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Yamaura

(54) **WIRELESS COMMUNICATION SYSTEM, WIRELESS COMUNICATION APPARATUS AND WIRELESS COMMUNICATION METHOD**

(71) Applicant: **Sony Corporation**, Tokyo (JP)

(72) Inventor: **Tomoya Yamaura**, Tokyo (JP)

(73) Assignee: **Sony Corporation**, Tokyo (JP)

(21) Appl. No.: **13/958,418**

(22) Filed: **Aug. 2, 2013**

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H04B 7/04 (2006.01)

(52) **U.S. Cl.**
CPC ***H04B 7/0456*** (2013.01); ***H04B 7/0421*** (2013.01)
USPC **375/267**

(57) **ABSTRACT**

A wireless communication system which performs data transmission using spatially multiplexed streams from a first terminal including N antennas to a second terminal including M antennas (N is an integer of 2 or more and M is an integer of 1 or more) is disclosed. The system includes notifying means, training means, channel matrix estimation means, beamforming information feedback means, transmission weight matrix setting means, and beamforming means.

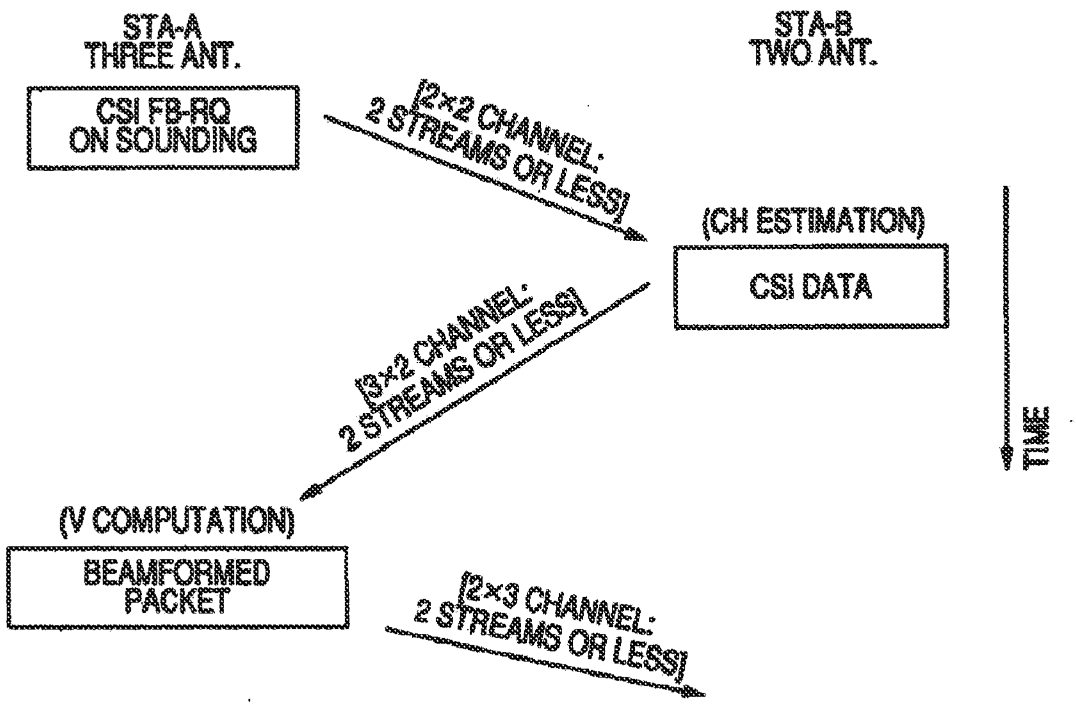


FIG. 1A

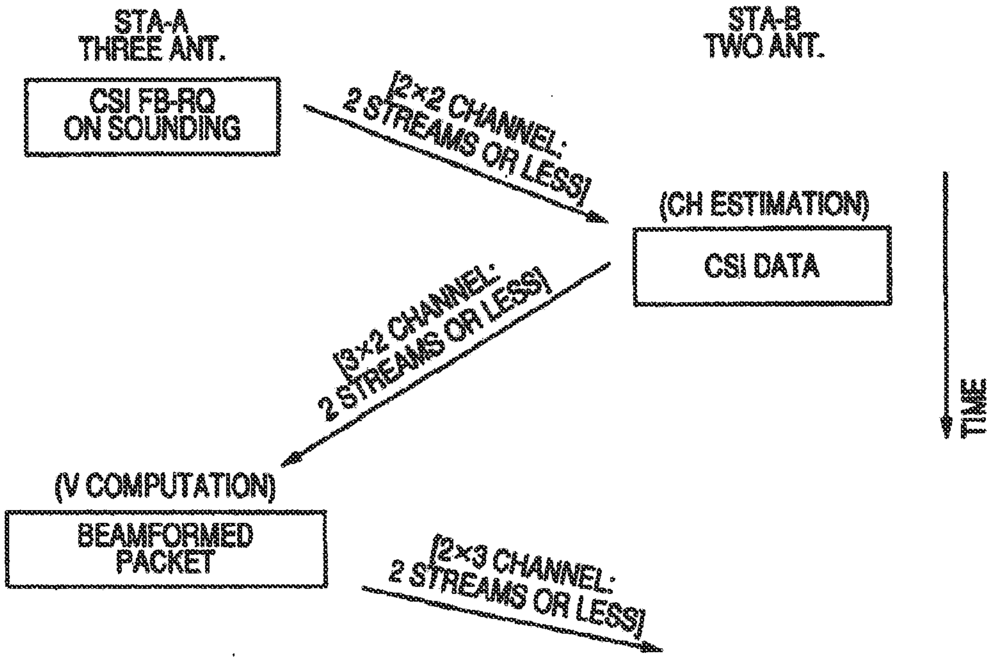

STA-A
THREE ANT.
STA-B
TWO ANT.
CSI FB-RQ
ON SOUNDING
[2×2 CHANNEL:
2 STREAMS OR LESS]
(CH ESTIMATION)
CSI DATA
[3×2 CHANNEL:
2 STREAMS OR LESS]
TIME
(V COMPUTATION)
BEAMFORMED
PACKET
[2×3 CHANNEL:
2 STREAMS OR LESS]

FIG. 1B

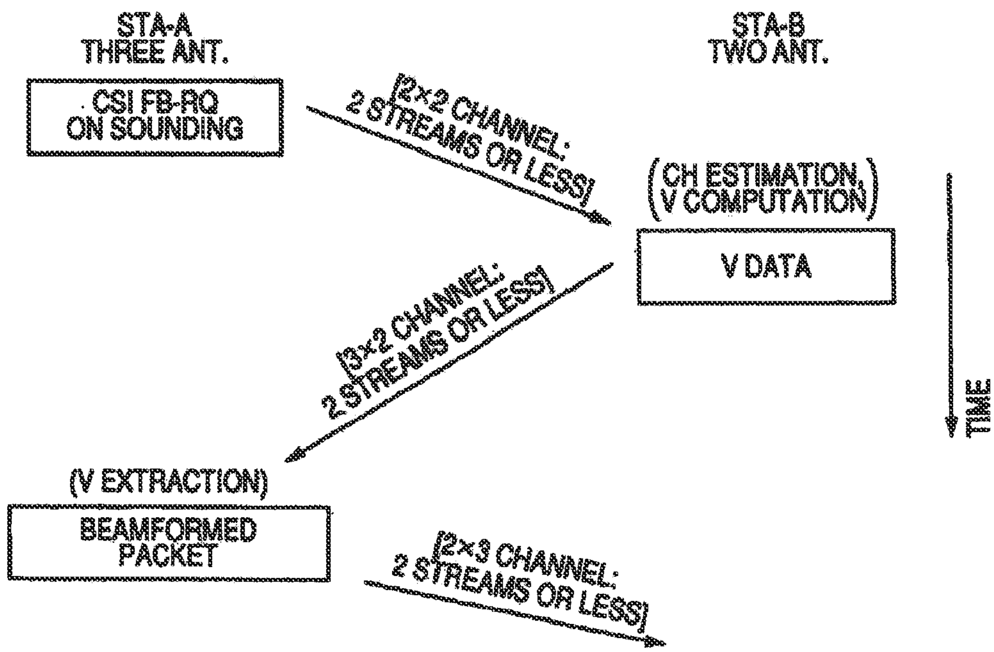
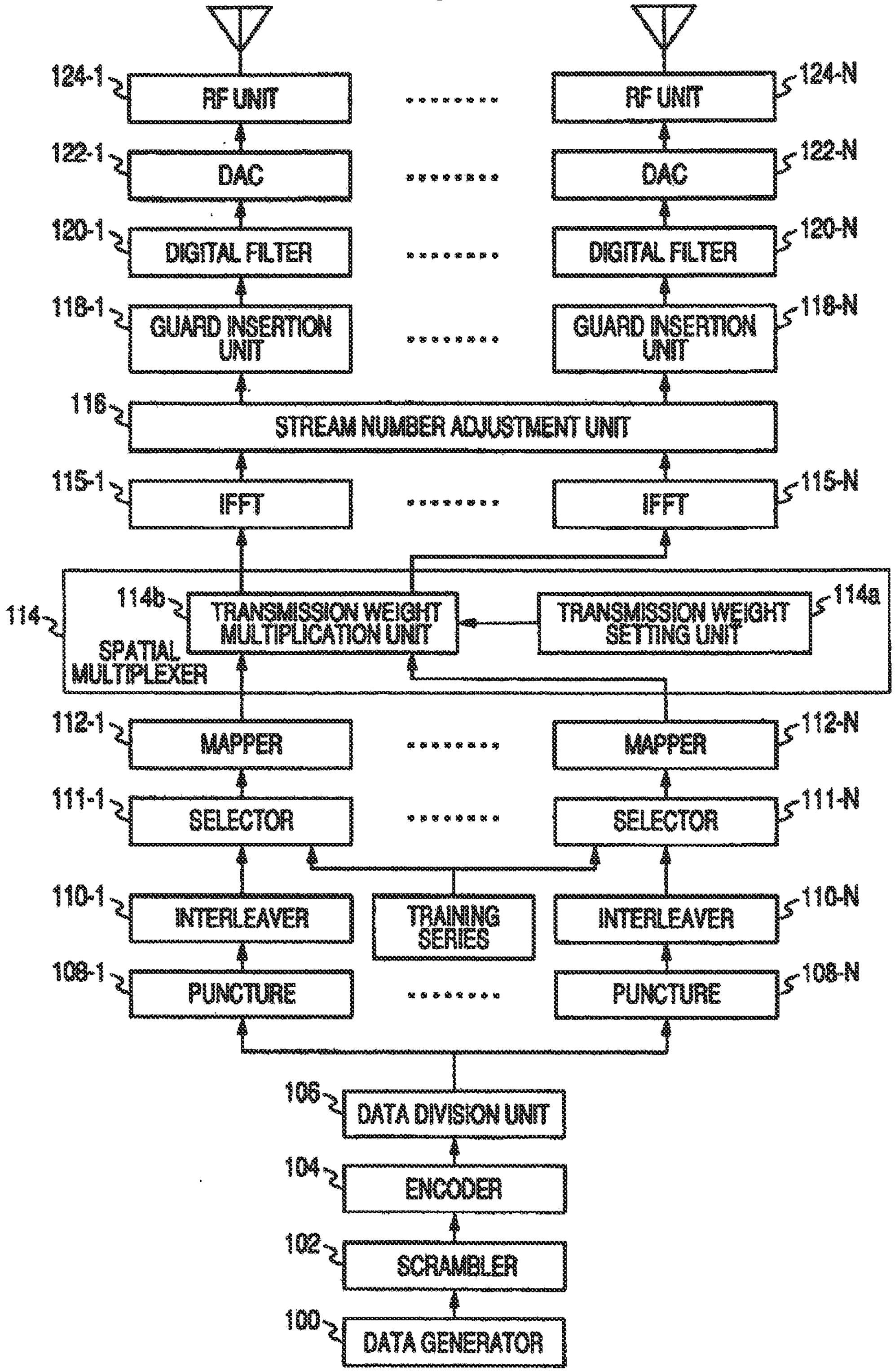

STA-A
THREE ANT.
STA-B
TWO ANT.
CSI FB-RQ
ON SOUNDING
[2×2 CHANNEL:
2 STREAMS OR LESS]
(CH ESTIMATION,
V COMPUTATION)
V DATA
[3×2 CHANNEL:
2 STREAMS OR LESS]
TIME
(V EXTRACTION)
BEAMFORMED
PACKET
[2×3 CHANNEL:
2 STREAMS OR LESS]

FIG. 2



124-1
RF UNIT
124-N
RF UNIT
122-1
DAC
122-N
DAC
120-1
DIGITAL FILTER
120-N
DIGITAL FILTER
118-1
GUARD INSERTION UNIT
118-N
GUARD INSERTION UNIT
116
STREAM NUMBER ADJUSTMENT UNIT
115-1
IFFT
115-N
IFFT
114
SPATIAL MULTIPLEXER
114b
TRANSMISSION WEIGHT MULTIPLICATION UNIT
114a
TRANSMISSION WEIGHT SETTING UNIT
112-1
MAPPER
112-N
MAPPER
111-1
SELECTOR
111-N
SELECTOR
110-1
INTERLEAVER
TRAINING SERIES
110-N
INTERLEAVER
108-1
PUNCTURE
108-N
PUNCTURE
106
DATA DIVISION UNIT
104
ENCODER
102
SCRAMBLER
100
DATA GENERATOR

