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Power control for flying base station

Abstract

A communication control apparatus for a communication system with a ground station, which is at least partly installed on the ground and can communicate with a communication device, and a flying base station, which can communicate with the ground station, includes: an available power estimation unit to estimate available power of the flying base station; a required total power estimation unit to estimate total power required by the flying base station for communication with each communication device connected to the ground station; and a communication mode change unit to change communication mode between at least one communication device and the flying base station, at least when the total power is more than the available power, so that the total power becomes less than the available power.

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Background/Summary

RELATED APPLICATIONS

(1) The present application is a National Phase of International Application No. PCT/JP2021/041640, filed Nov. 11, 2021, and claims priority based on Japanese Patent Application No. 2021-126679, filed Aug. 2, 2021.

BACKGROUND OF THE INVENTION

1. Field of the Invention

(2) The present disclosure relates to communication control technology in communication system.

2. Description of the Related Art

(3) The number, types, and applications of wireless communication devices, represented by smartphones and Internet of Things (IoT) devices, continue to increase, and wireless communication standards continue to be expanded and improved. For example, the commercial service of the fifth generation mobile communication system known as “5G” started in 2018, and the standards are still being developed by the 3GPP (Third Generation Partnership Project). Efforts are also underway to develop standards for “6G” or the sixth generation mobile communication system, which would be the next generation of wireless communication standards following 5G.

(4) Mobile communication networks for mobile or portable communication devices such as smartphones and cell phones (hereinafter collectively referred to as “communication device(s)”) are usually constructed by communication cells (hereinafter referred to as “terrestrial communication cell(s)”) provided by base stations installed on the ground (hereinafter referred to as “terrestrial base station(s)”). However, in some areas, it was difficult to install a sufficient number of terrestrial base stations for various reasons, resulting in a relatively low quality of mobile communications.

(5) In order to solve the issue of the disparity in mobile communication quality among different regions and the so-called “out-of-range” issue, where mobile communication devices cannot communicate in some regions, non-terrestrial networks (NTN) have been considered. In NTN, communication satellites or unmanned aircrafts flying in outer space or the atmosphere, such as the stratosphere, are used as base stations (hereinafter referred to as flying base station(s), and especially communication satellites are referred to as satellite base station(s)). The flying base station provides a communication cell on the ground (hereinafter referred to as flying communication cell(s), and especially communication cells provided by communication satellites are referred to as satellite communication cell(s)). A communication device in a flying communication cell communicates with a flying base station directly or indirectly via other communication devices. By providing flying communication cells in areas where terrestrial communication cells are not sufficient, the quality of mobile communication in such areas can be improved.

(6) Patent Literature 1: JP-A-2010-278886

SUMMARY OF THE INVENTION

(7) Flying base stations, such as communication satellites and unmanned aircrafts, communicate with many communication devices on the ground using power generated by solar cells or solar panels receiving sunlight, power stored in batteries, and the like. Although solar power generation can be sufficient for a standard or normal communication volume, the amount of power generated by sunlight varies greatly depending on the location and ephemeris of the flying base station, and the number of communication devices communicating with the flying base station and the communication volume also varies greatly depending on the time and area. It is extremely important to efficiently use the limited power of the flying base station under such highly uncertain circumstances, and the present disclosure has been completed.

- (8) The present disclosure was made in view of such circumstances, and the purpose thereof is to provide a communication control apparatus and the like that can efficiently use the power of a flying base station.
- (9) In order to solve the above-described issue, a communication control apparatus in a certain aspect of the present disclosure for a communication system with a ground station, which is at least partly installed on the ground and can communicate with a communication device, and a flying base station, which can communicate with the ground station, includes: an available power estimation unit to estimate available power of the flying base station; a required total power estimation unit to estimate total power required by the flying base station for communication with each communication device connected to the ground station; and a communication mode change unit to change communication mode between at least one communication device and the flying base station, at least when the total power is more than the available power, so that the total power becomes less than the available power.
- (10) According to the aspect, when the total power required by the flying base station for communication with each communication device on the ground is more than the available power of the flying base station, the communication mode change unit changes the communication mode between at least one communication device and the flying base station to reduce the required total power below the available power, so that the power of the flying base station can be used efficiently.
- (11) Another aspect of the present disclosure is a communication control method. The communication control method for a communication system with a ground station, which is at least partly installed on the ground and can communicate with a communication device, and a flying base station, which can communicate with the ground station, includes: estimating available power of the flying base station; estimating total power required by the flying base station for communication with each communication device connected to the ground station; and changing communication mode between at least one communication device and the flying base station, at least when the total power is more than the available power, so that the total power becomes less than the available power.
- (12) In addition, any combination of the above components, and any conversion of the expression of the present disclosure among methods, devices, systems, recording media, computer programs, and the like, is also valid as a form of the present disclosure.
- (13) According to the present disclosure, the power of the flying base station can be used efficiently.
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Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 schematically shows the overview of a wireless communication system to which the communication control apparatus is applied.
- (2) FIG. 2 schematically shows the wireless communication system with a communication satellite.
- (3) FIG. 3 is a functional block diagram of the communication control apparatus.
- (4) FIG. 4 is a schematic representation of an example of the sharing of communication-related information among terrestrial base stations by the communication-related information sharing unit.
- (5) FIG. 5 is a flowchart of communication control processes by the communication control apparatus.
- (6) FIG. 6 is a flowchart of the power control processes of communication satellite by the communication control apparatus.

