US 20240056136A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2024/0056136 A1**

Tashiro et al. (43) **Pub. Date: Feb. 15, 2024**

(54) **MASSIVE MIMO FOR HAPS BASED ON ANGLE INFORMATION ON USER APPARATUS**

(71) Applicant: **SoftBank Corp.**, Tokyo (JP)

(72) Inventors: **Koji Tashiro**, Tokyo (JP); **Mitsukuni Konishi**, Tokyo (JP); **Kenji Hoshino**, Tokyo (JP); **Yoshichika Ota**, Tokyo (JP); **Atsushi Nagate**, Tokyo (JP)

(73) Assignee: **Softbank Corp.**, Tokyo (JP)

(21) Appl. No.: **18/264,778**

(22) PCT Filed: **Jan. 12, 2022**

(86) PCT No.: **PCT/JP2022/000757**

§ 371 (c)(1),
(2) Date: **Aug. 9, 2023**

(30) **Foreign Application Priority Data**

Feb. 12, 2021 (JP) 2021-021330

Publication Classification

(51) **Int. Cl.**

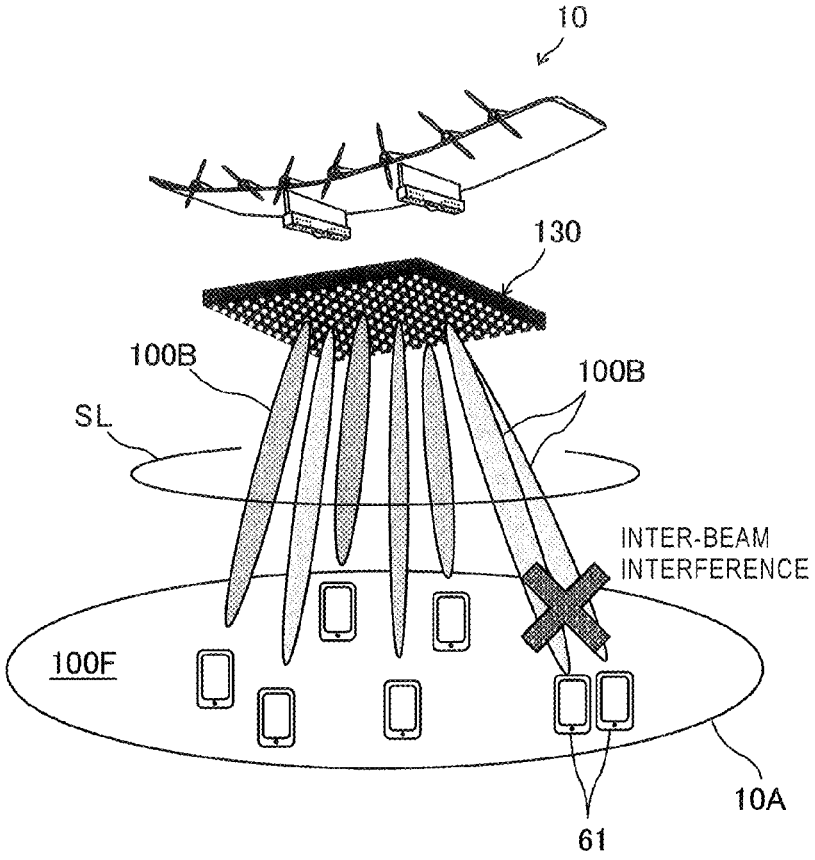
H04B 7/0452	(2006.01)
H04B 7/185	(2006.01)
H04W 72/541	(2006.01)

(52) **U.S. Cl.**

CPC ***H04B 7/0452*** (2013.01); ***H04B 7/18539*** (2013.01); ***H04B 7/18504*** (2013.01); ***H04W 72/541*** (2023.01)

(57) **ABSTRACT**

In an upper-airspace staying type communication relay apparatus that performs an MU-MIMO radio communication with plural terminal apparatuses located in a cell, it is intended to improve the communication quality of the entire cell and enhance the system capacity, while suppressing an increase in overhead in the terminal apparatus and the communication relay apparatus even if the number of terminal apparatuses located in the cell increases. The communication relay apparatus receives an uplink signal from each of plural terminal apparatuses via an array antenna, estimates angle information indicating a direction of the terminal apparatus for each of the plural terminal apparatuses, selects a terminal apparatus to be assigned to each of plural radio resources used for a downlink based on the estimation result of the angle information, calculates a downlink beamforming weight based on the estimation result of the angle information, and transmits a downlink signal to the terminal apparatus via the array antenna based on the beamforming weight corresponding to the terminal apparatus and the radio resources assigned to the terminal apparatus.