FIG. 3

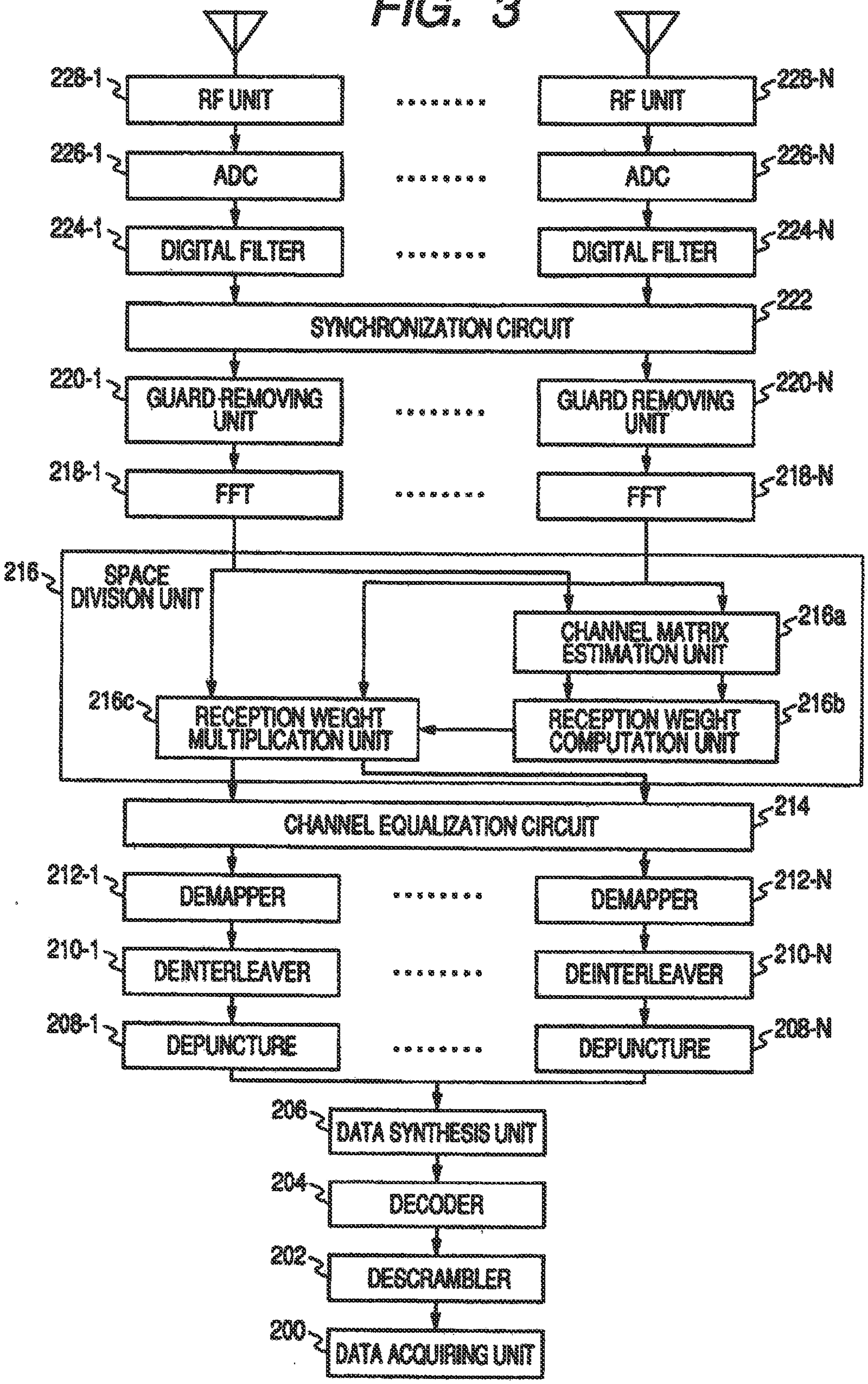

228-1
RF UNIT
RF UNIT
228-N
226-1
ADC
ADC
226-N
224-1
DIGITAL FILTER
DIGITAL FILTER
224-N
222
SYNCHRONIZATION CIRCUIT
220-1
GUARD REMOVING UNIT
GUARD REMOVING UNIT
220-N
218-1
FFT
FFT
218-N
216
SPACE DIVISION UNIT
CHANNEL MATRIX ESTIMATION UNIT
216a
216c
RECEPTION WEIGHT MULTIPLICATION UNIT
RECEPTION WEIGHT COMPUTATION UNIT
216b
214
CHANNEL EQUALIZATION CIRCUIT
212-1
DEMAPPER
DEMAPPER
212-N
210-1
DEINTERLEAVER
DEINTERLEAVER
210-N
208-1
DEPUNCTURE
DEPUNCTURE
208-N
206
DATA SYNTHESIS UNIT
204
DECODER
202
DESCRAMBLER
200
DATA ACQUIRING UNIT

FIG. 4A

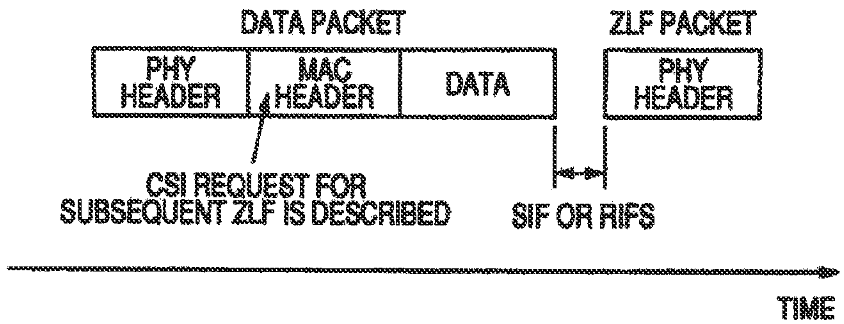


FIG. 4B

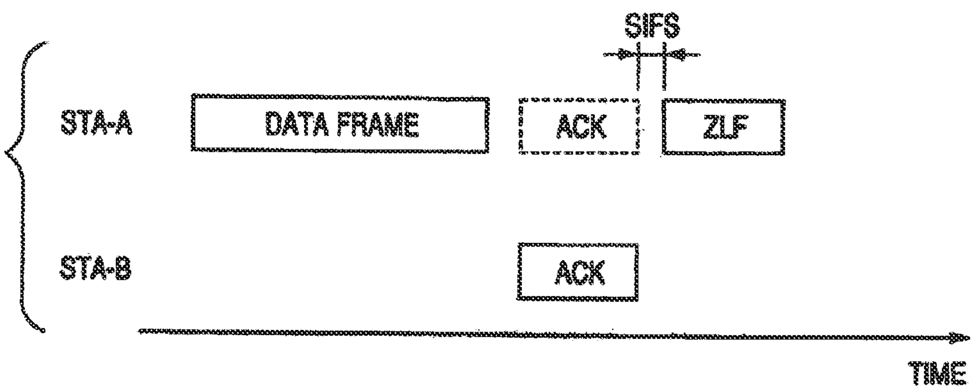


FIG. 5

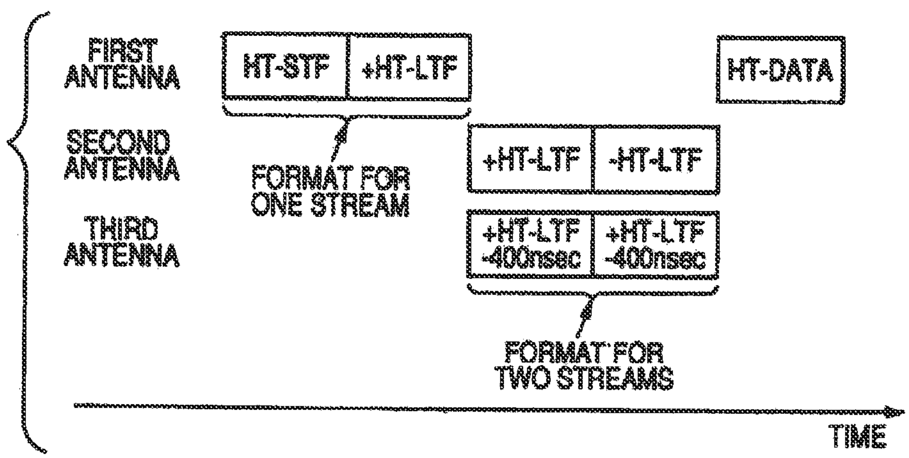


FIG. 6

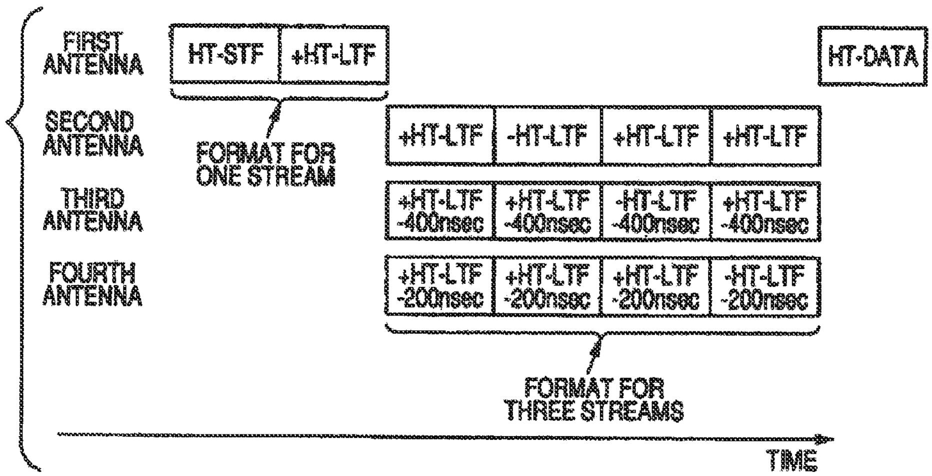

FIRST ANTENNA
HT-STF
+HT-LTF
HT-DATA
SECOND ANTENNA
FORMAT FOR ONE STREAM
+HT-LTF
-HT-LTF
+HT-LTF
+HT-LTF
THIRD ANTENNA
+HT-LTF -400nsec
+HT-LTF -400nsec
-HT-LTF -400nsec
+HT-LTF -400nsec
FOURTH ANTENNA
+HT-LTF -200nsec
+HT-LTF -200nsec
+HT-LTF -200nsec
-HT-LTF -200nsec
FORMAT FOR THREE STREAMS
TIME

FIG. 7

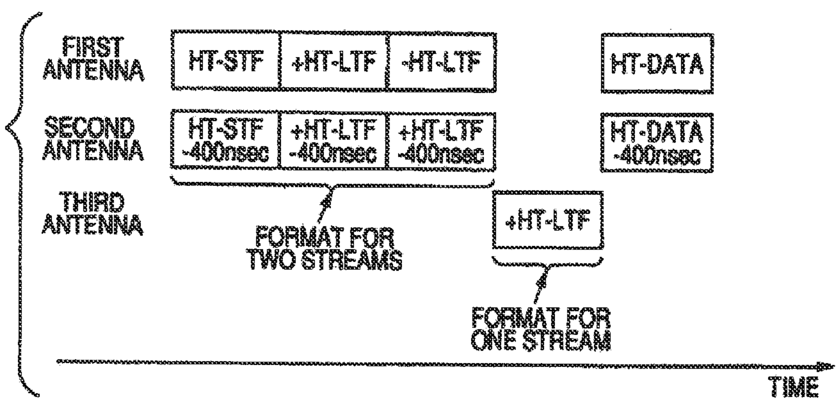

FIRST ANTENNA
HT-STF
+HT-LTF
-HT-LTF
HT-DATA
SECOND ANTENNA
HT-STF -400nsec
+HT-LTF -400nsec
+HT-LTF -400nsec
HT-DATA -400nsec
THIRD ANTENNA
+HT-LTF
FORMAT FOR TWO STREAMS
FORMAT FOR ONE STREAM
TIME