DETAILED DESCRIPTION OF THE INVENTION

- (7) FIG. 1 schematically shows an overview of a wireless communication system 1 to which the

communication control apparatus according to an embodiment of the present disclosure is applied. The wireless communication system **1** includes 5G wireless communication system **11**, 4G wireless communication system **12**, and satellite communication system **13**. 5G wireless communication system **11** that complies with the fifth generation mobile communication system (5G) uses NR (New Radio) or 5G NR (Fifth Generation New Radio) as the radio access technology (RAT) and 5GC (Fifth Generation Core) as the core network. 4G wireless communication system **12** that complies with the fourth generation mobile communication system (4G) uses LTE (Long Term Evolution) or LTE-Advanced as the radio access technology and EPC (Evolved Packet Core) as the core network. Satellite communication system **13** is for satellite communication via communication satellite **131**. Although not shown in the figure, the wireless communication system **1** may include wireless communication networks of a generation prior to 4G, a generation later than 5G (e.g. 6G), or any wireless communication networks that are not associated with generations, such as Wi-Fi (registered trademark).

(8) The 5G wireless communication system **11** may include a plurality of 5G base stations **111A**, **111B** and **111C** (hereinafter collectively referred to as 5G base station **111**) installed on the ground capable of communicating by 5G NR with communicators or communication devices **2A**, **2B**, **2C** and **2D** (hereinafter collectively referred to as communication device(s) **2**) such as smartphones, which are also referred to as UE (User Equipment). 5G base station **111** is also referred to as gNodeB (gNB). The coverage or support range of each 5G base station **111A**, **111B** and **111C** is referred to as a cell **112A**, **112B** and **112C** (hereinafter collectively referred to as 5G cell **112** or cell **112**).

(9) The size of the 5G cell **112** of each 5G base station **111** is arbitrary; however, typically ranges from a few meters to several tens of kilometers in radius. Although there is no established definition, cells with a radius of a few meters to ten meters are called femtocells, cells with a radius of ten meters to several tens of meters are called picocells, cells with a radius of several tens of meters to several hundred meters are called microcells, and cells with a radius of more than several hundreds of meters are called macrocells. In 5G, high frequency radio waves such as millimeter waves are often used, and their high tendency to propagate in a straight-line causes radio waves to be blocked by obstacles, shortening the communication distance. For the reason, 5G tends to use more small cells than 4G and earlier generations.

(10) The communication device **2** can conduct 5G communication when it is located within at least one of a plurality of 5G cells **112A**, **112B** and **112C**. In the example shown in the figure, communication device **2B** in 5G cells **112A** and **112B** can communicate with both 5G base stations **111A** and **111B** by 5G NR. In addition, the communication device **2C** in the 5G cell **112C** can communicate with the 5G base station **111C** by 5G NR. Communication devices **2A** and **2D** are outside of all 5G cells **112A**, **112B** and **112C**, so they are not able to communicate by 5G NR. The 5G NR-based 5G communication between each communication device **2** and each 5G base station **111** is managed by the 5GC, which is the core network. For example, the 5GC transfers data to and from each 5G base station **111**, transfers data to and from external networks such as the EPC, the satellite communication system **13** and the Internet, and manages the movement of the communication device **2**, and the like.

(11) The 4G wireless communication system **12** includes a plurality of 4G base stations **121** (only one of them is shown in FIG. **1**) installed on the ground that can communicate with the communication device **2** by LTE or LTE-Advanced. The base station **121** in 4G is referred to as eNodeB (eNB). Similarly to each 5G base station **111**, the communication range or support range of each 4G base station **121** is also called a cell and is shown as **122**.

(12) The communication device **2** can perform 4G communication when it is located within 4G cell **122**. In the example shown in the figure, the communication devices **2A** and **2B** in the 4G cell **122** can communicate with the 4G base station **121** by LTE or LTE-Advanced. Communication devices **2C** and **2D** are outside the 4G cell **122** and are not able to communicate by LTE or LTE-Advanced.

The 4G communication by LTE and LTE-Advanced between each communication device **2** and each 4G base station **121** is managed by the EPC, which is the core network. For example, the EPC manages the transfer of data to and from each 4G base station **121**, the transfer of data to and from external networks such as 5GC, the satellite communication system **13** and the Internet, and the movement management of the communication device **2**.

(13) If we take a look at each communication device **2A**, **2B**, **2C** and **2D** in the example shown in the figure, the communication device **2A** is in a state that enables 4G communication with 4G base station **121**, and communication device **2B** is in a state that enables 5G communication with 5G base stations **111A** and **111B** and 4G communication with 4G base station **121**, and communication device **2C** is in a state that enables 5G communication with 5G base station **111C**. When there are multiple base stations (**111A**, **111B** and **121**) as in the case of communication device **2B**, one base station is selected as the most suitable for the communication device **2B** in terms of communication quality and the like, under the control of the 5GC and/or the EPC, which is the core network. For the communication device **2D** that is not in a state that enables 5G communication with any 5G base station **111** or 4G communication with any 4G base station **121**, the communication is conducted using the satellite communication system **13** described below.

