WLAN System Toolbox™

User's Guide

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R2018a

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WLAN System Toolbox ™ User's Guide

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Tutorials

WLAN Parameterization

WLAN System Toolbox configuration objects initialize, store, and validate configuration properties. The functions in the toolbox use these properties to initialize parameter settings that define the characteristics of waveforms generated and to define the recovery process.

Configuration Objects in WLAN System Toolbox

The configuration objects are designed specifically as containers to store properties. They also provide some level of data validation for the function inputs that they maintain. Functions perform further data validation across input settings based on runtime conditions.

The configuration objects are optimized for iterative computations that process large streams of data, such as communications systems.

WLAN System Toolbox configuration objects define and configure format-specific and function-specific properties. The property page of each object contains descriptions, valid settings, ranges, and other information about the object properties.

- `wlanDMGConfig` — The DMG configuration object defines and configures directional multi-gigabit (DMG) transmission PPDUs. See wlanDMGConfig.
- `wlanS1GConfig` — The S1G configuration object defines and configures sub 1 GHz (S1G) transmission PPDUs. See wlanS1GConfig.
- `wlanVHTConfig` — The VHT configuration object defines and configures very high throughput (VHT) transmission PPDUs. See wlanVHTConfig.
- `wlanHTConfig` — The HT configuration object defines and configures high throughput (HT) transmission PPDUs. See wlanHTConfig.
- `wlanNonHTConfig` — The non-HT configuration object defines and configures non-high throughput (non-HT) transmission PPDUs. See wlanNonHTConfig.
- `wlanRecoveryConfig` — The recovery configuration object defines and configures information recovery characteristics for received WLAN transmission PPDUs. See wlanRecoveryConfig.

See Also

“WLAN Packet Structure” on page 1-4 | “Mapping of 802.11 Standards to WLAN System Toolbox Configuration Functions” on page 1-32 | “Create Configuration Objects” | “What Is WLAN?”

WLAN Packet Structure

Physical Layer Conformance Procedure Protocol Data Unit

IEEE® 802.11™[12] is a packet-based protocol. Each physical layer conformance procedure (PLCP) protocol data unit (PPDU) contains preamble and data fields. The preamble field contains the transmission vector format information. The data field contains the user payload and higher layer headers, such as MAC fields and CRC. The transmission vector format and the PPDU packet structure vary depending on the 802.11 version being configured for transmission. The transmission vector (*TXVECTOR*) format parameter is classified as:

- *DMG* to specify a directional multi-gigabit PHY implementation.

  - DMG refers to preamble fields formatted for association with 802.11ad™ data. IEEE Std 802.11ad-2012 [4] Section 21.3-21.6 defines and describes the DMG PHY layer and PPDU.
  - For DMG, the *TXVECTOR* parameters, as defined in IEEE Std 802.11ad-2012 [4] Table 21-1, determines the structure of PPDUs transmitted by a DMG STA. For a DMG STA, the *MCS* parameter determines the overall structure of the DMG PPDU.
- *S1G* to specify a sub 1 GHz PHY implementation.

  - S1G refers to preamble fields formatted for association with 802.11ah™ data. The draft standard IEEE P802.11ah/D5.0, defines and describes the S1G PHY layer and PPDU.
  - For S1G, the *TXVECTOR* parameters, as defined in IEEE P802.11ah/D5.0, Table 24-1, determines the structure of PPDUs transmitted by an S1G STA. For an S1G STA, the *FORMAT* parameter determines the overall structure of the S1G PPDU.
- *VHT* to specify a very high throughput PHY implementation.

  - VHT refers to preamble fields formatted for association with 802.11ac data. IEEE IEEE Std 802.11ac-2013 [3], Section 22 defines and describes the VHT PHY layer and PPDU.
  - For VHT, the *TXVECTOR* parameters, as defined in IEEE Std 802.11ac-2013 [3], Table 22-1, determine the structure of PPDUs transmitted by a VHT STA. For a VHT

[1] IEEE Std 802.11-2012 Adapted and reprinted with permission from IEEE. Copyright IEEE 2012. All rights reserved.

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    STA, the *FORMAT* parameter determines the overall structure of the PPDU and enables:

    - Non-HT format (*NON_HT*), based on Section 18 and including non-HT duplicate format.
    - HT-mixed format (*HT_MF*), as specified in Section 20.
    - HT-greenfield format (*HT_GF*), as specified in Section 20. WLAN System Toolbox does not support HT_GF format.
    - VHT format (*VHT*), as specified in Section 22. The VHT format PPDUs contain a preamble compatible with Section 18 and Section 20 STAs. The non-VHT portions of the VHT format preamble (the parts of VHT preamble preceding the VHT-SIG-A field) are defined to enable decoding of the PPDU by VHT STAs.

- *HT* to specify a high throughput PHY implementation.

  - HT refers to preamble fields formatted for association with 802.11n™ data. IEEE Std 802.11-2012 [2], Section 20 defines and describes the HT PHY layer and PPDU. The standard defines two HT formats:

    - *HT_MF* indicates the HT-mixed format and contains a preamble compatible with HT and non-HT receivers. Support for HT-mixed format is mandatory.
    - • *HT_GF* indicates the HT-greenfield format and does not contain a non-HT compatible part. WLAN System Toolbox does not support HT_GF format.

- *non-HT* to specify a PHY implementation that is not HT and is not VHT.

  - Non-HT refers to preamble fields formatted for association with pre-802.11n data. IEEE Std 802.11-2012 [2], Section 18 defines and describes the OFDM PHY layer and PPDU for non-HT transmission. In addition to supporting non-HT synchronization, the non-HT preamble fields are used in support of HT and VHT synchronization.

The table shows 802.11 versions that the toolbox supports, along with the supported *TXVECTOR* options and associated modulation formats.

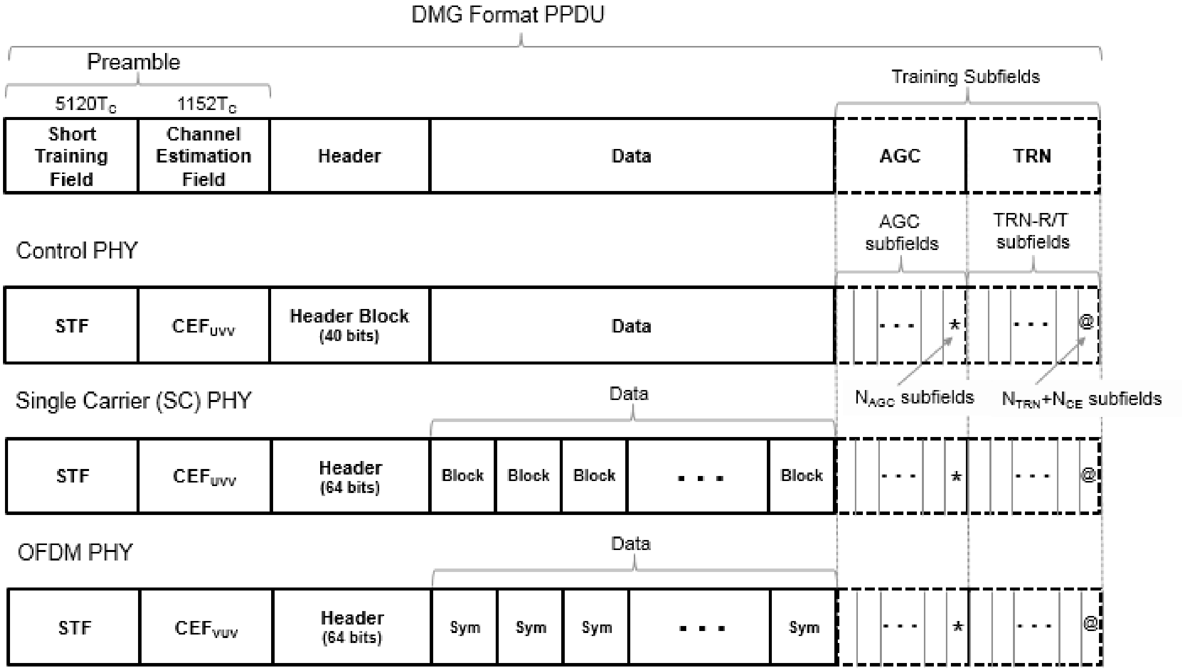
802.11 version	Transmission Vector Format	Modulation format	Bandwidths (MHz)
802.11b	non-HT	DSSS/CCK	11
802.11a	non-HT	OFDM only	5, 10, 20
802.11j	non-HT	OFDM only	10

802.11 version	Transmission Vector Format	Modulation format	Bandwidths (MHz)
802.11p	non-HT	OFDM only	5, 10
802.11g	non-HT	OFDM	20
	non-HT	DSSS/CCK	11
802.11n	HT_MF, Non-HT	OFDM only	20, 40
802.11ac	VHT, HT_MF, Non-HT	OFDM only	20, 40, 80, 160
802.11ah	S1G	OFDM only	1, 2, 4, 8, 16
802.11ad	DMG	Single Carrier and OFDM	2640

WLAN System Toolbox configuration objects define the properties that enable creation of PPDUs and waveforms for the specified 802.11 transmission format. See wlanDMGConfig, wlanS1GConfig, wlanVHTConfig, wlanHTConfig and wlanNonHTConfig

DMG Format PPDU Field Structure

In DMG, there are three physical layer (PHY) modulation schemes supported: control, single carrier, and OFDM.



The single-carrier chip timing, $T_C = 1/F_C = 0.57$ ns. For more information, see Waveform Sampling Rate on the `wlanWaveformGenerator` function reference page.

The supported DMG format PPDU field structures each contain these fields:

- The preamble contains a short training field (STF) and channel estimation field (CEF). The preamble is used for packet detection, AGC, frequency offset estimation, synchronization, indication of modulation type (Control, SC, or OFDM), and channel estimation. The format of the preamble is common to the Control, SC, and OFDM PHY packets.
  - The STF is composed of Golay *Ga* sequences as specified in 802.11ad-2012 [4], Section 21.3.6.2.
  - The CEF is composed of Golay *Gu* and *Gv* sequences as specified in 802.11ad-2012 [4], Section 21.3.6.3.

    - When the header and data fields of the packet are modulated using a single carrier (control PHY and SC PHY), the Golay sequencing for the CEF waveform is shown in 802.11ad-2012 [4], Figure 21-5.
    - When the header and data fields of the packet are modulated using OFDM (OFDM PHY), the Golay sequencing for the CEF waveform is shown in 802.11ad-2012 [4], Figure 21-6.
- The header field is decoded by the receiver to determine transmission parameters.
- The data field is variable in length. It carries the user data payload.
- The training fields (AGC and TRN-R/T subfields) are optional. They can be included to refine beamforming.

IEEE 802.11ad-2012 [4] specifies the common aspects of the DMG PPDU packet structure in Section 21.3. The PHY modulation-specific aspects of the packet structure are specified in these sections:

- The DMG control PHY packet structure is specified in Section 21.4.
- The DMG OFDM PHY packet structure is specified in Section 21.5.
- The DMG SC PHY packet structure is specified in Section 21.6.

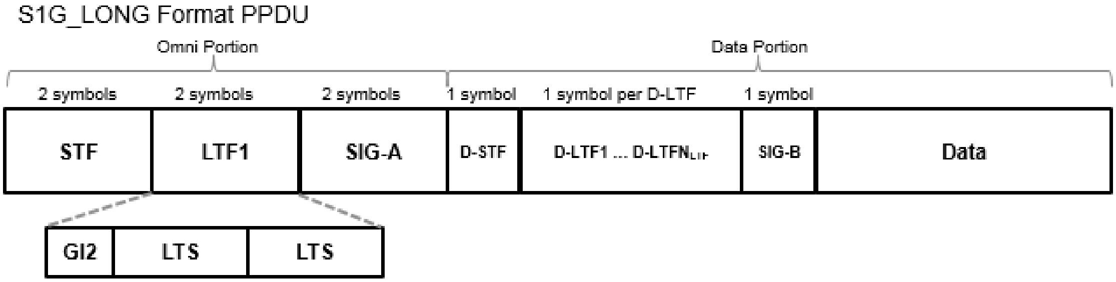
S1G Format PPDU Field Structure

In S1G, there are three transmission modes:

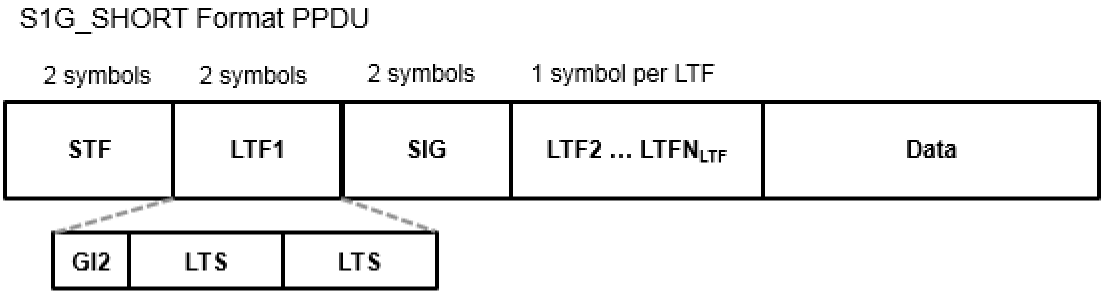
- ≥2-MHz long preamble mode
- ≥2-MHz short preamble mode
- 1-MHz mode

Each transmission mode has a specific PPDU preamble structure:

- An S1G ≥2-MHz long preamble mode PPDU supports single-user and multi-user transmissions. The long preamble PPDU consists of two portions; the omni-directional portion and the beam-changeable portion.



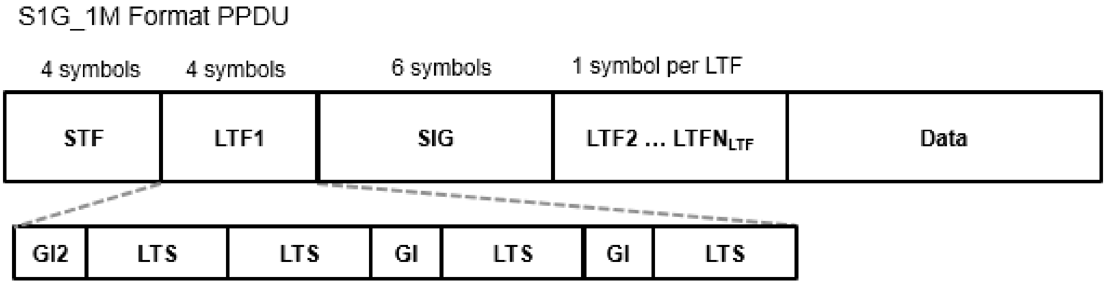
  - The omni-directional portion is transmitted to all users without beamforming. It consists of three fields:
    - The short training field (STF) is used for coarse synchronization.
    - The long training field (LTF1) is used for fine synchronization and initial channel estimation.
    - The signal A field (SIG-A) is decoded by the receiver to determine transmission parameters relevant to all users.
  - The data portion can be beamformed to each user. It consists of four fields:
    - The beamformed short training field (D-STF) is used by the receiver for automatic gain control.
    - The beamformed long training fields (D-LTF-N) are used for MIMO channel estimation.
    - The signal B field (SIG-B) in a multi-user transmission, signals the MCS for each user. In a single-user transmission, the MCS is signaled in the SIG-A field of the omni-directional portion of the preamble. Therefore, in a single-user transmission the SIG-B symbol transmitted is an exact repetition of the first D-LTF. This repetition allows for improved channel estimation.
    - The data field is variable in length. It carries the user data payload.
- An S1G ≥2-MHz short preamble mode PPDU supports single-user transmissions. All fields in the PPDU can be beamformed.



  The PPDU consists of these five fields:

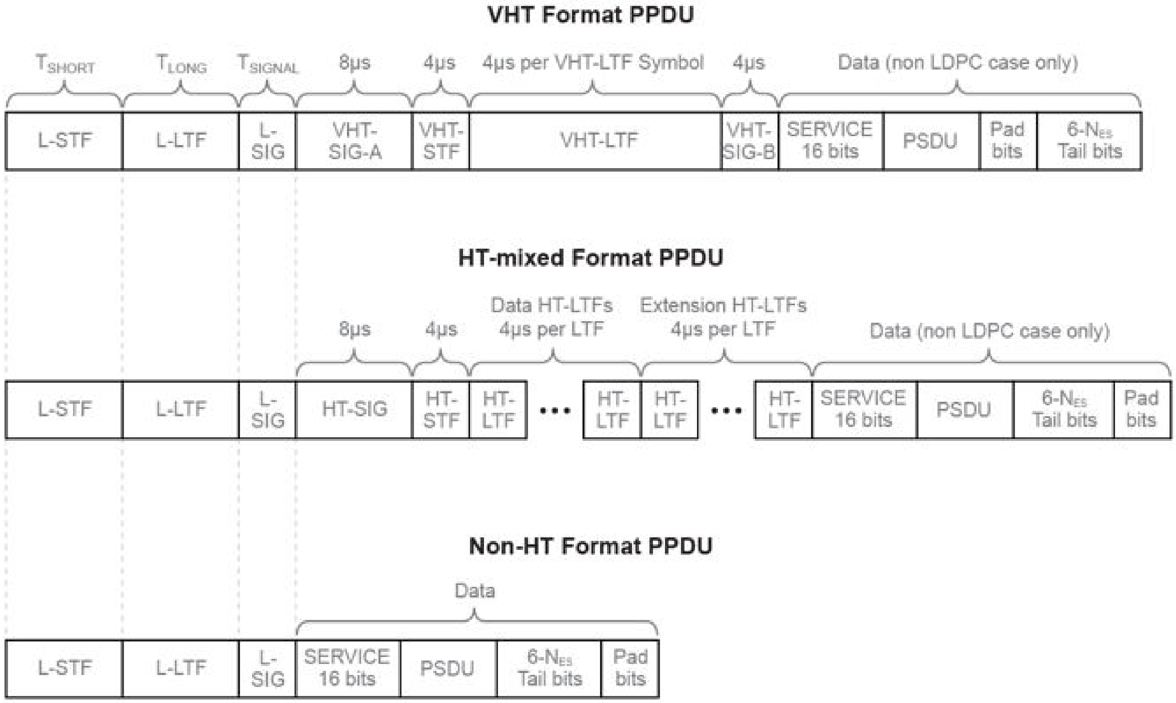
  - The short training field (STF) is used for coarse synchronization.
  - The first long training field (LTF1) is used for fine synchronization and initial channel estimation.
  - The signaling field (SIG) is decoded by the receiver to determine transmission parameters.
  - The subsequent long training fields (LTF2-N) are used for MIMO channel estimation. $N_{SYMBOLS}$ = 1 per subsequent LTF
  - The data field is variable in length. It carries the user data payload.

- An S1G 1-MHz mode PPDU supports single-user transmissions. It is composed of the same five fields as the S1G ≥2-MHz short preamble mode PPDU and all fields can be beamformed. An S1G 1-MHz mode PPDU has longer STF, LTF1, and SIG fields so this narrower bandwidth mode can achieve sensitivity that is similar to the S1G ≥2-MHz short preamble mode transmissions.



VHT, HT-Mixed, and Non-HT Format PPDU Field Structures

The field structure for VHT, HT, and non-HT PPDUs consist of preamble and data portions. The legacy preamble fields (L-STF, L-LTF, and L-SIG) are common to VHT, HT, and non-HT format preambles. VHT and HT format preamble fields include additional format-specific training and signaling fields. Each format defines a data field for transmission of user payload data.



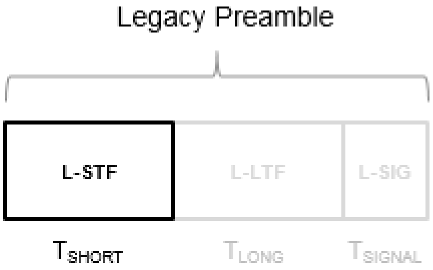
PPDU Field Abbreviation	Description
L-STF	Non-HT Short Training field
L-LTF	Non-HT Long Training field
L-SIG	Non-HT SIGNAL field
HT-SIG	HT SIGNAL field
HT-STF	HT Short Training field
HT-LTF	HT Long Training field, multiple HT-LTFs are transmitted as indicated by the MCS
VHT-SIG-A	VHT Signal A field
VHT-STF	VHT Short Training field
VHT-LTF	VHT Long Training field

PPDU Field Abbreviation	**Description**
VHT-SIG-B	VHT Signal B field
Data	VHT, HT, and non-HT Data fields include the service bits, PSDU, tail bits, and pad bits

See IEEE 802.11-2012 [2], Section 20.3.2 for more information.

Non-HT (Legacy) Short Training Field

The legacy short training field (L-STF) is the first field of the 802.11 OFDM PLCP legacy preamble. The L-STF is a component of VHT, HT, and non-HT PPDUs.



The L-STF duration varies with channel bandwidth.

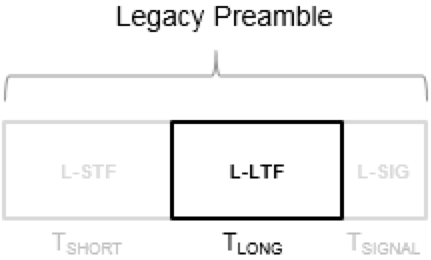
Channel Bandwidth (MHz)	**Subcarrier Frequency Spacing, Δ_F (kHz)**	**Fast Fourier Transform (FFT) Period (T_{FFT} = 1 / Δ_F)**	**L-STF Duration (T_{SHORT} = 10 × T_{FFT} / 4)**
20, 40, 80, and 160	312.5	3.2 μs	8 μs
10	156.25	6.4 μs	16 μs
5	78.125	12.8 μs	32 μs

Because the sequence has good correlation properties, it is used for start-of-packet detection, for coarse frequency correction, and for setting the AGC. The sequence uses 12 of the 52 subcarriers that are available per 20 MHz channel bandwidth segment. For 5

MHz, 10 MHz, and 20 MHz bandwidths, the number of channel bandwidths segments is 1.

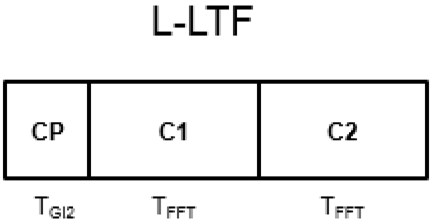
Non-HT (Legacy) Long Training Field

The legacy long training field (L-LTF) is the second field in the 802.11 OFDM PLCP legacy preamble. The L-LTF is a component of VHT, HT, and non-HT PPDUs.



Channel estimation, fine frequency offset estimation, and fine symbol timing offset estimation rely on the L-LTF.

The L-LTF is composed of a cyclic prefix (CP) followed by two identical long training symbols (C1 and C2). The CP consists of the second half of the long training symbol.

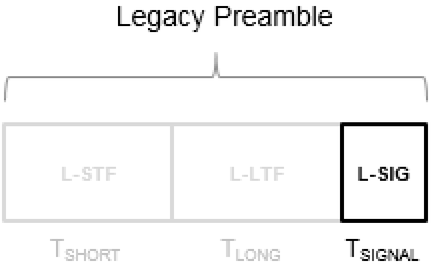


The L-LTF duration varies with channel bandwidth.

Channel Bandwidth (MHz)	**Subcarrier Frequency Spacing, Δ_F (kHz)**	**Fast Fourier Transform (FFT) Period (T_{FFT} = 1 / Δ_F)**	**Cyclic Prefix or Training Symbol Guard Interval (GI2) Duration (T_{GI2} = T_{FFT} / 2)**	**L-LTF Duration (T_{LONG} = T_{GI2} + 2 × T_{FFT})**
20, 40, 80, and 160	312.5	3.2 μs	1.6 μs	8 μs
10	156.25	6.4 μs	3.2 μs	16 μs
5	78.125	12.8 μs	6.4 μs	32 μs

Non-HT (Legacy) Signal Field

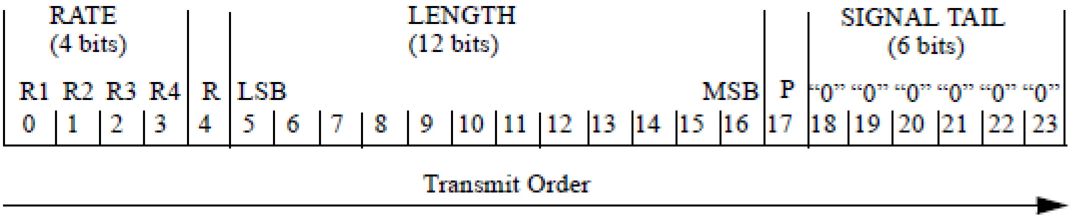
The legacy signal (L-SIG) field is the third field of the 802.11 OFDM PLCP legacy preamble. It consists of 24 bits that contain rate, length, and parity information. The L-SIG is a component of VHT, HT, and non-HT PPDUs. It is transmitted using BPSK modulation with rate 1/2 binary convolutional coding (BCC).



The L-SIG is one OFDM symbol with a duration that varies with channel bandwidth.

Channel Bandwidth (MHz)	Subcarrier frequency spacing, Δ_F (kHz)	Fast Fourier Transform (FFT) period ($T_{FFT} = 1 / \Delta_F$)	Guard Interval (GI) Duration ($T_{GI} = T_{FFT} / 4$)	L-SIG duration ($T_{SIGNAL} = T_{GI} + T_{FFT}$)
20, 40, 80, and 160	312.5	3.2 µs	0.8 µs	4 µs
10	156.25	6.4 µs	1.6 µs	8 µs
5	78.125	12.8 µs	3.2 µs	16 µs

The L-SIG contains packet information for the received configuration,



- Bits 0 through 3 specify the data rate (modulation and coding rate) for the non-HT format.

Rate (bits 0–3)	Modulation	Coding rate (*R*)	Data Rate (Mb/s)		
			20 MHz channel bandwidth	10 MHz channel bandwidth	5 MHz channel bandwidth
1101	BPSK	1/2	6	3	1.5
1111	BPSK	3/4	9	4.5	2.25
0101	QPSK	1/2	12	6	3
0111	QPSK	3/4	18	9	4.5
1001	16-QAM	1/2	24	12	6
1011	16-QAM	3/4	36	18	9
0001	64-QAM	2/3	48	24	12

Rate (bits 0–3)	Modulation	Coding rate (*R*)	Data Rate (Mb/s)		
			20 MHz channel bandwidth	10 MHz channel bandwidth	5 MHz channel bandwidth
0011	64-QAM	3/4	54	27	13.5

For HT and VHT formats, the L-SIG rate bits are set to `'1 1 0 1'`. Data rate information for HT and VHT formats is signaled in format-specific signaling fields.

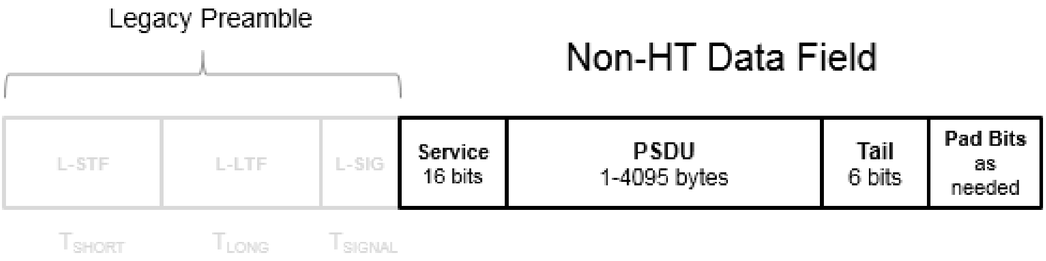
- Bit 4 is reserved for future use.
- Bits 5 through 16:
  - For non-HT, specify the data length (amount of data transmitted in octets) as described in IEEE Std 802.11-2012, Table 18-1 and Section 9.23.4.
  - For HT-mixed, specify the transmission time as described in IEEE Std 802.11-2012, Section 20.3.9.3.5 and Section 9.23.4.
  - For VHT, specify the transmission time as described in IEEE Std 802.11ac-2013, Section 22.3.8.2.4.
- Bit 17 has the even parity of bits 0 through 16.
- Bits 18 through 23 contain all zeros for the signal tail bits.

Note Signaling fields added for HT (`wlanHTSIG`) and VHT (`wlanVHTSIGA`, `wlanVHTSIGB`) formats provide data rate and configuration information for those formats.