FIG. 8

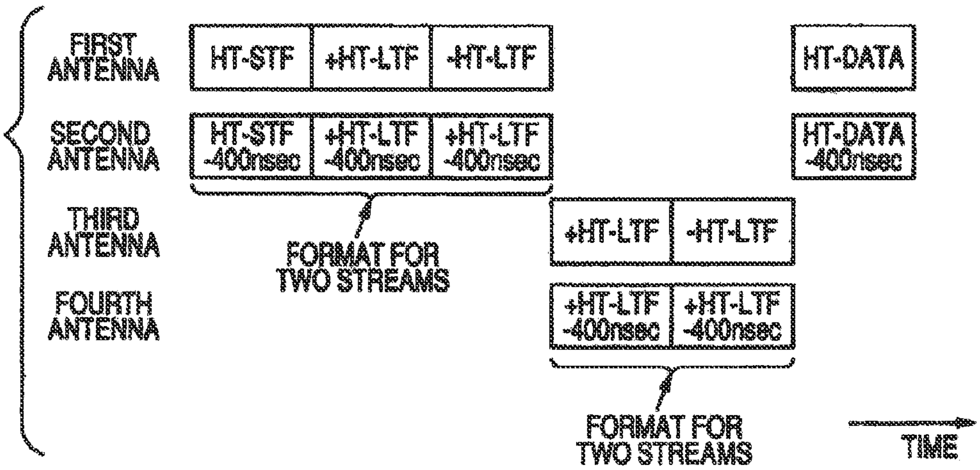


FIG. 9

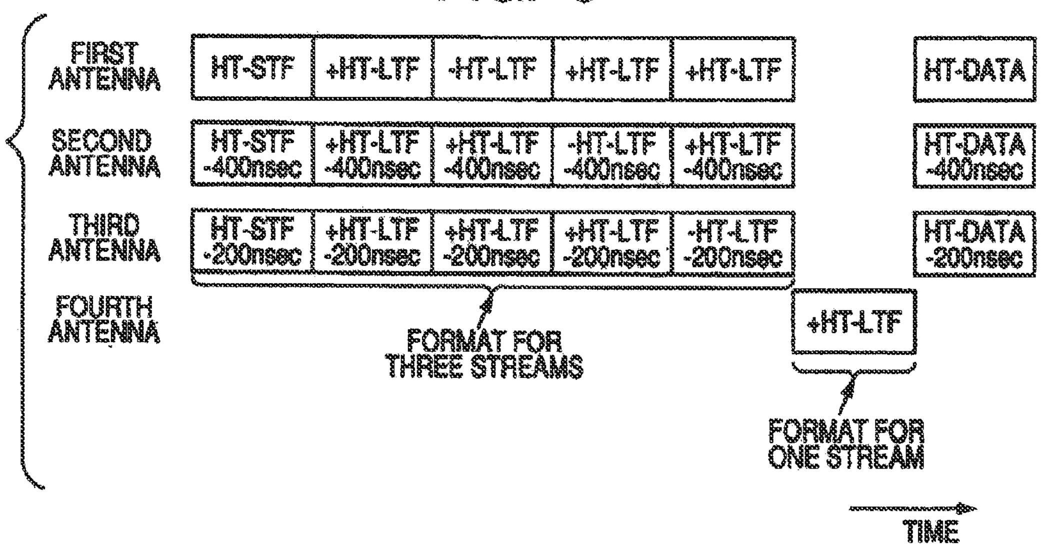


FIG. 10

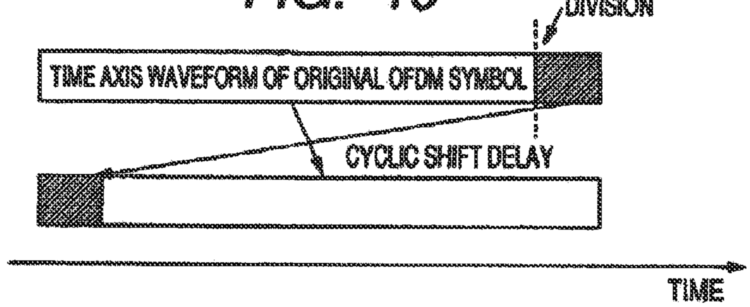


FIG. 11

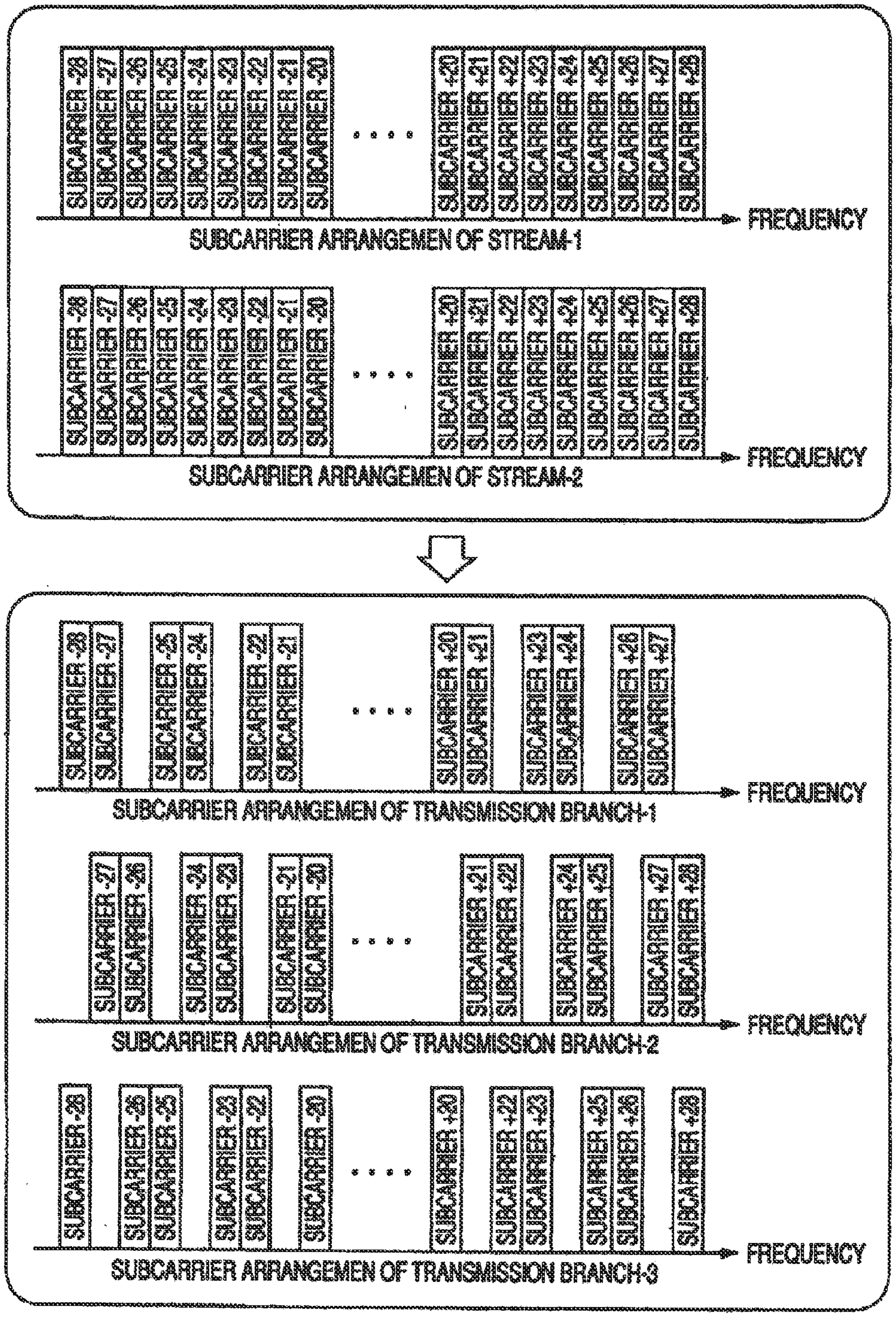

SUBCARRIER -28
SUBCARRIER -27
SUBCARRIER -26
SUBCARRIER -25
SUBCARRIER -24
SUBCARRIER -23
SUBCARRIER -22
SUBCARRIER -21
SUBCARRIER -20
SUBCARRIER +20
SUBCARRIER +21
SUBCARRIER +22
SUBCARRIER +23
SUBCARRIER +24
SUBCARRIER +25
SUBCARRIER +26
SUBCARRIER +27
SUBCARRIER +28
FREQUENCY
SUBCARRIER ARRANGEMEN OF STREAM-1
SUBCARRIER ARRANGEMEN OF STREAM-2
SUBCARRIER ARRANGEMEN OF TRANSMISSION BRANCH-1
SUBCARRIER ARRANGEMEN OF TRANSMISSION BRANCH-2
SUBCARRIER ARRANGEMEN OF TRANSMISSION BRANCH-3

FIG. 12

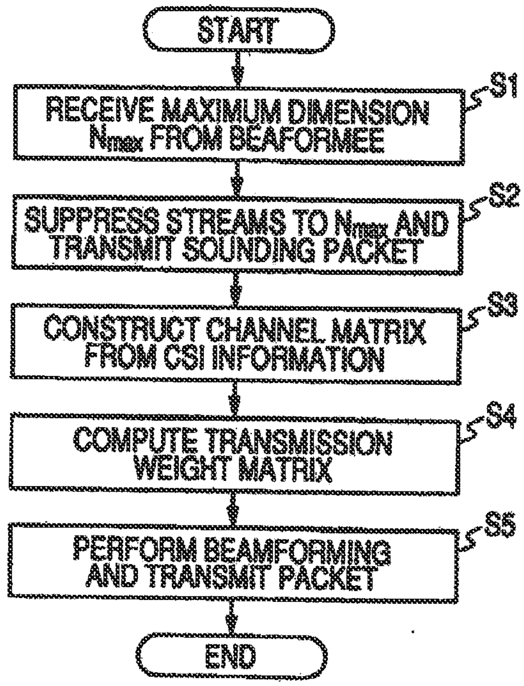

START
RECEIVE MAXIMUM DIMENSION N_{max} FROM BEAFORMEE
S1
SUPPRESS STREAMS TO N_{max} AND TRANSMIT SOUNDING PACKET
S2
CONSTRUCT CHANNEL MATRIX FROM CSI INFORMATION
S3
COMPUTE TRANSMISSION WEIGHT MATRIX
S4
PERFORM BEAMFORMING AND TRANSMIT PACKET
S5
END

FIG. 13

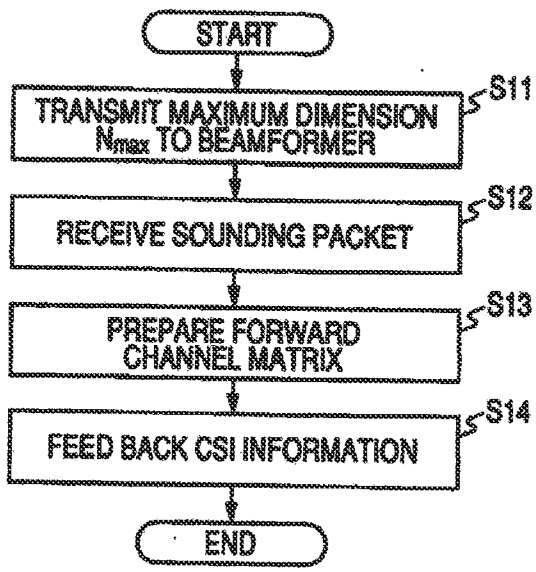

START
TRANSMIT MAXIMUM DIMENSION N_{max} TO BEAMFORMER
S11
RECEIVE SOUNDING PACKET
S12
PREPARE FORWARD CHANNEL MATRIX
S13
FEED BACK CSI INFORMATION
S14
END

FIG. 14

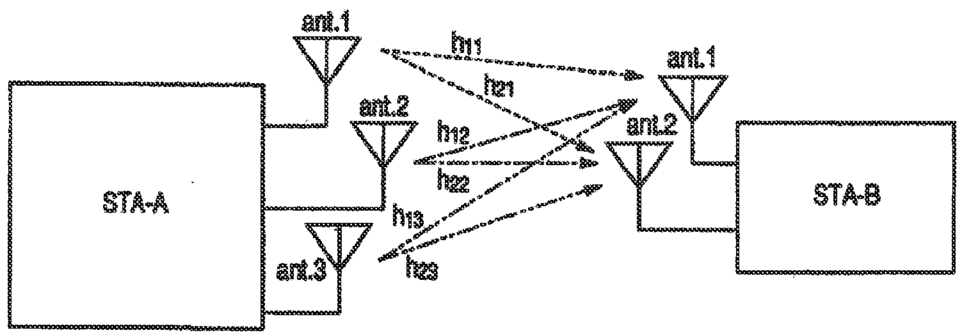

ant.1
h11
h21
ant.2
h12
h22
STA-A
h13
ant.3
h23
ant.1
ant.2
STA-B

FIG. 15

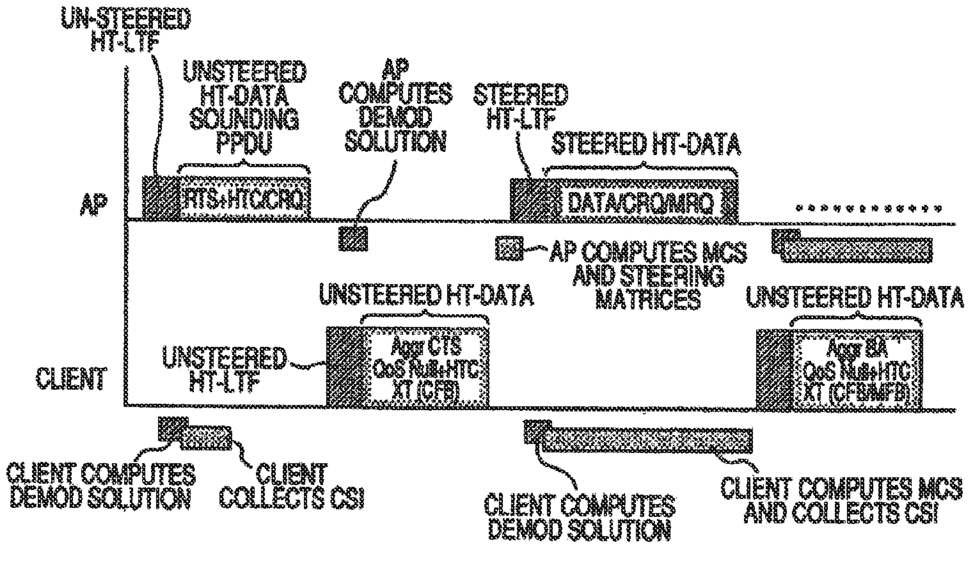

UN-STEERED HT-LTF
UNSTEERED HT-DATA SOUNDING PPDU
AP COMPUTES DEMOD SOLUTION
STEERED HT-LTF
STEERED HT-DATA
AP
RTS+HTC/CRQ
DATA/CRQ/MRQ
AP COMPUTES MCS AND STEERING MATRICES
UNSTEERED HT-DATA
UNSTEERED HT-DATA
UNSTEERED HT-LTF
CLIENT
Aggr CTS QoS Null+HTC XT (CFB)
Aggr BA QoS Null+HTC XT (CFB/MFB)
CLIENT COMPUTES DEMOD SOLUTION
CLIENT COLLECTS CSI
CLIENT COMPUTES DEMOD SOLUTION
CLIENT COMPUTES MCS AND COLLECTS CSI

FIG. 16

	B0-B15	B16-B17	B18-B19	B20-B21	B22-B23	B24	B25-B29	B30	B31
	LINK ADAPTATION CONTROL	CALIBRATION POSITION	CALIBRATION SEQUENCE	FEEDBACK REQUEST	CSI/ STEERING	ZLF ANNOUNCEMENT	RESERVED	AC CONSTRAINT	RDG/MORE PPDU
# BITS	16	2	2	2	2	1	5	1	1

FIG. 17

FIELD	MEANING	DEFINITION
CSI/STEERING	TYPE OF FEEDBACK	00 CSI 01 UNCOMPRESSED STEERING MATRIX 10 COMPRESSED STEERING MATRIX 11 ~ RESERVED

FIG. 18

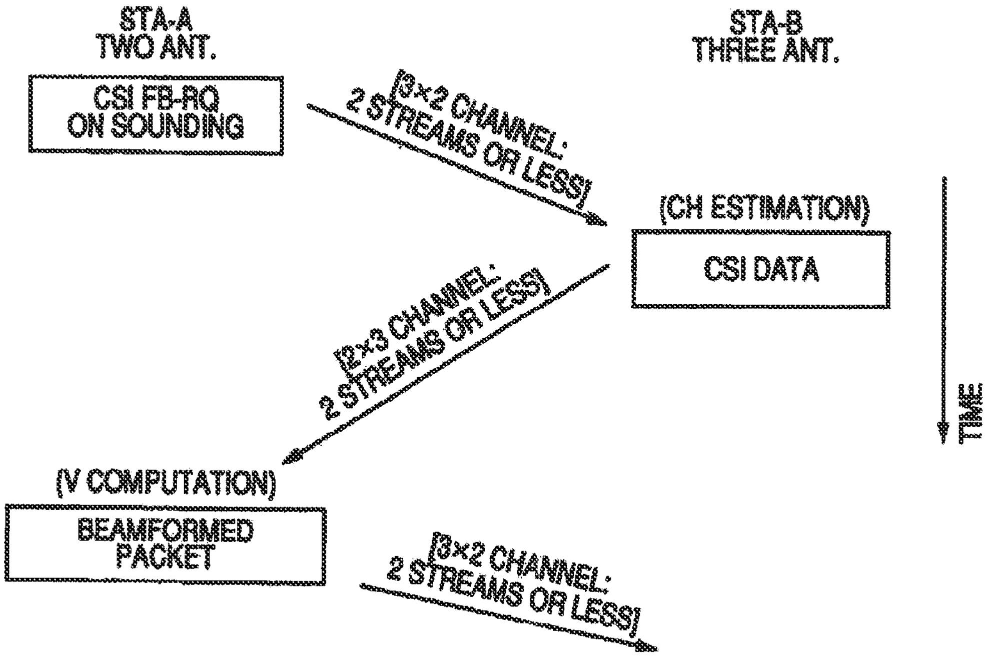

STA-A
TWO ANT.
STA-B
THREE ANT.
CSI FB-RQ
ON SOUNDING
[3×2 CHANNEL:
2 STREAMS OR LESS]
(CH ESTIMATION)
CSI DATA
[2×3 CHANNEL:
2 STREAMS OR LESS]
(V COMPUTATION)
BEAMFORMED
PACKET
[3×2 CHANNEL:
2 STREAMS OR LESS]
TIME

FIG. 19

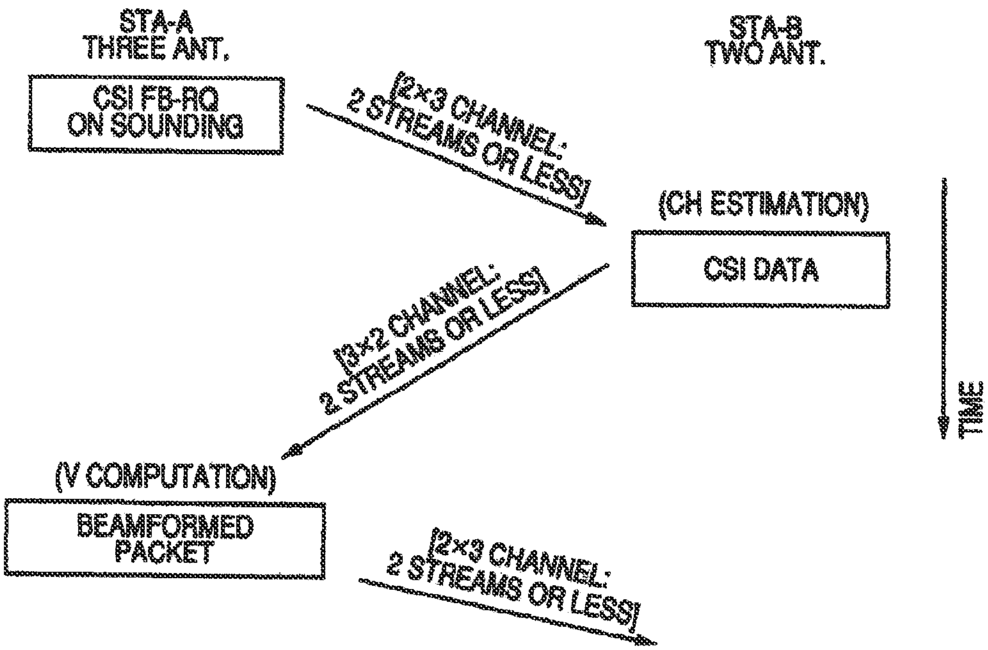

STA-A
THREE ANT.
STA-B
TWO ANT.
CSI FB-RQ
ON SOUNDING
[2×3 CHANNEL:
2 STREAMS OR LESS]
(CH ESTIMATION)
CSI DATA
[3×2 CHANNEL:
2 STREAMS OR LESS]
(V COMPUTATION)
BEAMFORMED
PACKET
[2×3 CHANNEL:
2 STREAMS OR LESS]
TIME

FIG. 20

OCTET	1	1	2	1	16	1	4	1
	ELEMENT ID	LENGTH (25)	HT CAPABILITIES INFO	MAC HT PARAMETERS INFO	SUPPORTED MCS SET	EXTENDED HT CAPABILITY INFO	TxBF CAPABILITIES	AS CAPABILITIES

FIG. 21

B0	B1	B2	B3	B4	B5	B6-B7	B8	B9
TxBF CAPABLE	RECEIVE STAGGERED SOUNDING CAPABLE	TRANSMIT STAGGERED SOUNDING CAPABLE	RECEIVE ZLF CAPABLE	TRANSMIT ZLF CAPABLE	IMPLICIT TxBF CAPABLE	CALIBRATION	EXPLICIT CSI TxBF CAPABLE	EXPLICIT UNCOMPRESSED STEERING MATRIX CAPABLE

