

Methods to enable efficient wideband operations in local area networks using OFDMA.

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

Different versions of the 802.11 standards work in the unlicensed bands. Most versions operate in the 2.4GHz ISM band and the 5GHz UNII band, however there are also versions of the standard being defined for operation below 1 GHz (viz. 802.11ah, 802.11af). The latest version of the standard – 802.11ac operation is defined only for the 5GHz UNII band whose frequencies are shown in Figure 1. 802.11ac also defines channel operations in 20, 40, 80 and 160MHz bandwidths. Additionally, a non-contiguous 160MHz operation defined as 80+80 is also optionally supported by the standard. 802.11n defines operations both in the 5GHz UNII band and 2.4GHz ISM bands and allows 20 and 40MHz operations. This DOI covers operations in unlicensed bands where 802.11 systems are likely to be deployed and includes any new bands that are likely to be considered for unlicensed operations in the future (e.g. 3.5 GHz bands).

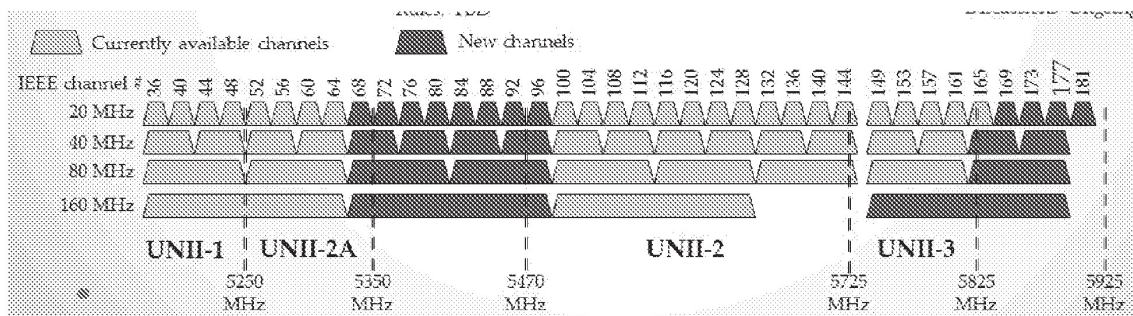


Figure 1 Available channels in the 5GHz UNII band

An illustration of the legacy devices and their bandwidths that can operate in the 5GHz UNII band is shown in Figure 2. These legacy devices can operate in any of the channels shown in Figure 1 thus fragmenting the available channel bandwidth further and reducing the number of contiguous channels available for channel bonding.

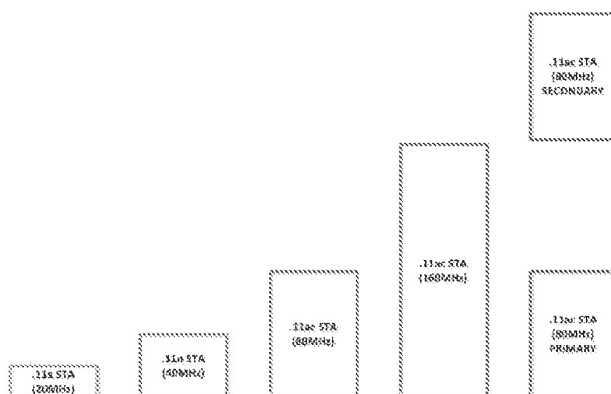


Figure 2 Legacy devices and their bandwidths of operation in the 5GHz UNII band.

Channel bonding procedures are based on extending the channel sensing mechanism to all bands that are being considered for channel bonding. For example, to aggregate 160MHz as shown in Figure 3, the primary channel goes through an AIFS + back-off procedure – the standard CSMA procedure during which the channel must be sensed free. The secondary channels are not held to the same sensing requirements as the primary - it is required that the secondary channels are sensed free for a PIFS duration just before the back off timer on the primary channel expires and the channel is sensed free. If both the primary and secondary channels are sensed free at the source, then data transmission is initiated by transmitting a request to send (RTS) message to the destination. If the destination also senses the secondary channels indicated in the RTS free for a PIFS duration before the RTS was received, then the destination responds with a clear to send (CTS) message after which data transmission can begin. The RTS and CTS are duplicated in both the primary and secondary channels such that all APs/STAs that communicate using the primary and secondary channels can set their NAV using the RTS and remain silent for the duration of data transmission. It is to be noted that in addition to the primary and secondary channels that are each 20MHz wide, the secondary40 (40MHz) and secondary80 (80MHz) are considered as one unit and a full channel back-off is completed i.e., even if one 20MHz segment in the secondary40 and secondary80 is occupied by a transmission from a legacy device, it is considered busy.