(14) The satellite communication system **13** is the wireless communication system using communication satellites **131** as flying base stations. The communication satellites **131** are low-earth-orbit satellites flying in low-earth-orbit outer space of 500 to 700 km above the ground. Similarly to 5G base station **111** and 4G base station **121**, the communication range or support range of each communication satellite **131** is also called a cell and is shown as **132**. Thus, a communication satellite **131** as a flying base station provides a satellite communication cell **132** as a flying communication cell onto the ground. Communication device **2** on the ground can conduct satellite communication when it is inside the satellite communication cell **132**. Similarly to 5G base station **111** in the 5G wireless communication system **11** and 4G base station **121** in the 4G wireless communication system **12**, communication satellite **131** as the base station in the satellite communication system **13** is capable of wireless communication directly or indirectly via aircraft and the like with the communication device **2** within the satellite communication cell **132**. The radio access technology used by the communication satellite **131** for wireless communication with the communication device **2** in the satellite communication cell **132** may be 5G NR, the same as the 5G base station **111**, or LTE or LTE-Advanced, the same as the 4G base station **121**, or any other radio access technology that the communication device **2** can use. Therefore, there is no need for the communication device **2** to have any special functions or components for satellite communication.

(15) The satellite communication system **13** includes a gateway **133** as a ground station that is installed on the ground and can communicate with the communication satellite **131**. The gateway **133** is equipped with a satellite antenna to communicate with the communication satellite **131**, and is connected to the 5G base station **111** and the 4G base station **121** as terrestrial base stations that constitute the terrestrial network (TN). In such a manner, the gateway **133** connects the non-terrestrial network (NTN), which includes communication satellites **131**, and the terrestrial network TN, which includes terrestrial base stations **111** and **121**, for mutual communication. When the communication satellite **131** conducts 5G communication with the communication device **2** in the satellite communication cell **132** by 5G NR, the 5GC connected via the gateway **133** and the 5G base station **111** in the TN (or the 5G radio access network) is used as the core network. When the communication satellite **131** conducts 4G communication with the communication device **2** in the satellite communication cell **132** by LTE or LTE-Advanced, the EPC connected via the gateway **133** and the 4G base station **121** in the TN (or the 4G radio access network) is used as the core network. In such a manner, appropriate coordination is made between different wireless communication systems such as 5G wireless communication system **11**, 4G wireless communication system **12**, satellite communication system **13** and the like through the gateway

133.

(16) Satellite communication by communication satellites **131** is mainly used for covering areas with no or few terrestrial base stations such as 5G base stations **111** and 4G base stations **121** and the like. In the example shown in the figure, a communication device **2D** that is outside the communication cells of all the terrestrial base stations communicates with the communication satellite **131**. On the other hand, communication devices **2A**, **2B** and **2C** that are in good communication with either of the terrestrial base stations, are also in the satellite communication cell **132** and can communicate with the communication satellite **131**. However, by communicating with the terrestrial base stations instead of the communication satellite **131** as the satellite base station in principle, the limited communication resources (including power) of the communication satellite **131** are saved for the communication device **2D** and the like. The communication satellite **131** uses beamforming to direct the communication radio wave to the communication device **2D** in the satellite communication cell **132**, thereby the communication quality with the communication device **2D** is improved.

(17) The size of the satellite communication cell **132** of the communication satellite **131** as a satellite base station depends on the number of beams emitted by the communication satellite **131**. For example, a satellite communication cell **132** with a diameter of approximately 24 km can be formed by combining up to 2,800 beams. As illustrated, a satellite communication cell **132** is typically larger than a terrestrial communication cell such as a 5G cell **112** or a 4G cell **122**, and could contain one or more 5G cells **112** and/or 4G cells **122** inside it. The above example shows a communication satellite **131** flying in low-earth-orbit outer space at a height of approximately 500 km to 700 km above the ground as a flying base station. However, a communication satellite flying in geostationary orbit or other higher orbit in outer space, or an unmanned or manned aircraft flying in stratosphere or other lower (e.g. approximately 20 km above the ground) atmosphere may be used as a flying base station in addition to or instead of the communication satellite **131**.

(18) FIG. 2 shows a schematic of the same wireless communication system **1** as in FIG. 1, with the communication satellite **131** in focus. As mentioned above, communication satellite **131** can combine up to 2,800 beams to create one or more satellite communication cells **132** on the ground. In the example in FIG. 2, a total of Y satellite communication cells **132-1** to **132-Y** (hereinafter collectively referred to as satellite communication cell **132**) are formed on the ground by the communication satellite **131**. The Communication device **2D** in FIG. 1, which could not communicate with 5G base station **111** and 4G base station **121** and could communicate only with the communication satellite **131** is shown in FIG. 2 within the Y-th satellite communication cell **132-Y**. Another communication device **2E** is shown schematically within the first satellite communication cell **132-1**. Through the NTN including the communication satellite **131** and gateway **133** and the like, the communication devices (**2D**, **2E** and the like) in any of the satellite communication cells **132** perform 5G communication and/or 4G communication with communication devices in remote TNs (**2A**, **2B**, **2C** and the like), and/or, perform communication with any other communication devices via 5GC and/or EPC as core network.

(19) Communication satellite **131** includes any number (Z in the example in FIG. 2) of radio units RU.sub.1 to RU.sub.z responsible for forming the satellite communication cell **132**, wireless communication with communication devices (**2D**, **2E** and the like) located within the satellite communication cell **132**, and wireless communication with the gateway **133** and the like. The Gateway **133** connecting NTNs and TNs for mutual communication **133** includes a satellite antenna for communication with communication satellite **131**, and distributed unit group **134** and central unit group **135** as a portion or node of RAN (Radio Access Network) including the terrestrial base stations **111**, **121** of TNs.

