

SYSTEM AND METHOD FOR IMPROVING CHANNEL ESTIMATION IN AN OFDM RECEIVER

Field of the Invention

This invention relates to a system and method for improving a channel estimation scheme in an Orthogonal Frequency-Division Multiplexing (OFDM) receiver when a transmitter transmits only one stream of data. In particular, the system and method utilizes the long training field (LTF) and signal symbol contained within the preamble portion of the single stream of a transmitted packet to improve the accuracy of the channel estimation at the receiver.

Summary of the Prior Art

An Orthogonal Frequency-Division Multiplexing (OFDM) scheme is a multi-carrier modulation scheme that is unaffected by multi-path interference and frequency selective fading in communication systems. The OFDM scheme achieves this robustness to interference and fading by dividing the channel bandwidth into multiple narrow band sub-channels or sub-carriers. These sub-carriers or sub-channels are then used for transmitting data in parallel resulting in a highly efficient use of the allocated spectrum. Communication systems that typically utilize OFDM schemes are wireless systems such as wireless local area networks (WLAN) or Wi-Fi networks, and/or digital audio/video broadcasting systems.

In a Wi-Fi network, data is transmitted between a transmitter and receiver via encoded data packets. These data packets are received and subsequently decoded at the receiver based on the channel estimation or channel state information (CSI) generated by the receiver. The channel estimation of the wireless channel provides the receiver with the channel properties of the wireless channel that was used to transmit the data packet from the transmitter to the receiver. The channel estimation of the wireless channel describes

how the signal deteriorated, e.g. through fading, scattering, decay, bandwidth fluctuations, delay spread, thermal noise etc., as the signal propagates from the transmitter to the receiver. Optionally, in accordance with the IEEE 802.11 n/ac WLAN standard, the obtained channel estimation of the wireless channel may be fed back to the transmitter so that the transmitter may adjust the transmission of the data packets accordingly. This optional feature is known in the art as transmit beam-forming. In summary, when an accurate estimation of the channel is obtained, this results in an accurate reconstruction of the transmitted signal at the receiver.

In order to obtain an accurate channel estimation of wireless channels in Wi-Fi networks, those skilled in the art have performed channel estimation at the receiver by analysing training fields or sequences that are transmitted from the transmitter prior to the transmission of the data. These training fields or sequences comprise patterns that are predetermined and known to the receiver. Variations of the received trainings fields or sequences that are known to the receiver are then utilized by the receiver to obtain a channel estimation of the wireless channel. For example, in a WLAN 802.11a/g system, the transmitted packet typically comprises a preamble portion and a data portion whereby the preamble portion is received first by the receiver before the data portion. The preamble portion will contain several types of fields including the training sequences or training fields that are known to the receiver. These known training sequences or training fields are then utilized by the receiver to obtain the channel estimations of the wireless channels. In this WLAN standard, as the wireless channel is expected to be static, the channel estimation is obtained once per packet from the preamble portion of the packet. The obtained channel estimation is then subsequently used to decode the data portion of the packet.

Various algorithms have been proposed to improve the channel estimations of wireless channels. In one approach, it is proposed that a Minimum Mean Square Error

(MMSE) based calculation be carried out to obtain low mean square estimation errors. This algorithm is impractical and is not sufficiently robust as this algorithm requires an assumption of the channel statistics and needs to be executed by highly complex computations. Another algorithm that has been proposed is the Least Square (LS) estimation approach. The LS estimation approach is much simpler and easier to execute as compared to the MMSE based calculations. The downside of the LS estimation approach is that it yields a much higher mean square estimation error as compared to the MMSE based algorithms. This results in a degradation of the system's performance due to the higher occurring bit error rate (BER) and packet error rate (PER).

A proposed method and apparatus for improving the LS estimation of wireless channels in OFDM systems involves determining and subsequently utilizing an LS estimate and an interpolation coefficient of each transmitting antenna. The interpolation coefficient is determined independently from the statistics of the channel and the interpolation coefficient is then multiplied by a LS estimate for each transmitting antenna to determine the channel estimate for each wireless channel. In another approach, it is proposed that for an OFDM system that is experiencing interference, improved channel estimation may be obtained by first estimating the interference present on the received training symbols. Based on the interference measured at the received training symbols, a weightage for the training symbols is then developed. The channel estimation is then obtained based on a weighted least square procedure. These techniques greatly enhance the LS estimation in an OFDM system however; the downside is that these techniques require multiple transmitter or receiver antennas rendering the system unnecessarily complex.

For the above reasons, those skilled in the art are constantly striving to come up with a system and method to obtain an improved channel estimation of the wireless channel that is sufficiently robust and may be implemented in present systems with minimal disruptions.

Summary of the Invention

The above problem is solved and an advance in the art is made by systems and methods provided by embodiments in accordance with the invention.

A first advantage of embodiments of systems and methods in accordance with the invention is that the Wi-Fi receiver is not limited to performing channel estimation calculations using only the training fields from the preamble portion of a received packet. As signal field symbols are also utilized in the channel estimation calculations, this greatly improves the accuracy of the obtained channel estimation of the wireless channel.

A second advantage of embodiments of systems and methods in accordance with the invention is that the proposed channel estimation method is compatible with the preambles of the various WLAN standards such as the 802.11a/g standard, the 802.11n HT-MF standard, 802.11n HT-GF standard and the 802.11 ac VHT standard.

According to a first aspect of the invention, a method for improving channel estimation of Orthogonal Frequency-Division Multiplexing (OFDM) signals in a Wi-Fi receiver is proposed, the method comprising the steps of receiving a preamble portion of a transmitted packet via a wireless channel, wherein the preamble portion includes a first long training field symbol and a first signal field symbol; using the first long training field symbol to obtain a first channel estimation of the wireless channel; decoding the first signal field symbol using the first channel estimation of the wireless channel to obtain a first binary pattern; using the first binary pattern to reconstruct a first new signal field symbol; dividing the first signal field symbol with the reconstructed first new signal field symbol to obtain a second channel estimation of the wireless channel; and using the obtained channel estimations of the wireless channel to generate a first improved channel estimation of the wireless channel.

With reference to the first aspect, in a first possible implementation manner of the first aspect, the first aspect further comprises the steps of obtaining a second signal field symbol from the preamble portion; decoding the second signal field symbol using the first channel estimation of the wireless channel to obtain a second binary pattern; using the second binary pattern to reconstruct a new second signal field symbol; dividing the second signal field symbol with the reconstructed new second signal field symbol to obtain a third channel estimation of the wireless channel; and using the obtained channel estimations of the wireless channel to generate a second improved channel estimation of the wireless channel

With reference to the first possible implementation manner of the first aspect, in a second possible implementation manner of the first aspect, the second possible implementation manner further comprises the steps of obtaining a second long training field symbol from the preamble portion; using the second long training field symbol to obtain a fourth channel estimation of the wireless channel; and using the obtained channel estimations of the wireless channel to generate a third improved channel estimation of the wireless channel.

With reference to the first aspect, in a third possible implementation manner of the first aspect, wherein before the using the obtained channel estimations of the wireless channel to generate the first improved channel estimation of the wireless channel, the method further comprises determining if a subcarrier amplitude of the first long training field symbol is equal to a subcarrier amplitude of the first signal field symbol; and if it is determined that the subcarrier amplitude of the first long training field symbol is not equal to a subcarrier amplitude of the first signal field symbol, normalizing amplitudes of the subcarriers of the first signal field symbol and the first long training field symbol.

With reference to the second possible implementation manner of the first aspect, in a fourth possible implementation manner of the first aspect, wherein before the using the obtained channel estimations of the wireless channel to generate the third improved channel estimation of the wireless channel, the method further comprises determining if a subcarrier amplitude of the first long training field symbol, a subcarrier amplitude of the first signal field symbol and a subcarrier amplitude of the second signal field symbol are all equal to a subcarrier amplitude of the second long training field symbol; and if it is determined that the subcarrier amplitude of the first long training field symbol, the subcarrier amplitude of the first signal field symbol and the subcarrier amplitude of the second signal field symbol are all not equal to the subcarrier amplitude of the second long training field symbol, normalizing amplitudes of the subcarriers of the first and second signal field symbols and subcarriers of the first long training field symbol.

With reference to the first aspect or the third possible implementation manner of the first aspect, in a fifth possible implementation manner of the first aspect, wherein the using the obtained channel estimations of the wireless channel to generate the first improved channel estimation for the wireless channel further comprises generating the first improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

With reference to the first possible implementation manner of the first aspect, in a sixth possible implementation manner of the first aspect, wherein the using the obtained channel estimations of the wireless channel to generate the second improved channel estimation for the wireless channel further comprises generating the second improved channel estimation of the wireless channel by weighting the obtained channel estimations,

summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights..

With reference to the second or fourth possible implementation manners of the first aspect, in a seventh possible implementation manner of the first aspect, wherein the using the obtained channel estimations of the wireless channel to generate the third improved channel estimation for the wireless channel further comprises generating the third improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

With reference to the first aspect or third possible implementation manner of the first aspect, in an eighth possible implementation manner of the first aspect, the eighth possible implementation manner further comprises using the first improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

With reference to the first or fourth possible implementation manners of the first aspect, in a ninth possible implementation manner of the first aspect, the ninth possible implementation further comprises using the second improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

With reference to the second possible implementation manner of the first aspect, in a tenth possible implementation manner of the first aspect, the tenth possible implementation manner further comprises using the third improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

With reference to the first aspect, in an eleventh possible implementation manner of the first aspect, wherein the using the first binary pattern to reconstruct the first new signal field symbol comprises encoding the first binary pattern; digitally modulating the encoded

first binary pattern; and adding pilot symbols to the digitally modulated first binary pattern to form the first new signal field symbol.

