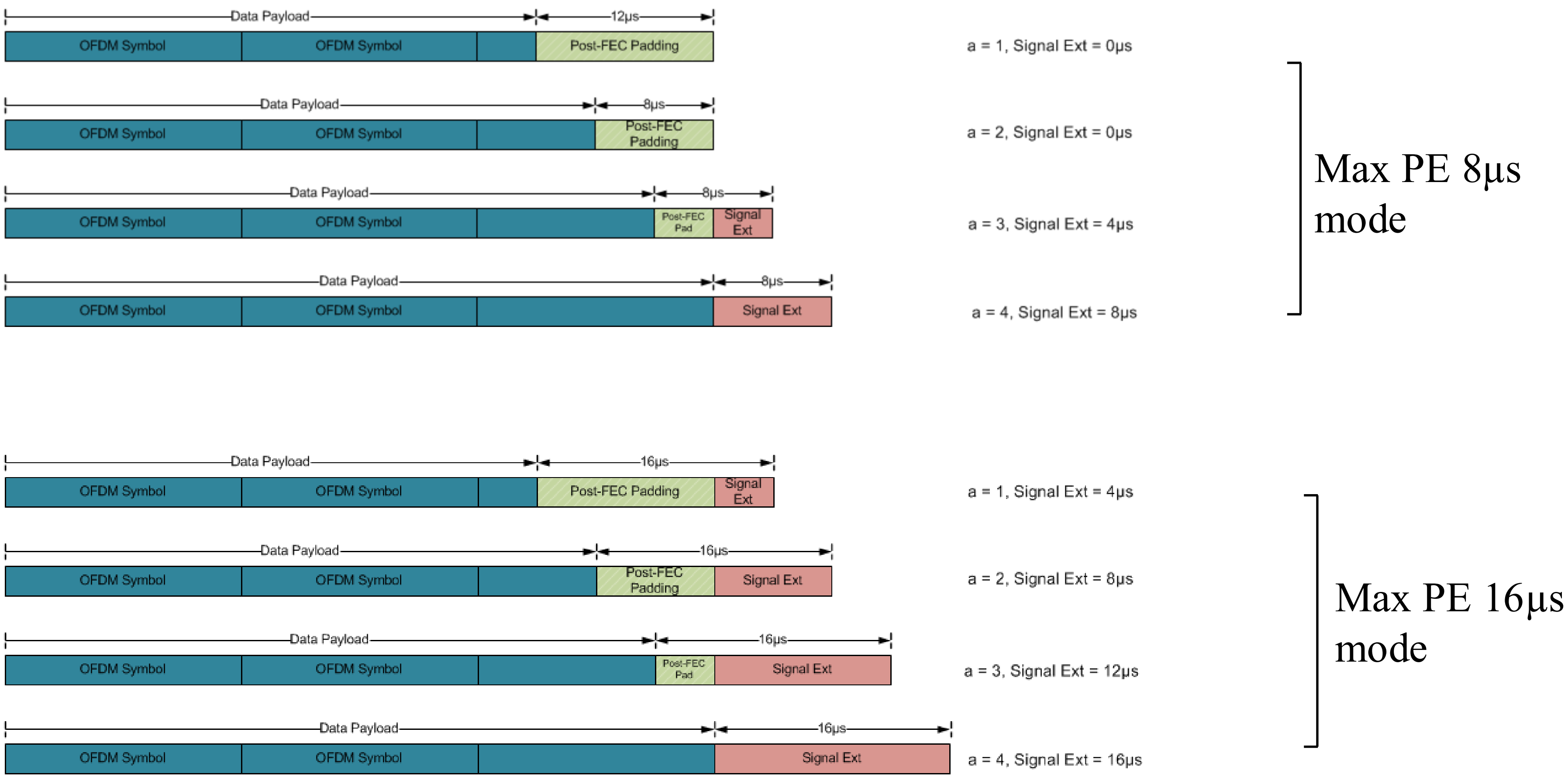
- A non-zero signal with the same average power as the data should be transmitted in PE field.
  - To avoid legacy receiver's early termination of CCA-Busy status, due to "carrier lost".

Packet Extension Field—cont'd

- Each STA may claim its PE Capability for receiving PPDUs for different {BW, N_{SS}, Constellation} combinations.
  - Defining two constellation thresholds per {BW, Nss} to split MCSs into 3 groups, corresponding to 0us, and two non-zero max PE durations (equivalent to max PE durations of 8us and 16us respectively).
    - To be clear, the 3 categories are:
      - "0us": T_{PE} = [0 0 0 0]us, for a=1~4 respectively
      - "8us": T_{PE} = [0 0 4 8]us, for a=1~4 respectively
      - "16us": T_{PE} = [4 8 12 16]us, for a=1~4 respectively

- When STA indicates 80MHz capability or higher, 0μs PE is applied for RU≤20MHz
  - No capability indicated for RU ≤ 20MHz in this case
  - Otherwise, PE capability is indicated down to TBD RU sizes.

