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).

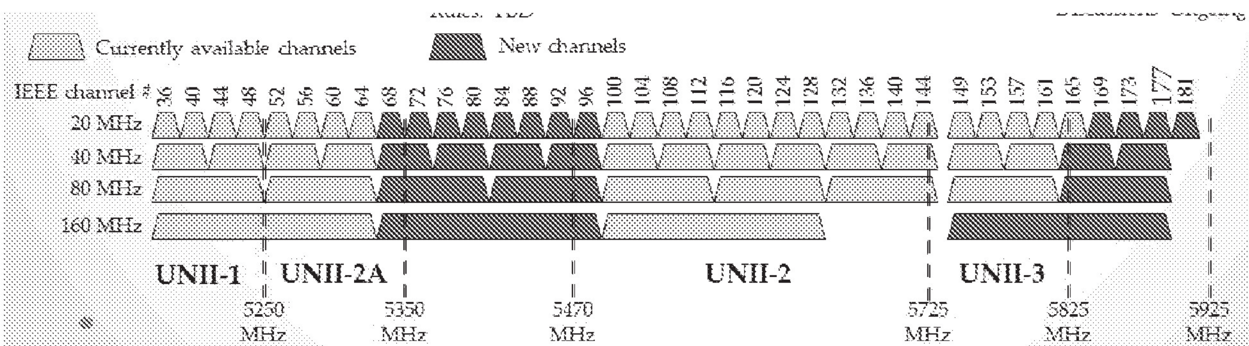

Figure 1 Available channels in the 5GHz UNII band

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.

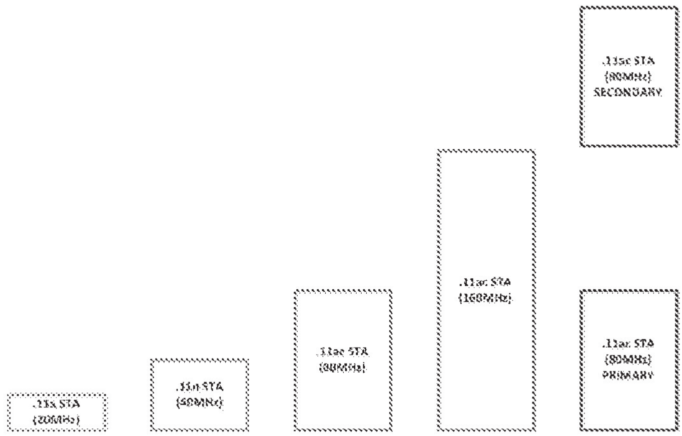

Figure 2 Legacy devices and their bandwidths of operation in the 5GHz UNII band.

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 intiated 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.