With reference to the first possible implementation manner of the first aspect, in a twelfth possible implementation manner of the first aspect, wherein the using the second binary pattern to reconstruct the second new signal field symbol comprises encoding the second binary pattern; digitally modulating the encoded second binary pattern; and adding pilot symbols to the digitally modulated second binary pattern to form the second new signal field symbol.

With reference to the second possible implementation manner of the first aspect, in a thirteenth possible implementation manner of the first aspect, wherein the using the obtained channel estimations of the wireless channel to generate the third improved channel estimation for the wireless channel further comprises determining if a difference between a legacy portion of the preamble and a high throughput portion of the preamble exceeds a threshold, wherein the legacy portion of the preamble includes the first and second signal field symbols and the first long training field symbol, and the high throughput portion includes the second long training field symbol; if the difference between the legacy portion and the high throughput portion does not exceed the threshold, using the fourth channel estimation of the wireless channel as the third improved channel estimation for the wireless channel.

With reference to the thirteenth possible implementation manner of the first aspect, in a fourteenth possible implementation manner of the first aspect, wherein the determining if the difference between the legacy portion of the preamble and the high throughput portion of the preamble exceeds the threshold comprises determining:

$$\left[\frac{\text{sum}(\text{metric}_{I(n)})}{\text{sum}(\text{metric}_{Q(n)})} \right] > \text{threshold}$$

where:

$[\text{sum}(\text{metric}_{I(n)}) / \text{sum}(\text{metric}_{Q(n)})]$ is the difference between the legacy portion of the preamble and the high throughput portion of the preamble;

threshold is any value between 1 and 4 ;

$$\text{metric}_{I(n)} = |\text{real}(\text{ChEst}_{\text{legacy}(n)} \times \text{conjugate}(\text{ChEst}_{\text{htvht}(n)}))|;$$

$$\text{metric}_{Q(n)} = |\text{imag}(\text{ChEst}_{\text{legacy}(n)} \times \text{conjugate}(\text{ChEst}_{\text{htvht}(n)}))|;$$

where:

$$\text{ChEst}_{\text{legacy}(n)} =$$

$$((W1 \times \text{ChEst}_{1\text{LTF}(n)}) + (W2 \times \text{ChEst}_{1\text{Sig}(n)}) + (W3 \times \text{ChEst}_{2\text{Sig}(n)})) / (W1 + W2 + W3);$$

$$\text{ChEst}_{\text{htvht}(n)} = \text{ChEst}_{2\text{LTF}(n)};$$

$\text{ChEst}_{1\text{LTF}(n)}$ is the first channel estimation for the n^{th} subcarrier index for the first long training field symbol;

$\text{ChEst}_{1\text{Sig}(n)}$ is the second channel estimation for the n^{th} subcarrier index for the first signal symbol field;

$\text{ChEst}_{2\text{Sig}(n)}$ is the third channel estimation for the n^{th} subcarrier index for the second signal symbol field;

$\text{ChEst}_{2\text{LTF}(n)}$ is the fourth channel estimation for the n^{th} subcarrier index for the second long training field symbol;

n is the subcarrier index; and $W1 = 2, W2 = 1, W3 = 2, W4 = 1$.

Brief Description of the Drawings

The above advantages and features in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating a block diagram of a Wi-Fi transceiver for encoding and transmitting an OFDM signal, and for receiving and decoding an OFDM signal in accordance with embodiments of the invention;

Figure 2 illustrating block diagrams of the various symbols in a transmitted packet in accordance with WLAN standards such as the 802.11a/g standard, the 802.11n HT-MF standard, 802.11n HT-GF standard and the 802.11 ac VHT standard.

Figure 3 illustrating a block diagram of a signal reconstructing module and a channel estimation module in accordance with embodiments of the invention;

Figure 4 illustrating an overall block diagram of the improved channel estimation system in accordance with embodiments of the invention;

Figure 5 illustrating a flow diagram of a process for obtaining an improved channel estimation of the OFDM signal at the Wi-Fi receiver in accordance with embodiments of the invention;

Figure 6 illustrating for a flow diagram of a process for obtaining a further improved channel estimation of the OFDM signal at the Wi-Fi receiver in accordance with embodiments of the invention;

Figure 7 illustrating a flow diagram of a process for determining whether a subcarrier weightings are to be applied to legacy subcarriers in accordance with embodiments of the invention;

Figure 8 illustrating a flow diagram of a process for generating the improved channel estimation from the individually obtained channel estimations of each symbol in accordance with embodiments of the invention;

Figure 9 illustrating a flow diagram of a process for reconstructing a binary pattern into an encoded and modulated signal in accordance with embodiments of the invention;

Figure 10 illustrating a flow diagram of a process for determining whether channel estimations obtained from legacy symbols are to be combined with channel estimations

obtained from high-throughput symbols in accordance with embodiments of the invention; and

Figure 11 illustrating a block diagram representative of processing systems providing embodiments in accordance with embodiments of the invention.

Detailed Description

This invention relates to a system and method for improving a channel estimation scheme in an Orthogonal Frequency-Division Multiplexing (OFDM) receiver when a transmitter of the system transmits only a single stream of data. In particular, the system and method utilizes a long training field (LTF) and a signal symbol contained within the preamble portion of the single stream of a transmitted packet to generate improved channel estimation at the receiver for decoding subsequent data portions of the transmitted packet.

Figure 1 illustrates a typical block diagram of the baseband processing that takes place in an OFDM transceiver in accordance with the IEEE 802.11a/g, 11n HT-MF, 11n HT-GF, or 11ac VHT WLAN standards. These standards stipulate that an allocated frequency band is divided into narrow communication channels. For example, for the IEEE 802.11a/g WLAN standards, the narrow channels, which each compose of narrow band sub-carriers, may be digitally modulated using binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16-QAM), or 64-QAM to support data rates up to 54 Mbps. As for the IEEE 802.11n/ac WLAN standards, the narrow band subcarriers may be digitally modulated using 256-QAM to support data rates up to 400 Mbps in a single transmitted stream.

In embodiments of the invention, OFDM transceiver 100 comprises of transmitter 101 for processing a binary signal that is transmitted as a data packet and receiver 102 for receiving the data packet and reversing the processing steps taken by the transmitter to

recreate the transmitted binary signal. The operation of the transmitter and receiver in transceiver 100 are described in detail below.

In transmitter 101, which is configured to transmit only one stream of data, binary signal “**Sig.**” is first encoded in encoder module 105. Encoder module 105 may encode the binary signal using a Viterbi encoder which adopts a 1/2 rate convolutional encoding algorithm which may be increased to 2/3 or 3/4 coding rate depending on the desired data rate of the system. After the binary signal has been encoded with the appropriate coding rate, the coded signal is then interleaved with an interleaving circuit provided within encoder module 105. The encoded data is then provided to mod map module 110. Mod map module 110 digitally modulates and maps the encoded binary values from encoder module 105 onto BPSK, QPSK, 16-QAM or 64-QAM constellation maps according to the desired data rate of the system. At this stage, the original signal would have been mapped from the binary type of data, e.g. {0, 1... 1, 0} to a constellation map comprising of IQ samples, e.g. {-1, +1... +j, -j}. Using add pilot module 115, pilot symbols are then added to the output from mod map module 110 to produce OFDM symbol, “**Y**”.

OFDM symbol **Y** is then converted into a time-domain signal using IFFT module 120. IFFT module 120 does this by applying an inverse fast Fourier transformation onto symbol **Y**. The output values from IFFT module 120 are then provided to MUX module 125. MUX module 125 utilizes the provided values to form the baseband discrete time samples which are then converted to analogue signals using DAC module 130. These analogue signals are then up-converted to a higher frequency band before they are amplified and transmitted as data packet 131 to a receiver via wireless channels 133.

As data packet 131 is transmitted over wireless channels 133, the transmitted data packet 131 will be altered by noise and/or distortion of the wireless channel. As a result,

when a receiver receives data packet 131, the receiver would typically receive a corrupted data packet 131 from wireless channels 133 whereby the data packet would have been mutated by channel distortion and/or noise.

The receiving and decoding of transmitted data packet 131 is carried out in receiver 102. The received data packet is first processed by ADC module 135. ADC module 135 is an analogue-to-digital converter that converts received data packet 131, which is in the radio frequency-domain, into digital samples. The digital samples are then provided to DEMUX module 140. At DEMUX module 140, the digital samples are de-multiplexed to reconstruct the received OFDM symbol in time-domain. The digital samples of the de-multiplexed signal are then provided to Fast Fourier Transform (FFT) module 145. FFT module 145 utilizes the received digital samples from DEMUX module 140 to recreate frequency domain OFDM symbol " $\mathbf{Yh}$ ", where $\mathbf{Y}$ is the OFDM symbol as generated from Add Pilot module 115 and $\mathbf{h}$ is the channel transfer function or channel estimation of wireless channel 133. It should be noted that the channel transfer function is also known as the channel state information of a wireless channel. In operation, once channel estimation $\mathbf{h}$ has been obtained by the receiver, channel estimation $\mathbf{h}$ may then be utilized to decode a data portion within a transmitted packet. The decoding of the data portion within the transmitted packet will be addressed in greater detail in the later sections below.