PE Capability—Illustration

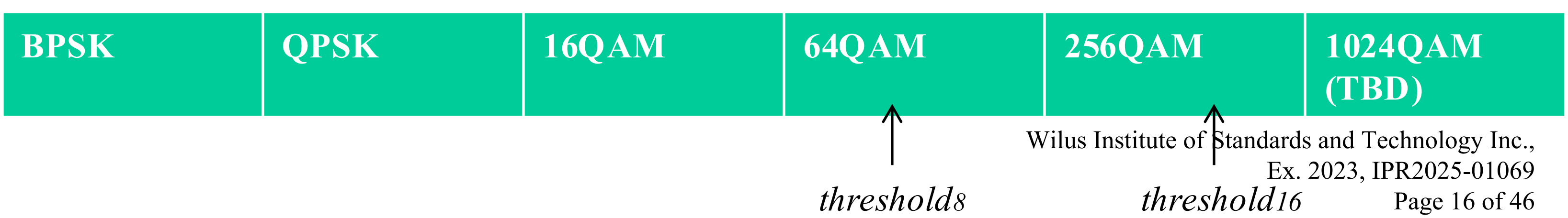


Constellation Thresholds for PE Capability (i)

- HE device capability for determining PE duration is based on two constellation thresholds per{NSS, BW}
- If constellation $\geq threshold_{16}$ apply max PE 16μs mode, else if constellation $\geq threshold_{8}$ apply max PE 8μs mode, else no packet extension
- The encoding constellation thresholds:

constellation	HE capability encoding
BPSK	000
QPSK	001
16QAM	010
64QAM	011
256QAM	100
1024QAM (TBD)	101
None	111

- Example: max PE 8us for 64QAM, max PE 16us for 256QAM and 1024QAM (TBD)



Constellation Thresholds for PE Capability (ii)

- Some special cases are as follows:
  - If no PE is required both $threshold_8$ and $threshold_{16}$ are set to 111
  - If only max PE 8μs mode is used, set $threshold_{16}$ to be 111, and $threshold_8$ to be the constellation at which max PE 8μs mode starts
  - If only max PE 16μs mode is used, set $threshold_{16}$ to be the constellation at which max PE 16μs mode starts, and $threshold_8$ to be 111

Padding Parameters to Avoid MCS Exclusion

- If we strictly choose ¼ number of tones, for certain BW and MCS, $N_{CBPS,short}$ and $N_{DBPS,short}$ (or $N_{DBPS,Short}/N_{ES}$) are not integers.
- The simplest approach to avoid excluding MCS: define a compatible $N_{SD.SHORT}$ for the last symbol.
  - Suggested $N_{SD,short}$ for each RU size as shown in the table below:
    - Integer $N_{CBPS,short}$, $N_{DBPS,short}$ and $N_{DBPS,short}/N_{ES}$ for 20MHz and below (≤242-RU)
    - Integer $N_{CPBS,short}$ and $N_{DBPS,short}$ for 40MHz and above (LDPC only).
  - The pre-FEC symbol segments become slightly uneven between a=1~3 and a=4 for some RU. But the performance difference should be very negligible.
  - Encoding procedure described in Appendix starts by:

$$N_{CBPS,short} = N_{SD,short} \cdot N_{SS} \cdot N_{BPSCS}$$

$$N_{DBPS,short} = N_{CBPS,short} \cdot R$$

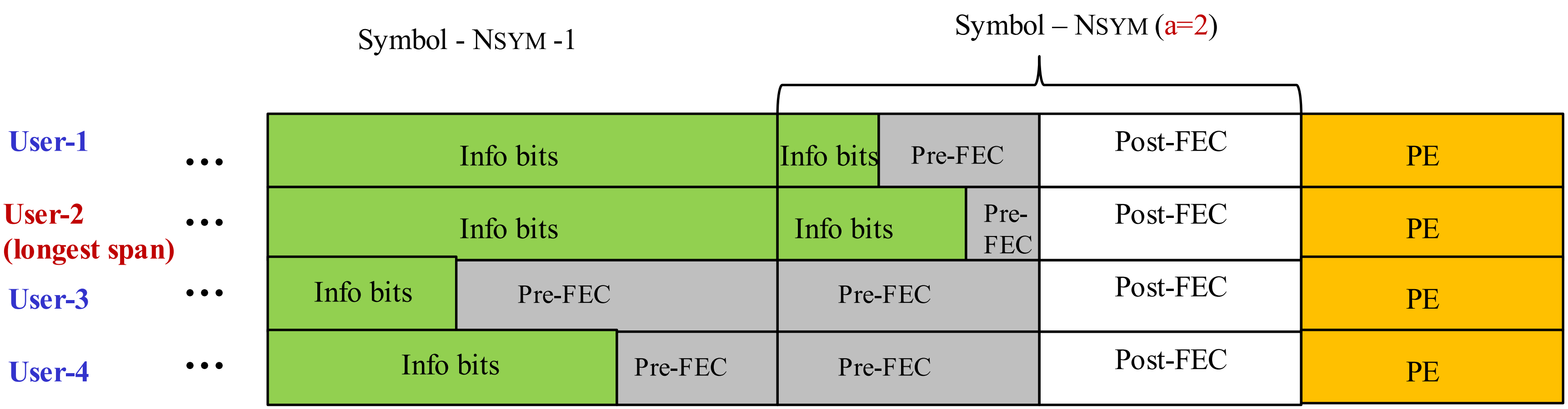
RU Size	$N_{SD,Short}$
26	6
52	12
106	24
242	60
484	120
996	240
996x2	492

