Methods for efficient signaling and addressing in wireless local area network systems

The following documents and standards descriptions are hereby incorporated into the present disclosure as if fully set forth herein:

IEEE 802.11ac specifications define very high throughput (VHT) transmissions from AP to a single STA using single user MIMO (SU-MIMO) and to multiple STAs using multi-user MIMO (MU-MIMO). The data packet transmitted is called a VHT physical layer convergence procedure (PLCP) protocol data unit (PPDU). A special PPDU called the MU PPDU contains the data streams meant for multiple STAs transmitted using MU-MIMO. When SU-MIMO is used, the packet is called SU PPDU. The header to both SU and MU PPDUs contains information necessary to decode the PPDU. Since the same header has to indicate different types of payload (in addition to SU and MU-MIMO, there are other types of packets) to the receiver's physical layer, signaling fields in the header have multiple interpretations depending on certain flags that are transmitted along with the signaling fields.

The basic structure of the header of a PPDU is shown in the Figure below. The header consists of training fields and packet type indication. The header consists of legacy short training field (L-STF), legacy long training field (L-LTF), legacy – signal field (L-SIG), VHT signal A (VHT-SIG-A), VHT short and long training symbols and VHT signal B (VHT-SIG-B) fields. The fields with prefix legacy are meant to indicate the packet type and duration to the non-VHT legacy users who may stop further processing of the PPDU after decoding the legacy header. The VHT portion of the preamble consists of the VHT SIG-A, VHT STF, VHT-LTF and VHT-SIG-B fields. This invention disclosure focuses on the modifications to the VHT preamble to support orthogonal frequency division multiple access (OFDMA) that will allow multiplexing of multiple users on different portions of the bandwidth. In particular, we will focus on VHT-SIG-A and VHT-SIG-B fields that carry information required to interpret the VHT-PPDUs. The different embodiments of this disclosure of invention cover the modifications necessary to support indication of bandwidth segments to different STAs in an OFDMA multiplexing protocol.

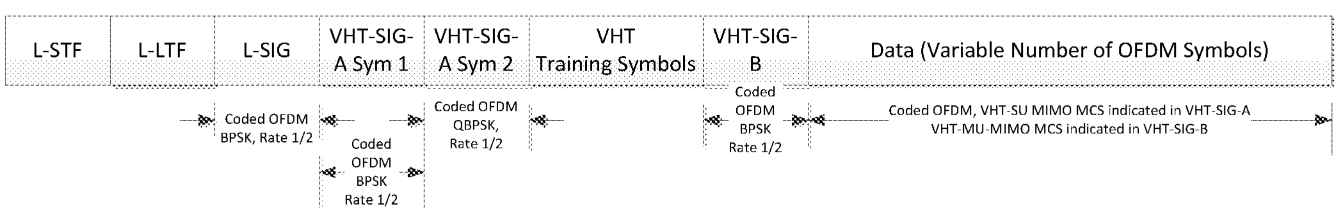


Figure 1 Header structure for VHT PPDU transmission

A brief review of VHT-SIG-A and VHT-SIG-B fields as specified in 802.11ac protocol follows: VHT-SIG-A consists of two parts; the first part is called VHT-SIG-A1 and a second part called VHT-SIG-A2. The structures of VHT SIG-A1 and VHT-SIG-A2 are shown in Figure 2 and Figure 3, respectively. Note that the mapping of the STBC field, the SU VHT-MCS/MU[1-3] coding field and the beamformed field is different for VHT-SU and MU PPDUs. The SU and MU PPDUs are differentiated based on the 6 bit GROUP_ID field carried at bit positions B4-B9: A value of 0 or 63 indicates a VHT SU PPDU; otherwise, indicates a VHT MU PPDU. For each user in MU PPDU, the number of spatial streams are indicated using 3 bits NSTS field where a value of 000 indicates that no spatial streams are transmitted for that user. The VHT-SIG-A field is transmitted at ½ code rate using BPSK modulation and occupies two consecutive OFDM signals.

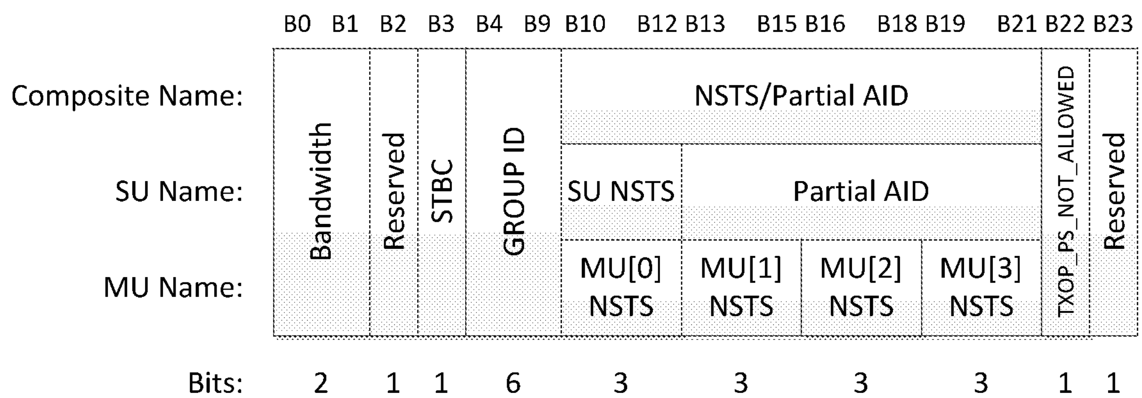


Figure 2 VHT-SIG-A1 Structure

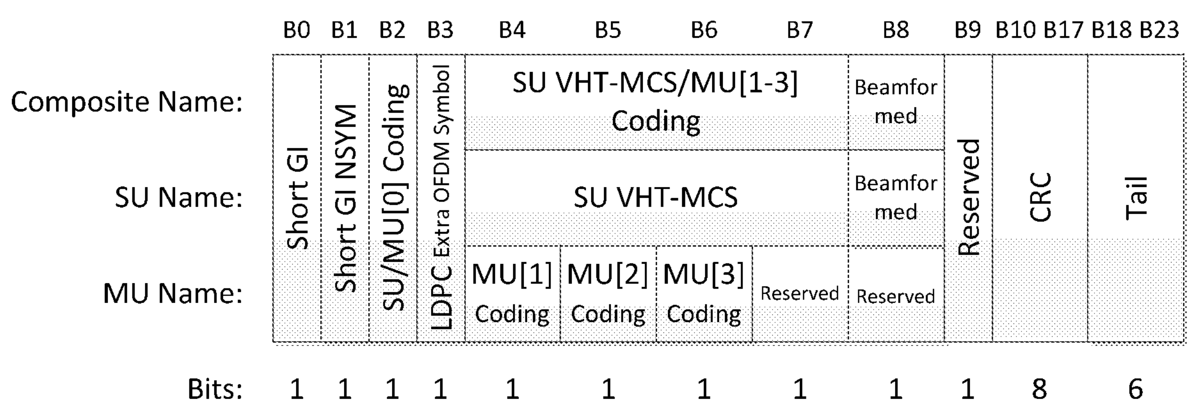


Figure 3 VHT-SIG-A2 Structure

The VHT-SIG-B field is one symbol and contains 26 bits in a 20MHz PPDU, 27 bits in a 40MHz PPDU and 29 bits in 80MHz, 160MHz and 80+80MHz PPDUs for each user. The fields in the VHT-SIG-B field are listed in Table I. The interpretation of the fields for MU or SU PPDU is drawn from the 6 bit GROUP_ID field carried at bit positions B4-B9 in VHT-SIG-A1: A value of 0 or 63 indicates a VHT SU PPDU; otherwise, indicates a VHT MU PPDU. VHT-SIG_B Length field for user u shall be set as $\left\lceil\frac{APEP-LENGTH_u}{4}\right\rceil$ where $APEP-LENGTH_u$ is the TXVECTOR parameter for APEP_LENGTH for user u. For each user u, the VHT-SIG-B field shall be BCC encoded at rate R = ½ and mapped to a BPSK constellation. Unlike VHT-SIG-A which is a commonly signaled for all users, VHT-SIG-B is user-specific and is mapped to $N_{STS,u}$ space-time streams by the user-specific elements of the first column of the P_{VHTLTF} matrix.

Table I Fields in VHG-SIG-B field

Field	VHT MU PPDU Allocation (bits)			VHT SU PPDU Allocation (bits)			Description
	20MHz	40MHz	80MHz 160MHz 80+80 MHz	20MHz	40MHz	80MHz 160MHz 80+80MHz	
VHT-SIG-B length	B0-B15 (16)	B0-B16 (17)	B0-B18 (19)	B0-B16 (17)	B0-B18 (19)	B0-B20 (21)	Length of A-MPDU pre-EOF padding in unit of four octets
VHT-MCS	B16-B19 (4)	B17-B20 (4)	B19-B22 (4)	N/A	N/A	N/A	
Reserved	N/A	N/A	N/A	B17-B19 (3)	B19-B20 (2)	B22-B22 (2)	All ones
Tail	B20-B25 (6)	B21-B26 (6)	B23-B28 (6)	B20-B25 (6)	B21-B26 (6)	B23-B28 (6)	All zeros
Total # of bits	26	27	29	26	27	29	

The GROUP_ID is indicated to an STA by the AP along with the user position of a STA for one of more group IDs. It is a managmement frame transmitted only to VHT STAs. It consists of two fields: Membership Status Array Field of length 8 octets (shown in Figure 4) and user position array field of length 16 octets (shown in Figure 5).

Within the 8 octet membership status array field, the 1-bit membership status sub-field for each group ID is set as follows

- Set to 0 if STA is not a member of the group
- Set to 1 if STA is a member of the group

The Membership Status subfields for group ID 0 (transmissions to AP) and group ID 62 (downlink SU transmissions) are reserved.

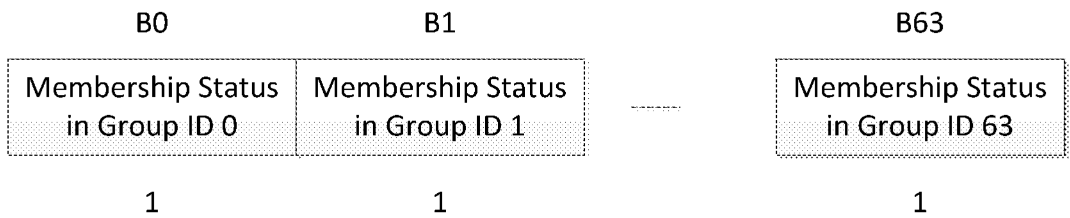


Figure 4 Membership Status Array field

User position array field is used in the Group ID Management frame. A 16 octet user position array field (indexed by the group ID) consists of a 2-bit User positon subfield for each of the 64 group IDs. If the membership subfield for a particular group ID is 1, then the corresponding user position subfield is encoded as shown in the Table II.

Table II Encoding of user position subfield

User Position subfield value	User Position
00	0
01	1
10	2
11	3

If the membership status subfield for a group ID is 0 (meaning the STA is not a member of the group), then the corresponding user position subfield in the user position array field is reserved. The user position subfields for for group ID 0 (transmissions to AP) and group ID 62 (downlink SU transmissions) are reserved.