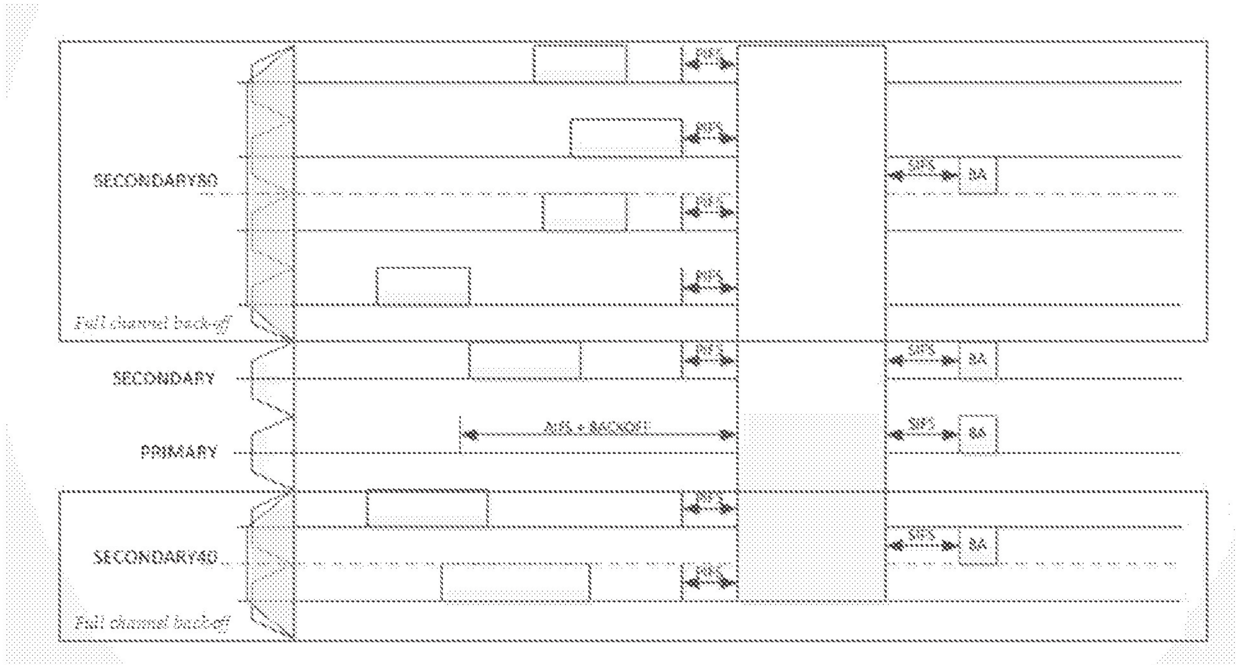

Figure 3 PIFS based chanel bonding and access procedure in 802.11ac system

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.

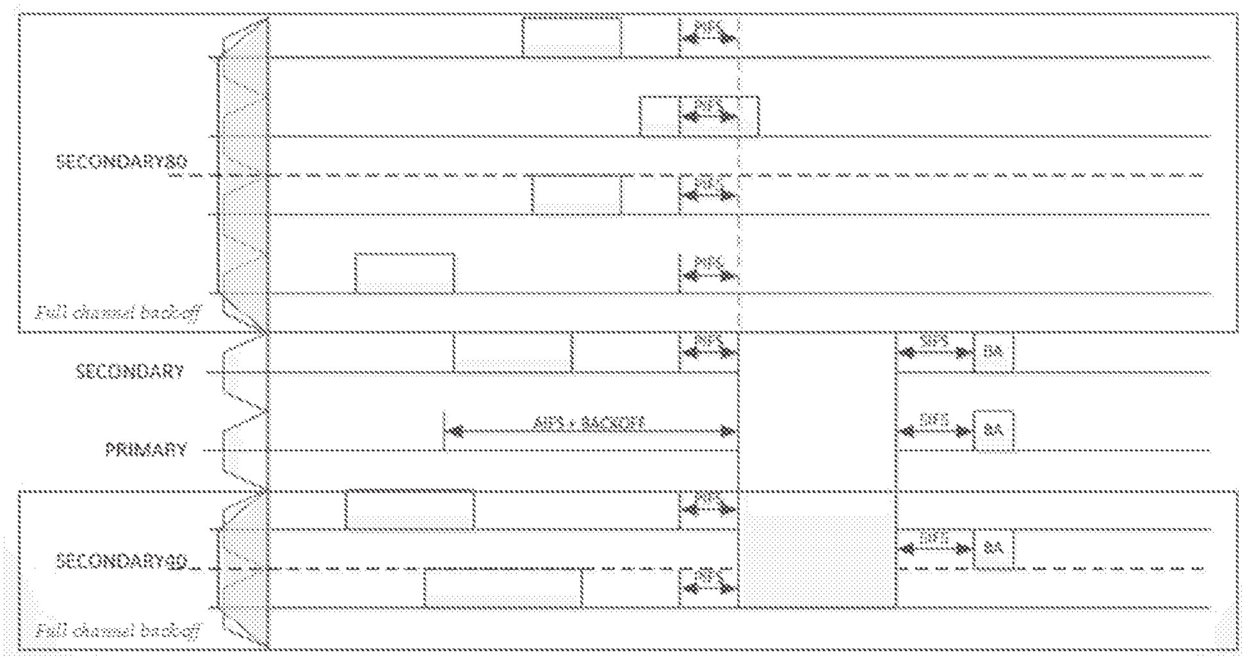

Figure 4 Channel Bonding with dynamic channel bandwidth capability in 802.11ac systems

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 b0, b1,b2,b3,b4,b5,b6 are initialized pseudo-randomly in the scrambling apparatus shown in Figure 5. However, if it is bandwidth signaling RTS/CTS, the first three bits b0,b1,b2are 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 initializaiton bits of the scrambling sequence are used to indicate the channel bandwidth and if the channel bonding procedure is operating in static/dynamic modes.

