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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
62/145,428	04/09/2015		130	A303AA-013600PV		

CONFIRMATION NO. 2452

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FILING RECEIPT

OC000000074759510

Date Mailed: 04/23/2015

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The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 62/145,428**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No
** **SMALL ENTITY** **

Title

EFFICIENT PADDING SCHEME FOR IEEE 802.11AX

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Attorney Docket No.: A303AA-013600PV
Client Reference No.: P15-054US0-P1

PROVISIONAL PATENT APPLICATION

EFFICIENT PADDING SCHEME FOR IEEE 802.11AX

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INVENTION DISCLOSURE FORM

TITLE OF THE INVENTION:

EFFICIENT PADDING SCHEME FOR IEEE 802.11AX

BACKGROUND OF THE INVENTION:

Wireless LAN (WLAN) devices are currently being deployed in diverse environments. These environments are characterized by the existence of many access points and non-AP stations in geographically limited areas. In the next generation WLAN, the longer OFDM symbol duration with narrower subcarrier spacing can be used for outdoor operations and employing an OFDMA modulation for efficient spectrum utilization.

MOTIVATION OF THE INVENTION:

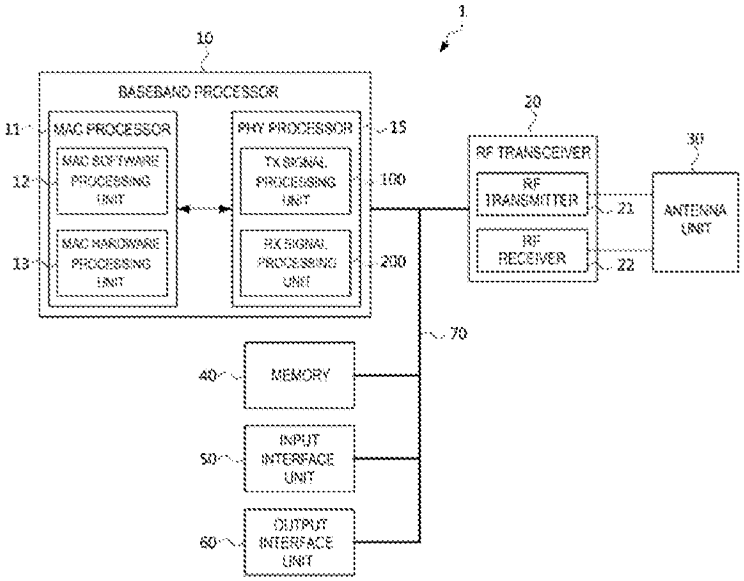
For the next generation of WLAN, 802.11ax (so called HEW, High Efficiency WLAN) requires robustness in outdoor channels, higher indoor efficiency. In 802.11ax, 4 times longer OFDM symbol duration of 12.8μsec (excluding cyclic prefix) is defined for outdoor operation and obtaining narrower subcarrier spacing. In cases of short packet transmission, however, lots are padding bits are required to fill out the all tone in the last OFDM symbol. By proposing a new method to make the last OFDM symbol, this efficiency can be overcome. This concept can be used to secure the longer decoding time in the receiver.

DETAILED DESCRIPTION:

In the following detailed description, only certain embodiments of the present invention have been shown and described, simply by way of illustration. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present invention. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements throughout the specification.

In a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of WLAN devices. The WLAN device may include a medium access control (MAC) layer and a physical (PHY) layer according to IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard. In the plurality of WLAN devices, at least one WLAN device may be an access point and the other WLAN devices may be non-AP stations (non-AP STAs). Alternatively, all the plurality of WLAN devices may be non-AP STAs in Ad-hoc networking. In general, the AP STA and the non-AP STA may be collectively called the STA. However, for easy description, only the non-AP STA may be called the STA.

The below drawing is a schematic block diagram exemplifying a WLAN device.



Referring the above drawing, the WLAN device 1 includes a baseband processor 10, a radio frequency (RF) transceiver 20, an antenna unit 30, a memory 40, an input interface unit 50, an output interface unit 60, and a bus 70.

The baseband processor 10 performs baseband signal processing, and includes a MAC processor 11 and a PHY processor 15.

In one embodiment, the MAC processor 11 may include a MAC software processing unit 12 and a MAC hardware processing unit 13. The memory 40 may store software (hereinafter referred to as "MAC software") including at least some functions of the MAC layer. The MAC software processing unit 12 executes the MAC software to implement the some functions of the MAC layer, and the MAC hardware processing unit 13 may implement remaining functions of the MAC layer as hardware (hereinafter referred to "MAC hardware"). However, the MAC processor 11 is not limited to this.

The PHY processor 15 includes a transmitting signal processing unit 100 and a receiving signal processing unit 200.

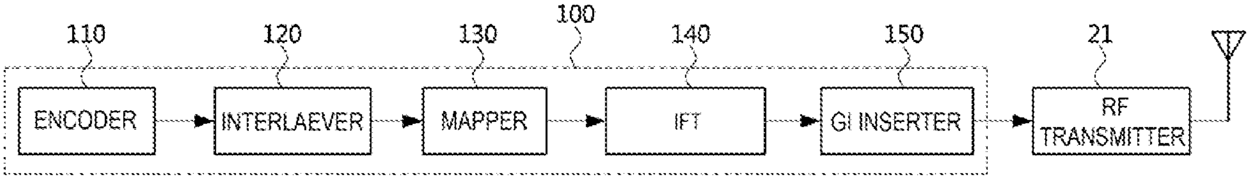
The baseband processor 10, the memory 40, the input interface unit 50, and the output interface unit 60 may communicate with each other via the bus 70.

The RF transceiver 20 includes an RF transmitter 21 and an RF receiver 22.

The memory may further store an operating system and applications. The input interface unit 50 receives information from a user, and the output interface unit 60 outputs information to the user.

The antenna unit 30 includes one or more antennas. When multiple-input multiple-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit 30 may include a plurality of antennas.

The below drawing is a schematic block diagram exemplifying a transmitting signal processor in a WLAN.



Referring the drawing, a transmitting signal processing unit 100 includes an encoder 110, an interlaever 120, a mapper 130, an inverse Fourier transformer (IFT) 140, and a guard interval (GI) inserter 150.

The encoder 110 encodes input data. For example, the encoder 100 may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder.

The transmitting signal processing unit 100 may further include a scrambler for scrambling the input data before the encoding to reduce the probability of long sequences of 0s or 1s. If BCC encoding is used in the encoder, the transmitting signal processing unit 100 may further include an encoder parser for demultiplexing the scrambled bits among a plurality of BCC encoders. If LDPC encoding is used in the encoder, the transmitting signal processing unit 100 may not use the encoder parser.

The interleaver 120 interleaves the bits of each stream output from the encoder to change order of bits. Interleaving may be applied only when BCC encoding is used. The mapper 130 maps the sequence of bits output from the interleaver to constellation points. If the LDPC encoding is used in the encoder, the mapper 130 may further perform LDPC tone mapping besides the constellation mapping.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit 100 may use a plurality of interleavers 120 and a plurality of mappers corresponding to the number of N_{SS} of spatial streams. In this case, the transmitting signal processing unit 100 may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers 120 or mappers 130. The transmitting signal processing unit 100 may further include a space-time block code (STBC) encoder for spreading the constellation points from the N_{SS} spatial streams into N_{STS} space-time streams and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming.