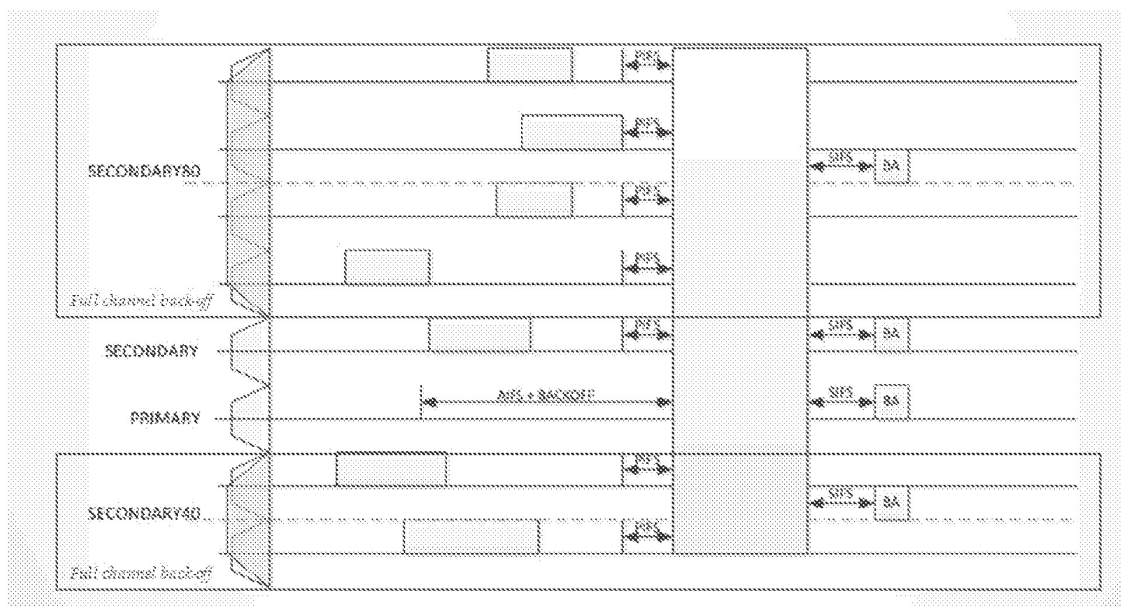


Figure 3 PIFS based channel bonding and access procedure in 802.11ac system

Additionally, static and dynamic operations are considered for channel bonding where the word *static* implies that the bandwidth specified in RTS is fixed and the receiving STA/AP transmits the CTS *only* if the bandwidth indicated in the RTS is sensed free for a PIFS duration before the RTS was received. *Dynamic* channel bonding means that the destination is free to respond with a subset of channels indicated by the bandwidth indicator in the RTS. The criterion for selecting the subset is as follows – the subset of channels must be sensed “free”, as defined above, for a modified CTS response. This accommodates scenarios where the bandwidth sensed free at the transmitter and receiver are different. An example of the dynamic channel bonding procedure is illustrated in Figure 4 where a 20MHz chunk in the Secondary80 is occupied allowing for only 80MHz aggregation to be possible even though the RTS indicated 160MHz channel operation.

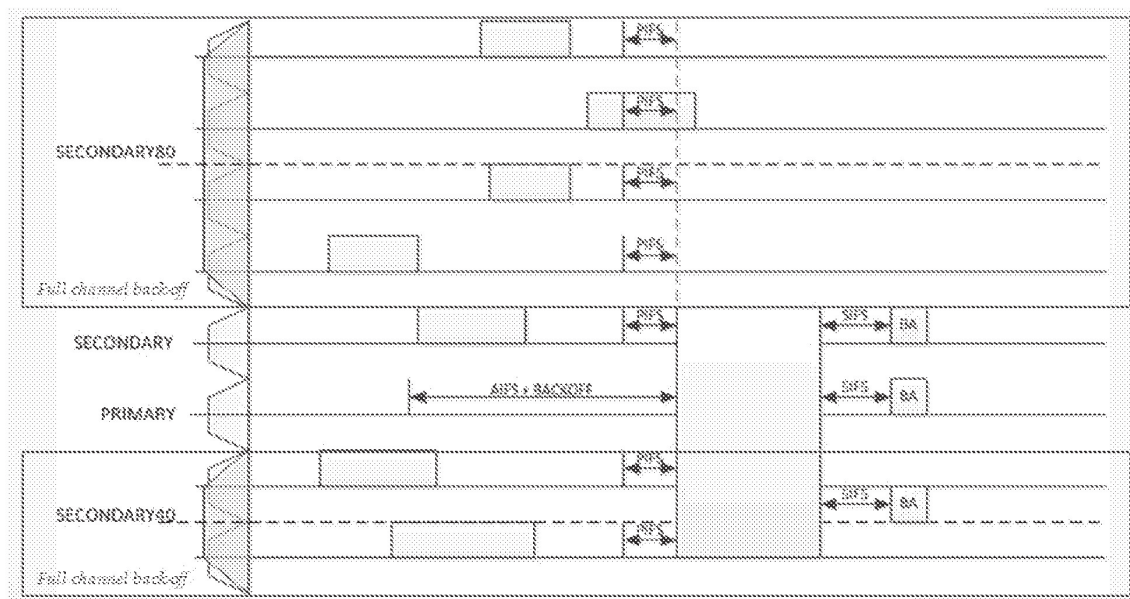


Figure 4 Channel Bonding with dynamic channel bandwidth capability in 802.11ac systems

There are two indicators necessary for the channel bonding procedure:

1. The *channel bandwidth* which requires 2 bits to support 20, 40, 80 and 160MHz.
2. The *dynamic/static channel bandwidth* operation indicator which requires 1 bit.

These three bits are embedded in 3 of the first 7 initialization bits of the scrambling sequence before the scrambling operation for the data bits pertaining to the RTS/CTS messages. During regular scrambling operation, the 7 bits $b_0, b_1, b_2, b_3, b_4, b_5, b_6$ are initialized pseudo-randomly in the scrambling apparatus shown in Figure 5. However, if it is bandwidth signaling RTS/CTS, the first three bits b_0, b_1, b_2 are used to indicate the 3 bits of bandwidth and its type. The RTS/CTS are duplicated and transmitted on all channels that are considered for data transmission. In each replica of the RTS/CTS transmission, the 3 of the 7 initialization bits of the scrambling sequence are used to indicate the channel bandwidth and if the channel bonding procedure is operating in static/dynamic modes.