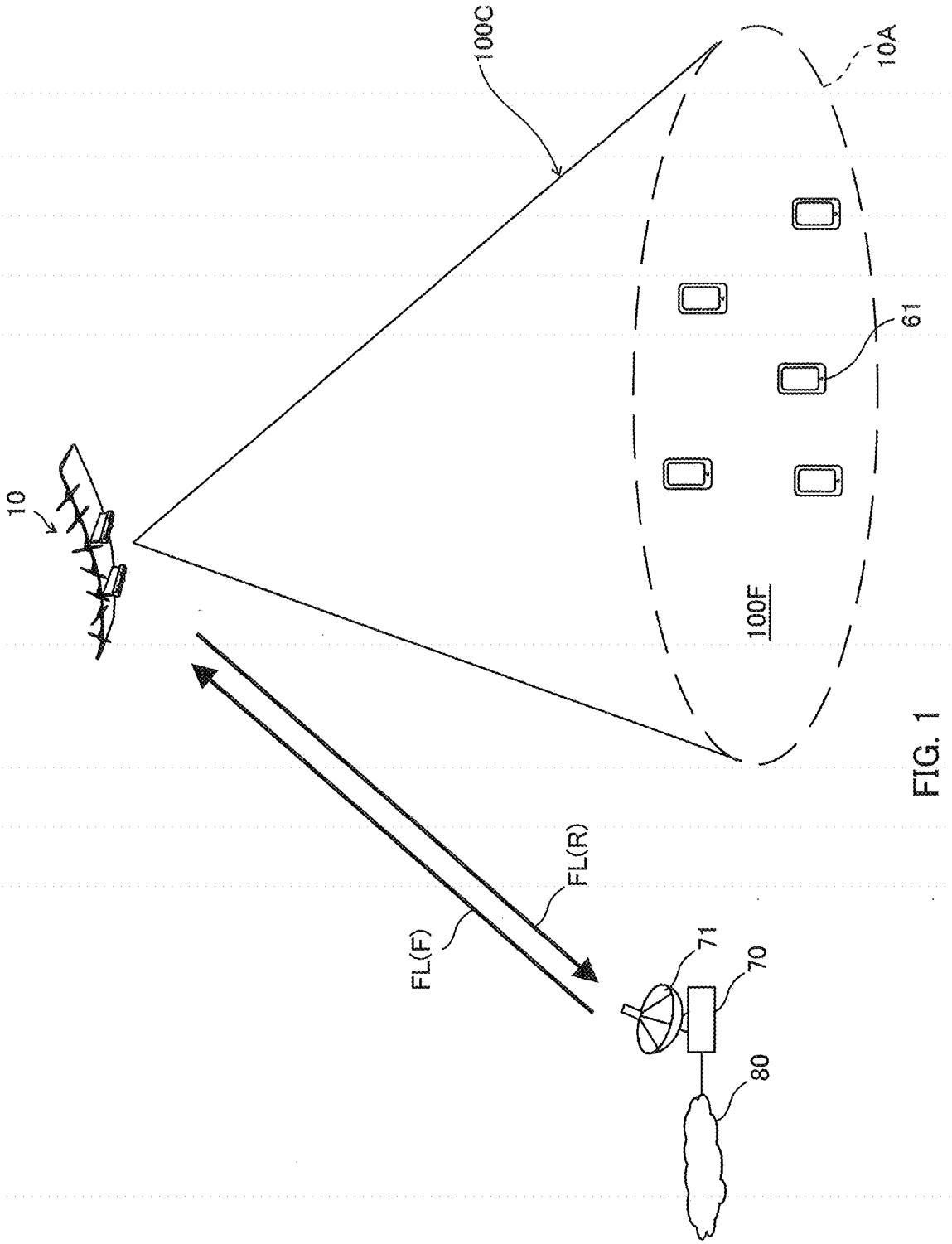


FIG. 1

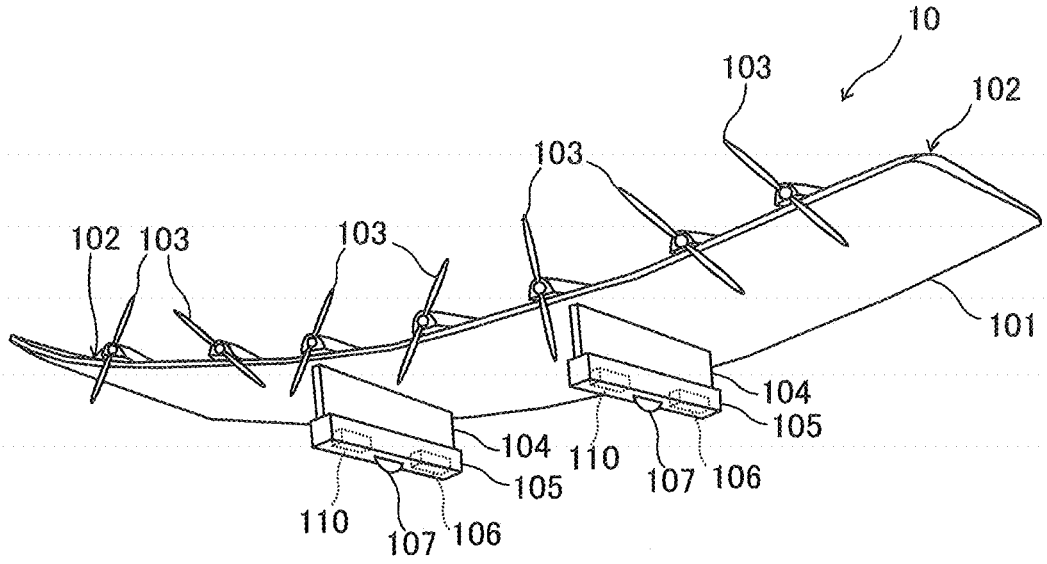

10
103
102
103
103
102
103
101
104
105
104
110
105
107
106
110
107
106

FIG. 2

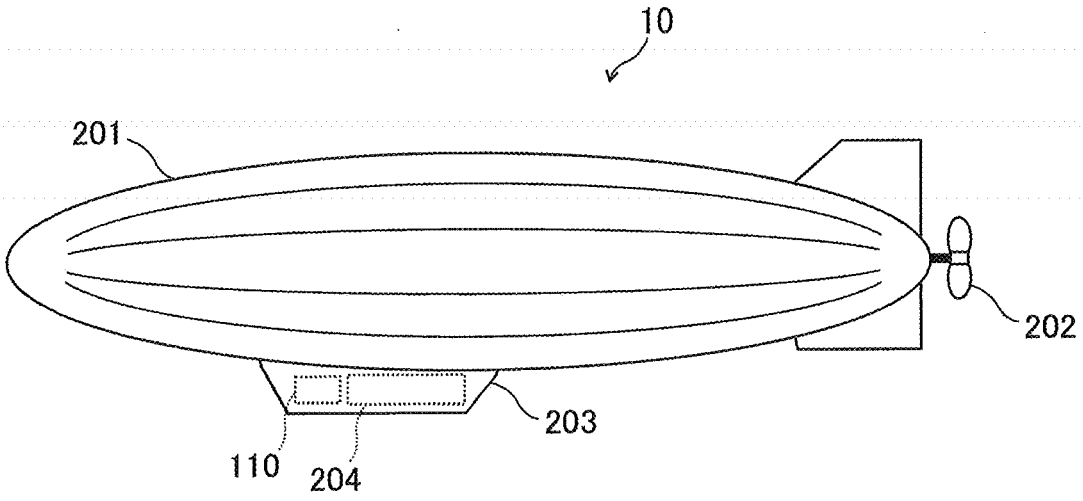

10
201
202
203
110
204

FIG. 3

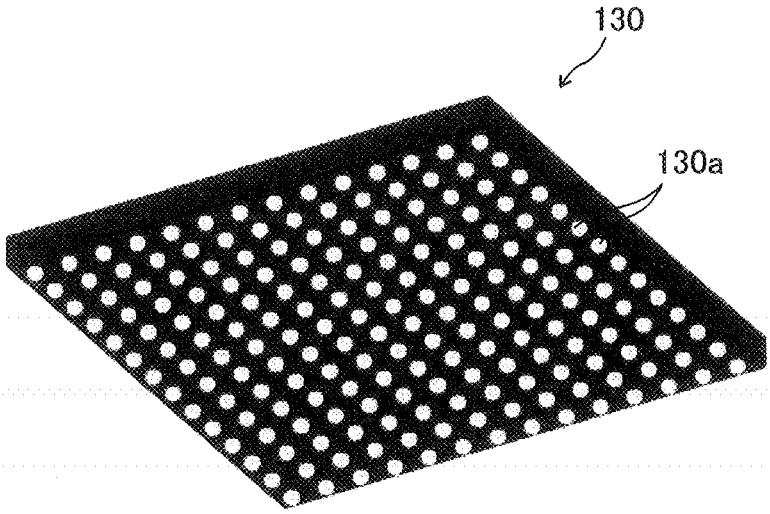


FIG. 4

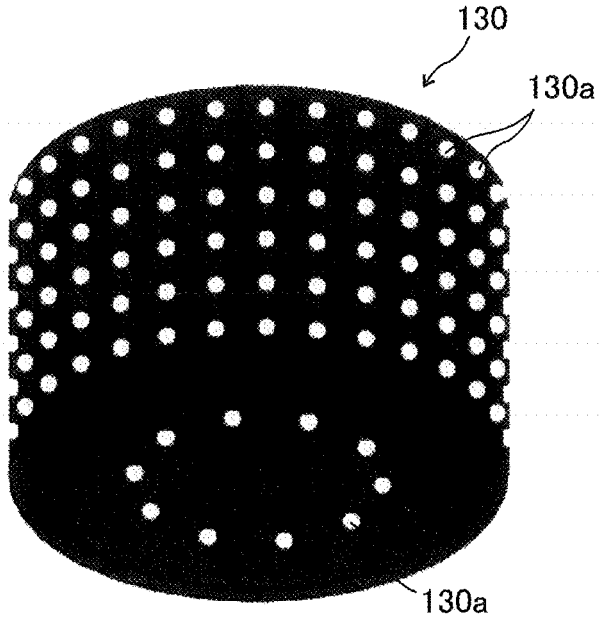


FIG. 5

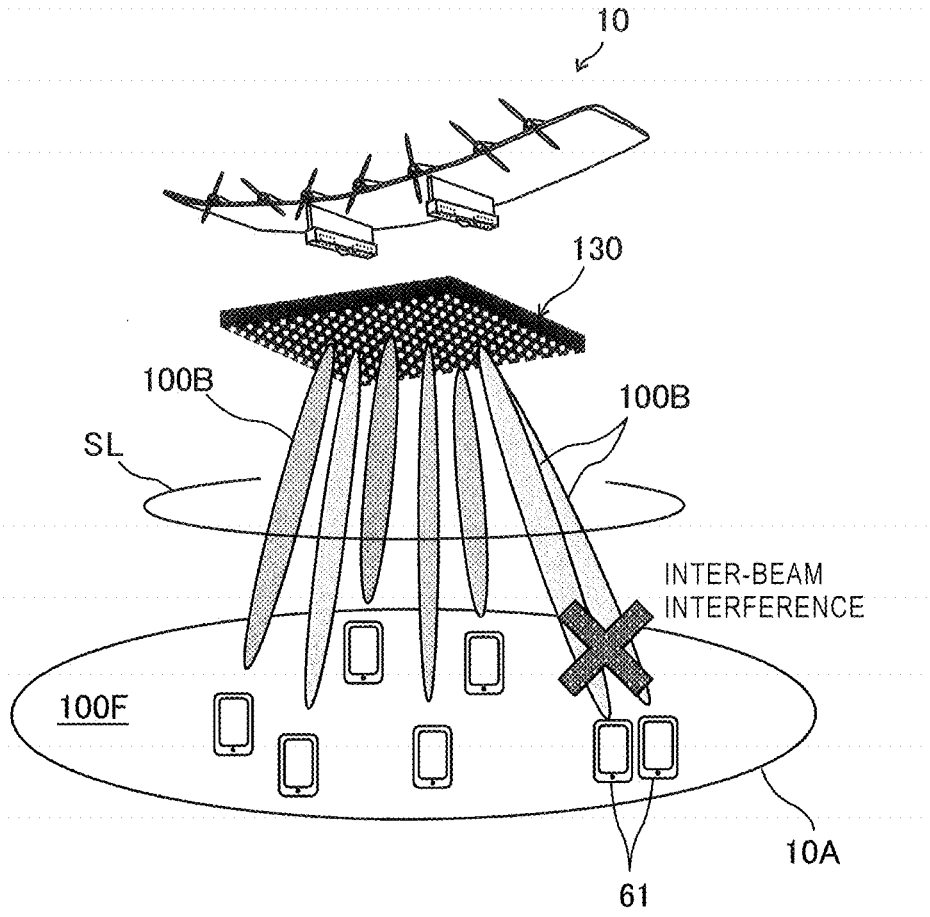


FIG. 6

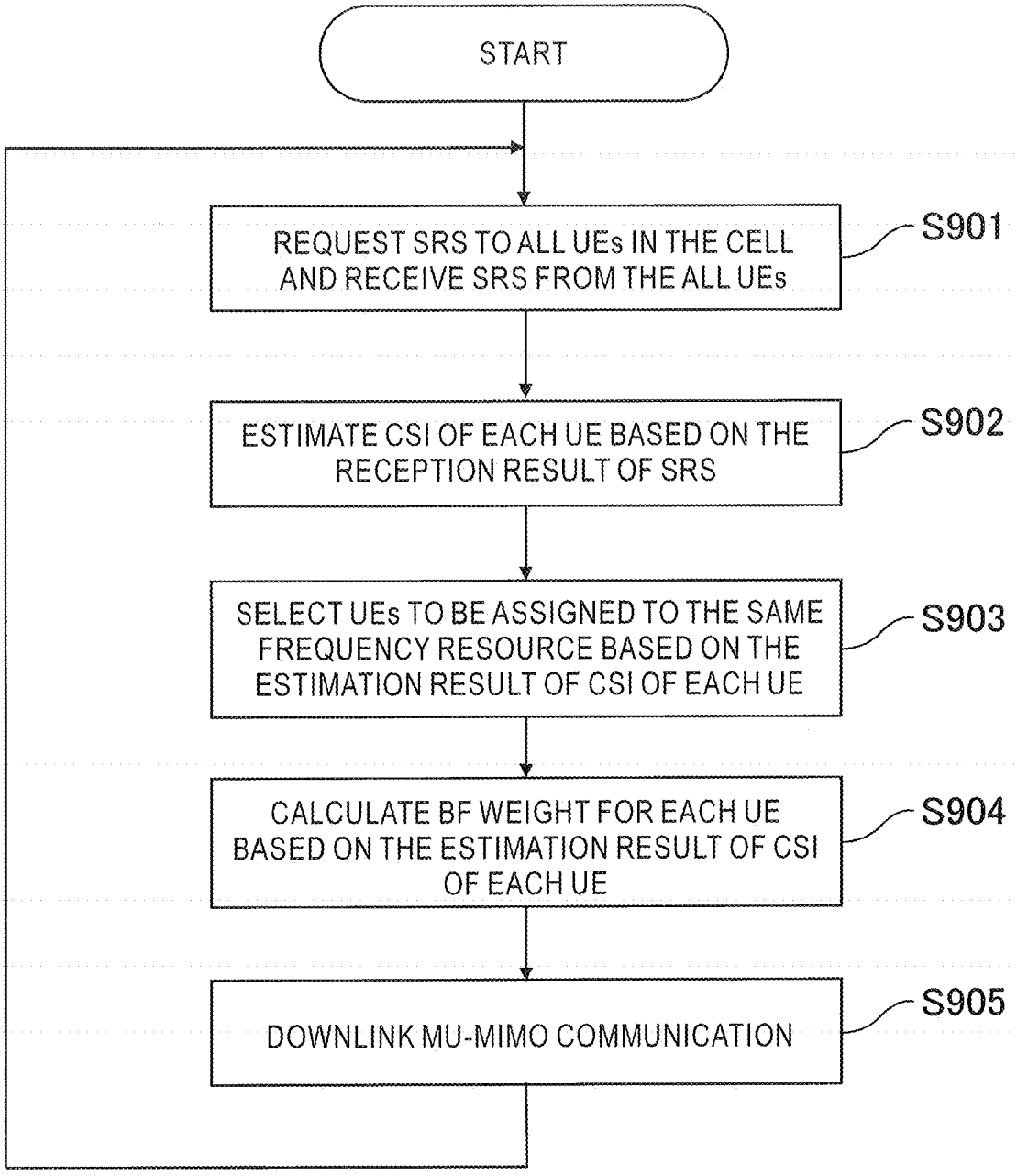

START
REQUEST SRS TO ALL UEs IN THE CELL AND RECEIVE SRS FROM THE ALL UEs
S901
ESTIMATE CSI OF EACH UE BASED ON THE RECEPTION RESULT OF SRS
S902
SELECT UEs TO BE ASSIGNED TO THE SAME FREQUENCY RESOURCE BASED ON THE ESTIMATION RESULT OF CSI OF EACH UE
S903
CALCULATE BF WEIGHT FOR EACH UE BASED ON THE ESTIMATION RESULT OF CSI OF EACH UE
S904
DOWNLINK MU-MIMO COMMUNICATION
S905

FIG. 7

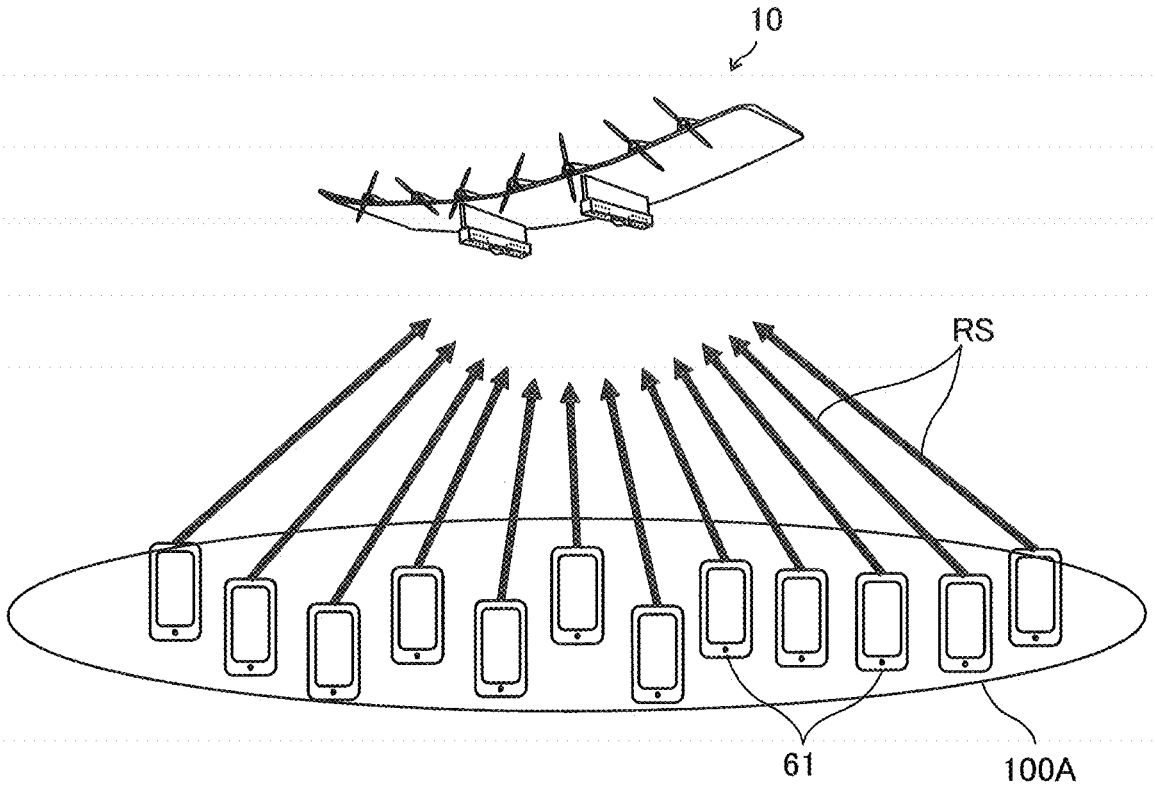


FIG. 8

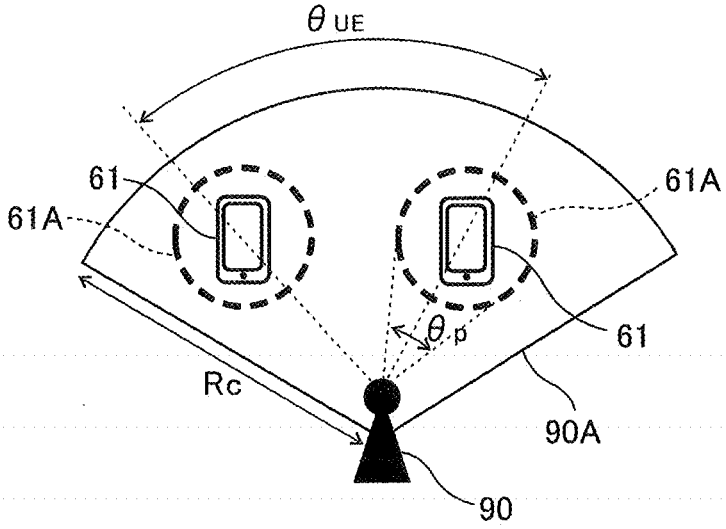


FIG. 9

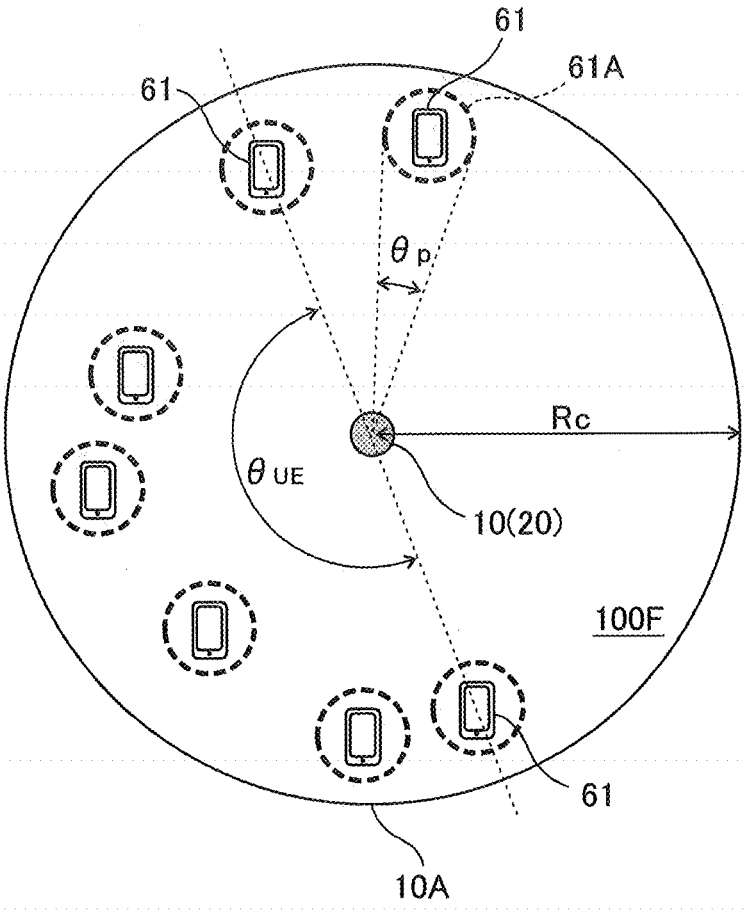


FIG. 10

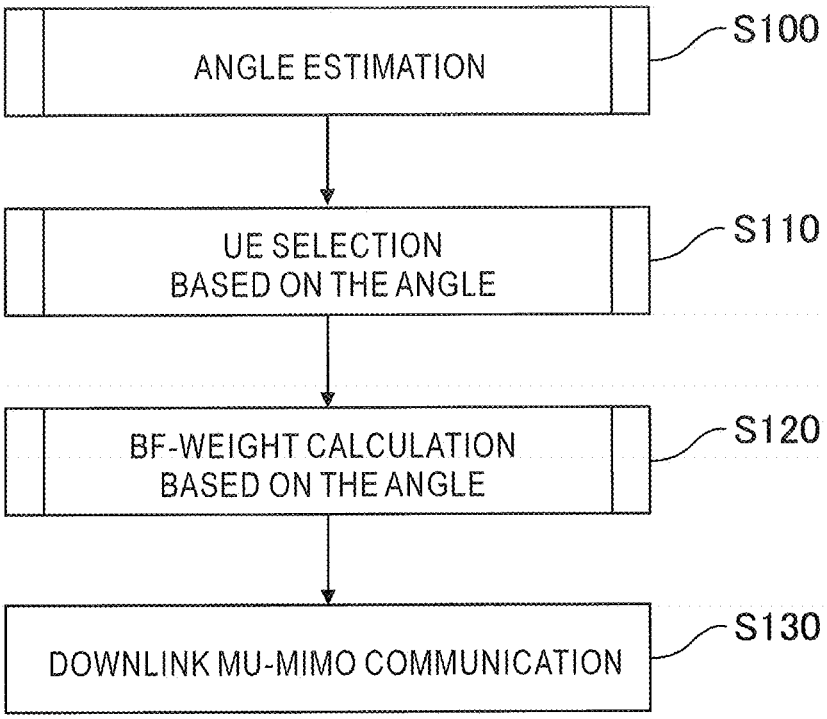

ANGLE ESTIMATION
S100
UE SELECTION
BASED ON THE ANGLE
S110
BF-WEIGHT CALCULATION
BASED ON THE ANGLE
S120
DOWNLINK MU-MIMO COMMUNICATION
S130

FIG. 11

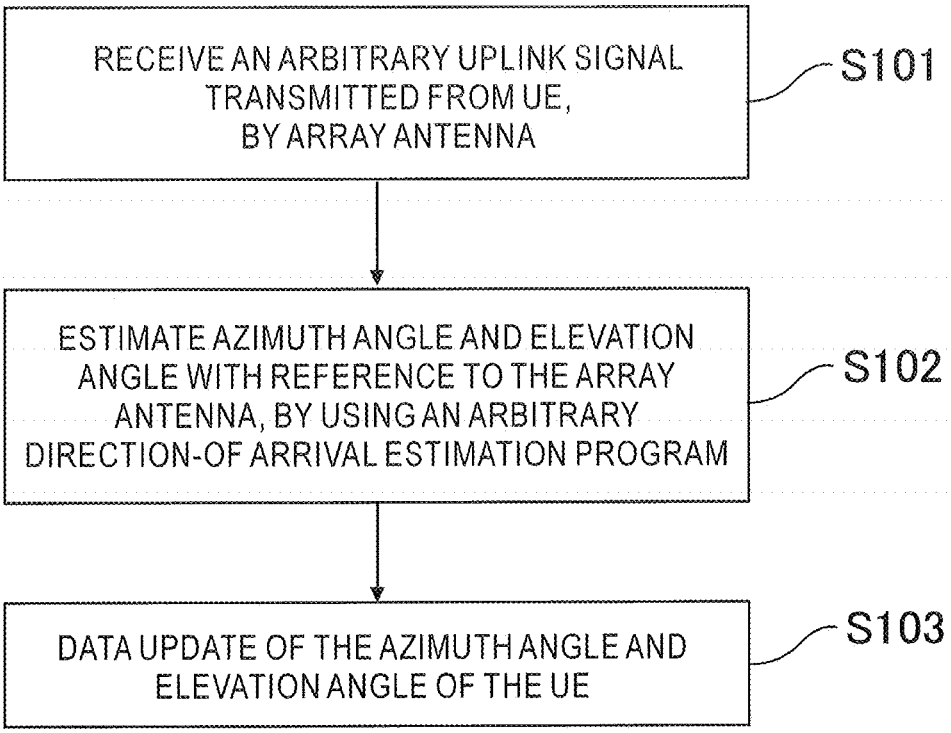

RECEIVE AN ARBITRARY UPLINK SIGNAL TRANSMITTED FROM UE, BY ARRAY ANTENNA
S101
ESTIMATE AZIMUTH ANGLE AND ELEVATION ANGLE WITH REFERENCE TO THE ARRAY ANTENNA, BY USING AN ARBITRARY DIRECTION-OF ARRIVAL ESTIMATION PROGRAM
S102
DATA UPDATE OF THE AZIMUTH ANGLE AND ELEVATION ANGLE OF THE UE
S103

