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(54) Title: METHOD AND APPARATUS OF TRANSMITTING TRAINING SIGNAL IN WIRELESS LOCAL AREA NET-
WORK SYSTEM

[Fig. 10]
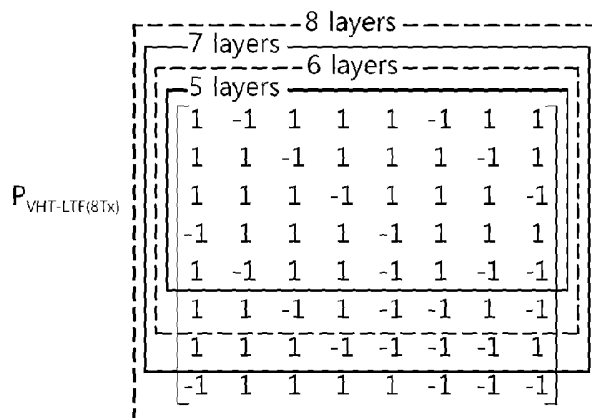
(57) Abstract: A method of transmitting a training signal in a Wireless Local Area Network (WLAN) system includes generating
one or more first training signals for a first destination station and one or more second training signals for a second destination sta-
tion by applying a mapping matrix P to a training signal generation sequence, mapping the first training signals and the second
training signals to a plurality of antennas according to an antenna mapping matrix, and performing Inverse Fast Fourier Transform
(IFFT) on each of the first training signals and the second training signals mapped to the plurality of antennas and transmitting the
training signals through the plurality of antennas.

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Description

Title of Invention: METHOD AND APPARATUS OF TRANSMITTING TRAINING SIGNAL IN WIRELESS LOCAL AREA NETWORK SYSTEM

Technical Field

[0001]   The present invention relates to wireless communication, and more particularly, to a method and apparatus for transmitting a training signal in a Wireless Local Area Network (WLAN) system.

Background Art

[0002]   With the recent development of information communication technology, a variety of wireless communication techniques are being developed. From among them, a WLAN is a technique which enables wireless access to the Internet at homes or companies or in specific service providing areas through mobile terminals, such as a Personal Digital Assistant (PDA), a laptop computer, and a Portable Multimedia Player (PMP), on the basis of radio frequency technology.

[0003]   Since and Electronics Engineers (IEEE) 802 (i.e., the standard organization of WLAN technology) was set up on February, 1980, lots of standardization tasks are being performed.

[0004]   The initial WLAN technology was able to support the bit rate of 1 to 2 Mbps through frequency hopping, band spreading, and infrared communication by using a 2.4 GHz frequency band in accordance with IEEE 802.11, but the recent WLAN technology can support a maximum bit rate of 54 Mbps by using Orthogonal Frequency Division Multiplex (OFDM). In addition, in the IEEE 802.11, the standardization of various techniques, such as the improvements of Quality of Service (QoS), the compatibility of Access Point (AP) protocols, security enhancement, radio resource measurement, wireless access vehicular environment for vehicle environments, fast roaming, a mesh network, interworking with an external network, and wireless network management, is put to practical use or being developed.

[0005]   Furthermore, as a recent technology standard for overcoming limits to the communication speed considered as vulnerabilities in the WLAN, there is IEEE 802.11n which has recently been standardized. The object of the IEEE 802.11n is to increase the speed and reliability of a network and to expand the coverage of a wireless network. More particularly, the IEEE 802.11n is based on a Multiple Inputs and Multiple Outputs (MIMO) technique using multiple antennas on both sides of a transmitter and a receiver in order to support a High Throughput (HT) having a data processing speed of 540 Mbps or higher, minimize transmission errors, and optimize

the data rate. Furthermore, the IEEE 802.11n may use not only a coding method of transmitting several redundant copies in order to increase data reliability, but also an Orthogonal Frequency Division Multiplex (OFDM) method in order to increase the data rate.

[0006]   With the spread of the WLAN being activated and applications using the WLAN becoming diverse, there is a need for a new WLAN system for supporting a higher throughput than the data processing speed supported by the IEEE 802.11n standard. A Very High Throughput (VHT) WLAN system is one of IEEE 802.11 WLAN systems recently proposed in order to support the data processing speed of 1 Gpbs, or higher. The term 'VHT WLAN system' is arbitrary, and a feasibility test for MIMO and a system using a channel bandwidth of 80 MHz or higher is in progress in order to provide the throughput of 1 Gpbs or higher.

[0007]   In order to handle an increase of the number of spatial streams that can be used to send data and to support MIMO transmission for multiple users, a method of generating and sending a training signal for the channel estimation of spatial streams between a transmission station and a reception station needs to be taken into consideration.

Summary of Invention

Technical Problem

[0008]   An object of the present invention is to provide a method of generating and sending a training signal in a WLAN system and an apparatus supporting the method.

Solution to Problem

[0009]   In an aspect of the present invention, there is provided a method of transmitting a training signal in a Wireless Local Area Network (WLAN) system, including generating one or more first training signals for a first destination station and one or more second training signals for a second destination station by applying a mapping matrix P to a training signal generation sequence; mapping the first training signals and the second training signals to a plurality of antennas according to an antenna mapping matrix; and performing Inverse Fast Fourier Transform (IFFT) on each of the first training signals and the second training signals mapped to the plurality of antennas and sending the training signals through the plurality of antennas.

[0010]   The mapping matrix $\mathbf{P}$ may be determined by Equation below.

[0011] $$\mathbf{P} = \begin{bmatrix} \mathbf{P}_{4\times4} & \mathbf{P}_{4\times4} \\ \mathbf{P}_{4\times4} & -\mathbf{P}_{4\times4} \end{bmatrix}$$

[0012]   where $\mathbf{P}_{4\times4}$ is a 4x4 orthogonal matrix.

[0013]   The $\mathbf{P}_{4\times4}$ may be equal to Equation below.

[0014]

$$\mathbf{P}_{4\times4} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$

[0015]   The first training signals may be used for the first destination station to demodulate data of the first destination station, transmitted after the first training signals are transmitted, or to estimate a channel between the first destination station and a transmission station transmitting the first training signals. The second training signals may be used for the second destination station to demodulate data of the second destination station, transmitted after the second training signals are transmitted, or to estimate a channel between the second destination station and the transmission station.

[0016]   In another aspect of the present invention, there is provided a method of transmitting a training signal in a WLAN system, including generating a plurality of training signals by applying a mapping matrix $\mathbf{P}_k$ to a training signal generation sequence and transmitting the plurality of training signals to one or more destination stations.

[0017]   The mapping matrix $\mathbf{P}_k$ may be determined by Equation below.

[0018] $$\mathbf{P}_k = \begin{bmatrix} \mathbf{P}_{k-1} & \mathbf{P}_{k-1} \\ \mathbf{P}_{k-1} & -\mathbf{P}_{k-1} \end{bmatrix}$$

[0019]   wherein is a natural number, and $\mathbf{P}_0$ is a 4x4 orthogonal matrix.

[0020]   The 4x4 orthogonal matrix $\mathbf{P}_0$ may be equal to Equation below.

[0021] $$\mathbf{P}_0 = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$

[0022]   The number of training signals may be equal to or larger than the number of spatial streams used to transmit data when the data is transmitted to the one or more destination stations after the training signals are transmitted.

[0023]   The training signal may be used for the destination station to demodulate data transmitted after the training signal is transmitted or to estimate a channel between the destination station and a transmission station transmitting the training signal.

[0024]   Transmitting the plurality of training signals to the one or more destination stations may include mapping the plurality of training signals to a plurality of antennas according to an antenna mapping matrix and performing IFFT on each of the plurality of training signals mapped to the plurality of antennas and sending the training signals through the plurality of antennas.

[0025]   The training signal generation sequence may be a predetermined value and selected according to a bandwidth of a channel used.

[0026] In yet another aspect of the present invention, there is provided a method of transmitting a training signal in a WLAN system, including generating a first training signal for a first destination station by applying a first mapping matrix to a training signal generation sequence, generating a second training signal for a second destination station by applying a second mapping matrix to the training signal generation sequence, and sending the first training signal and the second training signal to a plurality of destination stations, comprising the first destination station and the second destination station, by using Multi-User Multiple Input Multiple Output (MU-MIMO) technology.

