IEEE P802.11
Wireless LANs

Specification Framework for TGax

Date: 2015-12-07

Author(s):

Name	Affiliation	Address	Phone	email
Robert Stacey	Intel	2111 NE 25th Ave, Hillsboro OR 97124, USA	+1-503-724-893	robert.stacey@intel.com

Abstract

This document provides the framework from which the draft TGax amendment will be developed. The document provides an outline of each the functional blocks that will be a part of the final amendment. The document is intended to reflect the working consensus of the group on the broad outline for the draft specification. As such it is expected to begin with minimal detail reflecting agreement on specific techniques and highlighting areas on which agreement is still required. It may also begin with an incomplete feature list with additional features added as they are justified. The document will evolve over time until it includes sufficient detail on all the functional blocks and their inter-dependencies so that work can begin on the draft amendment itself.

Revision history

Revision	Date	Changes
0	January 13, 2015	As approved by TG motion at the November 2014 meeting [1]
1	January 13, 2015	Added motioned text from PM1 session January 13, 2015
2	January 15, 2015	Added motioned text from January 14, 2014
3	March 27, 2015	Added motioned text from PM1 session March 12, 2015
4	March 27, 2015	Some corrections to the March PHY motion numbers and missing statement added.
5	May 14, 2015	Removed duplicate statement on OFDMA operation in bandwidths less than 20 MHz. Added text for motions passed during the May 2015 session.
6	July 9, 2015	Fixed typo in reference #14. Tomo Adachi notified the editor by email that MU Motion 5 was added in error since the motion failed. Text removed.
7	July 16, 2015	Added text for motions passed July 16, 2015
8	September 18, 2015	Nrow → Nrot (per email from Youhan Kim). Grouped statements in appropriate subsections. Added missing MAC Motion 23 from July (thanks again Tomo Adachi). Added text that passed motion on September 17, 2015 as found in 15/0987r6.
9	September 22, 2015	Updated based on comments from Hongyuan: missing 40 MHz for mandatory LDPC; RL-SIG in HE NDP PPDU format
10	November 24, 2015	Added PHY motions passed November 12, 2015. Automated heading numbering.
11	November 28, 2015	Added remaining motions from November meeting
12	December 1, 2015	Previous revision appears to be an incomplete, perhaps a interim saved version of the document rather than the completed version. Corrected with this release.
13	December 7, 2015	Added missing MAC Motion 29 from Spetember 2015 session. Fixed type on PHY Motion 80.

1 Definitions

2 Abbreviations and acronyms

HE	High Efficiency
UL	Uplink
DL	Dowlink
OFDMA	Orthogonal Frequency-Division Multiple Access

3 High Efficiency (HE) Physical Layer

3.1 General

Section 3 describes the functional blocks in the physical layer.

3.2 HE preamble

3.2.1 General

An HE PPDU shall include the legacy preamble (L-STF, L-LTF and L-SIG), duplicated on each 20 MHz, for backward compatibility with legacy devices. [PHY Motion #3, January 2015, see [2]]

In an HE PPDU, both the first and second OFDM symbols immediately following the L-SIG shall use BPSK modulation.
NOTE–This is to spoof all legacy (11a/n/ac) devices to treat an HE PPDU as a non-HT PPDU.
[PHY Motion 15, July 16, 2015, see [3]]

MU-MIMO shall only be supported on allocations sizes ≥ 106 tones.
[PHY Motion 35, July 16, 2015, see [4]]

The number of spatially multiplexed users in a DL or UL MU-MIMO transmission is up to 8 (in a given RU).
[PHY Motion 92, November 2015, see [5]]

There are only three pre-HE-STF preamble formats defined:

- SU format (mandatory) / Trigger based UL
- MU format (mandatory)
- Extended range SU format

[PHY Motion 68, November 2015, see [6]]

Editorial note: Let's refer to the associated PPDU formats as the HE SU PPDU, HE Trigger-based UL PPDU, HE MU PPDU and HE Extended Range SU PPDU. When discussing features associated with all formats, we use the term HE PPDU.

The signaling of the three preamble formats is illustrated in Figure 1.

- LSIG length set as mod3=1 means SU format. Set as mod3=2 means either MU format or extended range SU format
- QBPSK on HE-SIGA2 means extended range SU format

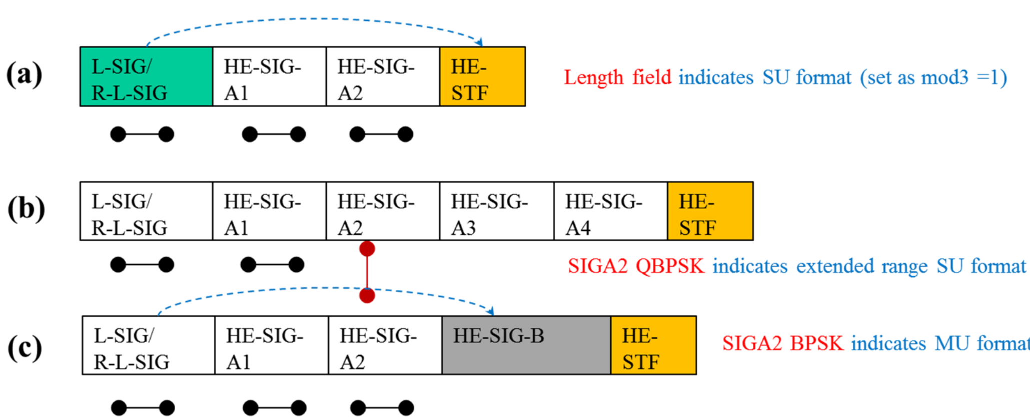

Figure 1 – Preamble format signaling

[PHY Motion 69, November 2015, see [6]]

The spec shall define an HE NDP PPDU for DL Sounding. The HE NDP PPDU format is based on the HE SU PPDU format and is shown in Figure 2. The presence and duration of packet extension at the end of HE NDP PPDU is TBD.

L-STF	L-LTF	L-SIG	RL-SIG	HE-SIG-A	HE-STF	HE-LTFs	Packet Extension

Figure 2 – HE NDP PPDU format

[PHY Motion 37, September 17, 2015, see [7], editorially changed TBD field to RL-SIG based on Motion 51]

If the Beam Change field in HE-SIG-A is 0 then the pre-HE-STF portion of the preamble shall be spatially mapped in the same way as HE-LTF1 on each tone.
[PHY Motion 84, November 2015, see [8]]

An HE PPDU has 4 extra subcarriers, two at each edge of each 20 MHz sub-channel for the L-SIG, RL-SIG, HE-SIG-A and HE-SIG-B fields:

- The 4 subcarriers added to the L-SIG and RL-SIG fields are transmitted with known TBD BPSK constellations (±1).
- The number of data subcarriers in HE-SIG-A and HE-SIG-B fields is increased by 4 in each 20 MHz sub-channel.
- The L-SIG, RL-SIG, HE-SIG-A and HE-SIG-B fields are always transmitted with same total power as L-LTF field (in cases when L-LTF is not being boosted).

[PHY Motion 72, November 2015, see [9]]

STBC is an optional feature in 11ax and it is ONLY defined for single spatial stream (Nss=1 and Nsts=2)
In an HE MU PPDU, all RUs are either STBC or not STBC.
[PHY Motion 75, November 2015, see [10]]

3.2.2 L-STF and L-LTF

L-STF power is boosted by 3 dB in the extended range preamble.
[PHY Motion 66, November 2015, see [11]]

L-LTF power is boosted by 3 dB in the extended range preamble.
[PHY Motion 67, November 2015, see [11]]

3.2.3 L-SIG and repeated L-SIG

In L-SIG, the L_LENGTH field is set to a value not divisible by 3. The value of L_LENGTH mod 3 will be used for signaling of one bit of TBD information.
[PHY Motion 52, September 17, 2015, see [12]]

The 11ax preamble shall have a 4 µs symbol repeating the L-SIG content right after the legacy section. This symbol shall be modulated by BPSK and rate ½ BCC.

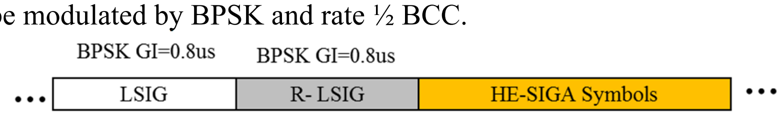

Figure 3 -- Repeated L-SIG

[PHY Motion 51, September 17, 2015, see [12]]

3.2.4 HE-SIG-A

HE-SIG-A (using a DFT period of 3.2 µs and subcarrier spacing of 312.5 kHz) is duplicated on each 20 MHz after the legacy preamble to indicate common control information.

[Motion #4, January 2015, see [2]]

HE-SIG-A is present in all 11ax packets and is two OFDM symbols long when it uses MCS0

- Information bits in HE-SIG-A are jointly encoded as in VHT-SIG-A (using 48 tones or 52 tones is TBD).
- SU packets and UL Trigger based packets do not contain HE-SIG-B symbols.

[PHY Motion 16, July 16, 2015, see [13]]

~~HE-SIG-A shall include the following fields in an SU PPDU (the size of each field is TBD and other fields are TBD):~~

- ~~Format indication~~
- ~~TXOP duration~~
- ~~BW~~
- ~~Payload GI~~
- ~~PE~~
- ~~MCS~~
- ~~Coding~~
- ~~LTF Compression~~
- ~~NSTS~~
- ~~STBC~~
- ~~BF~~
- ~~CRC~~
- ~~Tail~~

[PHY Motion 43, September 17, 2015, see [14], removed with PHY Motion 96, November 2015]

~~HE-SIG-A shall include the following fields in an MU DL PPDU the size of each field is TBD and other fields are TBD):~~

- ~~Format indication~~
- ~~TXOP duration~~
- ~~Number of HE-SIG-B symbols~~
- ~~MCS of HE-SIG-B~~
- ~~CRC~~
- ~~Tail~~

[PHY Motion 44, September 17, 2015, see [14], removed with PHY Motion 97, November 2015]

The MCS of HE-SIG-B field indicates the following MCS values for HE-SIG-B:

- MCS0, MCS 1, MCS 2, MCS 3, MCS4, MCS5
- Other MCS is TBD

The MCS of HE-SIG-B field is 3 bits in length. If two MCS values for BW >= 40 MHz are to be signaled, additional TBD bits used.
[PHY Motion 88, November 2015, see [15]]

~~HE-SIG-A shall include the following fields in an MU UL PPDU the size of each field is TBD and other fields are TBD):~~

- ~~Format indication~~
- ~~TXOP duration~~
- ~~CRC~~
- ~~Tail~~

[PHY Motion 45, September 17, 2015, see [14], removed with PHY Motion 98, November 2015]

~~The spec shall support adding a BSS Color field in the HE-SIG-A field. The BSS Color field is an identifier of the BSS (size TBD).~~

[PHY Motion 46, September 17, 2015, see [16], removed with PHY Motion 96, November 2015]

~~An UL/DL Flag field is present in the HE-SIG-A field of an HE SU PPDU. The UL/DL Flag field indicates whether the frame is UL or DL. The value of this field for TDLS is TBD.~~
[PHY Motion 48, September 17, 2015, see [16], removed with PHY Motion 96, November 2015]

~~HE-SIG-A includes a 1-bit DCM indication.~~
[PHY Motion 54, September 17, 2015, see [17], removed with PHY Motion 96, November 2015]

The format of the HE-SIG-A field for an HE SU PPDU is defined in Table 1.

Table 1 - HE-SIG-A field for an HE SU PPDU

Field	**Length (bits)**	**Description**	**Encoding**
DL/UL	1	Indicates whether the frame is UL or DL. The field is set to DL for TDLS. *NOTE: The TDLS peer can identify the TDLS frame by To DS and From DS fields in the MAC header of the MPDU.* [MAC Motion 57, November 2015, see [18]]	
Format	1	Differentiate between an SU PPDU and a Trigger-based UL PPDU. See [14].	
BSS Color	6	Base station identifier.	
Spatial Reuse	TBD	Exact bits TBD, e.g., indication of CCA Level, Interference Level accepted, TX Power	
TXOP Duration	TBD	Indicates the remaining time in the current TXOP. See [14].	
Bandwidth	2		
MCS	4		
CP+LTF Size	3		1x LTF + 0.8 µS 2x LTF + 0.8 µS 2x LTF + 1.6 µS 4x LTF + 3.2 µS
Coding	2		
Nsts	3		
STBC	1		
TxBF	1		
DCM	1	Dual carrier modulation indication	
Packet Extension	3	“a”-factor field of 2 bits and 1 disambiguation bit	
Beam Change	1	Indicate precoder change/no change between L-LTF and HE-LTF. See [8].	
CRC	4		
Tail	6		

[PHY Motion 96, November 2015, see [19]]

The format of the HE-SIG-A field for an HE MU PPDU is defined in Table 2.

Table 2 - HE-SIG-A field for an HE MU PPDU

Field	**Length (bits)**	**Description**	**Encoding**

DL/UL	1		
BSS Color	6	Base station identifier.	
Spatial Reuse	TBD		
TXOP Duration	TBD	Indicates the remaining time in the current TXOP. See [14].	
Bandwidth	≥ 2	May accommodate more than in SU case to take advantage of OFDMA	
SIGB MCS	3	See [15].	MCS0, MCS1, MCS2, MCS3, MCS4, MCS5 Other MCS TBD
SIGB DCM	1		
SIGB Number Of Symbols	4	Support about 16 users using MCS0 per BCC	
SIGB Compression Mode	≥ 1	Differentiates full bandwidth MU-MIMO from OFDMA MU PPDU. More compression modes TBD. See [20].	
Number of HE-LTF Symbols	3	Up to 8 LTF symbols possible	
CP+LTF Size	3		2x LTF + 0.8 μS 2x LTF + 1.6 μS 4x LTF + 3.2 μS
LPDC Extra Symbol	1		
Packet Extension	3		
CRC	4		
Tail	6		

[PHY Motion 97, November 2015, see [19]]

The format of the HE-SIG-A field for an HE Trigger-based UL PPDU is defined in Table 3.