The IFT 140 converts a block of the constellation points output from the mapper 130 or the spatial mapper to a time domain block (i.e., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are used, the inverse Fourier transformer 140 may be provided for each transmit chain.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit 100 may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The CSD insertion may occur before or after the inverse Fourier transform. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

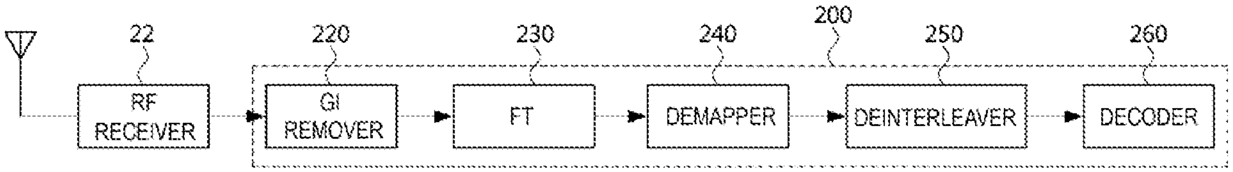
When the MU-MIMO is used, some blocks before the spatial mapper may be provided for each user.

The GI inserter 150 prepends a GI to the symbol. The transmitting signal processing unit 100 may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter 21 converts the symbols into an RF signal and transmits the RF signal via the antenna unit 30. When the MIMO or the MU-

INVENTION DISCLOSURE FORM

MIMO is used, the GI inserter 150 and the RF transmitter 21 may be provided for each transmit chain.

The below drawing is a schematic block diagram exemplifying a receiving signal processing unit in the WLAN.



Referring to the drawing, a receiving signal processing unit 200 includes a GI remover 220, a Fourier transformer (FT) 230, a demapper 240, a deinterleaver 250, and a decoder 260.

An RF receiver 22 receives an RF signal via the antenna unit 30 and converts the RF signal into the symbols. The GI remover 220 removes the GI from the symbol. When the MIMO or the MU-MIMO is used, the RF receiver 22 and the GI remover 220 may be provided for each receive chain.

The FT 230 converts the symbol (i.e., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT). The Fourier transformer 230 may be provided for each receive chain.

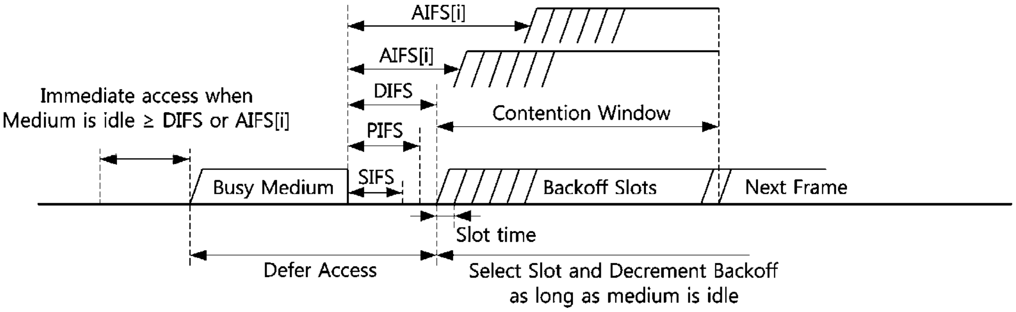
When the MIMO or the MU-MIMO is used, the receiving signal processing unit 200 may a spatial demapper for converting the Fourier transformed receiver chains to constellation points of the space-time streams, and an STBC decoder for despreading the constellation points from the space-time streams into the spatial streams.

The demapper 240 demaps the constellation points output from the Fourier transformer 230 or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper 240 may further perform LDPC tone demapping before the constellation demapping. The deinterleaver 250 deinterleaves the bits of each stream output from the demapper 240. Deinterleaving may be applied only when BCC encoding is used.

When the MIMO or the MU-MIMO is used, the receiving signal processing unit 200 may use a plurality of demappers 240 and a plurality of deinterleavers 250 corresponding to the number of spatial streams. In this case, the receiving signal processing unit 200 may further include a stream deparser for combining the streams output from the deinterleavers 250.

The decoder 260 decodes the streams output from the deinterleaver 250 or the stream deparser. For example, the decoder 100 may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder. The receiving signal processing unit 200 may further include a descrambler for descrambling the decoded data. If BCC decoding is used in the decoder, the receiving signal processing unit 200 may further include an encoder deparser for multiplexing the data decoded by a plurality of BCC decoders. If LDPC decoding is used in the decoder, the receiving signal processing unit 100 may not use the encoder deparser.

The below drawing exemplifies interframe space (IFS) relationships.

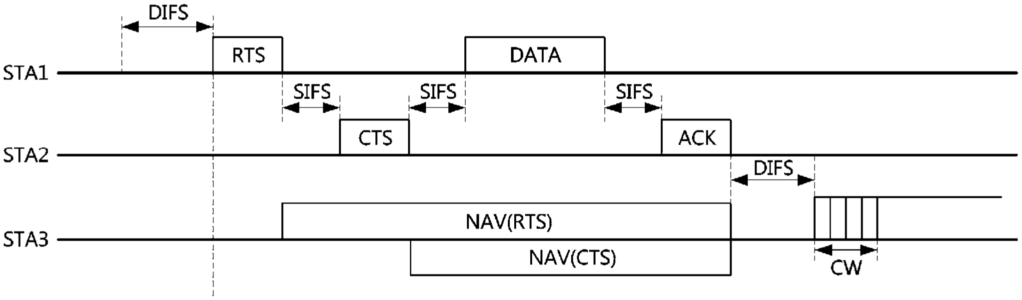


A data frame, a control frame, or a management frame may be exchanged between WLAN devices.

The data frame is used for transmission of data forwarded to a higher layer. The WLAN device transmits the data frame after performing backoff if a distributed coordination function IFS (DIFS) has elapsed from a time when the medium has been idle. The management frame is used for exchanging management information which is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame. The control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an acknowledgement (ACK) frame. In the case that the control frame is not a response frame of the other frame, the WLAN device transmits the control frame after performing backoff if the DIFS has elapsed. In the case that the control frame is the response frame of the other frame, the WLAN device transmits the control frame without performing backoff if a short IFS (SIFS) has elapsed. The type and subtype of frame may be identified by a type field and a subtype field in a frame control field.

On the other hand, a Quality of Service (QoS) STA may transmit the frame after performing backoff if an arbitration IFS (AIFS) for access category (AC), i.e., AIFS[AC] has elapsed. In this case, the data frame, the management frame, or the control frame which is not the response frame may use the AIFC[AC].

The below drawing is a schematic diagram explaining a CSMA (carrier sense multiple access)/CA (collision avoidance) based frame transmission procedure for avoiding collision between frames in a channel.



Referring the drawing, STA1 is a transmit WLAN device for transmitting data, STA2 is a receive WLAN device for receiving the data, and STA3 is a WLAN device which may be located at an area where a frame transmitted from the STA1 and/or a frame transmitted from the STA2 can be received by the WLAN device.

The STA1 may determine whether the channel is busy by carrier sensing. The STA1 may determine the channel occupation based on an energy level on the channel or correlation of signals in the channel, or may determine the channel occupation by using a network allocation vector (NAV) timer.

When determining that the channel is not used by other devices during DIFS (that is, the channel is idle), the STA1 may transmit an RTS frame to the STA2 after performing backoff. Upon receiving the RTS frame, the STA2 may transmit a CTS frame as a response of the CTS frame after SIFS.

When the STA3 receives the RTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS + CTS frame duration + SIFS + data frame duration + SIFS + ACK frame duration) by using duration information included in the RTS frame. When the STA3 receives the CTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS + data frame duration + SIFS + ACK frame duration) by using duration information included in the RTS frame. Upon receiving a new frame before the NAV timer expires, the STA3 may update the NAV timer by using duration information included in the new frame. The STA3 does not attempt to access the channel until the NAV timer expires.