- For the HT-mixed format, IEEE Std 802.11-2012, Section 20.3.9.4.3 describes HT-SIG bit settings.
- For the VHT format, IEEE Std 802.11ac-2013, Section 22.3.8.3.3 and Section 22.3.8.3.6 describe bit settings for VHT-SIG-A and VHT-SIG-B, respectively.

Non-HT Data Field

The non-high throughput data (non-HT data) field is used to transmit MAC frames and is composed of a service field, a PSDU, tail bits, and pad bits.



- **Service field** — Contains 16 zeros to initialize the data scrambler.
- **PSDU** — Variable-length field containing the PLCP service data unit (PSDU).
- **Tail** — Tail bits required to terminate a convolutional code. The field uses six zeros for the single encoding stream.
- **Pad Bits** — Variable-length field required to ensure that the non-HT data field contains an integer number of symbols.

Processing of an 802.11a™ data field is defined in IEEE 802.11-2012 [2], Section 18.3.5.

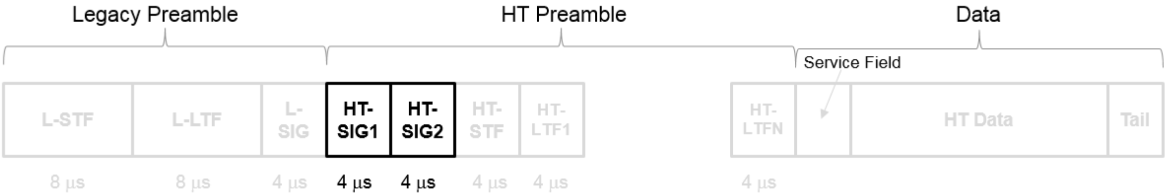
The six tail bits are set to zero after a 127-bit scrambling sequence has been applied to the full data field. The receiver uses the first seven bits of the service field to determine the initial state of the scrambler. Rate 1/2 BCC encoding is performed on the scrambled data. The zeroed tail bits cause the BCC encoder to return to a zero state. Puncturing is applied as needed for the selected rate.

The coded data is grouped into several bits per symbol, and two permutations of block interleaving are applied to each group of data. The groups of bits are then modulated to the selected rate (BPSK, QPSK, 16-QAM, or 64-QAM) and the complex symbols are then mapped onto corresponding subcarriers. For each symbol, the pilot subcarriers are inserted. An IFFT is used to transform each symbol group to the time domain and the cyclic prefix is prepended.

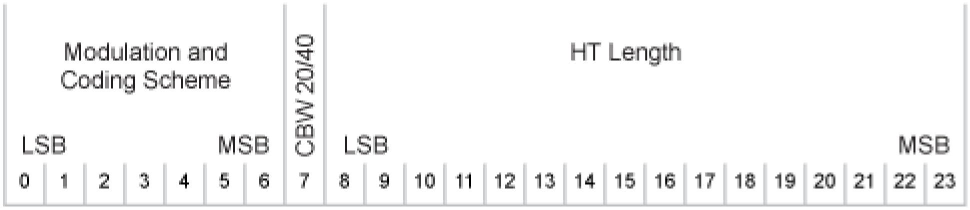
The final processing preceding DAC up-conversion to RF and the power amplifier is to apply a pulse shaping filter on the data to smooth transitions between symbols. The standard provides an example pulse shaping function but does not specifically require one.

High Throughput Signal Field

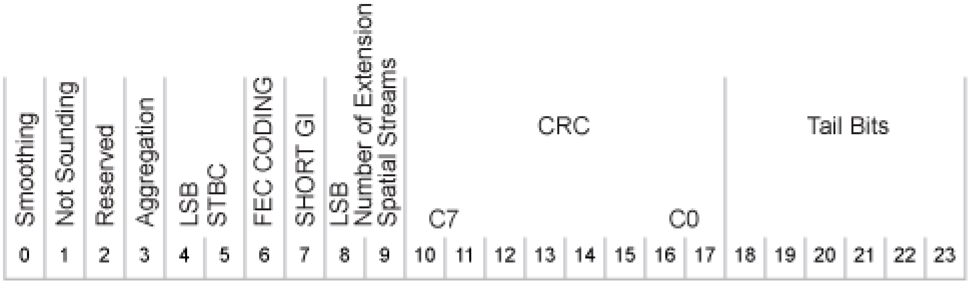
The high throughput signal (HT-SIG) field is located between the L-SIG field and HT-STF and is part of the HT-mixed format preamble. It is composed of two symbols, HT-SIG$_1$ and HT-SIG$_2$.



HT-SIG carries information used to decode the HT packet, including the MCS, packet length, FEC coding type, guard interval, number of extension spatial streams, and whether there is payload aggregation. The HT-SIG symbols are also used for auto-detection between HT-mixed format and legacy OFDM packets.



HT-SIG$_1$

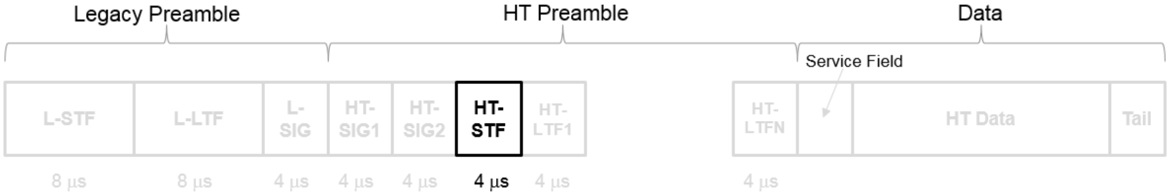


HT-SIG$_2$

Refer to IEEE Std 802.11-2012, Section 20.3.9.4.3 for a detailed description of the HT-SIG field.

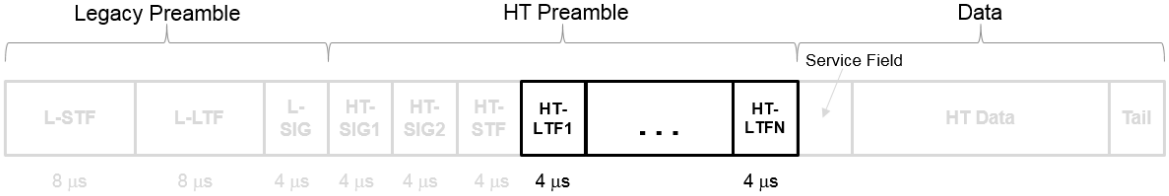
High Throughput Short Training Field

The high throughput short training field (HT-STF) is located between the HT-SIG and HT-LTF fields of an HT-mixed packet. The HT-STF is 4 μs in length and is used to improve automatic gain control estimation for a MIMO system. For a 20 MHz transmission, the frequency sequence used to construct the HT-STF is identical to that of the L-STF. For a 40 MHz transmission, the upper subcarriers of the HT-STF are constructed from a frequency-shifted and phase-rotated version of the L-STF.



High Throughput Long Training Fields

The high throughput long training field (HT-LTF) is located between the HT-STF and data field of an HT-mixed packet.



As described in IEEE Std 802.11-2012, Section 20.3.9.4.6, the receiver can use the HT-LTF to estimate the MIMO channel between the set of QAM mapper outputs (or, if STBC is applied, the STBC encoder outputs) and the receive chains. The HT-LTF portion has one or two parts. The first part consists of one, two, or four HT-LTFs that are necessary for demodulation of the HT-Data portion of the PPDU. These HT-LTFs are referred to as HT-DLTFs. The optional second part consists of zero, one, two, or four HT-LTFs that can be used to sound extra spatial dimensions of the MIMO channel not utilized by the HT-Data portion of the PPDU. These HT-LTFs are referred to as HT-ELTFs. Each HT long training symbol is 4 µs. The number of space-time streams and the number of extension streams determines the number of HT-LTF symbols transmitted.

Tables 20-12, 20-13 and 20-14 from IEEE Std 802.11-2012 are reproduced here.

N_{STS} Determination	N_{HTDLTF} Determination	N_{HTELTF} Determination
Table 20-12 defines the number of space-time streams (N_{STS}) based on the number of spatial streams (N_{SS}) from the MCS and the STBC field.	Table 20-13 defines the number of HT-DLTFs required for the N_{STS}.	Table 20-14 defines the number of HT-ELTFs required for the number of extension spatial streams (N_{ESS}). N_{ESS} is defined in HT-SIG$_2$.

N_{SS} from MCS	STBC field	N_{STS}
1	0	1
1	1	2
2	0	2
2	1	3
2	2	4
3	0	3
3	1	4
4	0	4

N_{STS}	N_{HTDLTF}
1	1
2	2
3	4
4	4

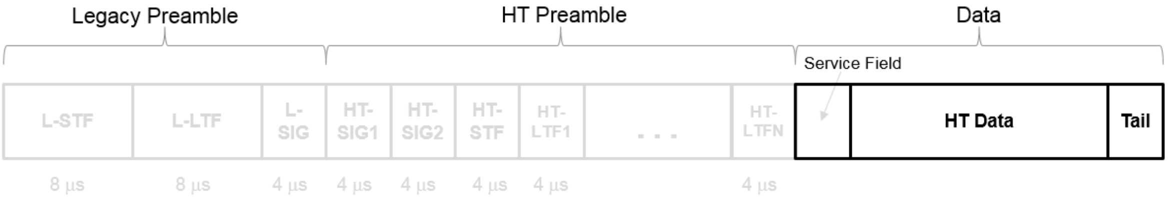
N_{ESS}	N_{HTELTF}
0	0
1	1
2	2
3	4

Additional constraints include:

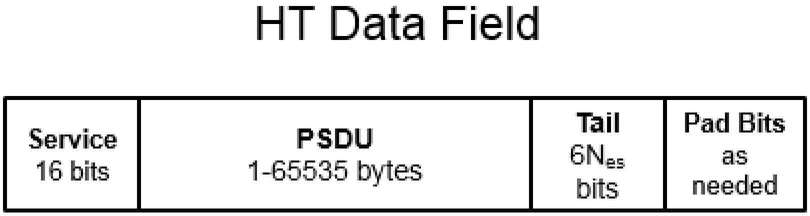
- $N_{HTLTF} = N_{HTDLTF} + N_{HTELTF} \leq 5$.
- $N_{STS} + N_{ESS} \leq 4$.
  - When $N_{STS} = 3$, N_{ESS} cannot exceed one.
  - If $N_{ESS} = 1$ when $N_{STS} = 3$ then $N_{HTLTF} = 5$.

HT Data Field

The high throughput data field (HT-Data) follows the last HT-LTF of an HT-mixed packet.



The high throughput data field is used to transmit one or more frames from the MAC layer and consists of four subfields.


HT Data Field

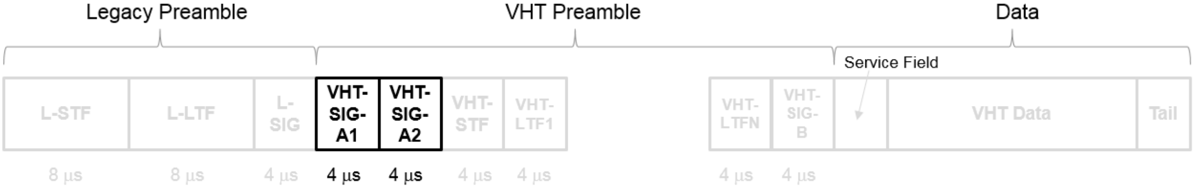
Service 16 bits	PSDU 1-65535 bytes	Tail $6N_{es}$ bits	Pad Bits as needed

- **Service field** — Contains 16 zeros to initialize the data scrambler.
- **PSDU** — Variable-length field containing the PLCP service data unit (PSDU). In 802.11, the PSDU can consist of an aggregate of several MAC service data units.
- **Tail** — Tail bits required to terminate a convolutional code. The field uses six zeros for each encoding stream.
- **Pad Bits** — Variable-length field required to ensure that the HT-Data field consists of an integer number of symbols.

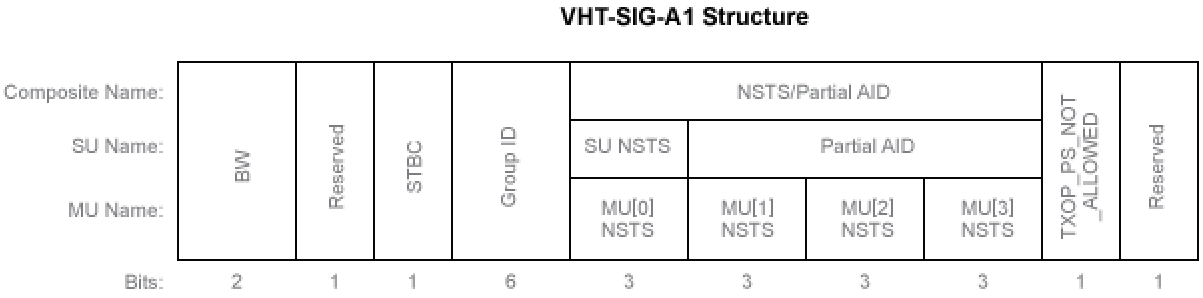
Very High Throughput SIG-A Field

The very high throughput signal A (VHT-SIG-A) field contains information required to interpret VHT format packets. Similar to the non-HT signal (L-SIG) field for the non-HT OFDM format, this field stores the actual rate value, channel coding, guard interval, MIMO scheme, and other configuration details for the VHT format packet. Unlike the HT-SIG field, this field does not store the packet length information. Packet length information is derived from L-SIG and is captured in the VHT-SIG-B field for the VHT format.

The VHT-SIG-A field consists of two symbols: VHT-SIG-A1 and VHT-SIG-A2. These symbols are located between the L-SIG and the VHT-STF portion of the VHT format PPDU.

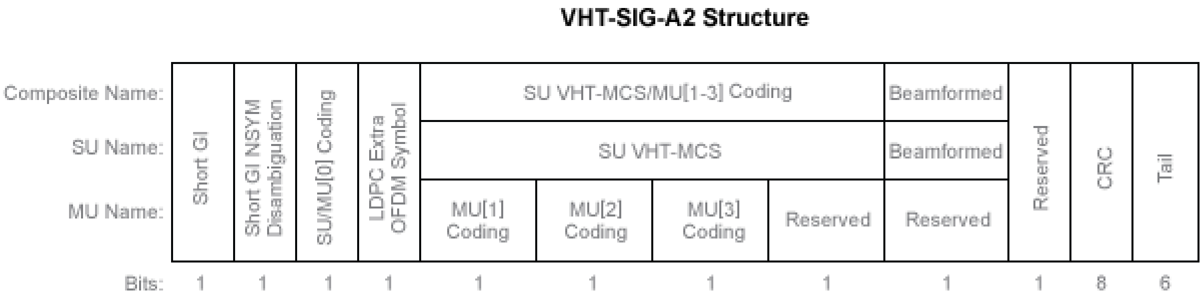


The VHT-SIG-A field is defined in IEEE Std 802.11ac-2013, Section 22.3.8.3.3.



VHT-SIG-A1 Structure

Composite Name:	BW	Reserved	STBC	Group ID	NSTS/Partial AID				TXOP_PS_NOT_ALLOWED	Reserved
SU Name:					SU NSTS	Partial AID				
MU Name:					MU[0] NSTS	MU[1] NSTS	MU[2] NSTS	MU[3] NSTS		
Bits:	2	1	1	6	3	3	3	3	1	1



VHT-SIG-A2 Structure

Composite Name:	Short GI	Short GI NSYM Disambiguation	SU/MU[0] Coding	LDPC Extra OFDM Symbol	SU VHT-MCS/MU[1-3] Coding				Beamformed	Reserved	CRC	Tail
SU Name:					SU VHT-MCS				Beamformed			
MU Name:					MU[1] Coding	MU[2] Coding	MU[3] Coding	Reserved	Reserved			
Bits:	1	1	1	1	1	1	1	1	1	1	8	6

The VHT-SIG-A field includes these components. The bit field structures for VHT-SIG-A1 and VHT-SIG-A2 vary for single user or multi-user transmissions.

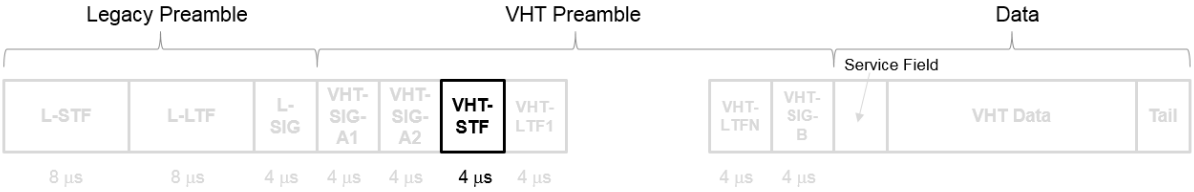
- **BW** — A two-bit field that indicates 0 for 20 MHz, 1 for 40 MHz, 2 for 80 MHz, or 3 for 160 MHz.
- **STBC** — A bit that indicates the presence of space-time block coding.

- **Group ID** — A six-bit field that indicates the group and user position assigned to a STA.
- **N_{STS}** — A three-bit field for a single user or 4 three-bit fields for a multi-user scenario, that indicates the number of space-time streams per user.
- **Partial AID** — An identifier that combines the association ID and the BSSID.
- **TXOP_PS_NOT_ALLOWED** — An indicator bit that shows if client devices are allowed to enter dose state. This bit is set to false when the VHT-SIG-A structure is populated, indicating that the client device is allowed to enter dose state.
- **Short GI** — A bit that indicates use of the 400 ns guard interval.
- **Short GI NSYM Disambiguation** — A bit that indicates if an extra symbol is required when the short GI is used.
- **SU/MU[0] Coding** — A bit field that indicates if convolutional or LDPC coding is used for a single user or for user MU[0] in a multi-user scenario.
- **LDPC Extra OFDM Symbol** — A bit that indicates if an extra OFDM symbol is required to transmit the data field.
- **MCS** — A four-bit field.

  - For a single user scenario, it indicates the modulation and coding scheme used.
  - For a multi-user scenario, it indicates use of convolutional or LDPC coding and the MCS setting is conveyed in the VHT-SIG-B field.
- **Beamformed** — An indicator bit set to 1 when a beamforming matrix is applied to the transmission.
- **CRC** — An eight-bit field used to detect errors in the VHT-SIG-A transmission.
- **Tail** — A six-bit field used to terminate the convolutional code.

Very High Throughput Short Training Field

The very high throughput short training field (VHT-STF) is a single OFDM symbol (4 μs in length) that is used to improve automatic gain control estimation in a MIMO transmission. It is located between the VHT-SIG-A and VHT-LTF portions of the VHT packet.

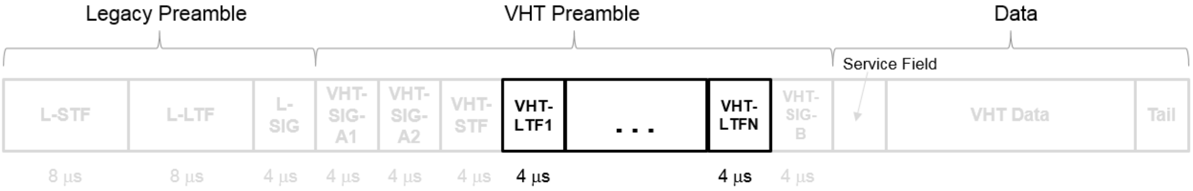


The frequency domain sequence used to construct the VHT-STF for a 20 MHz transmission is identical to the L-STF sequence. Duplicate L-STF sequences are frequency shifted and phase rotated to support VHT transmissions for the 40 MHz, 80 MHz, and 160 MHz channel bandwidths. As such, the L-STF and HT-STF are subsets of the VHT-STF.

The VHT-STF is defined in IEEE Std 802.11ac-2013, Section 22.3.8.3.4.

Very High Throughput Long Training Fields

The very high throughput long training field (VHT-LTF) is located between the VHT-STF and VHT-SIG-B portion of the VHT packet.



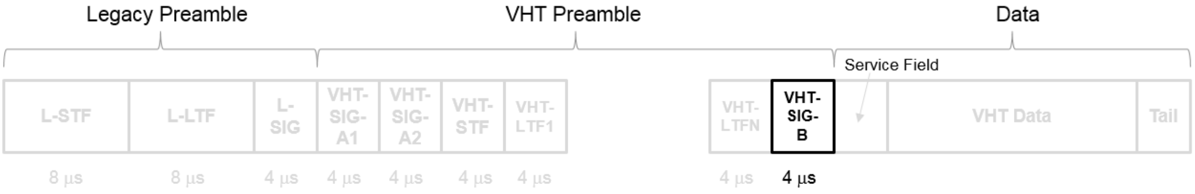
It is used for MIMO channel estimation and pilot subcarrier tracking. The VHT-LTF includes one VHT long training symbol for each spatial stream indicated by the selected MCS. Each symbol is 4 μs long. A maximum of eight symbols are permitted in the VHT-LTF.

The VHT-LTF is defined in IEEE Std 802.11ac-2013, Section 22.3.8.3.5.

Very High Throughput SIG-B Field

The very high throughput signal B field (VHT-SIG-B) is used for multi-user scenario to set up the data rate and to fine-tune MIMO reception. It is modulated using MCS 0 and is transmitted in a single OFDM symbol.

The VHT-SIG-B field consists of a single OFDM symbol located between the VHT-LTF and the data portion of the VHT format PPDU.



The very high throughput signal B (VHT-SIG-B) field contains the actual rate and A-MPDU length value per user. The VHT-SIG-B is defined in IEEE Std 802.11ac-2013, Section 22.3.8.3.6, and Table 22–14. The number of bits in the VHT-SIG-B field varies with the channel bandwidth and the assignment depends on whether single user or multi-user scenario in allocated. For single user configurations, the same information is available in the L-SIG field but the VHT-SIG-B field is included for continuity purposes.

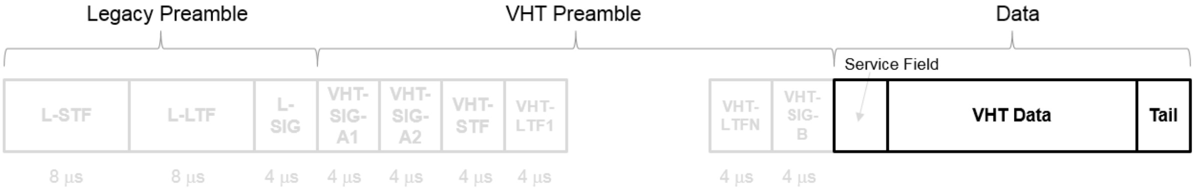
Field	VHT MU PPDU Allocation (bits)			VHT SU PPDU Allocation (bits)			Description
	20 MHz	40 MHz	80 MHz, 160 MHz	20 MHz	40 MHz	80 MHz, 160 MHz	
VHT-SIG-B	B0-15 (16)	B0-16 (17)	B0-18 (19)	B0-16 (17)	B0-18 (19)	B0-20 (21)	A variable-length field that indicates the size of the data payload in four-byte units. The length of the field depends on the channel bandwidth.
VHT-MCS	B16-19 (4)	B17-20 (4)	B19-22 (4)	N/A	N/A	N/A	A four-bit field that is included for multi-user scenarios only.
Reserved	N/A	N/A	N/A	B17–19 (3)	B19-20 (2)	B21-22 (2)	All ones

Field	VHT MU PPDU Allocation (bits)			VHT SU PPDU Allocation (bits)			Description
	20 MHz	40 MHz	80 MHz, 160 MHz	20 MHz	40 MHz	80 MHz, 160 MHz	
Tail	B20-25 (6)	B21-26 (6)	B23-28 (6)	B20-25 (6)	B21-26 (6)	B23-28 (6)	Six zero-bits used to terminate the convolutional code.
Total # bits	26	27	29	26	27	29	
Bit field repetition	1	2	4 *For 160 MHz, the 80 MHz channel is repeated twice.*	1	2	4 *For 160 MHz, the 80 MHz channel is repeated twice.*	

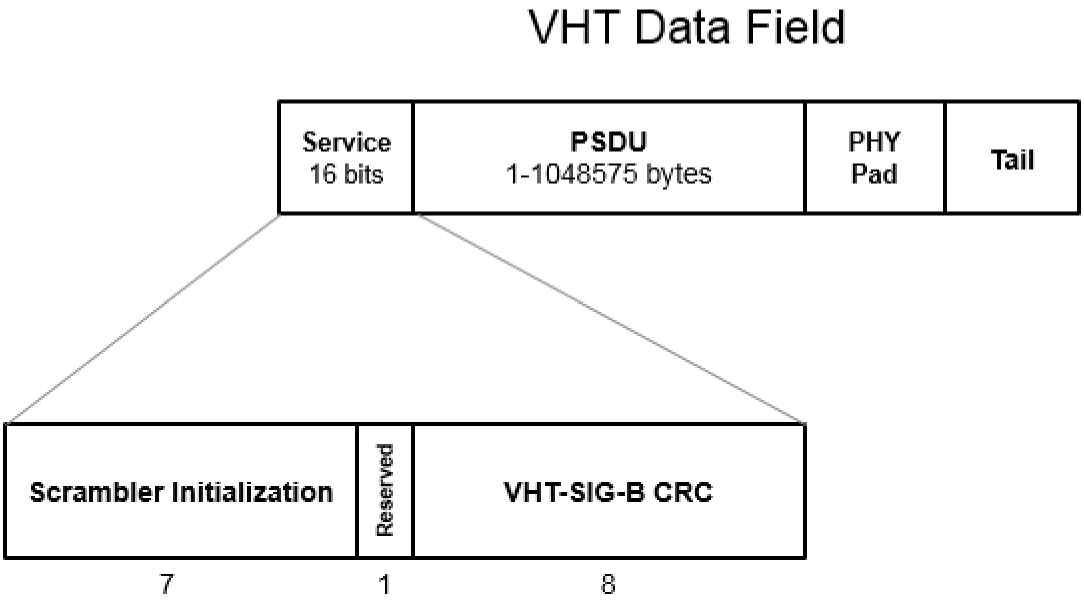
For a null data packet (NDP), the VHT-SIG-B bits are set according to IEEE Std 802.11ac-2013, Table 22-15.

VHT Data Field

The very high throughput data (VHT data) field is used to transmit one or more frames from the MAC layer. It follows the VHT-SIG-B field in the packet structure for the VHT format PPDUs.



The VHT data field is defined in IEEE Std 802.11ac-2013, Section 22.3.10. It is composed of four subfields.



- **Service field** — Contains a seven-bit scrambler initialization state, one bit reserved for future considerations, and eight bits for the VHT-SIG-B CRC field.
- **PSDU** — Variable-length field containing the PLCP service data unit. In 802.11, the PSDU can consist of an aggregate of several MAC service data units.
- **PHY Pad** — Variable number of bits passed to the transmitter to create a complete OFDM symbol.
- **Tail** — Bits used to terminate a convolutional code. Tail bits are not needed when LDPC is used.

References

[1] IEEE 802.11™: Wireless LANs. http://standards.ieee.org/about/get/802/802.11.html

[2] IEEE Std 802.11™-2012 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and

metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[3] IEEE Std 802.11ac™-2013 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications — Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz.

[4] IEEE Std 802.11ad™-2012 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications — Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band.

[5] Perahia, E., and R. Stacey. *Next Generation Wireless LANs: 802.11n and 802.11ac*. 2nd Edition. United Kingdom: Cambridge University Press, 2013.

See Also

"Waveform Generation" | "What Is WLAN?" | "Mapping of 802.11 Standards to WLAN System Toolbox Configuration Functions" on page 1-32

Mapping of 802.11 Standards to WLAN System Toolbox Configuration Functions

The table shows the mapping from 802.11 versions to the associated packet format and WLAN System Toolbox configuration object function.

802.11 Version	Transmission Packet Format	Toolbox Configuration Function	Packet Format Properties
802.11 b/a/g/j/p	non-HT	`wlanNonHTConfig`	wlanNonHTConfig
802.11n	HT	`wlanHTConfig`	wlanHTConfig
802.11ac	VHT	`wlanVHTConfig`	wlanVHTConfig
802.11ah	S1G	`wlanS1GConfig`	wlanS1GConfig
802.11ad	DMG	`wlanDMGConfig`	wlanDMGConfig

WLAN System Toolbox configuration objects define the properties that enable creation of PPDUs and waveforms for the specified 802.11 transmission format.