Table 3 - HE-SIG-A fields for the HE Trigger-based UL PPDU

Field	**Length (bits)**	**Description**	**Encoding**
Format	1	Differentiate between an SU PPDU and a Trigger-based UL PPDU	
BSS Color	6	Base station identifier.	
Spatial Reuse	TBD		
TXOP Duration	TBD	Indicates the remaining time in the current TXOP. See [14].	
Bandwidth	TBD		
CRC	4		
Tail	6		

[PHY Motion 98, November 2015, see [19]]

HE-SIG-A includes a 1-bit Beam Change field. A value 1 indicates that spatial mapping is changed and a value 0 indictes that spatial mapping is unchanged.
[PHY Motion 83, November 2015, see [8]]

A compression bit is carried in the HE-SIG-A MU format to differentiate full BW MU-MIMO from OFDMA MU PPDU. In case of full BW MU-MIMO, the following conditions hold:

- Only applicable for RU sizes 242, 484, 996, 2*996

- The RU information in HE-SIG-B common is not signaled
- For bandwidths > 20 MHz, the user specific sub-fields are split equitably between the two HE-SIG-B Channels

[PHY Motion 87, November 2015, see [20]]

HE-SIG-A shall have a repetition mode for range extension. In the repetition mode, HE-SIG-A symbols are repeated once in time. The bit interleaver is bypassed in the repeated HE-SIG-A symbols. The repetition mode is indicated before HE-SIG-A.
[PHY Motion 55, September 17, 2015, see [21]]

3.2.5 HE-SIG-B

HE-SIG-B only has one CP size equal to 0.8 µS.
[PHY Motion 71, November 2015, see [6]]

Downlink HE MU PPDU shall include HE-SIG-B field, and the number of OFDM symbols of HE-SIG-B field is variable.
NOTE—The HE-SIG-B field includes information required to interpret HE MU PPDU, and detail is TBD.
[PHY Motion #8, March 2015, see [22]]

HE-SIG-B shall use a DFT period of 3.2 µs and subcarrier spacing of 312.5 kHz. [Motion #14, May 2015]

HE-SIG-B does not have any OFDM symbol duplicated in each 20 MHz of the PPDU bandwidth. [PHY Motion 18, July 16, 2015, see [13]]

HE-SIG-B is encoded on a per 20 MHz basis using BCC with common and user blocks separated in the bit domain. [PHY Motion 22, July 16, 2015, see [23]]

For bandwidths ≥ 40 MHz, the number of 20 MHz subbands carrying different content is two and with structure as shown in Figure 4. Each square in the figure represents 20 MHz subband and 1/2 represents different signalling information. [PHY Motion 23, July 16, 2015, see [23]]

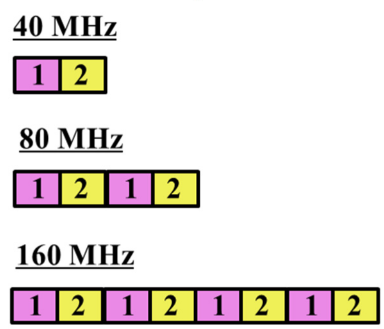

Figure 4 - 20 MHz subchannel content for HE-SIG-B for bandwidths ≥ 40 MHz

HE-SIG-B has a common field followed by a user specific field, where

- The common field includes the information for all of designated STAs to receive the PPDU in corresponding bandwidth
- The user specific field consists of multiple sub-fields that do not belong to the common field, where one or multiple of those sub-fields are for each designated receiving STA
- The boundary between the common and the user specific field is at the bit level and not the OFDM symbol level

[PHY Motion 19, July 16, 2015, see [24]]

The common field in HE-SIG-B contains Resource Unit (RU) allocation.

[PHY Motion 20, July 16, 2015, see [24]]

HE-SIG-B includes resource unit assignment and MCS per station for DL-OFDMA PPDU. PHY Motion 21, July 16, 2015, see [25]]

The encoding structure of each BCC in HE-SIG-B is shown in Figure 5 and described below:

- Two users are grouped together and jointly encoded in each BCC block in the user specific section of HE-SIG-B
- The common block has a CRC separate from the CRC of the user specific blocks
- The last user information is immediately followed by tail bits (regardless of whether the number of users is odd or even) and padding bits are only added after those tail bits

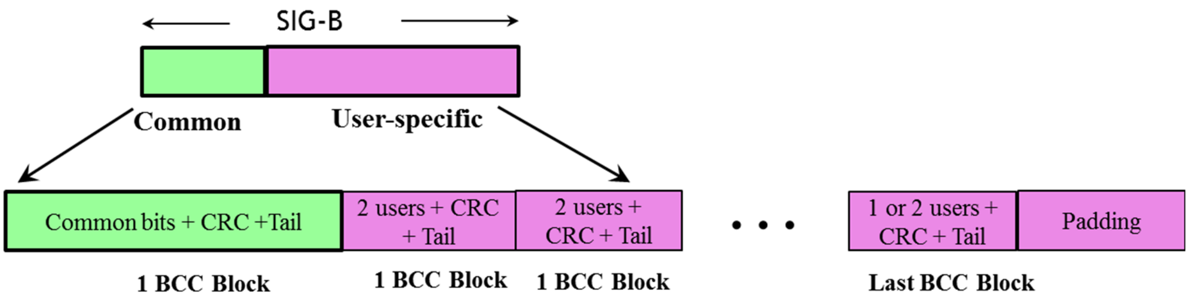

Figure 5 -- Encoding structure in HE-SIG-B

[PHY Motion 39, September 17, 2015, see [26], modified with PHY Motion 95, November 2015, see [27]]

The user specific subfields of HE-SIG-B containing the per user dedicated information include the following fields:

- STAID
- For single-user allocations in an RU: NSTS (Number of Spatial Streams), TxBF (transmit beamforming), MCS (Modulation and Coding Scheme), DCM (Dual Sub-Carrier Modulation) and Coding (Use of LDPC)
- For each user in a multi-user allocation in an RU: Spatial Configuraiton Fields, MCS, DCM and Coding.
- Other fields are TBD.

[PHY Motion 40, September 17, 2015, see [28], modified with PHY Motion 91, see [29]]

The STAID field in the user specific subfields of HE-SIGB is 11 bits in length. [PHY Motion 90, November 2015, see [29]]

For MU-MIMO allocation of RU size > 20 MHz, the user-specific subfields is dynamically split between two HE-SIG-B content channels (1/2) and the split is decided by the AP (on a per case basis). [PHY Motion 41, September 17, 2015, see [28]]

The RU allocation signaling in the common field of HE-SIG-B signals an 8 bit, per 20 MHz PPDU BW for signaling

- The RU arrangement in frequency domain
- Number of MU-MIMO allocations: The RUs allocated for MU-MIMO and the number of users in the MU-MIMO allocations.

The mapping of the 8 bits to the arrangement and the number of MU-MIMO allocations is defined in Table 4. Signaling for the center 26 unit in 80 MHz is TBD.

Table 4 - Arrangement and number of MU-MIMO allocations

8 bits indices	#1	#2	#3	#4	#5	#6	#7	#8	#9	Num of entries
000 0 0000	26	26	26	26	26	26	26	26	26	1
000 0 0001	26	26	26	26	26	26	26	52		1
000 0 0010	26	26	26	26	26	52		26	26	1
000 0 0011	26	26	26	26	26	52		52		1
000 0 0100	26	26	52		26	26	26	26	26	1
000 0 0101	26	26	52		26	26	26	52		1
000 0 0110	26	26	52		26	52		26	26	1
000 0 0111	26	26	52		26	52		52		1
000 0 1000	52		26	26	26	26	26	26	26	1
000 0 1001	52		26	26	26	26	26	52		1
000 0 1010	52		26	26	26	52		26	26	1
000 0 1011	52		26	26	26	52		52		1
000 0 1100	52		52		26	26	26	26	26	1
000 0 1101	52		52		26	26	26	52		1
000 0 1110	52		52		26	52		26	26	1
000 0 1111	52		52		26	52		52		1
000 1 xxxx	Definition TBD									16
00100 yyy	26	26	26	26	26	106				8
00101 yyy	26	26	52		26	106				8
00110 yyy	52		26	26	26	106				8
00111 yyy	52		52		26	106				8
01000 yyy	106				26	26	26	26	26	8
01001 yyy	106				26	26	26	52		8
01010 yyy	106				26	52		26	26	8
01011 yyy	106				26	52		52		8
011 xxxxx	Definition TBD									32
10 yyy yyy	106				26	106				64
11 0 00yyy	242									8
11 0 01yyy	484									8
11 0 10yyy	996									8
11 0 11yyy	2*996									8
11 1 xxxxx	Definition TBD									32

‘yyy’ = 000~111 indicates number of MU-MIMO STAs.
Definition for entries with ‘x’ bits is TBD.
[PHY Motion 64, September 17, 2015, see [28], modified with PHY Motion 89, November 2015, see [29]]

The resource allocation signaling in the common control field and user specific subfields for an STA carried in the HE-SIG-B are transmitted in the same 20 MHz sub-channel as the data for 20 MHz and 40 MHz PPDU. For an 80 MHz PPDU, the default mapping per 20 MHz is as shown in Figure 6.

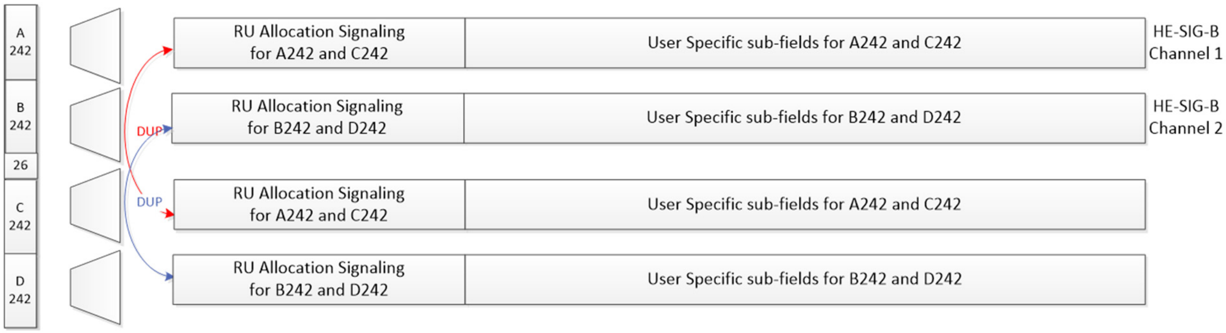

Figure 6 - Default mapping of the two HE-SIG-B channels for an 80 MHz HE PPDU

For a 160MHz PPDU, the default mapping per 20MHz is as shown in Figure 7.

Figure 7 - Default mapping of the two HE-SIG-B channels for a 160 MHz HE PPDU

[PHY Motion 86, November 2015, see [20]]

The length of the user specific subfield in HE-SIG-B for a single-user allocation is equal to the length of the user specific subfield of each user in a multi-user allocation.
[PHY Motion 65, September 17, 2015, see [28]]

The Nsts value for each user in a MU-MIMO RU is less than or equal to 4.
[PHY Motion 93, November 2015, see [5]]

A MU-MIMO user block includes a Spatial Config subfield of 4 bits indicating the number of spatial streams for each multiplexed STA. The subfield is constructed by using the entries corresponding to the value of Nuser of this RU in Table 5.

Table 5 - Spatial Config subfield encoding

Nuser	B0…B3	Nsts [1]	Nsts [2]	Nsts [3]	Nsts [4]	Nsts [5]	Nsts [6]	Nsts [7]	Nsts [8]	Number of Entries
2	0000~0011	1~4	1							10
	0100~0110	2~4	2							

	0111~1000	3~4	3							
	1001	4	4							
3	0000~0011	1~4	1	1						13
	0100~0110	2~4	2	1						
	0111~1000	3~4	3	1						
	1001~1011	2~4	2	2						
	1100	3	3	2						
4	0000~0011	1~4	1	1	1					11
	0100~0110	2~4	2	1	1					
	0111	3	3	1	1					
	1000~1001	2~3	2	2	1					
	1010	2	2	2	2					
5	0000~0011	1~4	1	1	1	1				6
	0100~0101	2~3	2	1	1	1				
6	0000~0010	1~3	1	1	1	1	1			4
	0011	2	2	1	1	1	1			
7	0000~0001	1~2	1	1	1	1	1	1		2
8	0000	1	1	1	1	1	1	1	1	1

[PHY Motion 94, November 2015, see [5]]

The STAID field that identifies the RU allocation in HE-SIG-B for broadcast traffic in DL OFDMA PPDU shall be defined as following:

- For single BSS AP, the STAID for Broadcast will be 0;
- For Multiple BSS AP, the STAID for Broadcast to a specific BSS will follow the group addressed AID assignment in the TIM according to the existing Multi-BSSID TIM operation;
- For Multiple BSS AP, the STAID for Broadcast to all BSSs of the AP will have a special STAID value reserved.

[MAC Motion 56, November 2015, see [30]]

3.2.6 HE preamble following the HE signalling fields

3.2.6.1 General

Gamma (tone rotation as defined in Clause 22.3.7.5 of 11ac amendment) is not applied on HE-STF and beyond.

- TBD in case of a duplicated HE PPDU (if ever defined)

[PHY Motion 82, November 2015, see [31]]

In all transmission modes, HE-STF and HE-LTF only populate RUs that are populated in the data field.
[PHY Motion 81, November 2015, see [31]]

3.2.6.2 HE-STF

HE-STF of a non-trigger-based PPDU has a periodicity of 0.8 µs with 5 periods.

- A non-trigger-based PPDU is not sent in response to a trigger frame

[PHY Motion #11, May 2015, see [32]]

The HE-STF of a trigger-based PPDU has a periodicity of 1.6 µs with 5 periods.

