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Multi-band MIMO repeater system with carrier aggregation capability

Abstract

A repeater comprises a plurality of donor antennas and a plurality of service antennas. The repeater comprises a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first and second transceivers. A controller is coupled to the plurality of signal processing paths. The controller is adapted to configure the repeater for a multiple-input-multiple-output (MIMO) operating mode and a carrier aggregation (CA) operating mode.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
8737509	12/2013	Yu	N/A	N/A
9363797	12/2015	Freda	N/A	N/A
10250290	12/2018	Khlat	N/A	N/A
10326510	12/2018	Ko	N/A	N/A
10455561	12/2018	Oh	N/A	N/A
2015/0085708	12/2014	Khlat	N/A	N/A
2016/0276748	12/2015	Ramachandran	N/A	N/A
2018/0019768	12/2017	King	N/A	N/A
2020/0336199	12/2019	Ashworth	N/A	N/A
2021/0099205	12/2020	Seyed	N/A	N/A
2023/0011531	12/2022	Black	N/A	N/A
2023/0361855	12/2022	Hatamian	N/A	H04B 7/15507

OTHER PUBLICATIONS

International Patent Application No. PCT/US2024/016346, filed Feb. 19, 2024; International Search Report / Written Opinion issued May 31, 2024; 13 pages. cited by applicant

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application claims the benefit of U.S. Provisional Patent Application No. 63/448,153, filed Feb. 24, 2023, which is incorporated herein by reference in its entirety.

SUMMARY
(1) Various embodiments are directed to a repeater comprising a plurality of donor antennas and a plurality of service antennas. The repeater comprises a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first

and second transceivers. A controller is coupled to the plurality of signal processing paths. The controller is adapted to configure the repeater for a multiple-input-multiple-output (MIMO) operating mode and a carrier aggregation (CA) operating mode. For example, the controller can be adapted to configure the repeater for an N×N MIMO operating mode and an M CA operating mode, where N and M are positive integers equal to or greater than 2.
(2) In some embodiments, a repeater comprises a plurality of donor antennas, a plurality of service antennas, and a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first and second transceivers. A controller is coupled to the plurality of signal processing paths. The controller is adapted to configure the repeater for a MIMO operating mode and a CA operating mode using first firmware, the MIMO operating mode without the CA operating mode using second firmware, and the CA operating mode without the MIMO operating mode using third firmware.
(3) The above summary is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The figures and the detailed description below more particularly exemplify illustrative embodiments.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Throughout the specification reference is made to the appended drawings wherein:
(2) FIG. **1**A is a block diagram of a repeater system in accordance with various embodiments;
(3) FIG. **1**B is a block diagram of a transmitter (TX) chain of a transceiver (e.g., TRX**1**) shown in FIG. **1**A;
(4) FIG. **1**C is a block diagram of a receiver (RX) chain of a transceiver (e.g., TRX**1**) shown in FIG. **1**A;
(5) FIG. **2** is a block diagram of a MIMO repeater system in accordance with various embodiments;
(6) FIG. **3** is a block diagram of a repeater system adapted to implement carrier aggregation in accordance with various embodiments;
(7) FIG. **4** is a block diagram of a MIMO repeater system adapted to implement carrier aggregation in accordance with various embodiments;
(8) FIG. **5** is a block diagram of a MIMO repeater system adapted to implement carrier aggregation in accordance with various embodiments;
(9) FIG. **6** is a block diagram of the repeater system shown in FIG. **5** which has been reconfigured to operate as a MIMO repeater using different firmware but with no change in circuitry in accordance with various embodiments; and
(10) FIG. **7** is a block diagram of the repeater system shown in FIG. **5** which has been reconfigured to operate as repeater which implements carrier aggregation using different firmware but with no change in circuitry in accordance with various embodiments;
(11) The figures are not necessarily to scale. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number.
DETAILED DESCRIPTION
(12) Embodiments of the disclosure are directed to a multi-band MIMO repeater system with carrier aggregation capability. Various embodiments are directed to a digital repeater that includes a multi-transceiver architecture. Advantages of the multi-transceiver architecture include the capability of configuring a digital repeater to operate in different modes with a change in firmware but without the need to change circuitry (e.g., hardware components) of the repeater. For example, a repeater can be configured to implement a MIMO operating mode with carrier aggregation, a

MIMO operating mode without carrier aggregation, or an operating mode with carrier aggregation but without a MIMO operating mode, by executing different firmware for each of the different operating modes. The flexibility and reconfigurability of the repeater's multi-transceiver architecture provides multiple options to meet the requirements of different carriers.