Frequency domain OFDM symbol $\mathbf{Yh}$ is then provided to Rem_Pilot module 150 whereby the pilot symbols are removed from symbol $\mathbf{Yh}$ in module 150. The output values from Rem_Pilot module 150 are then provided to DeMod module 155. DeMod module 155 de-modulates the "pilot-less" $\mathbf{Yh}$ symbol and converts the provided $\mathbf{Yh}$ symbol into an encoded binary signal. The encoded binary signal is then provided to decoder module 160 which in turn decodes the encoded binary signal to generate binary signal **Sig.**'.

This would mean that in an ideal situation, if data packet 131 were not distorted by wireless channels 133 and by any noise, the binary signal received would be equal to the binary signal that was transmitted, e.g. $\mathbf{Sig.} = \mathbf{Sig.}'$, and the value of channel estimation $\mathbf{h}$ would be equal to one. Unfortunately, such an ideal situation will never exist in an actual WLAN network.

In order to obtain a channel estimation $\mathbf{h}$ of wireless channel 133, training fields contained within the preamble portion of data packet 131 will first have to be analysed by the receiver. These training fields, which are transmitted as OFDM symbols, comprise patterns that are predetermined and known to the receiver.

Figure 2 illustrates exemplary packet formats as proposed by the IEEE 802.11a/g, 11n HT-MF, 11n HT-GF, or 11ac VHT WLAN standards. Of particular interest would be the individual symbols that make up the preamble portion of each standard. In particular, preamble 202a includes OFDM symbols such as Legacy Short Training Field (LSTF) 212, Legacy Long Training Field (LLTF) 214a, LLTF 214b and Legacy Signal Field (LSIG) 216 that make up the preamble portion of the IEEE 802.11a/g WLAN standard. As for preamble 202b, this preamble portion of the IEEE 802.11n HT-MF standard includes OFDM symbols such as LSTF 222, LLTF 223a, LLTF 223b, LSIG 224, High Throughput Signal Field (HTSIG) 225a, HTSIG 225b, High Throughput Short Training Field (HTSTF) 226 and High Throughput Long Training Field (HTLTF) 227. Preamble 202c of the IEEE 802.11n HT-GF standard includes OFDM symbols such as LSTF 232, HTLTF 234a, HTLTF 234b, HTSIG 236a and HTSIG 236b. As for preamble 202d of the IEEE 802.11ac VHT standard, this preamble portion includes OFDM symbols LSTF 242, LLTF 243a, LLTF 243b, LSIG 244, Very High Throughput Signal Field (VHTSIG) 245a, VHTSIG 245b, HTSTF 246 and HTLTF 247. Each of the WLAN standards will have a data field portion, i.e. data 218, 228, 238 and 248 that each contains data that is to be decoded by the receiver.

LSTF symbols such as symbols 212, 222, etc. are typically used by the receiver for synchronization and automatic gain control purposes, HTLTF symbols such as symbols 227, 234a, 234b, etc. are typically utilized to provide training sequences for the generation of channel estimation at the receiver while LLTF symbols such as 214a, 214b, 223a, 223b, etc. are typically utilized for synchronization and channel estimation calculations. HTSIG symbols such as symbols 225a, 225b, etc. are typically used to provide information for the decoding of the data contained within the data field of packet 131 and include data such as, but are not limited to, the modulation, coding rate, and number of spatial streams utilized to encode packet 131. Typically HTSIG symbols are digitally modulated with a high strength code and can very reliably be decoded at the receiver over a wide range of channel conditions. Furthermore, as HTSIG symbols are encoded using Phase-shift keying algorithms and also include a cycle redundancy check, this means that the received HTSIG symbols are almost error-free.

In the past, channel estimation of a wireless channel, such as wireless channel 133 has been restricted to use of only either the LLTF symbol or the HTLTF symbol of the preamble portion of packet 131. In accordance with embodiments of the invention, improved channel estimation is obtained by utilizing the Long Training Field symbol, such as LLTF or HTLTF, and at least one Signal Field symbol, such as LSIG or HTSIG.

Embodiment for IEEE 802.11a/g WLAN standard.

In embodiments of the invention, when the WLAN 802.11a/g standard is adopted, packet 131 having a preamble portion 202a and data portion 218 would be received by receiver 102 of transceiver 100. Hereinafter, with reference to preamble portion 202a, LLTF symbols 214a and 214b are collectively known as LLTF symbol 214. The LLTF symbol 214 will first be processed by modules 135, 140, and 145 to obtain the LLTF symbol 214 in the

frequency-domain. The LLTF symbol 214 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the LLTF symbol 214. To recap, LLTF symbol 214 is a training sequence or pattern that is known to both transmitter 101 and receiver 102. After Decoder module 160 has obtained the decoded signal of the LLTF symbol 214, module 160 then proceeds to retrieve the original training sequence of the LLTF symbol 214 from an internal database. Module 160 then divides the retrieved original training sequence with the decoded signal to obtain the channel estimation of wireless channel 133. This obtained channel estimation may be identified as $\text{ChEst}_{\text{LLTF214}}$.

Once this is done, receiver 102 then proceeds to process a Signal Field symbol in preamble 202a. The Signal Field symbol processed for this WLAN standard would be LSIG symbol 216. Similarly, LSIG symbol 216 will first be processed by modules 135, 140 and 145 to obtain the LSIG symbol 216 in the frequency domain. The LSIG symbol 216 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the LSIG symbol 216. To decode the LSIG symbol 216, the previously obtained channel estimation, $\text{ChEst}_{\text{LLTF214}}$ will be utilized by decoder module 160. Receiver 102 is also provided with reconstructing module 301 and divider module 305. These two modules are illustrated in Figure 3.

The decoded LSIG symbol 216 is then provided to reconstructing module 301. At reconstructing module 301, the decoded LSIG symbol 216 is recoded using the same type of encoding that was originally used in transmitter 101. In other words, decoded LSIG symbol 216, which comprises a binary signal, is encoded using encoder module 105, digitally modulated using Mod Map module 110 and added with pilot symbols using Add Pilot module 115. The reconstructed LSIG symbol 216 at output X of module 301 is then provided to Divider module 305. The LSIG symbol 216 in the frequency domain that was previously obtained from the output of FFT module 145 is also provided to Divider module 305. Upon

receipt of these two inputs, Divider module 305 will then proceed to compute a second channel estimation of wireless channel 133 by dividing the LSIG symbol 216 in the frequency domain (as obtained from the output of FFT module 145) with the reconstructed LSIG symbol 216 (as obtained at output X of module 301). This obtained channel estimation may then be identified as $ChEst_{LSIG216}$.

If the amplitude of the subcarriers in the LLTF symbol 214 are equal to the amplitude of the subcarriers in the LSIG symbol 216, an improved channel estimation of wireless channel 133 for the WLAN 802.11a/g standard is obtained by the following equation:

$$\text{Improved channel estimation} = \frac{(W1 \times ChEst_{LLTF214}) + (W2 \times ChEst_{LSIG216})}{W1+W2} \quad \dots (1)$$

whereby W1 is the weight to be applied to $ChEst_{LLTF214}$, W1 = 2; and W2 is the weight to be applied to $ChEst_{LSIG216}$, W2 = 1. W1 and W2 are the symbol weightings and the value of each of these weights each correspond to the respective number of symbols in the data packet, e.g. W1 = 2 because there are two LLTF symbols and W2 = 1 because there is one LSIG symbol. The calculated improved channel estimation may then be utilized by receiver 102 to decode data portion 218 of packet 131.

Embodiment for IEEE 802.11n HT-MF WLAN standard.

In embodiments of the invention, when the WLAN 802.11n HT-MF standard is adopted, packet 131 having a preamble portion 202b and data portion 228 would be received by receiver 102 of transceiver 100. Hereinafter, with reference to preamble portion 202b, LLTF symbols 223a and 223b are collectively known as LLTF symbol 223, while HTSIG symbols 225a and 225b are collectively identified as HTSIG symbol 225.

The LLTF symbol 223 will first be processed by modules 135, 140, and 145 to obtain the LLTF symbol 223 in the frequency-domain. The LLTF symbol 223 in the frequency

domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the LLTF symbol 223. After Decoder module 160 has obtained the decoded signal of the LLTF symbol 223, module 160 then proceeds to retrieve the original training sequence of the LLTF symbol 223 from an internal database. Module 160 then divides the retrieved original training sequence with the decoded signal to obtain the channel estimation of wireless channel 133. This obtained channel estimation may be identified as $\text{ChEst}_{\text{LLTF223}}$.

Once this is done, receiver 102 then proceeds to process a first Signal Field symbol from preamble 202b. The first Signal Field symbol processed for this WLAN standard would be LSIG symbol 224. Similarly, LSIG symbol 224 will first be processed by modules 135, 140 and 145 to obtain the LSIG symbol 224 in the frequency domain. The LSIG symbol 224 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the LSIG symbol 224. The previously obtained channel estimation $\text{ChEst}_{\text{LLTF223}}$ will then be utilized by decoder module 160 to decode the LSIG symbol 224.

The decoded LSIG symbol 224 is then provided to reconstructing module 301. At reconstructing module 301, the decoded LSIG symbol 224 is recoded using the same type of encoding that was originally used in transmitter 101. In other words, decoded LSIG symbol 224, which comprises a binary signal, is encoded using encoder module 105, digitally modulated using Mod Map module 110 and added with pilot symbols using Add Pilot module 115. The reconstructed LSIG symbol 224 at output X of module 301 is then provided to Divider module 305. The LSIG symbol 224 in the frequency domain that was previously obtained from the output of FFT module 145 is also provided to Divider module 305. Upon receipt of these two inputs, Divider module 305 will then proceed to compute a second channel estimation of wireless channel 133 by dividing the LSIG symbol 224 in the frequency domain (as obtained from the output of FFT module 145) with the reconstructed

LSIG symbol 224 (as obtained at output X of module 301). This obtained channel estimation may then be identified as $\text{ChEst}_{\text{LSIG224}}$.