B10-B12	B13-B15	B16-B18	B19-B20	B21-B22	B23-B24	B25-B31
EXPLICIT BF CSI FEEDBACK	EXPLICIT UNCOMPRESSED STEERING MATRIX FEEDBACK	EXPLICIT COMPRESSED STEERING MATRIX FEEDBACK	CSI NUMBER OF BEAMFORMER ANTENNAE	UNCOMPRESSED STEERING MATRIX OF BEAMFORMER ANTENNAE	COMPRESSED STEERING MATRIX OF BEAMFORMER ANTENNAE	RESERVED

FIG. 22

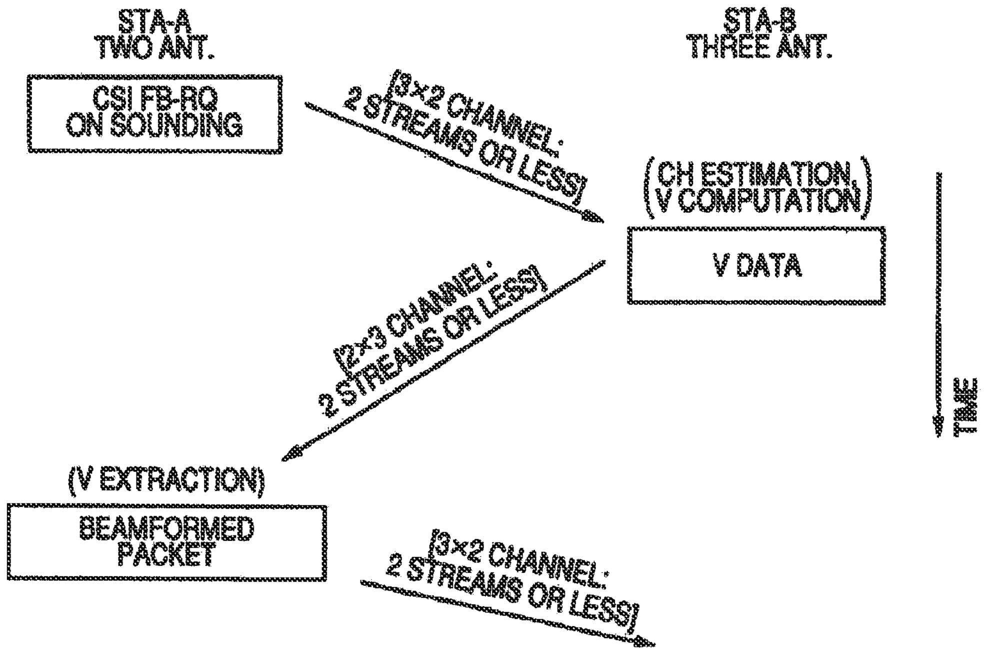
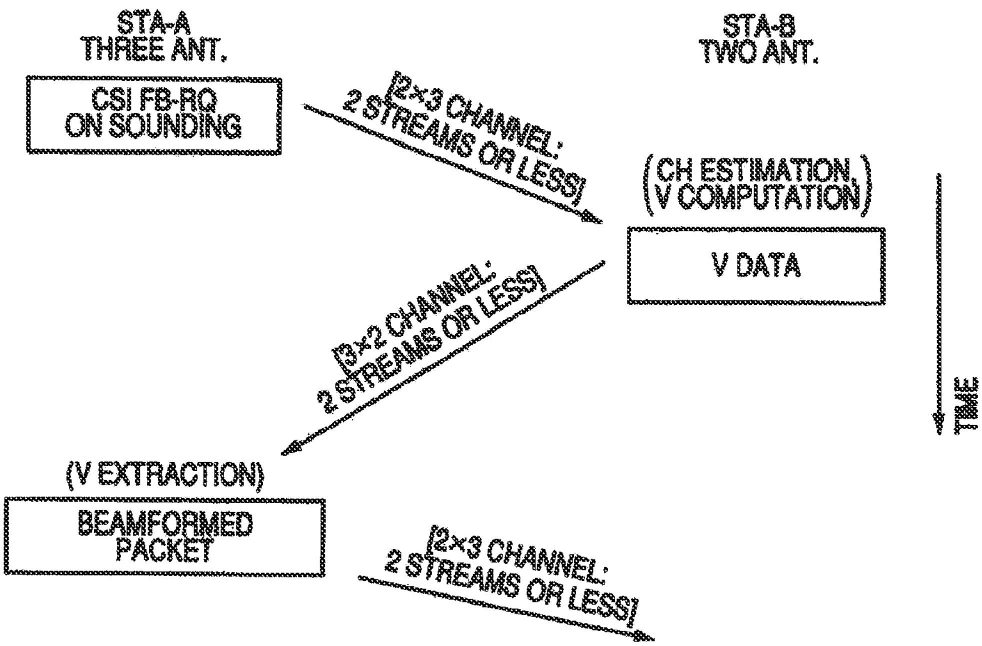

STA-A
TWO ANT.
CSI FB-RQ
ON SOUNDING
[3×2 CHANNEL:
2 STREAMS OR LESS]
STA-B
THREE ANT.
(CH ESTIMATION,
V COMPUTATION)
V DATA
[2×3 CHANNEL:
2 STREAMS OR LESS]
TIME
(V EXTRACTION)
BEAMFORMED
PACKET
[3×2 CHANNEL:
2 STREAMS OR LESS]

FIG. 23


STA-A
THREE ANT.
CSI FB-RQ
ON SOUNDING
[2×3 CHANNEL:
2 STREAMS OR LESS]
STA-B
TWO ANT.
(CH ESTIMATION,
V COMPUTATION)
V DATA
[3×2 CHANNEL:
2 STREAMS OR LESS]
TIME
(V EXTRACTION)
BEAMFORMED
PACKET
[2×3 CHANNEL:
2 STREAMS OR LESS]

WIRELESS COMMUNICATION SYSTEM, WIRELESS COMUNICATION APPARATUS AND WIRELESS COMMUNICATION METHOD

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] The present invention contains subject matter related to Japanese Patent Applications JP 2006-124538 and JP 2007-056245 filed in the Japanese Patent Office on Apr. 27, 2006, and Mar. 6, 2007, respectively, the entire contents of which being incorporated herein by reference.

BACKGROUND

[0002] 1. Technical Field

[0003] The invention relates to a wireless communication system, a wireless communication apparatus and a wireless communication method using spatial multiplexing, and more particularly, to a wireless communication system, a wireless communication apparatus and a wireless communication method, in which a transmitter and a receiver share channel information to perform closed loop type spatial multiplexing transmission.

[0004] In particular, the invention relates to a wireless communication system, a wireless communication apparatus and a wireless communication method, which perform beamforming on the basis of information which is fed back from a receiver when a transmitter transmits a packet, and more particularly, to a wireless communication system, a wireless communication apparatus and a wireless communication method, which perform beamforming by feeding back beamforming information between a beamformer and beamformee which are different from each other in the number of antennas or the number of supported streams.

[0005] 2. Background Art

[0006] As a system for removing wire in an existing wired communication method, a wireless network is attracting attention. A standard of the wireless network may be the IEEE (The institute of Electrical and Electronics Engineers) 802.11 or the IEEE 802.15.

[0007] For example, in the IEEE 802.11a/g, as a standard of a wireless LAN, an orthogonal frequency division multiplexing (OFDM) modulation method which is one of a multi-carrier method is employed. In the OFDM modulation method, since transmission data is distributed to a plurality of carriers having orthogonal frequencies and is transmitted, the band of each carrier becomes narrow, frequency use efficiency is very high, and frequency-selective fading interference is strong.

[0008] In addition, in the IEEE 802.11a/g standard, a modulation method for accomplishing a communication speed of a maximum of 54 Mbps is supported, but a next-generation wireless LAN standard for realizing a new high bit rate is required.

[0009] As one of a technology of realizing a high speed of wireless communication, multi-input multi-output (MIMO) communication is attracting attention. This is a communication method in which both a transmitter side and a receiver side respectively include a plurality of antennas to realize spatially multiplexed streams. The transmitter side performs spatial/temporal encoding and multiplexing of plural pieces of transmission data and distributes and transmits the plural pieces of transmission data to N transmission antennas through channels. The receiver side performs spatial/temporal decoding of reception signals received by M reception antennas through the channels to obtain reception data without crosstalk between the streams (for example, see JP-A-2002-44051 (Patent Document 1)). Ideally, spatial streams corresponding to the smaller number (MIN[N, M]) of the transmission and reception antennas are formed.

[0010] According to the MIMO communication method, a transmission capacity can increase according to the number of antennas and a communication speed improvement can be realized, without increasing a frequency band. Since the spatial multiplexing is used, frequency use efficiency is high. The MIMO method uses channel characteristics and is different from a simple transmission/reception adaptive array. For example, in the IEEE 802.11n which is the extension standard of the IEEE 802.11a/g, an OFDM_MIMO method using OFDM in primary modulation is employed. Currently, the IEEE 802.11n is being standardized in a task group n(TGn) and a specification established therein is based on a specification established in Enhanced wireless consortium (EWC) formed on October, 2005.

[0011] In the MIMO communication, in order to spatially divide a spatially multiplexed reception signal y into the stream signals x, a channel matrix H is acquired by any method and the spatially multiplexed reception signal needs to be spatially divided into a plurality of original streams using the channel matrix H by a predetermined algorithm.

[0012] The channel matrix H is obtained by allowing a transmitter/receiver side to transmit/receive existing training sequence, estimating the channels by a difference between the actually received signal and the existing sequence and arranging propagation channels of a combination of transmission and reception antennas in a matrix form. When the number of transmission antennas is N and the number of reception antennas is M, the channel matrix is M×N (row×column) matrix. Accordingly, the transmitter side transmits N training sequence and the receiver side acquires the channel matrix H using the received training sequence.

[0013] A method of spatially dividing a reception signal is largely classified into an open loop type method in which a receiver independently performs spatial division on the basis of the channel matrix H and a closed loop type method in which a transmitter side gives weights to the transmission antennas on the basis of the channel matrix to perform adequate beamforming toward a receiver to form an ideal spatial orthogonal channel.

[0014] As an open loop type MIMO transmission method, there is a zero force (for example, see A. Benjebbour, H. Murata and S. Yoshida, "Performance of iterative successive detection algorithm for space-time transmission", Proc. IEEE VTC Spring, vol. 2, pp. 1287-1291, Rhodes. Greece, May 2001 (Non-Patent Document 2)) or a minimum mean square error (MMSE) (for example, see A. Benjebbour, H. Murata and S. Yoshida, "Performance comparison of ordered successive receivers for space-time transmission", Proc. IEEE VTC Fall, vol. 4, pp. 2053-2057, Atlantic City, USA, September 2001 (Non-Patent Document 3)). The open loop type MIMO transmission method is a relative simple algorithm for obtaining reception weight matrix W for spatially dividing the reception signal from the channel matrix H, in which a feedback operation for sharing the channel information between the transmitter and the receiver is omitted and the transmitter and the receiver independently perform spatial multiplexing transmission.

[0015] As an ideal one of a closed loop type MIMO transmission method, a singular value decomposition (SVD)-MIMO method using SVD of the channel matrix H is known (for example, see http://radio3.ee.uec.ac.jp/MIMO(IEICE_TS). Pdf (Oct. 24, 2003) (Non-Patent Document 1)). In the SVD-MIMO transmission, a numerical matrix having channel information corresponding to antenna pairs as elements, that is, a channel information matrix H, is subjected to the singular value decomposition to obtain UDV^H. A transmitter side uses V in a transmission antenna weight matrix and transmits a beamformed packet to a receiver and a receiver side typically gives $(UD)^{-1}$ as a reception antenna weight matrix. Here, D is a diagonal matrix having square roots of singular values λ_i corresponding to qualities of the spatial streams in diagonal elements (the subscript i indicates an i^{th} spatial stream). The singular values λ_i are arranged in the diagonal elements of the diagonal matrix D in ascending order and power ratio distribution or modulation method allocation is performed according to communication quality represented by the level of the singular value with respect to the streams such that a plurality of spatial orthogonal multiplexed propagation channels which are logically independent are realized. The receiver side can extract a plurality of original signal sequence without crosstalk and theoretically accomplish maximum performance.

[0016] In the closed loop type MIMO communication system, adequate beamforming is performed when the transmitter transmits the packet, but information on the channel information needs to be fed back from the receiver side for receiving the packet.

[0017] For example, in the EWC HT (High Throughput) MAC (Media Access Control) Specification Version V1.24, two kinds of procedures, that is, "implicit feedback" and "explicit feedback", are defined as the procedure for feeding back the information on the channel matrix between the transmitter and the receiver.

[0018] In the "implicit feedback", the transmitter estimates a backward channel matrix from the receiver to the transmitter using training sequence transmitted from the receiver, and a forward channel matrix from the transmitter to the receiver is computed to perform beamforming on the assumption that bidirectional channel characteristics between the transmitter and the receiver are reciprocal.

[0019] In the "explicit feedback", the receiver estimates a forward channel matrix from the transmitter to the receiver using training sequence transmitted from the transmitter and returns a packet including the channel matrix as data to the transmitter, and transmitter performs the beamforming using the received channel matrix. Alternatively, the receiver computes a transmission weight matrix for allowing the transmitter to perform the beamforming from the estimation channel matrix and returns a packet including the transmission weight matrix as the data to the transmitter. In the explicit feedback, since the weight matrix is computed on the basis of the estimated forward channel matrix, it may not be assumed that the channels are reciprocal.

[0020] In view of packet transmission, the transmitter is an initiator and the receiver is a receiver. However, in view of beamforming, the initiator for transmitting the packet is a beamformer and the receiver for receiving the beamformed packet is a beamformee. Communication from the beamformer to the beamformee is referred to as "forward" and communication from the beamformee to the beamformer is referred to as "backward". For example, when an access point (AP) transmits a data frame to a client terminal (STA) as the beamformer, the access point perform the beamforming on the basis of the channel information transmitted from the client in the explicit feedback.

[0021] FIG. **14** shows a state where the beamformee estimates the channel matrix excited by a training signal transmitted from the beamformer. In the same drawing, a STA-A having three antennas is the beamformer and a STA-3 having two antennas is the beamformee and feedback is performed on the basis of a CSI format. In the below-described description or equations, a subscript AB indicates forward transmission from the STA-A to the STA-B. A numerical subscript corresponds to the antenna number of the corresponding terminal.

[0022] The training sequence transmitted from the antennas of the STA-A are $(t_{AB1}, t_{AB2}, t_{AB3})$ and the signals received by the antennas of the STA-A through a channel H_{AB} are (r_{AB1}, r_{AB2}), the following equation is obtained.

$$\begin{pmatrix} r_{AB1} \\ r_{AB2} \end{pmatrix} = H_{AB} \begin{pmatrix} t_{AB1} \\ t_{AB2} \\ t_{AB3} \end{pmatrix} \quad (1)$$

[0023] where, the channel matrix H_{AB} is a 2×3 matrix and expressed by the following equation. But, h_{ij} is a channel characteristic value of J^{th} antenna of the STA-A to i^{th} antenna of the STA-B.

$$H_{AB} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \end{pmatrix} \quad (2)$$

[0024] When the channel matrix H_{AB} is subjected to singular value decomposition, the following equation is obtained. Here, U_{AB} is a matrix having an inherent normalized vector of $H_{AB}H_{AB}^H$, V_{AB} is an inherent normalized vector of $H_{AB}^HH_{AB}$ and D_{AB} is a diagonal matrix having a square root of an inherent vector of $H_{AB}H_{AB}^H$ or $H_{AB}^HH_{AB}$ as the diagonal elements. In addition, U_{AB} and V_{AB} are unitary matrices and complex conjugate transposed matrices thereof become inverse matrices.

$$H_{AB}=U_{AB}D_{AB}V_{AB}^H \quad (3)$$

[0025] The transmission weight matrix necessary for forming the frame transmitted from the STA-A to the STA-B is the matrix V_{AB} obtained by performing the singular value decomposition with respect to the forward channel matrix H_{AB}. When the beamformee receives a sounding packet, the beamformee divides the sounding packet into spatial stream trainings to construct the estimation channel matrix H_{AB}. The CSI composed of MIMO channel coefficients $h_{11}, h_{12}, \ldots$ which are elements of the channel matrix is collected and fed back to the STA-A.