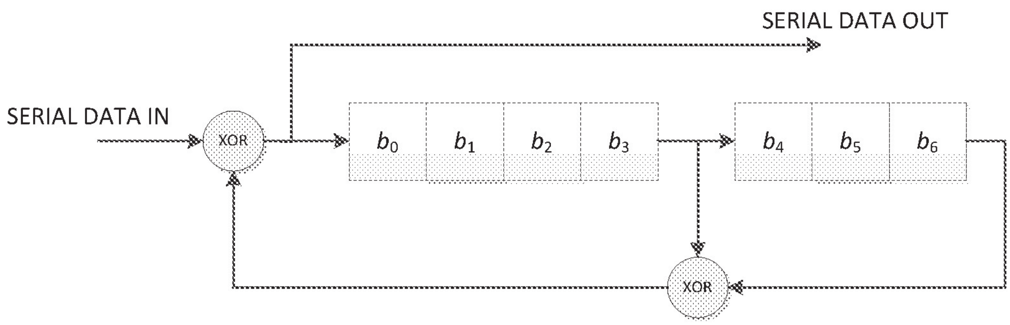

Figure 5 Scrambling Apparatus used for data scrambling in a IEEE 802.11 transmitter

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

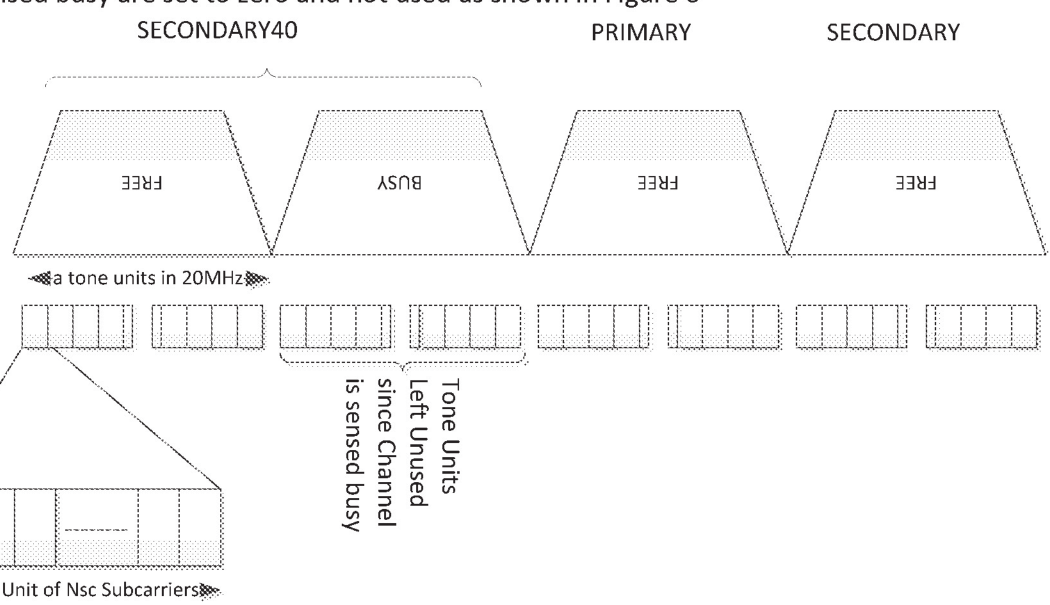

Figure 6 Tone units corresponding to the 20MHz channel sensed busy are left unused.

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.