After this is done, receiver 102 then proceeds to process a second Signal Field symbol from preamble 202b. The second Signal Field symbol processed for this WLAN standard would be HTSIG symbol 225. Similarly, HTSIG symbol 225 will first be processed by modules 135, 140 and 145 to obtain the HTSIG symbol 225 in the frequency domain. The HTSIG symbol 225 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the HTSIG symbol 225. The previously obtained channel estimation for the first training field symbol LLTF 223, which is $\text{ChEst}_{\text{LLTF223}}$, will then be utilized by decoder module 160 to decode the HTSIG symbol 225.

The decoded HTSIG symbol 225 is then provided to reconstructing module 301. At reconstructing module 301, the decoded HTSIG symbol 225 is recoded using the same type of encoding that was originally used in transmitter 101. In other words, decoded HTSIG symbol 225, which comprises a binary signal, is encoded using encoder module 105, digitally modulated using Mod Map module 110 and added with pilot symbols using Add Pilot module 115. The reconstructed HTSIG symbol 225 at output X of module 301 is then provided to Divider module 305. The HTSIG symbol 225 in the frequency domain that was previously obtained from the output of FFT module 145 is also provided to Divider module 305. Upon receipt of these two inputs, Divider module 305 will then proceed to compute a second channel estimation of wireless channel 133 by dividing the HTSIG symbol 225 in the frequency domain (as obtained from the output of FFT module 145) with the reconstructed HTSIG symbol 225 (as obtained at output X of module 301). This obtained channel estimation may then be identified as $\text{ChEst}_{\text{HTSIG225}}$.

The next step is for receiver 102 to process a second Long Training Field symbol from preamble 202b. The second Long Training Field symbol processed for this WLAN standard would be HTLTF symbol 227. Similarly, HTLTF symbol 227 will first be processed by modules 135, 140 and 145 to obtain the HTLTF symbol 227 in the frequency domain. The HTLTF symbol 227 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the HTLTF symbol 227. After Decoder module 160 has obtained the decoded signal of the HTLTF symbol 227, module 160 then proceeds to retrieve the original training sequence of the HTLTF symbol 227 from an internal database. Module 160 then divides the retrieved original training sequence with the decoded signal to obtain the channel estimation of wireless channel 133. This obtained channel estimation may be identified as $ChEst_{HTLTF227}$.

If the amplitudes of the subcarriers in the LLTF symbol 223, LSIG symbol 224 and HTSIG symbol 225 are equal to the amplitude of the subcarriers in the HTLTF symbol 227, an improved channel estimation of wireless channel 133 for the WLAN 802.11n HT-MF standard is obtained by the following equation:

Improved channel estimation =

$$\frac{(W1 \times ChEst_{LLTF223}) + (W2 \times ChEst_{LSIG224}) + (W3 \times ChEst_{HTSIG225}) + (W4 \times ChEst_{HTLTF227})}{W1 + W2 + W3 + W4} \dots (2)$$

whereby W1, W2, W3 and W4 are the symbol weightings and the value of each of these weights each correspond to the respective number of symbols in the data packet. For example, W1 is the weight to be applied to $ChEst_{LLTF223}$, W1 = 2; W2 is the weight to be applied to $ChEst_{LSIG224}$, W2 = 1, W3 is the weight to be applied to $ChEst_{HTSIG225}$, W3 = 2 and W4 is the weight to be applied to $ChEst_{HTLTF227}$, W4 = 1. The calculated improved channel estimation may then be utilized by receiver 102 to decode data portion 228 of packet 131.

Alternatively, if the amplitude of the subcarriers in the LLTF symbol 223, LSIG symbol 224 and HTSIG symbol 225 are not equal to the amplitudes of the subcarriers in the HTLTF symbol 227, the amplitudes of the subcarriers in the LLTF symbol 223, LSIG symbol 224, HTSIG symbol 225 and HTLTF symbol 227 will have to be normalized at the receiver.

In other words, if data packet 131 was transmitted with a bandwidth of 20 MHz, this means that at the transmitter side, the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 would each have 52 subcarriers while the HTLTF symbol 227 has 56 subcarriers. Therefore, prior to transmission, these symbols would have to be scaled. In particular, all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 would have been multiplied by $\sqrt{64/52}$ while the subcarrier amplitudes in the HTLTF symbol 227 would have been multiplied by $\sqrt{64/56}$. As such, at the receiver's side, to ensure that the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 are equal in power with the HTLTF symbol 227, all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 would have to be normalized. This is done by multiplying all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 by $\sqrt{52/56}$.

Alternatively, if data packet 131 was transmitted with a bandwidth of 40 MHz, this means that at the transmitter side, all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 would have been multiplied by $\sqrt{128/104}$ while the subcarrier amplitudes in the HTLTF symbol 227 would have been multiplied by $\sqrt{128/114}$. As such, at the receiver's side, in order to ensure that the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 are equal in power with the HTLTF symbol 227, all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225

would have to be normalized. This is done by multiplying all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 by $\sqrt{104/114}$.

In yet another alternative embodiment, if data packet 131 was transmitted with a bandwidth of 80 MHz, this means that at the transmitter side, all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 would have been multiplied by $\sqrt{256/208}$ while the subcarrier amplitudes in the HTLTF symbol 227 would have been multiplied by $\sqrt{256/242}$. As such, at the receiver's side, in order to ensure that the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 are equal in power to the HTLTF symbol 227, all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 would have to be normalized. This is done by multiplying all the subcarrier amplitudes in the LLTF symbol 223, LSIG symbol 224, and HTSIG symbol 225 by $\sqrt{208/242}$.

Alternatively, the improved channel estimation of wireless channel 133 for the WLAN 802.11n HT-MF standard may be obtained by applying subcarrier weightings to equation (2) above. This results in the following equation:

Improved channel estimation =

$$\frac{(s1 \times W1 \times ChEst_{LLTF223}) + (s2 \times W2 \times ChEst_{LSIG224}) + (s3 \times W3 \times ChEst_{HTSIG225}) + (s4 \times W4 \times ChEst_{HTLTF227})}{W1+W2+W3+W4}$$

... (3)

whereby,

when data packet 131 is transmitted with a 20 MHz bandwidth, s1, s2 and s3 represents a subcarrier weighting of $\sqrt{52/56}$ and s4 represents a subcarrier weighting of 1;

when data packet 131 is transmitted with a 20 MHz bandwidth, s1, s2 and s3 represents a subcarrier weighting of $\sqrt{104/114}$ and s4 represents a subcarrier weighting of 1;

when data packet 131 is transmitted with a 20 MHz bandwidth, s1, s2 and s3 represents a subcarrier weighting of $\sqrt{208/242}$ and s4 represents a subcarrier weighting of 1.

Embodiment for IEEE 802.11n HT-GF WLAN standard.

In embodiments of the invention, when the WLAN 802.11n HT-GF standard is adopted, packet 131 having a preamble portion 202c and data portion 238 would be received by receiver 102 of transceiver 100. Hereinafter, with reference to preamble portion 202c, HTLTF symbols 234a and 234b are collectively known as HTLTF symbol 234. The HTLTF symbol 234 will first be processed by modules 135, 140, and 145 to obtain the HTLTF symbol 234 in the frequency-domain. The HTLTF symbol 234 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the HTLTF symbol 234. After Decoder module 160 has obtained the decoded signal of the HTLTF symbol 234, module 160 then proceeds to retrieve the original training sequence of the HTLTF symbol 234 from an internal database. Module 160 then divides the retrieved original training sequence with the decoded signal to obtain the channel estimation of wireless channel 133. This obtained channel estimation may be identified as $\text{ChEst}_{\text{HTLTF234}}$.

Once this is done, receiver 102 then proceeds to process a Signal Field symbol in preamble 202c. The Signal Field symbol processed for this WLAN standard would be HTSIG symbol 236a and 236b which hereinafter are collectively known as HTSIG symbol 236. Similarly, HTSIG symbol 236 will first be processed by modules 135, 140 and 145 to obtain the HTSIG symbol 236 in the frequency domain. The HTSIG symbol 236 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the HTSIG symbol 236. To decode the HTSIG symbol 236, the previously obtained channel estimation, $ChEst_{HTLTF234}$ will be utilized by decoder module 160.

The decoded HTSIG symbol 236 is then provided to reconstructing module 301. At reconstructing module 301, the decoded HTSIG symbol 236 is recoded using the same type of encoding that was originally used in transmitter 101. The reconstructed HTSIG symbol 236 at output X of module 301 is then provided to Divider module 305. The HTSIG symbol 236 in the frequency domain that was previously obtained from the output of FFT module 145 is also provided to Divider module 305. Upon receipt of these two inputs, Divider module 305 will then proceed to compute a second channel estimation of wireless channel 133 by dividing the HTSIG symbol 236 in the frequency domain (as obtained from the output of FFT module 145) with the reconstructed HTSIG symbol 236 (as obtained at output X of module 301). This obtained channel estimation may then be identified as $ChEst_{HTSIG236}$.

An improved channel estimation of wireless channel 133 for the WLAN 802.11n HT-GF standard is then obtained by the following equation:

$$\text{Improved channel estimation} = \frac{(W1 \times ChEst_{HTLTF234}) + (W3 \times ChEst_{HTSIG236})}{W1+W3} \quad \dots (4)$$

whereby W1 is the weight to be applied to $ChEst_{HTLTF234}$, $W1 = 2$; and W3 is the weight to be applied to $ChEst_{HTSIG236}$, $W3 = 2$. The calculated improved channel estimation may then be utilized by receiver 102 to decode data portion 238 of packet 131.