[0026] If a transmission vector composed of transmission signals of the antennas of the STA-A is x and a reception signal of the STA-B is y, the reception signal becomes $y=H_{AB}x$ in a case where the beamforming is not performed (un-steered), but the reception signal y becomes the following equation in a case where the beamforming are performed by the transmission weight matrix V_{AB} (steered).

$$y = H_{AB}V_{AB}x = (U_{AB}D_{AB}V_{AB}^{H}) \cdot V_{AB}x = U_{AB}D_{AB}x \quad (4)$$

[0027] Accordingly, the STA-B can perform spatial division to the original stream by multiplying a reception vector including the reception signals of the antennas by $D_{AB}^{-1}U_{AB}^{H}$ as a reception weight.

[0028] FIG. **15** shows a frame exchange procedure for transmitting beamforming from the access point to the client terminal by the explicit feedback.

[0029] This procedure is initiated by the access point which sends the sounding packet including a CSI feedback request.

[0030] The sounding packet includes the training sequence excited by the channel matrix. Accordingly, when the sounding packet is received, the client terminal divides the spatial stream training to estimate the channel matrix H and collects the CSI. The CSI data is included in the packet as a CSI feedback (CFB) and returned to the access point.

[0031] The access point computes the transmission weight matrix for beamforming from the received CFB and multiplies the transmission signal by it to transmit the beamformed packet to the client terminal. Even in a place where the communication was hard to be accomplished in the past, communication is accomplished at a high transmission rate by the beamforming.

[0032] As described above, in the explicit feedback, the beamformer can receive the explicit feedback of the estimation channel matrix from the beamformee. The format of the feedback format of the estimation channel matrix is largely classified into a case where an MIMO channel coefficient is sent and a case where a transmission weight matrix V for beamforming computed by the beamformee.

[0033] The former format is called channel state information (CSI). The beamformer needs to compute the transmission weight matrix V for beamforming by constructing the channel matrix H from the received CSI and performing the singular value decomposition.

[0034] The latter is classified into a case where the transmission weight matrix V for beamforming is sent in an uncompressed format and a case where the transmission weight matrix V for beamforming is sent in a compressed format. According to the explicit feedback, a processing burden for estimating the channel matrix in the beamformer side and a processing burden for calculating the transmission weight matrix from the channel matrix are reduced.

[0035] FIG. **16** shows a scheme of a HT control field of an MAC frame defined in the EWC specification. The HTC field has 32 bits, but, among them, 22^{nd} to 23^{rd} CSI/steering fields can specify a feedback type received from the beamformee in the explicit feedback (see FIG. **17**).

[0036] As described above, the processing burden of the beamformer which performs beamforming with respect to a transmission frame is reduced by the explicit feedback. However, when the beamformer and the beamformee are different from each other in the number of antennas or the number of supported streams, several problems are caused at the time of beamforming.

[0037] In a spatial multiplexing type communication apparatus, the dimension number which is allowed by the processing capability including the estimation of the channel matrix H, the computation of the transmission weight matrix for beamforming, and the multiplication of the transmission vector and the transmission weight matrix V for beamforming is generally designed according to the number of antennas included therein. Accordingly, the transmission weight matrix for beamforming cannot be constructed by spatially dividing a training signal transmitted from the beamformer having the number of antennas which is larger than an allowable dimension, the transmission weight matrix for beamforming cannot be computed from the channel matrix which is fed back from the beamformee, or the transmission weight matrix for beamforming which is fed back from the beamformee cannot be multiplied with the transmission vector.

[0038] First, consider a case where the explicit feedback is performed with a CSI format.

[0039] In a case where the number N of antennas of the STA-A is smaller than or equal to the number M of antennas of the STA-B, no problem is specially caused in the beamformee side. FIG. **18** shows a state where the explicit feedback is performed with a CSI format when N=2 and M=3. The STA-B includes a processing capability of M streams, and can estimate an M×N channel matrix excited by a training signal including N streams and feed back the collected CSI information to the STA-A. The STA-A side can suppress the fedback M×N channel matrix to a range of N rows and compute the transmission weight matrix for beamforming by the singular value decomposition from the N×N channel matrix.

[0040] However, in a case of N>M, problems are caused. This is because, when the STA-B can process only M streams, the STA-B obtains only M×M estimation channel matrix using M packets although the STA-A side transmits the sounding packet for exciting N-dimensional spatial channel matrix. FIG. **19** shows a state where the explicit feedback is performed with the CSI format when N=3 and M=2.

[0041] In the EWC specification, when the explicit feedback is applied, a scheme of informing information on channel estimation maximum dimension is defined as one of the capabilities of the beamformee side. It is defined that the HT terminal corresponding to high-speed transmission declares that it itself is the HT terminal by including a HT capability field in a predetermined management frame.

[0042] FIG. **20** shows a format of a HT capability element. In a TxBF (transmit beamforming) capability field, any HT function of the beamforming is specified. FIG. **21** shows the configuration of the Tx beamforming capability field. The Tx beamforming capability field has 32 bits, but, among them, 19^{th} to 20^{th} bits are allocated to the CSI number of beamformer antennae, 21^{st} to 22^{nd} bits are allocated to the uncompressed steering matrix of beamformer antennae, and 23^{rd} to 24^{th} bits are allocated to the compressed steering matrix of beamformer antennae. In these fields, the spatial dimension number of the sounding packet which can be received from the beamformer when the beamformee performs the explicit feedback with each format is described.

[0043] However, in the EWC specification, since it is not defined which sounding packet is transmitted by the beamformer, the STA-A may transmit the sounding packet for exciting more than M channels even when the STA-B informs of its own maximum dimension number by the above-described scheme and thus the STA-B is forced to estimate M×N channel matrix.

[0044] As a method of solving such problems without deteriorating the beamforming characteristics, it may be considered that a channel estimation maximum dimension N_{max} corresponding to a rated maximum number of antennas is given to the STA-B as the beamformee (for example, if it is based on the IEEE specification, N_{max}=4).

[0045] For example, when the number of antennas of the STA-B is M=2 and the rated maximum number of antennas is N_{max}=4, the STA-B can compute only a 2×2 matrix in consideration of the communication with the terminal having the same number of antenna, but needs to compute a 2×4 matrix. In this case, since calculation or processing circuit needs to be doubled, miniaturization or low cost of the apparatus is hard to be realized.

[0046] The same is also applied to the explicit feedback for feeding back the transmission weight matrix V for beamforming, instead of the CSI format.

[0047] In a case where the number N of antennas of the STA-A is smaller than or equal to the number M of antennas of the STA-B, no problem is specially caused in the beamformee side. FIG. **22** shows a state where the transmission weight matrix V for beamforming is fed back by the explicit feedback when N=2 and M=3. The STA-B includes a processing capability of M streams, and can estimate an M×N channel matrix excited by a training signal including N streams, compute an N×M transmission weight matrix V for beamforming by the singular value decomposition from the estimation channel matrix, and feed backs the transmission weight matrix information to the STA-A. The STA-A side can perform beamforming using the fed-back transmission weight matrix for beamforming.

[0048] However, in a case of N>M, problems are caused. This is because, when the STA-B can process only M streams, the STA-B obtains only an M×M estimation channel matrix using M packets although the STA-A side transmits the sounding packet for exciting N-dimensional spatial channel matrix. FIG. **23** shows a state where the transmission weight matrix V is fed back by the explicit feedback when N=3 and M=2.

[0049] In the EWC specification, when the explicit feedback is applied, a scheme of informing information on channel estimation maximum dimension is defined as one of the capabilities of the beamformee side (described above). However, the STA-A may transmit the sounding packet for exciting more than M channels even when the STA-B informs of its own maximum dimension number by the above-described scheme and thus the STA-B is forced to estimate M×N channel matrix.

[0050] As a method of solving such a problem without deteriorating the beamforming characteristics, it may be considered that a channel estimation maximum dimension N_{max} corresponding to a rated maximum number of antennas is given to the STA-B as the beamformee (for example, if it is based on the IEEE specification, N_{max}=4) and a processing capability which can compute the transmission weight matrix for beamforming is given to the obtained N_{max}×N estimation channel matrix.

[0051] For example, when the number of antennas of the STA-B is M=2 and the rated maximum number of antennas is N_{max}=4, the STA-B can compute only a 2×2 matrix in consideration of the communication with the terminal having the same number of antenna, but must compute a 2×4 matrix. In this case, since calculation or processing circuit needs to be doubled, miniaturization, low cost and low power consumption of the apparatus are hard to be realized.

SUMMARY OF THE INVENTION

[0052] It is desirable to provide an excellent wireless communication system, wireless communication apparatus and wireless communication method, which are capable of performing communication at a high transmission rate by a beamformed packet by allowing a terminal which operates as a beamformer to suitably set a transmission weight matrix on the basis of an estimation channel matrix fed back from a terminal which operates as a beamformee.

[0053] It is also desirable to provide an excellent wireless communication system, wireless communication apparatus and wireless communication method, which are capable of suitably performing beamforming by the explicit feedback without deteriorating beamforming characteristics or increasing a processing capability of channel estimation or a computing capability of a matrix for beamforming in the beamformee even when a beamformer and a beamformee are different from each other in the number of antennas or the number of supported streams.

[0054] According to an embodiment of the invention, there is provided a wireless communication system which performs data transmission using spatially multiplexed streams from a first terminal including N antennas to a second terminal including M antennas (N is an integer of 2 or more and M is an integer of 1 or more), the system including: notifying means for notifying the first terminal of a maximum dimension N_{max} at the time of estimating a channel matrix of the second terminal (N_{max} is an integer of N or less); training means for transmitting a sounding packet including training sequence for exciting a channel corresponding to the maximum dimension N_{max} from the first terminal to the second terminal; in a case of N>M, channel matrix estimation means for dividing the training sequence received by the antennas of the second terminal into N_{max} or less streams and estimating the channel matrix having M rows and N_{max} or less columns; a beamforming information feedback unit which prepares beamforming information necessary for calculating a transmission weight matrix for beamforming in the first terminal on the basis of the channel matrix estimated in the second terminal and feeding back the beamforming information from the second terminal to the first terminal; transmission weight matrix setting means for setting the transmission weight matrix for beamforming at the time of transmitting data from the first terminal to the second terminal on the basis of the beamforming information fed back from the second terminal to the first terminal; and beamforming means for performing beamforming in transmission signals of the antennas of the first terminal using the transmission weight matrix for beamforming when a data packet is transmitted from the first terminal to the second terminal.

[0055] The term "system" described herein indicates a logical set of apparatuses (or function modules for realizing specific functions) and it is not specially considered whether the apparatuses or the function modules are included in a single casing (The same is true in the below description).

[0056] As a technology for realizing a high speed of wireless communication, there is an MIMO communication method which includes a plurality of antenna elements in a transmitter side and a receiver side and realizes spatially multiplexed streams. In particular, in a closed loop type MIMO communication system, a terminal of a data packet transmission side performs beamforming on the basis of feedback of information on an estimation channel matrix from a terminal of a reception side such that a plurality of spatial orthogonal multiplexed propagation channels which are logically independent are realized and the receiver side can extract a plurality of original signal sequence without crosstalk, thereby theoretically accomplishing maximum performance.

[0057] As a procedure of performing feedback of the channel matrix from the terminal of the reception side to the terminal of the transmission side, for example, two kinds of procedures, that is, "implicit feedback" and "explicit feedback", are defined in the EWC HT MAC specification. Among them, in the explicit feedback, the first terminal which operates as a beamformer performs the beamforming of a transmission packet to perform communication using the transmission weight matrix for beamforming based on the channel information fed back from the second terminal which operates as a beamformee. It is possible to reduce a processing burden necessary for performing the beamforming in the beamformer.

[0058] However, when the beamformer and the beamformee are different from each other in the number of antennas or the number of supported streams, there are several problems at the time of the beamforming. This is because the terminal having a smaller number of antennas needs to perform channel estimation, calculation of the transmission weight matrix and the multiplication of the transmission weigh matrix with the dimension number larger than or equal to the number which is considered at the time of designing.

[0059] In particular, in a case where the number N of antennas of the beamformer is larger than the number M of antennas of the beamformee and the STA-B can correspond to at most M streams, the STA-B cannot obtain the estimation channel matrix in spite that the sounding packet for exciting the spatial channel matrix of N dimensions is transmitted from the STA-A, because the STA-B can correspond to at most M×M estimation channel matrix.

[0060] Accordingly, in the wireless communication system according to the embodiment of the invention, when the beamforming is performed according to the explicit feedback, the maximum dimension N_{max} at the time of estimating the channel matrix of the second terminal is notified to the first terminal and the first terminal transmits the sounding packet including the training sequence for exciting the channel corresponding to the maximum dimension N_{max}. Here, "corresponding to the maximum dimension N_{max}" does not indicate that the excited spatial dimension is limited to N_{max}". Generally, it indicates that the second terminal estimates the channel in a format that an estimation process of a dimension larger than $M \times N_{max}$ is not performed. As an example, the below-described staggered sounding packet may be considered. In this case, the entire exciting channel dimension is $N(>N_{max})$, but the training sequence are divided into a part for exciting the channel of N_{max} dimensions and a part for exciting the channel of $N-N_{max}$ dimensions such that the second terminal can perform channel estimation using only the part N_{max} which can be processed. That is, even when the exciting channel space dimension is larger than N_{max}, the sounding packet which is considered such that the channel estimation is possible in the processing capability in consideration of the maximum dimension N_{max} at the time of estimating the channel matrix of the second terminal corresponds to "corresponding to the maximum dimension N_{max}".

[0061] That is, since the first terminal suppresses the number of streams of the channel for exciting the sounding packet according to the processing capability of the second terminal for estimating the channel matrix, the second terminal surely receives the sounding packet in a range of its own maximum dimension number. In this case, it is possible to reduce the size of the channel matrix estimation circuit of the second terminal as the beamformee and to realize low cost or low power consumption of the apparatus.

[0062] The first terminal is designed to include the processing capability corresponding to the number of its own streams and includes the processing capability such as computation for requesting the transmission weight matrix for beamforming from the channel matrix of N×N dimensions or less or multiplication of the transmission vector and the transmission weight matrix for beamforming of N×N dimensions or less. Accordingly, when the CSI information, that is, $M \times N_{max}$ channel matrix, is fed back from the second terminal, the first terminal can compute the transmission weight matrix for beamforming. Alternatively, even when the $M \times N_{max}$ transmission weight matrix for beamforming computed from the channel matrix (in the compressed or uncompressed format) is fed back from the second terminal, the transmission weight matrix for beamforming can be multiplied with the transmission vector in the range of its own processing capability and thus no problem is caused.

[0063] On a protocol according to the EWC specification, in a predetermined management frame, a capability description field for describing a possible maximum spatial dimension when a beamformee of explicit feedback receives a packet including training sequence is defined. Accordingly, the notifying means can notify the first terminal of the maximum dimension N_{max} at the time of estimating the channel matrix of the second terminal using the management frame for describing the capability description field. The management frame is, for example, a type of transmission frame of the beacon which is notified in a frame period, a measure pilot, an association response and a re-association response which respond to the request of association from the client terminal, a probe response which responds to the request of BBS information from the client terminal, or an association request and re-association request for requesting network association by the client terminal (or a communication station other than the access point) and a probe request for requesting BBS information to the access point. Accordingly, even when the second terminal operates as any one of an access point and a client terminal, the notifying means can perform notification.