(13) Embodiments of the disclosure are defined in the claims. However, below there is provided a non-exhaustive listing of non-limiting examples. Any one or more of the features of these examples may be combined with any one or more features of another example, embodiment, or aspect described herein.

(14) Example Ex1. A digital repeater comprises a plurality of donor antennas, a plurality of service antennas, a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first and second transceivers, and a controller coupled to the plurality of signal processing paths, the controller adapted to configure the repeater for a multiple-input-multiple-output (MIMO) operating mode and a carrier aggregation (CA) operating mode.

(15) Example Ex2. The repeater of Ex1, wherein the controller is adapted to configure the repeater for an N×N MIMO operating mode and an M CA operating mode, where N and M are positive integers equal to or greater than 2.

(16) Example Ex3. The repeater of Ex1, wherein the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode.

(17) Example Ex4. The repeater of Ex1, wherein the donor and service antennas are wideband antennas configured to receive radio frequency (RF) signals of at least a first frequency and a second frequency.

(18) Example Ex5. The repeater of Ex4, wherein each of the wideband antennas is switchably coupled to at least two of the signal processing paths via a combiner/multiplexer.

(19) Example Ex6. The repeater of Ex1, wherein at least a first set of the donor and service antennas are narrowband antennas configured to receive radio frequency (RF) signals of a first frequency, and at least a second set of the donor and service antennas are narrowband antennas configured to receive RF signals of a second frequency.

(20) Example Ex7. The repeater of Ex1, wherein each of the signal processing paths is configured to process radio frequency signals having a unique combination of frequency and diversity relative to other signal processing paths.

(21) Example Ex8. The repeater of Ex1, wherein a first signal processing path is configured to process radio frequency (RF) signals having a first frequency and a first diversity, a second signal processing path is configured to process RF signals having the first frequency and a second diversity, a third signal processing path is configured to process RF signals having a second frequency and the first diversity, and a fourth signal processing path is configured to process RF signals having the second frequency and the second diversity.

(22) Example Ex9. The repeater of Ex1, wherein the controller is adapted to configure the repeater for the MIMO operating mode and the CA operating mode using first firmware, and the controller is adapted to configure the repeater for the MIMO operating mode without the CA operating mode using second firmware.

(23) Example Ex10. The repeater of Ex1, wherein the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode using first firmware, and the controller is adapted to configure the repeater for a 4×4 MIMO operating mode without the CA operating mode using second firmware.

(24) Example Ex11. The repeater of Ex1, wherein the controller is adapted to configure the repeater for the MIMO operating mode and the CA operating mode using first firmware, and the controller is adapted to configure the repeater for the CA operating mode without the MIMO operating mode using third firmware.