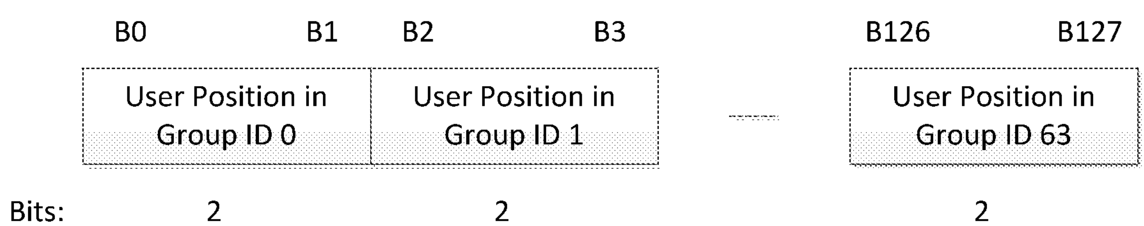


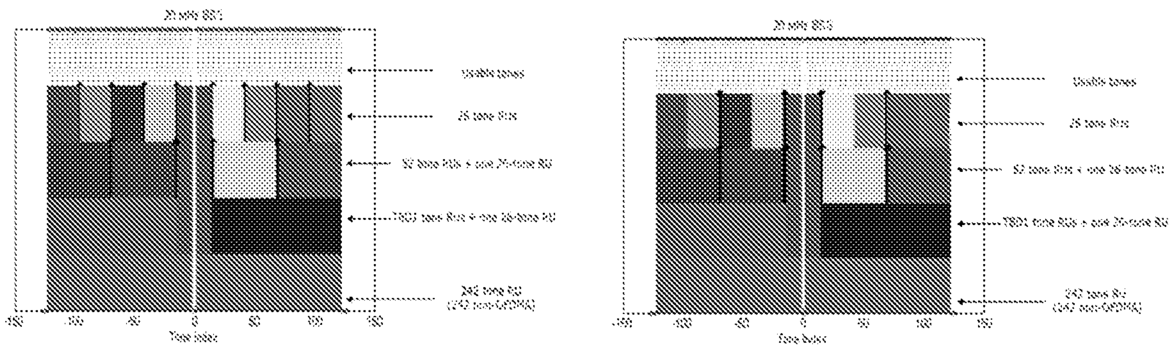
Figure 5 User Position Array Field

The OFDMA structure for 802.11ax consists of the following building blocks:

1. 26-tone RU consisting of 24 data tones and 2 pilot tones as defined for the S1G 1 MHz mode in 802.11ah
   - Possible locations of the 26-tone RUs are fixed as shown in Figure 6, Figure 7 and Figure 8 for 20 MHz, 40 MHz and 80 MHz OFDMA PPDUs, respectively.
2. 52-tone RU consisting of 48 data tones and 4 pilot tones as defined in 802.11a
   - Possible locations of the 52-tone RUs are fixed as shown in Figure 6, Figure 7 and Figure 8 for 20 MHz, 40 MHz and 80 MHz OFDMA PPDUs, respectively.
3. *TBD1*-tone RU consisting of 102 data tones and *TBD2* pilot tones
   - A single value to be chosen for *TBD2*, within the range of 4~6 (inclusive)
   - *TBD1* = 102 + *TBD2*
   - Interleaver parameter following that of VHT 40 MHz mode in 802.11ac, except that Ncol = 17
   - Possible locations of the TBD1-tone RUs are fixed as shown in Figure 6, Figure 7 and Figure 8 for 20 MHz, 40 MHz and 80 MHz OFDMA PPDUs, respectively.
4. 242-tone RU consisting of 234 data tones and 8 pilot tones as defined for the VHT 80 MHz mode in 802.11ac
   - Possible locations of the 242-tone RUs are fixed as shown in Figure 7 and Figure 8 for 40 MHz and 80 MHz OFDMA PPDUs, respectively
5. 484-tone RU consisting of 468 data tones and 16 pilot tones as defined for the VHT 160 MHz mode in 802.11ac
   - Possible locations of the 484-tone RUs are fixed as shown in Figure 8 for 80 MHz OFDMA PPDUs.

NOTE 1–Possible RU locations in a 40 MHz OFDMA PPDU is equivalent to two replicas of the possible RU locations in a 20 MHz OFDMA PPDU.

NOTE 2–Possible RU locations in an 80 MHz OFDMA PPDU is equivalent to two replicas of the possible RU locations in a 40 MHz OFDMA PPDU.



Exact location of leftover tones when using 26, 52 or *TBD1*-tone RUs within a 242 tone unit is TBD.

Figure 6 - Possible RU locations in a 20 MHz OFDMA PPDU

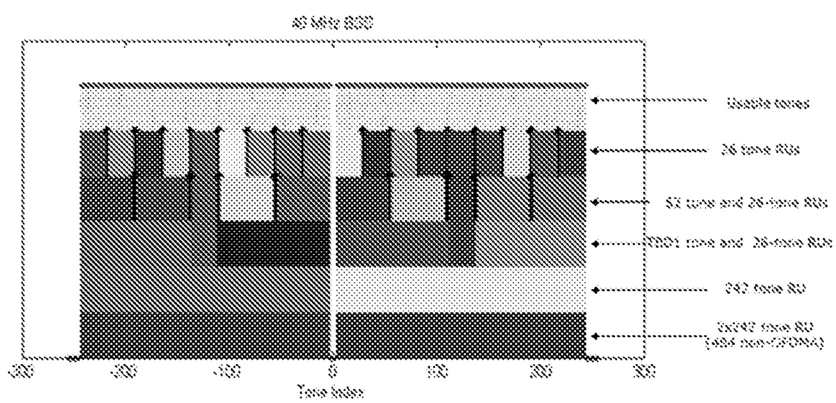


Figure 7 - Possible RU locations in a 40 MHz OFDMA PPDU

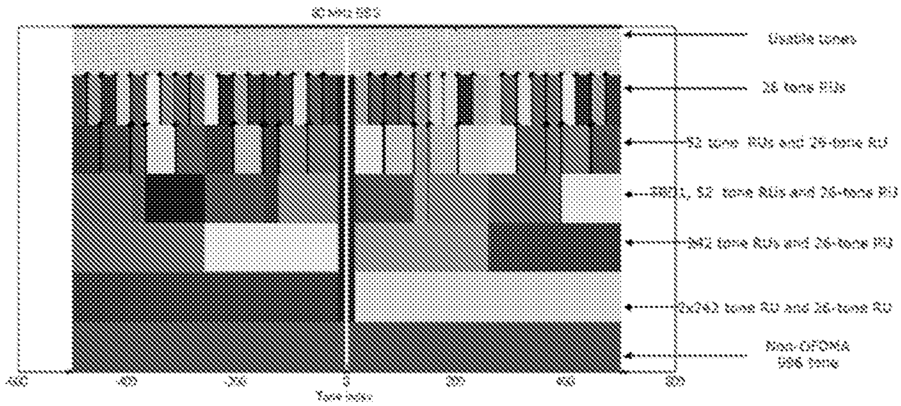


Figure 8 - Possible RU locations in an 80 MHz OFDMA PPDU

An OFDMA PPDU can carry a mix of different resource unit sizes within each 242 resource unit boundary.

This invention disclosure covers resource unit arrangement and signaling in HE-SIG-B fields of the PHY preamble. Specifically, we cover the following:

- RU arrangement indexing
- HE-SIG-B multiplexing
- Derivation of extended group ID by concatenation and user position update.
- Number of allocations implicit by use of extended group ID

A description of example embodiments is provided on the follow pages.

The text and figures are provided solely as examples to aid the reader in understanding the invention. They are not intended and are not to be construed as limiting the scope of this invention in any manner. Although certain embodiments and examples have been provided, it will be apparent to those skilled in the art based on the disclosures herein that changes in the embodiments and examples shown may be made without departing from the scope of this invention.

This invention covers the methods and apparatus required to enable signaling of orthogonal frequency division multiple access (OFDMA) and multi-user MIMO (MU-MIMO) allocations to different users addressed in a packet based wireless systems like IEEE 802.11.

The invention shows methods of enabling OFDMA and MU-MIMO in a packet in the latest version of the IEEE 802.11 standard known as 11ax currently under development. The flexibility in signaling and the acceptable overhead play a key role in determining efficient signaling mechanism for multi-user packets. We adapt and modify some legacy signaling elements to support OFDMA and MU-MIMO together in one DL MU packet.

RU arrangement indexing

In an embodiment of the current invention, an index of RU arrangement is transmitted in the HE-SIG. A combination of RUs, made up of different RU sizes, that cumulatively span the BW indicated is called an RU arrangement. For example, 9 RUs made up of 26 tones per RU arranged at locations indicated in Figure 1 is a combination and spans 20MHz. An RU arrangement also encodes positional information – i.e., in a 20MHz PPDU [52 26 26 26 26 26 26 26] arrangement is different from [26 26 52 26 26 26 26 26] arrangement. The different RU arrangements can be indexed and the index of an arrangement is signaled in the common duplicated portion of SIG-B. Using this index, the frequency domain arrangement of the RUs are indicated to the STAs receiving the packet. This indexing- RU arrangement indexing can save significant overhead compared to methods like bitmap based signaling of RU arrangement. For 20MHz bandwidth, there are a total of 25 different RU arrangements possible, each of which span the bandwidth as shown in Figure 9. Therefore, a total of 5 bits would be required to index all RU arrangements for 20MHz bandwidth. An index of 0 or 1(depending on where the index starts) can indicate that all the RUs are made of 26 tone tone RUs.

Arrangement Index	#1	#2	#3	#4	#5	#6	#7	#8	#9
1	26	26	26	26	26	26	26	26	26
2	52		26	26	26	26	26	26	26
3	26	26	52		26	26	26	26	26
4	26	26	26	26	26	52		26	26
5	26	26	26	26	26	26	26	52	
6	52		52		26	26	26	26	26
7	52		26	26	26	52		26	26
8	52		26	26	26	26	26	52	
9	26	26	52		26	52		26	26
10	26	26	52		26	26	26	52	
11	26	26	26	26	26	52		52	
12	102				26	26	26	26	26
13	26	26	26	26	26	102			
14	102				26	52		26	26
15	102				26	26	26	52	
16	102				26	52		52	
17	52		26	26	26	102			
18	26	26	52		26	102			
19	52		52		26	102			
20	102				26	102			
21	52		52		26	52		26	26
22	52		52		26	52		52	
23	52		52		26	26	26	52	
24	52		26	26	26	52		52	
25	26	26	52		26	52		52	

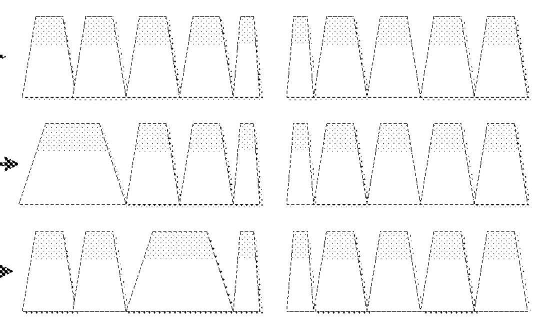


Figure 9 RU arrangement indexing for 20MHz BW

HE-SIG-B fields and their derivations

In an embodiment of the current invention, the user allocation for both single and multi-user PPDUs are indicated in HE-SIG-B fields. The allocation information for single-user MIMO PPDUs consists of an binary convolution code component that is duplicated every 20MHz over the bandwidth indicated in SIG-A. The allocation information for multi-user information consists of two parts:

1. a first part containing N_rua(BW) bit resource unit arrangement index indicating the resource unit arrangement in the frequency domain, the N_sta bit number of STAs signaled in the allocation and a list of N bits STA-IDs along with 1 bit SU/MU allocation per STA. Totally there will be N_rua(BW) + N_sta(N + 2) bits indicated in the first part. The 1 bit SU/MU allocation indicates if the STA is part of a MU allocation over the RU or not. The ordering of the STAs determines the user position in the MU allocation.
    a. A reserve STA-ID can indicate no allocation over a particular resource unit. For example, STA-ID 0 can indicate that the resource unit is left empty and no data is carried over the resource unit.
    b. The common part can be specific for each 20MHz segment and different among each 20MHz segments over which data is transmitted.
2. A second part containing user-specific information carried in the 20MHz segment in which the users data is transmitted. Each 20MHz segment contains an arrangement of RUs the largest of which is a 242 resource unit allocation. All allocations that fall with-in this 242 resource unit is carried in 20MHz channel whose center frequency is closest to the allocation. This per 20MHz indication carries STA specific information like STBC, Beamformed, LDPC coding, LDPC extra symbol, Number of spatial streams, MCS of the allocation. This information can be individually encoded with a CRC. Another option would be to jointly encode the information of all STAs scheduled in the 20MHz segment using a blind convolutional code. Since the STAIDs are indicated in the common portion, the information is arranged according to the order in which STAs are listed in the common portion of the signaling.
    a. Users scheduled as part of an MU-MIMO allocation can have different information content than a single user allocation. For example, MCS of the MU-MIMO information can be the same for all users – and the MCS field can be common for users scheduled in MU-MIMO.
    b. When users are scheduled using MU-MIMO over the entire BW, the user specific information portion is common in all 20MHz segments and is duplicated. The STAs scheduled in such an MU-MIMO allocation can derive the information from the RU arrangement index and SU/MU bit indicator in the HE-SIG-A. Another way for the STAs to derive this information is with a 2 bit SU/MU indicator where a particular 2 bit index indicates MU-MIMO over the entire bandwidth.
    c. Scheduling information for users scheduled in the center 26 tone resource unit of a 80MHz allocation or allocations greater than 20MHz can be carried
        i. As the last allocation information in the 20MHz whose subcarrier index precedes the first subcarrier index of the center 26 tone resource unit.
        ii. As the first allocation information in the 20MHz segment whose subcarrier index is greater than the first subcarrier index of the center 26 tone resource unit
        iii. Duplicated in the 20MHz segments that encase the central 26 tone allocation.

    The order of the STA-ID indicated in the common portion is maintained when carrying information for the center 26 tone resource unit when carried using any of the above 3 methods.

The above described HE-SIG-B is illustrated for a 80MHz OFDMA allocation in Figure 10.