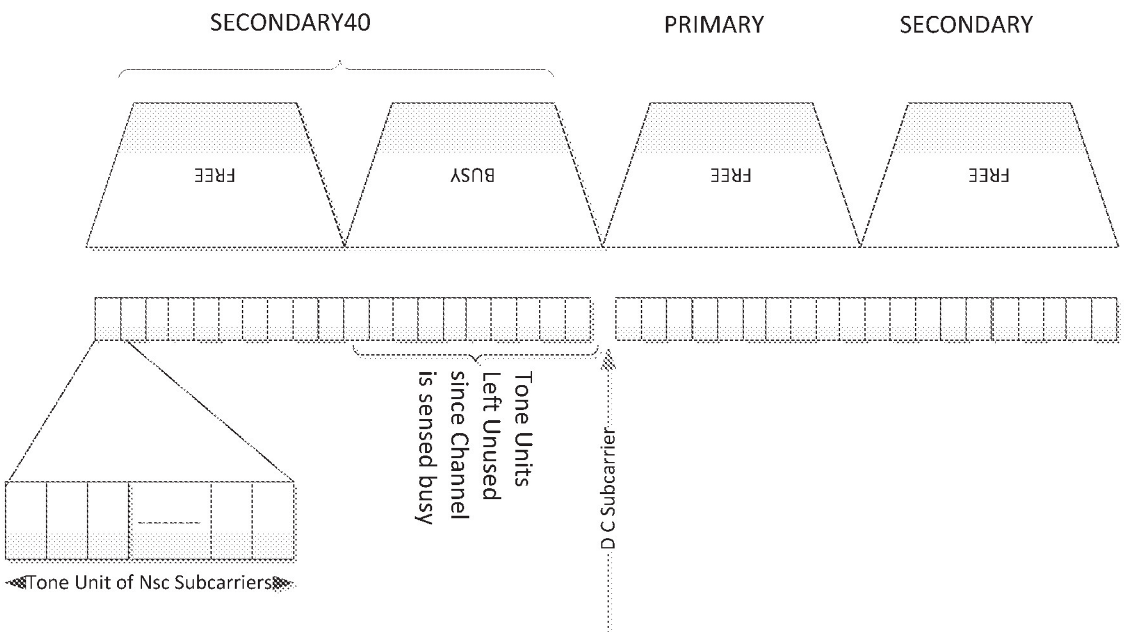

Figure 7 Nulling the tone-units co-incident with the bandwidth sensed busy

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 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 for 20 MHz, 40 MHz and 80 MHz OFDMA PPDUs, 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 Ncol = 17
   - Possible locations of the 106-tone RUs are fixed 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 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.

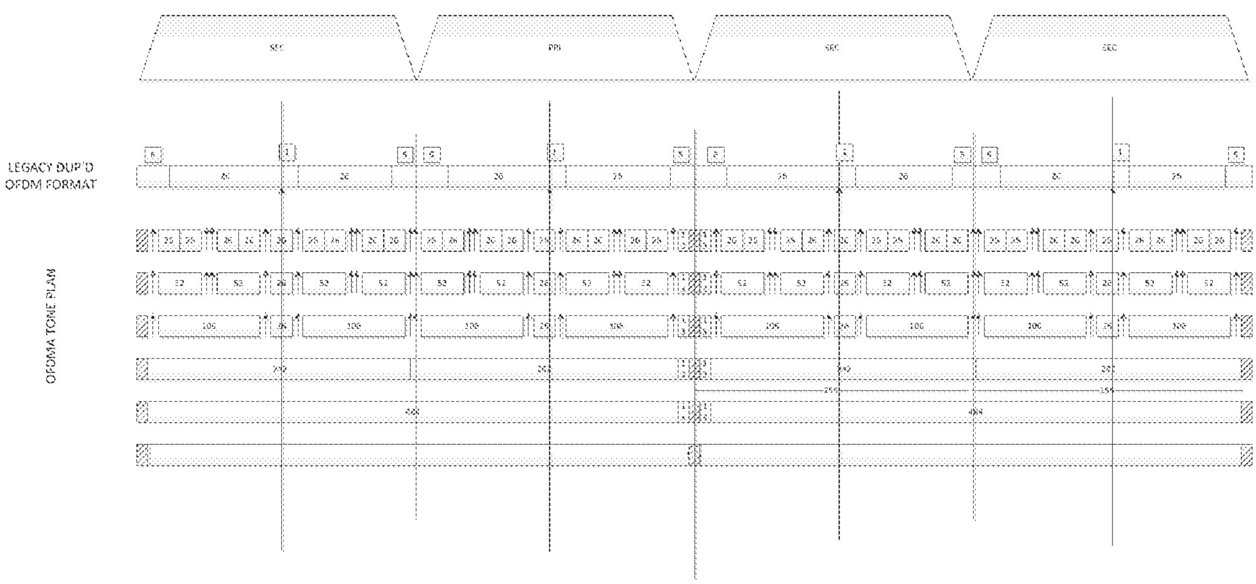

Figure 8 OFDMA Tone Plan for 80MHz consisting of RUs of different sizes and made up of 26 tone RU, 52 tone RU, 106 tone RU, 242 tone RU and 484 tone RU.

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 full 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.