FIG. 12

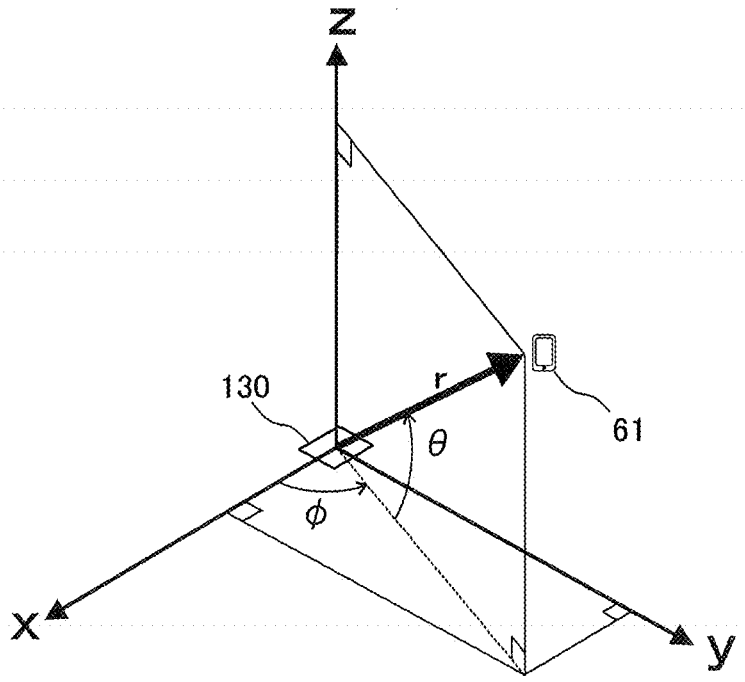

z
130
r
θ
61
ϕ
x
y

FIG. 13

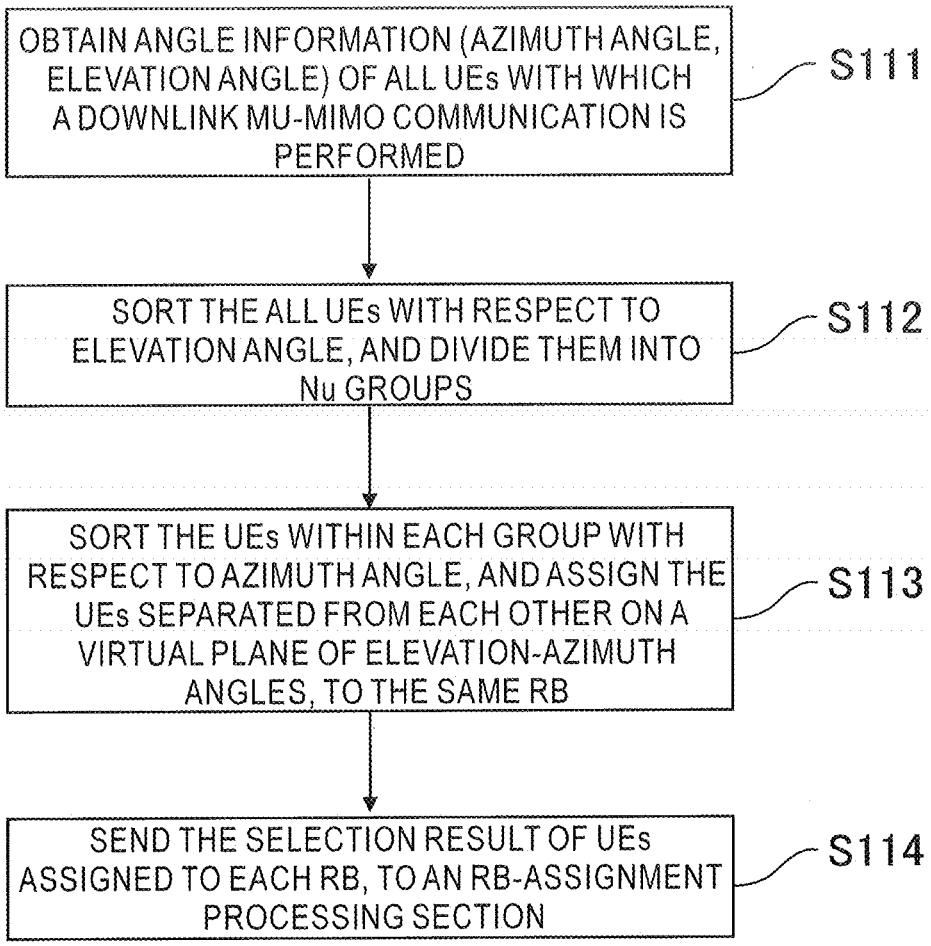

OBTAIN ANGLE INFORMATION (AZIMUTH ANGLE, ELEVATION ANGLE) OF ALL UEs WITH WHICH A DOWNLINK MU-MIMO COMMUNICATION IS PERFORMED
S111
SORT THE ALL UEs WITH RESPECT TO ELEVATION ANGLE, AND DIVIDE THEM INTO Nu GROUPS
S112
SORT THE UEs WITHIN EACH GROUP WITH RESPECT TO AZIMUTH ANGLE, AND ASSIGN THE UEs SEPARATED FROM EACH OTHER ON A VIRTUAL PLANE OF ELEVATION-AZIMUTH ANGLES, TO THE SAME RB
S113
SEND THE SELECTION RESULT OF UEs ASSIGNED TO EACH RB, TO AN RB-ASSIGNMENT PROCESSING SECTION
S114

FIG. 14

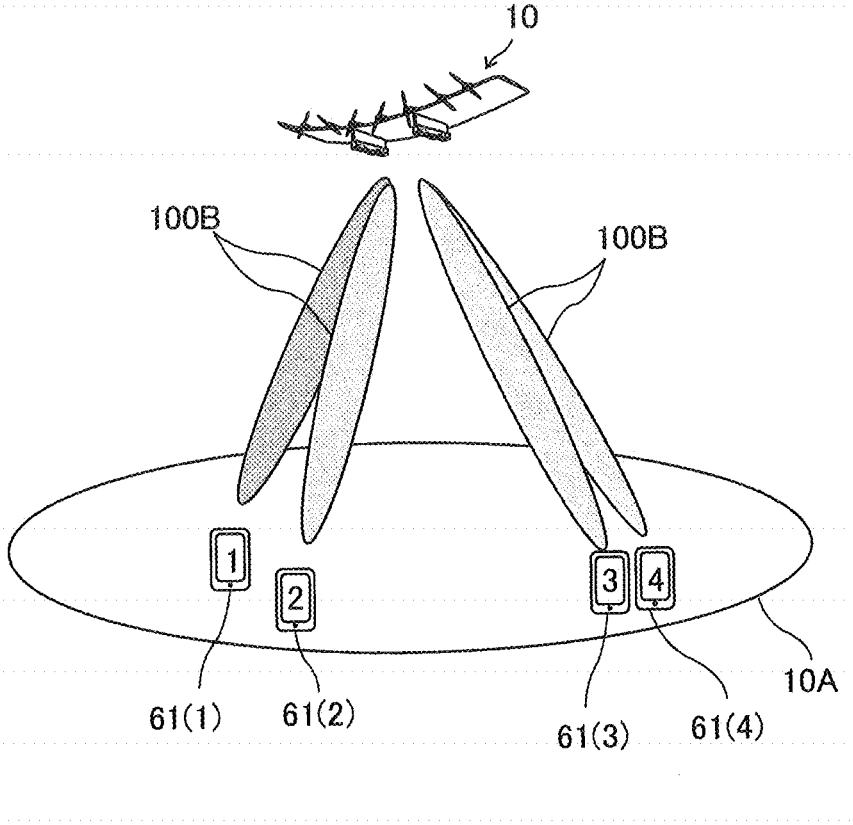


FIG. 15

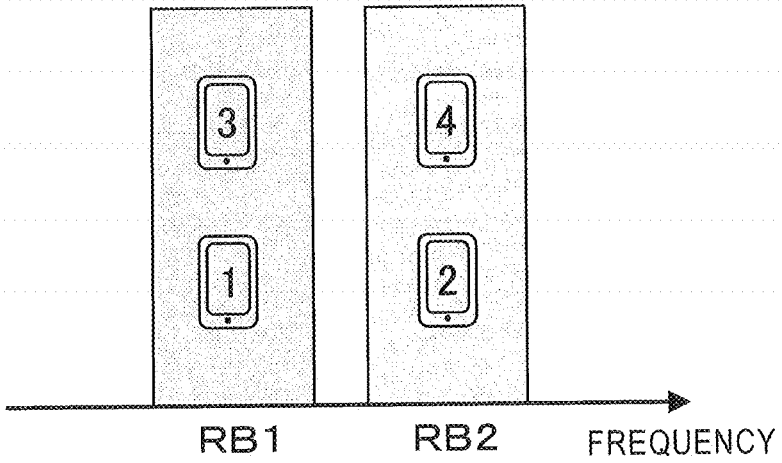

3
4
1
2
RB1
RB2
FREQUENCY

FIG. 16

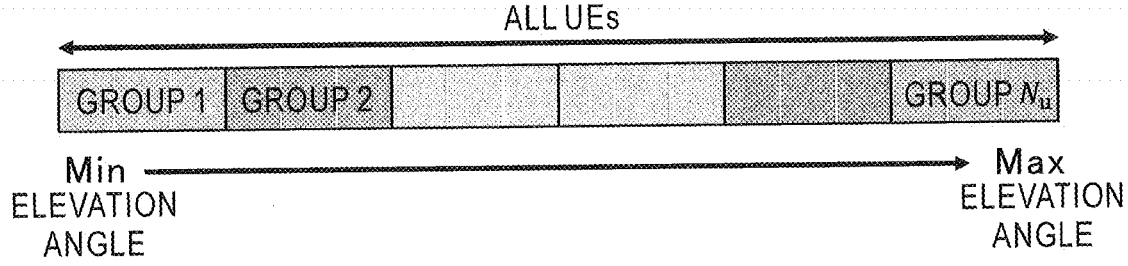

ALL UEs
GROUP 1
GROUP 2
GROUP N_u
Min
ELEVATION
ANGLE
Max
ELEVATION
ANGLE

FIG. 17

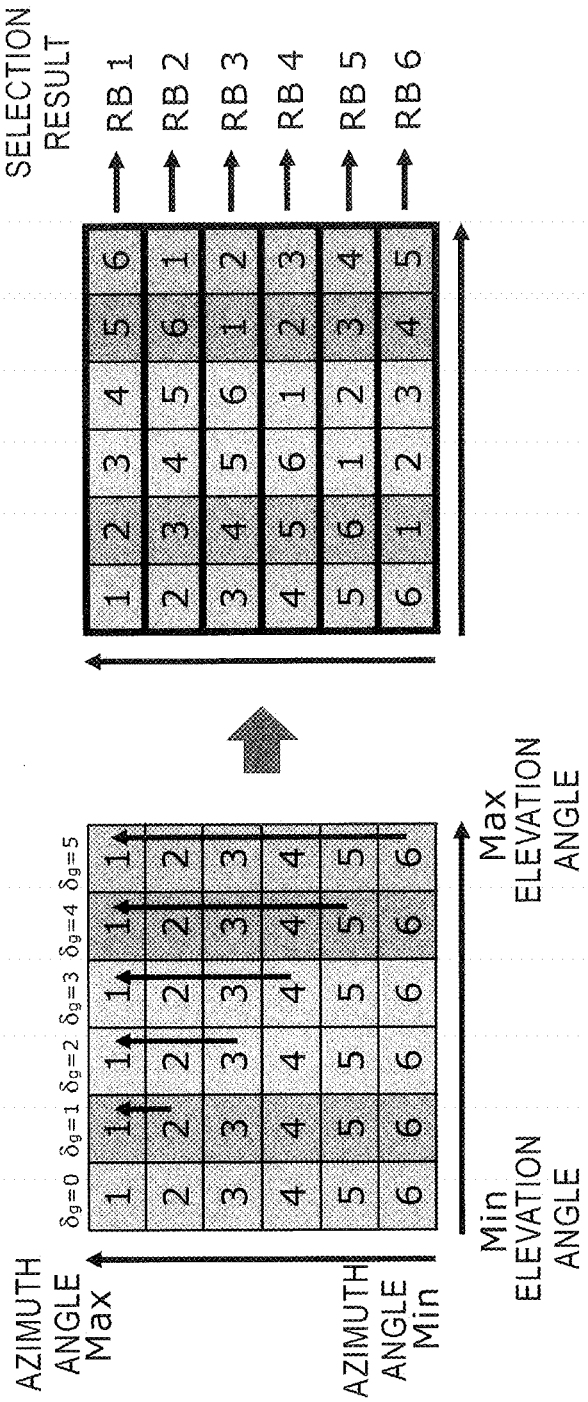

UE SELECTION RESULT
RB 1
RB 2
RB 3
RB 4
RB 5
RB 6
AZIMUTH ANGLE Max
AZIMUTH ANGLE Min
Min ELEVATION ANGLE
Max ELEVATION ANGLE
δg=0 δg=1 δg=2 δg=3 δg=4 δg=5

FIG. 18

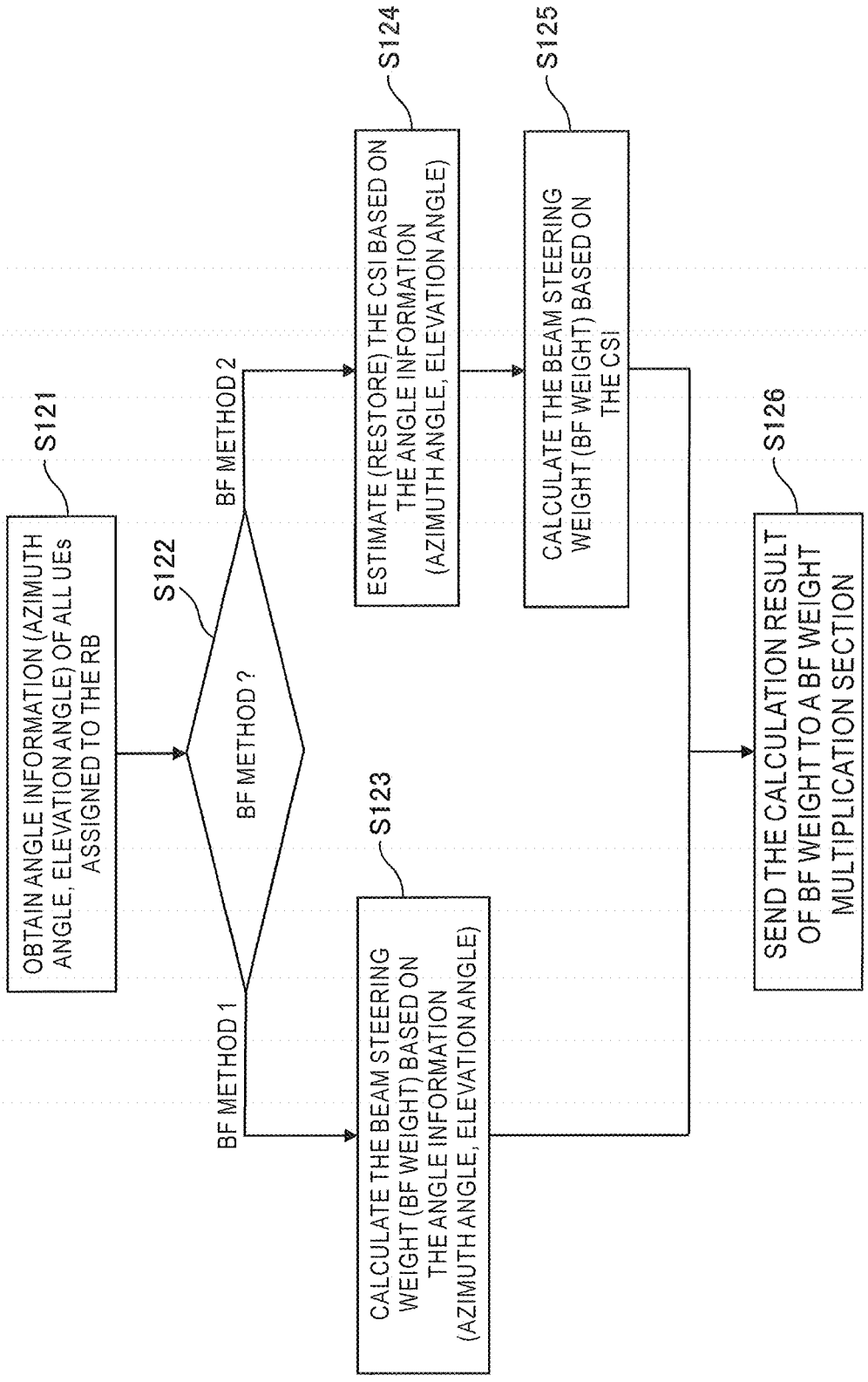

S121
OBTAIN ANGLE INFORMATION (AZIMUTH ANGLE, ELEVATION ANGLE) OF ALL UEs ASSIGNED TO THE RB
S122
BF METHOD ?
BF METHOD 1
BF METHOD 2
S123
CALCULATE THE BEAM STEERING WEIGHT (BF WEIGHT) BASED ON THE ANGLE INFORMATION (AZIMUTH ANGLE, ELEVATION ANGLE)
S124
ESTIMATE (RESTORE) THE CSI BASED ON THE ANGLE INFORMATION (AZIMUTH ANGLE, ELEVATION ANGLE)
S125
CALCULATE THE BEAM STEERING WEIGHT (BF WEIGHT) BASED ON THE CSI
S126
SEND THE CALCULATION RESULT OF BF WEIGHT TO A BF WEIGHT MULTIPLICATION SECTION