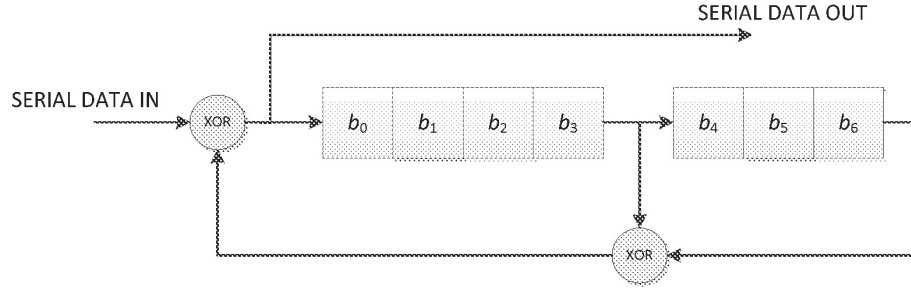


Figure 5 Scrambling Apparatus used for data scrambling in a IEEE 802.11 transmitter

In an earlier invention, we had described an embodiment where the PPDU transmission on the cleared channels uses an OFDM PHY where the OFDM mask is set to the sensing bandwidth. The sensing bandwidth is the total bandwidth sensed for transmission and cleared bandwidth is a subset of the sensing bandwidth that are unoccupied (free for transmission). The FFT/IFFT size is set to that of sensing bandwidth. Each 20MHz of the bandwidth is made up of a tone units where each tone unit contains N_{sc} subcarriers. For example, 20MHz segment is made up of 9 tone units where each tone unit contains 26 subcarriers and DC and guard subcarriers. When a particular 20MHz segment is the sensing bandwidth is not sensed free, then those tone units that are co-incident with the location of the 20MHz segment sensed busy are set to zero and not used as shown in Figure 6

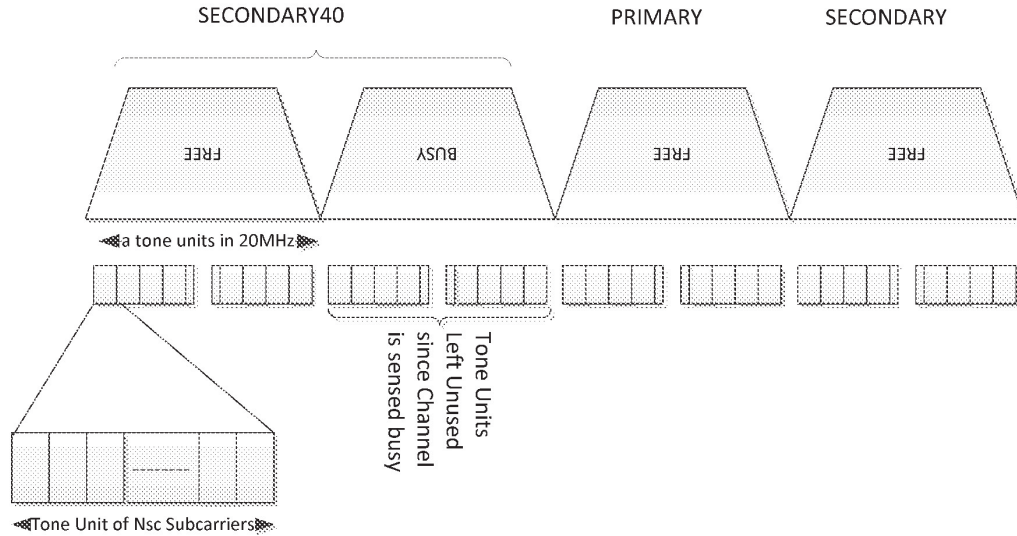


Figure 6 Tone units corresponding to the 20MHz channel sensed busy are left unused.

In an earlier invention, we had described an embodiment where the the PPDU transmission on the cleared channels uses an OFDM PHY where the OFDM mask is set to the sensing bandwidth. The sensing bandwidth is the total bandwidth sensed for transmission and cleared bandwidth is a subset of the sensing bandwidth that are unoccupied (free for transmission). The FFT/IFFT size is set to that of sensing bandwidth. If the sensing bandwidth is made up of multiple tone units each containing N_{sc} subcarriers.

When a particular segment BW_x of the bandwidth is sensed busy, then x tone units that are coincident with the location of the BW_x are set to zero and not used. The number of nulled tone units, x can be defined as

$$x = \left\lceil \frac{BW_x}{N_{sc}} \right\rceil$$

For example, if 20MHz segment is sensed busy and a tone unit is 26 subcarriers, then 13 tone units that are coincident with the 20MHz segment sensed busy are unused as illustrated in Figure 7.

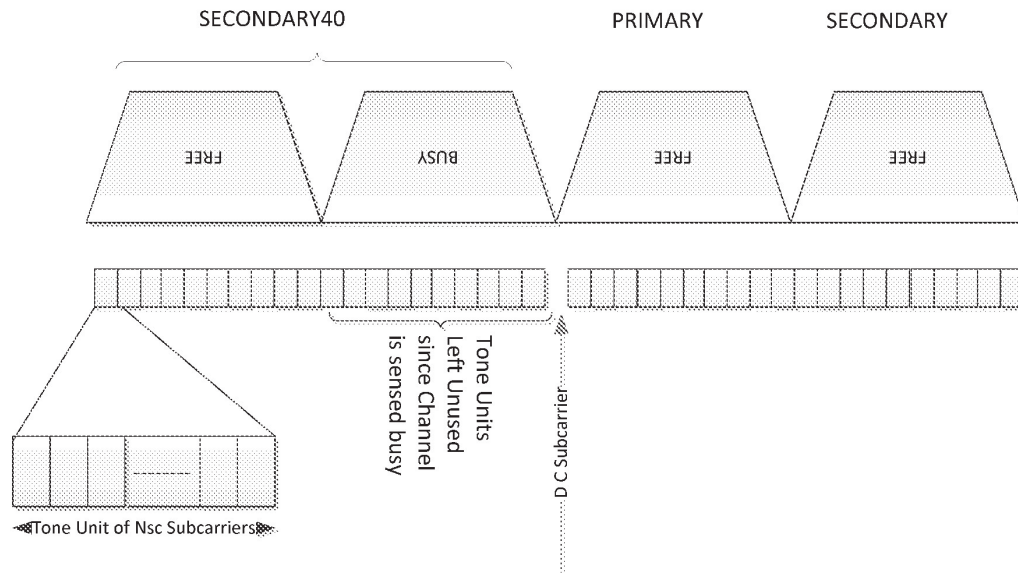


Figure 7 Nulling the tone-units co-incident with the bandwidth sensed busy

Now, the OFDMA structure for 802.11ax consists of the following building blocks called resource units (RU):