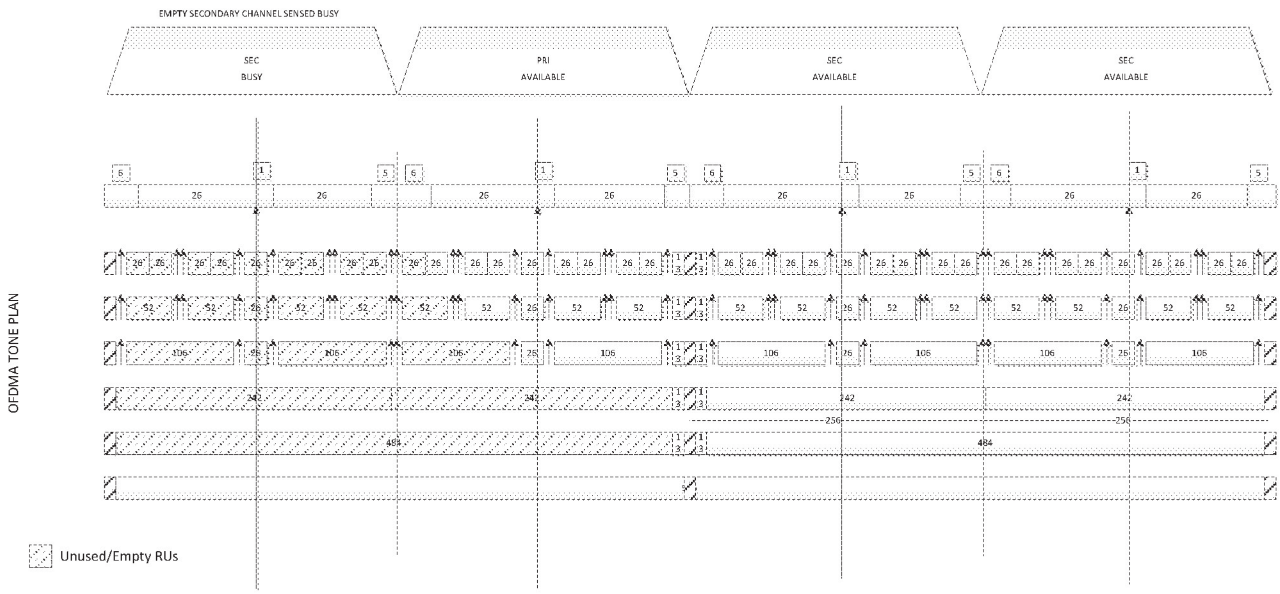

Figure 9 Nulling RUs to enable 20MHz nulling and enabling contiguous 60MHz operation in a 80MHz PPDU RUs to be nullled and not used are indicated as unused empty RUs.

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 nulled as shown in Figure 9, the spectral mask requirement for the band adjacent to the nulled segment can be defined by the tightest of the spectral masks corresponding to bandwidths greater than or equal to that being nulled. For example, the requirement for the out of band emissions in the channel adjacent to the nulled 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 nulled 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 rae greater than or equal to that being nulled.