DL-MU Padding Method (1)

- All user's data fields end at the same time in the DL-MU PPDU.
- All users share the same PE duration.
- All users share a common *a-factor* across all users, based on the user with the longest span.
  - Clean design, simple signaling, simple padding as in 11ac.
  - Minimize SIG field overhead, no per-user fields needed.
    - No per-user *a-factor* field.
    - As in 11ac DLMU, there is only 1 common bit needed for all users indicating "LDPC extra symbol", even if some users are doing BCC!
- Based on *a-factor* value and each user's PE capabilities, AP computes the PE duration for each user $T_{PE,u}$, and the PE duration of the whole DL-MU PPDU is $T_{PE} = \max_{u=0,\ldots,N_u-1}\left(T_{PE,u}\right)$.
- For DL-MU, AP indicates common Nsym , *a-factor* , LDPC Extra Symbol indication, and T_{PE} in the HE-SIG field for all users.

DL-MU Padding Method (2)

- Illustration (DL-OFDMA)



UL-MU Padding Method

- In UL-MU, AP does not have exact number of bytes in each user's buffer—hence cannot compute *a-factor* on a per user basis like SU and DL-MU. However, the STA can use pre-FEC padding to fill Nsym long symbols + a-factor short segments.

- Prefer a common *a-factor* design similar to DL-MU, i.e.
  - AP indicates common Nsym , *a-factor* , LDPC Extra Symbol indication, and T_{PE} for all users, in the trigger frame.

  - BCC users always pre-FEC pad to the pre-determined *a-factor*.

  - LDPC users:
    - If LDPC Extra Symbol = 1, always pre-FEC pad to $a_{init} = a-1$ in the last symbol(s), and always apply LDPC extra symbol using the last symbol segment ($a=a_{init}+1$).

    - If LDPC Extra Symbol = 0, always pre-FEC pad to $a_{init} = a$ in the last symbol(s), and always do not apply LDPC extra symbol.

SIG Field Signaling (1)

- HE-SIG Field:
  - 2-bits for *a-factor* .
  - 1 bit for PE dis-ambiguity .
    - For receiver to derive correct T_{PE} and N_{SYM} without ambiguity.
- *a-factor* field definition:

a	$HE-SIG\ field\ Encoding$
1	01
2	10
3	11
4	00

SIG Field Signaling (2)

- Timing Parameters:

$$TXTIME = T_{L\_PREAMBLE} + T_{HE\_PREAMBLE} + T_{HE\_DATA} + T_{PE}$$

where $$T_{HE\_DATA} = T_{HE\_SYM} \times N_{SYM} = (12.8 + T_{GI}) \times N_{SYM}$$

- L-SIG:

$$L\_LENGTH = \left\lceil \frac{TXTIME - 20}{4} \right\rceil \times 3 - 3 + m,\ m = 1 \text{ or } 2$$

SIG Field Signaling (3)

- HE-SIG-A: "PE-Disambiguity" Field:
  - Tx: if the following is met, set this field to 1; otherwise, set to 0.

$$T_{PE} + 4 \times \left(\left\lceil \frac{TXTIME - 20}{4} \right\rceil - \left(\frac{TXTIME - 20}{4} \right) \right) \geq T_{SYM}$$

- Rx Side Computation:

$$N_{SYM} = \left\lfloor \left(\frac{L\_LENGTH - m + 3}{3} \times 4 - T_{HE\_PREAMBLE} \right) / T_{SYM} \right\rfloor - b_{PE\_Disambiguity}$$