FIG. 19

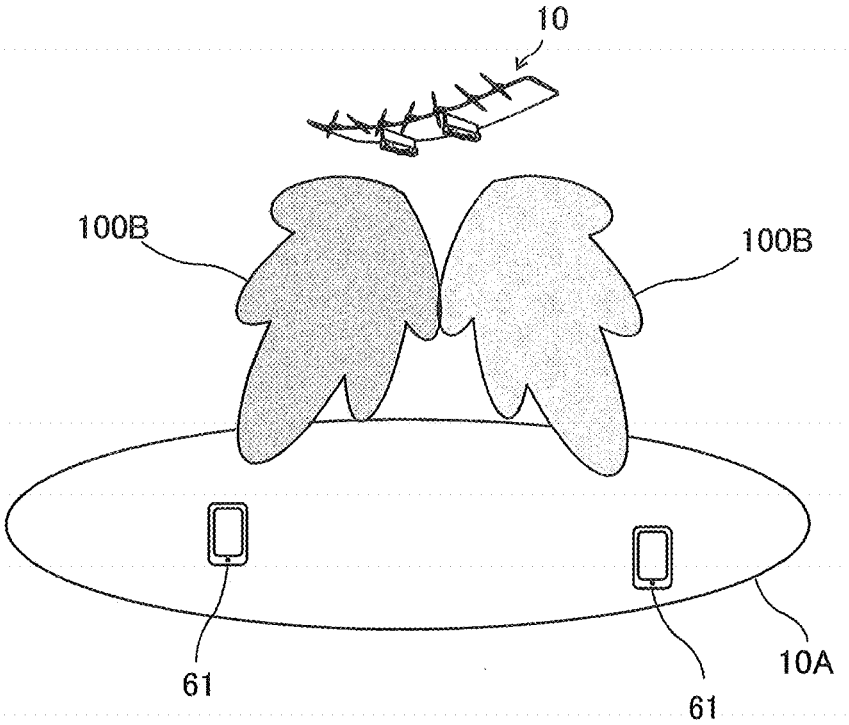


FIG. 20

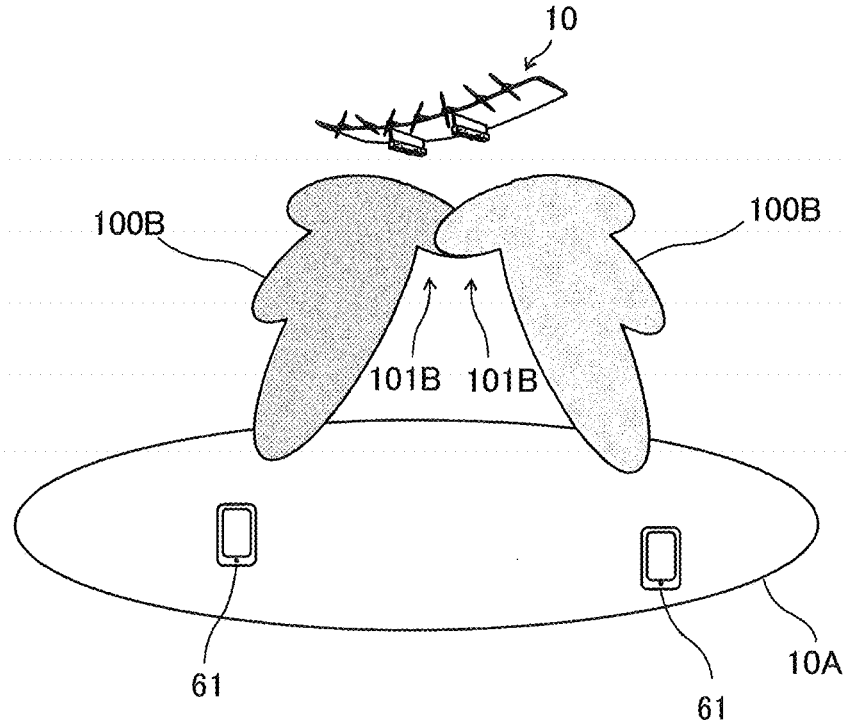


FIG. 21

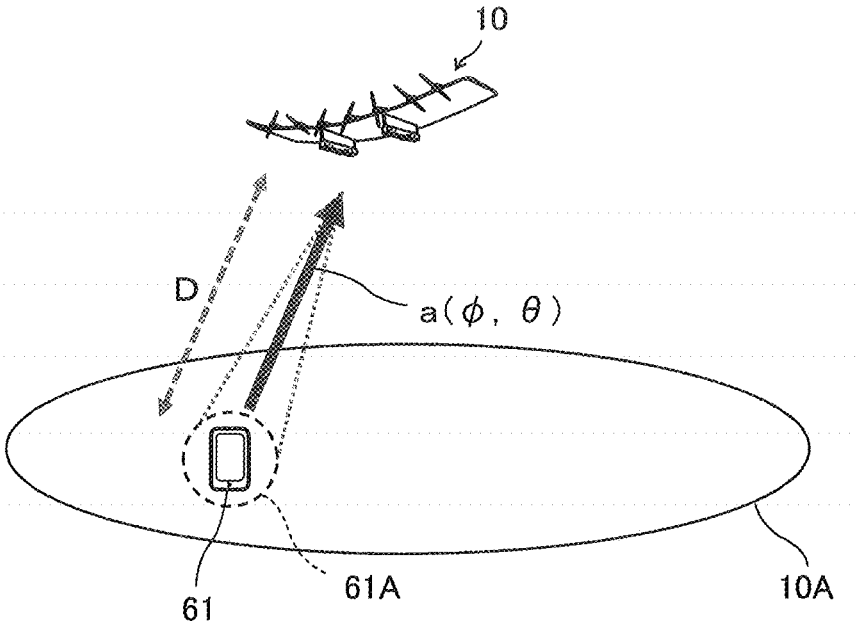

10
D
a(ϕ, θ)
61
61A
10A

FIG. 22

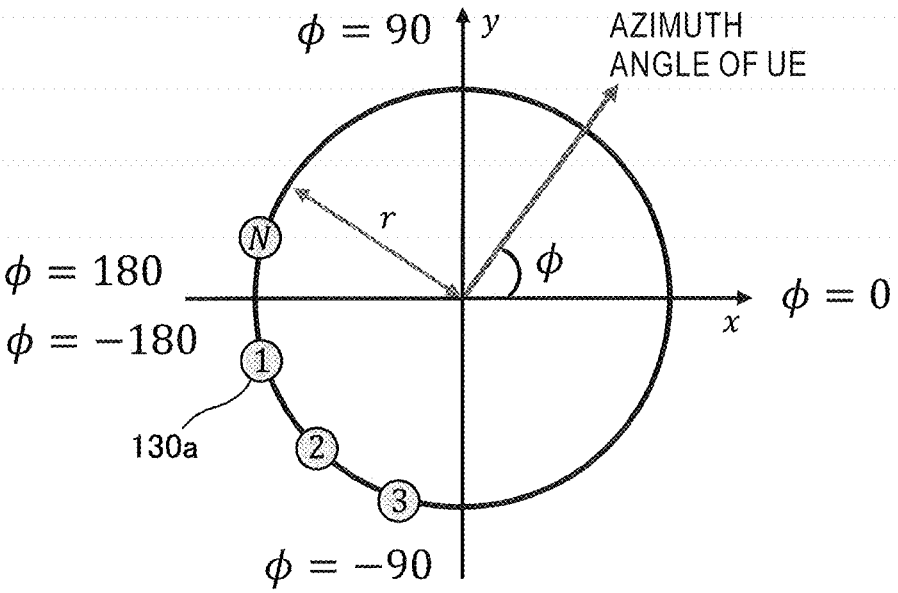

ϕ = 90
y
AZIMUTH
ANGLE OF UE
r
N
ϕ
ϕ = 180
ϕ = −180
ϕ = 0
x
1
2
3
130a
ϕ = −90

FIG. 23

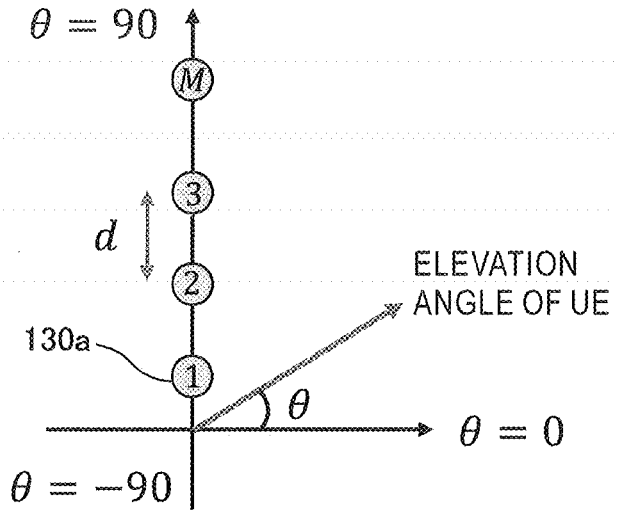

θ = 90
M
3
d
2
ELEVATION
ANGLE OF UE
130a
1
θ
θ = 0
θ = −90

FIG. 24

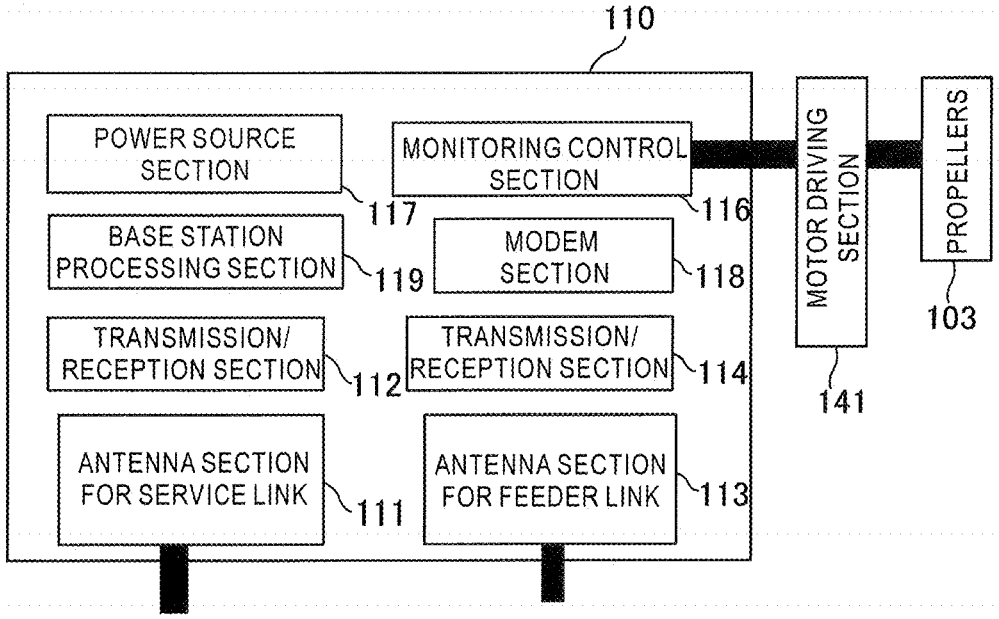

110
POWER SOURCE SECTION
117
MONITORING CONTROL SECTION
116
BASE STATION PROCESSING SECTION
119
MODEM SECTION
118
TRANSMISSION/ RECEPTION SECTION
112
TRANSMISSION/ RECEPTION SECTION
114
ANTENNA SECTION FOR SERVICE LINK
111
ANTENNA SECTION FOR FEEDER LINK
113
MOTOR DRIVING SECTION
141
PROPELLERS
103

FIG. 25

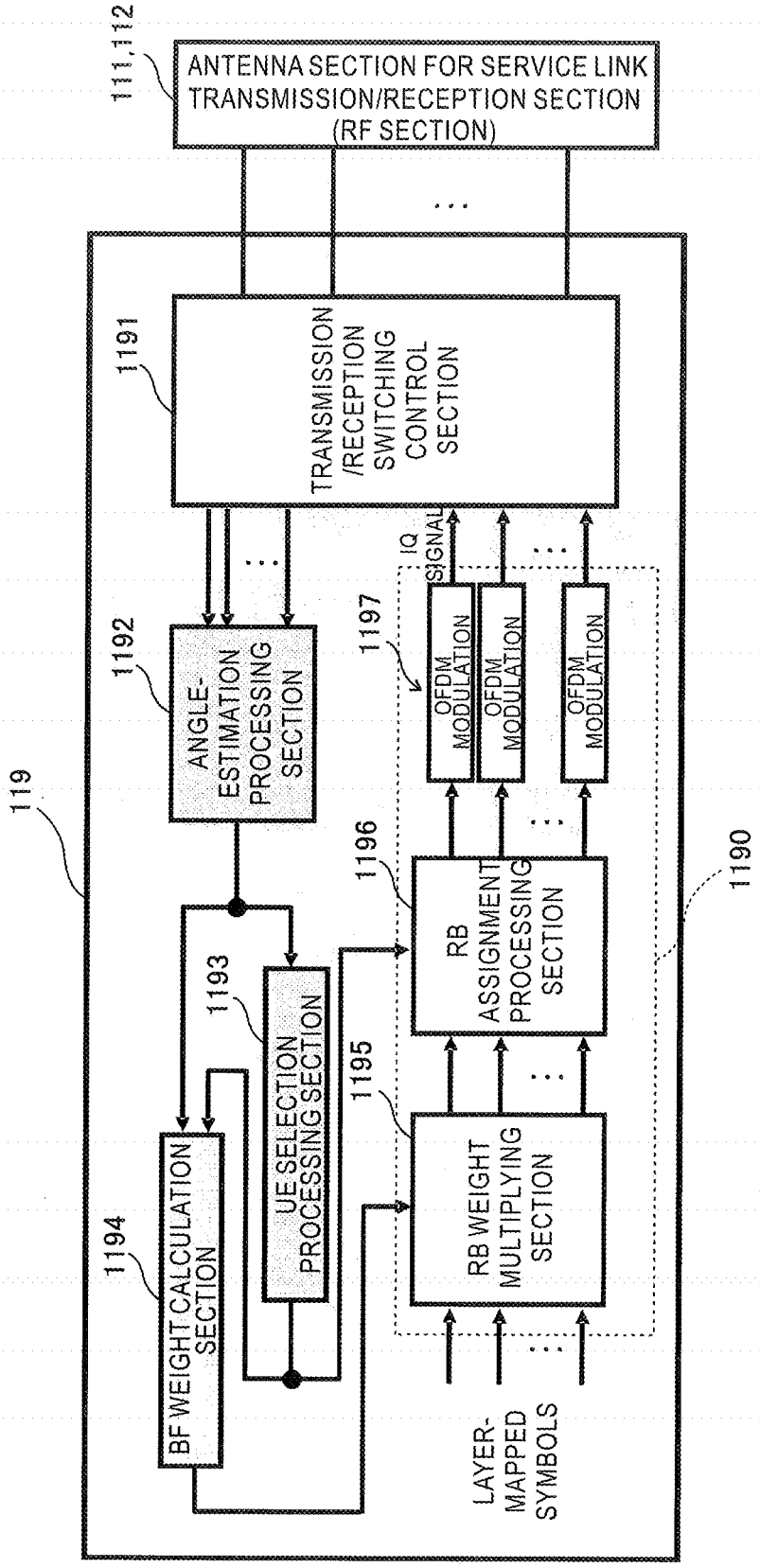

111,112
ANTENNA SECTION FOR SERVICE LINK TRANSMISSION/RECEPTION SECTION (RF SECTION)
1191
TRANSMISSION /RECEPTION SWITCHING CONTROL SECTION
1192
ANGLE-ESTIMATION PROCESSING SECTION
1193
UE SELECTION PROCESSING SECTION
1194
BF WEIGHT CALCULATION SECTION
1195
RB WEIGHT MULTIPLYING SECTION
1196
RB ASSIGNMENT PROCESSING SECTION
1197
OFDM MODULATION
IQ SIGNAL
LAYER-MAPPED SYMBOLS
119
1190

FIG. 26

MASSIVE MIMO FOR HAPS BASED ON ANGLE INFORMATION ON USER APPARATUS

TECHNICAL FIELD

[0001] The present invention relates to MU (multi user)-MIMO (multiple-input multiple-output) technology between plural terminal apparatuses located in a cell of a service area formed by an aerial-staying type communication relay apparatus such as a HAPS in an upper airspace.