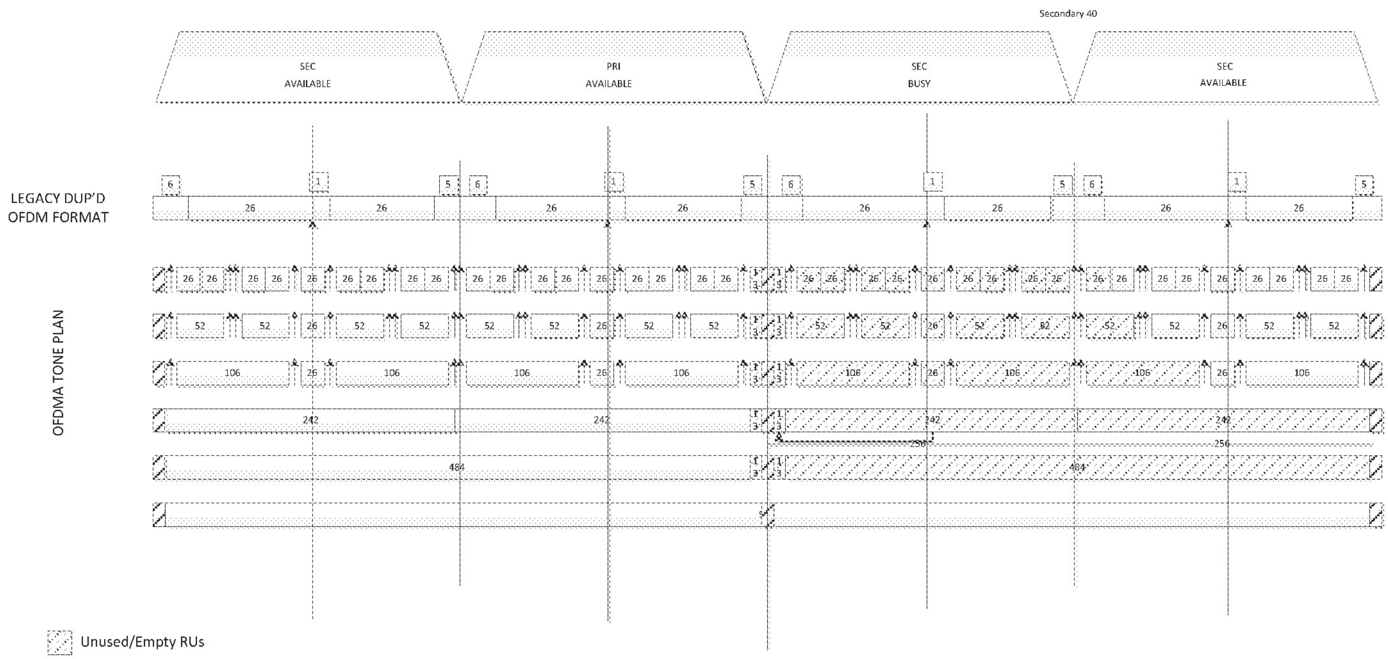

Figure 10 Nulling RUs to enable 20MHz nulling and enabling contiguous 60MHz operation in a 80MHz PPDU. RUs to be nullled and not used are indicated as unused empty RUs.

Nulling strategies in the previous two embodiments can be combined and used to null two 20 discontinous 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 .

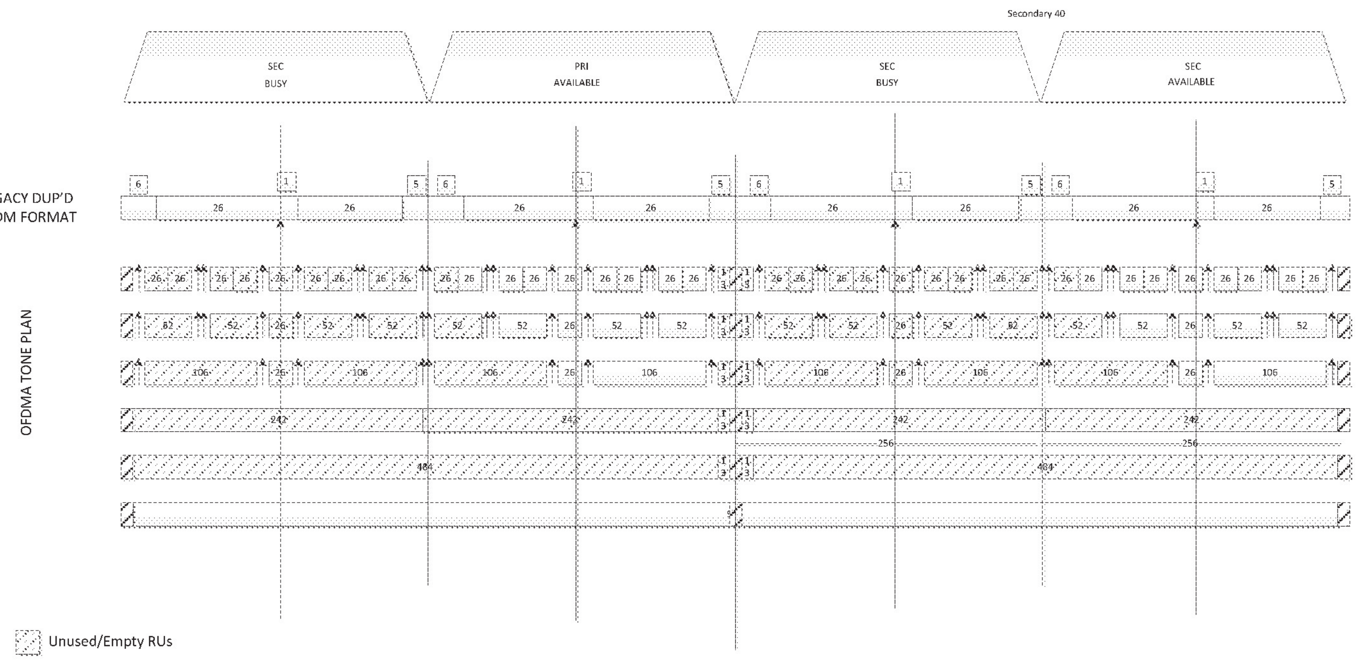

Figure 11 Nulling RUs to enable 40MHz nulling and enabling contiguous 40MHz operation in a 80MHz PPDU. RUs to be nullled and not used are indicated as unused empty RUs.

