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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

IEEE Computer Society

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**IEEE Standard for Information technology—
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Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

**Prepared by the 802.11 Working Group of the
LAN/MAN Standards Committee
of the
IEEE Computer Society**

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For a 160 MHz PPDU transmission,

$$\Upsilon_{k, 160} = \begin{cases} 1, & k < -192 \\ -1, & -192 \leq k < 0 \\ 1, & 0 \leq k < 64 \\ -1, & 64 \leq k \end{cases} \quad (21-17)$$

21.3.8 VHT preamble

21.3.8.1 Introduction

A VHT preamble is defined to carry the required information to operate in either single user or multi-user mode. To maintain compatibility with non-VHT STAs, specific non-VHT fields are defined that can be received by non-VHT STAs compliant with Clause 17 or Clause 19. The non-VHT fields are followed by VHT fields specific to VHT STAs.

21.3.8.2 Non-VHT portion of VHT format preamble

21.3.8.2.1 Cyclic shift for pre-VHT modulated fields

The cyclic shift value $T_{CS}^{i_{TX}}$ for the L-STF, L-LTF, L-SIG, and VHT-SIG-A fields of the PPDU for transmit chain i_{TX} out of a total of N_{TX} are defined in Table 21-10.

Table 21-10—Cyclic shift values for L-STF, L-LTF, L-SIG, and VHT-SIG-A fields of the PPDU

$T_{CS}^{i_{TX}}$ values for L-STF, L-LTF, L-SIG, and VHT-SIG-A fields of the PPDU									
Total number of transmit chains (N_{TX}) per frequency segment	Cyclic shift for transmit chain i_{TX} (in units of ns)								
	1	2	3	4	5	6	7	8	>8
1	0	—	—	—	—	—	—	—	—
2	0	−200	—	—	—	—	—	—	—
3	0	−100	−200	—	—	—	—	—	—
4	0	−50	−100	−150	—	—	—	—	—
5	0	−175	−25	−50	−75	—	—	—	—
6	0	−200	−25	−150	−175	−125	—	—	—
7	0	−200	−150	−25	−175	−75	−50	—	—
8	0	−175	−150	−125	−25	−100	−50	−200	—
>8	0	−175	−150	−125	−25	−100	−50	−200	Between −200 and 0 inclusive

21.3.8.3 VHT portion of VHT format preamble

21.3.8.3.1 Introduction

The VHT portion of the VHT format preamble consists of the VHT-SIG-A, VHT-STF, VHT-LTF, and VHT-SIG-B fields.

21.3.8.3.2 Cyclic shift for VHT modulated fields

The cyclic shift values defined in this subclause apply to the VHT-STF, VHT-LTF, VHT-SIG-B, and Data fields of the VHT PPDU. The cyclic shift values defined in 21.3.8.2.1 apply to VHT-SIG-A field in the VHT format preamble.

Throughout the VHT modulated fields of the preamble, cyclic shifts are applied to prevent unintended beamforming when correlated signals are transmitted in multiple space-time streams. The same cyclic shift is also applied to these streams during the transmission of the Data field of the VHT PPDU. The cyclic shift value $T_{CS, VHT}(n)$ for the VHT modulated fields for space-time stream n out of $N_{STS, total}$ total space-time streams is shown in Table 21-11.

Table 21-11—Cyclic shift values for the VHT modulated fields of a PPDU

$T_{CS, VHT}(n)$ values for the VHT modulated fields of a PPDU								
Total number of space-time streams ($N_{STS, total}$)	Cyclic shift for space-time stream n (ns)							
	1	2	3	4	5	6	7	8
1	0	–	–	–	–	–	–	–
2	0	–400	–	–	–	–	–	–
3	0	–400	–200	–	–	–	–	–
4	0	–400	–200	–600	–	–	–	–
5	0	–400	–200	–600	–350	–	–	–
6	0	–400	–200	–600	–350	–650	–	–
7	0	–400	–200	–600	–350	–650	–100	–
8	0	–400	–200	–600	–350	–650	–100	–750

In a VHT MU PPDU, the cyclic shifts are applied sequentially across the space-time streams as follows: the cyclic shift of the space-time stream number m of user u is given by $T_{CS, VHT}(M_u + m)$ of the row corresponding to $N_{STS, total}$ in Table 21-11.