[0027] In further yet another aspect of the present invention, there is provided a radio apparatus, including a training signal transmission unit transmitting a training signal and a training signal generation unit generating the training signal. The training signal generation unit generates one or more first training signals for a first destination station and one or more second training signals for a second destination station by applying a mapping matrix P toa training signal generation sequence. transmitting the first training signals and the second training signals to the first destination station and the second destination station is configured to map the first training signals and the second training signals to a plurality of antennas based on an antenna mapping matrix and to perform IFFT on each of the first training signals and the second training signals mapped to the plurality of antennas and tranmit the first training signals and the second training signals through the plurality of antennas.

[0028] The mapping matrix **P** may be determined by Equation below.

[0029]
$$P = \begin{bmatrix} \mathbf{P}_{4\times4} & \mathbf{P}_{4\times4} \\ \mathbf{P}_{4\times4} & -\mathbf{P}_{4\times4} \end{bmatrix}$$

[0030] where $\mathbf{P}_{4\times4}$ is a 4x4 orthogonal matrix.

[0031] The $\mathbf{P}_{4\times4}$ may be equal to Equation below.

[0032]
$$\mathbf{P}_{4\times4} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$

Advantageous Effects of Invention

[0033] There is provided a mapping matrix which can be used in a method of generating and sending a training signal in a WLAN system. Accordingly, multi-user Multiple Input Multiple Output (MU-MIMO) using a plurality of spatial streams can be supported.

Brief Description of Drawings

[0034] FIG. 1 is a diagram showing an example of a WLAN system to which an em-

bodiment of the present invention can be applied;

[0035]   FIG. 2 is a block diagram showing an HT-mixed mode PLCP format of an HT system;

[0036]   FIG. 3 schematically shows an example of a process of generating an LTF;

[0037]   FIG. 4 shows an example of an HT-LTF mapping matrix P_{HTLTF} according to the number of spatial streams;

[0038]   FIG. 5 shows an example of a PLCP frame format which may be used in a VHT system supporting MU-MIMO transmission using 8 or more spatial streams;

[0039]   FIG. 6 shows a method of generating VHT-LTFs according to an embodiment of the present invention;

[0040]   FIG. 7 shows a method of generating VHT-LTFs according to another embodiment of the present invention;

[0041]   FIG. 8 shows a method of generating VHT-LTFs according to yet another embodiment of the present invention;

[0042]   FIG. 9 shows an 8x8 VHT-LTF orthogonal mapping matrix and a method of using the same according to an embodiment of the present invention;

[0043]   FIG. 10 shows an 8x8 VHT-LTF orthogonal mapping matrix and a method of using the same according to another embodiment of the present invention;

[0044]   FIG. 11 shows an 8x8 VHT-LTF orthogonal mapping matrix and a method of using the same according to yet another embodiment of the present invention; and

[0045]   FIG. 12 is a block diagram of a radio apparatus in which embodiments of the present invention are implemented.

Mode for the Invention

[0046]   Some embodiments of the present invention are described in detail below with reference to the accompanying drawings.

[0047]   FIG. 1 is a diagram showing an example of a WLAN system to which an embodiment of the present invention can be applied.

[0048]   Referring to FIG. 1, the WLAN system includes one or more Basic Service Sets (hereinafter referred to as a 'BSS'). The BSS is a set of stations (hereinafter referred to as a 'STA') which can communicate with each other through successful synchronization. The BSS is not a concept indicating a specific area. Furthermore, as in a WLAN system to which an embodiment of the present invention can be applied, a BSS supporting ultra-high data processing of 1 GHz or higher at the MAC Service Access Point (SAP) is referred to as a VHT BSS.

[0049]   The VHT BSS can be classified into an infrastructure BSS and an Independent BSS (hereinafter referred to as an 'IBSS'). An infrastructure BSS is shown in FIG. 1. The infrastructure BSS BSS1 and BSS2 includes one or more Non-AP STAs STA 1, STA

3, and STA 4, Access Points AP 1 (STA 2) and AP 2 (STA 5) providing distribution service, and a Distribution System (hereinafter referred to as a 'DS') interconnecting the plurality of APs AP 1 and AP 2. In the infrastructure BSS, an AP STA manages the Non-AP STAs of the BSS.

[0050]   On the other hand, the IBSS (i.e., the independent BSS) is a BSS operating in the ad-hoc mode. The IBSS does not include a centralized management entity, performing a management function at the center, because it does not include an AP VHT STA. That is, in the IBSS, Non-AP STAs are managed in a distributed manner. Furthermore, in the IBSS, all STAs can be composed of mobile STAs, and they form a self-contained network because access to a DS is not permitted.

[0051]   An STA is certain function media, including a Medium Access Control (MAC) layer and a physical layer interface for a radio medium in accordance with the IEEE 802.11 standard, and it broadly includes both an AP and a Non-AP STA. Furthermore, an STA, supporting MU-MIMO transmission to be described later and ultra-high data processing of 1 GHz or higher, is referred to as a VHT STA. In a VHT WLAN system to which the embodiment of the present invention can be applied, all STAs included in the BSS may be VHT STAs or may be VHT STAs and non-VHT STAs (e.g., STAs supporting the IEEE 802.11 a/b/g/n standards) which coexist.

[0052]   An STA for wireless communication includes a processor and a transceiver and further includes a user interface, display means, etc. The processor is a function unit configured to generate a frame which will be transmitted over a wireless network or to process a frame received over the wireless network. The processor performs various functions for controlling the STA. Furthermore, the transceiver is functionally connected to the processor and configured to transmit and receive a frame over the wireless network for the STA.

[0053]   Portable terminal used by users, from among STAs, correspond to Non-AP STAs (e.g., STA1, STA3, and STA4). An STA may be simply referred as a Non-AP STA. The Non-AP STA may also be referred to as another terminology, such as a terminal, a Wireless Transmit/Receive Unit (WTRU), a User Equipment (UE), a Mobile Station (MS), a mobile terminal, or a mobile subscriber unit. Furthermore, a Non-AP STA, supporting ultra-high data processing on the basis of MU-MIMO technology to be described later, is referred to as a Non-AP VHT STA or simply a VHT STA.

[0054]   Furthermore, the APs AP1 and AP2 are function entities providing access to the DS via a radio medium for STAs (i.e., association STAs) associated therewith. In an infrastructure BSS including an AP, communication between Non-AP STAs is performed via the AP in principle. In case where a direct link is set up, communication can be directly performed between Non-AP STAs. The AP may also be referred to as a concentrated controller, a Base Station (BS), a node-B, a Base Transceiver System

(BTS), or a site controller. Furthermore, an AP, supporting ultra-high data processing on the basis of MU-MIMO technology to be described later, is referred to as a VHT AP.

[0055]   A plurality of infrastructure BSSs can be interconnected through a DS (Distribution System). The plurality of BSSs interconnected through the DS is called an Extended Service Set (ESS). STAs included in the ESS can communicate with each other. Non-AP STAs can continue to communicate with each other within the same ESS and move from one BSS to another BSS.

[0056]   A DS is a mechanism for enabling one AP to communicate with the other AP. According to the mechanism, an AP may send a frame to STAs which are managed by the AP and connected to a BSS, transfer a frame to any one STA in case where the STA has moved to another BSS, or transfer a frame over an external network, such as a wired network. The DS needs not to be necessarily a network, and it may have any type as long as it can provide predetermined distribution service regulated in the IEEE 802.11 standard. For example, the DS may be a wireless network, such as a mesh network, or a physical structure for interconnecting APs.

[0057]   In a VHT WLAN system, several STAs use the MU-MIMO technology in order to efficiently use a radio channel at the same time. In other words, several STAs are permitted to send and receive data to and from an AP at the same time. An AP may send spatially multiplexed radio frames to several STAs at the same time. To this end, the AP may measure a channel condition, perform beamforming, and send and receive data using a plurality of spatial stream.