(25) Example Ex12. The repeater of Ex1, wherein the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode using first firmware, and the controller is adapted to configure the repeater for a 4×4 CA operating mode without the MIMO operating mode using third firmware.
(26) Example Ex13. A digital repeater comprises a plurality of donor antennas, a plurality of service antennas, and a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first and second transceivers. A controller is coupled to the plurality of signal processing paths, the controller adapted to configure the repeater for a multiple-input-multiple-output (MIMO) operating mode and a carrier aggregation (CA) operating mode using first firmware, the MIMO operating mode without the CA operating mode using second firmware, and the CA operating mode without the MIMO operating mode using third firmware.
(27) Example Ex14. The repeater of Ex13, wherein the controller is adapted to configure the repeater for a N×N MIMO operating mode and a M CA operating mode using the first firmware, a 2N×2N MIMO operating mode without the CA operating mode using the second firmware, and a 2M×2M CA operating mode without the MIMO operating mode using the third firmware, where N and M are positive integers equal to or greater than 2.
(28) Example Ex15. The repeater of Ex13, wherein the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode using the first firmware, a 4×4 MIMO operating mode without the CA operating mode using the second firmware, and a 4×4 CA operating mode without the MIMO operating mode using the third firmware.
(29) Example Ex16. The repeater of Ex13, wherein the donor and service antennas are wideband antennas configured to receive radio frequency (RF) signals of at least a first frequency and a second frequency.
(30) Example Ex17. The repeater of Ex16, wherein each of the wideband antennas is switchably coupled to at least two of the signal processing paths via a combiner/multiplexer.
(31) Example Ex18. The repeater of Ex13, wherein at least a first set of the donor and service antennas are narrowband antennas configured to receive radio frequency (RF) signals of a first frequency, and at least a second set of the donor and service antennas are narrowband antennas configured to receive RF signals of a second frequency.
(32) FIG. **1**A is a block diagram of a repeater system in accordance with various embodiments. The repeater system **100***a* shown in FIG. **1** includes a donor antenna **102** and a service antenna **104** each coupled to a signal processing path **110**. The signal processing path **110** includes a first transceiver, TRX**1**, coupled to the donor antenna **102** and a second transceiver, TRX**2**, coupled to the service antenna **104**. A digital signal processor, DSP, is coupled to the first transceiver, TRX**1**, and the second transceiver, TRX**2**.
(33) FIG. **1**B is a block diagram of a transmitter (TX) chain **140** of a transceiver (e.g., TRX**1**) shown in FIG. **1**A. The transmitter chain **140** includes a digital-to-analog converter (DAC) **142** coupled to a filter **144**. The filter **144** can be a low-pass filter, a band-pass filter, or a high-pass filter. The filter **144** is coupled to an up converter **146**, and the upconverter **146** is coupled to a power amplifier (PA) **148**. It is understood that the sequence of components shown in FIG. **1**B can be different than illustrated. For example, the filter **144** can be positioned before or after the upconverter **146**.
(34) FIG. **1**C is a block diagram of a receiver (RX) chain **150** of a transceiver (e.g., TRX**1**) shown in FIG. **1**A. The receiver chain **150** includes a low-noise amplifier (LNA) **152** coupled to a down converter **154**. The down converter **154** is coupled to a filter **156**, and the filter **156** is coupled to an analog-to-digital converter (ADC) **158**. The filter **144** can be a low-pass filter, a band-pass filter, or a high-pass filter. It is understood that the sequence of components shown in FIG. **1**C can be different than illustrated. For example, the filter **156** can be positioned before or after the down

converter **154**.

(35) According to some embodiments, each of TRX**1** and TRX**2** can be implemented as a dual radio frequency (RF) transceiver comprising dual differential transmitters and dual differential receivers. In some embodiments, TRX**1** and TRX**2** can support receiver bandwidths up to 100 MHz. Suitable RF transceivers for implementing TRX**1** and TRX**2** include: models ADRV9002, ADRV9004, ADRV9026, AD9361, and AD9371 available from Analog Devices; model DW1000 available from Qorvo, and model LMS7002M available from Lime Microsystems. The DSP can include, for example, one or more of a microprocessor, microcontroller, application specific integrated circuit (ASIC), Field Programmable Gate Array (FPGA), or any other processing device configured to interpret and/or to execute program instructions and/or to process data. The core components of the repeater system shown in FIGS. **1**A-**1**C (e.g., TRX**1**-DSP-TRX**2**) are incorporated in other embodiments of this disclosure, and can have the same or different configuration as described above.

(36) FIG. **2** is a block diagram of a MIMO repeater system **100***b* which incorporates the core components of the repeater system shown in FIG. **1**A. FIG. **2** illustrates a 2×2 MIMO repeater system **100***b* comprising two donor antennas **102***a*, **102***b* and two service antennas **104***a*, **104***b*. A first signal processing path **110***a* is coupled to donor antenna **102***a* and service antenna **104***a*. The first processing path **110***a* is configured to process RF signals having a first frequency (Freq-1) and a first diversity (Div-A). The term diversity can include polarization diversity and/or spatial diversity. A second signal processing path **110***b* is coupled to donor antenna **102***b* and service antenna **104***b*. The second processing path **110***b* is configured to process RF signals having the frequency (Freq-1) and a diversity (Div-B). The core components of the MIMO repeater system shown in FIG. **2** (e.g., redundant sets of TRX**1**-DSP-TRX**2**) are incorporated in other embodiments of this disclosure, and can have the same or different configuration as described above.