(20) In the example in FIG. 2, distributed unit group **134** is equipped with X distributed units and central unit group **135** is equipped with X central units. The X pairs of distributed unit and central unit realize respective baseband functions of X terrestrial base stations **111**, **121** connected to the

gateway **133**. All or portion of the baseband functions may be provided in the respective terrestrial base stations **111**, **121** themselves and/or relay facilities or other equipment between the respective terrestrial base stations **111**, **121** and the gateway **133**, instead of being provided in the gateway **133**. In such a case, the gateway **133** would contain, in addition to the satellite antenna that interfaces with the NTN, only a simple interface function with the RAN of the TN.

(21) X distributed units in the distributed unit group **134** of the gateway **133** are connected with the same number of X terrestrial base stations **111**, **121**. In FIG. 2, four terrestrial communication cells **112**, **122** are illustrated in total: three of which are the three 5G cells **112A**, **112B** and **112C** as the terrestrial communication cells provided by the three 5G base stations **111A**, **111B** and **111C** in FIG. 1; and one of which is the one 4G cell **122** as the terrestrial communication cell provided by the one 4G base station **121** in FIG. 1. Each of the three 5G base stations **111A-111C** is connected one-to-one with either of the X distributed units in the distributed unit group **134** of the gateway **133**. One 4G base station **121** is also connected one-to-one with either of the X distributed units (which is not connected with the 5G base station **111A-111C**) in the distributed unit group **134** of the gateway **133**. It should be noted that since the concept of “distributed unit” and “central unit” did not exist in the 4G (and prior generation) wireless communication standards, the functions (baseband functions) performed by the units may actually be provided in the gateway **133** as similar functional unit (baseband unit) for 4G base station **121**, or provided in 4G base station **121** itself as described above.

(22) Each of the X central units in the central unit group **135** of the gateway **133** is connected one-to-one with the same number of X distributed units. Similar to the distributed units described above, the function of the central unit for 4G base station **121** may be provided in the gateway **133** as similar functional unit for 4G base station **121** or provided in 4G base station **121** itself. The central units corresponding to 5G base stations **111A-111C** are connected to the 5GC as CN via the 5G radio access network (5G RAN) of the 5G wireless communication systems **11**. The similar functional unit to central unit corresponding to 4G base station **121** is connected to the EPC as CN via the 4G radio access network (4G RAN) of the 4G wireless communication systems **12**.

(23) Thus, the gateway **133**, which interfaces with both of the 5G wireless communication system **11** and the 4G wireless communication system **12**, is connected to different CNs for each generation or standard. However, as described with respect to FIG. 1, the gateway **133** makes appropriate coordination among different CNs (5GC and EPC), thereby it can properly connect with wireless communication systems of different generations and standards. Note that the gateway **133** may be equipped with the function of interfacing only with a terrestrial wireless communication system of a particular generation or standard, such as the 5G wireless communication system **11**. In the case, the distributed unit group **134** of the gateway **133** is equipped with the same number of distributed units as 5G base stations (**111A-111C** and the like) to be connected, and central unit group **135** is equipped with the same number of central units as 5G base stations and distributed units.

(24) In the example of FIG. 2, the distributed unit group **134** of gateway **133** is connected with the three 5G base stations **111A-111C** that constitute the terrestrial network “5G TN” by the 5G wireless communication system **11** and connected with the one 4G base stations **121** that constitutes the terrestrial network “4G TN” by the 4G wireless communication system **12**. As in FIG. 1, the communications devices **2B** and **2C** exist within 5G cells **112A-112C** provided by the 5G base stations **111A-111C**, and the communications devices **2A** and **2B** exist within 4G cell **122** provided by the 4G base station **121**. It should be noted that the distributed unit group **134** of the gateway **133** may be connected with other TNs and terrestrial base stations (not shown), and other communication devices (not shown) may be present within each TN.

(25) Gateway **133**, as described above, is at least partly installed on the ground, and constitutes a ground station capable of communicating with communication devices (**2A-2C** and the like) within the connected TNs. The communication satellite **131** constitutes a flying base station that can

communicate with the gateway **133** as a ground station. Gateway **133** as a ground station connects the terrestrial base stations (**111A-111C**, **121** and the like) and the communication satellite **131** to establish communication between the communication devices (**2A-2C** and the like) connected to the terrestrial base station and the communication satellite **131**. In addition, the communication devices in the satellite communication cell **132** provided by the communication satellite **131** (**2D**, **2E** and the like) can communicate with the communication devices (**2A-2C** and the like) connected to gateway **133**, via the communications satellite **131** and the gateway **133**.

(26) FIG. **3** is a functional block diagram of the communication control apparatus **3** according to an embodiment of the present disclosure. The communication control apparatus **3** includes an available power estimation unit **31**, a sharing unit **32**, a required total power estimation unit **33**, a power comparison unit **34**, a communication-related information acquisition unit **35**, priority change unit **36** and a communication mode change unit **37**. The functional blocks are realized by the cooperation of hardware resources, such as the central processing unit, memory, input devices, output devices, and peripheral devices connected to the computer, and software that is executed using them. Regardless of the type of computer or the installation location, each of the above functional blocks may be realized with the hardware resources of a single computer, or by combining hardware resources distributed across multiple computers. Especially in the embodiment, some or all of functional blocks of the communication control apparatus **3** may be realized in computer and/or processor provided in the communication satellite **131**, the gateway **133**, each terrestrial base station (**111A-111C**, **121** and the like) and/or the communication device (**2A-2C** and the like).