[0058]   Hereinafter, to spatially multiplex data and send the spatially multiplexed data to a plurality of STAs is referred to as MU-MIMO transmission or SDMA transmission. In MU-MIMO transmission, at least one spatial stream is assigned to each STA which is a transmission target, and data can be sent to the STA using the assigned spatial stream.

[0059]   Hereinafter, an STA supporting the IEEE 802.11 a/b/g standards is referred to as a legacy STA and an STA supporting the IEEE 802.11n standard is referred to as an HT STA, in order to distinguish a VHT STA from the legacy STA and the HT STA. Likewise, a WLAN system supporting the IEEE 802.11 a/b/g standard is referred to as a legacy system and a WLAN system supporting the IEEE 802.11n standard is referred to as an HT system, in order to distinguish a VHT system from the legacy system and the HT system. The functions of fields, assigned the same name in a PLCP frame format described herein, are the same in the entire range of this specification, unless otherwise described.

[0060]   A PLCP frame is generated in the PLCP sublayer of an STA and transmitted to a destination STA via a PMD sublayer by using multiple antennas. Hereinafter, a PLCP

frame format and a method of sending fields constituting the PLCP frame format are only illustrative, and the sequence in which the fields are transmitted is not limited to that shown in the drawings. In the following description, the sequence in which the fields are transmitted may be changed, unless the sequence is specially described otherwise, and some of the fields may be omitted or additional fields may be added.

[0061]   FIG. 2 is a block diagram showing an HT-mixed mode PLCP format of an HT system.

[0062]   For detailed information about the HT-mixed mode PLCP format of an HT system, reference may be made to Paragraph 20.3 of IEEE 802.11n/D11.0 "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications; Amendment 5: Enhancements for Higher Throughput" disclosed on June, 2009.

[0063]   A PLCP frame is used to send a PLCP Protocol Data Unit (PPDU). The HT-mixed mode PLCP format of FIG. 2 is a PLCP format for guaranteeing the coexistence of an HT STA and a legacy STA in the HT system. To this end, the HT-mixed mode PLCP format includes a series of fields (e.g., L-STF, L-LTF, and L-SIG) for a legacy STA (so that the legacy STA can also recognize the fields).

[0064]   Elements included in the HT-mixed mode PLCP frame are listed in Table 1 below.

[0065]   [Table 1]

[0066]

Element	Description
L-STF (Non-HT Short Training Field)	Used for frame timing acquisition and Automatic Gain Control (AGC) convergence
L-LTF (Non-HT Long Training Field)	Used for channel estimation
L-SIG (Non-HT SIGNAL Field)	Including information for demodulating and decoding data for L-STA
HT-SIG (HT SIGNAL field)	Including information that an HT-STA demodulates and decodes data
HT-STF (HT Short Training Field)	Used for frame timing acquisition and AGC convergence
HT-GF-STF (HT-Green Field Short Training Field)	Used for frame timing acquisition and AGC convergence (only an HT STA can read HT-GF-STF)
HT-LTF1 (First HT Long Training Field)	Used for channel estimation
HT-LTF (HT Long Training Field)	Including data HT-LTF, used for channel estimation for data demodulation for HT-STA, and extension HT-LTF used for channel sounding
Data Field	Including PHY Service Data Unit (PSDU)

[0067]   STFs (Short Training Fields), such as L-STF, HT-STF, and HT-GF-STF, are used for frame timing acquisition, Automatic Gain Control (AGC), and so on and thus also referred to as a sync signal or a sync channel. That is, the STF is used for synchronization between STAs or between an STA and an AP.

[0068]   Long Training Fields (LTFs), such as L-LTF and HT-LTF, are used for channel es-

timation for the demodulation of data or control information or both and thus also referred to as a reference signal, a training signal, or a pilot.

[0069]   Fields, such as L-SIG and HT-SIG, are used to provide pieces of information necessary to decode data and thus also referred to as control information.

[0070]   In the HT-mixed mode PLCP format of an HT system, a Legacy Short Training Field (L-STF), a Legacy Long Training Field (L-LTF), and a Legacy Signal (L-SIG) are first transmitted. Accordingly, a legacy STA can read the PLCP format. An HT STA can know that a corresponding PLCP format is for an HT STA by acquiring control information from an HT-SIG field received after an L-SIG field.

[0071]   In the HT system, Single-User MIMO (SU-MIMO) transmission is possible. An L-STF, an L-LTF, an L-SIG, and an HT-SIG are transmitted omni-directionally according to a non-MIMO transmission scheme, and an HT-STF and data are transmitted according to a SU-MIMO transmission scheme.

[0072]   An HT-SIG includes information for interpreting an HT packet format following the HT-SIG. The HT-SIG consists of a total of 24 bits and includes the following information.

[0073]   - Modulation and Coding Scheme: 7 bits

[0074]   - Channel bandwidth 20/40 MHz: 1 bit

[0075]   - HT length: 16 bits

[0076]   - Smoothing: 1 bit

[0077]   - Not sounding: 1 bit

[0078]   - Reserved: 1 bit

[0079]   - Aggregation: 1 bit

[0080]   - STBC: 2 bits

[0081]   - FEC coding: 1 bit

[0082]   - Short GI: 1 bit

[0083]   - Number of Extension Spatial Streams: 2 bits

[0084]   - CRC: 8 bits

[0085]   - Tail bits: 6 bits

[0086]   As can be seen from Number of Extension Spatial Streams which is one of the fields constituting the HT-SIG, an HT STA supports SU-MIMO using a maximum of four spatial streams. Accordingly, there is a need for a new LTF for the channel estimation of multi spatial streams because channel estimation for each stream cannot be performed using a legacy LTF.

[0087]   An HT system defines an HT-LTF for MIMO channel estimation. An HT-LTF is used for channel estimation like an LTF described above, but differs from an L-LTF in that the HT-LTF is designed to estimate an MIMO channel.

[0088]   FIG. 3 is a diagram schematically showing an example of a process of generating an

LTF. In FIG. 3, the process of generating an HT-LTF is described as an example. However, the above process may be applied to the generation of a VHT-LTF of the present invention.

[0089] An HTLTF sequence (HTLTF$_k$) is multiplied by an HT-LTF mapping matrix P$_{HTLTF}$. The HT-LTF mapping matrix P$_{HTLTF}$ is an orthogonal mapping matrix multiplied to the HTLTF sequence such that an HT-LTF can use it to estimate a channel for an MIMO channel. The HT-LTF mapping matrix P$_{HTLTF}$ may be defined by Equation 1 below.

[0090] [Equation 1]

[0091]
$$P_{HTLTF} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$

[0092] Next, a Cyclic Shift Delay (CSD) process for preventing unwanted beamforming is performed, and the HTLTF sequence is mapped to a Transmit (Tx) antenna by means of an antenna map matrix Q$_k$ for a k subcarrier. The antenna map matrix Q$_k$ functions to map a space time stream and a transmit chain. The HTLTF sequence mapped to the transmit chain is subjected to Inverse Fast Fourier Transform (IFFT) and then transmitted through the Tx antenna.

[0093] The HTLTF sequence may be an example of a training signal generation sequence according to the present invention. The training signal generation sequence according to the present invention may be referred to as a VHTLTF sequence, but an arbitrary name. A different training signal generation sequence may be used according to a channel bandwidth used by a VHT WLAN system. In other words, a different training signal generation sequence may be used according to a channel bandwidth of 20 MHz, 40 MHz, 80 MHz, or 160 MHz. The training signal generation sequence is already known to an STA, transmitting a training signal, and an STA receiving the training signal. The receiving STA can estimate a channel and demodulate data using a training signal with reference to a training signal generation sequence which is used according to a bandwidth of the channel.

[0094] FIG. 4 shows an example of an HT-LTF mapping matrix P$_{HTLTF}$ according to the number of spatial streams.

[0095] As can be seen from the example of FIG. 4, a training symbol is defined per spatial stream and transmitted in order to estimate the channel of each spatial stream. When the number of spatial streams is 1, 2, or 4, 1, 2, or 4 HT-LTFs are transmitted. However, when the number of spatial streams is 3, one extra long training symbol is added, and four HT-LTFs are used.