(37) FIG. **3** is a block diagram of a repeater system adapted to implement carrier aggregation in accordance with various embodiments. There are various forms of carrier aggregation (e.g., as defined by 3GPP Release-10 of the LTE-Advanced standard), including intra-band adjacent CA, intra-band non-adjacent CA, and inter-band CA. In intra-band adjacent CA, aggregated component carriers (CCs) are within the same frequency band and adjacent to each other forming a contiguous frequency block. In intra-band non-adjacent CA, aggregated CCs are within the same frequency band but are not adjacent to each other. In inter-band CA, aggregated CCs are in different frequency bands. The maximum number of CCs and maximum bandwidth are generally limited as defined by a governing standard. For example, 3GPP Release-10 of the LTE-Advanced standard allows a maximum of five CCs to be allocated to a wireless communication device, such as repeater system **100***c*, at any given time. CCs can vary in size from 1.4 to 20 MHz, resulting in a maximum bandwidth of 100 MHz that can be allocated to the wireless communication device in the downlink/uplink.

(38) In the illustrative embodiment shown in FIG. **3**, the repeater system **100***c* is configured to implement carrier aggregation using two component carriers. The repeater system **100***c* includes a wideband donor antenna **102** and a wideband service antenna **104** for receiving and transmitting RF signals having a first frequency (Freq-1) and a second frequency (Freq-2). In this illustrative example, the RF signals have the same diversity (Div-A). A first combiner/multiplexer **120** is coupled to the donor antenna **102** and a second combiner/multiplexer **124** is coupled to the service antenna **104**. The first and second combiner/multiplexers **120**, **124** are configured to distribute RF signals having the first frequency (Freq-1) to signal processing path **110***a* and to distribute RF signals having the second frequency (Freq-2) to signal processing path **110***b*. The first and second combiner/multiplexers **120**, **124** are also configured to combine RF signals transmitted along signal processing paths **110***a* and **110***b* for transmission by the donor and service antennas **102** and **104**. The core components of the repeater system shown in FIG. **3** (e.g., redundant sets of TRX**1**-DSP-TRX**2**) are incorporated in other embodiments of this disclosure, and can have the same or different

configuration as described above.

(39) It is noted that the transceivers TRX**1** and TRX**2** of the different signal processing paths **110***a*, **110***b* include a superscript (**1** or **2**) to indicate that the transceivers TRX**1** and TRX**2** of the different signal processing paths **110***a*, **110***b* can be the same or different in terms of configuration. For example, TRX**1**(**1**) of signal processing path **110***a* may have the same or different LO frequency than TRX**1**(**2**) of signal processing path **110***b*. It is also noted that the transceivers TRX**1** and TRX**2** of the different signal processing paths shown in FIGS. **4**, **5**, and **7** also include a superscript (e.g., 1, 2, 3, 4) to indicate that the transceivers TRX**1** and TRX**2** of the different signal processing paths can be the same or different in terms of configuration.

(40) FIG. **4** is a block diagram of a MIMO repeater system adapted to implement carrier aggregation in accordance with various embodiments. In the illustrative embodiment shown in FIG. **4**, the repeater system **100***d* includes a 2×2 MIMO repeater configured to implement carrier aggregation using two component carriers (2CA). The repeater system **100***d* includes wideband donor antennas **102***a*, **102***b* and wideband service antennas **104***a*, **104***b* for receiving and transmitting RF signals having a first frequency (Freq-1) and a second frequency (Freq-2). In this embodiment, donor and service antennas **102***a*, **104***a* receive and transmit RF signals having a first frequency (Freq-1) and a first diversity (Div-A). Donor and service antennas **102***b*, **104***b* receive and transmit RF signals having a second frequency (Freq-2) and a second diversity (Div-B).