When the STA1 receives the CTS frame from the STA2, it may transmit a data frame to the STA2 after SIFS elapses from a time when the CTS frame has been completely received. Upon successfully receiving the data frame, the STA2 may transmit an ACK frame as a response of the data frame after SIFS elapses.

When the NAV timer expires, the STA3 may determine whether the channel is busy by the carrier sensing. Upon determining that the channel is not used by the other devices during DIFS after the NAV timer has expired, the STA3 may attempt the channel access after a contention window according to random backoff elapses.

In conventional 802.11a/g/n/ac using OFDM modulation, the last OFDM symbol includes padding bits to fill out the whole data subcarriers in an OFDM symbol when the number of bits to transmit in the last symbol is less than the number of data bits per OFDM symbol, N_{DBPS}. This padding bits are added in MAC and PHY layers. When using the longer OFDM symbol with narrower subcarrier spacing, the efficiency due to padding decreases especially in transmission of short packets. In the worst case, we have to spend "12.8μsec + CP duration" to transmit only a few bit in the last symbol. To minimize such inefficiency, we proposed the different OFDM subcarrier mapping and modulation methods depending on the payload size. In this patent, we explain with 20MHz OFDM transmission with 256 subcarrier with specific values of the numbers of data subcarriers and interleaver sizes. Simple extensions to another bandwidth and the different numbers of data subcarriers and interleaver sizes and so on can be considered. Additionally, the extension to the OFDMA carrier can also be considered.

It is assumed that 802.11ax has different OFDM numerology in different resource bandwidth for OFDMA operation. The following transmission resource blocks are assumed.

- 24(data tones) + 2(pilots) => size of interleaver : 24
- 48(data tones) + 4(pilots) => size of interleaver : 48
- 102(data tones) + 4 or 6 (pilots) => size of interleaver : 102
- 234(data tones) + 8 (pilots) => size of interleaver : 234

Therefore, interleavers with the size of 24, 48, 102, and 234 are included in the 802.11ax devices and we want to reuse them for OFDM modulation in the last OFDM symbol. In another case, we can use N_{d3} ($\leq N_d/8$), N_{d2} ($\leq N_d/4$), N_{d1} ($\leq N_d/2$), and N_d data tones and the interleavers with sizes of N_{d3} ($\leq N_d/8$), N_{d2} ($\leq N_d/4$), N_{d1} ($\leq N_d/2$), and N_d where N_d denote the number of total data subcarriers in a 20MHz OFDM symbol. From here, we will explain with the specific numbers of 24, 48, 102, and 234 for N_{d3}, N_{d2}, N_{d1}, and N_d, respectively.

The number of used data tones in the last OFDM symbol can be obtained by the payload size (the number of bytes), modulation and coding scheme (MCS), resource bandwidth, STBC option, and number of space-time streams. Depending on the number of used data tones in the last OFDM symbol (Here, we regarded the subcarrier, where the part of bits are used in the mapping symbol, as a used subcarrier), we can divide into 4 cases. In each case, the number of used data tones in the last symbol before padding, the number of padding bits (subcarriers), the used data tone indices, and the size of the interleaver are explained as follows: (We will continue to use the terminology of case1, 2, 3, and 4 in the patent.)

- case 1: the number of used data tones in the last symbol before padding ≤ 24 (N_{d3})
  Pad the dummy bits to make (fill) 24 (N_{d3}) data tones
  These tones allocated to data subcarriers with index of 8k (k= ±1, ±2,…)
  Interleaver size = 24 (N_{d3})

- case 2: 24 (N_{d3}) < the number of used data tones in the last symbol before padding ≤ 48 (N_{d2})
  Pad the dummy bits to make (fill) 48 (N_{d2}) data tones
  These tones allocated to data subcarriers with index of 4k (k= ±1, ±2,…)
  Interleaver size = 48 (N_{d2})

- case 3: 48 (N_{d2}) < the number of used data tones in the last symbol before padding ≤ 102 (N_{d1})
  Pad the dummy bits to make (fill) 102 (N_{d1}) data tones
  These tones allocated to 102 (N_{d1}) data subcarriers with index of 2k (k= ±1, ±2,…)
  Interleaver size = 102 (N_{d1})

- case 4: 102 (N_{d1})< the number of used data tones in the last symbol before padding ≤ 234 (N_d)
  Pad the dummy bits to make (fill) 234 (N_d) tones
  These tones allocated to 234 (N_d) data subcarriers with index of k (k= ±2, ±3,…) (0, ±1 indexed tones are assumed to be DC tones)
  Interleaver size = 234 (N_d)

In cases 1,2 and 3, every 2^{nd}, 4^{th} and 8^{th} subcarriers are used for OFDM modulation in the last symbol and then the waveforms of the IDFT output have the repetition property. In case 1, the IDFT output has 8 repeated waveforms with 8*1.6μsec, i.e. 1.6μs waveform is repeated 8 times. In case 2 and 3, the IDFT output has 4 and 2 repeated waveforms with 4*3.2μsec and 2*6.4μsec, respectively. In case 4, the all data subcarriers are used and there is no repetition. This is the same padding rules in the legacy systems are used with 234 data subcarriers.

To save the transmission time, the transmitter sends the only one repeated waveform with CP for the last OFDM symbol. Then we can save transmission duration of 7*1.6μsec, 3*3.2μsec and 1*6.4μsec for cases 1, 2, and 3, respectively, as shown in Fig. 1. To indicate the actual length of a packet, the structure of the last OFDM symbol, i.e., length of the last symbol, is considered in the length information in the legacy SIGNAL (L-SIG) field as in Fig. 2.

Instead of filling all data subcarriers of 24 or 48 or 102 or 234, the unfilled subcarriers can be replaced with the null subcarriers, i.e., "0" is transmitted. The unfilled data tones are as the dummy bits in the interleaver. Therefere, the same size of interleavers are used. Then, we can save the transmission power in the last symbol or boost the used subcarriers in the last symbol.