BACKGROUND ART

[0002] There is conventionally known an aerial-staying type communication relay apparatus such as a high altitude platform station (HAPS) (also referred to as "high altitude pseudo satellite") that can float and stay in an airspace (for example, see Patent Literature 1). There is known a communication of massive MIMO (hereinafter also referred to as "mMIMO") transmission method, as a communication between an aerial-staying type communication relay apparatus such as a HAPS and plural terminal apparatuses (hereinafter also referred to as "UE") located in a cell formed by the aerial-staying type communication relay apparatus. The mMIMO is a radio transmission technology that realizes a high-capacity and high-speed communication by transmitting and receiving data using an array antenna having a large number of antenna elements. A transmission method that simultaneously performs a beamforming for each of the plural UEs is also called "MU (Multi User)-MIMO". By performing the MU-MIMO transmission using multi-element array antenna, a communication can be performed by directing an appropriate beam for each UE according to a communication environment of each UE, so the communication quality of the entire cell can be improved. Furthermore, since a communication with plural UEs can be performed using a same radio resource (time/frequency resource), a system capacity can be enhanced.

CITATION LIST

Patent Literature

[0003] Patent Literature 1: U.S. Patent Application Publication No. 2016/0046387.

Non-Patent Literature

[0004] Non-Patent Literature 1: Z Lian, L Jiang, C He, D He, "User grouping and beamforming for HAP massive MIMO systems based on statistical-Eigenmode", IEEE Wireless Communications Letters, Volume 8, Issue 3, pp. 961-964 (June 2019).

SUMMARY OF INVENTION

Technical Problem

[0005] In case that the aerial-staying type communication relay apparatus performs an MU-MIMO communication with plural UEs using a multi-element array antenna, it is necessary to periodically obtain CSI (channel state information between the communication relay apparatus and the UE) of each UE in order to direct an appropriate beam for each UE. The communication quality varies greatly depending on which UE is assigned to a certain radio resource (time/frequency resource). For example, in case that the same frequency resource is assigned to plural UEs that are close to each other in spatial distance, the respective beams to the UEs interfere with each other, resulting in a significant deterioration in communication quality. In order to prevent this deterioration in communication quality, it is necessary to appropriately select UEs to be assigned to the same radio resource (time/frequency resource), and for this UE selection it is also necessary to periodically obtain the CSI of each UE. However, in order to obtain the CSI of each UE, it is necessary to frequently transmit a reference signal (for example, SRS: Sounding Reference Signal) from all UEs in the cell to the communication relay apparatus in the upper airspace, and there is a problem that the overhead increases in each UE and the communication relay apparatus.

[0006] In Non-Patent Literature 1, in a HAP (high altitude platform) system that performs a MU-MIMO transmission using a multi-element array antenna, with respect to each UE located in a cell, it is proposed to repeatedly evaluate a CD (Chordal Distance), which is an index of channel orthogonality between UEs, and perform a UE selection (grouping) and a beamforming based on the CD evaluation result. However, it is assumed that the number of UEs located in a cell formed by the HAP system reaches tens of thousands, and there is a problem that a calculation amount, a circuit scale and a power consumption for evaluating the CD in the HAP system increases.

Solution to Problem

[0007] A communication relay apparatus according to an aspect of the present invention is an upper-airspace staying type communication relay apparatus that forms a cell toward the ground or the sea and performs a MU-MIMO radio communication with plural terminal apparatuses located in the cell. This communication relay apparatus comprises an array antenna having plural antenna elements that forms a cell for performing radio communications of service link to and from the plural terminal apparatuses, an uplink reception section for receiving an uplink signal capable of identifying the terminal apparatus from each of the plural terminal apparatuses via the array antenna, an angle-estimation processing section for estimating angle information indicating a direction of the terminal apparatus with reference to a position of the array antenna for each of the plural terminal apparatuses, a selection processing section for selecting a terminal apparatus to be assigned to each of plural radio resources used for a downlink of the service link based on the estimation result of the angle information on the plural terminal apparatuses, a weight calculation section for calculating a downlink beamforming weight for the terminal apparatus by the array antenna based on the estimation result of the angle information, with respect to each of the plural terminal apparatuses, and a downlink transmission section for transmitting a downlink signal to the terminal apparatus via the array antenna based on the beamforming weight corresponding to the terminal apparatus and the radio resource assigned to the terminal apparatus, with respect to each of the plural terminal apparatuses.

[0008] A communication system according to another aspect of the present invention comprises the foregoing communication relay apparatus and a terminal apparatus that performs an MU-MIMO radio communication with the foregoing communication relay apparatus.

[0009] A method according to yet another aspect of the present invention is a method that forms a cell toward the ground or the sea and performs an MU-MIMO radio communication with plural terminal apparatuses located in the cell by an upper-airspace staying type communication relay apparatus. This method comprises receiving an uplink signal capable of identifying the terminal apparatus, from each of the plural terminal apparatuses via the array antenna having plural antenna elements that forms a cell for performing radio communications of a service link between to and from the plural terminal apparatuses, estimating angle information indicating a direction of the terminal apparatus with reference to a position of the array antenna for each of the plural terminal apparatuses, selecting a terminal apparatus to be assigned to each of plural radio resources used for a downlink of the service link based on the estimation result of the angle information on the plural terminal apparatuses, calculating a downlink beamforming weight for the terminal apparatus by the array antenna based on the estimation result of the angle information, with respect to each of the plural terminal apparatuses, and transmitting a downlink signal to the terminal apparatus via the array antenna based on the beamforming weight corresponding to the terminal apparatus and the radio resource assigned to the terminal apparatus, with respect to each of the plural terminal apparatuses.

[0010] A program according to yet another aspect of the present invention is a program executed by a computer or a processor installed in an upper-airspace staying type communication relay apparatus that forms a cell toward the ground or the sea and performs an MU-MIMO radio communication with plural terminal apparatuses located in the cell. This program comprises a program code for receiving an uplink signal capable of identifying the terminal apparatus from each of the plural terminal apparatuses via an array antenna having plural antenna elements that forms a cell for performing radio communications of a service link with the plural terminal apparatuses, a program code for estimating angle information indicating a direction of the terminal apparatus with reference to a position of the array antenna, with respect to each of the plural terminal apparatuses, a program code for selecting a terminal apparatus to be assigned to each of plural radio resources used for a downlink of the service link based on the estimation result of the angle information of the plural terminal apparatuses, a program code for calculating a downlink beamforming weight for the terminal apparatus by the array antenna based on the estimation result of the angle information, with respect to each of the plural terminal apparatuses, and a program code for transmitting a downlink signal to the terminal apparatus via the array antenna based on the beamforming weight corresponding to the terminal apparatus and the radio resource assigned to the terminal apparatus, with respect to each of the plural terminal apparatuses.

[0011] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, the terminal apparatuses may be selected such that a spatial correlation among the plural terminal apparatuses is low.

[0012] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, the terminal apparatus may be selected such that the same radio resource is assigned to the plural terminal apparatuses separated from each other by the angle.

[0013] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, the angle information may be an azimuth angle and an elevation angle of a direction to the terminal apparatus with reference to a position of the array antenna.

[0014] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, the plural terminal apparatuses located in the cell may be rearranged with respect to the elevation angle and divided into plural elevation angle groups, the plural terminal apparatuses belonging to the elevation angle group may be rearranged with respect to the azimuth angle, with respect to each of the plural elevation angle groups, and the selection of the terminal apparatuses may be performed such that the same radio resource is assigned to plural terminal apparatuses separated from each other on a virtual plane having coordinate axes of the elevation angle and the azimuth angle which intersect each other.

[0015] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, the beamforming weight may be calculated according to the angle information, with respect to each of the plural terminal apparatuses.

[0016] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, channel state information between the terminal apparatus and the communication relay apparatus or information equivalent thereto may be estimated based on the angle information, and the beamforming weight may be calculated based on the estimation result.

[0017] In each of the foregoing communication relay apparatus, the foregoing system, the foregoing method and the foregoing program, a mode vector consisting of a Hadamard product of an amplitude response vector of plural antenna elements of the array antenna and a phase difference vector between the antenna elements of the plural antenna elements may be substituted as the channel state information.

Advantageous Effects of Invention

[0018] According to the present invention, in the case of performing an MU-MIMO communication (or transmission) using a multi-element array antenna between an upper-airspace staying type communication relay apparatus and plural terminal apparatuses in a cell, it is possible to improve the communication quality of the entire cell and enhance the system capacity while suppressing an increase in overhead in the terminal apparatus and communication relay apparatus even if the number of terminal apparatuses located in the cell increases.

BRIEF DESCRIPTION OF DRAWINGS

[0019] FIG. **1** is a schematic configuration diagram showing an example of an overall configuration of a communication system including a HAPS according to an embodiment.

[0020] FIG. **2** is a perspective view showing an example of a HAPS of an embodiment.

[0021] FIG. **3** is a side view showing another example of a HAPS of an embodiment.

[0022] FIG. **4** is a perspective view showing an example of an array antenna for a service link of a HAPS of an embodiment.

[0023] FIG. **5** is a perspective view showing another example of an array antenna for a service link of a HAPS of an embodiment.

[0024] FIG. **6** is an illustration showing an example of beamforming in MU-MIMO using an array antenna of a HAPS.

[0025] FIG. **7** is a flowchart of a UE selection and a BF weight calculation in MU-MIMO according to a reference example.

[0026] FIG. **8** is an illustration of transmission of reference signals from UEs in a cell in MU-MIMO according to a reference example.

[0027] FIG. **9** is an illustration showing a positional relationship between a fixed base station and UEs within a service area in a communication system via a fixed base station on the ground according to a reference example.

[0028] FIG. **10** is an illustration showing a positional relationship between a HAPS and UEs within a service area in a communication system via a HAPS according to an embodiment.

[0029] FIG. **11** is a flowchart showing an example of a UE selection and a BF weight calculation in MU-MIMO of a HAPS according to an embodiment.

[0030] FIG. **12** is a flow chart showing an example of an angle estimation in FIG. **11**.

[0031] FIG. **13** is an illustration showing definitions of an azimuth angle and an elevation angle with reference to a direction of a UE in a coordinate system with reference to a position of the HAPS.

[0032] FIG. **14** is a flow chart showing an example of a UE selection based on angle information in FIG. **11**.

[0033] FIG. **15** is an illustration showing an example of a UE selection in FIG. **14**.

[0034] FIG. **16** is an illustration showing an example of assignment of resource blocks on a frequency axis to each UE selected in FIG. **15**.

[0035] FIG. **17** is an illustration showing an example of sorting and grouping of UEs for elevation angles in the UE selection process of FIG. **14**.

[0036] FIG. **18** is an illustration showing an example of sorting and selecting UEs for azimuth angles after the grouping of FIG. **17**.

[0037] FIG. **19** is a flow chart showing an example of a BF weight calculation based on angle information in FIG. **11**.

[0038] FIG. **20** is an illustration showing an example of a first BF method used for calculating the BF weights in FIG. **19**.

[0039] FIG. **21** is an illustration showing an example of a second BF method used for calculating the BF weights in FIG. **19**.

[0040] FIG. **22** is an illustration showing an example of a mode vector in the calculation of the BF weights in the case of the second BF method of FIG. **21**.

[0041] FIG. **23** is an illustration showing an example of coordinates of a virtual horizontal plane, placement of the antenna elements, and azimuth angles of UEs in a CSI estimation (restoration) in the case of a cylindrical array antenna.

[0042] FIG. **24** is an illustration showing an example of coordinates of a virtual vertical plane, placement of the antenna elements, and elevation angles of UEs in a CSI estimation (restoration) in the case of a cylindrical array antenna.

[0043] FIG. **25** is a block diagram showing an example of a main configuration of a relay communication station of a HAPS of an embodiment.

[0044] FIG. **26** is a block diagram showing an example of a main configuration of a base-station processing section in the relay communication station of FIG. **25**.

DESCRIPTION OF EMBODIMENTS

[0045] Hereinafter, embodiments of the present invention are described with reference to the drawings.

[0046] A system according to embodiments described herein is a communication system (HAPS system), that is provided with an upper-airspace staying type communication relay apparatus (HAPS) that forms a cell toward the ground or the sea and performs MU-MIMO communication using a multi-element array antenna with plural terminal apparatuses (UE) located in the cell, capable of improving a communication quality of an entire cell and enhancing a system capacity while suppressing an increase of overhead in the UE and HAPS even if the number of UEs located in the cell increases. The communication system according to the present embodiment is suitable for realizing a three-dimensional network for the next-generation mobile communication such as the fifth generation that supports simultaneous connection to a large number of terminal apparatuses and low delay, etc.

[0047] FIG. **1** is a schematic configuration diagram showing an example of an overall configuration of a communication system including a HAPS (upper-airspace staying type communication relay apparatus) according to an embodiment. In FIG. **1**, the communication system of the present embodiment (hereinafter also referred to as "HAPS system") is provided with a High-Altitude Platform Station (HAPS) (also referred to as "high altitude pseudo satellite" or "stratosphere platform") **10** as an upper-airspace staying type communication relay apparatus (radio relay apparatus). The HAPS **10** is located in an airspace at a predetermined altitude, and forms a three-dimensional cell **100**C. The HAPS **10** is a floating object (for example, solar plane, airship, drone, balloon) that is controlled by autonomous control or external control so as to float or fly and be located in an airspace (floating airspace) at a predetermined altitude from the ground level or the sea level, and has a relay communication station mounted thereon. The upper-airspace staying type communication relay apparatus may be an artificial satellite with a relay communication station mounted thereon. Moreover, the communication system of the present embodiment may include one or more terminal apparatuses with which the HAPS **10** communicates, and may include a gateway station (feeder station) described below.