(41) A first combiner/multiplexer **120***a* is coupled to the donor antenna **102***a* and a second combiner/multiplexer **124***a* is coupled to the service antenna **104***a*. The first and second combiner/multiplexers **120***a*, **124***a* are configured to distribute RF signals having the first frequency (Freq-1) and the first diversity (Div-A) to signal processing path **110***a* and to distribute RF signals having the second frequency (Freq-2) and the first diversity (Div-A) to signal processing path **110***b*. The first and second combiner/multiplexers **120***a*, **124***a* are also configured to combine RF signals transmitted along signal processing paths **110***a* and **110***b* for transmission by the donor and service antennas **102***a* and **104***a*.

(42) A third combiner/multiplexer **120***b* is coupled to the donor antenna **102***b* and a fourth combiner/multiplexer **124***b* is coupled to the service antenna **104***b*. The third and fourth combiner/multiplexers **120***b*, **124***b* are configured to distribute RF signals having the first frequency (Freq-1) and the second diversity (Div-B) to signal processing path **110***c* and to distribute RF signals having the second frequency (Freq-2) and the second diversity (Div-B) to signal processing path **110***d*. The third and fourth combiner/multiplexers **120***b*, **124***b* are also configured to combine RF signals transmitted along signal processing paths **110***c* and **110***d* for transmission by the donor and service antennas **102***b* and **104***b*.

(43) A controller **130** is coupled to the signal processing paths **110***a*, **110***b*, **110***c*, **110***d*. The controller **130** is adapted to configure the repeater **100***d* for a MIMO operating mode and a carrier aggregation operating mode. In the illustrative example shown in FIG. **4**, the controller **130** is adapted to configure the repeater **100***d* for a 2×2 MIMO operating mode and a 2CA operating mode.

(44) FIG. **5** is a block diagram of a MIMO repeater system adapted to implement carrier aggregation in accordance with various embodiments. In the illustrative embodiment shown in FIG. **5**, the repeater system **100***e* includes a 2×2 MIMO repeater configured to implement carrier aggregation using two component carriers (2CA). The core components of the repeater **100***e* shown in FIG. **5** (e.g., redundant sets of TRX**1**-DSP-TRX**2**) are the same as those shown in FIG. **4**. The repeater **100***e* shown in FIG. **5** operates in the same manner as the repeater **100***d* shown in FIG. **4**. In the embodiment shown in FIG. **5**, the repeater **100***e* has twice the number of antennas as the repeater **100***d* shown in FIG. **4**. As is shown in FIG. **5**, each signal processing path **110***a*, **110***b*, **110***c*, **100***d* is coupled to one donor antenna and one service antenna. In particular, signal processing path **110***a* is coupled to donor antenna **102***a* and service antenna **104***a*, signal processing path **110***b* is coupled to donor antenna **102***b* and service antenna **104***b*, signal processing path **110***c*

is coupled to donor antenna **102***c* and service antenna **104***c*, and signal processing path **110***d* is coupled to donor antenna **102***d* and service antenna **104***d*. In some implementations, as is in the case of repeater **100***d* shown in FIG. **4**, it may be more cost effective to share antennas (e.g., wideband antennas) among individual signal processing paths by incorporating combiner/multiplexer components as shown in FIG. **4**.

(45) As was previously discussed, the multi-transceiver architecture disclosed herein provides the capability of configuring a digital repeater to operate in different modes with a change in firmware but without the need to change circuitry of the repeater. In particular, the digital repeater can be operated in different modes without making a change to the core components (e.g., redundant sets of TRX**1**-DSP-TRX**2**) of the repeater. For example, the digital repeater can be configured to implement a MIMO operating mode with carrier aggregation (e.g., as shown in FIGS. **4** and **5**), a MIMO operating mode without carrier aggregation (e.g., as shown in FIG. **6**), or an operating mode with carrier aggregation but without a MIMO operating mode (e.g., as show in FIG. **7**), via inclusion and execution of different firmware by the controller **130** for each of the different operating modes.