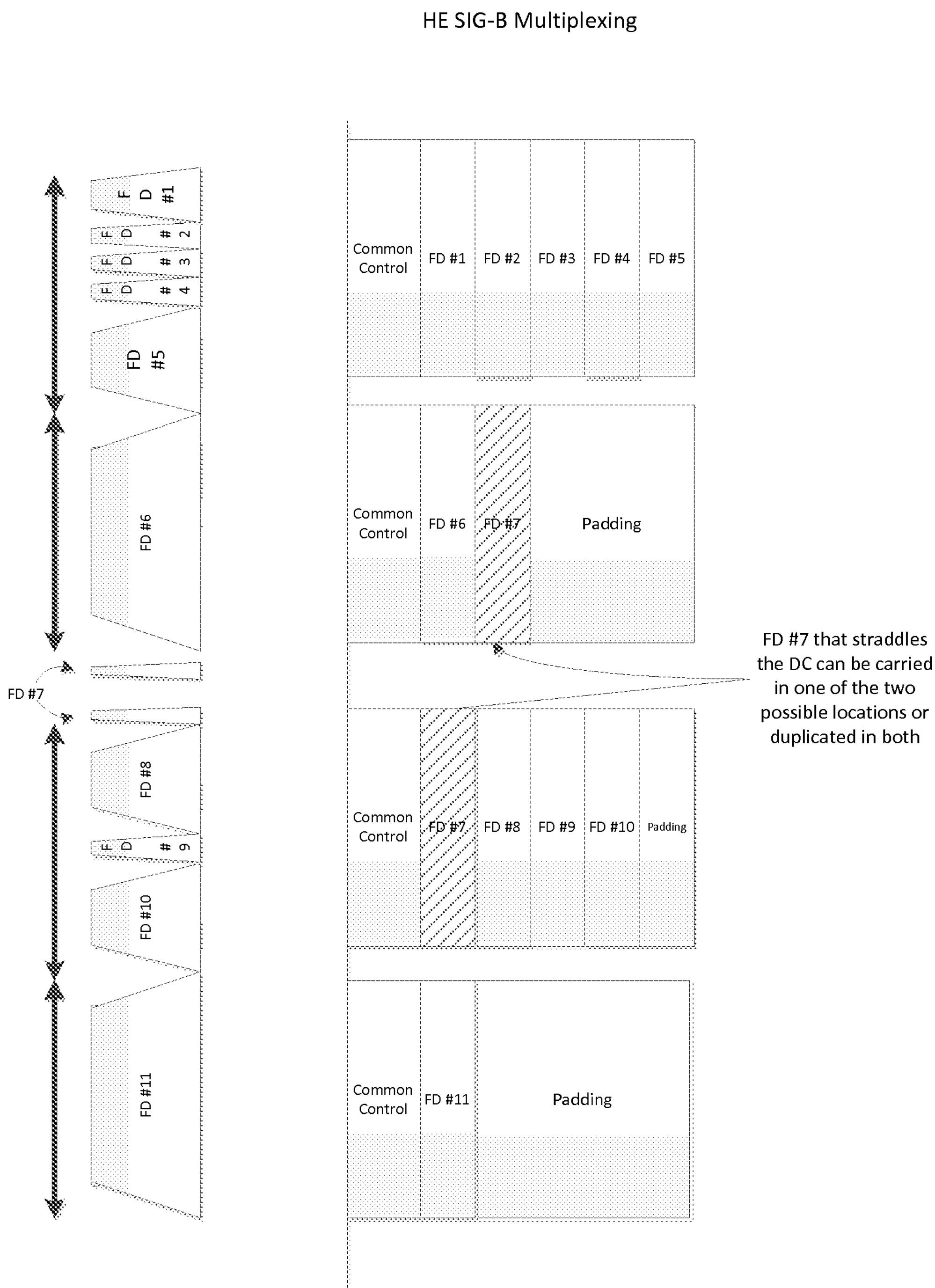


Figure 10 HE-SIG-B contents containing common signaling part that is duplicated per 20MHz and per 20MHz signaling containing relevant decoding information for STAs scheduled in the RUs under that 20MHz.

In an embodiment of the current invention, the user allocation for multi-user PPDUs are indicated in HE-SIG-B fields. The allocation information for multi-user information consists of two parts – a common part indicating the allocation index and other common fields as described in the preceding embodiment and a per 20MHz signaling part with fields carried as described in the preceding embodiment. The allocation information for a single user PPDU is carried in the HE-SIG-A.

In an embodiment of the current invention, the per 20MHz HE-SIG-B carry signaling information and the user data indicated by the signaling information are carried in the same 20MHz frequency channels as shown in Figure 11.

In an embodiment of the current invention, the MCS used for the common and user specific fields of HE-SIG-B in each 20MHz segment can be different. The MCS for the HE-SIG-B can be signaled in one of two ways:

1. The MCS for each 20MHz segment is indicated in HE-SIG-A.
2. The MCS for each 20MHz segment is carried in a section of the HE-SIG-B common fields. This section of the HE-SIG-B common fields can indicate the resource allocation and the MCS for the remaining allocation information and is encoded separately with a fixed MCS.

In an embodiment of the current invention, the common and user specific portions of the allocations per 20MHz can be encoded together using blind convolutional code. The STAs decode each HE-SIG-B in each 20MHz segment to identify which section carries information for them.

In an embodiment of the current invention, the common portion consisting of user allocation and STA-IDs can be encoded separately per 20MHz segment from the user specific portion. The user specific portion is encoded in a separate convolution code.

In an embodiment of the current invention, the 26 tone RU split around the DC tones may be left unused in an 80MHz MU PPDU.

In an embodiment of the current invention, the resource allocation for the 26tone RU split around the DC tones of a 80MHz MU PPDU may be indicated by an extra bit in either of the 20MHz segments or duplicated in both 20MHz segments surrounding the DC tones. The presence of the extra bit is triggered by the bandwidth signaling when set to 80MHz. The extra bit comes immediately preceding the 5 bit resource unit arrangement indication for the 20MHz segment. The STA ID and user specific portion also follow the same order of indication as the resource unit arrangement indication.

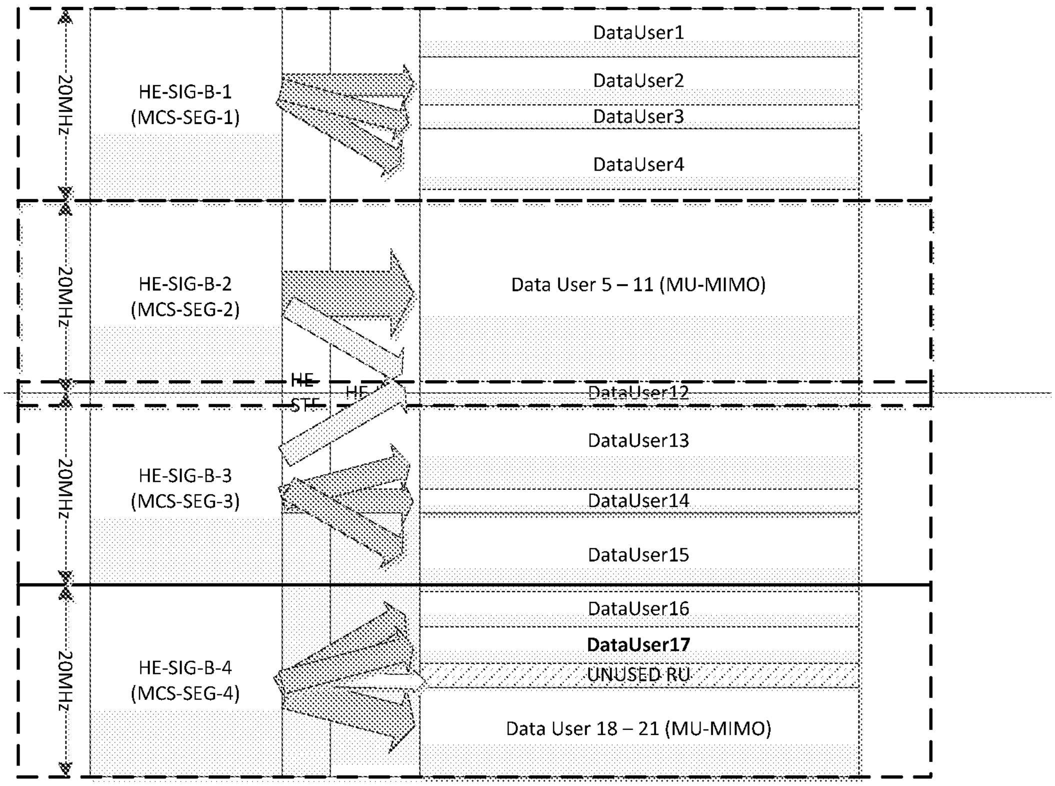


Figure 11 The signaling in HE-SIG-B and its relation to the user data - the signaling and the user data are carried in the same 20MHz segment.

Extended Group ID and updated user positions.

In an embodiment of the current invention, a new MU-MIMO allocation over the entire bandwidth or in a particular resource unit is indicated by a extended group ID derived by concatenating two group IDs where the notion of group ID is as defined in IEEE 802.11ac specification. The STAs are indicated to the groups they belong using the group ID and user position management messages. Each 6 bit group ID indicates a group of 4 users where each user is indicated a position going from 0 (00) to 3 (11). The concatenation of two group IDs produces a 12 bit extended group ID where the first 6 bits indicates the first group ID and the second 6 bits indicates the second group ID as illustrated in Figure 12. The user positions are updated to reflect the concatenation i.e., users in the first group ID retain their positions from 0(000) to 3(011) and the users in the second indicated group ID update their positions from 4(100) to 7(111) as shown in Figure 13. The concatenation of the group ID enlarges the number of users who can be scheduled in a MU-MIMO allocation to 8.

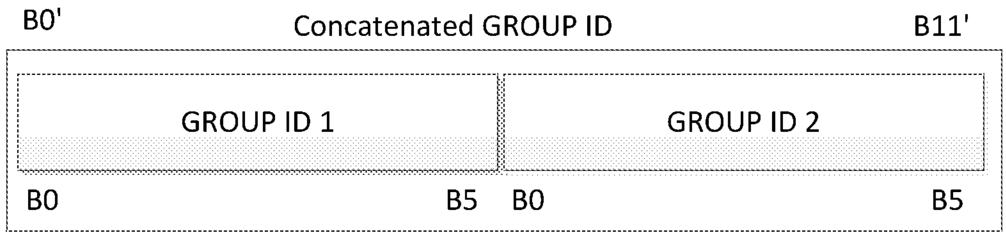


Figure 12 Concatenated or extended Group ID generation by concatenating two Group IDs

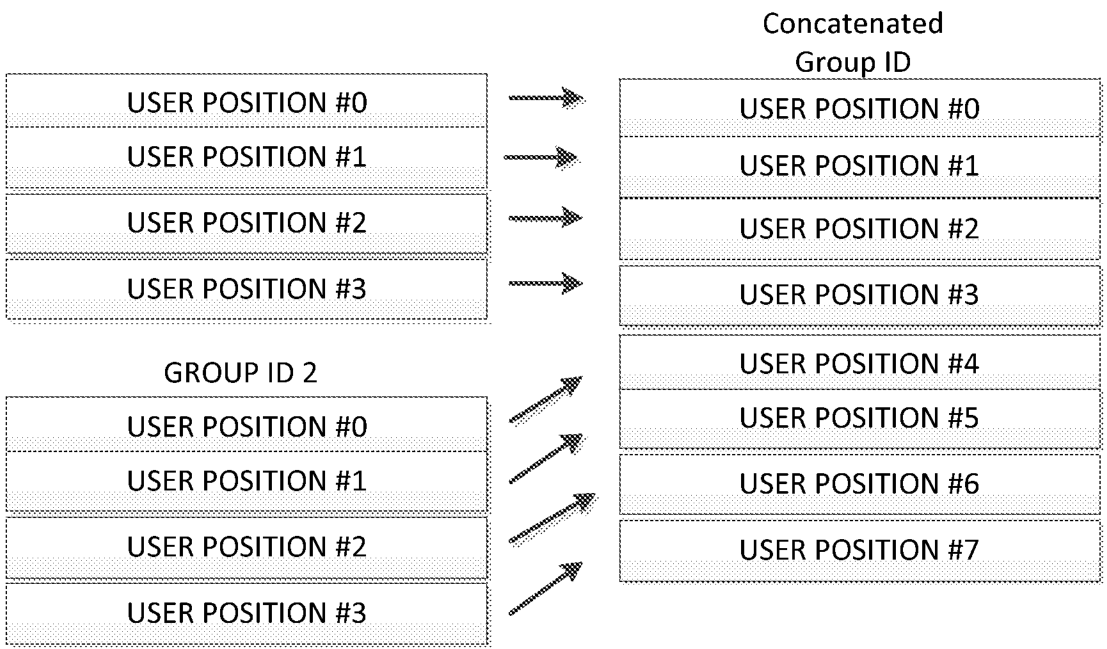


Figure 13 User Position Updated based on the group ID concatenation

The use of a reserve group ID index (for example group ID 0 or group ID 63) in the system in the second 6 bits of the concatenated group ID indicates a no-enlargement of MU-MIMO user group and the maximum number of users scheduled in MU-MIMO user group is 4. Only the users in the first 6 bits of the concatenated group ID are scheduled in the MU-MIMO allocation.