[0048] The airspace in which the HAPS **10** is located is, for example, a stratospheric airspace at an altitude of 11 [km] or more and 50 [km] or less on the ground (or on the water such as the sea or lake). The airspace may be an airspace at an altitude of 15 [km] or more and 25 [km] or less where weather conditions are relatively stable, and may be an airspace at an altitude of about 20 [km] in particular.

[0049] Since the HAPS is lower than the flight altitude of general artificial satellites and flies higher than base stations on the ground or on the sea, a high line-of-sight rate can be

ensured while the propagation loss is smaller than that of satellite communication. This feature enables a communication service from the HAPS to a terminal apparatus (mobile station) **61**, which is a user apparatus such as a cellular mobile terminal on the ground or on the sea. By providing the communication service from the HAPS, it is possible to cover a wide area with a small number of HAPS at once, where was previously covered by many base stations on the ground or on the sea, so there is an advantage capable of providing a stable communication service at low cost.

[0050] The relay communication station of the HAPS **10** forms the three-dimensional cell **100**C capable of performing a radio communication with the UE **61**, by forming a beam for radio communication with a user's terminal apparatus (hereinafter referred to as "UE" (user equipment)) toward the ground surface (or sea surface). A radius of a service area **10**A consisting of a footprint **100**F on the ground (or on the sea) of the three-dimensional cell **100**C is, for example, several tens [km] to 100 [km].

[0051] In the present embodiment, the relay communication station of the HAPS **10** may form plural three-dimensional cells (for example, three cells or seven cells), and form the service area **10**A consisting of plural footprints on the ground (or on the sea) of the plural three-dimensional cells.

[0052] The relay communication station of the HAPS **10** is, for example, a base station (for example, eNodeB, gNodeB) that wirelessly communicates with a gateway station (also referred to as a "feeder station") **70** as a relay station connected to a core network of a mobile communication network **80** on the ground (or on the sea) side and has an antenna **71** facing the upper airspace. The relay communication station of the HAPS **10** is connected to the core network of the mobile communication network **80** via the feeder station **70** disposed on the ground or on the sea. The communication between the HAPS **10** and the feeder station **70** may be performed by a radio communication using a radio wave such as a microwave, or may be performed by an optical communication using a laser light or the like.

[0053] The HAPS **10** may autonomously control its own floating movement (flight) and a process in the relay communication station by executing a control program by a control section configured with a computer incorporated inside or the like. For example, each of the HAPS **10** may obtain its own current position information (for example, GPS position information), position control information (for example, flight schedule information) stored in advance, position information on another HAPS located in a peripheral space, or the like, and may autonomously control the floating movement (flight) and the process in the relay communication station based on these kinds of information.

[0054] Further, the floating movement (flight) of the HAPS **10** and the process in the relay communication station may be controlled by a management apparatus (also referred to as a "remote control apparatus") as a management apparatus provided in a communication center of the mobile communication network **80** or the like. The management apparatus can be configured with, for example, a computer apparatus such as a PC, a server, or the like. In this case, the HAPS **10** may incorporate a communication terminal apparatus for control (for example, mobile communication module) so as to be capable of receiving control information from the management apparatus and transmitting various kinds of information such as monitoring information to the management apparatus, and may be assigned terminal identification information (for example, IP address, phone number, etc.) so as to be identified from the management apparatus. The MAC address of the communication interface may be used to identify the communication terminal apparatus for control. Moreover, the HAPS **10** may transmit information on the floating movement (flight) of the own HAPS or a surrounding HAPS and the process in the relay communication station, and monitoring information such as information on a status of the HAPS **10** and observation data obtained by various kinds of sensors, to a predetermined destination such as the management apparatus. The control information may include information on a target flight route of the HAPS. The monitoring information may include at least one of information on current position, flight-route history information, velocity relative to the air, velocity relative to the ground and propulsion direction of the HAPS **10**, wind velocity and wind direction around the HAPS **10**, and atmospheric pressure and temperature around the HAPS **10**.

[0055] FIG. **2** is a perspective view showing an example of the HAPS **10** used in the communication system of the embodiment.

[0056] The HAPS **10** in FIG. **2** is a solar-plane type HAPS, and is provided with a main wing section **101** with both ends in the longitudinal direction curved upward, and plural motor-driven propellers **103** as propulsion apparatuses for bus power system on one end section in the short direction of the main wing section **101**. On the upper surface of the main wing section **101**, a photovoltaic-power generation panel (hereinafter referred to as "solar panel") **102** is provided as a photovoltaic-power generation section having a photovoltaic-power generation function. At two locations in the longitudinal direction of the lower surface of the main wing section **101**, plural pods **105** serving as equipment housing sections for housing mission equipment are connected via plate-like connecting sections **104**. Inside each pod **105**, a relay communication station **110** as a mission equipment and a battery **106** are accommodated. On the undersurface side of each pod **105**, wheels **107** are provided for use during takeoff and landing. The electric power generated by the solar panel **102** is stored in the battery **106**, the electric power supplied from the battery **106** rotates the motor of the propeller **103**, and the radio relay process is performed by the relay communication station **110**.

[0057] FIG. **3** is a perspective view showing another example of HAPS **10** used in the communication system of the embodiment. The HAPS **10** in FIG. **3** is an unmanned-airship type HAPS, and it can be equipped with a large-capacity battery because it has a large payload. The HAPS **10** is provided with an airship body **201** filled with a gas such as helium gas for floating by buoyancy, a motor-driven propeller **202** as a propulsion apparatus for bus power system, and an equipment housing section **203** for housing mission equipment. Inside the equipment housing section **203**, the relay communication station **110** and the battery **204** are accommodated. The electric power supplied from the battery **204** drives the motor of the propeller **202** to rotate, and the relay communication station **110** performs the radio relay process. It is noted that, a solar panel having a photovoltaic-power generation function may be provided on

the upper surface of the airship body **201**, and the electric power generated by the solar panel may be stored in the battery **204**.

[0058] In the following embodiments, although it is illustrated and described for a case in which the upper-airspace staying type communication relay apparatus for wirelessly communicating with the UE **61** is either one of the solar-plane type HAPS **10** in FIG. **2** or the unmanned-airship type HAPS **20**, the upper-airspace staying type communication relay apparatus may be the unmanned-airship type HAPS **10** in FIG. **3**. The following embodiments can be similarly applied to other upper-airspace staying type communication relay apparatuses other than the HAPS **10**.

[0059] Links FL(F) and FL(R) between the HAPS **10** and a gateway station (hereinafter abbreviated as "GW station") **70** as a feeder station are called "feeder links", and a link between the HAPS **10** and the UE **61** is called a "service link". In particular, a section between the HAPS **10** and the GW station **70** is called a "radio section of feeder link". Moreover, a downlink of communication from the GW station **70** to the UE **61** via the HAPS **10** is called a "forward link" FL(F), and an uplink of communication from the UE **61** to the GW station **70** via the HAPS **10** is also called a "reverse link" FL(R).

[0060] Duplex methods of uplink and downlink for radio communication with the UE **61** via the relay communication station **110** are not limited to specific methods, and may be, for example, a time division duplex method (Time Division Duplex: TDD) or a frequency division duplex method (Frequency Division Duplex: FDD).

[0061] An access method for radio communication with the UE **61** via the relay communication station **110** is not limited to the specific method, but may be, for example, FDMA (Frequency Division Multiple Access) method, TDMA (Time Division Multiple Access) method, CDMA (Code Division Multiple Access) method, or OFDMA (Orthogonal Frequency Division Multiple Access).

[0062] In the radio communication of the service link of the present embodiment, a massive MIMO (Multi-Input and Multi-Output) technology is used, which has functions of diversity/coding, transmission beam forming, spatial division multiplexing (SDM: Spatial Division Multiplexing), etc., and which performs a multi-layer transmission using an array antenna with a large number of antenna elements. In particular, in the present embodiment, in a downlink communication from the relay communication station **110** as a base station (for example, eNodeB, gNodeB) to plural UEs **61** in the cell, a MU-MIMO (Multi-User MIMO) technology is used, which transmits signals to plural different UEs **61** at the same time and on the same frequency. By performing the MU-MIMO transmission using an array antenna with a large number of antenna elements, since it is possible to communicate by directing an appropriate beam for each UE **61** according to the communication environment of each UE **61**, the communication quality of the entire cell can be improved. Since the communication with plural UEs **61** can be performed using the same radio resource (time/frequency resource), a system capacity can be enhanced.

[0063] Each of FIG. **4** and FIG. **5** is perspective view showing an example of an array antenna **130** configured with multiple elements that can be used for the MU-MIMO transmission system in the HAPS **10** of the present embodiment.

[0064] The array antenna **130** in FIG. **4** is a planar-type array antenna, which has a planar antenna base, and in which a large number of antenna elements **130***a* such as patch antennas are two-dimensionally disposed along a planar antenna surface of the antenna base in axial directions orthogonal to each other.

[0065] The array antenna **130** in FIG. **5** is a cylinder-type array antenna, which has a cylindrical or columnar antenna base, and in which a large number of antenna elements **130***a* such as patch antennas are disposed along an axial direction and a circumferential direction of a circumferential side surface as a first antenna surface of the antenna base. In the array antenna **130** of FIG. **5**, as shown in the figure, plural antenna elements **130***a* such as patch antennas may be disposed in a circular shape along a bottom surface as a second antenna surface. The antenna base in FIG. **5** may be a polygonal tubular or polygonal cylindrical antenna base.

[0066] It is noted that, the shape of the array antenna **130**, and the number, types and placement of the antenna elements are not limited to those exemplified in FIG. **4** and FIG. **5**.

[0067] FIG. **6** is an illustration showing an example of beamforming in the MU-MIMO transmission system using the array antenna **130** of the HAPS **10**. In the service link SL between the array antenna **130** of the HAPS **10** and the service area **100**A (footprint **100**F of the cell **100**C) in FIG. **6**, using the MU-MIMO transmission system, by performing beamforming in which an appropriate beam **100**B is individually directed to each UE **61** according to the communication environment of each UE **61**, the communication quality can be improved. In particular, in the case of using the MU-MIMO transmission system that communicates with plural UEs **61** using the same radio resource (for example, the same time/frequency resource block (RB)) in the service link SL, the system capacity can be improved.

[0068] In the case of using the MU-MIMO transmission system with a beamforming control in the HAPS **10** of the present embodiment, CSI (channel state information) between each UE **61** and the HAPS **10** needs to be obtained in order to direct appropriate beam **100**B to each UE **61** individually.

[0069] The communication quality changes greatly depending on which UE **61** is assigned to a certain radio resource (RB). For example, in the case of assigning the same frequency resource to the UEs **61** that are close to each other in FIG. **6**, plural beams **100**B directed from the HAPS **10** to respective UEs **61** interfere with each other, and the communication quality may be significantly deteriorate.

[0070] As a MU-MIMO system that directs an appropriate beam individually to each UE by using a multi-element array antenna and suppresses the deterioration of communication quality by suppressing interference between plural beams that are close to each other in spatial distance, as shown in the following reference example, a CSI-based MU-MIMO system is generally used, which uses CSI estimated by receiving a reference signal (SRS: Sounding Reference Signal) from each UE.

[0071] FIG. **7** is a flowchart of a UE selection and a BF weight calculation in MU-MIMO according to a reference example. FIG. **8** is an illustration of transmission of reference signals from UEs in a cell in MU-MIMO according to a reference example. In FIG. **7**, the HAPS requests SRSs to all UEs in the cell, receives SRSs from all UEs as shown in FIG. **8** (S**901**), and estimates the CSI of each UE based on

the SRS reception results (S**902**). The HAPS selects UEs to be assigned to the same radio resource (RB) from all UEs in the cell, with respect to each of the plural radio resources (RB) used for downlink communication, based on the CSI estimation result of each UE (S**903**). By this UE selection, plural UEs with low spatial correlation are assigned to the same radio resource (RB). Based on the CSI estimation result of each UE, the HAPS calculates a BF weight to apply to the signal of each antenna element of the array antenna for forming individual beam to each UE (S**904**). The HAPS performs a downlink MU-MIMO communication for each UE based on the UE selection result for each radio resource (RB) and the BF weight calculation result for each UE (S**905**).

[0072] In the CSI-based MU-MIMO system of the reference example described above, in the UE selection and the BF weight calculation, the CSI of all UEs is required, and it is necessary to periodically receive the reference signals (SRS) from all UEs in the cell to obtain the CSI of each UE. In particular, in the case of the HAPS, it is assumed that the number of the connected UEs located in the cell reaches tens of thousands, and the overhead increases due to the frequent transmission of the reference signal (SRS) from each UE to the HAPS.

[0073] In the CSI-based MU-MIMO system of the reference example described above, the amount of computation and the like in the UE selection process increases rapidly depending on the increase in the number of UEs located in the cell of the HAPS. For example, assuming that the UE selection is performed by repeatedly evaluating an orthogonality degree of channel (CD) between the UEs, which is proposed in Non-Patent Literature 1 described above, with an orthogonality degree of CSI based on CSI obtained from the UEs, when the number of UEs is 5,000, the number of evaluations of the orthogonality degree of CSI reaches 12 million or more, and when the number of UEs reaches 20,000, the number of evaluations of the orthogonality degree of CSI reaches 200 million or more. Therefore, the amount of calculation, the size of the calculation circuit and the power consumption during the UE selection process increase, and the use of the UE selection method based on the orthogonality degree of CSI is not realistic in the MU-MIMO system in the cell of the HAPS.

[0074] Therefore, in the present embodiment, focusing on the characteristics of the HAPS system (a cellular-radio communication system forming a cell with the HAPS in the upper airspace) compared to the terrestrial system (a cellular-radio communication system forming a cell with fixed base stations on the ground), as described below, the UE selection and BF weight calculation are performed based on angle information indicating the direction to the UE in the cell without calculating the orthogonality degree of the CSI obtained based on the reference signal (SRS).

[0075] FIG. **9** is an illustration showing a positional relationship between a fixed base station **90** and the UE **61** in a service area (cell) **90**A in a communication system (terrestrial system) via the fixed base station on the ground according to the reference example. FIG. **10** is an illustration showing a positional relationship between the HAPS **10** and the UE **61** in the service area (cell footprint) **10**A in the communication system (HAPS system) via the HAPS **10** according to the present embodiment.

[0076] In the service area **90**A with a radius Rc of several kilometers in the terrestrial system of FIG. **9**, the size of the area is small, the number of UEs in the area is small, and the distance between the fixed base station **90** and the UE **61** is short. Therefore, an angle θ_{UE} between the UEs viewed from the antenna of the fixed base station **90** is small, and a scattering area **61**A due to multipath is large with respect to the propagation distance of radio waves between the fixed base station **90** and the UE **61**, and the prospective angle θp of the scattering area **61**A viewed from the antenna of the fixed base station **90** is large. Accordingly, in the terrestrial system, radio waves transmitted from one UE **61** tend to arrive from unspecified directions, and it is difficult to combine plural UEs with a large angle θ_{UE} between the UEs in the UE selection process described above.

[0077] On the other hand, in the service area **90**A with a radius Rc of several tens of kilometers to 100 kilometers in the HAPS system of FIG. **10**, the size of the area is large, the number of UEs in the area is large, and the distance between the HAPS **10** and the UE **61** is long. Therefore, UEs with a large angle θ_{UE} between UEs viewed from the antenna of the HAPS **10** exists in the area, and the scattering area **61**A due to multipath is small with respect to the propagation distance of radio waves between the HAPS **10** and the UE **61**, and the prospective angle θp of the scattering area **61**A viewed from the antenna of the fixed base station **90** is small.

[0078] Accordingly, in the HAPS system, radio waves transmitted from one UE **61** arrive from a specific direction, and plural UEs with a large angle θ_{UE} between the UEs are likely to be combined in the UE selection process described above.

[0079] As shown above, focusing on the features of the HAPS system compared to the terrestrial system, the UE selection and the BF weight calculation are performed based on the angle information indicating the direction of the UE **61** in the service area **10**A as shown below, without calculating the orthogonality degree of the CSI obtained based on the reference signal (SRS).

