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(54) **Title:** RADIO UNIT FOR WIRELESS COMMUNICATION WITH A BASE BAND UNIT ACCORDING TO A RADIO ACCESS NETWORK PROTOCOL AND A BASE BAND UNIT

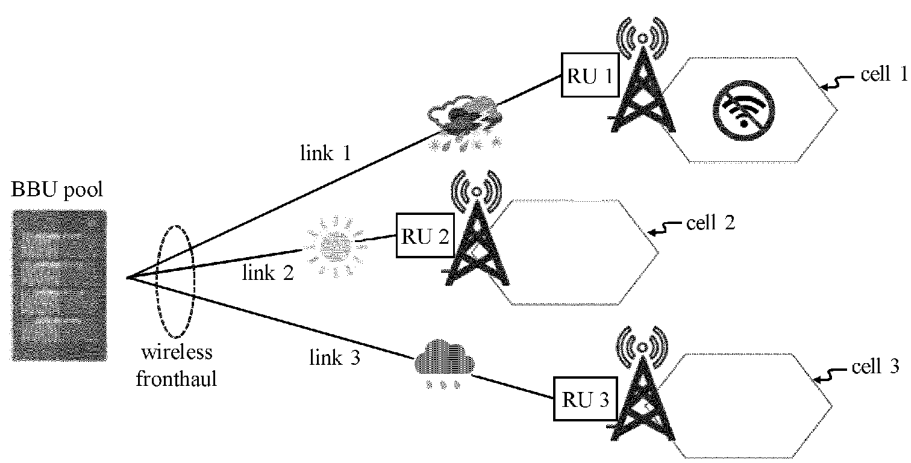

Figure 1

(57) **Abstract:** The present disclosure relates to a radio unit (RU) for wireless communication with a base band unit (BBU) according to a radio access network (RAN) protocol. The RU is configured to establish a first bidirectional connection with the BBU, the first bidirectional connection being allocated over a first frequency band of the electromagnetic spectrum. The RU is configured to establish a second bidirectional connection with the BBU, the second bidirectional connection being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication. The RU is configured to use the second bidirectional connection for communicating with the BBU in case one or more channel quality parameters of the first bidirectional connection do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted.

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RADIO UNIT FOR WIRELESS COMMUNICATION WITH A BASE BAND UNIT ACCORDING TO A RADIO ACCESS NETWORK PROTOCOL AND A BASE BAND UNIT

TECHNICAL FIELD

The present disclosure relates to a radio unit (RU) for wireless communication with a base band unit (BBU) according to a radio access network (RAN) protocol and to a BBU for wireless communication with a RU according to a RAN protocol. Further, the present disclosure relates to a method for a wireless communication between a BBU and a RU according to a RAN protocol. Furthermore, the present disclosure relates to a RU for wireless communication with a BBU of a BBU pool according to a RAN protocol and to a BBU pool for wireless communication with one or more RUs according to a RAN protocol.

BACKGROUND

Wireless communication devices, such as base band units (BBUs) and radio units (RUs), may wirelessly communicate with each other. Such wireless communication may be performed according to a radio access network (RAN) protocol. This allows providing a wireless communication according to the RAN protocol in an area that is covered by the communication devices, e.g. in one or more cells served by the RUs.

SUMMARY

In beyond-5G radio access networks, centralized RAN or cloud RAN (C-RAN) and its virtualized variant (vRAN) are becoming very popular and starting to be considered by operators as solutions to densify their network with reduced CAPEX and OPEX. C-RAN is a network paradigm that aggregates the main base band functionalities of multiple radio access points in centralized base band unit (BBU) pools, while leaving the radio frequency modules and possibly the first digital processing capabilities (e.g., analog-to-digital and digital-to-analog conversion, inverse fast Fourier transform (IFFT) / fast Fourier transform (FFT), beamforming, digital pre-distortion) at radio units (RUs) remotely deployed in the cell site. When network functions in the BBU are virtualized on general purpose x86 servers one can also refer to C-RAN as vRAN. The plurality of communication links connecting the BBU pools with the corresponding RUs is typically referred to as fronthaul infrastructure. In the following, the term “C-RAN” is used to generally refer to any one of centralized RAN or cloud RAN or virtualized RAN.

C-RAN not only reduces deployment and maintenance costs, but also provides performance enhancement e.g. through inter-cell (i.e., among multiple RUs) coordination, as well as by e.g. enabling network virtualization, slicing, and openness. Moreover, in scenarios where the radio infrastructure is managed by a third party (e.g., a tower company or a neutral host), C-RAN operators can share dynamically the radio and base band resources. On the other hand, C-RAN imposes a big challenge to the network architecture as well as to the design of adequate fronthaul transport links in the network.

Fiber-based connections have been conventionally the mainstream technology for fronthaul. However, fiber-based fronthaul may not scale efficiently to meet the higher degrees of densification and flexibility expected to be required in future network deployments, so wireless fronthaul has started to be considered as a viable, cost-effective and attractive alternative, especially in markets like Europe where the cost of deploying new fiber-optic infrastructure is very high.

Wireless fronthaul has the advantages of flexibility and scalability, compared to fiber-based fronthaul. However, it also raises challenges in delivering the required performance with full-time availability, especially in terms of capacity and latency. Millimetre-wave (i.e., in a range between 30 and 300 GHz), free space optics (FSO) and sub-Terahertz frequencies are promising candidates for meeting the transport rate requirements of radio fronthaul, but, on the downside, transmissions at these frequencies are particularly affected by propagation loss and atmospheric absorption, making wireless fronthaul links extremely susceptible to failure and interference.

FIG. 1 shows a base band unit (BBU) pool providing a wireless fronthaul connection for multiple radio units (RUs). FIG. 1 shows an example of a wireless fronthaul connection between a base band unit (BBU) pool comprising multiple BBUs and three different radio units (RUs) RU1, RU2 and RU3, wherein each RU is associated with a respective cell (i.e. cell 1, cell 2 and cell 3, respectively). The fronthaul connection between the BBU pool and the RU RU1, RU2 and RU3 is referred to as link 1, link 2 and link 3, respectively. According to the example of FIG. 1, the quality of the fronthaul connection link 2 is good due to good weather (e.g. sunny weather), i.e. the transmission of the radio signals between the BBU pool and the RU RU2 via the fronthaul connection link 2 is not disturbed by bad weather conditions (e.g. rain). The quality of the fronthaul connection link 3 is deteriorated, e.g. due to bad weather conditions (e.g. light rainfall). Nevertheless, the fronthaul connection link 3 still allows wireless communication between the BBU pool and the RU RU3 and, thus, there is no service interruption in the cell 3 served by the RU RU3. In the example of FIG. 1, it is assumed that the fronthaul connection link 1 is interrupted (i.e. fails) due to bad weather conditions, e.g. a heavy storm. This failure over the wireless fronthaul connection link 1 causes a service interruption in the cell 1 that is served by the RU RU1. In other words, the cell 1 may become an isolated cell without any service, as indicated in FIG. 1.

In view of the above, this disclosure aims to provide a wireless communication device, such as RU or BBU, that is configured to deal with a possible failure of a bidirectional connection with another wireless communication device. An objective of this disclosure may be providing a wireless communication device, such as RU or BBU, that is configured to minimize the failure period of a bidirectional connection with another communication device, e.g. by guaranteeing a full-time availability of the bidirectional connection with the other communication device.

These and other objectives are achieved by the solution of this disclosure as described in the independent claims. Advantageous implementations are further defined in the dependent claims.

A first aspect of this disclosure provides a radio unit (RU) for wireless communication with a base band unit (BBU) according to a radio access network (RAN) protocol. The RU is configured to establish a first bidirectional connection with the BBU, the first bidirectional connection being allocated over a first frequency band of the electromagnetic spectrum. The RU is configured to establish a second bidirectional connection with the BBU, the second bidirectional connection being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication. That is, the second frequency band is used for radio access communication. The RU is configured to use the second bidirectional connection for communicating with the BBU in case one or more channel quality parameters of the first bidirectional connection do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted.

Since the RU according to the first aspect is configured to switch from the first bidirectional connection to the second bidirectional connection in case one or more channel quality parameters of the first bidirectional connection do not fulfill the threshold for the respective channel quality parameter or the first bidirectional connection is interrupted (i.e. it fails), the RU according to the first aspect is configured to deal with a possible failure of the first bidirectional connection. Since the RU is configured to wirelessly communicate with the BBU via the second bidirectional connection in case the one or more channel quality parameters of the first bidirectional connection do not fulfill the threshold for the respective channel quality parameter or the first bidirectional connection is interrupted, the RU is configured to minimize the failure period of a bidirectional connection with the BBU, e.g. by guaranteeing a full-time availability of a bidirectional connection (either the first bidirectional connection or the second bidirectional connection) with the BBU.

The RAN protocol may be a 5G NR (new radio) RAN protocol. The RU may be configured to serve a cell. The first bidirectional connection may be referred to as “fronthaul connection”. The second bidirectional connection may be referred to as “midhaul connection” or “backhaul connection”. The radio access communication may for example comprise one or more international mobile telecommunications (IMT) services. The first bidirectional connection and second bidirectional connection are wireless connections. The first bidirectional connection and second bidirectional connection may be abbreviated as “first connection” and “second connection”, respectively.

The BBU may be implemented on one or more computational resources, e.g. one or more servers, one or more central processing units (CPUs) etc. The BBU may be part of a set of multiple BBUs, e.g. a BBU pool, for communicating with different RUs.

The RU may be configured for wireless communication with multiple BBUs, e.g. a BBU pool. The RU may be configured to wirelessly communicate with a BBU of the multiple BBUs. The RU may be referred to as “enhanced RU (eRU)”. The terms “channel” and “link” may be used as synonyms for the term “connection”.

The passage “the second frequency band is devoted to radio access communication” may be used as a synonym for the passage “the second frequency band is used for radio access communication”.

The RU may use the second bidirectional connection as an immediate response to an interruption (e.g. sudden interruption) of the first bidirectional connection. The terms “interruption”, “failure” and “outage” may be used as synonyms. The first frequency band is different from the second frequency band. For example, the first frequency band may be the E-band (e.g. frequencies between 70 GHz and 86 GHz) or the D-band (e.g. frequencies from 130 GHz to 175 GHz). For example, the second frequency band may be within the 5G NR Frequency Range 1 (FR1), e.g. frequencies from 3.4 GHz to 3.8 GHz, or within the 5G NR Frequency Range 2 (FR2), e.g. frequencies from 24 GHz to 71 GHz. The term “frequency range” may be used as a synonym for the term “frequency band”. The first frequency band may have a first frequency bandwidth. The second frequency band may have the first frequency bandwidth or a second frequency bandwidth.

The first bidirectional connection may employ one of free space optics (FSO) communication technology, E-band microwave radio communication technology and D-band microwave radio communication technology. That is, the first frequency band may be a band used in FSO communications (e.g., above 300 GHz). Alternatively, the first frequency band may be the D-band (e.g. from 130 GHz to 175 GHz) or a frequency range being a part of the D-band. Alternatively, the first frequency band may be the E-band (e.g. from 70 GHz to 86 GHz) or a frequency range being a part of the E-band.

In case the first bidirectional connection employs FSO communication technology, fog is one of the main/dominant atmospheric phenomena that may cause a failure (i.e., outage) of the first bidirectional connection. In case the first bidirectional connection employs E-band or D-band microwave radio communication technology, rain is one of the main/dominant atmospheric phenomena that may cause a failure (i.e., outage) of the first bidirectional connection. Since failure of the first bidirectional connection triggers the activation of the second bidirectional connection, the RU allows minimizing the failure period of a bidirectional connection with the BBU, e.g. by guaranteeing a full-time availability of the bidirectional connection with the BBU.

Each threshold for the respective channel quality parameter may be a pre-defined threshold. A respective channel quality parameter not fulfilling the threshold for the respective channel quality parameter may be smaller or greater than the threshold depending on the type of the respective channel quality parameter. The one or more channel quality parameters may be or may comprise for example a maximum bit-rate achievable for a target bit error rate (BER). For the maximum bit-rate achievable for a target BER, the threshold may be a minimum value of said channel quality parameter. For example, the maximum bit-rate achievable for a target BER of the first bidirectional channel does not fulfill the threshold for the maximum bit-rate achievable for a target BER in case the maximum bit-rate achievable for a target BER is smaller than the threshold for the maximum bit-rate achievable for a target BER. The one or more channel quality parameters may be one or more numerical values that enable to establish a comparison between the performance of a channel and a reference value (i.e. threshold). Said one or more numerical values can be derived through measurements performed either on the radio-frequency signals or the digitally converted radio-frequency signals transported over the channel. In addition or alternatively to the maximum bit-rate achievable for a target BER, the one or more channel quality parameters may be or may comprise for example at least one of: a receive signal strength (RSS), a mean square error (MSE) of a received symbol constellation with respect to a reference symbol constellation in use over the link, a signal-to-noise-ratio (SNR), and a signal-to-interference-plus-noise-ratio (SINR). RSS may be computed on the radio-frequency signals before analog-to-digital signal conversion by means of dedicated electronic circuits. MSE, SNR or SINR may be computed by a digital processor after analog-to-digital signal conversion.

The RU may be configured to wirelessly communicate such that the first bidirectional connection and the second bidirectional connection are mutually exclusive (i.e., when the first bidirectional connection is active the second bidirectional connection is not active, and, vice-versa, when the second bidirectional connection is active the first bidirectional connection is not active).

The RU may be used in a C-RAN system. In such a C-RAN system a BBU pool comprising multiple BBUs may be connected to one or more remote RUs via respective one or more fronthaul links. A fronthaul link represents a first bidirectional connection that the RU may be configured to establish with a BBU of the BBU pool, when the RU is used in the C-RAN system.

In an implementation form of the first aspect, the RU is configured to establish the first bidirectional connection with the BBU and provide access, by implementing layer-1 functionalities of the RAN protocol, for a user.

In an implementation form of the first aspect, the RU is configured to establish the second bidirectional connection with the BBU by implementing layer-1 functionalities and layer-2 functionalities of the RAN protocol.

In an implementation form of the first aspect, the RU is configured to activate the layer-2 functionalities of the RAN protocol for establishing the second bidirectional connection with the BBU in case the first bidirectional connection is interrupted.

Thus, the RU may automatically activate the layer-2 functionalities of the RAN protocol without a signaling exchange with the BBU. Optionally, the RU is configured to communicate with the BBU according to 5G New Radio protocol. The RU may be configured to establish the second bidirectional connection with the BBU by establishing a connection based on F1 interface between the RU and the BBU, wherein the RU comprises a distributed unit (DU) for managing the connection based on F1 interface. That is the RAN protocol may be a 5G NR (new radio) RAN protocol. The DU may be a 5G integrated access and backhaul DU (5G IAB DU). The RU may be configured to set up its DU without a signaling exchange with the BBU in case the first bidirectional connection is interrupted.

In an implementation form of the first aspect, the layer-1 functionalities comprise physical layer functionalities and/or radio frequency (RF) layer functionalities of the RAN protocol.

In an implementation form of the first aspect, the layer-2 functionalities comprise radio link control (RLC) functionalities and/or media access control (MAC) functionalities of the RAN protocol.

In an implementation form of the first aspect, the RU is configured to obtain the one or more channel quality parameters of the first bidirectional connection, and determine whether the one or more channel quality parameters of the first bidirectional connection fulfill the threshold for the respective channel quality parameter or not.

The RU may be configured to receive the one or more channel quality parameters from another entity, e.g. the BBU. In addition or alternatively, the RU may be configured to obtain the one or more channel quality parameters by monitoring the first bidirectional connection. Optionally, the RU may be configured to obtain the one or more channel quality parameters by performing measurements of radio frequency (RF) signals or digitally converted RF signals transported via the first bidirectional connection.

In an implementation form of the first aspect, the RU is configured to establish the second bidirectional connection and transmit a setup response message for establishing the second bidirectional connection in response to receiving a setup request message for establishing the second bidirectional connection.

In an implementation form of the first aspect, the RU is configured to de-activate the first bidirectional connection in case the second bidirectional connection is activated and to transmit a removal response message for de-activating the first bidirectional connection in response to receiving a removal request message for de-activating the first bidirectional connection.

The term “de-activating” may be used as a synonym for the term “removal”. The passages “de-activate a connection” and “end a connection” may be used as synonyms. Herein “establishing a connection” may mean setting-up the connection. Thus, when a connection has been established, it may mean that it has been setup. “Activating a connection” may mean that the connection is effectively used for its purpose, e.g. data transmission. Thus, when a connection has been activated, it may mean that the connection is used for data transmission.

In an implementation form of the first aspect, the RU is configured to establish the first bidirectional connection and transmit a setup response message for establishing the first bidirectional connection in response to receiving a setup request message for establishing the first bidirectional connection, in case the one or more channel quality parameters of the first bidirectional connection fulfill the threshold for the respective channel quality parameter.

In an implementation form of the first aspect, the RU is configured to de-activate the second bidirectional connection and transmit a removal response message for de-activating the second bidirectional connection in response to receiving a removal request message for de-activating the second bidirectional connection, in case the first bidirectional connection is activated.

In an implementation form of the first aspect, the RU is configured to communicate with the BBU according to 5G New Radio protocol. The RU may be configured to establish the second bidirectional connection with the BBU by establishing a connection based on F1 interface between the RU and the BBU, wherein the RU comprises a distributed unit (DU) for managing the connection based on F1 interface. That is the RAN protocol may be a 5G NR (new radio) RAN protocol. The DU may be a 5G integrated access and backhaul DU (5G IAB DU).

In an implementation form of the first aspect, the RU is configured to establish the second bidirectional connection and transmit a remote distributed unit (DU) setup response message and a F1 interface setup request message in response to receiving a remote DU setup request message.

In an implementation form of the first aspect, the RU is configured to de-activate the second bidirectional connection and transmit a F1 interface removal request, in case the first bidirectional connection is activated. The RU may be configured to transmit a remote distributed unit (DU) removal response message in response to receiving a remote distributed unit (DU) removal request message, in case the second bidirectional connection is de-activated.

In an implementation form of the first aspect, the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters is selected such that no communication is possible via the first bidirectional connection in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter. Alternatively, the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters may be selected such that communication with a reduced quality is possible via the first bidirectional connection in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter.

In an implementation form of the first aspect, the RU is configured to, in case the one or more channel quality parameters of the first bidirectional connection do not fulfill a second threshold for the respective channel quality parameter, wirelessly communicate with the BBU using the first bidirectional connection, and limit a cell performance according to a reduced capacity of the first bidirectional connection. The one or more channel quality parameters of the first bidirectional connection not fulfilling the second threshold for the respective channel quality parameter may indicate the reduced capacity of the first bidirectional connection and a channel quality of the first bidirectional connection that is better compared to the channel quality of the first bidirectional connection when the one or more channel quality parameters of the first bidirectional connection do not fulfill the threshold for the respective channel quality parameter.

In order to achieve the RU according to the first aspect of the disclosure, some or all of the implementation forms and optional features of the first aspect, as described above, may be combined with each other.

A second aspect of this disclosure provides a base band unit (BBU) for wireless communication with a radio unit (RU) according to a radio access network (RAN) protocol. The BBU is configured to establish a first bidirectional connection with the RU, the first bidirectional connection being allocated over a first frequency band of the electromagnetic spectrum. The BBU is configured to establish a second bidirectional connection with the RU, the second bidirectional connection being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication. That is, the second frequency band is used for radio access communication. The BBU is configured to use the second bidirectional connection for communicating with the RU in case one or more channel quality parameters of the first bidirectional connection do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted.

Since the BBU according to the second aspect is configured to switch from the first bidirectional connection to the second bidirectional connection in case one or more channel quality parameters of the first bidirectional connection do not fulfill the threshold for the respective channel quality parameter or the first bidirectional connection is interrupted (i.e. it fails), the BBU according to the second aspect is configured to deal with a possible failure of the first bidirectional connection. Since the BBU is configured to wirelessly communicate with the RU via the second bidirectional connection in case the one or more channel quality parameters of the first bidirectional connection do not fulfill the threshold for the respective channel quality parameter or the first bidirectional connection is interrupted, the BBU is configured to minimize the failure period of a bidirectional connection with the RU, e.g. by guaranteeing a full-time availability of the bidirectional connection (either the first bidirectional connection or the second bidirectional connection) with the RU.

The above description of the RU according to the first aspect is correspondingly valid for the BBU according to the second aspect.

The BBU may be used in a C-RAN system. In such a C-RAN system the BBU may be part of a BBU pool comprising multiple BBUs and may be connected to a remote RU via a fronthaul link. The fronthaul link represents a first bidirectional connection that the BBU may be configured to establish with the remote RU, when the BBU is used in the C-RAN system.

In an implementation form of the second aspect, the BBU is configured to establish the first bidirectional connection with the RU by implementing layer-2 functionalities of the RAN protocol.

In an implementation form of the second aspect, the BBU is configured to establish the second bidirectional connection with the RU without implementing layer-2 functionalities of the RAN protocol.

In an implementation form of the second aspect, the layer-2 functionalities comprise radio link control (RLC) functionalities and/or media access control (MAC) functionalities of the RAN protocol.

In an implementation form of the second aspect, the BBU is configured to obtain the one or more channel quality parameters of the first bidirectional connection, and determine whether the one or more channel quality parameters of the first bidirectional connection fulfill the threshold for the respective channel quality parameter or not.

The BBU may be configured to receive the one or more channel quality parameters from another entity. In addition or alternatively, the BBU may be configured to obtain the one or more channel quality parameters by monitoring the first bidirectional connection. Optionally, the BBU may be configured to obtain the one or more channel quality parameters by performing measurements of radio frequency (RF) signals or digitally converted RF signals transported via the first bidirectional connection.

In an implementation form of the second aspect, the BBU is configured to transmit a setup request message for establishing the second bidirectional connection, in case the one or more channel quality parameters of the first bidirectional connection are predicted to not fulfill the threshold for the respective channel quality parameter anymore within a specific time period or in case the first bidirectional connection is interrupted.

In an implementation form of the second aspect, the BBU is configured to transmit a removal request message for de-activating the first bidirectional connection in response to receiving a setup response message for establishing the second bidirectional connection.

In an implementation form of the second aspect, the BBU is configured to transmit a setup request message for establishing the first bidirectional connection, and use the first bidirectional connection for communicating with the RU in response to receiving a setup response message for establishing the first bidirectional connection.

In an implementation form of the second aspect, the BBU is configured to transmit a removal request message for de-activating the second bidirectional connection in response to receiving a setup response message for establishing the first bidirectional connection.

In an implementation form of the second aspect, the BBU is configured to communicate with the RU according to 5G New Radio protocol, and establish the second bidirectional connection with the RU by establishing a connection based on F1 interface between the BBU and the RU, wherein the BBU comprises a central unit (CU) for managing the connection based on F1 interface.

In an implementation form of the second aspect, the BBU is configured to transmit a remote distributed unit (DU) setup request message, in case the one or more channel quality parameters of the first bidirectional connection are predicted to not fulfill the threshold for the respective channel quality parameter anymore within a specific time period, and a F1 interface setup response message in response to receiving a F1 interface setup request message.

In an implementation form of the second aspect, the BBU is configured to transmit an F1 interface removal response message, in response to receiving a F1 interface removal request message, and transmit a remote distributed unit (DU) removal request message.

In an implementation form of the second aspect, the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters is selected such that no communication is possible via the first bidirectional connection in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter. Alternatively, the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters may be selected such that communication with a reduced quality is possible via the first bidirectional connection in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter.

The above description of the BBU according to the second aspect is correspondingly valid for the RU according to the first aspect.

The BBU of the second aspect and its implementation forms and optional features achieve the same advantages as the RU of the first aspect and its respective implementation forms and respective optional features.

In order to achieve the BBU according to the second aspect of the disclosure, some or all of the implementation forms and optional features of the second aspect, as described above, may be combined with each other.

A third aspect of this disclosure provides a method for a wireless communication between a base band unit (BBU) and a radio unit (RU) according to a radio access network (RAN) protocol. The method comprises using for the communication between the BBU and the RU a second bidirectional connection between the BBU and the RU, in case one or more channel quality parameters of a first bidirectional connection between the BBU and the RU do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted. The first bidirectional connection is allocated over a first frequency band of the electromagnetic spectrum. The second bidirectional connection is allocated over a second frequency band of the electromagnetic spectrum used for radio access communication. That is the second frequency band is used for radio access communication.

The above description of the RU according to the first aspect and the above description of the BBU according to the second aspect is correspondingly valid for the method of the third aspect.

The RU may be the RU of the first aspect. The BBU may be the BBU of the second aspect.

The method of the third aspect and its implementation forms and optional features achieve the same advantages as the RU of the first aspect and its respective implementation forms and respective optional features.

A fourth aspect of this disclosure provides a radio unit (RU) for wireless communication with a base band unit (BBU) of a BBU pool according to a radio access network (RAN) protocol. The RU is configured to establish a first bidirectional connection with the BBU, the first bidirectional connection being allocated over a first frequency band of the electromagnetic spectrum. The RU is configured to establish a second bidirectional connection with the BBU, the second bidirectional connection being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication. The RU is configured to use the second bidirectional connection for communicating with the BBU in case one or more channel quality parameters of the first bidirectional connection do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted.

The above description of the RU according to the first aspect is correspondingly valid for the RU of the fourth aspect. The RU of the fourth aspect may be the RU of the first aspect. The BBU may be the BBU of the second aspect.

The RU of the fourth aspect and its implementation forms and optional features achieve the same advantages as the RU of the first aspect and its respective implementation forms and respective optional features.

A fifth aspect of this disclosure provides a base band unit (BBU) pool for wireless communication with one or more radio units (RU) according to a radio access network (RAN) protocol. A BBU of the BBU pool is configured to establish a first bidirectional connection with a RU of the one or more RUs, the first bidirectional connection being allocated over a first frequency band of the electromagnetic spectrum. The BBU of the BBU pool is configured to establish a second bidirectional connection with the RU, the second bidirectional connection being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication. The BBU of the BBU pool is configured to use the second bidirectional connection for communicating with the RU in case one or more channel quality parameters of the first bidirectional connection do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted.

The above description of the BBU according to the second aspect is correspondingly valid for the BBU pool of the fifth aspect. The BBU of the BBU pool of the fifth aspect may be the BBU of the second aspect. The one or more RUs may be the RU of the first aspect or fourth aspect.

The BBU pool of the fifth aspect and its implementation forms and optional features achieve the same advantages as the RU of the first aspect and its respective implementation forms and respective optional features.

It has to be noted that all devices, elements, units and means described in the present application could be implemented in software or hardware elements or any kind of combination thereof. All steps which are performed by the various entities described in the present application as well as the functionalities described to be performed by the various entities are intended to mean that the respective entity is adapted to or configured to perform the respective steps and functionalities. Even if, in the following description of specific embodiments, a specific functionality or step to be performed by external entities is not reflected in the description of a specific detailed element of that entity which performs that specific step or functionality, it should be clear for a skilled person that these methods and functionalities can be implemented in respective software or hardware elements, or any kind of combination thereof.

BRIEF DESCRIPTION OF DRAWINGS

The above described aspects and implementation forms will be explained in the following description of specific embodiments in relation to the enclosed drawings, in which

FIG. 1 shows a base band unit (BBU) pool providing a wireless fronthaul connection for multiple radio units (RUs).

FIG. 2 shows an example of a radio unit (RU) according to an embodiment of this disclosure for wireless communication and an example of a base band unit (BBU) according to an embodiment of this disclosure for wireless communication.

FIG. 3 shows an example of an implementation form of the radio unit (RU) and base band unit (BBU) of FIG. 2.

FIG. 4 shows an example of an implementation form of the radio unit (RU) and base band unit (BBU) of FIG. 2.

FIG. 5 shows an example of an implementation form of the radio unit (RU) and base band unit (BBU) of FIG. 2.

FIG. 6 shows an example of operation of the radio unit (RU) and base band unit (BBU) of FIG. 2.

FIGs 7 and 8 show an example of operation of the radio unit (RU) and base band unit (BBU) of FIG. 4 or FIG. 5.

FIG. 9 shows an example of different states during a wireless communication between the radio unit (RU) and base band unit (BBU) of FIG. 2.

FIG. 10 shows an example of a method according to an embodiment of this disclosure for a wireless communication between a base band unit (BBU) and a radio unit (RU) according to a radio access network (RAN) protocol.

FIG. 11 shows an example of radio units (RUs) according to an embodiment of this disclosure for wireless communication and an example of a base band unit (BBU) pool according to an embodiment of this disclosure for wireless communication.

Same elements shown in the figures (FIGs) are labeled with the same reference sign, and may be implemented likewise.

DETAILED DESCRIPTION OF EMBODIMENTS

FIG. 2 shows an example of a radio unit (RU) according to an embodiment of this disclosure for wireless communication and an example of a base band unit (BBU) according to an embodiment of this disclosure for wireless communication. The RU 1 of FIG. 2 is an example of the RU according to the first aspect of this disclosure. Thus, the description of the RU according to the first aspect is correspondingly valid for the RU 1 of FIG. 2. The BBU 2 of FIG. 2 is an example of the BBU according to the second aspect of this disclosure. Thus, the description of the BBU according to the second aspect is correspondingly valid for the BBU 2 of FIG. 2.

The RU 1 of FIG. 2 is a RU for wireless communication with a BBU, such as the BBU 2 of FIG. 2, according to a radio access network (RAN) protocol. The RU 1 is configured to establish a first bidirectional connection 3a with the BBU 2. The first bidirectional connection 3a is allocated over a first frequency band of the electromagnetic spectrum. The RU 1 is configured to establish a second bidirectional connection 3b with the BBU 2. The second bidirectional connection 3b is allocated over a second frequency band of the electromagnetic spectrum, the second frequency band being used for radio access communication. The RU 1 is configured to use the second bidirectional connection 3b for communicating with the BBU 2 in case one or more channel quality parameters of the first bidirectional connection 3a do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection 3a is interrupted.

The RU 1 may comprise or be connected to one or more antennas for wireless communication. The one or more antennas are not limited to a specific antenna type. The RU 1 may comprise a processor or processing circuitry (not shown) configured to perform, conduct or initiate the various operations of the RU 1 described herein. The processing circuitry may comprise hardware and/or the processing circuitry may be controlled by software. The hardware may comprise analog circuitry or digital circuitry, or both analog and digital circuitry. The digital circuitry may comprise components such as application-specific integrated circuits (ASICs), field-programmable arrays (FPGAs), digital signal processors (DSPs), or multi-purpose processors. The RU 1 may further comprise memory circuitry, which stores one or more instruction(s) that can be executed by the processor or by the processing circuitry, in particular under control of the software. For instance, the memory circuitry may comprise a non-transitory storage medium storing executable software code which, when executed by the processor or the processing circuitry, causes the various operations of the RU 1 to be performed. In one embodiment, the processing circuitry comprises one or more processors and a non-transitory memory connected to the one or more processors. The non-transitory memory may carry executable program code which, when executed by the one or more processors, causes the RU 1 to perform, conduct or initiate the operations or methods described herein.

The BBU 2 of FIG. 2 is a BBU for wireless communication with a RU, such as the RU 1 of FIG. 2, according to a RAN protocol. The BBU 2 is configured to establish the first bidirectional connection 3a with the RU 1. The BBU 2 is configured to establish the second bidirectional connection 3b with the RU 1. The BBU 2 is configured to use the second bidirectional connection 3b for communicating with the RU 1 in case one or more channel quality parameters of the first bidirectional connection 3a do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection 3a is interrupted.

The BBU 2 may comprise or be connected to one or more antennas for wireless communication. The one or more antennas are not limited to a specific antenna type. The BBU 2 may comprise a processor or processing circuitry (not shown) configured to perform, conduct or initiate the various operations of the BBU 2 described herein. The processing circuitry may comprise hardware and/or the processing circuitry may be controlled by software. The hardware may comprise analog circuitry or digital circuitry, or both analog and digital circuitry. The digital circuitry may comprise components such as application-specific integrated circuits (ASICs), field-programmable arrays (FPGAs), digital signal processors (DSPs), or multi-purpose processors. The BBU 2 may further comprise memory circuitry, which stores one or more instruction(s) that can be executed by the processor or by the processing circuitry, in particular under control of the software. For instance, the memory circuitry may comprise a non-transitory storage medium storing executable software code which, when executed by the processor or the processing circuitry, causes the various operations of the BBU 2 to be performed. In one embodiment, the processing circuitry comprises one or more processors and a non-transitory memory connected to the one or more processors. The non-transitory memory may carry executable program code which, when executed by the one or more processors, causes the BBU 2 to perform, conduct or initiate the operations or methods described herein.

For further details on the RU 1 and the BBU 2 of FIG. 2, such as optional implementation forms, reference is made to the description of the RU according to the first aspect, the description of the BBU according to the second aspect and the description of Figures 3 to 9.

FIG. 3 shows an example of an implementation form of the radio unit (RU) and base band unit (BBU) of FIG. 2. The description of FIG. 2 is correspondingly valid for the RU 1 and BBU 2 of FIG. 3 and in the following main optional features and details of the RU 1 and BBU 2 are described.

As shown in FIG. 3, the RU 1 may comprise a first communication unit 11 for establishing the first bidirectional connection 3a (i.e. fronthaul connection) with the BBU 2, and a second communication unit 12 for establishing the second bidirectional connection 3b with the BBU 2. The RU 1 may comprise a control entity 13 for activating the first communication unit 11 or the second communication unit 12 and, thus, the first bidirectional connection 3a or second bidirectional connection 3b, respectively, with the BBU 2. The control entity 13 may be or may comprise at least one of a processor, microprocessor, controller, microcontroller, application specific integrated circuit (ASIC) and field programmable gate array (FPGA). Optionally, the control entity 13 is configured to monitor the quality (may be referred to as channel quality) of the first bidirectional connection 3a by monitoring one or more channel quality parameters of the first bidirectional connection 3a.

The first communication unit 11 may comprise a first connection interface 11a configured to wirelessly communicate with a first connection interface 21 of the BBU 2 via the first bidirectional connection 3a. The second communication unit 12 may comprise a second connection interface 12a configured to wirelessly communicate with a second connection interface 22 of the BBU 2 via the second bidirectional connection 3b.

The control entity 13 may be configured to disable radio link control (RLC) functionalities 1a and media access control (MAC) functionalities 1b of the RAN protocol while the first bidirectional connection 3a is active. That is, the RU 1 may be configured to establish the first bidirectional connection 3a with the BBU 2 without using the RLC functionalities 1a and the MAC functionalities 1b. The RU 1 may be configured to provide access for a user 4 by implementing layer-1 functionalities of the RAN protocol. That is, the RU 1 may be configured to provide access to the user(s) in the RU cell by implementing the layer-1 functionalities of the RAN protocol. The layer-1 functionalities of the RAN protocol may comprise physical layer (PHY) functionalities 1c and/or radio frequency (RF) functionalities 1d of the RAN protocol. The control entity 13 may be configured to enable (i.e. activate) RLC functionalities 1a and/or MAC functionalities 1b of the RAN protocol while the second bidirectional connection 3b is active. That is, the RU 1 is configured to establish the second bidirectional connection 3b with the BBU 2 by implementing layer-1 functionalities and layer-2 functionalities of the RAN protocol. The layer-2 functionalities of the RAN protocol may comprise RLC functionalities 1a and/or MAC functionalities 1b.

The control entity 13 may comprise a channel quality monitoring unit 13a for monitoring the channel quality of the first bidirectional connection 3a. The control entity 13 may comprise an activator 13b for enabling or disabling the RLC functionalities 1a and MAC functionalities 1b of the RAN protocol.

Thus, the first communication unit 11 may comprise software, circuit and processing blocks to enable the first bidirectional connection 3a (i.e., the fronthaul connection) towards (and from) the BBU 2 over the first frequency band. For example, these blocks are configured to provide all the following functionalities of the RAN protocol: RF functionalities 1d and low physical layer (low PHY) functionalities. Optionally, the aforementioned blocks of the first communication unit 11 may be configured to also provide high physical layer (high PHY) functionalities, i.e. the aforementioned blocks of the first communication unit 11 may be configured to provide RF functionalities 1d and PHY functionalities 1c. The low PHY and high PHY functionalities may be used to provide access to user(s) in the RU cell.

The second communication unit 12 may comprise software, circuit and processing blocks to enable the second bidirectional connection 3b towards (and from) the BBU 2 over the second frequency band (in use by radio access systems and devices). For example, these blocks are configured to provide all the following functionalities of the RAN protocol: the RF functionalities

1d, the PHY functionalities 1c, the MAC functionalities 1b and the RLC functionalities 1a. The PHY functionalities 1c may comprise low PHY functionalities and high PHY functionalities. The MAC functionalities 1b may comprise low MAC functionalities and high MAC functionalities. The RLC functionalities 1a may comprise low RLC functionalities and high RLC functionalities. When the second bidirectional connection is active, the PHY, MAC and RLC functionalities may be used for maintaining the second bidirectional connection and for providing access to user(s) in the RU cell.

As indicated in FIG. 3, the second communication unit 12 may be based on at least a module implementing the RF functionalities 1d and PHY functionalities 1c of RAN protocol of the first communication unit 11. The second communication unit 12 may be equipped with additional modules for implementing the MAC functionalities 1b and RLC functionalities 1a of the RAN protocol for establishing the second bidirectional connection 3b and for providing radio access to user(s) in the RU cell (i.e. allowing user(s) to access the RU 1).

The control entity 13, e.g. the activator 13b, may activate or de-activate the additional modules of the second communication unit 12 for implementing the MAC functionalities 1b and RLC functionalities 1a of the RAN protocol to establish the second bidirectional connection 3b depending on whether the second bidirectional connection 3b is to be activated or de-activated, respectively, based on the evolution of the quality of the first bidirectional connection 3a. That is, the control entity 13 is configured to manage the activation and de-activation of the RLC functionalities 1a and MAC functionalities 1b of the RAN protocol to activate or de-activate, respectively, the second bidirectional connection 3b. These higher layer functionalities can be activated or de-activated by the control entity 13 in conveniently selected time slots.

The first communication unit 11 may comprise a primary first bidirectional connection adaptation functionality unit 11b and a secondary bidirectional connection adaptation functionality unit 11c. They may be referred to as “first fronthaul adaptation functionality” and “second fronthaul adaptation functionality”, respectively. The primary first bidirectional connection adaptation functionality unit 11b may be configured to reduce the fronthaul capacity depending on channel conditions over the first bidirectional connection by reducing the radio access channel bandwidth for the user(s) connected to the RU 1 cell (i.e. the user(s) accessing the RU 1). For example, for this, the primary first bidirectional connection adaptation functionality unit 11b may be configured to change the overall cell bandwidth, or use a smaller bandwidth part (BWP) or number of available resource blocks. The secondary bidirectional connection adaptation functionality unit 11c may be configured to reduce the fronthaul capacity depending on channel conditions over the first bidirectional connection by reducing the number of multiple input multiple output (MIMO) layers (data streams) available for the user(s) connected to the RU 1 cell.

The RU 1 and the BBU 2 may be configured to perform a bidirectional signaling method between them. This method allows to de-activate the first bidirectional connection 3a (i.e. the wireless fronthaul connection) and to activate alternatively the second bidirectional connection 3b – and vice-versa – to de-activate the second bidirectional connection 3b and to activate alternatively the first bidirectional connection 3a according to an evolution of the quality of the first bidirectional connection 3a. Examples of such a method are described with regard to FIGs 6, 7, 8 and 10.

For monitoring the quality of the first bidirectional connection 3a (e.g. when the first bidirectional connection 3a is de-activated), the RU 1 and the BBU2 may be configured to perform a signaling (e.g. periodic signaling) between them. Examples of such signaling are described with regard to FIGs 6, 7 and 8.

The control entity 13 of the RU 1 may be configured to monitor the quality of the first bidirectional connection 3a by monitoring one or more channel quality parameters of the first bidirectional connection 3a. For example, the control entity 13 may be configured to monitor whether the one or more channel quality parameters of the first bidirectional connection 3a fulfil a threshold for the respective channel quality parameter. The control entity 13 may be configured to determine whether the first bidirectional connection 3a is interrupted (i.e., fails) so that no wireless communication is possible via the first bidirectional connection 3a.

The control entity 13 may be configured to de-activate at least one of a sub-set of multiple input multiple output (MIMO) layers, bandwidth parts (BWPs) and resource blocks (RBs) of a cell being served by the RU 1, and implement traffic steering actions to unload the cell as the quality of the first bidirectional connection 3a varies. The control entity 13 may be configured to avoid cell outage of a cell served by the RU 1 when the first bidirectional connection 3a is completely unavailable (i.e., is interrupted) by establishing the second bidirectional connection 3b allocated over the second frequency band (of the electromagnetic spectrum) that is devoted to radio access communications (e.g., IMT services).

As indicated in FIG. 3, the RU 1 may be connected with or may comprise one or more antennas 14 for serving a cell, e.g. serving a RAN user 4.

FIG. 4 shows an example of an implementation form of the radio unit (RU) and base band unit (BBU) of FIG. 2. The RU 1 and BBU 2 of FIG. 4 correspond to the RU 1 and BBU 2 of FIG. 3 with additional optional features. Thus, the description of the RU 1 and BBU 2 of FIG. 3 is correspondingly valid for the RU 1 and BBU 2 of FIG. 4 and in the following mainly the additional optional features of the RU 1 and BBU 2 of FIG. 4 are described.

According to the example of FIG. 4, the second bidirectional connection 3b between BBU 2 and the RU 1 may be implemented using 5G NR access technologies. For example, the second bidirectional connection 3b may be implemented using the F1 interface. Thus, according to the example of FIG. 4, the BBU 2 may comprise a central unit 22a (CU) as a logical entity in charge of managing the F1 interface at the BBU side. The CU 22a is part of the second connection interface 22 of the BBU 2. That is, the CU 22a of the BBU 2 is configured to manage the F1 interface used for implementing the second bidirectional connection 3b. The RU 1 may comprise a distributed unit 12b (DU) as a logical entity in charge of managing the F1 interface at the RU side. The DU 12b is part of the second communication unit 12 of the RU 1. That is, the DU 12b of the RU 1 is configured to manage the F1 interface used for implementing the second bidirectional connection 3b. In other words, according to the example of FIG. 4, the DU 12b of the RU 1 and the CU 22a of the BBU 2 are configured to manage the F1 interface for establishing the second bidirectional connection 3b between the RU 1 and the BBU 2.

FIG. 5 shows an example of an implementation form of the radio unit (RU) and base band unit (BBU) of FIG. 2. The RU 1 and BBU 2 of FIG. 5 correspond to the RU 1 and BBU 2 of FIG. 4 with additional optional features. Thus, the description of the RU 1 and BBU 2 of FIGs 3 and 4 is correspondingly valid for the RU 1 and BBU 2 of FIG. 5 and in the following mainly the additional optional features of the RU 1 and BBU 2 of FIG. 5 are described.

According to the example of FIG. 5, the second bidirectional connection 3b between the BBU 2 and the RU 1 may be implemented using 5G NR access technologies. For example, the second bidirectional connection 3b may be implemented using the F1 interface transported through 5G integrated access and backhaul (IAB) signaling. Thus, according to the example of FIG. 5, the BBU 2 may comprise the central unit 22a (CU) as a logical entity in charge of managing the F1 interface at the BBU side. That is, the CU 22a of the BBU 2 is configured to manage the F1 interface used for implementing the second bidirectional connection 3b. The RU 1 may comprise an IAB distributed unit 12b (IAB DU) as a logical entity in charge of managing the F1 interface at the RU side. That is, the IAB DU 12b of the RU is configured to manage the F1 interface used for implementing the second bidirectional connection 3b. The physical connection between the CU 22a of the BBU 2 and the IAB DU 12b may be achieved through an IAB-Donor DU entity 22b located at the BBU 2 communicating by means of the 5G NR air interface with an IAB mobile termination (IAB-MT) entity 12c located at the RU 1. That is, the BBU 2 may comprise the IAB-Donor DU entity 22b configured to communicate using the 5G NR air interface with the IAB-MT entity 12c of the

RU 1. Thus, the IAB-MT entity 12c of the RU 1 may be configured to communicate using the 5G NR air interface with the IAB-Donor DU entity 22b of the BBU 2.

FIG. 6 shows an example of operation of the radio unit (RU) and base band unit (BBU) of FIG. 2. The description of FIG. 2 is correspondingly valid for the RU 1 and BBU 2 of FIG. 6. The RU and BBU may be implemented as outlined with regard to FIG. 3.

During a normal operation state, it is assumed that there are good propagation conditions (e.g. due to good weather) over the first bidirectional connection 3a. Thus, as indicated in FIG. 6, during the normal operation state, the first bidirectional connection 3a between the RU 1 and the BBU 2 is active.

In an alert state bad propagation conditions over the first bidirectional connection 3a or a channel quality of the first bidirectional connection 3a not sufficient for data transmission are foreseen. During the alert state the first bidirectional connection 3a may remain active and the second bidirectional connection 3b between the RU 1 and the BBU 2 may be established (without exchanging data) through a signaling for connection setup. For this, the BBU 2 may transmit a setup request message for establishing the second bidirectional connection 3b. This message is referred to in FIG. 6 as "second connection setup request". In other words, the BBU 2 is configured to transmit the setup request message for establishing the second bidirectional connection 3b, in case the one or more channel quality parameters of the first bidirectional connection 3a are predicted to not fulfil the threshold for the respective channel quality parameter anymore within a specific time period or in case the first bidirectional connection is interrupted. As shown in FIG. 6, the RU 1 is configured to establish the second bidirectional connection 3b and transmit a setup response message for establishing the second bidirectional connection 3b ("second connection setup response") in response to receiving the setup request message for establishing the second bidirectional connection 3b ("second connection setup request).

As a result, in an emergency state, in which bad propagation conditions (e.g. due to bad weather) over the first bidirectional connection 3a lead to interruption of the first bidirectional connection 3a or the channel quality of the first bidirectional connection 3a is not sufficient for data transmission, the first bidirectional connection 3a may be de-activated and the second bidirectional connection 3b may be activated to carry data between the RU 1 and the BBU 2. As shown in FIG. 6, for this the BBU 2 is configured to transmit a removal request message for de-activating the first bidirectional connection 3a ("first connection removal request") in response to receiving the setup response message for establishing the second bidirectional connection 3b ("second connection setup response"). The RU 1 is configured to de-activate the first bidirectional connection 3a in case the second bidirectional connection 3b is activated and to transmit a removal response message for de-activating the first bidirectional connection 3a ("first connection removal response") in response to receiving the removal request message for de-activating the first bidirectional connection 3a ("first connection removal request").

During a fronthaul link status check state, the BBU 2 may periodically check the status of the first bidirectional connection 3a through signaling messages targeted at re-establishing the first bidirectional connection 3a. As shown in FIG. 6, for this, the BBU 2 is configured to transmit a setup request message for establishing the first bidirectional connection 3a ("first connection setup request"). The BBU 2 may be configured to periodically transmit this setup request message. The RU 1 is configured to establish the first bidirectional connection 3a and transmit a setup response message for establishing the first bidirectional connection 3a ("first connection setup response") in response to receiving the setup request message for establishing the first bidirectional connection 3a ("first connection setup request"), in case the one or more channel quality parameters of the first bidirectional connection 3a fulfill the threshold for the respective channel quality parameter (e.g., in case propagation conditions over the first bidirectional connection 3a are sufficient for data transmission). The BBU 2 is configured to use the first bidirectional connection 3a for communicating with the RU 1 in response to receiving the setup response message for establishing the first bidirectional connection 3a ("first connection setup response").

In a fronthaul link re-activation state, the propagation conditions over the first bidirectional connection 3a are good (e.g. due to good weather). Therefore, as shown in FIG. 6, the first bidirectional connection 3a is activated. The second bidirectional connection 3b is de-activated through proper signaling messages. These signaling messages may be transmitted via either the first bidirectional connection 3a or the second bidirectional connection 3b. For this, the BBU 2 is configured to transmit a removal request message for de-activating the second bidirectional connection 3b ("second connection removal request") in response to receiving a setup response message for establishing the first bidirectional connection 3a ("first connection setup response"). The RU 1 is configured to de-activate the second bidirectional connection 3b and transmit a removal response message for de-activating the second bidirectional connection 3b ("second connection removal response") in response to receiving a removal request message for de-activating the second bidirectional connection 3b ("second connection removal request"), in case the first bidirectional connection 3a is activated.

The setup request message for establishing the second bidirectional connection 3b ("second connection setup request"), the setup response message for establishing the second bidirectional connection 3b ("second connection setup response"), the removal request message for de-activating the first bidirectional connection 3a ("first connection removal request"), the removal response message for de-activating the first bidirectional connection 3a ("first connection removal response"), the removal request message for de-activating the second bidirectional connection 3b ("second connection removal request"), and the removal response message for de-activating the second bidirectional connection 3b ("second connection removal response") may be encoded in optional fields of packet units defined by the employed fronthaul protocol (e.g., eCPRI, Open Fronthaul, etc.) over the first bidirectional connection 3a. The abbreviation "eCPRI" stands for "enhanced common public radio interface".

FIGs 7 and 8 show an example of operation of the radio unit (RU) and base band unit (BBU) of FIG. 4 or FIG. 5. The description of FIGs 4 and 5 is correspondingly valid for the RU 1 and BBU 2 of FIGs 7 and 8.

During a normal operation state (shown in FIG. 7), it is assumed that there are good propagation conditions (e.g. due to good weather) over the first bidirectional connection 3a. Thus, as indicated in FIG. 7, during the normal operation state, the first bidirectional connection 3a between the RU 1 and the BBU 2 is active.

In an alert state (shown in FIG. 7) bad propagation conditions over the first bidirectional connection 3a or a channel quality of the first bidirectional connection 3a not sufficient for data transmission are foreseen. During the alert state the first bidirectional connection 3a may remain active and the second bidirectional connection 3b between the RU 1 and the BBU 2 using 5G NR access technologies may be established (without exchanging data) through a signaling for setting up the DU at the RU side and standardized signaling over the F1 interface. For this, the BBU 2 may transmit a remote distributed unit (DU) setup request message ("remote DU setup request"). That is, the BBU 2 is configured to transmit the remote DU setup request message ("remote DU setup request") in case the one or more channel quality parameters of the first bidirectional connection are predicted to not fulfill the threshold for the respective channel quality parameter anymore within a specific time period, and a F1 interface setup response message ("F1 setup response") in response to receiving a F1 interface setup request ("F1 setup request"). As shown in FIG. 7, the RU 1 is configured to establish the second bidirectional connection 3b and transmit a remote distributed unit (DU) setup response message ("remote DU setup response") and a F1 interface setup request message ("F1 setup request") in response to receiving a remote DU setup request message ("remote DU setup request").

As a result, in an emergency state (shown in FIG. 7), in which bad propagation conditions (e.g. due to bad weather) over the first bidirectional connection 3a lead to interruption of the first bidirectional connection 3a or the channel quality of the first bidirectional connection 3a is not sufficient for data transmission, the first bidirectional connection 3a may be de-activated and the second bidirectional connection 3b using 5G NR access technologies may be activated to carry data between the RU 1 and the BBU 2. The full activation of the second bidirectional connection 3b may be dictated and completed by the central unit (CU) of the BBU 2 through standardized F1 signaling. As shown in FIG. 7, for de-activating the first bidirectional connection 3a, in the alert state the BBU 2 is configured to transmit a removal request message for de-activating the first bidirectional connection 3a ("first connection removal request"). The RU 1 is configured to de-activate the first bidirectional connection 3a in case the second bidirectional connection 3b is activated and to transmit a removal response message for de-activating the first bidirectional connection 3a ("first connection removal response") in response to receiving the removal request message for de-activating the first bidirectional connection 3a ("first connection removal request").

During a fronthaul link status check state (shown in FIG. 8), the BBU 2 may periodically check the status of the first bidirectional connection 3a through signaling messages targeted at re-establishing the first bidirectional connection 3a. As shown in FIG. 8, for this the BBU 2 may be configured to transmit a setup request message for establishing the first bidirectional connection 3a ("first connection setup request"). The BBU 2 may be configured to periodically transmit this setup request message. The RU 1 is configured to establish the first bidirectional connection 3a and transmit a setup response message for establishing the first bidirectional connection 3a ("first connection setup response") in response to receiving the setup request message for establishing the first bidirectional connection 3a ("first connection setup request"), in case the one or more channel quality parameters of the first bidirectional connection 3a fulfill the threshold for the respective channel quality parameter (e.g., in case propagation conditions over the first bidirectional connection 3a are sufficient for data transmission). The BBU 2 is configured to use the first bidirectional connection 3a for communicating with the RU 1 in response to receiving the setup response message for establishing the first bidirectional connection 3a ("first connection setup response").

In a fronthaul link re-activation state (shown in FIG. 8), the propagation conditions over the first bidirectional connection 3a are good (e.g. due to good weather). The propagation conditions over the first bidirectional connection 3a may be good in case the one or more channel quality parameters of the first bidirectional connection 3a fulfill the threshold for the respective channel quality parameter (e.g., in case propagation conditions over the first bidirectional connection 3a are sufficient for data transmission). Therefore, as shown in FIG. 8, the first bidirectional connection 3a is activated. The second bidirectional connection 3b using 5G NR access technologies and the DU at the RU side is de-activated through proper signaling messages. For this, the BBU 2 is configured to transmit an F1 interface removal response message ("F1 removal response"), in response to receiving an F1 interface removal request ("F1 removal request") and transmit a remote distributed unit (DU) removal request message ("remote DU removal request"). The RU 1 is configured to de-activate the second bidirectional connection 3b and transmit a F1 interface removal request message ("F1 removal request"), in case the first bidirectional connection 3a is activated. The RU 1 is configured to transmit a remote distributed unit (DU) removal response message ("remote DU removal response") in response to receiving the remote distributed unit (DU) removal request message ("remote DU removal request"), in case the second bidirectional connection 3b is de-activated.

Thus, as outlined with regard to FIGs 7 and 8, the F1 signaling interface (F1-C) of the 5G F1AP (F1 Application Protocol) used in 5G NR to manage the F1 interface between CU and DU may be complemented with additional signaling messages to manage the activation/de-activation of the first bidirectional connection 3a. Such new signaling, namely the setup request message for establishing the first bidirectional connection 3a ("first connection setup request") and setup response message for establishing the first bidirectional connection 3a ("first connection setup response") may be encoded in appropriate regions of F1-C. The F1 interface setup request message ("F1 setup request"), the F1 interface setup response message ("F1 setup response"), the F1 interface removal request message ("F1 removal request"), and the F1 interface removal response message ("F1 removal response") may be standardized within 5G F1AP.

The remote distributed unit (DU) setup request message ("remote DU setup request"), the remote distributed unit (DU) setup response message ("remote DU setup response"), the removal request message for de-activating the first bidirectional connection 3a ("first connection removal request"), and the removal response message for de-activating the first bidirectional connection 3a ("first connection removal response") may be encoded in optional fields of packet units defined by the employed fronthaul protocol (e.g., eCPRI, Open Fronthaul, etc.) over the first bidirectional connection 3a.

FIG. 9 shows an example of different states during a wireless communication between the radio unit (RU) and base band unit (BBU) of FIG. 2. The description of FIG. 2 is correspondingly valid for the RU 1 and BBU 2 of FIG. 9. The RU 1 and BBU 2 of FIG. 9 may be for example the RU 1 and BBU 2 of any one of FIGs 3, 4 and 5. In this case, the description of the FIG. 3, 4 or 5, respectively, is correspondingly valid.

According to a first assumed case, i.e., case 1, the first bidirectional connection 3a between the RU 1 and the BBU 2 has full quality, and it can support the full cell performance (e.g., high resource block (RB) occupation, high number of multiple input multiple output (MIMO) layers, etc.). That is, in the case 1 the first bidirectional connection 3a between the RU 1 and the BBU 2 is active. Thus, in the case 1 the RU 1 may fully serve its cell due to the good quality of the first bidirectional connection 3a. This allows the full cell performance to occur. In the case 1, the RU 1, e.g. a control entity of the RU 1, may not take any action with regard to establishing the second bidirectional connection 3b, apart from a continuous monitoring of the channel quality of the first bidirectional connection 3a.

According to a second assumed case, i.e., case 2, the channel quality of the first bidirectional connection 3a has degraded compared to the case 1. For example, the maximum bit-rate achievable for a target bit error rate (BER) being a channel quality parameter of the first bidirectional connection 3a has degraded compared to the case 1. This may be due to e.g. lightly rainy weather and/or foggy weather. In the case 2, the RU 1, e.g. its control entity, may be configured to actively limit the cell performance according to the reduced available capacity of the first bidirectional connection 3a (i.e., reduced fronthaul capacity). For example, the RU 1 (e.g. its control entity) may achieve this by de-activating at least one of a sub-set of the MIMO layers, bandwidth parts (BWPs) and RBs, and by implementing traffic steering actions to unload the cell. These actions allow limiting the overall fronthaul capacity requirement.

In other words, the RU 1 may be configured to, in case the one or more channel quality parameters of the first bidirectional connection 3a do not fulfill a second threshold for the respective channel quality parameter (i.e. case 2 occurs), wirelessly communicate with the BBU 2 using the first bidirectional connection 3a, and limit a cell performance according to a reduced capacity of the first bidirectional connection 3a. The one or more channel quality parameters of the first bidirectional connection 3a not fulfilling the second threshold for the respective channel quality parameter may indicate the reduced capacity of the first bidirectional connection 3a and a channel quality of the first bidirectional connection 3a that is better compared to the channel quality of the first bidirectional connection 3a when the one or more channel quality parameters of the first bidirectional connection 3a do not fulfill the threshold for the respective channel quality parameter. The channel quality of the first bidirectional connection 3a when the one or more channel quality parameters of the first bidirectional connection 3a do not fulfill the threshold for the respective channel quality parameter may correspond to case 3 of FIG. 9.

According to a third assumed case, i.e., case 3, the channel quality of the first bidirectional connection 3a has degraded to the point of causing full link outage (i.e., the first bidirectional connection 3a is interrupted). In response thereto, the RU 1, e.g. its control entity, may activate the layer-2 functionalities in the RAN protocol stack (e.g. local RAN protocol stack) that were dormant before. That is, the RU 1 did not use the layer-2 functionalities for the first bidirectional connection 3a. These layer-2 functionalities may comprise MAC functionalities and/or RLC functionalities. Further, the RU 1, e.g. its control entity, may activate (i.e., establish) the second bidirectional connection 3b between the RU 1 and the BBU 2.

The second bidirectional connection 3b may provide a bidirectional transport of the higher layer protocol data units (PDUs) using radio access technologies, and it is characterized by lower capacity requirements with respect to the first bidirectional connection 3a. The RU 1 may be configured to employ radio resource management techniques to optimally manage the coexistence of the second bidirectional connection 3b with transmissions and receptions from radio access users over the second frequency band (e.g., through optimized frequency division multiple access considering the actual throughput requirements of the network nodes).

Optionally, the RU 1 may be configured to de-activate the first bidirectional connection 3a and to activate the second bidirectional connection 3b even if the first bidirectional connection 3a is not completely in outage. The RU 1 may be configured to do this, in case the channel quality of the first bidirectional connection 3a is degraded to the point that the second bidirectional connection 3b is considered more effective and able to provide higher capacity to the users in the cell served by the RU 1.

In other words, the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters may be selected such that no communication is possible via the first bidirectional connection 3a in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter. In this case, the channel quality parameter not fulfilling the threshold for the respective channel quality parameter may be assumed to represent interruption of the first bidirectional connection 3a (i.e. this corresponds to case 3 of Figure 9). Thus, the RU 1 may activate the second bidirectional connection 3b in case of an interruption of the first bidirectional connection 3a.

Alternatively, the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters may be selected such that communication with a reduced quality is possible via the first bidirectional connection 3a in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter. Thus, the RU 1 may de-activate the first bidirectional connection 3a and activate the second bidirectional connection 3b in case a wireless communication via the first bidirectional connection 3a is still possible, but the quality of the first bidirectional connection 3a is reduced such that a wireless communication via the second bidirectional connection 3b is preferable (e.g. more effective).

FIG. 10 shows an example of a method according to an embodiment of this disclosure for a wireless communication between a base band unit (BBU) and a radio unit (RU) according to a radio access network (RAN) protocol. The method of FIG. 10 is an example of the method according to the third aspect of this disclosure. Thus, the description of the method according to the third aspect is correspondingly valid for the method of FIG. 10.

The method of FIG. 10 is a method for a wireless communication between a BBU and a RU according to a radio access network (RAN) protocol. The BBU and the RU may be the BBU and RU, respectively, of any one of FIGs 1 to 9. As shown in FIG. 10, the method comprises a step S100 of using for the communication between the BBU and the RU a second bidirectional connection between the BBU and the RU, in case one or more channel quality parameters of a first bidirectional connection between the BBU and the RU do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted. The first bidirectional connection is allocated over a first frequency band of the electromagnetic spectrum. The second bidirectional connection is allocated over a second frequency band of the electromagnetic spectrum, the second frequency band being used for radio access communication.

FIG. 11 shows an example of radio units (RUs) according to an embodiment of this disclosure for wireless communication and an example of a base band unit (BBU) pool according to an embodiment of this disclosure for wireless communication. The RU 1 of FIG. 11 is an example of the RU according to the fourth aspect of this disclosure. Thus, the description of the RU according to the fourth aspect is correspondingly valid for the RU 1 of FIG. 11. The BBU pool 20 of FIG. 11 is an example of the BBU pool according to the fifth aspect of this disclosure. Thus, the description of the BBU pool according to the fifth aspect is correspondingly valid for the BBU pool 20 of FIG. 11.

Each RU 1 of the RUs 1 of FIG. 11 is a RU for wireless communication with a BBU 2 of a BBU pool 20 according to a radio access network (RAN) protocol. Each RU 1 is configured to establish a first bidirectional connection 3a with the BBU 2, the first bidirectional connection 3a being allocated over a first frequency band of the electromagnetic spectrum. Each RU 1 is configured to establish a second bidirectional connection 3b with the BBU 2. The second bidirectional connection 3b is allocated over a second frequency band of the electromagnetic spectrum, the second frequency band being used for radio access communication. Each RU 1 is configured to use the second bidirectional connection 3b for communicating with the BBU 2 in case one or more channel quality parameters of the first bidirectional connection 3a do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection 3a is interrupted.

The BBU pool 20 of FIG. 11 is a BBU pool for wireless communication with one or more RUs according to a radio access network (RAN) protocol. A BBU 2 of the BBU pool 20 is configured to establish the first bidirectional connection 3a with a RU 1 of the one or more RUs 1. The BBU 2 of the BBU pool 20 is configured to establish the second bidirectional connection 3b with the RU 1. The BBU 2 of the BBU pool 20 is configured to use the second bidirectional connection 3b for communicating with the RU 1 in case one or more channel quality parameters of the first bidirectional connection 3a do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection 3a is interrupted. The aforementioned may be valid for each BBU 2 of the BBU pool 20.

Each RU 1 of FIG. 11 may be a RU 1 of any one of FIGs 1 to 9. Each BBU 2 of the BBU pool 20 may be a BBU 2 of any one of FIGs 1 to 9.

According to the example of FIG. 11, there are two RUs 1. This number is only by way of example and may be different. That is, there may be one or more RUs 1. According to the example of FIG. 11, the BBU pool 20 comprises two BBUs 2. This number is only by way of example and may be different. That is, the BBU pool 20 may comprise two or more BBUs 2. Any one of the multiple BBUs 2 may be configured to wirelessly communicate with any one of the one or more RUs 1 according to the RAN protocol via the first bidirectional connection 3a or the second bidirectional connection 3b. Any one of the one or more RUs 1 may be configured to wirelessly communicate with any one of the multiple BBUs 2 of the BBU pool 20 according to the RAN protocol.

FIG. 11 exemplarily shows a first RU 1 (shown on the left side of FIG. 11) being configured to wirelessly communicate with a first BBU 2 (shown on the left side of FIG. 11) of the BBU pool 20 according to the RAN protocol, and a second RU 1 (shown on the right side of FIG. 11) being configured to wirelessly communicate with a second BBU 2 (shown on the right side of FIG. 11) of the BBU pool 20 according to the RAN protocol. This only by way of example and does not limit the present disclosure.

The one or more RUs 1 and the BBU pool 20 may form a wireless communication system. They may form a wireless communication network. The one or more RUs 1 and the BBU pool 20 may form a C-RAN system. The first bidirectional connection(s) 3a are fronthaul link(s).

The communication devices of this disclosure, such as the RU of the first aspect, the BBU of the second aspect, the RU of the fourth aspect and the BBUs of the BBU pool of the fifth aspect, may be used in a C-RAN system. In this case, a first bidirectional connection that may be established by any communication device of this disclosure is a fronthaul link.

The present disclosure has been described in conjunction with various embodiments as examples as well as implementations. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed matter, from the studies of the drawings, this disclosure and the independent claims. In the claims as well as in the description the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. A single element or other unit may fulfill the functions of several entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a combination of these measures cannot be used in an advantageous implementation.

CLAIMS

1. A radio unit (1), RU, for wireless communication with a base band unit (2), BBU, according to a radio access network, RAN, protocol, wherein the RU (1) is configured to:
   - establish a first bidirectional connection (3a) with the BBU (2), the first bidirectional connection (3a) being allocated over a first frequency band of the electromagnetic spectrum,
   - establish a second bidirectional connection (3b) with the BBU (2), the second bidirectional connection (3b) being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication, and
   - use the second bidirectional connection (3b) for communicating with the BBU (2) in case one or more channel quality parameters of the first bidirectional connection (3a) do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection (3a) is interrupted.

2. The RU (1) according to claim 1, wherein
   - the RU (1) is configured to establish the first bidirectional connection (3a) with the BBU (2) and provide access, by implementing layer-1 functionalities of the RAN protocol, for a user.

3. The RU (1) according to claim 1 or 2, wherein
   - the RU (1) is configured to establish the second bidirectional connection (3b) with the BBU (2) by implementing layer-1 functionalities and layer-2 functionalities of the RAN protocol.

4. The RU (1) according to claim 3, wherein
   - the RU (1) is configured to activate the layer-2 functionalities of the RAN protocol for establishing the second bidirectional connection (3b) with the BBU (2) in case the first bidirectional connection (3a) is interrupted.

5. The RU (1) according to any one of claims 2 to 4, wherein
   - the layer-1 functionalities comprise physical layer functionalities (1c) and/or radio frequency, RF, layer functionalities (1d) of the RAN protocol.

6. The RU (1) according to any one of claims 3 to 5, wherein
   - the layer-2 functionalities comprise radio link control, RLC, functionalities (1a) and/or media access control, MAC, functionalities (1b) of the RAN protocol.

7. The RU (1) according to any one of the previous claims, wherein the RU (1) is configured to:
   - obtain the one or more channel quality parameters of the first bidirectional connection (3a), and
   - determine whether the one or more channel quality parameters of the first bidirectional connection (3a) fulfill the threshold for the respective channel quality parameter or not.

8. The RU (1) according to any one of the previous claims, wherein

- the RU (1) is configured to establish the second bidirectional connection (3b) and transmit a setup response message for establishing the second bidirectional connection (3b) in response to receiving a setup request message for establishing the second bidirectional connection.

9. The RU (1) according to any one of the previous claims, wherein

- the RU (1) is configured to de-activate the first bidirectional connection (3a) in case the second bidirectional connection (3b) is activated and to transmit a removal response message for de-activating the first bidirectional connection (3a) in response to receiving a removal request message for de-activating the first bidirectional connection (3a).

10. The RU (1) according to any one of the previous claims, wherein the RU (1) is configured to:

- establish the first bidirectional connection (3a) and transmit a setup response message for establishing the first bidirectional connection (3a) in response to receiving a setup request message for establishing the first bidirectional connection (3a), in case the one or more channel quality parameters of the first bidirectional connection (3a) fulfill the threshold for the respective channel quality parameter.

11. The RU (1) according to any one of the previous claims, wherein the RU (1) is configured to:

- de-activate the second bidirectional connection (3b) and transmit a removal response message for de-activating the second bidirectional connection (3b) in response to receiving a removal request message for de-activating the second bidirectional connection (3b), in case the first bidirectional connection (3a) is activated.

12. The RU (1) according to any one of the previous claims, wherein the RU (1) is configured to:

- communicate with the BBU (2) according to 5G New Radio protocol, and
- establish the second bidirectional connection (3b) with the BBU by establishing a connection based on F1 interface between the RU (1) and the BBU (2), wherein
  - the RU (1) comprises a distributed unit (12b), DU, for managing the connection based on F1 interface.

13. The RU (1) according to claim 12, wherein

- the RU (1) is configured to establish the second bidirectional connection (3b) and transmit a remote distributed unit, DU, setup response message and a F1 interface setup request message in response to receiving a remote DU setup request message.

14. The RU (1) according to claim 12 or 13, wherein the RU (1) is configured to:

- de-activate the second bidirectional connection (3b) and transmit a F1 interface removal request message, in case the first bidirectional connection (3a) is activated, and
- transmit a remote distributed unit, DU, removal response message in response to receiving a remote distributed unit, DU, removal request message, in case the second bidirectional connection (3b) is de-activated.

15. The RU (1) according to any one of the previous claims, wherein the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters is selected such that:

- no communication is possible via the first bidirectional connection (3a) in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter, or
- communication with a reduced quality is possible via the first bidirectional connection (3a) in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter.

16. The RU (1) according to any one of the previous claims, wherein the RU (1) is configured to, in case the one or more channel quality parameters of the first bidirectional connection (3a) do not fulfill a second threshold for the respective channel quality parameter,
   - wirelessly communicate with the BBU (2) using the first bidirectional connection (3a), and
   - limit a cell performance according to a reduced capacity of the first bidirectional connection (3a); wherein
      - the one or more channel quality parameters of the first bidirectional connection not fulfilling the second threshold for the respective channel quality parameter indicate the reduced capacity of the first bidirectional connection (3a), and
      - a channel quality of the first bidirectional connection (3a) that is better compared to the channel quality of the first bidirectional connection (3a) when the one or more channel quality parameters of the first bidirectional connection do not fulfill the threshold for the respective channel quality parameter.

17. A base band unit (2), BBU, for wireless communication with a radio unit (1), RU, according to a radio access network, RAN, protocol, wherein the BBU (2) is configured to:
   - establish a first bidirectional connection (3a) with the RU (1), the first bidirectional connection (3a) being allocated over a first frequency band of the electromagnetic spectrum,
   - establish a second bidirectional connection (3b) with the RU (1), the second bidirectional connection (3b) being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication, and
   - use the second bidirectional connection (3b) for communicating with the RU (1) in case one or more channel quality parameters of the first bidirectional connection (3a) do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection (3a) is interrupted.

18. The BBU (2) according to claim 17, wherein
   - the BBU (2) is configured to establish the first bidirectional connection (3a) with the RU (1) by implementing layer-2 functionalities of the RAN protocol.

19. The BBU (2) according to claim 17 or 18, wherein
   - the BBU (2) is configured to establish the second bidirectional connection (3b) with the RU (1) without implementing layer-2 functionalities of the RAN protocol.

20. The BBU (2) according to claim 18 or 19, wherein
   - the layer-2 functionalities comprise radio link control, RLC, functionalities (1a) and/or media access control, MAC, functionalities (1b) of the RAN protocol.

21. The BBU (2) according to any one of claims 17 to 20, wherein the BBU (2) is configured to:
   - obtain the one or more channel quality parameters of the first bidirectional connection (3a), and
   - determine whether the one or more channel quality parameters of the first bidirectional connection (3a) fulfill the threshold for the respective channel quality parameter or not.

22. The BBU (2) according to any one of claims 17 to 21, wherein
   - the BBU (2) is configured to transmit a setup request message for establishing the second bidirectional connection (3b), in case the one or more channel quality parameters of the first bidirectional connection (3a)

are predicted to not fulfill the threshold for the respective channel quality parameter anymore within a specific time period or in case the first bidirectional connection (3a) is interrupted.

23. The BBU (2) according to any one of claims 17 to 22, wherein
- the BBU (2) is configured to transmit a removal request message for de-activating the first bidirectional connection (3a) in response to receiving a setup response message for establishing the second bidirectional connection (3b).

24. The BBU (2) according to any one of claims 17 to 23, wherein the BBU (2) is configured to:
- transmit a setup request message for establishing the first bidirectional connection (3a), and
- use the first bidirectional connection (3a) for communicating with the RU (1) in response to receiving a setup response message for establishing the first bidirectional connection (3a).

25. The BBU (2) according to any one of claims 17 to 24, wherein the BBU (2) is configured to:
- transmit a removal request message for de-activating the second bidirectional connection (3b) in response to receiving a setup response message for establishing the first bidirectional connection (3a).

26. The BBU (2) according to any one of claims 17 to 25, wherein the BBU (2) is configured to:
- communicate with the RU (1) according to 5G New Radio protocol, and
- establish the second bidirectional connection (3b) with the RU (1) by establishing a connection based on F1 interface between the BBU (2) and the RU (1), wherein
  - the BBU (2) comprises a central unit (22a), CU, for managing the connection based on F1 interface.

27. The BBU (2) according to claim 26, wherein the BBU (2) is configured to transmit:
- a remote distributed unit, DU, setup request message, in case the one or more channel quality parameters of the first bidirectional connection (3a) are predicted to not fulfill the threshold for the respective channel quality parameter anymore within a specific time period, and
- a F1 interface setup response message in response to receiving a F1 interface setup request message.

28. The BBU (2) according to claim 26 or 27, wherein the BBU (2) is configured to:
- transmit an F1 interface removal response message, in response to receiving a F1 interface removal request message, and transmit a remote distributed unit, DU, removal request message.

29. The BBU (2) according to any one of claims 17 to 28, wherein the threshold for the respective channel quality parameter for each channel quality parameter of the one or more channel quality parameters is selected such that:
- no communication is possible via the first bidirectional connection (3a) in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter, or
- communication with a reduced quality is possible via the first bidirectional connection (3a) in case the channel quality parameter does not fulfill the threshold for the respective channel quality parameter.

30. A method for a wireless communication between a base band unit, BBU, and a radio unit, RU, according to a radio access network, RAN, protocol, wherein the method comprises:
- using (S100) for the communication between the BBU and the RU a second bidirectional connection between the BBU and the RU, in case one or more channel quality parameters of a first bidirectional connection between

the BBU and the RU do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted, wherein

- the first bidirectional connection is allocated over a first frequency band of the electromagnetic spectrum, and
- the second bidirectional connection is allocated over a second frequency band of the electromagnetic spectrum used for radio access communication.

31. A radio unit (1), RU, for wireless communication with a base band unit (2), BBU, of a BBU pool (20) according to a radio access network, RAN, protocol, wherein the RU (1) is configured to:
- establish a first bidirectional connection (3a) with the BBU (2), the first bidirectional connection (3a) being allocated over a first frequency band of the electromagnetic spectrum,
- establish a second bidirectional connection (3b) with the BBU (2), the second bidirectional connection (3b) being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication, and
- use the second bidirectional connection (3b) for communicating with the BBU (2) in case one or more channel quality parameters of the first bidirectional connection (3a) do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection (3a) is interrupted.

32. A base band unit, BBU, pool (20) for wireless communication with one or more radio units (1), RUs, according to a radio access network, RAN, protocol, wherein a BBU (2) of the BBU pool (20) is configured to:
- establish a first bidirectional connection (3a) with a RU (1) of the one or more RUs (1), the first bidirectional connection (3a) being allocated over a first frequency band of the electromagnetic spectrum,
- establish a second bidirectional connection (3b) with the RU (1), the second bidirectional connection (3b) being allocated over a second frequency band of the electromagnetic spectrum used for radio access communication, and
- use the second bidirectional connection (3b) for communicating with the RU (1) in case one or more channel quality parameters of the first bidirectional connection (3a) do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection (3a) is interrupted.

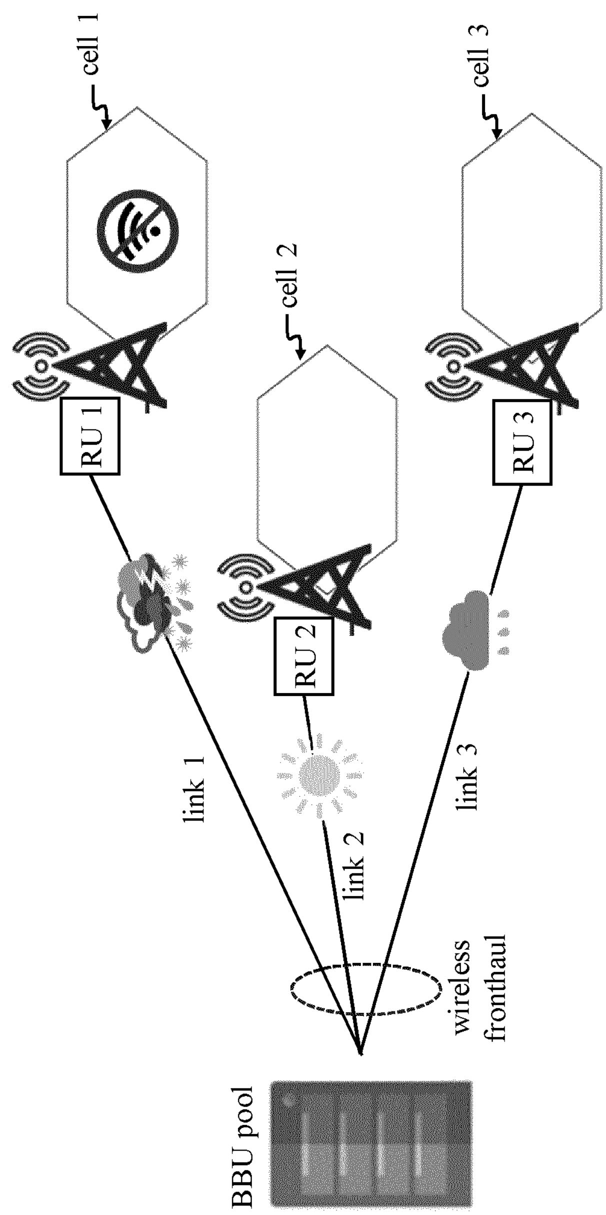
cell 1
cell 2
cell 3
RU 1
RU 2
RU 3
link 1
link 2
link 3
wireless fronthaul
BBU pool

Figure 1

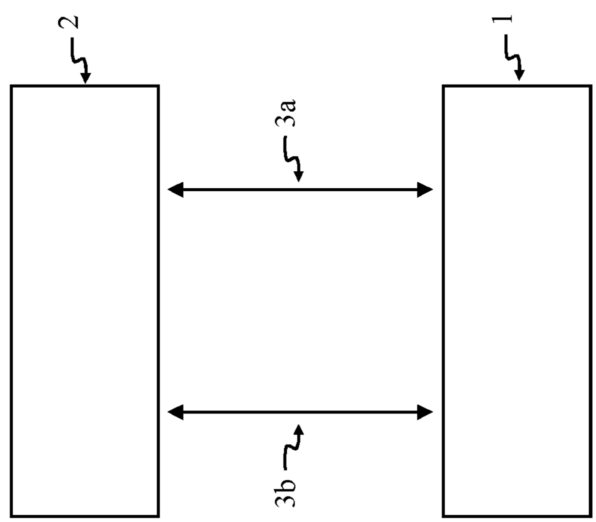

Figure 2

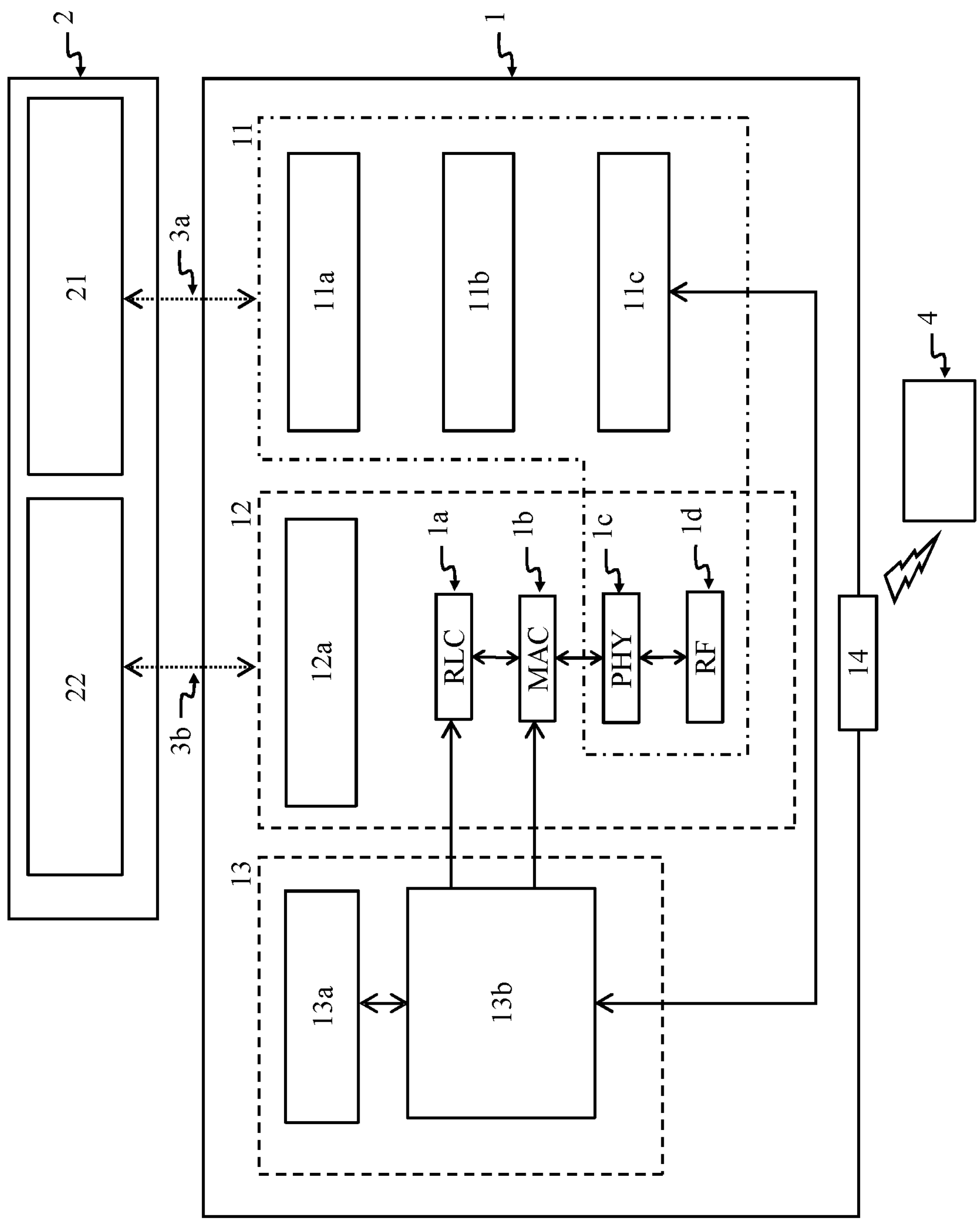
2
1
21
22
3a
3b
11
11a
11b
11c
12
12a
1a
1b
1c
1d
RLC
MAC
PHY
RF
13
13a
13b
14
4

Figure 3

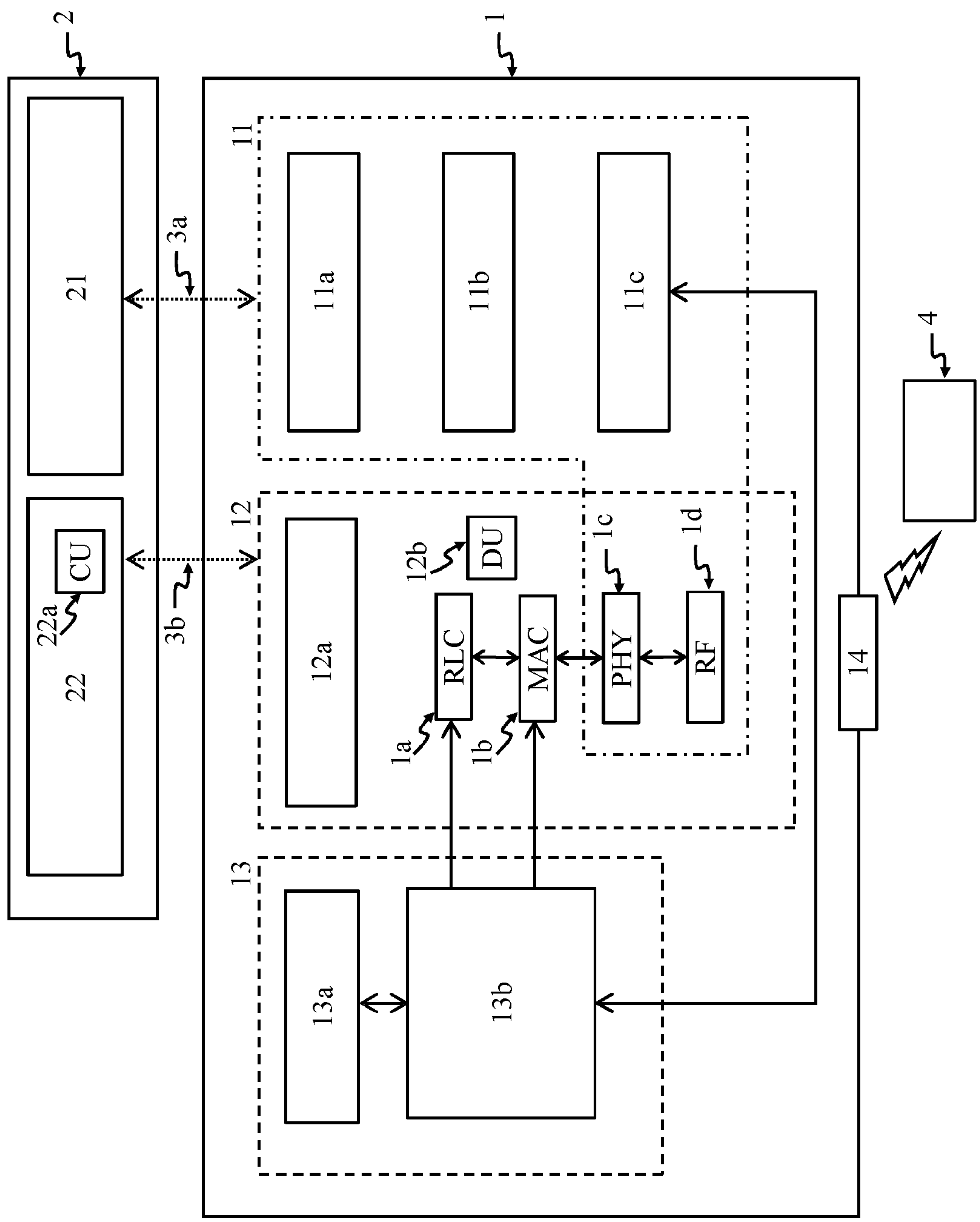
2
1
11
11a
11b
11c
21
3a
4
12
12a
12b
DU
1c
1d
CU
22a
22
3b
RLC
MAC
PHY
RF
14
1a
1b
13
13a
13b

Figure 4

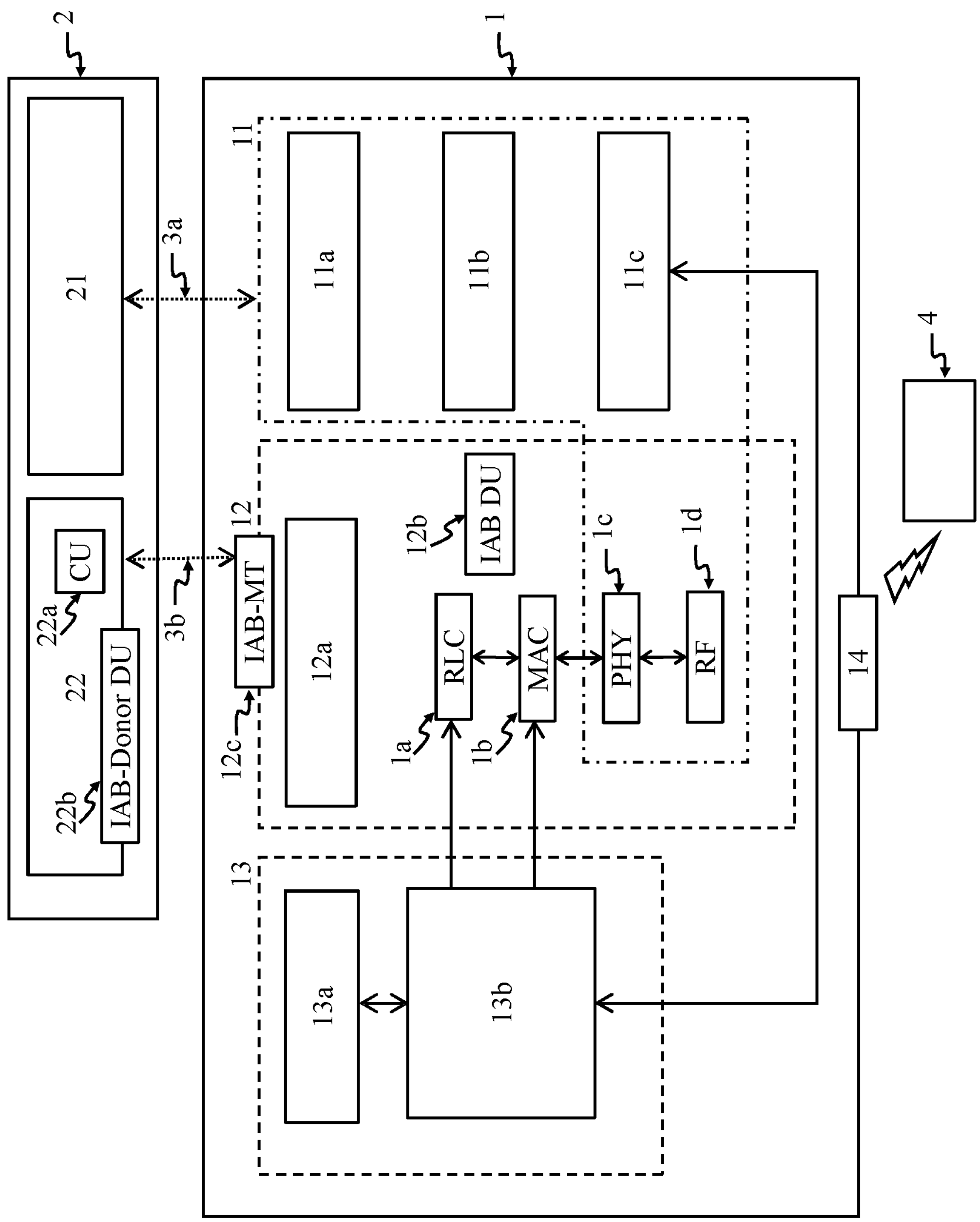
2
1
21
3a
11
11a
11b
11c
4
CU
22a
22
IAB-Donor DU
22b
3b
12
IAB-MT
12c
12a
12b
IAB DU
1c
1d
RLC
MAC
PHY
RF
1a
1b
14
13
13a
13b

Figure 5

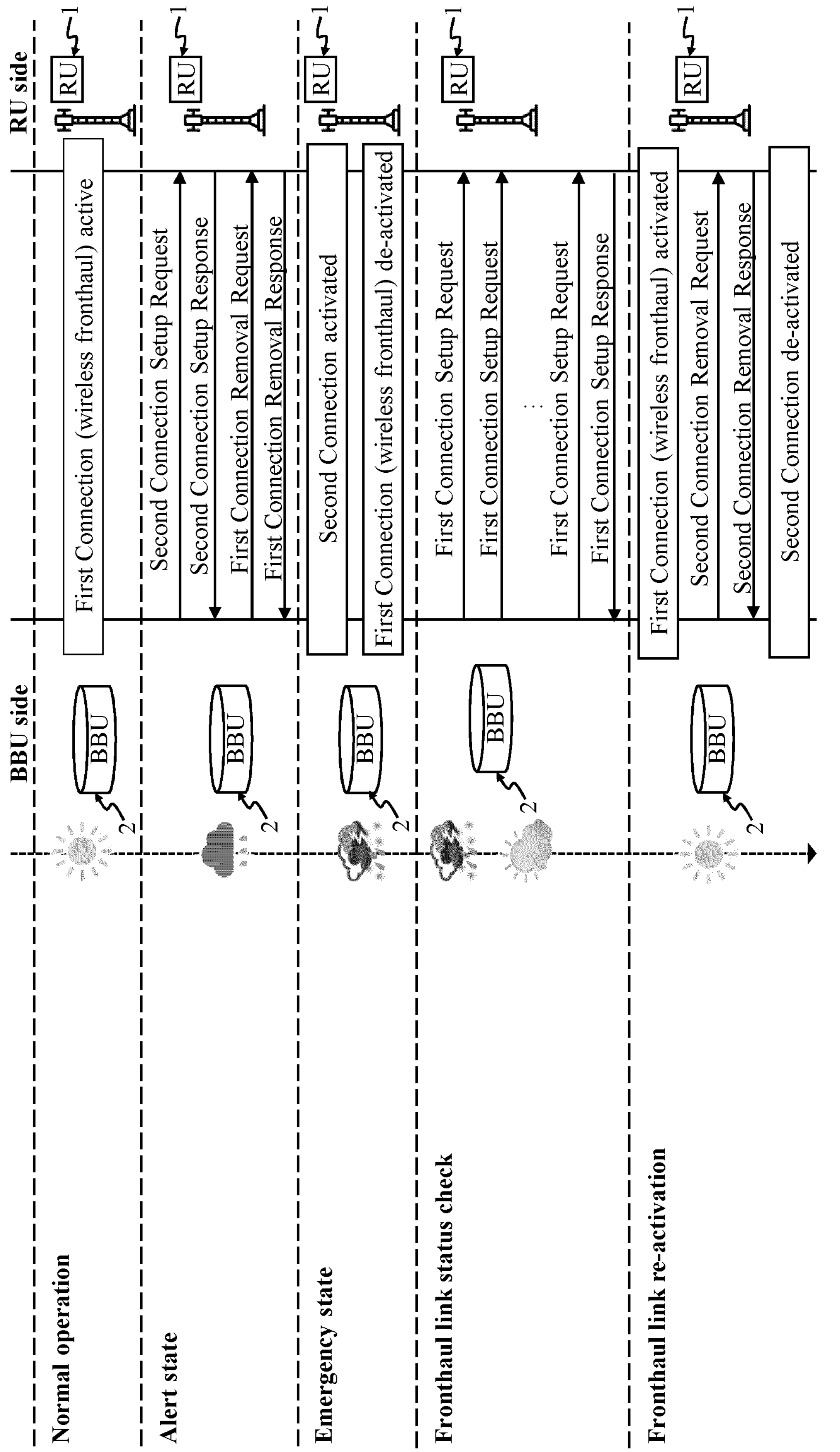
RU side
BBU side
RU
BBU
1
2
Normal operation
First Connection (wireless fronthaul) active
Alert state
Second Connection Setup Request
Second Connection Setup Response
First Connection Removal Request
First Connection Removal Response
Emergency state
Second Connection activated
First Connection (wireless fronthaul) de-activated
Fronthaul link status check
First Connection Setup Request
First Connection Setup Request
First Connection Setup Request
First Connection Setup Response
Fronthaul link re-activation
First Connection (wireless fronthaul) activated
Second Connection Removal Request
Second Connection Removal Response
Second Connection de-activated

Figure 6

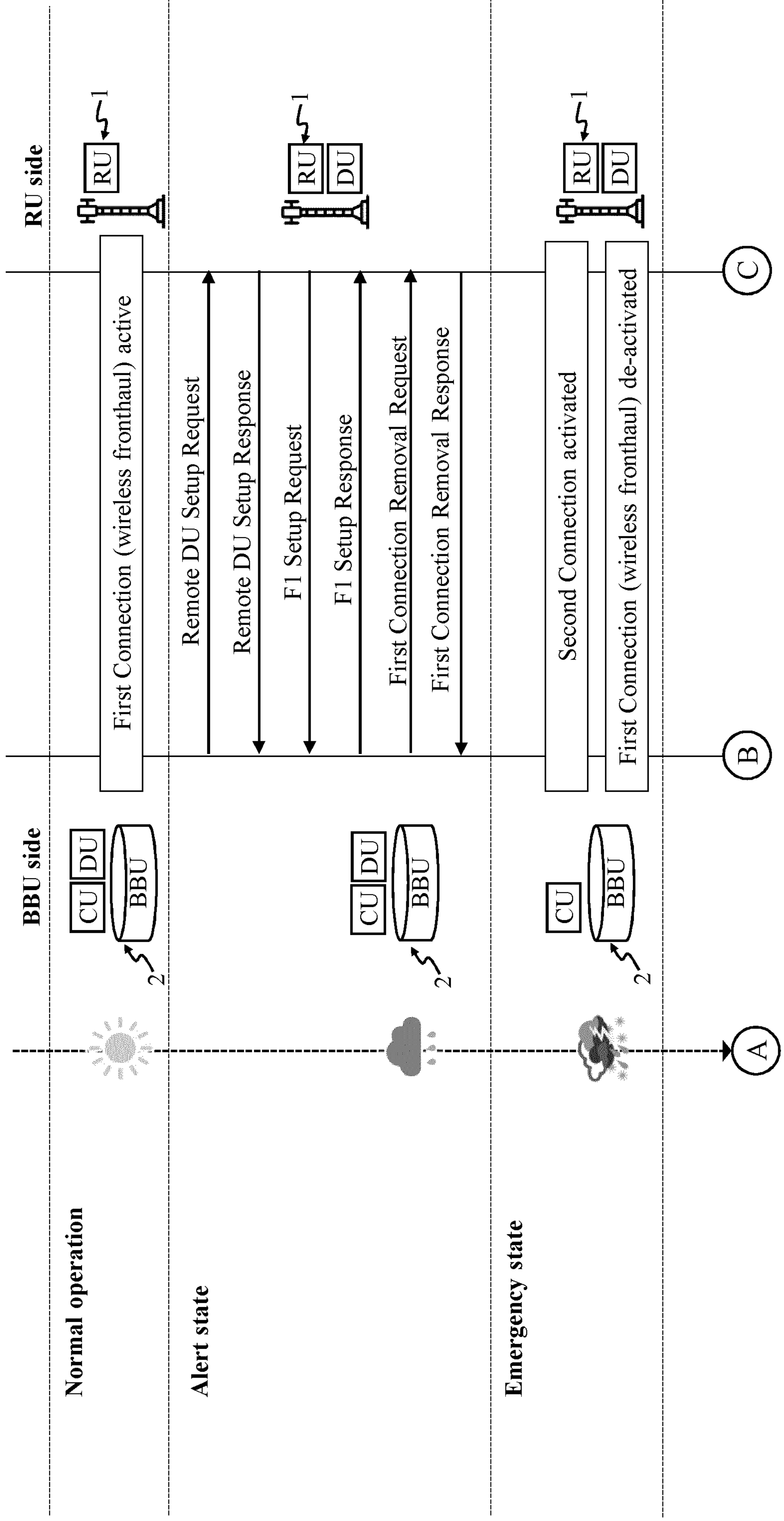
RU side
BBU side
RU
DU
CU
BBU
1
2
Normal operation
Alert state
Emergency state
First Connection (wireless fronthaul) active
Remote DU Setup Request
Remote DU Setup Response
F1 Setup Request
F1 Setup Response
First Connection Removal Request
First Connection Removal Response
Second Connection activated
First Connection (wireless fronthaul) de-activated
A
B
C

Figure 7

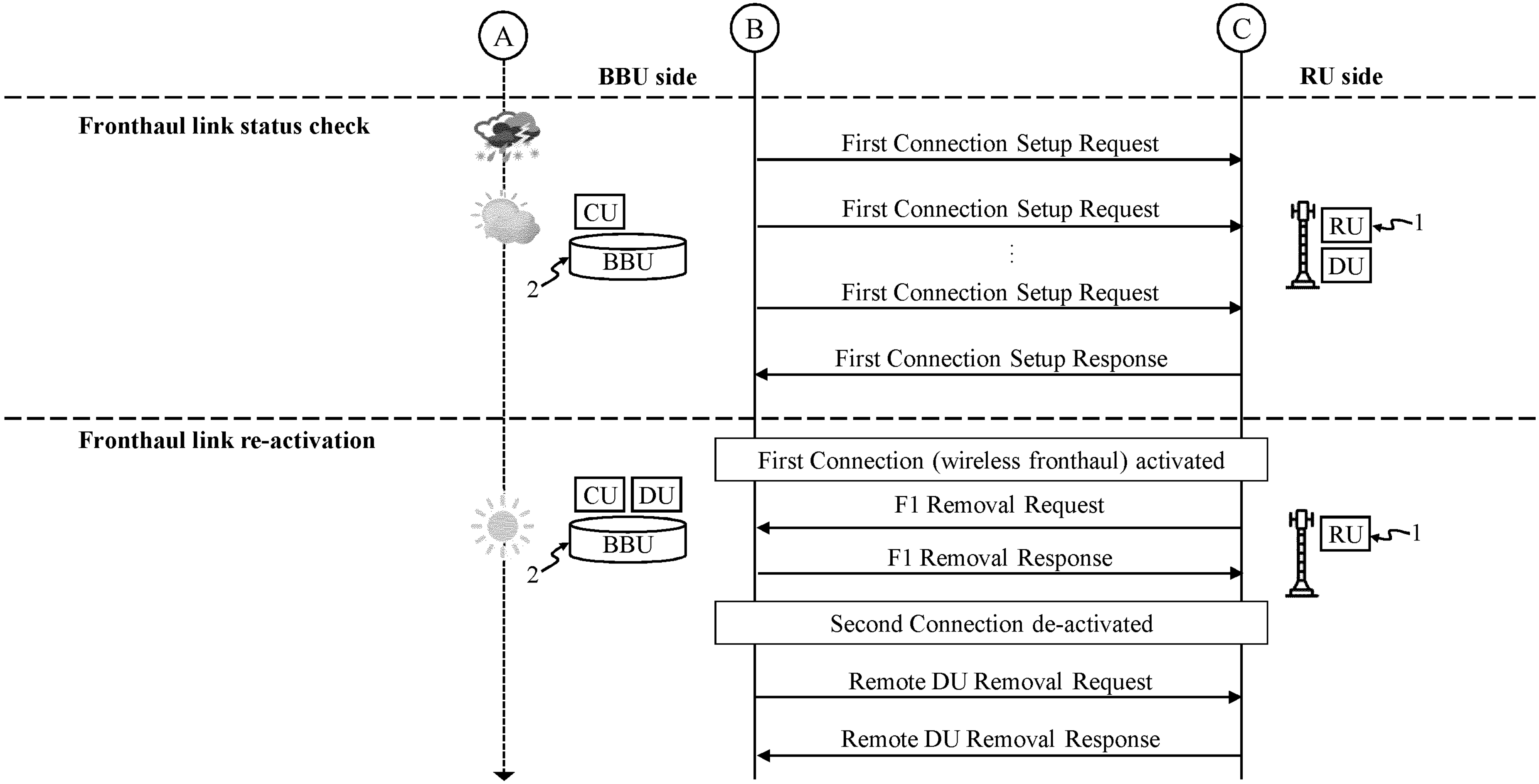
A
B
C
BBU side
RU side
Fronthaul link status check
First Connection Setup Request
First Connection Setup Request
⋮
First Connection Setup Request
First Connection Setup Response
CU
BBU
2
RU
DU
1
Fronthaul link re-activation
First Connection (wireless fronthaul) activated
F1 Removal Request
F1 Removal Response
Second Connection de-activated
Remote DU Removal Request
Remote DU Removal Response
CU
DU
BBU
2
RU
1

Figure 8

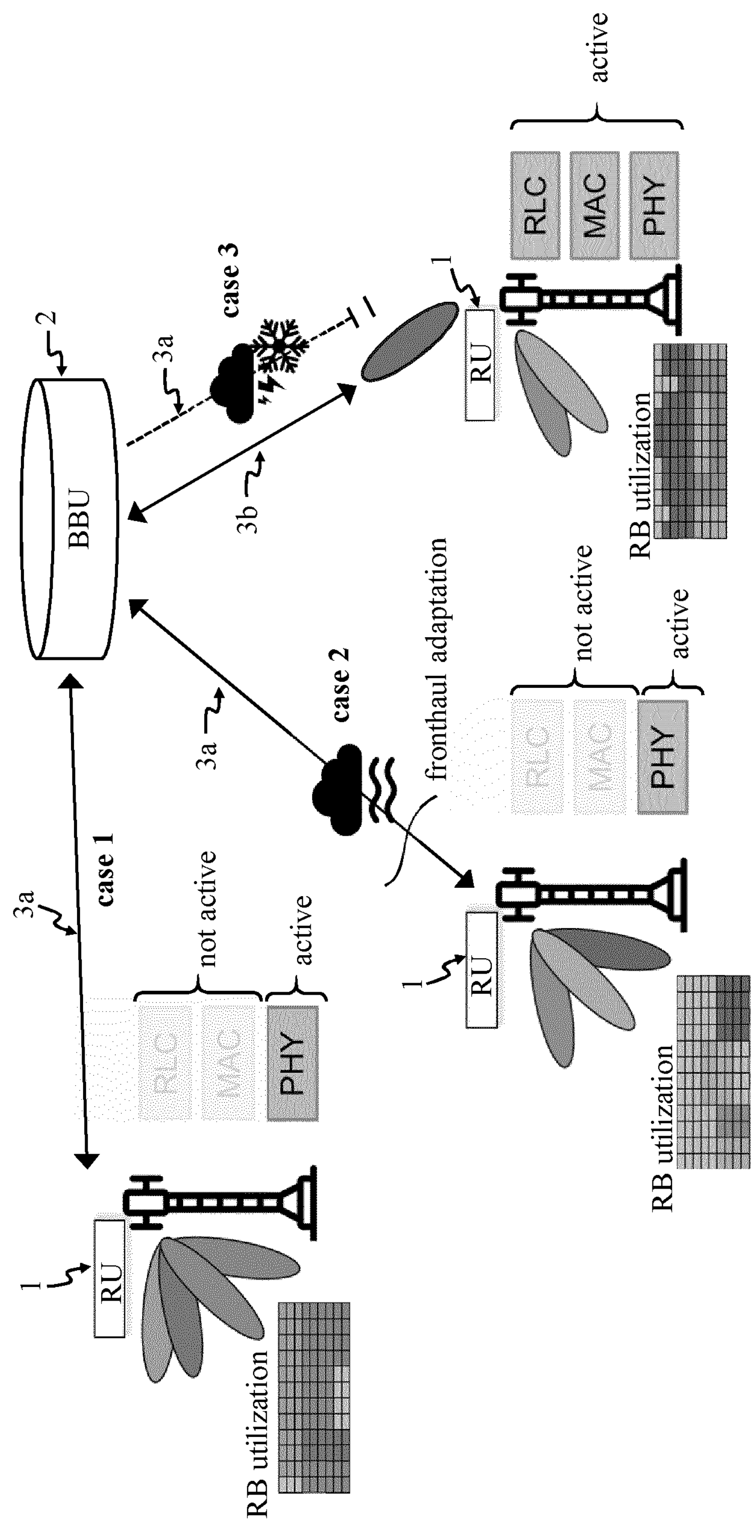
BBU
2
3a
3b
case 1
case 2
case 3
fronthaul adaptation
RU
1
RLC
MAC
PHY
not active
active
RB utilization

Figure 9

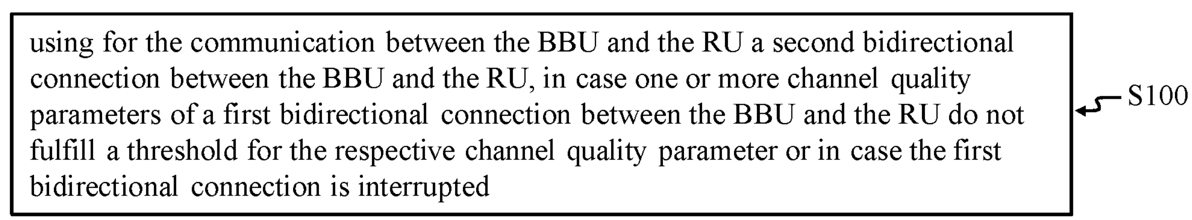
using for the communication between the BBU and the RU a second bidirectional connection between the BBU and the RU, in case one or more channel quality parameters of a first bidirectional connection between the BBU and the RU do not fulfill a threshold for the respective channel quality parameter or in case the first bidirectional connection is interrupted
S100

Figure 10

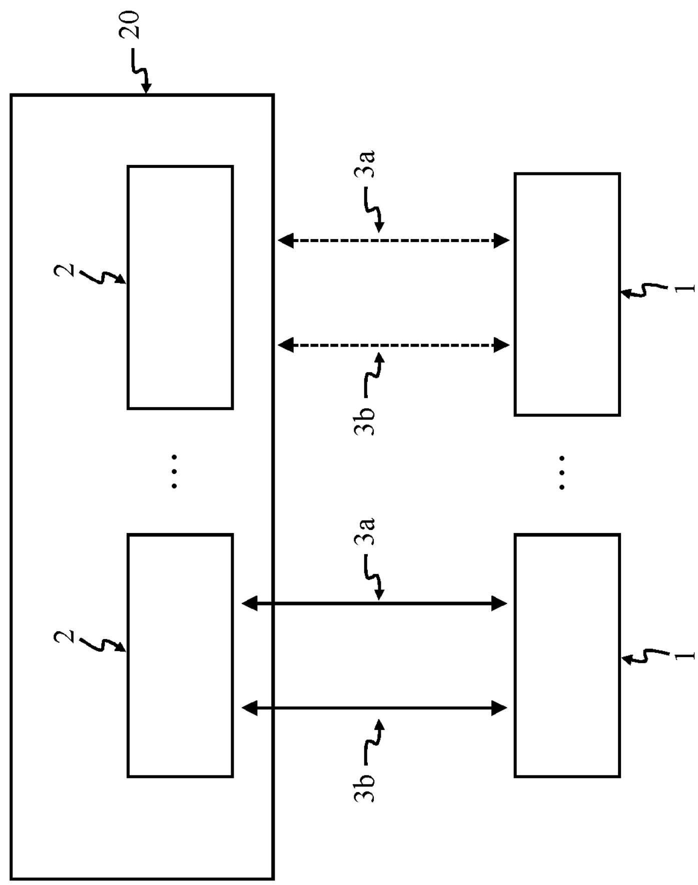

Figure 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/054303

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W24/04
ADD. H04W88/08 H04W76/15 H04W16/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2020/205017 A1 (TAKAHASHI GEN [JP]) 25 June 2020 (2020-06-25) paragraph [0047] paragraphs [0052] - [0056] paragraphs [0061] - [0066] paragraph [0096] figures 3, 6 -----	1-32

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 September 2024	16/09/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Costa, Elena

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NAJAFI MARZIEH ET AL: "C-RAN with Hybrid RF/FSO Fronthaul Links: Joint Optimization of RF Time Allocation and Fronthaul Compression", GLOBECOM 2017 - 2017 IEEE GLOBAL COMMUNICATIONS CONFERENCE, IEEE, 4 December 2017 (2017-12-04), pages 1-7, XP033300343, DOI: 10.1109/GLOCOM.2017.8254767 [retrieved on 2018-01-11] page I, right-hand column, paragraph 1 page 3, right-hand column, paragraph III.C -----	1-32
A	US 2022/123854 A1 (CEDERHOLM DANIEL [SE] ET AL) 21 April 2022 (2022-04-21) paragraph [0050] figures 4, 5 -----	1-32

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/054303

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2020205017 A1	25-06-2020	JP 7127642 B2	30-08-2022
		JP WO2018212158 A1	19-03-2020
		US 2020205017 A1	25-06-2020
		WO 2018212158 A1	22-11-2018
US 2022123854 A1	21-04-2022	CN 113796029 A	14-12-2021
		EP 3928448 A1	29-12-2021
		ES 2951016 T3	17-10-2023
		JP 7304958 B2	07-07-2023
		JP 2022520567 A	31-03-2022
		US 2022123854 A1	21-04-2022
		WO 2020171744 A1	27-08-2020