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.

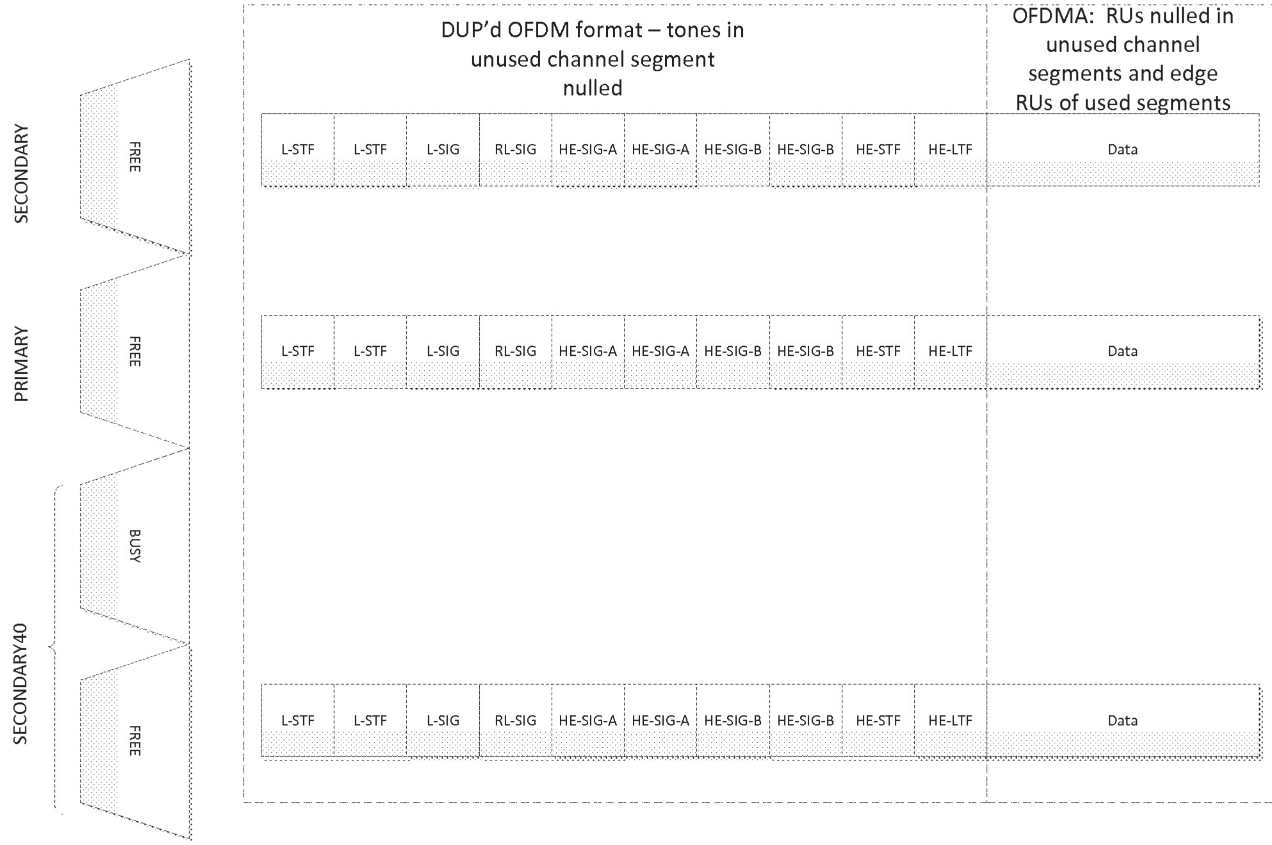

Figure 12 PHY PPDU transmission with 60MHz non-contiguous occupation in a 80MHz PPDU

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METHODS TO ENABLE EFFICIENT WIDEBAND OPERATIONS IN LOCAL AREA NETWORKS USING OFDMA

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