- A trigger-based PPDU is an UL PPDU sent in response to a trigger frame

[PHY Motion #12, May 2015, see [32]]

The HE-STF tone positions are defined in Equation 1 where N_{STF_sample} = 16 for a non-trigger-based PPDU and N_{STF_sample} = 8 for a trigger-based PPDU

$$i_{STF} \bmod N_{STF\_sample} = 0, \quad \lfloor N_{DC}/2 \rfloor < |i_{STF}| \le N_{SR} \qquad (1)$$

i_{STF} : HE-STF tone index

N_{DC} : number of DC tones

N_{SR} : highest data subcarrier index

[PHY Motion #13, May 2015, see [32]]

The HE-STF sequences for 0.8 µs and 1.6 µs periodicity are as follows:

$$M = \{-1,-1,-1,+1,+1,+1,-1,+1,+1,+1,-1,+1,+1,-1,+1\}$$

20 MHz 1x HE-STF sequence:

$$HES_{-112,112}(-112{:}16{:}112) = M \cdot (1+j) \cdot sqrt\left(\frac{1}{2}\right)$$

$$HES_{-112,112}(0) = 0$$

40 MHz 1x HE-STF sequence:

$$HES_{-240,240}(-240{:}16{:}240) = \{M,0,-M\} \cdot (1+j) \cdot sqrt(\frac{1}{2})$$

80 MHz 1x HE-STF sequence:

$$HES_{-496,496}(-496{:}16{:}496) = \{M,1,-M,0,-M,1,-M\} \cdot (1+j) \cdot sqrt(\frac{1}{2})$$

20 MHz 2x HE-STF sequence:

$$HES_{-120,120}(-120{:}8{:}120) = \{M,0,-M\} \cdot (1+j) \cdot sqrt(\frac{1}{2})$$

40 MHz 2x HE-STF sequence:

$$HES_{-248,248}(-248{:}8{:}248) = \{M,-1,-M,0,M,-1,M\} \cdot (1+j) \cdot sqrt\left(\frac{1}{2}\right)$$

$$HES_{-248,248}(\pm 248) = 0$$

80 MHz 2x HE-STF sequence:

$$HES_{-504,504}(-504{:}8{:}504) = \{M,-1,M,-1,-M,-1,M,0,-M,1,M,1,-M,1,-M\} \cdot (1+j) \cdot sqrt(\frac{1}{2})$$

$$HES_{-504,504}(\pm 504) = 0$$

[PHY Motion 79, November 2015, see [33]]

3.2.6.3 HE-LTF

The HE-LTF shall adopt a structure of using P matrix in the data tones as in 11ac. In the data tones, every space-time stream is spread over all HE-LTF symbols by one row of the P matrix as defined in 11ac. Different space-time streams use different rows in P matrix. [PHY Motion #5, March 2015, see [34]]

The HE PPDU shall support the following LTF modes:

- HE-LTF symbol duration of 6.4 µs excluding GI
    - Equivalent to modulating every other tone in an OFDM symbol of 12.8 µs excluding GI, and then removing the second half of the OFDM symbol in time domain
- HE-LTF symbol duration of 12.8 µs excluding GI

[PHY Motion #6, March 2015, see [34]]

In an HE PPDU, the HE-LTF section shall start at the same point of time and end at the same point of time across all users. [PHY Motion #7, March 2015, see [34]]

In an OFDMA PPDU using N HE-LTF symbols, an RU with $N_{sts,total}$ shall use the first $N_{sts,total}$ rows of the $N \times N$ P matrix. [PHY Motion 29, July 16, 2015, see [35]]

Single stream pilot (like 11ac) in HE-LTF shall be used for SU, DL and UL OFDMA as well as in DL MU-MIMO transmissions. [PHY Motion 26, July 16, 2015, see [36]]

The HE-LTF sequences for UL MU-MIMO shall be generated as follows. For each stream, a common sequence shall be masked repeatedly in a piece-wise manner by a distinct row of an 8x8 orthogonal matrix. When the length of the LTF sequence is not divisible by 8, the last M elements of the LTF sequence (M being the remainder after the division of LTF length by 8) shall be masked by the first M elements of the orthogonal matrix row.
[PHY Motion 56, September 17, 2015, see [37]]

The orthogonal matrix used to mask the HE-LTF sequence in SP1 is the 8x8 P-matrix used in 11ac.
[PHY Motion 57, September 17, 2015, see [37]]

The 4x HE−LTF sequence for 80 MHz is defined by the equation below:

HE−LTF$_{996}$(−500:500) =

{+1, +1, −1, +1, −1, +1, −1, −1, −1, +1, −1, −1, −1, +1, +1, −1, +1, +1, +1, +1, +1, −1,
−1, +1, +1, +1, +1, −1, +1, −1, +1, −1, −1, +1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1,
−1, +1, +1, +1, −1, −1, −1, −1, −1, −1, +1, +1, +1, +1, +1, +1, −1, +1, +1, +1, −1, +1, +1,
−1, −1, −1, +1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, +1, +1, −1, −1, +1, +1, +1,
−1, +1, +1, −1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1, −1, +1, +1, +1, +1, −1, −1,
+1, +1, +1, +1, +1, −1, +1, +1, −1, −1, −1, +1, −1, −1, −1, +1, −1, +1, −1, +1, +1, −1, +1,
−1, +1, −1, +1, +1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, −1,
−1, +1, −1, +1, −1, +1, +1, −1, −1, +1, −1, −1, −1, +1, +1, −1, +1, +1, +1, +1, −1, −1, −1,
+1, +1, +1, +1, −1, +1, +1, +1, +1, +1, +1, +1, −1, +1, +1, +1, −1, +1, +1, −1, −1, −1, +1,
−1, +1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, +1, +1, −1, −1, +1, +1, +1, −1, +1, +1, −1,
−1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1, −1, +1, −1, +1, −1, +1, −1, +1, +1, +1, −1,
+1, +1, +1, −1, −1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, −1, −1, +1, −1, +1, −1, +1, +1,
−1, −1, +1, −1, −1, −1, +1, +1, −1, +1, +1, +1, +1, −1, −1, −1, +1, +1, +1, +1, −1, +1, −1,
−1, −1, −1, −1, −1, +1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, −1, +1, +1, −1, −1, +1,
−1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, −1, −1, +1,
−1, −1, +1, −1, +1, +1, +1, +1, +1, +1, −1, −1, +1, +1, +1, +1, +1, −1, +1, +1, −1, −1, −1,
+1, −1, −1, −1, +1, −1, +1, −1, +1, +1, −1, +1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1,
−1, −1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, −1, −1, +1, −1, +1, −1, +1, +1, −1, −1, +1,
−1, −1, −1, +1, +1, −1, +1, +1, +1, +1, −1, −1, −1, +1, +1, +1, +1, −1, −1, +1, +1, +1, +1,
+1, +1, −1, +1, +1, +1, −1, +1, +1, −1, −1, −1, +1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1,
+1, +1, +1, +1, −1, −1, +1, +1, +1, −1, +1, +1, −1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1,
+1, −1, −1, −1, +1, −1, +1, −1, −1, −1, −1, +1, +1, +1, −1, −1, +1, 0, 0, 0, 0, 0, +1, −1,
−1, −1, −1, −1, −1, +1, −1, +1, +1, −1, −1, +1, +1, −1, +1, −1, +1, +1, −1, −1, +1, −1, +1,
−1, −1, −1, +1, +1, −1, +1, +1, +1, −1, +1, +1, +1, +1, +1, +1, +1, −1, +1, −1, −1, +1, −1,
−1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, −1, −1, +1, −1, −1, −1,
−1, −1, +1, +1, −1, −1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, +1, +1, −1, +1, −1, +1,
−1, −1, −1, −1, −1, +1, +1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, +1, −1, −1,
+1, −1, +1, −1, −1, −1, −1, −1, −1, −1, +1, +1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1,
−1, −1, +1, −1, −1, +1, −1, +1, +1, +1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, −1,
−1, +1, −1, −1, −1, +1, −1, −1, −1, −1, −1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1,
−1, −1, +1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, +1, +1, −1, +1, −1, −1, −1, −1, +1, +1,
−1, −1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, +1, +1, −1, +1, −1, +1, −1, −1, −1, −1,

−1, +1, +1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, +1, −1, −1, +1, −1, +1, −1,
+1, +1, +1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1, +1, −1,
−1, −1, −1, −1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, +1, +1,
+1, −1, −1, +1, +1, +1, +1, +1, −1, +1, +1, +1, +1, +1, −1, −1, +1, +1, +1, +1, +1, −1, +1,
+1, −1, −1, −1, +1, −1, −1, −1, +1, −1, +1, −1, +1, +1, +1, +1, +1, −1, −1, −1, +1, +1, +1,
+1, −1, +1, +1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, −1, −1, −1, −1, −1, −1, +1,
+1, −1, −1, −1, +1, −1, −1, +1, +1, +1, −1, +1, −1, −1, +1, −1, −1, +1, −1, +1, −1, +1, −1,
+1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1, +1, −1, −1, −1, −1, −1,
−1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, +1, +1, +1, −1, −1, +1,
+1, +1, +1, +1, −1, +1, −1, −1, −1, −1, +1, +1, −1, −1, −1, −1, −1, +1, −1, −1, +1, +1, +1,
−1, +1, +1, +1, −1, +1, −1, +1, −1, −1, −1, −1, −1, +1, +1, +1, −1, −1, −1, −1, +1, −1, −1,
+1, +1, +1, −1, +1, +1, −1, −1, +1, −1, +1, −1, +1}

The 2x HE−LTF sequence for 80 MHz is defined by the equation below:

HE−LTF$_{996}$(−500:2:500) =

{+1, +1, −1, +1, +1, +1, −1, +1, +1, +1, +1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, +1,
+1, −1, −1, −1, −1, +1, +1, +1, +1, −1, +1, +1, +1, −1, +1, −1, −1, +1, −1, −1, −1, +1, +1,
−1, −1, −1, +1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, −1, −1, −1, −1,
+1, −1, −1, +1, +1, −1, +1, +1, +1, −1, −1, −1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1, +1,
−1, −1, −1, +1, +1, +1, −1, −1, +1, +1, +1, −1, +1, +1, −1, +1, −1, −1, −1, −1, +1, −1, −1,
−1, +1, −1, +1, +1, −1, +1, +1, −1, −1, −1, +1, −1, −1, −1, +1, −1, +1, +1, −1, +1, +1, +1,
−1, −1, +1, +1, +1, −1, +1, +1, −1, +1, −1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1, +1, −1,
−1, −1, +1, −1, −1, +1, +1, −1, +1, +1, +1, −1, −1, −1, −1, +1, +1, +1, −1, −1, −1, −1, +1,
−1, −1, −1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, −1, +1, +1, −1, +1, −1, −1, −1, −1, +1,
−1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, +1, −1, −1, +1, −1, −1, −1, +1, +1, +1, +1,
−1, +1, −1, −1, −1, +1, −1, −1, −1, −1, +1, +1, +1, +1, −1, −1, −1, +1, +1, +1, 0, 0, 0, +1,
−1, −1, +1, +1, −1, +1, −1, −1, −1, +1, +1, +1, +1, −1, +1, +1, +1, −1, +1, −1, −1, −1, −1,
+1, +1, +1, −1, +1, +1, −1, −1, +1, −1, −1, +1, −1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1,
+1, −1, +1, −1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1,
+1, −1, −1, −1, +1, +1, +1, +1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, +1, +1, −1, −1, −1,
−1, +1, −1, −1, −1, +1, −1, +1, +1, −1, +1, −1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, +1,
−1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1, −1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, −1,
−1, −1, −1, +1, −1, +1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, −1, −1, −1, +1, +1, +1, +1,
−1, +1, +1, +1, −1, +1, −1, −1, −1, −1, +1, +1, +1, −1, +1, +1, −1, −1, +1, −1, −1, −1, −1,
+1, −1, −1, −1, +1, −1, +1, +1, −1, +1, +1, −1, +1, −1, −1, +1, −1, −1, −1, +1, +1, −1, −1,
−1, +1, −1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1, +1, −1, −1, −1, −1, +1, +1, +1, −1, +1,
+1, −1, −1, +1, −1, −1, −1, +1, +1, +1, +1, −1, +1, +1, +1, −1, +1, +1}

The 4x HE−LTF sequence for 40 MHz is defined by the equation below:

HE−LTF$_{484}$(−244:244) =

{ +1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, −1, +1, +1, −1, +1, −1, −1, −1,
+1, +1, −1, −1, −1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, −1, −1, −1, −1, +1, −1,
+1, +1, +1, −1, −1, +1, +1, +1, −1, −1, +1, +1, +1, +1, −1, +1, +1, −1, −1, +1, −1, +1, −1,
+1, −1, −1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1,
+1, −1, −1, −1, −1, −1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, +1, +1, +1, +1, +1, −1, +1,
+1, −1, −1, +1, −1, +1, +1, +1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, −1, −1, −1,
−1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, −1,
−1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, −1, −1, −1, −1, +1, −1, +1, +1, +1, −1,
−1, +1, +1, +1, −1, −1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, −1, +1, +1, −1,
+1, −1, −1, −1, +1, +1, −1, −1, −1, +1, +1, +1, +1, −1, +1, +1, −1, −1, +1, −1, +1, +1, +1,
+1, +1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, +1, 0, 0, 0, 0, 0, −1, +1, +1, +1, +1, −1,
+1, +1, −1, −1, +1, −1, +1, −1, +1, −1, −1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, +1, +1,
+1, +1, −1, +1, +1, −1, −1, +1, −1, +1, +1, +1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, −1,
−1, +1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, −1, +1, +1, −1, +1, −1, −1,

−1, +1, +1, −1, −1, −1, +1, +1, +1, +1, −1, +1, +1, −1, −1, +1, −1, +1, +1, +1, +1, +1, −1,
+1, −1, −1, −1, +1, +1, −1, −1, −1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1,
−1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1,
−1, +1, −1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1, −1, −1, −1, −1, −1, −1, +1, −1,
−1, +1, +1, −1, +1, −1, −1, −1, −1, −1, +1, −1, +1, +1, +1, −1, −1, +1, +1, +1, −1, +1, −1,
−1, −1, −1, +1, −1, −1, +1, +1, −1, +1, −1, +1, −1, +1, +1, −1, +1, −1, −1, −1, +1, +1, −1,
−1, −1, +1, +1, +1, +1, −1, +1, +1, −1, −1, +1, −1, +1, +1, +1, +1, +1, −1, +1, −1, −1, −1,
+1, +1, −1, −1, −1, −1}