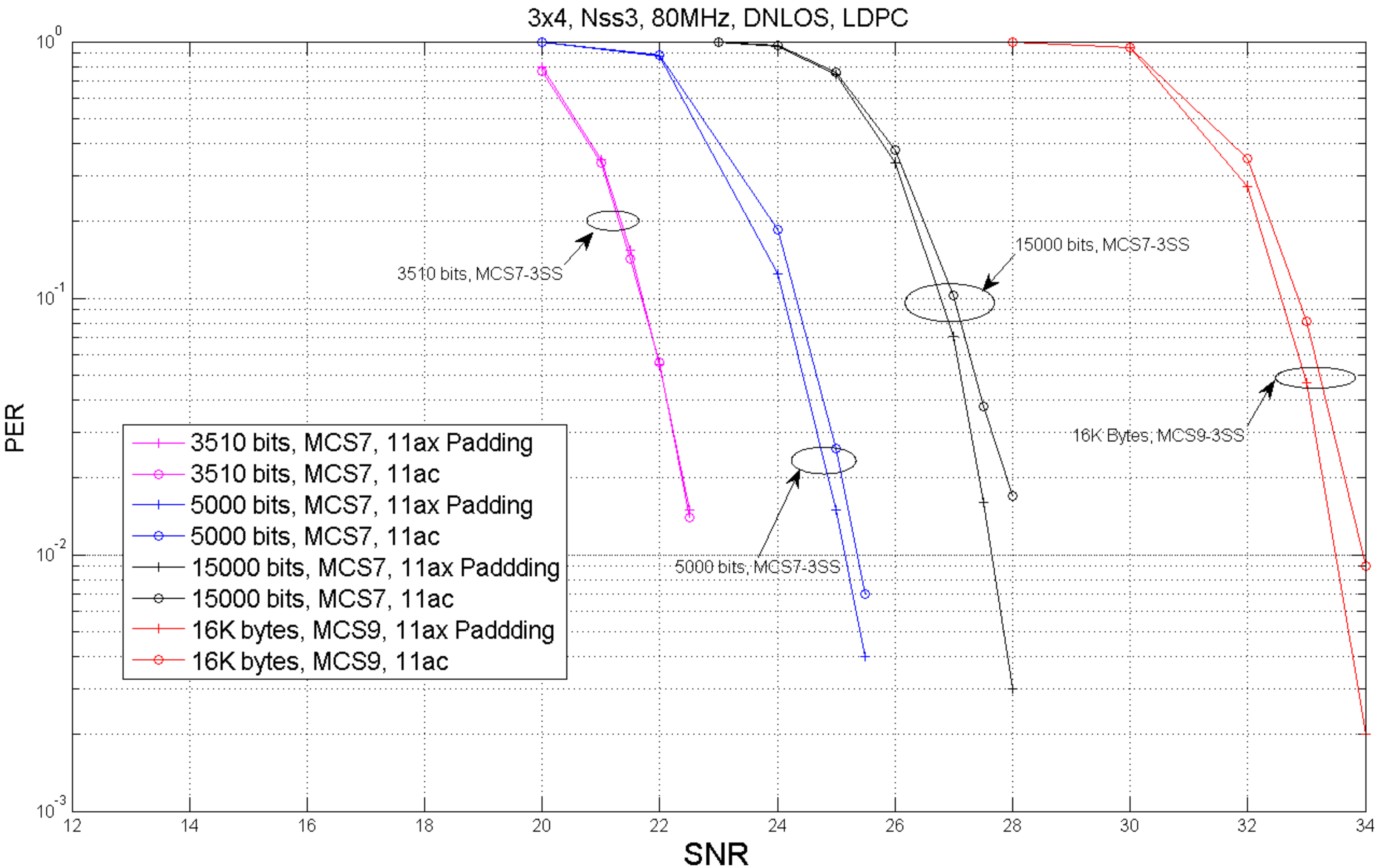
$$T_{PE} = \left\lfloor \frac{\left(\frac{L\_LENGTH - m + 3}{3} \times 4 - T_{HE\_PREAMBLE} \right) - N_{SYM} \times T_{SYM}}{4} \right\rfloor \times 4$$

Simulations: LDPC Performance Sanity Check

- Simulate the same MCS for 11ax and 11ac.
- 80MHz, 4 Rx 3SS, LDPC, DNLOS channel.