Use of group ID and derived # of allocations

In an embodiment of the current invention, the user allocation for both single and multi-user PPDUs are indicated in HE-SIG-B fields. The allocation information for single-user MIMO PPDUs consists of an binary convolution code component that is duplicated every 20MHz over the bandwidth indicated in SIG-A. The allocation information for multi-user information consists of two parts:

1. a first common part containing N_rua bit resource unit arrangement index indicating the resource unit arrangement in the frequency domai, and a list of N bits STA-ID(for SU allocation) or Group ID(for MU-MIMO allocation) along with 1 bit SU/MU allocation per ID. Totally there will be N_rua(BW) + N_sta(N + 1) information bits indicated in the first part. The 1 bit SU/MU allocation indicates if the succeeding N-bit ID is a

GroupID or a STA ID. The group ID used can be a concatenated group ID as described in the preceding embodiment or a new enlarged group ID mechanism used for 11ax. The user positions are updated if concatenation of group ID is used.

   a. A reserve STA-ID can indicate no allocation over a particular resource unit. For example, STA-ID 0 can indicate that the resource unit is left empty and no data is carried over the resource unit.

2. A second part containing user-specific information carried in the 20MHz segment in which the users data is transmitted. Each 20MHz segment contains an arrangement of RUs the largest of which is a 242 resource unit allocation. All RU allocations that fall with-in the umbrella of this 242 resource unit (as illustrated in Fig.) is carried in 20MHz channel whose center frequency is closest to the allocation. This per 20MHz indication carries STA specific information like STBC, Beamformed, LDPC coding, LDPC extra symbol, Number of spatial streams, MCS of the allocation. This information can be individually encoded with a CRC. Another option would be to jointly encode the information of all STAs scheduled in the 20MHz segment using a blind convolutional code. Since the STAIDs are indicated in the common portion, the information is arranged according to the order in which STAs are listed in the common portion of the signaling.
   a. Users scheduled as part of an MU-MIMO allocation can have different information content than a single user allocation. For example, MCS of the MU-MIMO information can be the same for all users – and the MCS field can be common for users scheduled in MU-MIMO.
   b. When users are scheduled using MU-MIMO over the entire BW, the user specific information portion is common in all 20MHz segments and is duplicated. The STAs scheduled in such an MU-MIMO allocation can derive the information from the RU arrangement index and SU/MU bit indicator in the HE-SIG-A. Another way for the STAs to derive this information is with a 2 bit SU/MU indicator where a particular 2 bit index indicates MU-MIMO over the entire bandwidth.
   c. Scheduling information for users scheduled in the center 26 tone resource unit of a 80MHz allocation or allocations greater than 20MHz can be carried
      i. As the last allocation information in the 20MHz whose subcarrier index precedes the first subcarrier index of the center 26 tone resource unit.
      ii. As the first allocation information in the 20MHz segment whose subcarrier index is greater than the first subcarrier index of the center 26 tone resource unit
      iii. Duplicated in the 20MHz segments that encase the central 26 tone allocation.

   The order of the STA-ID indicated in the common portion is maintained when carrying information for the center 26 tone resource unit when carried using any of the above 3 methods.

In an embodiment of the current invention, the user allocation for multi-user PPDUs are indicated in HE-SIG-B fields. The allocation information for multi-user information consists of two parts – a common part indicating the allocation index and other common fields as described in the preceding embodiment and a per 20MHz signaling part with fields carried as described in the preceding embodiment. TJhe allocation information for a single user PPDU is carried in the HE-SIG-A.

In an embodiment of the current invention, the number of OFDM symbols required to carry the common part may be variable and be indicated by a phase change in the pilot symbol of the last OFDM symbol carrying the common part HE-SIG-B. The number of OFDM symbols required to carry the per 20MHz signaling part may be variable and be indicated by a phase change in the pilot symbol of the last OFDM symbol carrying the per 20MHz signaling part.

In another embodiment, the number of OFDM symbols required in the per 20MHz signaling portion of the HE-SIG-B can be derived from the allocation size in the common portion and not explicitly signaled.

In an embodiment of the current invention, the resource allocation information can be indicated along with the user specific information in a self-contained block – where the user has all the information necessary to encode the data allocated to it. Each block contains information like STAID, the MCS/MIMO and other fields necessary to decode the data, the resource position index and a CRC that can be hashed with the STAID. The STA decodes each block and checks if the allocation belongs to him. The STA continues decoding till all the resource allocation blocks are completely decoded. Multiple resource units may be allocated to an STA.

In an embodiment of the current invention, each self contained block can be encoded separately using a convolutional code.

In an embodiment of the current invention, multiple self contained blocks that support the same MCS can be encoded together using a convolutional code.

In an embodiment of the current invention, the resource allocation information carried in the self contained block contains the index of the RU that carries the MPDU for a signaled STA. The RU index is a numerical index of the RU depending on its size. There are 9 26 tone RUs, 4 52 tone RUs, 2 106 tone RUs and 1 242 tone RUs – accounting for a total of 16 RU indices that can be indicated with 4 bits for 20MHz as shown in **Figure 14**. For40 MHz, **Figure 15** shows 33 different RU indices – needing 6 bits. For 80MHz, **Figure 16** shows 69 different RU indices – needing 7 bits of RU indexing to be transmitted.

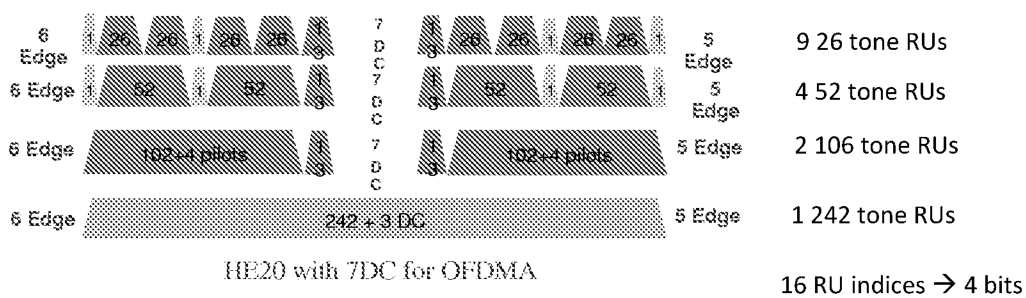


Figure 14 RU Position Indexing for 20MHz

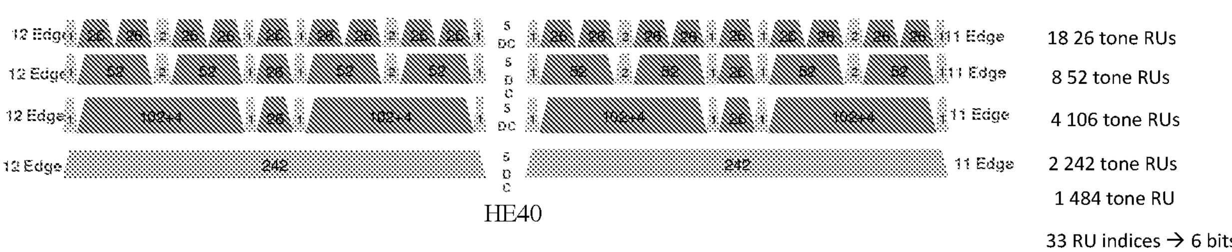


Figure 15 RU Position Indexing for 40MHz

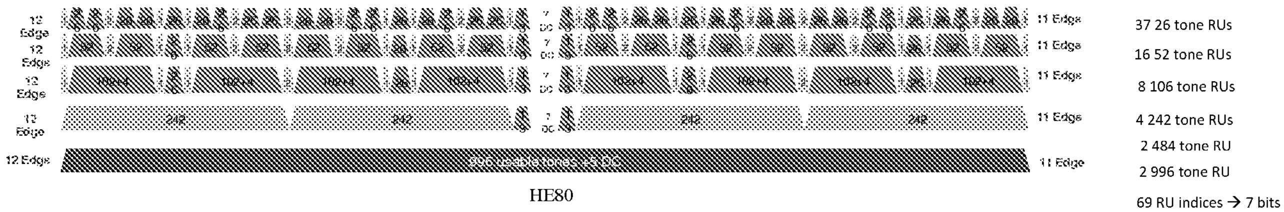


Figure 16 RU Position indexing for 80MHz

The size of the RU position index carried in the block of a user allocation information varies according to the bandwidth information signaled in the HE-SIG-A. If the size of the block of a user allocation is fixed, then the extra bits needed for the RU position indication is derived by shrinking the size of the partial STA-ID signaled in the block. For example, in a 20MHz MU PPDU, the STA-ID can take 9 bits and the RU position indexing can be 5 bits (4 bits + 1 bit reserved). In a 40MHz MU PPDU, the STA-ID can take 8 bits and the RU position indexing can be 6 bits. In a 80MHz MU PPDU, the STA-ID can take 7 bit and the RU position indexing can be 7 bits.

In an embodiment of the current invention, the block of allocation information for an STA in a MU PPDU can appear in a 20MHz segment that is different from the 20MHz segment that carries the data for the said STA. This flexibility allows better load balancing and packing efficiency for HE-SIG-B. The RU position indexing can indicate any resource unit in the bandwidth and therefore the block of allocation information for a STA in a MU PPDU can be carried in any 20MHz without being tied closely to the location of the assigned RU in the bandwidth.

In an embodiment of the current invention, the MCS used for different self contained block or group of self contained blocks can be different. The MCS used for each group is signaled in HE-SIG-A or a common information in the HE-SIG-B The use of different MCS can be different across different portions of the bandwidth and/or different OFDM symbols that the HE-SIG-B occupies.

In an embodiment of the current invention, given the fixed location of RUs in the OFDMA tone plan, the enumeration of possible RU arrangements over a specific bandwidth is specified and signaled. A 20MHz bandwidth with a span of 242 tone RUs or less is used as a building block. Specifying RU arrangement admits flexibility to signal only those resource units arrangement that are supported over a specified bandwidth. Using 4 building blocks -- a 26 tone RU, a 52 tone RU, a 106 tone RU and a 242 tone RU, a 20MHz channel admits 26 different RU arrangement as illustrated in Figure 17Figure 17 and would need 5 signaling bits. Even if we remove the bandwidth specificity, we would need 5 signaling bits to indicate RU arrangement possible with the 4 sizes of RU building blocks in a way that spans the bandwidth indicated by a 242 tone RU.

26 arrangements need no more than 5 bits. 5 bits can signal up to 32 different RU arrangement. Since we still have 6 more RU arrangements that can be indicated to use up the 5 bit width budget, larger RU building blocks can be indicated. As shown in Figure 18, a 484 tone RU, 996 tone RU and a 2*996 tone RU can be signaled by transmitting an index that encodes the arrangement of an RU.

	#1	#2	#3	#4	#5	#6	#7	#8	#9
1	26	26	26	26	26	26	26	26	26
2	52		52		26	52		52	
3	106				26	106			
4	52		26	26	26	26	26	26	26
5	26	26	52		26	26	26	26	26
6	26	26	26	26	26	52		26	26
7	26	26	26	26	26	26	26	52	
8	52		52		26	26	26	26	26
9	52		26	26	26	52		26	26
10	52		26	26	26	26	26	52	
11	26	26	52		26	52		26	26
12	26	26	52		26	26	26	52	
13	26	26	26	26	26	52		52	
14	52		52		26	52		26	26
15	52		52		26	26	26	52	
16	52		26	26	26	52		52	
17	26	26	52		26	52		52	
18	106				26	26	26	26	26
19	106				26	26	26	52	
20	106				26	52		26	26
21	106				26	52		52	
22	26	26	26	26	26	106			
23	26	26	52		26	106			
24	52		26	26	26	106			
25	52		52		26	106			
26	242								

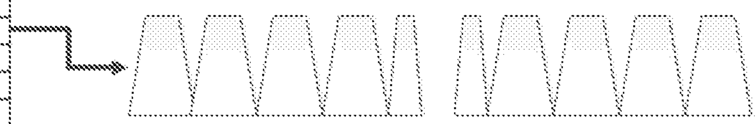


Figure 17: RU arrangement Indexing up to 242 tone RU

27	484
28	996
29	2*996

Figure 18 Extending RU arrangement indexing to indicate large RU sizes

IEEE 802.11ax agreed to support MU-MIMO on RUs of size greater than or equal to 106 tones. RU arrangements that indicate the use of an RU larger than or equal to 106 tone RUs are likely to have MU transmissions. The following embodiments show how signaling RU arrangement can be accommodated to indicate MU-MIMO resources. Specifically the contents of the common arrangement to specify both RU arrangement and MU-MIMO resource information is discussed. In addition to identifying the MU-resources, it is also important to know the number of users scheduled in an MU-MIMO resource.

In an embodiment of the current invention, the number of users scheduled using MU-MIMO is explicitly signaled. When an MU-MIMO capable RU is signaled in the RU arrangement, the bits following the RU arrangement will indicate the number of users per MU allocation. Since only some RU sizes can support MU-MIMO, the bit sequence will be all zero if the RU sizes cannot support MU-MIMO or if no MU-MIMO is used in the PPDU. If RU arrangements are indicated in granularity of 20MHz or 242 tone RUs, then there can be at most two RUs spanning the same bandwidth as a 242 tone RU that is capable of carrying MU-MIMO in a PPDU. Given a maximum of 8 users can be carried in an MU-MIMO PPDU, each RU capable of transmitting MU-MIMO needs 3 bits. Therefore, up to 6 bits necessary per SIG-B channel with granularity of 242 tone RU- 3 bits per 106 tone RU. So the common information contains a 5 bit RU arrangement and a 6 bit indication for number of users in MU-MIMO resource, 3 per 106 tone RU. When RU size greater than 106 tone RU is indicated in the arrangement, only the 3 LSBs are used to indicate MU-MIMO users. A non-zero indication in the 3 bits indicates positively for MU-MIMO, the specific value of 3 bits indicates the number of users signaled in the MU-MIMO resource. Set the # of STA users per MU field to 000000 –if RU arrangement precludes use of MU-MIMO.