The 2x HE−LTF sequence for 40 MHz is defined by the equation below:

HE−LTF$_{484}$(−244:2:244) =
{+1, −1, −1, −1, −1, −1, +1, +1, −1, −1, +1, −1, +1, −1, −1, −1, −1, −1, −1, +1, +1, +1,
+1, −1, +1, −1, +1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, +1, −1, +1, −1, +1, +1, +1, +1,
+1, −1, −1, −1, −1, +1, −1, +1, −1, +1, +1, +1, +1, +1, −1, +1, −1, −1, +1, −1, +1, −1, −1,
+1, +1, +1, +1, +1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, +1, +1, +1, −1, −1, −1, −1, +1,
−1, +1, −1, −1, −1, −1, −1, −1, −1, +1, +1, −1, −1, +1, −1, +1, −1, +1, +1, +1, +1, +1, −1,
−1, −1, −1, +1, −1, +1, −1, 0, 0, 0, −1, −1, −1, −1, −1, +1, +1, −1, −1, +1, −1, +1, −1, −1,
−1, −1, −1, −1, +1, −1, +1, +1, −1, +1, −1, +1, +1, +1, +1, +1, +1, +1, −1, −1, +1, +1, −1,
+1, −1, +1, −1, −1, −1, −1, −1, +1, −1, +1, +1, −1, +1, −1, +1, +1, +1, +1, +1, +1, +1, −1,
−1, +1, +1, −1, +1, −1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, +1, −1, +1, −1, −1, −1, −1,
−1, −1, +1, −1, +1, +1, −1, +1, −1, +1, +1, −1, −1, −1, −1, −1, +1, +1, −1, −1, +1, −1, +1,
−1, +1, +1, +1, +1, +1, −1, +1, −1, −1, +1, −1, +1, −1, +1}

The 4x HE−LTF sequence for 20 MHz is defined by the equation below:

HE−LTF$_{242}$(−122:122) =
{−1, −1, +1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1, −1, −1, +1,
+1, −1, −1, −1, −1, +1, +1, −1, +1, −1, +1, +1, +1, +1, −1, +1, −1, −1, +1, +1, −1, +1, +1,
+1, +1, −1, −1, +1, −1, −1, −1, +1, +1, +1, +1, −1, +1, +1, −1, −1, −1, −1, +1, −1, −1, +1,
+1, −1, +1, −1, −1, −1, −1, +1, −1, +1, −1, −1, −1, −1, −1, −1, +1, +1, −1, −1, −1, −1, −1,
+1, −1, −1, +1, +1, +1, −1, +1, +1, +1, −1, +1, −1, +1, −1, −1, −1, −1, −1, +1, +1, +1, −1,
−1, −1, +1, −1, +1, +1, +1, 0, 0, 0, −1, +1, −1, +1, −1, +1, +1, −1, +1, +1, +1, −1, −1, +1,
−1, −1, +1, −1, +1, −1, +1, +1, +1, −1, +1, +1, +1, −1, −1, +1, −1, −1, −1, −1, −1, +1, +1,
−1, −1, −1, −1, −1, −1, +1, −1, +1, −1, −1, −1, −1, +1, −1, +1, +1, −1, −1, +1, −1, −1, −1,
−1, +1, +1, −1, +1, +1, +1, +1, +1, +1, +1, −1, +1, +1, −1, −1, −1, −1, +1, −1, −1, +1, +1,
−1, +1, −1, −1, −1, −1, +1, −1, +1, −1, −1, +1, +1, +1, +1, −1, −1, +1, +1, +1, +1, +1, −1,
+1, +1, −1, −1, −1, +1, −1, −1, −1, +1, −1, +1, −1, +1, +1}

The 2x HE−LTF sequence for 20 MHz is defined by the equation below:

HE−LTF$_{242}$(−122:2:122) =
{−1, −1, −1, +1, +1, −1, +1, −1, −1, −1, −1, +1, −1, +1, −1, −1, +1, +1, −1, +1, +1, +1,
+1, +1, −1, +1, −1, +1, −1, −1, +1, +1, −1, +1, −1, −1, −1, −1, +1, −1, +1, +1, +1, −1, −1,
+1, −1, −1, −1, −1, −1, +1, −1, −1, −1, +1, +1, +1, −1, −1, +1, 0, +1, −1, +1, +1, −1, +1,
+1, −1, +1, +1, −1, −1, +1, −1, +1, +1, +1, +1, −1, +1, −1, +1, +1, −1, −1, +1, −1, −1, −1,
−1, −1, +1, −1, +1, +1, −1, −1, +1, +1, −1, +1, −1, −1, −1, −1, +1, −1, +1, +1, +1, −1, −1,
+1, −1, −1, −1, −1, −1, +1, −1, +1}

[PHY Motion 80, November 2015, see [31]]

The only mandatory combinations of LTF size and CP size are:

- 2x LTF + 0.8 μS
- 2x LTF + 1.6 μS
- 4x LTF + 3.2 μS

with HE-LTF and payload using the same CP size. The LTF size and CP size are jointly signaled using 3 bits.

[PHY Motion 70, November 2015, see [6]]

A 1x LTF as an optional mode in 11ax for SU PPDUs (TBD for MU-MIMO). The 1x LTF + 0.8 µs GI is one optional combination as indicated by the "GI and LTF size" sub-field in HE-SIG-A.
[PHY Motion 85, November 2015, see [8]]

3.3 HE Data field

3.3.1 General

The Data field in UL MU transmissions shall immediately follow the HE-LTF section.
[PHY Motion 17, July 16, 2015, see [13]]

Data symbols in an HE PPDU shall use a DFT period of 12.8 µs and subcarrier spacing of 78.125 kHz.
[PHY Motion #1, January 2015, see [38]]

Data symbols in an HE PPDU shall support guard interval durations of 0.8 µs, 1.6 µs and 3.2 µs. [PHY Motion #2, January 2015, see [38]]

HE PPDUs shall have single stream pilots in the data section

- All streams use the same pilot sequence even in UL MU-MIMO

[PHY Motion 24, July 16, 2015, see [39]]

3.3.2 Tone plan

3.3.2.1 Resource unit, edge and DC tones

HE-PPDU for UL-OFDMA shall support UL data transmission below 20 MHz for an HE STA. [MU Motion #3, March 2015]

Define 20 MHz OFDMA building blocks as follows:

- 26-tone with 2 pilots, 52-tone with 4 pilot and 106-tone with 4 pilots and with 7 DC Nulls and (6,5) guard tones, and at locations shown in Figure 8
- An OFDMA PPDU can carry a mix of different tone unit sizes within each 242 tone unit boundary
- ~~The following is TBD: Exact location of extra leftover tones~~ *[Ed: deleted, see 3.3.2.2]*

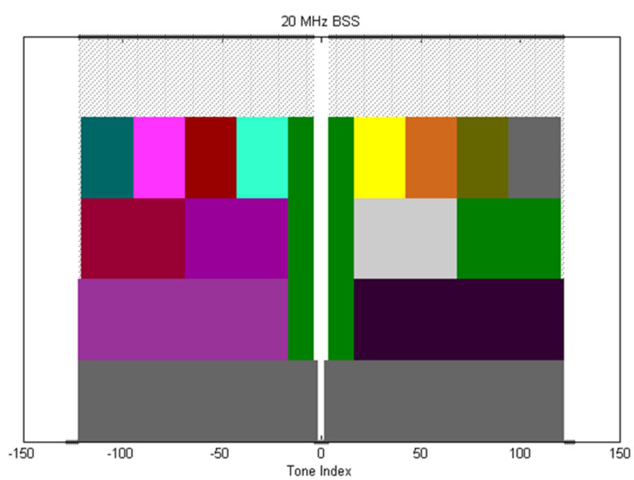

Figure 8 – 20 MHz tone plan

Define 40 MHz OFDMA building blocks as follows

- 26-tone with 2 pilots, 52-tone with 4 pilots, 106-tone with 4 pilots and 242-tone with 8 pilots and with 5 DC Nulls and (12,11) guard tones, and at locations shown in Figure 9
- ~~The following is TBD: exact location of extra leftover tones~~ *[Ed: deleted, see 3.3.2.2]*

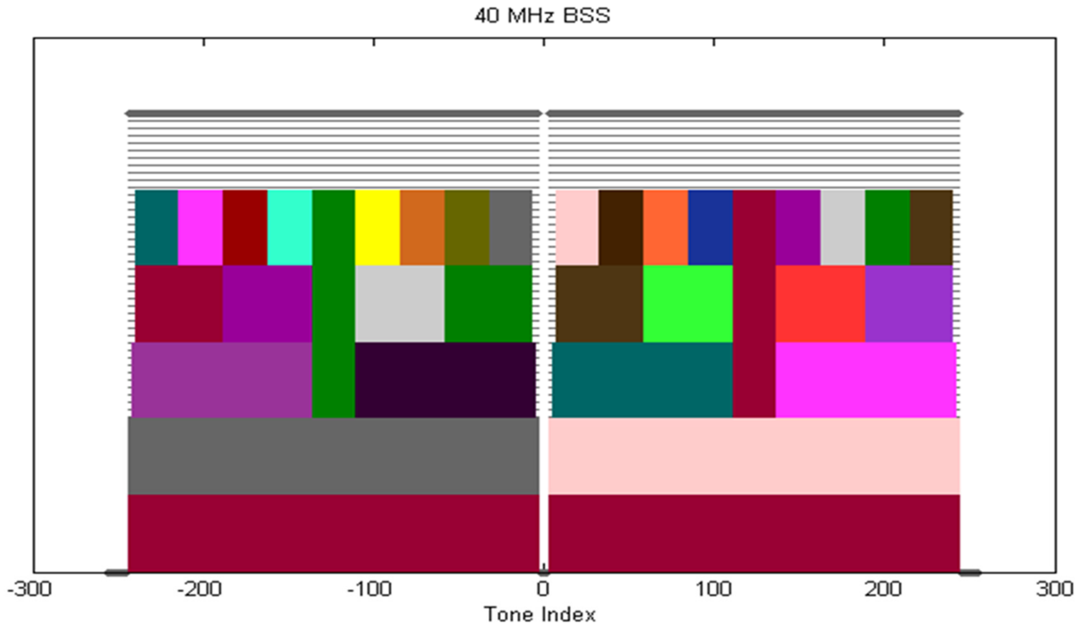

Figure 9 – 40 MHz tone plan

Define 80 MHz OFDMA building blocks as follows:

- 26-tone with 2 pilots, 52-tone with 4 pilots, 106-tone with 4 pilots, 242-tone with 8 pilots and 484-tone with 16 pilots and with 7 DC Nulls and (12,11) guard tones, and at locations shown in Figure 10
- ~~The following is TBD: exact location of extra leftover tones~~ *[Ed: deleted, see 3.3.2.2]*

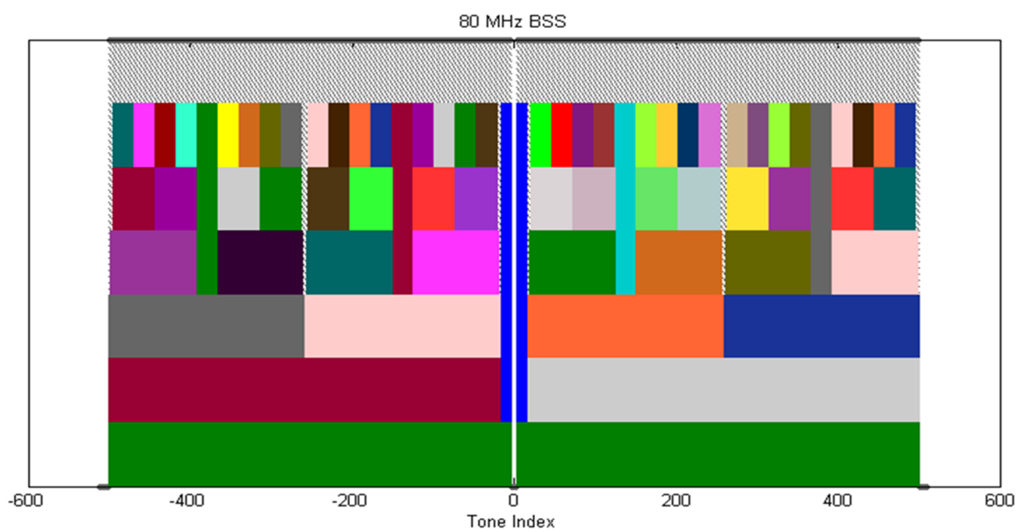

Figure 10 - 80 MHz tone plan

Define 160 MHz/80 MHz+80 MHz OFDMA building blocks as follows:

- 26-tone with 2 pilots
- 52-tone with 4 pilots
- 106-tone with 4 pilots
- 242-tone with 8 pilots
- 484-tone with 16 pilots

- 996-tone with 16 pilots (note that 996-tone is defined for 80 MHz HE-SA-PPDU or 80 MHz HE-SA-MU-PPDU)
- The following is TBD: exact location of extra leftover tones

[PHY Motion #10, May 2015, see [40]]

The 2x996-tone RU employs a segment parser (as in 11ac) between the two 996-tone frequency segments and the LDPC tone mapper in each 996-tone segment uses $D_{TM} = 20$.
[PHY Motion 74, November 2015, see [41]]

3.3.2.2 Left over tones

The left over tone locations for the 20 MHz, 40 MHz and 80 MHz tone plans are shown in Figure 11, Figure 12 and Figure 13 respectively.
NOTE—Left over tones have zero energy
[PHY Motion 25, July 16, 2015, see [36]]