$$r_{\text{VHT-STF}}^{(i_{\text{Seg}}, i_{\text{TX}})}(t) = \frac{1}{\sqrt{N_{\text{VHT-STF}}^{\text{Tone}} N_{\text{STS}, \text{total}}}} w_{T_{\text{VHT-STF}}}(t) \cdot \sum_{k=-N_{\text{SR}}}^{N_{\text{SR}}} \sum_{u=0}^{N_{\text{user}}-1} \sum_{m=1}^{N_{\text{STS}, u}} \left(\left[Q_k^{(i_{\text{Seg}})} \right]_{i_{\text{TX}}, (M_u + m)} Y_{k, \text{BW}}^{\text{VHTS}_k} \cdot \exp(j2\pi k \Delta_F (t - T_{\text{CS, VHT}}(M_u + m))) \right) \quad (21-33)$$

where

$N_{\text{VHT-STF}}^{\text{Tone}}$ has the value given in Table 21-8

$T_{\text{CS, VHT}}(n)$ is given in Table 21-11

$Q_k^{(i_{\text{Seg}})}$ is defined in 21.3.10.11.1

$Y_{k, \text{BW}}$ is defined in Equation (21-14), Equation (21-15), Equation (21-16), and Equation (21-17)

21.3.8.3.5 VHT-LTF definition

The VHT Long Training field (VHT-LTF) field provides a means for the receiver to estimate the MIMO channel between the set of constellation mapper outputs (or, if STBC is applied, the STBC encoder outputs) and the receive chains. The transmitter provides training for $N_{\text{STS}, \text{total}}$ space-time streams (spatial mapper inputs) used for the transmission of the PSDU(s). For each tone, the MIMO channel that can be estimated is an $N_{\text{RX}} \times N_{\text{STS}, \text{total}}$ matrix. A VHT transmission has a preamble that contains VHT-LTF symbols, where the data tones of each VHT-LTF symbol are multiplied by entries belonging to a matrix $P_{\text{VHT-LTF}}$, to enable channel estimation at the receiver. The pilot tones of each VHT-LTF symbol are multiplied by the entries of a matrix $R_{\text{VHT-LTF}}$ defined in the following text. The multiplication of the pilot tones in the VHT-LTF symbol by the $R_{\text{VHT-LTF}}$ matrix instead of the $P_{\text{VHT-LTF}}$ matrix allows receivers to track phase and frequency offset during MIMO channel estimation using the VHT-LTF. The number of VHT-LTF symbols, $N_{\text{VHT-LTF}}$, is a function of the total number of space-time streams $N_{\text{STS}, \text{total}}$ as shown in Table 21-13. As a result the VHT-LTF field consists of one, two, four, six or eight symbols.

Table 21-13—Number of VHT-LTFs required for different numbers of space-time streams

$N_{\text{STS}, \text{total}}$	N_{VHTLTF}
1	1
2	2
3	4
4	4
5	6
6	6
7	8
8	8

$$r_{\text{non-HT, BW}}^{i_{TX}}(t) = \frac{1}{\sqrt{N_{\text{NON_HT_DUP_OFDM-Data}}^{\text{Tone}}}} \sum_{n=0}^{N_{SYM}-1} w_{T_{SYM}}(t - nT_{SYM}) \cdot \sum_{i_{BW}=0}^{N_{20\text{MHz}}-1} \left(\sum_{k=-26}^{26} \Upsilon_{(k-K_{\text{Shift}}(i_{BW})), BW}(D_{k,n} + p_{n+1}P_k) \cdot \exp(j2\pi(k-K_{\text{Shift}}(i_{BW}))\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}})) \right) \quad (21-100)$$

where

$N_{20\text{MHz}}$ and $K_{\text{Shift}}(i)$ are defined in 21.3.8.2.4

P_k and p_n are defined in 17.3.5.10

$D_{k,n}$ is defined in Equation (21-26)

$\Upsilon_{k, BW}$ is defined in Equation (21-16) and Equation (21-17)

$T_{CS}^{i_{TX}}$ represents the cyclic shift for transmitter chain i_{TX} with a value given in Table 21-10

$N_{\text{NON_HT_DUP_OFDM-Data}}^{\text{Tone}}$ has the value given in Table 21-8

In an 80+80 MHz non-HT duplicate transmission, data transmission in each frequency segment shall be as defined for an 80 MHz non-HT duplicate transmission in Equation (21-100).