[0064] The beamformer may include a signal for requesting the CSI information in the sounding packet including the training sequence for exciting the channel. In particular, the CSI information may be requested by specifying the feedback method received from the beamformee in the explicit feedback, in the CSI/Steering field provided in the HT control field of the MAC frame. Accordingly, the training means may include a request signal for requesting feedback of the channel information from the first terminal to the second terminal in the sounding packet for exciting the channel.

[0065] In the EWC specification, a zero length frame (ZLF) (also called a null data packet (NDP) and hereinafter referred to as "ZLF") dedicated to the sounding packet, which includes only a PHY header part including the training sequence for exciting the channel and does not include an MAC frame, is defined. Since the ZLF does not have the MAC header, the CSI information cannot be requested by the HT control field. In such a case, the training means does not include the signal for requesting the CSI information in the sounding packet and requests the CSI information in the HT control field of a general packet transmitted prior thereto.

[0066] It is possible to reduce an operation amount necessary for estimating the channel matrix by transmitting the sounding packet in a staggered format for temporally dividing a training signal part used for a space division process of a data part and a training signal for exciting a channel of a spatial dimension larger than or equal to the number of streams of data from the first terminal to the second terminal.

[0067] In particular, the first terminal excites the channel of N_{max} spatial dimensions in a training signal part used for the space division process of the data part and allows a training signal for exciting the channel of $N-N_{max}$ remaining spatial dimensions to be not related to the space division of the signal, with respect to the sounding packet.

[0068] In this case, when the second terminal receives the sounding packet, the channel of N_{max} spatial dimensions is excited to estimate $M \times N_{max}$ channel matrix in the training signal part used for the space division process of the data part, but the training signal for exciting the channel of $N-N_{max}$ remaining spatial dimensions does not need to be processed. Although a part attached to the end of the training is not processed in order to excite remaining $N-N_{max}$ channels, no problem is caused in channel estimation or data symbol demodulation.

[0069] If the direct mapping for mapping one antenna branch to each transmission stream is performed when the first terminal transmits the sounding packet with the stream suppressed to the maximum dimension N_{max} or less which is allowed by the second terminal, the beamforming effect deteriorates. Since the first terminal includes N antennas but does not use all the antennas and the beamforming must be originally performed with respect to the $M \times N$ channel matrix but the dimension number is suppressed to $M \times N_{max}$, a beam gain is reduced and thus a transmission diversity gain is also reduced. The transmission power of N_{max} antenna branches used for transmission increases and distortion of the signal increases in a transmission end.

[0070] When the dimension number of the sounding packet is suppressed, for example, the first terminal may perform conversion for mapping N_{max} spatial streams to all N transmission antenna branches by a spatial expansion and compensate the deterioration of the characteristics by the transmission diversity. For example, it is possible to perform the mapping to the transmission signals to all N transmission antenna branches by multiplying the sounding packet of N_{max} dimensions specified from the second terminal by an $N \times N_{max}$ mapping matrix.

[0071] Correlation between the transmission antenna branches may not be sufficiently reduced by the multiplication of the mapping matrix. Accordingly, the first terminal may give different cyclic shift delay amounts to the transmission antenna branches after the multiplication of the mapping matrix. The undesired beamforming may be performed when identical or similar signals are transmitted through different spatial streams. However, it is possible to reduce the correlation between the transmission antenna branches to reduce the undesired directional characteristics. The cyclic shift delay described herein is an operation for cutting out a part of the time axis waveform of the OFDM symbol and fitting the part to the opposite end (corresponding to phase rotation on a frequency axis) (see FIG. **10**), which is different from the simple delay of the transmission timing between the transmission antenna branches.

[0072] When the first terminal performs the conversion for mapping the N_{max} spatial streams to all the N transmission antenna branches, other mapping to the transmission antenna branches may be performed in the subcarrier unit, as shown in FIG. **11**. In this case, since the correlation between the transmission antenna branches is high in the subcarrier unit, the cyclic shift delay may be used together, as described above.

[0073] According to the embodiment of the invention, it is possible to an excellent wireless communication system, wireless communication apparatus and wireless communication method, which are capable of performing communication at a high transmission rate by a beamformed packet by allowing a terminal which operates a beamformer to suitably set a transmission weight matrix on the basis of an estimation channel matrix fed back from a terminal which operates as a beamformee.

[0074] According to the embodiment of the invention, it is possible to provide an excellent wireless communication system, wireless communication apparatus and wireless communication method, which are capable of suitably performing beamforming by the explicit feedback without deteriorating beamforming characteristics or increasing a processing capability of channel estimation or a computing capability of a matrix for beamforming in the beamformee even when a beamformer and a beamformee are different from each other in the number of antennas or the number of supported streams.

[0075] According to the wireless communication system of the embodiment of the invention, it is possible to reduce complexity of the circuit or power consumption of a communication terminal which is the beamformee by suppressing the dimension number of the sounding packet transmitted from the beamformer according to the processing capability of the beamformee when the explicit feedback for feeding back CSI information or transmission weight matrix for beamforming is performed, even if the number of antennas of the beamformer is larger than the number of antennas of the beamformee.

[0076] According to the embodiment of the invention, it is possible to perform the beamforming while maintaining the transmission diversity effect to some extent by mapping transmission streams to all transmission antenna branches when suppressing the dimension number of the sounding packet transmitted from the beamformer.

[0077] The other objects, features and advantages of the invention will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0078] FIG. **1**A is a schematic diagram of an operation procedure (in a case where CSI information is fed back) of explicit feedback according to an embodiment of the invention.

[0079] FIG. **1**B is a schematic diagram of an operation procedure (in a case where a transmission weight matrix for beamforming is fed back) of the explicit feedback according to an embodiment of the invention.

[0080] FIG. **2** is a view showing the configuration of a transmitter side of a wireless communication apparatus which can operate as a STA-A (or STA-B) in a wireless communication system shown in FIGS. **1**A and **1**B.

[0081] FIG. **3** is a view showing the configuration of a receiver side of the wireless communication apparatus which can operate as the STA-A (or STA-B) in the wireless communication system shown in FIGS. **1**A and **1**B.

[0082] FIG. **4**A is a view showing an example of a transmission operation of a ZLF packet.

[0083] FIG. **4**B is a view showing an example of the transmission operation of the ZLF packet.

[0084] FIG. **5** is a view showing a format example of a staggered sounding packet.

[0085] FIG. **6** is a view showing a format example of the staggered sounding packet.

[0086] FIG. **7** is a view showing a format example of the staggered sounding packet.

[0087] FIG. **8** is a view showing a format example of the staggered sounding packet.

[0088] FIG. **9** is a view showing a format example of the staggered sounding packet.

[0089] FIG. **10** is a view showing a state where a cyclic shift delay is applied to an OFDM symbol.

[0090] FIG. **11** is a view showing an example of performing mapping to transmission antennas in a subcarrier unit when the number of antennas of the STA-A is N=3 and the number of antennas of the STA-B is M=2.

[0091] FIG. **12** is a flowchart illustrating a process when an apparatus operates as a beamformer on the basis of the explicit feedback procedure.

[0092] FIG. **13** is a flowchart illustrating a process when the apparatus operates as the beamformer on the basis of the explicit feedback procedure.

[0093] FIG. **14** is a view showing a state where a beamformee estimates a channel matrix excited by a training signal transmitted from a beamformer.

[0094] FIG. **15** is a view showing a frame exchange procedure for transmitting beamforming from an access point to a client terminal with the explicit feedback.

[0095] FIG. **16** is a view showing a scheme of a HT control field of an MAC frame defined in the EWC specification.

[0096] FIG. **17** is a view showing a scheme of a CSI/steering field included in the HT control field.

[0097] FIG. **18** is a view showing a state where the explicit feedback is performed with a CSI format.

[0098] FIG. **19** is a view showing a state where the explicit feedback is performed with the CSI format.

[0099] FIG. **20** is a view showing a format of a HT capability element.

[0100] FIG. **21** is a view showing the configuration of a Tx beamforming capability field included in the HT capability element.

[0101] FIG. **22** is a view showing a state where a transmission weight matrix V for beamforming is fed back by the explicit feedback.

[0102] FIG. **23** is a view showing the state where the transmission weight matrix V for beamforming is fed back by the explicit feedback.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0103] Hereinafter, embodiments of the invention will be described in detail with reference to the accompanying drawings.

[0104] A wireless communication system according to the embodiment of the invention performs closed loop type MIMO communication and more particularly, a terminal of a transmitter side performs beamforming in order of performing feedback for a channel matrix, for example, in order of the "explicit feedback" defined in the EWC HT MAC specification. In the explicit feedback, a beamformer beamforms a transmission packet using a transmission weight matrix for beamforming obtained on the basis of an estimation channel matrix fed back from a beamformee so as to perform communication.

[0105] However, a processing capability for performing channel estimation or a processing capability for computing a matrix for beamforming is given to a terminal in consideration of the number of its own antennas. Accordingly, if the number of antennas of the beamformer is large, the beamformee may not divide the packet into spatial stream trainings to estimate the channel matrix or obtain the matrix for beamforming from the estimation channel matrix because the spatial dimension number is large even when the beamformer transmits a sounding packet to excite the channel.

[0106] Accordingly, in the wireless communication system according to the embodiment of the invention, when the beamforming is performed by the explicit feedback, a maximum dimension N_{max} of the beamformee at the time of the channel matrix estimation is notified to the beamformer, and the sounding packet transmitted from the beamformer is excited such that the spatial dimension number of the channel to be estimated by the beamformee is suppressed to the maximum N_{max} or less. Accordingly, since the beamformee surely receives the sound packet in a range of its own capability, the size of a channel matrix estimation circuit can be reduced and low cost or low power consumption of an apparatus can be realized.

[0107] FIG. **1**A is a schematic diagram of an operation procedure of the explicit feedback according to the embodiment of the invention. Here, the number of antennas of a STA-A as the beamformer is 3 and the number of antennas of a STA-B as the beamformee or the maximum spatial dimension number at the time of computing the transmission weight matrix for beamforming is 2. The procedure is performed on the basis of the EWC MAC specification.

[0108] The STA-B previously notifies the STA-A that the maximum dimension number at the time of estimating the channel matrix is 2. The STA-A excites the channel to a format in which the spatial dimension of the channel to be estimated by the STA-B is 2×2 and transmits the sounding packet to the STA-B using two streams.

[0109] Since the STA-B receives the sounding packet in the range of its own capability, a 2×2 forward estimation channel matrix can be easily generated. CSI information composed of coefficients of the estimation channel matrix is prepared and fed back to the STA-A using two streams.

[0110] Since the STA-A receives the fed-back CSI information using three antennas, the information is received in a 3×2 spatial dimension, but is property processed because the STA-A is designed to include a processing capability corresponding to the number of its own streams. When the 2×2 channel matrix is extracted from the CSI information, computation such as singular value decomposition is performed such that a 2×2 transmission weight matrix V for beamforming can be easily obtained.

[0111] The STA-A multiplies a two-dimensional transmission vector by the 2×2 transmission weight matrix V for beamforming to perform beamforming and transmits two transmission streams in order to transmit a data packet. Alternatively, two transmission streams are mapped to three antennas by space expansion to perform the beamforming in a state where transmission diversity effect is maintained to some extent.

[0112] Thereafter, a request of the sounding packet and the channel estimation and the computation of the transmission weight matrix for beamforming due to the reception of the sounding packet are repeatedly performed whenever the STA-A performs the beamforming.

[0113] Since the STA-B surely receives the sounding packet in the range of its own capability, the size of the channel matrix estimation circuit can be reduced and low cost or low power consumption of the apparatus can be realized.

[0114] FIG. **1**B is a schematic diagram of an operation procedure of the explicit feedback when the transmission weight matrix V for beamforming is fed back, instead of the CSI information. Here, the number of antennas of the STA-A is **3** and the number of antennas of the STA-B and the maximum spatial dimension number at the time of computing the transmission weight matrix for beamforming are 2.

[0115] The STA-B previously informs the STA-A that the maximum dimension number at the time of estimating the channel matrix is 2. The STA-A excites the channel to a format in which the spatial dimension of the channel to be estimated by the STA-B is 2×2 and transmits the sounding packet to the STA-B using two streams.

[0116] Since the STA-B receives the sounding packet in the range of its own capability, a 2×2 forward estimation channel matrix can be easily generated. The 2×2 transmission weight matrix V for beamforming is obtained by performing the computation such as the singular value decomposition from the 2×2 channel matrix and fed back to the STA-A using two streams.

[0117] Since the STA-A receives the fed-back information using three antennas, the information is received in a 3×2 spatial dimension, but is property processed to extract the transmission weight matrix V for beamforming because the STA-A is designed to include a processing capability corresponding to the number of its own streams.

[0118] Since the spatial dimension number 2×2 of the transmission weight matrix V for beamforming is in the range of the capability of the STA-A having three antennas, the 2×2 transmission weight matrix V for beamforming can be easily multiplied with the two-dimensional transmission vector, the beamforming is performed and two transmission streams are transmitted in order to transmit a data packet. Alternatively, two transmission streams are mapped to three antennas by space expansion to perform the beamforming in a state where transmission diversity effect is maintained to some extent.

[0119] Thereafter, the request of the sounding packet, and the channel estimation and the computation of the transmission weight matrix for beamforming due to the reception of the sounding packet are repeatedly performed whenever the STA-A performs the beamforming.

[0120] Since the STA-B surely receives the sounding packet in the range of its own capability, the size of the channel matrix estimation circuit can be reduced and low cost or low power consumption of the apparatus can be realized.

[0121] In the operation procedure shown in FIGS. **1**A and **1**B, the STA-B needs to notify the STA-A of the maximum dimension number 2 at the time of estimating the channel matrix. In the EWC specification, when the explicit feedback is applied, a scheme of informing of information on the channel estimation maximum dimension as one of the capability of the beamformee is determined and can be used.

[0122] In the EWC specification, it is defined that the HT terminal corresponding to the high-speed transmission transmits a HT capability element to declare that it is the HT terminal. The HT terminal may include a HT capability field in a predetermined management frame and declare any element of a HT function by the HT capability element.

[0123] In the TxBF (transmit beamforming) capability field (see FIG. **21**) included in the format of the HT capability element, any HT function of the beamforming (see FIG. **20**) is specified.

[0124] The Tx beamforming capability field has 32 bits, but, among them, 19^{th} to 20^{th} bits are allocated to the CSI number of beamformer antennae, 21^{st} to 22^{nd} bits are allocated to the uncompressed steering matrix of beamformer antennae, and 23^{rd} to 24^{th} bits are allocated to the compressed steering matrix of beamformer antennae. In these fields, the spatial dimension number of the sounding packet which can be received from the beamformer when the beamformee performs the explicit feedback with each format is described.

[0125] The HT capability element may be included in the predetermined management frame. For example, when the STA-B operates as the access point, the HT capability field may be included in a type of transmission frame of the beacon which is notified in each frame period, a measure pilot, an association response and a re-association response which respond to the request of association from the client terminal, or a probe response which responds to the request of BBS information from the client terminal such that the dimension number of the CSI information is notified to the STA-A which participates in the network operated by the STA-B. When the STA-B operates as the client terminal (or a communication station other than the access point), the HT capability field may be included in a type of transmission frame of an association request and re-association request for requesting network association to the STA-A which operates as the access point and a probe request for requesting BBS information to the access point. Accordingly, when the STA-B operates as the access point or the client terminal, the maximum dimension which is allowed in the CSI information may be notified to the STA-B, by transmitting the HT capability element.