(46) In the embodiment shown in FIG. **5**, the controller **130** is adapted to configure the repeater **100***e* for a 2×2 MIMO operating mode and a 2CA operating mode using first firmware. In the embodiment shown in FIG. **6**, the repeater **100***e* includes the same core components (e.g., redundant sets of TRX**1**-DSP-TRX**2**) and has the same antenna configuration as that shown in FIG. **5**. In FIG. **6**, the controller **130** is adapted to configure the repeater **100***e* for a MIMO operating mode without a CA operating mode using second firmware. In particular, the controller **130** is adapted to configure the repeater **100***e* for a 4×4 MIMO operating mode without the CA operating mode using second firmware. In the embodiment shown in FIG. **7**, the repeater **100***e* includes the same core components (e.g., redundant sets of TRX**1**-DSP-TRX**2**) and has the same antenna configuration as that shown in FIGS. **5** and **6**. In FIG. **7**, the controller **130** is adapted to configure the repeater **100***e* for the CA operating mode without the MIMO operating mode using third firmware. In particular, the controller **130** is adapted to configure the repeater **100***e* for a 4×4 CA operating mode without the MIMO operating mode using third firmware.

(47) Although reference is made herein to the accompanying set of drawings that form part of this disclosure, one of at least ordinary skill in the art will appreciate that various adaptations and modifications of the embodiments described herein are within, or do not depart from, the scope of this disclosure. For example, aspects of the embodiments described herein may be combined in a variety of ways with each other. Therefore, it is to be understood that, within the scope of the appended claims, the claimed embodiments may be practiced other than as explicitly described herein. For example, a docking system may be installed on a surface of a vehicle other than the vehicle's roof (e.g., on the trunk).

(48) All references and publications cited herein are expressly incorporated herein by reference in their entirety into this disclosure, except to the extent they may directly contradict this disclosure. Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims may be understood as being modified either by the term “exactly” or “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein or, for example, within typical ranges of experimental error.

(49) The recitation of numerical ranges by endpoints includes all numbers subsumed within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5) and any range within that range. Herein, the terms “up to” or “no greater than” a number (e.g., up to 50) includes the number (e.g., 50), and the term “no less than” a number (e.g., no less than 5) includes the number (e.g., 5).

(50) The terms “coupled” or “connected” refer to elements being attached to each other either directly (in direct contact with each other) or indirectly (having one or more elements between and

attaching the two elements). Either term may be modified by “operatively” and “operably,” which may be used interchangeably, to describe that the coupling or connection is configured to allow the components to interact to carry out at least some functionality (for example, a radio chip may be operably coupled to an antenna element to provide a radio frequency electric signal for wireless communication).
(51) Terms related to orientation, such as “top,” “bottom,” “side,” and “end,” are used to describe relative positions of components and are not meant to limit the orientation of the embodiments contemplated. For example, an embodiment described as having a “top” and “bottom” also encompasses embodiments thereof rotated in various directions unless the content clearly dictates otherwise.
(52) Reference to “one embodiment,” “an embodiment,” “certain embodiments,” or “some embodiments,” etc., means that a particular feature, configuration, composition, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosure. Thus, the appearances of such phrases in various places throughout are not necessarily referring to the same embodiment of the disclosure. Furthermore, the particular features, configurations, compositions, or characteristics may be combined in any suitable manner in one or more embodiments.
(53) The words “preferred” and “preferably” refer to embodiments of the disclosure that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful and is not intended to exclude other embodiments from the scope of the disclosure.
(54) As used in this specification and the appended claims, the singular forms “a,” “an,” and “the” encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.
(55) As used herein, “have,” “having,” “include,” “including,” “comprise,” “comprising” or the like are used in their open-ended sense, and generally mean “including, but not limited to.” It will be understood that “consisting essentially of,” “consisting of,” and the like are subsumed in “comprising.” and the like. The term “and/or” means one or all of the listed elements or a combination of at least two of the listed elements.
(56) The phrases “at least one of,” “comprises at least one of,” and “one or more of” followed by a list refers to any one of the items in the list and any combination of two or more items in the list.