21.3.11 SU-MIMO and DL-MU-MIMO Beamforming

21.3.11.1 General

SU-MIMO and DL-MU-MIMO beamforming are techniques used by a STA with multiple antennas (the beamformer) to steer signals using knowledge of the channel to improve throughput. With SU-MIMO beamforming all space-time streams in the transmitted signal are intended for reception at a single STA. With DL-MU-MIMO beamforming, disjoint subsets of the space-time streams are intended for reception at different STAs.

For SU-MIMO beamforming, the steering matrix Q_k can be determined from the beamforming feedback matrix V_k that is sent back to the beamformer by the beamformee using the compressed beamforming feedback matrix format as defined in 19.3.12.3.6. The feedback report format is described in 9.4.1.49.

For DL-MU-MIMO beamforming, the receive signal vector in subcarrier k at beamformee u , $y_{k,u} = [y_{k,0}, y_{k,1}, \dots, y_{k, N_{RX_u}-1}]^T$, is shown in Equation (21-101), where $\mathbf{x}_k = [\mathbf{x}_{k,0}^T, \mathbf{x}_{k,1}^T, \dots, \mathbf{x}_{k, N_{user}-1}^T]^T$ denotes the transmit signal vector in subcarrier k for all N_{user} beamformees, with $\mathbf{x}_{k,u} = [x_{k,0}, x_{k,1}, \dots, x_{k, N_{STS,u}-1}]^T$ being the transmit signal for beamformee u .

$$y_{k,u} = \mathbf{H}_{k,u} \times [Q_{k,0}, Q_{k,1}, \dots, Q_{k, N_{user}-1}] \times \mathbf{x}_k + \mathbf{n} \quad (21-101)$$

where

$\mathbf{H}_{k,u}$ is the channel matrix from the beamformer to beamformee u in subcarrier k with dimensions $N_{RX_u} \times N_{TX}$

N_{RX_u}	is the number of receive antennas at beamformee u
$Q_{k,u}$	is a steering matrix for beamformee u in subcarrier k with dimensions $N_{TX} \times N_{STS_u}$
N_{user}	is the number of VHT MU PPDU recipients (see Table 21-6)
n	is a vector of additive noise and may include interference

The DL-MU-MIMO steering matrix $Q_k = [Q_{k,0}, Q_{k,1}, \dots, Q_{k,N_{user}-1}]$ can be determined by the beamformer using the beamforming feedback matrices for subcarrier k from beamformee u , $V_{k,u}$, and SNR information for subcarrier k from beamformee u , $SNR_{k,u}$, where $u = 0, 1, \dots, N_{user} - 1$. The steering matrix that is computed (or updated) using new beamforming feedback matrices and new SNR information from some or all of participating beamformees might replace the existing steering matrix Q_k for the next DL-MU-MIMO data transmission. The beamformee group for the MU transmission is signaled using the Group ID field in VHT-SIG-A (see 21.3.8.3.3 and 21.3.11.4).

21.3.11.2 Beamforming Feedback Matrix V

Upon receipt of a VHT NDP sounding PPDU, the beamformee shall remove the space-time stream CSD in Table 21-11 from the measured channel before computing a set of matrices for feedback to the beamformer. The beamforming feedback matrix, $V_{k,u}$, found by the beamformee u for subcarrier k shall be compressed in the form of angles using the method described in 19.3.12.3.6. The angles, $\phi(k,u)$ and $\psi(k,u)$, are quantized according to Table 9-68. The number of bits for quantization is chosen by the beamformee, based on the indication from the beamformer as to whether the feedback is requested for SU-MIMO beamforming or DL-MU-MIMO beamforming. The compressed beamforming feedback using 19.3.12.3.6 is the only Clause 21 beamforming feedback format defined.

The beamformee shall generate the beamforming feedback matrices with the number of rows (N_r) equal to the N_{STS} of the NDP.