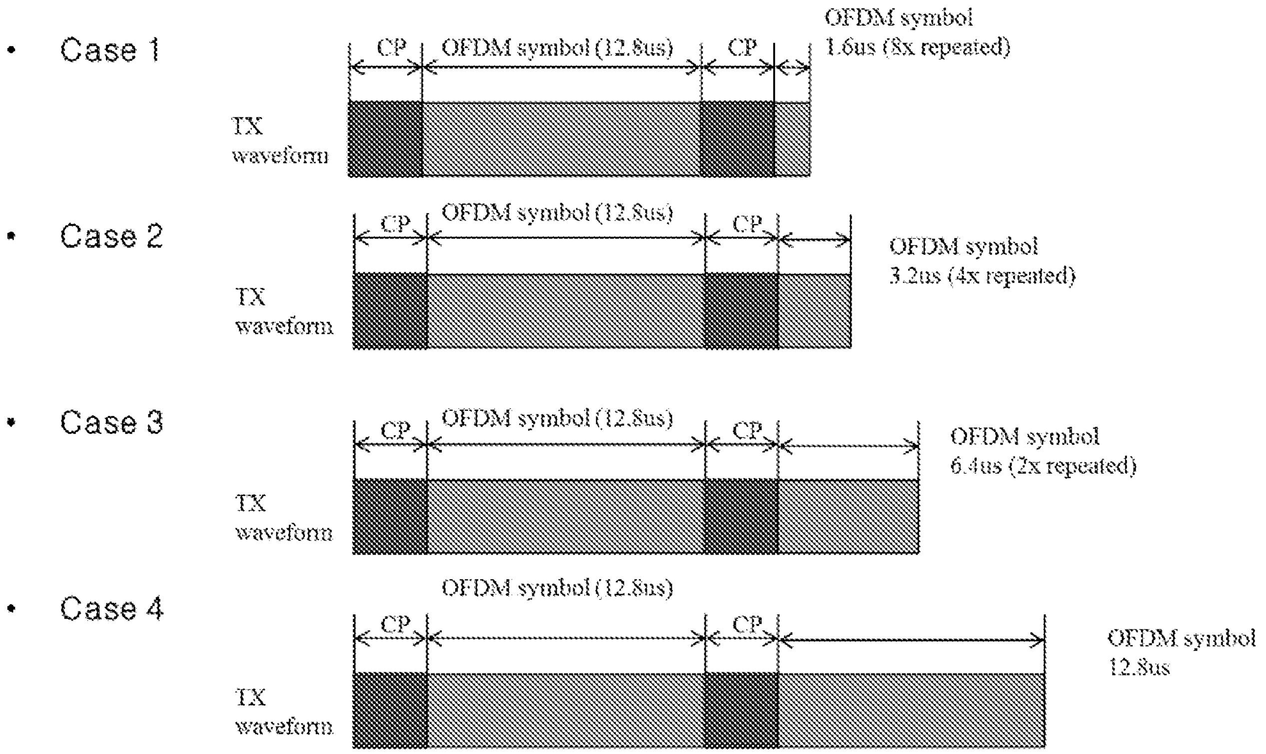


Fig. 1. OFMD symbol structure of the last 2 symbols depending on Case 1 to 4 (the number of used data tones before padding).

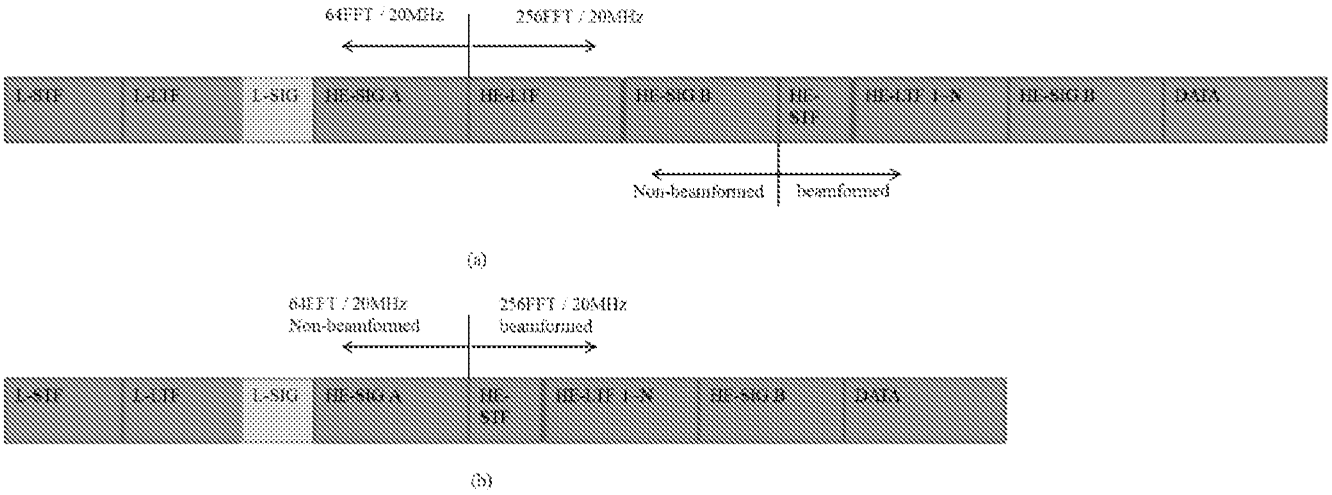


Fig. 2. Packet structures of IEEE 802.11ax (two examples).

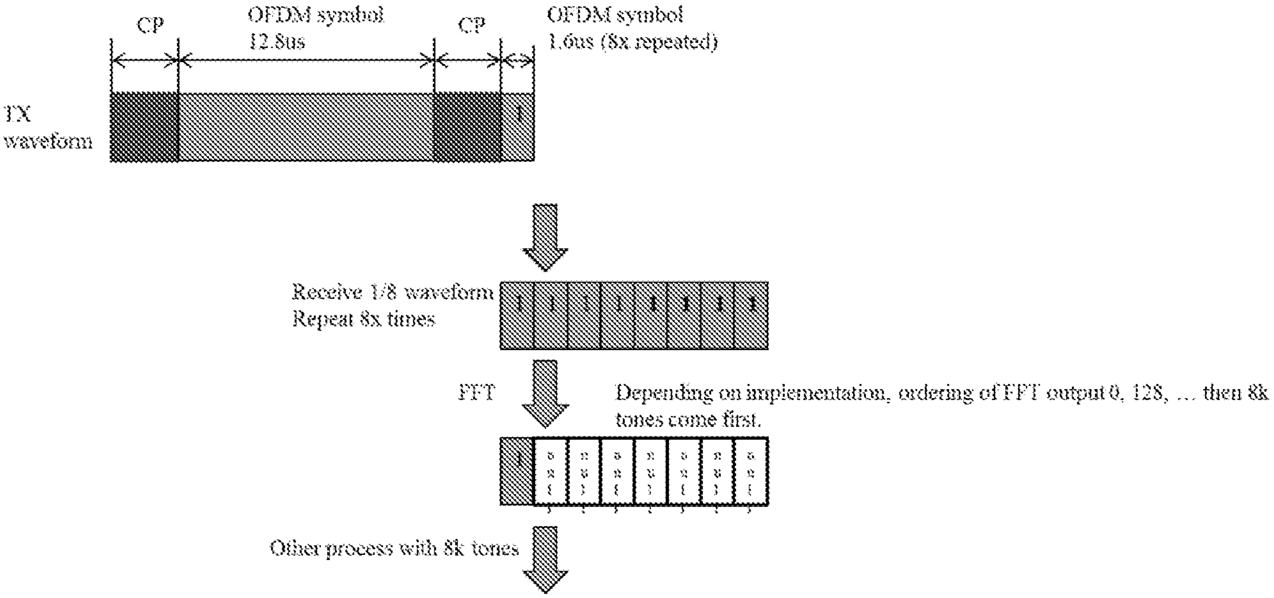


Fig. 3. Decoding process for case 1.

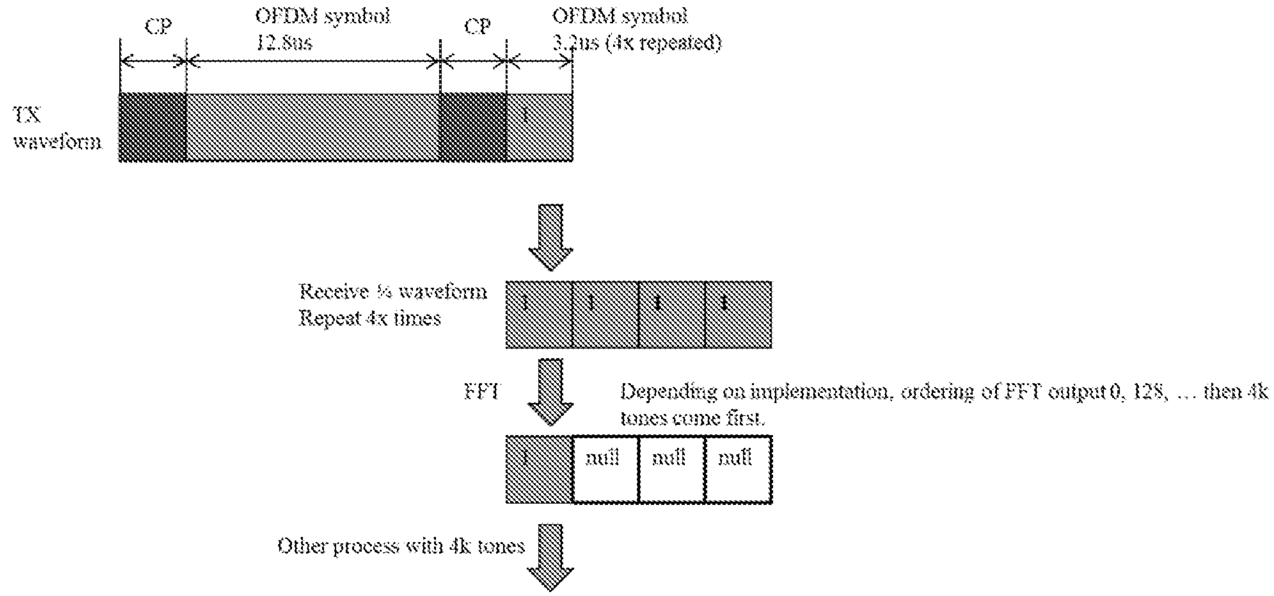


Fig. 4. Decoding process for case 2.