The RU-arrangement and the number of users per MU-MIMO resource together form the common portion of a HE-SIG-B channel and are illustrated in Figure 19. The following per-user signaling portion carries information individually for each users. The number of users for whom the information is carried is derived from the number of RUs indicated in the RU arrangement and the number of users indicated in MU-MIMO resources. The total # of per-STA information elements carried is a product of the number of RUs and the number of users in MU-MIMO. Each of the per-STA information elements carry a STA-ID field with a bit width to identify the STA scheduled in the MU-PPDU. Multiple per STA information elements can be encoded together in a group as illustrated in Figure 19.

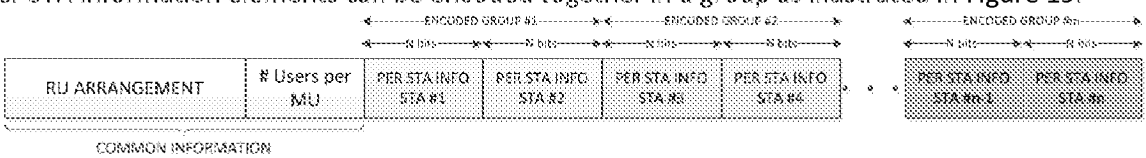


Figure 19: Common Information carrying RU information and Number of Users per MU allocation

In an embodiment of the current invention, a MU flag following the RU arrangement field indicates if an RU capable of carrying MU-MIMO carries MU-MIMO in the transmitted PPDU. If RU arrangements are indicated in granularity of 20MHz or 242 tone RUs, then there can be at most two RUs spanning the same bandwidth as a 242 tone RU that is capable of carrying MU-MIMO in a PPDU. Therefore, a 2 bit MU flag – indicates if MU is supported on the RU size (1 bit per 106 tone RU). The flag is set ot 0 if no MU-MIMO is used in the PPDU or if the RU arrangement precludes use of MU-MIMO. The flag is set to 1 if the RU indicated carries MU-MIMO – the first bit in the flag indicating the first RU of size 106 tones and a second bit in the flag indicating the second RU of size 106 tones. For RU arrangements indicating only 106 tone RU or 242 tone RU and higher sizes, the LSB of the 2 bits flag can indicate MU for the RUs indicated or both bits can be set to indicate presence of MU-MIMO in the resource. The RU arrangement and the MU flag comprises the common information portion in the HE-SIG-B channel as shown in Figure 20.

The per-user signaling portion follows the common information portion for the HE-SIG-B channel and carries information necessary to identify users as well as the decoding information for the data PPDU for the users. RU allocation addressed to a single user are identified by a STA-ID and are of a particular size. MU-MIMO RU allocations are identified using a Group ID and are of a size different from the SU allocations. The information for all users scheduled using MU-MIMO on a RU are carried together and all of them are identified using a common group ID. The size of MU-Allocation information is different from SU allocations. MU users are signaled and encoded together. SU allocation information are signaled separately and may be groups of SU allocations may be encoded together or separately. If the MU flag indicates the presence of MU-MIMO allocation, then the STA understand that the allocation info at position corresponding to the RU position in the bandwidth is a MU allocation and is of a size different from the STA allocation as shown in Figure 20.

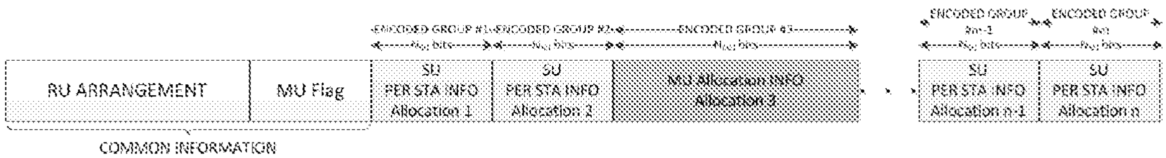


Figure 20 Common information carrying RU arrangement and MU flag.

In an embodiment of the current invention, the RU arrangement and MU-MIMO flag are encoded together in a transmitted sequence of bits that forms the common information portion of a HE-SIG-B channel. In addition to the 29 indices that show RU arrangements (Figure 17 and Figure 18), new arrangement fields are added that could indicate a same RU arrangement but are different – one indicates SU arrangements and the other indicates the presence of MU-MIMO. For example, index 3, 30, 31, and 32 refer to the same [106 26 106] arrangement but index 3 indicates only SU, while indices 30, 31 and 32 indicate presence of MU-MIMO in either or both of the 106 tone RUs. From the 20 indices with no MU-MIMO, we need 15 additional indices that have at least one MU-MIMO RU. So a total of 44 RU indices increases the RU signaling overhead to 6 bits and is carried in the common information portion of the HE-SIG-B channel as illustrated in Figure 22. The arrangement indices are indicated in Figure 21.

	#1	#2	#3	#4	#5	#6	#7	#8	#9
30	106				26	106			
31	106				26	106			
32	106				26	106			
33	106				26	26	26	26	26
34	106				26	26	26	52	
35	106				26	52		26	26
36	106				26	52		52	
37	26	26	26	26	26	106			
38	26	26	52		26	106			
39	52		26	26	26	106			
40	52		52		26	106			
41	242								

42	484
43	996
44	2*996

Figure 21 Additional indices for RU arrangement when signaling MU-MIMO resources

Encoding the MU-MIMO RUs along with the RU arrangement does not disambiguate the # of users per MU-MIMO RU when STAID addressing is used. In an embodiment of the current invention, additional signaling bits are necessary to indicate the # of users and are to be carried in the common information portion of the HE-SIG-B channel.

The per-user signaling portion follows the common information portion for the HE-SIG-B channel and carries information necessary to identify users as well as the decoding information for the data PPDU for the users. RU allocation addressed to a single user are identified by a STA-ID and are of a particular size. MU-MIMO RU allocations are identified using a Group ID and are of a size different from the SU allocations. The information for all users scheduled using MU-MIMO on a RU are carried together and all of them are identified using a common group ID. The size of MU-Allocation information is different from SU allocations. MU users are signaled and encoded together. SU allocation information are signaled separately and may be groups of SU allocations may be encoded together or separately. If the RU arrangement indicates MU-MIMO resource unit, then the STA understand that the allocation info at position corresponding to the RU position in the bandwidth is a MU allocation and is of a size different from the STA allocation as shown in Figure 22.

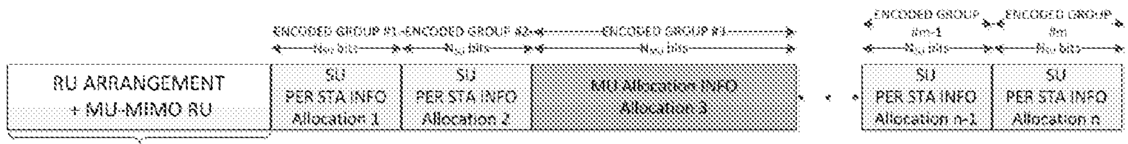


Figure 22 Common information containing resource allocation field that contains integrated RU arrangement and MU-MIMO RU

In an embodiment of the current invention, a resource allocation index signaled in the common portion of HE-SIG-B channel carries the following information:

- RU Arrangement
- If MU-MIMO Capable RUs carry MU-MIMO
- Number of users multiplexed using MU-MIMO

A transmitted resource allocation index will differ when different RU arrangements are used or when for the same RU arrangement, different number of users multiplexed using MU-MIMO. Since up to 8 users can be multiplexed in an MU-MIMO allocation, 8 indices indicating different # of users for a MU-MIMO capable RU within the same RU arrangement. The tabulated indices encoding jointly the RU arrangements and the number of users for a MU-MIMO index is shown in Figure 23. For example, as shown in Figure 23, Index 3 & 4 – Indicate an RU arrangement [106 26 106] over a channel: Index 3 – refers to SU transmissions in the RU while index 4 – refers to MU MIMO in the first 106 RU with 2 users and SU in the remaining RUs. There are total of 64 different indices that refer to the same [106 26 106] RU arrangement, each with differing # of users in either of the MU-MIMO capable 106 tone RU. For the different RU sizes and arrangements possible, a total of 175 different indices can be signaled and would require 8 signaling bits and is carried in the common information portion of the HE-SIG-B channel as illustrated in Figure 24.

	#1	#2	#3	#4	#5	#6	#7	#8	#9	Num User
1	26	26	26	26	26	26	26	26	26	1
2	52		52		26	52		52		1
3	106				26	106				64
66	52		26	26	26	26	26	26	26	1
67	26	26	52		26	26	26	26	26	1
68	26	26	26	26	26	52		26	26	1
69	26	26	26	26	26	26	26	52		1
70	52		52		26	26	26	26	26	1
71	52		26	26	26	52		26	26	1
72	52		26	26	26	26	26	52		1
73	26	26	52		26	52		26	26	1
74	26	26	52		26	26	26	52		1
75	26	26	26	26	26	52		52		1
76	52		52		26	52		26	26	1
77	52		52		26	26	26	52		1
78	52		26	26	26	52		52		1
79	26	26	52		26	52		52		1
87	106				26	26	26	26	26	8
95	106				26	26	26	52		8
103	106				26	52		26	26	8
111	106				26	52		52		8
119	26	26	26	26	26	106				8
127	26	26	52		26	106				8
135	52		26	26	26	106				8
143	52		52		26	106				8
151	242									8
159	484									8
167	996									8
175	2*996									8

Figure 23 Signaling the RU arrangement along with the number of users for MU-MIMO resources.

Indicating jointly the RU arrangement and the number of MU-MIMO users in an MU-MIMO resource results in the compact common information field. The per-user signaling portion follows the common information portion for the HE-SIG-B channel and carries information necessary to identify users as well as the decoding information for the data PPDU for the users. It admits both STAID and GroupID addressing for MU-MIMO. An arrangement of the per-user information element where each user is identified by an STAID is shown in Figure 24.

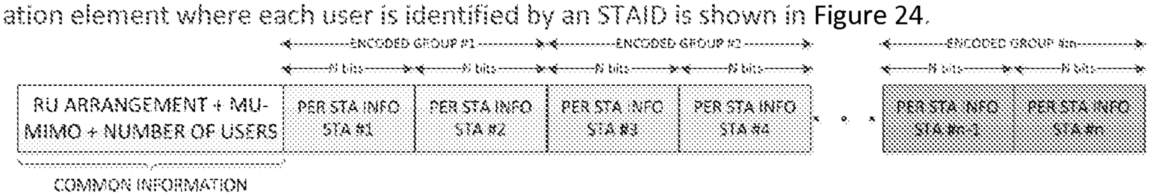


Figure 24 Arrangement of common information containing both RU arrangement and the number of users for MU-MIMO RUs in a HE-SIG-B Channel

In an embodiment of the current invention, the RU allocation index can communicate indices that indicates unused resources and used resources. The total number of per STA information fields that follow changes depending on the number of used resources indicated by the index. No per STA information fields are sent for resources indicated to be unused in the resource allocation index. For certain arrangements involving larger or equal RU sizes, the central 26 tone RU may not be used or allocated to any STAID to improve padding efficiency as shown in the table below.

	#1	#2	#3	#4	#5	#6	#7	#8	#9	Num User
176	106				X	106				64
240	52		52		X	52		52		1

Four different options for indicating the RU arrangement and MU-MIMO resources in the common information portion of a HE-SIG-B channel have been identified in the preceding embodiments. A summary of these choices identifying the number of bits required for each option and the impact of the signaling choice on the succeeding user signaling portion is in Figure 25. Options 1 and 4 are flexible and identify unambiguously, the number of users in an MU-MIMO allocation. There are flexible in accommodating either STA-ID and Group ID addressing the successing user signaling portion. Although, they slightly favor the STA-ID signaling with improved efficiency for the case. Options 2 and 4 can be supported by using Group ID to address users in MU-MIMO allocation since the MU-flag indicated separately or jointly does not disambiguate the number of users in the MU-MIMO allocation.