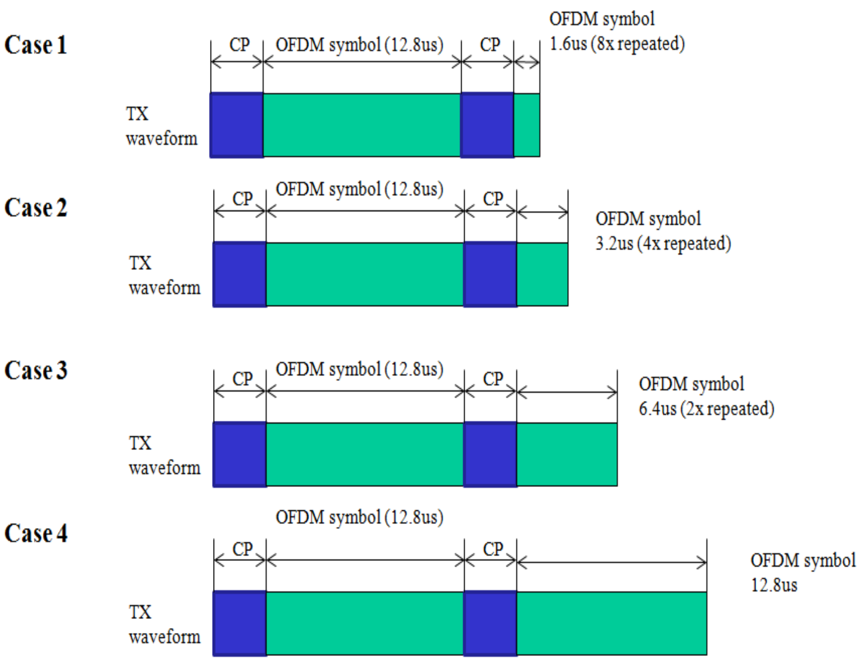
- For sanity check purpose, we tried different packet sizes to trigger difference scenarios:
  - L=16K Bytes, MCS9-3SS.
    - 11ax padding Op4: 7 symbols, $a = 3$, no LDPC additional symbol;
    - 11ac: 28 symbols , no additional symbol.
  - L=15000 bits, MCS7-3SS
    - 11ax padding Op4: 2 symbols, $a = 1$, no LDPC additional symbol;
    - 11ac: 5 symbols , no LDPC additional symbol.
  - L= 5000 bits, MCS7-3SS
    - 11ax padding Op4: 1 symbols, $a = 3$, with LDPC additional symbol;
    - 11ac: 3 symbols , with LDPC additional symbol.
  - L= 3150 bits, MCS7-3SS
    - 11ax padding Op4: 1 symbols, $a = 3$, with LDPC additional symbol;
    - 11ac: 2 symbols , with LDPC additional symbol.

Results

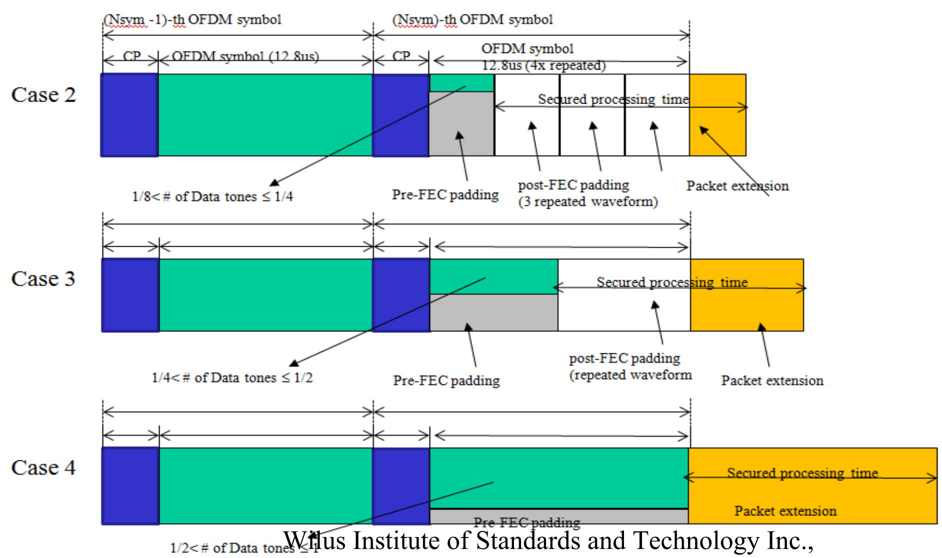

3x4, Nss3, 80MHz, DNLOS, LDPC
PER
SNR
10^0
10^-1
10^-2
10^-3
12
14
16
18
20
22
24
26
28
30
32
34
3510 bits, MCS7-3SS
15000 bits, MCS7-3SS
16K Bytes, MCS9-3SS
5000 bits, MCS7-3SS
3510 bits, MCS7, 11ax Padding
3510 bits, MCS7, 11ac
5000 bits, MCS7, 11ax Padding
5000 bits, MCS7, 11ac
15000 bits, MCS7, 11ax Paddding
15000 bits, MCS7, 11ac
16K bytes, MCS9, 11ax Paddding
16K bytes, MCS9, 11ac

Discussions of Alternative Methods-1

- An alternative method of reducing OFDM symbol durations was proposed in [3].
- It seems that [3] mentioned two different methods:
  - 1. Use short symbols (1/2x, 1x, 2x, 4x), no PE.
  - 2. Use short symbols ((1/2x),1x, 2x, 4x), but repeat to 4x, with PE.