See Also

“WLAN Parameterization” on page 1-2 | “WLAN Packet Structure” on page 1-4 | “Create Configuration Objects” | “Waveform Generation”

What is C Code Generation from MATLAB?

You can use WLAN System Toolbox together with MATLAB® Coder™ to create C/C++ code that implements your MATLAB functions and models. With this software, you can

- Create a MEX file to speed up your own MATLAB application.
- Generate a stand-alone executable that runs independently of MATLAB on your own computer or another platform.
- Include System objects in the same way as any other element.

In general, the code you generate using the toolbox is portable ANSI® C code. In order to use code generation, you need a MATLAB Coder license. Using WLAN System Toolbox requires licenses for DSP System Toolbox™, Signal Processing Toolbox™, and Communications System Toolbox™. See the "Getting Started with MATLAB Coder" (MATLAB Coder) page for more information.

Creating a MATLAB Coder MEX-file can lead to substantial acceleration of your MATLAB algorithms. It is also a convenient first step in a workflow that ultimately leads to completely standalone code. When you create a MEX-file, it runs in the MATLAB environment. Its inputs and outputs are available for inspection just like any other MATLAB variable. You can use MATLAB's visualization, and other tools, for verification and analysis.

Within your code, you can run specific commands either as generated C code or by running using the MATLAB engine. In cases where an isolated command does not yet have code generation support, you can use the `coder.extrinsic` command to embed the command in your code. This means that the generated code reenters the MATLAB environment when it needs to run that particular command. This also useful if you wish to embed certain commands that cannot generate code (such as plotting functions).

The simplest way to generate MEX-files from your MATLAB code is by using the `codegen` function at the command line. Often, generating a MEX-files involves nothing more than invoking the `coder` command on one of your existing functions. For example, if you have an existing function, `myfunction.m`, you can type the commands at the command line to compile and run the MEX function. `codegen` adds a platform-specific extension to this name. In this case, the `"mex"` suffix is added.

```
codegen myfunction.m
myfunction_mex;
```

You can generate standalone executables that run independently of the MATLAB environment. You can do this by creating a MATLAB Coder project inside the MATLAB

Coder Integrated Development Environment (IDE). Alternatively, you can issue the `codegen` command in the command line environment with appropriate configuration parameters. To create a standalone executable, you must write your own `main.c` or `main.cpp` function. See “C/C++ Code Generation” (MATLAB Coder) for more information.

Set Up Your Compiler

Before using `codegen` to compile your code, you must set up your C/C++ compiler. For 32-bit Windows platforms, MathWorks® supplies a default compiler with MATLAB. If your installation does not include a default compiler, you can supply your own compiler. For the current list of supported compilers, see Supported and Compatible Compilers on the MathWorks Web site. Install a compiler that is suitable for your platform. Then, read “Setting Up the C or C++ Compiler” (MATLAB Coder). After installation, at the MATLAB command prompt, run `mex -setup`. You can then use the `codegen` function to compile your code.

Functions and System Objects That Support Code Generation

All WLAN System Toolbox functions and System objects are supported for code generation. For a list of supported functions and System objects, see “WLAN System Toolbox” (MATLAB Coder).

Functions and System Objects Supported for MATLAB Coder and Compiler

These functions and System objects support code generation from MATLAB code. Code generation from MATLAB code requires the MATLAB Coder software.

If you have a MATLAB Compiler™ license, you can generate standalone applications that contain WLAN System Toolbox functions, System objects, and classes.

An asterisk (*) indicates that the reference page has usage notes and limitations for C/C++ code generation.

WLAN Modeling
wlanHTConfig*
wlanNonHTConfig*
wlanRecoveryConfig*
wlanS1GConfig*
wlanVHTConfig*
Signal Transmission
wlanBCCEncode*
wlanBCCInterleave*
wlanConstellationMap*
wlanDMGConfig*
wlanHTData*
wlanHTLTF*
wlanHTSIG*
wlanHTSTF*
wlanLLTF*
wlanLSIG*
wlanLSTF*
wlanNonHTData*
wlanScramble*

wlanSegmentDeparseSymbols*
wlanSegmentParseBits*
wlanStreamParse*
wlanVHTData*
wlanVHTLTF*
wlanVHTSIGA*
wlanVHTSIGB*
wlanVHTSTF*
wlanWaveformGenerator*
Signal Reception
wlanBCCDecode*
wlanBCCDeinterleave*
wlanCoarseCFOEstimate*
wlanConstellationDemap*
wlanDMGDataBitRecover*
wlanDMGHeaderBitRecover*
wlanFormatDetect*
wlanFieldIndices*
wlanFineCFOEstimate*
wlanGolaySequence*
wlanHTDataRecover*
wlanHTLTFChannelEstimate*
wlanHTLTFDemodulate*
wlanHTSIGRecover*
wlanLLTFChannelEstimate*
wlanLLTFDemodulate*
wlanLSIGRecover*
wlanNonHTDataRecover*
wlanPacketDetect*

wlanScramble*
wlanSegmentDeparseBits*
wlanSegmentParseSymbols*
wlanStreamDeparse*
wlanSymbolTimingEstimate*
wlanVHTDataRecover*
wlanVHTLTFChannelEstimate*
wlanVHTLTFDemodulate*
wlanVHTSIGARecover*
wlanVHTSIGBRecover*
Propagation Channel
wlanTGacChannel*
wlanTGahChannel*
wlanTGaxChannel*
wlanTGnChannel*

Note WLAN System Toolbox functionality with the MATLAB Function block is not supported.

Build HE PPDU

802.11ax Parameterization for Waveform Generation and Simulation

This example shows how to parameterize and generate different types of IEEE® 802.11ax™ high efficiency (HE) formats.

Introduction

IEEE P802.11ax/D1.1 [1] specifies four high efficiency (HE) packet formats:

1. Single user
2. Extended range single user
3. Multi user
4. Trigger-based

This example shows how packets can be generated for these different formats, and demonstrates some of the key features of the draft standard [1].

HE Single User Format

An HE single user (SU) packet is a full-band transmission to a single user. The transmit parameters for the HE SU format are configured using a heSUConfig object. The properties of heSUConfig are similar to those of wlanVHTConfig, as the transmission format is based on 802.11ac™. The heSUConfig object can be configured to operate in extended range mode. To enable or disable this mode, set the ExtendedRange property to true or false. In this example we create a configuration for an HE SU transmission and configure a number of properties.

```
cfgSU = heSUConfig;
cfgSU.ExtendedRange = false;      % Do not use extended range format
cfgSU.ChannelBandwidth = 'CBW20'; % Channel bandwidth
cfgSU.APEPLength = 1000;          % Payload length in bytes
cfgSU.MCS = 0;                    % Modulation and coding scheme
cfgSU.ChannelCoding = 'LDPC';     % Channel coding
cfgSU.NumSpaceTimeStreams = 1;    % Number of space-time streams
cfgSU.NumTransmitAntennas = 1;    % Number of transmit antennas
```

A single user packet can be generated with the HE waveform generator, heWaveformGenerator. The getPSDULength() method returns the required PSDU length given the transmission configuration. This length is used to create a random PSDU for transmission.

```
psdu = randi([0 1],getPSDULength(cfgSU)*8,1,'int8'); % Random PSDU
txSUWaveform = heWaveformGenerator(psdu,cfgSU);      % Create packet
```

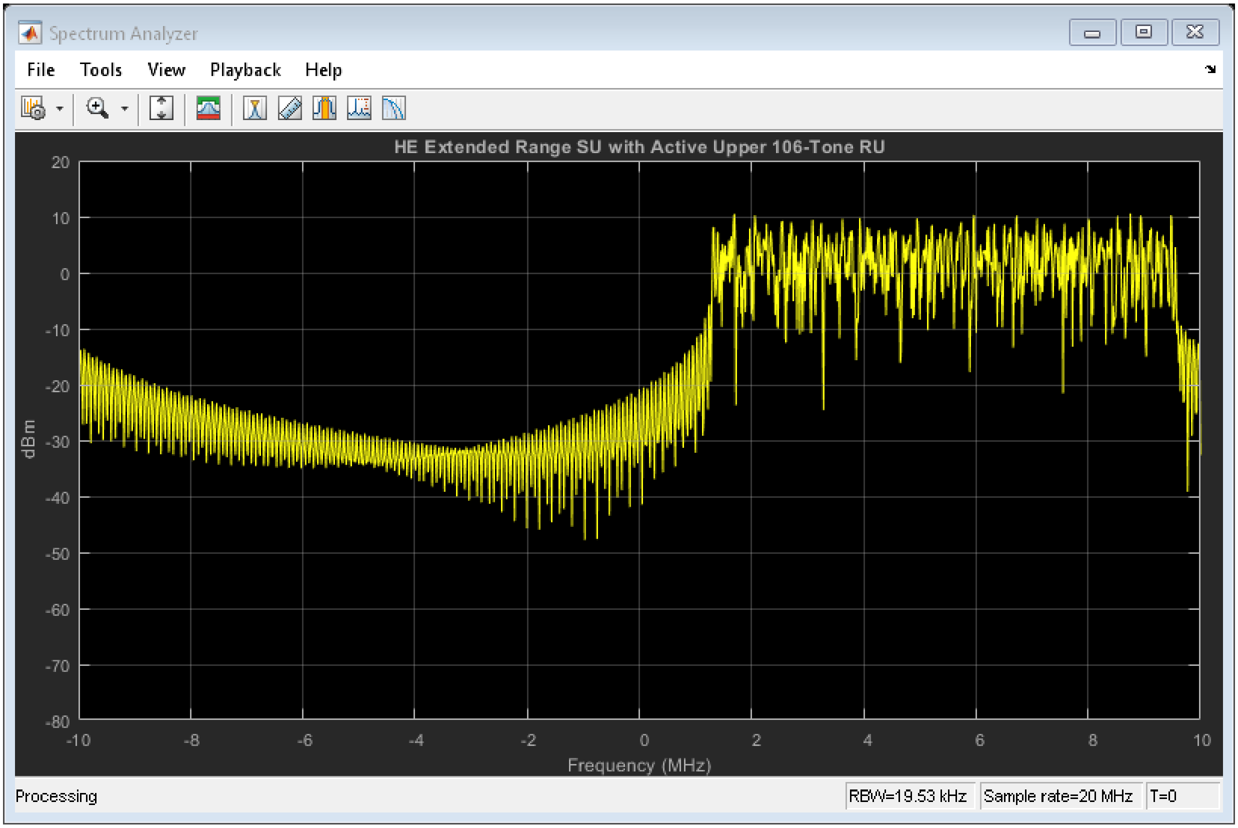
HE Extended Range Single User Format

An extended range single user packet has the same fields as the standard single user format, but the powers of some fields are boosted, and some fields are repeated to improve performance at low SNRs. An extended range packet can be configured using an `heSUConfig` object with `ChannelBandwidth` set to `'CBW20'` and `ExtendedRange` set to `true`. An extended range packet has an option to only transmit in the upper 106-tone resource unit (RU) within the 20 MHz channel, or over the entire bandwidth. This can be configured with the `Upper106ToneRU` property:

```
cfgExtSU = cfgSU;
cfgExtSU.ExtendedRange = true;  % Enable extended range
cfgExtSU.Upper106ToneRU = true; % Use only upper 106-tone RU

% Generate a packet
psdu = randi([0 1],getPSDULength(cfgExtSU)*8,1,'int8'); % Random PSDU
txExtSUWaveform = heWaveformGenerator(psdu,cfgExtSU);   % Create packet
```

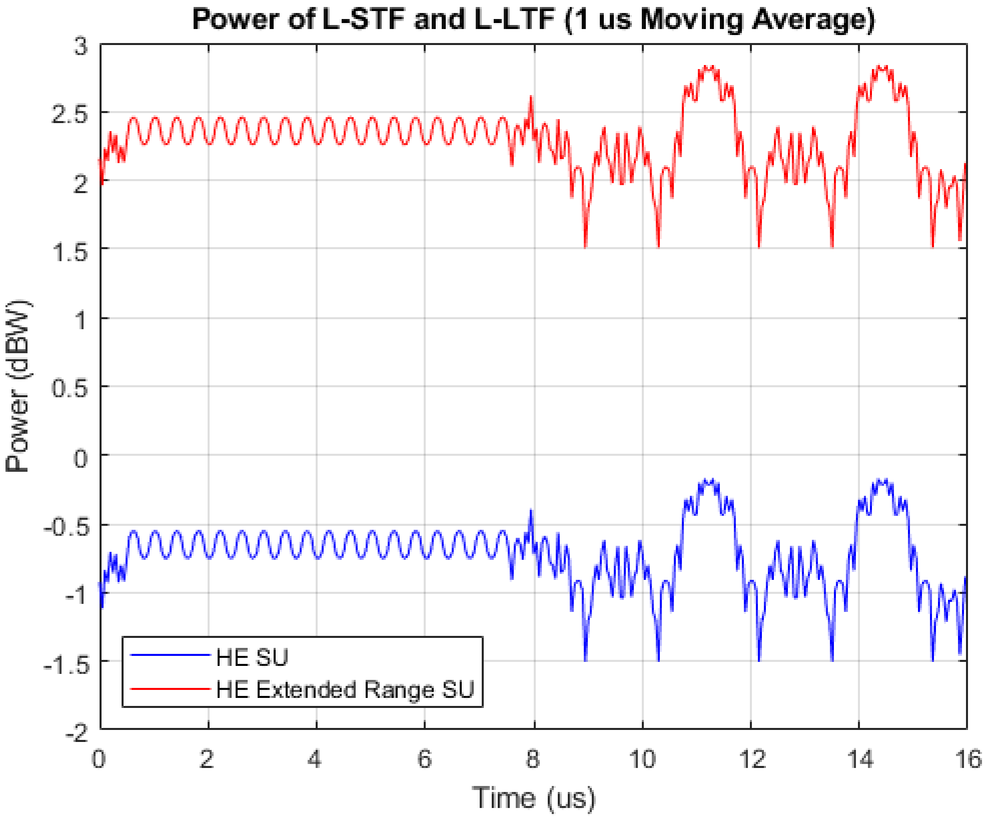
If we look at the spectrum of the data portion we can see only the upper half of the channel is used.

```
fs = heSampleRate(cfgExtSU); % Get baseband sample rate
spectrumAnalyzer = dsp.SpectrumAnalyzer;
spectrumAnalyzer.SampleRate = fs;
spectrumAnalyzer.Title = 'HE Extended Range SU with Active Upper 106-Tone RU';
ind = heFieldIndices(cfgExtSU);
spectrumAnalyzer(txExtSUWaveform(ind.HEData(1):ind.HEData(2),:));
```



If we compare the power of the L-STF and L-LTF fields we can see the extended range transmission is boosted by 3dB.

```
figure;
t = (0:(ind.LLTF(2)-1))/fs*1e6;
plot(t,20*log10(movmean(abs(txSUWaveform(1:ind.LLTF(2))),20)),'-b')
hold on;
plot(t,20*log10(movmean(abs(txExtSUWaveform(1:ind.LLTF(2))),20)),'-r')
grid on;
title('Power of L-STF and L-LTF (1 us Moving Average)');
xlabel('Time (us)');
ylabel('Power (dBW)');
legend('HE SU','HE Extended Range SU','Location','SouthWest');
```



HE Multi User Format - OFDMA

The HE multi-user (MU) format can be configured for an OFDMA transmission, a MU-MIMO transmission, or a combination of the two. This flexibility allows an HE MU packet to transmit to a single user over the whole band, multiple users over different parts of the band (OFDMA), or multiple users over the same part of the band (MU-MIMO).

For an OFDMA transmission, the channel bandwidth is divided into resource units (RUs). An RU is a group of subcarriers assigned to one or more users. An RU is defined by a size (the number of subcarriers) and an index. The RU index specifies the location of the RU within the channel. For example, in an 80 MHz transmission there are four possible 242-tone RUs, one in each 20 MHz subchannel. RU# 242-1 (size 242, index 1) is the RU occupying the lowest absolute frequency within the 80 MHz, and RU# 242-4 (size 242, index 4) is the RU occupying the highest absolute frequency. The draft standard defines possible sizes and location of RUs in Section 28.3.3.2 of [1].

The assignment of RUs in a transmission is defined by the allocation index. The allocation index is defined in Table 28-21 of [1]. For each 20 MHz subchannel, an 8 bit index describes the number and size of RUs, and the number of users assigned to each RU. The allocation index also determines which content channel is used to signal a user in HE-SIG-B. The allocation indices within Table 28-21, and the corresponding RU assignments, are provided in the table returned by the function `heRUAllocationTable`. The first 10 allocations within the table are shown below. For each allocation index, the 8 bit allocation index, the number of users, number of RUs, RU indices, RU sizes, and number of users per RU are displayed. A note is also provided about allocations which are reserved, or serve a special purpose. The allocation table can also be viewed in the appendix.

```
allocationTable = heRUAllocationTable;
disp('First 10 entries in the allocation table: ')
disp(allocationTable(1:10,:));
```

```
First 10 entries in the allocation table:
    Allocation    BitAllocation    NumUsers    NumRUs     RUIndices        RUSizes
    __________    _____________    ________    ______    ____________    ____________

        0          "00000000"         9          9       [1x9 double]    [1x9 double]
        1          "00000001"         8          8       [1x8 double]    [1x8 double]
        2          "00000010"         8          8       [1x8 double]    [1x8 double]
        3          "00000011"         7          7       [1x7 double]    [1x7 double]
        4          "00000100"         8          8       [1x8 double]    [1x8 double]
        5          "00000101"         7          7       [1x7 double]    [1x7 double]
        6          "00000110"         7          7       [1x7 double]    [1x7 double]
        7          "00000111"         6          6       [1x6 double]    [1x6 double]
        8          "00001000"         8          8       [1x8 double]    [1x8 double]
        9          "00001001"         7          7       [1x7 double]    [1x7 double]
```

An `heMUConfig` object is used to configure the transmission of an HE MU packet. The allocation index for each 20 MHz subchannel must be provided when creating an HE-MU configuration object, `heMUConfig`. An integer between 0 and 223, corresponding to the 8-bit number in Table 28-21 of [1], must be provided for each 20 MHz subchannel.

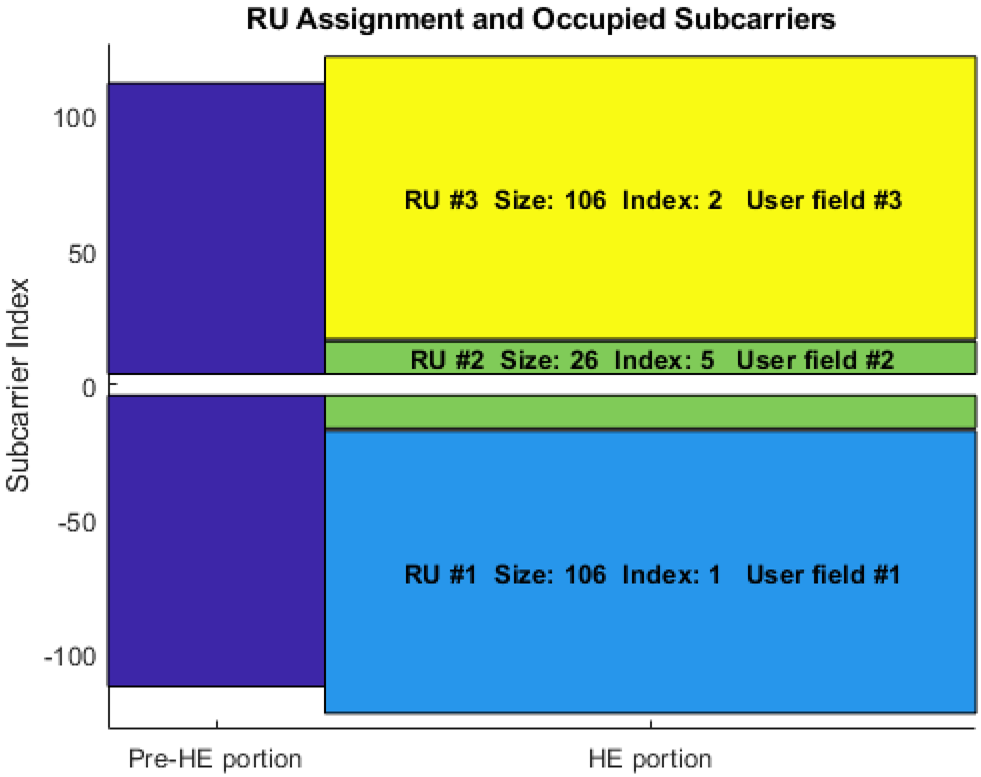
In this example, a 20 MHz HE-MU configuration is created with 8 bit allocation index [1 0 0 0 0 0 0 0], or 128. This configuration specifies 3 RUs, each with one user. To convert an 8 bit index to decimal use bi2de as shown below.

```
allocationIndexBits = [1 0 0 0 0 0 0 0]; % 3 RUs, 1 user per RU
allocationIndex = bi2de(allocationIndexBits,'left-msb'); % Convert to decimal
disp(['Allocation index: ' num2str(allocationIndex)])
cfgMU = heMUConfig(allocationIndex);
```

```
Allocation index: 128
```

The `plotAllocation()` method visualizes the occupied RUs and subcarriers for the specified configuration. The colored blocks illustrate the occupied subcarriers in the pre-HE and HE portions of the packet. White indicates subcarriers are unoccupied. The pre-HE portion illustrates the occupied subcarriers in the fields preceding HE-STF. The HE portion illustrates the occupied subcarriers in the HE-STF, HE-LTF and HE-Data field and therefore shows the RU allocation. The RU number corresponds to the i-th RU element of the `cfgMU.RU` property. The size and index are the details of the RU. The RU index is the i-th possible RU of the corresponding RU size within the channel bandwidth, for example Index 5 is the 5th possible 26-tone RU within the 20 MHz channel bandwidth. The user field index corresponds to how the user is signaled in HE-SIG-B.

```
figure;
plotAllocation(cfgMU);
axAlloc = gca; % Get axis handle for subsequent plotting
```



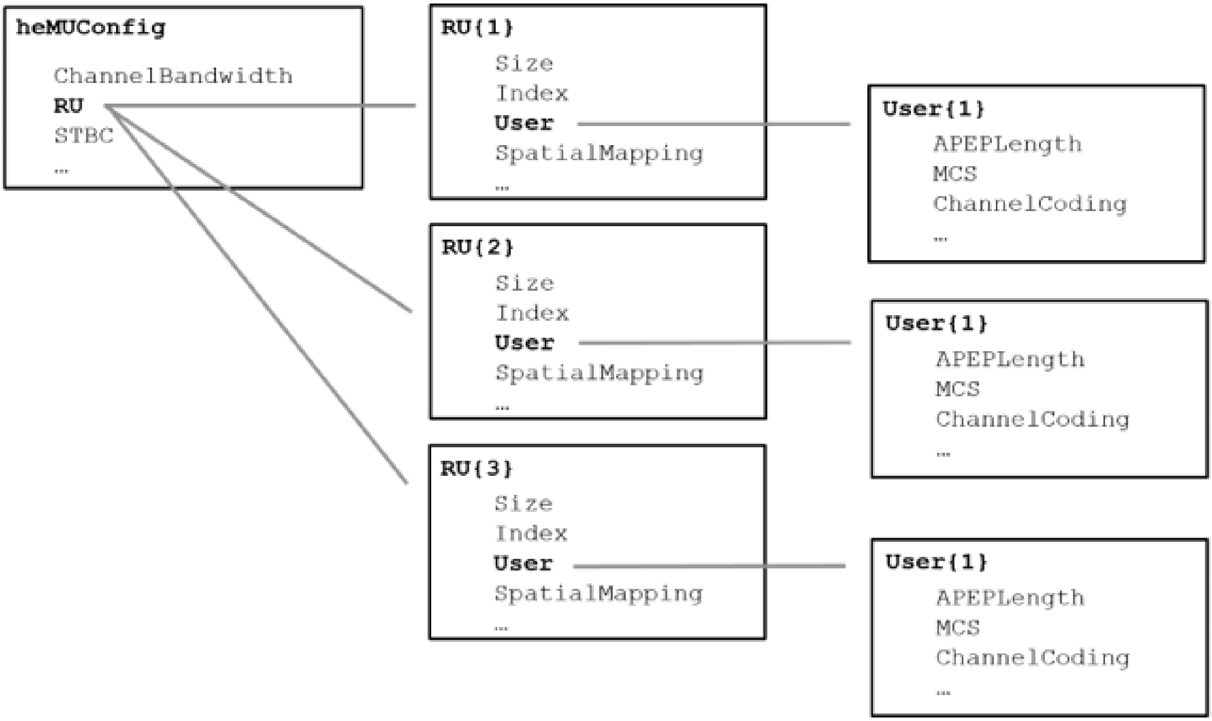
The `ruInfo` method provides details of the RUs in the configuration. In this case we can see three users and three RUs.

```
allocInfo = ruInfo(cfgMU);
disp('Allocation info:')
disp(allocInfo)
```

```
Allocation info:
                   NumUsers: 3
                     NumRUs: 3
                  RUIndices: [1 5 2]
                    RUSizes: [106 26 106]
              NumUsersPerRU: [1 1 1]
    NumSpaceTimeStreamsPerRU: [1 1 1]
```

```
        PowerBoostFactorPerRU: [1 1 1]
```

The properties of cfgMU describe the transmission configuration. The cfgMU.RU property of cfgMU is a cell array. Each element of the cell array contains properties to configure an RU, and the users associated with it. When the cfgMU object is created, the elements of cfgMU.RU are configured to create the desired number of RUs and users. Each element of cfgMU.RU is an heRU object describing the configuration of an RU. Each heRU object contains an heRU.User property, which allows each user within the RU to be configured. This object hierarchy is shown in the diagram below:



In this example, three RUs are specified by the allocation index 128, therefore cfgMU.RU is a cell array with three elements. The index and size of each RU are configured according to the allocation index used to create cfgMU. After the object is created, each RU can be configured to create the desired transmission configuration. For example, the spatial mapping and power boost factor can be configured per RU. For this configuration the first RU is RU# 106-1 (size 106, index 1).

```
disp('First RU configuration:')
disp(cfgMU.RU{1})
```

```
First RU configuration:
  heRU with properties:

                Size: 106
               Index: 1
                User: {[1x1 heUser]}
    PowerBoostFactor: 1
      SpatialMapping: 'Direct'
```

The `RU.User` property of an `heRU` object is a cell array. Each element is an `heUser` object with properties allowing the transmission for a single user associated with the RU to be configured. When the `cfgMU` object is created the requested number of users per RU are created. In this example only one user is assigned to the first RU, therefore `cfgMU.RU{1}.User` contains only one element. The properties of each user can be configured as required, for example the MCS, APEP length and channel coding scheme.

```
disp('First user configuration:')
disp(cfgMU.RU{1}.User{1})
```

```
First user configuration:
  heUser with properties:

             APEPLength: 1000
                    MCS: 0
    NumSpaceTimeStreams: 1
                    DCM: 0
          ChannelCoding: 'LDPC'
                  STAID: 0
```

Once the object is created, it is recommended that the indices and sizes of RUs are not changed, but transmission parameters can be set as demonstrated below.

```
% Configure RU 1 and user 1
cfgMU.RU{1}.User{1}.APEPLength = 1e3;
cfgMU.RU{1}.User{1}.MCS = 2;
cfgMU.RU{1}.User{1}.NumSpaceTimeStreams = 4;
cfgMU.RU{1}.User{1}.ChannelCoding = 'LDPC';
cfgMU.RU{1}.SpatialMapping = 'Direct';

% Configure RU 2 and user 2
```

```
cfgMU.RU{2}.User{1}.APEPLength = 500;
cfgMU.RU{2}.User{1}.MCS = 3;
cfgMU.RU{2}.User{1}.NumSpaceTimeStreams = 2;
cfgMU.RU{2}.User{1}.ChannelCoding = 'LDPC';
cfgMU.RU{2}.SpatialMapping = 'Fourier';

% Configure RU 3 and user 3
cfgMU.RU{3}.User{1}.APEPLength = 100;
cfgMU.RU{3}.User{1}.MCS = 4;
cfgMU.RU{3}.User{1}.DCM = true;
cfgMU.RU{3}.User{1}.NumSpaceTimeStreams = 1;
cfgMU.RU{3}.User{1}.ChannelCoding = 'BCC';
cfgMU.RU{3}.SpatialMapping = 'Fourier';
```