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 for 20 MHz, 40 MHz and 80 MHz OFDMA PPDU, 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 for 20 MHz, 40 MHz and 80 MHz OFDMA PPDU, respectively.
3. 106-tone RU consisting of 102 data tones and 4 pilot tones
 - Interleaver parameter following that of VHT 40 MHz mode in 802.11ac, except that $N_{col} = 17$
 - Possible locations of the 106-tone RUs are fixed for 20 MHz, 40 MHz and 80 MHz OFDMA PPDU, 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 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 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.

Figure 8 shows the placement and locations of the RUs for a 80MHz OFDMA PPDUs. An OFDMA PPDU can carry a mix of different resource unit sizes within each 242 resource unit boundary.

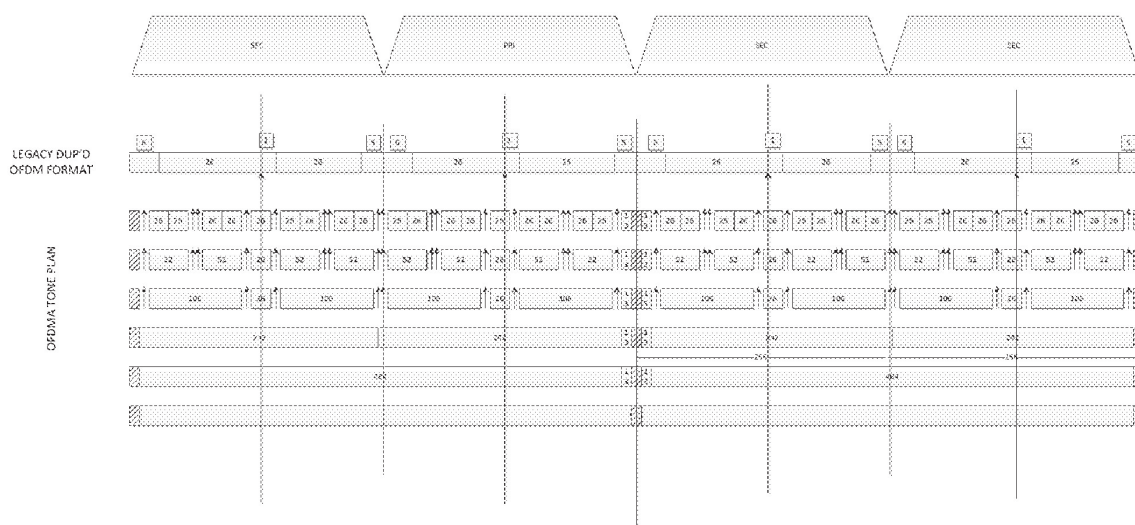


Figure 8 OFDMA Tone Plan for 80MHz consisting of RUs of different sizes and made up of 26 tone RU, 52 tone RU, 106 tone RU, 242 tone RU and 484 tone RU.

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.

The primary area of this invention is in the wireless local area networks that operate as per the 802.11 specifications. In particular, we focus on operations that deal with aggregation of bandwidth across multiple channels (often referred to as channel bonding).

For the purposes of this invention, we will consider the operations defined in 802.11ac systems as a basis and provide novel methods for obtaining more granular channel bonding and improve the bandwidth efficiency of the next generation 802.11 devices. In the current 802.11ac systems, the channel bonding procedure allows for bonding and operating only 40, 80 and 160MHz channel bandwidths. However, 802.11 systems must also allow for legacy devices that operate mostly at 20MHz and 40MHz bandwidths. In the presence of legacy devices and in dense deployments in particular, it is likely to be challenging to find 40, 80 and 160MHz of bandwidth that is free (idle) and available for transmission. Moreover, dense environments may not always lend themselves for contiguous bonding of channels and the situations may change quite dynamically. .

The teachings in this invention will further the state of the art by describing mechanisms for providing non-contiguous bonding of channels as well as more granular than allowed in the hitherto known art (IEEE 802.11 standards in particular). Specifically, we will look at nulling resource units in a OFDMA tone plan as a strategy to achieve goals of non-contiguous channel bonding.

The teachings in this invention describe mechanisms for providing non-contiguous bonding of channels as well as more granular than allowed in the hitherto known art (IEEE 802.11 standards in particular). Specifically, we will look at nulling resource units in a OFDMA tone plan as a strategy to achieve goals of non-contiguous channel bonding. Resource units of OFDMA that fall under the channel segment left unused are nulled. The nulling is always in units of resource units and not smaller

In an embodiment of the current invention, when a segment of the bandwidth is sensed busy, the RUs spanning the channel sensed busy are unused and left empty. Some RUs in the segment adjacent to the channel sensed busy, especially those that are closest to the channel segment sensed busy are also nulled to ensure compliance with spectral masks and out of band emission requirements. Specifically, the amount of nulling in the used channel segment adjacent to the one being left unused depends on the type of RUs used to compose the OFDMA PPDU. An RU is not partially nulled and nulling is always at a RU boundary. A 26tone RU that is the closest to the edge of the channel being nulled is the smallest RU size that needs to be nulled or left unused in the used band. That leaves the use of remaining 8 26tone RUs or a 3 52 tone RUs and 1 106 tone RUs in the used channel segment that is adjacent to the nulled channel. A 242 tone RU or higher sizes of RUs cannot be used in the channel segment adjacent to the nulled channel. An example of this nulling is illustrated in Figure 9 where a contiguous 60MHz operation is enabled by nulling RUs is shown.