Method-1 in [3]



Method-2 in [3]

Discussions of Alternative Methods-2

- Assuming that in [3] method-1 is used for low BW or MCS, while method-2 is used for high BW or MCS, we have the following issues:
  1. Method-1 requires OFDM symbol duration switching all the time, which complicates the receiver design.
  2. Although Method-2 may be realized by always using 4x symbol duration, but there is no efficiency gain over our method!
  3. It is undesirable to introduce different padding flows for different PHY configurations (BW, MCS, Nss, etc), which was never seen in previous generations (11a/n/ac).
     - With STBC and LDPC extra symbol, the number of modes will "explode" (e.g. 1/2x, 1x, 2x, 4x, two 1x, two 2x, two 4x, four 1x, four 2x, two 1/2x, four 1/2x)!
  4. It is hard to address LDPC extra symbol: e.g. what happens if 2x is selected at beginning but requires LDPC extra symbol? Same for 1/2x and 4x symbols.—may skew the effective coding rates.
  5. What is 1.6us OFDM symbol (1/2x)? Does it appear in method-2?
  6. Uneven bit splitting (1/2x, 1x, 2x, 4x).
  7. Unsure about 1/2x and 1x symbol performance in outdoor channels.
- Our proposal is a unified approach for all PHY modes that balances efficiency and implementation complexity.

Conclusions

- A HE PHY padding and Packet Extension method is proposed to address the area and overhead concern caused by 11ax 4x OFDM numerology.
- The two-step padding and variable PE duration properly addresses the tradeoff between implementation complexity and HE-PHY overhead.
- Further discussions on detailed padding parameters; PE capability definition; MU padding methods; and PHY signaling in HE-SIG.

Straw Poll #1

- Do you agree to add the following text into Section 3.4 HE Data Field of the current SFD:
  - An 11ax SU PPDU should apply the MAC/PHY pre-FEC padding scheme as in 11ac, to pad toward the nearest of the four possible boundaries ("*a*" factor) in the last Data OFDM symbol(s), and then use post-FEC padding bits to fill up the last OFDM symbol(s).
    - Packet Extension (PE) field is defined at the end of 11ax PPDUs.
    - PE should have the same average power as data field.

Straw Poll #2

- Do you agree to add the following text into SFD:
  - 11ax shall define the max packet extension modes of 8µs and 16µs, correspond to the short symbol segment padding boundaries ("*a*-factor") according to the following PE duration (T_{PE}) values:
    - Max packet extension mode 8 µs: T_{PE} = [0 0 4 8] µs for $a = 1\sim4$ respectively;
    - Max packet extension mode 16 µs: T_{PE} = [4 8 12 16] µs for $a = 1\sim4$ respectively.
  - HE Capability field shall define two constellation level thresholds ($threshold_{16}$ and $threshold_8$) for a given {NSS, BW} combination, to determine if and when max packet extension modes 8 µs and 16 µs are applied, i.e.
    - 3 bits are used to specify each threshold as the table below.
    - If constellation $\geq threshold_{16}$ apply max PE 16 µs mode, else if constellation $\geq threshold_8$ apply max PE 8 µs mode, else no packet extension.
    - If no PE is required for all constellations both $threshold_8$ and $threshold_{16}$ are set to 111
    - If only max PE 8 µs mode is required, set $threshold_{16}$ to be 111, and $threshold_8$ to be the constellation at which max PE 8 µs mode starts
    - If only max PE 16µs mode is required, set $threshold_{16}$ to be the constellation at which max PE 16µs mode starts, and $threshold_8$ to be 111
    - When ≥80 MHz is supported, no thresholds are defined for RU size less than or equal to 242 tones (20 MHz); otherwise, thresholds are defined down to a TBD RU size.

Constellation	Threshold Encoding in HE Capability
BPSK	000
QPSK	001
16QAM	010
64QAM	011
256QAM	100
1024QAM (TBD)	101
None	111

Straw Poll #3

- Do you agree to add the following text into SFD:
  - The number of uncoded bits for each of the first 3 short symbol segments (a=1~3) equals to the number of uncoded bits corresponding to $N_{SD.short}$ subcarriers as specified by the following table, and the number of uncoded bits for the last short symbol segment (a=4) equals to the number of bits of the whole OFDM symbol subtracting the total number of uncoded bits of the first three short symbol segments.