[0080] FIG. **11** is a flowchart showing an example of a selection of the UE **61** and a BF weight calculation in MU-MIMO of the HAPS **10** according to the present embodiment. In FIG. **11**, first, with respect to all UEs **61** in the service area **10**A, the relay communication station **110** of the HAPS **10** estimates angles (azimuth angle, elevation angle) indicating the direction to the UE **61** with reference to the array antenna **130** of the HAPS **10**, based on any uplink signal capable of uniquely identifying the UE which is received from the UE **61** (S**100**). Since the angles (azimuth angle, elevation angle) to the UE **61** can be estimated from any uplink signal, there is no overhead associated with the transmission and reception of the reference signal (SRS), unlike the reference example described above. Although the CSI used for the UE selection depends on the frequency in the reference example described above, the angles (azimuth angle, elevation angle) of the UE **61** estimated in the present embodiment does not depend on the frequency, so the angle of the UE **61** can be estimated regardless of TDD/FDD.

[0081] As an estimation method of the angles (azimuth angle, elevation angle) of the UE **61**, for example, a method of obtaining the azimuth angle/elevation angle of each UE **61** by applying an angle estimation algorithm based on the uplink signal from the UE **61** can be used. The estimation method of the angles (azimuth angle, elevation angle) of the UE **61** may be a method of directly notifying the position information (for example, GPS position information, etc.)

on the UE **61** itself to the HAPS **10** side and calculating the azimuth angle/elevation angle of each UE **61** from the position information.

[0082] Next, the relay communication station **110** of the HAPS **10** performs the UE selection so that the spatial correlation between the UEs is low, based on the angles (azimuth angle, elevation angle) of each UE **61** estimated for all the UEs **61** in the service area **10**A (S**110**). By performing the UE selection based on the angles (azimuth angle, elevation angle), the amount of computation can be significantly reduced compared to the UE selection based on the CSI in the above-described reference example.

[0083] Next, the relay communication station **110** of the HAPS **10** calculates the BF weight to be applied to each antenna element of the array antenna **130** when forming a beam for each UE **61**, based on the angles (azimuth angle, elevation angle) of each UE **61** estimated for all UEs **61** in the service area **10**A (S**120**). For this BF weight calculation, two types of BF methods can be selectively used as described below, for example. The first BF method is a method of calculating the BF weights so as to perform a beam forming control (beam steering) according to estimated values of angles (azimuth angle, elevation angle) of each UE **61**. Since the first BF method does not perform a CSI restoration process, the amount of calculation is smaller than that of the second BF method. The second BF method is a method of calculating the BF weights so as to perform a beam forming control (beam steering) by estimating (restoring) the CSI based on the estimated values of the angles (azimuth angle, elevation angle) of each UE **61**. In this second BF method, a general beam forming algorithm based on the CSI can be used.

[0084] Next, the relay communication station **110** of the HAPS **10** can perform a downlink MU-MIMO communication with each UE **61** based on the UE selection result and the BF weight calculation result, in the service link communicating with the UE **61** in the service area **10**A (S**130**).

[0085] FIG. **12** is a flow chart showing an example of the angle estimation in FIG. **11**. FIG. **13** is an illustration showing definitions of the azimuth angle φ and elevation angle θ for the direction to the UE **61** in the coordinate system with reference to the position of the HAPS **10**. It is noted that, in FIG. **12**, for simplification of description, the angle estimation process for one certain UE **61** is shown.

[0086] In the angle estimation process of FIG. **12**, first, the relay communication station **110** of the HAPS **10** receives an arbitrary uplink signal including information that can uniquely identify the UE **61**, by the array antenna **130** (S**101**). Since the arbitrary uplink signal transmitted from the UE **61** can be used, there is no need to separately request the UE **61** to receive the reference signal (SRS) as used in the above-described reference example. It is noted that, the step S**101** may be omitted if there is an uplink signal received immediately before the angle estimation process.

[0087] Next, the relay communication station **110** of the HAPS **10** uses an arbitrary radio wave direction-of-arrival estimation program to estimate the azimuth angle φ and the elevation angle θ (see FIG. **13**) indicating the direction to the UE **61** with reference to the position of the array antenna **130** of the HAPS **10** (S**102**). Herein, since the distance between the HAPS **10** in the upper airspace and the UE **61** on the ground (or on the sea) is sufficiently long, the influence of reflected waves and the like is small, and the angles (azimuth angle φ, elevation angle θ) can be estimated with sufficient accuracy even with the basic algorithm of arbitrary radio wave direction-of-arrival estimation program.

[0088] Next, the relay communication station **110** of the HAPS **10** updates the data of the angles (azimuth angle φ, elevation angle θ) of the UE **61** stored in a storage section such as a memory with the estimated values of the newly estimated angles (azimuth angle φ, elevation angle θ) of the UE **61** (S**103**).

[0089] FIG. **14** is a flow chart showing an example of the selection of the UE **61** based on the angle information (azimuth angle, elevation angle) in FIG. **11**. FIG. **15** is an illustration showing an example of the selection of the UE **61** in FIG. **14**. FIG. **16** is an illustration showing an example of assignment of resource blocks on the frequency axis to each UE selected in FIG. **15**. It is noted that FIG. **14** shows the UE selection process in one certain downlink MU-MIMO communication for simplification of explanation. FIG. **15** and FIG. **16** show an example in which the UEs **61**(**1**), **61**(**2**) and the UEs **61**(**3**), **61**(**4**) are located apart at area ends far from each other in the service area **10**A, the distance between the UE **61**(**1**) and the UE **61**(**2**) is short, and the distance between the UE **61**(**3**) and the UE **61**(**4**) is short.

[0090] The UE selection process in FIG. **14** is performed based on the following criteria. In order to reduce the inter-UE interference (inter-beam interference) in the service area **10**A and achieve a high throughput, it is generally used to assign plural UEs **61** with low spatial correlation with each other to the same radio resource (for example, the same RB (resource block)). As described above, in the HAPS system, the scattering area **61**A is narrow with respect to the propagation distance (the spread angle θp of the scattering area **61**A viewed from the HAPS **10** is small). Herein, in the case of the service area **10**A of the HAPS **10**, the plural UEs **61** with low spatial correlation with each other are plural UEs **61** that are spatially separated from each other as exemplified in FIG. **15**, that is, the plural UEs **61** whose angle information (azimuth angle φ, elevation angle θ) are separated from each other. Therefore, as exemplified in FIG. **16**, the plural UEs **61** whose angle information (azimuth angle φ, elevation angle θ) are separated from each other may be assigned to the same radio resource (same RB).

[0091] In the UE selection process of FIG. **14**, first, the relay communication station **110** of the HAPS **10** obtains angle information (azimuth angle φ, elevation angle θ) on all UEs **61** performing downlink communications in the service area **10**A (S**111**).

[0092] Next, the relay communication station **110** of the HAPS **10** sorts all the UEs **61** with respect to the elevation angle θ and divides them into Nu groups as exemplified in FIG. **17** (S**112** in FIG. **14**). Herein, Nu is the number of UEs **61** assigned to the same radio resource (same RB) when performing a MU-MIMO transmission. The value of Nu may vary according to the distribution of UEs **61** in the service area **10**A.

[0093] Next, as exemplified in FIG. **18**, the relay communication station **110** of the HAPS **10** sorts the UEs **61** with respect to the azimuth angle φ within each group, and assigns the UEs **61** separated from each other on a virtual plane of elevation-azimuth angle to the same radio resource (same RB) (S**113** in FIG. **14**). In the example of FIG. **18**, where Nu is 6, the 6 UEs are sorted with respect to the azimuth angle φ within each group, an offset δg in azimuth angle φ is applied by given to the g-th group, and the same

radio resource (the same RB) assigned to the 6 UEs **61** belonging to the same azimuth angle group in the virtual plane of elevation-azimuth angle after applying the offset δg. It is noted that the value of the offset δg may be changed for each elevation angle group according to the distribution of the UEs **61** in the service area **10**A.

[0094] Next, the relay communication station **110** of the HAPS **10** sends the selection result of the UE **61** assigned to each radio resource (same RB) to an RB-assignment processing section described below (S**114** in FIG. **14**).

[0095] FIG. **19** is a flowchart showing an example of BF weight calculation based on angle information (azimuth angle, elevation angle) in FIG. **11**. FIG. **20** is an illustration showing an example of the first BF method used for calculating BF weights in FIG. **19**. FIG. **21** is an illustration showing an example of the second BF method used for calculating BF weights in FIG. **19**. FIG. **22** is an illustration showing an example of mode vectors in the BF weight calculation in the case of the second BF method of FIG. **21**. It is noted that FIG. **19** shows a BF weight calculation process for one certain radio resource (1 RB) for simplification of explanation.

[0096] In FIG. **19**, first, the relay communication station **110** of the HAPS **10** obtains angle information (azimuth angle φ, elevation angle θ) on all UEs **61** assigned to the target RB (S**121**).

[0097] Next, the relay communication station **110** of the HAPS **10** determines the type of beam forming method (BF method) used for the downlink communication (S**122** in FIG. **19**), and in the case of the first BF method (BF method 1), calculates the beam steering weight (BF weight) exemplified in FIG. **20** based on the foregoing obtained angle information (azimuth angle φ, elevation angle θ) (S**123** in FIG. **19**). In the case of this first BF method (BF method 1), the amount of computation for calculating the BF weight is smaller than in the case of the following second BF method (BF method 2). It is noted that, in the case of this first BF method (BF method 1), although it is a simple calculation method without considering interference between the UEs (inter-beam interference) and the like, the interference between the UEs (inter-beam interference) is less likely to occur, because the plural UEs **61** assigned to the RB have a low spatial correlation with each other as described above.

[0098] In the case of the second BF method (BF method 2), the relay communication station **110** of the HAPS **10** estimates (restores) the CSI of each UE **61** (channel state information between the HAPS **10** and the UE **61**) based on the foregoing obtained angle information (azimuth angle φ, elevation angle θ) (S**124** in FIG. **19**), and calculates the beam steering weight (BF weight) exemplified in FIG. **21** based on the estimated (restored) CSI of each UE **61** (S**125** in FIG. **19**). In the case of this second BF method (BF method 2), since the BF weights are calculated based on the CSI estimation results (restoration results), an arbitrary general BF algorithm based on the CSI can be used to calculate the BF weights, and the accuracy of beamforming is higher than that of the first BF method (BF method 1) described above, and more advanced beamforming control is possible. For example, in case that the Zero-Forcing is used as the BF algorithm, the directivity of the mutually adjacent sections **101**B of the beam **100**B directed to each UE becomes null and there is no interference as exemplified in FIG. **21**, and the inter-UE interference becomes zero.

[0099] Next, the relay communication station **110** of the HAPS **10** sends the calculation result of the BF weight used for the downlink MU-MIMO communication with each UE **61**, to the BF multiplication section described below (S**126** in FIG. **19**).

[0100] FIG. **22** is an illustration showing an example of a mode vector used for the CSI estimation (restoration) in the BF weight calculation in the case of the second BF method (BF method 2) in FIG. **21**. As described above, in the case of the HAPS system, the scattering area **61**A of the UE **61** due to multipath is narrow with respect to the propagation distance D of radio waves, and the expected angle θp of the scattering area **61**A viewed from the array antenna of the HAPS **10** is small. Therefore, for example, as shown in FIG. **22**, the radio wave from the UE **61** to the HAPS **10** can be regarded as a set of direct waves including the reflected waves, without distinguishing between the direct waves and the multipath reflected waves. So, the mode vector a (φ, θ) for the array antenna of the HAPS **10** in the figure can be substituted for the CSI.

[0101] Herein, when the azimuth angle and elevation angle of the UE **61** viewed from the array antenna of the HAPS **10** are 9 and 0, respectively, and the total number of plural antenna elements constituting the array antenna of the HAPS **10** is Nt, an amplitude response vector g (φ, θ) and a phase-difference response vector d (φ, θ) consisting of 1×Nt elements for the plural antenna elements are expressed by the following equations (1) and (2), respectively.

$$g(\phi,\theta)=[g_1(\phi,\theta),\ldots,g_{N_t}(\phi,\theta)] \quad (1)$$

$$d(\phi,\theta)=[d_1(\phi,\theta),\ldots,d_{N_t}(\phi,\theta)] \quad (2)$$

[0102] $g_i(\phi,\theta)$

[0103] in the equation (1) is the amplitude response function of the i-th antenna element, and

[0104] $d_i(\phi,\theta)$

in the equation (2) is the phase-difference response function of the i-th antenna element.

[0105] Using the amplitude response vector g (φ, θ) of the equation (1) and the phase-difference response vector d (φ, θ) of the equation (2), the mode vector a (φ, θ) consisting of 1×Nt elements, which can be substituted for the CSI, can be calculated by the following equation (3).

$$a(\phi,\theta)=g(\phi,\theta)\odot d(\phi,\theta) \quad (3)$$

[0106] ⊙

in the equation (3) is the Hadamard product operator. It is noted that the CSI estimated (restored) by calculating the mode vector a (φ, θ) of the equation (3) does not include the influence of the propagation pass loss (path loss).

[0107] In case that the array antenna **130** of the HAPS **10** is the above-described cylindrical array antenna **130** in FIG. **5**, the mode vector a (φ, θ), which can be substituted for the CSI, can be calculated as follows.

[0108] FIG. **23** is an illustration showing an example of the coordinates of the virtual horizontal plane, the placements of the antenna elements **130***a* and the azimuth angle φ of the UE **61** in the CSI estimation (restoration) in the case of the cylindrical array antenna. A phase-difference response vector d_H (φ) in the horizontal direction (azimuth angle direction) along the virtual horizontal plane in FIG. **23** is expressed by the following equations (4) and (5). In the equation, N is the number of antenna elements (number of horizontal elements) in the virtual horizontal plane, and r is the radius of the cylindrical antenna base (radius of the circle

in which the antenna elements are disposed). Equation (5) is the phase-difference response function of the n-th antenna element in the virtual horizontal plane. In equation (5), j expresses the imaginary unit, π expresses the circular constant, and λ expresses the wavelength of the carrier wave.

$$d_H(\phi) = [d_{H,1}(\phi), d_{H,2}(\phi), \ldots, d_{H,N}(\phi)] \quad (4)$$

$$d_{H,n}(\phi) = \exp\left(j\frac{2\pi}{\lambda}r\cos\left(\phi - \frac{2\pi(n-1)}{N}\right)\right) \quad (5)$$

[0109] FIG. **24** is an illustration showing an example of the coordinates of the virtual vertical plane, the placements of the antenna elements **130***a* and the elevation angle θ of the UE **61** in the CSI estimation (restoration) in the case of the cylindrical array antenna. A phase-difference response vector $d_V(\theta)$ in the vertical direction (elevation angle direction) along the virtual vertical plane in FIG. **24** is expressed by the following equations (6) and (7). In the equation, M is the number of antenna elements (the number of vertical elements) in the virtual vertical plane, and d is the interval between the antenna elements (element interval). Equation (7) is a phase-difference response function of the m-th antenna element in the virtual vertical plane. In equation (7), j expresses the imaginary unit, π expresses the circular constant, and λ expresses the wavelength of the carrier wave.

$$d_V(\theta) = [d_{V,1}(\theta), d_{V,2}(\theta), \ldots, d_{V,M}(\theta)] \quad (6)$$

$$d_{V,m}(\theta) = \exp\left(-j\frac{2\pi}{\lambda}(m-1)d\sin\theta\right) \quad (7)$$

[0110] Using the phase-difference response vector $d_H(\varphi)$ of equation (4) in the virtual horizontal plane and the phase-difference response vector $d_V(\theta)$ of equation (6) in the virtual vertical plane, a phase-difference response vector d (φ, θ) for all antenna elements consisting of the cylindrical array antenna is expressed by the following equation (8).

$$d(\phi,\theta)=d_V(\theta)\otimes d_H(\phi) \quad (8)$$

[0111] ⊗
in the equation (8) is the Kronecker product operator.

[0112] Based on the above-described amplitude response vector g (φ, θ) of the equation (1) and the phase-difference response vector d (φ, θ) of the equation (8), the mode vector a (φ, θ) that can be substituted for the CSI can be calculated as shown in the above-described equation (3).

[0113] FIG. **25** is a block diagram showing an example of a main configuration of the relay communication station **110** of the HAPS **10** of the embodiment. The relay communication station **110** in FIG. **25** is an example of a base-station type relay communication station. The relay communication station **110** is provided with an antenna section for service link **111**, a transmission/reception section **112**, an antenna section for feeder link **113**, a transmission/reception section **114**, a monitor control section **116**, a power supply section **117**, a modem section **118**, and a base-station processing section **119**.