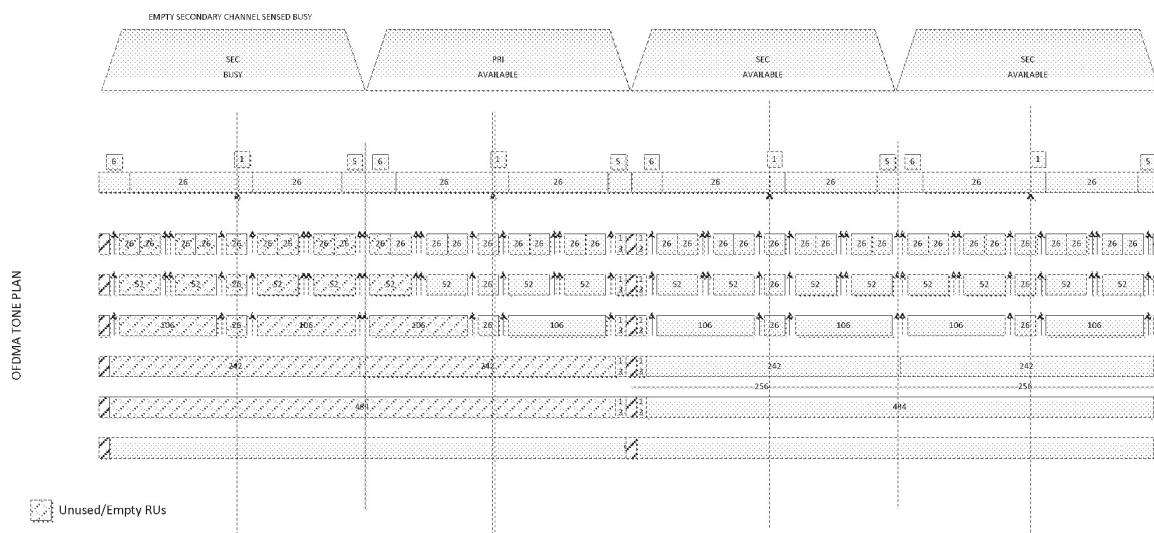


Figure 9 Nulling RUs to enable 20MHz nulling and enabling contiguous 60MHz operation in a 80MHz PPDU
RUs to be nulling and not used are indicated as unused empty RUs.

The requirement on the nulling is driven by the need to meet a spectral mask requirement that limits the out of band emissions from the bands being used to the bands that are not used in the immediate adjacency. The spectral mask requirements can be defined or implied. For example, when 20MHz at the edge of a 80MHz PPDU is nulling as shown in Figure 9, the spectral mask requirement for the band adjacent to the nulling segment can be defined by the tightest of the spectral masks corresponding to bandwidths greater than or equal to that being nulling. For example, the requirement for the out of band emissions in the channel adjacent to the nulling channel as shown in Figure 9 could be meet a 20MHz spectral mask requirement at the edge of the spectrum.

For some bandwidths, an RU can be split when around DC as shown in the OFDMA tone plan for 80MHz where a 26tone RU is split between around the DC tones. When one of the inner secondary 20MHz segments is to be nulling or left unused because it was sensed busy as shown in Figure 10, then the RU boundary to be maintained will be at the 26 tone unit that straddles the DC. In an embodiment of this invention, the primary channel adjacent to the secondary channel sensed busy can use the complete 20MHz OFDMA numerology all the way upto 242 tone RU and no additional nulling is required beyond the 13 tones at the edge of the segment as illustrated in Figure 10 to show a discontinuous 60MHz transmission using an 80MHz OFDMA PPDU. The requirement for the out of band emissions in the channels can be set based on the tightest of the spectral masks corresponding to the bandwidths that are greater than or equal to that being nulling.