Some transmission parameters are common for all users in the MU transmission.

```
% Configure common parameters for all users
cfgMU.NumTransmitAntennas = 4;
cfgMU.MCSSIGB = 2;
```

To generate the MU waveform, we first create a random PSDU for each user. A cell array is used to store the PSDU for each user as the PSDU lengths differ. The `getPSDULength()` method returns a vector with the required PSDU per user given the configuration. The waveform generator is then used to create a packet.

```
psduLength = getPSDULength(cfgMU);
psdu = cell(1,allocInfo.NumUsers);
for i = 1:allocInfo.NumUsers
    psdu{i} = randi([0 1],psduLength(i)*8,1,'int8'); % Generate random PSDU
end

% Create MU packet
txMUWaveform = heWaveformGenerator(psdu,cfgMU);
```

To configure an OFDMA transmission with a channel bandwidth greater than 20 MHz, an allocation index must be provided for each 20 MHz subchannel. For example, to configure an 80 MHz OFDMA transmission, four allocation indices are required. In this example four 242-tone RUs are configured. The allocation index `192` specifies one 242-tone RU with a single user in a 20 MHz subchannel, therefore the allocation indices `[192 192 192 192]` are used to create four of these RUs, over 80 MHz:

```
% Display 192 allocation index properties in the table (the 193rd row)
disp('Allocation #192 table entry:')
disp(allocationTable(193,:))
```

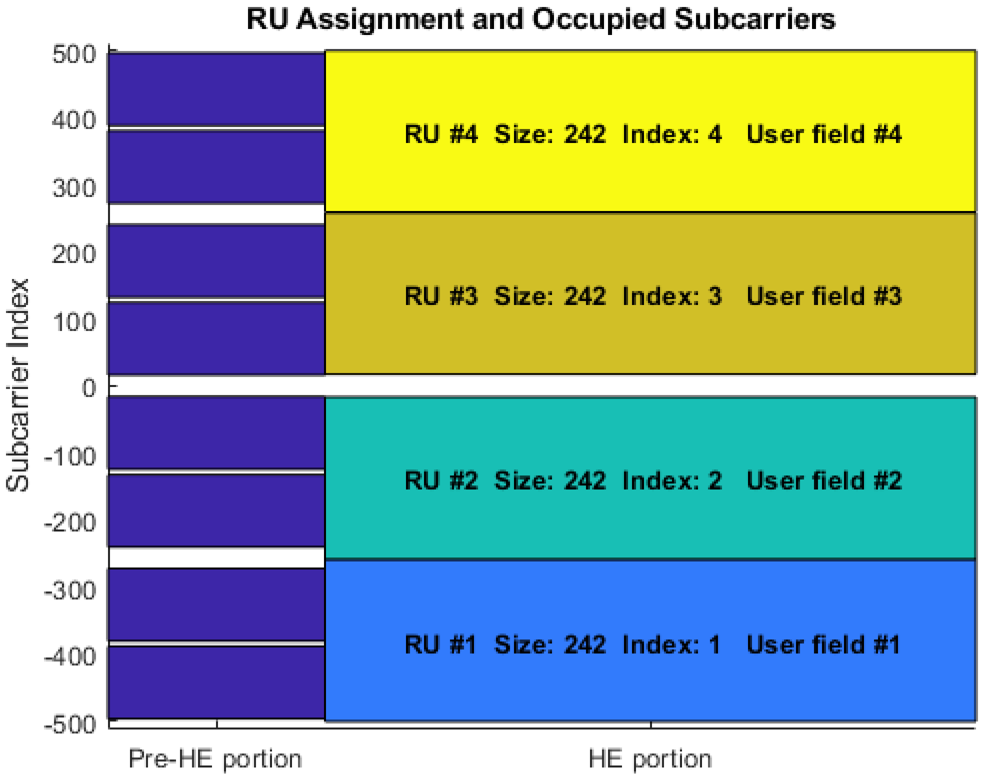
```
% Create 80 MHz MU configuration, with four 242-tone RUs
cfgMU80MHz = heMUConfig([192 192 192 192]);
```

```
Allocation #192 table entry:
    Allocation    BitAllocation    NumUsers    NumRUs    RUIndices    RUSizes    NumUse
    __________    _____________    ________    ______    _________    _______    ______

       192         "11000000"         1          1          [1]        [242]
```

When multiple 20 MHz subchannels are specified, the `ChannelBandwidth` property is set to the appropriate value. For this configuration it is set to `'CBW80'` as four 20 MHz subchannels are specified. This is also visible in the allocation plot.

```
disp('Channel bandwidth for HE-MU allocation:')
disp(cfgMU80MHz.ChannelBandwidth)
plotAllocation(cfgMU80MHz,axAlloc)
```

```
Channel bandwidth for HE-MU allocation:
CBW80
```



HE Multi User Format - MU-MIMO

An HE MU packet can also transmit an RU to multiple users using MU-MIMO. For a full band MU-MIMO allocation, the allocation indices between 192 and 199 configure a full-band 20 MHz allocation (242-tone RU). The index within this range determines how many users are configured. The allocation details can be viewed in the allocation table. Note the `NumUsers` column in the table grows with index but the `NumRUs` is always 1. The allocation table can also be viewed in the appendix.

```
disp('Allocation #192-199 table entries:')
disp(allocationTable(193:200,:)) % Indices 192-199 (rows 193 to 200)
```

```
Allocation #192-199 table entries:
    Allocation    BitAllocation    NumUsers    NumRUs    RUIndices    RUSizes    NumUse
    __________    _____________    ________    ______    _________    _______    _____

       192         "11000000"         1          1          [1]        [242]
       193         "11000001"         2          1          [1]        [242]
       194         "11000010"         3          1          [1]        [242]
       195         "11000011"         4          1          [1]        [242]
       196         "11000100"         5          1          [1]        [242]
       197         "11000101"         6          1          [1]        [242]
       198         "11000110"         7          1          [1]        [242]
       199         "11000111"         8          1          [1]        [242]
```

The allocation index 193 transmits a 20 MHz 242-tone RU to two users. In this example, we will create a transmission with a random spatial mapping matrix which maps a single space-time stream for each user, onto two transmit antennas.

```
% Configure 2 users in a 20 MHz channel
cfgMUMIMO = heMUConfig(193);

% Set the transmission properties of each user
cfgMUMIMO.RU{1}.User{1}.APEPLength = 100; % Bytes
cfgMUMIMO.RU{1}.User{1}.MCS = 2;
cfgMUMIMO.RU{1}.User{1}.ChannelCoding = 'LDPC';
cfgMUMIMO.RU{1}.User{1}.NumSpaceTimeStreams = 1;

cfgMUMIMO.RU{1}.User{2}.APEPLength = 1000; % Bytes
cfgMUMIMO.RU{1}.User{2}.MCS = 6;
cfgMUMIMO.RU{1}.User{2}.ChannelCoding = 'LDPC';
cfgMUMIMO.RU{1}.User{2}.NumSpaceTimeStreams = 1;

% Get the number of occupied subcarriers in the RU
ruIndex = 1; % Get the info for the first (and only) RU
ofdmInfo = helperOFDMInfo('HE-Data',cfgMUMIMO,ruIndex);
numST = ofdmInfo.NumTones; % Number of occupied subcarriers

% Set the number of transmit antennas and generate a random spatial mapping
% matrix
numTx = 2;
allocInfo = ruInfo(cfgMUMIMO);
numSTS = allocInfo.NumSpaceTimeStreamsPerRU(ruIndex);
cfgMUMIMO.NumTransmitAntennas = numTx;
cfgMUMIMO.RU{ruIndex}.SpatialMapping = 'Custom';
cfgMUMIMO.RU{ruIndex}.SpatialMappingMatrix = rand(numST,numSTS,numTx);
```

```
% Create packet with a repeated bit sequence as the PSDU
txMUMIMOWaveform = heWaveformGenerator([1 0 1 0],cfgMUMIMO);
```

A full band MU-MIMO transmission with a channel bandwidth greater than 20 MHz is created by providing a single RU allocation index within the range 200-223 when creating the `heMUConfig` object. For these allocation indices HE-SIG-B compression is used.

The allocation indices between 200 and 207 configure a full-band MU-MIMO 40 MHz allocation (484-tone RU). The index within this range determines how many users are configured. The allocation details can be viewed in the allocation table. Note the `NumUsers` column in the table grows with index but the `NumRUs` is always 1.

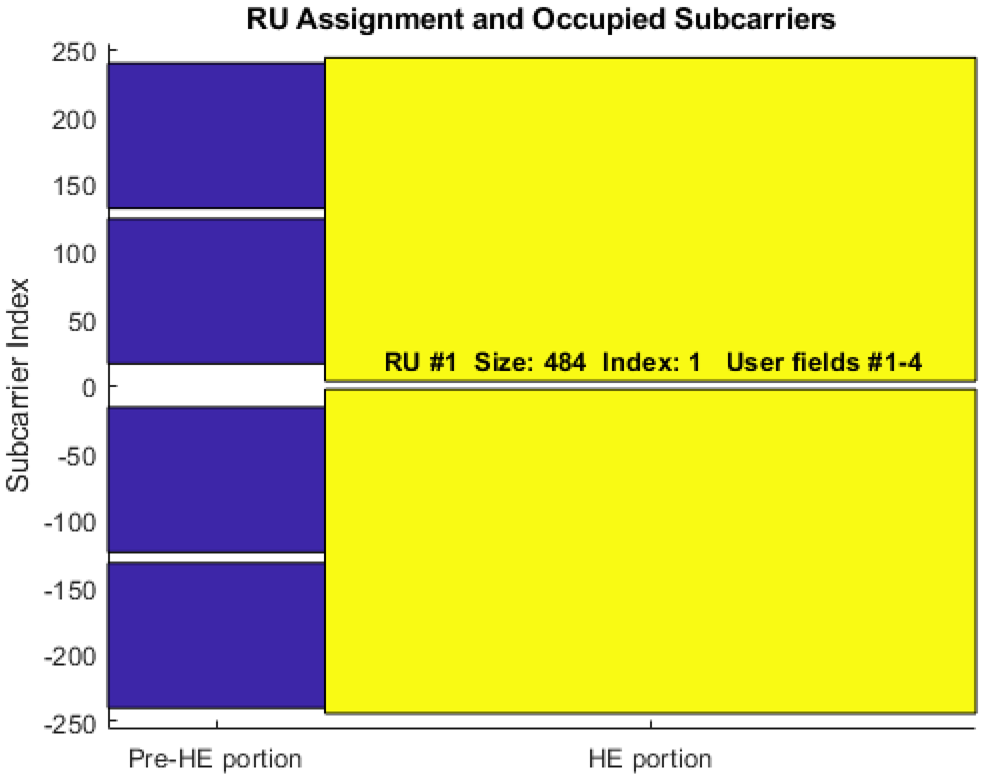
```
disp('Allocation #200-207 table entries:')
disp(allocationTable(201:208,:)) % Indices 200-207 (rows 201 to 208)
```

```
Allocation #200-207 table entries:
    Allocation    BitAllocation    NumUsers    NumRUs    RUIndices    RUSizes    NumUse
    __________    _____________    ________    ______    _________    _______    ______

       200         "11001000"         1          1          [1]        [484]
       201         "11001001"         2          1          [1]        [484]
       202         "11001010"         3          1          [1]        [484]
       203         "11001011"         4          1          [1]        [484]
       204         "11001100"         5          1          [1]        [484]
       205         "11001101"         6          1          [1]        [484]
       206         "11001110"         7          1          [1]        [484]
       207         "11001111"         8          1          [1]        [484]
```

Similarly, the allocation indices between 208 and 215 configure a full-band MU-MIMO 80 MHz allocation (996-tone RU), and the allocation indices between 216 and 223 configure a full-band MU-MIMO 160 MHz allocation (2x996-tone RU).

As an example, the allocation index `203` specifies a 484 RU with 4 users:

```
cfg484MU = heMUConfig(203);
plotAllocation(cfg484MU,axAlloc)
```



HE Multi User Format - OFDMA with RU Sizes Greater Than 242 Subcarriers

For an HE-MU transmission with a channel bandwidth greater than 20 MHz, two HE-SIG-B content channels are used to signal user configurations. These content channels are duplicated over each 40 MHz subchannel for larger channel bandwidths, as described in Section 28.3.10.8.2 of [1]. When an RU size greater than 242 is specified as part of an OFDMA system, the users assigned to the RU can be signaled on either of the two HE-SIG-B content channels. The allocation index provided when creating an `heMUConfig` object controls which content channel each user is signaled on. The allocation table in the appendix shows the relevant allocation indices.

As an example, consider the following 80 MHz configuration which serves 7 users:

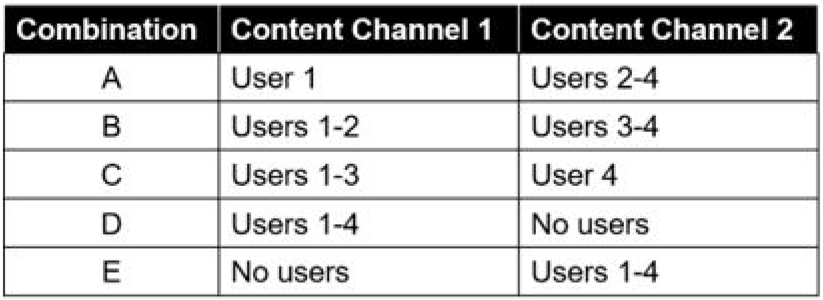
- One 484-tone RU (RU #1) with four users (users #1-4)
- One 242-tone RU (RU #2) with one user (user #5)
- Two 106-tone RUs (RU #3 and #4), each with one user (users #6 and #7)

To configure an 80 MHz OFDMA transmission, four allocation indices are required, one for each 20 MHz subchannel. To configure the above scenario the allocation indices below are used:

```
[X Y 192 96]
```

- X and Y configure the 484-tone RU, with users #1-4. The possible values of X and Y are discussed below.
- 192 configures a 242-tone RU with one user, user #5.
- 96 signals two 106-tone RUs, each with one user, users #6 and #7.

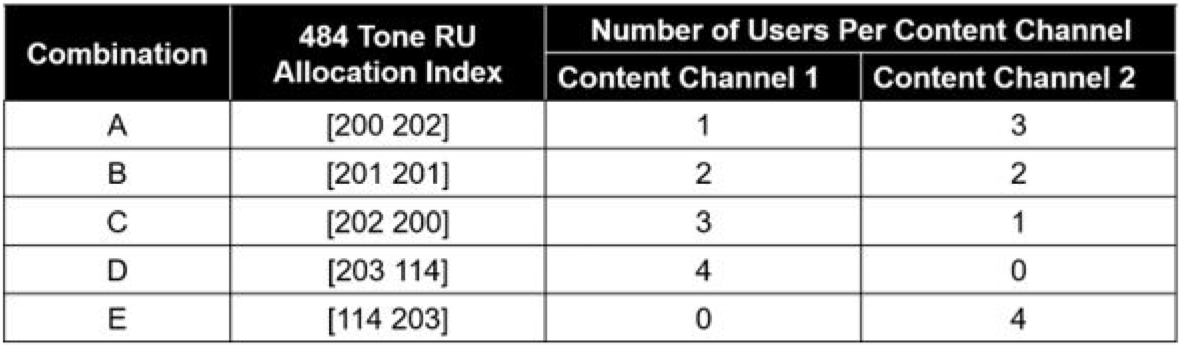
The selection of X and Y configures the appropriate number of users in the 242-tone RU, and determines which HE-SIG-B content channel is used to signal the users. A 484-tone RU spans two 20 MHz subchannels, therefore two allocation indices are required. All seven users from the four RUs will be signaled on the HE-SIG-B content channels, but for now we will only consider the signaling of users on the 484-tone RU. For the 484-tone RU, the four users can be signaled on the two HE-SIG-B content channels in different combinations as shown in Table 1.



Combination	Content Channel 1	Content Channel 2
A	User 1	Users 2-4
B	Users 1-2	Users 3-4
C	Users 1-3	User 4
D	Users 1-4	No users
E	No users	Users 1-4

Table 1

An allocation index within the range 200-207 specifies 1-8 users on a 484-tone RU. To signal no users on a content channel, the allocation index 114 or 115 can be used, for a 448-tone or 996-tone RU. Therefore, the combinations in Table 1 can be defined using two allocation indices as shown in Table 2. The two allocation indices in each row of Table 2 are X and Y.



Combination	484 Tone RU Allocation Index	Number of Users Per Content Channel	
		Content Channel 1	Content Channel 2
A	[200 202]	1	3
B	[201 201]	2	2
C	[202 200]	3	1
D	[203 114]	4	0
E	[114 203]	0	4

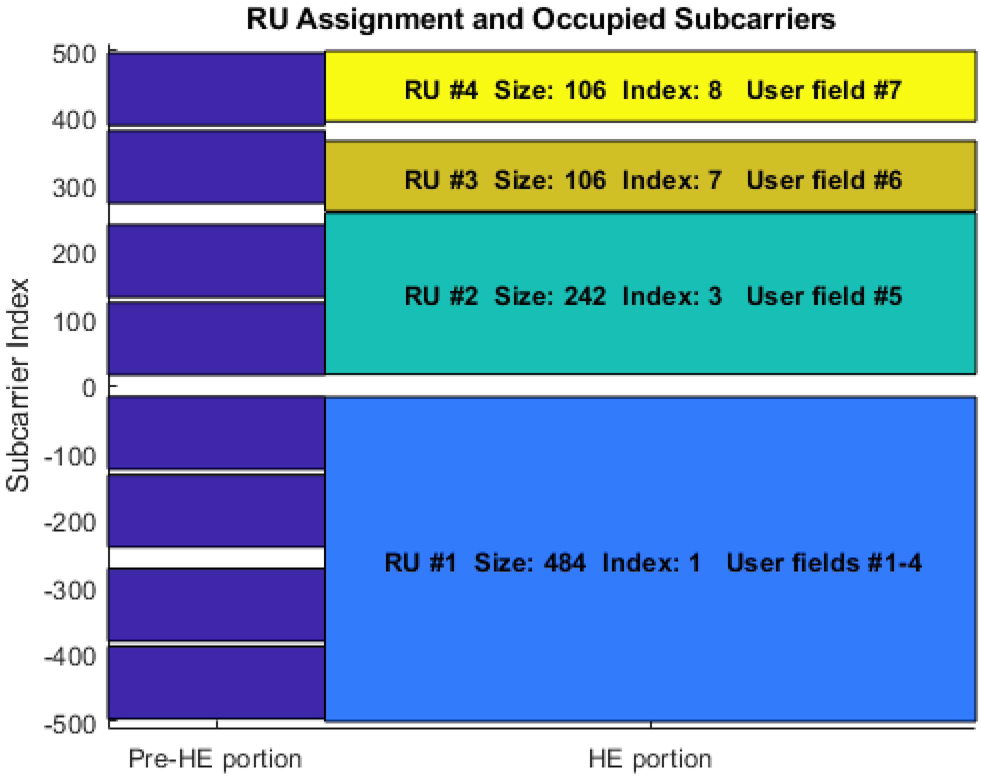
Table 2

Therefore, to configure 'Combination E' the following 80 MHz allocation indices are used:

```
[114 203 192 96]
```

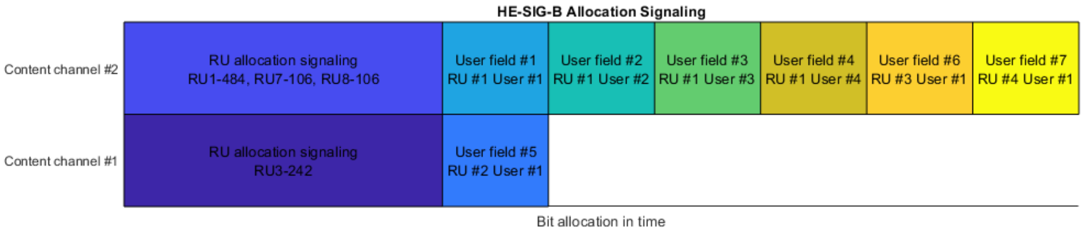
- `114` and `203` configure the 484-tone RU, with users #1-4.
- `192` configures a 242-tone RU with ones user, user #5.
- `96` signals two 106-tone RUs, each with one user, users #6 and #7.

```
cfg484OFDMA = heMUConfig([114 203 192 96]);
plotAllocation(cfg484OFDMA,axAlloc);
```



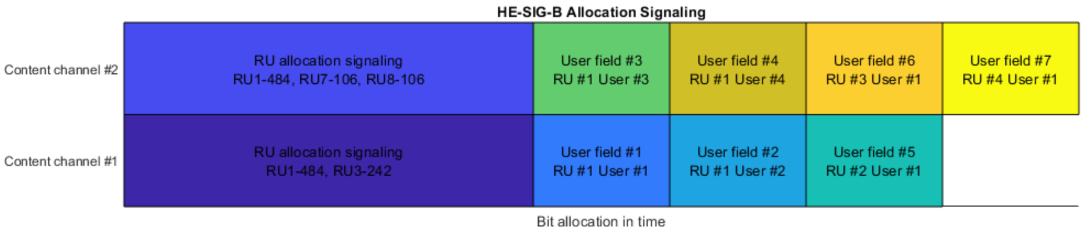
The HE-SIG-B allocation signaling can be viewed with the method `plotHESIGBAllocationMapping()`. This shows the user fields signaled on each HE-SIG-B content channel, and which RU and user in the `heMUConfig` object, each user field signals. In this case we can see the users on RU #1, 3 and 4 are all signaled on content channel 2, and the user of RU #2 is signaled on content channel 1. The second content channel signals six users, while the first content channel only signals one user. Therefore, the first content channel will be padded up to the length of the second for transmission.

```
figure;
plotHESIGBAllocationMapping(cfg484OFDMA);
axSIGB = gca; % Get axis handle for subsequent plotting
```



To balance the user field signaling in HE-SIG-B, we can use 'Combination B' in Table 2 when creating the allocation index for the 484-tone RU. This results in two users being signaled on each content channel of HE-SIG-B, creating a better balance of user fields, and potentially fewer HE-SIG-B symbols in the transmission.

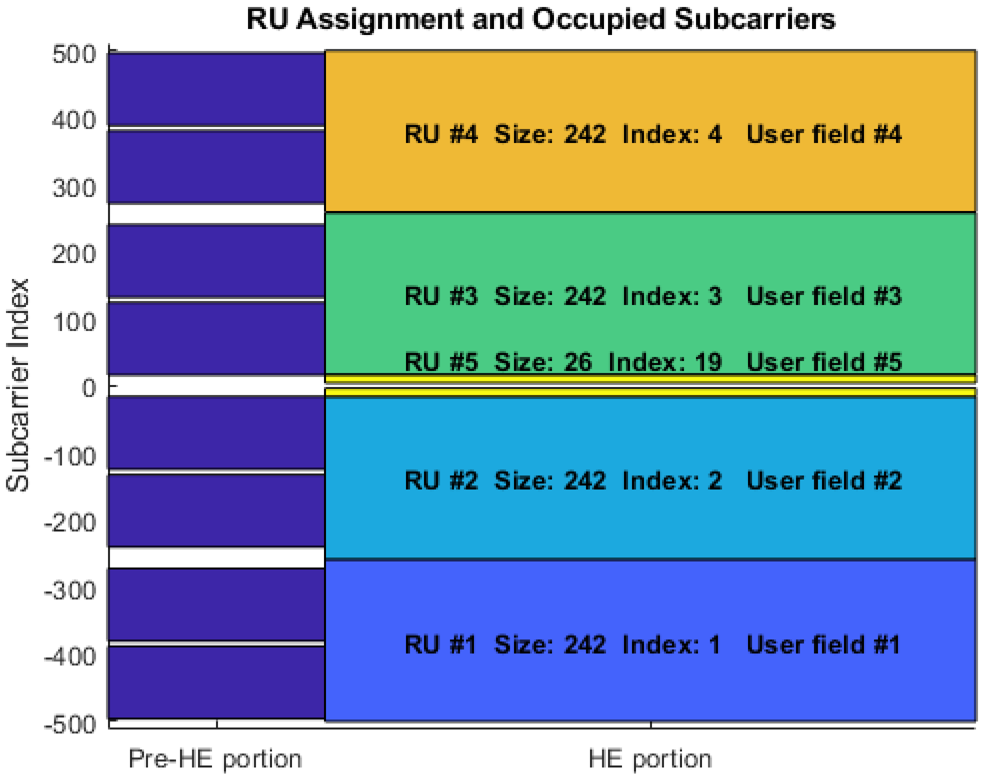
```
cfg484OFDMABalanced = heMUConfig([201 201 192 96]);
plotHESIGBAllocationMapping(cfg484OFDMABalanced,axSIGB);
```



HE Multi User Format - Central 26-Tone RU

In an 80 MHz transmission, when a full band RU is not used, the central 26 tone RU can be optionally active. This is configured by providing a second argument when creating the `heMUConfig` object, with the value of `true` to use the central 26-tone RU, or `false`. If no second argument is provided no central 26-tone RU is created.

```
% Create a configuration with no central 26-tone RU
cfgNoCentral = heMUConfig([192 192 192 192],false);
plotAllocation(cfgNoCentral,axAlloc);

% Create a configuration with a central 26-tone RU
cfgCentral = heMUConfig([192 192 192 192],true);
plotAllocation(cfgCentral,axAlloc);
```



Similarly, for a 160 MHz transmission, the central 26-tone RU in each 80 MHz segment can be optionally used. To configure this a 1-by-2 logical vector is passed as the second argument when creating the `heMUConfig` object. The first element controls the lower central 26-tone RU, and the second controls the upper 26-tone RU. The property `Center26ToneRU` allows the presence of the central RUs to be determined after the object is created. In this example only the upper central 26-tone RU is created. Four 242-tone RUs, each with one user are specified with the allocation index `[200 114 114 200 200 114 114 200]`.