[0096] In order to describe a method of estimating the channel of an HT-STA by using an

orthogonal mapping matrix, it is assumed that in an HT system, a transmitting STA sends a training symbol to a receiving STA through 2 layers. Here, the training symbol received by the receiving STA may be represented by Equation 2 below.

[0097]   [Equation 2]

[0098]

$$\begin{bmatrix} r_1(t) \\ r_2(t) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} P_1(t) \\ P_2(t) \end{bmatrix} + \begin{bmatrix} n_1(t) \\ n_2(t) \end{bmatrix} \qquad \left(\begin{array}{l} P_1(t_1) = HTLTF \\ P_1(t_2) = -HTLTF \\ P_2(t_1) = HTLTF \\ P_2(t_2) = HTLTF \end{array} \right)$$

[0099]   where h_{nm} indicates a channel between the nth antenna of a sender and the mth antenna of a receiver, $P_n(t)$ indicates a training symbol transmitted through the nth antenna of the sender, and $n_m(t)$ indicates Additive White Gaussian Noise (AWGN) experienced by the mth antenna of the receiver. Equation 2 may be represented into Equation 3 below by substituting a training symbol into Equation 2.

[0100]   [Equation 3]

[0101]

$$\begin{bmatrix} r_1(t_1) \\ r_2(t_1) \\ r_1(t_2) \\ r_2(t_2) \end{bmatrix} = \begin{bmatrix} h_{11} \times HTLTF + h_{12} \times HTLTF + n_1(t_1) \\ h_{21} \times HTLTF + h_{22} \times HTLTF + n_2(t_2) \\ -h_{11} \times HTLTF + h_{12} \times HTLTF + n_1(t_2) \\ -h_{21} \times HTLTF + h_{22} \times HTLTF + n_2(t_2) \end{bmatrix}$$

[0102]   If the channel h_{nm} is found for all n and m in Equation 3, it results in Equation 4 below.

[0103]   [Equation 4]

[0104]

$$h_{11} = \frac{r_1(t_1) - r_1(t_2)}{2 \times HTLTF}$$

$$h_{12} = \frac{r_1(t_1) + r_1(t_2)}{2 \times HTLTF}$$

$$h_{21} = \frac{r_2(t_1) - r_2(t_2)}{2 \times HTLTF}$$

$$h_{22} = \frac{r_2(t_1) + r_2(t_2)}{2 \times HTLTF}$$

[0105]   When the number of layers is 3 or 4, the channel h_{nm} can be found through the process of Equation 2 to Equation 4.

[0106]   Hereinafter, assuming that four Tx antennas and one Rx antenna exist, a channel information Signal power-to-Noise power Ratio (SNR) when a channel is estimated is found.

[0107]   Here, a signal received by the Rx antenna may be represented by Equation 5.

[0108]   [Equation 5]

[0109]

$$r(t_0) = +h_0 P + h_1 P + h_2 P - h_3 P + n(t_0)$$
$$r(t_1) = -h_0 P + h_1 P + h_2 P + h_3 P + n(t_1)$$
$$r(t_2) = +h_0 P - h_1 P + h_2 P + h_3 P + n(t_2)$$
$$r(t_3) = +h_0 P + h_1 P - h_2 P + h_3 P + n(t_3)$$

[0110]   A result of the channel estimation obtained by Equation 5 may be represented by Equation 6 below.

[0111]   [Equation 6]

[0112]
$$h'_0 = \frac{r(t_0) - r(t_1) + r(t_2) + r(t_3)}{4 \times P}$$
$$= h_0 + \frac{n(t_0) - n(t_1) + n(t_2) + n(t_3)}{4 \times P}$$

[0113]   In Equation 6, the second term on the right side indicates noise included in the received signal. From Equation 6, the SNR of a signal received by a receiving terminal can be found as in Equation 7 below.

[0114]   [Equation 7]

[0115]
$$\frac{S}{N} = \frac{E[|h_0|^2]}{E[\left|\frac{n(t_0) - n(t_1) + n(t_2) + n(t_3)}{4 \times P}\right|^2]}$$
$$= \frac{|h_0|^2}{\frac{1}{16} \times \frac{E[|n(t_0) - n(t_1) + n(t_2) + n(t_3)|^2]}{E[|P|^2]}}$$
$$= \frac{16 \times E[|P|^2] \times |h_0|^2}{E[|n(t_0) - n(t_1) + n(t_2) + n(t_3)|^2]}$$
$$= \frac{16 \times E[|P|^2] \times |h_0|^2}{4 \times \sigma^2}$$
$$= 4 \times \frac{|h_0|^2}{\sigma^2}$$

[0116]   In Equation 7, σ^2 is a noise power spectrum density. As can be seen from the expansion of the equation, a channel estimation gain of about 6 dB can be obtained from four times of LTF transmission.

[0117]   A VHT WLAN system supports MU-MIMO in addition to SU-MIMO. It is expected that a VHT system will support MIMO transmission of a minimum of 8 spatial streams. An example of a PLCP frame format which may be used in a VHT system supporting MU-MIMO transmission using 8 or more spatial streams is shown in FIG. 5.

[0118]   In FIG. 5, a VHT-Green Field Format is an example of a PLCP frame format which
           may be used in a system consisting of only VHT STAs. A VHT-Mixed Format is an
           example of a PLCP frame format which may be used in a system in which a legacy
           STA, an HT STA, and a VHT STA coexist. A VHT-Mixed Green Field Format is an
           example of a PLCP frame format which may be used in a system consisting of only an
           HT STA and a VHT STA. The names of fields constituting the PLCP frame format and
           the PLCP frame format shown in FIG. 5, the sequence in which the fields are
           transmitted, and a method of sending the fields are arbitrary. Hereinafter, the sequence
           and the method, unless specially described otherwise, are not limited to that shown in
           FIG. 5.

[0119]   The VHT-Mixed Format is different from the VHT-Green Field Format in that it
           further includes fields (e.g., an L-STF, an L-LTF, an L-SIG field, and an HT-SIG field)
           for a legacy STA and an HT STA existing in a system. Here, the fields (e.g., an L-STF,
           an L-LTF, an L-SIG field, and an HT-SIG field) for a legacy STA and an HT STA are
           transmitted without beamforming. Fields from a VHT-STF may be precoded, subjected
           to beamforming, and then transmitted.

[0120]   The VHT-Mixed Green Field Format may include an HT-GF-STF, an HT-LTF1, and
           an HT-SIG field for an HT STA.

[0121]   In the PLCP frame format of FIG. 5,the VHT-STF and the VHT-LTF for a VHT
           STA may be precoded, subjected to beamforming, and then transmitted. A PLCP
           frame format which is used in a VHT system supporting MU-MIMO using 8 or more
           spatial streams requires more transmission of a VHT-LTF and an extension VHT-LTF,
           as compared with an HT system. The VHT-LTF is used to estimate a channel and de-
           modulate data. The extension VHT-LTF is used to sound the extra spatial dimensions
           of an MIMO channel.

[0122]   The present invention proposes a method of generating VHT-LTFs for transmitting 5
           or more layers which may be used in a VHT system, an orthogonal mapping matrix
           used to generate the VHT-LTF, and a method of using the orthogonal mapping matrix.

[0123]   FIG. 6 shows the method of generating VHT-LTFs according to an embodiment of
           the present invention.

[0124]   According to the embodiment of the present invention, the orthogonal mapping
           matrix applied to the VHT-LTF may be used on an STA basis. In FIG. 6, it is assumed
           that in a VHT system, a VHT-STA0 is sought to perform MU-MIMO transmission to a
           VHT-STA1 and a VHT-STA2. It is also assumed that the VHT-STA1 and the VHT-
           STA2 (i.e., destination STAs for MU-MIMO transmission) can perform reception
           through 4 layers and 2 layers, respectively.