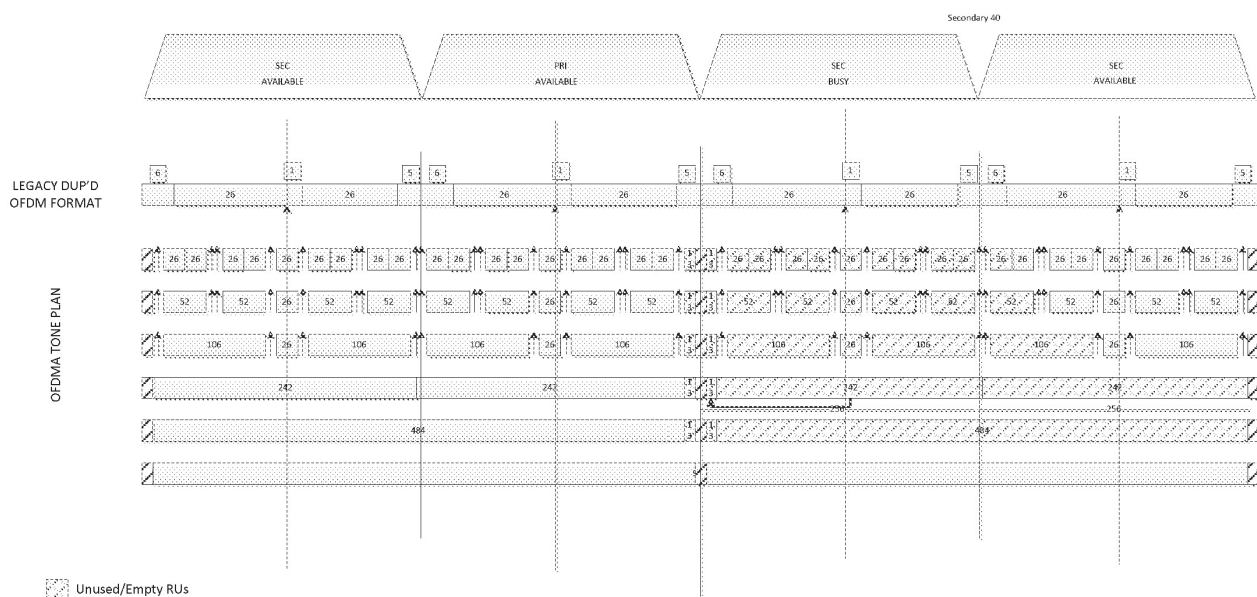


Figure 10 Nulling RUs to enable 20MHz nulling and enabling contiguous 60MHz operation in a 80MHz PPDU. RUs to be nulled and not used are indicated as unused empty RUs.

Nulling strategies in the previous two embodiments can be combined and used to null two 20 discontinuous 20MHz segments sensed busy in a 80MHz channel bandwidth as shown in Figure 11. The outer and the inner secondary 20MHz segments will follow their respectively nulling rules and the RUs in the channels adjacent to nulled channels will be nulled based on a 26tone RU .

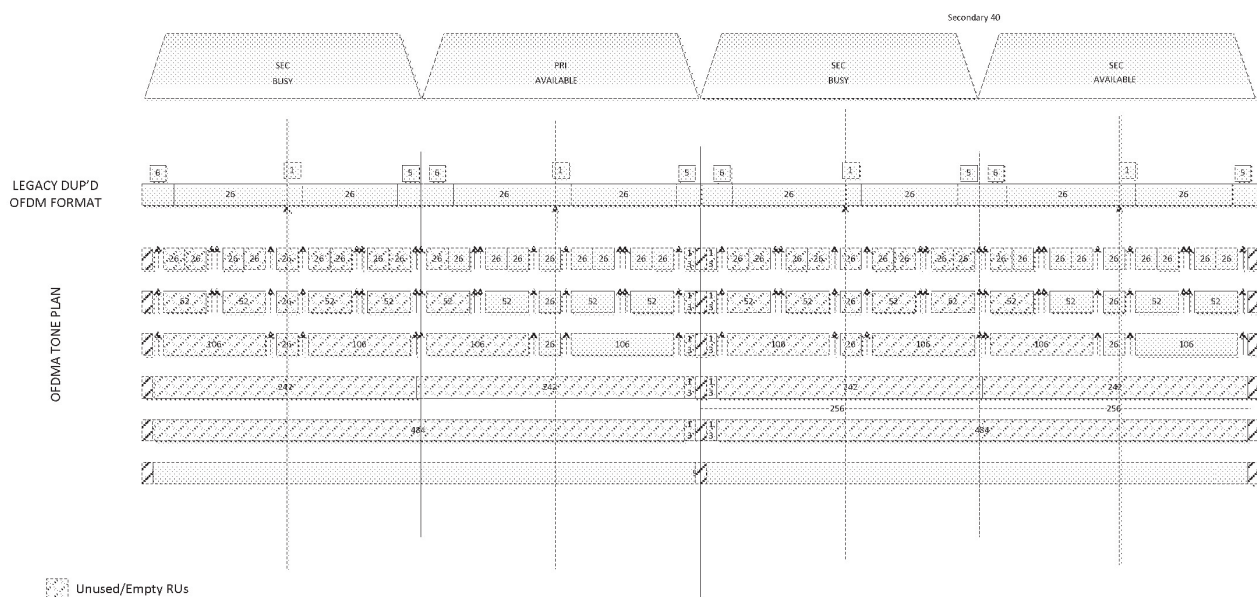


Figure 11 Nulling RUs to enable 40MHz nulling and enabling contiguous 40MHz operation in a 80MHz PPDU. RUs to be nulled and not used are indicated as unused empty RUs.

The channel sensed busy and nulled can be indicated in the physical layer convergence packet preamble. Once the unused channel is indicated, the RUs to be nulled are implicit as are RUs that are to be used in the transmission of the OFDMA PPDU.

As an example, the information about the channels being nulled can be carried as a bitmap or indicated using a code in the signal fields of the PHY header. Specifically, SIG-A fields could carry the code indicating the channels being left unused.

In an embodiment of the current invention, the PHY preamble is not carried in the channel being nulled as shown in Figure 12. It includes the legacy fields – L-STF, L-SIG, Repeated L-SIG (RL-SIG) as well as the HE-SIGNAL (HE-SIG-A and HE-SIG-B), HE-STF and HE-LTF fields. Since the legacy and HE-SIGNAL fields are carried in the duplication OFDM format, the tones corresponding to channel segment being unused are nulled.