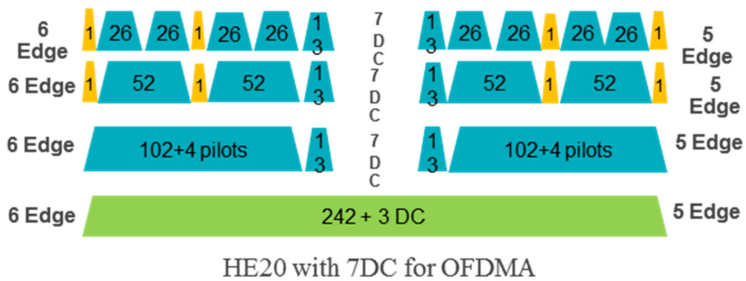

Figure 11 – Left over tone locations for 20 MHz

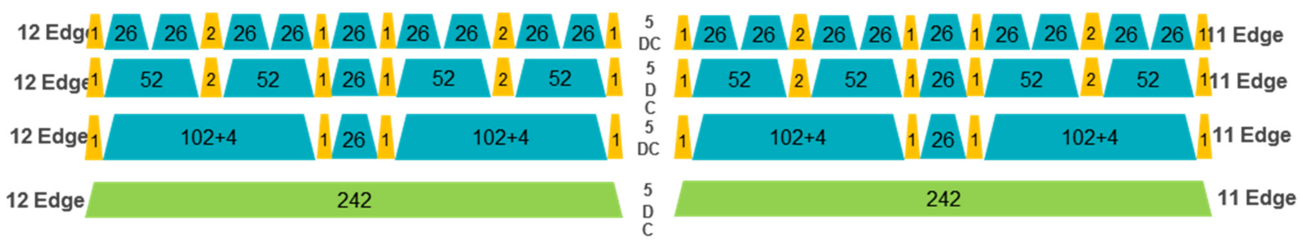

Figure 12 – Left over tone locations for 40 MHz

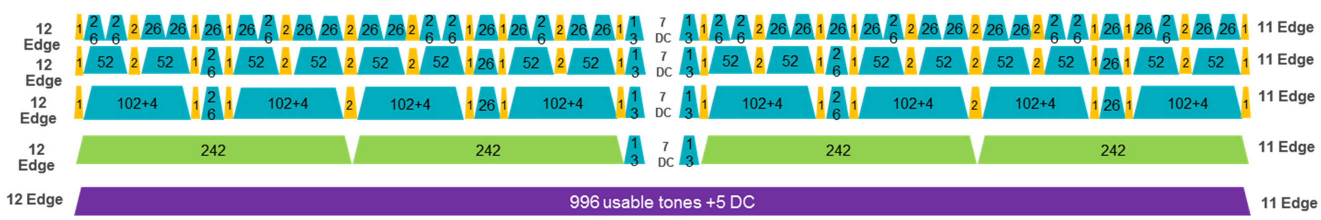

Figure 13 – Left over tone locations for 80 MHz

3.3.2.3 Pilot tones

All pilot tones in 4x data OFDMA symbol are at even indices. If pilots present in 4x HE-LTF, their tone indices shall be the same as those pilots in 4x data symbol. If pilots present in 2x HE-LTF, their tone indices shall be the same as the indices of those pilots in 4x data symbol divided by 2. [PHY Motion 27, July 16, 2015, see [36]]

The pilot tone locations for 20 MHz, 40 MHz and 80 MHz bandwidth are as shown in Figure 14, Figure 15 and Figure 16 respectively.
Note—80 MHz pilot positions are enumerated below for reference:

RU-26 pilots: ±10, ±24, ±38, ±50, ±64, ±78, ±92, ±104, ±118, ±130, ±144, ±158, ±172, ±184, ±198, ±212, ±226, ±238, ±252, ±266, ±280, ±292, ±306, ±320, ± 334, ±346, ±360, ±372, ±386, ±400, ±414, ±426, ±440, ±454, ±468, ±480, ± 494

RU-106/242/484 pilots: ±24, ±50, ±92, ±118, ±158, ±184, ±226, ±252, ±266, ±292, ±334, ±360, ±400, ±426, ±468, ±494

RU-996 pilots: ±24, ±92, ±158, ±226, ±266, ±334, ±400, ±468

The pilot locations for 160 MHz or 80+80 MHz use the same structure as 80 MHz for each half of the BW.

[PHY Motion 28, July 16, 2015, see [36]]

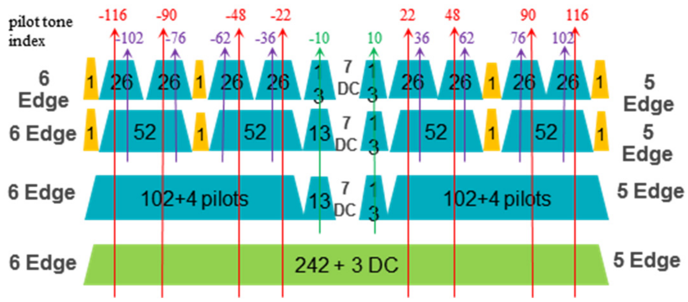

Figure 14 – Pilot tone locations for 20 MHz

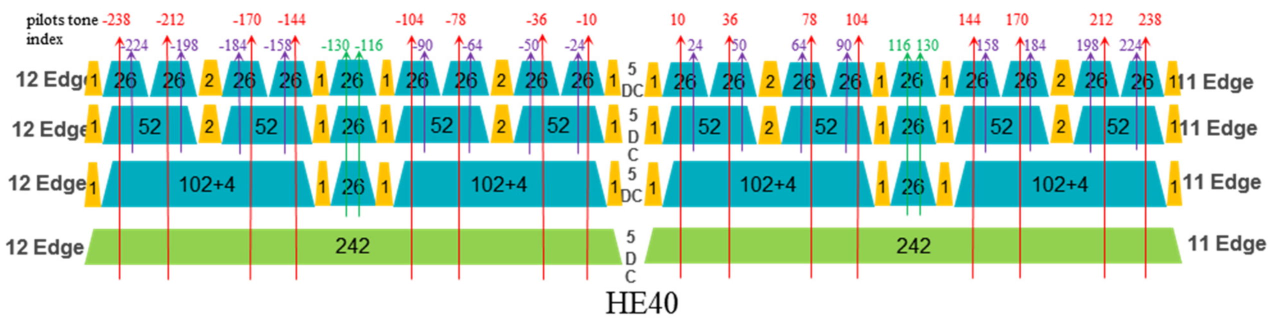

Figure 15 – Pilot tone locations for 40 MHz

Figure 16 – Pilot tone locations for 80 MHz

3.3.3 Coding

LDPC is the only coding scheme in the HE PPDU Data field for allocation sizes of 484 tones, 996 tones and 996*2 tones.

[PHY Motion 30, July 16, 2015, see [42], modified with PHY Motion 36, September 17, 2015, see [43]]

Support of BCC code is limited to less than or equal to four spatial streams (per user in case of MU-MIMO), and is mandatory (for both TX and RX) for RU sizes less than or equal to 242 tones (20MHz).

Support of LDPC code for both TX and RX is mandatory for HE STAs declaring support for at least one of HE 40/80/160/80+80 SU PPDU bandwidths, or for HE STAs declaring support for more than 4 spatial streams. Otherwise, support of LDPC code for either TX or RX is optional.

[PHY Motion 31, July 16, 2015, see [42]]

The 11ax MCS table shall not have any MCS exclusion and, when LDPC is applied, N_{DBPS} is computed as follows

$$N_{DBPS} = \lfloor N_{CBPS} R \rfloor$$, where R is the coding rate

[PHY Motion 32, July 16, 2015, see [42]]

The BCC interleaver and LDPC tone mapper parameters are defined in Table 6.

Table 6 - BCC interleaver and LDPC tone mapper parameters

RU size (tones)	BCC		LDPC
	N_{col}	N_{rot}	D_{TM}
26	8	2	1
52	16	11	3
106	17	29	6
242	26	58	9
484	-	-	12
996	-	-	20

[PHY Motion 33, July 16, 2015, see [42]]

3.3.4 Modulation

1024-QAM is an optional feature for SU and MU using resource units equal to or larger than 242 tones in 11ax.
[PHY Motion 42, September 17, 2015 see [44]]

Dual sub-carrier modulation (DCM) is an optional modulation scheme for the HE-SIG-B and Data fields. DCM is only applied to BPSK, QPSK and 16-QAM modulations.
[PHY Motion 53, September 17, 2015, see [17]]

3.3.5 Padding and packet extension

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 HE PPDU
- PE should have the same average power as data field

[PHY Motion 58, September 17, 2015, see [45]]

11ax shall define the max packet extension modes of 8 µs and 16 µs, correspond to the short symbol segment padding boundaries (*a-factor*) according to the following PE duration (TPE) values:

- Max packet extension mode 8 µs: T_{PE} = [0 0 4 8] µs for a = 1~4 respectively;
- Max packet extension mode 16 µs: T_{PE} = [4 8 12 16] µs for a = 1~4 respectively.

HE Capability field shall define two constellation level thresholds (*threshold16* and *threshold8*) 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 ≥ *threshold16* apply max PE 16 µs mode, else if constellation ≥ *threshold8* apply max PE 8 µs mode, else no packet extension.
- If no PE is required for all constellations both *threshold8* and *threshold16* are set to 111
- If only max PE 8 µs mode is required, set *threshold16* to be 111, and *threshold8* to be the constellation at which max PE 8 µs mode starts
- If only max PE 16 µs mode is required, set *threshold16* to be the constellation at which max PE 16 µs mode starts, and *threshold8* 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.

Table 7 - Threshold encoding in HE capability

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

[PHY Motion 59, September 17, 2015, see [45]]

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.

Table 8 - $N_{SD.short}$

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

[PHY Motion 60, September 17, 2015, see [45]]

HE-SIG-A field contains an a-factor field of 2 bits and a PE Disambiguity field of 1 bit that are set as described below.

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

The ecoding of the a-factor field in HE-SIG-A is defined in Table 9.

Table 9 - A Factor field encoding

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

The PE Disambiguity field in HE-SIG-A is set as follows:

- 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 $T_{SYM} = 12.8 + T_{GI}$, then this field is set to 1; otherwise this field is set to 0.
- At the receiver, the following equations are used to compute N_{SYM} and T_{PE} respectively:

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

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

[PHY Motion 61, September 17, 2015, see [45], modified with PHY Motion 73, November 2015]

When the AP transmits a DL MU PPDU:

- All users use the same N_{SYM} and *a-factor* values according to the user with the longest span
- Based on the *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 DL MU PPDU, $T_{PE} = \max_u(T_{PE,u})$
- In HE-SIG-A field, the a-factor field, the PE Disambiguity field and the LDPC Extra Symbol field are common to all users

[PHY Motion 62, September 17, 2015, see [45]]

For an UL MU PPDU transmission:

- The AP indicates its desired N_{SYM}, *a-factor*, LDPC extra symbol indication and PE duration values in the Trigger frame
- Possible PE values for UL MU are TBD
- Each user transmitting an UL MU PPDU shall encode and conduct PHY padding using the following 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

[PHY Motion 63, September 17, 2015, see [45]]

3.4 Transmit spectral mask

The spectral masks for non-OFDMA 20 MHz, 40 MHz, 80 MHz, 160 MHz and 80+80 MHz PPDUs are are defined below.

- The bandwidth of the applied spectrum mask for a (non-OFDMA) PPDU shall be determined by the bandwidth occupied by the pre HE-STF portion of the preamble in this PPDU, regardless of the BSS bandwidth
- The spectral mask requirements do not apply to LO leakage

The HE 20 MHz spectral mask is the 11ac 80 MHz mask downclocked by 4 (6/5 guard tones) as shown in Figure 17.

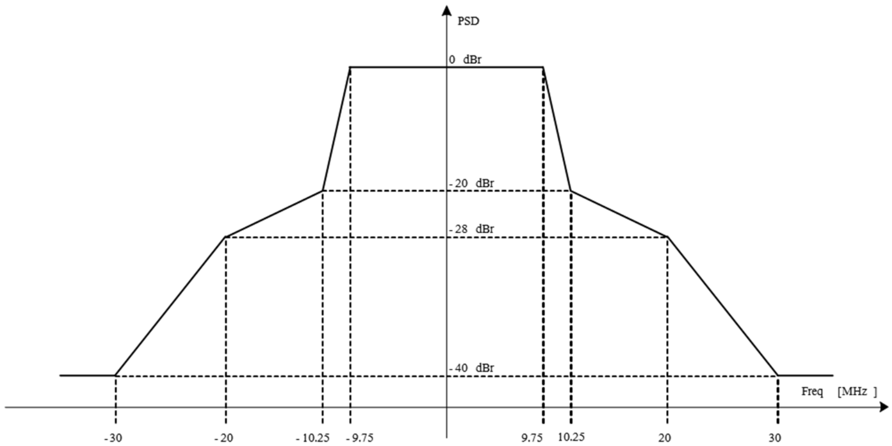

Figure 17 - Transmit spectral mask for an HE 20 MHz PPDU

The HE 40 MHz and 80 MHz spectral masks are the 11ac 80 MHz and 160 MHz masks downclocked by 2 (12/11 guard tones) as shown in Figure 18 and Figure 19.