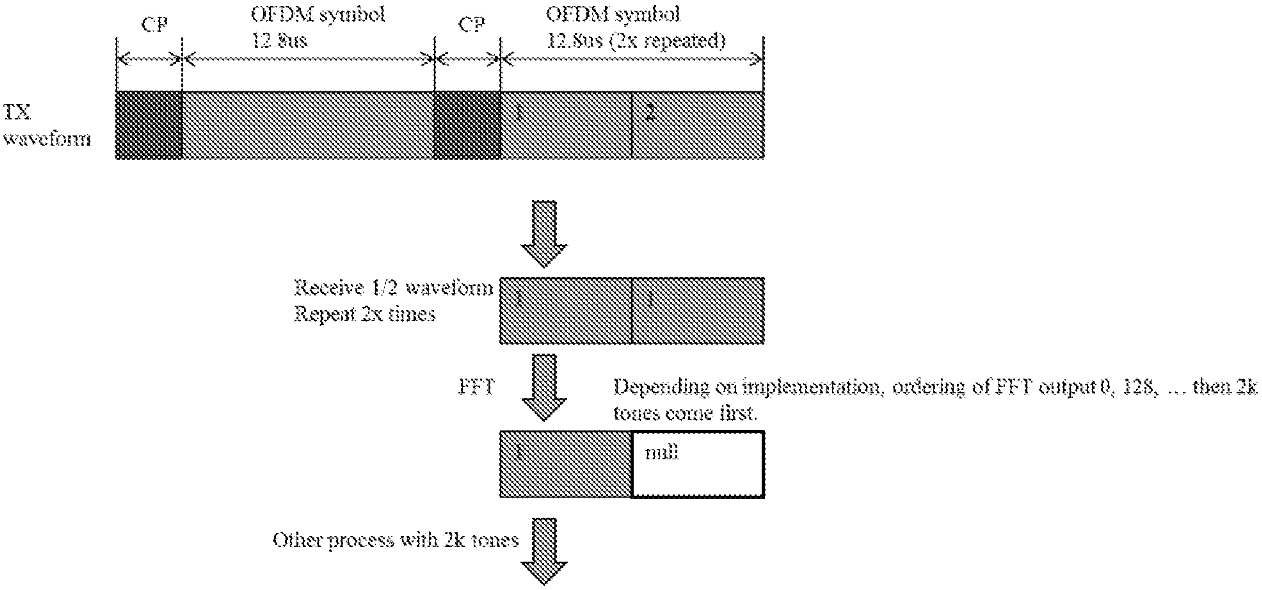


Fig. 5. Decoding process for case 3.

At the receiver, the last symbol for case 1 with the length of 1.6μsec is decoded as in Fig. 3. After receiving 1.6μsec, i.e., one repeated waveform, Repeat this waveform 7 times and input the repeated waveform to 256-point FFT. Due to butterfly architecture of an FFT operation, the 8k (k= ±1, ±2, …) indexed tones are outputted first and then the other unused tones later. The used data tones are performed the de-mapping process according to the MCS information and then deinterleaved with the size of 24. The remaining receiving processes are same as the conventional cases. The receiver operations for cases 2 and 3 are shown in Fig 4 and 5. These are the same as that for case 1 except the repetition time (3 and 1), the duration of the last symbol (3.2μsec and 6.4μsec) and deinterleaver size (48 and 102). For case 4, the decoding process is the same as conventional one except the FFT size (256) and deinterleaver size (234) because all data carriers are used.

Next, we explain how to assign pilots in the last symbol. The following three possible options can be considered for pilot insertion in the last symbol. For option 2 and 3, the different pilot allocation can be considered depending on which cases are adopted in the standard.

Option 1:

In the last symbol, pilot is not transmitted.

Option 2:

The pilot tones for 20MHz band are allocated in tones with 8k (k= ±1, ±2,…) indices. Case 1 to 4 are adopted.

The pilot tones for 20MHz band are allocated in tones with 4k (k= ±1, ±2,…) indices. Case 2 to 4 are adopted.

The pilot tones for 20MHz band are allocated in tones with 2k (k= ±1, ±2,…) indices. Case 3 to 4 are adopted.

Option 3:

For the last symbol, pilot tones are shifted to neighboring 8k (k= ±1, ±2,…) indices. Case 1 to 4 are adopted.

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For the last symbol, pilot tones are shifted to neighboring 4k (k= ±1, ±2,…) indices. Case 2 to 4 are adopted.

For the last symbol, pilot tones are shifted to neighboring 2k (k= ±1, ±2,…) indices. Case 3 to 4 are adopted.

In Option 1, no pilots are assigned to the last symbol because the phase tracking may not be used in the last symbol. In option 2, the pilots are assigned to 8k or 4k or 2k indices depending on the cases which are adopted in the standard. For example, all 4 cases are used in the standard, the pilot tones are allocated to 8k tone indices for 20MHz packets. Even though the standard adopts case 1 to 4, the pilots can be assigned to non-8k indices. In this case, we can shift the location of pilot to neighboring 8k indexed tone only for the last symbol. This is Option 3. In Fig. 1 and cases 1 to 4, we just explain the data tone allocation but the pilot allocation mentioned previously should be considered at the same time.

Next, we can also consider the STBC(space-time block code) and SFBC cases. In STBC, two OFDM symbols are the unit of STBC and then the last two symbols have the same structure as shown in Figs. 6, 7, and 8.

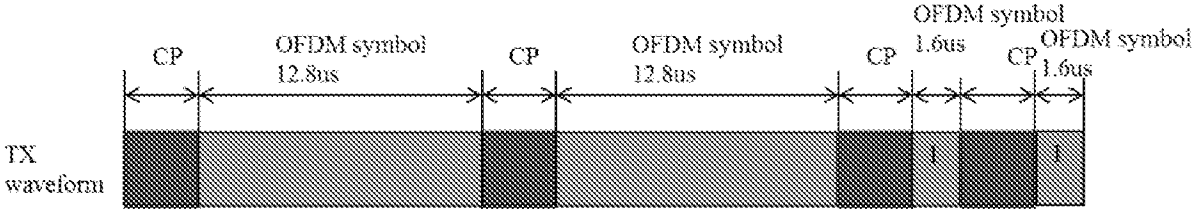

Fig. 6. Symbol structure of the last 4 symbols for case 1 when the STBC is used.