After receiving the angle information, $\phi(k,u)$ and $\psi(k,u)$, the beamformer reconstructs $V_{k,u}$ using Equation (19-79). For SU-MIMO beamforming, the beamformer can use this $V_{k,0}$ matrix to determine the steering matrix Q_k . For DL-MU-MIMO beamforming, the beamformer may calculate a steering matrix $Q_k = [Q_{k,0}, Q_{k,1}, \dots, Q_{k,N_{user}-1}]$ using $V_{k,u}$ and $SNR_{k,u}$ ($0 \leq u \leq N_{user} - 1$) in order to suppress crosstalk between participating beamformees. The method used by the beamformer to calculate the steering matrix Q_k is implementation specific.

The beamformee decides the tone grouping value to be used in the beamforming feedback matrix V . A beamformer shall support all tone grouping values and Codebook Information values.

21.3.11.3 Maximum Number of Total Spatial Streams in VHT MU PPDU

An MU beamformee capable STA shall support reception of VHT MU PPDU with the total number of space-time streams across the N_{user} users being less than or equal to the value indicated in the Maximum $N_{STS,total}$ subfield of the Supported VHT-MCS and NSS Set field of the VHT Capabilities element.

21.3.11.4 Group ID

A value in the Group ID field in VHT-SIG-A (see 21.3.8.3.3) in the range 1 to 62 indicates a VHT MU PPDU. Prior to transmitting a VHT MU PPDU, group assignments have been established by the AP for DL-MU-MIMO capable STAs using the Group ID Management frame as defined in 9.6.23.3.

After the PHY is configured using the PHYCONFIG_VECTOR parameter GROUP_ID_MANAGEMENT, the following lookup tables are populated:

- a) Group ID to Membership Status, denoted by MembershipStatusInGroupID[g] for $1 \leq g \leq 62$
- b) Group ID to User Position, denoted by UserPositionInGroupID[g] for $1 \leq g \leq 62$

When a STA receives a VHT MU PPDU where the Group ID field in VHT-SIG-A has the value k and where MembershipStatusInGroupID[k] is equal to 1, then the number of space-time streams for that STA is indicated in the MU[UserPositionInGroupID[k]] NSTS field in VHT-SIG-A. The space-time streams of different users are ordered in accordance to user position values, i.e., the space-time streams for the user in user position 0 come first, followed by the space-time streams for the user in position 1, followed by the space-time streams for the user in position 2, and followed by the space-time streams for the user in position 3.

A STA is also able to identify the space-time streams intended for other STAs that act as interference. VHT-LTF symbols in the VHT MU PPDU are used to measure the channel for the space-time streams intended for the STA and can also be used to measure the channel for the interfering space-time streams. To successfully demodulate the space-time streams intended for the STA, the STA may use the channel state information for all space-time streams to reduce the effect of interfering space-time streams.

If a STA finds that it is not a member of the group, or the STA is a member of the group but the corresponding MU NSTS field in VHT-SIG-A indicates that there are zero space-time streams for the STA in the PPDU, then the STA may elect to not process the remainder of the PPDU.

21.3.12 VHT preamble format for sounding PPDUs

NDP is the only VHT sounding format.

The format of a VHT NDP PPDU is shown in Figure 21-28.

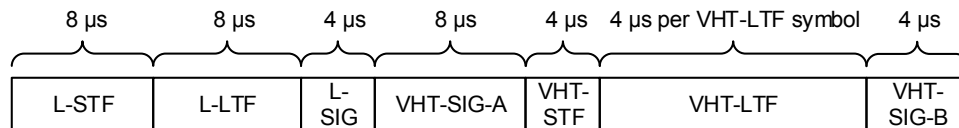


Figure 21-28—VHT NDP format

NOTE—The number of VHT-LTF symbols in the NDP is determined by the SU NSTS field in VHT-SIG-A.

The VHT NDP PPDU has the following properties:

- Uses the VHT PPDU format but without the Data field.
- Is a VHT SU PPDU as indicated by the VHT-SIG-A field.
- Has the data bits of the VHT-SIG-B field set to a fixed bit pattern (see 21.3.8.3.6).

21.3.13 Regulatory requirements

Wireless LANs (WLANs) implemented in accordance with this standard are subject to equipment certification and operating requirements established by regional and national regulatory administrations. The PHY specification establishes minimum technical requirements for interoperability, based upon established regulations at the time this standard was issued. These regulations are subject to revision or may be superseded. Requirements that are subject to local geographic regulations are annotated within the PHY specification. Regulatory requirements that do not affect interoperability are not addressed in this standard. Implementers are referred to the regulatory sources in Annex D for further information. Operation in