[0125]   The number of LTFs that should be received by the VHT-STA1 and the VHT-STA2
           may be signaled to the VHT-STA1 and the VHT-STA2 through a VHT-SIG field

transmitted prior to sending VHT-LTFs. When the transmitting STA VHT-STA0 sends a PLCP frame, the transmitting STA VHT-STA0 sends a total of 6 VHT-LTFs. The first 4 VHT-LTFs of the 6 VHT-LTFs may be received by the VHT-STA1 in order to estimate a channel. The remaining 2 VHT-LTFs of the 6 VHT-LTFs may be received by the VHT-STA2 in order to estimate a channel. An orthogonal mapping matrix 610 used to generate the VHT-LTFs for the VHT-STA1 and an orthogonal mapping matrix 620 used to generate the VHT-LTFs for the VHT-STA2 may be individually used.

[0126] For example, the HTLTF mapping matrix of an HT system in Equation 1 may be used as the orthogonal mapping matrix.

[0127] FIG. 6 shows an example in which a 4x4 HT-LTF orthogonal mapping matrix is used for the VHT-LTFs for the VHT-STA1 and a 2x2 HT-LTF orthogonal mapping matrix is used for the VHT-LTFs for the VHT-STA2.

[0128] FIG. 7 shows an example of a method of generating VHT-LTFs according to another embodiment of the present invention.

[0129] In accordance with the method of generating VHT-LTFs according to the embodiment of the present invention, VHT-LTFs may be generated and transmitted using one VHT-LTF orthogonal mapping matrix irrespective of the number of destination STAs. In other words, the VHT-LTF orthogonal mapping matrix may be configured and used according to the number of a total of layers (i.e., a required number of VHT-LTFs).

[0130] In FIG. 7, it is assumed that a source STA VHT-STA0 sends data to each of a destination STA VHT-STA1 and a destination VHT-STA2 through 3 layers. Here, the number of VHT-LTFs that should be sent to each of the VHT-STA1 and the VHT-STA2 is 4, and a total of eight times of VHT-LTF transmission is required. The method of FIG. 6 in which the VHT-LTF orthogonal mapping matrix is applied to each of destination STAs also requires eight times of VHT-LTF transmission.

[0131] The VHT-LTF orthogonal mapping matrix used to generate the eight VHT-LTFs may be configured as in the matrix 710 of FIG. 7.

[0132] A 3x4 matrix 710-1 used to generate four VHT-LTFs sent to the VHT-STA1 and a 3x4 matrix 710-2 used to generate four VHT-LTFs sent to the VHT-STA2 can be obtained by using a 3x4 HT-LTF orthogonal mapping matrix. The remaining elements of the matrix 710 other than the 3x4 matrix 710-1 and the 3x4 matrix 710-2 consist of 0.

[0133] The above method of sending the eight VHT-LTFs in a condition that the eight VHT-LTFs are sent to the destination STAs through a total of 6 layers may cause throughput loss.

[0134] In order to solve the above problem, according to another embodiment of the present invention, the VHT-LTF orthogonal mapping matrix may be used according to the

number of a total of layers. That is, the VHT-LTF orthogonal mapping matrix may be used for one layer, two layers, or four layers.

[0135]   This method can be used to prevent a reduction of transmission efficiency by reducing an unnecessary number of VHT-LTF transmissions.

[0136]   FIG. 8 shows a method of generating and sending VHT-LTFs according to yet another embodiment of the present invention.

[0137]   In case where data is sought to be sent to each of a VHT-STA1 and a VHT-STA2 through 3 layers, a total of 6 VHT-LTFs have to be generated. Here, a VHT-LTF orthogonal mapping matrix may be configured according to one layer, two layers, or 4 layers without distinguishing destination STAs to which data will be sent through the total of 6 layers.

[0138]   A VHT-LTF orthogonal mapping matrix 810 of FIG. 8 may have a 6x6 square matrix, including a 4x4 partial matrix 810-1 and a 2x2 partial matrix 810-2. The remaining elements of the VHT-LTF orthogonal mapping matrix 810 other than the 4x4 partial matrix 810-1 and the 2x2 partial matrix 810-2 consist of 0. Here, an HTLTF mapping matrix may be used as the 4x4 partial matrix 810-1, and a 2x2 HTLTF mapping matrix may be used as the 2x2 partial matrix 810-2.

[0139]   The 8 VHT-LTFs are used to send data through the total of 6 layers in the method of FIG. 7. However, if the VHT-LTF orthogonal mapping matrix of FIG. 8 is used, 6 VHT-LTFs can be used to send data through the total of 6 layers. Accordingly, a reduction of system efficiency can be prevented because two VHT-LTFs for data transmission can be reduced.

[0140]   Meanwhile, a conventional HT system is problematic in that it cannot be applied to a VHT system for supporting data transmission through at least 8 layers because it supports data transmission through a maximum of 4 layers. In other words, an 8x8 orthogonal mapping matrix that can be used in a VHT system for supporting data transmission through 5 or more layers must be taken into consideration.

[0141]   The present invention proposes an 8x8 orthogonal mapping matrix $P_{VHT\text{-}LTF(8Tx)}$ for a VHT system.

[0142]   An example of the 8x8 orthogonal mapping matrix $P_{VHT\text{-}LTF(8Tx)}$ for a VHT system, proposed by the present invention, can be obtained by using Equation 8 below.

[0143]   [Equation 8]

[0144]
$$H_{2^k} = \begin{bmatrix} H_{2^{k-1}} & H_{2^{k-1}} \\ H_{2^{k-1}} & -H_{2^{k-1}} \end{bmatrix}$$

(where =[1])

[0145]   The 8x8 VHT-LTF orthogonal mapping matrix obtained according to Equation 8 and a method of using the same are shown in FIG. 9.

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[0146] The 8x8 VHT-LTF orthogonal mapping matrix according to an embodiment of the present invention may be obtained and applied to transmission through 5, 6, 7, or 8 layers, as shown in FIG. 9. In the VHT-LTF orthogonal mapping matrix of FIG. 9, codes between the layers always maintain orthogonality. Accordingly, an STA receiving VHT-LTFs can easily obtain information about a channel to be estimated through calculation using + and - in the same manner as Equation 4. In the VHT-LTF orthogonal mapping matrix of FIG. 9, the sequence of column vectors may be randomly changed.

[0147] Another example of the 8x8 orthogonal mapping matrix $P_{VHT\text{-}LTF(8Tx)}$ for a VHT system, proposed by the present invention, can be obtained by using Equation 9 below.

[0148] [Equation 9]

[0149]
$$H_{2^k} = \begin{bmatrix} H_{2^{k-1}} & H_{2^{k-1}} \\ H_{2^{k-1}} & -H_{2^{k-1}} \end{bmatrix}$$

[0150] The matrix generation method according to Equation 9 is basically the same as that of Equation 8. Here,

$H_{2^{k-1}}$

of Equation 9 may become the LTF mapping matrix of an HT system. In other words, an 8x8 matrix, obtained by extending the HT LTF mapping matrix of Equation 1 according to Equation 9, can be used as the VHT-LTF orthogonal mapping matrix of the method of generating and sending VHT-LTFs, proposed by the present invention.

[0151] As described above, the 8x8 or 16x16 VHT-LTF orthogonal mapping matrix is obtained by using an HT system. The conventional transmission limit using a maximum of 4 layers can be overcome, and the VHT-LTF orthogonal mapping matrix that can be applied to a VHT system supporting 8 layers or more can be obtained. Furthermore, there is an advantage in terms of backward compatibility.

[0152] FIG. 10 shows the 8x8 VHT-LTF orthogonal mapping matrix described in connection with Equation 9 and a method of using the 8x8 VHT-LTF orthogonal mapping matrix for transmission through 5 to 8 layers according to another embodiment of the present invention.

[0153] For example, in case where transmission is performed through 5 layers, a partial matrix obtained by first to fifth row vectors may be used. In case where transmission is performed through 7 layers, a partial matrix obtained by first to seventh row vectors may be used. Here, the sequence of column vectors may be randomly changed.

[0154] FIG. 11 shows the 8x8 VHT-LTF orthogonal mapping matrix described in connection with Equation 9 and a method of using the 8x8 VHT-LTF orthogonal mapping matrix for transmission through 5 to 8 layers according to yet another embodiment of the present invention.