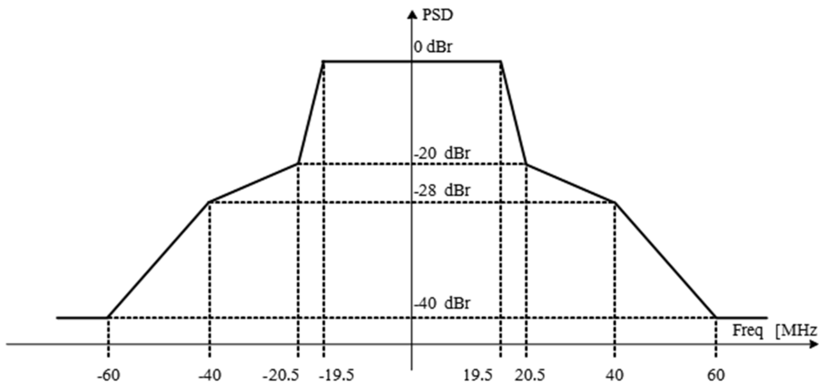

Figure 18 - Transmit spectral mask for HE 40 MHz PPDU

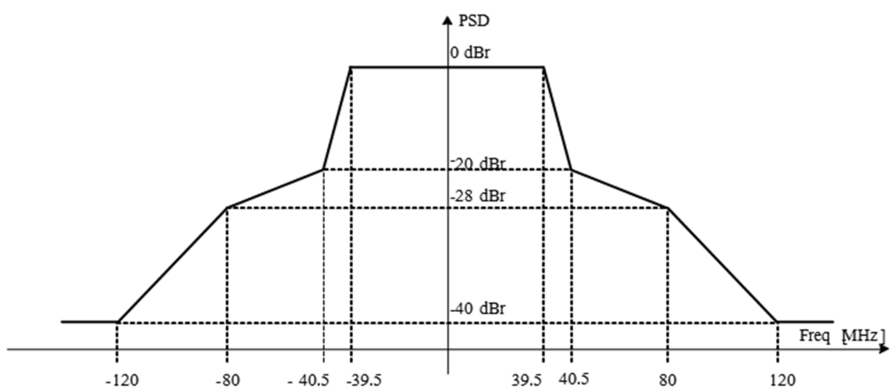

Figure 19 - Transmit spectral mask for HE 80 MHz PPDU

The HE 80+80 MHz and 160 MHz are similar to 11ac. The HE 160 MHz mask as shown in Figure 20 has the same skirt as that of 11ac 160 MHz and the 1st rolloff identical to HE 40/80 MHz. The 160 MHz tone plan has the same number of guard tones (12/11) as HE 40/80 MHz. The HE 80+80 MHz mask is a combination of two 80 MHz interim spectral masks as shown in Figure 21.

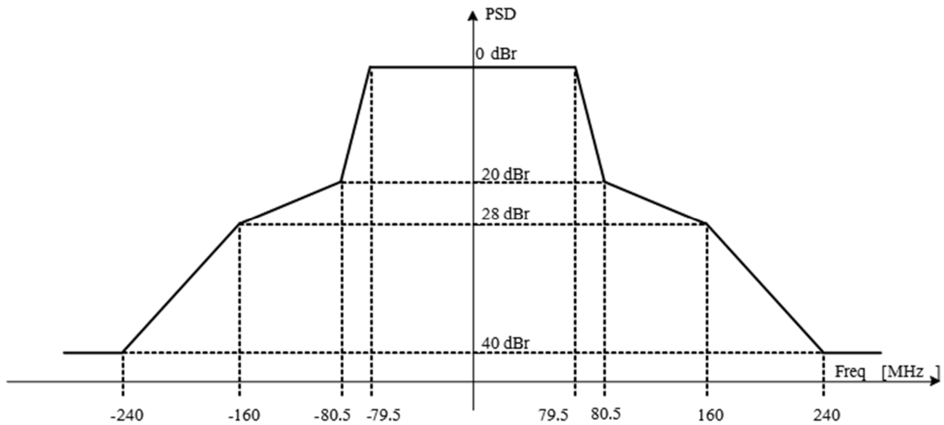

Figure 20 - Transmit spectral mask for HE 160 MHz PPDU

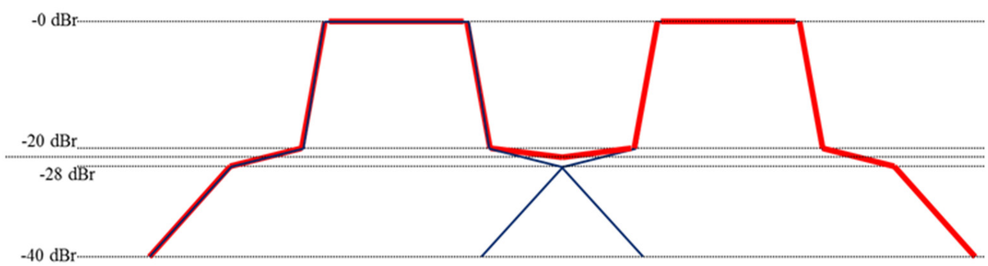

Figure 21 - Transmit spectral mask for HE 80+80 MHz PPDU

[PHY Motion 76, November 2015, see [46]]

4 Multi-user (MU) features

4.1 General

This section describes MU related features. MU features include UL and DL OFDMA and UL and DL MU-MIMO.

A TXOP can include both DL MU and UL MU transmissions.
[MAC Motion 14, July 16, 2015, see [47]]

The spec shall include the definition of a cascading TXOP structure, allowing alternating DL and UL MU PPDUs starting with a DL MU PPDU in the same TXOP

- The TXOP sequence has only one DL transmitter
- The TXOP sequence may have different UL transmitters within each UL MU PPDU
- The TXOP sequence may have a different set of transmitters in an UL MU PPDU as compared to the DL MU PPDU that follows the UL MU PPDU within the same TXOP

[MAC Motion 15, July 16, 2015, see [47]]

DL/UL OFDMA can multiplex different types of unicast frames in frequency domain. Types of frames can be data frame/control frame/management frame.
[MAC Motion 16, July 16, 2015, see [47]]

DL/UL MU-MIMO can multiplex different types of unicast frames in spatial domain. Types of frames can be data frame/control frame/management frame. Different types of frames are to/from different users.
[MAC Motion 17, July 16, 2015, see [47]]

The transmission for all the STAs in a DL MU (MIMO, OFDMA) PPDU shall end at the same time.

The A-MPDU padding per each STA follows the 11ac procedure.
[MAC Motion 22, July 16, 2015, see [48]]

The transmission from all the STAs in an UL MU PPDU shall end at the time indicated in Trigger frame. The A-MPDU padding per each STA follows the 11ac procedure.
[MAC Motion 23, July 16, 2015, see [48]]

DL-OFDMA may reuse the same sharing mechanism of an EDCA TXOP as DL MU-MIMO.
[MAC Motion 36, September 17, 2015, see [49]]

A STA shall consider CCA status to respond to a Trigger frame under a non-null TBD set of conditions.
[MU Motion 14, September 17, 2015, see [50]]

The spec shall allow multiple TIDs in a single PSDU between AP and a STA for DL/UL OFDMA/MU-MIMO. Multiple TIDs aggregation rules are TBD if necessary.
[MU Motion 16, September 17, 2015, see [51]]

The spec shall support fragmentation negotiation in A-MPDUs for HE STAs.
[MU Motion 19, September 17, 2015, see [52]]

4.2 DL MU operation

The amendment shall include a mechanism to multiplex BA/ACK responses to DL MU transmission.
[MU Motion #4, March 2015, see [53]]

In each payload within a DL MU PPDU a Trigger frame may be present that carries the information that enables the recipient of the STA to send its ACK/BA response frame a TBD IFS after the DL MU PPDU.
[MU Motion 11, July 16, 2015, see [54]]

A unicast Trigger frame for a single user may be included in an A-MPDU for that user in the DL MU PPDU that precedes the UL MU transmission by TBD IFS. [MAC Motion 20, July 16, 2015, see [55]]

Broadcast trigger transmitted in a subchannel of DL OFDMA shall not include the resource allocation information of the STAs which are recipients of frames in the other subchannels of the DL OFDMA. The subchannel of the broadcast trigger frame is identified by TBD signaling. [MAC Motion 21, July 16, 2015, see [55]]

The spec shall allow that the schedule information for OFDMA acknowledgement from STAs is contained in the MAC header of DL MPDU.
[MU Motion 23, September 17, 2015, see [56]]

The contents of the scheduling information for an UL OFDMA ACK/BA includes UL PPDU Length (9 bits) and RU Allocation (TBD).
[MU Motion 24, September 24, 2015, see [56]]

In a HE MU PPDU, at most one A-MPDU is allowed to contain one or more MPDUs that solicit an immediate response, except when an immediate response is carried in HE TB UL PPDU. In such case, one or more A-MPDUs are allowed to contain one or more MPDUs that solicit an immediate response carried in an HE TB UL PPDU.
[MAC Motion 29, September 2015, see [57]]

Scheduling information for UL MU Acknowledgement from STA may be contained within the HE variant of the HT Control Field.

[MU Motion 29, November 2015, see [58]]

Within an A-MPDU the trigger information for a STA, if present, shall be signaled either in Trigger frame(s) or in the MAC header of MPDU(s) contained in the A-MPDU but not both.
[MU Motion 38, November 2015, see [59]]

Ack Policy field set to 01 (Trigger based UL MU Ack) has the following normative behavior for an HE STA:

- The addressed recipient that receives the trigger information, within a DL MU PPDU returns an immediate Ack/BlockAck response, either individually or as part of an A-MPDU after the PPDU carrying the frame, according to the trigger information carried in the same DL MU PPDU
- The addressed recipient that does receive no valid trigger information takes no action upon the receipt of the frame, except for recording the state (if necessary)

[MAC Motion 42, November 2015, see [60]]

Ack Policy field in a frame soliciting an immediate response is set to 00 (Normal Ack or Implicit Block Ack Request) if the immediate response is carried in SU PPDU, or it is set to 01 (Trigger based UL MU Ack) if the immediate response is carried in MU PPDU.
[MAC Motion 43, November 2015, see [61]]

When an AP initiates a DL MU transmission soliciting more than one immediate response frames, the DL MU transmission is successful if the AP receives the response frame correctly from at least one STA indicated by any trigger information in the DL MU transmission.
[MAC Motion 46, November 2015, see [62]]

4.3 UL MU operation

An UL MU PPDU (MU-MIMO or OFDMA) is sent as an immediate response (IFS TBD) to a Trigger frame (format TBD) sent by the AP. [MAC Motion #3, March 2015]

The CP length for UL OFDMA/MU-MIMO transmissions shall be explicitly indicated by AP in the Trigger frame that allocates resources for the UL OFDMA/MU-MIMO transmission. The value of CP length for all users addressed by the Trigger frame shall be the same. [PHY Motion 34, July 16, 2015, see [63]]

A Trigger frame that addresses STAs in multiple BSSs corresponding to a multiple BSS set shall use a common address TBD in the A2 field.
[MAC Motion 55, November 2015, see [64]]

An UL OFDMA MPDU/A-MPDU is the acknowledgement of the trigger frame. When the AP receives MPDU correctly from at least one STA indicated by trigger frame, the frame exchange initiated by the trigger frame is successful. [MAC Motion 13, July 16, 2015, see [65]]

The amendment shall define a mechanism for multiplexing DL acknowledgments sent in response to UL MU transmissions. [MU Motion #1, January 2015, see [66]]

An AP shall not allocate UL subchannel in any 20 MHz channel that is not occupied by the immediately preceding DL PPDU that contains trigger information. In each 20 MHz channel occupied by the immediately preceding DL PPDU that contains trigger information, there is at least one allocated subchannel. [MAC Motion #10, May 2015, see [67], modified with MAC Motion 40, September 17, 2015, see [68]]

Non-AP STAs support using the QoS Control field in QoS Data and QoS Null frames to report per-TID Buffer Status information.
[MAC Motion 37, September 17, 2015, see [69]]

An AP can poll STAs for buffer status reports using the frame carrying the trigger info. The poll can request for specific buffer status information with TBD granularity.
[MAC Motion 38, September 17, 2015, see [69]]

A STA that is polled from a Trigger frame for UL MU transmission considers the NAV in determining whether to respond unless one of the following conditions is met

- The NAV was set by a frame originating from the AP sending the trigger frame
- The response contains ACK/BA and the duration of the UL MU transmission is below a TBD threshold
- The NAV was set by a frame originating from intra-BSS STAs
- Other condition TBD

[MU Motion 15, September 17, 2015, see [70], modified with MU Motion 28, November 2015, see [71]]

The spec shall allow DL OFDMA transmission of Multi-STA Block ACK frame in response to UL MU PPDUs.
[MAC Motion 44, November 2015, see [72]]

When an AP selects rate, MCS, NSS of M-BA or OFDMA BA that acknowledges the UL OFDMA, the AP may ignore the MCS, NSS of UL OFDMA PPDU that elicits the DL acknowledgement.
The AP shall transmit the M-BA using one of rate, MCS, NSS that all of the acknowledgement receivers support.
[MAC Motion 45, November 2015, see [73]]

4.4 MU RTS/CTS procedure

The spec shall define a frame that solicits simultaneous CTS responses from multiple STAs to protect DL MU transmission. [MU Motion 6, July 16, 2015, see [74]]

The scrambler seed of a simultaneous CTS is same as the scrambler seed of the frame that triggers the simultaneous CTS. The transmission rate of a simultaneous CTS shall use the primary rate based on the rate or MCS of the frame that triggers the simultaneous CTS. [MU Motion 7, July 16, 2015, see [74]]

MU-RTS/CTS frame exchange may be used for protection of MU transmissions during that TXOP.
[MU Motion 31, November 2015, see [75]]

The CTS sent in response to a frame that solicits simultaneous CTS shall be transmitted on one or more 20 MHz channels.
[MU Motion 33, November 2015, see [75]]

MU-RTS may request STAs to send non-HT CTS immediate response.
[MU Motion 34, November 2015, see [75]]

MU-RTS will carry signaling for each STA to indicate the 20 MHz channel(s) for transmitting CTS responses when CTS is sent in (duplicate) non-HT PPDU

- When a STA sends CTS in response to MU-RTS, the CTS response shall be transmitted in the 20 MHz channel(s) indicated in MU-RTS
  - provided other transmission conditions TBD are met (e.g. channel idleness)
- The indicated 20 MHz channel(s) can be either Primary20, Primary40, Primary80 or 160/80+80 MHz. Other indications are TBD.
- Exact Signaling TBD

[MU Motion 35, November 2015, see [75]]

4.5 UL OFDMA-based random access

The spec shall define a Trigger frame that allocates resources for random access. [MU Motion 8, July 16, 2015, see [76]]

An HE AP is allowed to broadcast a TBD parameter in the trigger frame to the STAs so that STAs can initiate the random access process after the trigger frames.
[MAC Motion 41, September 17, 2015, see [77]]

When an STA has a frame to send, it initializes its OBO (OFDMA Back-off) to a random value in the range 0 to CWO (OFDMA Contention window). For an STA with non-zero OBO value, it decrements its OBO by 1 in every RU assigned to AID value TBD within the TF-R. For a STA, its OBO decrements by a value, unless OBO=0, equal to the number of RUs assigned to AID value TBD in a TF-R. OBO for any STA can only be 0 once every TF-R. A STA with OBO decremented to 0 randomly selects any one of the assigned RUs for random access and transmits its frame.
[MU Motion 27, September 17, 2015, see [78]]