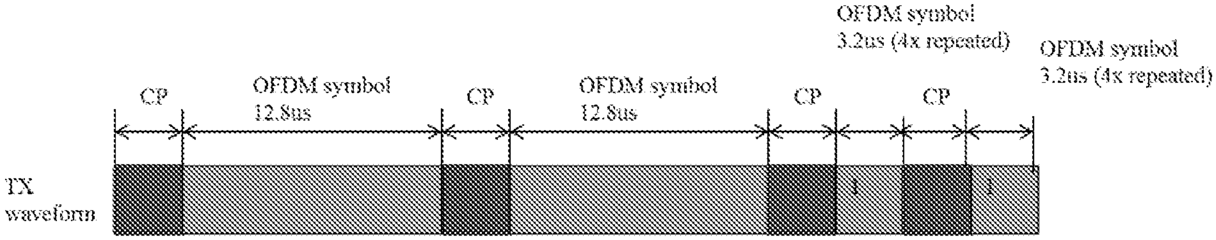

Fig. 7. Symbol structure of the last 4 symbols for case 2 when the STBC is used.

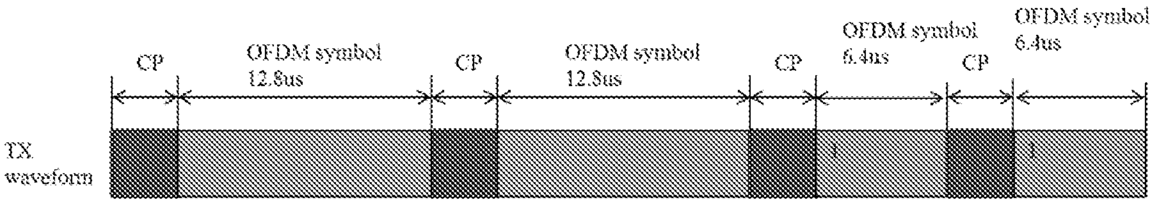

Fig. 8. Symbol structure of the last 4 symbols for case 3 when the STBC is used.

For SFBC, the consecutive data tones are encoded with the Alamouti code instead of to OFDM symbols for STBC. In the calculation of the number of used data tones, this factor, i.e., 1/2, should be considered.

If the symbol structure can be changed depending on the payload size, the way to indicate the structure of the last symbol is needed for a receiver to know the structure. We can consider both explicit and implicit manners. For an explicit method, HE-SIG field can be used. The dedicated bits can be assigned for the purpose. If the dedicated bits in HE-SIG is not available, we can use the proposed padding method only for single-user (SU) mode. HE-SIG bits can have the different meaning in SU and MU modes as in VHT-SIG B for 802.11ac. Then, the HE-SIG bits can be secured only for the SU mode. In VHT-SIG B for 802.11ac, the more reserved bits exist in the SU mode. We expect the similar operation in 802,11ax.

As an alternative, if only 3 cases are adopted, e.g., case 2, 3, and 4, the L-LENGTH field, the LENGTH filed in the legacy SIG, can be used. Use L-LEGNTH information with M in the following equation.

$$\text{Length} = \frac{\text{TXTIME-20}}{4} \times 3 - 3 - M,\ 0 \le M \le 2$$

Though 3 different values are possible with M = 0, 1, and 2, the legacy receiver identify the same length (the same packet duration) because one OFDM symbol with the lowest rate includes 3 bytes data. The L-LENGTH can imply three different states with the value of M without changing the operation of the legacy receiver. The cases 2, 3, and 4 can be information with the following example:

M= 0 : case 4

M= 1 : case 3

M= 2 : case 2

As an implicit method, the exact number of bytes of payload can be used. The exact size of payload in MAC header can be used to obtain the structure of the last symbol. Because the MAC header is located at the beginning of the packet, we can extract this information before decoding the last symbol. With the MCS, bandwidth, number of space-time streams, STB(F)C option information in addition to the payload size, the number of used data tones can be calculated.

This approach to save the symbol duration of the last symbol can be used in HE-SIG-B design in Fig. 2. If the number of bits in HE-SIG-B is small, we can reduce the duration of HE-SIG-B OFDM symbols by using 2k, 4k, or 8k tones as in the last symbol. In Fig. 2 (a), HE-LTF before HE-SIG-B is a training symbol only for HE-SIG-B decoding. Then HE-LTF also use the same tones as in HE-SIG-B. However, the HE-LTFs in Fig. 2. (b) is training symbols both for HE-SIG-B decoding and for DATA decoding and then the used tones for HE-LTFs will not identical with those for HE-SIG-B.

This different OFDM modulation at the last symbol can be used to secure the longer decoding time at the receiver. By using the longer OFDM symbol duration of "12.8μsec + CP duration" in 802.11ax, it can be difficult to meet the packet decoding delay which is less than SIFS given by 16μsec. To solve this problem, additional dummy signals can be transmitted. If the dummy signal is transmitted, the receiver can ignore this dummy signal and secure longer time to decode a packet. The L-LENGTH in the legacy SIGNAL (L-SIG) field indicates the end of the packet including the dummy signal. In the other 3rd party receivers, therefore, SIFS time is measured at the end of a packet including the dummy signal. Fig. 9 shows the packet structure according to the payload size. Compared with the Fig. 1, the last symbol included all repeated waveform with the duration of 12.8μsec. The number of used data tones in the last symbol for case 1 to 4 are the same as in Fig. 1. In case 4, one additional dummy OFDM symbol with all dummy data tones as shown in Fig. 9.

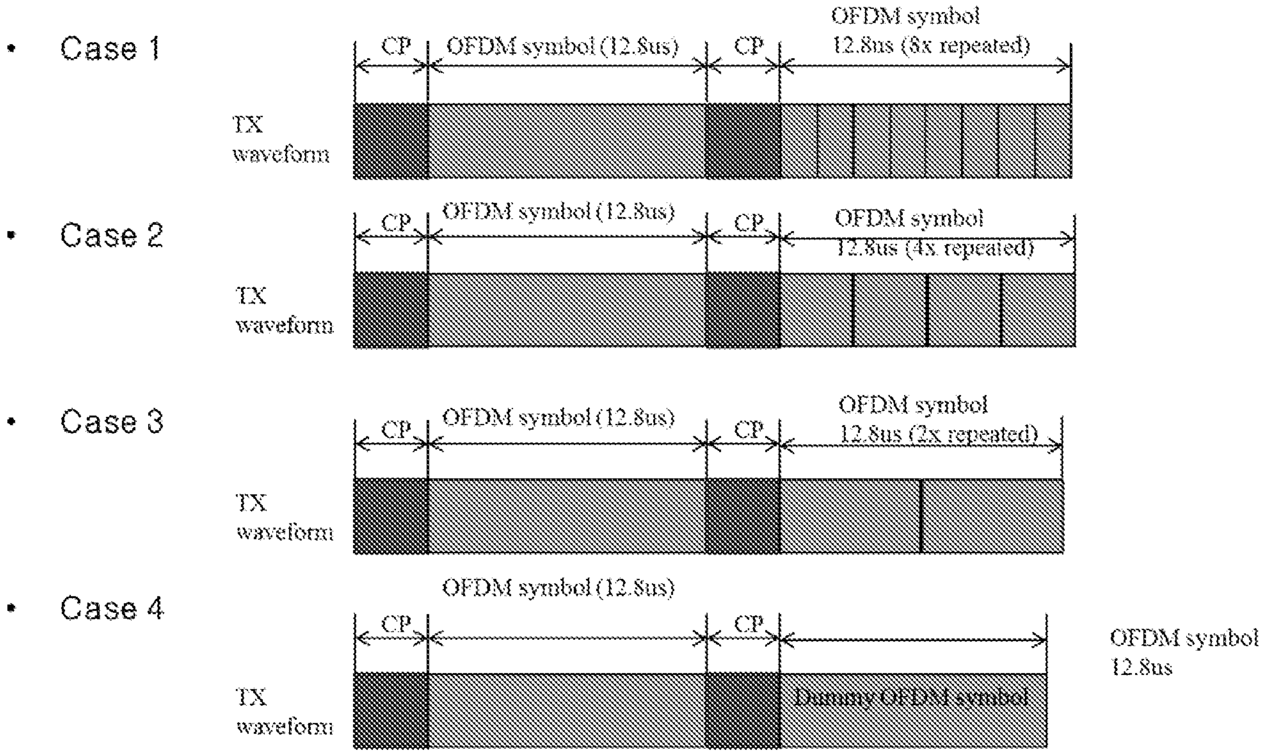

Fig. 9. Symbol structure of the last 2 symbols for case 1 to 4 to secure longer decoding time at the receiver.