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[0155]   If the method of generating and sending a training signal using the matrix of FIG. 11 is used, 1 to 4 layers may be used according to the existing HT system method, a 5x6 or 6x6 matrix set may be used in 5 or 6 layers, and a 7x8 or 8x8 matrix set may be used in 7 or 8 layers.

[0156]   In the above method of generating and sending VHT-LTFs, in case where VHT-LTFs are sought to be transmitted through 5 or 6 layers, only 6 VHT-LTFs can be transmitted. Accordingly, there is an advantage in terms of transmission efficiency.

[0157]   In the partial matrices used according to the number of layers in FIG. 11, the sequence of column vectors may be randomly changed.

[0158]   FIG. 12 is a block diagram showing a radio apparatus in which the embodiments of the present invention are implemented. The radio apparatus 1200 may be part of the non-AP STA or the AP of a WLAN system.

[0159]   The radio apparatus 1200 includes an LTF generation unit 1210 and an LTF transmission unit 1220. The LTF generation unit 1210 generates a training signal by using the VHT-LTF orthogonal mapping matrix according to the above-described embodiments. The LTF transmission unit 1220 sends the generated training signal to one or more radio apparatuses. The generation and transmission of the training signal may be performed through multiple antennas by multiplying the training signal sequence VHTLTF$_k$ by the VHT-LTF orthogonal mapping matrix and then performing processes, such as Cyclic Shift Delay (CSD) for preventing unwanted beamforming, mapping between a space time stream and a transmit chain, and Inverse Fast Fourier Transform (IFFT). To this end, the LTF transmission unit 1220 may include multiple antennas. The LTF transmission unit 1220 may send part of or the entire training signal, generated by the LTF generation unit 1210, through a beamforming process through precoding and beamforming. Here, the beamforming process through precoding may be performed by the LTF generation unit 1210.

[0160]   The LTF generation unit 1210 and the LTF transmission unit 1220 may be implemented in a single chip in the form of a processor. The above embodiments in which the training signal is generated and sent may be configured as a software module, stored in memory, and executed by a processor.

[0161]   While the invention has been described in connection with what is presently considered to be practical exemplary embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

[0162]

Claims

[Claim 1]   A method of transmitting a training signal in a Wireless Local Area
Network (WLAN) system, the method comprising:

generating one or more first training signals for a first destination
station and one or more second training signals for a second destination
station by applying a mapping matrix P to a training signal generation
sequence;

mapping the first training signals and the second training signals to a
plurality of antennas according to an antenna mapping matrix;

performing Inverse Fast Fourier Transform (IFFT) on each of the first
training signals and the second training signals mapped to the plurality
of antennas; and

transmitting the training signals through the plurality of antennas.

[Claim 2]   The method of claim 1, wherein the mapping matrix P is determined by
Equation below.

$$\mathbf{P} = \begin{bmatrix} \mathbf{P}_{4\times4} & \mathbf{P}_{4\times4} \\ \mathbf{P}_{4\times4} & -\mathbf{P}_{4\times4} \end{bmatrix}$$

where $\mathbf{P}_{4\times4}$ is a 4x4 orthogonal matrix.

[Claim 3]   The method of claim 2, wherein the $\mathbf{P}_{4\times4}$ is equal to Equation below.

$$\mathbf{P}_{4\times4} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$

[Claim 4]   The method of claim 1, wherein:

the first training signals are used for the first destination station to de-
modulate data of the first destination station, transmitted after the first
training signals are transmitted, or to estimate a channel between the
first destination station and a transmission station transmitting the first
training signals, and

the second training signals are used for the second destination station to
demodulate data of the second destination station, transmitted after the
second training signals are transmitted, or to estimate a channel
between the second destination station and the transmission station.

[Claim 5]   A method of transmitting a training signal in a WLAN system, the
method comprising:

generating a plurality of training signals by applying a mapping matrix

$\mathbf{P}_k$ to a training signal generation sequence; and

transmitting the plurality of training signals to one or more destination stations,

wherein the mapping matrix $\mathbf{P}_k$ is determined by Equation below.

$$\mathbf{P}_k = \begin{bmatrix} \mathbf{P}_{k-1} & \mathbf{P}_{k-1} \\ \mathbf{P}_{k\ 1} & -\mathbf{P}_{k\ 1} \end{bmatrix}$$

wherein is a natural number, and $\mathbf{P}_0$ is a 4x4 orthogonal matrix.

[Claim 6]   The method of claim 5, wherein the 4x4 orthogonal matrix $\mathbf{P}_0$ is equal to Equation below.

$$\mathbf{P}_0 = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$

[Claim 7]   The method of claim 5, wherein the number of training signals is equal to or larger than the number of spatial streams used to transmit data when the data is transmitted to the one or more destination stations after the training signals are transmitted.

[Claim 8]   The method of claim 5, wherein the training signal is used for the destination station to demodulate data transmitted after the training signal is transmitted or to estimate a channel between the destination station and a transmission station transmitting the training signal.

[Claim 9]   The method of claim 5, wherein transmitting the plurality of training signals to the one or more destination stations comprises:

mapping the plurality of training signals to a plurality of antennas according to an antenna mapping matrix, and

performing IFFT on each of the plurality of training signals mapped to the plurality of antennas and sending the training signals through the plurality of antennas.

[Claim 10]   The method of claim 5, wherein the training signal generation sequence is a predetermined value and selected according to a bandwidth of a channel used.

[Claim 11]   A method of transmitting a training signal in a WLAN system, the method comprising:

generating a first training signal for a first destination station by applying a first mapping matrix to a training signal generation sequence;

generating a second training signal for a second destination station by

applying a second mapping matrix to the training signal generation sequence; and

transmitting the first training signal and the second training signal to a plurality of destination stations, comprising the first destination station and the second destination station, by using Multi-User Multiple Input Multiple Output (MU-MIMO) technology.

[Claim 12]   A radio apparatus, comprising:

a training signal generation unit configured to generate a training signal; and

a training signal transmission unit operatively connected to the training signal generation unit and configured to transmit the training signal ;

wherein the training signal generation unit is configured to:

generate one or more first training signals for a first destination station and one or more second training signals for a second destination station by applying a mapping matrix P toa training signal generation sequence,

map the first training signals and the second training signals to a plurality of antennas based on an antenna mapping matrix, and

perform IFFT on each of the first training signals and the second training signals mapped to the plurality of antennas, and

the training signal transmission unit is configured to transmit the first training signals and the second training signals through the plurality of antennas.

[Claim 13]   The radio apparatus of claim 12, wherein the mapping matrix P is de-termined byEquation below.