[0114] The antenna section for service link **111** has an array antenna that forms a radial beam toward the ground (or the sea), and forms a three-dimensional cell **100**C that can communicate with the UE **61**. The transmission/reception section **112** constitutes a first-radio communication section together with the antenna section for service link **111**, has a duplexer (DUP: DUPlexer) and an amplifier, etc., and transmits radio signals to the UE **61** located in the three-dimensional cell **100**C and receives radio signals from the UE **61** via the antenna section for service link **111**.

[0115] The antenna section for service link **111** and the transmission/reception section **112** also function as an uplink (UL) reception section that receives an uplink signal capable of identifying the UE **61** from each of the plural UEs **61** via the array antenna **130**.

[0116] The antenna section for feeder link **113** has a directional antenna for radio communication with the feeder station **70** on the ground (or on the sea). The transmission/reception section **114** constitutes a second-radio communication section together with the antenna section for feeder link **113**, has a duplexer (DUP: DUPlexer) and an amplifier, etc., and transmits radio signals to the feeder station **70** and receives radio signals from the feeder station **70** via the antenna section for feeder link **113**.

[0117] The monitoring control section **116** is composed of, for example, a CPU and a memory, etc., and monitors the operation processing status of each section in the HAPS **10** and controls each section by executing a preinstalled program. In particular, the monitoring control section **116** controls the motor driving section **141** that drives the propellers **103** and **202** to move the HAPS **10** to the target position and to keep it near the target position by executing a control program.

[0118] The power supply section **117** supplies electric power output from the batteries **106** and **204** to each section in the HAPS **10**. The power supply section **117** may have a function of storing electric power generated by the photovoltaic panel, etc., or electric power supplied from the outside in the batteries **106** and **204**.

[0119] The modem section **118**, for example, performs demodulation process and decoding process on reception signals received from the feeder station **70** via the antenna section for feeder link **113** and the transmission/reception section **114**, and generates data signals to be output to the base-station processing section **119** side.

[0120] The modem section **118** performs encoding process and modulation process on data signals received from the base-station processing section **119** side, and generates transmission signals to be transmitted to the feeder station **70** via the antenna section for feeder link **113** and the transmission/reception section **114**.

[0121] The base-station processing section **119** has, for example, a function (for example, functions of e-NodeB, g-NodeB, etc.) that performs base band process based on the method that conforms to the LTE/LTE-AdVanced standard or the next-generation standard such as the 5th generation.

[0122] The base-station processing section **119**, for example, performs demodulation process and decoding process on reception signals received from the UE **61** located in the three-dimensional cell **100**C via the antenna section for service link **111** and the transmission/reception section **112**, and generates data signals to be output to the modem section **118** side. The base-station processing section **119** performs encoding process and modulation process on data signals received from the modem section **118** side, and generates base band signals (IQ signals) to be transmitted to the UE **61**

of the three-dimensional cell **100**C via the antenna section for service link **111** and the transmission/reception section **112**.

[0123] FIG. **26** is a block diagram showing an example of a main configuration of the base-station processing section **119** in the relay communication station **110** of FIG. **25**. In FIG. **26**, only the main configuration related to the present embodiment is illustrated, and illustration of other components necessary for communication with the UE **61** is omitted.

[0124] In FIG. **26**, the base-station processing section **119** is provided with a downlink (DL) transmission section **1190**, a transmission/reception switching control section **1191**, an angle-estimation processing section **1192**, a UE selection processing section (user-selection processing section) **1193**, a BF weight calculation section **1194**, a BF weight multiplying section **1195**, an RB assignment processing section **1196**, and an OFDM modulation section **1197**. The DL transmission section **1190** has the BF weight multiplying section **1195**, the RB assignment processing section **1196**, and plural OFDM modulation sections **1197**, and performs transmission signal processing by plural layers (streams) in downlink MU-MIMO communication.

[0125] The transmission/reception switching control section **1191** passes uplink signals from plural antenna elements received from each UE **61** in the cell **100**C by the antenna section for service link **111** and the transmission/reception section **112**, to the angle-estimation processing section **1192**. The transmission/reception switching control section **1191** passes a transmission signal (IQ signal) for each of plural layers (streams) simultaneously generated by the DL transmission section **1190**, to the transmission/reception section **112**.

[0126] The angle-estimation processing section **1192** estimates angle information (azimuth angle φ, elevation angle θ) indicating the direction of each UE **61** with reference to the position of the array antenna **130** based on an arbitrary uplink signal capable of identifying the UE received from each of all the UEs **61** in the cell **100**C, as exemplified in FIG. **12** described above.

[0127] The UE selection processing section (user-selection processing section) **1193** selects UE **61** to be assigned to the RE for each of plural time-frequency resource blocks (RBs) used for the downlink MU-MIMO communication, based on the angle information (azimuth angle φ, elevation angle θ) of all the UEs **61** targeted for performing downlink MU-MIMO communication, as exemplified in FIG. **14** described above. Selection information on the UE **61** assigned to each RE is sent to the RB assignment processing section **1196**.

[0128] The BF weight calculating section **1194** calculates BF weights for beam steering (beamforming control) that are multiplied by symbols when transmitting transmission signals of each UE, with respect to each of all UEs **61** targeted for performing the downlink MU-MIMO communication, based on the angle information (azimuth angle φ, elevation angle θ) on the UE **61**, as exemplified in FIG. **19** described above. The BF weight calculation result of each UE **61** is sent to the BF weight multiplying section **1195**.

[0129] The BF weight multiplying section **1195** multiplies each of symbols for the UE **61** mapped to a predetermined number of layers (transmission streams) by the BF weight corresponding to the UE **61**, with respect to each of all UEs **61** targeted for performing the downlink MU-MIMO communication, based on the BF weight calculation result received from the BF weight calculating section **1194**.

[0130] The RB assignment processing section **1196** assigns the symbol of the UE **61** multiplied by the BF weight to the RB corresponding to the UE **61**, with respect to each of all UEs **61** targeted for performing the downlink MU-MIMO communication, based on the UE (user) selection information received from the UE selection processing section (user-selection processing section) **1193**.

[0131] The plural OFDM modulation sections **1197** perform OFDM modulation on each of plural symbols mapped to a predetermined number of layers (transmission streams) of downlink MU-MIMO communication to generate plural IQ signals, and output them to the transmission/reception switching control section **1191**.

[0132] As described above, according to the present embodiment, in the case of performing the MU-MIMO communication using the multi-element array antenna between the relay communication station **110** of the HAPS **10** in the upper airspace and plural UEs **61** in the cell **100**C, it is possible to improve the communication quality of the entire cell **100**C and enhance the system capacity while suppressing an increase in overhead in the UEs **61** and the relay communication station **110** even if the number of UEs **61** located in the cell **100**C increases.

[0133] It is noted that, the process steps and configuration elements of the relay communication station of the communication relay apparatus such as the HAPS **10**, the feeder station, the gateway station, the management apparatus, the monitoring apparatus, the remote control apparatus, the server, the terminal apparatus (UE: user equipment, mobile station, communication terminal), the base station and the base station apparatus described in the present description can be implemented with various means. For example, these process steps and configuration elements may be implemented with hardware, firmware, software, or a combination thereof.

[0134] With respect to hardware implementation, means such as processing units or the like used for establishing the foregoing steps and configuration elements in entities (for example, relay communication station, feeder station, gateway station, base station, base station apparatus, relay-communication station apparatus, terminal apparatus (UE: user equipment, mobile station, communication terminal), management apparatus, monitoring apparatus, remote control apparatus, server, hard disk drive apparatus, or optical disk drive apparatus) may be implemented in one or more of an application-specific IC (ASIC), a digital signal processor (DSP), a digital signal processing apparatus (DSPD), a programmable logic device (PLD), a field programmable gate array (FPGA), a processor, a controller, a microcontroller, a microprocessor, an electronic device, other electronic unit, computer, or a combination thereof, which are designed so as to perform a function described in the present specification.

[0135] With respect to the firmware and/or software implementation, means such as processing units or the like used for establishing the foregoing configuration elements may be implemented with a program (for example, code such as procedure, function, module, instruction, etc.) for performing a function described in the present specification. In general, any computer/processor readable medium of materializing the code of firmware and/or software may be used for implementation of means such as processing units

and so on for establishing the foregoing steps and configuration elements described in the present specification. For example, in a control apparatus, the firmware and/or software code may be stored in a memory and executed by a computer or processor. The memory may be implemented within the computer or processor, or outside the processor. Further, the firmware and/or software code may be stored in, for example, a medium capable being read by a computer or processor, such as a random-access memory (RAM), a read-only memory (ROM), a non-volatility random-access memory (NVRAM), a programmable read-only memory (PROM), an electrically erasable PROM (EEPROM), a FLASH memory, a floppy (registered trademark) disk, a compact disk (CD), a digital versatile disk (DVD), a magnetic or optical data storage unit, or the like. The code may be executed by one or more of computers and processors, and a certain aspect of functionalities described in the present specification may by executed by a computer or processor.

[0136] The medium may be a non-transitory recording medium. Further, the code of the program may be executable by being read by a computer, a processor, or another device or an apparatus machine, and the format is not limited to a specific format. For example, the code of the program may be any of a source code, an object code, and a binary code, and may be a mixture of two or more of those codes.

[0137] The description of embodiments disclosed in the present specification is provided so that the present disclosures can be produced or used by those skilled in the art. Various modifications of the present disclosures are readily apparent to those skilled in the art and general principles defined in the present specification can be applied to other variations without departing from the spirit and scope of the present disclosures. Therefore, the present disclosures should not be limited to examples and designs described in the present specification and should be recognized to be in the broadest scope corresponding to principles and novel features disclosed in the present specification.

REFERENCE SIGNS LIST

[0138] **10**: HAPS
[0139] **10**A: service area
[0140] **61**: terminal apparatus (UE)
[0141] **61**A: scattering area
[0142] **70**: feeder station (GW station)
[0143] **71**: antenna
[0144] **80**: mobile communication network
[0145] **100**A: service area
[0146] **100**B: beam
[0147] **100**C: cell
[0148] **100**F: footprint
[0149] **110**: relay communication station
[0150] **111**: antenna section for service link
[0151] **112**: transmission/reception section
[0152] **113**: antenna section for feeder link
[0153] **114**: transmission/reception section
[0154] **119**: base-station processing section
[0155] **130**: array antenna
[0156] **130***a*: antenna element
[0157] **1190**: downlink transmission section
[0158] **1191**: transmission/reception switching control section
[0159] **1192**: angle-estimation processing section
[0160] **1194**: BF weight calculation section
[0161] **1195**: BF weight multiplying section
[0162] **1196**: assignment processing section
[0163] **1197**: OFDM modulation section

1. An upper-airspace staying type communication relay apparatus that forms a cell toward the ground or the sea and performs an MU-MIMO radio communication with plural terminal apparatuses located in the cell, comprising:

an array antenna having plural antenna elements, the array antenna forming a cell for performing radio communications of service link to and from the plural terminal apparatuses;

an uplink reception section for receiving an uplink signal capable of identifying the terminal apparatus, from each of the plural terminal apparatuses via the array antenna;

an angle-estimation processing section for estimating angle information indicating a direction of the terminal apparatus with reference to a position of the array antenna for each of the plural terminal apparatuses;

a selection processing section for selecting a terminal apparatus to be assigned to each of plural radio resources used for a downlink of the service link so that a same radio resource is assigned to the plural terminal apparatuses separated from each other by the angle, based on the estimation result of the angle information on the plural terminal apparatuses;

a weight calculation section for calculating a downlink beamforming weight for the terminal apparatus by the array antenna based on the estimation result of the angle information, with respect to each of the plural terminal apparatuses; and

a downlink transmission section for transmitting a downlink signal to the terminal apparatus via the array antenna based on the beamforming weight corresponding to the terminal apparatus and the radio resource assigned to the terminal apparatus, with respect to each of the plural terminal apparatuses.

2. The communication relay apparatus according to claim **1**,

wherein the angle information is an azimuth angle and an elevation angle of the direction of the terminal apparatus with reference to the position of the array antenna, and

wherein the weight calculation section calculates the beamforming weight according to the angle information, with respect to each of the plural terminal apparatuses.

3. The communication relay apparatus according to claim **1**,

wherein the angle information is an azimuth angle and an elevation angle of the direction of the terminal apparatus with reference to the position of the array antenna, and

wherein the weight calculation section estimates channel state information between the terminal apparatus and the communication relay apparatus or information equivalent thereto, based on the angle information, and calculates the beamforming weight based on the estimation result, with respect to each of the plural terminal apparatuses.

4. The communication relay apparatus according to claim 1,

wherein the selection processing section:

rearranges the plural terminal apparatuses located in the cell with respect to the elevation angle and divides them into plural elevation angle groups;

rearranges the plural terminal apparatuses belonging to the elevation angle group with respect to the azimuth angle, with respect to each of the plural elevation angle groups; and

performs the selection of the terminal apparatuses so that the same radio resource is assigned to plural terminal apparatuses separated from each other on a virtual plane having coordinate axes of the elevation angle and the azimuth angle, the coordinate axes intersecting each other; and

wherein the weight calculation section calculates the beamforming weight according to the angle information, with respect to each of the plural terminal apparatuses.

5. The communication relay apparatus according to claim 1,

the selection processing section:

rearranges the plural terminal apparatuses located in the cell with respect to the elevation angle and divides them into plural elevation angle groups;

rearranges the plural terminal apparatuses belonging to the elevation angle group with respect to the azimuth angle, with respect to each of the plural elevation angle groups; and

performs the selection of the terminal apparatuses so that the same radio resource is assigned to plural terminal apparatuses separated from each other on a virtual plane having coordinate axes of the elevation angle and the azimuth angle, the coordinate axes intersecting each other; and

wherein the weight calculation section estimates channel state information or information equivalent thereto between the terminal apparatus and the communication relay apparatus based on the angle information, and calculates the beamforming weight based on the estimation result, with respect to each of the plural terminal apparatuses.

6. The communication relay apparatus according to claim 3,

wherein communication relay apparatus substitutes a mode vector consisting of a Hadamard product of an amplitude response vector of the plural antenna elements of the array antenna and a phase difference vector between the antenna elements of the plural antenna elements, as the channel state information.

7. A system comprising the communication relay apparatus according to claim 1; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

8. A program executed by a computer or a processor installed in an upper-airspace staying type communication relay apparatus that forms a cell toward the ground or the sea and performs an MU-MIMO radio communication with plural terminal apparatuses located in the cell; comprising:

a program code for receiving an uplink signal capable of identifying the terminal apparatus from each of the plural terminal apparatuses via an array antenna having plural antenna elements forming a cell for performing radio communications of service link to and from the plural terminal apparatuses;

a program code for estimating angle information indicating a direction of the terminal apparatus with reference to a position of the array antenna, with respect to each of the plural terminal apparatuses;

a program code for selecting a terminal apparatus to be assigned to each of plural radio resources used for a downlink of the service link so that a same radio resource is assigned to the plural terminal apparatuses separated from each other by the angle, based on the estimation results of the angle information of the plural terminal apparatuses;

a program code for calculating a downlink beamforming weight for the terminal apparatus by the array antenna based on the estimation result of the angle information, with respect to each of the plural terminal apparatuses; and

a program code for transmitting a downlink signal to the terminal apparatus via the array antenna based on the beamforming weight corresponding to the terminal apparatus and the radio resource assigned to the terminal apparatus, with respect to each of the plural terminal apparatuses.

9. The communication relay apparatus according to claim 5,

wherein communication relay apparatus substitutes a mode vector consisting of a Hadamard product of an amplitude response vector of the plural antenna elements of the array antenna and a phase difference vector between the antenna elements of the plural antenna elements, as the channel state information.

10. A system comprising the communication relay apparatus according to claim 2; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

11. A system comprising the communication relay apparatus according to claim 3; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

12. A system comprising the communication relay apparatus according to claim 4; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

13. A system comprising the communication relay apparatus according to claim 5; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

14. A system comprising the communication relay apparatus according to claim 6; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

15. A system comprising the communication relay apparatus according to claim 9; and a terminal apparatus for performing an MU-MIMO radio communication with the communication relay apparatus.

* * * * *