Figs. 10, 11, 12, and 14 show the receiver operations for cases 1 to 4, respectively. For case 1, the receiver can start the decoding of the last symbol at the end of the first repeated waveform (red line) because the remaining part is the repeated format of the first one. By repeating the first waveform 7 times at the receiver, we can obtain full OFDM symbol for 256-FFT operation. The FFT output with indices of 8k (k= ±1, ±2, …) comes first and the remaining tones comes later due to the butterfly structure of the FFT operation. The used data tones are performed the de-mapping process according to the MCS information and then deinterleaved with the size of 24. The remaining receiving processes are same as the conventional cases. The receiver operations for cases 2 and 3 are shown in Figs. 11 and 12. These are the same as that for case 1 except the repetition time (3 and 1), the duration of the repeated waveform in the last symbol (3.2μsec and 6.4μsec) and deinterleaver size (48 and 102). For case 4, the last symbol is a dummy symbol and it is not decoded.

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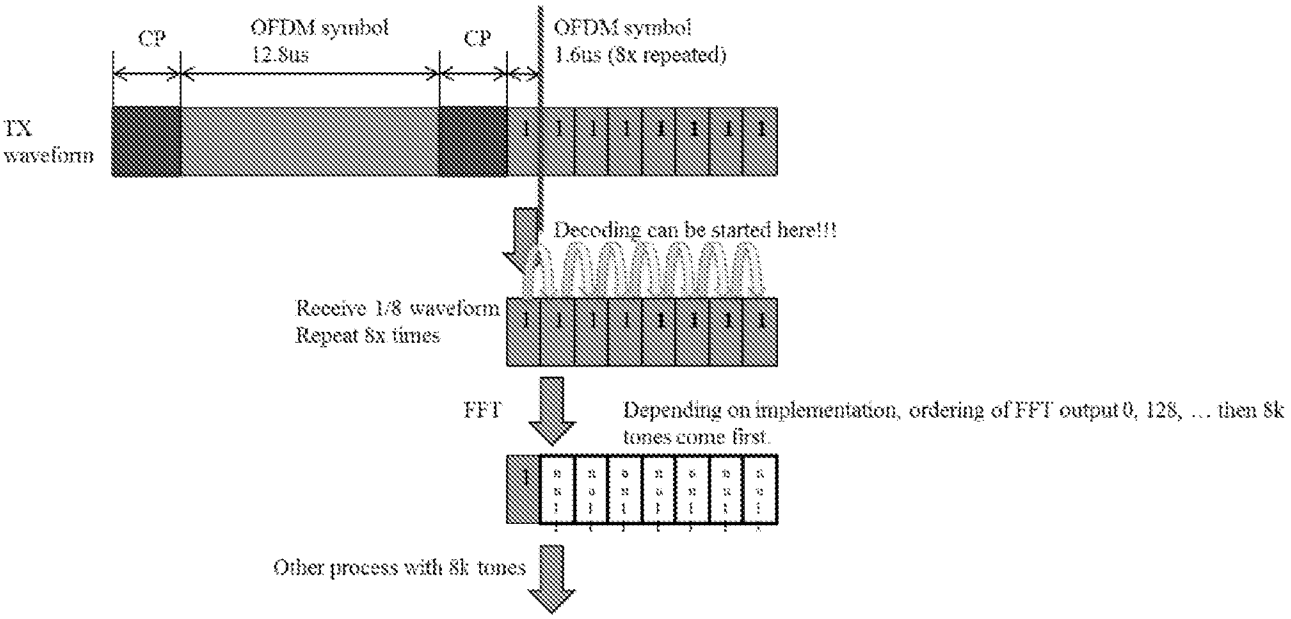

Fig. 10. Decoding process for case 1 to secure longer receiver processing time.

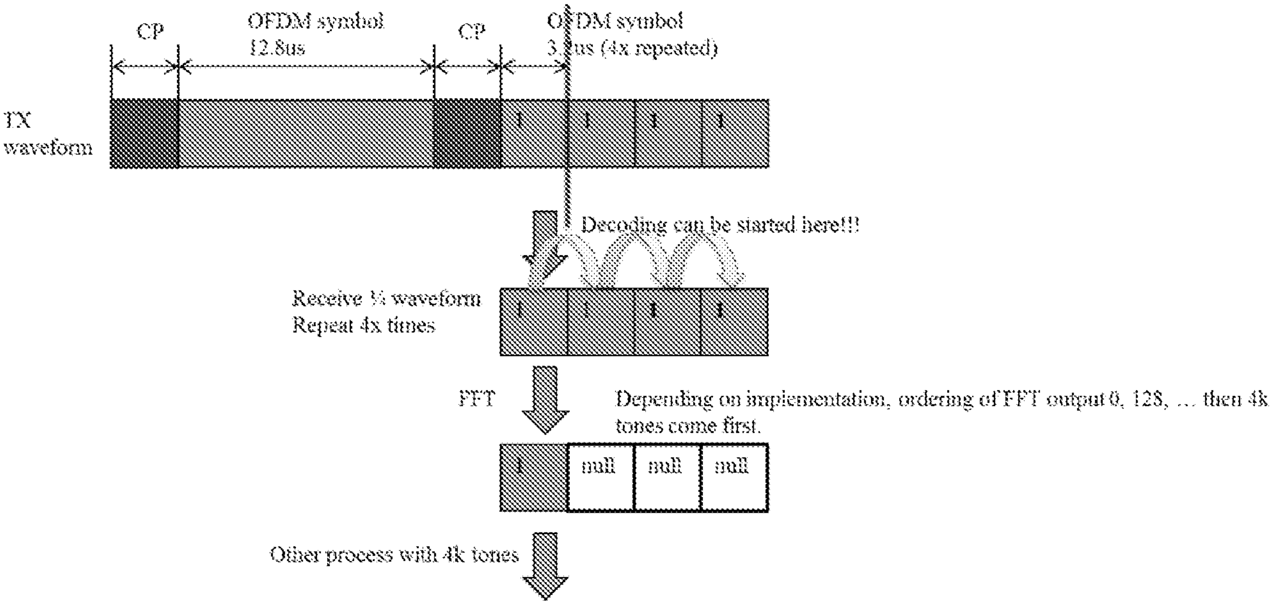

Fig. 11. Decoding process for case 2 to secure longer receiver processing time.