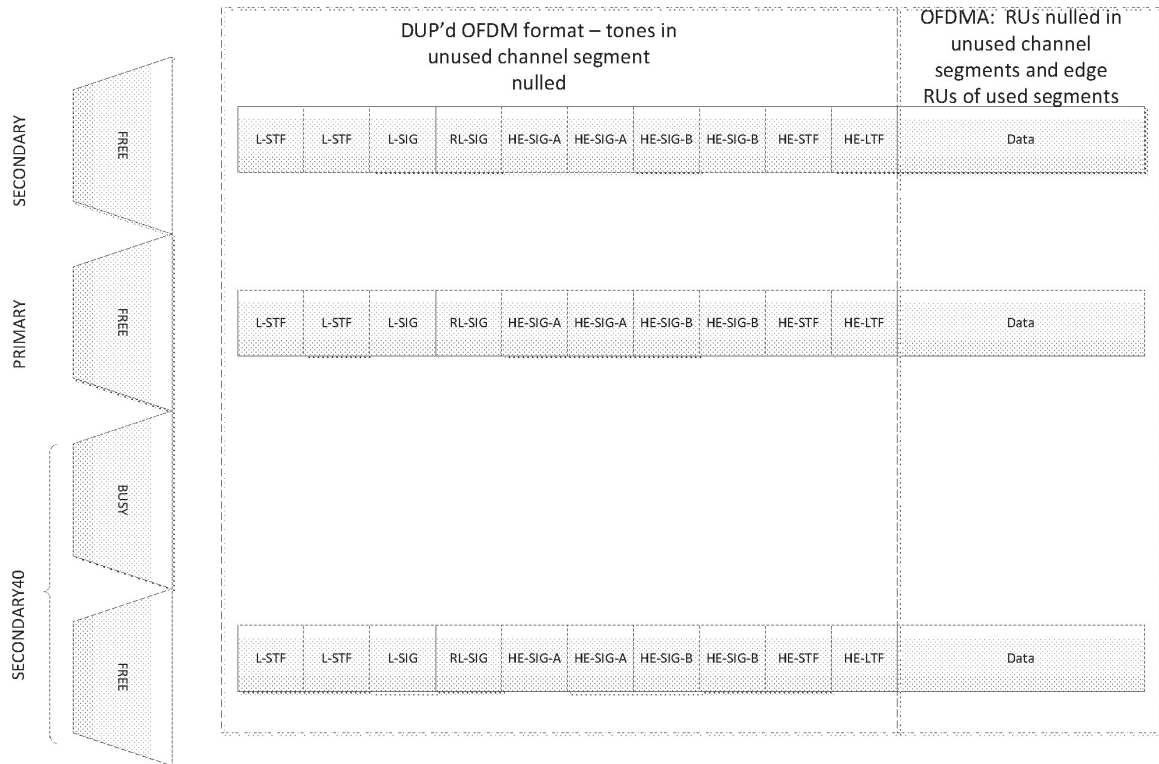


Figure 12 PHY PPDU transmission with 60MHz non-contiguous occupation in a 80MHz PPDU

Bandwidth signaling in HE-SIG-A

The bandwidth signaling in HE-SIG-A is constrained in bit width to indicate all combinations of used/unused 20MHz segments in the PPDU bandwidth. To signal used/unused 20MHz segments in the 20, 40, 80 and 160MHz PPDU BW, we need 7 bits in the bandwidth field. However, there is no room for 7 bits of bandwidth signaling in HE-SIG-A. Therefore, an embodiment of the DOI proposes to split the signaling between HE-SIG-A and HE-SIG-B – specifically using the RU signaling field of the HE-SIG-B common field. We take advantage of the duplication structure in the HE-SIG-B to signal the unused 20MHz segments in 80MHz and 160MHz PPDU. The HE-SIG-B duplication structure for a 80MHz and the primary 80MHz of a 160MHz (80+80) PPPDU is illustrated in Figure 13 where the two content channels of the HE-SIG-B are duplicated as follows: HE-SIG-B content channel #1 is carried in the primary and the U-20 (upper 20MHz segment) of the secondary40; HE-SIG-B content channel #2 is carried in the secondary 20 and L-20 (lower 20MHz segment) of the secondary40. Since the duplicated channels carry the exact same information, as long as one copy of each content channel is received (when applicable) or the unavailability of one of the

content channels is indicated in the bandwidth field, we can signal the use or disuse of a 20MHz segment in both 80MHz and 160MHz PPDU. The STA will use the indication in the bandwidth field to decipher both the bandwidth of the PPDU and the location of the content channel that it must decode in the HE-SIG-B. Since the 160MHz PPDU uses the same duplication structure over the secondary 80MHz as the primary 80MHz, it is sufficient if we indicate the availability of the HE-SIG-B content channels in the primary 80MHz. The STA does not have to begin processing the 160MHz PPDU until after decoding HE-SIG-B with this approach.

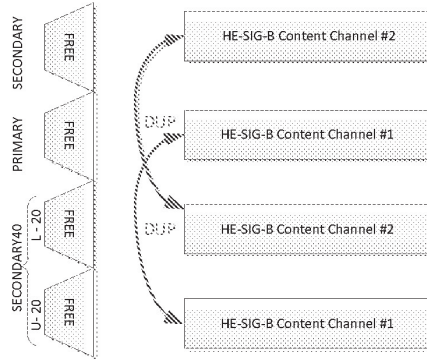


Figure 13 Duplication structure for the HE-SIG-B in the 80MHz PPDU or primary 80MHz of a 160MHz (80 + 80) PPDU.

Table 1 Table 1 3-bit Bandwidth Signaling sub-field in HE-SIG-A and its mapping to the PPDU bandwidth +HE-SIG-B channel indication

BW Signaling in HE-SIG-A	PPDU Bandwidth	HE-SIG-B Content Channel Indication		Description
		Content Channel 1	Content Channel 2	
000	20MHz	Primary	NA	
001	40MHz	Primary	Secondary	
010	80MHz	Primary	Secondary	
011	80MHz	Primary	20MHz in L20 of the Secondary 40	Secondary channel not used. HE-SIG-B Content channel 2 in secondary is not available.
100	80MHz	Primary	Not available	Secondary channel and L- 20MHz in secondary 40MHz not used. HE-SIG-B content

				channel 2 is not transmitted. No change in the size of the RU indication fields for the HE-SIG-B common.
101	160 (80 + 80)	Primary	Secondary	
110	160 (80 + 80)	Primary	20MHz in L20 if the Secondary 40	Secondary channel not used. HE-SIG-B Content channel 2 in secondary is not transmitted.
111	160 (80 + 80)	Primary	Not available	Secondary channel and L-20MHz in secondary 40MHz not used. HE-SIG-B content channel 2 is not transmitted. HE-SIG-B content channel 1 carries information for all 20MHz segments of secondary 80.