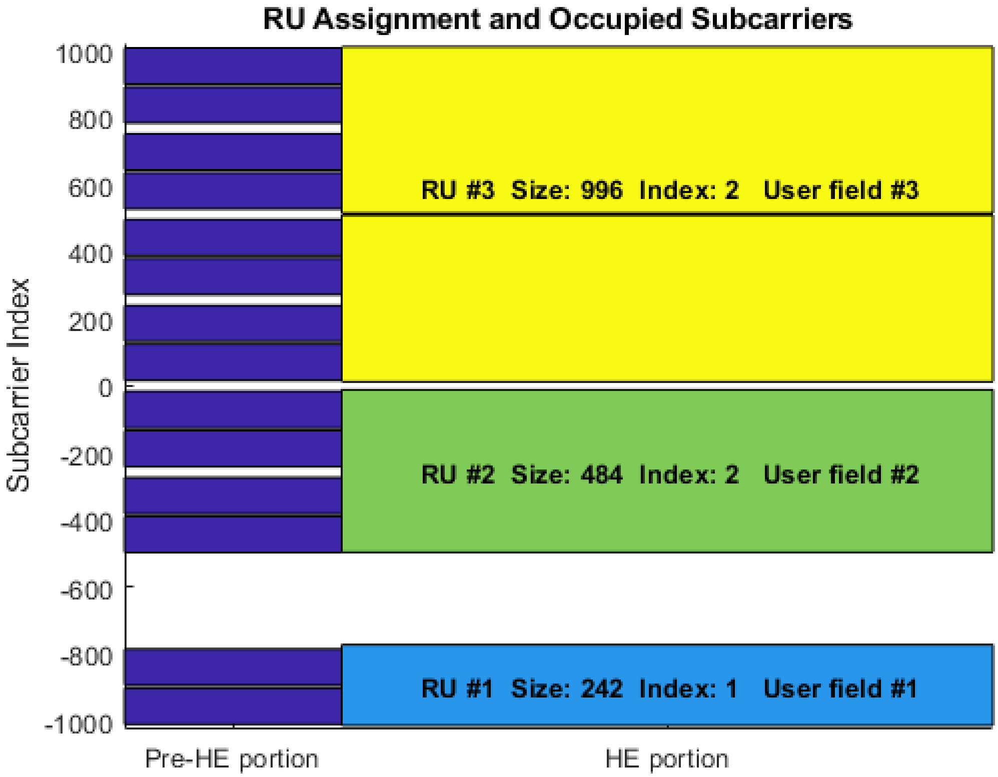
```
cfgCentral160MHz = heMUConfig([200 114 114 200 200 114 114 200],[false true]);
disp('Center 26-tone RUs used:')
disp(cfgCentral160MHz.Center26ToneRU)
```

```
Center 26-tone RUs used:
   0   1
```

HE Multi User Format - Preamble Puncturing

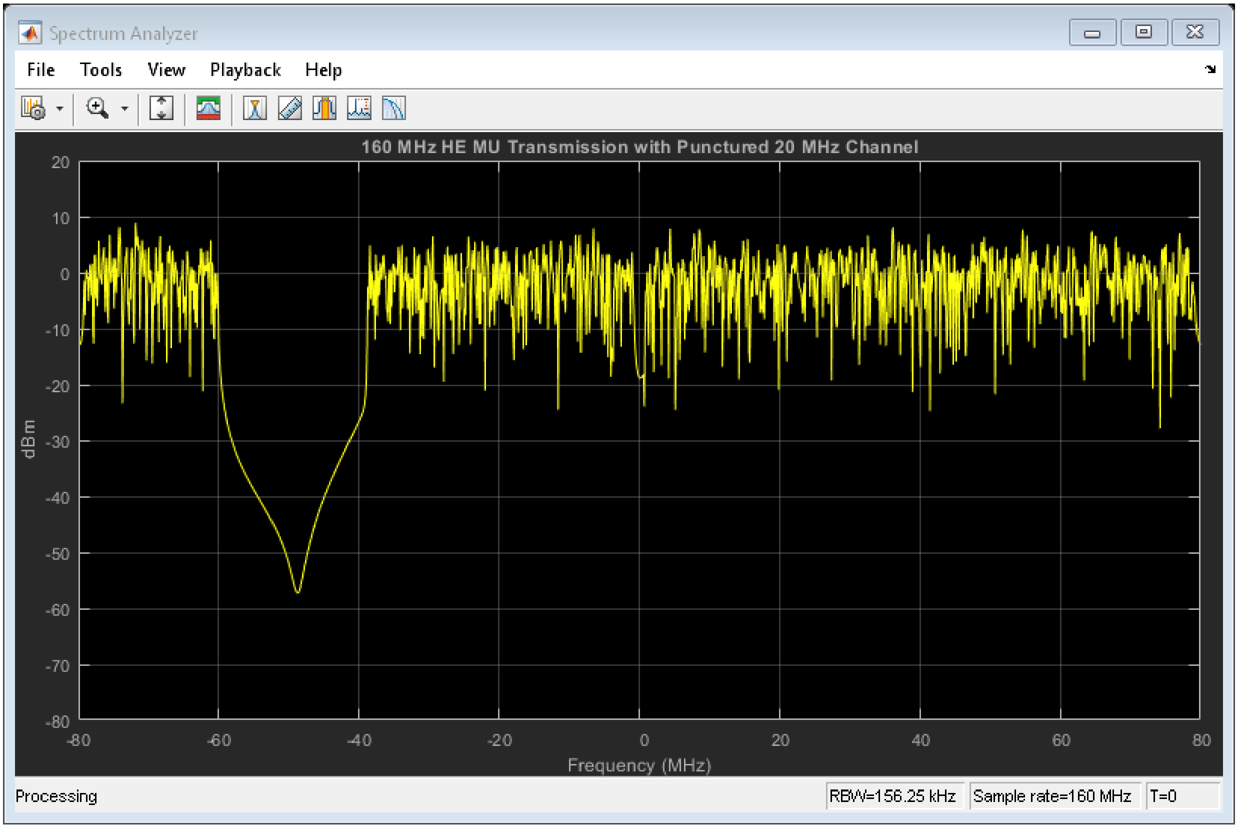
In an 80 MHz or 160 MHz transmission, 20 MHz subchannels can be punctured to allow a legacy system to operate in the punctured channel. This method is also described as channel bonding. To null a 20 MHz subchannel the 20 MHz subchannel allocation index `113` can be used. The punctured 20 MHz subchannel can be viewed with the `plotAllocation` method.

```
% Null second lowest 20 MHz subchannel in a 160 MHz configuration
cfgNull = heMUConfig([192 113 114 200 208 115 115 115]);

% Plot the allocation
plotAllocation(cfgNull,axAlloc);
```



The punctured 20 MHz can also be viewed with the generated waveform and the spectrum analyzer.

```
% Set the transmission properties of each user in all RUs
cfgNull.RU{1}.User{1}.APEPLength = 100;
cfgNull.RU{1}.User{1}.MCS = 2;
cfgNull.RU{1}.User{1}.ChannelCoding = 'LDPC';
cfgNull.RU{1}.User{1}.NumSpaceTimeStreams = 1;

cfgNull.RU{2}.User{1}.APEPLength = 1000;
cfgNull.RU{2}.User{1}.MCS = 6;
cfgNull.RU{2}.User{1}.ChannelCoding = 'LDPC';
cfgNull.RU{2}.User{1}.NumSpaceTimeStreams = 1;
cfgNull.RU{3}.User{1}.APEPLength = 100;
cfgNull.RU{3}.User{1}.MCS = 1;
cfgNull.RU{3}.User{1}.ChannelCoding = 'LDPC';
cfgNull.RU{3}.User{1}.NumSpaceTimeStreams = 1;

% Create packet
txNullWaveform = heWaveformGenerator([1 0 1 0],cfgNull);

spectrumAnalyzer = dsp.SpectrumAnalyzer;
spectrumAnalyzer.SampleRate = heSampleRate(cfgNull);
spectrumAnalyzer.Title = '160 MHz HE MU Transmission with Punctured 20 MHz Channel';
spectrumAnalyzer(txNullWaveform);
```



Trigger-Based MU Format

The HE trigger-based format allows for OFDMA or MU-MIMO transmission in the uplink. Each station (STA) transmits a trigger-based packet simultaneously, when triggered by the access point (AP). A trigger-based transmission is controlled entirely by the AP. All the parameters required for the transmission are provided in a trigger frame to all STAs participating in the trigger-based transmission. In this example a trigger-based transmission for three users in an OFDMA/MU-MIMO system is configured; three STAs will transmit simultaneously to an AP.

The 20 MHz allocation 97 is used which corresponds to two RUs, one of which serves two users in MU-MIMO.

```
disp('Allocation #97 table entry:')
disp(allocationTable(98,:)) % Index 97 (row 98)
```

```
Allocation #97 table entry:
    Allocation    BitAllocation    NumUsers    NumRUs     RUIndices        RUSizes
    __________    _____________    ________    ______    ____________    ____________

        97         "01100001"         3          2       [1x2 double]    [1x2 double]
```

The allocation information is obtained by creating a MU configuration with heMUConfig.

```
% Generate an OFDMA allocation
cfgMU = heMUConfig(97);
allocationInfo = ruInfo(cfgMU);
```

In a trigger-based transmission several parameters are the same for all users in the transmission. Some of these are specified below:

```
% These parameters are the same for all users in the OFDMA system
channelBandwidth = cfgMU.ChannelBandwidth; % Bandwidth of OFDMA system
numSymbols = 20;          % Number of HE data field symbols
preFECPaddingFactor = 2;  % Pre-FEC padding factor
ldpcExtraSymbol = false;  % LDPC extra symbol
numHELTFSymbols = 2;      % Number of HE-LTF symbols
```

A trigger-based transmission for a single user within the system is configured with an heTriggerBasedConfig object. In this example, a cell array of three objects is created to describe the transmission of the three users.

```
% Create a trigger configuration for each user
numUsers = allocationInfo.NumUsers;
cfgTriggerUser = repmat({heTriggerBasedConfig},1,numUsers);
```

The non-default system-wide properties are set for each user.

```
for userIdx = 1:numUsers
    cfgTriggerUser{userIdx}.ChannelBandwidth = channelBandwidth;
    cfgTriggerUser{userIdx}.NumSymbols = numSymbols;
    cfgTriggerUser{userIdx}.PreFECPaddingFactor = preFECPaddingFactor;
    cfgTriggerUser{userIdx}.LDPCExtraSymbol = ldpcExtraSymbol;
    cfgTriggerUser{userIdx}.NumHELTFSymbols = numHELTFSymbols;
end
```

Next the per-user properties are set. When multiple users are transmitting in the same RU, in a MU-MIMO configuration, each user must transmit on different space-time stream indices. The properties `StartingSpaceTimeStream` and `NumSpaceTimeStreamSteams` must be set for each user to make sure different space-time streams are used. In this example user 1 and 2 are in a MU-MIMO configuration, therefore `StartingSpaceTimeStream` for user two is set to `2`, as user one is configured to transmit 1 space-time stream with `StartingSpaceTimeStream = 1`.

```
% These parameters are for the first user - RU#1 MU-MIMO user 1
cfgTriggerUser{1}.RUSize = allocationInfo.RUSizes(1);
cfgTriggerUser{1}.RUIndex = allocationInfo.RUIndices(1);
cfgTriggerUser{1}.MCS = 4;                        % Modulation and coding scheme
cfgTriggerUser{1}.NumSpaceTimeStreams = 1;     % Number of space-time streams
cfgTriggerUser{1}.NumTransmitAntennas = 1;     % Number of transmit antennas
cfgTriggerUser{1}.StartingSpaceTimeStream = 1; % The starting index of the space-time s
cfgTriggerUser{1}.ChannelCoding = 'LDPC';      % Channel coding

% These parameters are for the second user - RU#1 MU-MIMO user 2
cfgTriggerUser{2}.RUSize = allocationInfo.RUSizes(1);
cfgTriggerUser{2}.RUIndex = allocationInfo.RUIndices(1);
cfgTriggerUser{2}.MCS = 3;                        % Modulation and coding scheme
cfgTriggerUser{2}.NumSpaceTimeStreams = 1;     % Number of space-time streams
cfgTriggerUser{2}.StartingSpaceTimeStream = 2; % The starting index of the space-time s
cfgTriggerUser{2}.NumTransmitAntennas = 1;     % Number of transmit antennas
cfgTriggerUser{2}.ChannelCoding = 'LDPC';      % Channel coding

% These parameters are for the third user - RU#2
cfgTriggerUser{3}.RUSize = allocationInfo.RUSizes(2);
cfgTriggerUser{3}.RUIndex = allocationInfo.RUIndices(2);
cfgTriggerUser{3}.MCS = 4;                        % Modulation and coding scheme
```

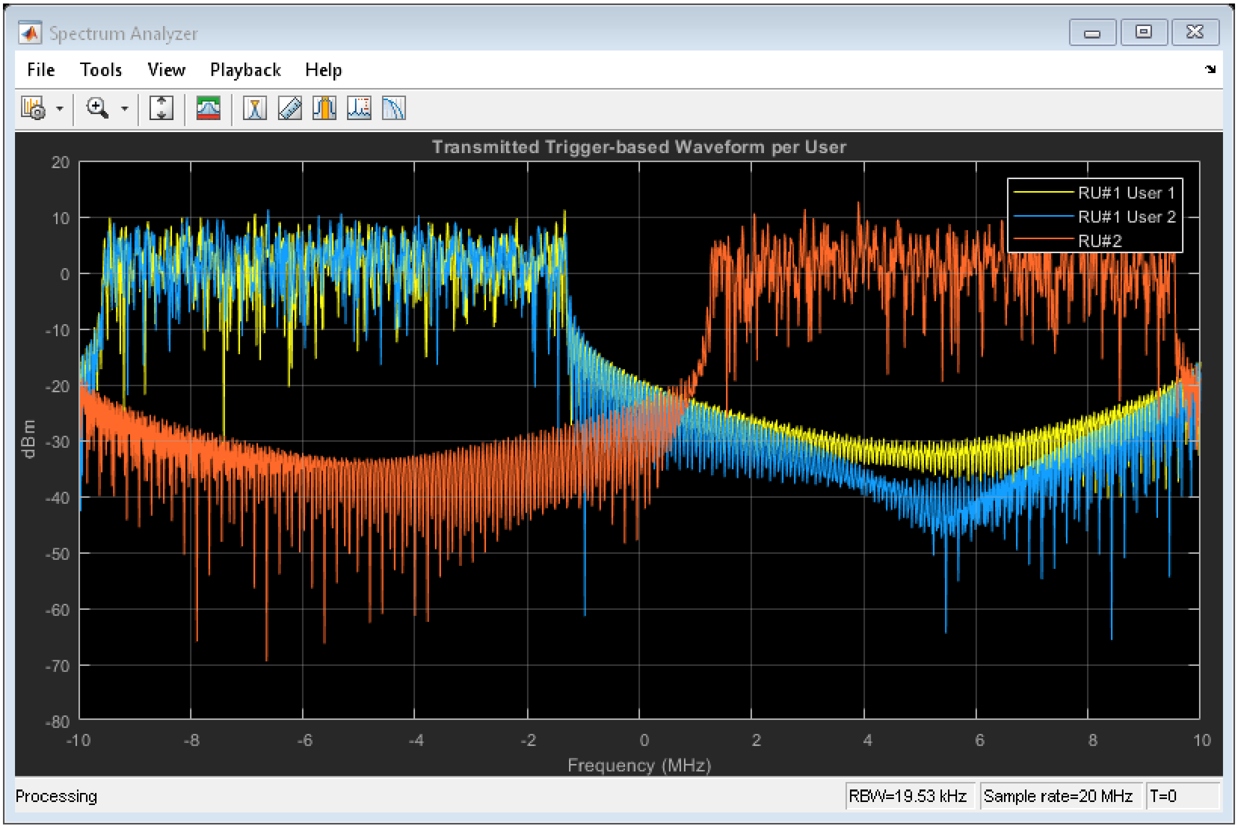
```
cfgTriggerUser{3}.NumSpaceTimeStreams = 2;     % Number of space-time streams
cfgTriggerUser{3}.StartingSpaceTimeStream = 1; % The starting index of the space-time s
cfgTriggerUser{3}.NumTransmitAntennas = 2;     % Number of transmit antennas
cfgTriggerUser{3}.ChannelCoding = 'BCC';       % Channel coding
```

A packet containing random data is now transmitted by each user with `heWaveformGenerator`. The waveform transmitted by each user is stored for analysis.

```
trigInd = heFieldIndices(cfgTriggerUser{1}); % Get the indices of each field
txTrigStore = zeros(trigInd.HEData(2),numUsers);
for userIdx = 1:numUsers
    % Generate waveform for a user
    cfgTrigger = cfgTriggerUser{userIdx};
    txPSDU = randi([0 1],getPSDULength(cfgTrigger)*8,1);
    txTrig = heWaveformGenerator(txPSDU,cfgTrigger);

    % Store the transmitted STA waveform for analysis
    txTrigStore(:,userIdx) = sum(txTrig,2);
end
```

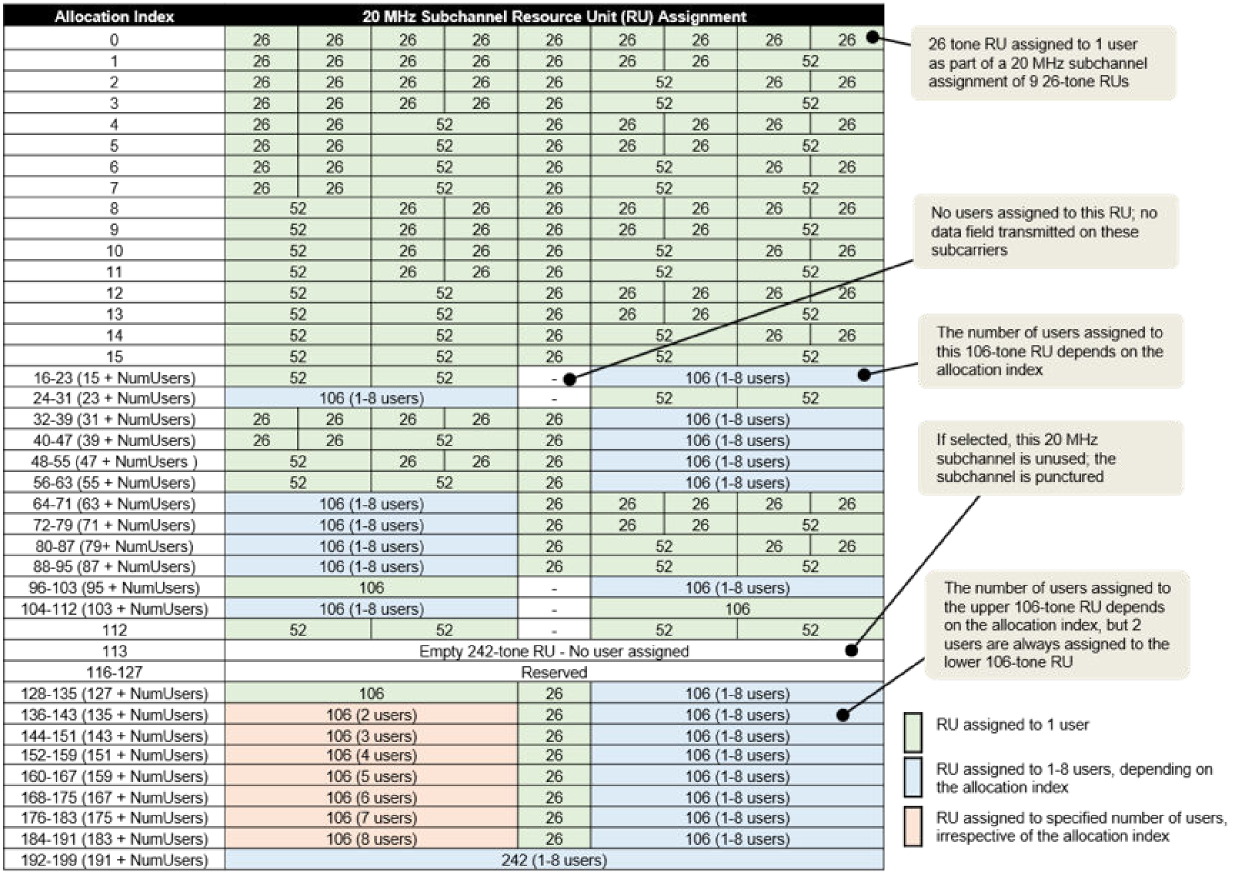
The spectrum of the transmitted waveform from each STA shows the different portions of the spectrum used, and the overlap in the MU-MIMO RU.

```
spectrumAnalyzer = dsp.SpectrumAnalyzer;
spectrumAnalyzer.SampleRate = heSampleRate(cfgTriggerUser{1});
spectrumAnalyzer.ChannelNames = {'RU#1 User 1','RU#1 User 2','RU#2','Received'};
spectrumAnalyzer.ShowLegend = true;
spectrumAnalyzer.Title = 'Transmitted Trigger-based Waveform per User';
spectrumAnalyzer(txTrigStore);
```



Appendix

The RU allocation table for allocations <= 20 MHz is shown below, with annotated descriptions.



Allocation Index	20 MHz Subchannel Resource Unit (RU) Assignment								
0	26	26	26	26	26	26	26	26	26
1	26	26	26	26	26	26	26	52	
2	26	26	26	26	26	52		26	26
3	26	26	26	26	26	52		52	
4	26	26	52		26	26	26	26	26
5	26	26	52		26	26	26	52	
6	26	26	52		26	52		26	26
7	26	26	52		26	52		52	
8	52		26	26	26	26	26	26	26
9	52		26	26	26	26	26	52	
10	52		26	26	26	52		26	26
11	52		26	26	26	52		52	
12	52		52		26	26	26	26	26
13	52		52		26	26	26	52	
14	52		52		26	52		26	26
15	52		52		26	52		52	
16-23 (15 + NumUsers)	52		52		-	106 (1-8 users)			
24-31 (23 + NumUsers)	106 (1-8 users)				-	52		52	
32-39 (31 + NumUsers)	26	26	26	26	26	106 (1-8 users)			
40-47 (39 + NumUsers)	26	26	52		26	106 (1-8 users)			
48-55 (47 + NumUsers)	52		26	26	26	106 (1-8 users)			
56-63 (55 + NumUsers)	52		52		26	106 (1-8 users)			
64-71 (63 + NumUsers)	106 (1-8 users)				26	26	26	26	26
72-79 (71 + NumUsers)	106 (1-8 users)				26	26	26	52	
80-87 (79+ NumUsers)	106 (1-8 users)				26	52		26	26
88-95 (87 + NumUsers)	106 (1-8 users)				26	52		52	
96-103 (95 + NumUsers)	106				-	106 (1-8 users)			
104-112 (103 + NumUsers)	106 (1-8 users)				-	106			
112	52		52		-	52		52	
113	Empty 242-tone RU - No user assigned								
116-127	Reserved								
128-135 (127 + NumUsers)	106				26	106 (1-8 users)			
136-143 (135 + NumUsers)	106 (2 users)				26	106 (1-8 users)			
144-151 (143 + NumUsers)	106 (3 users)				26	106 (1-8 users)			
152-159 (151 + NumUsers)	106 (4 users)				26	106 (1-8 users)			
160-167 (159 + NumUsers)	106 (5 users)				26	106 (1-8 users)			
168-175 (167 + NumUsers)	106 (6 users)				26	106 (1-8 users)			
176-183 (175 + NumUsers)	106 (7 users)				26	106 (1-8 users)			
184-191 (183 + NumUsers)	106 (8 users)				26	106 (1-8 users)			
192-199 (191 + NumUsers)	242 (1-8 users)								

26 tone RU assigned to 1 user as part of a 20 MHz subchannel assignment of 9 26-tone RUs

No users assigned to this RU; no data field transmitted on these subcarriers

The number of users assigned to this 106-tone RU depends on the allocation index

If selected, this 20 MHz subchannel is unused; the subchannel is punctured

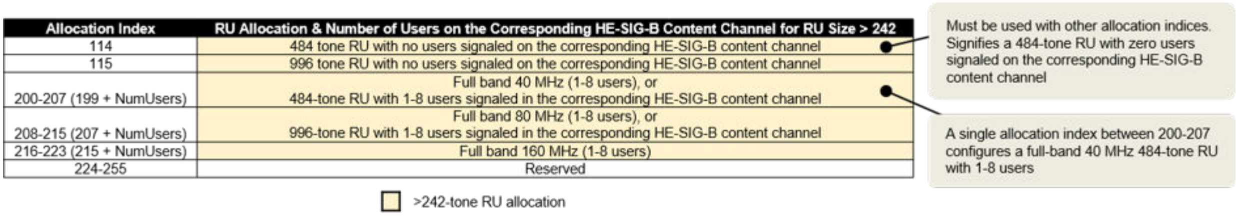
The number of users assigned to the upper 106-tone RU depends on the allocation index, but 2 users are always assigned to the lower 106-tone RU

🟩 RU assigned to 1 user

🟦 RU assigned to 1-8 users, depending on the allocation index

🟧 RU assigned to specified number of users, irrespective of the allocation index

The RU allocation and HE-SIG-B user signaling for allocations > 20 MHz is shown in the table below, with annotated descriptions.



Allocation Index	RU Allocation & Number of Users on the Corresponding HE-SIG-B Content Channel for RU Size > 242
114	484 tone RU with no users signaled on the corresponding HE-SIG-B content channel
115	996 tone RU with no users signaled on the corresponding HE-SIG-B content channel
200-207 (199 + NumUsers)	Full band 40 MHz (1-8 users), or 484-tone RU with 1-8 users signaled in the corresponding HE-SIG-B content channel
208-215 (207 + NumUsers)	Full band 80 MHz (1-8 users), or 996-tone RU with 1-8 users signaled in the corresponding HE-SIG-B content channel
216-223 (215 + NumUsers)	Full band 160 MHz (1-8 users)
224-255	Reserved

Must be used with other allocation indices. Signifies a 484-tone RU with zero users signaled on the corresponding HE-SIG-B content channel

A single allocation index between 200-207 configures a full-band 40 MHz 484-tone RU with 1-8 users

🟨 >242-tone RU allocation

This example uses the following helper objects and functions:

- heFieldIndices.m
- helperOFDMInfo.m
- heMUConfig.m
- heRUAllocationTable.m
- heSampleRate.m
- heSUConfig.m
- heTriggerBasedConfig.m
- heWaveformGenerator.m

Selected Bibliography

1. IEEE P802.11ax™/D1.1 IEEE Draft Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 6: Enhancements for High Efficiency WLAN.

Build DMG PPDU

Build DMG PPDUs by using the waveform generator function.

Waveform Generator

Create an DMG configuration object.

```
dmg = wlanDMGConfig
```

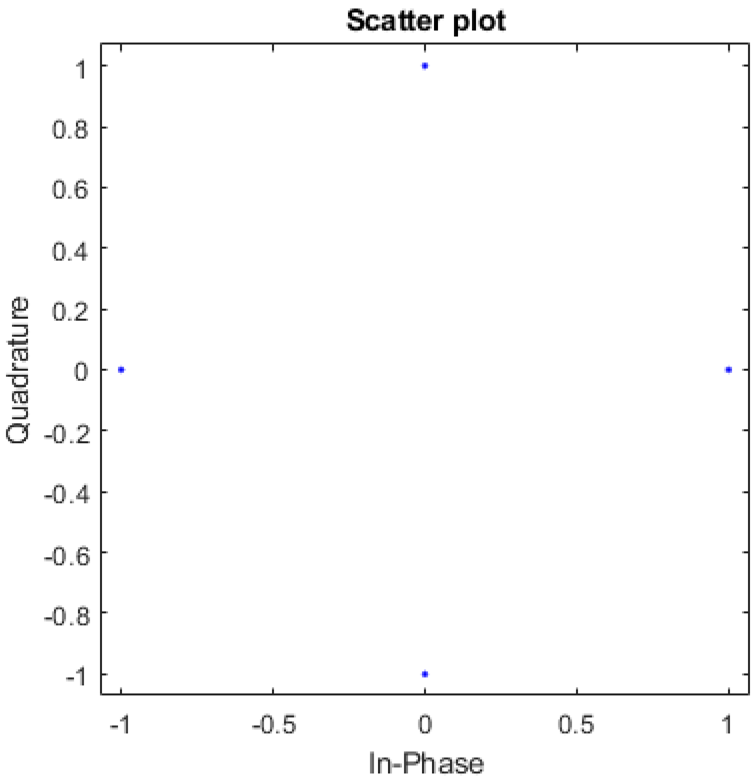
```
dmg = 
  wlanDMGConfig with properties:

                       MCS: '0'
            TrainingLength: 0
                PSDULength: 1000
    ScramblerInitialization: 2
                Turnaround: 0
```

Generate the DMG PPDU. The length of the input data sequence in bits must be 8 times the length of the PSDU, which is expressed in bytes. Turn off windowing.

```
psdu = randi([0 1],dmg.PSDULength*8,1);
tx = wlanWaveformGenerator(psdu,dmg,'WindowTransitionTime',0);
```

The waveform has MCS=0, which is single carrier and DBPSK modulated. Plot the constellation of the waveform.

```
scatterplot(tx)
```



See Also

“Build HT PPDU” on page 1-74 | “Build Non-HT PPDU” on page 1-77 | “Build VHT PPDU” on page 1-71 | “Build S1G PPDU” on page 1-69

Build S1G PPDU

Build S1G PPDUs by using the waveform generator function.

Waveform Generator

Create an S1G configuration object.