Claims

1. A digital repeater, comprising: a plurality of donor antennas; a plurality of service antennas; a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first and second transceivers; and a controller coupled to the plurality of signal processing paths, the controller adapted to configure the repeater for a multiple-input-multiple-output (MIMO) operating mode and a carrier aggregation (CA) operating mode.
2. The repeater of claim 1, wherein the controller is adapted to configure the repeater for an N×N MIMO operating mode and an M CA operating mode, where N and M are positive integers equal to or greater than 2.
3. The repeater of claim 1, wherein the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode.
4. The repeater of claim 1, wherein the donor and service antennas are wideband antennas configured to receive radio frequency (RF) signals of at least a first frequency and a second frequency.

5. The repeater of claim 4, wherein each of the wideband antennas is switchably coupled to at least two of the signal processing paths via a combiner/multiplexer.
6. The repeater of claim 1, wherein: at least a first set of the donor and service antennas are narrowband antennas configured to receive radio frequency (RF) signals of a first frequency; and at least a second set of the donor and service antennas are narrowband antennas configured to receive RF signals of a second frequency.
7. The repeater of claim 1, wherein each of the signal processing paths is configured to process radio frequency signals having a unique combination of frequency and diversity relative to other signal processing paths.
8. The repeater of claim 1, wherein: a first signal processing path is configured to process radio frequency (RF) signals having a first frequency and a first diversity; a second signal processing path is configured to process RF signals having the first frequency and a second diversity; a third signal processing path is configured to process RF signals having a second frequency and the first diversity; and a fourth signal processing path is configured to process RF signals having the second frequency and the second diversity.
9. The repeater of claim 1, wherein: the controller is adapted to configure the repeater for the MIMO operating mode and the CA operating mode using first firmware; and the controller is adapted to configure the repeater for the MIMO operating mode without the CA operating mode using second firmware.
10. The repeater of claim 1, wherein: the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode using first firmware; and the controller is adapted to configure the repeater for a 4×4 MIMO operating mode without the CA operating mode using second firmware.
11. The repeater of claim 1, wherein: the controller is adapted to configure the repeater for the MIMO operating mode and the CA operating mode using first firmware; and the controller is adapted to configure the repeater for the CA operating mode without the MIMO operating mode using third firmware.
12. The repeater of claim 1, wherein: the controller is adapted to configure the repeater for a 2×2 MIMO operating mode and a 2 CA operating mode using first firmware; and the controller is adapted to configure the repeater for a 4×4 CA operating mode without the MIMO operating mode using third firmware.
13. A digital repeater, comprising: a plurality of donor antennas; a plurality of service antennas; a plurality of signal processing paths each comprising a first transceiver coupled to at least one of the donor antennas, a second transceiver coupled to at least one of the service antennas, and a digital signal processor coupled to the first and second transceivers; and a controller coupled to the plurality of signal processing paths, the controller adapted to configure the repeater for: a multiple-input-multiple-output (MIMO) operating mode and a carrier aggregation (CA) operating mode using first firmware; the MIMO operating mode without the CA operating mode using second firmware; and the CA operating mode without the MIMO operating mode using third firmware.
14. The repeater of claim 13, wherein the controller is adapted to configure the repeater for: a N×N MIMO operating mode and a M CA operating mode using the first firmware; a 2N×2N MIMO operating mode without the CA operating mode using the second firmware; and a 2M×2M CA operating mode without the MIMO operating mode using the third firmware, where N and M are positive integers equal to or greater than 2.
15. The repeater of claim 13, wherein the controller is adapted to configure the repeater for: a 2×2 MIMO operating mode and a 2 CA operating mode using the first firmware; a 4×4 MIMO operating mode without the CA operating mode using the second firmware; and a 4×4 CA operating mode without the MIMO operating mode using the third firmware.
16. The repeater of claim 13, wherein the donor and service antennas are wideband antennas configured to receive radio frequency (RF) signals of at least a first frequency and a second

frequency.
17. The repeater of claim 16, wherein each of the wideband antennas is switchably coupled to at least two of the signal processing paths via a combiner/multiplexer.
18. The repeater of claim 13, wherein: at least a first set of the donor and service antennas are narrowband antennas configured to receive radio frequency (RF) signals of a first frequency; and at least a second set of the donor and service antennas are narrowband antennas configured to receive RF signals of a second frequency.