Embodiment for IEEE 802.11ac VHT WLAN standard.

In embodiments of the invention, when the WLAN 802.11ac VHT standard is adopted, packet 131 having a preamble portion 202d and data portion 248 would be received by receiver 102 of transceiver 100. Hereinafter, with reference to preamble portion 202d, LLTF symbols 243a and 243b are collectively known as HTLTF symbol 243, while VHTSIG symbols 245a and 245b are collectively identified as VHTSIG symbol 245.

The HTLTF symbol 243 will first be processed by modules 135, 140, 145, 150, 155 and 160 to obtain a decoded signal of the HTLTF symbol 243. After Decoder module 160 has obtained the decoded signal of the HTLTF symbol 243, module 160 then proceeds to retrieve the original training sequence of the HTLTF symbol 243 from an internal database. Module 160 then divides the retrieved original training sequence with the decoded signal to obtain the channel estimation of wireless channel 133. This obtained channel estimation may be identified as $\text{ChEst}_{\text{HTLTF243}}$.

Once this is done, receiver 102 then proceeds to process a first Signal Field symbol from preamble 202d. The first Signal Field symbol processed for this WLAN standard would be LSIG symbol 244. Similarly, LSIG symbol 244 will first be processed by modules 135, 140 and 145 to obtain the LSIG symbol 244 in the frequency domain. The LSIG symbol 244 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the LSIG symbol 244. The previously obtained channel estimation $\text{ChEst}_{\text{HTLTF243}}$ will then be utilized by decoder module 160 to decode the LSIG symbol 244.

The decoded LSIG symbol 244 is then provided to reconstructing module 301. At reconstructing module 301, the decoded LSIG symbol 244 is recoded using the same type of encoding that was originally used in transmitter 101. In other words, decoded LSIG symbol 244, which comprises a binary signal, is encoded using encoder module 105, digitally

modulated using Mod Map module 110 and added with pilot symbols using Add Pilot module 115. The reconstructed LSIG symbol 244 at output X of module 301 is then provided to Divider module 305. The LSIG symbol 244 in the frequency domain that was previously obtained from the output of FFT module 145 is also provided to Divider module 305. Upon receipt of these two inputs, Divider module 305 will then proceed to compute a second channel estimation of wireless channel 133 by dividing the LSIG symbol 244 in the frequency domain (as obtained from the output of FFT module 145) with the reconstructed LSIG symbol 244 (as obtained at output X of module 301). This obtained channel estimation may then be identified as $\text{ChEst}_{\text{LSIG244}}$.

After this is done, receiver 102 then proceeds to process a second Signal Field symbol from preamble 202d. The second Signal Field symbol processed for this WLAN standard would be VHTSIG symbol 245. Similarly, VHTSIG symbol 245 will first be processed by modules 135, 140 and 145 to obtain the VHTSIG symbol 245 in the frequency domain. The VHTSIG symbol 245 in the frequency domain is then further processed by modules 150, 155 and 160 to obtain a decoded signal of the VHTSIG symbol 245. The previously obtained channel estimation for the first training field symbol LLTF 243, which is $\text{ChEst}_{\text{LLTF243}}$, will then be utilized by decoder module 160 to decode the VHTSIG symbol 245. The decoded VHTSIG symbol 245 is then provided to reconstructing module 301. At reconstructing module 301, the decoded VHTSIG symbol 245 is recoded using the same type of encoding that was originally used in transmitter 101. In other words, decoded VHTSIG symbol 245, which comprises a binary signal, is encoded using encoder module 105, digitally modulated using Mod Map module 110 and added with pilot symbols using Add Pilot module 115. The reconstructed VHTSIG symbol 245 at output X of module 301 is then provided to Divider module 305. The VHTSIG symbol 245 in the frequency domain that was previously obtained from the output of FFT module 145 is also provided to Divider module

305. Upon receipt of these two inputs, Divider module 305 will then proceed to compute a second channel estimation of wireless channel 133 by dividing the VHTSIG symbol 245 in the frequency domain (as obtained from the output of FFT module 145) with the reconstructed VHTSIG symbol 245 (as obtained at output X of module 301). This obtained channel estimation may then be identified as $ChEst_{VHTSIG245}$.

The next step is for receiver 102 to process a second Long Training Field symbol from preamble 202d. The second Long Training Field symbol processed for this WLAN standard would be HTLTF symbol 247. Similarly, HTLTF symbol 247 will first be processed by modules 135, 140, 145, 150, 155 and 160 to obtain a decoded signal of the HTLTF symbol 247. After Decoder module 160 has obtained the decoded signal of the HTLTF symbol 247, module 160 then proceeds to retrieve the known training sequence of the HTLTF symbol 247 from an internal database. Module 160 then divides the retrieved original training sequence with the decoded signal to obtain the channel estimation of wireless channel 133. This obtained channel estimation may be identified as $ChEst_{HTLTF247}$.

If the amplitudes of the subcarriers in the LLTF symbol 243, LSIG symbol 244 and VHTSIG symbol 245 are equal to the amplitude of the subcarriers in the HTLTF symbol 247, an improved channel estimation of wireless channel 133 for the WLAN 802.11ac VHT standard may then be obtained by the following equation:

Improved channel estimation =

$$\frac{(W1 \times ChEst_{LLTF243}) + (W2 \times ChEst_{LSIG244}) + (W3 \times ChEst_{VHTSIG245}) + (W4 \times ChEst_{HTLTF247})}{W1+W2+W3+W4} \dots (5)$$

whereby W1, W2, W3 and W4 are the symbol weightings wherein the value of each of these weights correspond to the respective number of symbols in the data packet. For example, W1 = 2; W2 = 1, W3 = 2 and W4 = 1. The calculated improved channel estimation may then be utilized by receiver 102 to decode data portion 248 of packet 131.

Alternatively, if the amplitude of the subcarriers in the LLTF symbol 243, LSIG symbol 244 and VHTSIG symbol 245 are not equal to the amplitudes of the subcarriers in the HTLTF symbol 247, the amplitudes of the subcarriers in the LLTF symbol 243, LSIG symbol 244, VHTSIG symbol 245 and HTLTF symbol 247 will have to be normalized at the receiver.

In other words, if data packet 131 was transmitted with a bandwidth of 20 MHz, this means that at the transmitter side, the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would each have 52 subcarriers while the HTLTF symbol 247 has 56 subcarriers. Therefore, prior to transmission, these symbols would have to be scaled. In particular, all the subcarrier amplitudes in the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would have been multiplied by $\sqrt{64/52}$ while the subcarrier amplitudes in the HTLTF symbol 247 would have been multiplied by $\sqrt{64/56}$. As such, at the receiver's side, to ensure that the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 are equal in power to the HTLTF symbol 247, all the subcarrier amplitudes in the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would have to be multiplied by $\sqrt{52/56}$.

Alternatively, if data packet 131 was transmitted with a bandwidth of 40 MHz, this means that at the transmitter side, all the subcarrier amplitudes in the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would have been multiplied by $\sqrt{128/104}$ while the subcarrier amplitudes in the HTLTF symbol 247 would have been multiplied by $\sqrt{128/114}$. As such, at the receiver's side, in order to ensure that the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 are equal in power with the HTLTF symbol 247, all the subcarrier amplitudes in the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would have to be multiplied by $\sqrt{104/114}$.

In yet another alternative embodiment, if data packet 131 was transmitted with a bandwidth of 80 MHz, this means that at the transmitter side, all the subcarrier amplitudes in the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would have been multiplied by $\sqrt{256/208}$ while the subcarrier amplitudes in the HTLTF symbol 247 would have been multiplied by $\sqrt{256/242}$. As such, at the receiver's side, in order to ensure that the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 are equal in power to the HTLTF symbol 247, all the subcarrier amplitudes in the LLTF symbol 243, LSIG symbol 244, and VHTSIG symbol 245 would have to be multiplied by $\sqrt{208/242}$.

Alternatively, the improved channel estimation of wireless channel 133 for the WLAN 802.11n HT-MF standard may be obtained by applying subcarrier weightings to equation (2) above. This results in the following equation:

Improved channel estimation =

$$\frac{(s1 \times W1 \times ChEst_{LLTF243}) + (s2 \times W2 \times ChEst_{LSIG244}) + (s3 \times W3 \times ChEst_{VHTSIG245}) + (s4 \times W4 \times ChEst_{HTLTF247})}{W1+W2+W3+W4}$$

... (3)

whereby,

when data packet 131 is transmitted with a 20 MHz bandwidth, s1, s2 and s3 represents a subcarrier weighting of $\sqrt{52/56}$ and s4 represents a subcarrier weighting of 1;

when data packet 131 is transmitted with a 40 MHz bandwidth, s1, s2 and s3 represents a subcarrier weighting of $\sqrt{104/114}$ and s4 represents a subcarrier weighting of 1;

when data packet 131 is transmitted with a 20 MHz bandwidth, s_1 , s_2 and s_3 represents a subcarrier weighting of $\sqrt{208/242}$ and s_4 represents a subcarrier weighting of 1;

In the event receiver 102 samples guard intervals (GI) of a first and a second OFDM symbol at different intervals, timing adjustments of the guard intervals or frequency adjustments of the guard intervals of the first and second OFDM symbols will have to be carried out. Figure 4 illustrates an overall block diagram of the improved channel estimation system in accordance with embodiments of the invention whereby timing adjustment module 405 will be utilized if timing adjustments of the guard intervals of the first and second OFDM symbols have to be carried out, i.e. Path A, or frequency adjustment module 410 will be utilized in place of module 405 if frequency adjustments of the guard intervals of the first and second OFDM symbols have to be carried out, i.e. Path B.