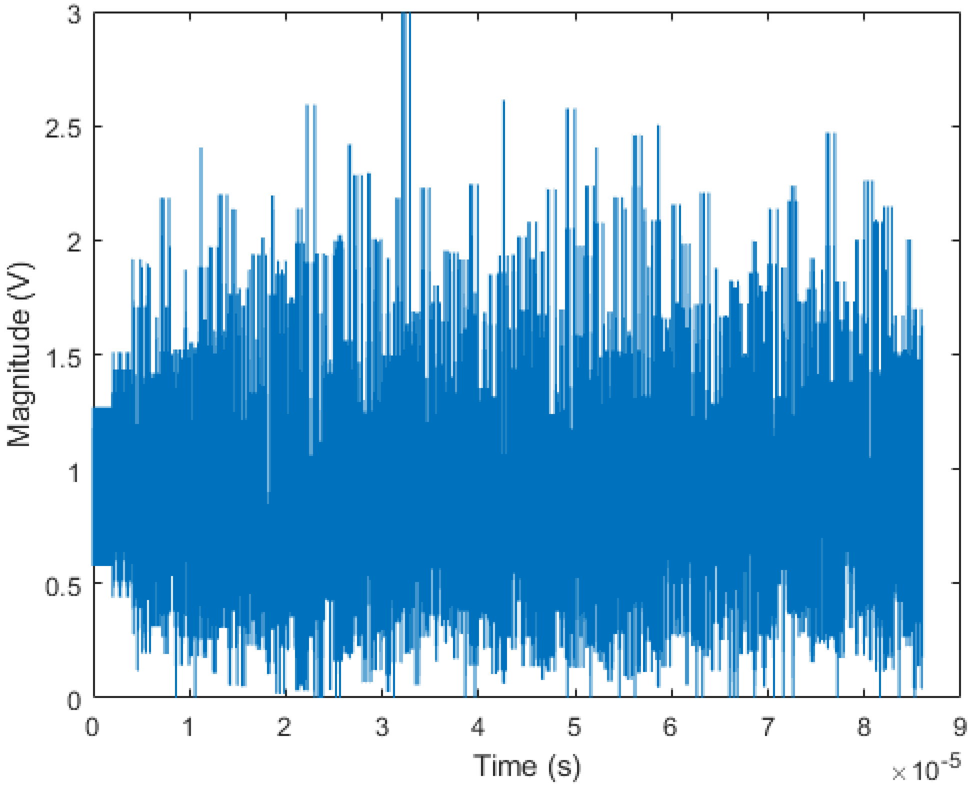
```
s1g = wlanS1GConfig;
```

Generate the S1G PPDU. The length of the input data sequence in bits must be 8 times the length of the PSDU, which is expressed in bytes. Turn off windowing.

```
x = randi([0 1],s1g.PSDULength*8,1);
y = wlanWaveformGenerator(x,s1g,'WindowTransitionTime',0);
```

Plot the magnitude of the waveform.

```
t = ((1:length(y))'-1)/80e6;
plot(t,abs(y))
xlabel('Time (s)')
ylabel('Magnitude (V)')
```



See Also

“Build DMG PPDU” on page 1-67 | “Build HT PPDU” on page 1-74 | “Build Non-HT PPDU” on page 1-77 | “Build VHT PPDU” on page 1-71

Build VHT PPDU

Build VHT PPDUs by using the waveform generator function or by building each field individually.

Waveform Generator

Create a VHT configuration object.

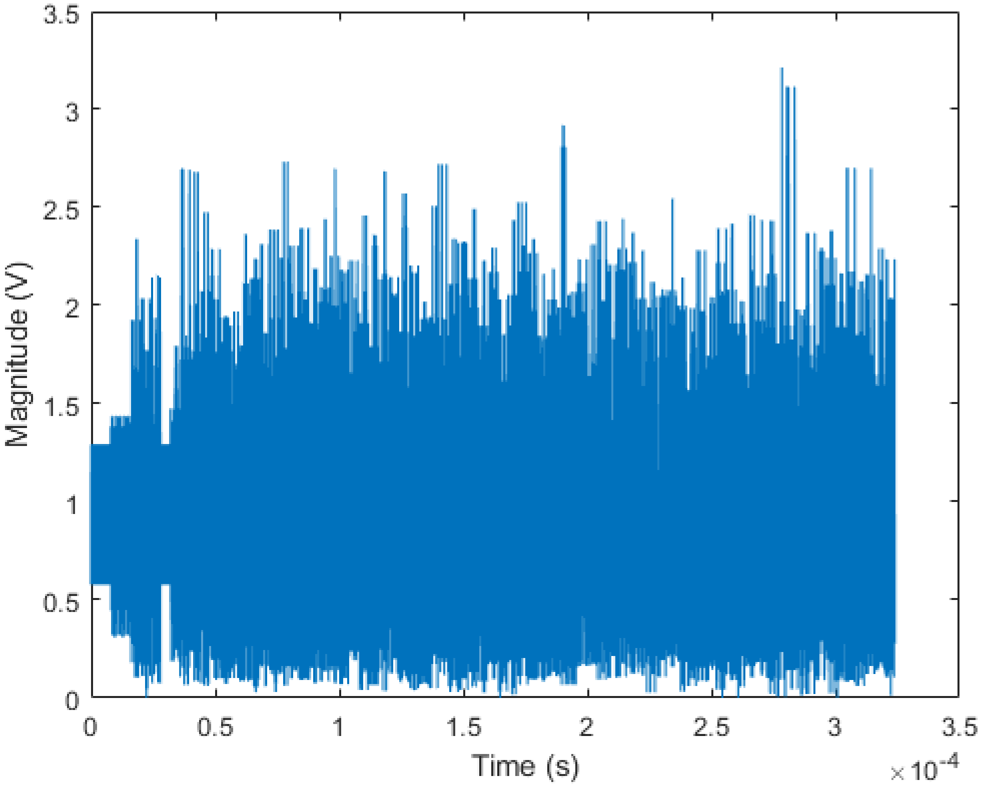
```
vht = wlanVHTConfig;
```

Generate the VHT PPDU. The length of the input data sequence in bits must be 8 times the length of the PSDU, which is expressed in bytes. Turn off windowing.

```
x = randi([0 1],vht.PSDULength*8,1);
y = wlanWaveformGenerator(x,vht,'WindowTransitionTime',0);
```

Plot the magnitude of the waveform.

```
t = ((1:length(y))'-1)/80e6;
plot(t,abs(y))
xlabel('Time (s)')
ylabel('Magnitude (V)')
```



Individual PPDU Fields

Create L-STF, L-LTF, L-SIG, VHT-SIG-A, VHT-STF, VHT-LTF, and VHT-SIG-B preamble fields.

```
lstf = wlanLSTF(vht);
lltf = wlanLLTF(vht);
lsig = wlanLSIG(vht);
vhtSigA = wlanVHTSIGA(vht);
vhtstf = wlanVHTSTF(vht);
vhtltf = wlanVHTLTF(vht);
vhtSigB = wlanVHTSIGB(vht);
```

Generate the VHT-Data field using input data field `x`, which was used as an input to the waveform generator.

```
vhtData = wlanVHTData(x,vht);
```

Concatenate the individual fields to create a single PPDU.

```
z = [lstf; lltf; lsig; vhtSigA; vhtstf; vhtltf; vhtSigB; vhtData];
```

Verify that the PPDUs created by the two methods are identical.

```
isequal(y,z)
```

```
ans = logical
   1
```

See Also

“Build DMG PPDU” on page 1-67 | “Build HT PPDU” on page 1-74 | “Build Non-HT PPDU” on page 1-77 | “Build S1G PPDU” on page 1-69

Build HT PPDU

Build HT PPDUs by using the waveform generator function or by building each field individually.

Waveform Generator

Create an HT configuration object.

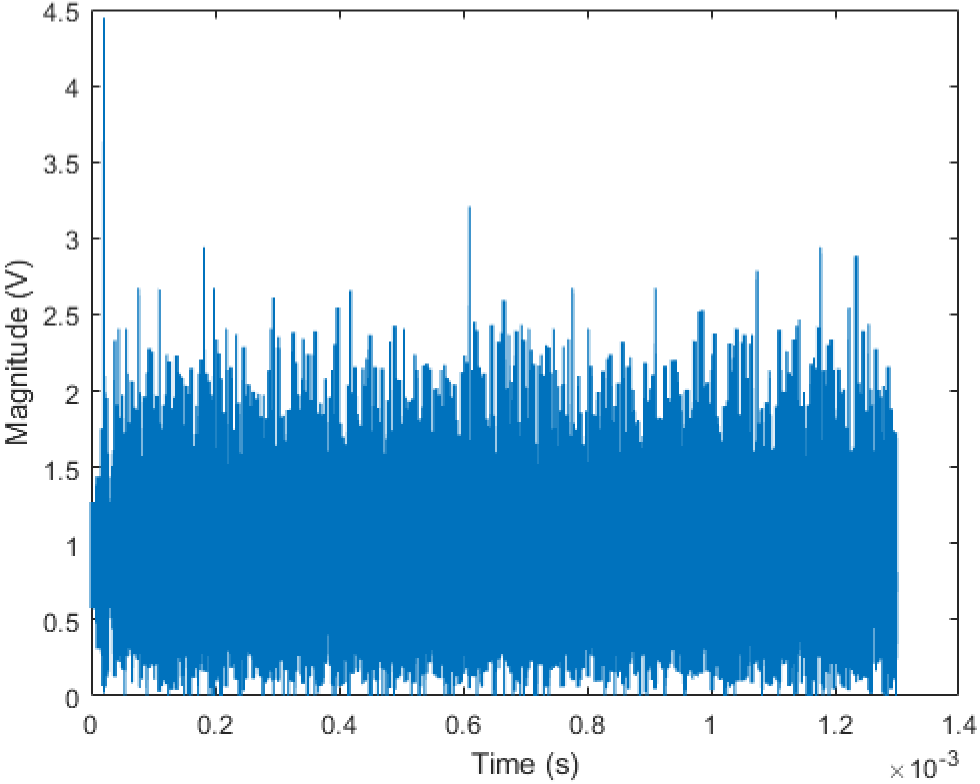
```
ht = wlanHTConfig;
```

Generate the HT PPDU. The length of the input data sequence in bits must be 8 times the length of the PSDU, which is expressed in bytes. Turn windowing off.

```
x = randi([0 1],ht.PSDULength*8,1);
y = wlanWaveformGenerator(x,ht,'WindowTransitionTime',0);
```

Plot the magnitude of the waveform.

```
t = ((1:length(y))'-1)/20e6;
plot(t,abs(y))
xlabel('Time (s)')
ylabel('Magnitude (V)')
```



Individual PPDU Fields

Create L-STF, L-LTF, L-SIG, HT-SIG, HT-STF, and HT-LTF preamble fields.

```
lstf = wlanLSTF(ht);
lltf = wlanLLTF(ht);
lsig = wlanLSIG(ht);
htsig = wlanHTSIG(ht);
htstf = wlanHTSTF(ht);
htltf = wlanHTLTF(ht);
```

Generate the HT-Data field using input data field x, which is the same input signal that was used with the waveform generator.

```
htData = wlanHTData(x,ht);
```

Concatenate the individual fields to create a single PPDU.

```
z = [lstf; lltf; lsig; htsig; htstf; htltf; htData];
```

Verify that the PPDUs created by the two methods are identical.

```
isequal(y,z)
```

```
ans = logical
   1
```

See Also

“Build DMG PPDU” on page 1-67 | “Build Non-HT PPDU” on page 1-77 | “Build S1G PPDU” on page 1-69 | “Build VHT PPDU” on page 1-71

Build Non-HT PPDU

Build non-HT PPDUs by using the waveform generator function or by building each field individually.

Waveform Generator

Create a non-HT configuration object.

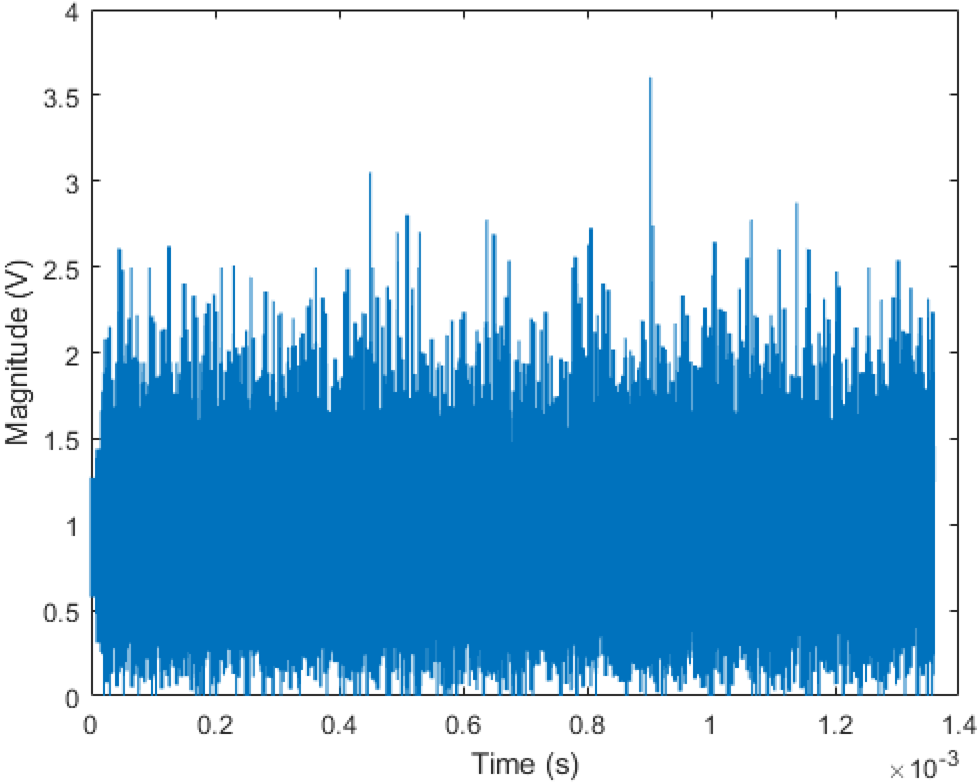
```
nht = wlanNonHTConfig;
```

Generate the non-HT PPDU. The length of the input data sequence in bits must be 8 times the length of the PSDU, which is expressed in bytes. Turn off windowing.

```
x = randi([0 1],nht.PSDULength*8,1);
y = wlanWaveformGenerator(x,nht,'WindowTransitionTime',0);
```

Plot the magnitude of the waveform.

```
t = ((1:length(y))'-1)/20e6;
plot(t,abs(y))
xlabel('Time (s)')
ylabel('Magnitude (V)')
```



Individual PPDU Fields

Create L-STF, L-LTF, and L-SIG preamble fields.

```
lstf = wlanLSTF(nht);
lltf = wlanLLTF(nht);
lsig = wlanLSIG(nht);
```

Generate the Non-HT-data field using input data field x, which was used as the input to the waveform generator.

```
nhtData = wlanNonHTData(x,nht);
```

Concatenate the individual fields to create a single PPDU.

```
z = [lstf; lltf; lsig; nhtData];
```

Verify that the PPDUs created by the two methods are identical.

```
isequal(y,z)
```

```
ans = logical
   1
```

See Also

“Build DMG PPDU” on page 1-67 | “Build HT PPDU” on page 1-74 | “Build S1G PPDU” on page 1-69 | “Build VHT PPDU” on page 1-71

Transmit and Recover L-SIG, VHT-SIG-A, VHT-SIG-B in Fading Channel

Transmit a VHT waveform through a noisy MIMO channel. Extract the L-SIG, VHT-SIG-A, and VHT-SIG-B fields and verify that they were correctly recovered.

Set the parameters used throughout the example.

```
cbw = 'CBW40';                     % Channel bandwidth
fs = 40e6;                         % Sample rate (Hz)
ntx = 2;                           % Number of transmit antennas
nsts = 2;                          % Number of space-time streams
nrx = 3;                           % Number of receive antennas
```

Create a VHT configuration object that supports a 2x2 MIMO transmission and has an APEP length of 2000.

```
vht = wlanVHTConfig('ChannelBandwidth',cbw,'APEPLength',2000, ...
    'NumTransmitAntennas',ntx,'NumSpaceTimeStreams',nsts, ...
    'SpatialMapping','Direct','STBC',false);
```

Generate a VHT waveform containing a random PSDU.

```
txPSDU = randi([0 1],vht.PSDULength*8,1);
txPPDU = wlanWaveformGenerator(txPSDU,vht);
```

Create a 2x2 TGac channel and an AWGN channel with an SNR=10 dB.

```
tgacChan = wlanTGacChannel('SampleRate',fs,'ChannelBandwidth',cbw, ...
    'NumTransmitAntennas',ntx,'NumReceiveAntennas',nrx, ...
    'LargeScaleFadingEffect','Pathloss and shadowing', ...
    'DelayProfile','Model-C');

chNoise = comm.AWGNChannel('NoiseMethod','Signal to noise ratio (SNR)',...
    'SNR',10);
```

Pass the VHT waveforms through a 2x2 TGac channel and add the AWGN channel noise.

```
rxPPDU = chNoise(tgacChan(txPPDU));
```

Add additional white noise corresponding to a receiver with a 9 dB noise figure. The noise variance is equal to *k***T***B***F*, where *k* is Boltzmann's constant, *T* is the ambient temperature, *B* is the channel bandwidth (sample rate), and *F* is the receiver noise figure.

```
nVar = 10^((-228.6+10*log10(290) + 10*log10(fs) + 9 )/10);
rxNoise = comm.AWGNChannel('NoiseMethod','Variance','Variance',nVar);

rxPPDU = rxNoise(rxPPDU);
```

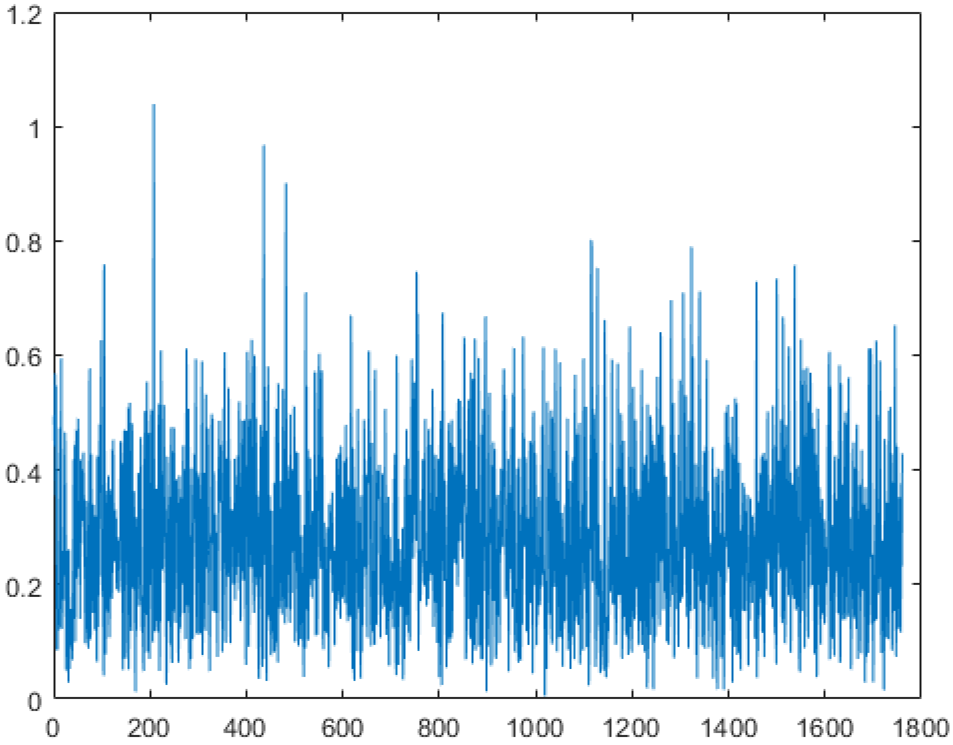
Find the start and stop indices for all component fields of the PPDU.

```
ind = wlanFieldIndices(vht)
```

```
ind = struct with fields:
       LSTF: [1 320]
       LLTF: [321 640]
       LSIG: [641 800]
    VHTSIGA: [801 1120]
     VHTSTF: [1121 1280]
     VHTLTF: [1281 1600]
    VHTSIGB: [1601 1760]
    VHTData: [1761 25600]
```

The preamble is contained in the first 1760 symbols. Plot the preamble.

```
plot(abs(rxPPDU(1:1760)))
```



Extract the L-LTF from the received PPDU using the start and stop indices determined by the `wlanFieldIndices` function. Demodulate the L-LTF and estimate the channel coefficients.

```
rxLLTF = rxPPDU(ind.LLTF(1):ind.LLTF(2),:);
demodLLTF = wlanLLTFDemodulate(rxLLTF,vht);
chEstLLTF = wlanLLTFChannelEstimate(demodLLTF,vht);
```

Extract the L-SIG field from the received PPDU and recover its information bits.

```
rxLSIG = rxPPDU(ind.LSIG(1):ind.LSIG(2),:);
infoLSIG = wlanLSIGRecover(rxLSIG,chEstLLTF,nVar,cbw);
```

Inspect the L-SIG rate information and confirm that the sequence `[1 1 0 1]` is received. This sequence corresponds to a 6 MHz data rate, which is used for all VHT transmissions.

```
rate = infoLSIG(1:4)'
```

```
rate = 1x4 int8 row vector

   0   1   1   1
```

Extract the VHT-SIG-A and confirm that the CRC check passed.

```
rxVHTSIGA = rxPPDU(ind.VHTSIGA(1):ind.VHTSIGA(2),:);
[infoVHTSIGA,failCRC] = wlanVHTSIGARecover(rxVHTSIGA, ...
    chEstLLTF,nVar,cbw);
failCRC
```

```
failCRC = logical
   1
```

Extract and demodulate the VHT-LTF. Use the demodulated signal to estimate the channel coefficients needed to recover the VHT-SIG-B field.

```
rxVHTLTF = rxPPDU(ind.VHTLTF(1):ind.VHTLTF(2),:);
demodVHTLTF = wlanVHTLTFDemodulate(rxVHTLTF,vht);
chEstVHTLTF = wlanVHTLTFChannelEstimate(demodVHTLTF,vht);
```

Extract and recover the VHT-SIG-B.

```
rxVHTSIGB = rxPPDU(ind.VHTSIGB(1):ind.VHTSIGB(2),:);
infoVHTSIGB = wlanVHTSIGBRecover(rxVHTSIGB,chEstVHTLTF,nVar,cbw);
```

Verify that the APEP length, contained in the first 19 bits of the VHT-SIG-B, corresponds to the specified length of 2000 bits.

```
pktLbits = infoVHTSIGB(1:19)';
pktLen = bi2de(double(pktLbits))*4
```

```
pktLen = 1676920
```

End-to-End VHT Simulation with Frequency Correction

This example shows how to generate, transmit, recover and view a VHT MIMO waveform.

Steps in the example:

- Transmit a VHT waveform through a MIMO channel with AWGN
- Perform a two-stage process to estimate and correct for a frequency offset
- Estimate the channel response
- Recover the VHT data field
- Compare the transmitted and received PSDUs to determine if bit errors occurred

Set the parameters used throughout the example.

```
cbw = 'CBW160';                    % Channel bandwidth
fs = 160e6;                        % Sample rate (Hz)
ntx = 2;                           % Number of transmit antennas
nsts = 2;                          % Number of space-time streams
nrx = 2;                           % Number of receive antennas
```

Create a VHT configuration object that supports a 2x2 MIMO transmission and has an APEP length of 2000.

```
vht = wlanVHTConfig('ChannelBandwidth',cbw,'APEPLength',2000, ...
    'NumTransmitAntennas',ntx,'NumSpaceTimeStreams',nsts, ...
    'SpatialMapping','Direct','STBC',false);
```

Generate a VHT waveform containing a random PSDU.

```
txPSDU = randi([0 1],vht.PSDULength*8,1);
txPPDU = wlanWaveformGenerator(txPSDU,vht);
```

Create a 2x2 TGac channel and an AWGN channel.

```
tgacChan = wlanTGacChannel('SampleRate',fs,'ChannelBandwidth',cbw, ...
    'NumTransmitAntennas',ntx,'NumReceiveAntennas',nrx, ...
    'LargeScaleFadingEffect','Pathloss and shadowing', ...
    'DelayProfile','Model-C');
awgnChan = comm.AWGNChannel('NoiseMethod','Variance', ...
    'VarianceSource','Input port');
```

Create a phase/frequency offset object.

```
pfOffset = comm.PhaseFrequencyOffset('SampleRate',fs,'FrequencyOffsetSource','Input po
```

Calculate the noise variance for a receiver with a 9 dB noise figure. Pass the transmitted waveform through the noisy TGac channel.

```
nVar = 10^((-228.6 + 10*log10(290) + 10*log10(fs) + 9)/10);
rxPPDU = awgnChan(tgacChan(txPPDU), nVar);
```

Introduce a frequency offset of 500 Hz.

```
rxPPDUcfo = pfOffset(rxPPDU,500);
```

Find the start and stop indices for all component fields of the PPDU.

```
ind = wlanFieldIndices(vht);
```

Extract the L-STF. Estimate and correct for the carrier frequency offset.

```
rxLSTF = rxPPDUcfo(ind.LSTF(1):ind.LSTF(2),:);

foffset1 = wlanCoarseCFOEstimate(rxLSTF,cbw);
rxPPDUcorr = pfOffset(rxPPDUcfo,-foffset1);
```

Extract the L-LTF from the corrected signal. Estimate and correct for the residual frequency offset.

```
rxLLTF = rxPPDUcorr(ind.LLTF(1):ind.LLTF(2),:);

foffset2 = wlanFineCFOEstimate(rxLLTF,cbw);
rxPPDU2 = pfOffset(rxPPDUcorr,-foffset2);
```

Extract and demodulate the VHT-LTF. Estimate the channel coefficients.

```
rxVHTLTF = rxPPDU2(ind.VHTLTF(1):ind.VHTLTF(2),:);
dLTF = wlanVHTLTFDemodulate(rxVHTLTF,vht);
chEst = wlanVHTLTFChannelEstimate(dLTF,vht);
```

Extract the VHT data field from the received and frequency-corrected PPDU. Recover the data field.

```
rxVHTData = rxPPDU2(ind.VHTData(1):ind.VHTData(2),:);
rxPSDU = wlanVHTDataRecover(rxVHTData,chEst,nVar,vht);
```

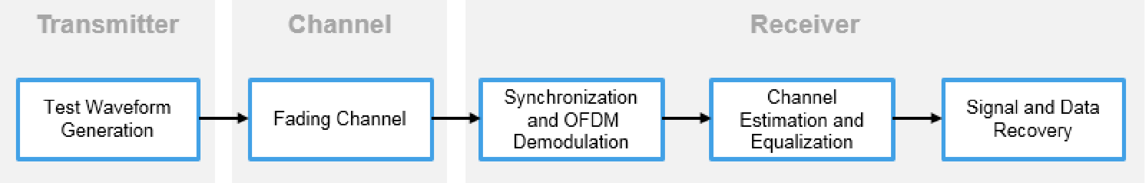
Calculate the number of bit errors in the received packet.

```
numErr = biterr(txPSDU,rxPSDU)
numErr = 0
```

Transmit-Receive Chain

In this section...
"Transmit Processing Chain" on page 1-87
"Receiver Processing Chain" on page 1-93

WLAN System Toolbox functionality includes elements of a standard transmitter–channel–receiver processing chain.



- Transmitter functions enable simulation of the various IEEE 802.11 [3][4] formats. The simulated waveform includes preamble and data fields of the PPDU. You can use this waveform in link-level simulations. You can also use it as a test signal for test devices and equipment.
- Channel functions model various types of AWGN, fading, or moving channel environmental effects.
- Receiver functions recover the transmitted signal.

Transmit Processing Chain

WLAN System Toolbox functions enable you to generate waveforms for a complete PPDU or for the individual fields of VHT, HT-mixed, and non-HT format PPDUs.