The spec shall indicate cascaded sequence of Trigger frames by using a bit in the Trigger frame.
[MU Motion 21, September 17, 2015, see [79], modified with MAC Motion 50, November 2015, see [80]]

The spec shall include a mechanism that allows the Beacon frame to indicate the target transmission time(s) of one or more Trigger frame(s) that allocate resources for random access.
[MU Motion 22, September 17, 2015, see [79]]

The AP may send trigger frame to elicit buffer status report (BSR) using random access.
[MU Motion 39, November 2015, see [81]]

4.6 Sounding protocol

The amendment shall include a CSI feedback mechanism which allows for a minimum feedback granularity of less than 20 MHz.
[MU Motion 9, July 16, 2015, see [82]]

The amendment shall define a mechanism to enable multiplexing of the Compressed Beamforming Action frame (CSI feedback) from multiple stations using UL MU (MIMO or OFDMA) mode.
[MU Motion 17, September 17, 2015, see [83]]

The amendment shall define a channel sounding sequence (Figure 22) initiated by an HE AP that includes a Trigger frame that is sent SIFS after the NDP frame in order to solicit UL MU mode of Compressed Beamforming Action frame from multiple HE STAs.
[MU Motion 18, Spetember 17, 2015, see [83], modified with MU Motion 37, November 2015, see [83]]

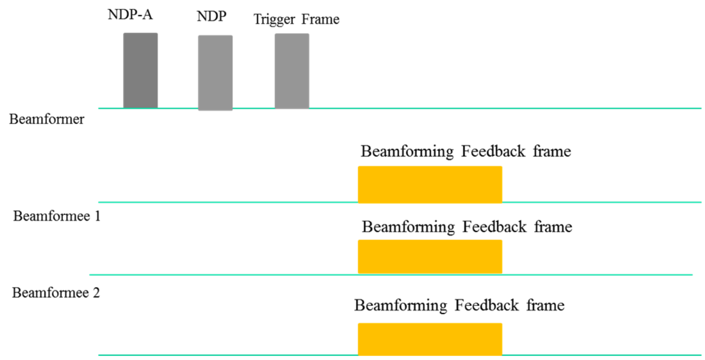

Figure 22 -- Illustration of DL Sounding Sequence

[MU Motion 20, September 17, 2015, see [84]]

The amendment shall define a mechanism to reduce the MIMO compressed beamforming feedback overhead.
[MU Motion 25, September 17, 2015, see [85]]

That mechanism shall use the compressed beamforming feedback as defined in section 8.4.1.48 in 802.11ac as a baseline.
[PHY Motion 100, November 2015]

4.7 GCR BA operation

The amendment shall include a mechanism to multiplex acknowledgment frames in response to Multicast receptions under GCR BA operation.
[MU Motion 12, September 17, 2015, see [86]]

5 Coexistence

This section describes the functional blocks that support coexistence.

5.1 Features for operation in dense environments

This section describes features that improve overlapping BSS (OBSS) operation in dense environments. This includes features such as deferral rules and CCA levels.

The STA determines whether the detected frame is an inter-BSS or an intra-BSS frame by using BSS color or MAC address in the MAC header. If the detected frame is an inter-BSS frame, under TBD condition, uses TBD OBSS PD level that is greater than the minimum receive sensitivity level
NOTE–Maybe extra rules need to be added to ensure that all 11ax STAs can make the decision in a consistent manner.
[MAC Motion 34, September 17, 2015, see [87]]

A STA should regard an Inter-BSS PPDU with a valid PHY header and that has a receive power/RSSI below the OBSS PD level used by the receiving STA and that meets additional TBD conditions, as not having been received at all (e.g., should not update its NAV), except that the medium condition shall indicate BUSY during the period of time that is taken by the receiving STA to validate that the PPDU is from an Inter-BSS, but not longer than the time indicated as the length of the PPDU payload. The OBSS PD level is greater than the minimum receive sensitivity level.
[SR Motion 1, September 17, 2015, see [88]]

The amendment shall include one or more mechanisms to improve spatial reuse by allowing adjustments to one or more of the CCA-ED, 802.11 Signal Detect CCA, OBSS_PD or TXPWR threshold values. The constraints on selecting threshold values are TBD.
[SR Motion 2, September 17, 2015, see [89]]

The specification to consider a procedure that may revise the NAV depending on TBD conditions at the recipient of the ongoing OBSS frame.
[SR Motion 3, September 17, 2015, see [90]]

An 11ax STA regards a valid OBSS PPDU as not having been received at all (e.g., should not update its NAV), except that the medium condition shall indicate BUSY during the period of time that is taken by the receiving STA to validate that the PPDU is from an Inter-BSS, but not longer than the time indicated as the length of the PPDU payload if the RXPWR of the received PPDU is below the OBSS_PD threshold and TBD conditions are met, noting that the OBSS_PD threshold is accompanied by a TXPWR value and a reduction in the TXPWR may be accompanied by an TBD increase in the OBSS_PD threshold value.
[SR Motion 4, September 17, 2015, see [91]]

An HE STA should have a mechanism to remember and distinguish NAVs set by intra-BSS frame and OBSS frame. A CF-end frame that comes from intra-BSS should not reset NAV that was set by a frame from OBSS. To determine which BSS is the origin of a frame, the HE STA may use BSS color.
[SR Motion 5, November 2015, see [92]]

6 MAC

6.1 General

This section describes general MAC functional blocks.

The amendment shall define a mechanism to allow the AP to configure the use of RTS/CTS initiated by non-AP STA.
[MAC Motion #1, January 2015, see [93]]

In 2.4 GHz HE STAs should send beacon and probe (request & response) frames at rates ≥ 5.5 Mb/s.
[MAC Motion 24, 2015, see [94]]

HE STAs shall support the Multiple BSSID Set.
[MAC Motion 28, September 17, 2015, see [95]]

When a STA receives a CF-End from an OBSS STA, if the last NAV update was caused by an Intra-BSS frame, the STA should not reset its NAV.
[MAC Motion 33, September 17, 2015, see [96]]

A STA maintains two NAVs

- One is the NAV for Intra-BSS frame, and second one is the NAV for Inter-BSS frame or frame that cannot be determined to be Intra-BSS or Inter-BSS
- Note that maintaining two NAVs does not imply maintaining two NAV timers
- The detailed method of maintaining two NAVs (e.g., two NAV timers or one NAV timer with difference of two NAV values, etc.) is TBD
- Mandatory or Optional TBD

[MU Motion 36, November 2015, see [97]]

6.2 Target Wake Time (TWT)

The spec shall include a mechanism that allows a target transmission time for a Trigger frame to be indicated. The mechanism is based on implicit TWT operation and additionally enables:

- Broadcast triggered TWT by including a TWT element in the Beacon
- Solicited triggered TWT by using implicit TWT negotiation procedure

[MAC Motion 25, July 16, 2015, see [98]]

When the broadcast triggered TWT is enabled, STA and AP may exchange TWT request/response to indicate the target Beacon frame to be monitored by the PS STA.
[MAC Motion 26, July 16, 2015, see [98]]

The TWT Flow Identifier field in the TWT IE included in the Beacon frame specifies the different types of flows allowed during the TWT SP.
[MAC Motion 48, November 2015, see [80]]

Multiple TWTs can be indicated in the TWT IE in the Beacon frame by allowing multiple TWT parameter sets in the same TWT IE.
[MAC Motion 49, November 2015, see [80]]

6.3 Power Save

An HE non-AP STA may enter the Doze state until the end of an HE DL MU PPDU if both the following conditions are true:

- The value of the PPDU's BSS Color field is equal to the BSS color of its BSS
- The value derived from any of the STA identifiers in the HE-SIG-B field does not match its own identifier or that of a broadcast/multicast identifier

An HE non-AP STA may enter the Doze state until the end of an HE UL MU PPDU if:

- The value of the PPDU's BSS Color field is equal to the BSS color of its BSS

[PHY Motion 47, September 17, 2015, see [16]]

An HE STA may enter the Doze state until the end of an HE SU PPDU if both the following conditions are true:

- The value of the PPDU's BSS Color field is equal to the BSS color of its BSS
- The value of the UL/DL Flag field indicates that the frame is UL

[PHY Motion 49, September 17, 2015, see [16]]

HE STA may use a notification of its operating mode changes for 802.11ax power saving mechanism.
[MAC Motion 30, September 17, 2015, see [99]]

The spec shall define a mechanism for a transmitting STA to indicate its RX operating mode, i.e. RX NSS, RX channel width, in a transmitted DATA type MAC header, so that the responding STA shall not transmit a subsequent PPDU using an NSS or channel width value not indicated as supported in the RX operating mode of the transmitting STA. The responding STA shall not adopt the new NSS and BW until a time TBD.
[MAC Motion 32, September 17, 2015, see [100]]

6.4 Fragmentation

The 11ax fragmentation negotiation shall allow the following fragmentation types (levels) to be indicated:

- Level 0: No support for fragments
- Level 1: Support for a fragment in a VHT single MPDU only
- Level 2: Support for up to one fragment per MSDU in an A-MPDU
- Level 3: Support for multiple fragments of an MSDU per A-MPDU

[MAC Motion 47, November 2015, see [101]]

7 Frame formats

7.1 Fields

7.1.1 HT Control field

The spec shall define an HE variant (of the VHT variant) of the HT Control field that carries one or more control fields for HE control information

- B0 and B1 of the HT Control field in this case are set to 1
- The control fields can be called HE Control field

[MAC Motion 39, September 17, 2015, see [102]]

HE link adaptation shall define reference payload size for the reported MCS in MFB. Reference payload size may be dependent on the frames involved in link adaptation or fixed in specification. Details are TBD.
[PHY Motion 77, November 2015, see [103]]

The HE link adaptation field, which is part of HE variant of HT control field, consists of MFB and TBD subfields. The MFB subfield includes NSS and MCS subfield.
[PHY Motion 78, November 2015, see [103]]

7.1.2 QoS Control field

Bits in QoS Control field		**Meaning**
Bit 5	**Bit 6**	
0	1	No explicit acknowledgment or PSMP Ack or Trigger based UL MU Ack. When bit 6 of the Frame Control field (see 8.2.4.1.3 (Type and Subtype fields)) is set to 1: … When bit 6 of the Frame Control field (see 8.2.4.1.3 (Type and Subtype fields)) is set to 0: The acknowledgment for a frame indicating PSMP Ack when it appears in a PSMP downlink transmission time (PSMP-DTT) is to be received in a later PSMP uplink transmission time (PSMP-UTT). … If the DL PPDU is HE MU PPDU, the addressed recipient returns an Ack/BA in MU format as an immediate response to a DL MU PPDU.

[MAC Motion 43, November 2015]

7.2 Frames

7.2.1 Trigger frame

The spec shall define a new control frame format that carries sufficient information to identify the STAs transmitting the UL MU PPDUs and allocating resources for the UL MU PPDUs. The format of the new frame is given in Figure 23. The presence of A1 is TBD. [MAC Motion 19, July 16, 2015, see [104]]

FC	Duration	(A1)	A2	Common Info	Per User Info 1		Per User Info N	FCS
2	2	TBD	6	TBD	TBD		TBD	4

Figure 23 - Trigger frame

Trigger frame is a new subtype of the control type as indicated in the FC B4 to B7 with the subtype not equal to 6.
[MAC Motion 53, November 2015, see [104]]

The Common Info field includes the following subfields:

- Length [12 bits]
  - Value of the L-SIG Length of the UL MU PPDU
  - A responding STA will copy this value in its L-SIG length field, hence the encoding shall be same as defined for the L-SIG Length of the UL MU PPDU
- Info bits content of the SIG-A of the response UL MU PPDU [# of bits TBD]
  - May Exclude the bits that may be implicitly already known by all responding STAs, if any TBD
- CP + HE LTF type [TBD # of bits]
- Allowed response type / trigger type [# of bits TBD]
  - Types TBD

[MAC Motion 51, November 2015, see [104]]

The Per User Info field includes the following subfields:

- MCS [4 bits]
- Coding type [# bits TBD]
- RU allocation information [# bits TBD]
- SS allocation [# bits TBD]
- DCM [1 bit]
- User identifier field [12 bits]
  - AID for STAs associated with AP; TBD for unassociated STAs

[MAC Motion 52, November 2015, see [105]]

The spec shall define optional type-specific Common Info and optional type-specific Per User Info of Trigger frame. The locations of type-specific Common Info and type-specific Per User Info are TBD.
[MAC Motion 54, November 2015, see [106]]

The MU BAR frame is a variant of Trigger frame whose Trigger Type subfield is MU BAR that carries additional BAR Control subfield (TBD) and an additional BAR Information subfield (TBD) in Common Info and/or each Per-User info.
[MU Motion 30, November 2015, see [107]]

The MAC format of MU-RTS is a variant of trigger frame format.
[MU Motion 32, November 2015, see [75]]

7.2.2 Multi-STA BA frame

The spec shall define a multi-STA BA frame by using the Multi-TID BlockAck frame format with the following changes:

- Add an indication that the frame is a multi-STA BA (TBD)
- Each BA Information field can be addressed to different STAs

- B0-B10 of the Per TID Info field carry a (Partial) AID identifying the intended receiver of the BA Information field

[MAC Motion #1, March 2015, see [108]]

The spec shall define a signaling in the Multi-STA BA frame that can indicate an ACK, as follows:

- If B11 in the per-TID info field is set, then the BlockAck bitmap and the SC subfields in the BA Info field are not present and this BA Info field indicates an ACK of either single MPDU or all MPDUs carried in the eliciting PPDU that was transmitted by the STA whose AID is indicated in the per-TID info field. [Modifed with MAC Motion #8, May 2015, see [109]]

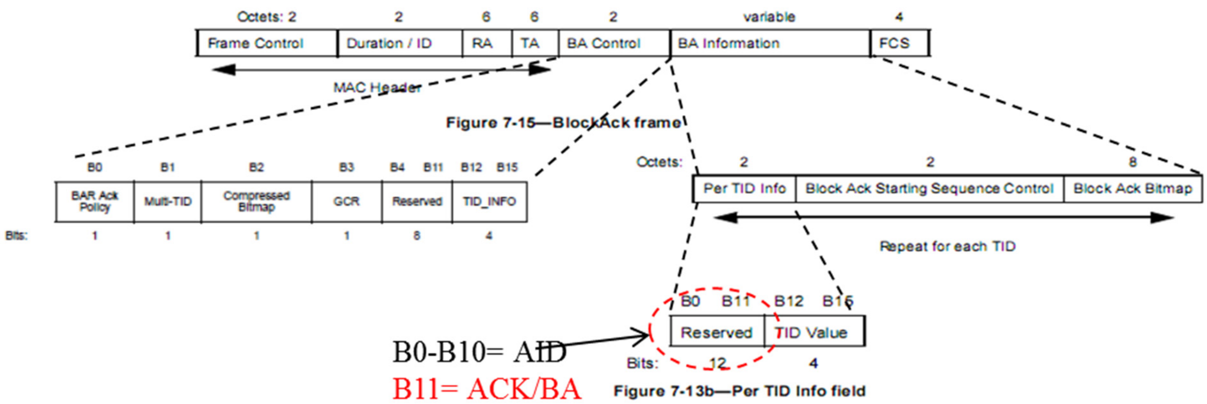

Figure 24 - Multi-STA BA frame

[MAC Motion #2, March 2015, see [108]]

7.2.3 MU-BAR frame

The spec shall define a MU-BAR frame to solicit BA/ACKs from multiple STAs in UL MU transmissions.