When timing adjustment of the guard intervals of the first and second OFDM symbols are to be carried out, digital samples of the de-multiplexed signals of the first and second OFDM symbols from DEMUX module 140 (see Figure 1) will be provided to timing adjustment module 405 instead of being provided directly to FFT module 145. The first OFDM symbol will then be utilized by timing adjustment module 405 as the reference symbol. Module 405 will then take part of the sampled guard interval from the second OFDM symbol and append this part to the data portion of the second OFDM symbol so that the second OFDM symbol is aligned in time with the first OFDM symbol. This type of timing adjustment may be performed on each of the LSIG, LLTF, HTSIG, VHTSIG, HTLTF and VHTLTF types of OFDM symbols using a point in the guard interval as a reference point.

Alternatively, when frequency adjustment of the guard intervals of the received OFDM symbols are to be carried out, the received OFDM symbols in the frequency domain,

as obtained from FFT module 145, will be provided to frequency adjustment module 410 instead, effectively bypassing timing adjustment module 405, i.e. Path B. The operation of frequency adjustment module 410 is as follows. First, it is assumed that the transmitter is configured to transmit data packets using a 20 MHz bandwidth. A person skilled in the art will recognize that the transmitter may be configured to transmit data packets using other bandwidths without departing from this invention. When the data packets are transmitted using the 20 MHz bandwidth, this means that the original samples that are provided to IFFT module 120 at the transmitter may be denoted as $r = r(0), r(1), r(2), \dots, r(n)$, whereby $n = 1$ to 63, i.e. a total of 64 samples. After these samples have been processed by IFFT module 120, this results in the following samples $w = w(0), w(1), w(2), \dots, w(n)$, whereby $n = 1$ to 63, i.e. a total of 64 samples. At the receiver side, after the samples have been processed by FFT module 145, this results in output y , whereby $y = \text{FFT}\{w(n)\}$ where n denotes the n^{th} sample. In order to ensure that output y is equal to r , frequency adjustment module 410 performs the following equation to obtain adjusted output y , i.e. $y_{\text{adjusted}(n)}$:

$$y_{\text{adjusted}(n)} = y(n) \times e^{\frac{j2\pi Xn}{64}}$$

whereby $n = 1$ to 63, and X is the guard interval sampling offset in the frequency domain

After the necessary adjustments have been made to the guard intervals of the OFDM symbols, the adjusted OFDM symbols are then provided to module 415 which then proceeds to carry out the steps for obtaining the channel estimations for each of the various types of received OFDM symbols as previously described above.

The obtained channel estimations for each of the received types of OFDM symbols, e.g. LLTF, HTLTF, VHTSIG, HTSIG, LSIG, are then provided to combiner module 420. Combiner module 420 is utilized to determine whether the channel estimations of these OFDM symbols may be combined or not. In particular, combiner module 420 determines

whether the channel estimations of legacy OFDM symbols such as, LLTF, LSIG, HTSIG and VHTSIG symbols may be combined with the channel estimation of HT/VHT OFDM symbols such as HTLTF and VHTSIG symbols. Combiner 420 does this by first computing a metric that represents a difference between the channel estimations of the legacy OFDM symbols and the channel estimation of the HT/VHT OFDM symbols. To compute the metric, the channel estimations of the legacy OFDM symbols are first combined. This results in the following equation:

$$ChEst_{legacy(n)} = \frac{[W1 \times ChEst_{LLTF(n)} + W2 \times ChEst_{LSIG(n)} + W3 \times ChEst_{HTSIG(n)}]}{(W1 + W2 + W3)}$$

whereby n is the subcarrier index and W1, W2, and W3 are the weightings for the respective OFDM symbols as previously described. To recap, the values of the weightings are: W1 = 2, W2 = 1; and W3 = 2.

The channel estimation for the HT/VHT OFDM symbol is then obtained using the following equation:

$$ChEst_{HTVHT(n)} = ChEst_{HTLTF(n)} \text{ or } ChEst_{VHTSIG(n)}$$

Separate real and imaginary parts of the metric are then computed as follows:

$$metric_{I(n)} = |real[ChEst_{legacy(n)} \times conjugate(ChEst_{HTVHT(n)})]|$$

$$metric_{Q(n)} = |imag[ChEst_{legacy(n)} \times conjugate(ChEst_{HTVHT(n)})]|$$

The metric that represents a difference between the channel estimations of the legacy OFDM symbols and the channel estimation of the HT/VHT OFDM symbols may then be obtained as the ratio between an accumulation of $metric_{I(n)}$ and an accumulation of $metric_{Q(n)}$ as:

$$metric = \frac{sum(metric_{I(n)})}{sum(metric_{Q(n)})}$$

Combiner 420 then determines whether the value of the obtained metric > threshold, whereby in embodiments of the invention, the value of threshold is typically in the range: $1 < \text{threshold} \leq 4$.

If combiner 420 determines that the obtained metric does not exceed the threshold, combiner 420 will only utilize the channel estimation of the HT/VHT OFDM symbol as the overall channel estimation of the receiver and the obtained channel estimations for the legacy OFDM symbols will be disregarded. This output is then provided to the next part of the receiver, i.e. via path C, and the channel estimation of the HT/VHT OFDM will be used to decode the data portion of the packet.

Conversely, if combiner 420 determines that the obtained metric exceeds the threshold, combiner 420 will provide all the obtained channel estimations to improved channel estimation generator module 425. Module 425 will then utilize the channel estimations of the legacy OFDM symbols and the HT/VHT OFDM symbol to compute the improved channel estimation of the receiver. This may be done using any one of equations (2), (3), (5) or (6). This calculated improved channel estimation will then be used to decode the data portion of the packet.

In accordance with an embodiment of the invention, a method for improving channel estimation for Orthogonal Frequency-Division Multiplexing (OFDM) signals in a Wi-Fi receiver is provided, whereby the method comprises the following six steps:

Step 1, receiving a preamble portion of a transmitted packet via a wireless channel, wherein the preamble portion includes a first long training field symbol and a first signal field symbol;

Step 2, using the first long training field symbol to obtain a first channel estimation of the wireless channel;

Step 3, decoding the first signal field symbol using the first channel estimation of the wireless channel to obtain a first binary pattern;

Step 4, using the first binary pattern to reconstruct a first new signal field symbol;

Step 5, dividing the first signal field symbol with the reconstructed first new signal field symbol to obtain a second channel estimation of the wireless channel; and

Step 6, using the obtained channel estimations of the wireless channel to generate a first improved channel estimation of the wireless channel.

In order to provide such a system or method, a process is needed for improving channel estimation for Orthogonal Frequency-Division Multiplexing (OFDM) signals in a Wi-Fi receiver. The following description and Figures 5-10 describe embodiments of processes that provide processes in accordance with this invention.

Figure 5 illustrates process 500 that is performed by a computer system to improve channel estimation for Orthogonal Frequency-Division Multiplexing (OFDM) signals in a Wi-Fi receiver in accordance with embodiments of this invention. Process 500 begins in step 505 whereby process 500 retrieves a preamble portion from a transmitted packet that is received by the receiver. The first long training field in the preamble portion is then selected from the preamble portion and a first channel estimation for the first long training field is then calculated at step 510. Process 500 then proceeds to retrieve a first signal symbol from the preamble portion at step 515. At this step, process 500 then proceeds to decode the first signal symbol using the first channel estimation to obtain a first binary pattern of the first signal symbol. Process 500 then proceeds to reconstruct a new first signal symbol using the

obtained first binary pattern. This takes place at step 520. After the new first signal symbol has been reconstructed, process 500 then proceeds to step 525. At step 525, a second channel estimation is obtained by dividing the first signal symbol with the new first signal symbol. The obtained channel estimations comprising the first and the second channel estimations are then utilized by process 500 to generate a first improved channel estimation. This occurs at step 530. Process 500 then ends.

Figure 6 illustrates process 600 that is performed by a computer system to obtain a second improved channel estimation in accordance with embodiments of the invention. Process 600 begins at step 605 whereby process 600 retrieves a second signal symbol from the preamble portion of the transmitted packet that was received at the receiver. At step 610, process 600 then proceeds to decode the second signal symbol using the first channel estimation (as previously calculated by process 500 in step 510) to obtain a second binary pattern of the second signal symbol. Process 600 then proceeds to reconstruct a new second signal symbol using the obtained second binary pattern. This takes place at step 615. After the new second signal symbol has been reconstructed, process 600 then proceeds to step 620. At step 620, a third channel estimation is obtained by dividing the second signal symbol with the new second signal symbol. The obtained channel estimations comprising the first, second and the third channel estimations are then utilized by process 600 to generate a second improved channel estimation. This occurs at step 625. Process 600 then ends.

Figure 7 illustrates process 700 that is performed by a computer system to determine if a subcarrier weightage is to be applied to the legacy OFDM symbols in the preamble portion of the packet. Process 700 begins at step 705 with process 700 selecting a subcarrier amplitude of a legacy OFDM symbol, i.e. from LLTF, HTSIG, or LSIG. Process 700 then proceeds to select a subcarrier amplitude of a HT/VHT OFDM symbol, i.e. from

VHTSIG or HTLTF. This takes place at step 710. Process 700 then determines at step 715 whether the amplitudes of the subcarriers of the legacy OFDM symbols are equal to the amplitude of the subcarriers in the HT/VHT OFDM symbol. If the amplitudes are equal, process 700 then ends. Alternatively, if the amplitudes are determined by process 700 to be different, process 700 proceeds to step 720 instead. At step 720, the channel estimations of the legacy OFDM symbols are all multiplied with subcarrier weightings. . Process 700 then ends.