In an embodiment of the current invention, the bandwidth signaling sub-field in HE-SIG-A field of a HE-multi-user (MU) PPDU indicates both the PPDU bandwidth being used for OFDMA and availability of the HE-SIG-B content channels. An example illustration of a 3 bit bandwidth signaling sub-field in the HE-SIG-A and its mapping to the PPDU bandwidth and HE-SIG-B content channel indication is shown in **Error! Reference source not found.** The bandwidth and the content channel indication together tell the STA where the signaling for the OFDMA resource units is carried in the HE-SIG-B. The signaling for both used and unused portions are carried in the HE-SIG-B common portion. Some segments that are unused in the primary 80MHz are indicated by the bandwidth signaling in HE-SIG-A. For example, when bandwidth signaling field indicates 010 – indicates that the 80MHz PPDU is transmitted and all 4 20MHz segments are occupied – HE-SIG-B content channels are carried in primary and secondary channels with the duplication in secondary 40. When bandwidth signaling field indicates 011 – the PPDU bandwidth is 80MHz, and the secondary 20MHz channel is not used – HE-SIG-B content channel 2 is carried in the U-20MHz segment of the secondary40. Further information on the 20MHz segment (L-20) used or unused is carried in RU signaling of the the HE-SIG-B common channel. When bandwidth signaling field indicates 100 – the PPDU bandwidth is 80MHz, and the secondary 20MHz and U-20 of the secondary 40 is not occupied – the HE-SIG-B content channel 2 is not transmitted; content channel one carries signaling for

Primary and L-20 of the secondary40 which are occupied. In this case, the contents of the HE-SIG-B common don't change – contains 2 8-bit resource indexing fields for the primary and L-20 of the secondary 40 along with a bit for the center 26 tone RU. When 111 is signaled the PPDU is a 160MHz (80 + 80) PPDU, where the secondary20, secondary40 are not used. All signaling for the primary and the secondary80 is carried in HE-SIG-B content channel 1 – the contents of the HE-SIG-B common field change to accommodate signaling for the primary and the 20MHz segments for the secondary 80 including the center 26 tones.

In an embodiment of the current invention, the 8-bit RU signaling information signals an unoccupied 20MHz segment by signaling an unused 242 tone RU. In cases where a specific content channel-2 is signaled empty, the corresponding RU signaling information for the RUs that occupied the same bandwidth as the content channel signaled empty is signaled as unoccupied by transmitting the 8-bit RU signaling information. This information is redundant, but this ensures the signaling structure of the HE-SIG-B remains unaltered.

In an embodiment of the current invention, the nulling of the RUs on the edge of the occupied bands to align the tone-plan is derived based on the bandwidth signaling in the HE-SIG-A and the 8-bit RU signaling information.

In an embodiment of the current invention, when a 20MHz segment is nulled in the PPDU, the tone plan can be modified to be constructed from constituent tone plans of a smaller bandwidth. For example, the primary and secondary channels that are used will use a 40MHz tone plan and the 20MHz used in the secondary 40 will use a 20MHz tone plan as illustrated in Figure 14. All 20MHz segments are indicated using a 8 bit RU arrangement signaling in HE-SIG-B common in the two content channels. The center 26 tone RU indicated is kept as 0 – indicating non-use.

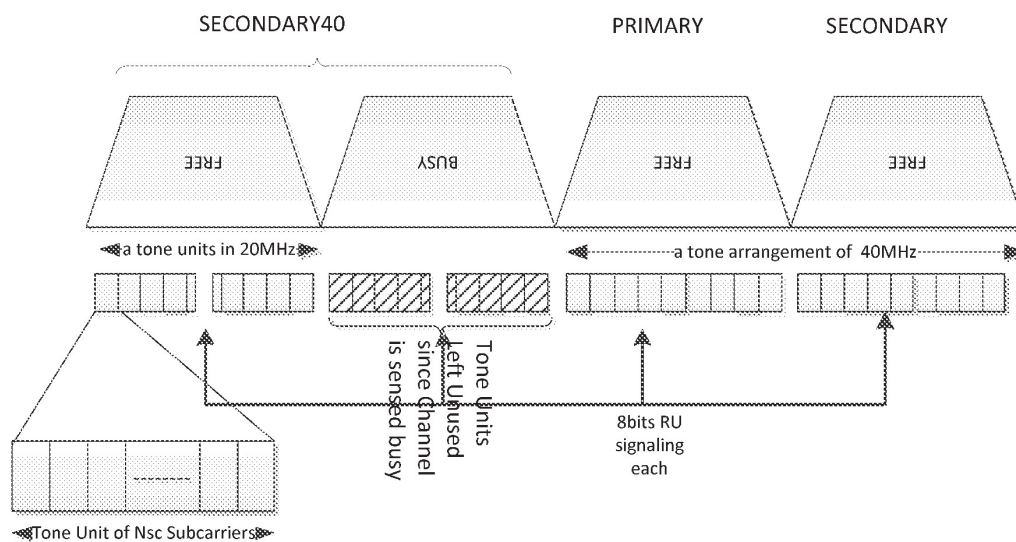


Figure 14 non-contiguous channel bonding for 80MHz PPDU with 20MHz tone plan for L20 in Secondary40 and a 40MHz tone plan for primary and secondary



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