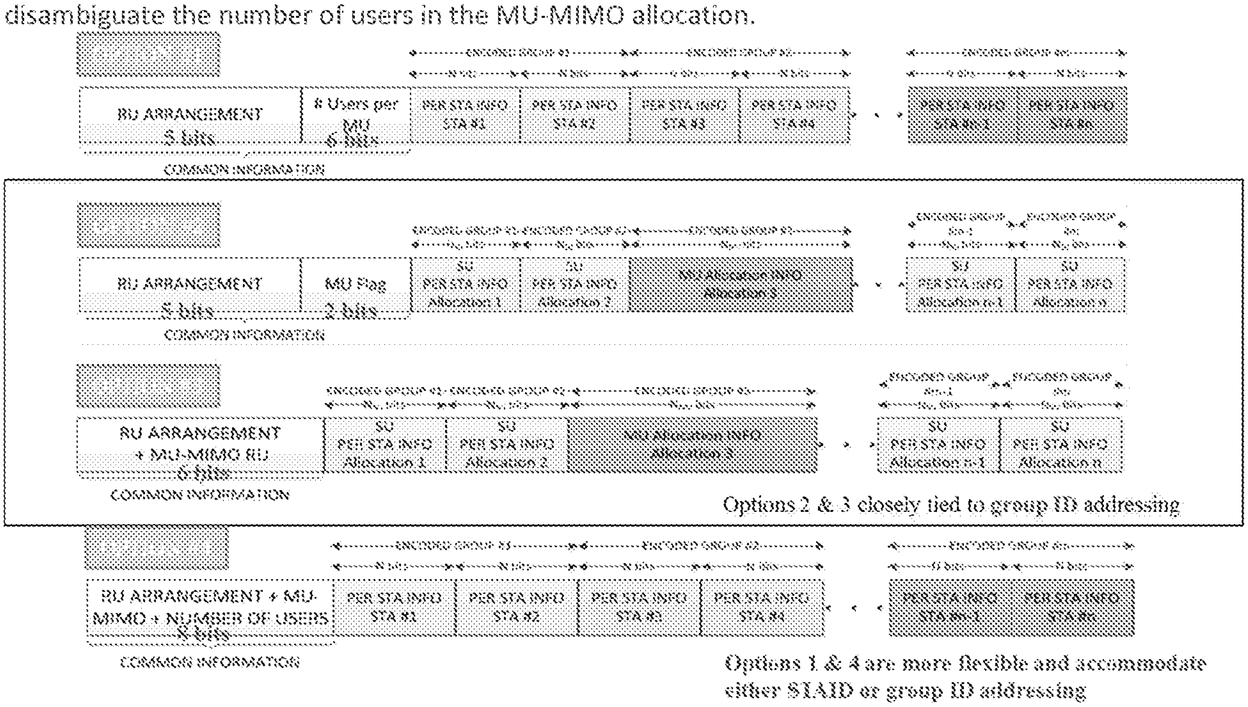


Figure 25 Summary of the different common information types possible.

The following embodiments describe the HE-SIG-B Multiplexing elements and considerations.

In an embodiment of the current invention, the HE-SIG-B for a 20MHz MU PPDU is constructed using a common information portion followed by a per-user allocation information as shown in Figure 26. The RU Arrangement + MU-MIMO information is signaled in the common information followed by per-user allocation information. An STA uses the common information and the position of its per-user allocation to unambiguously identify the RU containing its data.

Figure 26 HE-SIG-B channel for 20MHz containing a common information followed by per-user allocation information

In an embodiment of the current invention, the HE-SIG-B for a 40MHz MU PPDU contains two channels as illustrated in Figure 27. Each HE-SIG-B channel carries different information and each identifying a RU granularity up to 242 tone RU that span the 20MHz channel it is carried in. Thus, HE-SIG-B channels keep control information in the 20MHz sub-carriers closest to the data sub-carriers. Each channel carries RU allocation information for users scheduled and contains an common information portion as well as the user specific information portion. The common portion and user-specific portion for HE-SIG-B channel 1 indicates the allocation information for users scheduled in the primary 20MHz and the common portion and user specific portion for HE-SIG-B channel 2 indicates the allocation information for users scheduled in secondary 40MHz. The HE-SIG-B channels can be of different sizes and can indicate different number of users. However, they will end at the same symbol. When the number of users indicated are different in each HE-SIG-B channel, the HE-SIG-B channel indicating fewer users is required to pad to equalize the length of both HE-SIG-B channel and ensure symbol alignment.

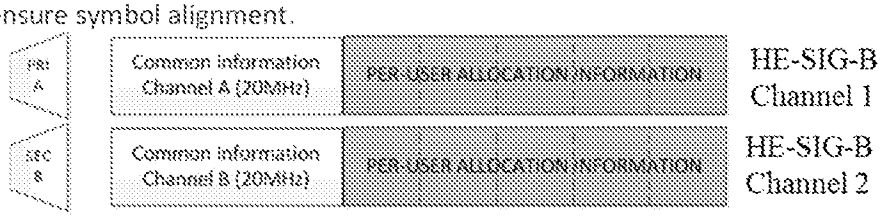


Figure 27 HE-SIG-B transmission for 40MHz BW contains two HE-SIG-B channels that carry information for their respective 20MHz channels.

In an embodiment of the current invention, When 484 unit RU is scheduled in a 40MHz MU PPDU, the two HE-SIG-B channels will indicate the same information i.e., the contents of HE-SIG-B channel 1 is duplicated in the HE-SIG-B channel 2 as shown in Figure 28.

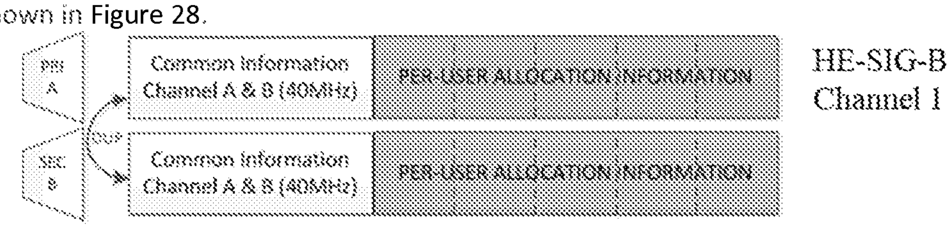


Figure 28 HE-SIG-B transmission when a 484 tone RU is signaled indicating transmission over the entire 40MHz.

In an embodiment of the current invention, when 484 tone RU is scheduled in 40MHz PPDU, the per-user allocation information is split equitably into the two HE-SIG-B channels. If there are N users scheduled in the MU-PPDU, then each HE-SIG-B channel can contain up to $\left\lfloor \frac{N}{2} \right\rfloor$ per-user allocation fields where the 1 to $\left\lfloor \frac{N}{2} \right\rfloor$ user allocation information is carried in HE-SIG-B Channel 1 and $\lceil \frac{N}{2} \rceil$ +1 to N user allocations are carried in HE-SIG-B Channel 2. The common information signaling for MU-PPU with 484 tone RU arrangement may either be duplicated in each HE-SIG-B channel or indicated in HE-SIG-A. When signaled in HE-SIG-A, the common information is not present in HE-SIG-B channels.

In an embodiment of the current invention, the HE-SIG-B for a 80MHz MU PPDU contains two channels as illustrated in **Figure 29**. Each HE-SIG-B channel carries different information and the HE-SIG-B channels are duplicated per 40MHz i.e., HE-SIG-B Channel 1 is carried in channel A & C of 80MHz while HE-SIG-B Channel 2 I scarried in B & D of 80MHz as shown in **Figure 29**. 80MHz channel consists of four 20MHz segments identified as Channels A, B, C and D in **Figure 29** and the multiplexing information required for decoding the PPDU for users scheduled in each of these segments have to be mapped to 2 HE-SIG-B channels duplicated per 40MHz.

The 80MHz tone plan in 802.11ax is not aligned with 20MHz segments. We redefine channels A, B, C, and D as segments in **Figure 29** to refer to a granularity of subcarriers corresponding to a 242 tones RUs – and can signal RU arrangements for smaller RU sizes when concatenated span the same space as the 242 tone RUs. The RU arrangement information and the per-user allocation information for segments A, B, C and D are mapped to the two HE-SIG-B channels as follows:

- The Common part for HE-SIG-B channel 1 consists of common information for segments A and C – identify the RU arrangement up to a granularity of 242 tone RUs in the said segments and the MU-MIMO resources as well as the number of users (if necessary). The common information for both segments A and C are encoded together using a convolutional code. The per-user allocation information follow where the first the per-user information for the users whose data are in the RUs of segment A are first transmitted followed by the per-user information for the users whose data are in the RUs of segment C. The number of per-user allocations are derived from the common information for each segment and the total number of per-user allocations is the sum of the allocations derived from the arrangement for each segment.
- The Common part for HE-SIG-B channel 2 consists of common information for segments B and D – identify the RU arrangement up to a granularity of 242 tone RUs in the said segments and the MU-MIMO resources as well as the number of users (if necessary). The common information for both segments B and D are encoded together using a convolutional code. The per-user allocation information follow where the first the per-user information for the users whose data are in the RUs of segment B are first transmitted followed by the per-user information for the users whose data are in the RUs of segment D. The number of per-user allocations are derived from the common information for each segment and the total number of per-user allocations is the sum of the allocations derived from the arrangement for each segment
- The common part of one of the HE-SIG-B channels also contains 1 bit indicated if the central 26 tone RU is assigned to an user or not. By convention, this indication may be carried in HE-SIG-B channel-1 after the RU arrangements for segments are indicated and encoded together. If the bit is set to 1, the per-user allocation information is carried at the end, after the user allocations for segments A & C are carried.

The RU index of the data PPDU for a user is computed by the position of the allocation in the segment based on the RU arrangement indicated minus the offset determined by the number of user allocations for the segments which are carried before the current segment in the same HE-SIG-B channel. For the first segment indicated, no offset needs to be computed.

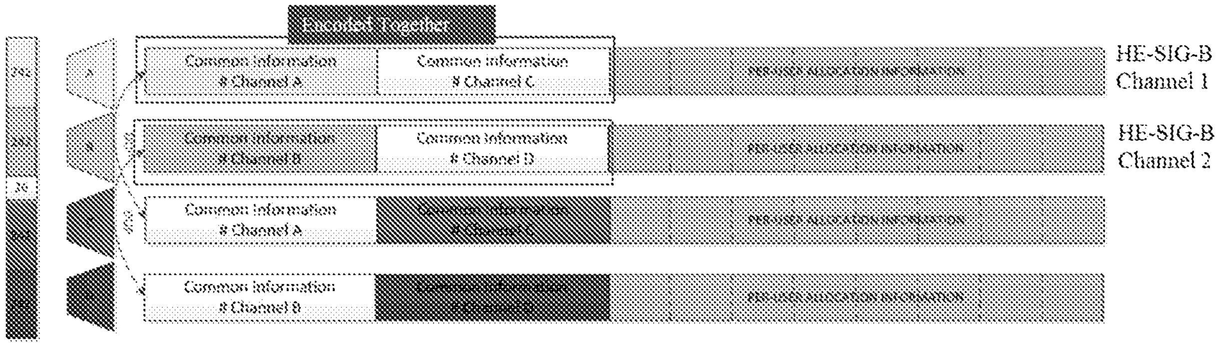


Figure 29 HE-SIG-B multiplexing for 80MHz consists of 2 channels , each carrying independent information per 20MHz HE-SIG-B channel

Duplication of HE-SIG-B channels keeps control information in the 20MHz sub-carriers closest to the data sub-carriers. Allows MCS adaptation for each HE-SIG-B channel relative to the data MCS used, subject to reliability constraints.

The efficiency of the HE-SIG-B multiplexing illustrated in Figure 29 does not scale well when large RU sizes (>242 tone RU) are used and needs to be modified. To illustrate the inefficiency, see Figure 30: If 80MHz wants to signal [484 26 484] arrangement, keeping the mapping granularity at 242 tones segments and two segments per HE-SIG-B channel results in a fully duplicated HE-SIG-B (same information is carried in every HE-SIG-B channel.

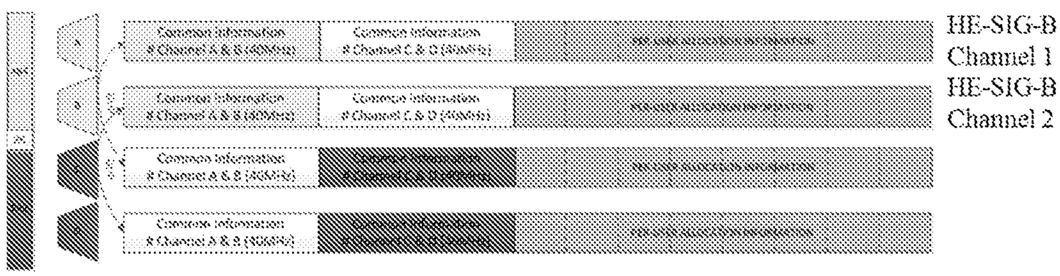


Figure 30 Issues with keeping one format for HE-SIG-B transmissions - signaling larger RUs result in unnecessary duplication

An efficient approach is to keep the information distinct in the two HE-SIG-B channels by making the mapping granularity flexible and tuned to the RU size being signaled. In an embodiment of the current invention, the information for larger RUs sizes is carried by signaling the mapping granularity per HE-SIG-B channel and is based on the RU size used in the MU-PPDU. A redefined segment definition is carried prior to the HE-SIG-B decoding. For example, when 2 484 tone RUs are signaled in MU PPDU, the RU arrangement in 80MHz is [484 26 484], then the common information for channels A & B, that span the 484 tone RU is carried in HE-SIG-B channel 1 while the common information for channels C & D that span the 484 tone RU is carried in HE-SIG-B channel 2 as shown in Figure 31. The per-user allocation information follow the common portion indication and carry the information for users scheduled in the segment for each channels. HE-SIG-B channels are duplicated per 40MHz. The common part of one of the HE-SIG-B channels also contains 1 bit indicated if the central 26 tone RU is assigned to an user or not. By convention, this indication may be carried in HE-SIG-B channel-1 after the RU arrangements for the 484 tone RU is indicated and encoded together. If the bit is set to 1, the per-user allocation information is carried at the end, after the user allocations assigned to the 484 tone RU are carried.