(27) The available power estimation unit **31** estimates the available power of the communication satellite **131** as a flying base station based on ephemeris information of the communication satellite **131**. The available power estimation unit **31** is preferably provided in the gateway **133**, and the communication satellite **131** transmits its own ephemeris information to the gateway **133** continuously or periodically.

(28) The available power estimation unit **31** in the gateway **133** is responsible for estimating the amount of power generated by the solar panels installed on the communication satellite **131** based on sunlight, based on the ephemeris information received from the communication satellite **131**, information regarding the activity of the sun which is known to change periodically, and information regarding the condition of the space in which the communication satellite **131** flies and the like. If the communication satellite **131** is equipped with a battery that stores power, the communication satellite **131** will report the amount of charged power or amount of dischargeable power of the battery to the gateway **133**. In such a case, the sum of the amount of power generated by the solar panels and the amount of charged power of the battery is estimated by the available power estimation unit **31** as the available power of the communication satellite **131**.

(29) The sharing unit **32** includes a terrestrial base station list sharing unit **321**, an available power sharing unit **322**, and a communication-related information sharing unit **323**. The terrestrial base station list sharing unit **321** is used to share a list of terrestrial base stations connected to the communication satellite **131** via the gateway **133** among such terrestrial base stations as information associated with the communication satellite **131**. In the example in FIG. **3**, the gateway **133** is connected with the three 5G base stations **111A-111C** and the one 4G base station **121**, and the list of the four terrestrial base stations **111A-111C** and **121** is shared among the four terrestrial base stations **111A-111C** and **121**. This allows each terrestrial base station **111A-111C** and **121** to recognize other terrestrial base station **111A-111C** and **121** connected to the gateway **133** and the communications satellite **131**. The list of terrestrial base stations is preferably included in information associated with the communication satellite **131**, for example, the satellite ID or satellite identification information of the communication satellite **131** that is generated during cell configuration. Such satellite ID is shared among the terrestrial base station **111A-111C** and **121**.

(30) In the so-called “transparent” gateway **133**, the grouping of terrestrial base stations through the

above satellite ID and the like is impossible. Therefore, the above solution of sharing satellite ID and the like among terrestrial base stations is practical. On the other hand, since the so-called “regenerative” gateway **133** can group terrestrial base stations, the terrestrial base station list sharing unit **321** may not be required in addition to the gateway **133**.

(31) The available power sharing unit **322** is used to share the available power of the communication satellite **131** estimated by the available power estimation unit **31** among the terrestrial base stations (**111A-111C**, **121** and the like) included in the list shared by the terrestrial base station list sharing unit **321**. This allows each terrestrial base station **111A-111C** and **121** to recognize the available power of the communication satellite **131**. Note that if the gateway **133** is a regenerative type and the like, the available power sharing unit **322** may not be necessary, and the gateway **133** may recognize the available power of the communication satellite **131** and lead subsequent processes such as power comparison described below.

(32) The communication-related information sharing unit **323** is used to share the communication-related information or communication load information concerning the communication that the communication device (**2A-2C** and the like) connected to each terrestrial base station (**111A-111C**, **121** and the like) connected to the gateway **133** performs with the communication satellite **131**, among the terrestrial base stations (**111A-111C**, **121** and the like) included in the list shared by the terrestrial base station list sharing unit **321**. This allows each terrestrial base station (**111A-111C**, **121** and the like) to recognize the communication that the communication device connected to other terrestrial base station performs with the communication satellite **131**.

(33) Examples of the communication-related information include the communication volume, required communication speed, required quality of service (QoS), communication type (e.g. data communication, voice call, priority communication such as emergency report, VoNR and VoLTE), RSRP (Reference Signal Received Power), channel state information (CSI) including CQI (Channel Quality Indicator) and the like.

(34) As shown schematically in FIG. 4, the sharing of the communication-related information among the terrestrial base stations by the communication-related information sharing unit **323** can be done according to “RESOURCE STATUS UPDATE” defined in 5G communication and the like. “NG-RAN node.sub.1” to “NG-RAN node.sub.4” in the figure represent 5G base stations, and each 5G base station can send “RESOURCE STATUS UPDATE” to each other, thereby the latest communication-related information is shared among all 5G base stations. One terrestrial base station that shares the communication-related information with other terrestrial base stations preferably simultaneously sends or multicasts the “RESOURCE STATUS UPDATE” including the communication-related information, addressed to all other terrestrial base stations included in the list shared by the terrestrial base station list sharing unit **321**. This can be easily achieved by including all other terrestrial base stations (target cells) in the address or “target cell ID” of the “RESOURCE STATUS UPDATE”. Note that if the gateway **133** is a regenerative type and the like, the communication-related information sharing unit **323** may not be necessary, and the gateway **133** may recognize the communication-related information of each terrestrial base station and lead subsequent processes such as required total power estimation described below.

(35) The required total power estimation unit **33** estimates the total power required by the communication satellite **131** for communication with each communication device (**2A-2C** and the like) connected to the gateway **133**. In other words, the required total power estimation unit **33** estimates the total power required by the communication satellite **131** for communication with the communication device (**2A-2C** and the like) connected to the terrestrial base stations (**111A-111C**, **121** and the like) included in the list shared by the terrestrial base station list sharing unit **321**. Specifically, the required total power estimation unit **33** estimates the total power required by the communication satellite **131** based on the communication-related information of each terrestrial base station shared by the communication-related information sharing unit **323**. To estimate the total power required by the communication satellite **131**, it is necessary to estimate the power

required by the communication satellite **131** for communication with each individual communication device (2A-2C and the like). The individual power estimation is further broken down into estimating the number of Physical Resource Blocks (PRBs) required for communication and estimating the required power per PRB.

(36) In the estimation of the required number of PRBs, the communication-related information (communication volume, required communication speed, required QoS, communication type, CSI and the like) shared by the communication-related information sharing unit **323** is used in whole or in part. For example, the higher the communication volume, the greater the number of PRBs required; the higher the required communication speed, the greater the number of PRBs required (per unit time); the higher the required QoS, the greater the number of PRBs required (or PRBs are preferentially assigned to communications with higher required QoS than to other communications); if the communication type is priority communication such as emergency report, VoNR, VoLTE and the like, the number of PRBs required is higher (or PRBs are preferentially assigned to the priority communications over other communications); and if the channel condition based on CSI is poor, the number of PRBs required is higher. Similarly, in the estimation of the required power per PRB, the communication-related information shared by the communication-related information sharing unit **323** is also used in whole or in part. For example, if the required QoS is high, the required power per PRB is larger, and if the communication type is priority communication such as emergency report, VoNR, VoLTE and the like, the required power per PRB is larger, and if the channel condition based on CSI is poor, the required power per PRB is larger. Multiplying the number of required PRBs estimated above by the required power per PRB estimated above, the individual power required by the communication satellite **131** for communication with each communication device can be obtained. And, the required total power of the communication satellite **131** can be obtained by summing the individual powers over all communication devices.

(37) The power comparison unit **34** compares the required total power estimated by the required total power estimation unit **33** with the available power of the communication satellite **131** shared by the available power sharing unit **322**. If the required total power is less than or equal to the available power, the communication satellite **131** can manage the communication with each communication device (2A-2C and the like) connected to the gateway **133** within the range of the current available power. On the other hand, if the required total power is more than the available power, the communication satellite **131** cannot manage the requested communication with the current available power, and subsequent processes such as the communication mode change described below is necessary.

(38) The power comparison unit **34** may compare the required power per PRB with the available power. The required power per PRB is calculated by dividing the required total power estimated by the required total power estimation unit **33** by the required total number of PRBs (the sum of the individually estimated required number of PRBs). The available power per PRB is calculated by dividing the available power estimated by the available power estimation unit **31** by the required total number of PRBs (or the number of free PRBs available for scheduling for the communication satellite **131**).

(39) The communication-related information acquisition unit **35**, the priority change unit **36**, and the communication mode change unit **37** perform the processes described below, at least when the total power required by the communication satellite **131** is more than the available power as a result of the comparison by the power comparison unit **34**. Therefore, if the required total power of the communication satellite **131** is less than the available power, the communication-related information acquisition unit **35**, the priority change unit **36**, and the communication mode change unit **37** do not have to perform the processes described below.

(40) The communication-related information acquisition unit **35** is used to acquire the communication-related information concerning the communication that each communication

device (2A-2C and the like) connected to the gateway **133** performs with the communication satellite **131**. In the example in FIG. **3**, the communication-related information acquisition unit **35** acquires all or portion of the communication-related information already shared by the communication-related information sharing unit **323**.

(41) The priority change unit **36** lowers the priority of at least one of each communication device (2A-2C and the like) based on the communication-related information acquired by the communication-related information acquisition unit **35**. For example, the priority level of the communication device that performs communications with high required QoS or priority communications such as emergency report, VoNR, VoLTE and the like is not lowered, while the priority level of the communication device that performs other communications is lowered.

(42) The communication mode change unit **37** changes communication mode between at least one communication device (2A-2C and the like) connected to the gateway **133** and the communication satellite **131**, so that the required total power estimated by the required total power estimation unit **33** becomes less than the available power estimated by the available power estimation unit **31**. Specifically, the communication mode change unit **37** changes the communication mode between at least one of the communication devices whose priority is lowered by the priority change unit **36** and the communication satellite **131**. Examples of changing the communication mode include: delaying the communication of the communication device to be changed to a later time than that of the communication device not to be changed, reducing the number of PRBs allocated to the communication device to be changed from the number of required PRBs estimated by the required total power estimation unit **33**, reducing the power per PRB allocated to the communication device to be changed from the required power per PRB estimated by the required total power estimation unit **33**, reducing the communication volume of the communication device to be changed, slowing down the communication speed of the communication device to be changed, lowering the required QoS of the communication device to be changed, increasing the tolerance for CSI of the communication device to be changed, and so on.

(43) According to the above embodiment, when the total power required by the communication satellite **131** for communication with each communication device (2A-2C and the like) on the ground is more than the available power of the communication satellite **131**, the communication mode change unit **37** changes the communication mode between at least one communication device and the communication satellite **131** to reduce the required total power below the available power, so that the power of the communication satellite **131** can be used efficiently.

(44) FIG. **5** is a flowchart of the communication control processes by communication control apparatus **3**. “S” in the flowchart description refers to a step or process. In S1, the available power estimation unit **31** estimates the available power of the communication satellite **131** based on ephemeris information and the like of the communication satellite **131**. In S2, the communication-related information sharing unit **323** shares the communication-related information or communication load information concerning the communication that the communication device (2A-2C and the like) connected to each terrestrial base station (**111A-111C**, **121** and the like) connected to the gateway **133** performs with the communication satellite **131**, among the terrestrial base stations (**111A-111C**, **121** and the like) included in the list shared by the terrestrial base station list sharing unit **321**. In S3, the required total power estimation unit **33** estimates the total power required by the communication satellite **131** for communication with each communication device (2A-2C and the like) connected to the gateway **133**, based on the communication-related information of each terrestrial base station shared in S2.

(45) In S4, the power comparison unit **34** compares the required total power estimated in S3 with the available power estimated in S1, and judges whether or not the required total power is more than the available power. If S4 is judged to be No, the communication satellite **131** can manage the communication with each communication device (2A-2C and the like) connected to the gateway **133** within the range of the current available power, so the later processes S5-S7 are skipped and

return to S1. If S4 is judged to be Yes, proceed to S5, where the communication-related information acquired by the communication-related information acquisition unit 35 is used to judge the presence or absence of a high priority user. For example, if there is a communication device that performs communication with high required QoS and/or priority communication such as emergency report, VoNR, VoLTE and the like, the communication-related information acquisition unit 35 judges the user of such communication device to be a high priority user.

(46) If S5 is determined to be Yes, proceed to S6, where the priority change unit 36 lowers the priority of the communication devices of users other than the high-priority user recognized in S5, and the communication mode change unit 37 delays the communication of the communication device of the low-priority users to a later time than that of the communication device of the high-priority user recognized in S5, so that the required total power estimated in S3 becomes less than the available power estimated in S1 (so that the S4 is judged to be No). Then the process returns to S1. If S5 is determined to be No, the process proceeds to S7, and the communication mode change unit 37 changes communication mode between at least one communication device (2A-2C and the like) connected to the gateway 133 and the communication satellite 131, so that the required total power estimated in S3 becomes less than the available power estimated in S1 (so that the S4 is judged to be No). Then the process returns to S1.

(47) FIG. 6 is a flowchart of the power control processes of the communication satellite 131 by the communication control apparatus 3. Steps or processes similar to those in FIG. 5 are marked with the same signs and the duplicated descriptions will be omitted. When the communication satellite 131 communicates with communication devices (2A-2E and the like) on the ground, power of the communication satellite 131 will be consumed both in the uplink communication to receive data from communication device on the ground and in the downlink communication to send data to communication device on the ground. However, in general, the power consumption during the downlink communication is dominant. Thus, the power control processes during the downlink communication will be mainly described in relation to the figure. As shown in FIG. 2, the downlink communication from the communication satellite 131 is categorized into two types: One type is for the communication devices (2D, 2E and the like) in the satellite communication cell 132 provided by the communication satellite 131; and another type is for the communication devices (2A-2C and the like) in TNs connected to the gateway 133.

(48) In the present embodiment, by recognizing the communication-related information or communication load information of the communication devices (2A-2C and the like) in the TN, the power of the communication satellite 131 (hereinafter also referred to as downlink power) can be effectively controlled for: the downlink communication that the communication devices (2A-2C and the like) in the TN performs with the communication devices (2D, 2E and the like) in the satellite communication cell 132 via the gateway 133 and the communication satellite 131; and the downlink communication that the communication devices (2D, 2E and the like) in the satellite communication cell 132 performs with the communication devices (2A-2C and the like) in the TN via the communication satellite 131 and the gateway 133 in response to request by the communication devices (2A-2C and the like) in the TN.

(49) If we take a look at the communication between the communication devices (2A-2C and the like) in the TN and the communication satellite 131, there are two cases of communications as outlined above: in one case, the uplink communication from the communication devices (2A-2C and the like) in the TN to the communication satellite 131 (and the downlink communication from the communication satellite 131 to the communication devices in the satellite communication cell 132) is performed; and in another case, the downlink communication from the communication satellite 131 to the communication devices (2A-2C and the like) in the TN (and the uplink communication from the communication devices in the satellite communication cell 132 to the communication satellite 131) is performed. In either case, by changing the communication mode between the communication devices (2A-2C and the like) in the TN and the communication

satellite **131**, the power of the communication satellite **131** can be effectively controlled for the downlink communications that originates on the satellite communication cell **132** side or the TN side.

(50) In **S8**, the communication satellite **131** performs downlink communication with the default downlink power. In **S1**, the available power estimation unit **31** estimates the available power of the communication satellite **131** based on ephemeris information and the like of the communication satellite **131**. In **S2**, the communication-related information sharing unit **323** shares the communication-related information or communication load information concerning the uplink communication or downlink communication that the communication device (**2A-2C** and the like) in the TN performs with the communication satellite **131**, among the terrestrial base stations (**111A-111C**, **121** and the like) on the TN side. In **S9**, the communication satellite **131** acquires CSI such as RSRP and CQI, which indicate path loss and the like related to the downlink communication, from the communication-related information shared in **S2**. In **S10**, the communication satellite **131** judges whether or not the downlink power needs to be controlled (increased or decreased). For example, if the channel state of the downlink communication based on the CSI obtained in **S9** is significantly worse than expected, a larger downlink power is required, therefore the judgment in **S10** should be Yes. Conversely, if the channel state of the downlink communication based on the CSI obtained in **S9** is significantly better than expected, there is little problem even if the downlink power is reduced, therefore the judgment in **S10** should be also Yes. In case judgment in **S10** is No, the process returns to **S1**.

(51) If **S10** is determined to be Yes, proceed to **S11**, where the communication satellite **131** determines whether or not an increase of downlink power is required. If the channel state of the downlink communication is significantly worse than expected and the like as described above, **S11** is determined to be Yes, and proceed to **S4**. In **S4**, the power comparison unit **34** compares the required total power (**S3** in FIG. 5) with increase of the downlink power with the available power estimated in **S1**, and judges whether or not the required total power is more than the available power. If **S4** is determined to be Yes, increasing the downlink power will cause the required total power to exceed the available power, therefore the downlink power is adjusted or redistributed among each communication device by changing the communication mode similar to **S5-S7** in FIG. 5. Then the process returns to **S1**. If **S4** is determined to be No, the required total power remains below the available power even if the downlink power is increased. Then in **S12**, the communication satellite **131** increases the downlink power mainly for high priority users. Then the process returns to **S1**. If **S11** is determined to be No, proceed to **S13** where the communication satellite **131** decreases the downlink power mainly for low priority users. Then the process returns to **S1**.

(52) The present disclosure has been described above based on embodiments. It is understood by those skilled in the art that the embodiments are exemplary and that various variations are possible in the combination of each component and/or each process thereof, and that such variations are also within the scope of the present disclosure.

(53) The functional configuration of each device described in the embodiment can be realized by hardware resources or software resources, or by the cooperation of hardware resources and software resources. As hardware resources, processors, ROM, RAM, and other LSIs can be used. Operating systems, applications, and other programs can be used as software resources.

(54) The present disclosure relates to communication control technology in communication system.

Claims

1. A communication control apparatus for a communication system with a ground station, which is at least partly installed on the ground and can communicate with a communication device, and a flying base station, which can communicate with the ground station, comprising: an available

power estimation unit to estimate available power of the flying base station; a required total power estimation unit to estimate total power required by the flying base station for communication with each communication device connected to the ground station; and a communication mode change unit to change communication mode between at least one communication device and the flying base station, at least when the total power is more than the available power, so that the total power becomes less than the available power.

2. The communication control apparatus according to claim 1, wherein the communication system further comprises a terrestrial base station installed on the ground and capable of communicating with the communication device, and the ground station is a gateway that connects the terrestrial base station and the flying base station to establish communication between the communication device connected to the terrestrial base station and the flying base station.

3. The communication control apparatus according to claim 2, wherein the available power estimation unit is provided in the gateway and shares the estimated available power with the terrestrial base station connected to the gateway.

4. The communication control apparatus according to claim 2, wherein a list sharing unit is further provided to share a list of the terrestrial base stations connected to the flying base station via the gateway among the terrestrial base stations as information associated with the flying base station, and the required total power estimation unit estimates the total power required by the flying base station for communication with the communication device connected to the terrestrial base station included in the list.

5. The communication control apparatus according to claim 2, wherein one terrestrial base station connected to the gateway shares the communication-related information concerning the communication that the communication device connected to the one terrestrial base station performs with the flying base station with other terrestrial base station connected to the gateway, and the required total power estimation unit estimates the total power required by the flying base station based on the communication-related information shared among the terrestrial base stations.

6. The communication control apparatus according to claim 1, further comprising: a communication-related information acquisition unit that acquires communication-related information concerning the communication that each communication device connected to the ground station performs with the flying base station, and a priority change unit that lowers the priority of at least one of the communication devices based on the communication-related information, wherein the communication mode change unit changes the communication mode between at least one of the communication devices whose priority is lowered by the priority change unit and the flying base station.

7. The communication control apparatus according to claim 1, wherein the available power estimation unit estimates the available power of the flying base station based on the ephemeris information of the flying base station.

8. The communication control apparatus according to claim 1, wherein the flying base station provides a flying communication cell on the ground and one communication device in the flying communication cell can communicate with other communication device connected to the ground station via the flying base station and the ground station.

9. The communication control apparatus according to claim 1, wherein the flying base station is a communication satellite flying in outer space.

10. A communication control method for a communication system with a ground station, which is at least partly installed on the ground and can communicate with a communication device, and a flying base station, which can communicate with the ground station, comprising: estimating available power of the flying base station; estimating total power required by the flying base station for communication with each communication device connected to the ground station; and changing communication mode between at least one communication device and the flying base station, at least when the total power is more than the available power, so that the total power becomes less

than the available power.

11. A non-transitory computer-readable medium storing a communication control program for a communication system with a ground station, which is at least partly installed on the ground and can communicate with a communication device, and a flying base station, which can communicate with the ground station, causing a computer to perform: estimating available power of the flying base station; estimating total power required by the flying base station for communication with each communication device connected to the ground station; and changing communication mode between at least one communication device and the flying base station, at least when the total power is more than the available power, so that the total power becomes less than the available power.