[0126] In the beamforming procedure shown in FIGS. **1**A and **1**B, the STA-A as the beamformer includes a signal for requesting the CSI information in the sounding packet including training sequence for exciting the channel. In particular, in a CSI/Steering field provided in the HT control field (see FIG. **16**) of the MAC frame, a feedback method received from the beamformee can be specified in the explicit feedback (see FIG. **17**).

[0127] In the EWC specification, a zero length frame (ZLF) dedicated to the sounding packet, which includes only a PHY header part including the training sequence for exciting the channel and does not include an MAC frame, is defined. Since the ZLF does not have the MAC header, the CSI information cannot be requested by the HT control field. In such a case, the signal for requesting the CSI information is not included in the sounding packet and the CSI information is requested in the HT control field of a general packet transmitted prior thereto.

[0128] FIG. **4**A shows an example of a transmission operation of the ZLF packet. As shown, the ZLF packet is transmitted when a short interframe space (SIFS) or a reduced inter frame space (RIFS) elapses after a general data packet is transmitted. In the HT control field in the MAC header included in the general data packet, the CSI request for the subsequent ZLF packet is performed by specifying the CSI/Steering field.

[0129] In an example shown in FIG. **4**B, the STA-A requests of the feedback of the CSI information in the data frame for requesting an immediate response, but declares that the ZLF is continuously transmitted therein. When the STA-B returns an ACK according to the immediate response, the STA-A transmits the ZLF when the SIFS elapses after the ACK is received.

[0130] Up to now, the STA-A which suppresses the spatial dimension number of the channel excited according to the processing capability of the STA-B and transmits the sounding packet was described. As a packet transmission method for suppressing the spatial dimension of the channel, there is a staggered format.

[0131] The staggered packet has a training signal part used for a space division process of a data part and a packet structure for temporally dividing a training signal for exciting a channel of the spatial dimension larger than or equal to the number of streams of data and the receiver side reduces an operation amount necessary for estimating the channel matrix.

[0132] The STA-A excites the channel of N_{max} spatial dimensions corresponding to the processing capability of the STA-B in a training signal part used for the space division process of the data part and allows a training signal for exciting the channel of $N-N_{max}$ remaining spatial dimensions to be not related to the space division of the signal, with respect to the sounding packet. In this case, when the STA-B receives the sounding packet, the channel of N spatial dimensions is excited to estimate $M\times N_{max}$ channel matrix in the training signal part used for the space division process of the data part, but the training signal for exciting the channel of $N-N_{max}$ remaining spatial dimensions does not need to be processed. Although a part attached to the end of the training is not processed in order to excite remaining $N-N_{max}$ channels, no problem is caused in channel estimation or data symbol demodulation.

[0133] Now, the procedure of the explicit feedback when the sounding packet of the staggered format is used will be described. For simplification of the description, although a case where each stream is directly mapped to each antenna branch will be described, the invention is not limited to the case.

[0134] FIG. **5** shows a format example of the staggered sounding packet when the beamformee having three antennas transmits data of one stream.

[0135] A HT-STF (short training field) is a training symbol for improving automatic gain control (AGC) in the MIMO system, which includes QPSK-modulated OFDM signals of 52 tones. A HT-LTF (long training field) is a training symbol for performing the channel estimation for each input signal which is spatially modulated in the receiver side, which includes BPSK-modulated OFDM signals of 56 tones. These are training signals defined in a HT mode of the EWC specification. A value of −400 nsec which is described in the HT-LTF simultaneously transmitted from a third antenna is a cyclic shift delay amount which is provided in order to avoid unintended beamforming when identical or similar signals are transmitted through different spatial streams, which shifts and connects a time axis wavelength of an OFDM symbol sent from the third antenna by −400 nanoseconds.

[0136] In the example shown in FIG. **5**, one stream is transmitted with a format having a data stream, but, with a temporal separation therefrom, training signals for exciting the channel of the remaining spatial dimension are transmitted from the other two antennas which are not used for the space division process of the data part.

[0137] FIG. **6** shows a format example of the staggered sounding packet when data of one stream is transmitted from the beamformee having four antennas. In the shown example, one stream is transmitted with the format having the data stream and, with a temporal separation therefrom, the training signals for exciting the channel of the remaining spatial dimension are transmitted from the other three antennas which are not used for the space division process of the data part. In the current EWC specification, it is defined that four HT-LTFs are used in the training of three streams.

[0138] FIG. **7** shows a format example of the staggered sounding packet when data of two streams is transmitted from the beamformee having three antennas. In the shown example, two streams are transmitted with the format having the data stream and, with a temporal separation therefrom, the training signals for exciting the channel of the remaining spatial dimension are transmitted from the other one antenna which is not used for the space division process of the data part.

[0139] FIG. **8** shows a format example of the staggered sounding packet when data of two streams is transmitted from the beamformee having four antennas. In the shown example, two streams are transmitted with the format having the data stream and, with a temporal separation therefrom, the training signals for exciting the channel of the remaining spatial dimension are transmitted from the other two antennas which are not used for the space division process of the data part.

[0140] FIG. **9** shows a format example of the staggered sounding packet when data of three streams is transmitted from the beamformee having four antennas. In the shown example, three streams are transmitted with the format having the data stream and, with a temporal separation therefrom, the training signals for exciting the channel of the remaining spatial dimension are transmitted from the other one antenna which is not used for the space division process of the data part. In the current EWC specification, it is defined that four HT-LTFs are used in the training of three streams.

[0141] As can be seen from FIGS. **5** to **9**, in a wireless communication apparatus in which the number of antennas is two and the maximum number of estimatable streams is two, the reception of the data part (payload) of the packet and the estimation of a necessary channel matrix are in the processing capability range which is considered upon designing, when the staggered sounding packet has the structure shown in FIG. **5**, **7** or **8**. FIG. **6** shows the staggered sounding packet of one stream, which is not suitably applied to the invention.

[0142] In a wireless communication apparatus in which the number of antennas is three and the maximum number of estimatable streams is three, the reception of the staggered sounding packet shown in FIGS. **5** to **9** and the estimation of a necessary channel matrix are in the processing capability range which is considered upon designing. In a wireless communication apparatus in which the maximum number of streams is three, the specification in which four HT-LTFs are received and the channel estimation of three streams is performed therefrom is originally requested and no problem is caused in the structure of the apparatus.

[0143] As can be seen from FIGS. **5** to **9**, when the number N of antennas in a initiator of the sounding packet (that is, the terminal which operates the beamformer in the explicit feedback) is larger than the number M of antennas in a receiver of the sounding packet (that is, the terminal which operates as the beamformee in the explicit feedback), the beamformee can selectively estimate only necessary M streams without performing the channel estimation of N streams (that is, without preparing an M×N channel matrix), by suitably using the staggered format.

[0144] If the beamformer includes four antennas and the beamformee includes two antennas, a circuit burden of the beamformer may not be reduced although the staggered sounding packet of the frame format shown in FIG. **6** is used. No problem is caused in the channel estimation from training (HT-LTF) of a first stream, but, in order to estimate the channel with respect to one stream, four HT-LTFs of the other three streams which are not used for the space division process of the data part transmitted with a temporal separation therefrom needs to be computed. Thus, the size of the circuit of the beamformee which can support at most two streams increases.

[0145] When the beamformer includes three antennas and the beamformee includes two antennas, the staggered sounding packet of the frame format shown in FIG. **5** or **7** is used.

[0146] When the sounding packet shown in FIG. **7** is transmitted from the beamformer, the beamformee can estimate the channel of two spatial dimensions necessary for the beamforming using the training signal part in a reception stream of the first to second antennas used for the space division of the data part. Since the reception streams of the third to fourth antennas which are not used for the space division of the data part transmitted with temporal separation do not need to be processed, the problem that the size of the circuit increases in the beamformee which can support at most two streams is not caused. No problem is caused in the channel estimation or the data symbol demodulation although the part attached to the end of the training is not processed in order to excite the third to fourth channels.

[0147] When the sounding packet shown in FIG. **5** is transmitted from the beamformer, the beamformee first estimates the channel using the training signal part in a reception stream of the first antennas used for the space division of the data part. However, two HT-LTF in each of the other two streams, which are not used for the space division of the data part transmitted with the temporal separation, needs to be processed, in order to estimate the channel with respect to one stream. The channel estimation of a 2×2 matrix may be performed from two HT-LTFs and the channel estimation of the other one stream may be performed. However, in this case, since the channel estimation result of a first stream needs to be buffered in another place, the size of the circuit slightly increases compared with the case shown in FIG. **7** which the buffer is not needed.

[0148] As another example, when the beamformer includes four antennas and the beamformee includes three antennas, the staggered sounding packet of the frame format shown in FIG. **6**, **8** or **9** is used.

[0149] When the sounding packet of the frame format shown in FIGS. **6** and **8** is used, as described above, the channel estimation is performed without a problem, but there is a problem that the channel estimation result of first one or two stream needs to be buffered in another place. When the sounding packet of the frame format shown in FIG. **9** is used, the beamformee can estimate the channel of two spatial dimensions necessary for the beamforming using the training signal part in a reception stream of the first to third antennas used for the space division of the data part. Since the reception stream of the fourth antenna which is not used for the space division of the data part transmitted with the temporal separation does not need to be processed, the problem that the size of the circuit increases in the beamformee which can support at most three streams is not caused. No problem is caused in the channel estimation or the data symbol demodulation although the part attached to the end of the training is not processed in order to excite the fourth channel.

[0150] However, if the direct mapping for mapping one antenna branch to each transmission stream is performed when the STA-A transmits the sounding packet with the stream suppressed to the maximum dimension N_{max} or less which is allowed by the STA-B, the beamforming effect deteriorates. Since the STA-A includes N antennas but does not use all the antennas and the beamforming must be originally performed with respect to the M×N channel matrix but the dimension number is suppressed to $M \times N_{max}$, a beam gain is reduced and thus a transmission diversity gain is also reduced. The transmission power of N_{max} antenna branches used for transmission increases and distortion of the signal increases in a transmission end.

[0151] With respect to such a problem, when the dimension number of the sounding packet is suppressed, for example, the STA-A may perform conversion for mapping N_{max} spatial streams to all N transmission antenna branches by a spatial expansion and compensate the deterioration of the characteristics by the transmission diversity. For example, it is possible to preform the mapping of to all N transmission antenna branches by multiplying the sounding packet of N_{max} dimensions specified from the STA-B by and $N \times N_{max}$ mapping matrix.

[0152] For example, when the number of antenna of the STA-A is N=3 and the number of antennas of the STA-B is M=2, the dimension number is suppressed to the two-dimensional transmission streams (s_1, s_2) in order to transmit the sounding packet from the STA-A, but the transmission signal can be, for example, mapped to three transmission antennas by a mapping matrix E described below.

$$E = \begin{pmatrix} a & b \\ c & d \\ e & f \end{pmatrix} \tag{5}$$

[0153] That is, in the STA-A, a three-dimensional transmission vector is obtained by the two-dimensional transmission stream (s_1, s_2) by the 3×2 mapping matrix E. The STA-B receives the two-dimensional stream (r_1, r_2) by propagating the channel composed of 2×3 dimension shown Equation 2.

$$\begin{pmatrix} r_1 \\ r_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \end{pmatrix} \begin{pmatrix} a & b \\ c & d \\ e & f \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \end{pmatrix} \tag{6}$$

[0154] When the stream conversion is performed at the time of transmitting the sounding packet, the same mapping matrix E needs to be multiplied even when the beamforming is performed to transmit the data stream.

[0155] When the transmission streams are mapped to the transmission branches using the mapping matrix, there is a typical problem that undesired directional characteristics occur due to strong correlation between the signals when the signals are transmitted from the antennas. In order to avoid this problem, it is preferable that an orthogonal matrix is used such that the correlation between the antenna transmission signals is reduced, if possible.

[0156] For example, when two streams are mapped to four transmission antenna branches, the following mapping matrix is multiplied.

$$\begin{pmatrix} 1/2 & 1/2 \\ 1/2 & -1/2 \\ 1/2 & -1/2 \\ 1/2 & 1/2 \end{pmatrix} \quad (7)$$

As a non-orthogonal example, when two streams are mapped to three transmission antenna branches, the following mapping matrix is multiplied.

$$\begin{pmatrix} 1/\sqrt{3} & 1/\sqrt{3} \\ 1/\sqrt{3} & -1/\sqrt{3} \\ 1/\sqrt{3} & 1/\sqrt{3} \end{pmatrix} \quad (8)$$

[0157] The correlation between the transmission antenna branches may not be sufficiently reduced by only the multiplication of the mapping matrix. In the STA-A, different cyclic shift delay amounts may be given to the transmission antenna branches after the multiplication of the mapping matrix. When identical or similar signals are transmitted through different spatial streams, an unintended beam may be formed, but the correlation between the transmission antenna branches can be reduced by giving the different cyclic shift delay amounts, thereby reducing undesired directional characteristics.

[0158] For example, when a valid symbol length of an OFDM symbol is about 3.2 microseconds and a guard interval is about 800 microseconds, the cyclic shift delay amounts, that is, 0 nanoseconds, 50 nanoseconds, 100 nanoseconds and 150 nanoseconds, are given to four transmission antenna branches such that the correlation between the transmission signals from the antennas can be reduced to reduce occurrence of the directional characteristics. In this case, the cyclic shift delay amounts may be described as described below.

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \exp(-j2\pi k\Delta_F 50nsec) & 0 & 0 \\ 0 & 0 & \exp(-j2\pi k\Delta_F 100nsec) & 0 \\ 0 & 0 & 0 & \exp(-j2\pi k\Delta_F 150nsec) \end{pmatrix} \quad (9)$$

[0159] In the above equation, Δ_F is a subcarrier interval and k is a serial number of the subcarrier. It is possible to simply realize mapping from the streams to the transmission antenna branches by multiplying the above-described mapping matrix E by such a matrix from the left (corresponding to the procedure of giving the cyclic shift delay after the multiplication of the mapping matrix), and it is possible to reduce the correlation between the transmission signals of the antennas to reduce the undesired directional characteristics. Such a conversion scheme is called “spatial expansion” defined in the EWC specification.

[0160] The cyclic shift delay described herein is an operation for cutting out a part of the time axis waveform of the OFDM symbol and fitting the part to the opposite end (corresponding to phase rotation on a frequency axis) (see FIG. **10**), which is different from the simple delay of the transmission timing between the transmission antenna branches.

[0161] In the STA-A, when the conversion for mapping the N_{max} spatial streams to all the N transmission antenna branches, other mapping to the transmission antenna branches may be performed in the subcarrier unit. FIG. **11** is a view showing an example of performing mapping to transmission antennas in a subcarrier unit when the number of antennas of the STA-A is N=3 and the number of antennas of the STA-B is M=2. In this case, since the correlation between the transmission antenna branches is high in the subcarrier unit, the cyclic shift delay may be used together, as described above.

[0162] FIGS. **2** and **3** show the configurations of the transmitter and the receiver of a wireless communication apparatus which can operate as the STA-A (or the STA-B) in the wireless communication system shown in FIG. **1**, respectively. The number of antennas of the STA-A is N (the number of antennas of the STA-B is M) and N (or M) is at most four, for example, on the basis of the IEEE specification, but only two antennas are shown in the figures in order to avoid conflict of the figures.

[0163] Transmission data supplied to a data generator **100** is scrambled by a scrambler **102**. Subsequently, error correction encoding is performed by an encoder **104**. For example, in the EWC HT PHY specification, the scrambling and encoding methods are defined according to the definition of the IEEE 802.11a. The encoded signal is input to a data division unit **106** to be divided into the transmission streams.