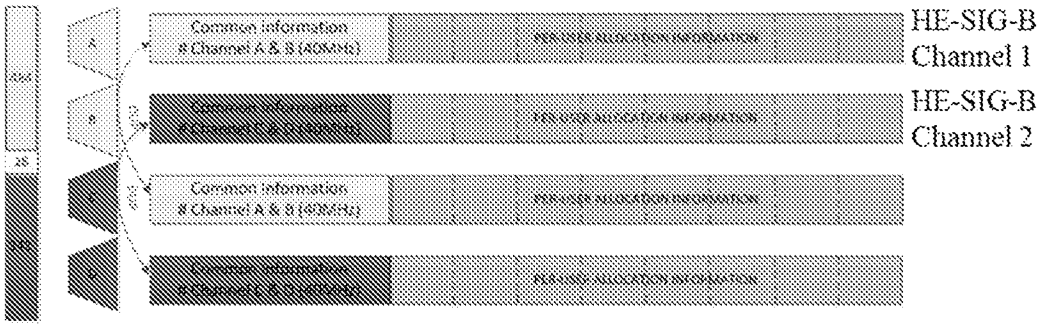


Figure 31 A simple multiplexing scheme where larger RUs are signaled in their respective channels.

Since the amount of common information changes between cases illustrated in Figure 29 and Figure 31. The receivers need to know the number of bits in the common information to prepare for decoding and therefore this change in the common information would have to be signaled prior to HE-SIG-B decoding.

The following describe the cases that benefit from redefining segment mapping granularity. For each of the cases described below, the amount of the common information in each HE-SIG-B channel changes and would have to be signaled before the HE-SIG-B decoding.

- One 484 tone RU appears in a 80MHz PPDU results in two different mapping strategies for the HE-SIG-B channels as shown in Figure 32.

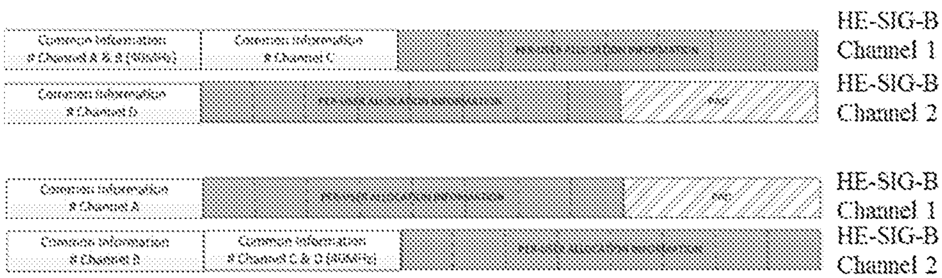


Figure 32 HE-SIG-B multiplexing in 80MHz when only one of the channels has a 484 tone RU multiplexed

- Two 484 tone RU appears in a 80MHz PPDU results in a compact common information segement for the HE-SIG-B channels as shown in Figure 33.

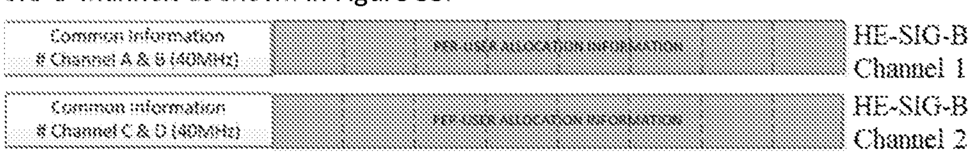


Figure 33 HE-SIG-B multiplexing when both channels indicate 40MHz transmissions

- One 996 tone RU appears in a 80MHz PPDU results in only one HE-SIG-B channel carrying an unique information indicating an RU arrangement of 996 tones and the per-user signaling information following the RU arrangements. This information can be carried in HE-SIG-B channel 1 and duplicated in HE-SIG-B channel 2 as shown in Figure 34 and duplicated in the other 40MHz i.e., HE-SIG-B is duplicated completely over the 80MHz. The other choice, also illustrated in Figure 34, is to transmit information only in HE-SIG-B channel 1 and not transmitting anything in HE-SIG-B channel 2. Over 80MHz, HE-SIG-B is duplicated in only channels A & C while channels B & D are left empty. Only one of the two options below needs to be supported.

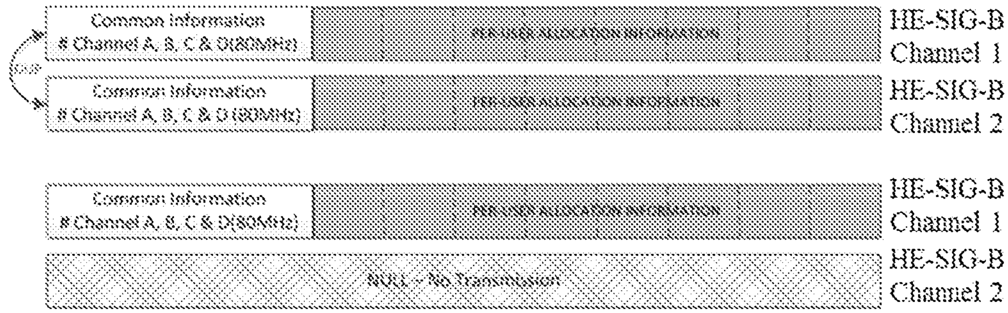


Figure 34 HE-SIG-B multiplexing when a single 996 tone RU is indicated for 80MHz

Multiplexing options for HE-SIG-B to support load balancing:

There are scenarios where allowing flexibility in mapping the 4 segment decoding information to HE-SIG-B channel could allow for a balanced load between the two HE-SIG-B channels and reduce the need for padding in either channels for symbol alignment. This need is likely to be acute when asymmetric distribution of RUs and users between the segments A, B, C & D occur. The flexibility depends on the segment size considered and the associated mapping rule.

In an embodiment of the current invention, the following cases of mapping to the segments to HE-SIG-B channels are also supported by an indication before the STA begins decoding HE-SIG-B.

- 1 case when four 242 tone RU segments are indicated for 80MHz.
    - Common and per-user information for Segments A & B are multiplexed together in HE-SIG-B channel #1 and common and per-user information for segments C&D can be multiplexed together in HE-SIG-B channel #2 as shown in Figure 35. This re-arrangement of segment mapping is supported in addition to the mapping described in Figure 29. During scheduling, depending on the RU arrangement and the number of users in each segment, the AP can decide the option that minimizes the padding overhead in either HE-SIG-B channel for symbol alignment.

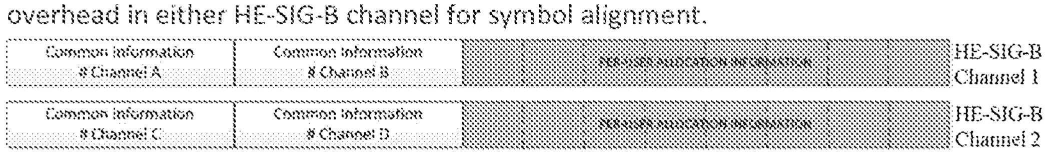


Figure 35 HE-SIG-B multiplexing that supports load balancing when multiple RUs are indicated.

- When 1 484 tone RU segment is indicated for 80MHz, we can consider signaling how the common information are multiplexed.
    - 2 additional cases to the ones illustrated in Figure 32.
- Different combinations of the segments to HE-SIG-B channel mapping. For example: The channels A, B, C are mapped to HE-SIG-B Channel 1 while D is mapped to HE-SIG-B Channel 2.
- Non-contiguous channel bonding support when no preamble and data is transmitted in at least one 20MHz secondary channel.

HE-SIG-B Multiplexing Format Field

Two reasons necessitate indicating a multiplexing format prior to HE-SIG-B decoding

- Efficient signaling when larger RU sizes are used in a 80MHz PPDU
  - 3 cases with 484tone RU in either or both HE-SIG-B channels
  - 1 case with 996 tone RU in HE-SIG-B channel
- Load balancing
  - 1 case with four 242 tone segments are to be signaled with asymmetric user distribution in each segment
  - 2 cases where at least one 484 tone segment is to be signaled
  - Specific configurations of segments to HE-SIG-B channel mapping. .

Together with the primary case shown in Figure 29, 8 cases change the multiplexing format and content in either HE-SIG-B channels.

  - Total of <u>3 signaling bits</u> for 80MHz
  - Needs to be indicated before HE-SIG-B decoding.

In an embodiment of the current invention, **<u>the HE-SIG-B Multiplexing Format Field</u>** indicates how information of the 4 segments are mapped to the two HE-SIG-B channels. The HE-SIG-B multiplexing format field is 3 bits for a 80MHz PPDU and the value of the 3 bits indicates how the segments are mapped to the two HE-SIG-B channels. The HE-SIG-B multiplexing format field is carried in HE-SIG-A.

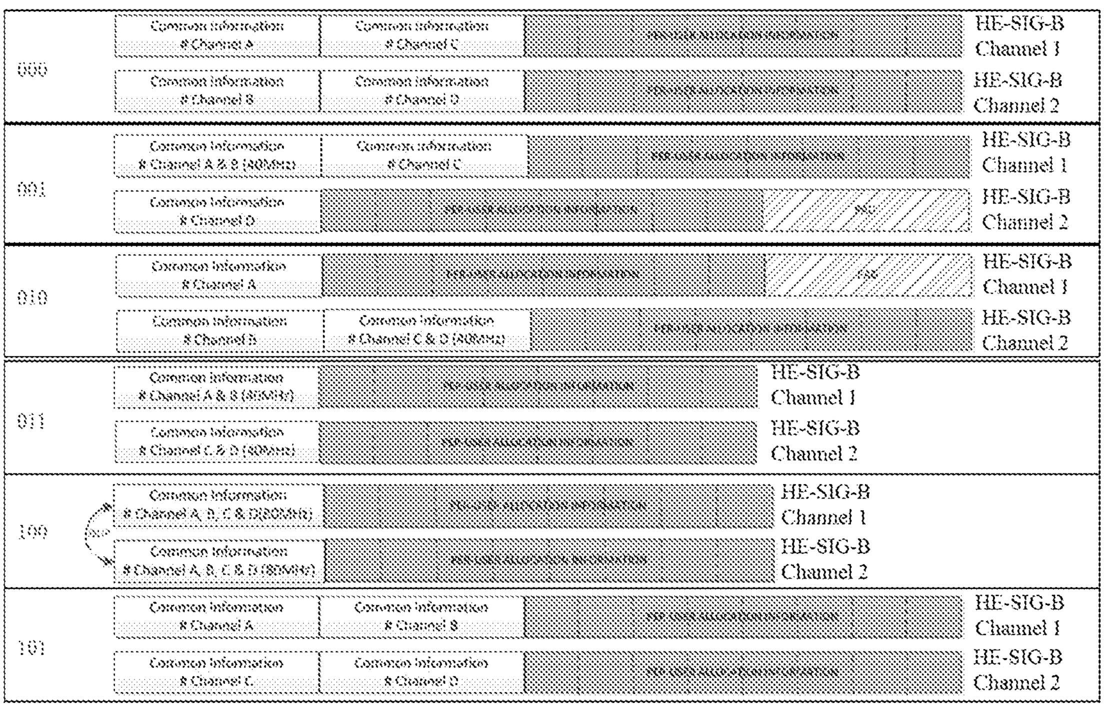


Figure 36 HE-SIG-B Multiplexing Format Field indicating how the common information is arranged in HE-SIG-B channels

In general, HE-SIG-B format field is made up of N bits that can be used to signal how common information is arranged, loadbalancing is supported and other optimizations including the lack of common information in HE-SIG-B for a MU-MIMO PPDU over the full bandwidths -- in which case, the number of users is indicated in HE-SIG-B format field to be carried in HE-SIG-A.

In an embodiment of the current invention, when 484 tone RU or larger size RU is scheduled in 80MHz PPDU, the per-user allocation information is split equitably into the two HE-SIG-B channels. If a 484 tone RU is scheduled for segments A and B and there are N users scheduled in the MU-PPDU, then each HE-SIG-B channel can contain up to $\left\lfloor \frac{N}{2} \right\rfloor$ per-user allocation fields where the 1 to $\left\lfloor \frac{N}{2} \right\rfloor$ user allocation information is carried in HE-SIG-B Channel 1 and $\left\lfloor \frac{N}{2} \right\rfloor$ +1 to N user allocations are carried in HE-SIG-B Channel 2. If a 484 tone RU is scheduled for segments B and C, there are N users scheduled in the MU-PPDU, then each HE-SIG-B channel can contain up to $\left\lfloor \frac{N}{2} \right\rfloor$ per-user allocation fields where the 1 to $\left\lfloor \frac{N}{2} \right\rfloor$ user allocation information is carried in HE-SIG-B Channel 2 and $\left\lfloor \frac{N}{2} \right\rfloor$ +1 to N user allocations are carried in HE-SIG-B Channel 1. When the per-user allocation field spills over the HE-SIG-B channels, the user allocation information for RU arrangement indicated in the common field of the HE-SIG-B channel is first carried followed by per user allocation information that is distributed from the other channel.