VHT Data Transmit Processing Chain

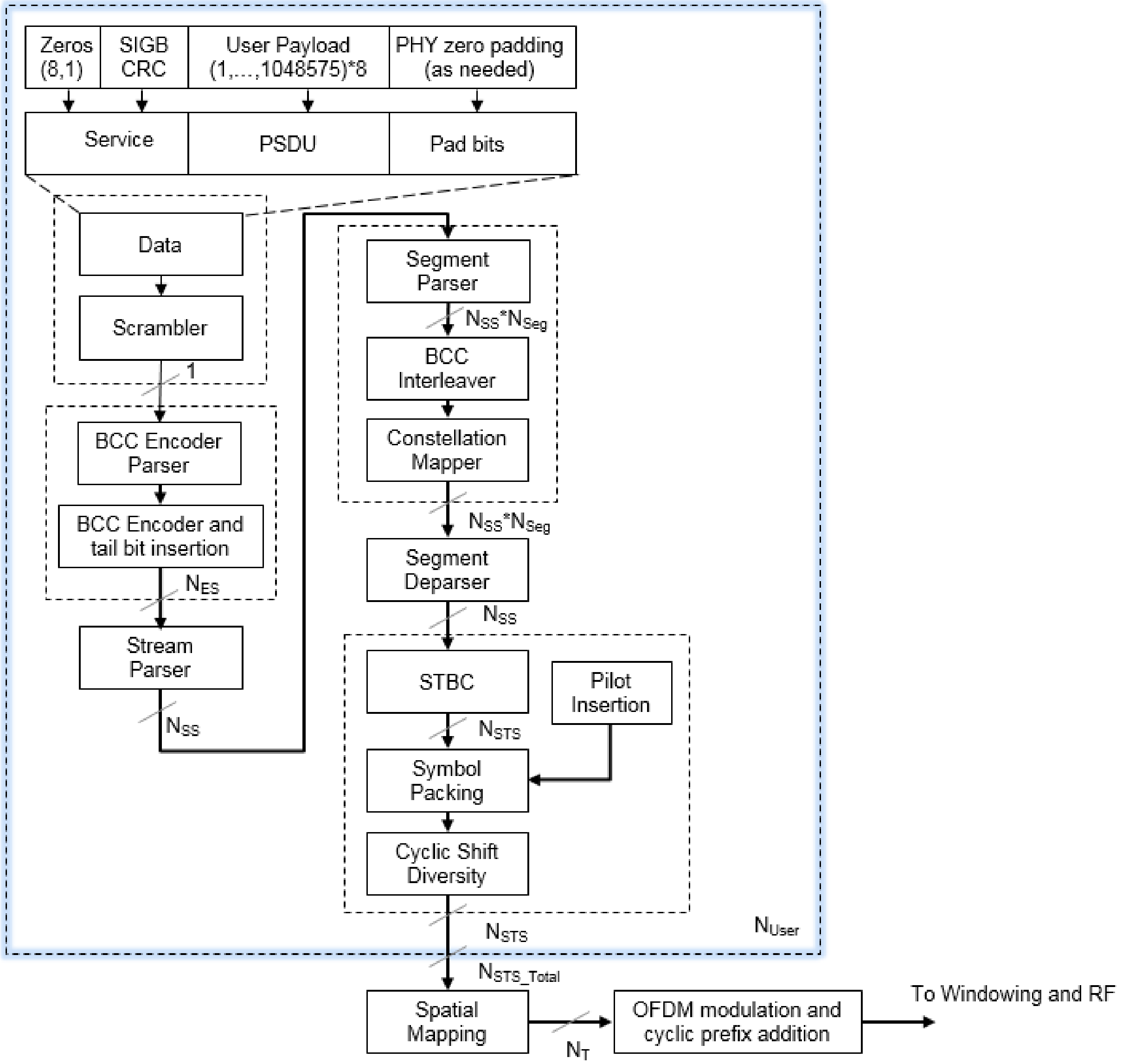
As described in IEEE 802.11ac-2013 [3], Section 22 specifies the PHY entity for a very high throughput (VHT) orthogonal frequency division multiplexing (OFDM) system. A

[3] IEEE Std 802.11-2012 Adapted and reprinted with permission from IEEE. Copyright IEEE 2012. All rights reserved.

[4] IEEE Std 802.11ac-2013 Adapted and reprinted with permission from IEEE. Copyright IEEE 2013. All rights reserved.

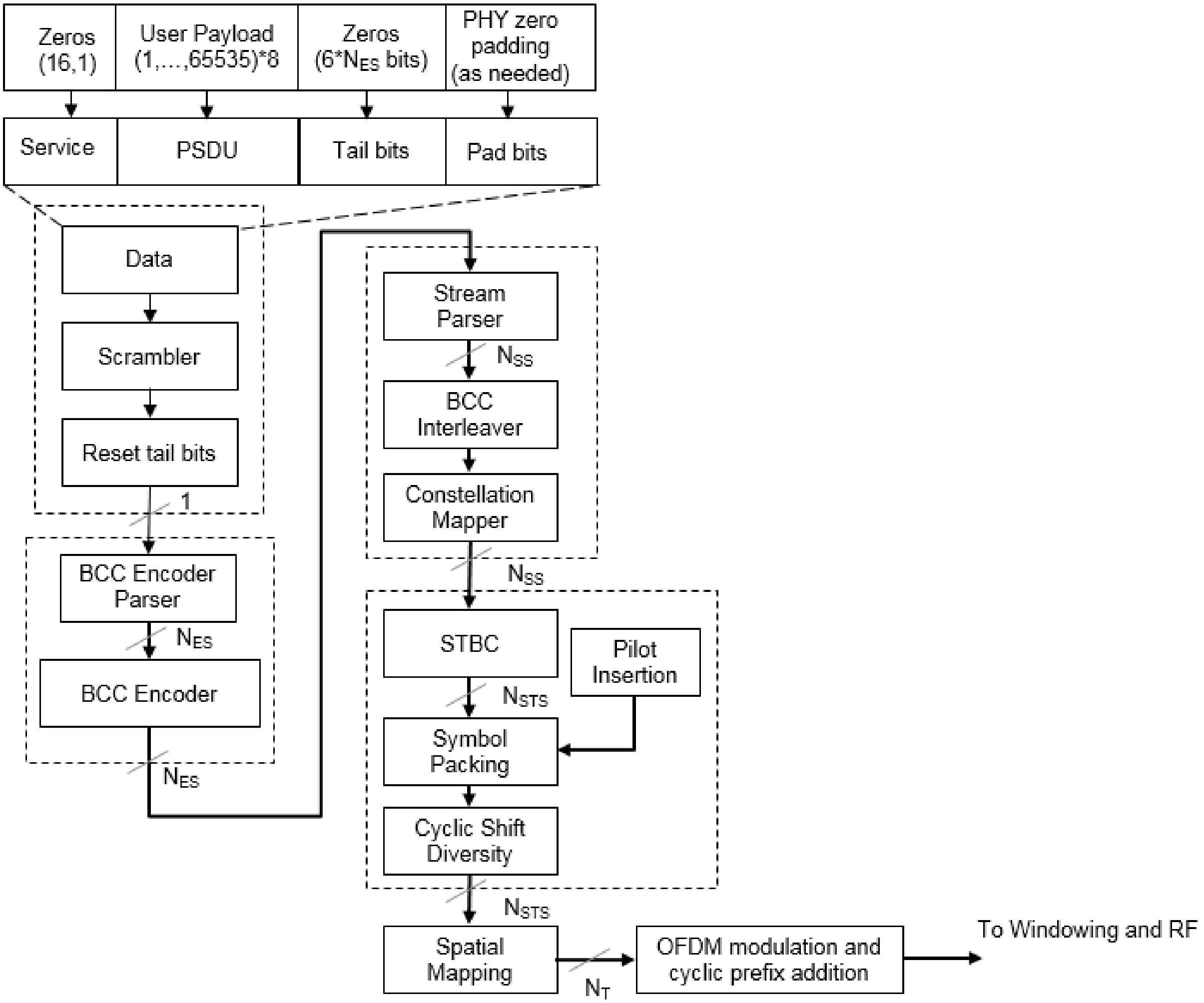
VHT STA must be capable of transmitting and receiving HT-PHY and non-HT-PHY-compliant PPDUs. Specifically, the VHT PHY is based on the HT PHY defined in Section 20, which in turn is based on the OFDM PHY defined in Section 18. The VHT PHY extends the maximum number of space-time streams supported to eight and provides support for downlink multi-user (MU) transmissions. A downlink MU transmission supports up to four users with up to four space-time streams per user, with the total number of space-time streams not exceeding eight.

IEEE Std 802.11ac-2013 [3], Section 22 defines requirements for physical layer processing associated with each PPDU field for the VHT format.


Zeros (8,1)
SIGB CRC
User Payload (1,...,1048575)*8
PHY zero padding (as needed)
Service
PSDU
Pad bits
Data
Scrambler
1
BCC Encoder Parser
BCC Encoder and tail bit insertion
NES
Stream Parser
NSS
Segment Parser
NSS*NSeg
BCC Interleaver
Constellation Mapper
NSS*NSeg
Segment Deparser
NSS
STBC
Pilot Insertion
NSTS
Symbol Packing
Cyclic Shift Diversity
NSTS
NUser
NSTS_Total
Spatial Mapping
NT
OFDM modulation and cyclic prefix addition
To Windowing and RF

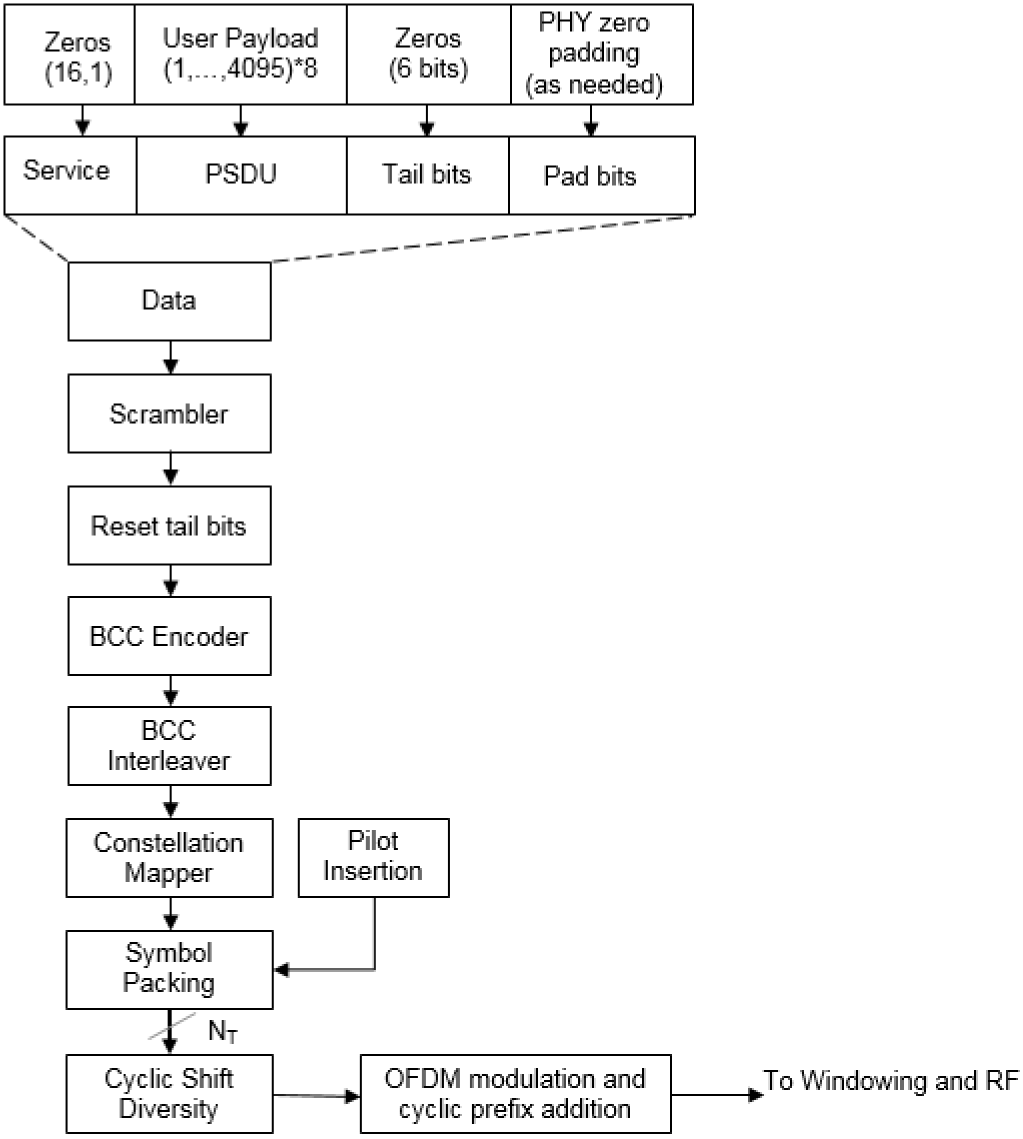
HT Data Transmit Processing Chain

IEEE 802.11-2012 [2], Section 20 defines requirements for physical layer processing associated with each PPDU field for the HT-mixed format.



Non-HT Data Transmit Processing Chain

IEEE 802.11-2012 [2], Section 18 defines requirements for physical layer processing associated with each PPDU field for the OFDM modulation scheme. IEEE 802.11-2012 [2], Section 17, and Section 19 define requirements for physical layer processing associated with each PPDU field for the DSSS modulation scheme.

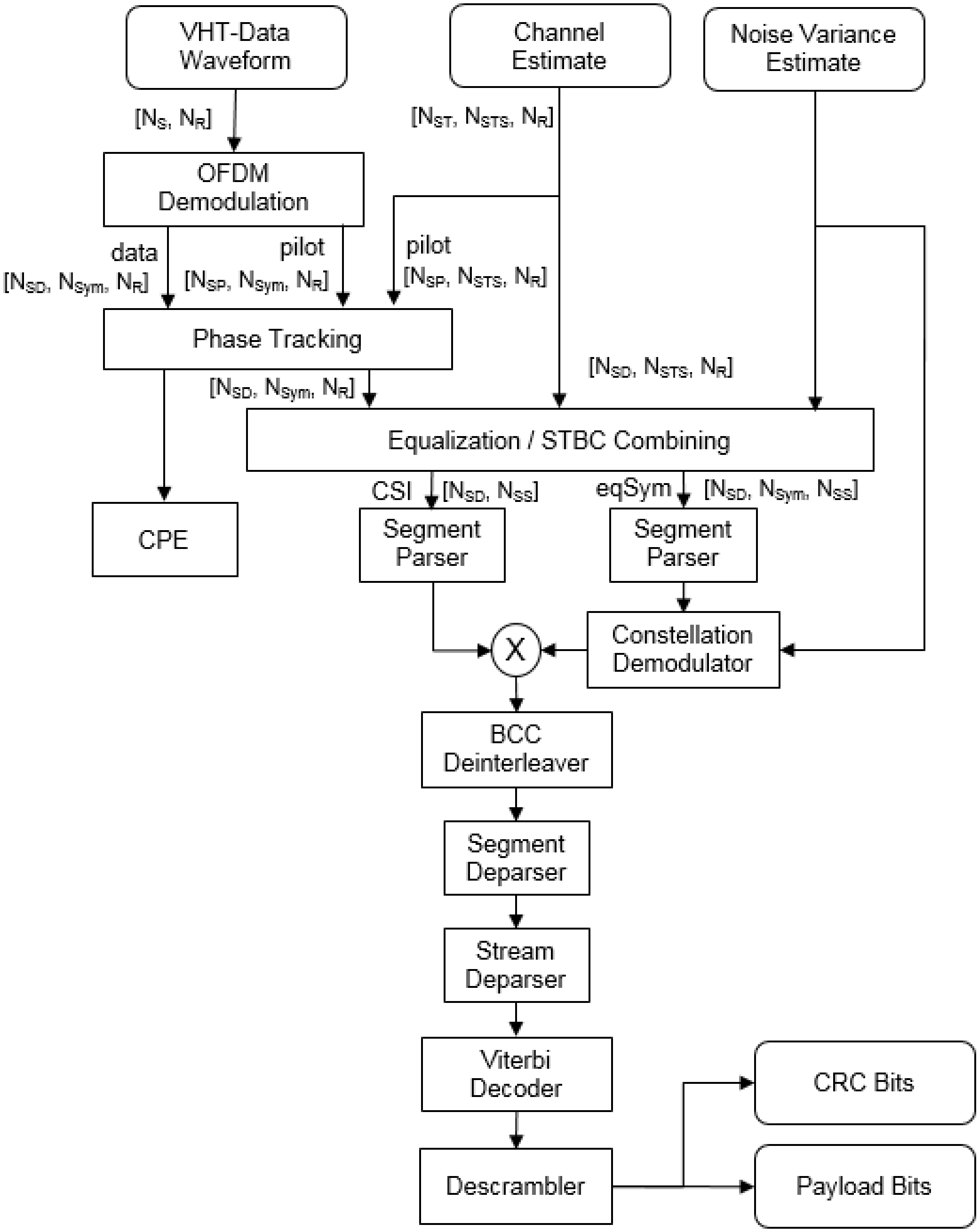

Zeros (16,1)
User Payload (1,…,4095)*8
Zeros (6 bits)
PHY zero padding (as needed)
Service
PSDU
Tail bits
Pad bits
Data
Scrambler
Reset tail bits
BCC Encoder
BCC Interleaver
Constellation Mapper
Pilot Insertion
Symbol Packing
N_T
Cyclic Shift Diversity
OFDM modulation and cyclic prefix addition
To Windowing and RF

Receiver Processing Chain

WLAN System Toolbox functions enable you to recover transmitted VHT, HT-mixed, and non-HT format PPDUs. The receive processing chain includes synchronization, OFDM demodulation, channel estimation, equalization, and signal and data recovery.

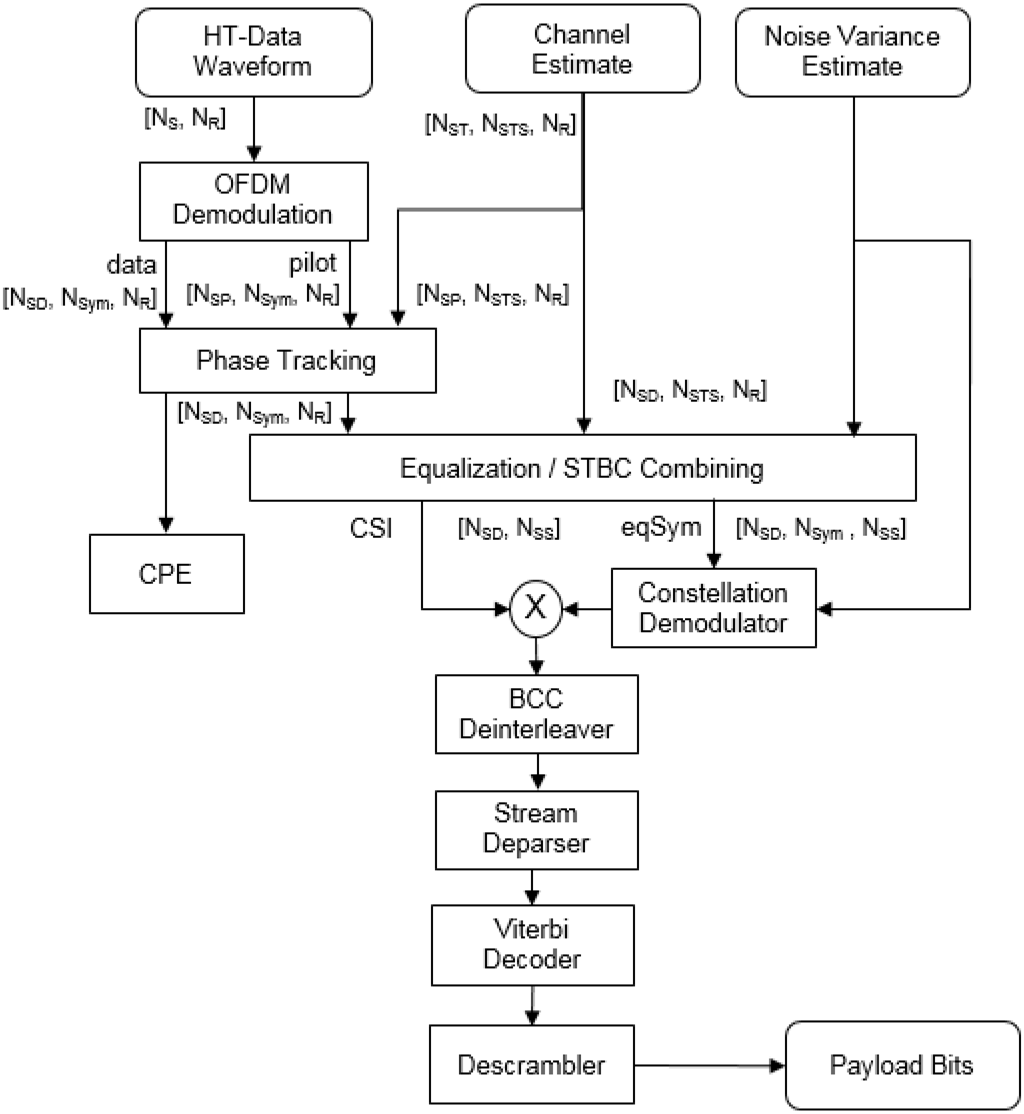
VHT Data Receive Processing Chain

This figure shows the receiver elements used to process the VHT Data field. The “Signal Reception” category includes a list of all receiver functions in the WLAN System Toolbox.


VHT-Data Waveform
Channel Estimate
Noise Variance Estimate
[Ns, NR]
[NST, NSTS, NR]
OFDM Demodulation
data
[NSD, NSym, NR]
pilot
[NSP, NSym, NR]
pilot
[NSP, NSTS, NR]
Phase Tracking
[NSD, NSTS, NR]
[NSD, NSym, NR]
Equalization / STBC Combining
CPE
CSI
[NSD, NSS]
eqSym
[NSD, NSym, NSS]
Segment Parser
Segment Parser
X
Constellation Demodulator
BCC Deinterleaver
Segment Deparser
Stream Deparser
Viterbi Decoder
Descrambler
CRC Bits
Payload Bits

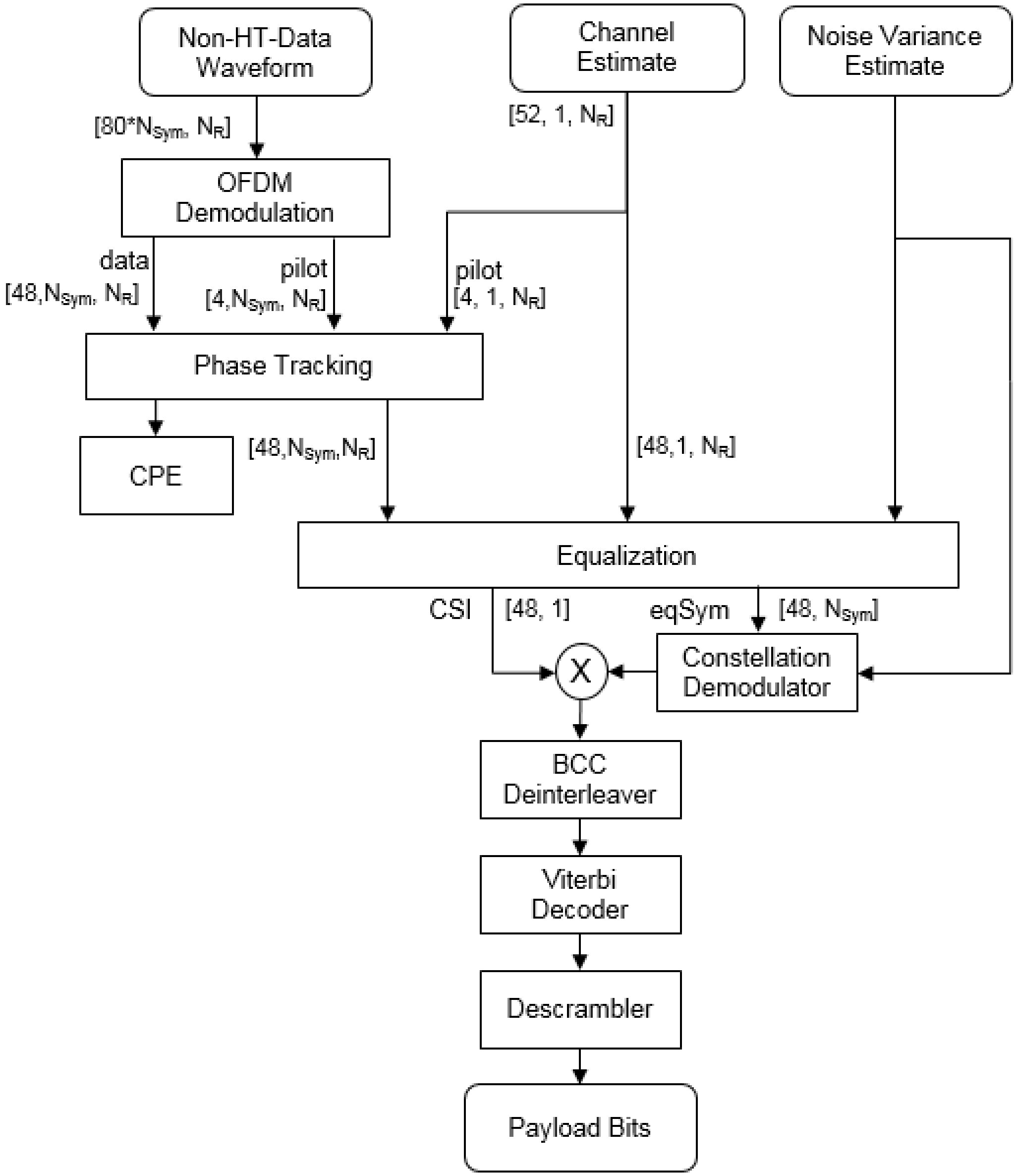
HT Data Receive Processing Chain

This figure shows the receiver elements used to process the HT Data field. The “Signal Reception” category includes a list of all receiver functions in the WLAN System Toolbox.


HT-Data Waveform
[NS, NR]
Channel Estimate
[NST, NSTS, NR]
Noise Variance Estimate
OFDM Demodulation
data
[NSD, NSym, NR]
pilot
[NSP, NSym, NR]
[NSP, NSTS, NR]
Phase Tracking
[NSD, NSym, NR]
[NSD, NSTS, NR]
Equalization / STBC Combining
CPE
CSI
[NSD, NSS]
eqSym
[NSD, NSym , NSS]
X
Constellation Demodulator
BCC Deinterleaver
Stream Deparser
Viterbi Decoder
Descrambler
Payload Bits

Non-HT Data Receive Processing Chain

This figure shows the receiver elements used to process the non-HT Data field. The "Signal Reception" category includes a list of all receiver functions in the WLAN System Toolbox.


Non-HT-Data Waveform
Channel Estimate
Noise Variance Estimate
[80*N_Sym, N_R]
[52, 1, N_R]
OFDM Demodulation
data
[48,N_Sym, N_R]
pilot
[4,N_Sym, N_R]
pilot
[4, 1, N_R]
Phase Tracking
CPE
[48,N_Sym,N_R]
[48,1, N_R]
Equalization
CSI
[48, 1]
eqSym
[48, N_Sym]
X
Constellation Demodulator
BCC Deinterleaver
Viterbi Decoder
Descrambler
Payload Bits

References

[1] IEEE 802.11™: Wireless LANs. http://standards.ieee.org/about/get/802/802.11.html

[2] IEEE Std 802.11™-2012 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[3] IEEE Std 802.11ac™-2013 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications — Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz.

[4] IEEE Std 802.11ad™-2012 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications — Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band.

[5] Perahia, E., and R. Stacey. *Next Generation Wireless LANs: 802.11n and 802.11ac*. 2nd Edition. United Kingdom: Cambridge University Press, 2013.

See Also

“Transmit and Recover L-SIG, VHT-SIG-A, VHT-SIG-B in Fading Channel” on page 1-80 | “End-to-End VHT Simulation with Frequency Correction” on page 1-84

Delay Profile and Fluorescent Lighting Effects

This example demonstrates the impact of changing the TGac delay profile, and it shows how fluorescent lighting affects the time response of the channel.

Delay Profile Effects

Create VHT configuration object. Set the sample rate to 80 MHz.

```
vht = wlanVHTConfig;
fs = 80e6;
```

Generate random binary data and create a transmit waveform using the configuration objects.

```
d = randi([0 1],8*vht.PSDULength,1);
txSig = wlanWaveformGenerator(d,vht);
```

Create a TGac channel object. Set the delay profile to `'Model-A'`, which corresponds to flat fading. Disable the large-scale fading effects.

```
tgacChan = wlanTGacChannel('SampleRate',fs, ...
    'ChannelBandwidth',vht.ChannelBandwidth, ...
    'DelayProfile','Model-A', ...
    'LargeScaleFadingEffect','None');
```

Pass the transmitted waveform through the TGac channel.

```
rxSigA = tgacChan(txSig);
```

Set the delay profile to `'Model-C'`. Model-C corresponds to a multipath channel having 14 distinct paths, with a 30 ns RMS delay spread. The maximum delay spread is 200 ns, which corresponds to a coherence bandwidth of 2.5 MHz.