[MU Motion 13, September 17, 2015, see [110]]

7.3 Sounding feedback

802.11ax spec shall not support *Ng* = *1* for sounding feedback.

NOTE—The tone grouping factor, Ng is defined with respect to data tones of the HE PPDU.

[PHY Motion 38, September 17, 2015, see [111]]

8 References

[1] Robert Stacey (Intel), "14/1453r2 Spec Framework Proposal".

[2] Jiayin Zhang (Huawei), "15/0101r1 Preamble structure for 11ax system".

[3] Hongyuan Zhang (Marvell), "15/0579r3 Preamble Design and Autodetection".

[4] Jiayin Zhang (Huawei), "15/0832r1 Performance evaluation of SU/MU MIMO in OFDMA".

[5] Yakun Sun (Marvell), "15/1350r1 Spatial Configuration And Signaling".

[6] Ron Porat (Broadcom), "15/1353r1 Preamble Formats".

[7] Young Hoon Kwon (Newracom), "15/1051r1 HE NDP frame for sounding".

[8] Jianhan Liu (Mediatek Inc.), Yakun Sun (Marvell), "15/1322r0 Channel Estimation Enhancement and Transmission Efficiency Improvement Using Beam-Change Indication and 1x HE-LTF".

[9] Xiaogang Chen (Intel), "15/1357r1 Extra tones in the preamble".

[10] Hongyuan Zhang (Marvell), "15/1305 STBC and Padding Discussions".

[11] Sameer Vermani (Qualcomm), “15/1309r1 Extended Range Support for 11ax”.
[12] Hongyuan Zhang (Marvell), “15/0579r4 Preamble Design and Autodetection”.
[13] Jianhan Liu (Mediatek Inc.), “15/0822r2 SIG-A Structure in 11ax Preamble”.
[14] Jiayin Zhang (Huawei), “15/1077r0 HE-SIG-A Content”.
[15] Dongguk Lim (LG), “15/1324r0 MCS for HE-SIG-B”.
[16] Alfred Asterjadhi (Qualcomm Inc.), “15/1122r0 Identifiers in HE PPDUs for power saving”.
[17] Jianhan Liu (Mediatek), “15/1068r1 Reliable Transmission Schemes for HE-SIG-B and Data”.
[18] Yingpei Lin (Huawei), “15/1355r0 Considerations for TDLS transmission in 11ax”.
[19] Ron Porat (Broadcom), “15/1354r1 SIGA fields and Bitwidths”.
[20] Kaushik Josiam (Samsung), “15/1315r1 HE-SIG-B Mapping and Compression”.
[21] Jiayin Zhang (Huawei), “15/0826r3 HE-SIG-A transmission for range extension”.
[22] Young Hoon Kwon (Newracom), “15/0344r2 SIG Field Design Principle for 11ax”.
[23] Ron Porat, “15/0873r0 SIG-B Encoding Structure”.
[24] Joonsuk Kim (Apple), “15/0821r2 HE SIG-B Structure”.
[25] Katsuo Yunoki (KDDI R&D Laboratories), “15/0827r2 Considerations on HE-SIG-A and B”.
[26] Ron Porat (Broadcom), “15/1059r1 SIG-B Encoding Structure Part II”.
[27] Ron Porat (Broadcom), “15/1059r2 SIG-B Encoding Structure Part II”.
[28] Kaushik Josiam (Samsung), “15/1066r0 HE-SIG-B Contents”.
[29] Le Liu (Huawei), “15/1335r2 HE-SIG-B Contents”.
[30] Liwen Chu (Marvell), “15/1352r0 broadcast STAID in HE SIG B”.
[31] Le Liu (Huawei), “15/1334r1 HE-LTF Sequence Design”.
[32] Yakun Sun (Marvell), “15/0381r1 HE-STF Proposal”.
[33] Eunsung Park (LG Electronics), “15/1323r1 HE-STF Sequences”.
[34] Hongyuan Zhang (Marvell), “15/0349r2 HE-LTF Proposal”.
[35] Yakun Sun (Marvell), “15/0817r0 P Matrix for HE-LTF”.
[36] Bin Tian (Qualcomm), “15/0819r1 11ax OFDMA Tone Plan Leftover Tones and Pilot Structure”.
[37] Xiaogang Chen (Intel), “15/0602r6 HE-LTF squence for UL MU-MIMO”.
[38] Sriram Venkateswaran (Broadcom), “15/0099r4 Payload Symbol Size for 11ax”.
[39] Sameer Vermani (Qualcomm), “15/0812r1 Pilot Design for Data Section”.
[40] Shahrnaz Azizi (Intel), “15/0330r5 OFDMA Numerology and Structure”.
[41] Bin Tian (Qualcomm), “15/1310r0 11ax LDPC Tone Mapper for 160MHz”.
[42] Hongyuan Zhang (Marvell), “15/0580r1 11ax coding discussion”.
[43] Hongyuan Zhang (Marvell), “15/0580r2 11ax coding discussion”.
[44] Eunsung Park (LG Electronics), “15/1070r3 1024 QAM Proposal”.
[45] Hongyuan Zhang (Marvell), “15/0810r1 HE PHY Padding and Packet Extension”.
[46] Bin Tian (Qualcomm), “15/1311r0 11ax Sppectral Masks”.
[47] David Xun Yang (Huawei), “15/0841r0 Cascading Structure”.
[48] Simone Merlin (Qualcomm), “15/0876r1 Duration and MAC Padding for MU PPDUs”.
[49] Jinsoo Ahn (Yonsei Univ.), “15/1116r1 Trigger Frame Channel Access”.
[50] Kiseon Ryu (LG Electronics), “15/1058r0 CCA consideration for UL MU transmission”.
[51] Chao-Chun Wang (Mediatek), “15/1065r1 11ax uplink Multi-TID aggregation”.
[52] Chittabrata Ghosh (Intel), “15/1102r0 Fragmentation with MU Operation”.
[53] Reza Hedayat (Newracom), “15/0379r1 DL OFDMA Performance and ACK Multiplexing”.

[54] Reza Hedayat (Newracom), “15/0829r3 Uplink ACK and BA Multiplexing”.
[55] Liwen Chu (Marvell), “15/0831r2 Broadcast and Unicast in DL MU”.
[56] Liwen Chu (Marvell), “15/1123r1 acknowledgement to DL MU”.
[57] Yongho Seok (NEWRACOM), “15/1033r0 Data field in HE PPDU”.
[58] Yujin Noh (Newracom), “15/1328r1 Scheduling information for UL OFDMA Acknowledgement”.
[59] Chittabrata Ghosh (Intel), “15/1364r0 Signaling Trigger Information for STAs in 11ax”.
[60] Yongho Seok (NEWRACOM), “15/1278r1 HE MU Acknowledgment Procedure”.
[61] Kiseon Ryu (LG Electronics), “15/1346r2 Ack Policy for UL MU Ack transmission”.
[62] Young Hoon Kwon (Newracom), “15/1300r0 DL MU transmission sequence”.
[63] Zhigang Rong (Huawei), “15/0813r0 CP Indication for UL MU Transmission”.
[64] Kaiying Lv (ZTE Corp.), “15/1389r0 TA Address Field in Trigger Frame”.
[65] Liwen Chu (Marvell), “15/0615r3 UL OFDMA Bandwidth”.
[66] Tomoko Adachi (Toshiba), “15/0064r1 Consideration on UL-MU overheads”.
[67] Liwen Chu (Marvell), “15/0615r2 UL OFDMA Bandwidth”.
[68] Young Hoon Kwon (Newracom), “15/1052r0 Bandwidth for UL MU transmission”.
[69] Alfred Asterjadhi (Qualcomm Inc.), “15/1120r0 Buffer Status Report”.
[70] Po-Kai Huang (Intel), “15/1062r1 NAV Consideration for UL MU Response to Trigger frame”.
[71] Yingpei Lin (Huawei), “15/1301r1 NAV Rule for UL MU Response”.
[72] Jeongki Kim (LG Electronics), “15/1330r0 A method of transmitting Multi-STA Block frame”.
[73] Liwen Chu (Marvell), “15/1351r0 Rate MCS Selection Rules for M-BA and DL OFDMA BA”.
[74] Po-Kai Huang (Intel), “15/0867r1 MU-RTS/CTS for DL MU”.
[75] Po-Kai Huang (Intel), “15/1325r0 MU-RTS/CTS Follow Up”.
[76] Chittabrata Ghosh (Intel), “15/0875r1 Random Access with Trigger Frames using OFDMA”.
[77] Russell Huang (MediaTek), “15/1137r1 Triggered OFDMA Random Access Observations”.
[78] Chittabrata Ghosh (Intel), “15/1105r0 UL OFDMA-based Random Access Procedure”.
[79] Chittabrata Ghosh (Intel), “15/1107r0 Power Save with Random Access”.
[80] Alfred Asterjadhi (Qualcomm Inc.), “15/1319r0 Scheduled Trigger frames-Follow up”.
[81] Woojin Ahn (Yonsei Univ.), “15/1369r1 Random access based buffer status report”.
[82] Kome Oteri (InterDigital), “15/0818r1 Further Analysis of Feedback and Frequency Selective Scheduling (FSS) for TGax OFDMA”.
[83] Narendar Madhavan (Toshiba), “15/1097r1 Reducing Channel Sounding Protocol Overhead for 11ax”.
[84] Chittabrata Ghosh (Intel), “15/1103r0 DL Sounding Sequence with UL MU Feedback”.
[85] Filippo Tosato (Toshiba), “15/1129r1 Feedback overhead in DL-MU-MIMO”.
[86] Kazuyuki Sakoda (Sony Electronics), “15/1043r1 Overall Protocol of UL MU BA for Multicast Transmission”.
[87] Chao-Chun Wang (MediaTek), “15/1063r1 11ax Channel access procedure”.
[88] Rossi Jun Luo(Huawei), “15/1109r1 OBSS NAV and PD Threshold Rule for Spatial Reuse”.
[89] Filip Mestanov (Ericsson), “15/1138r1 To DSC or not to DSC”.
[90] Reza Hedayat (Newracom), “15/1104r3 TXOP Considerations for Spatial Reuse”.
[91] James Wang (Mediatek), “15/1069r3 Adaptive CCA and TPC”.
[92] Sigurd Schelstraete (Quantenna), “15/1348r0 Multiple NAVs for Spatial Reuse”.
[93] Sigurd Schelstraete (Quantenna), “15/0059r1 Uplink RTS/CTS Control”.

[94] Guido R. Hiertz (Ericsson), "15/0874r0 Minimal data rates management frame transmissions in 2.4 GHz".

[95] Guido R. Hiertz (Ericsson), "15/1014r0 Multiple BSSID element".

[96] Jeongki Kim (LG Electronics), "15/1067r0 MU TXOP truncation".

[97] Po-Kai Huang (Intel), "15/1326r2 NAV Consideration for UL MU Response Follow Up".

[98] Alfred Asterjadhi (Qualcomm Inc.), "15/0880r2 Scheduled Trigger frames".

[99] Yongho Seok (NEWRACOM), "15/1034r0 Notification of Operating Mode Changes".

[100] Eric Wong (Apple), "15/1060r0 Receive Operating Mode Indication for Power Save".

[101] Alfred Asterjadhi (Qualcomm Inc.), "15/1318r0 Fragmentation for MU frames-Follow up".

[102] Alfred Asterjadhi (Qualcomm Inc.), "15/1121r0 HE A-Control field".

[103] Yujin Noh (Newracom), "15/1329r1 Link Adaptation for HE WLAN".

[104] Simone Merlin (Qualcomm), "15/0877r0 Trigger Frame Format".

[105] Simone Merlin (Qualcomm), "15/1344r1 Trigger Frame Content".

[106] Kiseon Ryu (LG Electronics), "15/1345r1 Trigger type specific information".

[107] Reza Hedayat (Newracom), "15/1312r2 MU BAR Frame Format".

[108] Simone Merlin (Qualcomm), "15/0366r2 Multi-STA BA".

[109] Jeongki Kim (LG Electronics), "15/0626r1 Further consideration on Multi-STA Block ACK".

[110] Guoqing Li (Apple), "15/1053r1 Multiuser Block ACK Request (MU-BAR)".

[111] Sameer Vermani (Qualcomm), "15/1071r2 Tone Grouping Factors and NDP format for 802.11ax".

[112] Narendar Madhavan (Toshiba), "15/1340r2 NDP Announcement for HE Sequence".