Generally, for larger size RUs that span multiple HE-SIG-B channels, the per user allocation information for the users scheduled in the RU is split equitably among the HE-SIG-B channels. For M HE-SIG-B channels and N users, $\left\lfloor \frac{N}{M} \right\rfloor$ users are carried in every HE-SIG-B channel that the RU allocation spans with any extra users carried in the last channel.

Extending Multiplexing Support to 160MHz

In an embodiment of the current invention, eight 20MHz segments are mapped to 2 HE-SIG-B channels duplicated per 40MHz for a MU PPDU that spans 160MHz as follows:

- 160MHz tone plan built as two concatenated 80MHz tone plans that is not aligned with 20MHz segments. . We redefine channels A1, B1, C1, D1, A2, B2, C2 and D2 as segments in Figure 36 to refer to a granularity of subcarriers corresponding to a 242 tones RUs – and can signal RU arrangements for smaller RU sizes when concatenated span the same space as the 242 tone RUs.The Common part for HE-SIG-B channel 1 consists of common information for segments A1, C1, A2 and C2 – identify the RU arrangement up to a granularity of 242 tone RUs in the said segments and the MU-MIMO resources as well as the number of users (if necessary). The common information for segments A1, C1, A2 and C2 are encoded together using a convolutional code. The per-user allocation information follow where the first the per-user information for the users whose data are in the RUs of segment A1 are first transmitted followed by the per-user information for the users whose data are in the RUs of segment C1 and then by A2 and C2. The number of per-user allocations are derived from the common information for each segment and the total number of per-user allocations is the sum of the allocations derived from the arrangement for each segment.
- The Common part for HE-SIG-B channel 2 consists of common information for segments B1, D1, B2, and D2 –

identify the RU arrangement up to a granularity of 242 tone RUs in the said segments and the MU-MIMO resources as well as the number of users (if necessary). The common information for both segments B1, D1, B2, and D2 are encoded together using a convolutional code. The per-user allocation information follow where the first the per-user information for the users whose data are in the RUs of segment B1 are first transmitted followed by the per-user information for the users whose data are in the RUs of segment D1 and then by those of B2 and D2. The number of per-user allocations are derived from the common information for each segment and the total number of per-user allocations is the sum of the allocations derived from the arrangement for each segment

- Two 26 tone RU signaled using 1 bit separately. By convention, one in HE-SIG-B channel-1 and the other in HE-SIG-B channel-2. The common part in each of the HE-SIG-B channels also contains 1 bit indicated if the central 26 tone RU is assigned to an user or not. By convention, this indication may be carried in HE-SIG-B channel-1 after the RU arrangements for segments are indicated and encoded together. If the bit is set to 1, the per-user allocation information is carried at the end, after the user allocations for other segments are carried.

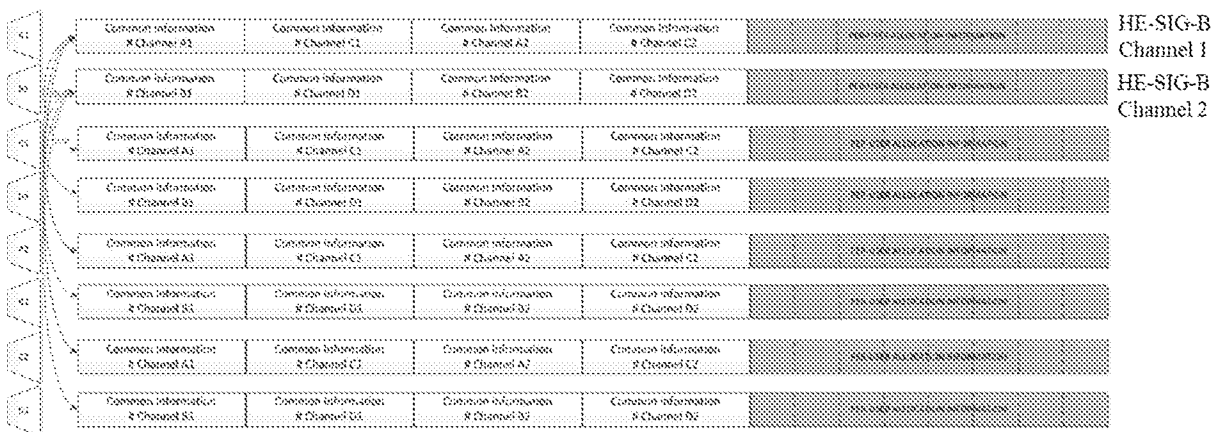


Figure 37 Channel Structure and Duplication for Multiplexing control information in HE-SIG-B for 160MHz

Use of larger RUs of size greater than 242 tone RU results in inefficiencies similar to what we saw for 80MHz. An efficient approach is to keep the information distinct in the two HE-SIG-B channels by making the mapping granularity flexible and tuned to the RU size being signaled. In an embodiment of the current invention, the information for larger RUs sizes is carried by signaling the mapping granularity per HE-SIG-B channel and is based on the RU size used in the MU-PPDU. A redefined segment definition is carried prior to the HE-SIG-B decoding. Given the bandwidth size, there are a large number of multiplexing formats given the size – 25 different cases as shown in Table 3 whose multiplexing format will have to be signaled. 5 Signaling bits to indicate all multiplexing formats in the **HE-SIG-B Multiplexing Format Field in** HE-SIG-A for 160MHz

Table 3 Cases for which the common information changes for HE-SIG-B channels when 160MHz BW is indicated

RU used in 160MHz PPDU	Cases
1 484 tone RU	4 cases
2 484 tone RUs	6 cases
3 484 tone RUs	4 cases
4 484 tone RUs	1 case
1 996 tone RU	2 cases
1 996 tone RU and 1 484 tone RUs	4 cases
1 996 tone RU and 2 484 tone RUs	2 cases
2 996 tone RUs	1 case
1 2x996 tone RU	1 case

In an embodiment of the current invention, the HE-SIG-B multiplexing format field is a fixed size irrespective of the bandwidth of the MU PPDU and is signaled in HE-SIG-A.

In an embodiment of the current invention, the HE-SIG-B multiplexing format is derived by the STA by blind decoding the common information section with different size hypothesis. The common information section for each section can have N sizes. The STA tries decoding code blocks corresponding to each sizes and only uses the information for which the CRC passes.

In an embodiment of the current invention, when non-contiguous channel bonding is indicated in HE-SIG-A, the edge RUs of the channels adjacent to the channels being nulled don't carry any information and no per STA information fields are carried for those RUs. Even if the RU arrangement indicates the presence or use of an RU, the presence of per-STA information fields is determined based on whether the non-contiguous channel bonding field is set to indicate certain unused channels. For example, if one sec channel is unused, the primary channel adjacent to the secondary channel as shown in Figure 38 will not use the edge RU. Depending on the arrangement, a 26 tone RU at the edge may be unused or a 52 tone edge RU may be nulled. For different channels being nulled, the common information containing the RU arrangement may not be carried. For those channels that carry data, common control and per-user signaling fields are mapped to their respective HE-SIG-B channels as per the mapping rules. Different types of channel bonding can be supported as shown in Figures 38, 39 and 40. Depending the nulling indicated in HE-SIG-A, the RU arrangement for the channels that carry data indicates where the data are carried and the edge RUs that need to be ignored as illustrated in the arrangement in Figure 41.

Figure 38 RU nulling for non-contiguous channel bonding

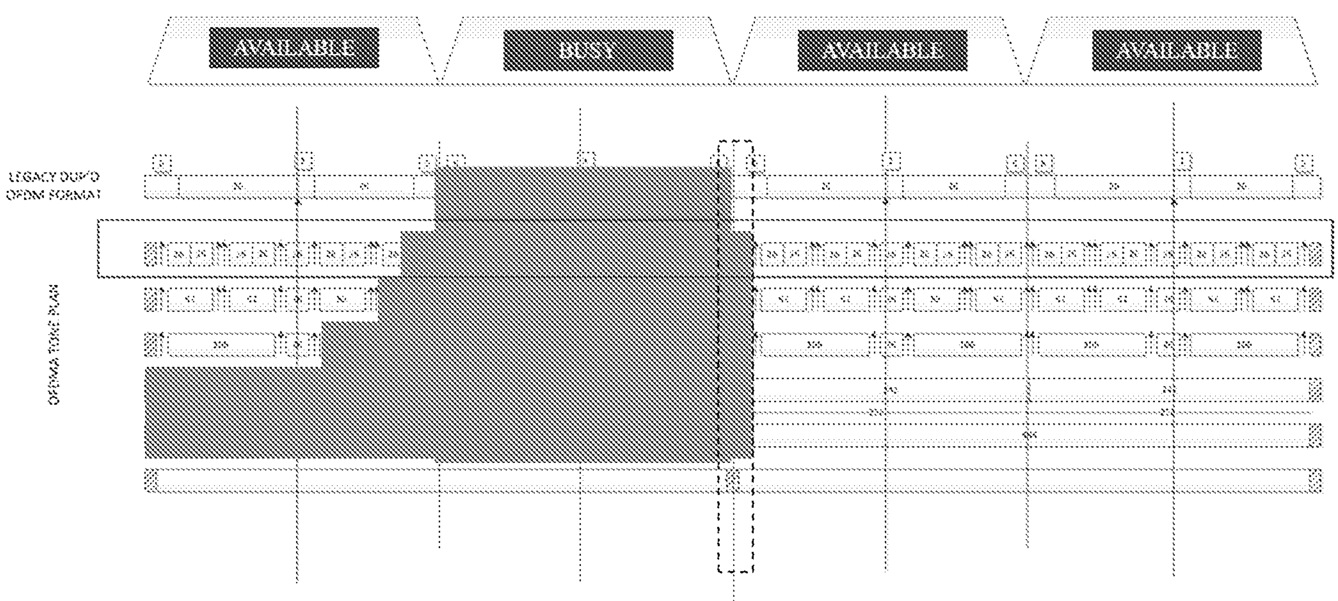


Figure 39 RU nulling (green) When a channel on the inside is nulled using non-contiguous channel bonding

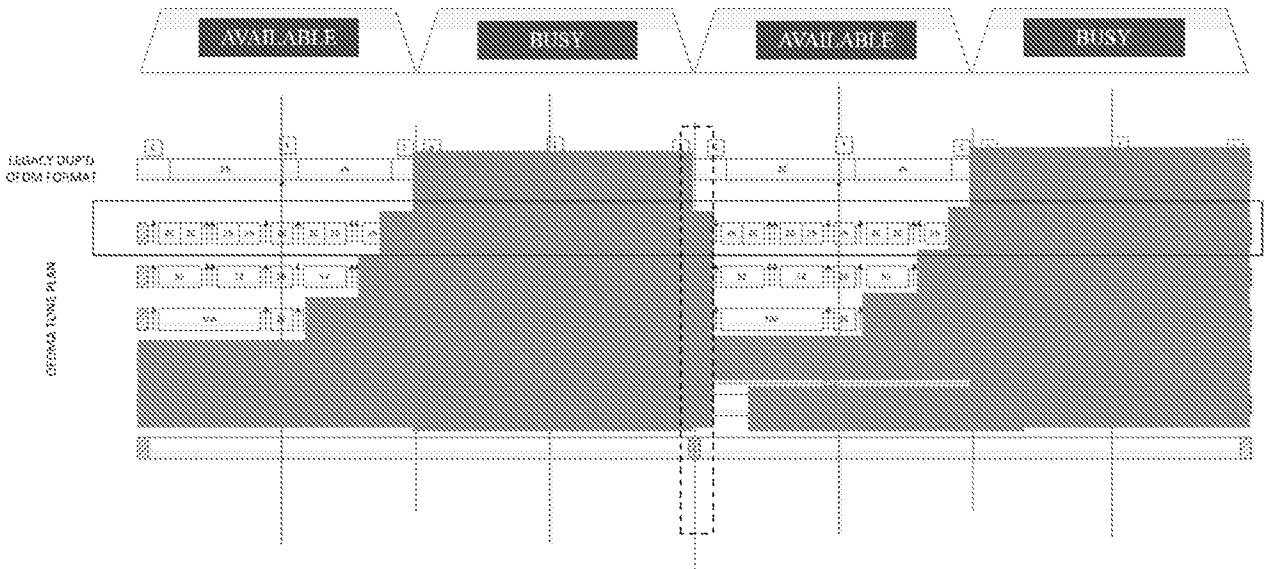


Figure 40 RU nulling when two channels are nulled

Figure 41 Processing at the STA to interpret RU arrangement when non-contiguous channel bonding is used.