$$P = \begin{bmatrix} P_{4\times4} & P_{4\times4} \\ P_{4\times4} & -P_{4\times4} \end{bmatrix}$$
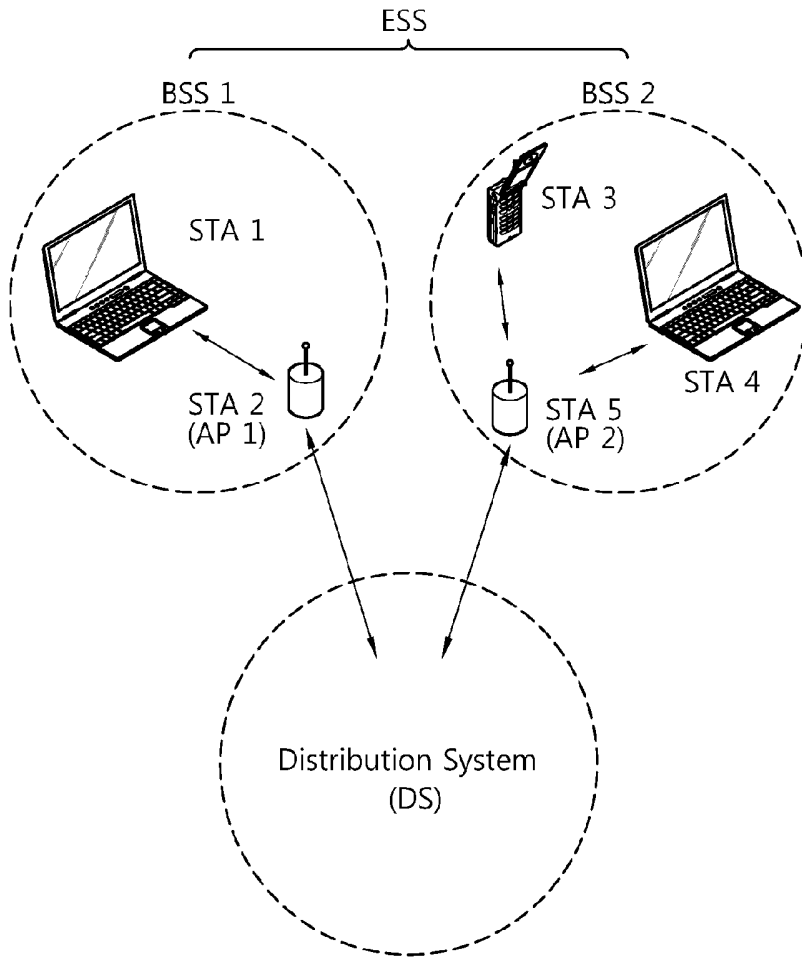
where $P_{4\times4}$ is a 4x4 orthogonal matrix.

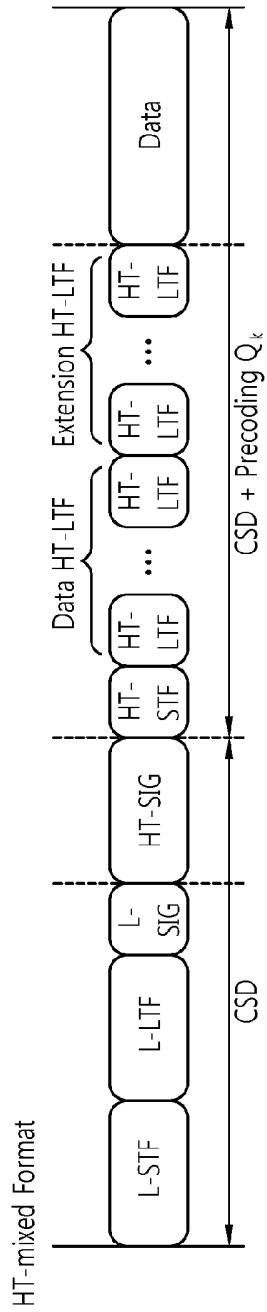[Claim 14]   The radio apparatus of claim 13, wherein the $P_{4\times4}$ is equal to Equation below.

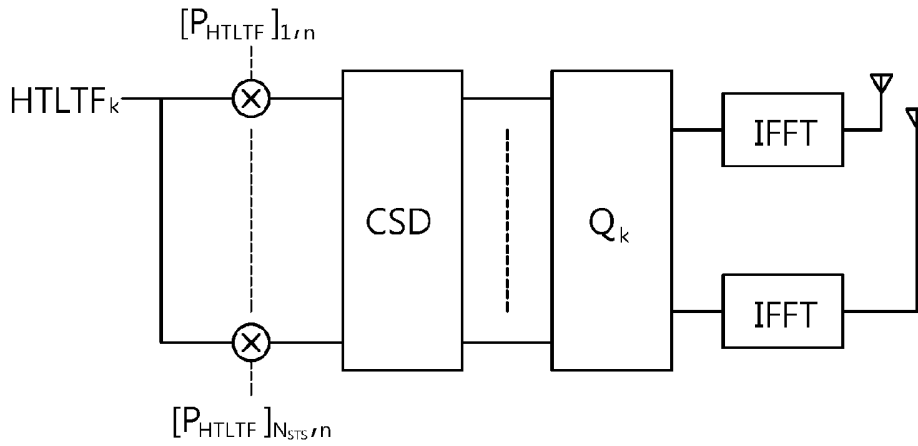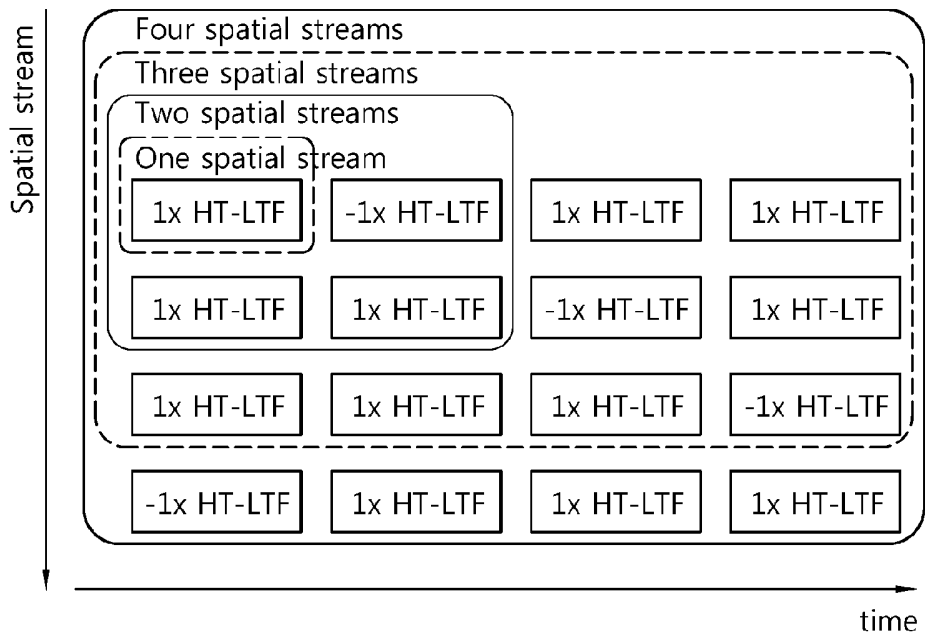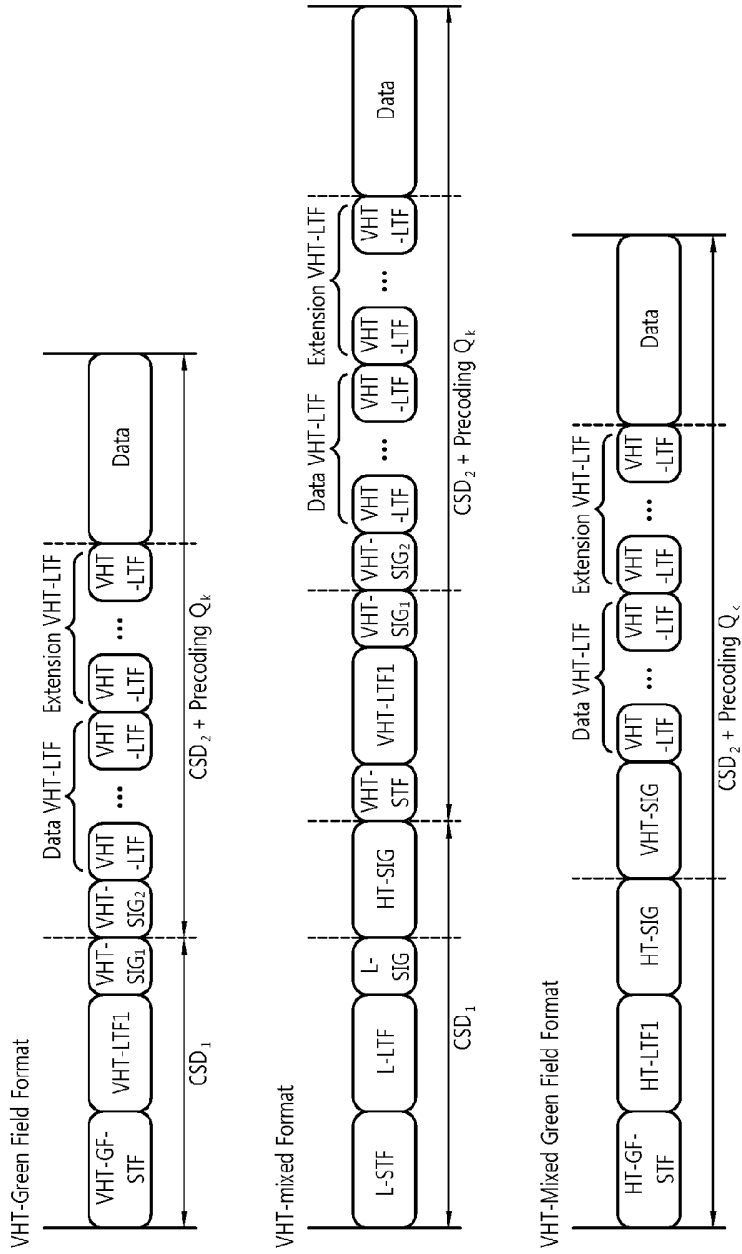$$P_{4\times4} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix}$$
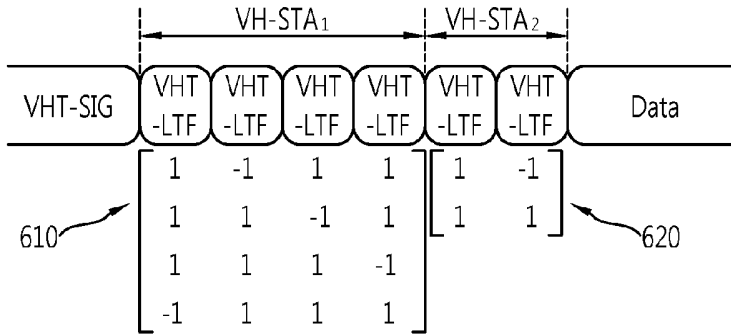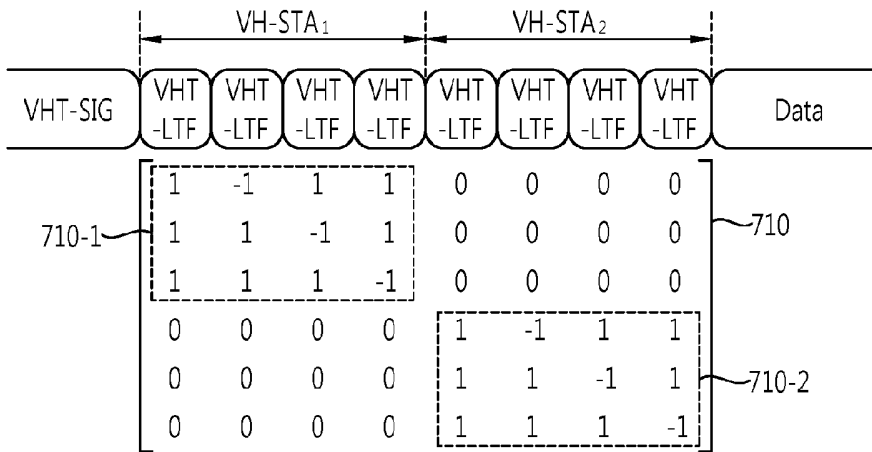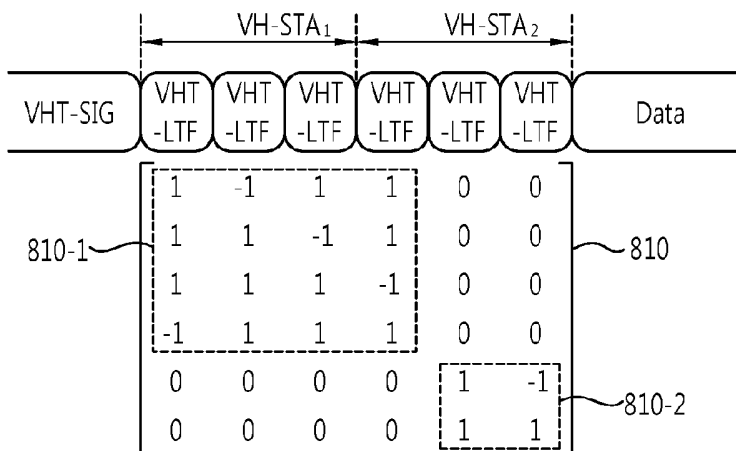
[Fig. 1]