Figure 8 illustrates process 800 that is performed by a computer system generate an improved channel estimation using the individual obtained channel estimations. Process 800 begins at step 805. At this step, each individually obtained channel estimation is multiplied with its corresponding weight. For example, for the channel estimation obtained for a LLTF symbol, this channel estimation is multiplied with a weightage of 2; for the channel estimation obtained for a LSIG symbol, this channel estimation is multiplied with a weightage of 1; for the channel estimation obtained for a HTSIG symbol, this channel estimation is multiplied with a weightage of 2; for the channel estimation obtained for a VHTSIG symbol, this channel estimation is multiplied with a weightage of 2; and for the channel estimation obtained for a HTLTF symbol, this channel estimation is multiplied with a weightage of 1. Process 800 then proceeds to sum all the weighted channel estimations at step 810. The improved channel estimation is then calculated at step 815 whereby process 800 divides the sum of the weighted channel estimations with the sum of the weights. Process 800 then ends.

Figure 9 illustrates process 900 that is performed by a computer system to reconstruct a new signal symbol from an obtained binary pattern. Process 900 begins at step 905 whereby the binary pattern is encoded using the same encoder or encoding algorithm that was used at the transmitter. Process 900 then proceeds to step 910 whereby

the encoded binary pattern is digitally modulated using the same modulation algorithm as that used at the transmitter side. At step 915, process 900 then adds pilot symbols to the modulated pattern to produce the reconstructed new signal symbol. Process 900 then ends.

Figure 10 illustrates process 1000 that is performed by a computer system to determine whether the individually obtained channel estimations are to be combined to generate an improved channel estimation. Process 1000 begins at step 1005 with process 1000 retrieving the individually obtained channel estimations. A metric which represents the difference between a legacy portion of the preamble, i.e. legacy OFDM symbols, and a HT/VHT portion of the preamble, i.e. HT/VHT OFDM symbols is then calculated. At step 1010, process 1000 determines whether the metric exceeds a predetermined threshold. If the metric does not exceed this threshold, process 1000 proceeds to step 1015. At step 1015, process 1000 will set the obtained channel estimation for the HT portion as the improved channel estimation of the receiver. Process 1000 then ends. With regard to step 1010, if process 1000 determines at this step that the metric exceeds the threshold, process 1010 then progresses to step 1020. At step 1020, process 1000 will then proceed to obtain the improved channel estimation using the individually obtained channel estimations as described by process 800.

Processes provided by instructions stored in a non-transitory computer-readable media are executed by a processing unit in a computer system. For the avoidance of doubt, non-transitory computer-readable media shall be taken to comprise all computer-readable media except for a transitory, propagating signal. A computer system may be provided in one or more mobile devices and/or transceivers to provide this invention. The instructions may be stored as firmware, hardware, or software. Figure 11 illustrates an example of such a processing system. Processing system 1100 may be the processing system in the mobile devices and/or servers that execute the instructions to perform the processes for providing a

method and/or system in accordance with embodiments of this invention. One skilled in the art will recognize that the exact configuration of each processing system may be different and the exact configuration of the processing system in each mobile device may vary and Figure 11 is given by way of example only.

Processing system 1100 includes Central Processing Unit (CPU) 1105. CPU 1105 is a processor, microprocessor, or any combination of processors and microprocessors that execute instructions to perform the processes in accordance with the present invention. CPU 1105 connects to memory bus 1110 and Input/ Output (I/O) bus 1115. Memory bus 1110 connects CPU 1205 to memories 1120 and 1125 to transmit data and instructions between memories 1120, 1125 and CPU 1105. I/O bus 1115 connects CPU 1105 to peripheral devices to transmit data between CPU 1105 and the peripheral devices. One skilled in the art will recognize that I/O bus 1115 and memory bus 1110 may be combined into one bus or subdivided into many other busses and the exact configuration is left to those skilled in the art.

A non-volatile memory 1120, such as a Read Only Memory (ROM), is connected to memory bus 1110. Non-volatile memory 1120 stores instructions and data needed to operate various sub-systems of processing system 1100 and to boot the system at start-up. One skilled in the art will recognize that any number of types of memory may be used to perform this function.

A volatile memory 1125, such as Random Access Memory (RAM), is also connected to memory bus 1110. Volatile memory 1125 stores the instructions and data needed by CPU 1105 to perform software instructions for processes such as the processes required for providing a system in accordance with embodiments of this invention. One skilled in the art

will recognize that any number of types of memory may be used as volatile memory and the exact type used is left as a design choice to those skilled in the art.

I/O device 1130, keyboard 1135, display 1140, memory 1145, network device 1150 and any number of other peripheral devices connect to I/O bus 1115 to exchange data with CPU 1105 for use in applications being executed by CPU 1105. I/O device 1130 is any device that transmits and/or receives data from CPU 1105. Keyboard 1135 is a specific type of I/O that receives user input and transmits the input to CPU 1105. Display 1140 receives display data from CPU 1105 and display images on a screen for a user to see. Memory 1145 is a device that transmits and receives data to and from CPU 1105 for storing data to a media. Network device 1150 connects CPU 1105 to a network for transmission of data to and from other processing systems.

The above is a description of embodiments of a system and process in accordance with the present invention as set forth in the following claims. It is envisioned that others may and will design alternatives that fall within the scope of the following claims.

CLAIMS:

1. A method for improving channel estimation for Orthogonal Frequency-Division Multiplexing (OFDM) signals in a Wi-Fi receiver, the method comprising:

receiving a preamble portion of a transmitted packet via a wireless channel, wherein the preamble portion includes a first long training field symbol and a first signal field symbol;

using the first long training field symbol to obtain a first channel estimation of the wireless channel;

decoding the first signal field symbol using the first channel estimation of the wireless channel to obtain a first binary pattern;

using the first binary pattern to reconstruct a first new signal field symbol;

dividing the first signal field symbol with the reconstructed first new signal field symbol to obtain a second channel estimation of the wireless channel; and

using the obtained channel estimations of the wireless channel to generate a first improved channel estimation of the wireless channel.

2. The method according to claim 1 further comprising:

obtaining a second signal field symbol from the preamble portion;

decoding the second signal field symbol using the first channel estimation of the wireless channel to obtain a second binary pattern;

using the second binary pattern to reconstruct a new second signal field symbol;

dividing the second signal field symbol with the reconstructed new second signal field symbol to obtain a third channel estimation of the wireless channel; and

using the obtained channel estimations of the wireless channel to generate a second improved channel estimation of the wireless channel.

3. The method according to claim 2 further comprising:

obtaining a second long training field symbol from the preamble portion;

using the second long training field symbol to obtain a fourth channel estimation of the wireless channel; and

using the obtained channel estimations of the wireless channel to generate a third improved channel estimation of the wireless channel.

4. The method according to claim 1 wherein before the using the obtained channel estimations of the wireless channel to generate the first improved channel estimation of the wireless channel, the method further comprises:

determining if a subcarrier amplitude of the first long training field symbol is equal to a subcarrier amplitude of the first signal field symbol; and

if it is determined that the subcarrier amplitude of the first long training field symbol is not equal to a subcarrier amplitude of the first signal field symbol, normalizing amplitudes of the subcarriers of the first signal field symbol and the first long training field symbol.

5. The method according to claim 3 wherein before the using the obtained channel estimations of the wireless channel to generate the third improved channel estimation of the wireless channel, the method further comprises:

determining if a subcarrier amplitude of the first long training field symbol, a subcarrier amplitude of the first signal field symbol and a subcarrier amplitude of the second signal field symbol are all equal to a subcarrier amplitude of the second long training field symbol; and

if it is determined that the subcarrier amplitude of the first long training field symbol, the subcarrier amplitude of the first signal field symbol and the subcarrier amplitude of the second signal field symbol are all not equal to the subcarrier amplitude of the second long

training field symbol, normalizing amplitudes of the subcarriers of the first and second signal field symbols and subcarriers of the first long training field symbol.

6. The method according to any one of claims 1 or 4 wherein the using the obtained channel estimations of the wireless channel to generate the first improved channel estimation for the wireless channel further comprises:

generating the first improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

7. The method according to claim 2 wherein the using the obtained channel estimations of the wireless channel to generate the second improved channel estimation for the wireless channel further comprises:

generating the second improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

8. The method according to any one of claims 3 or 5 wherein the using the obtained channel estimations of the wireless channel to generate the third improved channel estimation for the wireless channel further comprises:

generating the third improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

9. The method according to any one of claims 1 or 4 further comprising:

using the first improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

10. The method according to any one of claims 2 or 5 further comprising:

using the second improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

11. The method according to claim 3 further comprising:

using the third improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

12. The method according to claim 1 wherein the using the first binary pattern to reconstruct

the first new signal field symbol comprises:

encoding the first binary pattern;

digitally modulating the encoded first binary pattern; and

adding pilot symbols to the digitally modulated first binary pattern to form the first new signal field symbol.

13. The method according to claim 2 wherein the using the second binary pattern to reconstruct the second new signal field symbol comprises:

encoding the second binary pattern;

digitally modulating the encoded second binary pattern; and

adding pilot symbols to the digitally modulated second binary pattern to form the second new signal field symbol.