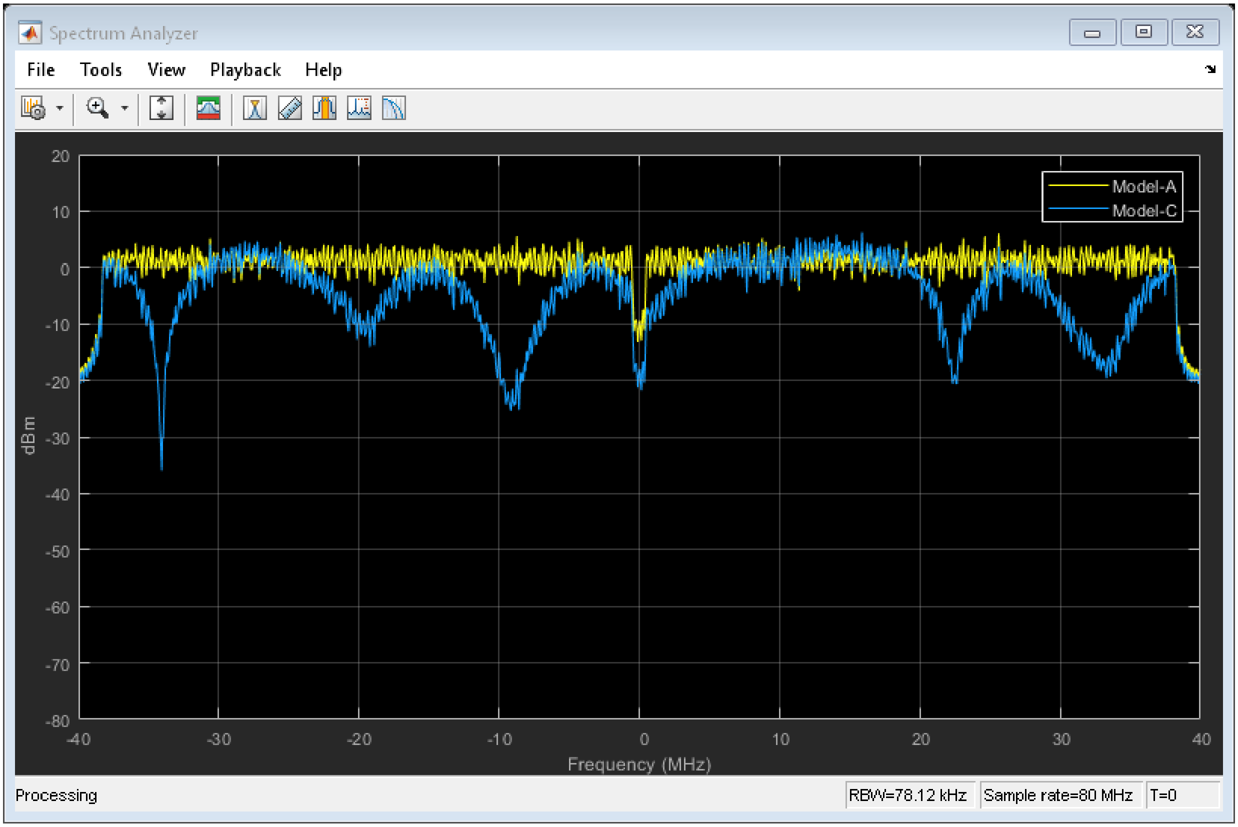
```
release(tgacChan)
tgacChan.DelayProfile = 'Model-C';
```

Pass the waveform through the model-C channel.

```
rxSigC = tgacChan(txSig);
```

Create a spectrum analyzer and use it to visualize the spectrum of the received signals.

```
saScope = dsp.SpectrumAnalyzer('SampleRate',fs, ...
    'ShowLegend',true,'ChannelNames',{'Model-A','Model-C'}, ...
    'SpectralAverages',10);
saScope([rxSigA rxSigC])
```



As expected, the frequency response of the model-A signal is flat across the 80 MHz bandwidth. Conversely, the model-C frequency response varies because its coherence bandwidth is much smaller than the channel bandwidth.

Fluorescent Effects

Release the TGac channel, and set its delay profile to `'Model-D'`. Disable the fluorescent lighting effect.

```
release(tgacChan)
tgacChan.DelayProfile = 'Model-D';
tgacChan.FluorescentEffect = false;
```

To better illustrate the Doppler effects of fluorescent lighting, change the bandwidth and sample rate of the channel. Generate a test waveform of all ones.

```
tgacChan.ChannelBandwidth = 'CBW20';
fs = 20e6;
tgacChan.SampleRate = fs;

txSig = ones(5e5,1);
```

To ensure repeatability, set the global random number generator to a fixed value.

```
rng(37)
```

Pass the waveform through the TGac channel.

```
rxSig0 = tgacChan(txSig);
```

Enable the fluorescent lighting effect. Reset the random number generator, and pass the waveform through the channel.

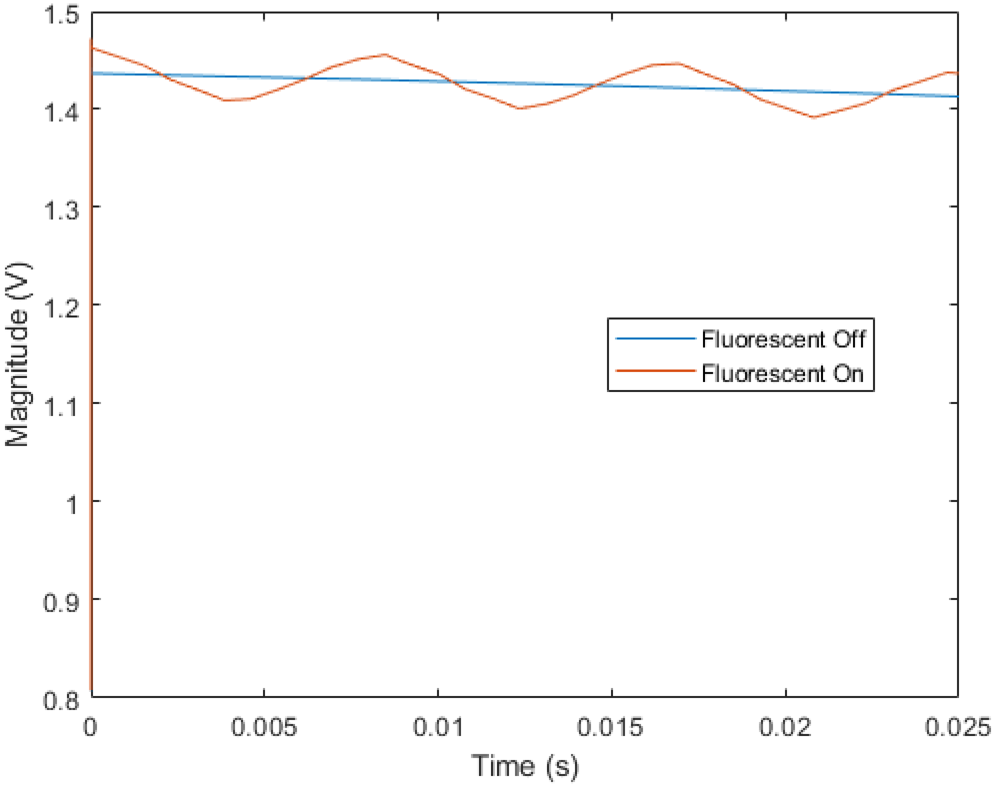
```
release(tgacChan)
tgacChan.FluorescentEffect = true;
rng(37)
rxSig1 = tgacChan(txSig);
```

Determine the time axis and channel filter delay.

```
t = ((1:size(rxSig0,1))'-1)/fs;
fDelay = tgacChan.info.ChannelFilterDelay;
```

Plot the magnitude of the received signals while accounting for the channel filter delay.

```
plot(t(fDelay+1:end),[abs(rxSig0(fDelay+1:end)) abs(rxSig1(fDelay+1:end))])
xlabel('Time (s)')
ylabel('Magnitude (V)')
legend('Fluorescent Off','Fluorescent On','location','best')
```



Fluorescent lighting introduces a Doppler component at twice the power line frequency (120 Hz in the U.S.).

Confirm that the peaks are separated by approximately 0.0083 s (inverse of 120 Hz) by measuring distance between the second and third peaks.

```
[~,loc] = findpeaks(abs(rxSig1(1e5:4e5)));
peakTimes = loc/fs;
peakSeparation = diff(peakTimes)
```

```
peakSeparation = 0.0085
```

Generate Multi-User VHT Waveform

This example shows how to generate a multi-user VHT waveform from individual components. It also shows how to generate the same waveform by using the `wlanWaveformGenerator` function. The data fields from the two approaches are compared and shown to be identical.

Create a VHT configuration object having 3 users and 3 transmit antennas.

```
vht = wlanVHTConfig('NumUsers',3,'NumTransmitAntennas',3);
```

Set the number of space-time streams to the vector `[1 1 1]`, which indicates that each user is assigned one space-time stream. Set the user positions to `[0 1 2]`. Set the group ID to 5. Group ID values from 1 to 62 apply for multi-user operation.

```
vht.NumSpaceTimeStreams = [1 1 1];
vht.UserPositions = [0 1 2];
vht.GroupID = 5;
```

Set a different MCS value for each user.

```
vht.MCS = [0 2 4];
```

Set the APEP length to 2000, 1400, and 1800 bytes. Each element corresponds to the number of bytes assigned to each user.

```
vht.APEPLength = [2000 1400 1800]
```

```
vht = 
  wlanVHTConfig with properties:

       ChannelBandwidth: 'CBW80'
               NumUsers: 3
          UserPositions: [0 1 2]
    NumTransmitAntennas: 3
    NumSpaceTimeStreams: [1 1 1]
         SpatialMapping: 'Direct'
                    MCS: [0 2 4]
          ChannelCoding: 'BCC'
             APEPLength: [2000 1400 1800]
          GuardInterval: 'Long'
                GroupID: 5

   Read-only properties:
```

```
             PSDULength: [2000 6008 12019]
```

Display the PSDU lengths for the three users. The PSDU length is a function of both the APEP length and the MCS value.

```
vht.PSDULength
```

```
ans = 1×3

        2000        6008       12019
```

Display the field indices for the VHT waveform.

```
ind = wlanFieldIndices(vht)
```

```
ind = struct with fields:
       LSTF: [1 640]
       LLTF: [641 1280]
       LSIG: [1281 1600]
    VHTSIGA: [1601 2240]
     VHTSTF: [2241 2560]
     VHTLTF: [2561 3840]
    VHTSIGB: [3841 4160]
    VHTData: [4161 48000]
```

Create the individual fields that comprise the VHT waveform.

```
lstf = wlanLSTF(vht);
lltf = wlanLLTF(vht);
lsig = wlanLSIG(vht);
[vhtsigA,sigAbits] = wlanVHTSIGA(vht);
vhtstf = wlanVHTSTF(vht);
vhtltf = wlanVHTLTF(vht);
[vhtsigB,sigBbits] = wlanVHTSIGB(vht);
```

Extract the first two VHT-SIG-A information bits and convert them to their decimal equivalent.

```
bw = bi2de(double(sigAbits(1:2)'))
```

```
bw = 2
```

The value, 2, corresponds to an 80 MHz bandwidth (see `wlanVHTSIGA`).

Extract VHT-SIG-A information bits 5 through 10, and convert them to their decimal equivalent.

```
groupid = bi2de(double(sigAbits(5:10)'))
```

```
groupid = 5
```

The extracted group ID, 5, matches the corresponding property in the VHT configuration object.

Extract the packet length from the VHT-SIG-B information bits. For multi-user operation with an 80 MHz bandwidth, the first 19 bits contain the APEP length information. Convert the field lengths to their decimal equivalents. Multiply them by 4 because the length of the VHT-SIG-B field is expressed in units of 4 bytes.

```
pktLen = bi2de(double(sigBbits(1:19,:)'))*4
```

```
pktLen = 3×1

        2000
        1400
        1800
```

Confirm that the extracted APEP length matches the value set in the configuration object.

```
isequal(pktLen',vht.APEPLength)
```

```
ans = logical
   1
```

Extract the MCS values from the VHT-SIG-B information bits. The MCS component is specified by bits 20 to 23.

```
mcs = bi2de(double(sigBbits(20:23,:)'))
```

```
mcs = 3×1

     0
     2
     4
```

The values correspond to those set in the VHT configuration object.

Create three data sequences, one for each user.

```
d1 = randi([0 1],vht.PSDULength(1)*8,1);
d2 = randi([0 1],vht.PSDULength(2)*8,1);
d3 = randi([0 1],vht.PSDULength(3)*8,1);
```

Generate a VHT data field using these data sequences.

```
vhtdata = wlanVHTData({d1 d2 d3},vht);
```

Generate a multi-user VHT waveform with windowing is disabled. Extract the data field from the waveform.

```
wv = wlanWaveformGenerator({d1 d2 d3},vht,'WindowTransitionTime',0);
```

```
wvdata = wv(ind.VHTData(1):ind.VHTData(2),:);
```

Confirm that the two generation approaches produce identical results.

```
isequal(vhtdata,wvdata)
```

```
ans = logical
   1
```

Basic VHT Data Recovery Steps

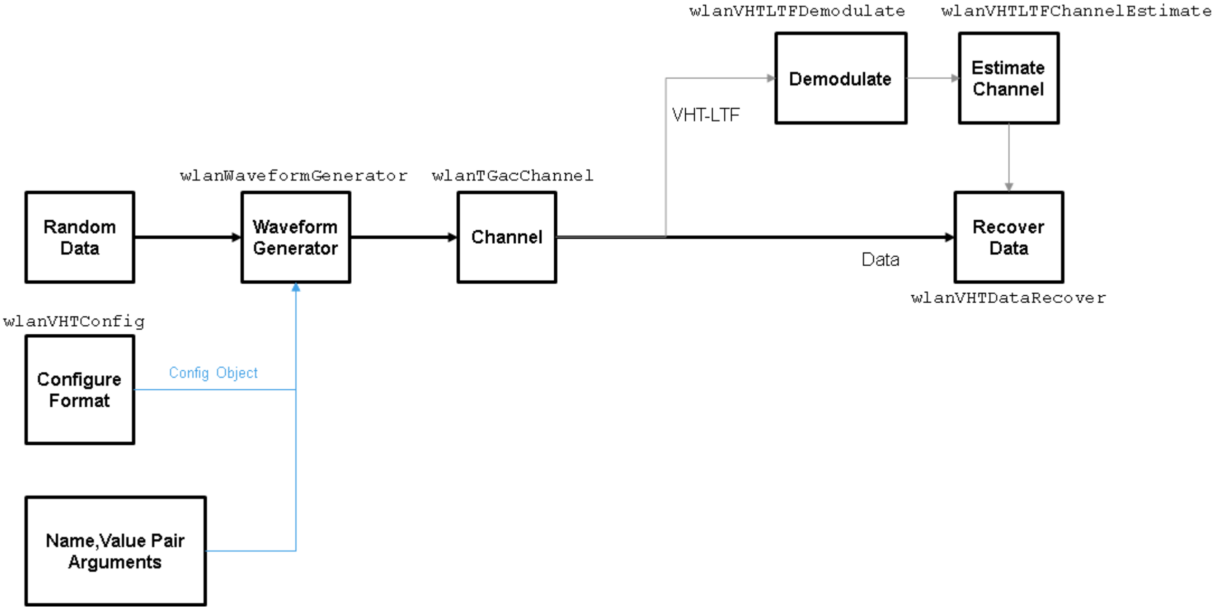
This example shows how to perform basic VHT data recovery. It also shows how to recover VHT data when the received signal has a carrier frequency offset. Similar procedures can be used to recover data with the HT and non-HT formats.

Basic Data Recovery

The WLAN System Toolbox™ provides functions to generate and recover IEEE® 802.11ac™ standards compliant waveforms. Data recovery is accomplished by these steps:

1. Generate a VHT waveform
2. Pass the waveform through a channel
3. Extract the VHT-LTF and demodulate
4. Estimate the channel by using the demodulated VHT-LTF
5. Extract the data field
6. Recover the data by using the channel and noise variance estimates

The block diagram shows these steps, along with their corresponding commands.



Create VHT format configuration object.

```
vht = wlanVHTConfig;
```

Create a VHT transmit waveform by using the VHT configuration object. Set the data sequence to `[1;0;1;1]`. The data sequence is repeated to generate the specified number of packets.

```
txSig = wlanWaveformGenerator([1;0;1;1],vht);
```

Pass the received signal through an AWGN channel.

```
rxSig = awgn(txSig,10);
```

Determine the field indices of the waveform.

```
ind = wlanFieldIndices(vht);
```

Extract the VHT-LTF from the received signal.

```
rxVHTLTF = rxSig(ind.VHTLTF(1):ind.VHTLTF(2),:);
```

Demodulate the VHT-LTF. Estimate the channel response by using the demodulated signal.

```
demodVHTLTF = wlanVHTLTFDemodulate(rxVHTLTF,vht);
chEst = wlanVHTLTFChannelEstimate(demodVHTLTF,vht);
```

Extract the VHT data field.

```
rxData = rxSig(ind.VHTData(1):ind.VHTData(2),:);
```

Recover the information bits by using the channel and noise variance estimates. Confirm that the first 8 bits match two repetitions of the input data sequence of `[1;0;1;1]`.

```
rxBits = wlanVHTDataRecover(rxData,chEst,0.1,vht);
```

```
rxBits(1:8)
```

```
ans = 8x1 int8 column vector

   1
   0
   1
   1
   1
   0
   1
   1
```

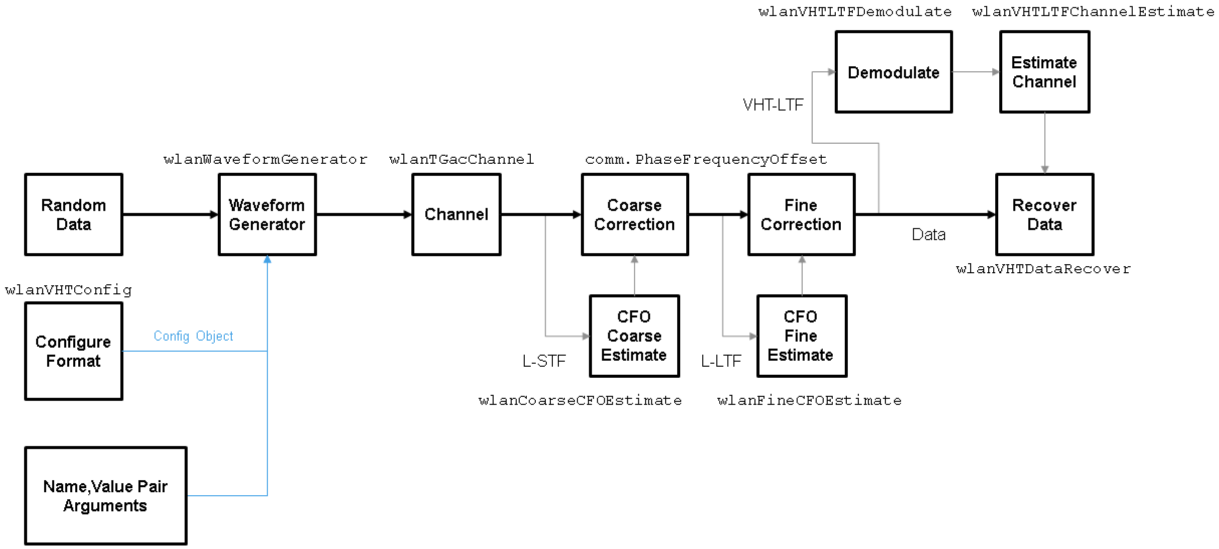
Data Recovery with Frequency Correction

Data recovery when a carrier frequency offset is present is accomplished by these steps:

1. Generate a VHT waveform
2. Pass the waveform through a channel
3. Extract the L-STF and perform a coarse frequency offset estimate
4. Correct for the offset by using the coarse estimate
5. Extract the L-LTF and perform a fine frequency offset estimate
6. Correct for the offset by using the fine estimate
7. Extract the VHT-LTF and demodulate
8. Estimate the channel by using the demodulated VHT-LTF

9 Extract the data field
10 Recover the data by using the channel and noise variance estimates

The block diagram shows these steps, along with their corresponding commands.



Set the channel bandwidth and sample rate.

```
cbw = 'CBW160';
fs = 160e6;
```

Create a VHT configuration object that supports a 2x2 MIMO transmission.

```
vht = wlanVHTConfig('ChannelBandwidth',cbw, ...
    'NumTransmitAntennas',2,'NumSpaceTimeStreams',2);
```

Generate a VHT waveform containing a random PSDU.

```
txPSDU = randi([0 1],vht.PSDULength*8,1);
txSig = wlanWaveformGenerator(txPSDU,vht);
```

Create a 2x2 TGac channel.

```
tgacChan = wlanTGacChannel('SampleRate',fs,'ChannelBandwidth',cbw, ...
    'NumTransmitAntennas',2,'NumReceiveAntennas',2);
```

Create a phase and frequency offset object.

```
pfOffset = comm.PhaseFrequencyOffset('SampleRate',fs,'FrequencyOffsetSource','Input por
```

Pass the transmitted waveform through the noisy TGac channel.

```
rxSigNoNoise = tgacChan(txSig);
rxSig = awgn(rxSigNoNoise,15);
```

Introduce a frequency offset of 500 Hz to the received signal.

```
rxSigFreqOffset = pfOffset(rxSig,500);
```

Find the start and stop indices for all component fields of the PPDU.

```
ind = wlanFieldIndices(vht);
```

Extract the L-STF. Estimate and correct for the carrier frequency offset.

```
rxLSTF = rxSigFreqOffset(ind.LSTF(1):ind.LSTF(2),:);

foffset1 = wlanCoarseCFOEstimate(rxLSTF,cbw);
rxSig1 = pfOffset(rxSigFreqOffset,-foffset1);
```

Extract the L-LTF from the corrected signal. Estimate and correct for the residual frequency offset.

```
rxLLTF = rxSig1(ind.LLTF(1):ind.LLTF(2),:);

foffset2 = wlanFineCFOEstimate(rxLLTF,cbw);
rxSig2 = pfOffset(rxSig1,-foffset2);
```

Extract and demodulate the VHT-LTF. Estimate the channel coefficients.

```
rxVHTLTF = rxSig2(ind.VHTLTF(1):ind.VHTLTF(2),:);
demodVHTLTF = wlanVHTLTFDemodulate(rxVHTLTF,vht);
chEst = wlanVHTLTFChannelEstimate(demodVHTLTF,vht);
```

Extract the VHT data field from the received and frequency-corrected PPDU. Recover the data field.

```
rxData = rxSig2(ind.VHTData(1):ind.VHTData(2),:);
rxPSDU = wlanVHTDataRecover(rxData,chEst,0.03,vht);
```

Calculate the number of bit errors in the received packet.

```
numErr = biterr(txPSDU,rxPSDU)
```

```
numErr = 2
```

Packet Size and Duration Dependencies

WLAN standards specify a maximum packet duration (*TXTIME*) for the various formats. The S1G format additionally specifies the maximum PSDU length (*PSDU_LENGTH*) and number of symbols (N_{SYM}). These WLAN properties are a function of transmission properties set in WLAN System Toolbox configuration objects. The settings of WLAN format-specific configuration objects are validated when the object is used. Command-line feedback informs you when the configuration violates the packet size or duration limits.

This table indicates relevant properties that help determine the packet duration and length for the various WLAN formats. It also provides references to the IEEE standards for further details.

WLAN Format	Length-Related Validation	Relevant and Dependent Properties
DMG	*TXTIME* requires validation. *TXTIME* is defined by the equations in IEEE Std 802.11ad [2], Section 21.12.3. As specified by *aPPDUMaxTime* in Table 21-31, the maximum *TXTIME* is 2 ms.	**1** MCS (dmg_1) **2** PSDULength **3** TrainingLength (dmg_1) **4** PacketType (dmg_1) **5** BeamTrackingRequest (dmg_1) (dmg_1) The property helps determine whether the packet is a beam refinement protocol (BRP) packet containing training fields or if it is a general packet signaling the number of fields to append. For more information, see 802.11ad [2], Table 4.

WLAN Format	Length-Related Validation	Relevant and Dependent Properties
S1G	*TXTIME*, *PSDU_LENGTH*, and N_{SYM} require validation. The equations for all three are defined in draft standard IEEE P802.11ah/D5.0, Section 24.4.3, and the maximum *TXTIME* and *PSDU_LENGTH* is defined in Table 24-37. In Table 24-37: • As specified by *aPPDUMaxTime*, the maximum *TXTIME* is 27.92 ms. This *TXTIME* is the maximum PPDU duration for an S1G_1M PPDU with: • A bandwidth of 1 MHz • S1G MCS set to 10 • One spatial stream, limited by a PSDU length of 511 octets. • As specified by *aPPDUMaxLength*, the maximum *PSDU_LENGTH* is 797,159 octets. This PSDU length is the maximum length in octets for an S1G SU PPDU with: • A bandwidth of 16 MHz • S1G-MCS set to 9 • Four spatial streams, limited by 511 data symbols supported by the *Length* field in the S1G SIG field, excluding the *SERVICE* field and tail bits. • The maximum N_{SYM} is 511.	For *TXTIME*, the relevant properties are: **1** `ChannelBandwidth` **2** `STBC` (s1g_1) **3** `GuardInterval` **4** `ChannelCoding` (MU) **5** `APEPLength` (MU) **6** `PSDULength` – This property is read-only. When undefined, `PSDULength` is returned as empty of size 1×0. An empty return can happen when the set of property values for the object define an invalid state. (MU) **7** `MCS` (MU) **8** `NumSpaceTimeStreams` (MU) **9** `NumUsers` For *PSDU_LENGTH* and N_{SYM}, the relevant properties are: **1** `ChannelBandwidth` **2** `STBC` (s1g_1) **3** `ChannelCoding` (MU) **4** `APEPLength` (MU) **5** `PSDULength` – This property is read-only. When undefined, `PSDULength` is returned as empty, `[]`. An empty return can happen when the set of property values for the object define an invalid state. (MU)

WLAN Format	Length-Related Validation	Relevant and Dependent Properties
		6 `MCS` (MU) **7** `NumSpaceTimeStreams` (MU) **8** `NumUsers` (s1g_1) The property is relevant only when `NumUsers` = 1. (MU) The property has multiple values for multi-user operation.
VHT	*TXTIME* requires validation. *TXTIME* is defined by the equations in IEEE Std 802.11ac-2013 [3], Section 22.4.3 and the maximum *TXTIME*. As specified by *aPPDUMaxTime* in Table 22-29, the maximum *TXTIME* is 5.484 ms.	**1** `ChannelBandwidth` **2** `STBC` (vht_1) **3** `GuardInterval` **4** `ChannelCoding` (MU) **5** `APEPLength` (MU) **6** `PSDULength` – This property is read only. When undefined, it is returned as an empty of size 1×0. (MU) **7** `MCS` (MU) **8** `NumSpaceTimeStreams` (MU) **9** `NumUsers` (vht_1) The property is relevant only when `NumUsers` = 1. (MU) The property has multiple values for multi-user operation.

WLAN Format	Length-Related Validation	Relevant and Dependent Properties
HT	*TXTIME* requires validation. *TXTIME* is defined by the equations in IEEE Std 802.11-2012 [1], Section 20.4.3. As specified by *aPPDUMaxTime* in Table 20-25, the maximum *TXTIME* is 10 ms.	**1** `ChannelBandwidth` **2** `GuardInterval` **3** `ChannelCoding` **4** `PSDULength` **5** `MCS` **6** `NumSpaceTimeStreams` **7** `NumExtensionStreams`
non-HT	*TXTIME* requires validation. *TXTIME* is defined by the equations in IEEE Std 802.11-2012 [1], Section 18.4.3. Based on equation 18–29 and a valid combination of property settings, the maximum *TXTIME* is 21.936 ms.	**1** `Modulation` (non-ht_1) **2** `PSDULength` **3** `MCS` (non-ht_1) **4** `DateRate` (non-ht_1) (non-ht_1) `DataRate` or `MCS` might be relevant depending on the `Modulation` setting.

References

[1] IEEE Std 802.11™-2012 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[2] IEEE Std 802.11ad™-2012 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications — Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band.

[3] IEEE Std 802.11ac™-2013 IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications —

Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz.