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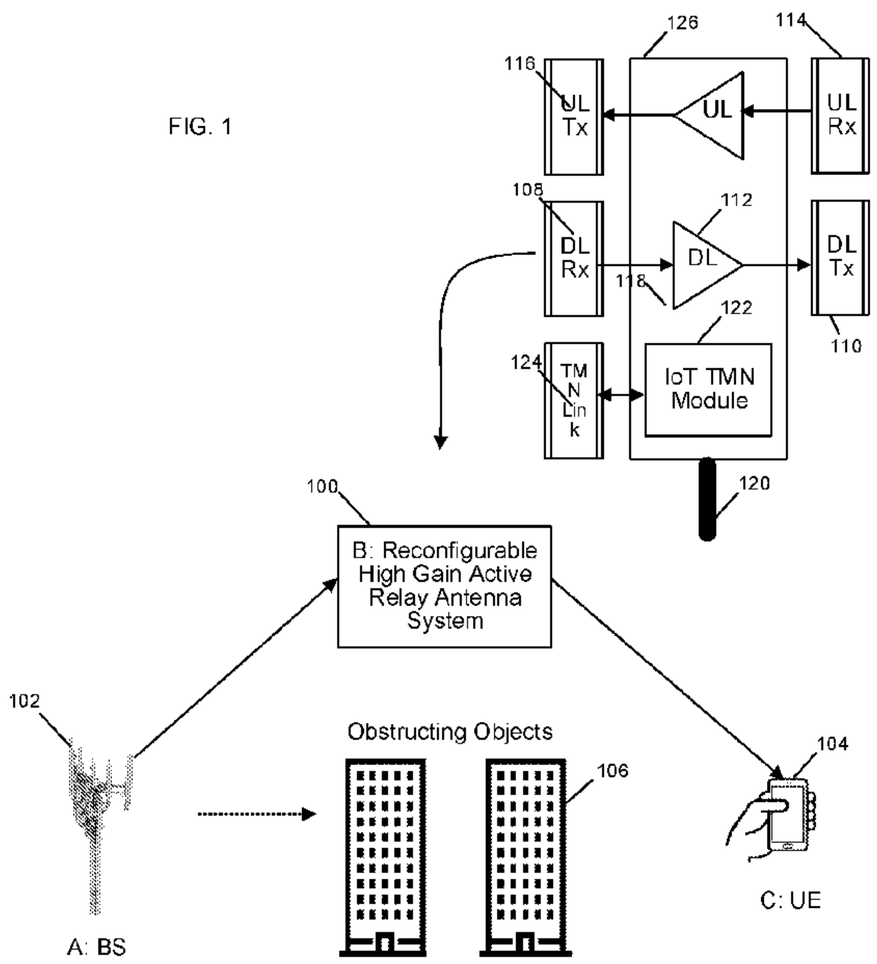
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(54) Title: RECONFIGURABLE HIGH GAIN ACTIVE RELAY ANTENNA SYSTEM FOR ENHANCED 5G COMMUNICATIONS

FIG. 1



(57) Abstract: Examples disclosed herein relate to a high gain active relay antenna system and a wireless communication system having the relay antenna system. The system includes a base station, and a high gain active relay antenna having a first and second receive relay antennas, and a first and second transmit relay antennas. In various embodiments, the first receive relay antenna aligns a beam of signal from the base station, the first transmit relay antenna transmits the aligned beam of signal to a plurality of users in a user area, including non-line-of-sight (NLOS) area and/or line-of-sight (LOS) area, the second receive relay antenna receives a request for communication from a user of the plurality of users in the user area and the second transmit relay antenna transmits the request to the base station. In some embodiments, the system provides an adjustable power gain in the wireless signals.

[Continued on next page]

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RECONFIGURABLE HIGH GAIN ACTIVE RELAY ANTENNA SYSTEM FOR ENHANCED 5G COMMUNICATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/937,024 filed on November 18, 2019, which is incorporated by reference in its entirety for all purposes.

BACKGROUND

[0002] New generation wireless networks are increasingly becoming a necessity to accommodate user demands. Mobile data traffic continues to grow every year, challenging the wireless networks to provide greater speed, connect more devices, have lower latency, and transmit more and more data at once. Users now expect instant wireless connectivity regardless of the environment and circumstances, whether it is in an office building, a public space, an open preserve, or a vehicle. In response to these demands, a new wireless standard known as the fifth-generation new radio ("5G NR") has been designed for deployment in the near future. The fifth-generation ("5G") standards extend operations to millimeter wave bands, which covers frequencies beyond 6 gigahertz ("GHz"), and to planned 24 GHz, 26 GHz, 28 GHz, and 39 GHz, and up to 300 GHz, all over the world.

[0003] The millimeter wave spectrum provides narrow wavelengths in the range of approximately one to ten millimeters, which are susceptible to high atmospheric attenuation and have to operate over short ranges (about one kilometer or so). In millimeter wave systems, array antennas present several advantages by providing high gain, narrow beams, and beam steerability. For dense-scattering areas (e.g., street canyons, in buildings, and in shopping malls), due to multipath by shadowing and geographical obstructions, blind spots may exist. For remote areas, where the ranges are longer and sometimes extreme climatic conditions with heavy precipitation exist, operators are prevented from using large array antennas due to strong winds and storms. These and other challenges in providing millimeter wave wireless communications for 5G networks impose stringent requirements on system design, including the ability to generate desired beamforms at a controlled direction, while avoiding interference among the many signals and

structures of the surrounding environment. Compared to previously deployed relay scenarios, different millimeter wave band relay solutions would be required to meet the very different and varying operational requirements in terms of performance and cost. Therefore, improvements are needed in array antenna systems that are suitable for next generation wireless communication systems operating in the millimeter wave bands.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present application may be more fully appreciated in connection with the following detailed description taken in conjunction with the accompanying drawings, which may not be drawn to scale and in which like reference characters refer to like parts throughout, and in which:

[0005] FIG. 1 is a schematic diagram showing a reconfigurable high gain active relay antenna system in an example environment and configuration, according to various implementations of the subject technology;

[0006] FIG. 2 is a schematic diagram showing a reconfigurable high gain active relay antenna system in another example environment and configuration, according to various implementations of the subject technology;

[0007] FIG. 3 shows a 5G millimeter wave network environment where a reconfigurable high gain active relay system is deployed to enhance wireless coverage and performance in the network;

[0008] FIG. 4 is a schematic diagram of a high gain active relay antenna system having multiple service units, according to various implementations of the subject technology;

[0009] FIG. 5 illustrates a reconfigurable high gain active relay antenna system implementation in accordance with various examples;

[0010] FIG. 6 illustrates an example implementation of an active relay for use in a reconfigurable high gain active relay antenna system;

[0011] FIG. 7 illustrates another example implementation of an active relay for use in a reconfigurable high gain active relay antenna system;

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[0012] FIGs. 8A-8C illustrate other example implementations in which an active relay is split into two separate functionalities, which are provided by a separate receive architecture and transmit architecture, according to various implementations of the subject technology;

[0013] FIG. 9 illustrates a flow chart for configuration and monitoring of a high gain active relay antenna system, according to various implementations of the subject technology;

[0014] FIG. 10 illustrates a flow chart for activating beam switching in a high gain active relay antenna system, according to various implementations of the subject technology;

[0015] FIG. 11 illustrates a signal flow diagram of operation of a relay node in establishing communications, according to various implementations of the subject technology; and

[0016] FIG. 12 illustrates a flow chart for a method of initiating communication in a wireless system, in accordance with various implementations.

DETAILED DESCRIPTION

[0017] A reconfigurable high gain active relay antenna system is disclosed. The high gain active relay antenna system is suitable for many different millimeter wave applications, and can be deployed in a variety of different environments and configurations. Millimeter wave applications are those operating with frequency allocations between 24 GHz and 300 GHz or a portion thereof, including 5G applications in the 24, 26, 28, 39, and 60 GHz range, among others. In various examples, the reconfigurable high gain active relay antenna system provides a high gain amplification of a wireless signal to connect with wireless devices and user equipment ("UE") that are operational in complicated environments, including outdoors with obstructing structures (e.g., skyscrapers, buildings, trees, etc.), and non-line-of-sight areas and indoors with walls and constructs. The reconfigurable high gain active relay antenna system has an active amplification subsystem that is made of amplifiers in several stages, which may include low noise amplifier stages, gain-control attenuators, variable gain amplifier stages, and power amplifier stages. In various implementations, the reconfigurable high gain active relay antenna system also includes an IoT Telecommunication Management Network ("TMN") module with an independent TMN radio link for TMN functionalities and operation-related control functions and modules.

[0018] Optional functionalities, such as filtering, phase shifting, beam-steering, beamforming (e.g., performed by beamforming networks), and matching (e.g., performed by matching networks ("MNs"), which may employ step-adjustable attenuators) may also be implemented. In particular, for relay solutions involving higher layers, such as the Media Access Control ("MAC") layer, network layer processing, analog-to-digital conversion, digital-to-analog conversion, digital channelization filtering, and other physical layer functionalities may also be implemented. Frequency conversion operations in both up-conversion and down-conversion may also be implemented in the reconfigurable high gain active relay antenna system. The main applications supported by the disclosed relay antenna system include general wireless cellular communication network optimization in various scenarios (e.g., planned or temporary), which may include, for example, range extension of relay links, availability enhancements of radio links in extreme conditions, and all possible solutions for mission critical applications. The reconfigurable high gain active relay antenna system described hereinbelow provides a way for a network operator to provide ubiquitous coverage, and vastly improve coverage, at a low cost. The disclosed system can provide a basis for efficient network planning and optimization solutions in the context of network densification, which is one of the major 5G NR features.

[0019] It is appreciated that, in the following description, numerous specific details are set forth to provide a thorough understanding of the examples. However, it is appreciated that the examples may be practiced without limitation to these specific details. In other instances, well-known methods and structures may not be described in detail to avoid unnecessarily obscuring the description of the examples. Also, the examples may be used in combination with each other.

[0020] FIG. 1 illustrates a schematic diagram showing a reconfigurable high gain active relay antenna system 100 in an example environment and configuration. Reconfigurable high gain active relay antenna system 100, or simply referred to as "relay 100" for description purposes, is a robust and low-cost relay solution that is positioned as illustrated between a base station ("BS") 102, such as a next-generation NodeB (or gNB) and user equipment ("UE") 104 to optimize network coverage. Relay 100 can be a fixed or mobile relay positioned in different elements (e.g., buildings, vehicles, lifters, airliners, etc.) across a network environment (e.g., remote areas, underground, off-shore, on the sea, etc.). In various examples, relay 100 can be used for wireless communications from the BS 102 to the UE 104, and vice-versa from the UE 104 to the BS 102. In either scenario,

relay 100 provides a high gain to compensate for any propagation loss that occurs within the environment, which can be as high as 110 to 130 decibels ("dB") in a 28 GHz 5G network, over a distance of about 150 to 300 meters ("m"), in a line-of-sight ("LOS") area or in a non-line-of-sight ("NLOS") area. The link from the BS 102 to the UE 104 is referred to herein as the downlink ("DL"), and involves a backhaul section from the BS 102 to the relay 100, and an access section from the relay 100 to the UE 104. The link from the UE 104 to the BS 102 is referred to herein as the uplink ("UL"), and involves an access section from the UE 104 to the relay 100, and a backhaul section from the relay 100 to the BS 102. Using a different terminology, the radio links between the BS 102 and the relay 100 (i.e. Relay Node "RN")) are referred to as "donor links", and the radio links between the relay 100 and the UE 104 are referred to as the "service links". Note that because the backhaul link (of the backhaul section) between the relay 100 and the BS 102 is a point-to-point link, the relay 100 can be implemented with high gain array antennas for a long distance. Service links are usually point-to-multiple points in a forward direction, and multiple points-to-point in a return direction and, consequently, wide-beam antennas are usually used and the distance is shorter.

[0021] As shown with the dotted arrows, the path between the BS 102 and the UE 104 is blocked by obstructing objects 106, which may include an infrastructure(s) (e.g., high rise buildings), vegetation, and so on. The BS 102, the relay 100, and the UE 104 are positioned in a large turning angle ABC ("∠ ABC") configuration. The positioning of the relay 100 in this configuration enables the BS 102 to provide wireless coverage to the UE 104 at a high gain and, therefore, achieve the desired performance and wireless experience for the users (i.e. at the UEs (e.g., UE 104)). In various examples, the relay 100 includes two pairs of antennas for data traffic: one antenna pair for the DL and another antenna pair for the UL. The DL antenna pair includes a DL receive ("Rx") antenna 108 to receive signals transmitted from the BS 102, and a DL transmit ("Tx") antenna 110 to relay (transmit) the signals to the UE 104 after power amplification of the signals by a DL active section 112 of the relay 100. The UL antenna pair includes a UL Rx antenna 114 to receive signals transmitted from the UE 104, and a UL Tx antenna 116 to relay (transmit) the signals to the BS 102 after power amplification of the signals by a UL link active section 118 of the relay 100. The antennas transmitting and receiving signals between the relay 100 and the UE 104 (i.e. the DL Tx 110 and the UL Rx antenna 114) are referred to as "access link antennas". Conversely, the antennas

transmitting and receiving signals between the relay 100 and the BS 102 (i.e. the DL Rx antenna 108 and the UL Tx antenna 116) are referred to as "backhaul link antennas".

[0022] An active relay is located between each pair of relay antennas (e.g., a DL active relay 112 is located between the DL Rx antenna 108 and the DL Tx antenna 110, and a UL active relay 118 is located between the UL Rx antenna 114 and the UL Tx antenna 116). The active relays (i.e., DL active relay 112 and UL active relay 118) are designed to provide a high power gain, which boosts a weak signal plagued by propagation loss from the receive antennas (i.e. DL Rx antenna 108 and UL Rx antenna 114) to a specific gain level to drive the transmit antenna (i.e., DL Tx antenna 110 and UL Tx antenna 116). The relay 100 also includes support mounts, such as mount 120, to serve as support members for the antennas (i.e., DL Tx antenna 110, UL Tx antenna 116, DL Rx antenna 108, and UL Rx antenna 114) and the active relays (i.e., DL active relay 112 and UL active relay 118) of the relay 100. In should be noted that, in one or more examples, the relay 100 may comprise more than two pairs of antennas as is shown in FIG. 1. For example, the relay 100 may comprise two pairs of DL antennas (with an active relay located between each pair of antennas) and two pairs of UL antennas (with an active relay located between each pair of antennas), as opposed to only one pair of DL antennas (i.e., DL Ex antenna 108 and DL Tx antenna 110) and one pair of UL antennas (i.e. UL Rx antenna 114 and UL Tx antenna 116) as is depicted in FIG. 1. In another example, the relay 100 may comprise one or more donor units with antennas for communication between the relay 100 and the BS 102, and one or more service units with antennas for communication between the relay 100 and UE 104.

[0023] Note that the terminology "downlink" and "uplink" is intuitive: downlink referring to communications from a BS tower positioned above the relay and UE, and uplink referring to communications from UE to the BS tower up above. Similarly, the terminology "donor" and "service" refers to how the wireless signals are conveyed in the wireless network. The wireless signals are transmitted from a BS tower (the donor) to serve its customers UE (the service). A donor unit interfaces with a BS to distribute the downlink signaling from the base station to one or more service units associated with UE.

[0024] In various implementations, the relay 100 also includes an IoT Telecommunication Management Network ("TMN") module 122 with an independent TMN radio link 124 for TMN functionalities and operation-related control functions and modules. These operation-related

control functions may include, for example, antenna orientation switching of the DL and UL Tx/Rx antennas, channelization configuration as part of the configuration/reconfiguration functions that are carried over the IoT TMN link 124, telemetry functions for monitoring, alarming and reporting conditions of the relay 100, controlling functions for the relay 100 (e.g., on/off, standby, protection, etc.), and simple network management protocol ("SNMP") functions for operation, administration and maintenance ("OAM") purposes, among others. The IoT TMN module 122, described in more detail herein below, may also interface with a multipoint control unit ("MCU"). It is appreciated that the IoT TMN link 124 is a high reliability link with low data rate and independent of the DL/UL traffic links to ensure full access to operability control of the relay 100. It is also appreciated that the IoT TMN link 124 is shown with the DL antennas 108-110 and the UL antennas 114 outside an enclosure 126 housing the active relays (i.e., DL active relay 112 and UL active relay 118) and the IoT TMN module 122. In other configurations, such as that shown in FIG. 2, the IoT TMN link 124 may be a part of the IoT TMN module 122 inside the enclosure 126.

[0025] The proposed architecture of the relay 100 is particularly suitable for millimeter wave relay applications, where the backhaul link is typically a point-to-point link and the access link is a point-to-multipoint link. Further, the architecture of the relay 100 allows for a separation between the access link antennas and the backhaul link antennas so that they are optimized in an independent way without any constraint from each other (e.g., the access link antennas may be designed for a wide and/or shaped coverage area to provide optimized connectivity with UE(s) (e.g., UE 104), while the backhaul link antennas can be implemented with high directivity designs with narrow beams to compensate for the high path loss in the millimeter wave band), thereby alleviating the interference caused by other cells within the network. The backhaul link antennas can be optimally pointed to the BS(s) (e.g., BS 102), and the access link antennas can be pointed to the coverage area of the UE(s) (e.g., UE 104) at the best orientation angles.

[0026] Note that for an access link antenna, its gain is reduced when it is designed to cover a wide area with a wide beam. In such circumstances, the coverage area will not be large with the limited beamforming gain for these types of access link antennas. The access link antennas can be designed to form shaped beams (e.g., beams with specific shapes to cover an area in which most of the subareas are covered and some of the areas can be masked without signals reached). This is a unique feature of the disclosed two-antenna architecture for the relay 100. Also note that an

active solution becomes necessary, and even indispensable, in millimeter wave wireless applications. The power amplification functionality provided by the active relays (e.g., DL active relay 112 and UL active relay 118) enables a power gain from some tens of dB up to over hundreds of dB to boost the relayed signal in both the downlink and uplink signals, thereby meeting the connectivity requirements in the access links.

[0027] In one example, illustrated in FIG. 2, a reconfigurable high gain active relay antenna system 200 (also referred to herein as "relay 200") is mounted on a mobile vehicle 202 between a BS (e.g., gNB) 204 and a UE 206. As shown with the dotted arrows, the path between the BS 204 and the UE 206 is blocked by obstructing objects 208, which may include an infrastructure(s) (e.g., high rise buildings), vegetation, and so on. The BS 204, the relay 200 and the UE 206 are positioned in a turning angle ∠ ABC configuration. The positioning of the relay 200 on the vehicle 202 in this configuration enables the BS 204 to provide wireless coverage to the UE 206 at a high gain and, therefore, achieve the desired performance and wireless experience for the users (i.e. at the UEs (e.g., UE 206)). As shown here, relay 200 has an IoT TMN link 210 inside enclosure 212 housing the active DL and UL relays 214 and 216. The DL and UL antennas 218-220 and 222-224 are externally attached to the enclosure 212. Note also that although a single UE 206 is shown, multiple UE may be served by the relay 200 to enhance their wireless coverage. The reconfigurability of the relay 200 enables a wireless network operator to configure and monitor the relay 200 before and during deployment to ensure optimal coverage and performance of the wireless network.

[0028] Attention is now directed at FIG. 3, which shows a 5G millimeter wave network environment where a reconfigurable high gain active relay system is deployed to enhance wireless coverage and performance in the network. 5G technology is driven by a number of specification requirements, including up to 100 Gbps data rate, which translates into a 10 to 100x improvement over 4G and 4.5G networks, 1-millisecond latency, 1000x bandwidth per unit area, up to 100x network connected devices per unit area (compared with 4G LTE), 99.999% availability, 100% coverage, 90% reduction in network energy usage, and up to 10-year battery life for low power IoT devices. Network environment 300 is a 5G wireless network leveraging both millimeter wave and "sub-6" GHz frequency bands to realize the full gamut of throughput, capacity, speeds, low latency and ubiquitous coverage promised by the 5G specifications. While the millimeter wave

frequency band supports high speeds, its limited range, high propagation losses, and susceptibility to atmospheric attenuation, makes it challenging to fully deploy a 5G wireless network in congested environments. A more feasible solution and compatible with latest industry standards uses the sub-6 GHz band to provide larger areas of coverage in these congested environments. As shown in network 300, a sub-6 GHz BS 302 covers a large area in the environment to reach massive multiple-input-multiple-output ("MIMO") antennas 304-306 that operate in millimeter wave with highly directional beams delivering high speeds, capacity and efficiency to multiple UE 308-312.

[0029] Wireless performance and coverage in the network environment 300 is optimized with the use of reconfigurable high gain relay antenna systems such as relay system 314 strategically positioned in locations in environment 300 that would benefit for a boost in the millimeter wave wireless signals. These locations may include stationary locations such as buildings (e.g., building 316), stadiums, walls, light poles, etc., or mobile locations in the network 300 (e.g., car 202). Use of the reconfigurable high gain relay antenna system 314 enables signals to reach both LOS and NLOS areas with a significant performance gain. The relay 314 is shown with a donor unit 318 for communication between the relay 314 and the massive MIMO antenna 306 and a service unit 320 for communication between the relay 314 and the various UE in network environment 300 (e.g., UE 308-312). Although a single donor unit 318 and a single service unit 320 are shown in relay 314, various implementations may include multiple donor and service units as desired. In some implementations, relay 400 is configured to incorporate one or more antennas at one or more of the service unit locations. In this way, the network design may desire a system having a single service unit and a single donor unit with the flexibility of placing the service unit in different locations. A variety of configurations are possible with such designs as described herein.

[0030] In another example, relay 314 has a single donor unit for communication with its nearest MIMO antenna and multiple service units configured to communicate in different directions with multiple UEs in different LOS and NLOS areas, such as illustrated in FIG. 4 with relay 400 with donor unit 402 in the back of relay 400 and service units 404-408 on different surfaces of relay 400. Relay 400 communicates with gNB 410 via both a data link and an IoT link. The IoT link, as described above, is used for configuration and monitoring of relay 400. Service units 404-408 are

used for communication between relay 400 and UE 412-418. The IoT TMN module in relay 400 enables remote access, configuration and periodic monitoring of the status of relay 400.

[0031] Attention is now directed to FIG. 5, which illustrates a reconfigurable high gain active relay antenna system 500 (also referred to herein as "relay 500") implementation in accordance with various examples. The relay 500 comprises a plurality of active relay stages such as a UL relay stage 502 and a DL relay stage 504 for the downlink. UL relay stage 502 provides a gain between a UL Rx antenna and a UL Tx antenna in service unit 530, and DL relay stage 504 provides a gain between a DL Rx antenna and a DL Tx antenna in donor unit 528. The relay 500 may also include other circuit components for a flexible configuration suitable for different 5G applications at different frequency bands, such as 28 GHz and others.

[0032] Included in the relay 500 is an autonomous direct current ("DC") power supply (not shown) and an IoT TMN module 506 having an external digital control interface, such as a serial peripheral interface ("SPI") bus 508. The IoT TMN module 506 also includes an IoT transceiver 510 connected in parallel with the SPI bus 508, both of which using a simple network management protocol ("SNMP") unit 512 with SNMP interfaces 514 and a Management Information Database ("MIB") 516 for operation, administration and maintenance ("OAM") purposes. The SPI interface may be used with an external multipoint control unit ("MCU") 518. Also in the IoT TMN module 506 are sensors 520, such as a temperature sensor to monitor the temperature of relay 500.

[0033] A suitable IoT solution supports OAM functions wirelessly with remote access of relay 500. In particular, these functions may include powering on/off, reconfiguring, status monitoring, alarming, reporting, as well as billing. A telemetry module 532 (which can be integrated with or coupled to IoT TMN module 506) implements the monitoring, alarming and reporting functions. These functions can all be provided via either an SPI interface or an IoT interface, or both for redundancy. Additional circuit components may be included in the relay 500 architecture as desired to boost the gain from a receive antenna to a transmit antenna. In various examples, the transmit and receive antennas in donor unit(s) and service unit(s) coupled to relay 500, may be optimally and separately designed as per the coverage requirements. A beamforming antenna design, for example, may be implemented and used in 5G applications without constraints, while achieving both high performance and low cost. The relay 500 provides an adjustable power gain, so that active relay solutions can be applied universally to almost any wireless communications

scenario, both indoors and outdoors. Further, in active relay solutions with separate antennas and transceivers, interference is mitigated, and sophisticated time division duplexing ("TDD") is not necessary.

[0034] In various examples, the transmit and receive antennas used with relay 500 for both downlink and uplink transmissions are reconfigurable antennas capable of having their frequency and radiation properties dynamically configured. The configuration of the antennas may take place upon placement of relay 500 in a wireless network or periodically upon request or as needed based on network, environmental and other monitoring conditions. The reconfigurable antennas may change their orientation (i.e., azimuth or elevation) with beam switching module 522 or apply beam steering with phase shifter 526. Further, a switched filter bank module 524 is used to configure the relay 500 for operation in different frequency bands as desired by network operators. An IoT control module 534, which may be integrated with or coupled to IoT TMN module 506, controls the operation of the beam switching module 522, phase shifter 526 and switched filter bank module 524. The control takes place via the high reliability, low data throughput IoT link between the IoT TMN module 506 and the BS served by relay 500.

[0035] The reconfigurable antennas may be array antennas designed for a specific application, environment (e.g., a city environment, a rural environment, etc.), and/or associated conditions (e.g., weather, population, etc.). In various examples, the antennas can be manufactured from metastructures, which are specially designed structures that manipulate electromagnetic signals to suite various applications. More specifically, metastructures are engineered, non- or semi-periodic structures that are spatially distributed to meet a specific phase and frequency distribution. A metastructure antenna can be designed with metastructure reflector elements that are very small relative to the wavelength of the wireless signals. The metastructure antennas are able to generate directed, narrow beams to improve wireless communications between UE and a BS serving the UE in a wireless network.

[0036] Each antenna can be made to be three-dimensionally ("3D") maneuverable in roll, pitch, and yaw by using a suitable mechanical structure. Note that the yaw rotation adjusts the antenna in azimuth, the pitch rotation adjusts the antenna in elevation, and the roll rotation can be used to adjust the antenna to operate at a specific linear polarization (i.e. horizontal and/or vertical polarization). The beam switching module 522 works to remotely adjust the orientation of the

antennas as needed. The maneuverable and reconfigurable design allows for the antennas to cover areas of different shapes and ranges with wide beams, while avoiding interferences. Compared to metallic parabolic antennas, phased array antennas, do not employ separate feed structures and, as such, are lighter and provide for better aerodynamics. In one or more examples, the feed networks for the reconfigurable antennas in donor unit 528 and service unit 530 are embedded in a phased array printed circuit board ("PCB").

[0037] FIG. 6 illustrates an example implementation of an active relay for use in a reconfigurable high gain active relay antenna system. The active relay 600 (also referred to herein as "relay 600") can be implemented as the UL relay 502 and/or the DL relay 504 in relay 500. The active relay 600 includes wideband stages, without passband filtering, because it is assumed that the use of phased array antennas can provide frequency selectivity. The stages in the active relay 600 include a low-noise amplifier ("LNA") stage having two LNAs (comprising LNA 602 and LNA 604) (used for amplifying the received signals without significantly degrading the signal-to-noise ratio), both of which are by-passable with a switch; a first linear amplifier ("LA") stage (comprising LA 606) and a second LA stage (comprising LA 608) (used for adjusting the signals to a desired input power level for the PA), both of which have a gain regulation feature; and a power amplifier ("PA") stage (comprising PA 610) (used for amplifying the signals for transmission). These amplification stages 602-610 are able to generate an adjustable power gain to boost wireless signals in a 5G wireless network and improve the overall coverage and network performance to the network users. It should be noted that, in one or more examples, the LNA stage of the active relay 600 may comprise a greater or fewer number of LNAs than as shown in FIG. 6. In addition, the active relay 600 may comprise a greater or fewer number of LA stages, and/or a greater number of PA stages than as shown in FIG. 6.

[0038] Another example implementation of an active relay architecture is shown in FIG. 7, which shows an active relay architecture 700 (also referred to herein as "relay 700") that may be suitable for both transmit and receive antennas. The active relay architecture 700 includes an LNA stage comprising switchable LNAs 702, 704, 706, 708 (used to amplify the received signals without significantly degrading the signal-to-noise ratio), a first step-adjustable attenuation stage 710 (used to adjust the signals to a desired input power level for the PA), a PA stage 712 (used to amplify the signals for transmission), and a second step-adjustable attenuation stage 714 (used for

impedance matching the signals with the transmit antenna). Similar to active relay architecture 600 in FIG. 6, active relay architecture 700 also provides an adjustable power gain to boost wireless signals and optimize the performance in a 5G wireless network. In one or more examples, the LNA stage of the active relay architecture 700 may comprise a greater or fewer number of LNAs than as shown in FIG. 7. In addition, the active relay architecture 700 may comprise a greater number of PA stages than as shown in FIG. 7. Also, the active relay architecture 700 may or may not comprise the first step-adjustable attenuation stage 710 and/or the second step-adjustable attenuation stage 714 as is shown in FIG. 7.

[0039] These various stages can be implemented with radio frequency ("RF") amplifier parts designed for high performance and low cost for millimeter wave bands, including 28 GHz and 60 GHz. Using such an active signal processing architecture, requirements on array antennas and their associated mechanical supporting devices are relaxed and simplified. In certain circumstances, for example, for deployments in remote windy sites, array antennas with compact form factors could be more advantageous to employ than a larger array antenna. In considering the installation, maintenance, and system reliability, the proposed solutions employing compact array antennas would be preferable over the use of large array antennas.

[0040] As modularity is another feature that the example implementation addresses with considerations in system architecture, the proposed system configurations are based on semi-opened modules, separating the receive and transmit antennas, thereby allowing the insertion of filtering, frequency conversion, and digital signal generation and processing. The proposed modular subsystems are provided with interfaces for a digital control and bus with register access, an autonomous power supply, and possibly wireless modules with remote connectivity for system configuration, calibration, monitoring, and updating.

[0041] In particular, another example implementation is to split the active relay architecture into two separate functionalities, which are provided by a separate receive architecture and transmit architecture, as is shown in FIGs. 8A, 8B, and 8C. In particular, FIG. 8A shows the receive architecture 800, FIG. 8B shows the transmit architecture 802, and FIG. 8C shows the combination architecture 804 comprising the receive architecture 800 of FIG. 8A combined with the transmit architecture 802 of FIG. 8B, along with additional optional functionalities. Several advantages of this architectural arrangement are that the architecture allows for more flexible implementations

and applications. One of the advantages of the architecture is in design consideration, where the transmit architecture 802 (comprising a second LA stage and a PA) is designed with thermal precautions as it works in a higher regime of power handling, whereas the receive architecture 800 (having an LNA stage comprising two switchable LNAs, and a first LA stage) is designed in a small signal regime and, thus, a low noise design methodology is applied. A further advantage of the architecture is that the transmit architecture 802 provides for high flexibility to meet various and differing system level requirements for different applications. For example, frequency filtering and converting, digital processing, L2 switching, L3 routing, and/or etc. can all be accommodated as depicted by the functional block located between the receive and transmit antennas, as shown in architecture 804 of FIG. 8C.

[0042] In other system configurations, beam steering can be supported, and the proposed solutions consist of phase shifters and feed networks in the front-end configurations. One of the proposed features is automatic gain control ("AGC") capability based on assessments of the link status, such as, for example, received signal strength indicator ("RSSI") or more collaborated system procedures including link quality monitoring and control functions. The AGC function is also separated and distributed to separate transmit and receive sections, so that the FWD link and RTN links are controlled and maintained independently.

[0043] Attention is now directed to FIG. 9, which illustrates a flow chart for configuration and monitoring of a high gain active relay antenna system in accordance with various examples. First, a reconfigurable high gain relay antenna system is placed in the wireless network environment (900). The relay's placement takes into consideration where the blind spots in a coverage area are identified. When a relay node is needed, the main reason is for filling one or several blind spots in the coverage area. The blind spots are to be characterized in a formatted data, so that a suitable tool can handle them efficiently. These data can include 3D coordinates of the centers and ranges, shapes, etc., of the blind spots. Placement of the relay node can also include determining the number, locations, and antenna angles that will be used to optimize the coverage provided by the relay, by feeling the identified blind spots. In some implementations, a Light Detection and Ranging ("lidar") scanning and AI-based deployment tool can be performed to efficiently plan, install, test and validate large scale relay node deployment. In some aspects, a laser range finder and a laser angle finder may be used for the lidar scanning. Placement of the relay node may also

consider a path loss for a link to the relay. For example, the path loss in the field can be measured to prepare the complete data that may include all the real path losses for all the links. A link budget analysis is also performed to validate the relay node parameters at set-up and placement.

[0044] Next, an IoT link is established with the BS communicating with the relay (904). An initial IoT test is conducted between the BS and the relay. Once communication is established, the relay is remotely accessed through the IoT link for configuration (906). The configuration may include, for example, setting up the orientation and beam steering angles of the DL and UL antennas in the donor and service units, respectively, as well as setting the frequency band in the switched filter bank for operation of the relay in the wireless network. Once the relay is configured and ready for operation, the relay is periodically monitored through the IoT link to ensure it is operating as expected and to reconfigure it as needed (908).

[0045] FIG. 10 illustrates a flow chart for activating beam switching in a high gain active relay antenna system. First, the relay receives a control signal in the IoT link from a network operator (1000). If the relay decides to send a message to network (1002), the relay responds to the network accordingly (1004). Otherwise, if the control signal indicates that the relay antennas are to have its orientation configured, beam switching of the antennas is activated (1006). Beam switching may be implemented by measuring the strength of a signal received from the BS as the beams' orientation are adjusted. If the signal strength is above a given threshold (1008), the relay is in the right configuration and the beam is locked to the BS (1010). If not, the beam switching process continues by adjusting the beam orientation (1012) and troubleshooting as needed (1014).

[0046] Another option for beam management (beam alignment and handover) is to utilize 5G NR network signaling and control signals, which is shown in the present invention. A new system procedure is based on SSB/PRACH preamble detection via links with gNB and UE with an active relay node, with a support of handover. The proposed solution of beam management with a RN (relay node) includes receiving the SSB/PBCH (Synchronization Signal Block /Physical Layer Broadcast Channel) from 5G BS (Base Station, or gNB) side, and then to detect the RSS (Received Signal Strength) to align the BS-side beam at first. In a second step, the beam alignment between an RN and a UE includes receiving the PRACH preamble (Physical layer Random Access Channel) from 5G BS (Base Station, or gNB) side, and then to detect the RSS (Received Signal Strength) of PRACH preamble to align the UE-side beam. This includes a set of interactions

between a user device (UE) and a base station BS via RN, where the passive, non-generative (not decoding any bits), RN (Relay Node) acts as a relay unit for RACH procedure. In both SSB/PBCH and PRACH procedures, beam alignments are achieved BS and UE would not be aware of the presence of the RN.

[0047] In some embodiments, Received Signal Strength (RSS), or which can be denoted as Received Signal Strength Indicator (RSSI), is usually implemented in modern cellular system receivers. In wireless receivers, the RSS is a RFFE (Radio Frequency Front-End) feature and not a digital processing functionality, the proposed beam alignment procedure does not use any baseband digital processing. In some embodiments, the RSS can be used for estimating the received signal's strength as its power level, e.g., the cumulated energy in a predefined period of time.

[0048] When the first step of BS-RN beam alignment (based on SSB/PBCH) is achieved, the RN relays BS signals from BS to UE, trigging UE's reaction to SSB/PBCH. Upon receiving SSB/PBCH, UE starts the RACH (Random Access Channel) system procedure in order to access the BS, since by decoding the MIB data (from gNB) contained in SSB/PBCH, UE has obtained all the necessary information for starting PRACH. The RN then utilizes PRACH signal to get its UE-side beam aligned with the UE beam. Since both UL (Uplink) and DL (Downlink) are split into two sections: BS-RN, and RN-UE, and RN only performs analog signal processing (RSS detection), based on a generic codebook approach, and in addition, MAC layer processing is performed in gNB and UE in some embodiments. RN works with its own codebook for beam steering and selection. Referring to FIG. 11, the proposed beam alignment procedure ("Beam alignment procedure with relay") is given as below (here and throughout this document, gNB is used as a synonym of BS).

[0049] FIG. 11 is a signal flow diagram 1100 showing interactions of an end user, UE 1120, an access point (relay node), RN 1140, and a base station, gNB 1160. At time t_1, the gNB 1160 sends a synchronization signal block (SSB 1130) to potential UE 1120 (or a plurality of UEs 1120) that are searching for cells to join; however, the SSB 1130 with beam sweeping goes to the RN 1140 (not seen by the UE). In this situation, the UE 1120 is an idle state, such as RRC_IDLE in 5G, where RRC 1125 refers to "Radio Resource Control" signals transmitted over a radio network. The RN 1140 aligns its beam with the gNB 1160 based on detection of the strength of the signal,

RSS detection. As the gNB 1160 sweeps the beam, RN 1140 also sweeps its receive beam to align with the BS beam. In this example, at time t_2 the RN 1140 receives the SSB 1130 at various beam directions (including various angles), for example, from 8 different angles or directions (or 4 or 16 different angles or directions), and starts to sweep its RX beam (receiving beam) to match the gNB direction. The RN 1140 aligns with gNB 1160 and then confirms periodically, such as 10 ms, 20 ms or 40 ms, or any other suitable time intervals or schemes. At this time, gNB 1160, without receiving signal from the UE 1120 yet, will continue to sweep its beam, so that RN 1140 relays the gNB 1160 SSB signal to UE 1120 once every 20 ms (or 40 ms or 80 ms).

[0050] As shown in FIG. 11, at time t_3, the RN 1140 then relays the SSB 1130 (from gNB 1160) to the UE 1120 at time t_3. In some embodiments, the RN 1140 sweeps its beam toward the UE 1120. The RN 1140 relays the SSB 1130 periodically, such as 20 ms, 40 ms or 80 ms, while the UE 1120 sweeps its RX beam to search BS (gNB 1160). UE 1120 can, however, align its receive beam with RN 1140 based on the relayed SSB. At time t_4, the UE 1120 aligns its beam with the RN 1140 direction. At time t_5, based on received SSB/PBCH relayed by RN from BS, the UE 1120 decodes a Management Information Database (MIB) of gNB**,** to gain the necessary system information and UL synchronization. At time t_6, the UE 1120 initiates the RACH procedures by sending a PRACH preamble to the RN 1140. PRACH is Random Access Channel, a logical channel sent by a user device, e.g., the UE 1120 (User Equipment to get access to gNB's connection). RACH is logical channel name and when mapped to physical layer, it can be renamed then PRACH. At time t_7, the RN 1140 receives the PRACH preamble and detects the RSS_RACH. For example, when PRACH is transmitted and received by RN 1140, the RN 1140 receiver detects an RSS ramp up, which then estimates the RSSI (RSS Indicator). In some embodiments, the RN 1140 receives PRACH preamble (PRACH preamble is transmitted). In accordance with embodiments, the RN 1140 does not decode the context of the PRACH. The RN 1140 estimates its strength. The result is denoted RSS_RACH. The RN 1140 relays PRACH preambles to the UE 1120 so that UE 1120 can decode RACH in total. The RN 1140 aligns its beam with the UE 1120 at time t_8, based on received PRACH preamble. The gNB 1160 aligns its beam with the RN 1140 at time t_9 and transmits the physical downlink shared channel (PDSCH) signal, or PDBCH (Physical layer Broadcast Channel) at time t_{10}. At the same time, having time synchronized and obtained resource for using UL, UE 1120 can send PUSCH data to gNB 1160. In various

embodiments, upon reception of the PRACH preamble in UL, the RN 1140 aligns its beam with the UE 1120, and that the PRACH preamble sent by UE 1120 is relayed by RN 1140 to gNB 1160, which aligns with the beam of RN 1140.

[0051] In some embodiments, the procedure can be repeated as needed or configured for other UEs 1120 in different beam angular space and/or for UE handovers. For example, a handover may be trigged by an absence of RSS detection which is constantly monitored in the receivers. In some embodiments, RN 1140 can detect the loss of RSS from either gNB 1160 or UE 1120. Once a handover order is detected, the RN 1140 can begin detecting RSS of SSB/PBCH. This is because the BS has restarted beam alignment procedure by using SSB/PBCH procedure by restarting it. In some embodiments, the SSB/PBCH includes tentative sending by the gNB 1160 (or generally a BS), and receiving of SSB/PBCH by the RN 1140 if the beam is not aligned in the beginning, and as such the UE 1120 does not receive SSB/PBCH. In these instances, the UE 1120 will receive the SSB/PBCH only when the RN 1140 relays the SSB/PBCH to it. Once the SSB/PBCH procedure, and then RACH/PRACH procedure, are both completed, the handover process is complete.

[0052] FIG. 12 illustrates a flow chart for a method S1200 of initiating communication (with a user or a user device) in a wireless system, in accordance with various implementations. The method S1200 is an embodiment of an implementation of the signal flow illustrated in FIG. 11. The method S1200 includes sweeping a receive beam of a relay unit to measure received signal strength of the receive beam, at step S1210. The method S1200 includes, at step S1220, identifying a directed beam carrying a signal from a base station based on the received signal strength of the receive beam. The method S1200 includes locking a direction of the receive beam with a direction of the base station based on alignment with the directed beam, at step S1230. The method S1200 includes, at step S1240, sweeping a transmit beam of the relay unit to a user area, the transmit beam relaying the signal from the base station. In some embodiments, the user area includes a non-line-of-sight (NLOS) area. In some embodiments, the user area includes a LOS (line-of-sight) area far (too far) away from the base station BS and/or has a minimal signal strength (e.g., a low signal strength with a low enough signal that it may cause intermittent signal loss, or slightly above thereof). In some embodiments, the user area may include an area with a high density of users with a high congestion of communication traffic. The method S1200 includes, at step S1250,

receiving a request for access (PRACH) or request for establishing communication from the user device in the user area. The method S1200 includes, at step S1260, transmitting the request to the base station (relayed by RN). The method S1200 includes, at step S1270, facilitating a communication between the user device and the base station based on the request for communication or access. In various embodiments, the relay unit includes an uplink set of antennas (e.g., UL Rx antenna 114 and UL Tx antenna 116, UL antennas 222-224) for uplink to the base station and a downlink set of antennas for downlink to the user. In various embodiments, the uplink set of antennas includes a plurality of radiating elements (not shown).

[0053] In accordance with some embodiments, the method S1200 optionally includes adjusting a gain of the uplink set of antennas to form an uplink beam and/or adjusting a gain of the downlink set of array antennas to form a downlink beam, at step S1280. In accordance with some embodiments, the method S1200 optionally includes adjusting a phase of the uplink set of antennas to sweep at first multiple angles, and/or adjusting a phase of the downlink set of antennas to sweep at second multiple angles, at step S1290. In various embodiments, the uplink set of antennas includes a plurality of radiating elements arranged in a symmetric configuration. In various embodiments, the uplink set of antennas includes a plurality of radiating elements arranged in an asymmetric configuration.

[0054] In accordance with various embodiments, a wireless communication system is disclosed. The system includes a base station, and a high gain active relay antenna having first and second receive relay antennas, and first and second transmit relay antennas, wherein the first receive relay antenna aligns a beam of a signal from the base station and the first transmit relay antenna transmits the aligned beam of the signal to a plurality of users in a user area. and the second receive relay antenna receives a request for access or to establish communication from a user of the plurality of users in the user area and the second transmit relay antenna transmits the request to the base station. In various embodiments, the user area includes a non-line-of-sight (NLOS) area. In various embodiments, the user area includes a line-of-sight (LOS) area far away from the base station, or with a low signal. In various embodiments, the user area includes an area with a high density of users with a high congestion of communication traffic. In some embodiments, the NLOS conditions are meant to be similar to other radio propagation conditions including shadowing,

masking, climatic effects such as raining and snowing, and so on, where a relay device can be deployed at low cost for high availability of the communication services.

[0055] In various embodiments of the antenna system, the first and second relay receive antennas and the first and second transmit relay antennas include phase array antennas or metastructure-based antennas. In some embodiments, the first and second relay receive antennas and the first and second transmit relay antennas include a series of amplification stages comprising one or more of a low-noise amplifier (LNA) stage, a low-noise amplifier (PA) stage, or a linear amplifier stage. In various embodiments, the amplification stages further include a step-adjustable attenuation stage. In various embodiments, the first and second relay receive antennas and the first and second transmit relay antennas further include a phase shifter.

[0056] In various embodiments of the antenna system, the system further includes a power combining network coupled to the first and second receive relay antennas. In various embodiments of the antenna system, the system further includes a power dividing network coupled to the first and second transmit relay antennas. In some embodiments, at least one of the first or second relay receive antennas or the first or second transmit relay antennas includes a plurality of radiating elements arranged in an asymmetric configuration.

[0057] In accordance with various embodiments, a high gain active relay antenna system is disclosed. The system includes a phase array receive antenna configured to align a beam of a signal from a base station, the phase array receive antenna having a plurality of receive antenna elements, a phase array transmit antenna configured to transmit the beam of the signal to a plurality of user devices in a user area, the phase array transmit antenna having a plurality of transmit antenna elements, and a plurality of active relays configured to provide adjustable power gain to the beam of the signal received at the phase array receive antenna and transmitted by the phase array transmit antenna.

[0058] In various embodiments, the user area includes a non-line-of-sight (NLOS) area. In various embodiments, the user area includes a line-of-sight (LOS) area far away from the base station, or with a low signal. In various embodiments, the user area includes an area with a high density of users with a high congestion of communication traffic.

[0059] In accordance with various embodiments, the system further includes a power combining network coupled to the phase array receive antenna, and a power dividing network coupled to the phase array transmit antenna. In some embodiments, the plurality of active relays are coupled between the power combining network and the power dividing network and configured to provide the adjustable power gain to the beam of the signal. In various embodiments, the phase array receive antenna is a first phase array receive antenna and the phase array transmit antenna is a first phase array transmit antenna, and the system further includes a second phase array receive antenna configured to receive a request for communication from a user device of the plurality of user devices in the user area, and a second phase array transmit antenna configured to transmit the request to the base station.

[0060] In various embodiments, a plurality of phases at the plurality of receive antenna elements are aligned with a plurality of phases at the plurality of transmit antenna elements. In various embodiments, the phase array receive antenna and the phase array transmit antenna further include a phase shifter.

[0061] In accordance with various embodiments, a method for initiating communication with a user device in a wireless system is disclosed. The method includes sweeping a receive beam of a relay unit to measure received signal strength of the receive beam, identifying a directed beam carrying a signal from a base station based on the received signal strength of the receive beam, locking a direction of the receive beam with a direction of the base station based on alignment with the directed beam, sweeping a transmit beam of the relay unit to a user area, the transmit beam relaying the signal from the base station, transmitting the request to the base station, and facilitating a communication between the user device and the base station based on the request for communication.

[0062] In various embodiments, the user area includes a non-line-of-sight (NLOS) area. In various embodiments, the user area includes a line-of-sight (LOS) area far away from the base station, or with a low signal. In various embodiments, the user area includes an area with a high density of users with a high congestion of communication traffic.

[0063] In some embodiments, the relay unit includes an uplink set of antennas for uplink to the base station and a downlink set of antennas for downlink to the user device. In accordance with various embodiments, the method further includes adjusting a gain of the uplink set of antennas to

form an uplink beam and/or adjusting a gain of the downlink set of array antennas to form a downlink beam.

[0064] In accordance with various embodiments, the method further includes adjusting a phase of the uplink set of antennas to sweep at first multiple angles, and adjusting a phase of the downlink set of antennas to sweep at second multiple angles.

[0065] In various embodiments, the uplink set of antennas includes a plurality of radiating elements arranged in a symmetric configuration. In some embodiments, the uplink set of antennas includes a plurality of radiating elements arranged in an asymmetric configuration.

[0066] It is appreciated that the previous description of the disclosed examples is provided to enable any person skilled in the art to make or use the present disclosure. Various modifications to these examples will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other examples without departing from the spirit or scope of the disclosure. Thus, the present disclosure is not intended to be limited to the examples shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0067] As used herein, the phrase "at least one of" preceding a series of items, with the terms "and" or "or" to separate any of the items, modifies the list as a whole, rather than each member of the list (i.e., each item).The phrase "at least one of" does not require selection of at least one item; rather, the phrase allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, the phrases "at least one of A, B, and C" or "at least one of A, B, or C" each refer to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

[0068] Furthermore, to the extent that the term "include," "have," or the like is used in the description or the claims, such term is intended to be inclusive in a manner similar to the term "comprise" as "comprise" is interpreted when employed as a transitional word in a claim.

[0069] A reference to an element in the singular is not intended to mean "one and only one" unless specifically stated, but rather "one or more." The term "some" refers to one or more. Underlined and/or italicized headings and subheadings are used for convenience only, do not limit the subject technology, and are not referred to in connection with the interpretation of the

description of the subject technology. All structural and functional equivalents to the elements of the various configurations described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and intended to be encompassed by the subject technology. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the above description.

[0070] While this specification contains many specifics, these should not be construed as limitations on the scope of what may be claimed, but rather as descriptions of particular implementations of the subject matter. Certain features that are described in this specification in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable sub combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub combination or variation of a sub combination.

[0071] The subject matter of this specification has been described in terms of particular aspects, but other aspects can be implemented and are within the scope of the following claims. For example, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. The actions recited in the claims can be performed in a different order and still achieve desirable results. As one example, the processes depicted in the accompanying figures do not necessarily require the particular order shown, or sequential order, to achieve desirable results. Moreover, the separation of various system components in the aspects described above should not be understood as requiring such separation in all aspects, and it should be understood that the described program components and systems can generally be integrated together in a single hardware product or packaged into multiple hardware products. Other variations are within the scope of the following claim.

[0072] Where methods described above indicate certain events occurring in certain order, those of ordinary skill in the art having the benefit of this disclosure would recognize that the ordering

may be modified and that such modifications are in accordance with the variations of the present disclosure. Additionally, parts of methods may be performed concurrently in a parallel process when possible, as well as performed sequentially. In addition, more steps or less steps of the methods may be performed. Accordingly, examples are intended to exemplify alternatives, modifications, and equivalents that may fall within the scope of the claims.

WHAT IS CLAIMED IS:

1. A wireless communication system, comprising:

a base station; and

a high gain active relay antenna having first and second receive relay antennas, and first and second transmit relay antennas, wherein:

the first receive relay antenna aligns a beam of a signal from the base station and the first transmit relay antenna transmits the aligned beam of the signal to a plurality of users in a user area, and

the second receive relay antenna receives a request for communication from a user of the plurality of users in the user area and the second transmit relay antenna transmits the request to the base station.

2. The system of claim 1, wherein the first and second relay receive antennas and the first and second transmit relay antennas comprise phase array antennas or metastructure-based antennas.

3. The system of claim 1, wherein the first and second relay receive antennas and the first and second transmit relay antennas comprise a series of amplification stages comprising one or more of a low-noise amplifier (LNA) stage, a low-noise amplifier (PA) stage, or a linear amplifier stage.

4. The system of claim 3, wherein the amplification stages further comprise a step-adjustable attenuation stage.

5. The system of claim 3, wherein the first and second relay receive antennas and the first and second transmit relay antennas further comprise a phase shifter.

6. The system of claim 1, further comprising:

a power combining network coupled to the first and second receive relay antennas.

7. The system of claim 1, further comprising:

a power dividing network coupled to the first and second transmit relay antennas.

8. The system of claim 1, wherein the user area includes a non-line-of-sight (NLOS) area.

9. The system of claim 1, wherein the user area includes a LOS (line-of-sight) area far away from the base station or an area with a high density of users with a high congestion of communication traffic.

10. A high gain active relay antenna system, comprising:

a phase array receive antenna configured to align a beam of a signal from a base station, the phase array receive antenna having a plurality of receive antenna elements;

a phase array transmit antenna configured to transmit the beam of the signal to a plurality of user devices in a user area, the phase array transmit antenna having a plurality of transmit antenna elements; and

a plurality of active relays configured to provide adjustable power gain to the beam of the signal received at the phase array receive antenna and transmitted by the phase array transmit antenna.

11. The system of claim 10, further comprising:

a power combining network coupled to the phase array receive antenna; and

a power dividing network coupled to the phase array transmit antenna.

12. The system of claim 11, wherein the plurality of active relays are coupled between the power combining network and the power dividing network and configured to provide the adjustable power gain to the beam of the signal.

13. The system of claim 10, wherein the phase array receive antenna is a first phase array receive antenna and the phase array transmit antenna is a first phase array transmit antenna, the system further comprising:

a second phase array receive antenna configured to receive a request for communication from a user device of the plurality of user devices in the user area; and

a second phase array transmit antenna configured to transmit the request to the base station.

14. The system of claim 10, wherein a plurality of phases at the plurality of receive antenna elements are aligned with a plurality of phases at the plurality of transmit antenna elements.

15. The system of claim 10, wherein the phase array receive antenna and the phase array transmit antenna further comprise a phase shifter.

16. A method for initiating communication with a user device in a wireless system, comprising:

sweeping a receive beam of a relay unit to measure received signal strength of the receive beam;

identifying a directed beam carrying a signal from a base station based on the received signal strength of the receive beam;

locking a direction of the receive beam with a direction of the base station based on alignment with the directed beam;

sweeping a transmit beam of the relay unit to a user area, the transmit beam relaying the signal from the base station;

receiving a request for communication from the user device in the user area;

transmitting the request to the base station; and

facilitating a communication between the user device and the base station based on the request for communication.

17. The method of claim 16, wherein the relay unit comprises an uplink set of antennas for uplink to the base station and a downlink set of antennas for downlink to the user device.

18. The method of claim 17, further comprising:

adjusting a gain of the uplink set of antennas to form an uplink beam; and

adjusting a gain of the downlink set of antennas to form a downlink beam.

19. The method of claim 17, further comprising:

adjusting a phase of the uplink set of antennas to sweep at first multiple angles; and

adjusting a phase of the downlink set of antennas to sweep at second multiple angles.

20. The method of claim 17, wherein the user area includes a non-line-of-sight (NLOS) area.

126
114
116
UL Tx
UL
UL Rx
108
112
DL Rx
DL
DL Tx
118
122
110
124
TM N Lin k
IoT TMN Module
120
100
B: Reconfigurable High Gain Active Relay Antenna System
102
Obstructing Objects
106
104
A: BS
C: UE

FIG. 1

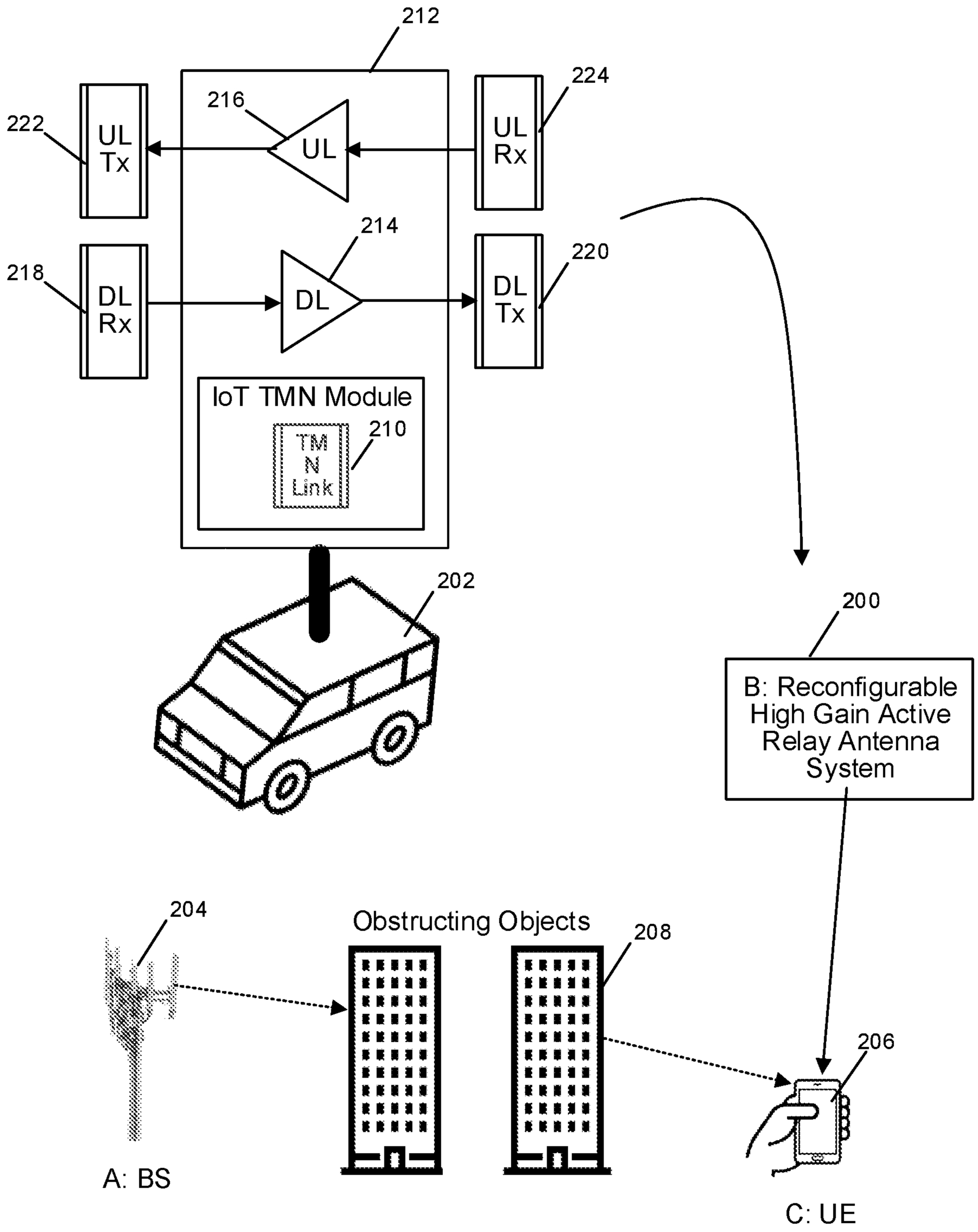

212
216
222
UL Tx
UL
224
UL Rx
214
218
DL Rx
DL
220
DL Tx
IoT TMN Module
210
TM N Link
202
200
B: Reconfigurable High Gain Active Relay Antenna System
204
Obstructing Objects
208
206
A: BS
C: UE

FIG. 2

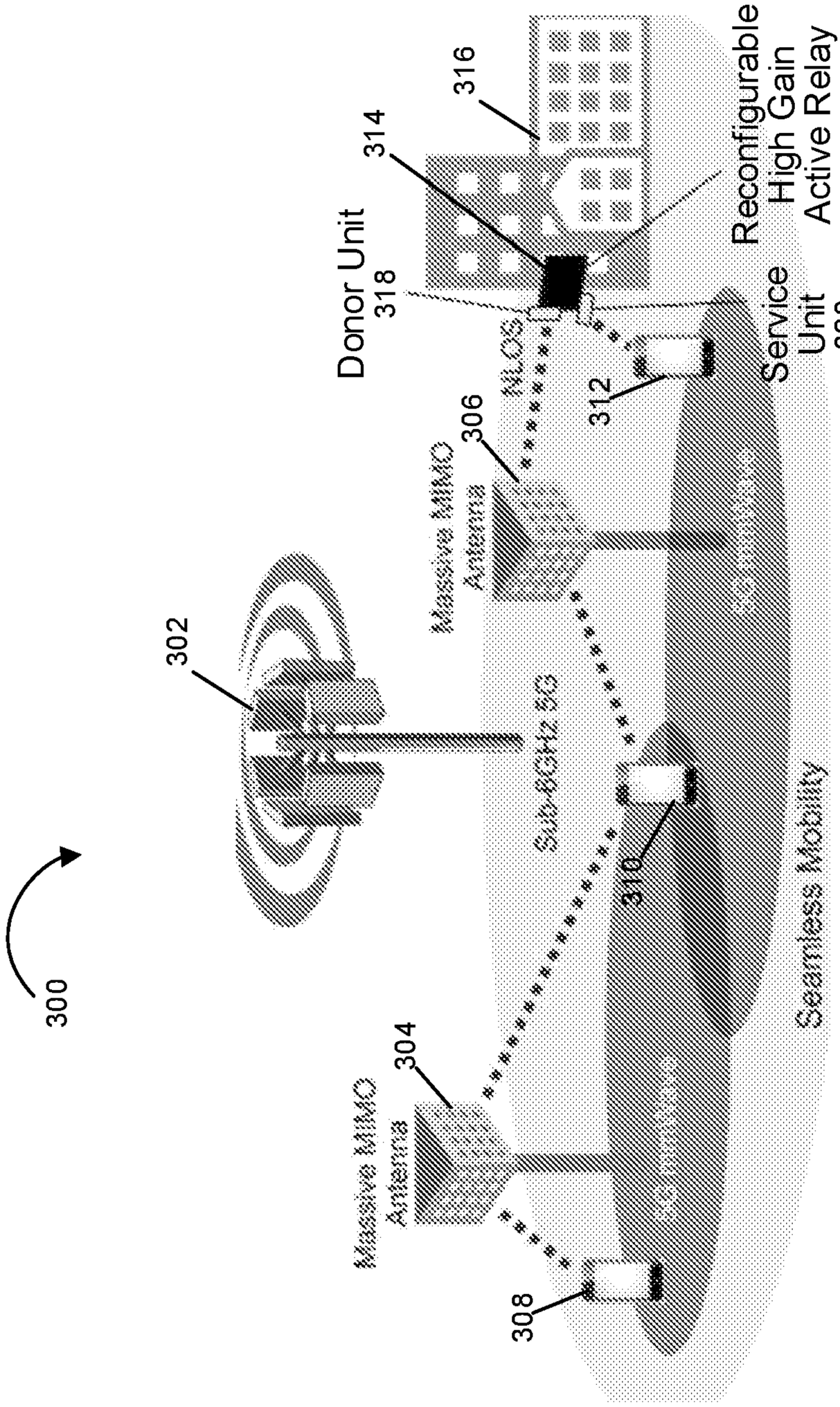

300
302
Massive MIMO Antenna
304
306
Sub-6GHz 5G
308
310
312
Seamless Mobility
Donor Unit
314
316
318
Reconfigurable High Gain Active Relay Service Unit
320

FIG. 3

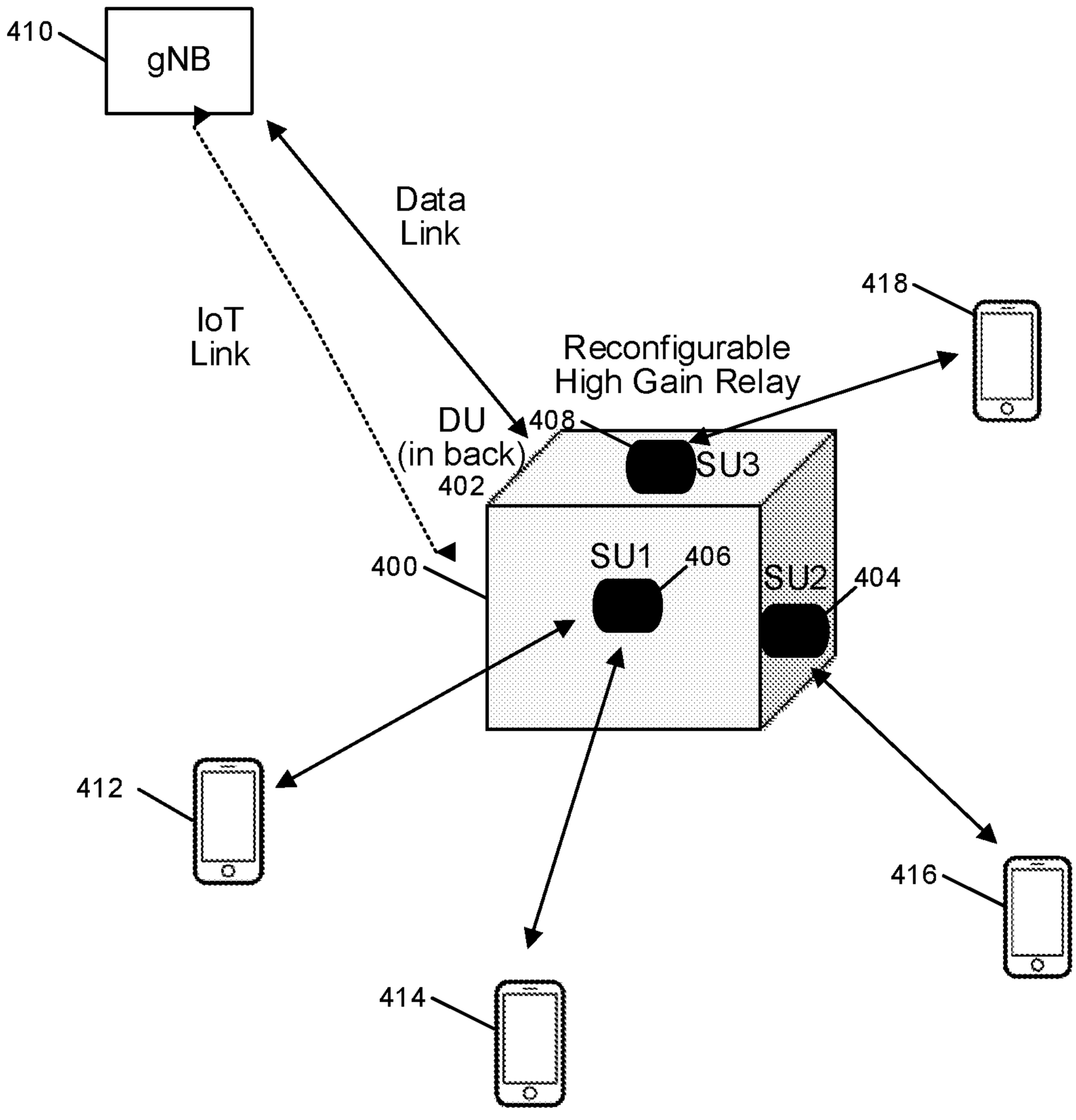

410
gNB
Data
Link
IoT
Link
418
Reconfigurable
High Gain Relay
DU
(in back)
402
408
SU3
SU1
406
SU2
404
400
412
414
416

FIG. 4

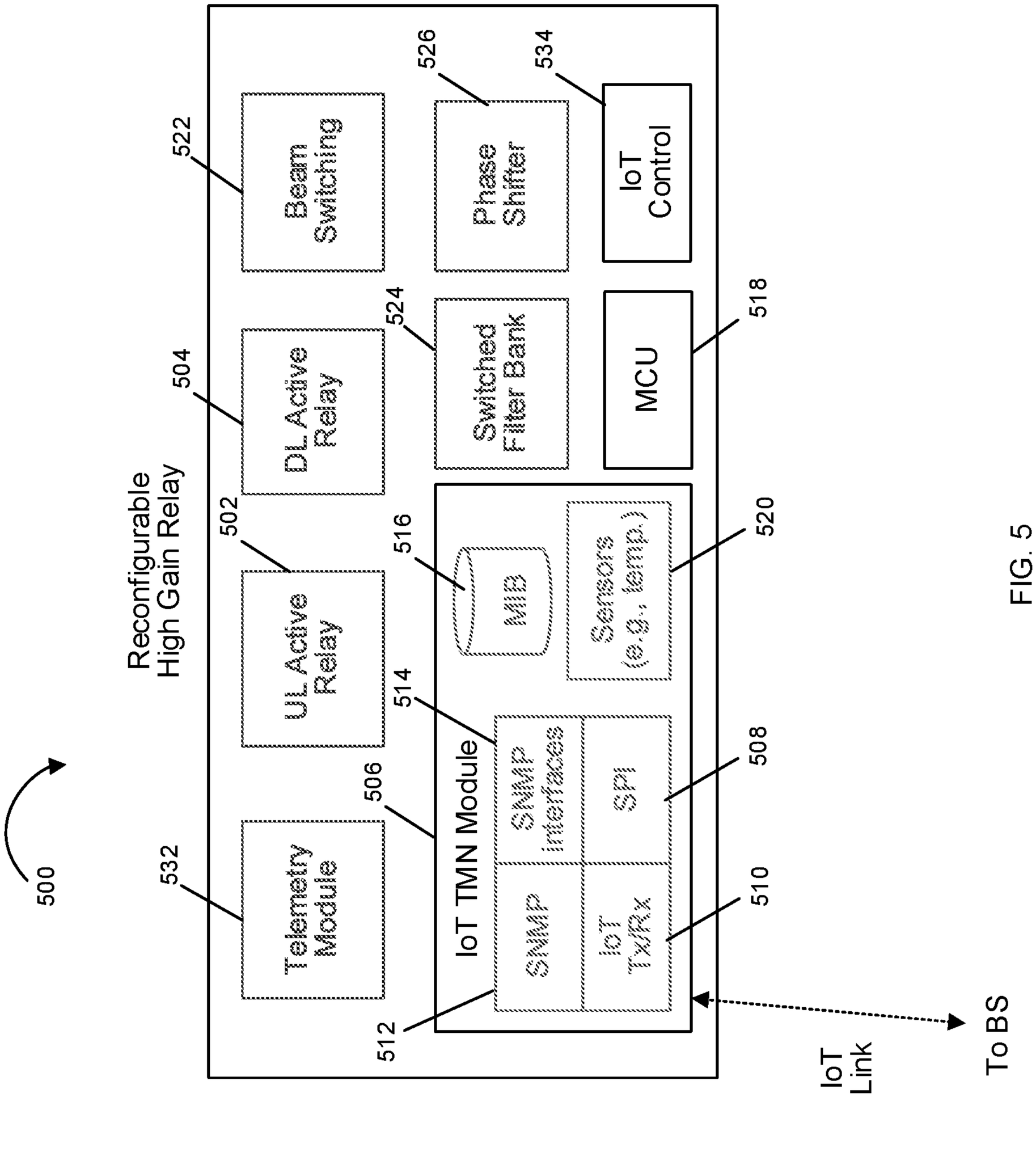

500
Reconfigurable
High Gain Relay
502
UL Active
Relay
504
DL Active
Relay
506
IoT TMN Module
508
SPI
510
IoT
TX/RX
512
SNMP
SNMP
interfaces
514
516
MIB
518
MCU
520
Sensors
(e.g., temp.)
522
Beam
Switching
524
Switched
Filter Bank
526
Phase
Shifter
532
Telemetry
Module
534
IoT
Control
IoT
Link
To BS

FIG. 5

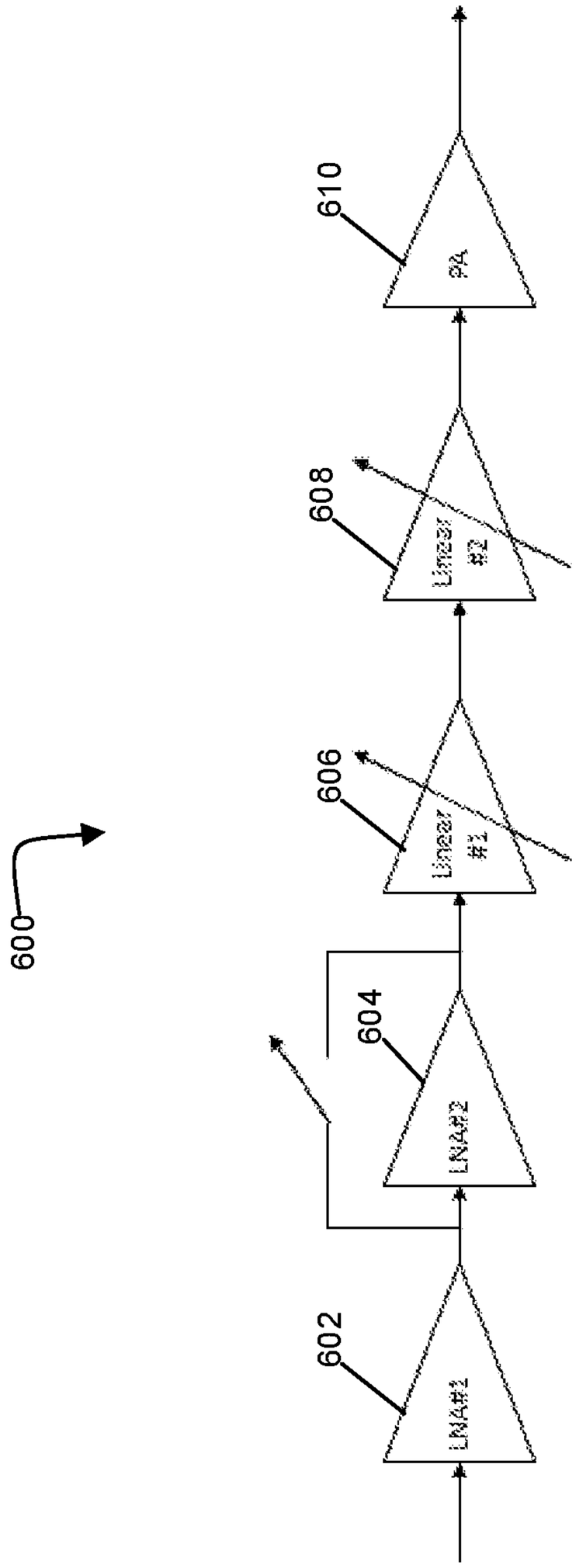


FIG. 6

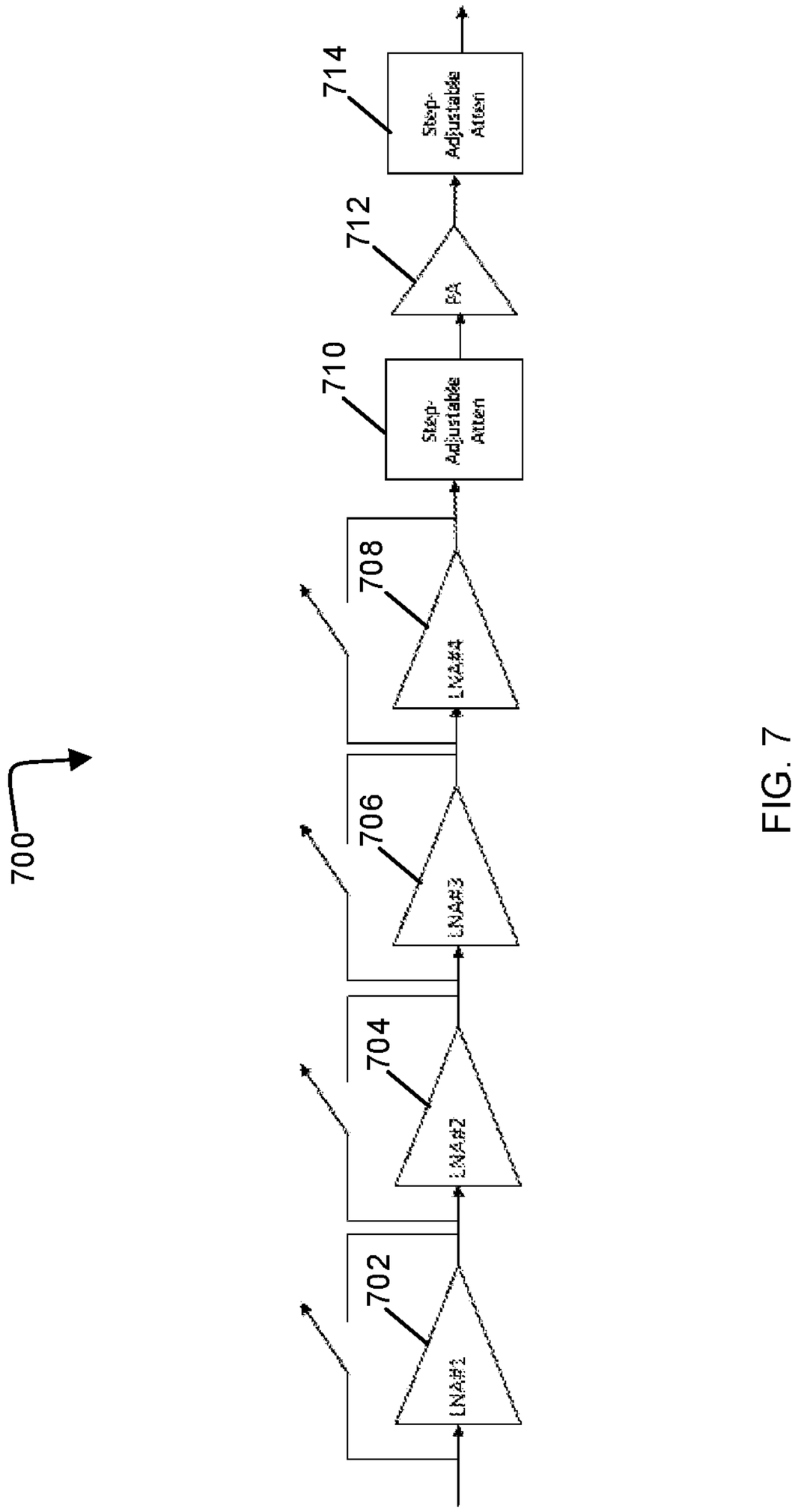

700
LNA#1
702
LNA#2
704
LNA#3
706
LNA#4
708
Step-Adjustable Atten
710
PA
712
Step-Adjustable Atten
714

FIG. 7

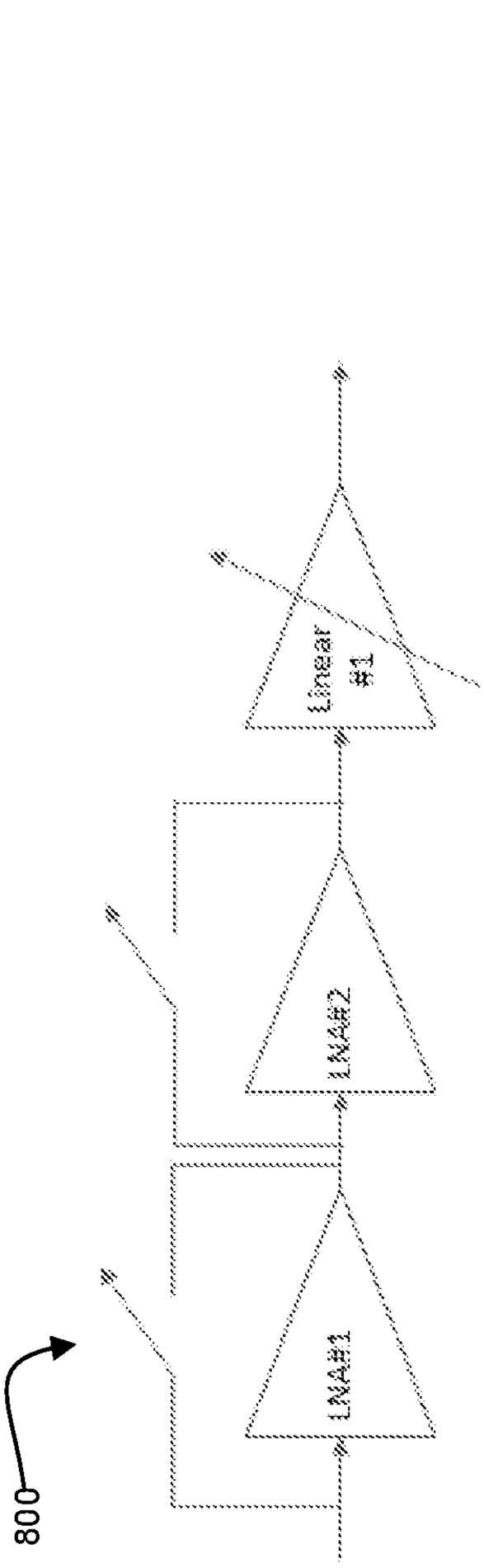


FIG. 8A

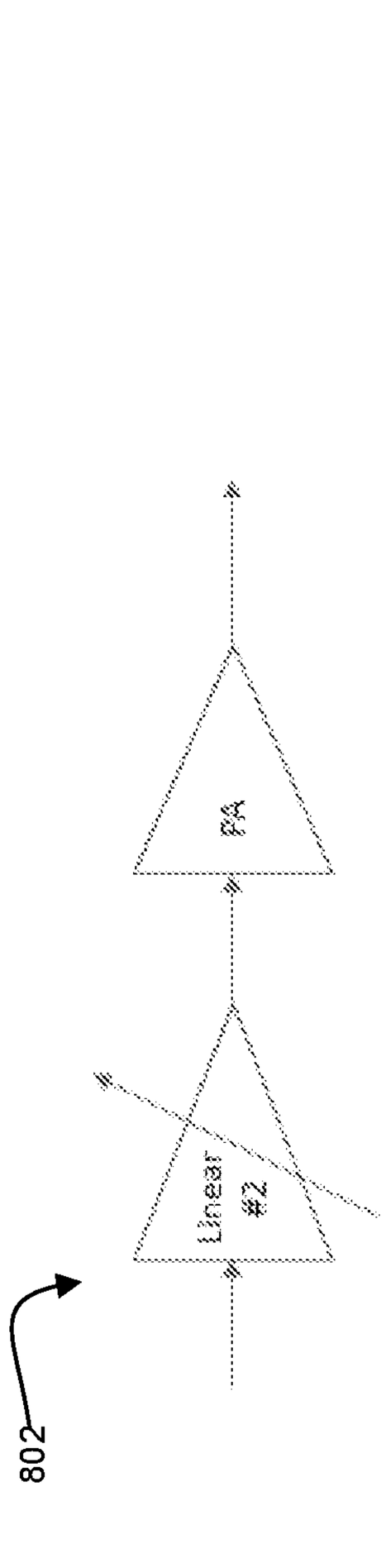


FIG. 8B

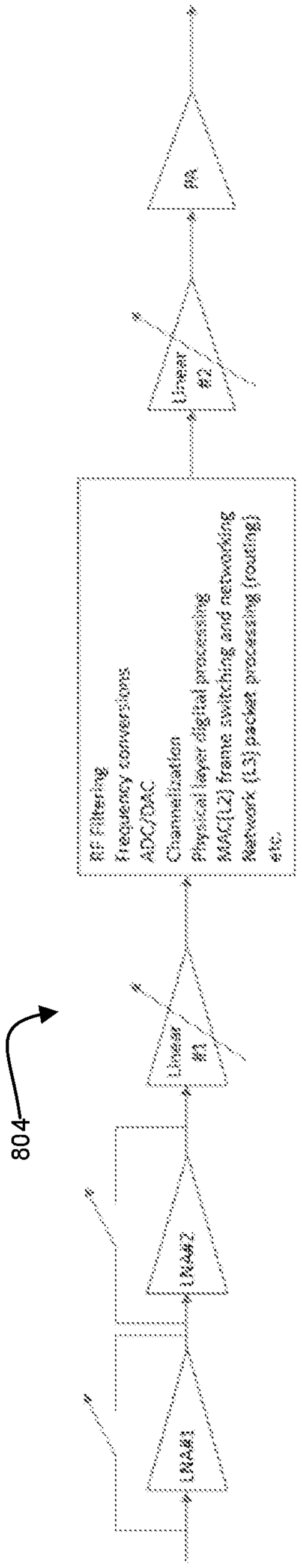


FIG. 8C

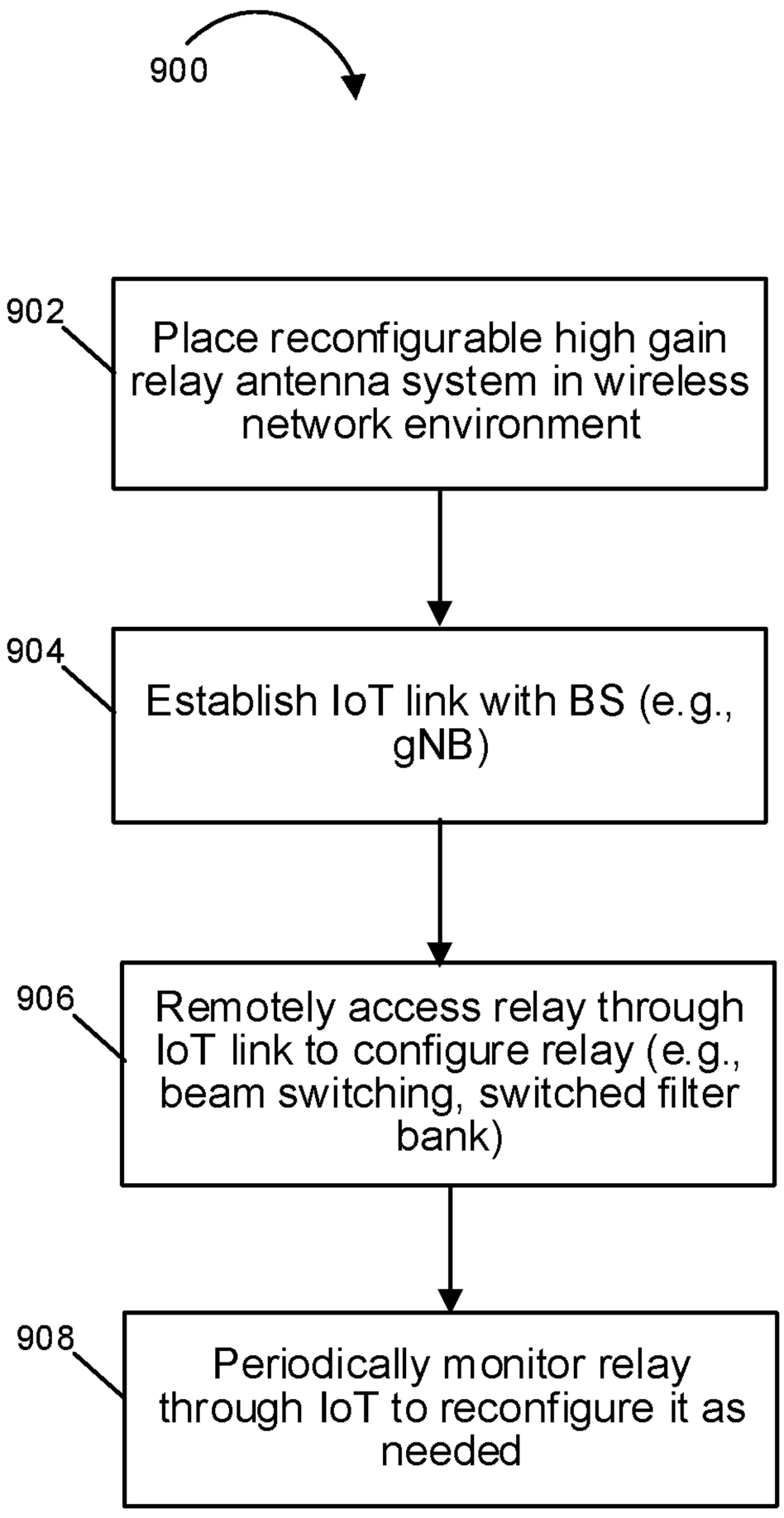

900
902
Place reconfigurable high gain relay antenna system in wireless network environment
904
Establish IoT link with BS (e.g., gNB)
906
Remotely access relay through IoT link to configure relay (e.g., beam switching, switched filter bank)
908
Periodically monitor relay through IoT to reconfigure it as needed

FIG. 9

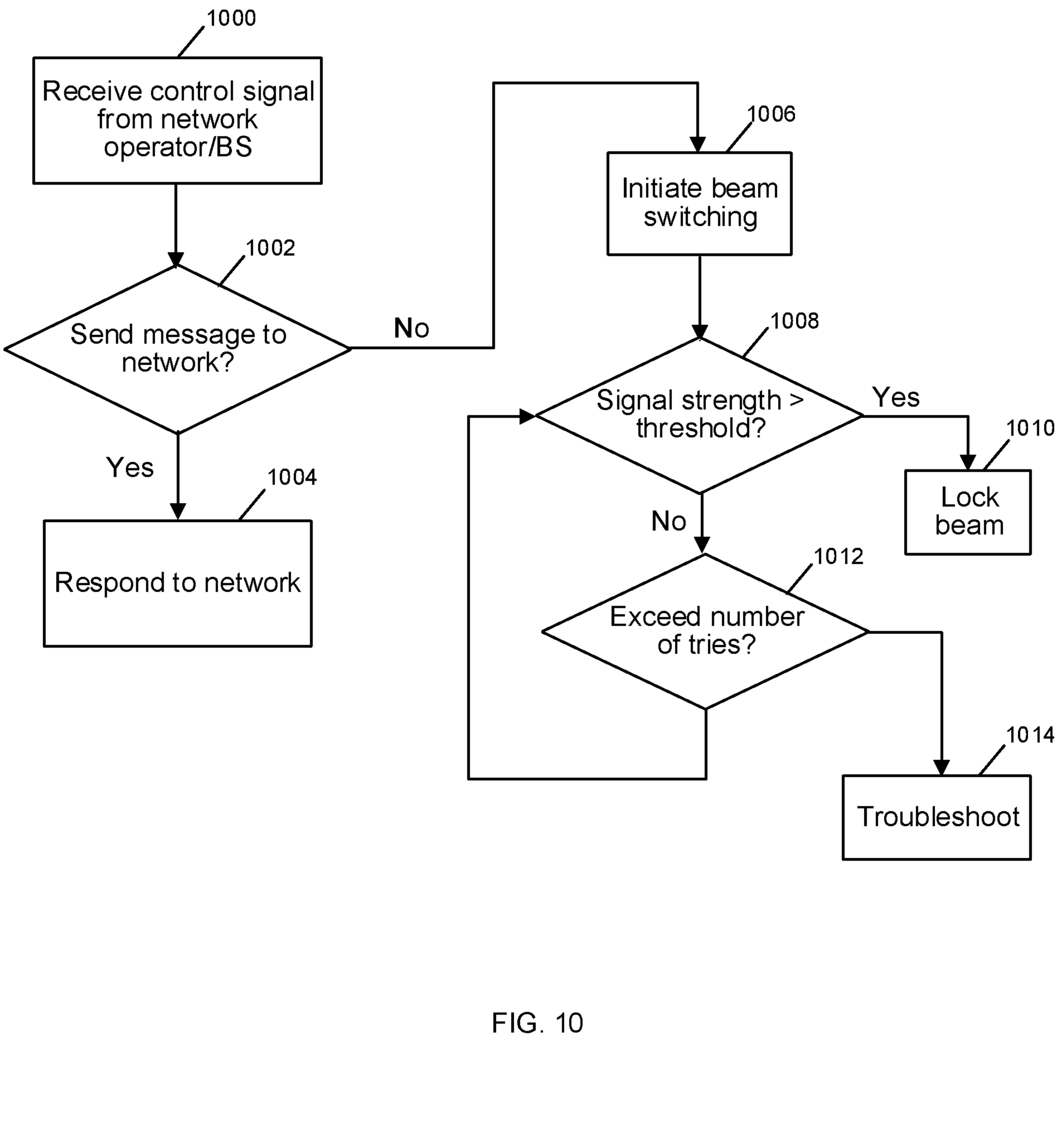

1000
Receive control signal from network operator/BS
1002
Send message to network?
No
Yes
1004
Respond to network
1006
Initiate beam switching
1008
Signal strength > threshold?
Yes
No
1010
Lock beam
1012
Exceed number of tries?
1014
Troubleshoot

FIG. 10

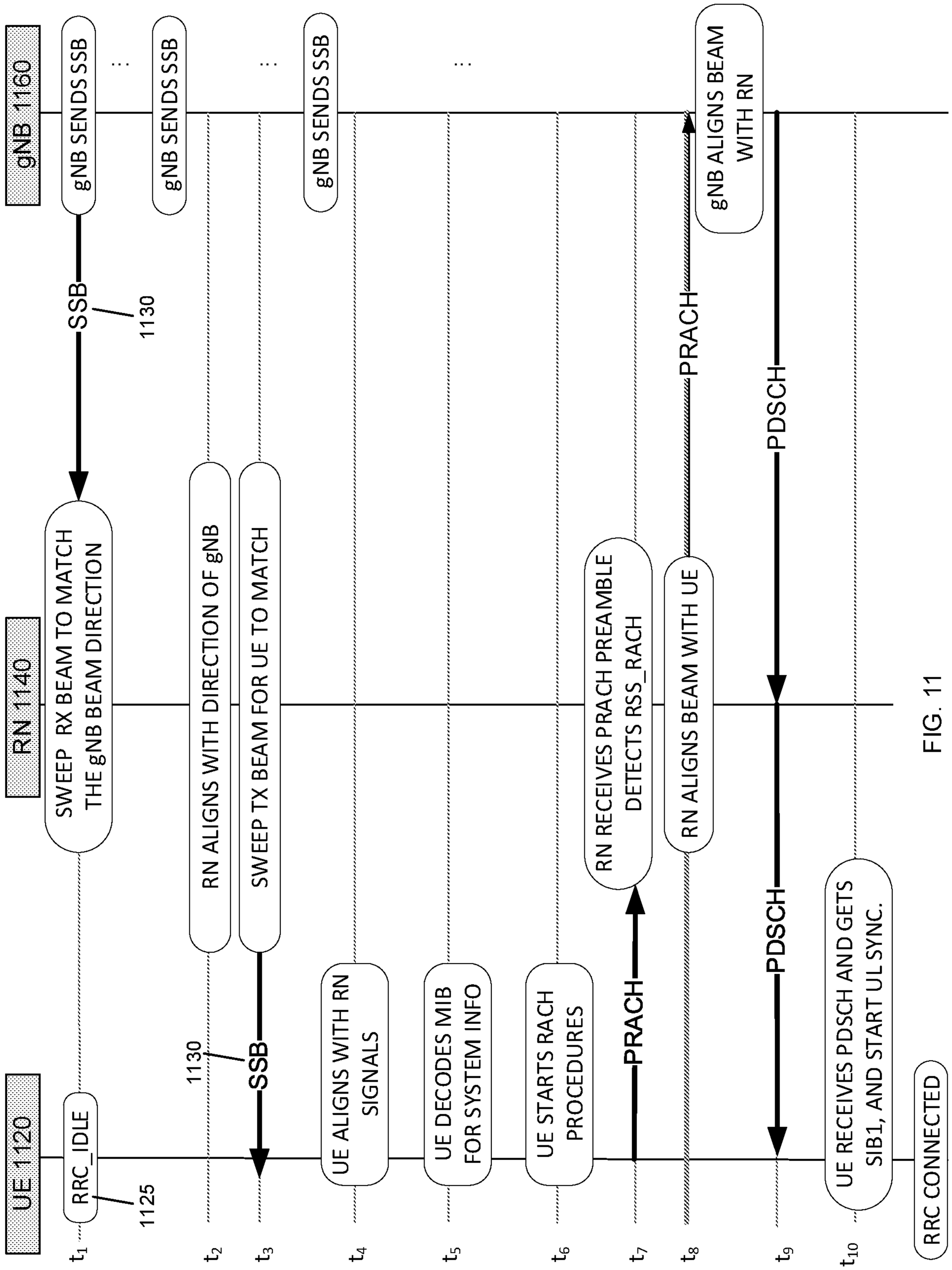

gNB 1160
gNB SENDS SSB
gNB SENDS SSB
gNB SENDS SSB
gNB ALIGNS BEAM WITH RN
SSB
1130
PRACH
PDSCH
RN 1140
SWEEP RX BEAM TO MATCH THE gNB BEAM DIRECTION
RN ALIGNS WITH DIRECTION OF gNB
SWEEP TX BEAM FOR UE TO MATCH
RN ALIGNS WITH SSB SIGNALS
RN DECODES MIB FOR SYSTEM INFO
RN STARTS RACH PROCEDURES
RN RECEIVES PRACH PREAMBLE AND DETECTS RSS_RACH
RN ALIGNS BEAM WITH UE
PDSCH
RN RECEIVES PDSCH AND GETS SIB1, AND START UL SYNC.
1100
UE 1120
RRC_IDLE
1125
1130
SSB
UE ALIGNS WITH SSB SIGNALS
UE DECODES MIB FOR SYSTEM INFO
UE STARTS RACH PROCEDURES
PRACH
UE RECEIVES PDSCH AND SIB1, AND START UL SYNC.
RRC CONNECTED
t1
t2
t3
t4
t5
t6
t7
t8
t9
t10

FIG. 11

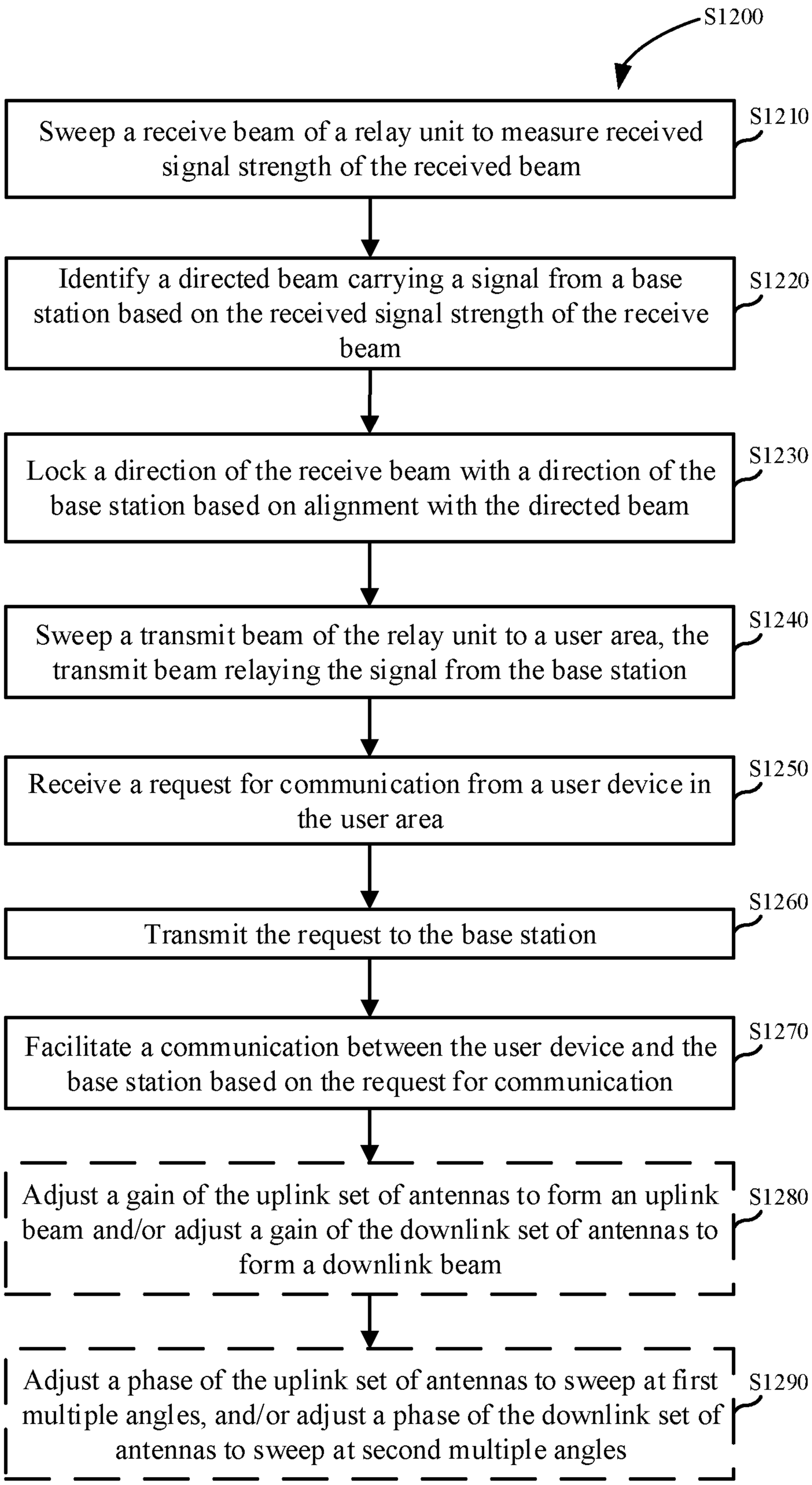

S1200
Sweep a receive beam of a relay unit to measure received signal strength of the received beam
S1210
Identify a directed beam carrying a signal from a base station based on the received signal strength of the receive beam
S1220
Lock a direction of the receive beam with a direction of the base station based on alignment with the directed beam
S1230
Sweep a transmit beam of the relay unit to a user area, the transmit beam relaying the signal from the base station
S1240
Receive a request for communication from a user device in the user area
S1250
Transmit the request to the base station
S1260
Facilitate a communication between the user device and the base station based on the request for communication
S1270
Adjust a gain of the uplink set of antennas to form an uplink beam and/or adjust a gain of the downlink set of antennas to form a downlink beam
S1280
Adjust a phase of the uplink set of antennas to sweep at first multiple angles, and/or adjust a phase of the downlink set of antennas to sweep at second multiple angles
S1290

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/61119

A. CLASSIFICATION OF SUBJECT MATTER

IPC - H01Q 25/00; H04B 7/204; H04B 7/02; H01Q 3/26 (2020.01)

CPC - H04B 7/204; H04B 7/2041; H01Q 3/26; H01Q 3/2664; H01Q 25/00; H01Q 25/007; H01Q 3/40

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)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 2017/0257155 A1 (Liang et al.) 07 September 2017 (07.09.2017); entire document, especially, abstract, FIG.1, 3, para [0015], [0027], [0028], [0031]-[0034], [0037], [0039], [0049], [0074],[0075], [0078], [0079]	1-3, 8-10,13,14 ------ 4-7, 11,12,15
Y	US 2004/0224629 A1 (Moon) 11 November 2004 (11.11.2004); entire document, especially, abstract, FIG.1, para [0028], [0038], [0040], [0046]	4-7, 11,12,15
A	US 2004/0166802 A1 (McKay SR. et al.) 26 August 2004 (26.08.2004); entire document,	1-15
A	US 2018/0206132 A1 (Samsung Electronics Co., Ltd.) 19 July 2018 (19.07.2018); entire document	1-15
A	US 2005/0075139 A1 (Shapira) 07 April 2005 (07.04.2005); entire document	1-15
A	US 2011/0142104 A1 (Coldret et al.) 16 June 2011 (16.06.2011); entire document, especially, abstract, para [0015], [0062], [0079], [0092], [0098]	1-15

☐ Further documents are listed in the continuation of Box C. ☐ 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
"D" document cited by the applicant in the international application
"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
12 January 2021	APR 01 2021
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/61119

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-15 drawn to a high gain active relay antenna system.

Group II: Claims 16-20 drawn to a method for initiating communication with a user device in a wireless system.

--continued on Supplemental Page---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-15

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US 20/61119

Continuation of Box No. III - Lack of Unity -

The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

Special technical features

Group I requires a plurality of active relays configured to provide adjustable power gain to the beam of the signal received at the phase array receive antenna and transmitted by the phase array transmit antenna, not found in the other group.

Group II requires sweeping a receive beam of a relay unit to measure received signal strength of the receive beam, not found in the other group.

Shared technical features:

The only technical features shared by Groups I and II that would otherwise unify the groups are a wireless system; a base station; a user device; a relay unit;a lign a beam of a signal from the base station; receives a request for communication from a user device in the user area; transmitting the request to the base station.

However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by US 2011/0142104 A1 to Coldret et al. (hereinafter 'Coldret') published on 16 June 2011 (16.01.2011). Coldret discloses a wireless system (para [0062] " The system comprises a base station repeater station pair, comprising a base station 1 and a repeater station 2.");

a base station (base station 1, para [0062] " The system comprises a base station repeater station pair, comprising a base station 1 and a repeater station 2.");

a user device (para [0092] "Furthermore, the broadcast antennas 29 on the forward side of the repeater station 22 (the antennas communicating with the users) do not necessarily need to be of the same polarisation.");

a relay unit (repeater station 2, para [0062] " The system comprises a base station repeater station pair, comprising a base station 1 and a repeater station 2.");

align a beam of a signal from the base station (para [0015] " In the case where the base station can control the relative phases and amplitudes of the signals transmitted from the broadcast antennas on the repeater station, the pair may be arranged such that the combined beam may be steered and/or shaped by varying the relative phase and/or amplitude of the signals transmitted over the link.") receives a request for communication from a user device in the user area (para [0079] "If the line of sight channel for each polarisation introduces an unknown time-invariant phase and/or amplitude change and thus the resulting beam form at the repeater station broadcast antennas 9 becomes unknown, then the base station can use the strategy of slowly varying the beamformer weights from (6) above over a longer timescale at the same time log statistics of users' signal quality reports. Then the system can use the collected statistics to choose the beam weights that according to some desired criterion yield the best performance for a particular time frame and adjust the weights for the next time frame, and so on in a self-tuning fashion.", para [0098] "FIGS.1 and 3 show downlink radio chains, corresponding uplink radio chains can be present, assuming that the repeater station provides duplex functionality. In duplex operation, uplink signals are routed from the repeater station broadcast antennas, via repeater station uplink amplifiers, to the transfer antennas for transmission to the base station. Duplex functionality, a well-known concept often implemented using duplex filters, for a frequency-division duplex (FDD) system, or switches, for a time-division duplex (TDD) system, separates downlink and uplink signals such that they are routed via the proper duplex radio chain for amplification.");

transmitting the request to the base station (para [0079] "If the line of sight channel for each polarisation introduces an unknown time-invariant phase and/or amplitude change and thus the resulting beam form at the repeater station broadcast antennas 9 becomes unknown, then the base station can use the strategy of slowly varying the beamformer weights from (6) above over a longer timescale at the same time log statistics of users' signal quality reports. Then the system can use the collected statistics to choose the beam weights that according to some desired criterion yield the best performance for a particular time frame and adjust the weights for the next time frame, and so on in a self-tuning fashion.", para [0098] "FIGS.1 and 3 show downlink radio chains, corresponding uplink radio chains can be present, assuming that the repeater station provides duplex functionality. In duplex operation, uplink signals are routed from the repeater station broadcast antennas, via repeater station uplink amplifiers, to the transfer antennas for transmission to the base station. Duplex functionality, a well-known concept often implemented using duplex filters, for a frequency-division duplex (FDD) system, or switches, for a time-division duplex (TDD) system, separates downlink and uplink signals such that they are routed via the proper duplex radio chain for amplification.").

As the shared technical features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Groups I and II therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.