RU Size	$N_{SD.short}$
26	6
52	12
106	24
242	60
484	120
996	240
996x2	492

Straw Poll #4

- Do you agree to add the following text (this page and next page) into SFD:

  – HE-SIG-A field contains a "*a-factor*" field of 2 bits, and a "PE-Disambiguity" field of 1 bit, with setting methods as blow:
  – In L-SIG, the L-LENGTH field is set by:

$$L\_LENGTH = \left\lceil \frac{TXTIME - 20}{4} \right\rceil \times 3 - 3 + m, \ m = 1 \text{ or } 2$$

where $TXTIME = T_{L\_PREAMBLE} + T_{HE\_PREAMBLE} + T_{HE\_DATA} + T_{PE}$

$$T_{HE\_DATA} = T_{HE\_SYM} \times N_{SYM} = (12.8 + T_{GI}) \times N_{SYM}$$

T_{PE} is the PE duration

  – In HE-SIG-A:
  – ***a-factor* field:**

a-factor value	a-factor field encoding
1	01
2	10
3	11
4	00

SP4—cont'd

– **PE Dis-ambiguity Field:**
  - If $T_{PE} + 4 \times \left(\left\lceil \frac{TXTIME - 20}{4} \right\rceil - \left(\frac{TXTIME - 20}{4} \right) \right) \geq T_{SYM}$, where $T_{SYM} = 12.8 + T_{GI}$, set this field to 1; otherwise, set to 0.
  - At receiver side, the following equations may be run to compute N_{SYM} and T_{PE} respectively:

$$N_{SYM} = \left\lfloor \left(\frac{L\_LENGTH - m + 3}{3} \times 4 - T_{HE\_PREAMBLE} \right) / T_{SYM} \right\rfloor - b_{PE\_Disambiguity}$$

$$T_{PE} = \left\lfloor \frac{\left(\frac{L\_LENGTH - m + 3}{3} \times 4 - T_{HE\_PREAMBLE} \right) - N_{SYM} \times T_{SYM}}{4} \right\rfloor \times 4$$

Straw Poll #5

- Do you agree to add the following text into SFD:
  - When the AP transmits DL-MU packets:
    - All users use the same N_{SYM} and *a-factor* values according to the user with the longest span.
    - Based on *a-factor* value and each user's PE capabilities, compute the PE duration for each user $T_{PE,u}$, and the PE duration of the whole DL-MU PPDU is $T_{PE} = \max_u(T_{PE,u})$.
    - In HE-SIG-A field, the "a-factor" field, the "PE Disambiguity" field, and the "LDPC extra symbol" field, are common for all users.

Straw Poll #6

- Do you agree to add the following text into SFD:
  - For UL-MU packet transmission:
    - AP indicates its desired *Nsym*, *a-factor,* LDPC Extra Symbol indication and *PE* duration values in trigger frame.
    - Possible PE values for UL-MU are TBD.
    - Each user when transmitting the UL-MU PPDU, shall encode and conduct PHY padding using the parameters:
    - N_{SYM} as indicated in the trigger frame;
    - *a-factor* as indicated in the trigger frame;
    - LDPC Extra Symbol as indicated in the trigger frame;
    - Append PE specified in the trigger frame.

Appendix: Example Math for SU Padding

Initiating Parameters

$$N_{CBPS,short} = N_{SD,short} \cdot N_{SS} \cdot N_{BPSCS}$$

$$N_{DBPS,short} = N_{CBPS,short} \cdot R$$

Where $N_{SD.short}$ is defined as in below table:

RU Size	$N_{SD,Short}$
26	6
52	12
106	24
242	60
484	120
996	240
996x2	492

Step-1

- **Compute initial number of payload symbols.**
  - **BCC:**

$$N_{SYM.init} = m_{STBC} \cdot \left\lceil \frac{8.APEP\_LENGTH + N_{Tail}.N_{ES} + N_{service}}{m_{STBC}.N_{DBPS}} \right\rceil$$

  - **LDPC:**

$$N_{SYM.init} = m_{STBC} \cdot \left\lceil \frac{8.APEP\_LENGTH + N_{service}}{m_{STBC}.N_{DBPS}} \right\rceil$$

Step-2

- Compute <u>initial</u> numbers of data bits and coded bits in the last symbol and <u>initial excess factor *a*</u> value, based on number of excess bits:
  - BCC: $N_{\text{Excess}} = \text{mod}\left(8.\text{APEP\_LENGTH} + N_{Tail}.N_{ES} + N_{service},\ m_{STBC}.N_{DBPS}\right)$
  - LDPC: $N_{\text{Excess}} = \text{mod}\left(8.\text{APEP\_LENGTH} + N_{service},\ m_{STBC}.N_{DBPS}\right)$
  - Initial *a-factor* value:

If $0 < N_{\text{Excess}} \le m_{STBC}.N_{DBPS.SHORT}$, then $a_{init} = 1$

If $m_{STBC}.N_{DBPS.SHORT} < N_{\text{Excess}} \le 2.m_{STBC}.N_{DBPS.SHORT}$, then $a_{init} = 2$

If $2.m_{STBC}.N_{DBPS.SHORT} < N_{\text{Excess}} \le 3.m_{STBC}.N_{DBPS.SHORT}$, then $a_{init} = 3$

If $3.m_{STBC}.N_{DBPS.SHORT} < N_{\text{Excess}} \le m_{STBC}.N_{DBPS}$, or $N_{\text{Excess}} = 0$, then $a_{init} = 4$

$$N_{DBPS.LAST.init} = \begin{cases} a_{init}.N_{DBPS.SHORT}, & \text{if } a_{init} < 4 \\ N_{DBPS}, & \text{if } a_{init} = 4 \end{cases}$$

$$N_{CBPS.LAST.init} = \begin{cases} a_{init}.N_{CBPS.SHORT}, & \text{if } a_{init} < 4 \\ N_{CBPS}, & \text{if } a_{init} = 4 \end{cases}$$

Step-3

- Compute number of (pre-FEC) MAC/PHY padding bits as below, and conduct MAC/PHY Padding as in 11ac.
  - BCC:

$$N_{PAD,PRE-FEC} = (N_{SYM.init} - m_{STBC}).N_{DBPS} + m_{STBC}.N_{DBPS.LAST.init} - 8.APEP\_LENGTH - N_{Tail}.N_{ES} - N_{service}$$

  - LDPC:

$$N_{PAD,PRE-FEC} = (N_{SYM.init} - m_{STBC}).N_{DBPS} + m_{STBC}.N_{DBPS.LAST.init} - 8.APEP\_LENGTH - N_{service}$$

Step-4

- **FEC coding and Compute final** *NSYM* **and** *a-factor***:**
  - BCC: $N_{SYM} = N_{SYM.init}, \;\; a = a_{init}$
    - Then conduct regular BCC coding based on these parameters.
  - LDPC: $N_{pld} = (N_{SYM.init} - m_{STBC}).N_{DBPS} + m_{STBC}.N_{DBPS.LAST.init}$

$$N_{avbits} = (N_{SYM.init} - m_{STBC}).N_{CBPS} + m_{STBC}.N_{CBPS.LAST.init}$$

    - Compute LDPC encoding parameters {*LLDPC, NCW, Nshrt, Npunc*} as in 802.11n (clause **20.3.11.7.5**) starting from *Navbits*.
    - In step d) of clause **20.3.11.7.5**, if the condition for "LDPC Extra Symbol" is met, then

$$N_{avbits} = \begin{cases} N_{avbits} + m_{STBC}.\left(N_{CBPS} - 3.N_{CBPS.SHORT}\right), & \text{if } a_{init} = 3 \\ N_{avbits} + m_{STBC}.N_{CBPS.SHORT}, & \text{otherwise} \end{cases}$$

$$N_{punc} = \max\left(0, \; (N_{CW} \times L_{LDPC}) - N_{avbits} - N_{shrt}\right)$$

$$\begin{cases} N_{SYM} = N_{SYM.init} + m_{STBC}, \text{ and } a = 1, & \text{if } a_{init} = 4 \\ N_{SYM} = N_{SYM.init}, \text{ and } a = a_{init} + 1, & \text{otherwise} \end{cases}$$

Step-4 (Cont'd)

- (LDPC Cont'd) if the above mentioned "LDPC Extra Symbol" condition is not met:

$$a = a_{init},\ N_{SYM} = N_{SYM.init}$$

- Conduct Regular LDPC encoding using these parameters.

– Finally, update below:

$$N_{CBPS.LAST} = \begin{cases} a.N_{CBPS.SHORT}, & \text{if } a < 4 \\ N_{CBPS,} & \text{if } a = 4 \end{cases}$$

Step-5

- **Post-FEC padding and remaining Tx steps:**

$$N_{PAD,POST-FEC} = N_{CBPS} - N_{CBPS.LAST}$$

  – Pad $N_{PAD.POST\text{-}FEC}$ bits after encoded bits in each of the last m_{STBC} OFDM symbols, and then continue with the following transmission steps

Step-6

- **Packet Extension Insertion:**
  - Insert Packet Extension Field at the end of the PPDU, according to *a-factor* value, the MCS, BW and Nss parameters used in the data field, and the PE capability of the intended recipient of the PPDU

References

[1] 11-15-0132-02-00ax-spec-framework
[2] 11-15-0580-02-00ax 11ax coding discussion
[3] 11-15-0887-03-00ax-effcient-padding-for-last-ofdm-symbol