[0164] In a case where the apparatus operates as the beamformer, the data generator **100** generates an MAC frame for describing the request of CSI information when performing the explicit feedback. In a case where the apparatus operates as the beamformee, a channel matrix estimation unit **216*a*** of the receiver constructs a data frame including the CSI information on the basis of the estimated channel matrix, in response to the reception of the CSI information request. Alternatively, compressed or uncompressed data frame composed of transmission weigh matrix coefficients for beamforming calculated from the estimation channel matrix may be constructed.

[0165] In each transmission stream, the transmission signal is punctured by a puncture **108** according to a data rate applied to each stream, interleaved by an interleaver **110**, mapped to an IQ signal space by a mapper **112**, thereby becoming a conjugate baseband signal. In the EWC HT PHY specification, an interleaving scheme expands the definition of the IEEE 802.11a such that the same interleaving is not performed among a plurality of streams. As the mapping scheme, BPSK, QPSK, 16QAM or 64QAM is applied according to the IEEE 802.11a.

[0166] A selector **111** inserts the training sequence into the transmission signal of each interleaved spatial stream at an adequate timing and supplies it to the mapper **112**. The training sequence include the HT-STF for improving the AGC in the MIMO system and the HT-LTF for performing the channel estimation for each input signal which is spatially modulated in the receiver side. For example, in the HT-LTF, the training sequence of each the transmission stream is inserted with the staggered format.

[0167] When the beamforming is performed with respect to the transmission signal, in a spatial multiplexer **114**, a beamforming transmission weight matrix computation unit **114***a* calculates the transmission weight matrix V for beamforming from the channel matrix H using a computation method such as the singular value decomposition and a transmission weight matrix multiplication unit **114***b* multiplies the transmission vector having the transmission streams as the element by the transmission weight matrix V set by the transmission weight matrix setting unit **114***a*, thereby performing the beamforming. In order to transmit the sounding packet, the beamforming is not performed with respect to the transmission signal.

[0168] When the CSI information is fed back from the beamformee, the transmission weight matrix setting unit **114***a* calculates the transmission weight matrix V for beamforming on the basis of the CSI information and sets it to the transmission weight matrix multiplication unit **114***b*. When the compressed or uncompressed transmission weight matrix V for beamforming is fed back from the beamformee, it is set to the transmission weight matrix multiplication unit **114***b* without change.

[0169] An inverse fast Fourier transform unit (IFFT) **115** converts the subcarriers arranged in a frequency region into a time axis signal.

[0170] A stream number adjustment unit **116** adjusts the number of transmission streams to the maximum dimension N_{max} or less which is received from the STA-B as the beamformee. When the direct mapping is performed, from the problem that the beamforming effect deteriorates, the transmission signals may be mapped to all the N transmission antenna branches by multiplication of the $N \times N_{max}$ mapping matrix and the deterioration of the characteristics may be compensated by the transmission diversity. Occurrence of the undesired directional characteristics may be reduced by giving the different cyclic shift delay amounts to the transmission branches. The stream number adjustment unit **116** may be realized by first multiplying the transmission vector by the mapping matrix and then multiplying it by a matrix for cyclic shift delay.

[0171] A guard insertion unit **118** adds a guard interval. A digital filter **120** performs band limitation, a DA converter (DAC) **122** converts it into an analog signal, and an RF unit **124** up-converts the analog signal to an adequate frequency band and transmits it to the channel through each transmission antenna.

[0172] Meanwhile, the data which reaches the receiver through the channel is analog-processed in an RF unit **228**, converted into a digital signal by an AD converter (ADC) **226**, and input to a digital filter **224**, in each reception antenna branch.

[0173] Subsequently, a synchronization circuit **222** performs processes including packet detection, timing detection and frequency offset correction and a guard removing unit **220** removes the guard interval added to the top of the data transmission section. The fast Fourier transform unit (FFT) **218** transforms a time axis signal to a frequency axis signal.

[0174] A space division unit **216** performs a space division process of the spatially multiplexed reception signal. In particular, a channel matrix estimation unit **216***a* divides the spatial stream training included in the PHY header of the sounding packet and constructs an estimation channel matrix H from the training sequence.

[0175] An antenna reception weight matrix computation unit **216***b* calculates an antenna reception weight matrix W on the basis of the channel matrix H obtained by the channel matrix estimation unit **216***a*. In a case where the beamforming is performed with respect to the reception packet and the estimation channel matrix is subjected to the singular value decomposition (see Equation 3), the estimation channel matrix becomes equal to an UD and the antenna reception weight W is calculated therefrom. A method of calculating the antenna reception weight W is not limited to the singular value decomposition and a calculation method such as zero forcing or MMSE may be used. An antenna reception weight matrix multiplication unit **216***c* multiplies the reception vector having the reception streams as the element by the antenna reception weight matrix W to perform spatial decoding of the spatial multiplexed signal, thereby obtaining independent signal sequence for each stream.

[0176] In the explicit feedback, when the apparatus operates as the beamformee, the CSI information is constructed from the estimation channel matrix H obtained by the channel matrix estimation unit **216***a* and fed back from the transmitter side to the beamformer as the transmission data. When the transmission weight matrix V for beamforming is requested from the beamformer instead of the CSI information, the matrix V obtained by performing the singular value decomposition with respect to the estimation channel matrix H in the antenna reception weight matrix computation unit **216***b* is fed back.

[0177] A channel equalization circuit **214** performs remaining frequency offset correction and channel tracking with respect to the signal sequence of each stream. A demapper **212** demaps the reception signal on the IQ signal space, a deinterleaver **210** performs deinterleaving, and a depuncture **208** performs depuncturing at a predetermined data rate.

[0178] A data synthesis unit **206** synthesizes a plurality of reception streams to one stream. This data synthesis process performs an operation which is opposed to the data division performed in the transmitter side. A decoder **204** performs error correction decoding, a descrambler **202** performs descrambling, and a data acquiring unit **200** acquires the reception data.

[0179] When the apparatus operates as the beamformer, the CSI information acquired by the data acquiring unit **200** or the compressed/uncompressed transmission weight matrix V for beamforming is sent to the transmission weight matrix setting unit **114***a* of the transmitter side when the explicit feedback is performed.

[0180] When the wireless communication apparatus operates as the terminal of the data transmission side, that is, the beamformee, in the closed loop type MIMO communication, the beamformee notifies the beamformer of its own allowable maximum dimension N_{max} and the spatial dimension number of the channel excited by the sounding packet transmitted from the beamformer is suppressed to the maximum dimension N_{max} or less. Accordingly, since the beamformee surely receives the sounding packet in the range of its own capability, it is possible to reduce the size of the circuit of the channel matrix estimation unit **216***a* and to realize low cost or low power consumption of the apparatus.

[0181] FIG. **12** is a flowchart illustrating a process when the wireless communication apparatus shown in FIGS. **2** and **3** operates as the initiator, that is, the beamformer, on the basis of the explicit feedback procedure. Here, it is assumed that the number of antennas of the beamformer is N and the number of antennas of the beamformee is M.

[0182] First, notification of the maximum spatial dimension number N_{max} is received from the receiver which operates as the beamformee (step S**1**). Hereinafter, it is assumed that N_{max}=M. The notification is performed by receiving the management frame such as the message of network association or the signal including the HT capability field.

[0183] Subsequently, the spatial dimension number of the excited channel is suppressed to M×M and the sounding packet is transmitted to the STA-B using two streams to obtain the feedback of the transmission weight matrix V for beamforming or the CSI information (step S**2**).

[0184] Since the channel of M spatial dimensions is excited in the training signal part of the sounding packet such that the beamformee receives it using M antennas, it is possible to estimate an M×M channel matrix. According to the CSI information request, the CSI information is prepared on the basis of the estimation channel matrix and a packet in which the information is carried in a data part returns to the beamformer. Alternatively, when the feedback of the transmission weight matrix V for beamforming is requested, the estimation channel matrix is subjected to the singular value decomposition and a packet in which the coefficient data of the transmission weight matrix V for beamforming is included in the compressed or uncompressed format returns to the beamformer.

[0185] When the CSI information is received, the beamformer constructs the channel matrix (step S**3**) and obtains the transmission weight matrix for beamforming at the time of forward data transmission (step S**4**). Alternatively, the transmission weight matrix V for beamforming may be received in the step S**3** and the step S**4** may be skipped.

[0186] The beamforming is performed using the transmission weight matrix for beamforming in the transmission vector having the transmission signal from the antennas as the element and the data packet is transmitted to the receiver (step S**5**). It is possible to make an ideal spatial orthogonal channel by applying the transmission antenna weight on the basis of the channel matrix and performing adequate beamforming which is directed to the receiver.

[0187] FIG. **13** a flowchart illustrating a process when the wireless communication apparatus shown in FIGS. **2** and **3** operates as the receiver, that is, the beamformee, on the basis of the explicit feedback procedure. Here, it is assumed that the number of antennas of the beamformer is N and the number of antennas of the beamformee is M.

[0188] First, the maximum spatial dimension number N_{max} of the sounding packet is notified to the initiator which operates as the beamformer (step S**11**). Hereinafter, it is assumed that N_{max}=M. The notification is performed by receiving the management frame such as the message of network association or the beacon including the HT capability field.

[0189] Subsequently, when the sounding packet is transmitted from the beamformer, the channel of M spatial dimensions is excited. The beamformee receives it using M antennas (step S**12**) and estimates the M×M channel matrix (step S**13**).

[0190] The CSI information is prepared from the estimation channel matrix and the packet in which it is included in the data part returns to the beamformer (step S**14**).

[0191] Alternatively, when the feedback of the transmission weight matrix V for beamforming is requested as the sounding packet, in the step S**13**, the estimation channel matrix is subjected to the singular value decomposition to obtain the transmission weight matrix V for beamforming. In the step S**14**, the packet in which the coefficient data of the transmission weight matrix V for beamforming is included in the compressed or uncompressed format instead of the CSI information returns to the beamformer.

[0192] Since the beamformee surely receives the sounding packet in the range of its own capability, it is possible to reduce the size of the circuit of the channel matrix estimation unit **216***a* and to realize the low cost or low power consumption of the apparatus.

[0193] Although the invention will be described in detail with reference to the specific embodiment, it is apparent to those skilled in the art that the embodiment may be modified or substituted without departing from the scope of the invention.

[0194] Although the embodiment in which the invention applies to the MIMO communication system according to the EWC specification in the IEEE 802.11n is described in the present specification, the scope of the invention is not limited to the embodiment. As the MIMO communication system using the stream which is spatially multiplexed from a first terminal including N antennas to a second terminal including M antennas, it is possible to suitably apply the invention to various types of communication systems in which the beamformer performs the beamforming using the channel information fed back from the beamformee.

[0195] Although the embodiment which is applied to the IEEE 802.11n which is extension standard of the IEEE 802.11 is described in the present specification, the invention is not limited to the embodiment. The invention is applicable to a variety of wireless communication systems using an MIMO communication method such as a mobile WiMax (Worldwide Interoperability for Microwave) based on the IEEE 802.16e, the IEEE 802.20 which is a high-speed wireless communication standard for a mobile object, the IEEE 802.15.3c which is a high-speed wireless PAN (Personal Area Network) using 60 GHz (milliwave) band, a wireless HD (High Definition) which transmitting an uncompressed HD image using wireless transmission of 60 GHz (milliwave) band, and a fourth generation (4G) mobile telephone.

[0196] The invention is disclosed as an exemplary aspect and the contents described in the present specification are restrictively analyzed. The scope of the invention is defined by claims.

[0197] It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

1-32. (canceled)

33. A receiving device for wireless communication, the receiving device comprising:

processing circuitry configured to:

transmit a channel estimation capability including a maximum number of space time streams, the channel estimation capability being included in a beamforming capability field of a management frame defined in wireless network standard IEEE 802.11;
estimate a channel matrix;
transmit feedback information generated based at least in part on the estimated channel matrix; and
receive a data signal by explicit feedback beamforming using the transmission weight matrix generated based at least in part on the feedback information.

34. The receiving device of claim **33**, wherein the beamforming capability field is included in a HT (high throughput) capabilities element defined in wireless network standard IEEE 802.11.

35. The receiving device of claim **34**, wherein the HT capabilities element is present in a management frame.

36. The receiving device of claim **35**, wherein the management frame includes a beacon signal, a measure pilot, an association response, a re-association response, and/or a probe response.

37. The receiving device of claim **33**, wherein the maximum number of space time streams indicates a number of columns of a MIMO (multiple-input multiple output) channel matrix for the wireless communication.

38. The receiving device of claim **37**, wherein the channel state information is estimated as a channel state information matrix, a number of columns of the channel state information matrix being equal to or less than the number of columns of MEMO channel matrix.

39. The receiving device of claim **33**, further configured to:
receive a sounding data unit, the received sounding data unit being used to estimate the channel matrix.

40. The receiving device of claim **39**, wherein a length of the sounding data unit is equal to or less than a number indicated by the channel estimation capability.

41. The receiving device of claim **39**, wherein the sounding data unit is generated as a staggered sounding packet.

42. The receiving device of claim **33**, wherein the channel estimation capability is represented by two bits, the two bits being located adjacent to a bit field including an information of maximum beamformer capability.

43. The receiving device of claim **33**, wherein the beamforming capability field further includes both implicit beamforming capability information and explicit beamforming capability information.

44. The receiving device of claim **33**, further comprising:
a plurality of antennas configured to transmit or receive signals including the channel estimation capability.

45. The receiving device of claim **44**, wherein a number of the plurality of antennas is two or three.

46. The receiving device of claim **44**, further comprising:
a plurality of digital filters configured to perform band limitation, a number of the plurality of digital filters being equal to a number of the plurality of antennas.

47. A mobile receiving apparatus for wireless communication, the mobile receiving apparatus comprising:
a plurality of antennas; and
processing circuitry configured to:
transmit a channel estimation capability including a maximum number of space time streams, the channel estimation capability being included in a beamforming capability field of a management frame defined in wireless network standard IEEE 802.11;
estimate a channel matrix;
transmit feedback information generated based at least in part on the estimated channel matrix; and
receive a data signal by explicit feedback beamforming using the transmission weight matrix generated based at least in part on the feedback information.

48. The mobile receiving apparatus of claim **47**, wherein the mobile receiving apparatus is a mobile telephone.

49. A receiving method for wireless communication, the receiving method comprising:
transmitting a channel estimation capability including a maximum number of space time streams, the channel estimation capability being included in a beamforming capability field of a management frame defined in wireless network standard IEEE 802.11;
estimating a channel matrix;
transmitting feedback information generated based at least in part on the estimated channel matrix; and
receiving a data signal by explicit feedback beamforming using the transmission weight matrix generated based at least in part on the feedback information.

50. The receiving method of claim **49**, wherein the beamforming capability field is included in a HT (high throughput) capabilities element defined in wireless network standard IEEE 802.11.

51. The receiving method of claim **50**, wherein the HT capabilities element is present in a management frame.

52. The receiving method of claim **51**, wherein the management frame includes a beacon signal, a measure pilot, an association response, a re-association response, and/or a probe response.

53. The receiving method of claim **49**, wherein the maximum number of space time streams indicates a number of columns of a MIMO (multiple-input multiple output) channel matrix for the wireless communication.

54. The receiving method of claim **53**, wherein the channel state information is estimated as a channel state information matrix, a number of columns of the channel state information matrix being equal to or less than the number of columns of MIMO channel matrix.

55. The receiving method of claim **49**, further including:
receiving a sounding data unit, the received sounding data unit being used to estimate the channel matrix.

56. The receiving method of claim **55**, wherein a length of the sounding data unit is equal to or less than a number indicated by the channel estimation capability.

57. The receiving method of claim **55**, wherein the sounding data unit is generated as a staggered sounding packet.

58. The receiving method of claim **49**, wherein the channel estimation capability is represented by two bits, the two bits being located adjacent to a bit field including an information of maximum beamformer capability.

59. The receiving method of claim **49**, wherein the beamforming capability field further includes both implicit beamforming capability information and explicit beamforming capability information.

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