14. The method according to claim 3 wherein the using the obtained channel estimations of the wireless channel to generate the third improved channel estimation for the wireless channel further comprises:

determining if a difference between a legacy portion of the preamble and a high throughput portion of the preamble exceeds a threshold, wherein the legacy portion of the preamble includes the first and second signal field symbols and the first long training field symbol, and the high throughput portion includes the second long training field symbol;

if the difference between the legacy portion and the high throughput portion does not exceed the threshold, using the fourth channel estimation of the wireless channel as the third improved channel estimation for the wireless channel.

15. The method according to claim 14 wherein the determining if the difference between the legacy portion of the preamble and the high throughput portion of the preamble exceeds the threshold comprises determining:

$$\left[\frac{\text{sum}(\text{metric}_{I(n)})}{\text{sum}(\text{metric}_{Q(n)})} \right] > \text{threshold}$$

where:

$[\text{sum}(\text{metric}_{I(n)}) / \text{sum}(\text{metric}_{Q(n)})]$ is the difference between the legacy portion of the preamble and the high throughput portion of the preamble;

threshold is any value between 1 and 4 ;

$$\text{metric}_{I(n)} = |\text{real}(\text{ChEst}_{\text{legacy}(n)} \times \text{conjugate}(\text{ChEst}_{\text{htvht}(n)}))|;$$

$$\text{metric}_{Q(n)} = |\text{imag}(\text{ChEst}_{\text{legacy}(n)} \times \text{conjugate}(\text{ChEst}_{\text{htvht}(n)}))|;$$

where:

$$\text{ChEst}_{\text{legacy}(n)} =$$

$$((W1 \times \text{ChEst}_{1\text{LTF}(n)}) + (W2 \times \text{ChEst}_{1\text{Sig}(n)}) + (W3 \times \text{ChEst}_{2\text{Sig}(n)})) / (W1 + W2 + W3);$$

$$ChEst_{htvht(n)} = ChEst_{2LTF(n)};$$

$ChEst_{1LTF(n)}$ is the first channel estimation for the n^{th} subcarrier index for the first long training field symbol;

$ChEst_{1Sig(n)}$ is the second channel estimation for the n^{th} subcarrier index for the first signal symbol field;

$ChEst_{2Sig(n)}$ is the third channel estimation for the n^{th} subcarrier index for the second signal symbol field;

$ChEst_{2LTF(n)}$ is the fourth channel estimation for the n^{th} subcarrier index for the second long training field symbol;

n is the subcarrier index; and

$$W1 = 2, W2 = 1, W3 = 2, W4 = 1.$$

16. A system for improving channel estimation for Orthogonal Frequency-Division Multiplexing (OFDM) signals in a Wi-Fi receiver, the system comprising:

a processing unit; and

a non-transitory media readable by the processing unit, the media storing instructions that when executed by the processing unit, cause the processing unit to:

receive a preamble portion of a transmitted packet via a wireless channel, wherein the preamble portion includes a first long training field symbol and a first signal field symbol;

use the first long training field symbol to obtain a first channel estimation of the wireless channel;

decode the first signal field symbol using the first channel estimation of the wireless channel to obtain a first binary pattern;

use the first binary pattern to reconstruct a first new signal field symbol;

divide the first signal field symbol with the reconstructed first new signal field symbol to obtain a second channel estimation of the wireless channel; and

use the obtained channel estimations of the wireless channel to generate a first improved channel estimation of the wireless channel.

17. The system according to claim 16 further comprising:

instructions for directing the processing unit to:

obtain a second signal field symbol from the preamble portion;

decode the second signal field symbol using the first channel estimation of the wireless channel to obtain a second binary pattern;

use the second binary pattern to reconstruct a new second signal field symbol;

divide the second signal field symbol with the reconstructed new second signal field symbol to obtain a third channel estimation of the wireless channel; and

use the obtained channel estimations of the wireless channel to generate a second improved channel estimation of the wireless channel.

18. The system according to claim 17 further comprising:

instructions for directing the processing unit to:

obtain a second long training field symbol from the preamble portion;

use the second long training field symbol to obtain a fourth channel estimation of the wireless channel; and

use the obtained channel estimations of the wireless channel to generate a third improved channel estimation of the wireless channel.

19. The system according to claim 16 wherein before the using the obtained channel estimations of the wireless channel to generate the first improved channel estimation of the wireless channel, the system further comprises:

instructions for directing the processing unit to:

determine if a subcarrier amplitude of the first long training field symbol is equal to a subcarrier amplitude of the first signal field symbol; and

if it is determined that the subcarrier amplitude of the first long training field symbol is not equal to a subcarrier amplitude of the first signal field symbol, normalize amplitudes of the subcarriers of the first signal field symbol and the first long training field symbol.

20. The system according to claim 18 wherein before the instructions to use the obtained channel estimations of the wireless channel to generate the third improved channel estimation of the wireless channel, the system further comprises:

instructions for directing the processing unit to:

determine if a subcarrier amplitude of the first long training field symbol, a subcarrier amplitude of the first signal field symbol and a subcarrier amplitude of the second signal field symbol are all equal to a subcarrier amplitude of the second long training field symbol; and

if it is determined that the subcarrier amplitude of the first long training field symbol, the subcarrier amplitude of the first signal field symbol and the subcarrier amplitude of the second signal field symbol are all not equal to the subcarrier amplitude of the second long training field symbol, normalize amplitudes of the subcarriers of the first and second signal field symbols and subcarriers of the first long training field symbol.

21. The system according to any one of claims 16 or 19 wherein the instructions to use the obtained channel estimations of the wireless channel to generate the first improved channel estimation for the wireless channel further comprises:

instructions for directing the processing unit to:

generate the first improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

22. The system according to claim 17 wherein the instructions to use the obtained channel estimations of the wireless channel to generate the second improved channel estimation for the wireless channel further comprises:

instructions for directing the processing unit to:

generate the second improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

23. The system according to any one of claims 18 or 20 wherein the instructions to use the obtained channel estimations of the wireless channel to generate the third improved channel estimation for the wireless channel further comprises:

instructions for directing the processing unit to:

generate the third improved channel estimation of the wireless channel by weighting the obtained channel estimations, summing the weighted channel estimations and dividing the summed weighted channel estimations with a sum of the weights.

24. The system according to any one of claims 16 or 20 further comprising:

instructions for directing the processing unit to:

use the first improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

25. The system according to any one of claims 17 or 20 further comprising:

instructions for directing the processing unit to:

use the second improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

26. The system according to claim 18 further comprising:

instructions for directing the processing unit to:

use the third improved channel estimation of the wireless channel to decode a data portion of the transmitted packet.

27. The system according to claim 16 wherein the instructions to use the first binary pattern to reconstruct the first new signal field symbol comprises:

instructions for directing the processing unit to:

encode the first binary pattern;

digitally modulate the encoded first binary pattern; and

add pilot symbols to the digitally modulated first binary pattern to form the first new signal field symbol.

28. The system according to claim 17 wherein the instructions to use the second binary pattern to reconstruct the second new signal field symbol comprises:

instructions for directing the processing unit to:

encode the second binary pattern;

digitally modulate the encoded second binary pattern; and

add pilot symbols to the digitally modulated second binary pattern to form the second new signal field symbol.

29. The system according to claim 18 wherein the instructions to use the obtained channel estimations of the wireless channel to generate the third improved channel estimation for the wireless channel further comprises:

instructions for directing the processing unit to:

determine if a difference between a legacy portion of the preamble and a high throughput portion of the preamble exceeds a threshold, wherein the legacy portion of the preamble includes the first and second signal field symbols and the first long training field symbol, and the high throughput portion includes the second long training field symbol; and

if the difference between the legacy portion and the high throughput portion does not exceed the threshold, use the fourth channel estimation of the wireless channel as the third improved channel estimation for the wireless channel.

30. The system according to claim 29 wherein the instructions to determine if the difference between the legacy portion of the preamble and the high throughput portion of the preamble exceeds the threshold comprises determining:

$$\left[\frac{\text{sum}(\text{metric}_{I(n)})}{\text{sum}(\text{metric}_{Q(n)})} \right] > \text{threshold}$$

where:

$[\text{sum}(\text{metric}_{I(n)}) / \text{sum}(\text{metric}_{Q(n)})]$ is the difference between the legacy portion of the preamble and the high throughput portion of the preamble;

threshold is any value between 1 and 4 ;

$$metric_{I(n)} = |real(ChEst_{legacy(n)} \times conjugate(ChEst_{htvht(n)})|;$$

$$metric_{Q(n)} = |imag(ChEst_{legacy(n)} \times conjugate(ChEst_{htvht(n)})|;$$

where:

$$ChEst_{legacy(n)} =$$

$$((W1 \times ChEst_{1LTF(n)}) + (W2 \times ChEst_{1Sig(n)}) + (W3 \times ChEst_{2Sig(n)})) / (W1 + W2 + W3);$$

$$ChEst_{htvht(n)} = ChEst_{2LTF(n)};$$

$ChEst_{1LTF(n)}$ is the first channel estimation for the n^{th} subcarrier index for the first long training field symbol;

$ChEst_{1Sig(n)}$ is the second channel estimation for the n^{th} subcarrier index for the first signal symbol field;

$ChEst_{2Sig(n)}$ is the third channel estimation for the n^{th} subcarrier index for the second signal symbol field;

$ChEst_{2LTF(n)}$ is the fourth channel estimation for the n^{th} subcarrier index for the second long training field symbol;

n is the subcarrier index; and

$$W1 = 2, W2 = 1, W3 = 2, W4 = 1.$$