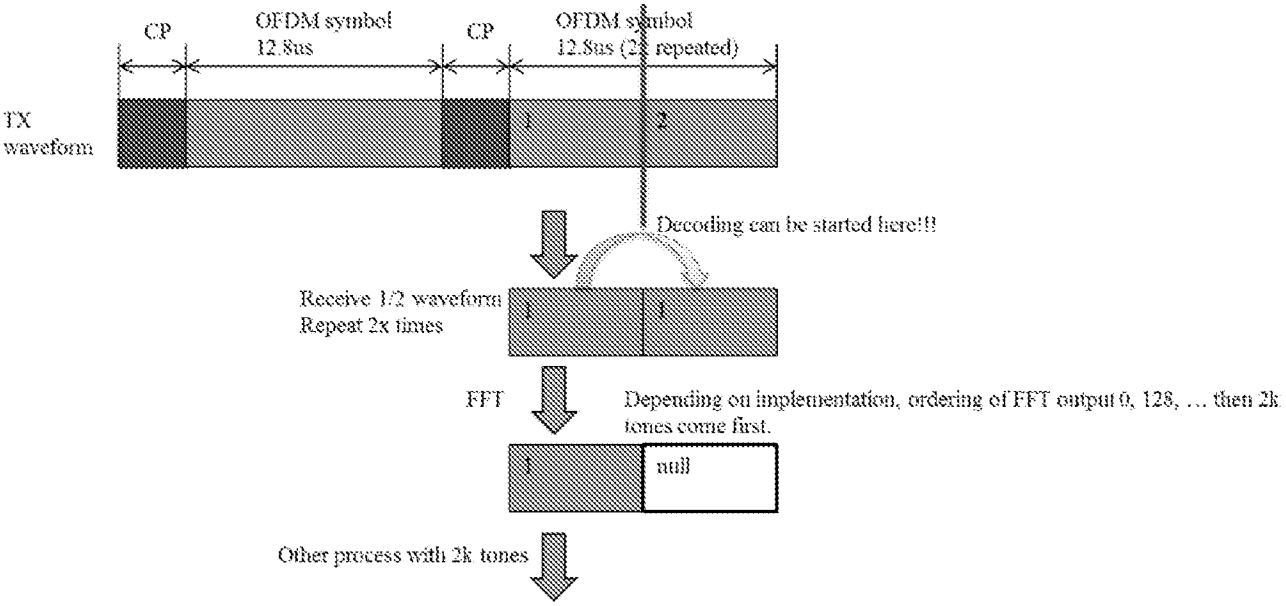

Fig. 12. Decoding process for case 3 to secure longer receiver processing time.

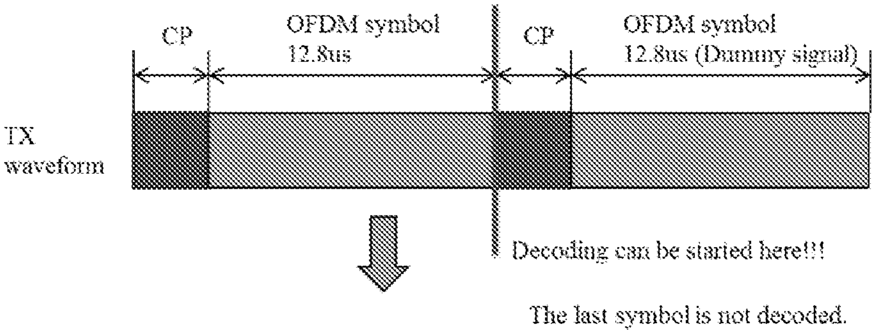

Fig. 13. Decoding process for case 4 to secure longer receiver processing time.

If the STBC is applied, the last two OFDM symbols have the same structure. As an example, we show the combination of case 1 and STBC in Fig. 14.

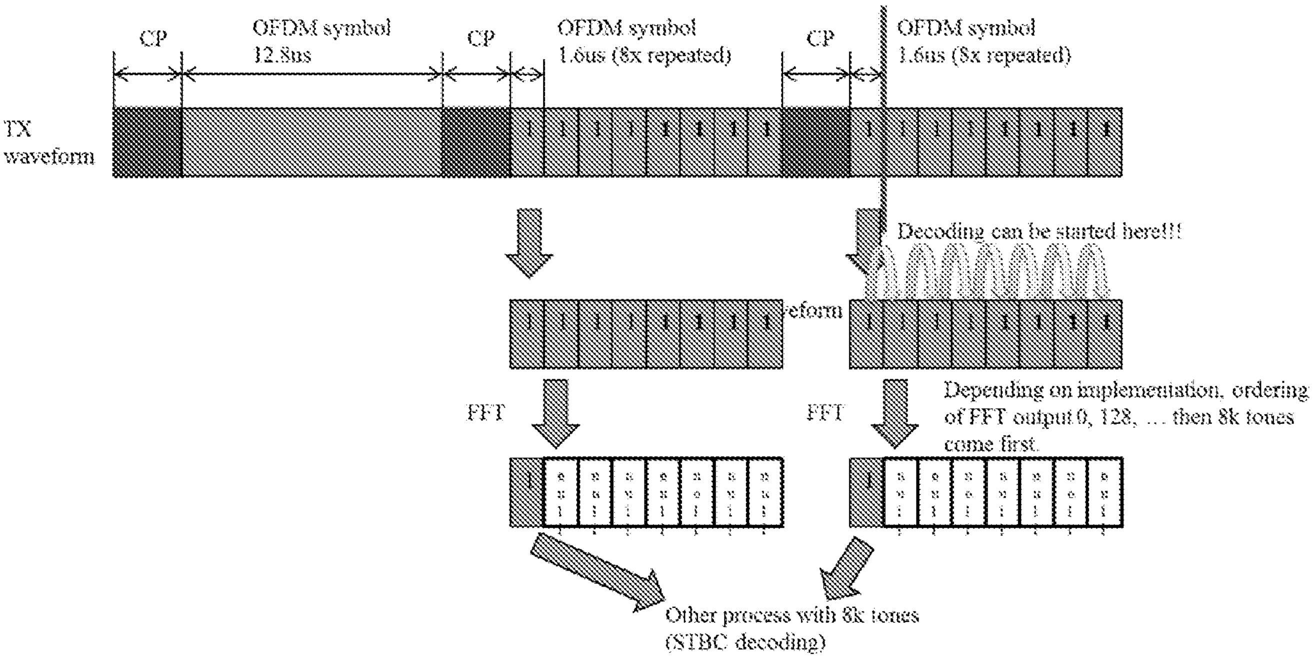

Fig. 14. Symbol structure and decoding process for case 1 with STBC to secure longer receiver processing time.

In the previous embodiment, 8k, 4k or 2k (k= ±1, ±2, …) tones are used. For case 1, 8k+i (k= ±1, ±2, …,) with any shift value of i ∊{ 0, 1, 2, …,7} indices can be used. For case 2, 4k+i (k= ±1, ±2, …,) with any shift value of i ∊{ 0, 1, 2, 3} indices can be used. For case 3, 2k+i (k= ±1, ±2, …,) with any shift value of i ∊{ 0, 1} indices can be used. When i=0, the output of IDFT has the repeated waveform as explained previously. However, when i≠0, the output of IDFT is not repeated. Due to the property of DFT, the output with i≠0 is the phase shifted version of the repeated waveform when i=0. Then, the shift value of "i" is known, the received can know and construct the whole waveform of IDFT output with only first 1.6μsec, 3.2μsec, or 6.4μsec waveform in cases 1, 2, and 3, respectively. This shift value information of "i" can be included in HE-SIG field or other way to inform this information i.e. "i", can be considered. As an alternative to the explicit way to inform the shift value of "i", an implicit method can be considered. As explained, the difference in waveform with different shift values of "i" is the slope of phase in the time domain. Therefore, the receiver can recover the slope of phase, i.e, the shift value "i", if the two repeated waveforms is available. Even when the part of the second repeated waveform is available, we can estimate the slope of phase, i.e., shift value "i" but this accuracy of estimation can be degraded.

ABSTRACT:

In this invention, an efficient padding methods are proposed. The different padding structures are defined according to the number of used data tones, i.e., payload size, are applied. By allocating to every 2nd, 4th, or 8th tones in an OFDM symbol, the repeated waveforms are generated. By sending only one repeated waveform, we can save the packet duration. In additional, the concept can be used to secure longer decoding time by transmitting all repeated waveform at the transmitter and starting the decoding of the last symbol at the end of the first repeated waveform.