[Fig. 2]

[Fig. 3]

[Fig. 4]

[Fig. 5]

[Fig. 6]

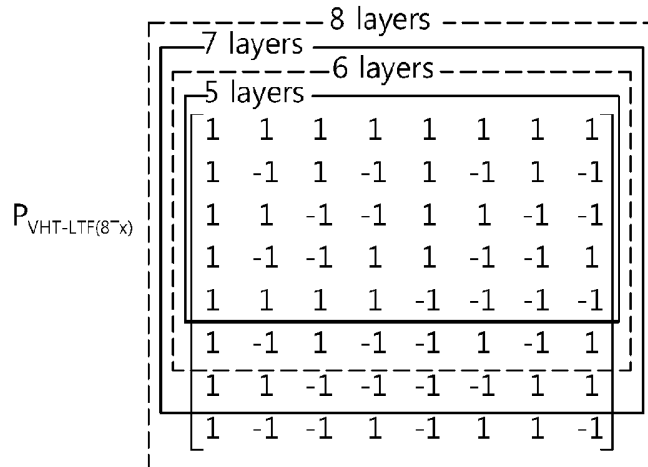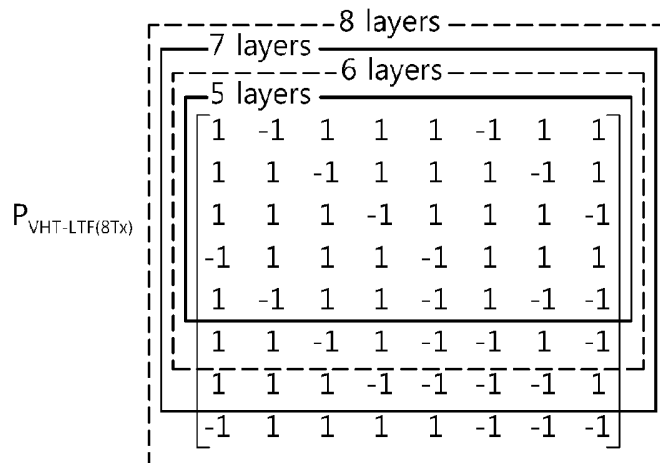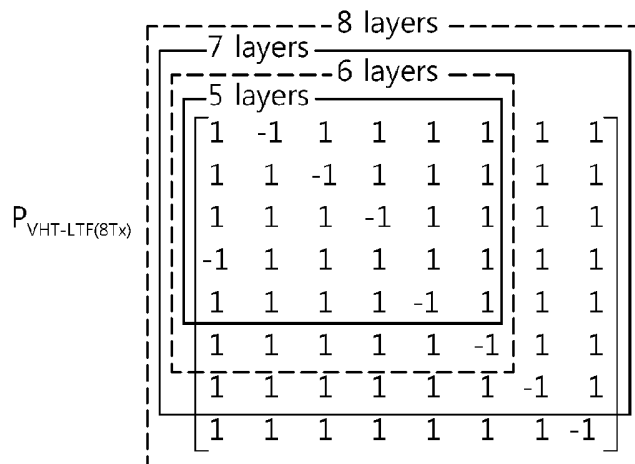
[Fig. 7]

[Fig. 8]

[Fig. 9]

8 layers
7 layers
6 layers
5 layers

$$P_{VHT\text{-}LTF(8\text{-}x)} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

[Fig. 10]

8 layers
7 layers
6 layers
5 layers

$$P_{VHT\text{-}LTF(8Tx)} = \begin{bmatrix} 1 & -1 & 1 & 1 & 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 \\ 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 \\ -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \end{bmatrix}$$

[Fig. 11]

8 layers
7 layers
6 layers
5 layers

$$P_{VHT\text{-}LTF(8Tx)} = \begin{bmatrix} 1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 & 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & -1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \end{bmatrix}$$

[Fig. 12]

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